PART V: Technological Dimensions of Arctic Governance

Opportunities and Challenges of Space-based Infrastructures for Arctic governance: Assessment from an innovation system perspective

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Introduction

The satellite sector has experienced dramatic developments over the last decade, mainly driven by improved technological innovations and increasing privatization of the sector. Miniaturized components for satellites, lower costs for satellite manufacturing and launching, coupled with improvements in large data management, have allowed satellite systems to advance rapidly. In recent years, space-based infrastructures such as Earth-observation and communication satellites are increasingly used for remote areas with extreme conditions. These technologies can help improve Arctic governance in a number of ways. This trend is expected to grow quickly in the coming decade as satellite technologies get more integrated with different Arctic-related applications and as different satellite-based infrastructures become increasingly aligned, such as among observation, communication, and navigation systems, as well as with technological progress in cloud computing and deep learning.

Space-based infrastructures are therefore expected to shape Arctic governance in the coming years, ranging from new problem identification to new regime design. This chapter uses an “innovation system” perspective to assess the development of the rising satellite sector in general and how that may influence opportunities and challenges for Arctic governance in particular. The Technological Innovation System (TIS) perspective has been usefully applied in many sectoral fields to analyze success and failure conditions of newly emerging technologies and industries (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008; Binz & Truffer, 2017; Suurs & Hekkert, 2009). Following the TIS perspective, several innovation processes are critical to facilitate successful development and diffusion of space-based infrastructures in the Arctic, including transforming innovation policy of the space sector, knowledge or technological development, entrepreneurial experimentation, guidance and standardization, technology legitimation, industry formation, and downstream market integration. This chapter will outline different potentials offered by advanced space-based infrastructures in governing different Arctic related issues. Subsequently, the chapter discusses the most salient innovation processes taking place in the space sector in general, but also assesses how that may influence opportunities and challenges in shaping Arctic governance in particular.

How space-based technologies may reshape Arctic governance

Conservation of Arctic biodiversity

One promising area is in the potential of using satellite images to assist in tracking and counting cetaceans such as whales. These efforts can be substantially enhanced when combined with open satellite data and deep learning (Guirado et al., 2019). Scientists are increasingly working on these data and developing models that contribute to the assessment of whale populations to guide conservation activities generally, and which can also be used in the Arctic. The conventional way of identifying or estimating the population of cetaceans is in situ, involving ships, planes, or ground stations. With satellite observation systems, remote sensing, and appropriate scientific modelling, whale tracking could now become more convenient, more efficient in terms of time, and less costly – especially in remote places like the Arctic. Besides spotting whales that are trapped inside sea ice (Williams et al., 2015), the ability to track movements of whales in real-time also helps guide the operation of ships, potentially minimizing the likelihood of ship strikes on whales. This in turn could enhance the scope of the Polar Code.

Satellite technologies can also be used for tracking migratory animals, which will be useful to inform the design of existing regimes concerning the area of protection coverage for those animals. In particular, the use of satellite telemetry combined with satellite navigation systems such as GPS can help track the movement of animals over long distances and a relatively long timeframe (Perras & Nebel, 2012). For instance, scientists recently studied the journey of an arctic fox over 76 days using the Argos Data Collection System, which is a long-term international program that connects to sensors and transmitters on over 21,000 satellites that are orbiting the Earth pole-to-pole.[1] The scientists were able to track the journey of the fox from Svalbard northeast across Spitsbergen island onto sea ice, the open ocean, and finally to northern Greenland and then to Ellesmere Island in the northernmost Canada. These satellite systems can also be used for tracking polar bears, which could be informative to the formulation or revision of conservation policies.[2] The ability to track the movements of wildlife could therefore be helpful in determining suitable boundaries for the establishment of protected areas relevant to the Arctic, such as the Ecologically or Biologically Significant Marine Areas (EBSAS) as envisioned in the Convention on Biological Diversity.

