More than ‘Nature’

Research on Infrastructure and Settlements in the North

edited by

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The Arctic Circle as a Space Weather Sentinel Territory

A. R. E. Taylor

This chapter traces the emergence of the Arctic as a vital region for generating scientific data on “space weather.” Space weather is an umbrella term that is used to describe a range of electromagnetic disturbances in the near-Earth space environment that affect technology systems. The Sun regularly ejects radiation particles that can damage satellite computer chips, interrupting GPS and internet connectivity. These electrically-charged particles also interact with the Earth’s magnetic field (fig. 1). The northern lights (*aurora borealis*) and southern lights (*aurora australis*) are understood to be visible manifestations of this electromagnetic interactivity. Along with auroral displays, these energetic interactions can generate powerful electrical currents that can disrupt communications systems and the electronics of aircraft. They can also cause damage to conducting material on Earth, such as pipelines and power grids (fig. 2). Over the course of the twentieth century, space weather has steadily emerged as a growing security threat to the critical infrastructures that underpin industrialized societies (Taylor 2020). According to the UK Government’s 2015 National Risk Register, a severe space weather event could cause “disruption to the ground digital components found in all modern technology” (Cabinet Office 2015: 26). In film, TV, and the popular press, space weather events are often represented as entailing the prolonged loss of digital technologies and electrical infrastructure on a continental or planetary scale, lasting for weeks, if not months. The imagined technological and societal disruption is typically configured temporally as a violent “return” to an earlier techno-evolutionary stage of preindustrial being, with news headlines frequently proclaiming that a severe space weather event would send humanity back to the "Stone Age."

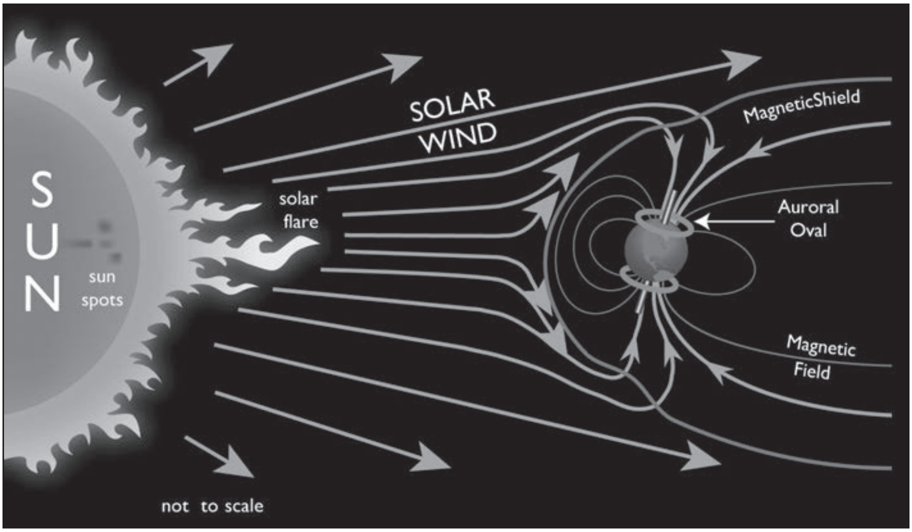

Figure 1: Diagram of the solar "wind": a stream of charged particles continuously ejected from the Sun. According to contemporary scientific understandings, the northern and southern lights arise when these particles interact with the Earth's magnetic field. Diagrams of solar-terrestrial interactivity like this frequently circulate in public-facing space weather literature and play an important role in communicating (and visually constructing) the significance of the polar regions in space weather science. (Credit: Illustration by Todd Salat)

Space weather preparedness is now becoming an ever-expanding global security project, weaving together a vast array of scientific knowledge producers, political actors, and technical systems into a security assemblage that extends from radars and laboratories on the terrestrial surface to satellites and spacecraft monitoring the Sun in outer space. China, Japan, India, the US, the UK, and many European countries have invested in infrastructure and research programs in efforts to build national and international preparedness for space weather events. In 2010 the Asia-Oceania Space Weather Alliance (AOSWA) was formed, consisting of organizations from 13 countries in Asia and Oceania. The following year, the World Meteorological Organization (WMO) released their Statement on Global Preparedness for Space Weather Hazards, calling for the coordination and implementation of near-term and long-term plans among all WMO members for addressing the space weather risk. In July 2014 the UK Government published their Space Weather Preparedness Strategy. In October of that year, as part of a GBP 4.6 million investment programme, the Met Office Space Weather Operations

Centre (MOSWOC) was launched. This facility compiles space weather forecast reports from data collected by satellites and radar systems to “help protect the technologies our day-to-day lives rely on” (Cabinet Office 2013).

