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Summary

The Arctic is evolving rapidly due to the effects of climate change. The most dramatic of these changes is the receding ice on land and at sea that allows greater access to transportation routes and resources. Analysts and observers have actively debated the potential consequences of these developments for regional and global security. As states look to the Arctic as a potential area for military operations, the changing climate and the promise of new human activities in the region are only a few of the relevant factors that should be considered. What will characterize the Arctic operating environment over the next 30 years?

One of the challenging dilemmas in defense planning is the need to prepare for unknown future contingencies that necessitate the use of military force. Military operations are highly situational, and context influences the character of the operation and potentially its outcome. One way to avoid being utterly unprepared is through a structured process of constructing potential futures and exploring how various combinations of relevant factors might influence military operations. An important aspect of the operating environment is the interaction between these factors and the second and third order effects that result.

This analysis explores three possible Arctic futures, using an analytical framework comprised of five factors: geopolitical, environmental, societal, military systems, and doctrines and operating concepts. One future represents a simple and almost linear extrapolation of current trends into the future, another considers a future in which Russia and China have a close partnership in the Arctic, while a third future envisions significant technological change that reduces the need for resource extraction in the Arctic. We assess the implications for military operations within each of these futures by considering the implications of the altered operational context on the joint functions of command and control, intelligence and information, maneuver and mobility, fires, sustainment, and protection.

We find that certain factors of the future Arctic operating environment will influence aspects of military operations such as mobility and sustainment regardless of how the future unfolds, mainly due to climate change effects that are “locked” into the atmosphere regardless of the progress that might be made to reduce emissions. The likely expansion of civilian infrastructure for resource extraction, greater numbers of satellites in polar orbit, and technological solutions that improve certain aspects of sustainment are also relevant. Although many aspects of the Arctic region may evolve as anticipated, they are far from predestined. Norwegian decisionmakers should prepare for a broader range of potential tasks in this perpetually challenging operating environment.

Sammendrag

Utviklingen går raskt i Arktis, drevet av klimaendringene. Den mest dramatiske av disse endringene er isen som trekker seg tilbake på land og til havs, noe som åpner for nye transportruter og nye muligheter for å utvinne ressurser. Analytikere og observatører har aktivt debattert de mulige konsekvensene av denne utviklingen for regional og global sikkerhet, og en rekke stater ser på Arktis som et mulig område for militære operasjoner. Et endret klima og det at den menneskelige aktivitet i regionen trolig vil øke, utgjør bare noen få av de relevante faktorene som bør vurderes. Hva vil kjennetegne det arktiske operasjonsmiljøet om 30 år?

Et av dilemmaene i forsvarsplanlegging er behovet for å forberede seg på ukjente fremtidige hendelser som kan innebære bruk av militær makt. Militære operasjoner er imidlertid svært situasjonsbetingede, og konteksten påvirker en operasjons karakter og potensielt utfallet. En måte å unngå det å være fullstendig uforberedt på er gjennom en strukturert prosess der vi konstruerer mulige fremtidssituasjoner med ulike kombinasjoner av relevante faktorer for å se hvordan disse vil påvirke gjennomføringen av militære operasjoner. Et viktig aspekt ved operasjonsmiljøet er samspillet mellom disse faktorene og særlig de andre og tredje ordens effektene som resulterer.

I denne analysen utforsker vi tre mulige arktiske «fremtider» ved å bruke et analytisk rammeverk som består av fem faktorer: geopolitikk, miljø, samfunn, militære systemer, og doktriner og operasjonskonsepter. Den første av de konstruerte fremtidene består av en enkel og nesten lineær ekstrapolering av dagens trender. Den andre tar for seg en fremtidsutvikling der Russland og Kina har et tett partnerskap i Arktis, og i den tredje fremtiden ser vi for oss betydelige teknologiske endringer som reduserer behovet for å utvinne ressurser i Arktis. Vi evaluerer implikasjonene for militære operasjoner innenfor hver av disse fremtidene ved å ta for oss hvordan de endrer den operasjonelle konteksten på fellesfunksjonene: kommando og kontroll, etterretning og informasjon, mobilitet og manøver, ild, understøttelse og beskyttelse.

Vi finner at noen elementer ved det fremtidige arktiske operasjonsmiljøet vil påvirke enkelte aspekter ved militære operasjoner som mobilitet og forsyning nesten uansett hvordan fremtiden utspiller seg. Dette er hovedsakelig på grunn av effekter ved klimaendringene som er «låst» i atmosfæren, og som vil påvirke regionen uavhengig av eventuelle reduksjoner i klimagassutslipp. Andre relevante aspekter inkluderer utvidelsen av sivil infrastruktur for å utvinne ressurser, økningen i antall satellitter i polar bane, og teknologiske løsninger som forbedrer visse forsyningsaspekter av understøttelse. Selv om mange av endringene vi antar vi vil se i den arktiske regionen kan utvikle seg som forventet, er det ikke garantert. Norske beslutningstakere bør forberede seg på et bredere spekter av mulige oppgaver i et stadig mer krevende operasjonsmiljø.

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Preface

This report is a product of the Tekno project, a research initiative at the Norwegian Defence Research Establishment (FFI) examining the potential implications of emerging technology for military operations and the Norwegian Armed Forces. The Tekno project was established in 2019 and focuses primarily on the deep future, first and foremost by leveraging the substantial technical expertise found at the FFI. The methodological approaches we employ in this and previous reports are known collectively as foresight analysis, a field of research that attempts to understand potential future developments in a structured manner. Foresight analysis is a widely used analytical and policy tool, and we therefore encourage other analysts making use of similar approaches to reach out to us so that we might learn from each other's experiences and share best practices.

We have benefitted greatly from discussions regarding methodology and substance with both national and international colleagues. These include the Strategic Analyses and Joint Systems division at FFI as well as our cooperative relationships with partner institutions in Sweden, Finland, the Netherlands, and the United Kingdom. Finally, we would like to express our appreciation to the various units within the Norwegian Armed Forces with which we have had fruitful discussions and workshop activities, including the Joint Headquarters, the Army Land Warfare Center, the Winter Warfare School, Finnmark Land Command, the Garrison of Sør-Varanger, the Special Operations Command, and various entities and individuals associated with the Defense University College. As always, we alone are responsible for the contents of this report, which is based on publicly available information.

Kjeller, 30 May 2024

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1 Introduction

Imagine that a military contingency arises in the Arctic during the late 2040s involving the Norwegian Armed Forces. Having undergone significant changes over the past quarter century, the region is a different place than it was during the early 2020s. Climate change has significantly altered the physical environment in ways that have made certain aspects of human activity less challenging while others have become more difficult. The multiyear sea ice has almost completely disappeared, opening new transport routes, new fisheries for displaced pelagic species, and new seabed mining operations for rare earth minerals. Maintaining roadways has become even more difficult with increasingly unstable permafrost and fierce winter storms that cause severe coastal erosion in areas once protected by the now-absent sea ice. Regional infrastructure has nevertheless expanded to keep pace with the significant growth in commercial activity and includes new deep-water ports and a robust network of sensing and communication satellites. Populations around the globe in both advanced and developing countries alike have experienced a technological revolution powered by exponential advances in machine intelligence that have altered the economic and political fabric of society, while advances in biotechnology have challenged traditional distinctions between humans and machines. These societal changes are also present in the small but bustling Arctic communities.

In this new Arctic environment, new state and non-state actors have become economically influential and politically relevant. Governments and corporate-owned paramilitary groups deploy modern military systems and use novel operating concepts that merge Arctic-capable autonomous systems, space-based assets, cyber and electromagnetic effects targeting platforms, and cognitive and biological tools targeting personnel. Warfare has evolved in unanticipated and significant ways since the early 21st century. Given these shifts, an Arctic military operation in the late 2040s would combine the uncertainties of evolving military technology with other changes to the physical and social environment. Looking back from the 2040s, have Norwegian military leaders and political decisionmakers made the necessary preparations in terms of capabilities, personnel, and doctrine?

Some of the analytical work needed to have a positive answer to this question is well underway. Over the past several years, three high level security and defense analyses have been conducted, including a special Norwegian Defense Commission report in addition to the usual quadrennial Chief of Defense assessment (*Forsvarssjefens fagmilitære råd*) and the Long Term Plan on Defense (*Langtidsplan for forsvarssektoren* or LTP). Given the current geopolitical landscape, these assessments were hardly routine in terms of their substance (Forsvarsdepartementet, 2024; Forsvarskommisjonen, 2023; Kristoffersen, 2023). The 2024 LTP outlined a particularly ambitious roadmap for the revitalization of the Norwegian Armed Forces and the country's defense sector. This report seeks to provide additional insights as a supplement to these analyses and in support of ongoing defense planning and decision-making processes.

The analysis contained in this report explores three possible Arctic futures and their implications for military operations in the region. One of the challenging dilemmas in defense planning is the need to prepare for unknown future contingencies necessitating the use of military force. Military operations are highly situational, and this context influences the character of the operation and potentially its outcome. Due to the unpredictable nature of military conflict and the need to make timely decisions regarding material investments, personnel, and training, there is always a significant risk of experiencing a mismatch between mission requirements and the military capabilities available. Our inability to predict the future prevents achieving a perfect match between requirements and capabilities, but one way to avoid being utterly unprepared is through a structured process of constructing potential futures and exploring how various combinations of relevant factors might influence the conduct of military operations. Imagining how such factors combine and interact in a future contingency allows us to test the conceptual viability of long-term planning assumptions and consider how the interplay between emerging trends might alter these assumptions.

1.1 Assessing the future operating environment

The set of relevant factors that a military commander must contend with during the planning and implementation of a military operation is often termed the *operating environment*.[1] According to NATO doctrine, there are multiple environments (such as information, maritime, political, or human) that "define the surroundings of a mission and combine all the elements, conditions, circumstances and influences of applicable factors that affect a commander's decisionmaking in accomplishing their mission" (NATO, 2022, p. 94). These factors can be organized and described in a number of ways, from the more simplistic categorization of diplomatic, informational, military and economic (DIME) to the more complex operational planning tool that include political, military, economic, social, information, infrastructure, physical, and temporal (PMESII-PT) elements.

For our analysis of the *future operating environment* (FOE) in the Arctic, we selected a modified and simplified set of these variables that has, from a historical perspective, strongly influenced how military operations have been conducted and might therefore adequately capture potential shifts in the character of warfare. The first three – *geopolitical*, *environmental,* and *societal* factors – are fundamental and structural in nature. They usually evolve more slowly and frame the underlying context for military operations. Examples might include the latent geostrategic potential for conflict escalation, the effects resulting from a combination of relevant environmental and meteorological conditions, or non-kinetic means to target the civilian population such as cyber attacks. These three factors are also structural in the sense that individual governments have less influence over how these aspects of the operating environment evolve, particularly at the global level. The two remaining factors are the *military systems* wielded by state and non-state actors, along with the *doctrines and operating concepts* guiding their use. Unlike the three structural variables, state-level decisionmakers in their respective defense ministries and military staffs have some control over force structures and military doctrines.

[1] Other analyses use the slightly different variation *operational environment*, but we follow the terminology from NATO joint doctrine AJP-1.

Many of the relevant factors influencing the regional context of any military operation are often influenced by (if not a direct extension of) global developments. Our methodology reflects this fact by first assessing the likely trajectory of a set of global trends and then extrapolating the relevant regional consequences. This approach can be useful in creating a notional FOE for any region but is particularly suited to understanding future developments in the relatively undeveloped and rapidly changing Arctic. Our analytic process began by assessing existing global trend studies and extrapolating from them a set of global drivers or trends for each of the five factors considered. One important consideration underpinning our entire analysis was a desire for simplicity amid an exceptionally complex topic, such that we strove to find the fewest number of drivers that might provide the greatest descriptive power for the analysis.

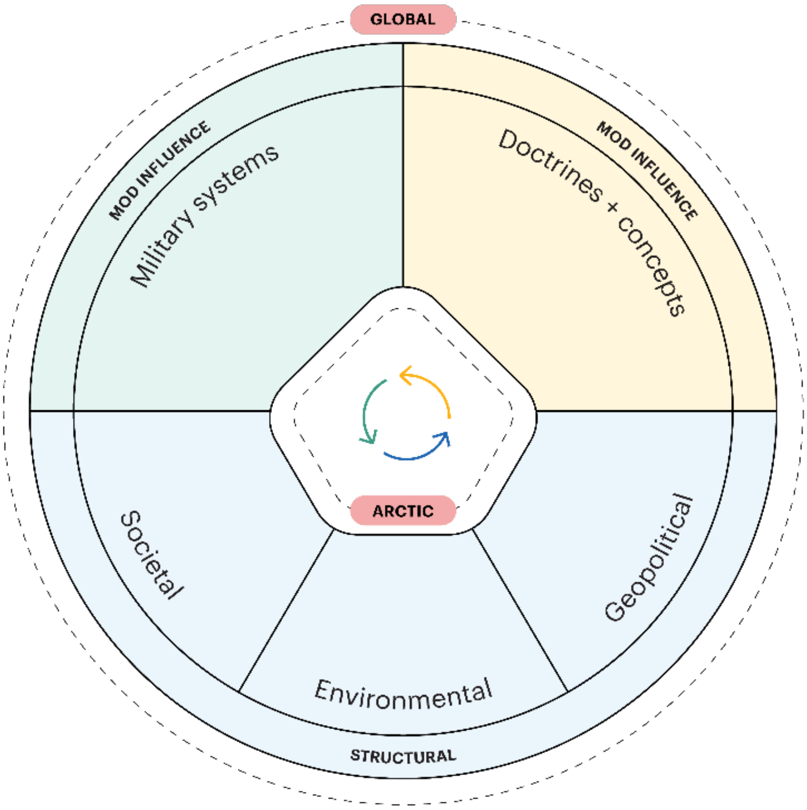

Figure 1.1 *Modelling the operating environment. Global trends for the factors are assessed before considering their impact in the Arctic. Three of the five factors are structural, while states have more control over military systems and doctrine.*

From our five principal factors we derived a set of 13 drivers, which we then used to create three possible futures. For each of these futures, we considered how the drivers might influence global developments within each factor by 2050. Afterwards, we extrapolated the immediate effects of these global developments to the Arctic, as well as their first order effects. For example, the continued global demand for renewable energy (driver) will likely encourage the development of new sources of critical minerals, thus leading to mining operations in the Arctic (Arctic effect). The increased commercial activity in the region will require new infrastructure to support mining operations, as well as some civilian workers (assuming much of the operation is autonomous by 2050), which constitute first order effects.

Figure 1.2 ***Defining the Arctic**. Several definitions exist for defining the Arctic. We adopt the definition used by the Arctic Council's Arctic Monitoring and Assessment Program (AMAP): the terrestrial, airspace and marine areas north of the Arctic Circle, along with areas north of 62° N in Asia and 60° N in North America. Illustration from [ArcticPortal.org.](ArcticPortal.org)*

We then considered the interplay between factors within the Arctic region, attempting to understand the entire operating environment. What are the implications of an increasing number of Arctic actors, the disappearing summer sea ice, the growth of satellite coverage in the Arctic, new ways of resource extraction such as seabed mining, the growing number of autonomous systems in the maritime domain, and algorithmic-based warfare concepts that place the human commander over the decisionmaking loop rather than inside it? Only by examining the set of factors together will a clearer picture of the operating environment emerge. Importantly, we paid considerable attention to consistency issues, making sure the futures we created were logically consistent across all the factors. If we assumed that global trading blocs would emerge that reduced east-west trade, we also needed to consider the effect of this on the Northern Sea Route. We purposely avoid treating "technology" as an independent factor in our analysis simply because technological progress is not a separate force, but rather an element that is deeply integrated into most aspects of human activity. Technology factors heavily into our thinking about how civil society will evolve, the shape and function of future force structures, and the creation of new doctrines that incorporate these shifts in societal and military affairs.

Using our five-factor framework, we first describe the current operating environment in the Arctic and how it impacts the six joint functions of command and control, maneuver and mobility, intelligence, fires, sustainment, and protection. With these three possible futures, we consider how the changes in context might influence the joint functions from our current Arctic operating environment. Finally, we look across the three sets of joint functions looking for similarities among them. In other words, which functions had similar outcomes regardless of our assumptions about the future? Which aspects of the FOE appeared consistent and therefore might contribute to "safer" policy choices?

Table 1.1 Selected global trends and drivers[2]

Geopolitical	Power diffusion among states
	Further weakening of globalization trends
	Growing influence of private actors
Environmental	Effects of climate change
Societal	Continued digitalization and human-AI teaming
	Growing global energy demand: uncertain fossil fuels/renewables balance
	Growing technology divide between autocratic and democratic states
Military Systems	Proliferation of affordable sensors
	Machine intelligence for autonomy and decision support
	Creation of integrated networks and "combat clouds"
Doctrines and concepts	Cross-domain integration of military effort
	Concepts leveraging human-autonomous teaming
	Asymmetric approaches to counter a transparent battlefield

[2] This set of trends and drivers are derived from global trend reports, including the National Intelligence Council from the United States and DCDC from the UK (National Intelligence Council, 2021; UK Ministry of Defence, 2018).

Our approach is a combination of various methods but draws on similar works. Secondary literature on global trends from governmental institutions, research facilities and independent think tanks have provided much of the raw material for our analysis.[3] We also incorporate our previous work on the implications of technology on military operations and future force structures (Andås, 2020; Mayer, 2022; Mayer et al., 2021). Our colleagues at the Norwegian Defense Research Establishment have conducted valuable research on the potential effects of climate change in the Arctic that has informed our work as well (Granlund et al., 2022; Pedersen, 2023).

To understand the interactions between factors and their second order effects, we conducted a series of workshops with other researchers and members of the Norwegian Armed Forces to explore the future character of warfare. Underpinning these analyses is a persistent focus on the role of emerging technologies and its impact on civil society and military operations. Constructing an Arctic FOE analysis represents a significant contribution to long-term defense planning as practiced in Norway and among its allies and partners. Due to its geography, Norway is an Arctic actor with interests and responsibilities that require its armed forces to be capable of operating in the region. Understanding potential developments in its own neighborhood is an important component in its defense and security planning process. The Norwegian scenario- and capability-based planning process incorporates a structured morphological analysis of potential actors and the possible ends, ways and means by which they might threaten state security (Vatne et al., 2020). We view our FOE analysis as a useful precursor to that process by seeking to describe the context within which these scenarios might occur, as well as better understanding the interaction between key factors making up the operating environment. Finally, foresight analyses such as this report offer an alternative analysis, approaching a similar problem set with a different methodology to encourage new thinking and insights to existing planning processes.

1.2 Report structure

To understand how the operating environment in the Arctic might change over the next three decades, we deemed it necessary to start by establishing a baseline of current operating conditions. In chapter two, we therefore assess the current Arctic operating environment using the five factors outlined above. The following chapter offers three possible futures for the Arctic. The first portrays the combination of factors we consider to be a likely outcome based on current trends and constitutes our “baseline” future scenario. The second future explores the implications of a world in which China has become a global power and an Arctic actor. In the third and final future, we adopt an especially optimistic view regarding the evolution of societal technology and envision how military operations in the Arctic might be influenced by revolutionary advances in AI and biotechnology. Following the descriptions of the three possible futures, we conduct a structured analysis of the joint functions to identify differences and, importantly, assess whether any commonalities exist between the futures. We conclude by outlining some implications of the FOE analysis for Norwegian policymakers.

[3] Among the most notable are the UK’s Development, Concepts and Doctrine Centre (DCDC), US Army Futures Command, NATOs Allied Command Transformation (ACT) and reports from the Congressional Research Service (CRS) and the Center for Strategic and International Studies (CSIS).

2 Current operating environment

To understand the context for future military operations in the Arctic, we need to start in the present. If a military operation were to be conducted next year, how might geopolitical, environmental, and societal factors influence the operation? How would the military platforms and systems deployed by relevant actors in the Arctic operate in the region and what doctrines and operating concepts would guide their use? Establishing this baseline provides a useful reference point to assess changes in the region as well as persistent challenges that planners will be required to manage regardless of how the regional dynamics change.[4]

2.1 Geopolitical

There are eight states with territory in the Arctic region: Russia, Finland, Sweden, Norway, Denmark (via Greenland), Iceland, Canada, and the United States (via Alaska). Of these, Russia, Norway, Denmark, Canada, and the United States all have coastlines north of the Arctic Circle and are therefore considered Arctic coastal states. The eight Arctic states have (with the exception of Russia) multiple and overlapping organizational and institutional partnerships such as European Union membership (Finland, Sweden, and Denmark), the Schengen area (EU states plus Norway and Iceland) or the North Atlantic Treaty Organization (NATO). With the integration of Finland and Sweden into NATO, the littoral Arctic has largely become a bilateral NATO-Russian theatre from a security perspective.

The eight Arctic states are also the members of the Arctic Council, an intergovernmental consensus-based forum created in 1996 to promote peaceful cooperation in the Arctic and has become the primary diplomatic forum for Arctic issues. In addition to delegates from these eight member states, six Indigenous Peoples organizations have a status as Permanent Participants and observer status has also been granted to 13 non-Arctic states and 25 intergovernmental and nongovernmental organizations (O'Rourke, 2023, p. 12). Most notable among the observer states is China, which has declared itself to be a "near-Arctic state". Discussions within the forum have led to legally binding treaties on search and rescue cooperation (2011), oil pollution response (2012), and scientific research (2017). According to its charter, however, "the Arctic Council should not deal with matters related to military security" (O'Rourke, 2023, p. 12). Since the February 2022 Russian invasion of Ukraine, activity in the forum has stalled. Research efforts continue, however, and remain a significant and ongoing activity that generates relevant scientific data on the Arctic as well as providing a rationale for state actors to maintain a presence in the

[4] A note regarding sources in this section: despite the large number of reports and articles published on the Arctic, a surprising amount of basic information remains scattered about the internet and has been difficult to find in reliable and structured reports and analyses. We have noted our sources when applicable and have tried to ensure the accuracy of facts that appear unsourced in the text. Unsourced information – particularly regarding military systems in the Arctic – has come from a variety of sources such as Arctic specific websites or even Wikipedia, but has been cross-checked as thoroughly as possible.

region. Svalbard has hosted research stations from Poland, China, Italy, India, and the Czech Republic.

