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An artist's depiction of an ICEYE SAR satellite in orbit. Source: ICEYE.

The Last Frontier From Space

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IMPACTS OF CLIMATE CHANGE

In 2020 we faced substantial heatwaves, intense wildfires, severe hurricanes, continued permafrost thaw, as well as migration of fauna. This was because the global average temperature was about 2.25 degrees Fahrenheit warmer than the 1850-1900 average, based on data from the Copernicus Climate Change Service.

What kinds of phenomena did we endure? Let's have a look at some of them. According to NOAA:

> The U.S. experienced a record-smashing 22 weather and climate disasters that killed at least 262 people and injured scores more. … The seven billion-dollar tropical cyclones were the most in one year since NOAA started keeping track of billion-dollar disasters in 1980. The extremely active 2020 Atlantic hurricane season produced an unprecedented 30 named storms, with 12 making landfall in the continental U.S. The combined cost of the seven tropical systems was approximately $40.1 billion, more than 42% of the total U.S. billion-dollar disaster price tag in 2020 (National Oceanic and Atmospheric Administration, 2021).

Arctic examples of these phenomena include two severe landslides in Norway, and the most recent one led to casualties at the end of the year (BBC News, 2021). In Siberia, there are new holes forming in the soil with a depth of more than 100 feet. These sinkholes have become more common as permafrost thaw releases methane into the atmosphere and

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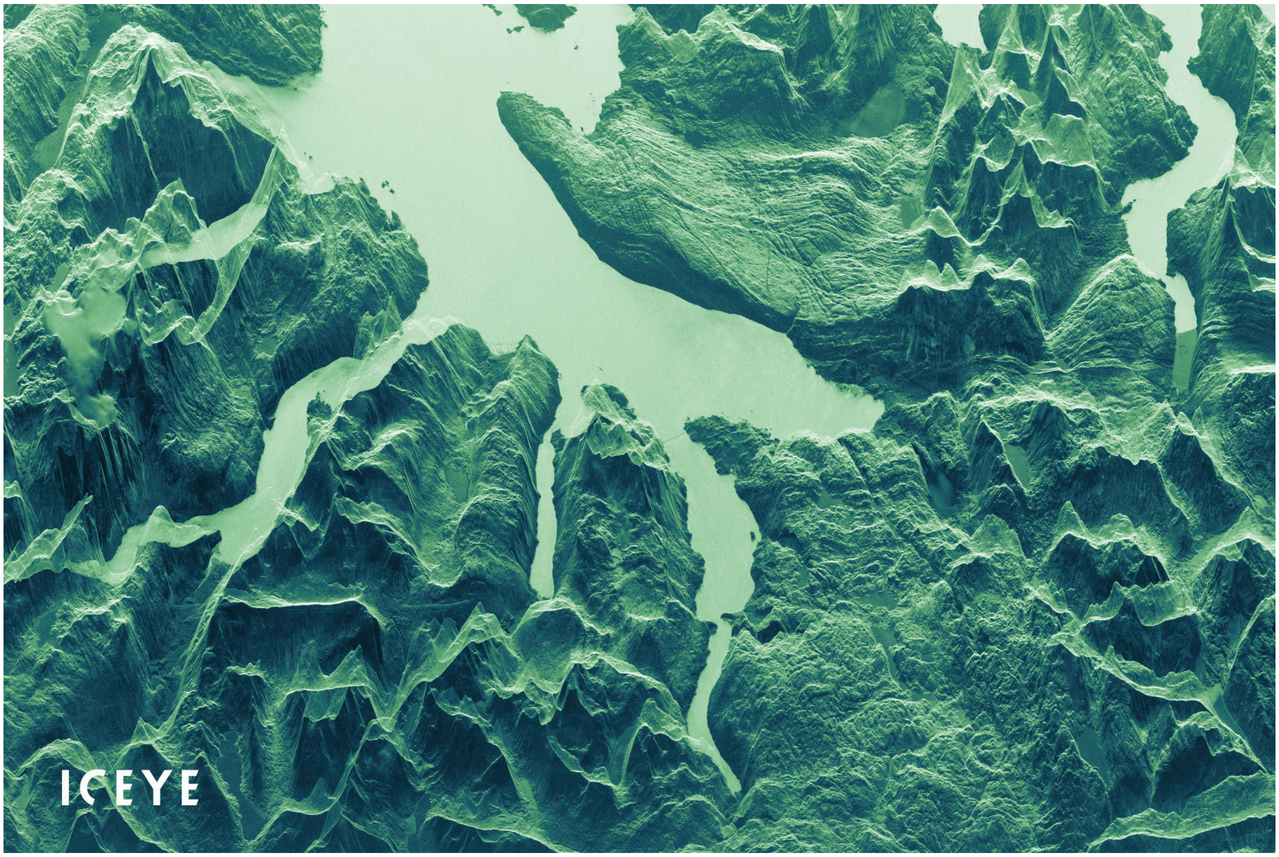
accelerates the greenhouse gas effect (Hunt, 2020). Severe rains have led to landslides in Alaska as well, where the most recent one took place in Haines in early December 2020.