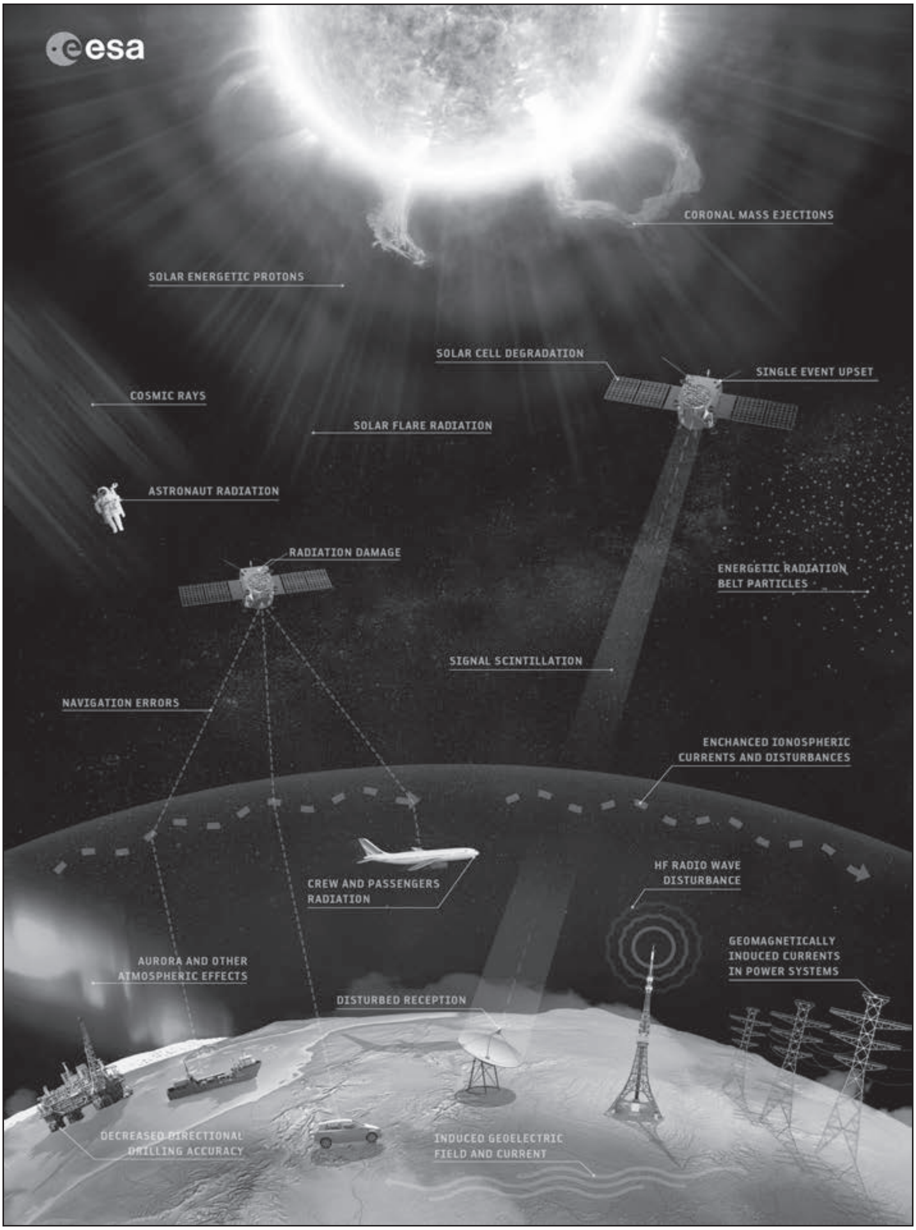

Figure 2: An image released by the European Space Agency (ESA) detailing the effects of space weather on critical infrastructure. (Credit: ESA/Science Office)

In 2015, the White House released their National Space Weather Action Plan and National Space Weather Strategy, while in 2016, the European Commission published their policy paper on Space Weather and Critical Infrastructures. In November 2019, the United Nations launched a 24/7 space weather network to provide real-time updates for global aviation.

Amidst these intensifying efforts to anticipate and prepare for space weather events, scientific infrastructure and equipment stationed in the Arctic plays a strategic role. As a high-latitude region where the Earth's magnetic field lines converge, the Arctic is seen to offer a unique site for the generation of data on space weather effects in the ionosphere—the uppermost part of Earth's atmosphere that overlaps with the boundary of space (roughly 70 to 1,000 km in altitude). Geophysical observatories and atmospheric measuring equipment in Arctic regions have played an important part in producing knowledge of Earth's magnetic field since the nineteenth century (e.g., Kataja 1999). Today, a large amount of space weather research in this region is conducted by the European Incoherent Scatter Association (EISCAT). EISCAT is an international consortium of space agencies, research councils, and national institutes from the UK, Finland, Norway, Sweden, Japan, and China, among several other countries. EISCAT facilitates research on space weather, among other research programs, using high-power radars that are distributed across four sites in the Arctic Circle: Tromsø (Norway), Longyearbyen (Svalbard, Norway), Kiruna (Sweden), and Sodankylä (Finland).

In this chapter I explore the role that space science technology and infrastructure in the Fenno-Scandinavian Arctic plays in building space weather preparedness. Large-scale threats like space weather, which are sometimes classed as "global catastrophic risks" or even "existential risks," have become a key target of interest for a growing number of risk studies programs and research centers (Bostrom and Ćirković 2008; Currie and Ó hÉigeartaigh 2018). Yet, while such risks are typically positioned as objects of "global" threat, the infrastructures and practices of preparedness they call forth are often impactfully and meaningfully emplaced within specific locales or regions. Tracing the history of the polar region as a data-generation site for auroral and ionospheric science, and how this later inaugurated an imaginary of the Arctic as a "sentinel territory" for space weather preparedness, I examine how developments in space science and technology have repositioned polar geographies in relation both to outer space and to the global space of the international knowledge economy. In doing so, this chapter provides a window both onto the geopolitics of space infrastructure and the political-strategic significance of space science in the Fenno-Scandinavian Arctic, which has served as a key vehicle through which this area has been reconfigured into a science region of international importance. Whilst contributing to histories of science in the Arctic (Sörlin 2013), this discussion is primarily situated at the intersection of two emerging fields within the social sciences: the anthropology of preparedness and social studies of outer space. I begin by providing a brief overview of these literatures. I then explore the history of auroral research in the Arctic, tracing the emergence of space weather both as a scientific field and as a global security threat. In the final two sections I proceed to discuss the EISCAT infrastructure that generates space weather data. The aim of this exploration is to examine how space weather scientists perceive, construct, and leverage the geographical attributes of this region of the planet through the anticipation of a future space weather event: how they attempt to make use of this geography; how they understand its electromagnetic and atmospheric affordances; and how they connect it to the futures of a humanity that is constructed as increasingly "technology-dependent."

Un-Earthing Preparedness

The last decade has seen a "turn to space" (Dunnett et al. 2017: 2; Olson and Messeri 2015) within the disciplines of anthropology, history, sociology, and geography. Resisting techno-utopian tendencies to conceptualize space as detached from Earthly geographies and politics, this literature has emphasized the relational nature of space, investigating the myriad ways that terrestrial sites are connected to technologies, imaginaries, and discourses of outer space (Battaglia et al. 2015; Klinger 2017; MacDonald 2007: 593; Valentine 2016). Oceans, mountains, deserts, and other extreme landscapes have been reimagined as "analogue" sites for simulating alien worlds on Earth (Collis 2016; Helmreich 2006; Lane 2008; Praet and Salazar 2017). "Infrastructure" and "place," in particular, have emerged as key analytics with which social scientists have grappled with the cultural, political, and economic activities that configure relations between social life on Earth and the cosmos (Bischel 2020; Messeri 2016). If the relational capacities of infrastructure have long been noted (Star 1999), deployments of space infrastructure in the second half of the twentieth century led to reconfigurations of terrestrial geographies in relation to outer space. During the Cold War, regions of the planet that had previously existed on the periphery of modern colonial projects, such as the tropics, took on strategic political significance as spaceports for equatorial rocket launches (Redfield 2000; Siddiqi 2015). While an important body of work has explored the social impact of space science in equatorial regions, considerably less attention has been paid to the Arctic. Lapland also arose as an area of geo-strategic importance for space science, with the establishment of the Andøya and Esrange Space Centers in the mid-1960s. These rocket ranges reconfigured the reindeer herding lands of Indigenous Sámi populations into drop zones for falling rocket debris (Sheehan 2018; Sörlin and Wormbs 2010). The development and deployment of space science and infrastructure has been shown to powerfully reshape and reorder local economies, communities, and geographies. In the process, outer space has arisen not simply as a distant and remote realm but as intimately and problematically connected to questions of place and identity across plural scales of context that range from the national to the global to the extraterrestrial. Contributing to social scientific understandings of "the place of outer space" (Redfield 2002: 791), this chapter focuses on the scientific and technical work that led to new and unexpected relationships and attachments between the Arctic and the solar system.

