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THE CIRCLE

MAGAZINE

3.2025

THE ARCTIC IN THE AGE OF TECH

COVER: Dr. Von Walden and graduate student Andrew Martin at a suite of instruments that measure subsurface temperatures and firn surface height evolution in real time.
Photo credit: Michael Gallagher, CIRES

THIS PAGE: Researchers assemble the primary instrumentation platform as part of the ICECAPS-MELT experiment, which monitors melting in Greenland's ice sheet.
Photo credit: Michael Gallagher, CIRES

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THE ARCTIC IN THE AGE OF TECH

EDITORIAL

Editorial

At the edge: Innovation in the Arctic

AT FIRST LIGHT in Churchill, Manitoba, Canada, a ranger's phone buzzes: an automated text from an artificial intelligence (AI) radar network warns that a polar bear has lumbered into town. Alerts ripple through the community, prompting children to wait for the all-clear before starting their walk to school. Human safety and wildlife protection are two sides of the same Arctic story, and digital tools are now mediating peaceful co-existence.

Faster warming, shrinking resources and vast distances make the Arctic the ultimate stress-test for conservation. Fortunately, a new generation of AI-powered forecasts, smart sensors and community dashboards is closing knowledge gaps in real time—enabling faster decision-making, safer travel and earlier interventions when wildlife or communities are at risk.

Yet at WWF, we have learned a simple truth: technological solutions only work when people remain at the centre.

The Arctic is changing too swiftly for yesterday's tools. Average air temperatures have warmed nearly four times faster than the global mean since 1979, and September sea ice extent is shrinking by about 12.5 per cent each decade—a 40 per cent loss since satellite records began. But when technology is guided by local knowledge and a clear conservation purpose, it helps communities and scientists keep pace with this shifting landscape, turning raw data into purpose-driven, rapid responses rooted in local knowledge and conservation needs.

MEET MUCHHALA is the Strategic Innovation & AI Lead with the WWF Global Innovation Team.

This photo shows the "bear-dar" being tested in the Churchill Wildlife Management Area in fall 2024.

Photo credit: Handcraft Creative / polarbearsinternational.org

We are seeing that predictions can save time and lives. IceNet, a deep-learning model developed by the British Antarctic Survey and WWF partners, forecasts sea-ice conditions up to three months ahead, twice the range of traditional models. Indigenous hunters, shipping operators and conservation planners use its maps to reroute travel, avoid walrus haul-outs and schedule fieldwork more safely.

We are also seeing the unseen. Passive acoustic recorders beneath pack ice capture whale calls and propeller noise, and machine-learning classifiers can now parse these sounds within hours, revealing how vessel traffic fragments feeding grounds. Likewise, satellite-driven tools have mapped four decades of glacier retreat in Svalbard, giving policymakers concrete evidence that melting is accelerating.

And we are seeing that technologies keep people in the loop. The SMART mobile platform, rolled out with the Nunavut Wildlife Management Board, turns patrol notes into georeferenced data that inform harvest quotas and predator management, blending ancestral knowledge with digital insight.

Our WWF Global Innovation team convenes a quarterly community of practice around the topic of emerging technologies like AI, with more than 35 offices sharing lessons and ideas and offering peer support. We aim to accelerate progress by building capacity from the bottom up through training, resources and showcases.

Our wider innovation approach begins with the following vision statement: "Innovation is always delivered with purpose, for direct or indirect conservation impact. No innovation for the sake of innovating." Technology is an expression of innovation, but it's not the only one. We see it as a tool to amplify, not replace, the wisdom, priorities and co-created solutions that emerge from frontline communities.

Across the network, we host open learning sessions, covering innovation literacy, toolkits and design tools so that as conservationists, researchers and analysts from the Arctic to Africa, we can build shared competence together rather than outsourcing it. The goal is a WWF where technologists, ecologists and local communities co-design solutions.

Technological solutions only work when people remain at the centre.

In a region racing against time, technology can amplify every conservation dollar and every hour in the field. Innovation is not the destination—it's how we'll get there. With purpose as our compass and technology in our kit, WWF is helping Arctic communities navigate a rapidly changing world. ●

More shrubs is bad news for ground-nesting birds like the common eider.

Photo credit: © WWF / Sindre Kinnerød

WINNERS AND LOSERS

Arctic plants changing with the climate

CLIMATE CHANGE IS altering Arctic plant communities—but whether plants are better or worse off depends on the species, according to a recent study in *Nature*. Researchers looked at more than 2,000 Arctic plant communities from 1981 to 2022, focusing on those in the Canadian Arctic, Alaska and Scandinavia.

More than 54 researchers from 50 institutions collaborated on the project. They found that although the total number of plant species remained the same over the four decades, some have been declining in response to warmer temperatures, while others are flourishing.

The researchers found that locations that experienced more warming gained new species—but in some cases, these newcomers contributed to the decline of existing species. For example, shrubs are now a dominant plant species at many of the sites examined, and their spread has reduced the abundance of shorter plants by limiting their access to sunlight.

Changes to plant species are also having a ripple effect on animal species. To continue with the shrubs example, more shrubs spells bad news for certain migratory birds, such as ground nesting birds, because they prefer open landscapes and shorter vegetation.

CROSS-BORDER POLLUTION

Volcanic emissions travel 2,000 km to the Arctic

IN 2023, a volcanic eruption in Iceland sent sulphur dioxide pollution more than 2,000 km across the North Atlantic, triggering severe smog in the Svalbard Islands. This is according to a study by a Chinese-led research team from the Hefei Institutes of Physical Science, published recently in *The Innovation Geoscience*.

Using a powerful combination of satellite data and ground-based monitoring, researchers traced 80 per cent of the sulphur dioxide in Ny-Ålesund in Svalbard to the 2023 eruption of Iceland's Sundhnúkagigar volcano. The team relied on two Chinese satellites equipped with an environmental trace gas monitoring instrument along with real-time data from the Yellow River Station in Svalbard—the Arctic's only continuous atmospheric monitoring post.

Volcanic eruptions spew millions of tons of gases like sulphur dioxide into the atmosphere. These can transform into sulphate particles that reflect sunlight, potentially causing global cooling. However, they also contribute to acid rain, and fine volcanic ash particles can trigger respiratory problems in humans.

The research highlights how technology is revolutionizing environmental science, offering precise tools to track pollution on a global scale and protect human health and fragile ecosystems from far-reaching effects.

GLACIER RETREAT

Greenland's coastline expands by more than 1,600 km

GREENLAND HAS GAINED more than 1,600 kilometres of new coastline over the past two decades due to accelerating glacial retreat, according to a study published in *Nature Climate Change*.

The research, conducted by an international team of scientists, used satellite imagery from 2000 to 2020 to track the recession of marine-terminating glaciers (those that flow into the ocean) across the northern hemisphere. The team found that about 2,466 kilometres of new coastline have emerged, with Greenland accounting for some two-thirds of the total.

The retreat of the glaciers has also exposed 35 new islands larger than 0.5 square kilometres in size, 29 of which are in Greenland. Some of these islands had never been recorded on maps before, indicating they were concealed by ice for centuries.

While the newly exposed land may present opportunities for resource exploration and shipping routes, scientists caution that these changes also bring significant risks. The freshly uncovered coastlines are often unstable and prone to erosion, landslides or tsunamis, posing threats to local communities and ecosystems.