In Norway, these phenomena were caused by changes in the soil structure, in which salt dissolves due to more water; in Alaska, severe rains have caused the landfalls. Flooding has increased, and its consequences have become more severe and costly over the past three decades. Costs have risen more than 2.5 billion USD over the period, according to E&E News (Frank, 2021). These, and many other adverse events, are either a direct or an indirect consequence of climate change. Some of them are an active part of the process.

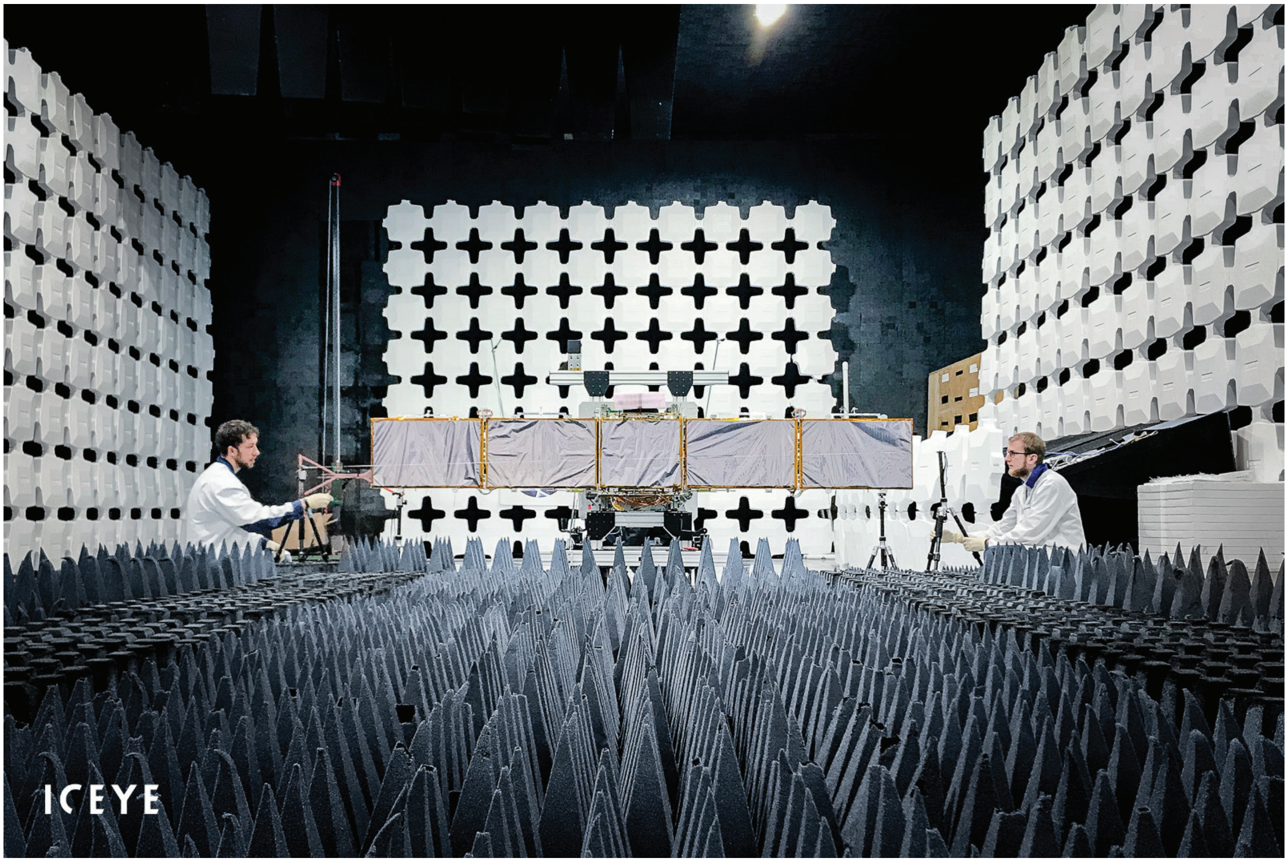
SOLUTIONS FROM SPACE?