The eight Arctic littoral states have jointly declared that the International Law of the Sea Convention (LOSC) is applicable to the Arctic. Importantly, the territorial claims and exclusive economic zones (EEZ) of these states are mostly settled, albeit with a few exceptions such as Danish, Canadian and Russian claims to areas around the North Pole (Barkham, 2014; Breum, 2021).[5] Navigation rights are a more contentious issue. Canada has argued that the *Northwest Passage (NWP)*, a sea route connecting the Atlantic and Pacific Oceans by passing through Canadian islands in the Arctic, are internal waters for which ships require permission from Canadian authorities to transit. Russia has similarly argued that portions of the *Northern Sea Route (NSR)*, a similarly useful transit route from the Pacific to the Atlantic that is becoming increasingly relevant as sea ice recedes, are internal waters (Burgess et al., 2017, pp. 60–64). For decades, states such as the US have challenged Russia's exclusive claim to the NSR. Recent activities such as a 2018 freedom of navigation operation (FONOPS) by a French naval resupply ship and the more northerly transit of US Coast Guard icebreaker and research ship Healy in 2023 have signaled a continued willingness to resist Russian restrictions of the route (Staalesen, 2023; Zysk & Pincus, 2023). Given the current extent of summer sea ice, these routes have emerged as geostrategically important transit routes that enhance the importance of well-known "choke points" such as the Bering Strait and the GIUK (Greenland-Iceland-United Kingdom) gap that serve as entry points to the Arctic.

Russia has a dominant position in the region, with "at least half of the Arctic in terms of area, coastline, population and probably mineral wealth" (O'Rourke, 2023, p. 27). The Russian icebreaker fleet comprised of 38 ships dwarfs that of other states: Canada (6), Sweden (5), Finland (3), the United States (2), China (2), and the remaining states with one each (Norway, France, Germany, Japan, and South Korea) (Bronder, 2021; TRADOC, 2020, p. 11). Other states have sizable Arctic coastlines as well, including sparsely populated Canada and Greenland, and valuable energy and mineral deposits are spread throughout the region (13% world's undiscovered oil and 30% gas). This has led to a persistent narrative that competition over these resources will dominate Arctic geopolitics, but in fact nearly all energy and mineral deposits in the region lie within internationally recognized EEZs (Economist, 2012, p. 8). Current oil and natural gas production in the Arctic regions of Russia, the United States, and Norway is slated to continue for the foreseeable future, as are significant mining activities in Russia, Canada, Greenland, and on Svalbard. On Greenland, a self-governing territory whose ambitions for independence have been limited by the substantial Danish subsidies its residents receive, may have the incentive to expand its mining activities for rare earth minerals or uranium as the ice recedes (Halm, 2023).

The Svalbard archipelago, located 650 kilometers north of the Norwegian mainland, includes a cluster of islands around the largest island of Spitsbergen as well as Bear Island about 230 km to

[5] A territorial dispute between Canada and Denmark over an island in the Nares Strait was successfully resolved in 2022 (Beaumont, 2022).

the south. Svalbard is strategically located at the northern end of the GIUK Gap and, as an article on the Russian Ministry of Foreign Affairs website stated in 2020, it is therefore "essentially the gates to the Arctic" (Kostin, 2022). It has a unique legal status grounded in the 1920 Svalbard Treaty that recognizes Norway's absolute sovereignty over the territory but also ensures the right of other signatories to the treaty to pursue economic activities. An example of this are the Russian state-owned coal mining activities and its company town of Barentsburg populated by Russian citizens (Østhagen et al., 2023, p. 3). Norway's Kongsberg Satellite Service (KSAT) operates one of the largest satellite ground stations in the world just outside the main settlement of Longyearbyen, with subsea communications cables connecting the island to the mainland. The Svalbard treaty states that the archipelago "may never be used for warlike purposes". Interpretations of this somewhat vague formulation have sparked disagreement in the past, including after visits by Norwegian Naval frigates or when the island's main airport was used as a stopover for Chechen special forces trainers on their way to a military exercise (Baudu, 2023, p. 78). Russia has also taken issue with Norway's position that the treaty's equal rights and commercial access provision does not extend outward from the islands to the continental shelf, where rich energy and mineral deposits are found (Kostin, 2022).

The geopolitical dynamics of the Arctic have been hotly debated over the past several decades, as awareness has grown regarding the ongoing effects of climate change on sea ice coverage and the subsequent opportunities for increased access to the region. Current events also play a role. One likely effect of Russia's 2022 invasion of Ukraine and the significant losses in materiel and personnel it has since sustained is the increased importance of its nuclear forces based in the European Arctic (Hilde, 2023). The Arctic littoral states have, though the Arctic Council, have historically pursued productive and cooperative solutions to their disagreements over issues of common interest such as fisheries or search and rescue operations. This atmosphere of cooperation has stood in contrast to persistent predictions of a "great game" competition and conflict over resources and access (Rauhala, 2023). Whether this stability will continue, as existing players more firmly reassert their interests and new actors such as China pursue their strategic goals, remains unclear.

2.2 Environmental

The principal characteristics of the Arctic environment that are most obvious from a quick glance at a map are also among the most relevant: the region is remote and dominated by the maritime domain. Large portions of the Arctic Ocean are covered in sea ice, although climate change has caused a continual melting of multi-year ice and the extent of sea ice during the summer months has shrunk. Weather conditions in the region remain severe, with the small settlement in Alert, Canada (82° North) experiencing average winter temperatures of -30° C and summer temperatures just above freezing. The Norwegian city of Kautokeino, just inside the Arctic at 69° North and situated on an inland plataeu, has a slightly more hospitable climate (average temperatures of -14°C and 13°C). These averages do not reflect the extreme cold that commonly settles over inland portions of Norway, Canada, or Russia. Nor does it adequately describe the frequent mixed precipitation occurring along many Arctic coastlines that is challenging for both personnel and equipment. In contrast, many of the inland portions of the Arctic receive such low levels of precipitiation that they are considered polar deserts (NSIDC, n.d.).

The landscape itself is varied, including relatively open plains and plateaus throughout portions of the Russian and Canadian Arctic, as well as mountain ranges on the northern edge of the Canadian archipelago, across Greenland and on Svalbard (Britannica, 2024). Boreal forests filled with firs and birch trees can be found along the southern edges of the Arctic, but temperatures and weather conditions limit tree growth farther north. This tree line along the 10°C isotherm – which varies across the Arctic but is roughly analogous to the AMAP regional delination displayed on the map presented earlier – is gradually moving northward (Rawlence, 2022). Low-lying vegetation such as grasses, small shrubs and moss cover much of the Arctic landscape and the poorly draining soil beneath the tundra creates muddy conditions during the summers. Significant portions of the region are either permafrost (permanently frozen ground covering large portions of the Alaska, Canadian and Russian Arctic) or poorly draining boggy terrain that is most accessible when frozen and snow-covered during the winter months. During the summer, the top layer of permafrost (which is hundreds of meters deep in many places) often thaws for a brief period before freezing again.

Another unique aspect of the high polar latitudes are the large swings in daylight hours throughout the seasons. The Arctic Circle is defined by the southernmost extent of polar night (the period during the winter when the sun remains below the horizon) and midnight sun (the period during the summer when the sun does not set below the horizon). Between early April and early September, the settlement of Alert Canada experiences continuous sunlight, while Kautokeino has a shorter "midnight sun" season from the end of May until late July. During the rest of the year, four additional categories are useful: *civil twilight* in which the sun is just below the horizon and providing sufficient light for human activities without artificial illumination; during *nautical twilight* stars can be seen but enough light remains to retain visibility up to about 400 meters; darker still is *astronomical twilight* in which most celestial objects are visibile yet a very small amount of refracted sunlight remains; and *nighttime* in which absolutely no sunlight is visible.[6] Many locations throughout the Arctic have some form of light during the winter even when the sun remains below the horizon, and many locations experience some type of darkness during the late spring and early autumn. Whereas Alert Canada has two full months of night or astronomical twilight, Kautokeino at its midwinter darkest still retains civil twilight for four hours a day.

Another well-known Arctic phenomenon is the *Aurora Borealis* or Northern Lights, which occurs when the sun's emission of charged particles hit the upper atmosphere (ionosphere) and are deflected towards the pole by the earth's magnetic field. This interaction generates the colorful flourescent displays that are visible during the dark winter months. The intensity of solar emissions bombarding the ionosphere varies greatly, from periods of near calm "space weather" to intense geomagnetic storms that generate dramatic light shows but are also highly disruptive to GPS signals and radio communications. The sun's emissions follow an 11 year cycle, with the

[6] A useful source for checking the diurnal sunlight patterns of any city can be found here.

previous period of maximum intensity occurring in 2014 and therefore the next peak is expected in 2025 (NOAA/NWS, n.d.; Waldek & Dobrijevic, 2022).

Alongside some of these more permanent fixtures of the Arctic are the dynamic and increasingly disruptive effects of climate change. Temperatures in the region are rising much faster (between two and four times) than the global average, a phenomenon known as Arctic amplification (Rantanen et al., 2022). Even more dramatically, Svalbard is warming at least twice as fast as the Arctic (Charuchandra, 2023). A number of feedback loops exacerbate the warming. Among these are the loss of ice that also means the loss of its reflective properties, or the thawing permafrost releasing centuries of stored methane that is another powerful greenhouse gas. This is in addition to other effects such as fish species moving northward as the waters around their traditional habitats become warmer. Climate change is altering an already challenging environment.

2.3 Societal

The Arctic is sparsely populated and remote, with limited civilian infrastructure such as railroads and highways. Approximately four million people live in the region, with half of them living in Russia and 1.5 million across Scandinavia (roughly distributed evenly between Finland, Sweden and Norway).[7] In North America, the resident population of Alaska (approx. 735.000) has held steady for the past decade after continual growth, while the Canadian Arctic – and Nunavut in particular – has increased dramatically but still with a relatively small population of just over 100.000 inhabitants.[8] The population density in the Arctic regions of the Nordic countries, for example, is approximately six inhabitants per kilometer, quite modest numbers compared with Scotland (70/km), France (120/km) or Germany (230/km) (Arctic Review, n.d.). Around 75% of the Arctic's inhabitants live in larger urban settlements, and economic growth related to resource extraction is reinforcing this trend (Lanata, 2021, p. 39). Around ten percent of the Arctic's inhabitants are indigenous peoples with distinct cultural and societal traditions. Many continue to rely on the surrounding environment for subsistence in the form of fishing and hunting. Indigenous peoples across Scandinavia and Russia are engaged in reindeer husbandry as a commercial enterprise.

Civilian infrastructure is limited and localized in the Arctic. The cold climate increases the demand for electricity, but some localities, particularly in Asian or North America, are not connected to regional power grids like most communities in the European Arctic and therefore rely on local grids. Other governmental resources such as schools and hospitals are quite limited. Communication via cellular telephone networks is possible in most areas within the Nordic countries, as well as near population centers in Canada and Alaska. Outside these zones, telecommunications options for residents consist of long-distance very high frequency (VHF) or high frequency (HF) radio links or Iridium satellite telephone, although coverage and connectivity is often inconsistent (TRADOC, 2020, p. 16). One recurring issue is the geomagnetic disturbances

[7] This varies according to how the Arctic is defined and can include as many as 7 million. See Lanata (2021, p. 39).
[8] Population figures from Statista here and here, as well as the Arctic Demography Index from the Arctic Council found here.

in the ionosphere that cause the aurora borealis. This and other types of space weather can disrupt HF transmissions. Satellite coverage can also be poor. Signals from communications satellites in geosynchronous orbit (GEO) around the equator have a low angle relative to the horizon in the polar region and negatively affects coverage. Satellite navigation suffers from a similar issue with most global navigation satellite systems (GNSS) in medium earth orbit (MEO), but this depends on the inclination of the satellite network's orbit (Yastrebova et al., 2021). GPS signals can also be affected by space weather, limiting receiver connectivity with the system's satellites or reducing the accuracy of stated positions (NOAA/NWS, n.d.).

Transportation infrastructure is not widespread. The most accessible transportation option for Arctic populations continues to be the numerous small and medium sized airports that are spread throughout the region, although few major airports have onward connections to major airline hubs (Nordregio, 2019). Road and rail infrastructure is extremely limited: a single highway stretches north in Alaska and western Canada, some access to the easternmost and westernmost corners of Russia, as well as some routes in the Scandinavian countries. In some parts of the Arctic such as Alaska, unpaved gravel roads are a preferred highway surface due to the persistent need for repairs from the constant melting and freezing of the upper layer of permafrost. The warming in the Arctic from climate change has significantly exacerbated this problem, with implications for road surfaces, airport runways, and building infrastructure (Bernton, 2019).

Maritime operations to the Arctic remain challenging. Sea ice prevents the use of permanent navigation aids such as buoys and some parts of the region lack adequate charts. Access to deep-water ports is scarce as well. US Coast Guard icebreakers have a draft of 12-13 meters while other research vessels may anywhere from 5-10 meters (O'Rourke, 2023, p. 50). The northern coastline of the North American Arctic is quite shallow, and the closest options are Dutch Harbor in the Alaskan Aleutian Island chain and the Canadian near-Arctic port of Churchill on the Hudson Bay. The Nordics have far more alternatives, and Russia alone operates at least eight civilian ports spread along its northern coast. Russian nuclear-powered icebreakers are in operation year-round to ensure access from the liquid natural gas (LNG) facility on the Yamal Peninsula and onward through the Northern Sea Route (Nilsen, 2023).

The lack of economic infrastructure offers an opportunity for external actors to provide financing as a means of establishing a foothold in the region. The Yamal LNG facilities exemplify the economic cooperation between Russia and China in the Arctic, with Beijing holding minority shares (along with the French energy company Total) in several LNG projects and committing to future gas imports. China has expressed a desire to incorporate the Northern Sea Route into its strategic commercial transit Belt and Road Initiative (BRI) effort as an alternative to dependence on the Malacca Straits (Conley et al., 2020, p. 8). China therefore heralded the creation of a "Polar Silk Road" in 2017, but tangible investments in infrastructure projects have yet to materialize. Apart from their Russian partnership, China has thus far been largely unsuccessful in its attempts to gain a commercial foothold in the European Arctic. Investments in aluminum smelting (Iceland), uranium and rare earth mining (Greenland) and harbor development projects (Norway) have not moved forward due to a combination of local resistance and governmental pushback (Almén & Hsiung, 2022, pp. 23–30).

In general, the harshness of the Arctic climate and its unique geology has limited human activities and prevented the development of infrastructure needed to encourage greater access to the region. Arctic populations are concentrated in small urban centers, and population growth often comes from economic activity tied to resource extraction. Infrastructure and communications are fairly limited and regularly disrupted by environmental factors.

2.4 Military Systems

Through modern military logistics, equipment and forces can be transported almost anywhere in the world if adequate resources and time are provided. This is partially true in the Arctic. Maritime assets without ice-strengthened hulls can venture far into the region, depending on the limits of sea ice. The only limits for aircraft deploying to the polar region are weather conditions, operating ranges, and the availability of suitable runways. Properly trained land forces outfitted with appropriate equipment can rapidly deploy to the region. In other words, military forces outside the Arctic can still be relevant to military operations in the Arctic. However, there are several important caveats to consider. Simply because forces and equipment can be transported to the Arctic does not mean they will be able to operate effectively in the harsh environment – proper cold weather training and equipment standards are crucial. An additional challenge is the lack of proper infrastructure that limits options for debarkation.

Our overview of military assets relevant to the region will be limited primarily to those forces stationed within or near the Arctic, although other units may have trained extensively in the region and are accustomed to operating there. Assets include permanent facilities in the region such as military bases or radar stations, military forces such as the Russian Northern Fleet that are permanently stationed in the Arctic, and coast guard vessels from the respective states that are likely to have a functional role in a military operation such as search and rescue. The following overview focuses primarily on the forces and infrastructure of the seven Arctic states (as a matter of policy, Iceland does not have military forces), and is not intended to be an exhaustive catalogue of all forces in the region.

The *United States* operates several military bases in Alaska, including Elmendorf-Richardson (near Anchorage) and Eielson (near Fairbanks). The Alaskan-based air assets include F-22 and F-35 fighters, E-3 AWACS, C-130 transport planes and rotary wing aircraft. The US operates a number of early warning radars, including the large Cobra Dane installation on the Aleutians, and access to the Thule base in Greenland. The US Army's 11th Airborne Division comprising two infantry brigade combat teams is based at Elmendorf-Richardson. The Alaskan Army National Guard has several thousand reservists and maintains facilities throughout the state. There are no naval capabilities permanently stationed in Alaska, but US attack submarines routinely pass through the area. The US Coast Guard has two icebreakers, but only the Healy regularly operates in the Arctic. The new class of national security cutters are not ice-strengthened.

The *Canadian* armed forces have a range of relevant assets but not a significant number of forces permanently stationed in the Arctic with adequate reach into the region. The navy has surface ships capable of reaching the northernmost portions of the country, some of which are ice-hardened. The coast guard operates six icebreakers and seven smaller vessels. There are plans to acquire additional Arctic Offshore Patrol Boats that may be based at the coast guard facility at Halifax, and an additional secondary coast guard base is located on Nunavut. Canadian fighter aircraft based in the southeast and central parts of the country regularly conduct Arctic patrols, as do the P-3 Orion anti-submarine warfare patrol aircraft stationed on the east coast. The Canadian air force operates tankers and both C-17 and C130J aircraft for Arctic search and rescue. While the air bases are not in the Arctic, there are secondary airfields in several far north locations. A collection of early warning radars spread across the country dating back to the Cold War are currently being refurbished and updated, and the "Polar Epsilon" satellite surveillance effort will improve situational awareness in the region. Land forces include Canadian Arctic Rangers, a lightly armed force of about 5000 troops that conducts year-round reconnaissance patrols, and a small reserve unit in Yellowknife in the western part of the country. A small military base is located in the northern settlement of Alert.

The Nordic countries have small but capable Arctic forces. *Denmark's* military presence on Greenland is fairly limited, but a military base at Thule is shared with the United States and can be used to host Danish maritime patrol aircraft and F-35s. The country operates surface vessels capable of operating from a naval base in southern Greenland, including both frigate and corvette classes of ice-hardened offshore patrol vessel. Several land force units are worthy of mention, including the Frogman Corps and the Jæger SOF, both approximately 200-300 strong. The small but renowned sledge patrol Sirius (comprising just 12 personnel in total) also conducts reconnaissance patrols in northeastern Greenland. *Norway's* F-35s are stationed at Ørland airbase outside the sub-Arctic city of Trondheim and operates P-8 maritime patrol aircraft and additional F-35s from the Arctic base of Evenes. The Norwegian navy operates four frigates (not ice-strengthened) and a small number of diesel-electric attack submarines in the region while the coast guard has one medium icebreaker. Norwegian land forces include a light infantry battalion near the Russian border, a mechanized brigade with main battle tanks and infantry fighting vehicles (IFV) in Bardufoss, the MJK Naval Special Operations base in Ramsund, and mechanized infantry with IFVs in Porsanger. The Home Guard reserve force represents an important military capacity in the country's northernmost province. The *Swedish* armed forces have some assets stationed in the north specializing in Arctic operations, including the Ranger light infantry battalion, the Norrbotten regiment with an armored battalion and a ranger battalion, an artillery regiment, and an air wing comprised of JAS 39 Gripen fighters along with NH-90 helicopters. *Finland* maintains army light infantry brigades in Rovaniemi, Sodankylä, Kajaani and Kouvola. An air wing of F-18 fighter aircraft is stationed at Rovaniemi, although the unit will begin receiving the first of over 60 F-35s in 2026. The naval forces of both Sweden and Finland operate primarily in the Baltic Sea.

Russia's military forces are spread unevenly across its northern coastline, the most significant being the Northern fleet's cluster of military facilities on the western portion of the Kola peninsula, a location that ensures ice-free access to the North Atlantic. The naval forces based here include the ballistic submarines that constitute an important part of the country's nuclear deterrent, its sole aircraft carrier, and numerous surface ships. The bases are protected by land forces associated with the army and navy, along with significant air defense systems and a chain of small radar purportedly designed to detect low signature aircraft. The islands to the northeast, Franz Josef and Novaya Zemlya, both have military airfields and air defense systems, with the latter hosting MiG-31BM interceptors and Su-24 attack aircraft. Bases on the islands and mainland Russia in the central and western Arctic, Moscow has built new military bases, emplaced radar units, defensive missile systems and garrisons for land forces (Kjellén, 2022).

Figure 2.1 Russian military and civilian infrastructure in the Arctic (Kjellén, 2022, p. 43).

Viewing the current status of military forces deployed in or near the Arctic, there are relatively few permanently stationed assets in the region. Apart from air assets stationed in Alaska, the preponderance of military capabilities is located in the European Arctic among Russia and the Scandinavian countries. Russia operates a much broader network of military bases than the other Arctic nations combined, although most states have a fairly robust network of radar installations. Many of the Arctic navies lack ice-strengthened ships apart from coast guard vessels, limiting their utility for much of the year in northern waters.

2.5 Doctrines and Concepts

Any military operation conducted in the Arctic will likely be organized and executed in accordance with the relevant military doctrines and operating concepts, along with more specific tactics, techniques and procedures (TTPs). *Doctrine* is a set of “fundamental principles” guiding the employment of military forces. A military concept, on the other hand, is a “description of a method or scheme for employing specified military capabilities in the achievement of a stated objective or goal” that could be viewed in terms of ends, ways and means, whereas *operating concepts* describe the “application of military art and science within some defined set of parameters” (Schmitt, 2002, p. 7). Concepts are “at the core of all doctrine”, John Schmitt notes, but “concepts are not doctrine until tested, approved and promulgated as such by proper authorities” (Schmitt, 2002, p. 4). Contained within doctrines and concepts are more specific ways of employing military force such as tactics, techniques, and procedures (TTP) that have been developed over time.

The armed forces of the NATO-aligned Arctic states, along with their allies and partners, have well-established doctrines, concepts and TTPs that allow them to operate together. These organizing principles should, in theory at least, be equally applicable to Arctic operations as they would be for an operation in the tropics. The United States and its NATO allies have also developed more specific concepts and TTPs for cold weather operations. The following section outlines some of these underlying principles and how they are likely to apply in an Arctic context, as well as the more specific TTPs relevant for the region.

Modern military operations are normally planned as *joint* operations involving more than one service branch (land, air, maritime, special operations forces, cyber, or space). In a NATO context, these are usually *combined* joint operations, signaling that the armed forces of more than one country are involved. Combined joint operations in the Arctic are complicated due to the region’s remoteness. The region’s low population density has implications for logistical support from allies, including significant transport times and a lack of staging facilities. The limited military capacity of most Arctic NATO members – with air power as one exception – will entail allied support in a combined joint operation, but member states must then provide personnel and equipment appropriate for the environment. The NATO Center of Excellence for Cold Weather Operations (CWO) in Elverum, Norway, is tasked with developing best practices as well as operating a facility for training NATO personnel in cold weather operations. A guiding principle in that effort is that forces can only *master* the environment and succeed in their mission if they are first able to *survive* as well as *operate* in cold weather conditions.