Governing Arctic fisheries

Companies offering satellite-enabled Automatic Identification System (AIS) services can work with government agencies, especially in the detection of illegal fisheries or in investigations of causes and impacts of fishing activities. AIS has been used to help review or verify spatial distribution patterns of main fishing operations used in the Arctic Sea (FAO Area 18) as estimated by the Global Fishing Watch (GFW). In particular, AIS-generated datasets can be used to characterize fishing activities by fishing style, such as in detailing the presence or absence of fishing activity, its intensity, and hot spots (FAO., 2019, p. 117). For instance, AIS data could identify that most of the fishing activity in FAO Area 18 is by trawlers, taking place in the far northwestern corner of the Russian Federation that is less covered by sea ice, as well as in the eastern edge of the Hudson Straight in Canadian waters (FAO., 2019, p. 118). Overall, AIS based information on fishing activities can be useful for monitoring purposes in the short

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[1] https://www.space.com/arctic-fox-epic-journey-satellite-tracking.html?jwsource=cl

[2] https://www.wwf.ch/sites/default/files/doc-2017-09/2013-03-factsheet-polar-bear-conservation.pdf

run but may also provide insights to new regime design in the long run. However, it will also be important to address the issue of fishing activities via smaller vessels in the future, such as those close to land, as these vessels are not required to be equipped with AIS.

Governing marine litter/ debris

Scientists are also increasingly combining satellite systems with artificial intelligence/ deep learning to detect marine plastic pollution or to identify the extent of marine debris distribution (Biermann et al., 2020). This indicates that it will be easier in the near future to detect debris littering in the Arctic seas, but also to identify sources of marine debris coming into and leaving the Arctic seas. This might therefore lead to the identification of new governance needs for the Arctic with regard to marine debris mitigation.

Governing Arctic shipping

AIS can also substantially improve day-to-day administration in the Arctic. An important example is through enriching geospatial analysis with AIS data for the purpose of ship and vessel tracking. Advanced AIS can record positions, routes, destinations, and estimated time arrivals for daily logistics issues. These data can furthermore be augmented to derive historical vessel positions or voyage data. This can enhance ship detection, port monitoring, vessel route optimization, etc. With these tools, maritime traffic in the Arctic can be better managed, including identifying ships stranded in sea ice.

Combining satellite systems with AIS can also aid processes related to monitoring, reporting and verification. In particular, this can help track seafaring vessels equipped with AIS devices beyond coastal areas. Satellite-based AIS allows more comprehensive terrestrial coverage, potentially covering any given area on Earth, including the Arctic. An example of an ongoing project is the European Space Agency’s (ESA) effort to build a European-based satellite-AIS system in collaboration with the European Maritime Safety Agency, which aims to complement the SafeSeaNet (SSN) system. This can help with monitoring vessels in different maritime areas in terms of their routes, activities, etc.

In addition, satellite-based AIS can also help monitor the emission compliance of ships or vessels. The emissions from ship or vessel navigation are expected to increase in the future as a result of the decline in Arctic sea ice coverage and accompanying rise in ship traffic. Satellite-based AIS data can be useful in this regard. The increasing availability of satellite-based data for ship tracking allows the formulation of detailed fleet specific emission inventories that provides high temporal and spatial resolutions for the Arctic (Winther et al., 2014). This will encourage seafaring ships or vessels to be more compliant. As scientists continue to conduct different modelling scenarios, it is expected that these methods can also help assess the emission consequences of future diversion shipping routes – which contributes also to new regime designs.

The increasing number of Internet satellites and their applications can also help boost connectivity in the Arctic, allowing shipping in the region to have more seamless communications. Combining different satellite systems (communication, navigation and observation) can furthermore aid the transmission of distress signals and search and rescue activities, ensuring a safer Arctic in the near future. Table 1 below summarizes how different satellite technologies may contribute to Arctic governance in the near future, along with some ongoing examples.