Drawing from recent discussions within the anthropology of preparedness on the topic of "sentinels" (Keck and Lakoff 2013), I approach the Arctic Circle as a space weather "sentinel territory." Sentinels are typically conceptualized as early warning systems that produce signs of an impending threat before it becomes perceptible at the level of human sensory experience. The paradigmatic sentinel is the canary that coal miners carried to alert them of the presence of toxic gases like carbon monoxide. Anthropologists Frédéric Keck and Andrew Lakoff (2013) have identified sentinels as a key technology of preparedness. While preparedness was most fully articulated as a mode of governance during the Cold War, throughout the second half of the twentieth century, practices of preparedness were mobilized as generic tools with which a diversity of disaster scenarios could be managed across a range of sectors and policy domains (Lakoff 2006; 2008). By envisioning dystopian future scenarios, preparedness practitioners seek to produce and administer a world in which threatening events do not catch humanity off guard or by surprise. These threatening events are constructed as inevitable and unpreventable but potentially manageable, if the right measures are taken to prepare for them. If action is not taken, "a threshold will be crossed and a disastrous future will come about" (Anderson 2010: 780).

Severe space weather events are just one of many threatening future scenarios that have been brought into political organization through preparedness frameworks. Styles of reasoning like preparedness typically target large-scale threats classed as "low-probability, high-consequence" events. Such threats are unpredictable and potentially unbounded in their impact. They typically lack a statistical-archival past from which to calculate probabilities, or sometimes even possibilities. Historical records indicate that space weather events can arise quite randomly and with varying intensities, configuring the present as a time of anticipation. Uncertain, but ever-present, occurring randomly, without warning and with potentially far-reaching consequences, the threats targeted by preparedness tend to defy expectation and challenge the calculative logic of risk, which relies on quantitatively measurable threats (Lakoff and Collier 2010: 263). As such, the generation of statistical data where there previously was none plays a significant part in preparedness. The collecting and analyzing of large volumes of digital data—"Big

Data"—is increasingly framed as an essential component of national, international and even planetary preparedness efforts. Sentinels play a central role in producing data with which new forms of knowledge and vigilance are generated to anticipate security threats. Keck's (2013; 2019; 2020) ethnographic work has examined how chickens, virus cells, wild birds, and other actants are mobilized as sentinels for emerging diseases in Hong Kong. In exploring how these sentinels produce early warning signals at different scales, Keck draws attention to the larger spatial and relational configurations that preparedness produces, with entire regions being reconceptualized as sentinel "territories" for the early detection of threatening events. "A sentinel is not only a technical device of prediction or a military post of surveillance and preparedness," Keck (2019: 252) informs us, "it is also a territory."

Unlike Hong Kong, the Arctic is not a site of emergence, from which the next space weather event will arise. Nor is the Arctic a site from which an incoming space weather event will first be detected—sentinel spacecraft stationed in space between the Sun and Earth primarily fulfil this role (Poppe and Jorden 2006). Rather, the Arctic's role as a space weather sentinel territory stems from its unique geographical position and magnetical properties, which makes it a valuable site for collecting data on how space weather affects the Earth's magnetic field. If a sentinel territory is "where different actors, human and more-than-human […] interact in the anticipation of future threats" (Keck 2019: 252), then the upper atmosphere of the Arctic is a region where more-than-earthly energies interact with the beams of human radar systems in anticipation of space weather. The Arctic has, of course, long operated as a sentinel territory for global climate change, with its disappearing icecaps functioning as sentinels for the melting futures of a warming world. While a growing body of work has focused on the Arctic in relation to the climate emergency (Radin and Kowal 2017), the aim of this chapter is to take anthropological engagements with the Arctic—and the planetary futures it signals—in a different direction. In what follows I thus examine how this northern region of the Earth is being oriented toward another dystopian planetary future in the form of the global space weather event.

A New Mythos of the Northern Lights

The northern lights have played a central role in configuring the Arctic as a unique region for space weather research. In the following two sections, I trace a history of how observations of the *aurora borealis*, from the Enlightenment period onward, led astronomers, meteorologists, and physicists to draw epistemic correlations between terrestrial magnetism and solar activity, correlations that would culminate in the construction of the Arctic as a space weather sentinel territory. In doing so, I emphasize continuities in mytho-cosmological understandings of the northern lights.

