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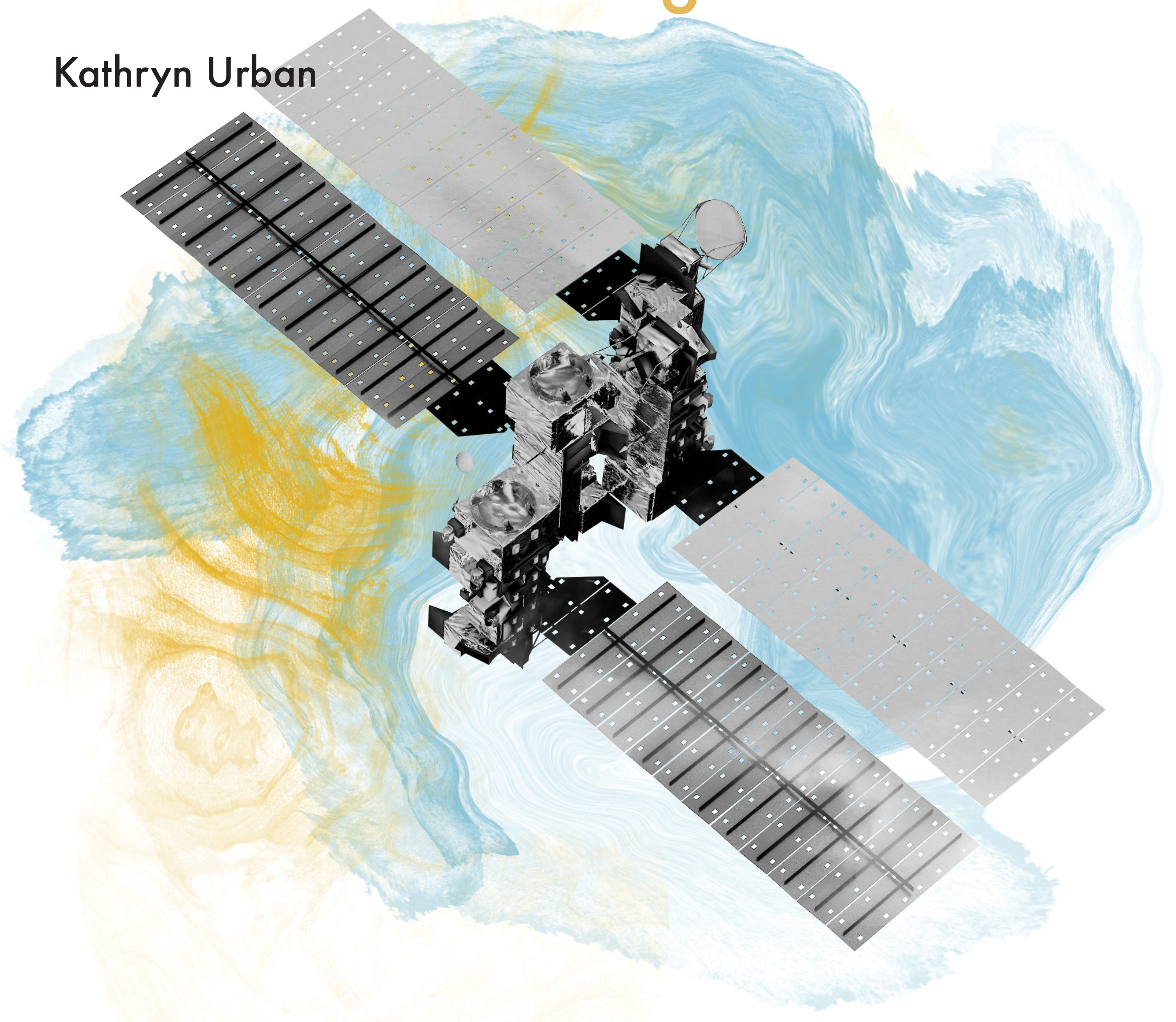
Multi-stakeholder Data Access in Space-Based Climate Monitoring

Kathryn Urban



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About the Author

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Acronyms and Abbreviations

CASC	China Aerospace Science and Technology Corporation
CSDA	Commercial Smallsat Data Acquisition
ESA	European Space Agency
ISR	intelligence, surveillance and reconnaissance
LEO	low-Earth orbit
MEO	medium-Earth orbit
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Aerospace Defense Command

Executive Summary

Data collected from satellite imagery and space-based instruments is essential to informing climate modelling. However, there is a fundamental tension between the public and private entities, who fund and maintain most of the data collection assets in orbit, and the civilian researchers, who seek to use that data to further our understanding of a changing climate. This paper puts forward a multi-stakeholder framework for climate data access, drawing out existing synergies across the public, private and scientific sectors to build on current climate data initiatives. This framework portends a leading role for defence actors owing to data requirements that mirror gaps in current researcher climate data access. The paper concludes with highlighting potential flashpoints in implementing the framework and makes recommendations for alleviating the concerns of key stakeholders.

Introduction

Earth is relying on her brightest scientific minds to track the impacts of climate change, provide ample warning of impending natural disasters and devise solutions for mitigating the worst effects of global warming and adaptation strategies for unavoidable outcomes. But the answers that researchers are able to deliver hinge on the quality of data used in modelling and analysis. There is a major disconnect between the interests of the government and commercial actors who operate most climate data collection assets, and the civilian researchers who seek access to that data. Bridging this owner-user gap means scientists are working with long lag times between collection and publication, patchy data coverage and competing priorities among collection organizations. Nowhere is this disjoint more keenly felt than in space-based data collection. Outer space is one of the key domains of actionable climate data and is made up of assets that are prohibitively expensive to most researchers. Scientists are therefore entirely reliant on the limited body of climate data regularly released by government satellite operators.

The status quo state of climate data access is not commensurate to the increased demands being made of the scientific community. As researchers are asked to devise solutions to save a planet facing record levels of heat and sea level rise, issues of irregular data coverage, poor satellite imagery resolution and restrictions on processing power represent important limitations. But these are also challenges with relatively low-cost and low-effort solutions. A comprehensive redress plan to these data access challenges is therefore a climate initiative with one of the best payoff ratios.

This paper puts forward a multi-stakeholder framework for climate data monitoring, proposing a whole-of-government approach to collecting, reviewing and releasing satellite data on climate indicators that covers data gathered both intentionally and incidentally. This framework carves out continued lines of effort for government scientific agencies, advisory roles for civilian researchers and supplementary programs by which proprietary information from commercial satellite actors can be brought into national repositories of climate data. The most important improvement over existing government climate data collection efforts, however, is a lead role for the defence sector. Military and intelligence agencies are not only major existing operators of satellites and other space-based assets, but their data collection needs also represent crucial complements to those of civilian climate researchers.

The implementation of this framework should not be taken up lightly. There are immense security implications associated with releasing data collected by military and intelligence agencies, and appropriate precautions must be taken both to secure buy-in from defence actors and to ensure that climate data efforts do not compromise national security priorities. Nevertheless, military and intelligence agencies have generally played a limited role thus far in living up to national commitments for climate change alleviation and readiness. This proposal represents an opportunity for these actors to bear out rhetoric on climate change as a national security priority by mitigating the data access problems that currently plague space-based data collection initiatives.

