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# ENHANCED DIGITAL ELEVATION MODEL FOR THE ARCTIC

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## EXECUTIVE SUMMARY

The Earth's land surface topography is arguably the most important single data set in the geosciences, geographical sciences, and civil engineering as it provided the basis or reference analysis and design. Accurate and timely elevation models are essential to determining the location of rivers and the extent of watersheds in hydrology, to permafrost collapse in areas, to the change in the shape of volcanoes in volcanology and to the effects of human activities. The Polar Geospatial Center (PGC) and its partners at The Ohio State University and University of Colorado Boulder adapted PGC's digital elevation model (DEM) production capabilities from small-area, on-demand creation to systematically process and mosaic the entire Arctic area from the sub-meter stereoscopic commercial imagery archive made available by the National Geospatial Intelligence Agency. Such datasets make the Arctic one of the best-mapped regions on Earth and enable new aspects of Polar science. This dataset also allows for precise detection of change over time, enabling highly accurate measurements on this rapidly evolving landscape.

## RESEARCH CHALLENGE

There is a lack of high-resolution, consistent, high-quality elevation data available for the Arctic and other regions. In 2000, the Shuttle Radar Topography Mission acquired Synthetic Aperture Radar data for the Earth that was processed into an elevation model with a 30-meter horizontal resolution. While invaluable for temperate regions, this mission could not provide coverage in Polar Regions because of the shuttle's orbital inclination. The National Geospatial-Intelligence Agency (NGA), DigitalGlobe (DG), and PGC built a near-seamless archive of polar sub-meter stereo imagery that consists of almost 100,000 stereo pair strips from the Worldview-1, -2, and -3 satellites. Using photogrammetric algorithms, we are able to construct digital elevation models (DEMs) from the stereo pairs, enabling mapping of surface features at the 2-meter scale for the first time. These data are already being used by the Arctic research community to support activities that include transportation, national defense, land management, sustainable development, and scientific studies. Further, most areas include repeat coverage with a frequency of months or even days. Such temporal coverage can be used for change detection facilitating studies from land use to resource management and environmental change. The scale of this effort–to cover 1/6 of the earth's land at one time, is unprecedented.