PREVENTING SHIP STRIKES

Harnessing the power of AI to protect whales

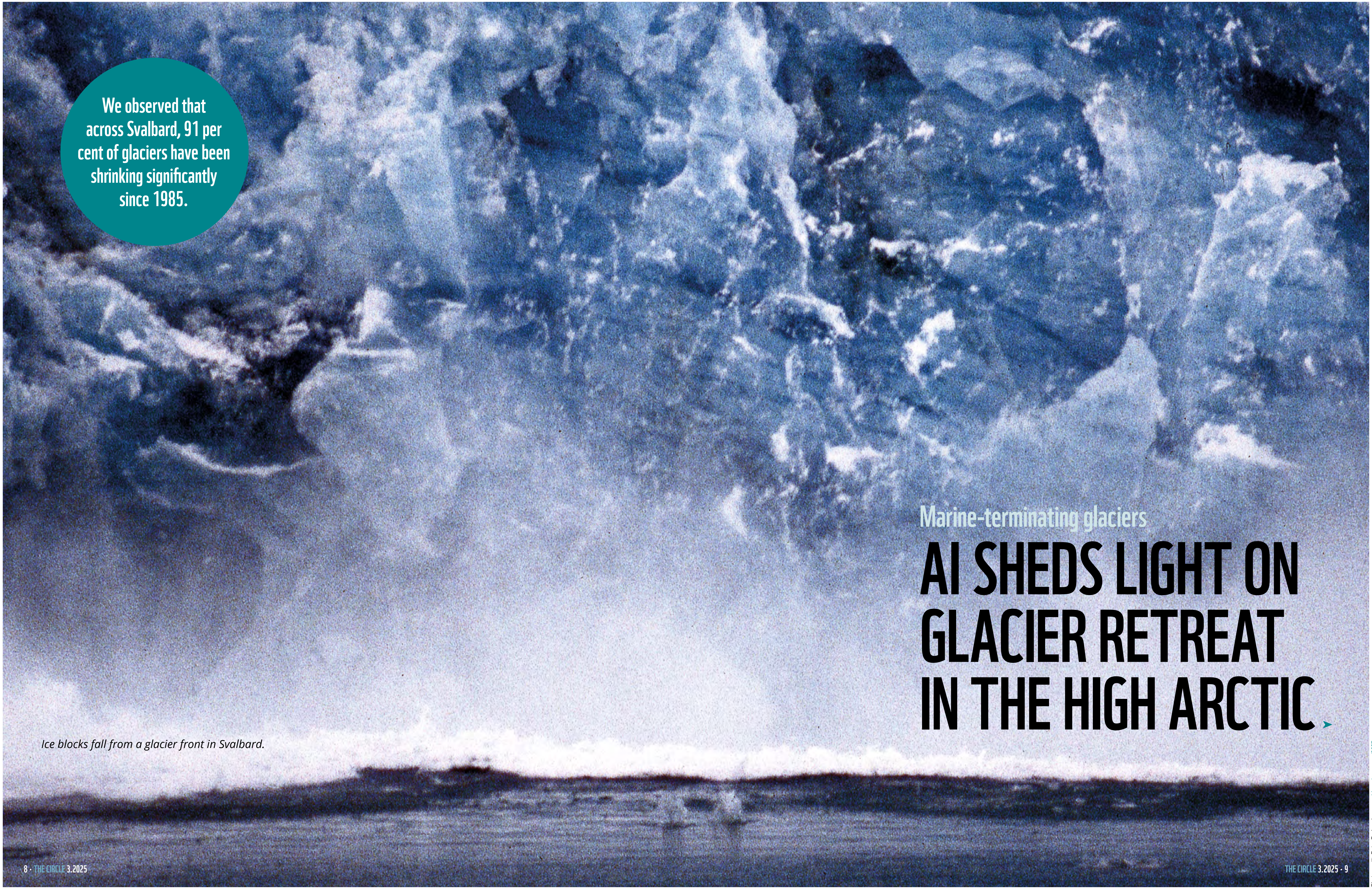
RESEARCHERS from Rutgers University–New Brunswick in the US have developed an artificial intelligence (AI) tool that will help prevent ship strikes on whales. The tool is designed to predict endangered whale habitats and help ships along the Atlantic coast steer clear of them.

The researchers describe the new tool in a report published in *Nature*'s journal, *Scientific Reports*. By analyzing vast datasets using AI-powered software, their method improved upon existing monitoring techniques, offering a more precise way to track the movements of important marine species, such as the critically endangered North Atlantic right whale. These whales have been listed as endangered since 1970, and only approximately 370 individuals are left today.

Along with reducing deadly ship strikes, the AI tool is meant to inform conservation strategies and promote responsible ocean development in general. Although the researchers initially created it to protect the North Atlantic right whale, they say it could be valuable for anyone engaged in the blue economy, including those who work in fisheries, shipping or sustainable energy.

A juvenile right whale breaching.

Photo credit: Georgia DNR, NOAA Permit #15488, CC BY-NC-SA 2.0 via Flickr.com



> We observed that across Svalbard, 91 per cent of glaciers have been shrinking significantly since 1985.

Marine-terminating glaciers

AI SHEDS LIGHT ON GLACIER RETREAT IN THE HIGH ARCTIC

Ice blocks fall from a glacier front in Svalbard.

Photo credit: Peter Prokosch, www.grida.no/resources/3627

It's no surprise that glaciers are shrinking as the climate warms—especially in Svalbard, Norway, which is experiencing some of the fastest warming on the planet. Glaciers that flow into the ocean, known as marine-terminating glaciers, have long been difficult to study because of their remote location and complicated behaviours. But as **TIAN LI** writes, artificial intelligence (AI) is helping scientists better understand how and why these glaciers are changing.

> **We applied this model to analyze more than a million satellite images of 149 marine-terminating glaciers in Svalbard using open-access data from Google Earth Engine.**

GLACIERS ARE SLOW-MOVING rivers of ice formed from years of accumulated snowfall. They store large amounts of freshwater and serve as sensitive indicators of climate change. When temperatures rise, glaciers lose mass by melting and calving (the term for when large chunks of ice break off into the ocean).

These changes can have significant and far-reaching consequences for marine ecosystems and coastal communities. For example, glaciers help supply freshwater to people and wildlife, and the meltwater they produce can deliver important nutrients to downstream environments. But glacier meltwater also contributes to sea level rise, increasing the risk of coastal erosion and flooding and endangering low-lying communities.

The Arctic is especially vulnerable to these effects. Its glaciers, particularly those that are marine-terminating, are experiencing some of the most dramatic and rapid changes anywhere on the planet.

WHY MARINE-TERMINATING GLACIERS MATTER

Glacier calving where a glacier meets the ocean is a key process driving ice loss. It can speed up glacier ice flow—the slow, steady movement of solid ice toward the ocean—causing even more ice to be discharged. This creates a self-reinforcing cycle, known as a positive feedback loop, whereby faster ice flow causes more calving and further retreat of the glacier front.

Understanding this process is essential for making accurate predictions about sea level rise by the end of this century, especially under different climate change scenarios. Yet calving remains one of the least understood glaciological processes. It is highly dynamic and influenced by a complex mix of environmental and geophysical factors.

I've studied how much ice marine-terminating glaciers have lost over the past four decades and how quickly they have been retreating at different time scales across Svalbard.

WATCHING GLACIERS FROM SPACE USING AI

Studying glacier calving fronts in the high Arctic is no easy task. Fieldwork is challenging, expensive and often limited by the harsh and remote environmental conditions. Fortunately, satellite remote sensing is revolutionizing this work. Earth observation satellites can capture high-resolution images of the Earth's surface, providing both optical and radar images that reveal detailed information at glacier fronts.

