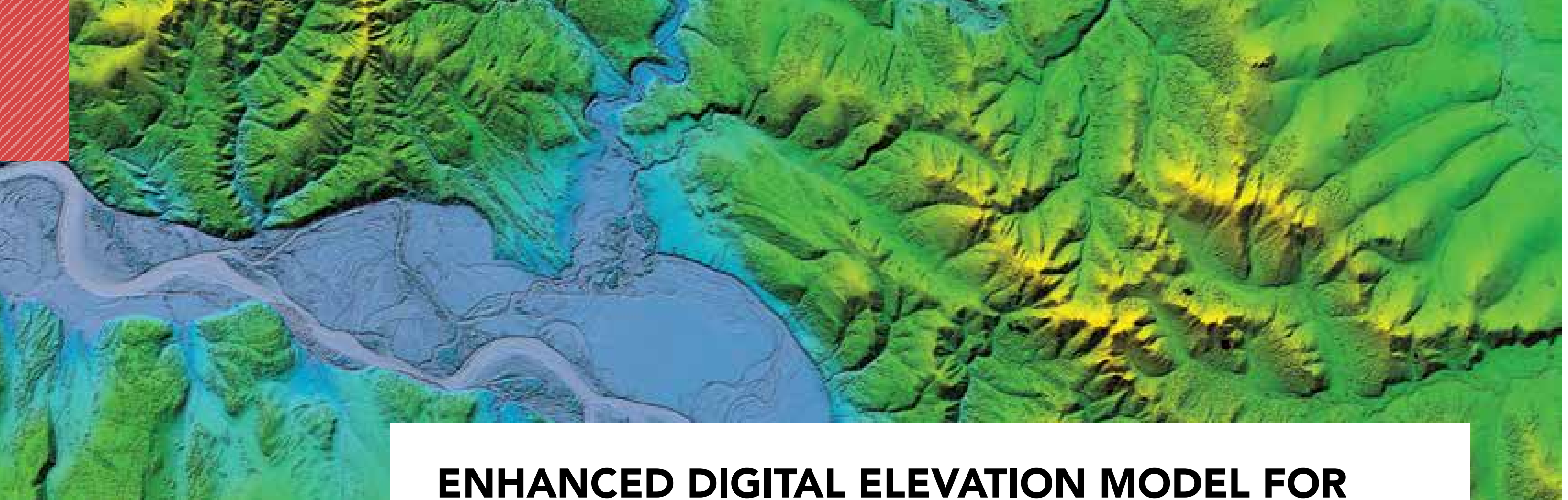

ENHANCED DIGITAL ELEVATION MODEL FOR THE ARCTIC

FIGURE 1: Meandering through Brooks 2m sm cc. This is a river meandering through the Brooks Range on its way to the North Slope. Note that the texture next to the rivers and along some of the mountain slopes is vegetation. In one image you can see the interplay between tectonics, vegetation, erosion and sediment transfer in a remote and unmodified high-relief environment.

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PI: Paul Morin[1]
Collaborators: Charles Nguyen[1], Ian Howat[2], MJ Noh[2], Michael Willis[3], Brian Bates[4], and Cathleen Williamson[4]

[1]University of Minnesota
[2]The Ohio State University
[3]Cornell University
[4]National Geospatial-Intelligence Agency

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 disciplines 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 (OSU) and Cornell University are adapting PGC's digital elevation model (DEM) production capabilities from a small area, on-demand production to systematically process and create high resolution stereo elevation mosaics of the entire Arctic sub-meter commercial imagery archive. Such a DEM not only catapults the Arctic from the worst to among the best mapped regions on Earth, it also allows precise detection of change over time, creating a new quality basis for measuring this rapidly evolving landscape.

INTRODUCTION

There is little high-resolution, consistent, high-quality elevation data in the Arctic. In 2000, the Shuttle Radar Topography Mission (SRTM) began by acquiring Synthetic Aperture data for the earth that was processed into an elevation model with a 30 meter resolution. This mission had limited geographic coverage between the latitudes of 60N and 56S because of the shuttle's orbital inclination.