In order to lay the groundwork for these policy proposals, this paper proceeds in six parts. The first section, "The Current State of Space-Based Climate Monitoring," details the role space-based data plays in climate research, outlines the major actors responsible for current satellite collection of climate data and describes current data-sharing practices between the public sector and scientific communities. The second section, "Major Challenges of the Existing Space-Based Climate Monitoring Regime," highlights pressing areas for improvement in the space-collected data currently available to researchers. The third section, "The Need for Multi-stakeholder Co-operation on Climate Data Access," describes the current allocation of data collection satellite capabilities and details difficulties in cross-sectoral collaboration. The fourth section, "Current, Future and Potential Roles for Militaries in Satellite Data Collection," addresses trajectories in the defence sector's use of space-based data collection assets and points to major synergies between military and intelligence agencies' data requirements and those of civilian climate researchers. The fifth section, "A Framework for Multi-stakeholder Climate Data Access," offers specific recommendations for how civilian and military government actors can effectively engage researchers and commercial satellite firms to provide data on pressing climate indicators. The sixth and final section, "Potential Flashpoints," anticipates challenges in implementing the framework and offers solutions for alleviating them.

The Current State of Space-Based Climate Monitoring

Space-collected data plays a major role in modelling the ongoing effects of climate change across the globe. But there is a disconnect between the public actors, who fund most of the data-collection space assets in orbit, and the civilian scientists, who draw on that data to produce robust research. Understanding the politics of climate data collection therefore requires a survey of the field of the types of space-collected data used in climate research, the primary actors who pursue that data collection and aggregation and existing policies on sharing climate data across sectors.

Role of Space-Based Data Collection in Climate Science

Good data is key to how scientists understand the progression and ramifications of climate change. After all, according to John E. Kutzbach, "One golden observation is worth a thousand simulations" (Kutzbach 1988, 5). Researchers draw on a variety of Earth-based monitoring systems to obtain data, including from weather stations, buoys and soil samples. But more than half of the Essential Climate Variables — the key indicators of climate change — can be obtained through space-based monitoring. Satellite imaging and data from space-based systems are therefore an essential component of climate research.

The full breadth of uses for space-based data in climate research is impossible to capture here. But among the most common applications are:

- atmospheric observations to measure greenhouse gas emissions;
- radiometer data calculating the amount of energy radiating from Earth and the temperature of the land and sea surfaces, tracking heatwaves and small changes in climate temperature;
- remote sensing of wind speeds and satellite imaging to track the scale, course and extent of severe weather patterns and flooding;
- scatterometer observations to measure surface soil moisture levels, providing insight into potential drought conditions;
- satellite imaging to track glacier retreat and remote sensing to monitor sea-level changes with up to a millimetre of precision;
- microwave radiometer data and images to create a digital picture of Earth's surface, differentiating between land, water and ice and monitoring changes in surface composition;
- radar and laser altimetry to measure the thickness of sea ice, delivering highly precise data even across spots of uneven melting or rough terrain; and
- satellite imaging to track the burn patterns and smoke pollution from wildfires and to monitor deforestation.

Most space-based data collection initiatives rely on satellites: imaging equipment and scientific measurement tools are mounted to the outer shell of satellites that then gather data during an orbit path and transmit this data back to Earth to be received by antennae at ground stations. Larger outer space installations such as the International Space Station also house scientific instruments that collect and transmit data.

Major Climate Data Collection Actors and Initiatives

Ideally, climate scientists would launch their own research satellites to collect the types of data most useful to pressing scientific concerns and to set an orbit pattern that maximizes the quality of that data collection or that passes over regions of the Earth that are most pertinent to the research question at hand. But satellite launches are astronomically expensive. Rates generally range from US$5,000 to US$50,000 per kilogram of payload (Roberts 2022), meaning that even a relatively small satellite would cost tens of millions of dollars to get into orbit. Cost is a limiting factor in most scientific endeavours launching their own data collection satellites. Therefore, researchers must instead rely on the data put forward by the government and multilateral actors (as well as commercial satellite firms, to a much lesser extent) who do routinely operate observation satellites and choose to make that data available via public channels.

It is primarily highly economically developed states who maintain extensive scientific satellite programs to gather data on climate indicators. North America has perhaps the strongest presence in such government initiatives. In the United States, the National Aeronautics and Space Administration (NASA) has numerous projects dedicated to space-based climate data collection, including a dedicated carbon-monitoring system and Landsat Earth observation satellite. The National Oceanic and Atmospheric Administration (NOAA) also maintains satellite systems for early warning on Earth weather systems and space storms. Canada's suite of climate data collection and weather tracking satellites are maintained jointly by Natural Resources Canada, the Canadian Space Agency and Environment and Climate Change Canada. The European Union is also a major player in scientific endeavours in outer space, with the European Space Agency (ESA) running the Copernicus program dedicated to routine environmental monitoring as well as a series of Sentinel observational satellite missions. China is a more recent addition to this lineup of state climate actors, with the China Aerospace Science and Technology Corporation (CASC) maintaining a series of satellites aimed at monitoring oceans, forestry and biodiversity, meteorological trends and solar activity. While most satellite-monitoring initiatives are unilaterally administered by national governments, there are also co-operative multilateral programs. The Northern View Project, for example, is jointly supported by Canada, Finland, Germany, Norway, Sweden and the United Kingdom under the auspices of ESA to prioritize satellite coverage in the Arctic. The Arctic Council also runs a global earth observations program to coordinate Far North imaging among Arctic stakeholders.

Most state actors operating scientific satellites release at least some of their collected data to the public for civilian scientists to use in ongoing research. Among the countries outlined above, Canada has the most comprehensive commitment to climate data transparency, committing to a whole-of-society strategy for collecting actionable data and ensuring that actors in both government offices and in non-governmental spaces have access (Government of Canada 2022, 9). The Arctic Council maintains similar open access standards (Arctic Council 2021), but these standards are non-binding for member states. NASA, NOAA, ESA and, to some extent, CASC maintain institutional data portals through which researchers can download data sets — although these platforms have piecemeal coverage, may be missing key collection details and can be difficult to navigate. This inconsistency of open climate data can leave researchers frustrated, especially since state actors have thus far resisted scientific requests for greater access (Borowitz 2017).

Major Challenges of the Existing Space-Based Climate Monitoring Regime

Because climate scientists rely so heavily on the satellite data published by government agencies, their research agenda is necessarily bound by the parameters of that data collection process. Public scientific endeavours face trade-offs on equipment design, orbit coverage and data aggregation to fit their internal data requirements and budget restrictions. Those decisions have pronounced impacts on the breadth and quality of civilian climate research produced using government data. Three of the most significant challenges facing civilian scientists are the lack of high-resolution satellite imagery, limited satellite coverage of remote areas of the globe and data processing challenges.

