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Use of digital technology to follow the consequences of a warming Arctic climate

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Abstract. The rapid warming climate is causing the Arctic ice to retreat and the permafrost to melt. These visible manifestations of the ongoing climate change are few of many environmental and societal changes that take place in the Arctic. The acceleration of digitalization and implementation of digital technology bring new opportunities to follow the consequences of the warmer arctic climate, but also introduces new challenges in this region as the dependency on the digital technology increases. This paper focuses on the cyber ecosystem and discusses digital technology available for monitoring the consequences of a warming Arctic and its impact on Critical Infrastructure (CI) in Norway, such as communication networks, electric power transfer systems, water and wastewater, transportation infrastructure, oil and gas infrastructure. The need for reliable satellite communications is emphasized.

Keywords: Arctic Region, Cyber-ecosystem, Remoteness, Climate change, Critical Infrastructure, Digital technology

1. Introduction

Rising global temperatures causes impacts to the Arctic Region. The area is one of the most rapidly changing regions in the world, and changes observed since the 1970's, like diminishing sea ice, melting glaciers and melting permafrost are all direct effects of this [1,2]. There are many consequences of the warming that influence this vulnerable icy ecosystem and understanding the changes occurring in this remote area are of scientific and practical urgency [3]. Everyone can be said to be a stakeholder when it comes to the changing Arctic climate and ecosystems, as the Arctic Region influences on the entire globe. Further to noticing the visible melting ice, highly influenced by human-made emissions, one should also be aware of the changing man-made Cyber-ecosystem in the Arctic [4], caused by increasing use, spread of and dependence on digital tools and cyber technology.

The wording "digital tools" in the context of this paper are referred by meaning computer programs, online access and websites, which can be accessed in web browsers. "Cyber technology" is meaning all computer technology that involves connection to internet or cyberspace. It involves all satellite and antenna-based communication systems. In principle, connections to the internet can open up for hackers to access the IT system of individuals and companies and barriers are needed to ensure that the digital tools can operate in secure mode [4].

The rapid digitalization and implementation of digital technology bring new opportunities to monitor the effects of the warming climate and to introduce mitigation measures, however, the technology also introduces new challenges in the Arctic as one becomes dependent on the continuous uptime of the



technology [4]. A variety of technologies have been utilized in this area to understand the climate emergency and new technologies are forming digital toolboxes of solutions that can help us understand these changes. This also introduces new challenges as the adoption and integration of digital tools and devices has led to an increasing interconnection of Cyber and physical infrastructure (e.g., buildings, roads, power lines, transport on land and on sea, etc.) making the society more vulnerable to threats and risks in case of malfunctioning cyber technologies. Adding climate change to the risk picture in the Arctic makes the use of digital technology even more challenging, as the possible consequences on safety, security and privacy are widening.

There is a need for new methods for modeling these cyber – physical and hybrid threats and their impact on Critical Infrastructure (CI) in the Arctic. Using digital technology to monitoring consequences in the Arctic can introduce opportunities but also unwanted events. In the following section, we summarize key findings in the latest AMAP publication [1] and discuss the use of digital technology for monitoring the impact of a warming Arctic and its impact on Critical Infrastructure in Norway. Thereafter, in the subsequent sections we discuss the term “climate risk” and refer to infrastructure gaps caused by short to medium term design considerations and the dependency on digital tools and cyber technology. In the main part of the paper, a discussion of digital technology available for monitoring the consequences of a warming Arctic and its impact (and limitations) on some selected Critical Infrastructure sectors in Norway is presented. We also include a brief section on reindeer herding which is critical for the indigenous people of the Arctic. Finally, conclusions and discussions regarding further research are presented.