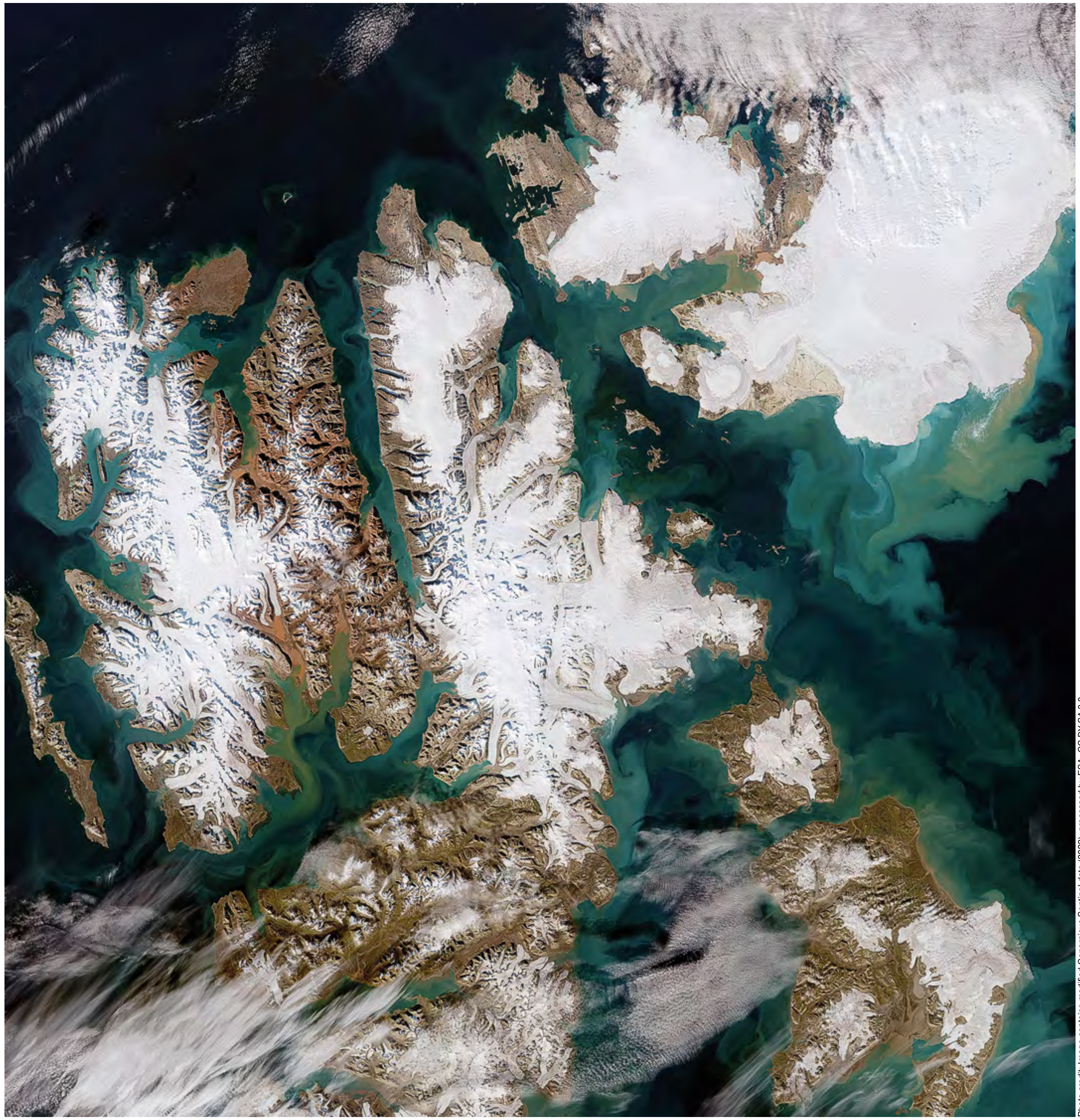
However, the sheer volume of satellite imagery now available presents a new challenge: How do we efficiently extract meaningful information from millions of images?

To tackle this, we trained a deep learning model to detect calving fronts automatically under a wide range of environmental conditions and for a variety of glacier types. By teaching the model to interpret both optical and radar images, we enabled it to identify calving fronts across diverse settings with high accuracy. We then applied this model to analyze more than a million satellite images of 149 marine-terminating glaciers in Svalbard using open-access data from Google Earth Engine. This allowed us to track changes in glacier fronts from 1985 to today, offering unprecedented detail about how glaciers in the high Arctic have evolved.

WHAT THE MODEL IS TELLING US

We found that 62 per cent of marine-terminating glaciers in Svalbard experience seasonal cycles—that is, the calving fronts retreat in summer and advance in winter. Ocean temperatures have a large impact on peak seasonal retreat rates, with glacier retreats on the west coast occurring before those on the east coast, likely because warm ocean waters carried by the West Spitsbergen current arrive at different times in different areas.

These seasonal changes show us just how sensitive and important interactions between the ocean and ice are. Over longer time periods, we observed that across Svalbard, 91 per cent of glaciers have been shrinking significantly since 1985. The peak retreat rate occurred in 2016, when the weather was unusually warm, possibly because of an extreme weather pattern called atmospheric blocking, which traps warm air. Over the past 40 years, atmospheric blocking events have been occurring more frequently and with greater intensity. This is mainly in response to amplified Arctic warming. We expect that glacier retreat rates will accelerate in the future, causing even more ice loss.



This rare cloud-free image of the Norwegian archipelago was captured by the Copernicus Sentinel-2 mission in August 2022.

The behaviours of marine-terminating glaciers in Svalbard offer valuable insights into what may lie ahead for glaciers across the Arctic. What we are seeing now is just the start—and our AI model can be applied to glacier systems in other locations. Thanks to tools like this, we are gaining insights into glacier dynamics in unprecedented detail. What we discover could ultimately inform efforts to reduce the risks that glacier retreat poses to vulnerable coastal communities. ●

TIAN LI is a glaciologist and Leverhulme Early Career Research Fellow at the University of Bristol in the UK who uses artificial intelligence and satellite remote sensing to study changes in polar glaciers.

A bird's eye view

MONITORING WHALE MIGRATION FROM SPACE

Whales often swim deep below the water's surface, but a lot can be learned about their migration routes and behaviours by watching them from hundreds—or even thousands—of kilometres above the Earth's surface. Making use of high-resolution satellite technology, Whale Seeker is working with WWF and other collaborators to pilot the use of high-resolution satellite imagery for monitoring Arctic whale migrations. As **EMILY CHARRY TISSIER** explains, collaborations like these are essential for enhancing marine conservation efforts in the face of growing threats from climate change and ship traffic.

FOR MILLIONS OF years, whales have embarked on epic seasonal migrations to and from the Arctic in search of areas that are rich in food and that offer ideal temperatures and conditions for mating and calving. The backdrop to these voyages was once pristine, icy water and a cacophony of natural sounds—from the eerie creaking of ice to the clicks, whistles and songs that marine mammals use to communicate.

But as the climate crisis has heated up, the backdrop has shifted, and is now also characterized by melting ice and rising industrial activity. The accompanying hazards—from ship strikes to underwater noise pollution—are making whales' migrations more difficult.

Yet their migrations are critical, not just for the whales' own survival, but for the marine ecosystem and the cultural heritage of Indigenous Peoples, who face threats to their cultures, livelihoods and food security as the environment transforms.

EMILY CHARRY TISSIER is the CEO of Whale Seeker, an organization committed to finding innovative marine conservation solutions.

STUDYING WHALES FROM SPACE

Whale Seeker is using advanced satellite imagery and machine learning to test the utility of high-resolution satellite imagery for monitoring whales and safeguarding their future.

To detect the whales, Whale Seeker uses a combination of high-resolution satellite images and a proprietary artificial intelligence (AI) platform trained to recognize the unique shapes and shadows of whales near the surface of the water. These images, captured from hundreds of kilometres above Earth, are filtered to identify areas where whales are likely to be found. Then, machine learning algorithms scan the imagery for visual patterns that match known whale characteristics, such as body length and fin shape.

This process dramatically reduces the time and effort required to detect whales in expanses of ocean that are too large to survey from a plane, drone or boat. These tasks once took days or months of manual work to complete, but can now be done in a matter of hours. The result is a rapid stream of data that we can share with marine biologists, environmental regulators and shipping companies.

In Arctic regions where remoteness or ice cover limits access for human observers monitoring from boats or small aircraft, this satellite-based approach opens new possibilities for understanding and protecting marine mammal populations with minimal intrusion. ●

This aerial image shows a lone narwhal among ice floes (outlined in green). The whale was detected by Möbius, Whale Seeker's AI-powered image annotation system.

Whale Seeker is using advanced satellite imagery and machine learning to test the utility of high-resolution satellite imagery for monitoring whales and safeguarding their future.

This aerial image features a close crop of a beluga pod. Each beluga was detected by Möbius, Whale Seeker's AI-powered image detection system. Labels show how confident Möbius was for each detection: 0.98 indicates that the model was 98% confident that it found a whale.

Photo credit arial photos: Fisheries and Oceans Canada.

A high-tech crystal ball

MODELLING SEA ICE AND MAKING CLIMATE PROJECTIONS

Imagine the Arctic in the years and decades to come. What environmental changes will occur? What new climate extremes will the area face? How will these developments affect people within and beyond the Arctic? Comprehensive earth system models are critical tools for addressing questions like these. As **MARIKA M. HOLLAND** explains, they can inform thoughtful approaches for mitigating Arctic environmental degradation.

SEA ICE CREATES a bright, floating ocean seascape that waxes and wanes with the seasons. It is a defining part of the visually stunning Arctic landscape—so much so that it's easy to forget the Arctic is also alive. Many iconic species that are uniquely adapted to this frozen environment make the Arctic their home. People and communities have thrived on these lands for thousands of years.