Lack of High-Resolution Imaging

Not all satellites are designed for the same data collection activities: some are globe-scanning assets constantly taking in and transmitting data, while others are "point and shoot" designs to collect readings on specifically aimed targets. Some satellite instruments, such as laser-based sensors, operate within narrow bands while others are hyper-spectral and capture a wider range of wavelengths (Reuland and Gordon 2020). These differing technical specifications mean that the satellite operators must decide how to balance breadth and depth. Ideally, different types of satellites would work in tandem to capture data that is both nuanced and far-reaching. That is the approach used by some of the most advanced and well-resourced initiatives. Since 2020, for example, ESA's CryoSat-2 and NASA's ICESat-2 satellites have synchronized their Arctic overpasses, collectively delivering simultaneous wide-band radar and narrow-band laser observations (NASA Earth Observatory 2020). These overlapping orbits and near-constant delivery of information create a comprehensive time series data set, allowing analysts to track changes in ice flows, flooding, snow melt and snow water content on a daily basis (Ustin and Middleton 2021, 23). In most cases, however, collection agencies prioritize maximizing data collection based on limited human, capital and fiscal resources. That usually means space assets are designed for globe-scanning, and that such broad satellite data is supplemented with focused observations from shore stations, ships and aircraft.

One major problem with such breadth-oriented satellite assets is the rarity of capturing quality, high-resolution imaging of relevant climate targets. Most assets are in medium-Earth orbit (MEO) or low-Earth orbit (LEO), which are satellites that continuously circle the globe. These tools can effectively capture coarse climate observations such as sea ice coverage or wildfire burn acreage. But these assets are too fast-moving to effectively capture fine-grained indicators of climate problems, such as oil spills, landfill fires, weak oil or gas pipeline connections, grass burnout, low crop yields or poor livestock production. Temporality is also a challenge. Given the rotation of the Earth, there may be a span of days or even weeks between satellite orbits over a given point on Earth. That makes it extremely challenging for scientists to track fine-grained natural phenomena with temporal variability. One of the most frequently cited examples is monitoring private sector emissions to pinpoint sites violating climate restrictions: stationary satellite assets could more effectively monitor major industry sites, since they provide frequent imaging of a given area over time (Dubovik et al. 2021, 2).

Limited Data on Remote Areas of the Globe

Theoretically, space-based monitoring programs should be the most viable option for collecting climate data in regions of the world where it is challenging to construct land-based data collection facilities. Such challenges may emerge from areas that are difficult to access, have extremely rugged geography or experience very cold or hot weather that could interfere with collection equipment. The problem is that space-based monitoring does not exist exclusively in space — maintaining robust outer space systems require in situ land-based infrastructure to service and calibrate satellites. Developing in situ infrastructure in geographically or climactically challenging areas of the globe therefore renders space-based data collection impractical for scientific entities (Gabarró et al. 2023). For example, programs aimed at tracking Arctic and Antarctic sea ice coverage or glacier melt in the Himalayas primarily collect data through local aircraft overflights. This circumvents the onerous challenges of satellite-support infrastructure requirements. However, the resulting imaging has greater quality variability due to weather conditions and data is collected on a less regular schedule. Scientists seeking to understand changing climate conditions in remote areas of the globe — often the regions facing the most imminent climactic threats — struggle to piece together accurate climate modelling when overflight data only returns annual observations.

Data Processing Challenges

Climate researchers face the difficult task of aggregating massive amounts of data from disparate national sponsors and collection agencies, as well as trying to effectively compare readings gathered from space-, land- and sea-based sources. Scientific teams aim for climate models that simultaneously perform with high degrees of accuracy and have the processing power to pull in large amounts of data. Investments in machine-learning approaches are currently the only feasible way to balance these competing tensions in order to extract usable patterns from remote sensing and geospatial data, and even these models have their limitations (Dubovik et al. 2021, 5). Governments such as Canada that host a centralized repository of climate data eliminate some of these processing challenges. But even when researchers do have access to centralized and pre-processed data, aggregation remains a difficult task, especially when collection details such as time of day and geographic coordinates make it impossible to cross-check readings.

The Need for Multi-stakeholder Co-operation on Climate Data Access

The most time- and resource-effective means of addressing critical shortcomings in civilian researcher access to space-collected climate data is to adopt a multi-stakeholder framework for climate data access. Doing so allows stakeholders to draw on existing satellite assets, leverage current and forthcoming capabilities in cutting-edge satellite data collection, draw on human talent within government and private sector circles and integrate data collection efforts building upon existing (though nascent) multi-stakeholder frameworks.

Current Distribution of Data Collection Satellite Assets

Although the most straightforward solution to addressing critical gaps in space-collected climate data is increasing the number of climate monitoring satellites in orbit, this approach carries significant drawbacks. Not only are new satellite launches prohibitively expensive for most scientific entities, but launching new sole-purpose assets contributes to the growing problem of a congested space environment. Proliferating space assets generates a sustainability problem as space actors face a growing "graveyard orbit" of dead satellites, as well as practical concerns around collisions in orbit. A safer and more practical approach is to leverage existing hardware and allow for future satellites to serve multiple purposes. This strategy is particularly pertinent for climate data collection projects that rarely require the commitment of a satellite's entire collection and transmission capabilities.

As of 2020, just 16 percent of the operational satellites in orbit were launched by civilian government agencies — a category that includes most environmental monitoring capabilities as well as other functions such as border management, law enforcement, land management, urban planning and infrastructure monitoring. Nearly as many operational satellites were launched by military actors and 54 percent, by far the largest category, served commercial purposes (Rome 2023). If just a fraction of these military and commercial satellites could be leveraged to gather information on climate phenomena to some degree, it could more than double the amount of data available to climate researchers. But combination data-collection satellites, which usually represent joint ventures by private companies, researchers and civil society groups, are uncommon due to funding and coordination challenges among these actors. Civilian research entities have made some efforts to engage corporate actors, though usually in a limited way. NASA runs a Commercial Smallsat Data Acquisition (CSDA) program to buy data from commercial sources that it deems important to support ongoing scientific goals. But the program is limited to small businesses, excluding major firms such as SpaceX that rank among top satellite owners. The United Nations-sponsored Data for Climate Action challenge is a program aimed specifically at climate-relevant data, bringing together coalitions of industry leaders to contribute anonymized open access versions of their proprietary data on climate conditions for researchers. Importantly, however, the initiative relies on corporate goodwill. It is difficult to incentivize firms to release data for free that they would normally charge for, especially satellite vendors, who already contend with high overhead costs and risks from space collision or launch fails.

Coordination challenges and mismatched incentives have thus far hindered robust co-operation between government and corporate actors in the climate data space. Although it may be possible to overcome these challenges with dedicated effort, it is difficult to imagine firms wholesale relinquishing their profit incentive or an exclusive pathway of government purchase of climate data as a viable path forward. While commercial actors may have a limited role to play in an effective multi-stakeholder framework, such an initiative must be led by government agencies with the interest and ability to operate outside of revenue returns. Defence actors may therefore be a natural partner to civilian research agencies in space-based data collection efforts. Military and intelligence agencies are prolific operators of data collection satellites and have the human talent to support such operations. Indeed, there is compelling evidence that military satellite data can play a key role in climate monitoring. A civilian research team has made extensive use of historic imagery from United States intelligence satellites to track impacts on the Himalayas, a site that is difficult to access by most monitoring means because of its remoteness and difficult terrain (Mondal and Blik 2022). The challenge facing these researchers, however, is the decades that it took for the satellite imagery to be declassified. A key element of an effective multi-stakeholder regime for climate data access, therefore, is a streamlined method of data review and declassification to make data available for researchers working on time-sensitive climate issues.