What is happening above us? Mankind has launched approximately 10,000 satellites or other objects into space since Sputnik 1 in 1957 (Wood, 2020). Currently, around 6000 of them exist and approximately half of them are operational. Around 1000 of them are used for Earth observation and scientific purposes. Approximately one-quarter of the whole fleet, around 2500 objects, has been launched solely within the past four years. Activity has increased rapidly as more nations and private companies want to have space access.

These progressive steps in 2019 and 2020 grew even faster with the advent of new technologies and the so-called "New Space" approach. This model



ICEYE SAR satellite image of fjords near Narvik, Norway. Satellite SAR imagery enables persistent monitoring of environmental changes in the areas hardly accessible for analysis with conventional methods. Source: ICEYE.

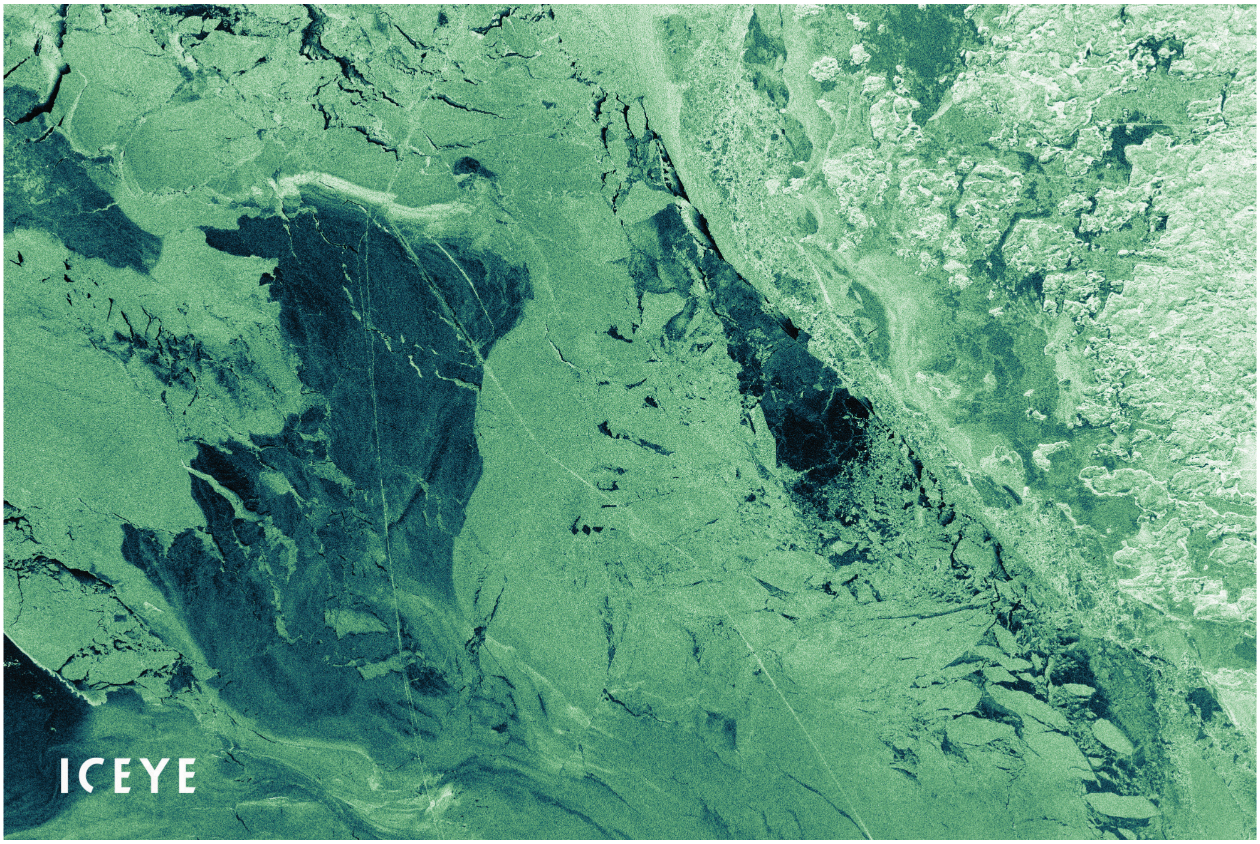


ICEYE professionals testing an ICEYE SAR satellite in an anechoic chamber. ICEYE is the first company which has successfully launched a SAR satellite of a total mass under 100 kg. Source: ICEYE.

means the commercialization of space, which has conventionally been an area for governments is now increasingly for private companies and end users as well (Russon, 2021). The biggest increase has taken place in the communication satellites sector, with SpaceX and Planet Labs as the biggest operators each with several hundred satellites. Spire Global, Iridium, and Oneweb follow with around 100 each.

On June 30, SpaceX succesfully launched yet another a rideshare mission, this time with 88 satellites (Thompson, 2021). The company is working on a plan to significantly improve connectivity even in the most distant areas of the world, including the Arctic. Improved communications will also mean better and more efficient communication in Arctic research.

Government and military satellite constellations mainly create a separate sector, and the most active ones are, by no surprise, the United States, the Russian Federation, and China. NOAA has an Arctic program dedicated to Arctic space observation. Sweden has plans to begin satellite launching services from the Arctic town of Kiruna, where Esrange Space Center is to facilitate this activity