Table 1. Potential satellite applications for Arctic governance

Governance potentials	Application details	Examples of relevant projects
Tracking and counting of cetaceans	Combining satellite imagery data with deep learning/ modelling can help with tracking and counting of cetaceans in the Arctic, such as whales that are trapped in sea ice. This was not easily done before.	Mostly done by scientific researchers in universities/ institutes at the moment
Tracking of migratory animals	The use of satellite telemetry (in combination with satellite navigation systems) can help track migratory animals such as arctic foxes and also help protect animals such as polar bears.	Migratory animals by Argos Data Collection System; WWF-supported research teams for polar bears
Sustainable fisheries and preservation	AIS can help identify spatial distribution patterns of main fishing gear used in the FAO Area 18. AIS data can also be used to verify estimates of fishing activities provided by Global Fishing Watch.	SAT-AIS by ESA in collaboration with European Maritime Safety Agency
Identifying the distribution of marine debris	Combining satellite systems with artificial intelligence can help detect marine plastic pollution or to identify the extent of marine debris distribution.	NASA is active in this regard, as well as university scientists
Shipping and vessel tracking/ logistics	SAT-AIS can help track seafaring vessels equipped with AIS devices beyond coastal areas with comprehensive coverage, including the Arctic. Subscribing to improved AIS can help determine route efficiency, plan emission compliance, etc. Advanced AIS can also be a solution to the High Traffic Zones data gap issue.	Partnership between UP42 and exactEarth; Spire Maritime
Reduce risks related to maritime traffic such as beset	Satellite images can help predictions for ice conditions for each point along the Northern Sea Route. Ships of different Polar Ship Categories can become stranded in ice along the Northern Sea Route. Ships of a lower category are most at risk to become stranded. This can help inform legislation planning.	Aalto University, University of Helsinki
Safety for ship navigation	This Arctic waterway monitoring/imaging satellite has the capability to improve the safety of ship navigation in the icy waters along Russia's Northern Sea Route.	China Synthetic Aperture Radar (SAR) satellite (expected to launch in 2022)
Emissions from ships or vessels	Satellite-based data for ship tracking allows to set up more detailed fleet-specific emission inventories that provide a high temporal and spatial resolutions for the Arctic.	Mostly done by scientific researchers in universities/ institutes at the moment

Internet broadband to aid Arctic shipping	There has been a boost in connectivity speed in the passage through northern shipping routes and Arctic waters (the Northern Sea Route), as a result of Iridium CertusTM network. This service is connected to a compatible network management solution 'OneGate', which allows their customers better visibility over their remote satellite assets.	Iridium CertusTM network
Distress management/ search and rescue	To retransmit distress signals from ships, aircraft, or people in remote areas as part of the international Cospas-Sarsat satellite-based search and rescue programme.	Arktika-M in February 2021

Source: Author's compilation.

Assessing innovation processes of space-based infrastructures for Arctic governance

Different space-related innovation activities are emerging across different places in the world, which are rapidly shaping the development and diffusion of the abovementioned technological opportunities. In the following, we first discuss the fundamental developments that are rapidly shaping the emergence of space-based infrastructures, i.e. recent shifts in innovation policy of the space sector and increasing integrated technologies enabled by the current Information and Communication Technology (ICT) revolution. Against this background, we subsequently assess the TIS of different space-based infrastructures (i.e. satellite navigation, Internet satellite constellation, and Earth observation) in general but also their specific potential for shaping new Arctic governance.

Recent fundamental shifts in the space sector

Scientists argue that the globe is progressing into a new techno-economic paradigm, driven by rapid ICT advancement, along with the Fourth Industrial Revolution, as well as increasing globalization and new sustainability challenges (Mathews, 2013; Perez, 2013; Schot & Kanger, 2018; Young, 2021). This rising techno-economic paradigm may bring new windows of opportunity to reconfigure the ways technologies are used and diffused, including new business models and new market creation. Human capital with increasing computer literacy, industry opportunities following the so-called green economy, and advanced ICT allow integrating different technological systems to be more feasible than before.

The space sector is a critical component to the abovementioned new techno-economic paradigm (Yap & Truffer, 2021). The space sector has been increasingly privatized over the last decade, following renewed innovation policies of leading space agencies such as the U.S. National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) that foster space commercialization. This led to the so-called "New Space" era in which the multiplication of private spacefaring actors emerges across the world. In particular, there has been a shift in space innovation policy, moving from a top-down framework towards a more bottom-up orientation. While the former can be understood as the conventional "moonshot" model in the last space race, the latter focuses on diffusing space-based technologies through bottom-up participation of actors, with downstream application and commercialization the center of policy attention (Mazzucato & Robinson, 2018; Robinson & Mazzucato, 2019).