Current, Future and Potential Roles for Militaries in Satellite Data Collection

Climate scientists working with space-collected data face challenges of data quality, coverage and aggregation. It seems unlikely that those limitations can reasonably be addressed by public science agencies balancing dozens of competing priorities, profit-driven private satellite firms or academic institutions with insufficient cash flows to fund satellite launches for the purpose of data collection. Instead, militaries are uniquely poised to augment the space-based collection of climate data. Not only are security actors playing an increasingly important role in outer space, but the objectives and existing capabilities of militaries and intelligence services are well-positioned to mitigate the challenges facing civilian climate researchers. There is also compelling evidence that shifting weather and terrain conditions due to climate effects will impact combat operations (Cullum 2022; Espach, Zvijac and Filadelfo 2016), construction and maintenance of military bases (Colgan 2018), recruitment and retention (Best et al. 2023), and field logistics (Robinson et al. 2023; Kaltrider 2017). Security actors therefore have a vested interest in supporting civilian researchers furthering our understanding of the effects of climate change to address implications for warfighting and military readiness.

Militaries' Role in Space-Based Data Collection

Satellites have played a role in military operations since the Soviet Union launched Sputnik in 1957. Military actors worldwide have long relied on space assets for communications and navigation. These functions have only increased in importance in recent years. Secure and reliable communication and navigation systems ensure that field commanders can reliably receive and carry out orders from senior officials, even from battlefields in remote corners of the Earth. Interoperable logistics systems are also imperative for successful multilateral military operations. Established alliances are recognizing the importance of ensuring mutual access to military satellite capabilities, with pre-emptive asset-sharing agreements recently being reached between the United States and Canada (Saballa 2023), as well as among North Atlantic Treaty Organization (NATO) member states,[1] to facilitate seamless integrated training programs, formal military exercises or combat operations.

Advances in satellite technology are also heightening the role space-collected data plays in routine military operations. Militaries pursuing intelligence, surveillance and reconnaissance (ISR) information collection initiatives via satellite previously settled for grainy imaging of enemy missile silos. Subsequent improvements in imaging quality and in data transmission capabilities now allow for more regular and granular types of information. Field commanders can now receive virtually real-time updates on weather conditions, terrain and enemy

1 See www.nato.int/cps/en/natohq/topics_183281.htm.

actions to coordinate tactical operations with the best possible likelihood of success.

Future Trends in Space-Based Data Collection by Security Actors

As much as satellite capabilities have influenced warfighting in recent years, the role of space-based assets is projected to continue rising. Militaries and intelligence agencies are investing in technical research to continue upgrading satellite bandwidth capacity, system security and anti-jamming measures and geolocation accuracy. These actors are likewise supporting the development of secure LEO satellites. Militaries have historically prioritized long-term assets at higher altitudes. LEO satellites are cheaper and faster to develop, are designed to be more temporary (and can therefore be routinely upgraded with the latest technology) and can be deployed in arrays of dozens of satellites, each equipped with different types of sensors to collect a broader suite of data (Borowitz 2022). Because LEO assets are closer to the Earth they can communicate information in real time, and they are generally more secure both because they are smaller targets and because it is harder for rivals to detect and strike assets in LEO (Thomas 2023). It will take time for military investments in LEO satellites to yield robust results, especially because this approach represents such a radical departure from traditional outer space postures. Canada is a leading actor in this area, debuting a microsatellite project for domain awareness in outer space in 2023. Still, the pilot satellites are not expected to be launched until 2026 (Pugliese 2023). But once security actors have established a robust presence in LEO, they will be among the only actors with data collection abilities across outer space altitudes. They will therefore be able to capitalize on the distinct advantage of assets in geosynchronous orbit, as well as the imaging quality and data transmission advantages of LEO, leaving them well poised to facilitate incidental data collection on non-military targets.

Expectations of increased reliance on satellite assets is impacting how militaries operate vis-à-vis outer space. One of the most salient changes is in spending levels: the global military satellite market is expected to hit US$27.62 billion by 2032, almost double the size of that market in 2022 (Precedence Research 2023). States are also shifting the structure of their militaries to prioritize outer space activity. The United States made perhaps the most visible change in creating the Space Force as an independent military service. John F. Plumb, assistant secretary of defense for space policy, made an explicit connection between the founding of the Space Force and American commitments to extraterrestrial force posture in saying, "Space is in our DNA for the military. It's absolutely essential to our way of war" (Garamone 2023a). Canada has also reorganized its military to more effectively coordinate space operations in establishing the Space Division of the Royal Canadian Air Force in 2022 (Hitchens 2022).

Civil-Military Synergies in Addressing Climate Data Collection Challenges

The way that security actors have positioned their current and future space-based assets, as well as their bureaucratic capabilities for evaluating data collected for military planning purposes, offer promise for overcoming the challenges civilian researchers face in working with climate data from other public agencies. Of course, the meeting of these challenges is conditioned on security actors taking an active role in climate initiatives and making collected data available to the public. More precise recommendations for such a whole-of-government approach to climate data are outlined in the subsequent sections.

Priority on High-Resolution Imaging

Satellites launched by security agencies tend to be equipped with high-quality imaging capabilities because visual data needs to be high-resolution in order to be useful for intelligence purposes. Granular details are essential for accurately planning military operations, verifying the details of adversary capabilities and tracking construction of military or strategic infrastructure. In 2019, then-US President Donald Trump tweeted an image presumed to have been collected by a military satellite of the Semnan Launch Site One in Iran that suffered a rocket explosion. In the image, which is one of the sharpest satellite-collected images to date, the viewer can clearly see the launch tower, service vehicles and evidence of burn damage from the explosion (Trump 2019). Most experts estimate that sophisticated spy satellites can return images with resolution as high as 10 cm/pixel (Werner 2022). Compare this figure to the normal resolution of NASA's Landsat

8 Earth observation satellite at 15 m/pixel,[2] and the potential gains of leveraging defence assets for climate data purposes are obvious.

Military and intelligence satellites follow orbit paths carefully designed to capture data on national competitors and adversaries, or any other actor presumed to pose a security threat. But many satellite instruments collect information continuously. All of the data collected by satellites during orbit is transmitted to the relevant authorities on the ground; information that is not immediately pertinent to ongoing operations is usually stored for future mapping, detection and identification purposes. This represents a massive source that could potentially provide climate researchers with more precise data than that available from civilian sources.

Satellite Coverage over Remote Areas of the Globe

The Arctic is an area of the world that is most relevant to pressing climate research. It is also an area from which civilian researchers have struggled to access regular, high-quality data, in part because of the challenges of locating in situ infrastructure in the Far North. But recent increases in the salience of Arctic geopolitical competition means that many Arctic and near-Arctic nations are putting a higher priority on that part of the world in their military planning and ISR efforts. There are currently more than 50 military bases in the region, most of which are operated by Russia, Canada and the United States. Military actors have sunk tremendous amounts of resources into building up infrastructure in the Arctic because it is such a strategic site for surveilling rival states, providing early warning for missile detection and facilitating emergency search and rescue (Gronholt-Pedersen and Fouche 2022). These military installations likely already serve in situ purposes for government space assets, given the extensive network of North American Aerospace Defense Command (NORAD) satellites that currently operate over the region. It therefore seems like a natural extension of existing capabilities for military satellites to collect critical environmental data concurrently with security functions, or to offer calibration functions for scientific satellites. The United States and Norway are currently pursuing a bilateral program for situational awareness in the Far North that makes extensive use of satellite assets. Project developers floated the idea of satellites serving dual purposes of environmental surveillance and military monitoring, but there is no evidence that this multi-purpose function was incorporated into the final design (Bjørkum 2022, 113–15).