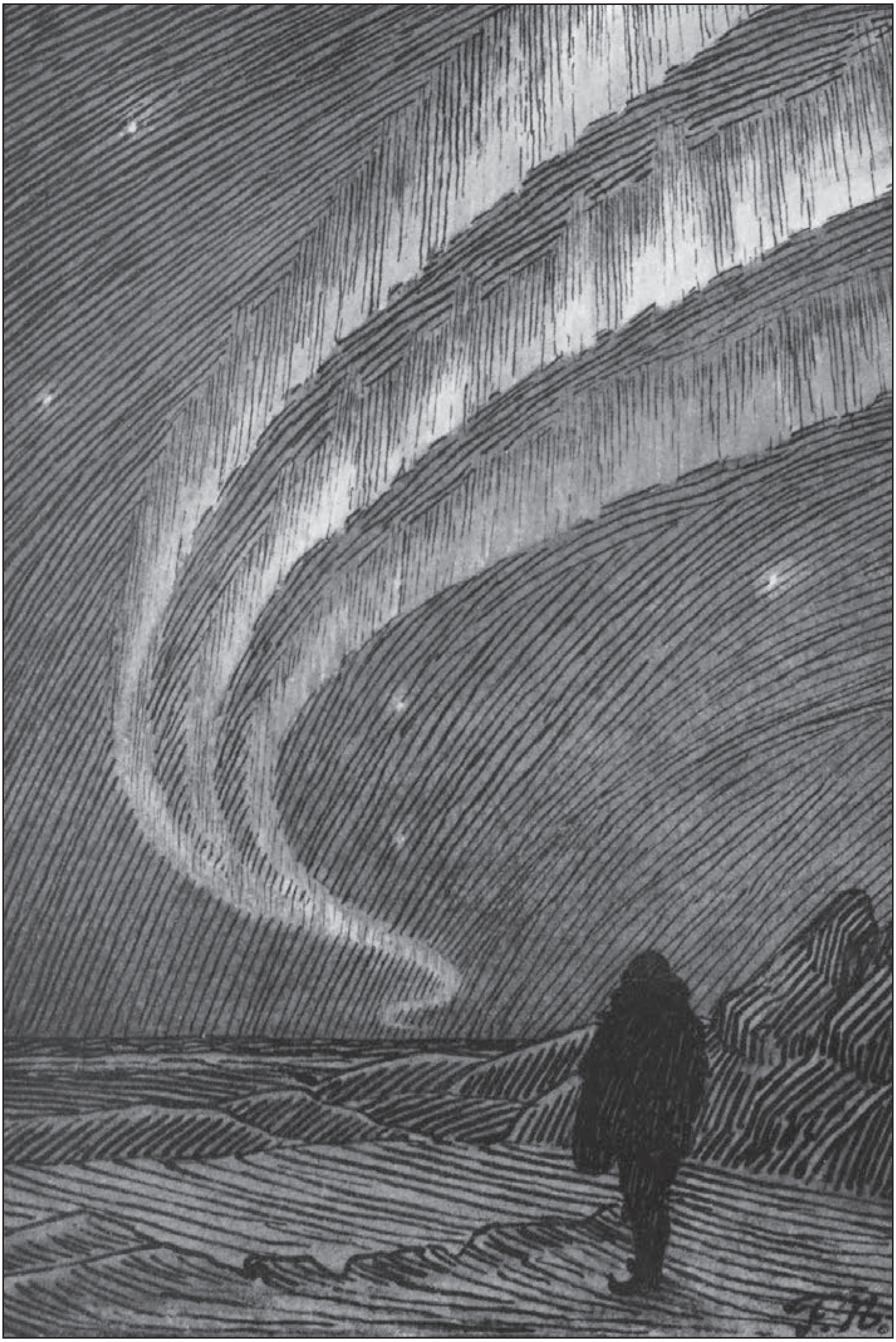

Figure 3: Woodcut by Fridtjof Nansen (1861–1930) from an aurora observation on 28 November 1893. (Credit: Wikimedia Commons)

Deified, mythologized or scientifically objectified, the northern lights have long been entangled with human beings' understanding of the cosmos and their place within it. For centuries, the iridescent glow of this fleeting optical phenomenon has captivated the imaginations of the Arctic's inhabitants, generating a rich history of cultural meanings expressed through mythology, art, and literature (fig. 3). In many cosmologies, the lights were associated with nonhuman and supernatural forces. The Finnish name for the northern lights, "Revontulet," meaning "Fox Fires," comes from an ancient Finnish myth in which the lights were caused by a magical fox sweeping its tail across the snow and spraying it up into the sky. The Sámi people traditionally believed that the lights were the energies of departed souls, while in Norwegian folklore, the lights were understood to be the spirits of maids dancing in the sky. Similarly, due to their undulating motion, in Scotland, the lights were sometimes called "the merry dancers." Many Inuit and Yupik groups also connected the lights with dancing. The Kalaallit of Greenland attributed the northern lights to the spirits of dancing children who had died at birth, while people who lived on the lower Yukon River believed that the aurora was the dance of animal spirits, especially those of deer, seals, salmon, and beluga whales.[1]

Knowledge and observations of the northern lights were by no means restricted to peoples inhabiting the high northern latitudes. Tales of the mysterious lights were circulated by travelers returning from the far north and there are many observational accounts of their appearance at lower latitudes. As Robert Marc Friedman (2010: 54–55) has observed, "[i]n the era of pre-electric lighting, when night skies were still dark over European cities, brilliant displays of the aurora were sometimes seen much farther south on the continent." Chroniclers from outside of the Arctic regions, where auroral displays were less common, often interpreted them as bad omens or harbingers of disaster (Odenwald 2007: 17).

While natural philosophers and astronomers of the Enlightenment period would call upon "reason" to refute popular interpretations of the aurora as warning signs, today, scientific understandings of the northern lights as an index of space weather re-embed this atmospheric spectacle within eschatological-mythical frameworks. In discourse on the space weather threat, the mythical relation between the *aurora borealis* and future disaster endures, as the northern lights become a key component in images and imaginaries of the space weather-induced collapse of the Global North. In representations of space weather events in films such as *The Carrington Event* (2013) and TV shows such as *Cobra* (2020), the northern lights eerily illuminate the

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[1] These accounts of aurora folklore and mythology have been paraphrased from Jokinen (2007) and Falck-Ytter (1985).

night sky as power circuits explode, radio reception fades out, and lights flicker off, cutting inhabitants of the Global North off from the modern technologies that underpin their lives. The space weather-induced end-of-the-world scenario provides an illustrative example of Déborah Danowski and Eduardo Viveiros de Castro's (2016: 6) observation that "the semiotic regime of myth […] comes into play whenever the relation between humans as such and their most general conditions of existence imposes itself as a problem for reason." Faced with a threat that is constructed as unpredictable yet certain to arise at some unknowable point, space weather preparedness operates within what Claudia Aradau (2010: 3) has called the "mythical space of inevitable fate." Aradau (2010: 3) has commented on the "mythical tendencies" of disaster preparedness, noting that in its "confrontation with the unexpected, the incalculable and the unpredictable," preparedness enacts "a return to myth."

Figure 4: Frederic Edwin Church's 1865 painting, "Aurora Borealis." Some speculate that Church took his inspiration from the Great Auroral Storm of 1859. (Credit: Wikimedia Commons)

The foundation for the eschatological-mythical imaginary that guides discourses, practices, and imaginaries of space weather preparedness today is based upon an event that occurred in the late summer of 1859, when a series of dramatic auroral displays were reported over Europe and North America (fig. 4). During the displays, telegraph operators noticed anomalous electrical currents sweeping through the telegraph wires, which interrupted the sending of messages. In some cases, these currents were so intense that they produced power surges, causing fires in telegraph stations, and giving operators electric shocks (Clauer and Siscoe 2006). Today, this event is known as "The Carrington Event." It was named after the English astronomer Richard Carrington (1826–1875), who happened to witness a bright eruption on the Sun during the period of telegraphic disruption. Carrington's subsequent inquiries revealed that the instruments at the magnetical observatory in Kew, London, had registered a significant disturbance around the same time that he saw the eruption. This led him to tentatively suggest that a connection might exist between terrestrial electromagnetic disturbances and solar activity. Today, the Carrington Event recurrently arises as a "reasonable worst case scenario" in risk analyses of the space weather threat, with preparedness practitioners asking "What would happen if a Carrington-level event should occur today?"