NATO forces operate in accordance with a combined arms maneuverist approach. Combining various capabilities such as tanks, artillery and dismounted infantry can create advantageous synergies between them and reduce some of their inherent vulnerabilities. These quickly become joint operations with the integration of assets from other domains such as close air support, satellite imagery, or long-range fires from surface vessels. Achieving the necessary coordination and the required vertical and horizontal flow of information often involves overly time-consuming operational planning processes and places a premium on robust command and control structures.

Applying military force according to a maneuverist approach entails targeting an adversary’s capabilities with the primary goal of reducing their cohesion and resolve by imposing multiple dilemmas on their decisionmaking. An attrition-based approach, on the other hand, emphasizes the destruction of an opponent's capabilities to sufficiently erode their warfighting ability (NATO, 2022, pp. 82–84). The continued evolution in precision standoff weaponry and intelligence, surveillance and reconnaissance (ISR) sensors has made some observers begin to question the traditional battlefield geography distinctions of relatively safe areas in areas controlled by one's own forces (rear), those areas adjacent to an adversary's forces (close) and the areas behind the adversary's front lines (deep). This rear-close-deep construction remains useful in discussing operational elements such as intelligence gathering, tactical maneuver, or sustainment activities (Freedberg, 2017).

For operations in the Arctic, the basic doctrinal approach described above remains relevant for certain geographic areas such as northern Scandinavia, where elements can combine to create joint effects. Even so, the environment, terrain features and existing infrastructure restrict mobility to such an extent that fully implementing tactical and operational maneuver can be challenging (Dzwonczyk & Radunzel, 2020). In most areas of the Arctic, the remoteness and significant distances serves to limit options to maritime, air and space assets. Conducting modern joint operations requires significant intelligence-gathering capabilities, substantial planning and coordination, as well as robust command and control to synchronize and de-conflict tactical efforts. All three aspects are particularly difficult in an austere Arctic environment.

2.6 Joint functions analysis: Implications for military operations[9]

For military commanders faced with conducting an operation in the Arctic today, the confluence of geopolitical, environmental, societal, military, and doctrinal factors creates a challenging set of conditions. The remoteness and harshness of the region imposes a basic set of requirements at the tactical and operational levels.

Command and Control (C2). Satellite coverage remains limited in the polar region, whether for ISR or communications. Communication between one's forces can be unreliable in the Arctic, particularly if those forces are dispersed. Tactical engagements in separate domains are most often coordinated but not synchronized. In denied environments, units are more likely to operate independently based on the commander's intent rather than maintaining direct and continuous contact with the higher headquarters.

Maneuver and mobility. Simply moving and positioning forces into the theater can be difficult given the limited number of suitable options for debarkation by air or sea due to the large number of small local airfields and shallow seas near the coast (particularly in the North American Arctic). Local residents are keenly aware that land mobility in the Arctic is season-dependent, and this is even more applicable for military forces. During the cold winter months, mechanized forces can travel across the frozen ground if snow depths allow, while lighter equipment such as snowmobiles provide a good transportation option for smaller units or special operations forces. Personnel using skis or snowshoes may be able to move relatively freely but far more slowly across terrain, and the strenuous effort can easily reduce combat effectiveness. Winter conditions

[9] This section relies heavily on Dept of the Army (2016, p. 3); NATO (2007); and TRADOC (2020).

serve to reduce operational tempo and can limit both maneuver and the potential for decisive action.

Figure 2.2 *US Naval Special Warfare Operator (SEALs) and Norwegian Naval Special Operations Commandos during the joint submarine/special operations forces exercise* Arctic Edge *in March 2024. Photo from the United States* [Naval Special Warfare Command.](#)

The transition periods between seasons can often be the most challenging, with rainy and muddy conditions that are difficult for mobility. Once the short summer season finally arrives, it brings a new set of problems as the ground remains soft and vehicles are confined to the limited roadways in the region, constricting the options for feints and other forms of deceit and surprise. The constant summer daylight and the soft and open Arctic tundra terrain offer few possibilities for concealment or complex maneuver. In the air domain, operations are relatively unchanged for fixed wing aircraft apart from the specialized equipment such as parachutes for landing on icy runways, while rotary wing aircraft can be more susceptible to inclement winter weather such as whiteouts. In the maritime domain, sea ice limits movement for surface vessels but provides cover for submarines.

Intelligence. Collecting information and establishing situational awareness in the Arctic have some unique aspects that provide both challenges and opportunities. The extended winter darkness, particularly if combined with inclement weather, can be problematic for optical sensors and thus can provide cover for maneuver. In fair weather, movements can be more difficult to conceal due to tracks left in the snow. Thermal imaging may be more effective due to the temperature gradient between the human body and the ambient winter air, although precipitation may reduce the efficacy of thermal optics. Good countermeasures to partially shield the thermal signatures of personnel and equipment are possible but are easier to utilize in static positions rather than while moving. The lack of a civilian population in some areas will make civil-military relations a non-issue, while military personnel in other regions of the Arctic may face skepticism from local residents accustomed to the isolation and autonomy that remote regions offer. In the Scandinavian Arctic, however, the civilian populations are often closely intertwined with the armed forces with robust reserve components and Home Guards comprising a substantial portion of the population.

Fires. The cold reduces the effects of small arms and artillery fire, possibly requiring more ammunition to achieve the same effects. Gunpower burns more slowly, affecting precision (COE CWO, 2021). The C2 issues inherent in the Arctic may reduce the precision of long-range fires, and the availability of Arctic-capable land forces may limit supporting fires. On the other hand, the open terrain and relatively modest civilian population make joint targeting and long-range fires less complicated as adversarial targets are easier to positively identify.

Sustainment. Sustaining forces over time will be difficult and expensive due to the substantial distances involved and the increased fuel and food needed to counter the cold temperatures. Limited civilian infrastructure in many Arctic regions means that military forces will often be required to be entirely self-sufficient, with few auxiliary options for food, fuel, electrical grids or communication. Equipment issues or lack of resupply can quickly degrade readiness unless forces are well prepared and well trained.

Protection. Force protection considerations start with individual protection from the elements, as they can often be as lethal as an adversary. Proper clothing and cold weather techniques will be crucial. The Arctic poses particularly severe trade-offs between protection and mobility, as heavier vehicles can struggle in deep snow or muddy springtime conditions.

These and many other aspects of conducting Arctic operations are well-known to military forces that regularly train and operate in the northern latitudes. Many NATO members have become more aware of the realities of cold weather operations as well as the need to invest in adequate equipment and training. In a rapidly evolving region, however, these tactical and operational aspects of military operations may also be changing as climate change affects not only the physical environment but also the geopolitical and societal dimensions of the Arctic.

3 Future scenarios in the Arctic

This chapter contains descriptions of three possible Arctic futures based on a careful assessment of the logical assumptions and implications derived from future trends within each of the five FOE factors. The transition from evaluating the current operating environment to evaluating a potential future in the context of long-term defense planning raises several analytical challenges. The cognitive pitfalls associated with foresight analysis are well-known and yet difficult to avoid. These can include arriving too quickly at (and retaining for too long) faulty conclusions, a tendency to succumb to group-think or tunnel vision, ascribing too much weight to current trends and threats, or disregarding elements that are less obvious and sometimes less understood (Beadle, 2016). The linkages and interactions between relevant factors in an operational environment are complex and difficult to identify and visualize, even when trying to conceptualize relationships between well-understood factors in a contemporary environment.

One common analytical method for combining factors and examining the interactions between them is through the use of scenarios (Beadle, 2016, p. 59; Johansen, 2022; Vatne et al., 2020, p. 14). By creating a hypothetical context that incorporates more detailed assumptions about the relevant factors, we are able to more clearly understand the relationships between these factors and the second order effects that can emerge. Scenarios enable us to conduct a more multi-dimensional analysis instead of exploring one variable at a time, which makes it easier to visualize and contextualize the hypothetical environment. On the other hand, we must be cautious with the use of scenarios for understanding future operating environments. It is possible to create a credible, detailed, and completely faulty future context by making a series of assumptions about certain factors, which then form the foundation for additional assumptions about how these factors influence each other. It can be tempting to accept a detailed and believable scenario and its logical conclusions as *the* likely future and overlook its weak empirical foundations. Scenarios are simply a tool for exploring possible futures and challenging our current set of assumptions about future requirements.

Scenarios vs. futures

For nearly two decades, FFI has utilized a portfolio of specific scenarios to better understand long-term defense planning requirements. These hypothetical situations involving the Armed Forces are focused primarily on the short to medium term (up to 20 years) and derived from a structured morphological analysis of actors, objectives, methods and means.

In contrast, the three future scenarios analyzed in this report seek to look farther into the future, and with a broader focus on the overarching context within which the threat analyses from the FFI scenario portfolio might transpire. The three futures in this chapter are therefore not comparable to FFIs scenario portfolio but are intended as a supplement to the planning process that can enrich the current set of planning scenarios and potentially even identify new ones.

As noted in the introductory chapter, we have relied on a variety of source material for the trends and assumptions within each factor.[10] Three distinct future contexts have been created from various combinations of assumptions about the drivers of future change and the consequences of those drivers, along with a short "fictional intelligence" (or FICINT) vignette for each of the three futures. These are intended to help the reader better understand the various aspects of each of these futures and the interaction between the five factors. The first two futures have drawn inspiration from the brief scenario descriptions in the NATO report *Regional Perspectives on the Arctic* (Lanata, 2021, pp. 57–59).[11] It is worth noting that we have included references throughout these future scenarios. These are intended simply to demonstrate some connection to events, trends or discussions occurring today surrounding a particular trend or potential future development. The references are not intended to be documentation that these trends will come to fruition, but simply to provide the reader with additional background and suggested sources for additional reading.

3.1 Future one: An active and unregulated Arctic

Geopolitical

Receding US global influence and leadership, combined with China's strategic focus remaining primarily on the Asia-Pacific region, has resulted in a disorderly and fragmented international system by 2050. Global economic growth has stalled, and previously strong transnational commercial ties have now fractured into a balkanized structure of regional and ideological trading blocs. The past decades of expanding economic and regulatory regionalization have resulted in parallel ecosystems of technological development (or *techno-spheres*) as well. Economic actors have therefore expanded primarily within the confines of their respective regions and blocs. The fractured economic landscape and lack of a dominant actor – particularly one such as the United States that previously had a stake in preserving the liberal international economic order – leaves the international security system dominated by alliances and regional power dynamics. International laws and norms that once governed state conduct have been severely weakened. European states struggle with a combination of climate change mitigation costs and an influx of climate migrants from regions that have become unlivable due to temperatures and lack of water.

The security landscape in the Arctic is characterized by a weak euro-centric NATO and the dominant position of Russia, which remains somewhat isolated internationally but has further solidified its position in the region over the past decades.[12] States and private actors are actively pursuing natural resources in the region, including land-based and seabed mining operations,

[10] Generally, the source material is as follows: geopolitical (primarily NIC (2021) for their global trends scenarios), environmental (varied IPCC reports and media accounts), societal (synthesis of future trends reports), and military and doctrine (our earlier FFI reports on state and non-state actors).

[11] More specifically, these are "Alternative Scenario 1: Fragmented Arctic" and "Scenario 2: Enhanced Russia-China cooperation and militarization". Additional inspiration was derived from the scenarios developed in the National Intelligence Council's *Global Trends 2040* report (National Intelligence Council, 2021, pp. 112–117).

[12] For a well-constructed scenario of how Russian political developments through 2025 might lead to this outcome, see Kendall-Taylor et al. (2022, pp. 6–8).

commercial fishing fleets, and offshore oil and gas development. Regulatory structures and cooperation among actors are ineffective due to crumbling international laws and norms and the inability of a severely weakened Arctic Council to handle these conflicting interests. As a function of diminishing respect for international rules and regulations, commercial actors are pushing the legal and ethical boundaries for resource extraction, particularly in international waters and increasingly intruding on national EEZs.

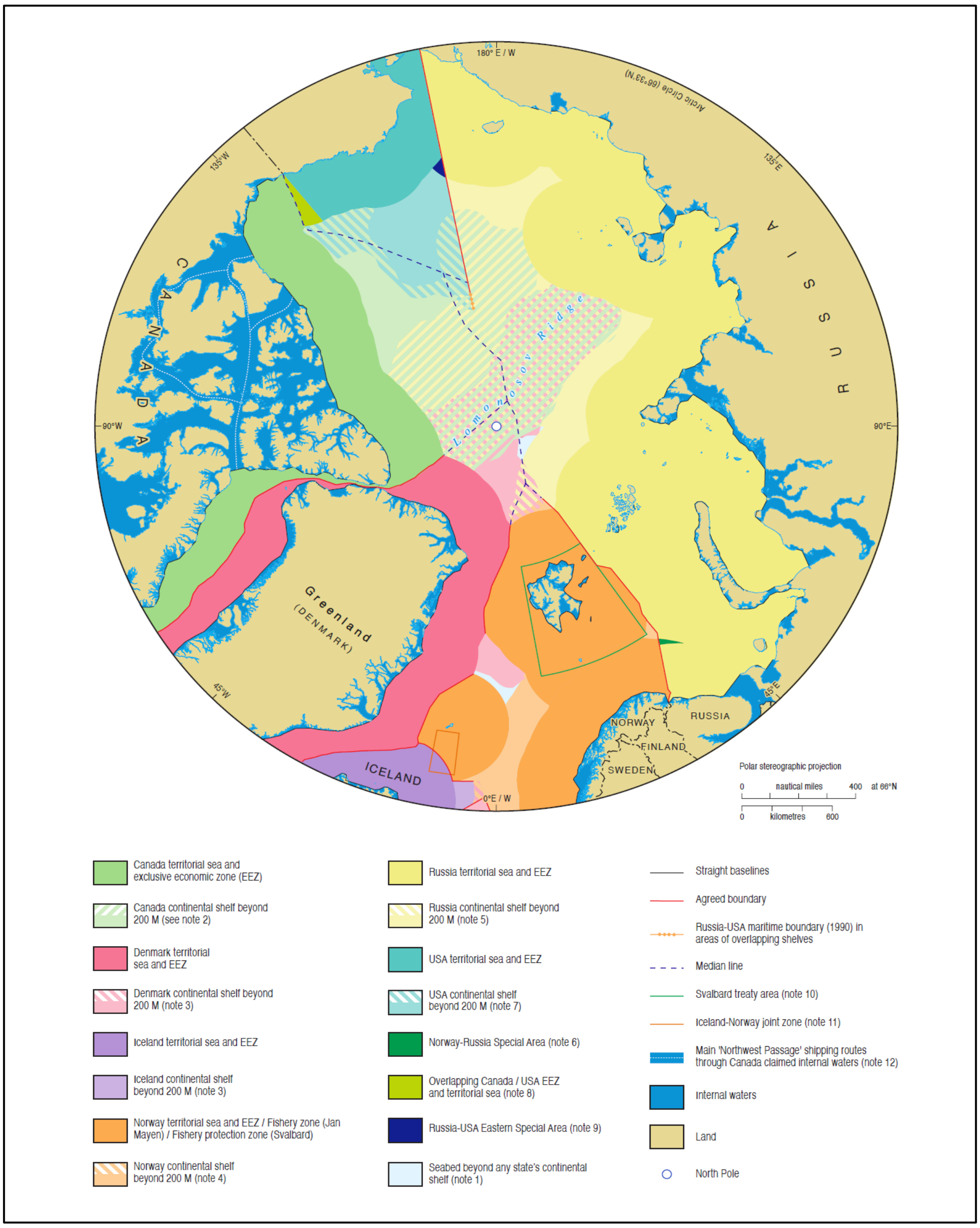

Figure 3.1 Current maritime jurisdiction and boundaries in the Arctic (from Durham University Department of Geography).

The United States, once a leader in the region, has de-prioritized the Arctic as it did decades ago during the Trump administration (Buchanan, 2023). Across the region, commercial actors have contributed to a limited amount of infrastructure development. This has made states more reliant on private infrastructure to operate in the Arctic, leaving them vulnerable to corporate pressures. Western actors are engaged in more friendly competition, while the competition with Russian state and non-state actors has intensified in this increasingly fractious environment. The balkanized economic system and the West-East technological divide is clearly visible in the region, as the Arctic states utilize varying levels of technological sophistication in the solutions they implement. Technology from the transatlantic techno-sphere is more efficient, whereas the Russian solutions are adequate but less reliable and with greater safety issues. Incidents of corporate espionage are more prevalent.

Environmental

The negative impact from climate change became apparent during the 2030s as extreme droughts, heat waves, violent storms, and coastal flooding affect large swaths of the globe. The fracturing of the global economy and subsequent solidification of distinct informational spheres resulted in little progress on finding global solutions to the climate crisis, as the various economic blocs were unwilling to bear the necessary economic burdens without assurances that the costs would be distributed equitably. As the global average crept past two degrees over pre-industrial levels, the Arctic continues its transformation as it warms at a much faster rate than the rest of the planet (Rantanen et al., 2022). Summer sea ice in the Arctic has disappeared completely and multi-year ice levels have dropped precipitously (Kaur & Mooney, 2023). The single year sea ice that does form is usually thinner and more easily broken into loose ice from wave action, creating greater numbers of small icebergs and floating ice chunks that remain a serious hazard to surface vessels (AMAP, 2017, p. 109; Lanata, 2021, p. 21; O'Rourke, 2023, p. 49). The Greenland glaciers continue their retreat, revealing land that had previously been covered in ice for thousands of years and contributing to rising sea levels globally.

Precipitation amounts have increased but fall more often as rain since the snow season has been shortened by several months. Along the coast, erosion has become severe without the sea ice to protect it, and foggy conditions that previously were a rarity in the Arctic are now far more common (Dzwonczyk & Radunzel, 2020; Lanata, 2021, p. 24). Some fish stocks have migrated northward in search of colder water, while others have simply disappeared (Herff, 2023). On land, smaller streams and rivers are more susceptible to flooding from the frequent extreme weather events that now affect the region. Despite the increased precipitation, higher temperatures have increased the rate of evaporation and the soil is paradoxically too dry in some areas (Norwegian Climate Service, 2022). Permafrost melting across the Arctic has made the land more unstable, released massive amounts of methane into the atmosphere, and revealed plant and animal life that lay frozen for millennia – including ancient bacteria and diseases for which modern society lacks immunity or effective medicines (UK Ministry of Defence, 2018, p. 260). Due to the changing weather and its effects on the land, reindeer husbandry has mostly disappeared as an income source for indigenous peoples (Rawlence, 2022).[13]

Societal

By 2050, the Arctic population has experienced modest growth due to increased economic activity from resource extraction. Some traditional white-collar workers have also relocated to the region, mostly those who have relocated due to their interest in winter activities as colder winters disappear further south in Europe. Artificial intelligence has powered significant advances in other fields such as science, engineering, and medicine. It has transformed many sectors of the economy, particularly in the highly developed democracies. Many of the more cognitively demanding professions such as law, economics, engineers, coding specialists or scientific research are now partnerships with intelligent AI agents (Cazzaniga et al., 2024). The workforce of 2050 has evolved in significant ways.

Satellite coverage in the Arctic is now robust enough to support reliable global communication via high-speed satellite internet. Indigenous populations have reluctantly transitioned to tourism after losing their traditional commercial activity once reindeer herding became economically unviable. The world has yet to completely replace fossil fuels, particularly as economic and population growth in the Global south continues to drive energy demand. The mostly autonomous oil and gas production facilities established in the European and Russian Arctic during the early 2030s remain commercially viable. Manufacturing and transportation have undergone significant changes during the fifth industrial revolution as machine intelligence merged with advanced robotics (Callaghan, 2022). Skilled laborers such as carpenters, plumbers, and electricians have seen fewer disruptions. Robotic repair facilities, themselves a combination of robotic technicians and humans, are in high demand. Many of these facilities are based in Norwegian coastal ports such as Kirkenes and Tromsø. Medical facilities have been at the forefront of this technological evolution, but health facilities remain limited to the larger urban centers. The technological divide between Western countries and Russia is obvious from the human-intensive mining and fishing activities being conducted on the Russian side of the border.

Civilian residential infrastructure and transportation in the Arctic is widely electrified, fed mostly by renewable energy production in the European Arctic and with fossil fuels in the Asian Arctic. The transmission networks have been expanded to handle the increased consumption from industry, although some offshore windfarms support maritime resource extraction activities (Ljønes, 2023; Statnett, 2021). Nuclear energy is utilized in military-industrial hubs in the Russian Arctic. Terrestrial transport in the Arctic remains primarily fossil-fuel based for heavy transport due to the long distances involved, but civilian private transport is more often hybrid (Det Norske Veritas, 2023a, p. 19). Seaborne transport in the Arctic still relies on diesel due to the limited

[13] Unable to forage through the once dry powdery snow for lichen on the open Arctic tundra, either due to rain-on-snow events that freeze the snow surface or the northerly expansion of birch trees that collect snow in drifts, winter grazing becomes impractical and alternate feeding solutions too costly. Winter grazing has already become a recurring issue in northern Norway (Faugstad & Estenstad, 2024; Norvang et al., 2020; Rawlence, 2022).

support infrastructure in the region needed for the new fuels, which is prevalent in other regions. Aviation for passenger and cargo transport relies on fossil energy and in a few instances e-fuels.[14]

Land-based infrastructure remains limited due to permafrost heaving and coastal erosion, but existing roadways have made accommodations for commercial autonomous transport. Ship traffic has instead expanded to handle the increased demand for supplies and consumer goods. Fishing grounds have moved farther north and the waters off Svalbard have become particularly productive, causing the international moratorium on central Arctic fisheries to expire in 2037 (Anania, 2023; Grossman, 2021). Ships from the Northern Sea Route mingle with supply vessels from these facilities, along with those servicing the fully autonomous seabed mining installations off the coast of Greenland and Norway. Mining operations for key minerals supplying the IT, robotics and battery industries remains insatiable. Supplies from non-aligned states in the global south have become unreliable in this globally divided economy, making the costly Arctic resources a more dependable alternative (Fouche & Adomaitis, 2023; Halm, 2023; Watson et al., 2023). The autonomous land- and sea-based transports carry valuable cargo have been subject to thefts and hijackings.

Military systems[15]

Above the Arctic, civilian satellite constellations travel in polar orbit and provide reliable communication and internet service to both urban and isolated populations in the region. A smaller number of military-grade communications and ISR satellites cover the polar region as well, providing capabilities that are less suited to civilian infrastructure. High-flying hydrogen-powered UAVs act as pseudo-satellite relay nodes for ground-based communications to provide an affordable redundant capability (T. Robinson, 2020). The space-based sensors complement the enhanced ground-based early warning radar network that forms a half-ring around the North American Arctic, able to identify and track potential incoming ballistic and cruise missiles over the pole (Bye, 2022). These installations and the significant air capabilities still based in Alaska – which include sixth generation fighters and bombers as well as fleets of collaborative combat aircraft (CCA) –represent the bulk of US assets in the Arctic, having ceded responsibility of the region to its NATO allies to focus on Asia. The Canadians retain their reservist land forces in the Yukon and Arctic Ranger groups spread across the northern part of the country. Its navy and coast guard regularly patrol the navigable waters of the Northwest passage and around the northwestern edge of Greenland near Nunavut, relying heavily on unmanned systems for situational awareness.