As a result, the space sector is drawing increasing numbers of public-private partnerships (PPPs). Many space missions today are led by private actors with support from state governments. Large technological enterprises tend to receive favoritism from national space agencies in a number of areas. Among others, billionaire-owned enterprises leading satellite constellation projects (for high-speed broadband) received various forms of state support, such as receiving licenses for satellite launching. SpaceX also received funding support from NASA through their joint space missions, which facilitated the company's rocket-related innovations and cost reductions. Other private enterprises focusing on Earth monitoring (or telecommunication purposes) are also expected to receive continuous support from their national governments, since governments tend to perceive these missions as valuable to national technological supremacy or national security.

Under the conditions of this new techno-economic paradigm, integrating different space-based systems or combining these systems with other technology fields become more feasible than before. For instance, data scientists today make major leaps in combining Earth monitoring technology with big data and deep learning. Successful integration and diffusion of these technologies can substantially reconfigure the infrastructures in place for the Arctic, as new modelling can help design governance (e.g. fisheries regimes) and contribute to day-to-day operating regimes (e.g. regimes for the conservation of migratory wildlife).

Transformative potentials for Arctic governance

Realizing the potentials of space-based infrastructures for Arctic governance as outlined above will require well-aligned technological innovation system (TIS) processes, including *technology development, entrepreneurial experimentation, guidance of search, market formation, and technology legitimation* (Bergek et al., 2008; Hekkert et al., 2007). Table 2 below presents a brief assessment on the performance of these innovation processes so far in the three major space-based infrastructure fields and their potential for Arctic governance. In general, the three space fields experienced rapid expansion of knowledge and technological development in recent years. Some of the opportunities discussed above, such as the combined use of satellite telemetry and navigation for tracking migratory animals, have attracted increased research and development (R&D) activities in the Arctic by universities, but diffusion will still require entrepreneurial experimentation by industry actors. Otherwise, these technologies will remain as scientific experiments and are expensive to be diffused.

To ensure successful development and diffusion of different space-based infrastructures, the Arctic will require access to stable, high-speed 5G Internet in the region. Without comprehensive Internet coverage, data generated from Earth monitoring and satellite navigation will not be able to be transmitted effectively and communication will not be efficient. In other words, enhanced Internet and broadband services is a critical enabler to the successful diffusion of other new space-based technologies in the Arctic. Service installations of Internet satellite constellations are therefore critical. At the moment, there is substantial entrepreneurial experimentation in this area, given intense industry competition among large technological companies like SpaceX and OneWeb, which are also actively exploring new services for the Arctic region. This field is also favored by their respective state policies, given geopolitical interests in the 5G race. Following this trend, Internet satellites might increasingly diffuse in the Arctic in the near future, although initially with limited coverage in the region.

However, there is still a lack of market formation among the three fields of space-based infrastructures. Market formation here requires integrating the space-based technologies with downstream applications, most of the time by translating raw satellite data into usable information and through the delivery of new services. Combining big data and deep learning could bring manifold opportunities in this regard. Private actors are core to lead these activities, from the translation of raw data to identifying new market segments and shaping different use contexts, as well as developing relevant software or apps which can then be diffused as services to specific industry areas or local contexts.

Over the last few years, an increasing number of data service companies have emerged in the global satellite sector (Haarler, 2020). However, the number of private actors active in developing downstream market integration of space technologies in the Arctic is low at the moment. This will be critical for the successful diffusion of satellite technologies and AIS-generated data for Arctic governance. More entries of these data service companies focusing on applications in the Arctic is needed, by engaging with needs and preferences of users, operators, or governance officials in the Arctic. The core challenge lies in incentivizing more entries of application service companies and creating a business case for these companies. In other words, who will be the users that pay for these services and for what applications?

Since the Arctic has a relatively lower number of commercial activities as compared to other parts of the world, policy, regulations and standardization - also known as guidance of search in TIS - are key elements that will shape initial market segments for these data application services. More specifically, guidance of search activities defines the set of criteria to be included in a "selection environment" with the aim to facilitate rapid diffusion of specific technologies (Yap & Truffer, 2019). More stringent governance or expanded regulations such as through new additions to the Polar Code as discussed above will create demand for actors in the Arctic to sign up for those space-based systems or data application services, including shipping companies, fishermen, and specific governing agencies. Therefore, these actors/ agencies are ideally among the first to pay for these services, attract entries of application service companies, and subsequently set in motion market competition that leads to lower costs in long run.