2. Climate change: Key trends and impacts

According to the AMAP report “Arctic Climate Change Update 2021” [1], the climate change causes environmental changes at a rapid pace. The report summarizes 6 key findings/ trends:

1. The physical drivers of Arctic change continue to change rapidly
2. Extreme events in the Arctic are changing in frequency and intensity
3. Climate change is having major impacts on Arctic communities
4. Arctic ecosystems are experiencing rapid, transformational changes
5. Changes in the Arctic have global consequences
6. The latest climate models continue to project that the Arctic will warm rapidly over the course of this century

These findings are based on observations, surveillances and recording of data from the ocean, the atmosphere, the tundra, the glaciers, etc. The data supporting the findings are both qualitative and quantitative and the methodology of research vary. All these trends impact Critical Infrastructure (CI) and to develop specific measures to protect CI from unwanted events, an understanding of climate risks is needed. Data, which can serve as a basis for risk evaluations are needed. Digital tools and technology can help collect data, and to some extent analyze the data, but to ensure a holistic understanding, indigenous, traditional and local knowledge should be included. This is also recognized by AMAP [1].

Key climate indicators are related to the air and permafrost temperature, precipitation, terrestrial snow cover, river ice and water volume, sea ice, land ice, and trends in extreme events, Figure 1 [5].

3. Climate risks

Climate change is a global risk, and potential impacts from the 6 key findings in the AMAP report [1] are reviewed and often incorporated into decision-making processes on a global, regional, corporate, and community level [6]. Concerns about these risks are present in local Arctic communities, especially among indigenous communities vulnerable to changes in weather, ice and snow distribution, often relying on traditional knowledge. There is a growing concern about the potential impacts of changes to marine and terrestrial ecosystems, more unpredictable environmental conditions and geophysical hazards related to climate change. Key climate indicators such as surface temperature, precipitation, ocean acidification, snow cover, permafrost thaw, sea-ice thickness and extent can be used when analysing climate risks.

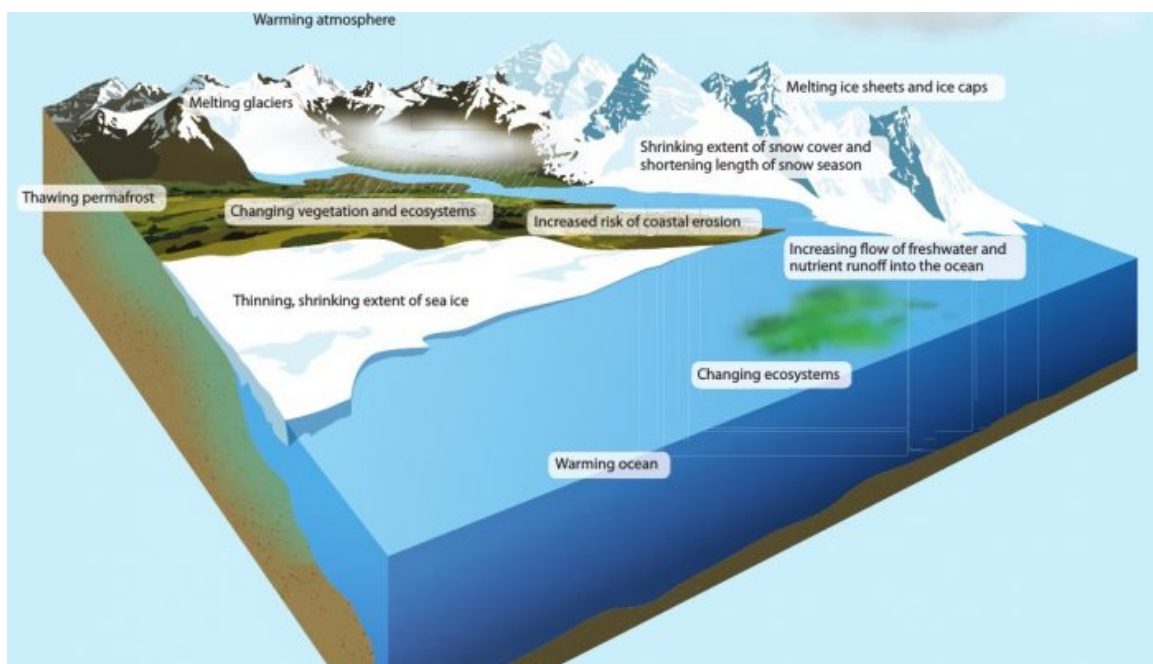


Figure 1. Effects of a warmer climate on the Arctic environment (Credit: Fig. 1.2 of [5]), adapted from US National Centre for Atmospheric Research (NCAR).

