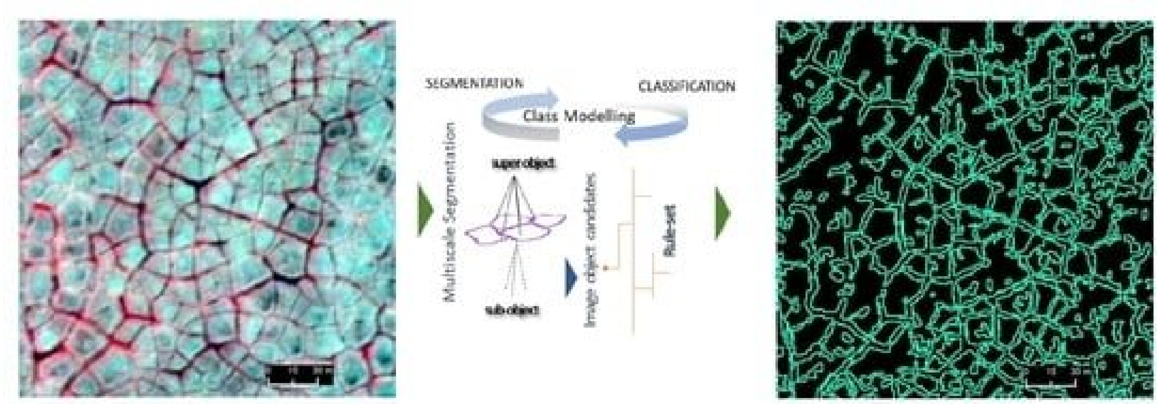
Monitoring Arctic permafrost with satellites, supercomputers, and deep learning

February 22 2022, by Aaron Dubrow



Progress of automated ice-wedge polygon prediction from sub-meter resolution commercial satellite imagery. So far, researchers have mapped more than 1 billion individual-ice wedge polygons across the Arctic tundra. In addition to polygon outline, each detected ice-wedge polygon comes with a suite of analysis-ready attributes, such as ice-wedge polygon type, size, length, and width. Credit: Chandi Witharana, University of Connecticut

Permafrost—ground that has been permanently frozen for two or more years—makes up a large part of the Earth, around 15% of the Northern Hemisphere.

Permafrost is important for our climate, containing large amounts of biomass stored as methane and carbon dioxide, making tundra soil a carbon sink. However, permafrost's innate characteristics and changing nature are not broadly understood.

As global warming heats the Earth and causes soil thawing, the permafrost carbon cycle is expected to accelerate and release soil-contained greenhouse gases into the atmosphere, creating a feedback loop that will exacerbate climate change.