But the nature of the Arctic is under extreme threat, and the icy land and seascape we know is disappearing. Over the past several decades, in response to greenhouse gas emissions generated by human activity, the Arctic environment has undergone dramatic changes, including rapid warming, declining sea ice, thawing permafrost, and extensive coastal erosion. We are in unprecedented territory. The consequences of these ongoing changes—for ecosystems, for people living in the region, and for socio-economic and geopolitical concerns—are immense.

What if we could peer into the future? What if we had a "crystal ball" that would allow us to understand what changes are still to come—including how much and what aspects of the Arctic might be lost, and how rapidly these losses will occur? What if we could find out what impacts these changes will have for the species (including humans) that rely on the Arctic environment? And, perhaps most critically, how will the choices we make today determine the Arctic's future? ➤

These Svalbard walruses live and thrive on sea ice.

Photo credit: Christopher Michel, CC BY 2.0, via Flickr.com

MARIKA M. HOLLAND is a scientist with the NSF National Center for Atmospheric Research in the US.

HARNESSING SUPERCOMPUTERS

The good news is that we do have such tools: they are known as comprehensive earth system models. Unlike crystal balls, these models are based on fundamental physics—which defines how the Earth system functions—and they can be described in mathematical equations solved on supercomputers.

These models have been improved and refined over decades as researchers have gained knowledge through theory, observations and experimentation. Recent innovations in observing technologies—for example, from ICESat-2, a satellite-based, photon-counting laser that provides information about the surface height of ice—have enabled a more comprehensive and detailed look at our polar regions. This, in turn, has led to new insights into how the system works—insights we can incorporate into improved models.

These earth system models have proven themselves skilful. They can make accurate predictions and reliably simulate how the Earth responds to influences like volcanic eruptions and greenhouse gas emissions. They also reflect the complexity of the Earth system, where understanding one part requires considering the whole. To capture this intricacy, the models include multiple interacting components and teleconnections between distant, remote regions. They simulate an Arctic—its atmosphere, ocean, sea ice and land—that both responds to and influences the global system.

By providing information about how disruptions in one aspect, such as sea ice cover, can have cascading effects throughout the environment, the models allow us to predict the system's response to future climate drivers. When paired with ecological conservation, infrastructure or economic information, the systems are powerful tools for decision-making and can help us to mitigate the effects of environmental degradation in the Arctic.

PREDICTING THE ARCTIC'S RESPONSE

In addition, these modelling systems are allowing us insights into a host of implications for the changing Arctic. For example, they can simulate projected ocean temperatures, ocean acidity and marine ecosystems, providing information about the shifting likelihood of harmful algal blooms in Arctic waters. This information has profound consequences for the safety of subsistence foods that are of great value to coastal Arctic communities.

The models can also project how sea ice conditions will change seasonally and regionally across the Arctic Ocean, affecting not only ice-dependent species, such as polar bears, seals and walrus, but also shipping accessibility and the risks of pollution and oil spills. The models simulate the location and timing of ongoing permafrost degradation, with effects on the safety and stability of infrastructure. Ongoing research on these topics is allowing us to devise more thoughtful, responsive solutions to Arctic environmental change.

> **Earth system models can simulate an Arctic—its atmosphere, ocean, sea ice and land—that both responds to and influences the global system.**

Today's modelling systems are complex, sophisticated tools that provide critically useful information. But they are not without limitations. We need continued scientific advancements to enhance their applicability to emerging threats. We also need deeper integration across fundamental and applied science to fully realize their potential to support thoughtful decision-making.

The degradation of the Arctic environment is ongoing, rapid and complex. It is stressing ecosystems and communities, with profound effects. Future changes will be more extreme and push the environment into unprecedented territory. We need to create and use the best possible tools and knowledge to address the challenges this will bring. There is no time to lose.

A WORK IN PROGRESS

Although the initial results of our collaboration have been promising, there is still much to do to perfect the detection methods. A key challenge is accurately identifying whale species and distinguishing whales from other large marine animals or objects. Enhancing the precision of our algorithms will be crucial to ensure that the data we transmit are reliable enough to inform effective conservation strategies.

As the Arctic continues to warm, the retreat of sea ice is opening new areas to shipping and industrial exploitation, making effective monitoring and mitigation strategies even more critical. Our aim is to create a comprehensive framework for the sustainable management of Arctic marine resources. We are also collaborating closely with policymakers, Indigenous communities and international stakeholders to implement measures that will protect whale populations and habitats. By combining advanced technologies with traditional ecological knowledge, we aim to adopt a holistic approach to marine conservation. ●

Fluke of a bowhead whale, Northwest Passage, Canada.

Photo credit: © Cameron Dueck / WWF

Conservation and wildlife management

THE POWER OF TRADITIONAL KNOWLEDGE AND TECHNOLOGY IN NUNAVUT

The Canadian territory of Nunavut is home to just over 36,000 Inuit. For centuries, Inuit have harvested Arctic char, caribou, beluga whales, ring seals and other species to support their economic, cultural and nutritional needs. But the numbers and behaviours of these species are changing because of climate warming and other environmental stressors.

In 2012, the Nunavut Wildlife Management Board (NWMB) started the Community-Based Monitoring Network (CBMN).The network collaborates with Inuit hunters to record their travel routes, wildlife observations and harvests in order to gather the data needed to address concerns related to wildlife management, conservation and harvesting rights.


Denis Etiendem Ndeloh

Now, the network is tapping into the power of the SMART conservation area management platform to enable participating Inuit hunters to collect data about Arctic species. Compatible with almost any mobile device, the SMART app allows the 300 Inuit hunters who participate in the network to work with conservationists to collect, visualize, store, analyze, report and act on a wide range of data. *The Circle* spoke to NWMB's director of wildlife, **DENIS ETIENDEM NDELOH**, about the benefits of the technology. ➤

> We encourage hunters to record their observations of wildlife habits. For example, if they see polar bear tracks, they can take out their phone and take a picture.


CBMN harvesters go spring fishing in the ice cracks near Arviat, Nunavut.

Photo credit: Richard Kakkianiun, CBMN participant

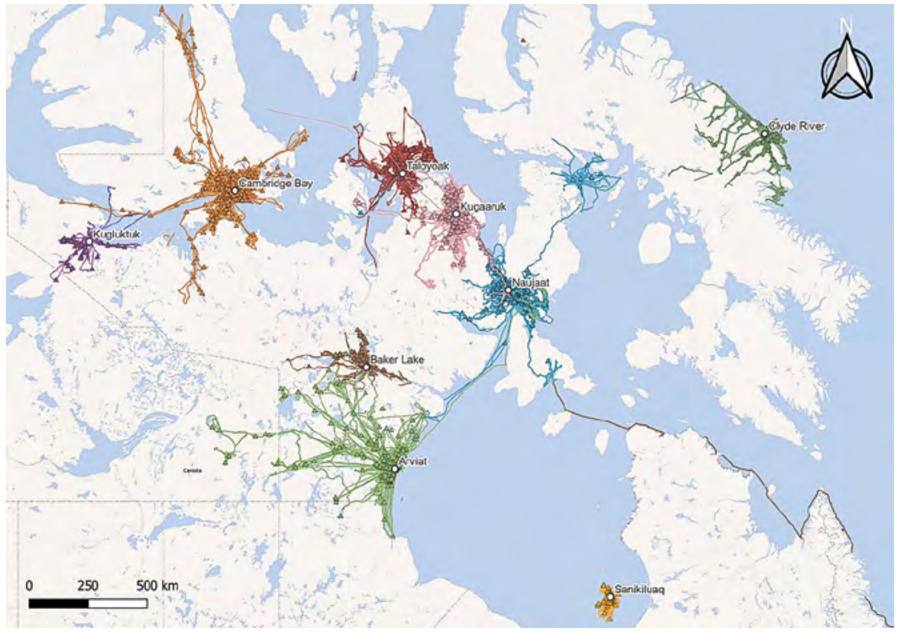


Image credit: Kyle Ritchie, NWMB

This map shows data collected from 10 CBMN communities from 2012 to 2023.

Why did you start the Community-Based Monitoring Network?
In 2012, the Nunavut Wildlife Management Board decided that in order to be comprehensive in its knowledge-gathering and support decision-making, it needed to capture not only information coming from Indigenous Knowledge and scientific research, but from contemporary Inuit harvesting practices. What are Inuit seeing on the land? What are they taking from the land? And how does that change across the territory? In addition, the board wanted to be able to see the changes that are happening over time through the lens of those who spend the whole year harvesting or living on the land.