The NATO countries have leveraged the development of new materials and production techniques to develop more robust, long-lasting and cold-resistant batteries as well as UAVs with integrated warming elements to prevent icing and moisture build-up. This has proven invaluable in the Arctic, as has the new generation of 25-meter hybrid drive USVs that act as scouts and echelon support ships for the navies of small states such as Norway and Denmark (Slayton, 2022). Equipped with organic AUSs and UAVs, these autonomous surface vessels have greatly increased the maritime capacity of these countries without relying on unsustainable personnel levels. The

[14] Battery weight makes fully electrical systems only viable for small aircrafts travelling short distances. E-fuels based on green or purple hydrogen-energy technologies is more widely in use in the developed world (Det Norske Veritas, 2023a, pp. 20, 58). See the appendix for more details on the potential trajectory of civilian technology and its possible effects on society.

[15] This section is largely based on Mayer (2022).

growth in infrastructure on the seabed as given rise to military systems that can operate deep underwater (Klawans, 2023). Denmark's military presence in Greenland has increased substantially and works in close cooperation with the Norwegian armed forces.

The Nordics have several armored brigades permanently stationed in the Arctic with main battle tanks and UGVs, and field advanced tactical air defense systems with electronic warfare and directed energy weapons for swarm defense. The Nordic air forces are therefore fully integrated and regularly operate and train their ageing fifth generation aircraft together. The algorithms and models governing the tactics used by their CCA are shared between them, allowing squadrons of F-35s, JAS Gripens and their unmanned "wingmen" to operate seamlessly. Modern military forces have further developed the communications and data links necessary to connect their systems into one battlefield network. The network data collected by the nodes in the system are continuously monitored and analyzed by artificial intelligence.

Russia recovered from its disastrous Ukrainian campaign during the 2020s to fully recapitalize its military forces. Western sanctions and a deglobalized economy forced the country to revitalize and fully modernize its domestic defense industrial base. Strategically, its military posture now focuses almost exclusively on the Arctic as a means of remaining globally relevant. The country's nuclear deterrent continues to be the most relevant aspect of its Arctic military posture, comprising SLBM-armed submarine as well as land- and surface ship-based nuclear-armed cruise missiles. The broad network of air and naval bases along its northern coastline are bustling with activity, most notably facilities from Wrangel island in the east to Franz Josef Land and the Kola peninsula in the west. Modern air and ship-defense systems coupled with long range hypersonic cruise missiles represent a significant A2/AD threat. A fleet of both modern and antiquated atomic icebreakers keep the Northern Sea Route navigable for commercial vessels and the Russian navy's littoral frigates and destroyers despite the thin winter sea ice. Russian UAVS have become more effective despite technology that is inferior to the West, making up for lower quality with greater numbers. Their communication and navigational systems are also less reliable due to an ineffective space program that has had limited success in maintaining the GLONASS system.

Doctrine and concepts

Advances in machine intelligence and autonomy within civil society has accustomed this generation of military personnel to interact on a cognitive level with machines. New materials and energy storage innovations have increased the agility and stamina of everyday robotics. Improved natural language processing and microsensors have made the human-machine interface nearly the same as human interpersonal communication. Given the wealth of information that ubiquitous sensing and networked military systems provides, algorithmic monitoring and analysis has become an absolute necessity upon which military leaders at all levels of warfare comfortably rely even though military systems have yet to reach similar levels of human-autonomy teaming that are seen elsewhere in society (Clark et al., 2020; Mayer, 2022, p. 23,29,36). Access to the sensor feeds of the many commercial autonomous systems operating in the Arctic has become an important source of open-source intelligence. The use of national armed forces to ensure the security of commercial interests in the Arctic and conduct demonstrations of national sovereignty have grown in importance.

The ambition of a fully networked battlefield took nearly four decades to realize, but this connectivity has now been the main operating principle of modern militaries for over a decade. The Arctic has proven to be a difficult region to fully realize networked warfare despite these advances, simply because there are fewer assets available to connect and only a limited number of uncrewed systems that are certified "Arctic capable". Limited assets, reduced mobility, and challenging environmental conditions have increased the importance of coordination between surface units separated geographically by hundreds of kilometers. Concepts for protecting and targeting systems on the bottom of the ocean – termed seabed warfare – have become well-developed and integrated into maritime operational concepts (Klawans, 2023).

Reflecting the ongoing EW and counter-AI competition, denied communications environments are expected, and C2 now emphasize greater independent decision making at the unit level, even for autonomous systems. Personnel receive extensive training in AI and autonomous systems to accurately gauge the performance of their robotic counterparts and properly calibrate their level of trust in the systems. Concepts for Arctic operations emphasize and leverage the rapid decision making provided by AI for maritime and air operations, particularly given the need for larger platforms to respond rapidly to incoming threats such as intelligent drone and missile swarms. Land-based operations proceed more slowly and rely on both tactical air defenses and complex methods of concealment (including EW methods and signature reduction materials) to evade an adversary's sensor network.

Assessing the joint functions

The joint functions in this future version of the Arctic are influenced, as in every notional future representation, by a series of conflicting trends that have the potential to enhance or degrade existing capabilities. In many cases, the combination of positive and negative aspects (such as the measure-countermeasure competition in a particular area such as electronic warfare) will result in a situation in which the overall effectiveness of the function remains neutral although the content and context of that function may have changed significantly. This overview assesses whether, from a Norwegian perspective, each function's effectiveness has been enhanced, degraded, or remains neutral.

Command and control. Improved civilian and military satellite coverage over the polar region has enabled better communication at all levels. Persistent UAVs in the upper atmosphere act as relays for various forms of communication, including line-of-sight optical transmissions. More land-based civilian infrastructure such as expanded cellular coverage offers alternative communications options for military forces in some regions. On the other hand, this dependency on civilian infrastructure can quickly become a vulnerability. With greater doctrinal reliance on robust C2 for synchronized effects across warfighting domains, the effects of natural electromagnetic disturbances such as the aurora borealis or adversarial EW disruptions become more serious. *Conclusion: Enhanced.*

Maneuver and mobility. The damage to roadways due to permafrost melting and increased coastal and riverine erosion will complicate land-based mobility during the warmer months, while a lack of frozen terrain during early and late winter will limit wintertime mobility. More extreme weather on land and at sea, along with increased rain and fog, will make air and maritime operations more difficult. Reduced sea ice will improve maritime mobility while increased amounts of loose sea ice will present a hazard to surface vessels without ice-hardened hulls. Improved adversarial ISR will require better signature management and force protection capabilities, potentially slowing mobility and decreasing the ability to surprise an adversary. Deploying military assets to the Arctic in sufficient quantities remains a persistent challenge. In contrast, the use of unmanned systems for reconnoiter and decoys can facilitate maneuver in contested environments. Improvements in human-machine interfaces will increase decision speeds and improve efficiency of maneuver. *Conclusion: Degraded.*

Intelligence. The sheer number of civilian sensors, particularly from autonomous systems in commercial use, provide unprecedented situational awareness when military forces can leverage the sensor data. Improved polar satellites with multispectral sensors offer excellent coverage of the region, particularly given improved data fusion among sensors combined with AI processing. Warmer sea surface temperatures and decreased salinity may degrade passive and active sonar detection (Gilli et al., 2024). Algorithms are also useful for conducting image and signature analyses of an adversary's capabilities as well as their operational patterns. On the other hand, AI-generated disinformation has the potential to clutter the environment and degrade situational awareness. The balkanized technological and informational spheres may decrease the efficacy of one's models and algorithms, and these separate technology spheres may make it more difficult to evaluate an adversary's capabilities. The increase in civilian activity may make it easier to hide sensors among civilian infrastructure and these ubiquitous sensors may challenge the ability to operate covertly in urban areas without detection. Reliance on non-HUMINT sources may quickly hinge upon the level of trust and comfort level with these sensors. One potential source of local knowledge, the indigenous populations that now travel across the Arctic wilderness, may disappear if climate change disrupts their traditional livelihood. *Conclusion: Neutral.*

Fires. The increase in sensors and improved C2 allows for more rapid target acquisition and engagement, as well as increase volume and precision of fire from crewed-autonomous systems teaming and swarming functions. This is particularly applicable for the integrated air assets among the Scandinavian countries. Improved human-machine interfaces have increased the decision speed, efficiency, and coordination of fires. Despite these advances, adversarial integrated air defense systems have also improved, and the competition between offense and defense continues unabated. Greater civilian traffic on land, in the air and at sea increases the challenge of identifying adversarial platforms, particularly as deception and subterfuge have become more common. Weather continues to be a hindrance in some aspects of targeting. Russian nuclear weapons aboard surface vessels and submarines in the Arctic pose a continued threat. The number of actors and weakened international laws and norms increase the risk of miscommunication and uncontrolled escalation if targets are engaged improperly or unadvisedly. *Conclusion: Enhanced.*

Sustainment. The limited growth in civilian infrastructure provides some additional options for sustainment, including access to emergency medical facilities, alternative energy sources, deep-water ports and (to some degree) roadways. Technological advances in additive manufacturing, battery technology and materials have improved the ability of military forces to operate in remote

FICINT vignette: Norwegian Armed Forces and a non-state actor

The operator spotted the alert message first, the orange text flashing insistently in the corner of the ship's virtual heads-up display. Without turning, she calmly informed the skipper.

- Commander, something is disrupting our link with the autonomous patrol boat. And that oil platform just sent a second warning. The system automatically translated it as: "Harassment of peaceful and legal fishing activity will not be tolerated. Retreat immediately."

- They can jam our signals now? I thought our algos would be better at frequency hopping. Commander Solem grumbled.

Solem peered through SWIR enhanced window at the trawler off the port bow, rolling in the Arctic Ocean swells. Not a bad night at sea, she thought. This sector off the east coast of Svalbard was getting crowded with fishing vessels, though, especially for late autumn. Tonight, a particularly vivid night of aurora borealis was wreaking havoc with their ability to pull surveillance data from the polar satellites. Commander Solem reviewed the information packet the ship's AI-assistant, ShipSys, had already pulled up, perfectly collated and interpreted intel from all available civilian and military sensors. They knew IceOil was a Russian offshore outfit, but it was widely assumed that a notorious private military contractor had personnel aboard. Personnel aboard this type of facility was itself somewhat of a novelty, as European facilities had gone fully autonomous years ago. IceOil had located its extraction facilities precisely on the outer edge of the Svalbard economic zone. Increased civilian traffic and one close encounter with a floating iceberg had prompted IceOil to insist on advanced self-protective capabilities on its platforms. What exactly this entailed was uncertain. Solem was sure of one thing: boarding the trawler wasn't worth the risk if the IceOil rig had some retaliatory response in mind.

She spotted their trusty autonomous USV just rounding the trawler's stern, which had been sending back all sorts of data, including biometrics, CBRN scans, structural information on the vessel. But not anymore. *Initial scanning in progress. 34%. Alert: Extensive icing. Scan quality medium.* The little USV's automatic kinetic response function would be enabled only after a positive military ID of the attacker. There were no explicit military capabilities registered to the oil platform's dossier, which would likely enact a shoot-lock. However, the ShipSys AI was struggling to maintain situational awareness with the jamming, and the space weather wasn't helping matters either. The AI-assistant searched its archives for more information on the PMC and requested support from allied systems. Solem looked at the status overview of the patrol's systems.

- ShipSys, run a simulation of sensor performance impact on systems' autonomous response options, Solem ordered, hoping she was wrong in remembering that autonomous response would only be engaged with an average of 70% or more sensor function. She wouldn't have time to issue an override command manually if the situation escalated quickly.

and challenging environments. Autonomous systems with AI decisionmaking and routing abilities may discover creative and unique supply routes in challenging terrain or denied environments. The adverse weather conditions in the Arctic, potentially worse along the coastal regions where freezing rain during the winter months is particularly challenging, remains an issue. Infrastructure is vulnerable to the effects of climate change, including melting, coastal erosion, and poor weather conditions. *Conclusion: Enhanced.*

Protection. Improvements in clothing, personal equipment and biosensor monitoring have improved survivability and operational readiness at the individual level. The protection of military forces is further enhanced by improved ISR from sensor networks. More robust air defenses, including directed energy weapons and AI-directed EW capabilities, protects against swarms and other massed fires. Autonomous agents act as decoys to facilitate concealment and deception to protect friendly assets, while improvements in armor and other materials will offer better ballistic protection as well as reduced signatures. Signature management remains a significant challenge, however, particularly with a doctrine reliant on networked warfare. Systems with electric drivetrains have reduced their thermal signatures compared with internal combustion engines. High-speed long-range fires such as hypersonic glide vehicles have reduced detection times and therefore shortened response times as well, except in areas where space-based sensors provide adequate coverage. *Conclusion: Neutral*.

The future battlefield

This potential future is significantly influenced by the influx of new actors and new technologies, making the future battlefield transparent, connected, autonomous, and remote. In this future world, the US has reduced its military activities, Russia remains an active (albeit less technologically advanced) military actor, civilian activity has increased. There is more to monitor and fewer actors and systems to conduct the monitoring. Improved satellite coverage over the polar region has combined with durable autonomous systems operating in all domains. The systems are connected via a reliable digital network to provide vastly greater amounts of information on civilian and military activities. Militaries rely heavily on machine intelligence for operating and monitoring autonomous systems, analyzing this volume of sensor data, and maintaining situational awareness in a region that is increasingly utilized by commercial traffic. The expansion of undersea resource extraction – along with the economic value attached to these facilities – results in an even greater interest for maritime surveillance and seabed situational awareness, a task for which autonomous systems are particularly suited. Remote sensing, already an important source of information in the Arctic, has become even more relevant.

Larger surface vessels will continue to have few options regarding mobility and concealment (i.e. unable to run or hide), enhancing battlefield transparency in a region dominated by the maritime domain. The reduced sea ice offers less concealment as well, but the depths of the northern Arctic Ocean north of Svalbard and Franz Josefs Land are more advantageous for submarines. In contested areas, the role of surface vessels will be limited without some type of organic defensive systems able to blunt large numbers of long-range missiles or loitering munitions swarms. The vast distances in the Arctic places a premium on range and speed for stand-off engagements, which in turn relies on robust sensing and target data. The mountainous coastline in some regions of the Arctic will continue to offer the possibility of concealment for smaller land forces, but mechanized equipment will become even more confined to roadways for movements over any significant distance and therefore more predictable. The practical application of distributed operations that leverage battlefield data networks will be more challenging in the Arctic due to fewer options for maneuver, perhaps leading to creative tactical uses for autonomous systems. For military personnel and their equipment, this potential future Arctic battlefield will remain challenging and far less predictable, as weather patterns fluctuate and provide less extreme cold but greater amounts of cold rain. Advances in biotechnology and materials may mitigate some of these challenges. Due to the capacity of space-based and aerial sensors to track larger platforms, small units with limited signatures may be at less risk of detection. Even so, the Arctic battlefield is predominately characterized by remote warfare.

3.2 Future two: Chinese-Russian Arctic cooperation

The global drivers that influence future developments in the Arctic, when interpreted differently than we have done in the previous future, can be combined to construct a different context for military operations in the region. In this alternative future, we retain some of the assumptions from the previous Arctic future described in section 3.1 but explore how changing geopolitical dynamics might influence the context for military operations in the Arctic. We assess how the combination of a continued US global leadership role and the introduction of China as an actual Arctic actor might significantly alter the types of military technology present in the region and therefore influence the operating environment.

Geopolitical

Although the United States continues to struggle with domestic political tensions, it recovered from a period of instability during the 2020s and plays a fairly active leadership role in a western NATO-led security alliance. As a result, international laws and institutions are stable and generally respected, although routinely challenged and leveraged to best advantage by Arctic actors. The world remains roughly divided into economic and security blocs, but significant trading activity between these blocs still occurs. The decades following the Russo-Ukrainian conflict left Moscow facing the significant task of rebuilding its military forces and finding new markets for its primarily resource-based economy. The nascent domestic industries that experienced a revival during the 2020s while the country was under a strict economic sanctions regime encouraged a continued separation between Russian and Western markets.

Significantly, Russia and China entered into a partnership of convenience in the late 2020s, building on their limited wartime economic cooperation in which Moscow provided natural resources and energy reserves to its neighbor in exchange for much needed capital and manufactured goods (Low & Singer, 2022).[16] The Russo-Chinese partnership has evolved to include a closely intertwined technology innovation ecosystem, which is now on par with their

[16] For a good description of how the Russian-Chinese relationship might develop over the short term, see Kendall-Taylor et al. (2022, pp. 8–10).

western counterparts. Russian and Chinese commercial actors dominate the Asian arctic economy, while European actors pursue resource extraction in the European Arctic alongside their Russian and Chinese counterparts. There is a significant amount of civilian-military cooperation among the actors in the region that ranges from infrastructure protection to partnerships related to logistics and other sustainment issues, although this is bifurcated into separate Western and Sino-Russian spheres.

To realize its long-held Arctic ambitions, Beijing eventually acquired the rights to lease several properties in the eastern and central Russian Arctic. Due to the continued vital strategic importance of the Kola peninsula to Russian defense strategy, this sector of the Arctic remained off limits to foreign investment. China has established several dual-use maritime facilities that make up a significant part of its Polar Silk Road. Due to coastal erosion, port facilities are situated inland with significant and continuous dredging operations to maintain the approaches from the sea. The string of Russian military bases maintains a constant presence along the NSR as a policing force, ensuring that transit fees are paid. Chinese merchant vessels and naval patrol vessels are continuously present in the region. After decades of discussion and a steadily growing income from land and sea-based resource extraction and tourism, Greenland declared its independence from Denmark and the significant subsidies from Copenhagen that provided a strong economic incentive to remain Danish (Wehmeyer, 2023; Wenger, 2023). Mimicking the diplomatic tactics employed by Central Asian countries to balance great powers off one another and lacking sufficient military forces to defend its own sovereign territory, Greenland's leadership has offered partnership opportunities to several competing actors (Lemon & Jardine, 2021). Chinese-owned firms are therefore among the companies operating along the new country's northeastern coast.

The United States, seeking to balance Chinese and Russian influence in the Arctic, has significantly enhanced its military cooperation with allies such as Canada and Norway. The Americans retained access to the Thule military base on Greenland's western coast and contributes to ensuring freedom of navigation for vessels transiting Arctic international waters. At the same time, the US has been instrumental to the revitalization of the Arctic Council, which now serves as an important multinational forum for deconflicting sensitive topics such as border demarcations, transit issues, and mineral rights. China's extensive portfolio of activities in the Arctic has made them a logical and active member of the Council. Areas of common interest such as common infrastructure for search and rescue are also discussed at the Council. Mostly out of self-interest and Russia's continued desire to keep some limits on their Arctic partnership with China, all actors in the region generally respect existing international laws and norms.

Environmental

The effects of climate change remain consistent with the future presented in 3.1. The negative impacts of climate change have become even more visible as the Arctic continues its transformation, warming at a faster rate than the rest of the planet (Rantanen et al., 2022). Summer sea ice in the Arctic disappeared completely by 2040 and multi-year ice levels have now dropped precipitously, with smaller icebergs and floating ice chunks still posing a hazard to surface vessels

(Kaur & Mooney, 2023; O'Rourke, 2023). Precipitation has increased but falls mostly as rain due to a shortened snow season, coastal and riverine erosion has become severe, and foggy conditions are more common (Dzwonczyk & Radunzel, 2020; Lanata, 2021, p. 24). Some fish stocks have migrated northward in search of colder water, while others have simply disappeared (Herff, 2023). Permafrost melting across many parts of the Arctic has made the land more unstable.

Societal

The east-west flow of goods from Asia to Europe remains lower than during the golden era of shipping of the 2000s, but repeated closures of the Panama Canal due to climate change induced droughts has led shipping companies to utilize transpolar routes during the summer and the permanently ice-free Northern Sea Route during the winter (Board, 2024). The European Arctic has become particularly busy due to increased tourism, trans-Arctic shipping, commercial fishing, land and sea-based mining activity, and oil and gas exploration. Many of these economic activities incorporate autonomous systems although humans oversee their operation and perform maintenance on the equipment together with their robotic partners. The Arctic population has therefore held steady and has become even more urbanized, with an international workforce seeking well-paying jobs in a harsh climate. The state of societal technology is overall consistent with the previous future presented in 3.1.

Settlements across the Arctic are technologically sophisticated modern societies with interwoven digital infrastructures that contribute to streamlined resource consumption and economic activity. The divergent technological development in the West and the Sino-Russian spheres has made mutual technical and logistical support impractical, causing two sets of facilities to emerge to service their respective activities. Arctic research facilities have proliferated and are actively used by many Arctic and non-Arctic states. Hospitals and other health-related facilities are technologically advanced but remain located in urban centers. Above the Arctic, significant numbers of civilian and military satellites fly in polar orbit. Due to the somewhat splintered nature of the global economic and security landscape, the polar orbits are filled with Russian, Chinese and Western satellites that supply communication and sensor data to their users (Humpert, 2022). Private firms operate fleets of microsatellites in LEO, offering their services to a mix of civilian and military customers.

Military

The presence of the Chinese military in the Arctic has shifted the military balance in the region. Although skeptical of Chinese activity in their region, Russian dependencies on Chinese technology and investment capital has forced an accommodation. Similarly, Beijing recognizes its inability to operate effectively in the region without Russian logistical support. Russia's regional expertise has been essential for China's ability to operate effectively in the harsh environment that contrasts sharply with the warm waters of the South China Sea. The quasi-civilian merchant fleet and extensive mining operations also provide the PLA with valuable experience regarding cold weather operations. Throughout the Arctic, civilian repair facilities and logistics infrastructure serves state military vessels when necessary due the distances involved and scarcity of other infrastructure. Chinese commercial facilities in particular are dimensioned especially with this function in mind. Chinese submarines and frigates with ice-hardened hulls frequent the Arctic waters, ostensibly providing security and safe passage for its merchant fleet. Accompanying these vessels are several types of autonomous systems and substantial onboard defensive systems, including high energy lasers and EW capabilities. (Mayer, 2022, p. 59). Russian A2/AD assets and radar stations scattered throughout the Russian portion of the Arctic are thoroughly modernized, monitoring ship traffic transiting the NSR as well as some transpolar routes. Russia and China both possess arctic capable UAV-swarms deployable from surface vessels.