Data Processing Capabilities

Intelligence communities are no strangers to the challenge of aggregating many different types of data from numerous sources and ensuring that the resulting database is easily accessible and relies on useful, accurate categorizations. These agencies have developed sophisticated systems for drawing together data from open sources, human intelligence, signals intelligence and imagery intelligence. A timely example of this multi-source data integration is in NORAD's All Domain Situational Awareness program in which the United States and Canada jointly committed to upgrading ground-based and space-based information collection and processing capabilities (Johnson 2021). Given that defence actors have existing data-intensive mission requirements, they are well-equipped to assist security actors with organizing satellite data relevant to climate researchers and integrating it with climate data collected from scientific agencies.

Military-Commercial Synergies in Satellite Data Collection

Security actors are increasingly recognizing that optimizing space-based data collection for battlefield purposes necessitates engagement with the commercial sector. Several projects reveal specific efforts to incorporate private firms. The US Army's Project Convergence in 2020 relied on commercial satellites to augment government-collected data of battlefield sites. Army technicians pre-emptively downlinked private firms' data to ground service stations so that automated systems could search this data repository for information on targets identified by battlefield operators. The integration of commercial data was such a success — cutting down sensor-to-shooter time from 20 minutes to 20 seconds — that the US Space Development Agency is currently evaluating project extensions that would directly connect commercial satellites to military intersatellite links, offering even quicker access (Strout 2021). Canada is also experimenting with leveraging commercial satellite data for military ISR. A recent Defence Research

2 See https://landsat.gsfc.nasa.gov/satellites/landsat-8/.

and Development Canada exercise in the Arctic experimented with accessing small commercial satellites for imaging of the ships that participated in the exercises, as well as data of marine automatic identification system messages. The exercise aimed at evaluating how data from private firms could reduce the time for collecting, processing and acting upon relevant information in the event of a real military crisis (Government of Canada 2024).

Beyond the climate space specifically, security actors lean on commercial agents to procure access to satellite data. This may be carried out through direct contracting, purchasing commercial data with exclusive rights and purchasing commercial data with unrestricted usage rights. Each channel is addressed below in turn.

Military and intelligence agencies may contract with satellite providers to fund specific projects carried out with commercial assets. Ordinarily, contractors will design or update satellite assets, launch them and then coordinate data gathering specifically to accommodate security actors' requirements. The satellite contractor industry has boomed in recent years, as militaries pour hundreds of millions of dollars into such programs. This also means that contracted programs can be subject to comparable security requirements as that of in-house government missions: security actors retain the rights to screen personnel working on the project and can classify any collected data. Firms in this space include established military contractors such as Raytheon and Northrop Grumman that also operate in non-outer space domains; companies such as SES Space & Defense and Intelsat that established themselves specifically for military space contracts; and companies such as Boeing, Airbus and SpaceX that act as both military contractors and market-oriented commercial entities (Erwin 2023).

An alternative to contracting out entire space operations is the selective purchase of satellite data collected by commercial firms. Security actors have the option of buying specific relevant pieces of data on an exclusive basis — which is markedly more expensive but precludes other actors from accessing the same information — on a non-exclusive basis, in which a military or intelligence agency is just one of many buyers. Some commercial satellite firms also offer subscription models for customers to access their entire catalogue of data, usually on a non-exclusive basis. Government security protocols and acquisition restrictions have historically been barriers to military or intelligence agencies purchasing commercial data (Harrison and Strohmeyer 2022), though that is beginning to change (Cooper 2024). Not only is purchasing off-the-shelf data a cost-savings measure, but having access to information flows not publicly associated with security actors also increases their resiliency in case of attack on national satellite infrastructure.

One trend driving military and intelligence actors' reliance on the private sector is simply the increased demand for satellite data. Contracting and data acquisition remains much cheaper than independent satellite launches and information can be more readily procured. Another trend worth noting is the rising fragmentation of the commercial satellite market. As the number of firms operating in outer space has grown exponentially, firms are able to remain profitable while delivering extremely narrow types of data (Patriarca, Costantino and Di Gravio 2019). This ensures that security actors can bid for very specialized information. It also means that any type of coordinated effort on climate data access must necessarily be state driven, since there are so many disparate interests and capabilities represented in the commercial space.

A Framework for Multi-stakeholder Climate Data Access

Given that civilian researchers are facing serious shortfalls in their existing access to space-collected climate data and that defence actors have a unique synergy of hardware capabilities and human capital to fill those gaps, an effective framework for climate data access necessitates a whole-of-government approach with a more limited role for the commercial sector. This section outlines the essential tenets of such a framework and points to leverage buy-in from relevant stakeholders.

Essential Tenets of the Framework

Whole-of-Government Commitment to Climate Data Review and Release

Although it may not be feasible to consistently redirect military and intelligence satellites toward climate objectives, the incidental data collected by these assets could be of enormous importance to civilian researchers. The first key tenet of the framework is therefore a whole-of-government commitment to reviewing the data routinely collected by space-based assets and releasing information with climate relevance to the extent allowable by national security. This necessitates the establishment of satellite data review offices within the defence establishments of major satellite operators such as the United States, Canada, China and the European Union. It will certainly be necessary for data review processes to scrub some information from the collected data to prevent compromising ongoing military operations. However, reviewers should be apprised of the scientific value of collection details such as precise collection dates, times and locations, and should strive to maintain complete records of such data points as much as possible. State actors should also follow Canada's example in establishing a single national portal through which to release data from all government offices, maximizing the ease of access and analysis for civilian researchers.

Opportunities for Civilian Researchers to Weigh in on Collection Priorities

A second tenet of the framework is giving climate researchers opportunities to engage with government actors in voicing their priorities for data access. A multilateral body such as the UN Climate Change office may be a natural intermediary to host regular convocations of top climate scientists from around the world to assemble lists of climate data priorities to be passed along to government actors. For emergency climate data access, such as to track rapidly spreading wildfires or an impending super-storm, this body of scientists may petition state actors to launch or re-route satellite assets to specifically collect the needed data. For routine climate data requests, the framework should establish a regular process by which civilian scientists can request data collection instruments be embedded on government or commercial satellites with comparable orbit paths. Investing in this on-orbit servicing, assembly and manufacturing approach by which data collection instruments can be added to satellites already in orbit rather than returning them to Earth means that monitoring capabilities can be attached at minimal cost, can be tacked on as satellites approach a beneficial orbit pattern with minimal deviations, and can be replaced with the most up-to-date monitoring technologies as they become available. The data collected by civilian-placed instruments would also be subject to government review, particularly for those mounted to defence assets. But giving civilian scientists access to data collected by their chosen instruments along an optimized orbit path offers researchers greater buy-in to the data collection process, improves the quality of resulting scholarship, and does so at minimal cost to state satellite operators.