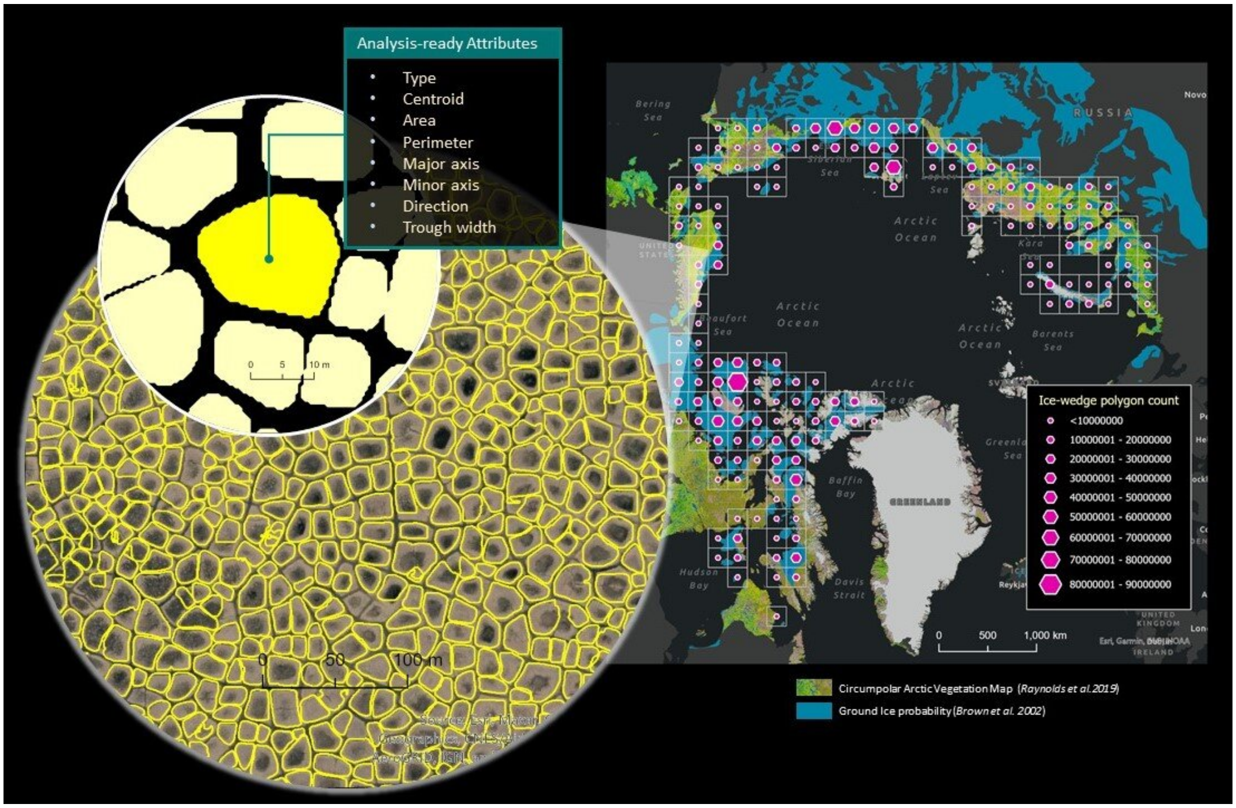
Remote sensing is one way of getting a handle on the breadth, dynamics, and changes to permafrost. "It's like a virtual passport to see this remote and difficult to reach part of the world," says Chandi Witharana, assistant professor of Natural Resources & the Environment at the University of Connecticut. "Satellite imaging helps us monitor remote landscape in a detailed manner that we never had before."

Over the past two decades, much of the Arctic has been mapped with extreme precision by commercial satellites. These maps are a treasure trove of data about this largely underexplored region. But the data is so large and unwieldy, it makes scholarship difficult, Witharana says.

With funding and support from the U.S. National Science Foundation (NSF) as part of the "Navigating the New Arctic" program, Witharana, as well as Kenton McHenry from the National Center for Supercomputing Applications, and Arctic researcher Anna Liljedahl of the Woodwell Climate Research Center, are making data about Arctic permafrost much more accessible.

The team was given free access to archives of over 1 million image scenes taken in the Arctic. That's a lot of data—so much that traditional analysis and features extraction methods failed. "That's where we brought in AI-based deep learning methods to process and analyze this large amount of data," Witharana said.

One of the most distinctive, and telling, features of permafrost are ice wedges, which produce recognizable polygons in satellite imagery.



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"The ice wedges form from the freezing and melting of soil in the tundra," said Liljedahl. "Some of them are tens of thousands of years old."

The shape and dimensions of ice wedge polygons can provide important information about the status and pace of change in the region. But they short-circuit conventional analysis.

"I was on Facebook some years ago and noted that they were starting to use facial recognition software on photos," recalled Liljedahl. "I wondered whether this could be applied to ice wedge polygons in the Arctic."

She contacted Witharana and McHenry, whom she had met at a panel review in Washington, D.C., and invited them to join her project idea. They each offered complementary skills in domain expertise, code development, and big data management.

Starting in 2018, Witharana began using neural networks to detect not friends' faces, but polygons from thousands of Arctic satellite images. To do so, Witharana and his team first had to annotate 50,000 individual polygons, hand-drawing their outlines and classifying them as either low-centered or high-centered.