An ICEYE SAR satellite of North Quark, Gulf of Bothnia, Finland image showing land (down-right corner) a mixture of water and sea-ice. ICEYE SAR imagery enables frequent monitoring of sea-ice during day, night and all weather conditions. Source: ICEYE.

starting in 2022 (Swedish Space Corporation, 2021). In December 2020, China announced its plans to launch a microsatellite to monitor Arctic shipping routes (Humpert, 2020).

New Space technologies have brought novel possibilities to Earth observation. Sea ice developments have been one of the most observed issues in the Arctic. After RADARSAT-1 went out of operation, RADARSAT-2 observed sea ice developments, among other subjects (ESA Earth Observation Portal, 2021). The problem was that the single satellite could only revisit a given area after twenty-four days. By contrast, a comprehensive constellation of satellites could provide images of one spot many times per day. The European Union has the Copernicus program, which is designed to serve several areas of research and other activity, including climate change. The data is publicly available and based on Sentinel satellites with more than 30 "contributing missions" from European or national organizations, including private companies (European Space Agency, 2021).

SYNTHETIC APERTURE RADAR (SAR) DATA AND IMAGES

There are various technologies used for image capturing and processing. These include optical images, SAR (Synthetic Aperture radar) data, and LIDAR (Light Detection and Ranging). Each of the technologies has its strengths and weaknesses; however, the use of SAR from microsatellites is one of the most important and recent developments.

NASA has used SAR technology since the 1970s to detect sub-meter changes to the Earth's surface. Instead of optical capture, SAR uses radio waves, and the data observed is processed to create an image. The radio waves used to gather SAR data may vary from just centimeters up to a few meters in wavelength. Importantly, these waves are much longer than the wavelength of visible light used to make optical images. Because these radio waves all fall within the microwave section of the electromagnetic spectrum, microsatellites can be used.