How did you plan to use this knowledge?
The number one priority was to support more effective wildlife management decisions. The board is the main instrument of wildlife management and is responsible for making decisions related to wildlife harvesting by Inuit and others in Nunavut. The board needed this information to make its decisions, but also to support Inuit knowledge transfer and the continuation of Inuit harvesting practices. If you build a comprehensive database in a community where harvesters have been documenting their harvest—what they're taking from the land, where they're taking it, how far they travel, what equipment they used—then the next generation will have access to this information.

How do Inuit hunters use the SMART app?
They download the SMART app on their phones. If they don't have a phone, we give them a rugged handheld device with the app preloaded. Then when they wake up in the morning and want to go harvest a caribou or check their nets, they turn on the app and answer a one-minute harvesting questionnaire. Then they just put their phone or device in their pocket, and it tracks them.

That's where we're getting really important information about travel . As the climate is changing, it's becoming very important to track travel routes—and it will be even more important in the future. Because the conditions are changing rapidly, making certain areas less safe to hunt in. These data will also tell us how far people travel in order to access wildlife. That will help us track the cost of harvesting and whether it's increasing or decreasing over time.

A caribou herd near Arviat, Nunavut.

Photo credit: Okatsiak Romeo, CBMN participant

As the climate is changing, it's becoming very important to track travel routes—and it will be even more important in the future.

We also encourage hunters to record their observations of wildlife habits. For example, if they see polar bear tracks, they can take out their phone and take a picture. Then they add what information they can, like how fresh the tracks are. At the end of the trip, they can click on a button to upload the information to the database. That creates a record of a polar bear on the land.

How has the SMART program helped you collect the data you're looking for?
It has improved our monitoring efforts because we've been able to streamline the process for harvesters. The interface is more user-friendly. For example, the icons for all the species were inspired by Inuit artists, and the communities themselves chose them. We also have an open communication line right up to the developers so we can fix issues that come up or make additions to the software. Those behind SMART really adapted their data model to accommodate us, and we continue to work together to fine-tune maps and create new reports. Our liaison officers in the community can generate a report just by clicking a few buttons, then share it with the harvesters to verify the data (or with the community), as needed.

How does this technology complement what traditional knowledge can tell us?
This technology serves a very important purpose, but it doesn't replace traditional ways of knowing. It can also be used to support oral arguments that are based on Inuit knowledge. Community-based monitoring data are not more important than Indigenous Knowledge, but supplement it. The survival of the Inuit depends on their ability to continue practicing their culture—which is linked to harvesting. So, any program that supports harvesting supports the Inuit.

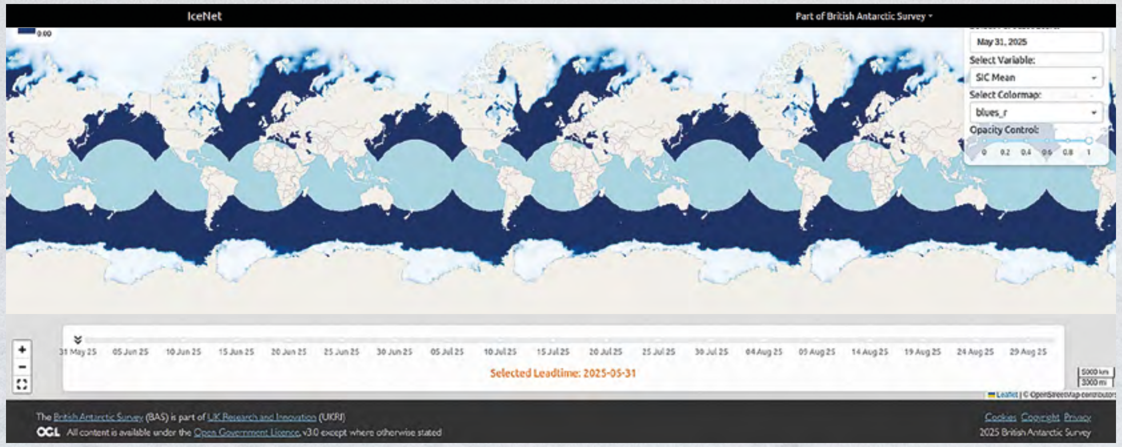
The data also support conservation efforts and environmental impact assessments. The information helps researchers identify critical habitats and migration corridors that need protection and can be used to develop guidelines and regulations to minimize the impact of human activities on whale populations. ●

Polar bears on sea ice in Churchill, Manitoba, Canada.

As climate change thins sea ice, fuelling a step-change in historical patterns, the frozen ocean is becoming harder than ever to read.

Forecasting sea ice

NAVIGATING A CHANGING ICE WORLD



A iceNet dashboard showing the ice forecasts for the period May 31 to August 29, 2025.

Navigating Arctic sea ice is a critical challenge for wildlife, researchers and maritime operators alike. But IceNet, a cutting-edge forecasting system, predicts sea ice changes with remarkable accuracy. As **BRYN NOEL UBALD** and **JONATHAN SMITH** write, from ship routing to wildlife monitoring, IceNet supports safer, more sustainable polar operations and offers a powerful tool in the face of a changing climate.

EVERY DAY, BILLIONS of people check the weather to plan everything from what to wear to how they would escape a potential climate emergency, such as a hurricane or wildfire. But in the Arctic, it's not just the weather that dictates the routines of daily life—it's the sea ice.

Shifting ice conditions can have a profound impact on the day-to-day lives of Arctic wildlife, maritime crews and Indigenous communities. As climate change thins sea ice, fuelling a step-change in historical patterns, the frozen ocean is becoming harder than ever to read. Traditional physics-based models are falling short when it comes to capturing the complex interactions between ice, ocean and atmosphere, leaving a critical shortfall in forecasting ability.

TRAINING ON DECADES OF DATA

Fortunately, the IceNet project may help close the gap. IceNet is a cutting-edge initiative led by the British Antarctic Survey (BAS) in collaboration with the Alan Turing Institute. It uses an artificial intelligence (AI)-based system to predict future sea ice by learning from past observations to interpret the impact of climate change on the Arctic. IceNet combines satellite data and weather observations to forecast both ➤

BRYN NOEL UBALD is a research software engineer with the British Antarctic Survey (BAS) who works on the use of artificial intelligence (AI) and machine learning to forecast how sea ice and weather evolve over time.

JONATHAN SMITH IS a principal research scientist in AI and machine learning and the Deputy Science Leader of the BAS AI Lab.

pan-Arctic and pan-Antarctic sea ice concentrations on a daily timescale up to several months ahead. These forecasts can help Arctic communities, researchers, conservationists and shipping operators prepare for increasingly unpredictable conditions.

> **An earlier version of IceNet outperformed the leading physics-based models in forecasting summer sea ice, which is particularly difficult due to rapid melting and variability.**

To train the system, IceNet combined decades of satellite observations with detailed historical weather data, such as wind speeds, temperatures and other atmospheric variables. Over time, the system has evolved from producing monthly forecasts to generating daily sea ice concentration maps at 25 km resolution, with experimental work underway to train it on 6 km resolution data (which would offer greater detail and precision). The model learns how sea ice responds to different weather and sea ice patterns over time—information that enables it to forecast sea ice concentrations up to three months ahead of time.

This approach has proven to be remarkably effective: an earlier version of IceNet outperformed the leading physics-based models in forecasting summer sea ice, which is particularly difficult due to rapid melting and variability.

DIVERSE USE CASES

To bring these forecasts into operation, research software engineers developed a fast, flexible digital ecosystem that enables the generation of real-time predictions and integrates with other tools, leading to a wide range of downstream applications. Workflows have been created to process the large amounts of data needed to train the model and generate daily sea ice forecasts. Researchers are using this digital ecosystem to develop more advanced models.

In addition, a digital ecosystem has been created that enables users to visualize the sea ice forecasts. For example, researchers with the Government of Nunavut (Canada) trialled use of the ecosystem during their survey of the Foxe Basin polar bear population last year. The IceNet forecasts highlighted areas where sea ice was likely to linger—meaning polar bears might gather. These places might have been missed by a survey that focused solely on coastal regions. Because the team was often based at remote Arctic field camps, low-bandwidth delivery systems were developed to ensure they could access the forecasts during the survey.