While Carrington was one of the first to draw connections between terrestrial magnetism, auroral displays, and solar activity, he drew upon a longstanding body of scientific work that had explored the relationship between the northern lights and magnetism. A large auroral display that was witnessed in 1716 over much of Europe prompted Edmund Halley (1656–1742) to draw a speculative connection between the aurora and the Earth's geomagnetic poles (Cook 2001). Halley had a longstanding interest in geomagnetism. Since the publication of *De Magnete* (1600), in which William Gilbert had conceptualized the Earth as a planetary-scale magnet, natural philosophers had increasingly understood the Arctic as a magnetical region (Cook 2001). Halley, reflecting on the materiality of the aurora, thus suggested that it could be a luminous "magnetical effluvia" (Halley 1716: 421–422) that enters the Earth "near its Southern Pole" and passes out "into the Ether […] from the Northern (Pole)." Empirical data on the relationship between the northern lights and terrestrial magnetism came from Swedish astronomers Anders Celsius (1701–1744) and Olof Hiorter (1696–1750), who made observations of the agitated movement of compass needles when the aurora was present. The Prussian polymath Alexander von Humboldt (1769–1859) used the phrase "magnetic storms" to refer to these magnetic disturbances. In the early 1800s, Humboldt set out to establish an early "global knowledge infrastructure" (Edwards 2010) of magnetic observatories stationed around Europe, the Americas, Africa, and Asia for the purpose of synchronizing and sharing magnetic data on a world-wide scale (Malin and Barraclough 1991; Tresch 2010). The data collected suggested that magnetic storms were not local events but occurred simultaneously at widely separated points on the Earth's surface. The northern lights came to be understood as visual indexes of this otherwise invisible magnetic activity.

It is Edward Sabine (1788–1883), the chief British promoter of magnetic studies and the person responsible for organizing most of Humboldt's magnetical observatories in the British colonies, who is often credited with drawing a connection between terrestrial magnetic disturbances and solar activity. Analyzing disturbance data recorded by magnetical stations, Sabine (1852) noticed an almost perfect parallelism between magnetic storms on Earth and the number of sunspots that appeared on the solar surface over time. However, within nineteenth century knowledge frameworks, astronomers found it difficult to conceive of a mechanism by which matter from the Sun could be conveyed to the Earth and were hesitant to suggest a direct link between sunspots, auroral displays, and magnetic storms. Auroral research would accelerate in the late nineteenth century when science would take "a vertical and atmospheric turn" (Valentine 2016: 515), leading to the formation of new epistemic linkages between terrestrial magnetism and solar activity, and giving rise to new imaginations of the Arctic's relationship to the cosmos.

A Passage to an Electromagnetic Cosmos

Late nineteenth century expeditions to the polar regions would transform the Arctic from a frozen frontier at the top of the world into a passageway to an electromagnetic cosmos. The aurora was a decidedly interdisciplinary attraction, drawing the attention of astronomers, physicists, meteorologists, chemists, and amateurs from across Europe. During the first International Polar Year (1882–1883), a number of aurora observatories were established in the Arctic, including a geophysical observatory at Sodankylä and an observing station at Kultala, both in Finnish Lapland (Kataja 1999). Further aurora observatories would be constructed across the Arctic throughout the late nineteenth and early twentieth centuries, with data being exchanged between these sites and the larger scientific community primarily through the publication of annual station books. Maps of the northern hemisphere plotting the frequency of auroral accounts presented new global perceptions of the aurora as spatially distributed in an oval-shaped zone around the geomagnetic North Pole. This region came to be known as the auroral zone (which would later be renamed the auroral oval).

It was experimental work investigating the impact of magnetic action on cathode rays (streams of electrons that are observed in vacuum tubes) that provided physicists with a theoretical model for understanding the relationship between the northern lights and solar activity. Norwegian physicist Kristian Birkeland (1867–1917) speculated that the northern lights and the magnetic storms associated with them could be the result of cathode ray-like particles ejected from the Sun interacting with the Earth's magnetic poles. Between 1897 and 1903, Birkeland established a number of aurora observatories across the Scandinavian Peninsula.[2] He developed a theory that solar particles are conducted along the Earth's magnetic field lines where they spiral into the atmosphere near the polar regions and react with atmospheric gases, becoming luminous in the process, giving rise to the aurora (Kragh 2013). Birkeland's theory was later incorporated into plasma physics, when it was proposed that magnetic storms were caused by streams of plasma ejected from the Sun (Chapman and Ferraro 1930).

Auroral physics would assume "military strategic significance" (Friedman 2010: 52) during World War II and the early years of the Cold War.[3] It was frequently noted that along with telegraph systems, radio communications also experienced disruptions during auroral activity. To send a signal to a receiver, radio broadcasters transmit radio waves that bounce off the ionosphere back down to a desired location on Earth (fig. 5). However, as the uppermost part of the Earth's atmosphere, the ionosphere was subject to the electromagnetic disruptions that caused auroral displays and geomagnetic storms. Italian electrical engineer Guglielmo Marconi (1928: 59) noted of radio interference that "times of bad fading practically always coincide with the appearance of large Sun-spots and intense *aurora borealis* usually accompanied by magnetic storms." The regular failure of long-distance radio communications with aircraft at auroral latitudes was a matter of growing concern for military air forces throughout World War II. In the 1940s and 1950s, efforts to better understand and forecast ionospheric communications disruptions thus gained momentum, leading to a militarization of the ionosphere during the Cold War. Ionospheric physicists were incorporated into national defense research programs and further geophysical observatories were established throughout the Arctic regions.

The International Geophysical Year (IGY) (1957–1958) promised a valuable opportunity to better understand the dynamics of this region of the upper atmosphere, eventually giving rise to the new scientific field of solar-terrestrial physics. Sixty-seven nations participated in the IGY, which transformed the Earth, sea, sky, and outer space into experimental zones of military-scientific data collection. During the IGY, global optical surveillance of the northern lights and the Sun was undertaken. Rocket-borne instruments for measuring the Sun's emission spectra provided high-altitude data with which physicists demonstrated that X-rays from powerful eruptions on the

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[2] During this period, the northern lights came to have a role in politics, with claims of national identity and scientific superiority staked in auroral science. Friedman (2010) has argued that Birkeland's efforts were thus as much about constructing and defining relations between auroral physics and Norwegian national identity as they were about unlocking the mystery of the northern lights.

[3] As Barbara B. Poppe and Kristen P. Jorden (2006: 30) have observed: "War made the need for knowledge about the Sun global and urgent."

Sun, known as "solar flares," could cause the ionospheric disturbances that were responsible for radio fade-outs. Scientific understandings of the form and limit of the Earth's magnetic field were radically reconfigured when the US satellite *Explorer 1* detected two large zones of highly energetic solar particles trapped in the Earth's magnetic field (the Van Allen belts). Based on IGY data, the US astrophysicist Eugene Parker (1965) developed the concept of "solar wind" to refer to the cascade of plasmas, magnetic fields, and high-energy particles ejected from the Sun, against which the Earth's magnetic field formed a protective bubble. The "magnetosphere" was the name given to this new spatial boundary. Just as new boundaries were being constructed, so too were disturbances to those boundaries, as "space weather" became an established term in the military-scientific lexicon (Cade III and Chan-Park 2015). These new renderings of outer space led to a rethinking of Earth's place in the cosmos, with the planet conceived as precariously placed within a dynamic solar "environment" (Olson 2013; 2018) that was awash with electromagnetic forces, fluxes, fields, and energies.

