ENHANCED DIGITAL ELEVATION MODEL FOR THE ARCTIC

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EXECUTIVE SUMMARY

The Earth's land surface topography is arguably the most fundamental single data set in the geosciences, geographical sciences, and civil engineering. It is essential to research ranging from the location of rivers and the extent of watersheds in hydrology, to permafrost collapse in built-up areas, to the change in the shape of volcanoes in volcanology. The Polar Geospatial Center (PGC) and its partners at The Ohio State University and Cornell University will adapt PGC's digital elevation model (DEM) production capabilities from small-area, on-demand production to systematically process and mosaic the entire Arctic sub-meter stereo commercial imagery archive. Such a DEM would not only catapult the Arctic from the worst- to among the best-mapped regions on Earth, it would also allow for precise detection of change over time, creating a benchmark for measuring this rapidly evolving landscape.

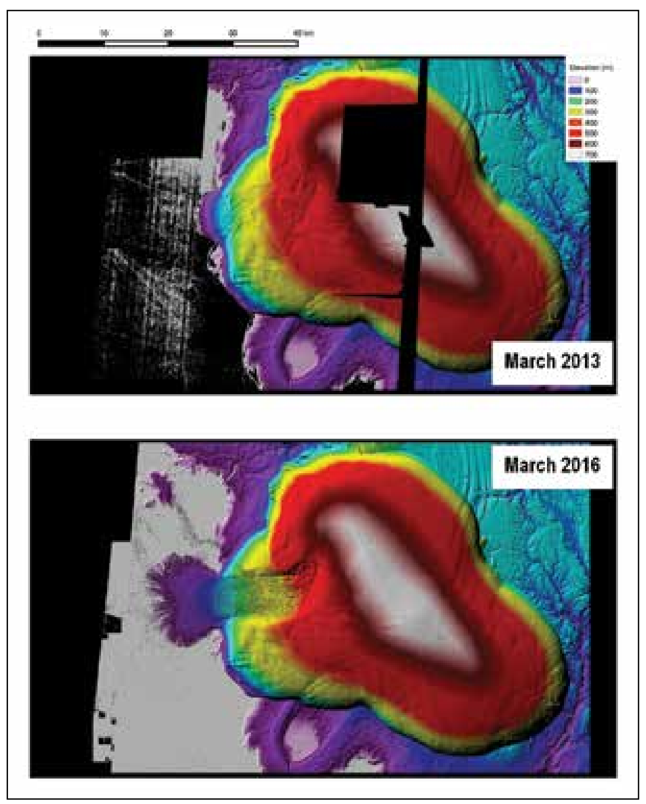

Figure 1: The Vavilov Ice Cap on the island of Severnaya Zemlya in Arctic Russia was known to be stable. In 1996, the ice cap was moving at 20 meters per year. By 2016, the interior of the outlet glacier from Vavilov was moving at 25 meters per *day*. This image pair captures the collapse of the Vavilov Ice Cap as no other resource could, given the temporal frequency and spatial resolution.

RESEARCH CHALLENGE

There is a lack of high-resolution, consistent, high-quality elevation data available for the Arctic. In 2000, the Shuttle Radar Topography Mission began by acquiring Synthetic Aperture data for the Earth that was processed into an elevation model with a 30-m posting. This mission had limited geographic coverage between the latitudes of 60°N and 56°S because of the shuttle's limited orbital inclination. The National Geospatial-Intelligence Agency (NGA), Digital Globe (DG), and PGC have built up a near-seamless archive of polar sub-meter stereo imagery that consists of almost 70,000 stereo pair strips from the Worldview 1, 2, and 3 satellites. Using photogrammetric algorithms, we are able to construct digital elevation models (DEM) from the stereo pairs, allowing for mapping of surface features at the same scale as Airborne LiDAR (Light Detection and Ranging) without the cost or logistics constraints of LiDAR. This imagery collection increases at a rate of more than one California-area equivalent per day while there is sufficient Arctic sun. These data will be used by the Arctic research community to support activities that include transportation, national defense, land management, sustainable development, and scientific studies. Further, repeat DEMs with frequencies of months or even days, can be used for change detection, with applications ranging from studies of land use, to resource management, to environmental change.

METHODS & CODES

Our team has spent three years developing an efficient algorithm for constructing photogrammetric DEMs from satellite imagery with the objective of creating a fully automated system capable of handling large amounts of data. Development of the Surface Extraction from TIN-based Search-space Minimization (SETSM) algorithm was begun to facilitate an automated processing pipeline for the PGC operations. SETSM DEMs have been extensively validated [1], are node parallelized using OpenMP, and have been applied to processing large-area DEM mosaics in proof-of-concept studies. Uniquely, SETSM's structure eliminates the need for an existing (i.e., "seed") DEM for *a priori* constraint or any data-specific, user-defined search parameters, making it a truly automated algorithm. SETSM is called from a single command line with the only required inputs being the filenames of the two stereo images and the RPC (remote procedure call) file, typically provided in XML format.