Sea ice also has direct impacts on the movement of ships in the Arctic. In addition to IceNet, the BAS AI Lab is developing a suite of state-of-the-art AI systems to support ship navigation and operations in changing sea ice conditions. As you might imagine, navigating around or through sea ice can be tricky. It can burn more significant amounts of fuel, or you might be unable to traverse certain ice-packed areas at all. The AI systems will use IceNet forecasts as inputs to map out ideal ship routes to enable sustainable navigation. The systems will include ecological information—such as areas where animals are likely to be present—to help ships steer away from fragile ecosystems.

In our work to close a critical gap in sea ice forecasts for a region on the frontline of global warming, we hope to make IceNet as powerful and everyday as the weather forecasts available in our pockets—and in an openly accessible manner, both in terms of the code it is built on and the forecasts it generates. ●

"Bear-dar" is a medium-range radar system that can survey a wide area. Polar Bears International is training it to detect and identify polar bears so it can alert communities or remote camps when one approaches.

Photo credit: Kieran McIver / polarbearsinternational.org

"Bear-dar"

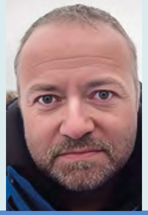
TEACHING RADAR HOW TO SEE POLAR BEARS

> **Using radar to detect a moving object is one thing, but determining which of many objects might be a polar bear is something else entirely.**

As climate change causes sea ice to retreat, polar bears may venture inland more frequently in search of food—and these outings can bring them into conflict with humans. As **KIERAN MULVANEY** writes, Polar Bears International (PBI) is collaborating with Spotter Global to create an early alert radar system—dubbed "Bear-dar"—to alert communities and remote camps when a bear is approaching.

THE IDEA BEHIND the initiative is to create a system that comprises two parts: a radar to detect approaching objects, and artificial intelligence (AI) software to determine whether any of those objects is a polar bear. Somewhat surprisingly, the first step—sourcing a radar and related hardware—was relatively straightforward. After trialling a few systems, PBI settled on the Spotter Global version that it uses now.

Polar Bears International (PBI) is the only nonprofit organization dedicated solely to the conservation of polar bears and the sea ice habitat they depend upon.



KIERAN MULVANEY has written extensively about polar bears and the Arctic for PBI and publications including *National Geographic*, *The Guardian*, and *The Washington Post*.

TEACHING AI TO RECOGNIZE POLAR BEARS

Most radar excels at detection, especially when it comes to moving objects. But the identification piece—where the AI software comes in—is more challenging, especially when the target is a furry animal. Using radar to detect a moving object is one thing, but determining which of many objects might be a polar bear is another thing entirely. The AI requires human intervention to teach it to recognize potential polar bears and ignore everything else.

That is why PBI tested the radar near Churchill, Manitoba, Canada. Every fall, polar bears in the region wander past—and sometimes through—the town on their way to the shores of Hudson Bay, where they wait for ice to form on the water's surface. Unfortunately, those polar bears have proven a tricky subject to track because while they are waiting to head out onto the ice, they tend not to be particularly active.

"They might flop down for 10 minutes, or they might flop down for several days," explains Geoff York, PBI's senior director of research and policy. "And when they go still, the radar drops their signal."

That's why the system also spent a summer pointed at the polar bear enclosure at Assiniboine Park Zoo in Winnipeg under the direction of PBI's Kieran McIver.

"The software requires quite a number of data points, and it's really difficult to get the number required with wild polar bears here in Churchill," says McIver. "So we determined that if we could get the system to Winnipeg, we'd have these bears at the zoo, and we would know where they were—and we knew there were quite a few of them. We reasoned that we could easily acquire the data points. Now that we've done that, we've put the system back in front of wild bears."

FOCUSING ON COEXISTENCE

The added advantage of the zoo is that it is full of people, vehicles and other animals, so in addition to teaching the AI which signals are polar bears, McIver and his team could help it learn which ones weren't.

Equipped with those extra data points, the "bear-dar" is once again being tested in the wild. Ultimately, PBI hopes to deploy the devices in interested Arctic communities.

"I think we as conservation organizations have a responsibility—especially when we're talking about conserving a large mammal that's a predator—to the people who live among them," says York. "That's one of the reasons we are focusing more and more on coexistence and trying to make sure communities have resources that enable them to feel safer." ●

The Polar Bear Holding Facility, colloquially known as the Polar Bear Jail, is a special building in Churchill, Manitoba, Canada where polar bears that are considered troublesome or dangerous are isolated until they can be relocated.

Photo credit: Theraven.au, CC BY-SA 4.0 via Wikimedia Commons

Two members of the Oshen team launch a C-Star wind-propelled sailing robot from a boat.

Photo credit: Ciaran Dowds

Recognizing tipping points

CREATING AN ARCTIC ALARM

Climate extremes are causing disruptions for millions of people around the world, inflicting massive economic damage, and causing strain for fragile ecosystems. But as **GEMMA BALE** and **SARAH BOHNDIEK** write, these impacts pale in comparison to what will happen if we cross an ominous "tipping point." For example, what is the critical threshold beyond which the Greenland Ice Sheet could begin an irreversible melt (or crucial ocean circulations could fundamentally alter), with devastating consequences? And how will we know when we're approaching that point?

GEMMA BALE and **SARAH BOHNDIEK** lead an initiative called Scoping our Planet with the Advanced Research and Invention Agency (ARIA).

WHEN WE'RE REGULARLY faced with stark warnings of extreme climate shifts reminiscent of dystopian disaster movies, it's natural to worry about what the future holds. We know we're in an urgent race to cut global emissions and prevent the worst impacts—and the Arctic is on the frontline. Scientists have warned that a global temperature rise of just 2° Celsius could set off the irreversible collapse of the Greenland Ice Sheet.

But just how much time we have left is unclear: right now, we have very little data on when, how or even whether these events might happen. So the question arises: could we build an early warning system to notify us about looming tipping points and equip us with the data we need to confront the threat of abrupt climate change head on?

We already know it is possible to create an early warning system for certain hazardous weather events. For example, we can monitor for and warn people about potential tsunamis. But achieving an early warning system for climate tipping points is a much more complex task, and may not even be possible. Our best observational datasets are still in the early stages, while our best climate models are computationally expensive and still provide forecasts with poorly characterized uncertainties.

BRIDGING RESEARCH GAPS

At the UK's Advanced Research + Invention Agency, we're harnessing the power of technology to tackle these limitations, with a focus on the tipping points of the Greenland Ice Sheet and the adjacent subpolar gyre ocean circulation. Backed by £81 million (or about USD$109 million), the Forecasting Tipping Points programme aims to capitalize on innovation in low-cost distributed measurements to tackle measurement gaps in harsh environments, then unite these new sensing systems with artificial intelligence (AI)-accelerated modelling to create an early warning system that is affordable, sustainable and justified.

Why is it important to develop and deploy new sensing systems right now? Billions of Earth observations are made daily by satellites, weather stations and other sources, but there are major gaps in sensitivity, resolution and coverage. Arctic regions are chronically under-observed because of the region's harsh conditions—the instruments must survive freezing temperatures or extreme deep-sea pressures. But we urgently need to better understand the potential melting of the ice sheet and its likely impact on the surrounding ocean circulations.

A "TEAMS" APPROACH

We are funding 26 teams to do just that.

For example, our GAMB2LE team is creating a modular and scalable polar observatory, putting Arctic-hardened drones to use in a unique approach to collecting aerial data. Meanwhile, our ICEBERG team is pioneering self-installing base stations to make never-before-seen measurements beneath the ice.

At the coast, the GRAIL team will examine melting and calving at marine glaciers—the key link between the Greenland Ice Sheet and the North Atlantic. While out at sea, another team is creating wind-propelled sailing robots to transform our understanding of ocean circulation.

Delivering these new sensing systems to the field to make better measurements can underpin more accurate climate predictions, but only if we invest in quality assurance standards to ensure rigorous calibration and validation. The Advanced Research and Invention Agency (ARIA) teams are fortunate to be partnering with the National Physical Laboratory to deliver on this goal.

> **If the ARIA programme succeeds, the next question will be: when do we sound an alarm?**

In tandem, we are investing in state-of-the-art mathematical, physical and computational methods to characterize tipping point dynamics. The key to success is bringing together measurement and modelling teams to develop new data-driven techniques that can detect early warning signals of tipping points and help target when, where and what to observe.

BUILDING TRUST—AND HOPE

If the ARIA programme succeeds in implementing a prototype early warning system, the next question will be: when do we sound an alarm? And how do we build confidence that the early warning signals being detected are trustworthy and actionable?