Using Blue Waters, the National Geospatial-Intelligence Agency (NGA), Digital Globe (DG) and PGC have built a nearly seamless archive of polar sub-meter stereo imagery that consists of almost 50,000 stereo pair strips from the Worldview 1, 2, and 3 satellites. Using photogrammetric algorithms to construct DEMs from the stereo satellite image pairs allows mapping surface features at the same scale as airborne LIDAR without the cost or logistics constraints. This imagery collection increases at a rate to more than the equivalent in area of California every day while there is sufficient Arctic sun. The data will be used by the Arctic research and government communities to support activities including transportation, national defense, land management, sustainable development, and scientific studies. Further, repeating DEMs with frequencies of months or even days, can be used for change detection, with applications ranging from studies of land use such as deforestation, to land and water resource management, to environmental change.

METHODS & RESULTS

At their most basic level, all stereo-photogrammetric DEM extraction algorithms use a statistical procedure, usually cross-correlation, to locate conjugate pixels in one image to those of the same point on the ground in a second image acquired from a different camera position. The difference in position of conjugate pixels between nearly simultaneous images provides the parallax from which the relative height of the surface can be derived using known ground-to-image geometry. In the case of the WorldView satellites, ground-to-imagery geometry is estimated from a set of rational polynomial coefficients (RPCs), determined from the satellite orbital position, which constrain a cubic model of the spatial relationship between image and ground. Locations of conjugate points between images are typically determined starting from an initial estimate provided by the RPC positioning, followed by determining the precise location from statistical image matching.

Our team has spent three years developing an efficient algorithm for constructing photogrammetric DEMs from satellite imagery to create a fully automated system capable of handling large amounts of data. Development of the Surface Extraction from TIN-based Search-space Minimization (SETSM) algorithm began to facilitate an automated processing pipeline for the PGC operations. SETSM DEMs have been extensively validated [1], are node parallelized using the OpenMP application programming interface, 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") elevation measurement for a priori constraint or any data specific, user-defined search parameters, making it a truly automated algorithm. SETSM only requires the two stereo images and the RPC file.

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. The initial step halts the process at 8 meter resolution. This is done for two reasons: 1) any poor-quality source imagery will fail to reach this step, allowing us to identify problematic jobs early on, and 2) the 8 meter product is extremely useful to the scientific community because of the reduced file size. We convert the TIN-based (vector) elevation model to a raster and use the success rate to assess the feasibility of continuing to process to 2 meter. This quality-assessment filter reduces the amount of computer time spent on data unlikely to result in high-quality output. For image pairs that pass this filter, we submit another set of jobs to refine the 8 meter elevation model to 2 meter. The final step in the workflow is to convert the 2 meter TIN-based model to a raster.

WHY BLUE WATERS

We will generate a publicly available, 2 meter posting elevation model of the entire Arctic landmass poleward of 60N and extended south to include all of Alaska, Greenland, and Kamchatka. This ArcticDEM will be constructed from stereo-photogrammetric DEMs extracted from pairs of sub-meter resolution WorldView satellite imagery and vertically registered using ground control from GPS-surveyed points, coordinated airborne LIDAR surveys by NASA's Operation IceBridge, and historical elevations from the NASA IceSAT mission. This project is to be performed during the U.S.'s tenure as Arctic Council chair (2015–2017) [2]. Due to the large footprint of the project (18M km^2) and the limited 2 year timeframe for production, it will require over 19 million node hours (600 million core hours equivalents) to complete.

To simply explain the impact of Blue Waters, we have 12.5^2 improvements in resolution, 58,500 times improvement in time to solution compared to a single workstation, and 220 times improvement in cost. This equates to a **9 billion time** productivity improvement.

NEXT GENERATION WORK

The next generation of this work will involve accelerated DEM projections, expanding the range of application of ground control from a wide variety of sources, and the mosaicing of 20 trillion 2m x 2m elevation grid cells.

FIGURE 2: Western Alaska Braided Stream. Braided streams are found in rivers with a high sediment load and little vegetation. This example shows the ever changing bars being corralled by topography above and vegetation (the textured area) to the south.