The now-integrated Nordic states have several brigades stationed in the Arctic with main battle tanks and easily deployable UGVs. High-flying UAVs act as relay nodes for ground-based communications to provide affordable redundancy. The Nordics have tightly integrated their fleets of now-ageing 5th generation combat aircrafts through shared algorithms and models for tactical decisionmaking. The shared digital infrastructure enables the aircrafts to cooperate seamlessly with the forces' unmanned aerial 'wingmen." Several of the Nordic states operate large USVs for underwater surveillance and a larger fleet of autonomous unmanned systems can be sent on independent missions. Enhanced ground-based early warning radar networks form a half ring over the North American Arctic and integrate input from space-based sensors aimed at identifying incoming ballistic and cruise missiles.

In a textbook example of the security dilemma, the Arctic NATO countries have increased their military presence in the European Arctic to keep pace with the growing Chinese and Russian activity. The United States, after investing more heavily in its military presence along the western coast of Alaska and on the Aleutian chain, has also expanded its military engagement with Canada and Norway. US naval vessels regularly call on Norwegian ports and assist their UK counterparts in patrolling the waters of the GIUK gap between Greenland, Iceland, and Norway.

Doctrines and concepts

Most advanced militaries – including those of China, Russia, the US and its NATO allies – adhere to some form of networked multidomain warfighting concept enhanced by machine intelligence. In this regard, the most relevant doctrines in this future are similar to those presented in 3.1. Dependencies on autonomous systems and AI-enabled sensor fusion to make sense of the highly dynamic environment are coupled with human-machine teaming for most aspects of modern warfighting. A significant difference in this potential future is the presence of two great powers in the region. This has generated a higher level of urgency and investment in developing concepts for operating and leveraging the advantages of autonomous systems in the Arctic. Additionally, the Chinese presence in the High North has accelerated the development of concepts that combine electromagnetic warfare, cyber capabilities and satellite resources. The significant number of civilian vessels and quasi-civilian enterprises in the Arctic have made sub-threshold or hybrid approaches to military operations particularly attractive. Chinese warfighting doctrine emphasizes both asymmetric disruption and deception, both of which are a necessity in a barren environment dominated by the maritime domain (Mayer, 2022, p. 30). This is a region in which concealment and camouflage must be supplemented with deception and subterfuge.

Joint functions analysis

This alternative future has adjusted just one of the five factors that make up the operating environment, changing the geopolitical landscape with the introduction of China as an Arctic player. At the same time, some aspects of the other factors have evolved in a manner similar to the previous future scenario. The geopolitical shift alters the operating environment in important ways, and these changes have implications for six joint functions from a Norwegian perspective. As in the previous future, the following descriptions are simply potential implications based on the potential future context presented on the previous pages.

Command and control. The extensive satellite coverage over the Arctic has improved communication and the ability to maintain adequate command and control, especially with commercial infrastructure as an important source of redundancy. Artificial intelligence has contributed to improved C2 due to the nimble software-defined radios and the various communications nodes comprising the interlaced set of cognitive networks. The number of autonomous systems in the operating environment complicates coordination and command decisions, even though machine intelligence has lightened the cognitive load. Less beneficial too are the more capable state adversaries with robust cyber and electromagnetic capabilities for disrupting these networks, particularly relating to upper-atmosphere and space-based infrastructure. *Conclusion: Degraded.*

Maneuver and mobility. These C2 networks, when operating properly, provide much improved coordination and synchronization across domains and between manned and unmanned systems. Mobility has improved due to greater access to the expanded civilian infrastructure that has been more forthcoming due to a predictable investment climate based on robust international laws and norms. The increased maritime activity has led to greater numbers of icebreakers plying the Arctic waters during the winter months. The greater number of allied assets in the region offers improved operational flexibility, but potential adversaries operate in greater numbers as well. Arctic mobility continues to be limited by coastal erosion, melting tundra, floating ice and extreme weather phenomena. The increased number of satellites in polar orbit has expanded the threat from counter-space capabilities, including jamming and spoofing that threatens dependency on space-based sensors and navigation for legacy systems that still relying on this infrastructure. The sheer number of state-owned systems with sensors operating in the European Arctic make concealment difficult. Covert activities such as sub-threshold special operations are more attractive because of escalation risk and the number of state actors, but are challenging to conduct because of the vast amount of civil and military sensors. The presence of capable adversarial A2/AD assets complicates mobility and maneuver, even with adequate air defenses. *Conclusion: Degraded.*

Intelligence: The decades-long competition between the US and China has simply expanded to include the Arctic region, and Washington's allies have benefitted from its wealth of experience dealing with this particular actor. Military access to sensor data from commercial autonomous systems has become an important and sought after OSINT source. Space-based sensors are prevalent and provide near-continuous coverage for ISR-purposes. The number of actors in polar orbits means improved conditions for intercepting space-based communications for all parties. Intelligence analysis happens at greater speeds and incorporate more complexity and data volume by leveraging AI for data analysis, open-source collection, and offensive data acquisition through cyber and electronic means. The presence of both Chinese and Russian assets in the region increases the likelihood of deceptive activities that make obfuscation more likely to succeed, complicating attribution efforts. Additional information on all actors' autonomous systems comes from recovering units that are lost due to adverse weather or malfunctioning equipment. Chinese civil repair facilities situated in the European Arctic represent a potential avenue for gaining access and knowledge of their military technology through espionage efforts against these weaker links in the supply chains. All sides deploy designated autonomous systems tasked with observing, analyzing, and understanding adversarial algorithmic decisionmaking models to identify patterns and potential weaknesses. Counter-AI efforts against civilian sensors may weaken operational trust in these. The partial severance of Western and Sino-Russian technology development paths makes knowledge of the latter's capabilities more difficult. This presents a particular disadvantage for the democratic free-market West. *Conclusion*: *Neutral.*

Fires. The possibilities for various joint fires combinations improve with greater numbers of allied assets in the region, and targeting has also improved with better sensor data. At the same time, the combination of Chinese and Russian A2/AD assets – particularly the enhanced integrated air defense systems that have evolved from combining Russian and Chinese technology – have made effective target engagement far more challenging. The risk of uncontrolled escalation with three nuclear powers in the region has grown, particularly with several actors wielding nuclear armed cruise missiles aboard their surface vessels. In this context, unmanned systems represent the lowest rung on the escalatory ladder and are used for low-level signaling, while the presence of crewed platforms signifies a more robust sign of determination and risk acceptance. The prevalence of unmanned systems and the entire breadth of digital infrastructure required for their operation represents a significant non-kinetic avenue of attack. Cyber defenses related to these systems are not impregnable, with particularly some commercial systems harboring vulnerabilities. Access to an adversary's civilian sensors may increase the options for sabotage against key points in their infrastructure. Non-kinetic counterspace attacks are more of a risk because all sides are dependent space assets, and kinetic attacks will result in uncontrolled debris that threaten the space assets of all actors equally. *Conclusion*: *Degraded.*

Sustainment. The growth in commercial actors and better infrastructure has expanded the options available for resupply, logistics, and secondary power sources. The changing climate continues to be an impediment to maintaining military forces in the region. Autonomous transport within the logistical supply chains have proven effective for some aspects of sustainment. Adversary A2/AD capabilities increase the risk of supply lines being targeted but can be mitigated by using smaller dispersed autonomous systems for transport and transit route choices. Ubiquitous civilian and military sensors contribute to supply chain vulnerability, although advances in additive

FICINT vignette: NOR and US SOF combined operation on the Greenland coast

Sven and his NORSOF team quietly emerged from the frigid Arctic waters, the stones of the small Greenlandic beach crunching softly underfoot. After nearly 24 hours crammed inside the small autonomous submarine that served as an expensive underwater taxi, it was good to be on solid ground again. The UUV had performed well in avoiding detection, given the number of underwater early warning glider sensors off the coast. Fortunately, the sensors had to make allowance for biologics and had for several years been tracking the migratory patterns and acoustic signatures of local species, particularly Bowhead and Fin whales. The UUV was programmed to mimic these sounds as well as from other species new to the area, since they were less likely to trigger anomaly alarms. The team had conducted numerous VR training runs using a high-fidelity digital twin of the local environment. There was more free-floating ice than they had seen in the sim, though, and they lost time on the final swim onto the beach once flushed out of the UUV. Luckily, their sealed and specially coated suits had kept them warm and dry in the ice-cold waters without radiating any additional heat that might trigger the underwater sensors.

Their objective was a commercial Chinese installation supporting an offshore subsea mining operation. The Chinese had a chain of these sites along the northeast coast of the now-independent Greenland. Until now, it has been mostly civilian, only occasionally providing maintenance to the occasion Chinese military vessel. However, recent communication disturbances experienced by shipping vessels crossing the Greenland Sea led NATO to suspect some kind of new electronic warfare tool. And US intel sources pointed to Moscow's involvement at this facility.

Sven consciously thought the command "*rendezvous at the boulder on the ridge*" and his neurolinked heads-up display registered the command and transmitted it to the rest of his team. Their suits created an ultra-low signature local mesh-network for sharing data and communication. The sprinkled passive sensors were known to be most sensitive to heat and human voice signatures, so the team kept their miniature closed circuit airlung-masks on. The suits disguised their body heat as well as their warm breath against the cold Arctic air. The team moved silently up to a small ridgeline overlooking the Chinese facility, relieved when the USSOF team confirmed they too had arrived undetected. They had a small temporal window to perform their mission. Chinese surveillance was topnotch and the team knew the smallest spark could send the tense geopolitical situation spiraling out of control. If things turned dicey, they had direct orders not to engage. Three autonomous trucks approached along the icy road to their left on their way into the Chinese Installation, Sven received an optically sent message from his American counterparts.

- Positive ID on the contents of the second trailer. Russian components for the EW jammer and that 5th gen Chinese underwater recce drone. It's enough. Get ready for exfil.

Just then, a fog-like cloud emerged from the Chinese installation. It moved unnaturally quickly toward the USSOF's position. Sven immediately sent a warning to the US team:

- Incoming patrol cloud of smartdust. Stop all electromagnetic emission immediately!

manufacturing, battery technology and materials have improved the ability of military forces to operate in remote and challenging environments. The expanded role of autonomous systems and the importance of developing unique tactics for manned-unmanned teaming have shifted the purpose and character of large training exercises, whereby training in the physical domain is limited to testing and adversarial signaling. Training for operational concepts and unit-level tactics have largely shifted to synthetic environments which the autonomous systems learn equally well. Retaining fidelity to the "ground truth" regarding the actual physical environment remains a key challenge and a vulnerability, as disparities between synthetic training environments and the "real world" create inaccurate training outcomes and harmful learning. *Conclusion*: *Neutral.*

Protection: New materials and better signature management options (such as reduced thermal signatures from electric drivetrains) will improve protection of personnel and platforms, while greater US participation increases the protection afforded by great power deterrence. The use of autonomous systems in new and unexpected ways – such as decoys for tactical and operational maneuver – provides more protection for crewed systems. The counterspace threat is greater in this future, given the number of adversarial satellites in proximity. The increased number of advanced platforms with long range fires also places allied systems at risk and decreases decisionmaking windows. *Conclusion*: *Neutral.*

The future battlefield

This potential future is greatly influenced by China's emergence as an Arctic actor, and the battlefield has become congested, competitive, and sensitive. With an expanded civilian commercial footprint across the region, there is significantly greater traffic on the seas and in the skies. The military presence has also increased, and the systems operated by the US, Russia, China and the Nordics utilize the latest military technology. A Chinese-Russian military partnership creates a new and challenging operating environment characterized by greater numbers of advanced sensors, long range weapons, and capable air and missile defenses. Crewed platforms, carrying deployable autonomous systems for localized situational awareness and platform defense, conduct freedom of navigation exercises in the Arctic global commons and reassure the quasi-commercial actors who are extracting valuable natural resources in the region.

The many sensors throughout the Arctic provide both state and non-state actors with continuously updated information about activities in all domains, and HUMINT from corporate espionage is a non-trivial source in this future. The broad interdependence on space-based assets provides a relatively stable yet uneasy moratorium on space weaponry, although all the primary actors have the ability to disrupt their adversaries ability to operate in that domain. A similar situation has emerged underneath the oceans, as capabilities and concepts for conducting seabed warfare have been developed, but yet to be used operationally due to mutual vulnerabilities among potential adversaries whereby one attack may lead to an unintended and damaging escalatory spiral.

The electromagnetic spectrum has become highly competitive due to ubiquitous sensing, networked communications, and control systems for autonomous platforms. Actors use technological solutions to make their networks as robust as possible while simultaneously seeking to intercept and disrupt their adversaries. Comparable to activities in the cyber domain, actors are not necessarily willing to reveal the extent of their capabilities unless absolutely necessary and a significant amount of probing activity therefore occurs during peacetime. Another reason for caution among the regional powers is the unclear escalatory risks associated with kinetic engagements between intelligent autonomous systems or between state military forces and a potential proxy force protecting resource extraction facilities, particularly since nuclear weapons remain a facet of 21st century warfare. Given the difficulties of defending surface vessels, land-based systems are likely to be strategically placed in new coastal locations reflecting the changing geostrategic landscape. Although the Arctic is far from crowded with military assets and distances remain a prominent feature of the battlefield, a kinetic interstate engagement in the region would likely involve large numbers of long-range weapons and autonomous assets and occur initially within a fairly compressed time frame.

3.3 Future three: Technological revolution amid Russian decline

The pace of technological development has accelerated dramatically in this final Arctic future, which once again takes the current 2020s situation as its point of departure. The combination of advances in artificial intelligence, biotechnology, material sciences, quantum computing and other related fields have significantly altered aspects of civil society such as energy production, transportation, and economic activities. These breakthroughs have also impacted the functionality of military systems and a corresponding development in doctrines and concepts. After quantum-enabled AI unlocks a bevy of technologically advanced alternatives to the minerals currently being mined and renewables are fueling much of the world’s energy requirements, the Arctic is much quieter than previously anticipated.

Geopolitical

The Arctic region in this future is not an arena for geopolitical rivalry, but instead is characterized by a cooperative atmosphere among the Arctic states and low levels of militarization. International laws and regulations are generally respected, and the Arctic Council works as intended to tackle common challenges. The United States and China, largely preoccupied with their own internal challenges, remain locked in a regional competition across the Asia Pacific although the tensions between them do not dominate the global security landscape. The US remains a willing security partner for its NATO allies in the region, but its activities are constrained by domestic prioritizations and budgetary challenges. Russia has suffered decades of stagnate economic growth and continued negative demographic trends, not helped by the dwindling income from its energy exports after the collapse of the global hydrocarbon market and the effects of the capital-intensive tactics used by Moscow to deal with Western sanctions after its failed invasion of Ukraine in 2022. Russia has therefore deteriorated into a politically weak and domestically dysfunctional state, but nevertheless considers the Arctic its principle strategic focus and remains somewhat active in its sector of the polar region with limited oil and gas energy production for domestic consumption.

Global economic activity has become divided into several distinct trading blocs – a trend strengthened by dissimilar approaches to privacy, internet access and intellectual property rights protections. The partial decoupling of global markets has provided an opening for domestic Russian industries, which in turn generate non-exportable products that are less compatible with Western technology. Technology development in autocratic states also leverages advances in AI but follows paths different from western democracies due to domestic legal frameworks and political prioritization. Diverging quality in technology between the blocs leads to Western states experience a steady stream of Russian espionage efforts against the technology sector. For their part, European countries are enjoying relatively positive economic growth driven by the tech industry, although a continuous flow of climate refugees from the Global South – and, increasingly, from Russia – have exacerbated political tensions and weakened EU's cohesion and ability to act collectively.

The technological advances within society over the previous 30 years have influenced the region's geopolitics. The technology-infused green energy transition has proceeded rapidly with a substantially reduced need for fossil fuels or mineral mining in the Arctic (McCallum, 2024; Rubin, 2023). Most of the fish species that were widely assumed to migrate northward in search of cooler water did not thrive in the Arctic ecosystem, and the widely anticipated fisheries failed to emerge. Even transpolar shipping routes are less active than anticipated as companies and their insurance agents grew skeptical of the adverse weather, persistent fog, and floating ice that complicates the mostly autonomous shipping operations. The cruise ship industry is the only operator experiencing real growth, particularly in the European Arctic. With far less overall activity in the polar global commons, political tensions are low, and the Arctic Council remains a strong and effective forum for regional cooperation. As many had anticipated, artificial intelligence has become a powerful tool for innovation as well as political manipulation, and the use of AI-generated media for disinformation has become normalized also in the sparsely populated Arctic region.

Environmental

By 2050, the world has finally turned the corner on greenhouse emissions due to a combination of effective technological solutions and policy tools. Despite impressive advances in renewal energy production and storage, however, the carbon emissions "locked in" from the 20th century have nevertheless raised global temperatures by nearly two degrees Celsius and much higher average temperatures in the Arctic. Greenland's glaciers have experienced extreme melting and the Arctic summer sea ice has disappeared completely, although floating ice remains a hazard during the shoulder seasons. The changing environment has shortened the winter season by several months and increased precipitation falls mostly as rain, accompanied by more intense storm systems that cycle through the region. A few fish species have migrated further north from the now unsuitably warm sea temperatures in their original habitats, while others are unable to adapt to certain aspects of the Arctic ecosystem and simply disappear (Hollowed et al., 2013). Genetically modified species have been successfully bred for farmed fish operations along the coastlines of most Arctic states, however, making this industry an important food source. The land-based changes are noticeable as well. The treeline has moved northward and upwards at higher elevations in mountainous areas, permafrost melting has created more unstable terrain in many parts of the Arctic, and coastal erosion remains a significant challenge as well.

Societal

The technological revolution propelled forward by significant advances in artificial intelligence, quantum technologies, biotechnology and material sciences has fundamentally altered the structures and behaviors in society. Industry workers and other kinds of blue-collar occupations from plumbers to carpenters have integrated automation and robotic assistants in their work, making human-machine partnerships a normal part of human life. Much of the cognitive work associated with professional occupations has now been partially co-opted by machine intelligence, changing the fundamental role of millions of engineers, scientists, designers and lawyers. These and many other professions are now performed in partnership with AI assistants in ways that incentivize other types of skill sets. In the wealthier Scandinavian countries, for example, progressive approaches to biotechnology have led to citizens who have incorporated advances in biosensors, non-invasive brain-computer interfaces, and genetic modifications to enhance their cognitive functions. Medical advances have been significant and health care facilities in the Arctic are highly advanced but still limited to urban centers. Although a few large corporations dominate the tech market, the accessibility of new technology has caused midrange developers and innovators to flourish within a more modular tech ecosystem.

The impact on human health has been profound, increasing life expectancies while ensuring that older populations remain far healthier and therefore less costly to national health services (Chui et al., 2020). Health services infrastructure is restructured to fit the new level of public health. Older citizens are healthy and capable enough to postpone their retirements, but the technology-infused economy has increased innovation and production capacity while requiring fewer employees. Some states have even instituted a universal basic income for their citizens that has alleviated some concerns and created other challenges. Digitalization trends have continued, and robust “digital watermark” validation methods have ensured the continued existence of trusted information and media outlets in an era when schoolchildren and AI-bots can create fabricated video content that is indistinguishable from video taken from real events. This distinction between digital and “real” content has nevertheless become less relevant. Large segments of the economy have moved to fully digitalized platforms, such that an increasing portion of societally relevant content has its origin in digital media rather than the physical world (Weller et al., 2019, pp. 10–12, 19–22). The explosion in space infrastructure and global internet coverage has allowed the Arctic populations to fully integrate into this digital society, although rural areas remain sparsely populated as most inhabitants prefer urban centers. Russia has its own separate and far less advanced satellite capability covering the Arctic but is only intermittently operational. Limited growth in resource extraction and fisheries has dampened the need for extensive constellations of satellites in polar orbit, making a public-private partnership between Norwegian and Swedish satellite providers the most reliable space infrastructure provider in the polar region.

Electrical power is sourced from renewable sources that have become extraordinarily efficient due to AI-developed materials and techniques but still require substantial physical space for solar arrays and wind power generators. Battery technologies have become far more sophisticated, with decreased weight and increased capacity. Many vehicles for sea- air- and land-transport now have designs where the battery is built into the vehicle structure (Katwala, 2018). The open areas of the Canadian Arctic and northern Scandinavia have become more attractive for energy generation now that energy transmission and storage capacity allows for the full utilization of Arctic summer months despite the limited generation during the winter (Mulhern, 2021). These substantial energy farms are serviced almost exclusively by autonomous UAVs, reducing the need for ground-based support infrastructure. Political agreements with indigenous populations have paved the way for these facilities to be located on traditional reindeer grazing areas in exchange for solutions to winter grazing issues, although this has also been offset by longer summer grazing seasons and shorter winters. The fish farms that have proliferated along the coastline are also highly automated and create few employment opportunities. Apart from some limited industries located close to the urban centers, industries have not flourished in the Arctic and the region's demographic trend lines remain relatively flat. The locals who remain have good access to inexpensive energy, and vehicle charging infrastructure is available in population centers.

Military systems

The technological revolution in the civilian sphere has inevitably fueled advances in military technology as well. Quantum communications and cryptography solutions have enabled more robust and secure data transfers despite persistent vulnerabilities in other segments of the communication chain. Space sensors and high-flying UAVs provide unparalleled wide area ISR and communications for military operations, particularly important for the secure links between headquarters and the many uncrewed air and maritime systems operating in the region. Under the surface of the ocean, convergence trends in AI, autonomy, sensing, and communication have also made undersea operations far more transparent. Through developments in materials science, products ranging from extremely lightweight and signature-reducing armored vehicles to clothing with enhanced sensor capabilities. Energy storage is performed by a vehicle's structural framework rather than requiring a distinct battery. The combination of inexpensive lightweight materials, next generation additive manufacturing, and cheap electronics has made inexpensive yet smart munitions possible. Although the region has become far more transparent and concealing one's movements and intentions has become exceedingly challenging, the technological competition within the electromagnetic spectrum has continued with new countermeasures in the form of new materials and methods for disguising and reflecting electromagnetic signatures.

Biotechnology and human enhancement measures have increased human survivability in extreme environments with greater resistance to low temperatures, better night vision, and reduced caloric requirements. The combined forces of biotechnology, AI and resurfaced biological agents from tundra melting have allowed some states to develop non-lethal bioweapons for incapacitating troops. Improvements in BCIs have enabled the practical implementation of cognitively controlled swarms, but autonomous systems are also able to carry out missions based on commander's intent without the need for humans directly in the decisionmaking loop. Even so, the limited number of assets present in the Arctic is a reflection of the region's relative stability

FICINT vignette: NOR Arctic search and rescue operation

- Mayday! Mayday! Our engines have shut down. We have cascading systems disruptions and the ETA on replacement parts from our home base is over 10 hours...