The VERIFY team is tackling that question. They are building digital twins of past tipping events to allow the wider programme to evaluate the performance of new technologies in detecting tipping, honing observational systems and new models.

Instead of simply facing a future of unknown risks, ARIA's programme aims to develop an early warning system that can provide critical information for proactive adaptation and mitigation. Our programme is about harnessing cutting-edge research and innovation to offer not just data, but a greater capacity for resilience and informed hope—in the Arctic and beyond—in the face of profound environmental change. ●

Dr. Von Walden digs to prepare anchors for the raised solar panels that will power the science instrumentation used in the ICECAP-MELTS project.

Photo credit: Michael Gallagher, CIRES

> Passive acoustic monitoring (PAM) has emerged as a crucial tool for studying and understanding marine environments, particularly in challenging regions like the Arctic Ocean.

Cold sounds

EAVESDROPPING ON THE ARCTIC OCEAN

In the Arctic Ocean, underwater sounds contain important clues for scientists who study marine mammals and the acoustic environment (soundscape) they live in. As **KAROLIN THOMISCH** and **RAMONA MATTMÜLLER** write, passive acoustic monitoring (PAM) is a non-invasive, cost-effective technique that provides critical data to support ecological research, conservation and informed policymaking.

Humpback whales (mother and calf).

AT A GLANCE, the Arctic Ocean might seem like a quiet place. Vast, slow-moving sheets of ice stretch out to the horizon. Through a narrow opening in the ice, the occasional rise of a whale's blow is followed by a grey back. The sun disappears for months, blanketing the area in darkness. But beneath this scenery, the Arctic Ocean is alive with sound. The deep rumbles of shifting ice, high-pitched clicks of narwhals, and mournful songs of bowhead whales produce an invisible symphony. Other sources of sound—such as from human activity or wind-created waves—also contribute to an area's soundscape.

Studying marine life—and marine mammals in particular—in remote areas like the Arctic Ocean can be challenging. Because these mammals spend substantial parts of their lives underwater, it is hard to study them through visual observation, such as from ships. In addition, Arctic-endemic species, like bowhead whales or narwhals, often inhabit areas that are seasonally inaccessible to researchers, covered by sea ice much of the year.

PASSIVE ACOUSTIC MONITORING

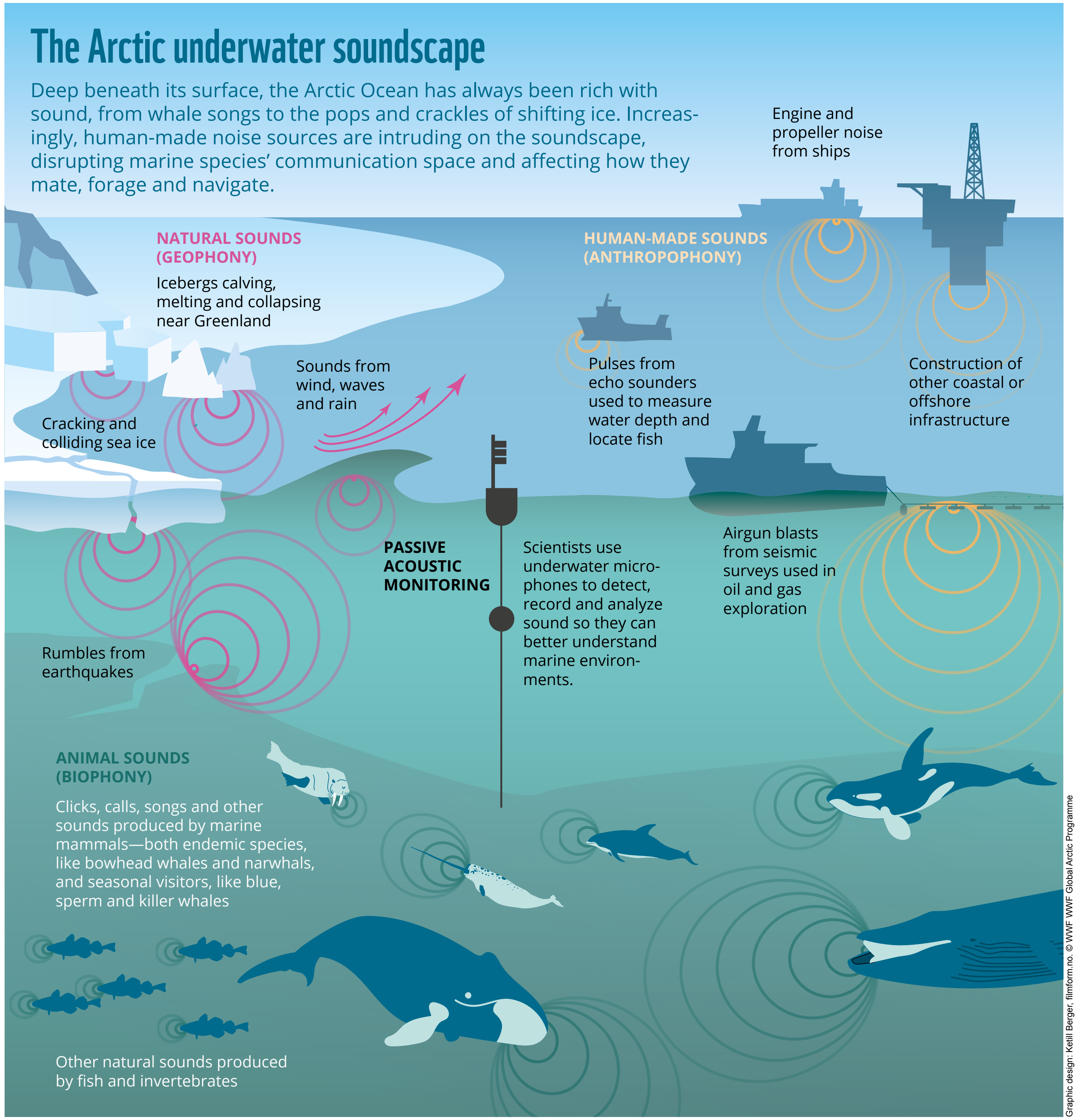
So how do we study this remote, unseen world? The answer lies in an unexpected approach: by listening.

For many marine mammals, sound is an integral part of life. Many species produce sound in various behavioural contexts—such as when communicating, mating, foraging and navigating. These vocalizations are often distinctive, and can yield information not only about individual species, but even about specific populations. ➤

KAROLIN THOMISCH IS a marine ecologist who uses passive acoustic monitoring to study marine mammals in the polar oceans.

RAMONA MATTMÜLLER IS a marine ecologist who studies polar ocean soundscapes using passive acoustic monitoring.

Both work with the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research.



Passive acoustic monitoring (PAM) has emerged as a crucial tool for studying and understanding marine environments, particularly in challenging regions like the Arctic Ocean. This non-invasive method relies on underwater microphones, known as hydrophones, to record, analyze and detect sound in the ocean. Unlike active sonar, which emits sound waves, PAM listens silently, creating no disturbance. This makes it ideal for long-term observation.

PAM is also uniquely suited to the Arctic environment because of its resilience. Instruments used in the Arctic must be able to withstand extreme cold, ice and pressure, and they need to operate autonomously because there is limited access for maintenance. Fortunately, technological advances have enabled the development of robust, durable recording units capable of collecting data for months or even years at a time.

