University of New Hampshire
University of New Hampshire Scholars' Repository

Center for Coastal and Ocean Mapping | Center for Coastal and Ocean Mapping

5-2014

Satellite-Derived Bathymetry Using Multiple Images: The Alaska North Slope Case Study

Shachak Pe'eri
University of New Hampshire, Durham, shachak.peeri@unh.edu

Shep M. Smith LT
NOAA

Leland P. Snyder
NOAA

Brian Madore
University of New Hampshire, Durham

Follow this and additional works at: https://scholars.unh.edu/ccom

Part of the Oceanography and Atmospheric Sciences and Meteorology Commons

Recommended Citation

Satellite-Derived Bathymetry Using Multiple Images:
The Alaska North Slope Case Study

Shachak Pe'eri[1], *Shepard Smith*[2], Leland Snyder[2], and Brian Madore[1] of authors

[1] Center for Coastal and Ocean Mapping, University of New Hampshire, Durham, NH 03824, USA
[2] Marine Chart Division, NOAA/NOS, Office of Coast Survey, Silver Spring, MD 20910, USA

Abstract

Currently, charting data in much of the U.S. Arctic North Slope is inadequate or nonexistent and most of its areas have not been updated since the early-1950s. Although the charting infrastructure is out of date, ship transportation (such as, fishing and transit between the towns) has increased. NOAA conducted a preliminary multibeam survey in 2013 that reached Point Barrow, AK. However, all the Arctic North Slope remained untouched. Previous studies have shown that satellite-derived bathymetry (SDB) is a useful reconnaissance tool in tropical and sub-tropical waters in clear water conditions, especially over sandy seafloor. However, it is very difficult to extract good information over the Arctic using a single satellite image, especially over the U.S. North Slope. The glacial powder from land reduces the water clarity that limits the light penetration depth. Also, this turbidity is not uniform along the coast line and may affect the calculations. In this paper, a new SDB approach was developed that compiles multiple satellite images to extract only areas that were identified "clear" by comparison (i.e., minimum water clarity change between two satellite images). Preliminary results using Landsat 7 imagery from 1999-2002 and Landsat 8 imagery from 2013 are presented.

Introduction

NOAA's publication, "Arctic Nautical Charting Plan – a plan to sustainable marine charting transportation in Alaska" (NOAA, 2013), discusses the need to ensure sustainable marine transportation throughout the Arctic. Accordingly, the infrastructure that supports safety, environmental protection, and commercial efficiency must be enhanced. Modern updated nautical charts of the appropriate scale can provide the foundation for improving transportation in the area. However, currently, charting data in much of the Arctic is inadequate or nonexistent. According to the NOAA's U.S. Coast Pilot (NOAA, 2010), much of the Bering Sea area is "only partially surveyed, and the charts must not be relied upon too closely, especially near shore. The currents are much influenced by the winds and are difficult to predict; dead reckoning is uncertain, and safety depends upon constant vigilance." Apart from a recent survey (2013) near Point Barrow area, most of the U.S. Arctic North Slope has not been updated since the mid-1940 to early 1950, depending on the region (Figure 1). This out of date charting infrastructure poses a challenge as ship transportation (mainly, energy, fishing and transit between the towns) has

increased over recent years. As part of NOAA's Marine Chart Division's (MCD) periodic review, NOAA's Arctic charts are now being assessed for survey planning and prioritization. The goal of such an assessment is not to directly produce chart updates, but rather obtain quantifiable information related to the amount of change since the last hydrographic survey upon which the charted information is based.

This paper presents the development of one of the tools used in this assessment, satellite-derived bathymetry (SDB). Due to the water turbidly and other environmental conditions in Arctic, it is not possible to generate reliable bathymetry using a single satellite image that assumes uniform water clarity. This modified SDB procedure derives bathymetry from only areas that are considered "clear" using multiple satellite images over the same areas and only area.
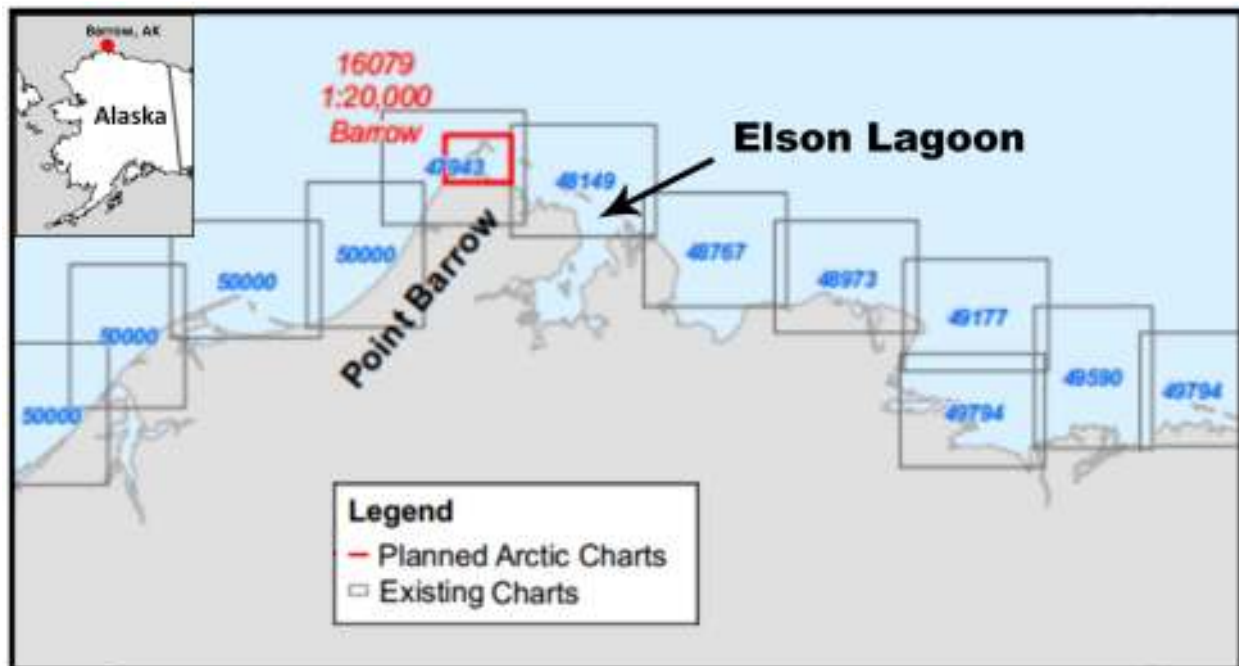