Commander Vegsund looked at the man in the hologram and watched as his lips moved asynchronous from the perfect English fed into Vegsund's BCI-set. The nametag turned from Cyrillic to Latin letters as Vegsund looked at it. Captain Alexeev. The AI-assistant's micro expression analysis determined that Alexeev spoke truthfully and showed genuine signs of distress. Vegsund flicked a finger through the air in front of him and opened a new window in his XR rig's field of vision to show the live sensor feed from the NOR-SWE satellite constellation currently orbiting above the Arctic. The AI-assistant highlighted a few icebergs, but the fog was thicker than usual and hindered a trusted classification. The Norwegian Joint Headquarters had plenty of digital blueprints ready to print spare parts, but none were compatible with an ageing Russian fossil fuel engine.

- We have your position, Captain. Can you confirm that you are twelve people on board?

Captain Alexeev confirmed. Vegsund saw from the satellite stream that the EM signatures onboard corresponded to 12 sets of personally wearable BCI sets, standard issue for the Russian Armed Forces. The bureaucracy involved in a supposedly "joint" Norwegian-Russian military rescue operation was going to be massive. Vegsund inaudibly tasked one of his operators to command an ISR swarm to the scene via his BCI. He would need a more granular 3D comprehension of the scene for a rescue operation, especially with high waves, thick fog and poor tracking of floating icebergs. The Russian military had prioritized high-tech signature-limiting "stealthy" coatings on their surface vessels, but the internal systems were suspected to be an assortment of old and new materials that often generated mixed results. Vegsund could see through the satellite-view that the coatings did in fact disturb certain bands within the space sensors' multispectral reading of the vessel.

Vegsund's view of the scene switched to an interactive three-dimensional rendition once the UAV swarm reached the Russian vessel. They swirled while mapping the immediate surroundings, adding icebergs in the vicinity and feeding information about the underlying currents, wind speeds and directions, and sea state data. The technology for immersive XD gamified operations had piggybacked on the explosion in online gaming industry and the broader social trends toward increased economic and social activities in virtual spaces. Vegsund's UAV operator could enact the system's SAR mode, cooperating with the swarm to find the safest way to evacuate the personnel. The swarm was not robust enough to hold the ship in place, however, and the strong waves pushed the vessel southward toward the Norwegian coast.

Vegsund's AI-assistant suddenly issued an alert from a search in NATOs database. *This vessel may carry non-lethal chemical defensive measures. Estimated effects: nausea, temporary blindness and hearing loss.* A chemical event that could adversely affect the Norwegian civilian population on land would not be a good look – either for those affected or for the Armed Forces that would be seen as allowing it to happen.

and the lack of interest in acquiring too many costly "arctic-proof" systems. Minimally crewed surface vessels wield high-energy lasers and cannisters of autonomous mini-swarms of defensive munitions that combine to efficiently protect these larger surface vessels against long range fires.

All the maritime Arctic states have also invested in fully autonomous "optionally-crewed" surface platforms, autonomous collaborative combat aircraft in a "loyal wingman" function, as well as UGVs for land operations. The quality of Arctic states' military systems reflects their respective ability to leverage AI in technology development and their economic ability to modernize. Russian military systems are therefore numerous and somewhat technically sophisticated yet at the same time ageing and plagued by inadequate maintenance and updating procedures, leaving them less competitive compared with Western systems. Democratic states with open market economies have been more successful in incorporating civilian technology developments into their military systems, even during periods of limited defense budgets.

Doctrines and concepts

Most advanced militaries employ a networked multidomain warfighting concept enhanced by machine intelligence that leverages the quantitative advantages of numerous attritable autonomous systems. Much of the operational planning – and the professional military education that forms the basis for that planning – occurs virtually in a highly secure military "metaverse" that allows for seamless holographic displays and avatar interactions. Joint headquarters elements remain physically co-located for physical security purposes, but operational planning can be done more broadly than ever before. Dependencies on these autonomous systems and AI-enabled sensor fusion to make sense of the resulting dynamic environment take advantage of human-machine teaming for military operations. The lack of military tension in the region and its uncontested nature, combined with technological advancements in communication and managing autonomous systems, make remote military operations more feasible. Undersea operations remain highly relevant as underwater sensors are most prevalent near the coastlines of most Arctic states but not throughout the polar global commons. Asymmetric approaches are more prominent also in this future, with AI-supported information operations normalized almost as background music amid the flurry of digital communication. Technologically advanced democracies have taken advantage of their educated populations with biotech-enhanced abilities and technological expertise to build resilience against subterfuge and influence attempts.

Joint function analysis

This final future scenario evaluates the effects of accelerated technological progress amid the almost total collapse of the Russian state. With an Arctic that is less active and lacking a technologically advanced adversary, a high-tech military will unsurprisingly enjoy enhanced functionality in almost all areas. Some of the environmental challenges may also be partially addressed with technological solutions. This may nevertheless increase single point dependencies and introduces operational risk given that lower levels of commercial activity in the region will likely reduce the need for infrastructure investments that could provide redundancies.

Command and control. The ubiquitous nature of human-machine teaming in this technologically advanced future has generated reliable and efficient concepts for managing large numbers of autonomous systems. Sufficient space-based infrastructure and upper-atmosphere UAVs provide redundancy with multiple relay nodes. Improvements in the weight, power and efficiency of communications gear has provided lighter gear for both humans and robotic systems. The networks themselves have become more secure due to quantum communications solutions, although the lack of a technological peer competitor limits the risk of serious EW disruptions. Space weather and the aurora borealis remain an issue in the Arctic but are more readily handled due to multiple communication alternatives, although these options are more limited in the maritime domain and the more remote portions of the region. Conclusion: *Enhanced.*

Maneuver and mobility. The environmental aspects of operating in the Arctic will not disappear completely in a high-tech future: more intense weather patterns, rain-on-snow events, widespread fog, and floating ice will limit mobility in all domains. In some cases, this can be advantageous to partially conceal movements, but these environmental effects will nonetheless reduce the effective movement of people and equipment in the region. In a less populated and active Arctic, there are fewer road and rail options for military forces, but advances in materials and energy storage make autonomous air transport a far more robust and feasible alternative. Biotechnology and materials have also made humans more robust and better able to withstand the harsh environment, and material advances have reduced signatures for humans and equipment. Conclusion: *Neutral*.

Intelligence and info. The wealth of information generated by nationally controlled space-based sensors and an array of remote sensors on land, sea and air should lead to vastly improved situational awareness in all domains (including space) when combined with algorithmically data-driven analysis methods for making sense of the data. The lack of commercial activity provides fewer additional sensors but makes tracking of existing targets much easier, particularly given the high level of technological sophistication among the populace that generates a substantial individual digital footprint. AI-enabled technology development and the closed defense innovation ecosystems in autocracies presents challenges in monitoring and understanding the development of new military capabilities. Conclusion: *Enhanced*.

Fires. Due to better sensor networks and materials science improvements that produce lighter, cheaper and more efficient munitions, it has become easier to have large quantities of “smart” weapons and effective autonomous swarms. Combined with a robust and secure data and communications network, these swarms enable flexible and adaptable kill-webs that are difficult to defend against. Fires in other domains are vastly improved as well, with cyber and EW attacks more precisely crafted using quantum computer enabled modelling and testing. A similar situation has occurred with bioweapons, which have become powerful and narrowly tailored for specific effects. In the Arctic, however, fewer assets and longer distances limit the utility of all such systems. Conclusion: *Enhanced.*

Sustainment. In an almost non-contested environment, autonomous air and maritime transportation for sustainment will function well, particularly when civilian infrastructure is limited. The planning for such operations will be enhanced with a host of powerful digital tools for modelling and testing. Biological enhancements to personnel will certainly reduce the logistical burden, as new adaptations reduce heat loss and energy use so that caloric requirements are reduced. Access to emergency medical facilities remains limited, although the level of care has improved considerably. Conclusion: *Enhanced*.

Protection. New materials will offer far better protection and lower weight for all types of platforms and with patterns, coatings and substances that lower signatures. Battery powered platforms will reduce thermal signatures. Biotech will improve resistance to cold and frostbite, while nano-biosensors monitor the body without added weight. The advances in AI and autonomy have enabled systems to act according to commander's intent rather than requiring a constant C2 data link, reduced electromagnetic signatures. Conclusion: *Enhanced*.

The future battlefield

This potential future envisions the Arctic as a less active region that bears some resemblance to the situation during the 2020s, but is an environment characterized by transparency and stability amid some asymmetrical activities. The modest levels of commercial activity in the region are matched by similarly modest levels of military activity with NATO allies – and Norway in particular – assuming a caretaker and monitoring role. The dramatic evolution in civilian technology has significantly increased the ability to conduct remote sensing and monitoring, most of which is carried out by autonomous systems that report anomalies to their human commanding officers. The climate has altered the conditions for conducting land-based operations with intense weather systems and shorter winters, but these challenges are met by corresponding technological improvements that enable mobility. The lack of a peer competitor can be felt in all domains, particularly activities within the electromagnetic spectrum. Communication and data networks are far less apt to be disrupted or intercepted. The Russian lag in technological innovation has made it possible for the Nordic states to balance their conventional forces with a combination of quantity and quality that relies on distributed forces wielding autonomous loitering swarm munitions and EW capabilities.

While the Arctic region remains stable, certain Russian activities in the eastern portion of the European Arctic require monitoring. Ageing military equipment, particularly those systems relying on atomic power or armed with nuclear warheads, present a risk to civilian populations. The instability of the Russian government poses a risk of more radical factions gaining control over Russian weapons, and a total economic collapse might lead to uncontrolled migration. Even without these more dramatic developments, the Russian skepticism of Western intentions has led them to prioritize asymmetrical approaches for weakening the political cohesion of NATO members. The shift towards digital workplaces and online immersion entertainment have offered entirely new forms of strategic communication, AI-supported cognitive warfare, and influence operations. As an inexpensive means of effecting political change, Russian cyber warriors exacerbate social tensions and create uncertainties within democratic societies via

Table 3.1 Summary table of the three alternative future scenarios (Alt 1-3) and the potential implications for joint functions (either enhanced [E], degraded [D], or that the balance between positive and negative inputs result in a neutral [N] effect).

		Alt 1	Alt 2	Alt 3
FACTORS	**Geopolitical**	Resurgent Russia, absent USA, non-state actors	Russia-China coop, Some US Arctic engagement	Weak Russia, absent USA and China
	Environmental	Climate change effects: sea ice, unstable terrain, weather, erosion	Climate change effects: sea ice, unstable terrain, weather, erosion	Climate change effects: sea ice, unstable terrain, weather, erosion
	Societal	High resource extraction & infrastructure, some population growth	High resource extraction & infrastructure, some population growth	Limited resource extraction, little infrastructure or population growth
	Military Systems[17]	Multiple state and non-state armed actors, autonomous systems, space assets	Great power military actors, autonomous systems, space assets	Few armed actors except Russia, autonomous systems, space assets
	Doctrines[18]	Networked, multidomain warfare	Networked, multidomain warfare	Networked, multidomain warfare
JOINT FUNCTIONS	**Command and control**	**E**	**D**	**E**
	Maneuver and mobility	**D**	**D**	**N**
	Intelligence/information	**N**	**N**	**E**
	Fires	**E**	**D**	**E**
	Sustainment	**E**	**N**	**E**
	Protection	**N**	**N**	**E**

[17] The range of systems available by 2050 remains consistent through all three futures and is based on earlier research, but those relevant for the Arctic will vary according to the actors operating in the region.
[18] For the sake of simplicity, the methodological choice was made to keep doctrinal aspects roughly consistent across all three futures although these will certainly vary according to actor type. For more details regarding the potential doctrinal choices of regional actors, see Mayer (2023).

extended reality gaming platforms, new social media sites, and the many AI-supported news organizations scouring the metaverse for gossip. As Russia teeters on the brink of becoming something resembling a failed state, a large-scale territorial invasion is a far less relevant contingency in the portfolio of relevant military operations in the Arctic than asymmetrical threats or CBRN accidents. These are threats for which the NATO countries, having invested in technologically advanced force structure elements for high intensity interstate warfare, are less equipped to address.

4 Implications for Norway's Armed Forces

This report is a work of foresight analysis, an approach that has certain fundamental weaknesses and limitations. The analysis is based on multiple sets of suppositions and deductions about the future trajectory of a range of global trends. As noted in earlier chapters, there are significant cognitive pitfalls associated with this type of analytical work, not least the dangers of thinking linearly about a future that is complex and unpredictable. Despite these shortfalls, the exploration of possible futures remains a valuable and necessary exercise for expanding our thinking and challenging our underlying and potentially faulty assumptions about the future. In addition to supporting long term defense planning, the creation and analysis of potential futures should also offer some practical utility for policymakers.

With that ambition in mind, we have extracted three categories of insights from this report's analysis of potential futures. First, we describe some aspects of the Arctic that are almost certain to remain constant in the operating environment regardless of the future trajectory of global and regional trends. Second, we discuss a set of factors that we have determined to be the principal uncertainties or levers of change. During the analysis, we repeatedly faced proverbial forks in the road requiring a choice between several – often equally plausible – future developments. From our perspective, a number of these analytical decision nodes are particularly consequential, even though we acknowledge that this can be impossible to gauge as the future effects of seemingly insignificant developments can be profound. Third, we present some implications for the Armed Forces based on the aspects of the operating environment that appear constant across all three futures considered in this report, suggesting potential policy-relevant implications regardless of how the FOE evolves.

4.1 Constant element in the Arctic

Expansive and austere environment. Arctic distances will remain a dominant feature of the operating environment, even if the changing climate leads to more human activity in the form of increased tourism, resource extraction, fisheries, or maritime transit routes. The predominance of the maritime domain in the Arctic acts as a natural barrier to new settlements in closer proximity to each other, so that distance remains an inescapable facet of civilian life. Environmental conditions will continue to be severe and challenging for human activities, making the region a less attractive destination for large-scale immigration. Arctic populations will continue to coalesce in urban environments in search of convenience, services, and access to infrastructure.

Inhospitable weather conditions, aurora borealis and day/night extremes. Environmental change is already occurring. The Arctic of 2050 will differ in significant ways from the current environment. The region will nevertheless retain many of its climatic characteristics even if these are either diminished or altered in some way. These include severe cold, large expanses of sea ice during the winter, marshy terrain, and the unique electromagnetic effects of space weather responsible for the aurora borealis. The constant light in the northern parts of the Arctic during polar summers and the long periods of darkness during the winter remain a permanent feature of the polar region that will continue to have relevance for military operations.

Geostrategic realities in the High North. Unless an extreme political event occurs, the territorial borders of the Arctic states will remain stable, and certain aspects of the region's geostrategic context are likely to persist. The relevance of ballistic and cruise missile trajectories from Russia to North America over the Arctic means that space and airspace over the region has a fundamental and lasting strategic relevance for the United States. Early warning radars and submarine tracking capabilities will continue to be important. Given current national borders and coastlines, Finland and Sweden will likely continue to have their maritime focus on the Baltic Sea region rather than the Arctic, whereas closer Nordic military cooperation in the air and land domains is a logical outcome. The Kola peninsula is likely to remain an important military region for Russia due to its advantageous position in relation to access to the North Atlantic and the infrastructure connecting the area to the rest of the country. It will therefore constitute a continued A2/AD threat in the region as Moscow seeks to ensure the survivability of its second-strike capability. It is nevertheless worth considering how the changing character of Arctic sea ice might potentially alter Russian operational patterns regarding access to the deep waters of the northern Arctic, the GIUK gap and the North Atlantic.

4.2 Principle uncertainties from FOE analysis

Amid these few relatively consistent features of the Arctic can be found significant uncertainties regarding future trajectories in the region. With the 30-year future perspective in mind, it is important not to neglect the potential for low probability outcomes that could negate much of the preceding analysis. A US-China confrontation over Taiwan concerns many observers, particularly given the risk that such a conflict might escalate to include a nuclear exchange (Erickson et al., 2024). Some academics and scholars are concerned about the threat to humanity from advanced artificial intelligence and the potential lack of alignment between the interests of humankind and those of superintelligent machines (Piper, 2020). Others have noted with concern the instability of the complex set of major Atlantic Ocean currents that, if they were to stop functioning, could cause a rapid and lasting 15 degree temperature drop in Western Europe and up to a meter of sea level rise (Kaplan, 2023). Future geoengineering measures to control or reverse the effects of climate change by manipulating the atmosphere might have significant potential but could come with unpredictable and damaging secondary effects (Grisé et al., 2021).

These and other unlikely but plausible outcomes serve as an important reminder of the long-term focus of foresight analysis. Much can transpire over the next thirty years and certain developments could easily render much of the analysis contained in this report irrelevant. The uncertainty surrounding even the more plausible outcomes in the Arctic has the effect of limiting our ability to understand, plan, and invest for the future operating environment. One way of coping with this challenge is by identifying a few of the most consequential sources of uncertainty. This allows us to focus more closely on a limited number of trends and recognize the significant events and thresholds that might act as "signposts" revealing which of the futures discussed in this report is most likely to develop. For each of the five factors, we have selected one principal uncertainty that might have the greatest impact on the future of the Arctic.

The future of Russia. With a dominant position in the Arctic, the future of Russia is an obvious candidate for a consequential source of uncertainty. Moscow's ongoing war in Ukraine and its authoritarian leadership heightens the unpredictable nature of a country whose military will need a massive defense recapitalization effort amid international sanctions and demographic trends that will hinder economic growth and an ageing leader with an unclear successor. Russia appears intent on solidifying its posture in the Arctic with a string of military facilities and its political focus on the Northern Sea Route. Russian domestic stability and its defense posture have both direct and indirect effects on Arctic security.

A strong and stable Russia will continue to play an active role in the region based on its geostrategic interests and as a source of national pride. In such a situation, there is little interest in supporting or enabling Chinese activities in the region, and Russian opposition would seriously complicate Beijing's efforts to expand its presence there. A weakened Russia dependent on China for international trade or access to technology, however, may be forced to acquiesce to Chinese demands for access to the Arctic while simultaneously boosting Russia's military capabilities. At the other extreme, a severely weakened Russia on the verge of internal collapse presents a significantly reduced threat of territorial conquest but increases the risk of uncontrolled migration, rogue elements gaining access to weapons of mass destruction, or simply dangerous accidents involving military or civilian infrastructure.

The interests and actions of Arctic actors – both old and new – will likely have a decisive impact on the potential for conflict in the region. A popular framing of the region's future has long been one of competition and potential conflict over natural resources, even though the majority of these resources are clearly within existing national boundaries and exclusive economic zones. Fishing in international waters of the central Arctic is a possible exception, but even here the Arctic states and other interested actors have imposed an international moratorium through 2037. Russia has demonstrated a willing to violate international laws and norms elsewhere but has shown surprising adherence to them in the Arctic. As long as states continue to respect international law in the region, there should be little cause for conflict. The Arctic is nevertheless a large and remote region that makes monitoring and enforcement efforts a costly and challenging proposition. If actors decide to violate established laws and norms, there will be few avenues of recourse and the potential for conflict will increase.

The true regional impact of climate change. There is little doubt that climate change is already significantly altering the Arctic in many ways. Given the uncertainties associated with technological progress and human decisionmaking, climate modelling can appear to be a more reliable predictor of the region's future. Different portions of the Arctic are affectedly differently by climate change, complicating accurate descriptions of the region's future and how climatic trends will affect human activities. Even within one area of the Arctic, these trends can have contradictory effects that counteract each other. One example is the likelihood of increased precipitation, which would suggest more moisture in the soil and less mobility due to muddy conditions. On the other hand, increased summer temperatures will encourage greater evaporation that may instead lead to dryer conditions and water shortages. A similar uncertainty is seen with fish species that are moving northward in search of cooler waters, but other aspects of the ocean ecosystem may not necessarily provide the conditions for those species to thrive in a new environment.

Demand and access of Arctic natural resources. Current trends suggest a growing interest in carbon-based energy from the Arctic, expanded mining activities to extract minerals relevant for the transition to renewable resources and other modern technologies, and expanded fisheries to take advantage of northerly migrating fish stocks. Increased human activity in the region carries significant second order effects such as expanded infrastructure development and potential tension over how various actors utilize the Arctic global commons. The potential for conflict over resources, seen from the mid-2020s at least, appears to be low due to the longstanding tradition for cooperation and respect for international law in the Arctic. For actors such as Russia that do not necessarily respect international laws and norms in other parts of the world, this policy approach in the Arctic is based on self-interest.[19] Were the established Arctic states or potential newcomers to the region deviate from this tradition of respecting laws and norms, the potential for conflict might increase significantly. The region's future also looks quite different if polar maritime transport routes are not fully utilized as anticipated, oil and gas development does not expand, and mining operations are either not needed or deemed less economically feasible. Much of the attention surrounding the Arctic today is based on the anticipated increase in human activity in the region, but these activities are not predetermined. Although it appears that the Arctic will be an important region for economic activity by 2050, we should treat these developments as a highly probable future outcome rather than a certainty.

Autonomous systems in the Arctic. One of the clearest trends in military technology over the past decade has been the rapid maturity of enabling technologies for autonomous systems, including wireless communication, energy storage, sensor technology, and machine intelligence for autonomous decisionmaking. Some of the largest producers of autonomous systems – including the United States, China, and Turkey – have their focus on operational theaters much closer to the equator. As many states continue to develop autonomous systems and concepts for their use in operational settings, it remains to be seen how these systems will fare in Arctic conditions. It will be possible for system designers to overcome some of the region's challenges, which include heating and de-icing abilities, other limitations posed by the severe cold such as battery life, robustness in high winds and/or high seas, and deep snow and mud. The geography of the Arctic suggests that, in addition to adaptations for making systems "Arctic-proof", other concepts for overcoming the tyranny of distance may be necessary such as ferrying drone swarms aboard larger systems for tactical use. One important question is whether the increased cost associated with adaptation and/or the potential reduction in reliability will influence the extent to which these systems are employed in the Arctic.

[19] For a good overview of Russian policy in the Arctic see Buchanan (2023)

Networked warfare and distributed operations. A doctrinal development closely related to the growth in autonomous systems is the effort to achieve truly networked operations with a robust and seamless flow of data between platforms and decisionmakers. Networked operations are a fundamental aspect of multi-domain operations as well as the Chinese concept of "intelligentized" warfare. The full realization of such concepts that incorporates crewed platforms, autonomous systems, and perhaps even machine intelligence integrated in the decisionmaking loop would signify a substantial shift in warfighting that would allow truly distributed operations. Some version of this concept has existed for decades, and its implementation has long been "just around the corner", a fact that only serves to illustrate the complexity of the challenge. The full integration of sensor, effector and decision maker has thus far proven to be elusive, but the military state of the art has crept steadily closer to realizing these ambitions. For the Arctic, the implementation of a networked warfighting system will entail the deployment of sufficiently robust communications nodes and a sufficient number of assets that could properly leverage the advantages of distributed operations.