Establishment of Robust Bounty Programs for Commercial Climate Data

A final tenet of the framework is the establishment (or expansion) of government bounty programs to buy proprietary data from commercial satellite providers that has relevance to climate indicators. This represents an additional means by which state actors can meet the climate data priorities set forth by researchers, should government satellites be unable to provide the needed data. Commercial actors may agree to freely provide information in the case of climate emergencies, as in existing agreements for private satellite operators to share data on imminent threats to space assets with national intelligence agencies (Erwin 2023). Otherwise, states should expect to provide compensation to private actors for their data, using initiatives such as NASA's CSDA program as a template.

Structure and Authority of the Framework

Ideally, a multi-stakeholder framework for climate data sharing would be implemented at the global level with a UN agency as coordinator. However, it is unlikely that such a multinational effort would include full buy-in from all states with national satellite assets. The United States, Russia, and China have an extensive track record of disagreement and mistrust surrounding both climate issues and outer space governance. Rather than expect that all three powers would back an agenda for co-operation on both contentious issues, the framework is best implemented within existing state partnerships.

One area that may benefit from piloting the framework is the Arctic. This is a space of great interest to climate researchers, but with relatively limited commercial satellite data coverage. Militaries, however, are investing heavily in both land-based and space-based Arctic observation capabilities. The Arctic Council is a promising institutional facilitator for this framework for several reasons: It has a long track record of coordinating multilateral co-operation, including on satellite observation; it already coordinates with scientists working on climate protection and resiliency initiatives; and although the Arctic Council explicitly excludes work on military issues, there is precedent for security actors being involved in co-operation around search and rescue and other human security issues. The Arctic therefore represents the case in which a co-operative framework for climate data sharing could be both most useful and most easily accepted. Should the efforts yield promising results in the Far North, governments may be incentivized to expand the framework's coverage elsewhere.

Stakeholder Buy-In

There is little reason for civilian researchers or commercial actors to reject the proposed framework. The scientific community gains access to better climate data, processing and aggregation assistance, and opportunities for more direct participation in setting monitoring priorities. Private firms have limited data reporting obligations outside of emergency circumstances and therefore have the opportunity to profit off of government bounties for data they may be collecting incidentally. This revenue channel becomes particularly attractive if government actors recruit likely satellite vendors instead of relying exclusively on requests for proposals. Even civilian government actors should find the proposed framework attractive. Beyond the resourcing requirements associated with unified national portals for climate data access, the framework does not ask scientific research agencies to do much more than they are already doing. The funding and personnel sacrifice these agencies are asked to make remain closely tied to their core mission of scientific discovery. The stakeholder most likely to resist the framework, therefore, is the defence sector.

Military and intelligence agencies in most countries have had a limited role to play in national climate policies, other than building resiliency into military operations. However, NATO (NATO 2023), the United States (Garamone 2023b), Canada (Bronskill 2023) and the European Union (European Commission 2023) have all issued official statements calling climate change a national or multilateral security threat. The seeming disconnect between these statements and the subsequent lack of action has opened up defence actors to criticisms of hypocrisy in their climate policies. Militaries are frequently cited as major polluters, with the global military footprint estimated to be responsible for 5.5 percent of greenhouse gas emissions and the United States military pointed to as the globe's single largest consumer of petroleum (De la Garza 2022). The United States military's Climate Action Plan and similar efforts are criticized as grasping at low-hanging fruit such as infrastructure initiatives by the Army Corps of Engineers (Myers 2022). And military actors have virtually entirely ignored calls to "supplement ongoing data-driven efforts" in climate communities (Best et al. 2023) and regularly share "information related to climate change impacts and adaptation" (United Nations 2015, 11), even among signatory states to the Paris Climate Accords bound by provisions for state participation in "strengthening scientific knowledge on climate" (ibid., 6).

Participating in the proposed multi-stakeholder framework for climate data access gives defence actors a means of addressing criticisms that they have shirked efforts to expand the scope of military missions to address the threats presented by climate change. But this is not an instance of cheap talk. Bringing the defence sector into the framework would address important shortcomings in the existing quality and availability of climate data and would go a long way toward improving climate modelling and adaptation and mitigation research. Furthermore, the framework prioritizes existing capabilities and talent to minimize the resource outlays or bureaucratic reorganization asked of governments.

Potential Flashpoints

A multi-stakeholder framework for space-based climate data collection is a relatively low-cost and low-effort way for governments to advance critical climate research and demonstrate their commitment to climate security. But despite clear benefits for states, commercial actors and the scientific community, implementing such a framework will not be without controversy. Drawing on contemporary debates around climate politics and satellite data, the following are anticipated challenges that could threaten the initiative, as well as proposals for ameliorating them, focusing primarily on issues that could be of major concern to military and intelligence agencies, as the actor with the least inherent buy-in.

Government Fears of National Security Risks

Military and intelligence actors are understandably hesitant to release information collected as part of classified operations for fear of adversaries gleaning insight into forthcoming foreign policy or national security efforts. Defence actors are notoriously plagued by over-classification problems due to fear that even seemingly innocuous information could later be weaponized by adversaries. Such resistance would likely be magnified in this instance, since climate change tends to be classified as a human security challenge as opposed to the hard security issues on which military actors usually focus. State actors would obviously need to vet collected data in order to remove observations that pertain to ongoing military operations, identifying intelligence assets or data that could otherwise damage national security. However, security actors may remain fearful that compromising information could slip past censors.

There are several reasons to believe that the satellite-collected data that would be released as part of the multi-stakeholder framework would have a negligible risk of compromising national security. First, climate scientists have little use for high-resolution images of foreign military bases or weapons installations. The data that would be valuable to these civilian actors is incidental to military targets — images and instrument readouts collected during the normal course of satellite orbit. Second, most of the satellite-collected data that is currently available from civilian agencies is not published in its raw form. These state analysts instead devote personnel and resources to aggregating raw data into databases that are less computationally intensive and in software readable formats. Certain pieces of information collected from military and intelligence satellites, such as high-resolution images of sea ice, would be valuable to researchers. But aggregating the majority of data prior to public release further shields research consumers from potentially sensitive information and minimizes seepage of compromising details due to human error.

If it is highly unlikely that climate data published by military and intelligence agencies will be damaging to national security, then the only other potential risk is that the released data would reveal classified satellite orbits and therefore the targets of interest to state security actors. This is not an insignificant risk, but it is one that is already null. It is challenging to shield the presence and path of satellites for the simple reason that space is transparent. Numerous websites exist for amateur astronomers to monitor the progress of different satellites and make educated guesses at the purpose and national origin of each due to distinctive design features and orbit patterns.

Cybersecurity

Cybersecurity is an ongoing concern for the military and intelligence agencies that rely on satellites for critical information. Cyber incursions from an adversary risk compromising data relays to Earth, taking down expensive pieces of hardware or causing collisions with other space-based equipment. And while government actors are prioritizing robust defences against cyber vulnerabilities (Gedeon 2023), commercial actors — especially those that profit off of small, low-cost satellites in LEO — have largely failed to engage in cyber concerns. Given the lax regulatory requirements on private firms to protect against malicious cyber incursions (Verco 2021), there is little incentive for commercial satellite actors to do so going forward. Governments may therefore be concerned about deepening involvement with private satellite firms if such partnerships risk bringing government systems into contact with malware or compromised data.