The term “risk” has been interpreted in different ways and is an important concept in several scientific fields [7]. Engineering and health science are examples of specific areas that may require specific models of risk. This paper will not try to define “Climate Risk”, point to or discuss what it should be based on (probabilities, uncertainties, objectives or expected values) as a critical review of the understanding and description of the IPCC approach when it comes to climate risk is provided by Aven and Renn [8] and by Aven [9].

Our contribution in this paper focuses on potential unwanted events caused by climate changes as described in AMAP [1], the consequences and their impact on Critical Infrastructure in Norway. The increased digitalization and interdependence between infrastructure systems exposes and amplifies risks. Surveillance systems dedicated to monitor Critical Infrastructure, and data used to track behaviors and physical changes are considered important to ensure efficient risk management and the development of adaption to changes.

4. Arctic infrastructure gaps

In parallel with climate change and its side effects, like the retreat of the Arctic Sea ice, there is an increased interest towards the High North.

Intensified investments, development, economic activity and human affairs underlines the need for a resilient infrastructure development in the Arctic. Resilience is defined as “*the intrinsic ability of a system to adjust its functioning prior to or following changes and disturbances, so that it can sustain operations even after a major mishap or in the presence of continuous stress*” [10].

The physical infrastructure is often built, in response to isolated short-to-medium needs, with limited “design life” of buildings and infrastructure, without analyzing the long-term effects nor the possibilities of long-term changes of the environment.

Additionally, the acceleration of digitalization and increased use and spread of digital tools and cyber technology affects the Critical infrastructure, making it dependent on a robust Cyber-ecosystem. It can be argued that the Critical Infrastructure sector is becoming more complex and vulnerable because of this interdependency.

5. Digitalization of Critical Infrastructure sectors in the Arctic

A discussion of digital technology available for monitoring the consequences of a warming Arctic and its impact (and limitations) on some selected Critical Infrastructure sectors in Norway is presented. This will represent a background for further research and adaption within the field.

5.1. Satellite communication

The umbrella term that refers to all global satellite positioning systems “Global Navigation Satellite System” (GNSS) has a global space-based positioning, navigation and timing (PNT) capability. Precise navigation positioning can rely on correction of transmitted signal, which can be achieved by using a fixed receiver/station in a known position as a reference (differential satellite navigation). This information is integrated in the calculation process improving the location accuracy. Today’s GPS have high precision (typically within +/- 5m) [11], however, less in the Arctic because the vast open sea makes it difficult to have fixed receiver/station on the ground. The signals have many applications and are used in many fields as in transportation, manufacturing, emergency services, agriculture and telecommunication.

Satellite observations can provide a long-term view of ice thickness [12] and have the advantage of providing complete datasets and removing the “human-error” from the sampling/measurement process etc. Satellites reach even the most sparsely populated Arctic areas where there are few persons who can make any observations.

Communication through satellites is important in the Arctic but there are issues related to high speed and reliability of data transmission. Satellite communication is normally operating at microwave frequency range, and data achieved by C, Ku, or Ka-band transmission (via high-orbit geosynchronous satellites) tend to be distorted due to meteorological conditions such as rain. The retreat of sea ice increases evaporation, that leads to formation of more clouds and more precipitation. This affects the quality of satellite communication, but clouds and fog also attenuate optical signals [13]. Other disruptions of satellite signals include jamming of signals, making navigation and aviation difficult, like experienced in Finnmark, Northern Norway [14,15].