4.3 Implications and recommendations for the Armed Forces

The Norwegian Armed Forces will have different sets of tasks depending on how the Arctic security environment evolves. In our first potential future, the High North has become crowded with commercial actors intent on resources extraction within a broader global context of weakened international laws and limited multinational cooperation. The status of Svalbard is increasingly contentious as outside actors test the boundaries of the treaty's legal status and, with weak international institutions, routinely circumvent the established norms for activities on or near the archipelago. Norway will need to constantly demonstrate an ability and willingness to protect its own resources and territorial waters through onboard inspections and sovereignty patrols. The second future is dominated by Sino-Russian cooperation and continued respect for international laws and norms as Russia attempts to limit Chinese freedom of action. This highly competitive and contested environment poses significant operational challenges for the Armed Forces and partnerships with the United States and other NATO allies remains vital, particularly in the maritime domain. In the third future, a civilian technological revolution unleashes a corresponding wave of military innovation, Russia struggles mightily with internal challenges, and the Arctic is surprisingly quiet. The Norwegian Armed Forces have something akin to a caretaker role in the region, ensuring the safety of those transiting the area and monitoring for potential illegal activities. The risk of a Russian resurgence or an eventual collapse that would create a civilian border crisis remains a constant concern.

The roles for Norway's Armed Forces vary across the three futures, but certain fundamental responsibilities such as territorial defense, exercising sovereignty rights, and policing commercial activity within mandated areas remain highly relevant tasks. Our analysis has revealed some implications for military operations that are context dependent and tied to the potential futures described. Some lessons and implications can be extracted, however, that have validity across all three futures and may therefore be relevant regardless of how the future unfolds. A Norwegian military commander who is suddenly and magically transported from the early 2020s to the Arctic operational environment of 2050 will face significant differences that influence how a military operation is conducted. Many of the recommendations presented here will not be unique to this report and some may describe ongoing programs. In these instances, our policy recommendations should simply be treated as an additional rationale to continue those important efforts.

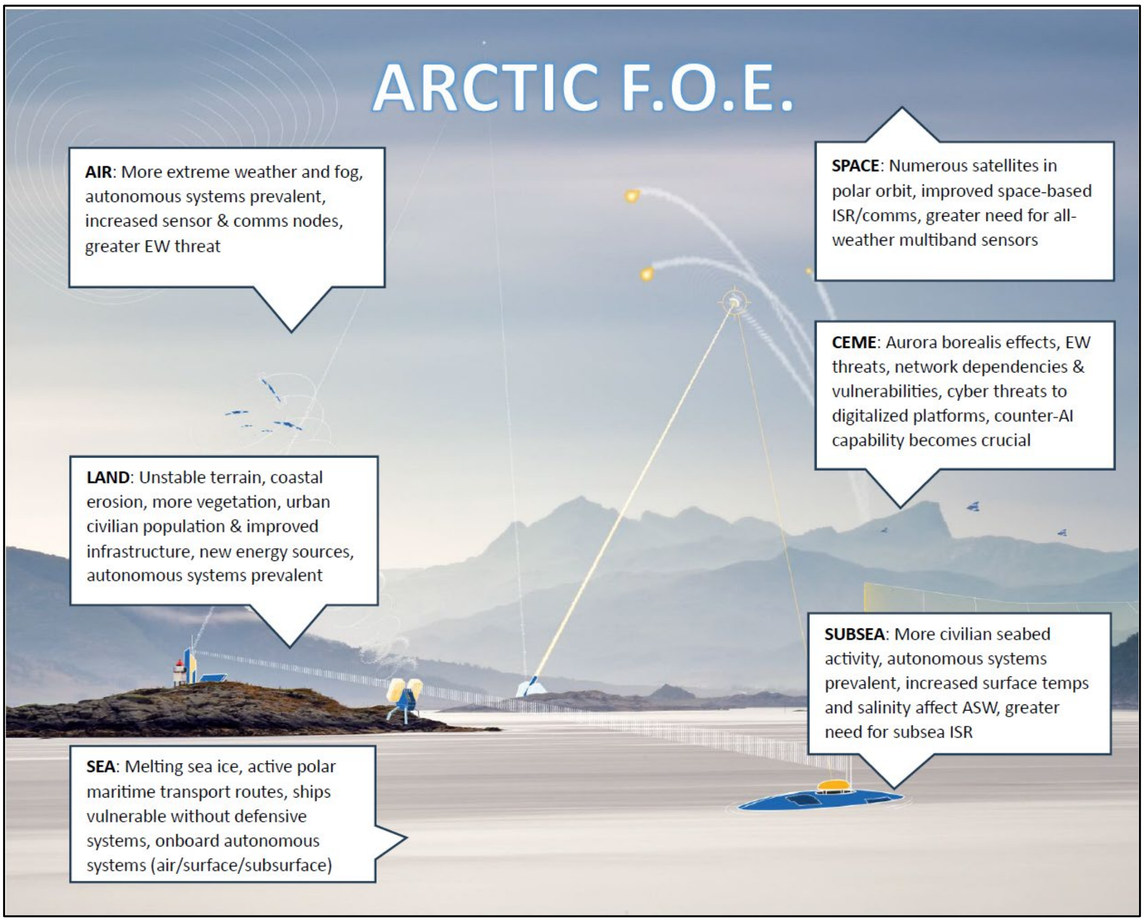

Figure 4.1 Summary of selected implications by domain for the future Arctic operating environment. CEME: cyber and electromagnetic effects.

Command and control

The communication options in 2050 are likely to be more robust and offer greater redundancy, including significant numbers of satellites in polar orbit, the widespread use of larger unmanned aerial systems that act as relay nodes, and expanded infrastructure for civilian communications. Natural disruptions from the aurora borealis persist, although new techniques have mitigated the most adverse effects of this phenomenon. Disruptions from potential adversaries are far more relevant, as state and non-state actors disturb and manipulate the electromagnetic spectrum to create uncertainty about their movements and actions in an environment of ubiquitous sensing.

Fully networked military forces are able to share data across platforms and weapons systems, and autonomous systems have added an additional layer of complexity to both command and control aspects of military operations. These C2 improvements may allow improved decisionmaking and tighter "just in time" margins for a wide range of operational decisions from fuel consumption to target engagement. Robust connectivity may be difficult and unreliable amid adversarial EW.

The use of autonomous systems together with either crewed platforms or small units in human-autonomy teaming (HAT) situations will necessitate close coordination and sufficient levels of trust. Achieving adequate levels of trust may hinder the Armed Forces from leveraging the operational benefits of autonomy. Correctly tasked and developed autonomous systems can increase operational tempo, and improve protection of manned systems through scouting and decoy missions, logistics in denied areas, and independent long-range ISR. Using autonomous systems may also be the only realistic way to understand the reasoning and behavioral models of adversary autonomous systems. The granularity of data needed to understand such processes requires long-term and perhaps continuous surveillance of adversarial capabilities, a requirement for which autonomous systems are ideally suited.

Recommendations

- Build the digital data-sharing infrastructure needed for future networked operations while ensuring proper redundancies are in place in the event the network is compromised or disrupted. Invest in adequate EW capabilities to disrupt adversarial networks.
- Develop new doctrinal approaches for distributed operations in denied environments as well as techniques to disrupt an adversary's distributed operations.
- Develop concepts for human autonomous teaming and begin active training with autonomous systems to build experience and trust and employ AI tools to analyze and model adversarial use of autonomous systems.

Maneuver and mobility

Melting sea ice will afford greater access to the maritime zones north of Svalbard, but the thinner single-year ice that forms during the winter can more easily fracture and create floating ice hazards. More intense storm systems along with more precipitation and coastal fog create challenging conditions for surface vessels. Norway's land mass continues to rise slightly due to a decompression effect from the previous ice age, but IPCC models nevertheless suggest a potential 20-30 cm aggregate rise in sea levels and accompanying threat of severe storm surge in northern Norway by 2050.[20] Land-based mobility has been enhanced by some improvements to civilian

[20] According to the Norwegian Mapping Authority analysis found here.

road and rail infrastructure, but mobility has otherwise become more difficult in many aspects of Arctic travel. The encroaching tree line has made portions of the Finnmark plateau less accessible. Shorter winters provide fewer weeks with good transport over frozen terrain, replaced by longer transition seasons with muddy conditions and more frequent storms and riverine flooding.

Adversarial sensor networks make movement far more dangerous – any movement leads to rapid detection, targeting, and potential engagement. Whereas the UxV systems currently being deployed are largely operated remotely by humans, advances in autonomy will allow multiple systems operating independently alongside crewed platforms with human supervision rather than control. Autonomous systems may have provided a partial solution for mobility by 2050, acting as decoys to draw enemy fire or as dispersed transport solution for logistical support. All Arctic maritime platforms – autonomous or not – require robust features able to handle the adverse weather, challenging sea states and freezing sea spray.

A versatile yet cost-effective approach for land-based autonomous systems would need to ensure that UGVs are able to operate in a variety of conditions from softer terrain and snow or hardened ice. Arctic-capable UGVs could complement crewed systems by offering mobility in areas that are more difficult for heavier armored platforms. Utilizing these systems together with crewed platforms will require adaptations to the crewed platforms for energy requirements, UxV maintenance needs, and additional C2 infrastructure such as communications links and data sharing abilities.

Recommendations

- Identify potential threats to mobility from changes to the physical environment within the Norwegian area of responsibility such as new areas at risk of riverine flooding, new traverses with increased risk of landslides, or areas with encroaching vegetation that hinder mobility.
- Ensure that new civilian infrastructure projects are conducive to use by military equipment.
- Prepare for increased restrictions on air and maritime operations due to the increased frequency of inclement weather.
- Develop concepts for using arctic-capable autonomous systems for maneuver in challenging or unstable terrain and adversary-denied areas.

Intelligence and Information

Widespread civilian and military sensors such as satellites and autonomous systems, combined with artificial intelligence applications that allow for rapid and effective data fusion, will substantially improve situational awareness for all actors. Many intelligence-related tasks that currently require human involvement may in the future be performed by autonomous systems alone. The continued digitalization of most aspects of civilian life creates massive amounts of data that can be leveraged for intelligence analysis purposes, given adequate algorithmic processing. However, having complete access to all data streams will likely not be possible and adapting to this incomplete information may be challenging for AI systems. Autonomous analysis and senor fusion may over- or underestimate the importance of absent data streams, potentially sowing confusion and distrust. Separate geopolitical technological and informational spheres will continue to complicate data access from the opposing sphere, and affect confidence levels in the conclusions drawn from it. Whether non-military owned data will be accessible for contributing to military situational awareness in peace, crisis and open conflict is a complex question. Democratic states with respect for proprietary data and legal limits to intelligence collection will have other approaches than autocracies. However, commercially owned data may be available through subscription services, be open access or volunteered through tipping the Armed Forces of anomaly-detections. How approaches to these issues evolve will shape the size of their contribution to future situational awareness.

Civilian activities such as resource extraction, fisheries, and maritime transport through and adjacent to the Norwegian EEZ will require an increased monitoring capacity. The increase in civilian traffic creates more opportunities for covert activities, which have become a more attractive option due to the sensor density. This is not entirely unproblematic for those intent on covert activities, however, due to an enhanced ability by most actors to fuse sensor data from a variety of sources and detect such activity. The growing volume of maritime traffic in the region has increased the ambient noise below the surface, complicating anti-submarine warfare efforts (ASW). The effects of climate change further hamper ASW efforts as lower salinity and higher sea surface temperatures affect sensor ranges. Increased activity below the surface will require an expanded ISR capability to retain situational awareness as well as kinetic options. Due to the expanded nature of the maritime domain, assets for maintaining situational awareness over large areas will become an even more vital capability. The limitations of surface-based platforms will likely dictate a combination of space, air, sea, and subsea sensors. Prioritizing sensors that are not adversely affected by poor weather will give greater operational flexibility, particularly since an adversary may be able to hide its operations by taking advantage of poor weather conditions.

Recommendations

- Invest in greater ISR capabilities, particularly in emerging domains such as space and the maritime seabed environment. Ensure that changes to the Arctic Ocean (salinity, temperature, sea ice coverage) and the impact on ASW are well understood.
- Develop new methodologies and technologies to detect an adversary's deceptive or covert use of civilian activities or vessels.
- Continue to experiment with nationally developed and controlled artificial intelligence analysis tools to manage the massive increase in data available for analysis.

Fires

Improved ISR and C2 capabilities allow for more rapid target acquisition and engagement, particularly with a new generation of human-machine interface that increases reaction times. This applies to offensive capabilities that now comprise a combination of crewed and uncrewed systems as well as integrated air defense systems. Decisions regarding offensive action are complicated by the influx of new actors in the region and the potential for unclear and potentially unintended escalation, particularly as the escalatory dynamics surrounding the use of autonomous systems continue to evolve. Engagements between autonomous systems may be a low risk means of signaling resolve, while other applications might be regarded as escalatory. Signaling with autonomous systems in the Arctic, particularly when such systems might be the only military assets present in an area, constitutes a potentially useful yet underdeveloped concept. The reliance on networked operations, AI decision making, and autonomy among all actors in the Arctic serves to increase the importance of cyber and electromagnetic effects on the battlefield. Space has become a decisive warfighting domain. Disrupting, manipulating, or disturbing data from space-based assets through various non-kinetic counterspace tools represent additional conceivable options for an adversary.

Recommendations

- Conduct multi-sector “whole of government” (Armed Forces, Coast Guard, Police, MFA, MOD, etc) exercises and wargames based on potential confrontations with new and therefore less familiar Arctic actors to better understand escalation risks and potential de-escalatory options.

- Consider using affordable attritable autonomous systems to increase volume of combat power in Arctic, but with most focus on long range fires.

- Develop concepts for the tactical use of autonomous systems, particularly the neutralization of subsea systems.

Sustainment

Despite advances in technology that can mitigate certain challenges, the Arctic will remain a difficult region to sustain military operations. With the probable increase in civilian infrastructure in the Arctic, the Armed Forces will find it advantageous to explore options for maintaining potential compatibility with civilian infrastructure such as communication and energy sources for an extra layer of redundancy in remote locations. Alternative logistic solutions such as expanding current efforts to integrate additive manufacturing aboard surface vessels may be wise given the continued remoteness of the Arctic even with an expanded civilian footprint. Other sustainment issues may arise that limit the transport of heavy material, which will be vulnerable for disruptions from the impact of climate change. Naval bases in some areas may have some issues with sea level rise. Amid the focus on hardware, it is important to remain cognizant of the advances likely to increase the survivability and efficacy of personnel operating in cold weather environments ranging from biometric sensors, improved materials, and other human enhancement applications.

Autonomous systems currently depend on large amounts of training data, which should ideally incorporate 'ground truths' and experiences about how the Arctic environment shapes the possibilities and limitations for operations. Trust in autonomous system will be undermined if the system misunderstands or reacts poorly to Arctic conditions. Allowing the systems to gain experience in the physical environment poses a risk when an opponent has a potentially continuous surveillance capability over our territory through space assets and other sensors. Operational concepts leveraging autonomy in man-machine teaming are also complicated to train under such conditions. Using simulated environments can be an option, but the unpredictable development path of the impact of climate change will demand frequent updating cycles. Autonomous systems with strong improvisational skills may limit this problem. Utilizing AI-decision support for optimizing planning and operations can also make us predictable to our adversaries, with any divergence from the most resource effective course of action lighting up as an anomaly.

Recommendations

- Explore ways to better leverage new technologies such as additive manufacturing or energy storage technologies to increase self-sustainment in austere Arctic environments.
- Analyze and understand how developments in civilian infrastructure – including communications and energy usage patterns, in particular – will affect future military sustainment options.
- Ensure that the predictability resulting from AI modeling and optimization tools do not become a vulnerability.
- Prepare for the potential adverse effects of sea level rise on coastal military infrastructure.

Protection

Technological advances will improve protection against the elements as well as potential adversaries. For crewed surface vessels, operations in almost the entirety of the Norwegian Navy's usual operational area will be ice-free by 2050 but thinner first year ice and threat of smaller icebergs may present challenges for winter operations north of Svalbard. Ice-strengthened hulls – but not necessarily icebreakers – are likely to be useful. Weather conditions remain challenging, however. New actors in the Arctic (both civilian and military) lacking experience dealing with the extreme conditions that characterize the region might end up requiring assistance, thereby creating a greater need for search and rescue capacity.

Technologies for countering an adversary's sensors (and anticipating adversarial counters to our sensors) will continue to be characterized by constant competition, either through electromagnetic measures or advances in materials sciences that create coatings, camouflage and techniques that mimic cloaking functions. Civilian and military dependence on digital connectivity will encourage improvements to communications infrastructure with additional network nodes in the form of both space-based assets and high-flying UAVs. Therefore, smaller Arctic states such as Norway may benefit from expanding their military capability in this domain, accompanied by a corresponding expansion of concepts to protect this infrastructure. The potential rise in the number of Arctic space powers in the region may create a more competitive environment, which in turn will increase the amount of terrestrial space support infrastructure such as ground stations that will be viewed as installations of strategic value. This can represent a potential conundrum for Norway, as increased interest heightens the country's strategic position while at the same time potentially increasing threat against it and reducing its strategic autonomy.

Recommendations

- Develop plans for securing new critical infrastructure resulting from emerging commercial and military activities in the Arctic from kinetic and non-kinetic threats, ranging from seabed activities to space-based assets.
- Consider the hull requirements necessary for the potential expansion of maritime operations north of Svalbard given the changing sea ice characteristics in the area.
- Invest in new materials and fabrics designed to mitigate the effects of precipitation and cold weather on personnel and equipment, as well as reducing electromagnetic signatures.

5 Conclusion

The visible and dramatic shifts to the Arctic's physical environment due to climate change will directly affect how the Armed Forces operate in the region. These environmental changes alone will require adaptation if military forces are to remain effective while operating in the Arctic. The operating environment will likely evolve in other ways as well, including the potential for new commercial and military actors, demographic trends and subsequent expansion of civilian infrastructure, the types of military technology deployed, and the operating concepts that ensure operations are effective. The evolution of the Arctic towards 2050 is nevertheless full of contradictions and unclear trends. This is partially due to the remoteness of the region, a characteristic that is likely to persist even if resource extraction becomes more prevalent. Certain aspects such as the disappearing sea ice and melting permafrost are more certain elements of the future Arctic. Other outcomes are more uncertain, including substantial increases in commercial shipping, the emergence of China as an Arctic actor, widespread seabed mining operations, or the utility of autonomous systems in Arctic conditions. For this reason, we have tried to emphasize the greatest areas of uncertainty as well as imagining how these factors might interact with each other in a potential future scenario.

The analysis contained in this report does not offer any predictions regarding the future of the Arctic as an operating environment. The potential permutations within each of the factors analyzed are far too numerous for any definitive answers regarding the future. Extrapolating current trends into the future is always risky approach given that history often unfolds in a non-linear fashion. The inherent value of foresight analysis lies in its function as a structured thought experiment drawing attention to elements that might otherwise be neglected in long term defense planning. For this study, our multi-dimensional approach emphasizing the cross-cutting and second order effects appears to offer additional insights that can assist decisionmakers as they consider future force structures, doctrinal approaches, and infrastructure and basing requirements. Even as we acknowledge the unpredictability of future events, we should nevertheless be mindful of persistent trends that can be unwise to ignore. After several smaller and more localized respiratory pandemics (in 2003 and 2012, for example), experts consistently warned about the threat of a global pandemic prior to the COVID-19 outbreak. In a similar fashion, certain trends are worth extrapolating and examining their potential future impact. Advances in such fields as artificial intelligence, biotechnology, and space technology are among the many emerging and "emerged" technologies that appear poised to significantly alter how civil society and military forces operate. We must evaluate the potential linear evolution of such trends while remaining cognizant of the fact that such projections are likely to be flawed.

There is therefore more work to be done. Outlining potential futures is a valuable exercise only if it can inform the planning process in productive ways. Future studies will more closely examine how these types of products are best utilized, and the areas within long-term defense planning that are most relevant for foresight analysis. As always, many aspects of the future remain a mystery. Through this type of analysis, however, we expand our thinking regarding the operating environment and are better able to prepare for any number of potential futures.

Appendix

A Technology and society

Civilian technology and infrastructure are relevant factors for the Armed Forces as it conducts military operations. Assessing how technological development might alter various aspects of civilian society is therefore important to understanding the future operating environment. Previous reports from the Tekno project have analyzed technological trends as well as the ways in which non-state and state actors alike might utilize emerging technologies, but the society impact from technological advances has not been fully explored. This think piece therefore sketches out an image of how technology might develop at the global level over the next 30 years. The analysis begins with an overarching description of global societal trends viewed from a possible future world in 2050. This is followed by a discussion of specific technology areas considered relevant for military operations, including communication infrastructure, energy infrastructure, industry, transportation, production, and information.

The global picture

The 5th industrial revolution[21] is well underway in 2050, with the widespread application of various forms of AI in most parts of society.[22] The international security environment has undergone a period of intense interstate competition for markets, technology, and resources. Many new technologies have been rolled out in commerce, production, and services, but their dispersion among various states and within socio-economic groups remains unequally distributed. New sources of energy production and environmentally friendly "cleantech" have experienced a surge due to government incentives and private investments as the implications of climate change have become more apparent.[23] However, the transition to a greener economy has been less successful than hoped, as states experience budgetary strains from climate change mitigation and aging populations with steadily increasing life expectancies. Multinational business conglomerates hold more power relative to states, and by extension exercise stronger bargaining power in infrastructure development choices and investments. The regulatory approach to global and regional challenges – examples include health, migration, climate change and conflict – remain patchy due to lack of political consensus and the waning influence of international institutions. Advances in surveillance technology and data driven analysis have, on the other hand, made many states (and autocracies in particular) more agile in addressing crises such as extreme weather or

[21] The 5th industrial revolution is here understood as characterized by humans interacting, engaging, and collaborating with AI-systems on a regular basis. This includes AI systems in different sectors interacting seamlessly without the need for human interference to perform routine tasks such as transport and manufacturing (Noble et al., 2022).
[22] This part is a development of points put forth in (National Intelligence Council, 2021).
[23] Access to critical minerals for the development of these technologies is a dimension present in the geopolitical struggle between states. Resource nationalism and climate change influencing different stages of minerals supply chains, makes this market more volatile than in the 20 preceding years. Critical minerals alliances are growing in strength, but fail to eliminate the competitive friction between states (Dou et al., 2023).

nascent epidemics. Some democratic states have come quite far in integrating ambitious green industry strategies and a semi-circular economy.[24]

Notable demographic trends include continued population growth in developing countries and a slight decline in Europe, North America, East Asia, and Oceania (United Nations Population Division, 2022). Migration patterns are influenced by climate change, with extreme heat and the impact on the physical environment forcing populations away from the areas near the equator (United Nations, 2020). Countries with declining populations are accepting skilled migrants to tackle growing labor shortages. Urbanization is increasing globally, but this trend is even more distinct in areas with lower income levels (Dyvik, 2023; Ritchie & Roser, 2023). Growing megacities as well as smaller middle-sized urban areas are structured as complex smart cities with vast systems of Internet of Things (IoTs) in services (Weller et al., 2019). Data production and automated analyses facilitate increased efficiencies in public and commercial services, but also makes anonymity practically impossible.