SAR data in microsatellites was introduced as an idea a few years ago by a new Finnish space company, ICEYE. In 2018, the company launched its first microsatellites weighing 100 kgs to a 500 km altitude. ICEYE aims to operate a constellation of more than 15 satellites by the end of 2021, and new satellites were successfully launched on January 24, 2021. Several companies are also following the forerunner, ICEYE, with planned expansions of SAR microsatellite service provisions.

As SAR technology provides data for images irrespective of weather, clouds, and darkness, it provides many advantages. With improved bypass frequency, images can be captured at various times throughout each day. New opportunities emerge: SAR technology is very important because the Arctic is mainly dark throughout the day during winter periods, and optical observation is not possible. Furthermore, many areas are often covered by clouds and optical imaging becomes impossible. But with SAR, data is fully operational.

By detecting changes in SAR data, analytics and artificial intelligence can potentially provide new solutions for risk management with Arctic Earth observation. Considering changes in the environment, soil, coastlines, water basins, rivers, and glaciers, SAR data may inform early warning methods to prevent or prepare for potentially forthcoming disasters like landslides, glacier and iceberg movements, or flooding. Every disaster has its triggering event — the point of no return. Early recognition with reliable observation data may provide an opportunity to take preventive measures to change course before the triggering event. The SAR microsatellite constellation enables this with a new level of frequency and a resolution of just around 0.25 – 0.5 meters.

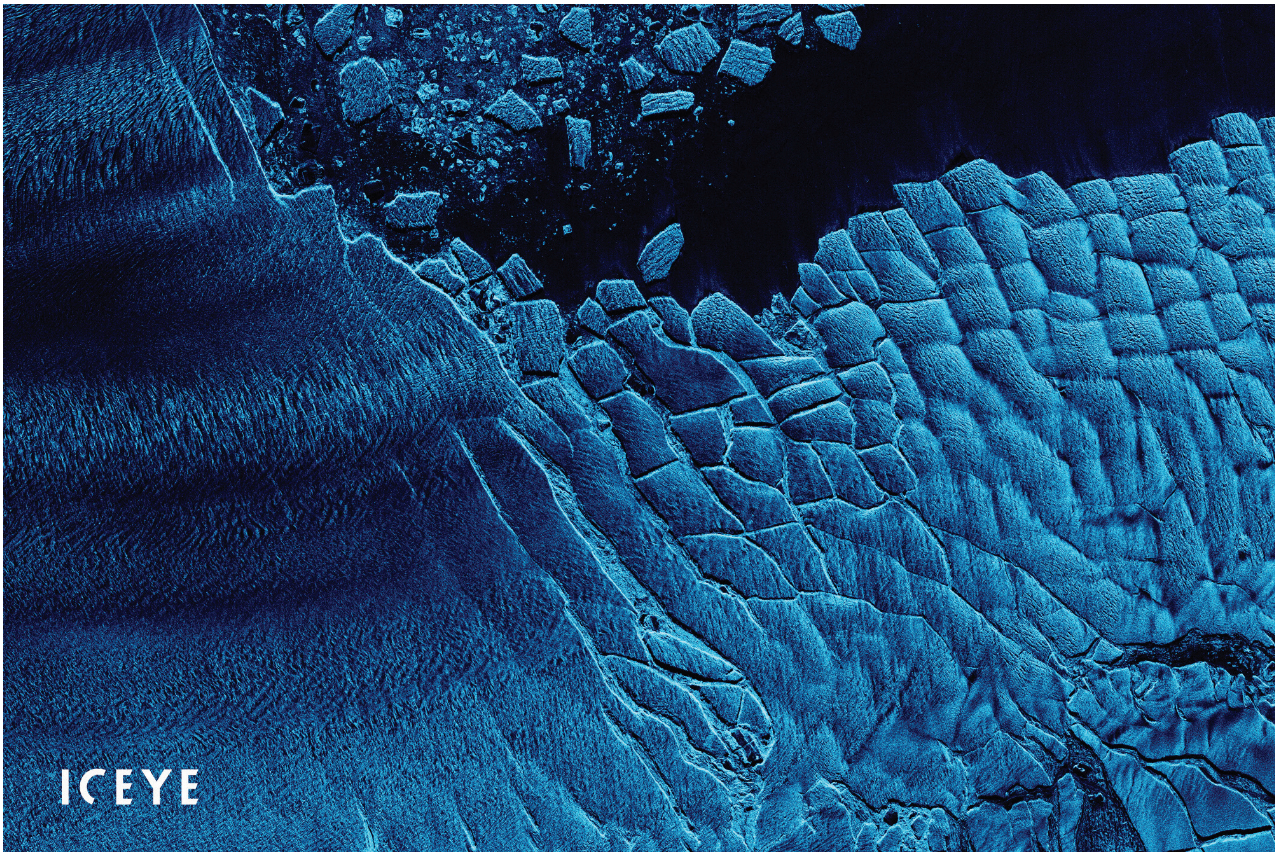
A practical Arctic solution is the use of data and images for ice monitoring. ICEYE, the Finnish Meteorological Institute (FMI), and the Finnish Transport Infrastructure Agency (Väylä) conducted a trial deployment of high-resolution ICEYE X-band SAR imagery in winter 2019. ICEYE SAR frames were used for ice charting, and they were also sent to icebreakers to test the suitability of the imagery for ice navigation. The objective was to study whether the use of SAR imagery could cost-effectively guarantee the safe and smooth operation of merchant shipping in Finnish sea areas under icy conditions.