Incommensurable cybersecurity standards represent a challenge, but not an insurmountable one. Most states already have protocols in place for engagement with the private sector, for either long-term contracts or one-off services or both. NASA's CSDA program could act as a template for putting in place security protocols on external satellite data. Alternatively, state actors may rely on extensive software scanning or off-network information systems to handle any suspicious files.

Resourcing

Government spending is a reflection of state priorities. Implementing a whole-of-government commitment for climate data collection and distribution therefore represents an opportunity cost for prioritizing other domestic programs. Funding would certainly be a sticking point for many governments. One advantage to this proposal is that climate data collection makes use of the material and human resources that many states currently rely on for other purposes. The additional costs involved to private firms and civilian researchers for data review and outreach are relatively minimal; it is therefore low risk for states seeking to deliver on their commitment to climate change as a security priority. States could also invoke principles enshrined in the Outer Space Treaty or UN Principles Relating to Remote Sensing of the Earth from Outer Space, both of which commit governments to carrying out activities in space for the benefit of all humankind. Despite their reliance on existing capabilities and the virtue-signalling advantages of participating in the framework, some states with significant government satellite usage will likely refuse. There is no reasonable way to compel these states to participate, but participant governments putting pressure on their allies and security partners may be a starting point. The involvement of civilian researchers could also be a benefit in this regard, since their position as intellectual elites may carry weight in lobbying their home governments for public access to state-collected climate data.

Politicization of Climate Data Collection

Climate change is already a politicized topic in many states, sparking ongoing debates among national leaders about the scale of its impact, the role of humans in causing it, the degree to which the state should be involved in its mitigation and adaptation and the global balance of responsibility for it— and for addressing its consequences. There is therefore a risk that implementing a whole-of-government approach to collecting and distributing climate data could create political backlash. Opposition leaders may co-opt such initiatives as a political talking point. The program could also face variability across administrations, with sympathetic politicians bolstering support only to face defunding as a new leader comes to power.

One source for optimism is that climate data collection is a relatively technical matter: a national leader or political candidate looking to take aim at climate initiatives would likely begin with more obvious targets, such as decarbonization. The best defence against politicization is therefore keeping the framework as a technical initiative. Governments and citizens should lobby to bring on board a diverse set of satellite-operating states. However, details of the framework should be negotiated within the professional circles of multilateral institutions and security partnerships and advocated for by the scientists who seek data access. It is not an issue that should be put forward by national leaders as a hallmark of international climate accords, used as leverage in climate bargaining between the Global North (which launches the greatest proportion of government satellites) and the Global South or hammered as a political talking point in national debates. Preventing climate data collection from becoming a hot-button political topic can insulate it from a variability of support with changes in national politics and prevent it from becoming an attrition target when government resources are constrained.

Conclusion

The urgency of addressing climate change demands a cohesive and proactive approach to climate modelling. Yet the current state of satellite data collection and dissemination presents significant challenges to effective scientific enterprises. This paper has explored the constraints of the existing data-sharing regime driven by civilian scientific agencies, assessed the role various sectoral stakeholders can play in improving climate data, put forward an initial multi-stakeholder framework prioritizing high-quality data of the type normally collected by the defence sector and closed with recommendations for implementing this framework with full buy-in.

Outer space has long been hailed as a domain of co-operation transcending divisions here on Earth. As the planet faces impending climate catastrophes, the need for such co-operation is more important than ever. This multi-stakeholder framework for climate data access is a relatively low-cost and low-effort initiative that could lay the groundwork for future co-operation across sectors. Leveraging such points of common cause represents the fundamental ethos of the ideal of the final frontier.

Works Cited

Arctic Council. 2021. "Ten Years of Sustained Arctic Observing." May 10. https://arctic-council.org/news/ten-years-of-sustained-arctic-observing/.

Best, Katharina Ley, Scott R. Stephenson, Susan A. Resetar, Paul W. Mayberry, Emmi Yonekura, Rahim Ali, Joshua Klimas et al. 2023. *Climate and Readiness: Understanding Climate Vulnerability of U.S. Joint Force Readiness.* May 24. Santa Monica, CA: RAND Corporation. www.rand.org/pubs/research_reports/RRA1551-1.html.

Bjørkum, Kjetil. 2022. "Above the Arctic: Increased Security in the Arctic through Cooperation in Space." *Journal of Indo-Pacific Affairs* (September–October): 111–23.

Borowitz, Mariel. 2017. *Open Space: The Global Effort for Open Access to Environmental Satellite Data.* Illustrated edition. Cambridge, MA: MIT Press. https://doi.org/10.7551/mitpress/10659.001.0001.

———. 2022. "The Military Use of Small Satellites in Orbit." Briefings de l'Ifri, March 4. www.ifri.org/en/publications/briefings-de-lifri/military-use-small-satellites-orbit.

Bronskill, Jim. 2023. "CSIS warns climate change threatens Canadian security, prosperity." *The Globe and Mail*, March 5. www.theglobeandmail.com/canada/article-csis-warns-climate-change-threatens-canadian-security-prosperity/.

Colgan, Jeff D. 2018. "Climate Change and the Politics of Military Bases." *Global Environmental Politics* 18 (1): 33–51. https://doi.org/10.1162/GLEP_a_00443.

Cooper, Naomi. 2024. "Space Force Leads Adoption of Commercial Satellite Imagery for Military Use." *ExecutiveGov*, February 13. https://executivegov.com/2024/02/space-force-leads-adoption-of-commercial-satellite-imagery-for-military-use/.

Cullum, Robert. 2022. "Hell or High Water? Exploring how navies understand and respond to climate change in the United States, Britain, and Australia." Ph.D. dissertation, Aberystwyth University. https://research.aber.ac.uk/en/studentTheses/hell-or-high-water-exploring-how-navies-understand-and-respond-to.

De la Garza, Alejandro. 2022. "To Take Climate Change Seriously, the U.S. Military Needs to Shrink." *Time*, February 17. https://time.com/6148778/us-military-climate-change/.

Dubovik, Oleg, Gregory L. Schuster, Feng Xu, Yongxiang Hu, Hartmut Bösch, Jochen Landgraf and Zhengqiang Li. 2021. "Grand Challenges in Satellite Remote Sensing." *Frontiers in Remote Sensing* 2. www.frontiersin.org/articles/10.3389/frsen.2021.619818.

Erwin, Sandra. 2023. "U.S. intelligence agencies take steps to protect commercial satellites." *SpaceNews*, August 9. https://spacenews.com/u-s-intelligence-agencies-take-steps-to-protect-commercial-satellite-operators/.

Espach, Ralph, David Zvijac and Ronald Filadelfo. 2016. "Impact of Climate Change on U.S. Military Operations in the Western Pacific." *MCU Journal,* Special Issue: Climate Change & Policy. https://doi.org/10.21140/mcuj.2016si05.

European Commission. 2023. "EU proposes comprehensive new outlook on threats of climate change and environmental degradation on peace, security and defence." Press release, June 28. https://ec.europa.eu/commission/presscorner/detail/en/ip_23_3492.