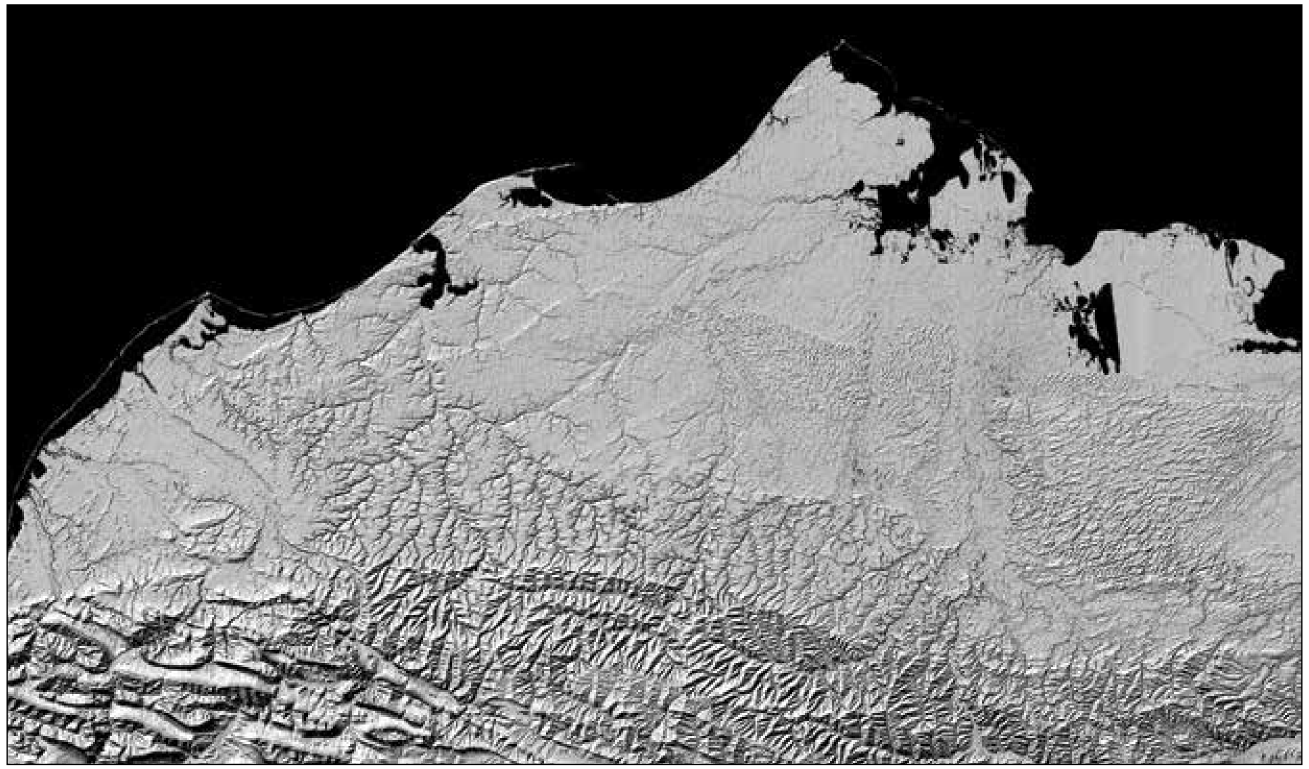

Figure 1: Mosaic tiles from Release 6 of ArcticDEM in color hillshade. The final ArcticDEM release will include updated DEMs and mosaics for the entire Arctic.

## METHODS & CODES

Our team has spent five years developing an efficient algorithm for constructing photogrammetric DEMs from satellite imagery with the objective of creating a fully automated pipeline capable of handling large amounts of data and very large areas. The Surface Extraction from TIN-based Search-space Minimization (SETSM) algorithm, initially designed to extract elevation data over ice sheets, has been refined and optimized to handle stereoscopic imagery over any land cover [1,2]. Unlike other DEM extraction algorithms, SETSM's structure eliminates the need for an existing (i.e., "seed") DEM for *a priori* constraints or any data-specific, user-defined search parameters, making it a truly automated algorithm. After an initial preprocessing step that corrects the source imagery for sensor-specific detector alignment artifacts, SETSM takes the two source images and derives increasingly detailed elevation models using its pyramid-based approach. The DEM extraction workflow currently runs on all cores of a single node for efficiency, and several thousand of these single-node tasks are bundled together using the Swift workflow management package in order to effectively submit jobs in hundreds to thousands of node batches. The method can also run across multiple nodes using MPI if needed.

## RESULTS & IMPACT

Thus far, we have produced over 136,000 individual 2-m DEMs of the Arctic area. On average, the Arctic is covered six times with images taken over time, with some areas having over 100 unique DEMs for a given location. These data are also processed into continuous mosaics for over 99% of the 20,000,000-km$^2$ Arctic. All of these data have been or will shortly be released to the science community and the public though ArcticDEM.org. The Environmental Systems Research Institute (Esri) has developed web services and an interactive viewer for this and other DEM data. These data are now being used by scientists, national institutions, and regional and local governments for a broad range of scientific, civil engineering, and mapping applications. In addition, 18 scientific publications have used ArcticDEM data since our first release in Aug 2016 and the summer of 2018, with more underway.

## WHY BLUE WATERS

No other open research/academic computer has the capacity for this project. Over 17 million node hours (more than ½ billion core hours) were used to process the archive of stereoscopic imagery that was made available. Additionally, the staff at the Blue Waters Project were invaluable in adapting the leadership system to handle the single-node, high-throughput ArcticDEM workflow. With their help, the ArcticDEM project adopted a strategy that enabled ArcticDEM jobs to use primarily backfill nodes on a low priority, which increased overall system utilization, minimized impact on other projects and expanded the amount of computing that was achievable.

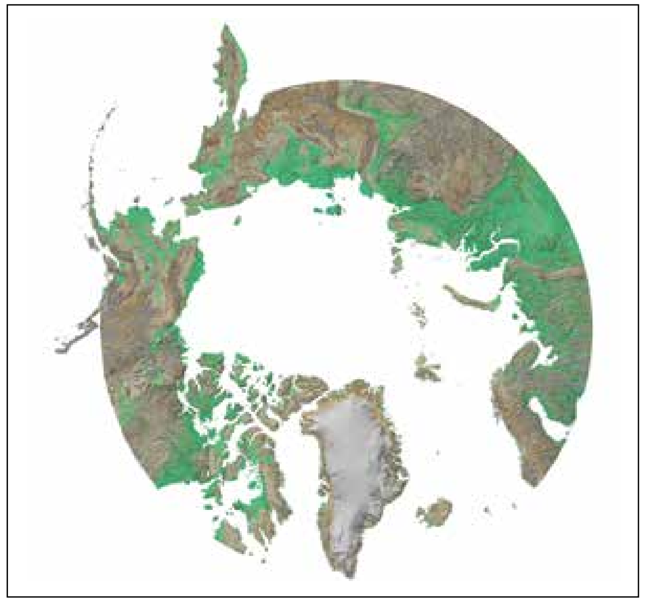

Figure 2: The North Slope of Alaska is the most poorly mapped and rapidly changing area of the United States. This image shows detailed topography over the transition from the Brooks Range in the south to permafrost tundra on the northern shores.