5.2. Electric power transfer systems

The electric power infrastructure operations in the Arctic region face challenges due to climate risks. The potential impacts of unwanted events in this sector can cause disasters because of the harsh conditions and safety and security in this sector should be given high priority. Downstream users of electricity are residential, commercial, industrial and community services and unwanted events in the Electric power transfer systems could impact the basic functioning of community health, environment and economic activities. Economic growth, international competitiveness and national security are, due to the acceleration of digitization, becoming more dependent on digital technologies, and the electricity demand is increasing. The need to protect the electric power transfer systems from disruption, modification, or destruction should be of high concern. Extreme events in the Arctic are changing in frequency and intensity and low visibility and harsh weather conditions (already common in the Arctic) makes the repair of e.g., broken, collapsed power lines or high voltage power transmission towers more difficult, costly and time-consuming. Storms, accumulation of snow and ice, high ambient temperatures but also infrastructure inter-dependencies impact climate risks relevant for the electric power transfer systems. Failure or disruption of another infrastructure sector represents a risk and these vulnerabilities should be addressed in future assessments.

However, with the use of modern digital technology, it is possible to monitor the transmission system to determine exactly where a failure has occurred. This enables rapid repair, of considerable benefit to quick re-establishment of the electric power transmission infrastructure

5.3. Oil and gas infrastructure

The oil and gas (O&G) sector is one of the most important CI sectors for the Norwegian economy. Unwanted events in the Arctic O&G sector can have adverse effects on health, human safety, and the

environment, but also include multiple countries (pollution or delivery disruption) and have severe consequences for geopolitical areas. Buildings, installations, and equipment required upstream, midstream and downstream [16] are facing negative impacts due to changes in the environmental and ecological conditions and risks related to climate (precipitation, storm, clouds etc) and changes in cryosphere can have a great impact on this sector. An example of civil works and structures that may be affected are jetties and quays, tunnels, shafts and caverns, tall buildings and structures or facilities requiring special tolerances. The ongoing digitalization and decentralization of oil and gas (O&G) systems and resources in the Arctic increases vulnerability, and this is an important factor that should be addressed before new approaches are proposed.

Potential consequences from climate risks, like downtime in an O&G plant or platform, can be expensive, and the sector is dependent of other CI in the Arctic to be working as intended. Companies are starting to incorporate climate change risks and opportunities in their assessments and new application of information technologies (based on the Internet of Things (IoT) smart sensors, wireless networks and cloud technologies) have potential to increase reliability, effectiveness and reduce vulnerabilities. The O&G infrastructure exposure and response to climate risks is complex but some general areas and activities are identified:

- Technical basis must be updated and include climate changes to support required accuracy (geology and geo-technical conditions, topography, bathymetry, meteorological and oceanic data etc)
- The capability of existing infrastructure in the Arctic should be assessed
- Interdependency and dependency on other infrastructure should be assessed
- Include local knowledge, familiar with the geographical area and environment in Arctic
- Unproven or unfamiliar technology that involve high risk for health, environment, safety or security should not be applied in the Arctic

A thoroughly review of scope and activities focusing on potential climate change risks in the design phase can contribute to safe and secure execution and operation phase and new application of information technologies (based on the Internet of Things (IoT) smart sensors, wireless networks and cloud technologies) have potential to increase reliability, effectiveness and reduce vulnerabilities. It must be noted, however, that cyber disruption may cause shut down of facilities and that safety critical systems must be operative should all digital communication systems be lost.