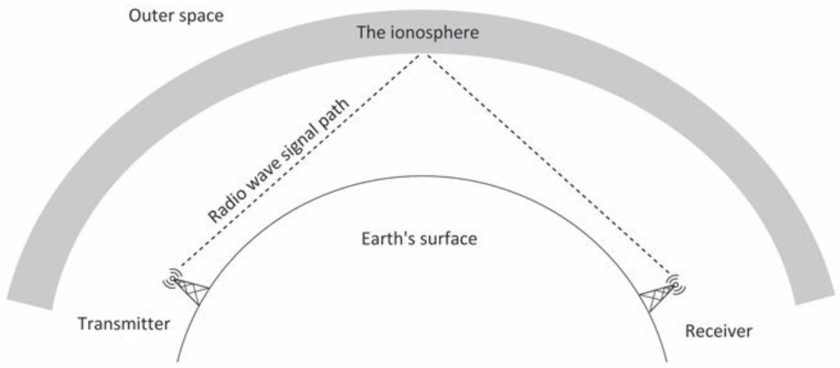

Figure 5: Basic diagram of ionospheric radio propagation.
(Credit: diagram by A. R. E. Taylor)

Modern physics posits that the electromagnetic force of the solar wind greatly deforms the Earth's magnetosphere, producing a comet-like magnetic tail on the side of the Earth facing away from the continuous stream of solar plasma (fig. 6). The Arctic acquired new significance through its relation to the magnetosphere. In geomagnetic representations of the world, the Earth's magnetic field lines are nearly vertical at the poles, resulting in "funnel-like" (Falck-Ytter 1985: 78) openings through which solar plasma is able to enter and interact with the upper atmosphere, generating the northern lights (fig. 7). "These high latitudes are unique," space physicist Lisa Baddeley explains in an EISCAT (2010) video titled *Our Sun the Hydrogen Bomb*, "because it is where the energy from the Sun is dumped […] which is why you only get the aurora over the northern and southern polar regions" (EISCAT 2010). In this new perception of the magnetosphere-enveloped Earth, the Arctic thus emerged as an opening onto the electromagnetic space environment. As a site where the boundary between Earth and outer space was regularly disturbed, it promised unique encounters with an electromagnetic solar system. This understanding of solar-terrestrial relationality also gave rise to new visions of the role that solar and ionospheric physics could play in safeguarding technological futures on Earth.

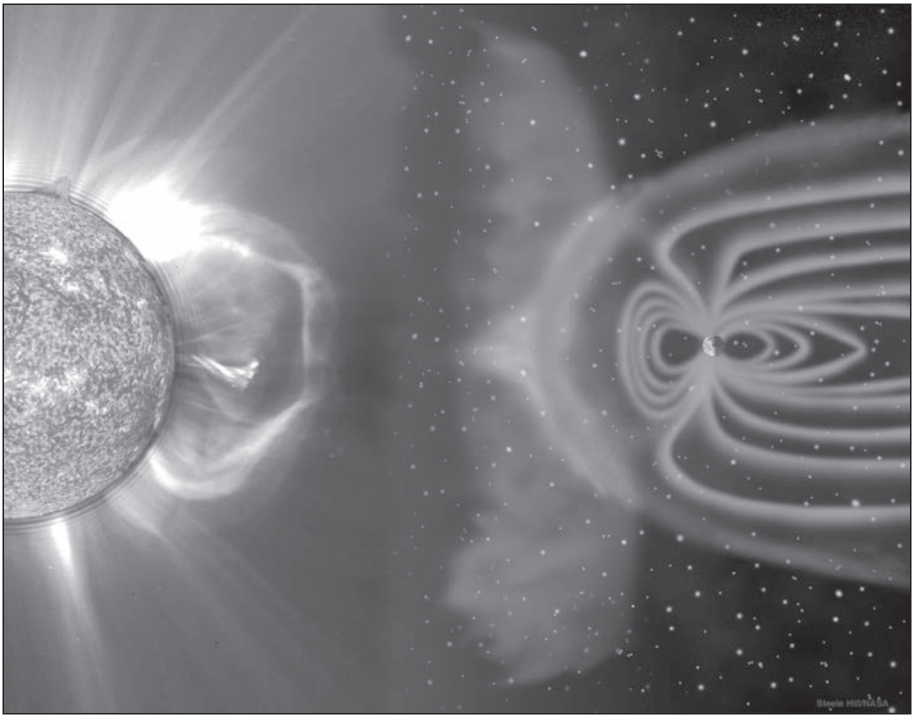

Figure 6: The solar wind interacting with the Earth's magnetosphere. (Credit: NASA)

Building Space Weather Preparedness in the Arctic

The scientific representation of the polar atmosphere as an entry-point to electromagnetic space had a technological impact on the ground, leading to the implementation of extensive research equipment and infrastructure for the study of solar-terrestrial physics. During the IGY, new methods for investigating the ionosphere were developed, including the incoherent scatter radar technique. This technique entails the use of an array of powerful ground-based radars that transmit pulses of electromagnetic waves into the ionosphere, which cause electrons to scatter their energy incoherently in all directions. Detecting this scattered energy, sensitive receiving instruments can measure parameters such as electron density, ion and electron temperatures, ion composition, and plasma velocity. This technique was pioneered by US physicists backed by enormous levels of military funding. Ionospheric research facilities, such as those operated by the High-frequency Active Auroral Research Program (HAARP) in Alaska, became entangled in conspiracy theories related to experiments about radio wave-induced mind control, death beams, and the weaponization of weather (Smith 2002).