Table 2: Assessing the TIS processes of different space-based infrastructures and their potentials for Arctic governance

TIS processes	**Internet satellite constellation**	**Satellite navigation**	**Earth monitoring**
Knowledge/ technology development	Well developed, R&D by high-profile technological companies.	Well developed, R&D by states (the United States, Russia, EU, and China). R&D specifically for Arctic is unclear.	Well developed, by space agencies, universities, research institutes, smaller companies
Entrepreneurial experimentation	Progressing quite rapidly, driven by competition among high- profile companies.	More experimentation by companies for use contexts are needed.	Still weak in the Arctic. More bottom-up participation by small and local companies will be critical.

Guidance of search/ standardization	Progressing quite steadily. The installation of services is currently weakly governed. Technology standards are driven by competing companies and the quality of services differs.	Standards are shaped by national system operators. In general, new standards shaped by Chinese BeiDou and EU’s Galileo are emerging. But this is still quite disconnected from Arctic purposes.	Still weak. Due to low business participation for Arctic purposes, the lack of standardization also leads to weak progress in data translation/ interpretation.
Market formation (downstream integration)	Still weak. Shaping markets for Arctic governance purposes will require identifying potential customers. This should start with industry or governmental users.	This will require the subscription of industry and governmental users, e.g. shipping companies. Countries that have built up their own ports in the Arctic e.g. Russia most likely use their own national systems. These systems can also be combined with monitoring data and deep learning.	Weak. Market formation here will require more data application service companies translating raw satellite data of the Arctic into real application services. These companies will have the incentive to combine satellite data with modelling and deep learning.
Technology legitimation	Strong. It is expected that users in remote regions (in this case the Arctic) tend to favor the access to stable and high-speed connection.	User acceptance could be higher among the shipping community, as navigation can substantially improve shipping efficiency and safety.	Different actors in the Arctic in general will have to accept that they (or their natural environments) are increasingly monitored.

Source: Author. Note: Information in this table is drawn from broader research that is still in progress.

Successful guidance of search helps shape technology legitimacy for deploying these space-based infrastructures, which is critical given that users might find resistance to subscribe to these new technology services, at least in the beginning. There might be operational users who are locked-in to existing practices and hence refuse to adopt new ways of doing things. For instance, the daily jobs of actors in the “old regime” might have to integrate new application services based on navigation or Earth monitoring data. These old-regime actors, however, might still prefer on-the-ground field inspections and so refuse to switch to new and arguably more advanced methods. Meanwhile, there might also be users or actors exposed to increasing satellite monitoring or surveillance therefore leading to resistance, controversies, or even backlash. To gain legitimacy among these users, the introduction of new policies or regulations will be critical. There could also be other means of legitimizing these new technologies, such as shaping the media narrative concerning the benefits of new Arctic governance as enabled by the new space-based infrastructure.

Overall, innovation processes for the global satellite sector will increasingly align in the coming years, rapidly shaping next-generation space-based infrastructure. More feasible applications for Arctic governance, however, seem to lack demand for rapid diffusion. The potential of space-based infrastructure for Arctic governance is still limited to scientific projects led by universities using research funding granted by governments, public agencies, or international organizations. Given that the Arctic is furthermore attracting new arrays of geopolitical interests in recent years (Young, 2020), the abovementioned innovation processes for diffusing space-based infrastructure in the Arctic will need to take into consideration the different value orientations or conflicting interests among different actors, including nation states, agencies and the private sector. In view of that, PPPs might be key in the beginning in order to diffuse those technologies in the Arctic, through the provision of market incentives and supportive contexts (such as protected licenses, dedicated standardization, and revision of regulatory criteria) driven by states with vested interests in their respective national technological companies. In addition, strengthening governance requirements in the Arctic such as through enhancing the Polar Code accordingly will attract smaller downstream application service companies. These strategies may help establish a business case for the Arctic, create demand for space-based services, and incentivize private actors to work with public actors to facilitate activities related to Arctic governance. This may overall expedite entrepreneurial experimentation in the Arctic, followed by industry competition that can substantially reduce costs, allowing a quicker uptake of application services in that region.

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