Using deep learning and supercomputers, researchers have been able to identify and map 1.2 billion ice wedge polygons in the Arctic permafrost based on satellite imagery. The data helps establish a baseline from which to detect changes to the region. Credit: Anna Liljedahl, Woodwell Climate Research Center

Low-centered ice wedge polygons form a pool in the middle of the ridged outer part. High-centered ice wedges look more like muffins, Liljedahl said, and are evidence of ice wedge melting. The two types have different structural hydrological characteristics, which are important to understand in terms of their role in climate change, and to plan future infrastructure in Arctic communities.

"Permafrost isn't characterized at these spatial scales in climate models," said Liljedahl. "This study will help us derive a baseline and also see how changes are occurring over time."

Training the model with the annotated images, they fed the satellite imagery into a neural network and tested it on un-annotated data. There were initial challenges—for instance, images trained for Canada were less effective in Russia, where the ice wedges are older and differently shaped. However, three years later, the team is seeing accuracy rates between 80 and 90%.

They have described the results of this research in the ISPRS Journal of Photogrammetry and Remote Sensing (2020), the Journal of Imaging (2020) and *Remote Sensing* (2021).

After showing that their deep learning method worked, they turned to the Longhorn supercomputer, operated by the Texas Advanced Computing Center (TACC)—a GPU-based IBM system that can perform AI inference tasks rapidly—as well as the Bridges-2 system at the Pittsburgh Supercomputing Center, allocated through the NSF-funded Extreme Science and Engineering Discovery Environment (XSEDE), to analyze the data.

As of the end of 2021, the team had identified and mapped 1.2 billion ice wedge polygons in the satellite data. They estimate they are about halfway through the full dataset.

Each individual image analysis involves pre-processing (to improve the clarity of the image and remove non-land features like lakes), processing (where polygons are detected and characterized) and post-processing (reducing the data to a manageable scale and uploading it to a permafrost data archive). In addition to identifying and classifying ice-wedge polygons, the method derives information about the size of the wedge, the size of the troughs, and other features.

The individual analysis can be performed in less than an hour. But the sheer number of them make it unfeasible to run anywhere but on a large supercomputer, where they can be computed in parallel.

Recently, Witharana and collaborators benchmarked their workflow to find the optimal configuration to run efficiently on supercomputers. Writing in Photogrammetric Engineering and Remote Sensing (PE&RS) in 2022, they evaluated four workflow designs on two different high performance computing systems and found the optimal setup for high speed analysis. A separate 2022 study in PE&RS explored the efficacy of different image augmentation methods (such as changing the hue or saturation) when applied to deep learning convolutional neural net algorithms to recognize ice-wedge polygons from commercial satellite imagery. (Both projects were presented at the American Geophysical Union Fall Meeting in December 2021.)

"Every year, we get an almost near real-time pulse meter on the Arctic in the form of sea ice extent," Liljedahl said. "We want to do the same with permafrost. There are so many rapid changes. We need to be able to really understand, and communicate, what's happening in the permafrost."

The ice wedge data will be available for rapid analysis on the new Permafrost Discovery Gateway, which will "make information about the Arctic more accessible to more people," Liljedahl said. "Instead of having to wait 10 years to learn about something, they can learn about it right away and explore it directly through their own experience."

Another important phase of the research project will come when the researchers analyze satellite imagery representing different years and times of year. Comparing the state of the ice-wedge polygons can show trends and trajectories, such as how fast the landscape is changing, and where those changes will cross paths with settlements or infrastructure.

"This is a perfect example of how previous investments in computing infrastructure, combined with new understanding of deep learning techniques, are building a resource to help with an important issue in the Arctic," said NSF Program Director Kendra McLauchlan.

"Plato said, 'Man must rise above the Earth—to the top of the atmosphere and beyond—for only thus will he fully understand the world in which he lives,'" Witharana said. "Earth observation technologies enable us to see how climate change is happening and how even the land is changing. It's the main tool to observe, monitor, predict and make decisions to prevent a negative impact on fragile regions."

More information: An Optimal GeoAI Workflow for Pan-Arctic Permafrost Feature Detection from High-Resolution Satellite Imagery, *Photogrammetric Engineering & Remote Sensing* (2022)

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