The DEM extraction workflow starts with a preprocessing step that corrects the source imagery for sensor-specific detector alignment artifacts and outputs a GeoTIFF-formatted set of source rasters. Once the source imagery is corrected, SETSM takes the two source images and derives increasingly detailed elevation models using its pyramid-based approach.

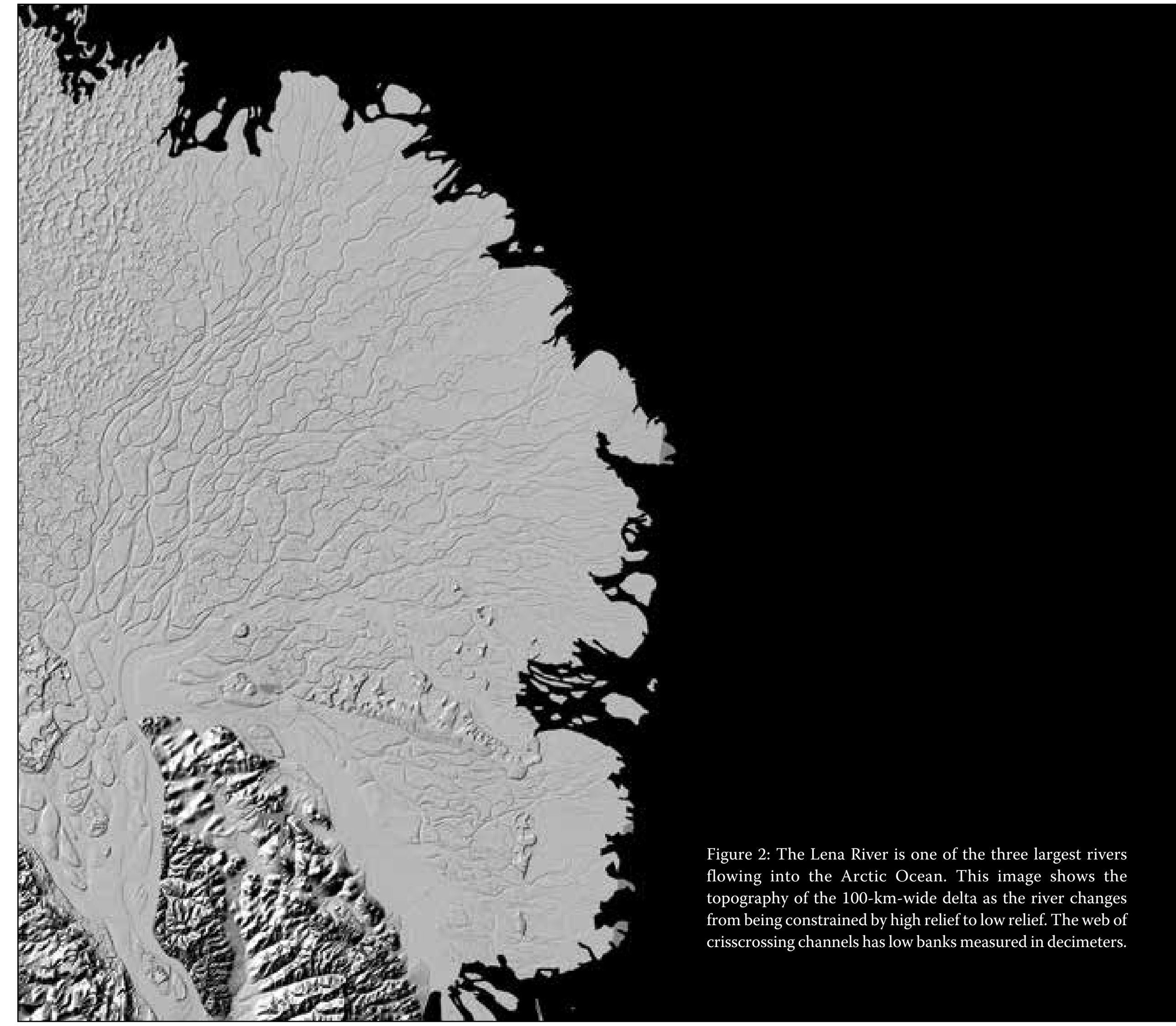

Figure 2: The Lena River is one of the three largest rivers flowing into the Arctic Ocean. This image shows the topography of the 100-km-wide delta as the river changes from being constrained by high relief to low relief. The web of crisscrossing channels has low banks measured in decimeters.

RESULTS & IMPACT

Thus far, we have produced over 57,000 individual 2-m posting DEMs that total approximately 80,000,000 km^2 of the Arctic. This means that the Arctic is covered four times, on average, though some areas are more poorly covered and some have over 100 time steps. These data were also processed into continuous mosaics for over 92% of the 20,000,000 km^2 Arctic. All of these data have been released to the science community and the public though ArcticDEM.org, and Esri has developed viewer and Amazon Web services. These data are now being used by scientists, national geographic surveys, and regional and local governments for a broad range of scientific, civil engineering, and mapping applications.

WHY BLUE WATERS

No other academic computer had the capacity, at the time, for this project. Blue Waters was able to execute the ArcticDEM workload without significantly impacting throughput of other projects. The project had a timeline that precluded the use of cloud services because of time required for development and porting of the SETSM code.