In the introduction to the study of SAR imagery from existing SAR missions for ice navigation and ice charting, three well-defined problems were acknowledged (Eriksson et al., 2019).

First, the low resolution of SAR imagery sensors make it challenging to detect certain features in the ice. In comparison, a high-resolution X-band SAR image with 3x3m resolution makes it possible to detect small changes and finer details. The high-resolution imaging mode is especially suitable for icebreakers and the detection of certain ice features. Previous commercial SAR satellite platforms supported higher resolution imagery (3–5 m), but since the area of ice navigation is often large, there was no possibility of obtaining both a wide swath covering, for example the Gulf of Bothnia or Davis Strait, and a complementing narrow swath with high resolution over certain areas of interest.

Second, frequency and availability of SAR imagery was very limited before New Space constellations. It was challenging to get sufficient image updates over the areas that needed to be mapped and the areas where ice navigation occurred. Although data availability, reliability, and frequency of old space technology have been relatively satisfactory for routine monitoring, the acquisition plans are predefined without much flexibility. The possibility of ordering radar satellite imagery on demand has existed, but the prices have been fairly high. The ICEYE constellation of SAR satellites enables frequent delivery of high-resolution images, allowing the timely detection of changes in ice movements in specific locations.

Third, the old space technology process of planning and ordering SAR imagery do not allow for quick response to dynamic changes. Image acquisition was planned more than a month in advance before the platforms would enable it in the first place. This



ICEYE SAR Satellite image of Thwaites Glacier, Antarctica acquired in April 2019. SAR satellite data is an effective tool for monitoring of Glaciers and its changes throughout the globe. Source: ICEYE.

procedure works satisfactorily in normal day-to-day operations. However, it does not respond to situations in which rough weather causes rapid changes in the ice pack. In such cases, rapid tasking with optimized decision processes concerning the areas that must be imaged and at what times would enable proper situational awareness for tactical decision-making. Shorter cycles could fill imaging gaps in routine long-term tasking, saving resources and ensuring sufficient imagery for ice charting and ice navigation in critical locations. New Space technology ordering processes respond to this requirement.

As the New Space approach provides more opportunities for space observation, the Arctic region could use space technology to serve itself and many other parts of the world. Since many satellites travel on polar orbits, Arctic areas may also benefit from satellite communication. Examples can be found, for instance, in Svalbard and Finnish Lapland.

SAR data based images and analytical solutions open a new era to Arctic observation based solutions. No matter Arctic darkness or the presence of clouds, data is becoming available for researchers, governments, authorities, and commercial users for better and quicker decision-making and risk management.

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