5.4. Transportation infrastructure

Transportation infrastructure is defined as critical in Norway. It is essential in emergency situations in the Arctic because of the long distances between different areas in the Arctic but also for economic activity as it provides passengers, material and goods to be transported from one place to another. Development of transportation infrastructure in the Arctic region needs to be robust to ensure growth and progress of industry and technologies [6]. Scenarios rising from the combination of an increasing level of transportation activity (tourism boom, increased shipping traffic etc), long distances between populated locations, harsh weather conditions and impacts from climate change should receive attention when discussing options for the future. Roads, rail lines and airports will be affected by subsidence and deformation of roads and surfaces (due to thawing of permafrost). Integration and use of real-time data and analytics to track status of transportation systems can enable infrastructure managers to reduce the probability of unwanted events and minimize impact of climate risks. Drones can be used for monitoring of the infrastructure over long distances, and messages can be sent back to maintenance stations for immediate warning and quick repair.

5.5. Water availability and wastewater handling

Climate change is emerging as an issue for water and wastewater management in the Arctic region. The warming climate will influence quantity and quality of water; water lines can break, warming of permafrost can make water containment structures unstable, and improper treatment of wastewater can impact Arctic environment and cause diseases. Rising water temperatures and risk of pollution due to

flooding can potentially become more problematic in the future. The International Telecommunication Union (ITU) classifies six Smart water management (SWM) tools [17, p.4]:

1. Data acquisition and integration (e.g., sensor networks, smart pipes, smart meters, etc.),
2. Modelling and analytics,
3. Data dissemination (e.g., radio transmitters, WIFI, Internet etc.),
4. Data processing and storage; (e.g., cloud computing.),
5. Management and control,
6. Visualization and decision support (e.g., web-based communication tools).

These tools represent an already ongoing development and implementation of Smart water technologies that can improve design, monitoring and maintenance of water and wastewater systems. [18].

It is possible that the use of digital tools and technology can overcome some of the challenges the Arctic is facing due to climate change faced in this sector, but new challenges are also introduced. Cyber-security, inter-dependencies, data protection and recovery activities in case infrastructure is disrupted must be assessed. Water is a basic human need and water security, and accessibility is of great importance.

6. Reindeer herding

Traditionally and also today, the indigenous people of the Arctic have been dependent on reindeer herding. We consider reindeer herding as a critical element of the life in the indigenous people of the Arctic. The reindeers graze on large areas of land and are dependent on suitable snow conditions (without layers of ice) during the winter period. It is possible to use drone technology to monitor large areas to obtain information on the conditions of the ground and it is also possible to use this technology for monitoring the individual reindeers in case they be equipped with radio senders to identify each individual [19].

7. Conclusions

Climate change is threatening to increase the vulnerability of Critical Infrastructure. Digital tools offer a potential to relieve this concern, as it can be used for monitoring climate change and the effects on Critical Infrastructure, and for mitigation and adaption to these changes.

However, interdependencies are important to understand when assessing the implementation of digital tools and systems as foundation of Critical Infrastructure. Digital tools are, amongst other, dependent on energy, which is among the CI sectors, Downtime in the energy sector can cause cascading failure in other infrastructures. Dependable CI protection in the Arctic cannot be realized overnight, systems must be fitted to the unique requirements in the Arctic. Digital tools can be utilized to monitor key climate indicators such as surface temperature, precipitation, snow cover etc. but the process of choosing methods for identification and detection of unwanted events, risk reducing barriers to protect CI etc. should include indigenous, traditional and local knowledge. This can increase the ability to manage and respond to unwanted events and the ability to recover quickly.

In this paper we have discussed the use of digital tools and cyber technology in a number of critical Infrastructure systems in the Arctic:

1. Satellite communications
2. Electric power transfer systems
3. Oil and gas infrastructure
4. Transportation infrastructure
5. Water availability and wastewater treatment

Also, reindeer herding has been reviewed with reference to use of modern digital technology. In the discussion of the Critical Infrastructure, we have pointed to the benefits of introducing digital technology and we have pointed to the limitations of the modern technology. With an even wider use of the technology, it is necessary to continue research on how to mitigate negative effects and how Critical Infrastructure can be operable in case the digital technology should be non-available.

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