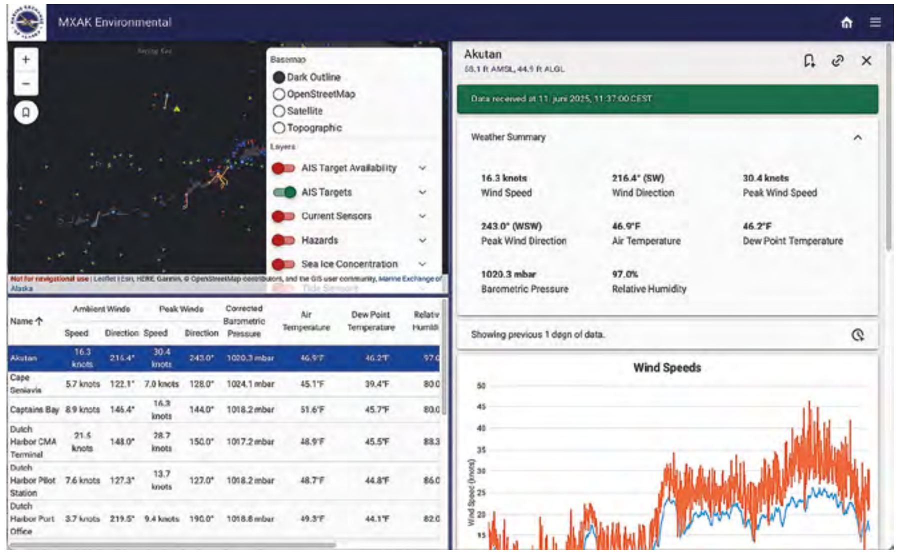
Finally, sound travels great distances in the ocean—up to hundreds of kilometres, for some species. This makes PAM a highly suited tool for studying resident and migrating marine mammals in remote areas of the Arctic Ocean. Researchers can use it to track seasonal migrations, population trends and behavioural changes.

BUILDING A HOLISTIC SOUNDSCAPE PICTURE

But PAM also plays a vital role in assessing human-generated noise and its impact on the Arctic ecosystem. As sea ice continues to decline, previously inaccessible areas are opening up to increased human activity, including shipping, oil and gas exploration, and commercial fishing. These developments contribute to increasing noise pollution in the ocean, potentially affecting the behaviours and well-being of marine life. By using PAM to record and analyze noise levels, researchers can assess the spatial and temporal extent of human-generated noise and work toward mitigating its impact through policy and regulation.

The Arctic is warming four times faster than the rest of the globe. The consequences of increasing temperatures and declining sea ice for marine mammals are far-reaching: northward shifts of their distribution ranges, habitat loss due to receding sea ice, growing competition for food, and pressures from predation as species (and more humans) move further into the Arctic Ocean, drawn by the warmer temperatures.

Given the pressing need to monitor the effects of climate change in this vulnerable ecosystem and the challenges presented by the vastness of the region—and the transboundary nature of many marine species—international collaboration and coordination of PAM efforts in the Arctic Ocean is critical. By using signal processing and machine learning techniques to analyze long-term PAM recordings and assess trends in sound patterns (including biological, natural and human sound sources), we can build a clear, holistic picture of the Arctic Ocean soundscape—and ultimately, contribute to scientific knowledge and conservation strategies. ●



Screenshot of an online app built by the Marine Exchange of Alaska (MXAK). The app integrates environmental and ship data in a publicly available format.

Arctic Watch

A COLLABORATIVE APPROACH TO SAFE SHIPPING

As sea ice diminishes, global players are eyeing the Arctic for fishing, resource extraction, and faster global trade routes. To prepare for the expected increase in ship traffic, non-governmental organizations (NGOs), Tribes, and government agencies in Alaska are teaming up to build a dynamic sea traffic management system, known as Arctic Watch. As **ALEXIS WILL** writes, this system will help protect the Arctic's unique ecosystem and the people and wildlife that call it home.

ALEXIS WILL is a marine biologist with the WWF Oceans Team. She is building a research programme for the US Arctic to support wildlife monitoring and area-based conservation work.

CAPTAIN ED PAGE describes the need for Arctic Watch like this: To get people to slow down in a school zone, you can post a speed limit, and some people will comply. Add some lights and a flashing sign that displays their speed, and even more people will comply. To guarantee that every single car complies with the speed limit, enrol drivers in ➤

a programme that includes police car monitoring. The Marine Exchange of Alaska (MXAK) is that police car, and Page is its former executive director. The exchange monitors enrolled vessels 24/7 from an operations centre in Juneau, Alaska, with wraparound displays to enhance maritime safety and prevent conflicts in waterway use.

Now, in collaboration with other organizations, including WWF, MXAK is expanding this model of sea traffic management to the Bering Strait, which is both a constricted waterway and biodiversity hotspot.

PROTECTING ARCTIC COMMUNITIES

The Arctic is home to people who rely on the health of their ocean to support their families and maintain their cultural, spiritual and physical well-being. In the Bering Strait region, Iñupiaq, Yup'ik and Siberian Yupik have been raising concerns about vessel traffic for more than a decade.

We need to know who is traveling near our island, explains Edwin Noongwook, Arctic Watch Tribal delegate for Savoonga, a town of some 800 people on Sivuqaq/St. Lawrence Island, Alaska. "We harvest to sustain nutrition and life around our environment. These are sentimental values that our families generated from. If something happens, we are the first responders. It's our fish, our marine mammals, our seabirds that are affected. If something happens, I may not be able to provide for my family."

Arctic communities are the pillars of Arctic Watch. They are partners in monitoring vessel traffic and provide information to support safe navigation through their waters. In January 2024, Arctic Watch hosted a partners' meeting during which Tribal delegates saw firsthand the technological capabilities of MXAK and discussed the vision for the system. The resulting recommendations, summarized in a recently published workshop report, outline how building out marine safety sites, increasing VHF coverage, and integrating community protocols will strengthen Arctic Watch and ensure its success.

SAFEGUARDING WILDLIFE

In collaboration with federal and university scientists, Indigenous experts, vessel operators, and the tech team at MXAK, Arctic Watch is now building a suite of voluntary measures tailored to marine wildlife and their behaviours. Based on the idea that slow-down zones reduce whale strikes by vessels, the vision is to issue "wildlife alerts," or short messages that ships will receive via their automated information systems when they enter wildlife hotspots, such as a migratory corridor, foraging area or walrus haul-out. A message to the effect of "recommended speed 10 knots, whales likely" will pop up.

The project is based on guidelines from both western and Indigenous experts. For example, hunters in Kotzebue Sound have pointed out that beluga whales in the area have changed their movement patterns in response to the higher number of vessels in the area. These experts recommend that vessels at anchor turn off their sonar to reduce the noise impact, so we are working on a corresponding alert. We are also refining this model to accommodate for ship behaviours that might trigger too many alerts (for example, zigzagging in and out of a zone), to avoid sending unnecessary alerts (such as when a ship is not travelling that fast), and to provide ship operators with real-time information.

CREATING PARTNERSHIPS TO FOSTER COMMUNICATION

At its core, Arctic Watch is an information exchange initiative. Ships need to know where ice is, communities want to know what ships are carrying and where they are going, and emergency response agencies want to know right away if a vessel is encountering difficulties. MXAK is building the necessary communication and technical capabilities for all these needs.

This includes installing new marine safety sites in collaboration with local experts to increase communication coverage and avoid known obstacles to VHF transmission. It also includes developing tools to make the information that is collected more accessible to a broad audience. For example, MXAK has built an online app that integrates environmental and ship data in a publicly available format.

> **If something happens, we are the first responders. It's our fish, our marine mammals, our seabirds that are affected.**

"We need to break down the stovepipes!" explains Captain Steve White, the current executive director of MXAK. "Our job is to centralize information and create a centre of excellence." Fuelled by his enthusiasm and a "let's do this together" attitude, the initiative has made significant progress. It is succeeding not just because there is a clear and compelling need for it, but because diverse partners have come together with commitment and purpose to thoughtfully and carefully bring the project closer to realization.

In addition to the organizations already mentioned, others that have contributed significant time and resources include: Kawerak Inc., Ocean Conservancy, Alaska Ocean Observing System, Ikaaġun Engagement, Aleutians Bering Sea Initiative, and the Marine Mammal Commission. As a result, Arctic Watch now has a strong foundation. But we still have key components to develop, such as a governing body and operational guidelines.

The changes happening in the Arctic are profound, and to those of us who live and work here, they are deeply distressing. We cannot bring back the cold winters or *galusiq* (Mother Ice). But preparing for the changes ahead is one way we can contribute to protecting the Arctic. ●

The 800 people living in Savoonga on Sivuqaq/St. Lawrence Island, Alaska need to know what is going on in the area and how their environment might be affected.

Photo credit: © WWF-US/Emma Barnes

THE BACK PAGE

Photo credit: Unknown photographer, Svalbard museum

100 years of the Spitsbergen Treaty

The Spitsbergen Treaty came into force 100 years ago, making the Svalbard archipelago part of the Kingdom of Norway. Until then, it had been considered unclaimed territory. Although the treaty was signed on February 9, 1920, it wasn't until August 14, 1925, that the "Svalbard law" came into force, turning the treaty into national law. The day is now considered Svalbard's national day.