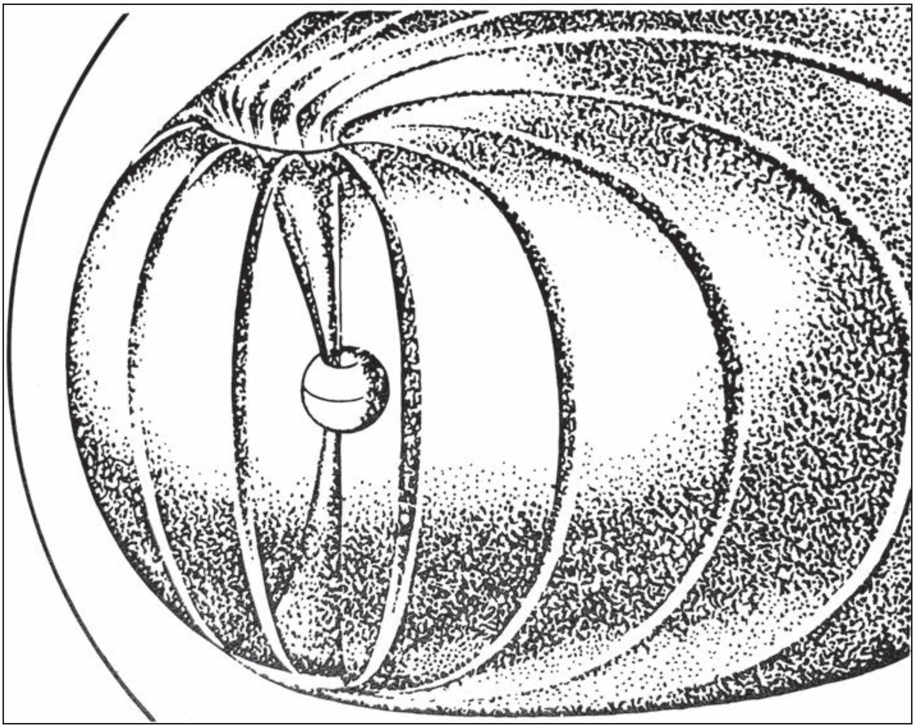

Figure 7: Representation of the Earth's magnetic field, showing the funnel-like polar "cusp" or "cleft" that forms around the geomagnetic north and south poles (Falck-Ykker 1985: 77). (Copyright: Verlag Freies Geistesleben)

With the polar regions understood as "the seat of many of the complex processes that control the upper atmosphere" (Rishbeth and van Eyken 1993: 525), during the IGY, the Kiruna Geophysical Observatory was established (with US military links (Sörlin and Wormbs 2010)) and a research program was developed around the study of ionospheric physics in the auroral zone. In the late 1960s, efforts were initiated to establish an incoherent scatter radar facility in the Nordic Arctic (Holt 2012; Hultqvist 2011; Oksman 2011).

Map 1: The four sites of the EISCAT radar system.
(Credit: map by A. R. E. Taylor)

A proposal for a radar facility that would be jointly operated by ionospheric scientists from research councils in Sweden, Norway, Finland, France, Germany, and Great Britain was produced in 1971. The aim was to form an international research infrastructure for generating and sharing data on space weather, the solar wind, and the ionosphere. The proposal outlined the "special importance of the auroral region to upper atmosphere physics":

> (T)his region is near the boundary between the open and closed field lines of the Earth's magnetosphere. The polar cap region north of the boundary is open to bombardment by energetic particles and to other disturbances originating from the Sun or from the magneto-tail. The ionosphere in the polar cap, and especially in the auroral region, is thus highly disturbed. (du Castel et al. 1971: 9)

The European Incoherent Scatter Association (EISCAT) was formally inaugurated in 1976. The radar system began operating in 1981, after 10 years of construction and planning (du Castel and Testud 1974; EISCAT 1974). The administrative headquarters were established at the Kiruna Geophysical Observatory in Swedish Lapland. The radar complex itself was distributed across three sites (map 1), with a transmitter and ionospheric heater located in Ramfjordmoen near Tromsø and two receiving stations: one in Kiruna and another in Sodankylä (fig. 8). These radars are still in operation today and can observe the atmosphere in a range that stretches from an altitude of 20 to 2,000 kilometers. With these spatially distributed sites looking into a common volume of the ionosphere from different angles, scientists construct detailed vector data on disturbances in this energetic aerial region. EISCAT has procured other polar sites since their initial founding. In 1996, an additional station was constructed on the island of Spitsbergen, near Longyearbyen, in the Svalbard archipelago (fig. 9).[4]

Infrastructures can powerfully remake space and place. The equipment that EISCAT installed in the Arctic did not only bring this region into close proximity with an electromagnetic cosmos, but also into a new global economy of data handling and exchange. EISCAT provides space weather instruments and data products to a range of organizations, universities, and research councils from around the world, forming an "instrumental community" (Mody 2011) for space weather and ionospheric science. Scientists access the facilities by applying for observing time. "The research system is highly competitive," infrastructure and policy analysts Folke Snickars and Simon Falck (2015: 229) observe, "with long contracts among researchers in different countries to perform experiments in a market where societal demand for results are increasing rapidly." EISCAT is also a highly exclusive facility, shaping who can and cannot access ionospheric space, with priority of access given to user communities within the member states (currently Fin-

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[4] Also in the 1990s, but not directly connected to EISCAT, the Auroral Large Imaging System (ALIS) was established. This is a network of insulated camera houses stationed across the Kiruna Municipality and other parts of northern Scandinavia that measure the height of auroral displays through multi-station imaging (Backman 2015).

land, Norway, Sweden, China, Japan, and the UK). EISCAT also has affiliate members, including Russia, France, South Korea, and the Ukraine. Researchers from non-member states can access the facilities with a lower level of priority, and a limited amount of observation time that is determined by peer-review.

Figure 8: An EISCAT receiver antenna in Sodankylä, Finnish Lapland. (Credit: Antti Leppänen)

Figure 9: EISCAT's radars in Svalbard. (Credit: Tom Grydeland)

The research infrastructure has attracted funding to the Arctic Circle and produced an extensive trade in scientific output within the global knowledge economy. While EISCAT itself has a relatively small number of in-house staff, made up of engineers, scientists, computer technicians, and administrative assistants, it must be seen as part of a much larger Arctic-based space science industry that has attracted a growing number of space workers since the 1990s, leading to the branding of Kiruna as a "space town" (Backman 2015). As Sverker Sörlin and Nina Wormbs (2010: 149) have observed, Kiruna, where EISCAT is headquartered, has become the seat of a "billion dollar" Nordic space industry, with the nearby Esrange Space Center attracting space physicists, engineers, administrators, university professors, and students. Space knowledge is now a key strategic export of this region (Backman 2015; Snickars and Falck 2015; Sörlin and Wormbs 2010).