Many of the overall metrics regarding public health are improving on global basis. Industrialized countries are reaping the greatest benefits from advances in less invasive surgical practices, easy and widespread personalized medication, and early diagnostics and treatment due to AI-supported test analyses (Weller et al., 2019). Diseases spread and erupt more quickly than earlier due to urbanization and travel patterns[25], but identification, contagion tracking & control and treatment is much more efficient.[26] Direct gene editing on the human body is used in the health sector for elimination of the most severe hereditary diseases (Mani, 2021). New biotechnology laws in democracies have strictly regulated the use of gene editing techniques for obtaining superhuman abilities, although a black marked exists where sellers claim to offer such products.[27] Enhancement of human psychological and physical performance are obtained through personalized performance enhancement drugs leveraging gene-sequencing technology.[28] The editing technology is most widespread in agriculture for climate change mitigation purposes.

[24] The incentive structured for prompting green investments in the 2020s has been effective. Technology advancements in particularly recycling techniques, energy efficiencies, and eco-design play a role in this development. See for example Maris et al. (2014).

[25] In addition to travel patterns and urbanization, climate change may play a role in the spread of infectious diseases by facilitating pathogens' livelihoods in warmer temperatures. See Baker et al. (2022) for an overview of factors influencing this picture.

[26] Examples of methods currently in use are serological surveys exposing antibodies in small blood samples, genomic surveillance systems tracking genetic alterations and geographical spread of pathogens. It is expected that AI-modelling techniques will play an important role in the future (Baker et al., 2022). This response disproportionally benefits developed democracies and autocracies. Counties in the global south have imported some surveillance infrastructure from autocratic states that can aid in these challenges, but these are mostly used for political surveillance and control.

[27] Legislation in the global south and autocracies are either silent or unclear on these issues, opening for technology development of this kind. There are signals indicating that some autocratic states have invested extensively in such tools.

[28] The construction of microbes with specialized abilities for physical perseverance during sports and other physically demanding activities are also used. A submarket for gene editing survival-gear made from edited microbes can supply its user with emergency nutrition and heat (Monsen et al., 2020).

New areas for services and goods are emerging leveraging advances in synthetic biotechnology to mimic natural functions and limit the negative ripple-effects of nature degradation.[29] There is widespread use of bio-edited natural organisms for increasing resiliency and output in food production. However, further monoculture is making the food supply extra vulnerable for diseases and naturally occurring inhibitors for continued growth and expansion.[30] Human intervention continues to be reactive and struggles to keep up with these forces.[31]

Communications infrastructure

Continued advances in both space technologies and information and communication technologies (ICT) have ensured more widespread and stable access to high-speed internet and telecommunication with the capacity to handle a vastly expanded network of IoTs in the private and commercial spheres. Space-based infrastructure is heavily dominated by commercial actors operating satellite constellations that offer services for communication, surveillance and navigation, with significant redundancy in services available to government and commercial customers on land and at sea.[32] The surge in satellite launches in high-elliptical orbits after the opening of new launch sites further north has made the coverage north of the Arctic Circle almost as good as further south, but with fewer options for redundancy.[33] The expanded use of edge computing onboard orbiting satellites has made most satellites launched in the past 15 years independent of the ground segment for downloading, processing and dissemination of collected data (Business Wire, 2023; Denby & Lucia, 2020; Leyva-Mayorga et al., 2023).[34]

The digital domain has formed into a partially balkanized structure, as states are dragged between the competing interests of implementing their chosen principles for control or freedom and nurturing economic activity dependent on digital services. Digital security is stronger with the use

[29] The transport and leasing of honey bees for pollinating crops is a large industry in the US today and serves as an example of this trend (Bond et al., 2021). Other examples include increasing level of aerosols in the atmosphere to reflect solar light into space and limit the rising temperature on earth, and fertilizing oceans to bind carbon dioxide (Oxford Geoengineering Programme, 2018; SEAS Communications, 2012).

[30] See (Natural Resources Defense Council, 2020) for an overview of the hazards of monocultures, GMO, and other aspects of industrial food production. Monoculture has made banana farming fragile as 99% of the exported production is of a variety that is vulnerable to the destructive Panama disease (Kambhampaty, 2019).

[31] The totality of our biosphere has proven to be too complex for modelling and simulating. The natural world continues to be analogue, and only the parts understood by humans can be 'inserted' in the digital world and further developed by AI.

[32] Fears of space debris threatening the safety of space-based assets in low earth orbit has led several actors to move more activities to mid-earth orbit, where similar services can be provided with slightly higher latency (Congressional Budget Office, 2023). Collective fear of possible lockout from LEO due to excessive debris has led to active debris collection infrastructure fielded by the European Space Agency, with the support of the other space powers created through open and collaborative structures (J. Robinson, 2010; Whitt, 2021). The shared interest in keeping space secure and free from weapons facilitated states finding common ground on this issue (Weeden, 2011). Collaboration in this area is among the few that remain efficient in the global frame. The increase in internet-satellite coverage is providing much better access in remote areas, and better bandwidth in densely populated areas with poor communications infrastructure. This is leveraged for economic development and public services. See (Maroju et al., 2023) for a contemporary example.

[33] Launch sites include Andøya, Norway; Kiruna, Sweden; and the Scottish Shetland Islands (Bye, 2023; Loughran, 2023; SaxaVord, n.d.).

[34] Legacy systems have in some cases been supplied by 'computation-support' from satellites orbiting in proximity.

of autonomous agents for surveillance and security response. Use of edge computing is now widespread, enabling the increased production of data and consumption of digital services in the population (Bigelow, n.d.). People have become accustomed to a self-healing digital network structure that quickly restores the system from attempted disruptions by cyber criminals. Advanced security mechanisms leveraging biometrics instead of passwords have reduced the risk of identity theft but has also limited the ability for opposition groups to organize and communicate anonymously online in autocratic states.[35] Democracies are developing privacy-enabling technologies, although with several challenges along the way. Encryption methods that are secure against quantum computation, such as quantum key distribution and asymmetrical key-exchange systems, have been rolled out for high-level systems and critical infrastructure in the countries with access to the technology.[36] The ability to breach conventional encryption methods with quantum computation is controlled by a few large actors and access to the technology is heavily controlled through expanded export control regimes developed over the past few decades.[37]

Energy infrastructure

The global energy production in 2050 is still primarily based on fossil energy sources, but heavily supplied with renewables in many regions. Electrification is extensive in most regions, although in varying degrees. Advances in green energy technologies have been driven by ambitious policies and generous subsidies in democracies so that profitable alternatives abound.[38] Expanded networks of weather based intermittent renewables are combined with storage through advances in battery technologies and hydrogen, as well as other chemicals (Det Norske Veritas, 2023a, pp. 54–61).[39] Developing countries are lagging in the transition to clean energy but have developed significant capacity in solar power technologies.

[35] Clandestine networks and forums such as the dark web are made available to the inhabitants in autocracies from infrastructure harbored in democracies, as well as network connection via satellite.
[36] The states with companies developing such methods are the first to implement and later spread these methods to their allies. States in the global south are slow to gain access but do so in a combination of transfers from more powerful states as a means of security diplomacy or as development aid.
[37] A wave of export controls in the early 2020s was fueled by the increased attention afforded to strategic emerging technologies, such as components in the development of AI, quantum technologies and biotechnologies. The controls were further tightened and implementer through the 2030s, which slowed the pace of development somewhat, but had the main effect of solidifying separate development paths of the technologies. However, as the technologies were increasingly commercialized, access to the services derived from them was more freely exported.
[38] Examples include The EU Green New Deal and the US inflation reduction act (European Commission, 2022; United States White House, 2023).
The market power of Western democracies has aided in the proliferation of electrification and other green tech in the developing world. However, the growing importance of markets in the more populous autocratic and developing states dampens this trend by providing cheaper fossil alternatives.
[39] These *Hybrid plants* combine different renewable energy sources with corresponding storage techniques for short and long term, enabling a flexibility on both supply and demand (Det Norske Veritas, 2023a; Tomescu et al., 2023, pp. 54–56). The need for large areas for renewables production has led to many states creating offshore energy islands (Horschig, n.d.). Hydrogen production is closely tied to the expansion in clean energy, making it mostly *green*, but sometimes *blue* or *purple*, meaning that it is produced through either burning fossil fuels and capturing the emitted carbon dioxide, or from nuclear energy sources, respectively (Arnfinnsson & Tønsberg, 2023, pp. 14–15).

The prevalence of nuclear energy infrastructure experienced only modest growth between the 1990s and 2020s.[40] Developing countries saw small increases as reactor technology became safer and more affordable. The states with growing renewables-infrastructures mostly replaced older reactors with more secure and affordable small modular power plants (SMRs)[41] as they reached retirement age. The largest increase in nuclear energy occurs in large industrialized densely populated countries and immense energy needs for industry, such as China and India (World Nuclear Association, 2022, p. 2).

Advances in electric energy production serves the vast increase in consumption in households and industry, land-based transport, and some short distance air travel. International shipping leans on a mix of sources, such as e-fuel[42], hydrogen, biofuel and ammonia, or on legacy systems with diesel, often coupled with on board CCS-systems[43] (Det Norske Veritas, 2023a, pp. 22, 58, 2023b, pp. 34–35). [44] Aviation for passenger and cargo transport relies on mostly hybrid fossil-electric systems.[45]

The combination of highly electrified societies with large quantities of weather-dependent energy production and an increased occurrence of extreme weather phenomena has necessitated an interwoven and highly automated energy distribution and control system (Klepper et al., 2023). This system leverages advances in IoT and communications technologies and adopts strong hardening techniques to avoid cascading effects from minor disruptions. The digitized and highly automated production and transportation industries are tightly integrated into this structure, which facilitates effectivizations and increased profitability, but with a low tolerance for interferences that may affect the financial bottom line. This stance is seen implemented in its most aggressive form in autocracies, complemented with detailed data streams from private and commercial consumption patterns that are otherwise protected by privacy laws in democracies.

[40] Some reasons for this are that the establishment of a nuclear energy infrastructure is very resource intensive, demands large state subsidies, and faces financial insecurity through long development timelines that may span decades before energy production can begin (Iurshina et al., 2019). Although the production capacity is large when the plant is operational, the establishment costs are so vast that mostly established nuclear energy powers represent the increase in this field.

[41] SMRs are defined as nuclear reactors with a capacity between 300 and 700 megawatts. Concepts exist for very small nuclear reactors (vSMR) for systems with a capacity below 15 megawatts (World Nuclear Association, 2023).

[42] E-fuel is a synthetic fuel where the hydrocarbons are typically created from CO2 and hydrogen. The carbon dioxide may be collected from the use of fossil fuel or captured from the atmosphere. The hydrogen used is created either from renewables (green hydrogen), or from nuclear energy (purple hydrogen). Other techniques exist for producing E-fuels, leveraging advances in synthetic biology (Arnfinnsson & Tønsberg, 2023, pp. 31–32).

[43] Carbon capture and storage (Det Norske Veritas, 2023b, pp. 34–35).

[44] Hybrid designs leaning to a larger extent on batteries are used for inland waterway transport, where the strain of the elements in the open seas does not have the same scale of impact (Allen, 2022).

[45] Battery weight makes fully electrical systems only viable for small aircrafts travelling short distances. E-fuels based on green or purple hydrogen-energy technologies is more widely in use in the developed world (Det Norske Veritas, 2023a, pp. 20, 58).

Industry, transport, and work

Industry and transportation have seen extensive technological advancement and adaptation. The Global South continues to be the main producers of consumer goods for global markets due to the low cost of labor and permissive legislation for advanced autonomous roboticized systems. Production capacity in high-cost democratic states continues to be within selected high tech-areas, some of which are kept in the region for strategic purposes. Although AI is used in some form in most sectors, legislation is more permissive in sectors that are not in direct contact with humans. Technology development, production design and innovation are among the sectors utilizing potent AI systems most freely.[46] This is a driving force behind global technological advancement in 2050.

Autonomy has become widespread in most parts of the goods and services industries. AI planning systems are combining IoT in production with fully autonomous logistical infrastructure for efficient transport, facilitating 'just-in-time' manufacturing and logistics.[47] Human intervention is possible, but seldom used due to small margins that can quickly and negatively affect profitability. International networks connect and optimize transport infrastructure over sea, land, air and in a few instances space. Infrastructure along the main international transport routes and in high-tech developed countries are designed with these functions in mind. The speed and capacity of transport infrastructure is the most developed in these areas. Remote areas in developing countries with little industry or resource extraction are, unsurprisingly, far less developed.

The introduction of new technologies in the economy influences the workforce structure globally and prompts reorganizations in production and the knowledge industry.[48] Moravec's paradox[49] has diminished validity after decades of training, tracking and amelioration of AI-systems and robotics.[50] Blue collar workers in heavy industry and trade are kept in supervisory positions to

[46] The newly adopted AI Act from the EU illustrates how legislation protecting human rights and freedoms are shaped reactively when emerging technologies spread in societies (European Parliament, 2023). It would be expected that democratic states go further in this endeavor that autocracies. However, some restrictions would likely be adopted in autocracies as well, particularly to limit public discontent from errors and unexpected side effects.

[47] The 'just-in-time'-concept is incorporated in certain commercial companies today on a different scale and scope than what would be expected in 2050 (Banton et al., 2023).

[48] The impact of different systems leveraging AI on global labor markets has been viewed with alarmist and optimist lenses for some time (Vallance, 2023). Felten et al (2021; 2023) provide analyses of exposure of different industries and occupations to different AI systems. Earlier, automation trends in blue collar functions in the early 2000s prompted a fear that this would lead to a vast increase in unemployment in the developed countries. The opposite turned out to be true, showcased by the decrease in unemployment in the time following (The Economist, 2023). Similar waves have followed the fielding of generative AI systems in 2022, where white collar and creative sectors were more affected (Hui et al., 2023). Although many of the concerns regarding this trend are well-founded, key shaping factors such as legislation, regulation, technology adaptation, trust and effectiveness of the systems are yet to enter the stage. The stance taken here on this issue is one of cautious optimism.

[49] Moravec's paradox refers to how it is it is relatively easy to teach computers to do things humans find difficult, and difficult to teach them things humans find easy. Examples of the former could be complex mathematics and processing large quantities of data quickly, and of the latter; walking or understanding social sub-context (Thakur, 2023).

[50] Micro-work has played an important role, with vast populations in need of paid work combined with the needs of AI-systems to include regional cultural understanding. Globally available high-capacity ICT infrastructure has been an important facilitator in achieving this.

the autonomous systems due to both political and economic reasons such as corporate responsibility structures and traceability of actions and decisions.[51] Heavy, dull and dangerous tasks leverage advanced robotics for such tasks as search and rescue or heavy construction, which are aided by digital twin simulations of physical production facilities for efficiency and predictive maintenance procedures.[52] Generative AI systems are widely used as robust and specialized support functions for white collar workers in most areas of the world.[53] Over time, fewer workers have been hired to replace the first wave of AI-enhanced workforce, fueling large investments in complex re-skilling systems to provide the specialized skills needed. This trend is most prominent in commercial sectors where effectivization pressures are high, and less so in public sectors where adaptation of new tech is slower. Areas where human contact proved essential are growing, filled partially by foreign migration in states experiencing a population decline. A selection of customer-near-services industries as well as care-related public functions are housing a larger percentage of the workforce than before (The Economist, 2023).[54] New technologies, services and societal developments leads to the creation of many new jobs, but not all are able to reskill quickly enough to meet these. Overall, workers' rights are under pressure. Surveillance and big-data analysis is rampant in all sectors. Despite investments in re-skilling programs to keep the workforce relevant, many, especially low-skilled workforce in states with weak public services, are murmuring with discontent.

Interaction and information

Digital services and products remain an integrated part of everyday life, leveraging advances in software development and communications technologies. The increased quality of digital services are leaning on the access of data and insights into human psychology (Finck, 2021). Over time, legislation in liberal democracies limiting access to data and the more invasive manipulation practices has reduced their competitive advantage. Some technologically advanced states are more permissive of the amelioration of models and platforms. Big data from developing countries are being traded as a commodity to fuel commercial AI-development. States and companies in

[51] Insurance companies are pulling the trend toward automation, due to statistically favorable outcomes regarding faults and risk.

[52] The roles in industry where one person steers one machine are near eliminated, and changed for surveilling self-adjusting systems powered by AI and edge-computing. Most of these industries can be optionally steered and adjusted by the few human overseers, with seamless human-machine interface through advanced sensors and lenses, glasses, hologram or BRI-implants. These can provide many of the same functions, but different uses need different perspectives in the integration. Examples, steering one node in a logistical network, versus looking at the health of the entire system. Surgery and maintenance or construction of complex factories can demand a closer perspective. Different solutions will have different cost frames, also influencing choice of solution.

[53] This includes research, medical personnel, lawyers and public Despite early alarmist views, the functions eliminated by generative AI are mostly routine processing and clerical tasks. The systems serve as *augmenting* the job functions rather than eliminating whole groups (Gmyrek et al., 2023; Milanez, 2023).

[54] AI support tools in planning and support leads to a strong productivity increases for the people remaining in the workforce. Leveraging bioinformatics in career choice and recruitment adds to this trend. Advances in health monitoring and early treatment reduces the absence from work for health reasons, and AI-powered efficiency tools for peoples' private life eases the stress factors limiting productivity. These trends combined minimize the 'inconveniences' of a non-roboticized work force.

democracies are worried of losing their competitive edge in this race, and ultimately whether this will affect their comparative military power.

Populations are increasingly interconnected through digital platforms and communities. A larger percentage of daily social interaction has moved online or into hybrid environments. Immersive and interactive interfaces with the potential for life-like avatars are projected in one's physical environment. Online interaction is more widely used in professional life as well. Urbanization and rising real estate prices in the large cities, combined with better connectivity and energy production, has led highly skilled labor to work remotely from suburbs, exurbs, and rural areas. At the same time, people's identities and views of the world are being split along more axes than before. Most states have adopted some strategy for creating a common public sphere for debate and collective view of reality. High profile cases highlighting the power of commercial algorithms have created a market for services placing the filtration agency of news and information with the consumer (Miller, 2021).

In most countries, news is communicated through immersive solutions that give an interactive experience of world events. The entertainment industry is leading in the development the technological solutions that commercial actors are leveraging with a now-profound understanding of human psychology. Continued gamification of digital services and work results in a population that struggles to separate entertainment from reality. Some high-profile cases in the late 2020s of deep-fake videos enticing public uproar has made visible their manipulative power, but these realizations are spread unevenly between societies and within them. Lack of interest, or targeted policies for information control, create the same effect of certain info-spheres being particularly vulnerable for deception and personalized manipulation.

The trend of digital isolation and societal control in autocracies is creating a difficult tradeoff with access to international markets for digital products (National Intelligence Council, 2021, pp. 64–65, 112–115). On the other side, democracies have moved through a time of debates on how to reconcile democratic values in the infosphere with need for commercial and public data collection and surveillance for amelioration of goods and services. As the public is becoming more accustomed to an agile and personalized service provider in the commercial sphere, the states are feeling the pressure to meet the expectation of efficacy and ease the public now has to public rights and services. This has led to public acceptance of connecting public databases siloed for democratic control and privacy protection with extra hardening of the external shell of the systems. In parallel, the trust gap is increasing globally, and the division between educated well-off population, and the disillusioned lower socio-economic classes has deepened over time (National Intelligence Council, 2021, p. 21). Alterations in the job market prompted by new technologies makes many in the former group joining the disillusioned, supplying momentum to the frustration felt by many.

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About FFI

The Norwegian Defence Research Establishment (FFI) was founded 11th of April 1946. It is organised as an administrative agency subordinate to the Ministry of Defence.

FFI's mission

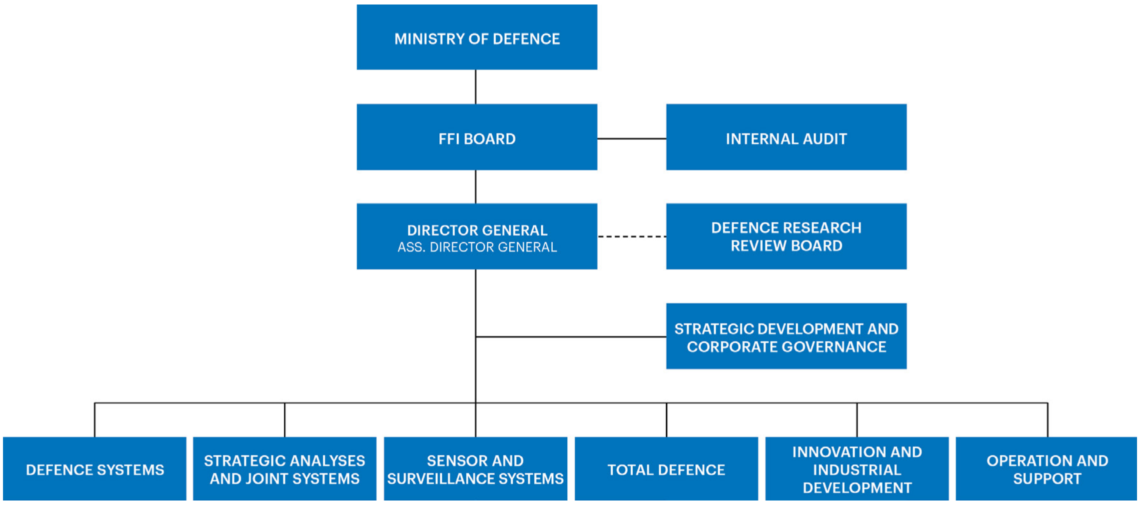
FFI is the prime institution responsible for defence related research in Norway. Its principal mission is to carry out research and development to meet the requirements of the Armed Forces. FFI has the role of chief adviser to the political and military leadership. In particular, the institute shall focus on aspects of the development in science and technology that can influence our security policy or defence planning.

FFI's vision

FFI turns knowledge and ideas into an efficient defence.

FFI's characteristics

Creative, daring, broad-minded and responsible.



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