Gabarró, Carolina, Nick Hughes, Jeremy Wilkinson, Laurent Bertino, Astrid Bracher, Thomas Diehl, Wolfgang Dierking et al. 2023. "Improving satellite-based monitoring of the polar regions: Identification of research and capacity gaps." *Frontiers in Remote Sensing* 4. https://doi.org/10.3389/frsen.2023.952091.

Garamone, Jim. 2023a. "Space Integral to the DOD Way of War, Policy Chief Says." U.S. Department of Defense, July 20. www.defense.gov/News/News-Stories/Article/Article/3465982/space-integral-to-the-dod-way-of-war-policy-chief-says/https%3A%2F%2F.

———. 2023b. "Hicks Defines Need to Focus DOD on Climate Change Threats." U.S. Department of Defense, August 30. www.defense.gov/News/News-Stories/Article/Article/3510772/hicks-defines-need-to-focus-dod-on-climate-change-threats/.

Gedeon, Joseph. 2023. "For the first time, U.S. government lets hackers break into satellite in space." *Politico*, August 11. www.politico.com/news/2023/08/11/def-con-hackers-space-force-00110919.

Government of Canada. 2022. *Resourceful, Resilient, Ready: Canada's Strategy for Satellite Earth Observation.* https://publications.gc.ca/collections/collection_2022/asc-csa/ST99-80-2022-eng.pdf.

———. 2024. "DRDC demonstrates commercial satellites can be used for Arctic surveillance during Op NANOOK – TUUGAALIK – NUNAKPUT." *Defense and Security Science* (blog), January 8. https://science.gc.ca/site/science/en/blogs/defence-and-security-science/commercial-satellites-nanook-tuugaalik-nunakput.

Gronholt-Pedersen, Jacob and Gwladys Fouche. 2022. "Dark Arctic: NATO allies wake up to Russian supremacy in the region." Reuters, November 16. www.reuters.com/graphics/ARCTIC-SECURITY/zgvobmblrpd/.

Harrison, Todd and Matthew Strohmeyer. 2022. "Commercial Space Remote Sensing and Its Role in National Security." Center for Strategic & International Studies, February 2. www.csis.org/analysis/commercial-space-remote-sensing-and-its-role-national-security.

Hitchens, Theresa. 2022. "Canada's new Space Division: Evolution not Revolution." *Breaking Defense* (blog), July 26. https://breakingdefense.sites.breakingmedia.com/2022/07/canadas-new-space-division-evolution-not-revolution/.

Johnson, Benjamin T. 2021. "Sensing the Arctic: Situational awareness and the future of northern security." *International Journal: Canada's Journal of Global Policy Analysis* 76 (3): 404–26. https://doi.org/10.1177/00207020211048424.

Kaltrider, Veronica L. 2017. "Our Tail Has a Tail: Using Hybrid Logistics to Adapt to Water Scarce Environments with Minimum Impact to Military Operations from 2025 and Beyond." Master's thesis, USMC Command and Staff College. https://apps.dtic.mil/sti/pdfs/AD1176516.pdf.

Kutzbach, John E. 1988. "Climate Modeler's Commandments." *Climate & Global Dynamics Division News*, September.

Mondal, Monika and Alek Blik. 2022. "Satellites Investigate Climate Peril Over Himalayas." Supercluster, March 29. www.supercluster.com/editorial/satellites-investigate-climate-peril-over-himalayas.

Myers, Chandler. 2022. "Designing A More Climate Credible US Military." Modern War Institute, October 31. https://mwi.westpoint.edu/designing-a-more-climate-credible-us-military/.

NASA Earth Observatory. 2020. "Taking a Measure of Sea Level Rise: Ice Height." November 5. https://earthobservatory.nasa.gov/images/147438/taking-a-measure-of-sea-level-rise-ice-height.

NATO. 2023. "Secretary General at COP28: climate change matters for our security, and therefore it matters to NATO." News, December 1. www.nato.int/cps/en/natohq/news_220668.htm.

Patriarca, Riccardo, Francesco Costantino and Giulio Di Gravio. 2019. "Risk, safety, reliability and satellites: Chronicles of a fragmented research field." *Journal of Space Safety Engineering* 6 (3): 201–11. https://doi.org/10.1016/j.jsse.2019.08.002.

Precedence Research. 2023. *Military Satellite Market Size, Share, and Trends 2024 to 2034*. September. www.precedenceresearch.com/military-satellite-market.

Pugliese, David. 2023. "Canadian military orders space surveillance micro satellite." *SpaceNews*, March 10. https://spacenews.com/canadian-military-orders-space-surveillance-micro-satellite/.

Reuland, Frances and Deborah Gordon. 2020. "For Emissions Monitoring, Satellites Shouldn't Fly Solo." RMI, December 2. https://rmi.org/for-emissions-monitoring-satellites-shouldnt-fly-solo/.

Roberts, Thomas G. 2022. "Space Launch to Low Earth Orbit: How Much Does It Cost?" Center for Strategic & International Studies Aerospace Security Project, September 1. https://aerospace.csis.org/data/space-launch-to-low-earth-orbit-how-much-does-it-cost/.

Robinson, Yohan, Amir Khorram-Manesh, Niclas Arvidsson, Cave Sinai and Fabian Taube. 2023. "Does climate change transform military medicine and defense medical support?" *Frontiers in Public Health* 11. https://doi.org/10.3389/fpubh.2023.1099031.

Rome, Primož. 2023. "Every Satellite Orbiting Earth and Who Owns Them." *Data Acquisition Knowledge Base* (blog), February 9. https://dewesoft.com/blog/every-satellite-orbiting-earth-and-who-owns-them.

Saballa, Joe. 2023. "US Allows Canada Access to Advanced Military Satellite for Secure Comms." *The Defense Post*, December 5. www.thedefensepost.com/2023/12/05/us-canada-access-satellite/.

Strout, Nathan. 2021. "The US military wants to plug commercial satellites into its orbital networks." C4ISRNet, December 23. www.c4isrnet.com/intel-geoint/2021/12/23/the-us-military-wants-to-plug-commercial-satellites-into-its-orbital-networks/.

Thomas, Richard. 2023. "Low Earth orbit: disruptive military technologies." Airforce Technology, June 11. www.airforce-technology.com/comment/low_earth_orbit_disruptive_military_technologies/.

Trump, Donald J. 2019. "The United States of America was not involved in the catastrophic accident during final launch preparations for the Safir SLV Launch at Semnan Launch Site One in Iran. I wish Iran best wishes and good luck in determining what happened at Site One." Twitter, August 30, 1:44 p.m. https://twitter.com/realDonaldTrump/status/1167493371973255170.United Nations. 2015. *The Paris Agreement*. United Nations. www.un.org/en/climatechange/paris-agreement.

Ustin, Susan L. and Elizabeth M. Middleton. 2021. "Current and near-term advances in Earth observation for ecological applications." *Ecological Processes* 10, 1. https://doi.org/10.1186/s13717-020-00255-4.

Verco, Edward. 2021. "Satellites Are Cyber Insecure: We Need Regulation to Avoid a Disaster." *ANU Journal of Law and Technology* 2 (2): 57–94.

Werner, Debra. 2022. "Near Space Labs to offer 10-centimeter resolution imagery." *SpaceNews*, February 3. https://spacenews.com/near-space-labs-to-offer-10-centimeter-resolution-imagery/.

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