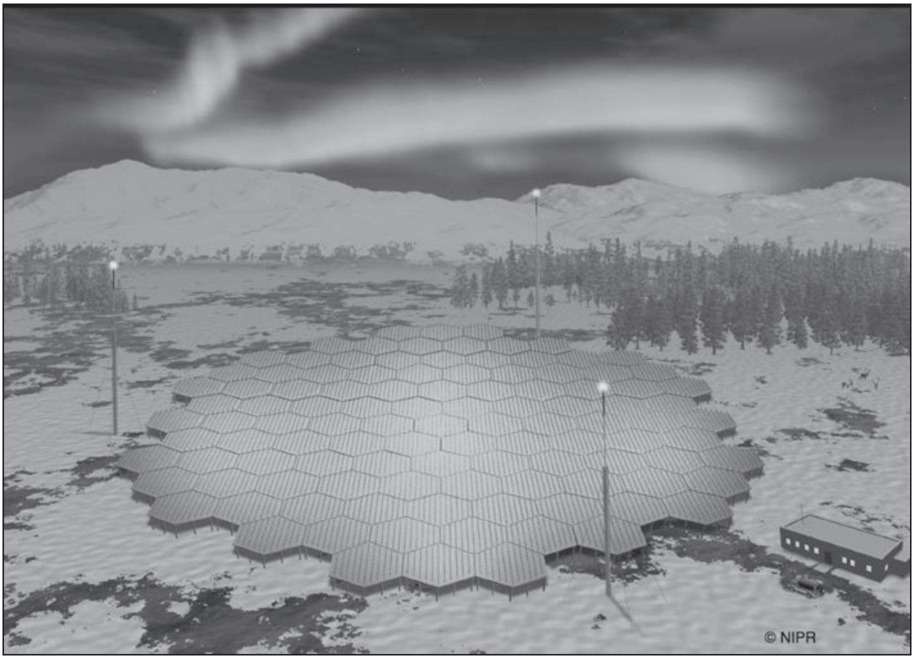

Figure 10: An artist's impression of one the EISCAT_3D (E3D) radar sites, with the northern lights above. (Copyright: National Institute of Polar Research (NIPR))

Tacking between the regional and the global, the space research infrastructure sited in the Arctic bolsters both local and global scientific, political, and economic interests, with EISCAT members and municipal leaders promoting the universal importance of the research it facilitates. Promotional material released by EISCAT emphasizes the societal value and global significance of the research produced, often by evoking a universal "humanity" as the benefactors of space weather science (EISCAT 2010). A severe solar storm could cause far-reaching disruption to infrastructure and communications networks, potentially on a global scale. Scaling threats to the level of the planetary does important work in generating research funding and demonstrating the societal importance of the scientific work conducted by EISCAT. As this electromagnetic threat moves onto national security agendas, transforming from a scientific object into a security and policy object, space weather science has also benefited from growing public and political awareness. EISCAT has recently received funding for the development of a new ionospheric research facility: the EISCAT_3D Radar (E3D) (fig. 10). Billed as "the most advanced space weather radar" (BAS 2017), it will comprise large clusters of high-power antennae (fig. 11) that are currently being installed across several sites in the Arctic Circle: Skibotn and Andøya (Norway), Kiruna, Bergfors, and Jokkmokk (Sweden), and Karesuvanto (Finland).

Figure 11: An early digital visualization of one of the EISCAT_3D antennae fields. (Copyright: EISCAT Scientific Association 2009)

Figure 12: The front cover of a brochure produced by the National Institute of Polar Research (NIPR) in Japan promoting the EISCAT_3D radar project. (Copyright: National Institute of Polar Research (NIPR))

In a press release on the website of the British Antarctic Survey (BAS), climate physicist Duncan Wingham highlights the importance of this infrastructure:

> EISCAT_3D will give us a 3D picture of interactions between space weather and our upper atmosphere with a detail we've not seen before, giving us answers to questions researchers have about the impacts of space weather on the upper atmosphere. We need this information to reduce the risks posed by space weather on our communications systems, satellites and power grids, which we all rely on. (BAS 2017)

This multi-sited infrastructure promises to facilitate space weather preparedness by providing continuous streams of data that will be used for monitoring, nowcasting, and modelling ionospheric activity. Through continuous observation of the upper atmosphere, the radar array promises to ensure that scientists "don't miss important data […] about how space weather effects evolve" (BAS 2017). News coverage of the development is steeped in the language of the data sublime, highlighting that the system will produce 20,000 gigabytes of data per second, making it "the single most powerful data source in the whole of Scandinavia" (Vollertsen 2016). A semantic field of monitoring and surveillance positions the new radar array as a sky-scanning sentinel device. Space physicists have likened the powerful beam of the EISCAT_3D radar to a "searchlight" (McCrea 2017). Similarly, press images and Google Earth visualizations released by EISCAT communicate the sublime security ambitions of this data infrastructure by stylizing the radar as a planetary-scale surveillance searchlight (fig. 12). Such visuals do important work in attracting funders, shareholders, and construction tenders. Costing EUR 135 million, this multi-sited radar complex is expected to be fully operational by 2021, with the first measurements for scientific use possible from 2022.

Conclusion: A Space Weather Sentinel Territory

Over the centuries, auroral observers and their instruments have assembled the Arctic atmosphere into an electromagnetic gateway that exists in open relation to a threatening solar system. Since the 1980s, EISCAT has provided the scientific community with data on solar-terrestrial interactivity, as revealed by disturbances in the ionosphere. EISCAT equipment does not operate as an early-warning signal of solar storm eruptions and does not therefore configure the northern circumpolar region into a site from which "an alarm can be sent to the rest of the world" (Keck 2019: 253). Rather, EISCAT produces space weather preparedness through the data it generates, with the Arctic ionosphere conceptualized as a data-rich territory from which new knowledge about space weather activity can emerge. As such, an analysis of the Arctic Circle as a space weather sentinel territory draws attention to the ways that different forms of sentinel construct and enable different temporalities of preparedness. Ionospheric data collection in the Arctic does not operate within a temporal frame of emergency, but promises to build preparedness through the long-term accumulation, analysis, and dissemination of data. Equipped with data-generating sentinel devices, the Arctic thus arises as a "slow sentinel" within the much larger security assemblage of space weather preparedness.

As a security object, space weather pulls together powerful discourses and imaginaries about earthly futures and vulnerabilities. In Peter Redfield's (2000) ethnography of the Franco-European Ariane rocket program in French Guiana, he explored how the equator, where the Earth's gravitational pull is slightly weaker, became an ideal place for satellite launches. If equatorial regions have been key to the development of twentieth century communications as satellite launching sites, then this chapter has traced how the Arctic, as a strategic site of space weather science, has been positioned as key for the protection and security of communications infrastructure. Since the nineteenth century, auroral and ionospheric research has carved out a new way to imagine the Arctic as a site of unique proximity to an electromagnetic cosmos. In the newly constituted imaginary of the Arctic as a space weather sentinel territory today, the geographical attributes of this region are leveraged not only to generate data for disaster preparedness but as political and economic instruments to help stimulate investment in an increasingly internationalized Arctic. Through the development of infrastructure in the auroral oval, new relationalities between the Earth and outer space have been constructed, as have new relationalities between the Arctic and the global knowledge economy, as mediated through the EISCAT network. In the process, the Arctic ionosphere has been configured as a valuable site for generating data with which to prepare the Global North for inevitable cosmic processes and with which to position this polar region on the international stage of space weather science.

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