Figure 1. Existing and Planned charts overlaid along the central and eastern Arctic U.S. coastline. The numbers indicate the chart scales (Based on NOAA, 2010).

Satellite-derived bathymetry

Satellite-derived bathymetry procedure provides a simple reconnaissance tool for hydrographic offices around the world. The procedure is already in commercial use and its steps are documented in public literature (e.g., IHO, 2013; Pe'eri et al., 2014). The satellite imagery provides repeatable coverage of remote areas. In this study, imagery from Landsat 7 and Landsat

8 were used because of their footprint coverage areas. With 185 km swath, five to six images are suffice to cover the whole U.S. North Slope from Point Barrow up to the Canadian border.

The concept of single-image SDB began in the late 70's and over the past few decades has been investigated by international hydrographic offices (e.g., SHOM and UKHO). The most common approach used for deriving bathymetry is an optimization approach using band ratio calculation (Stumpf et al., 2003; Philpot et al., 2004). Key steps in the procedure include:

Pre-processing– Satellite imagery is downloaded based on the geographic location and environmental conditions (e.g., cloud coverage and sun glint) had to be used.

Water separation– Dry land and most of the clouds are removed.

Spatial filtering– 'Speckle noise' in the Landsat imagery is removed using spatial filtering.

Glint/cloud correction–Radiometric contributions from sun glint and low clouds are corrected .

Applying the bathymetry algorithm– The bathymetry is calculated using the blue and green bands.

Identifying the extinction depth– The optic depth limit for inferring bathymetry (also known as, the extinction depth) is calculated.

Vertical referencing– A statistical analysis between the algorithm values to the chart soundings references the Digital Elevation Model (DEM) to the chart datum.

The Arctic environment

This single image SDB procedure has proven itself as a reconnaissance tool in tropical and sub-tropical waters, especially over sandy seafloor. However, the Arctic is a more complex environment. The water in the arctic are considered non uniform turbid water conditions (Secchi disc measurements of 3-4 m) with mixed-sediment seafloor (glacial powder/mud, sand and gravel). In addition to the water column and seafloor conditions, ice is present on the water surface most of the year, which makes it challenging to estimate its bathymetry from satellite imagery.

Because of its geographic location, many resources are required for each survey campaign. Until recently, it has been positioned as a low priority because of its accessibility and vessel traffic. According to the charts and the NOAA's survey descriptive reports, the sounding over the Arctic North Slope are from the early 1950s or earlier. Single image SDB results produce elevation datasets with erroneous bathymetry. The cause for these errors are sediment plumes that vary over time.

Multiple image satellite-derived bathymetry procedure

The ability to separate turbidly that produces "false bathymetry" areas from the actual bottom bathymetry is not trivial. We assume that the calculated depth difference between bathymetry models over areas containing clear waters or waters with very small amount of suspended sediment will not be any elevation difference. This assumption was confirmed after investigating worldview-2 (WV-2) imagery over Elson Lagoon inlet, AK (Figure 2). Difference maps between SDB solutions (models) to the reference soundings and difference maps between two SDB models from different time periods showed similar patterns that are typical to turbidity patterns expected around inlets. Thus, differences in elevation between two SDB models is correlated with turbidly.
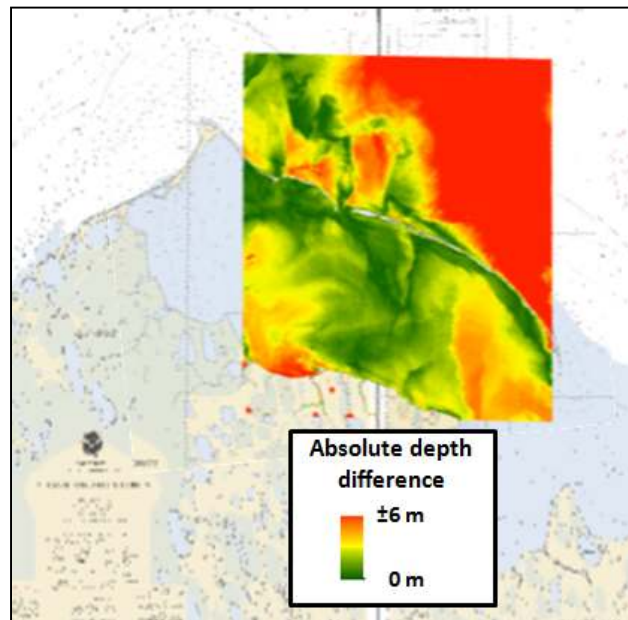

Figure 2. Difference map between two satellite-derived bathymetry models using worldview-2 (WV-2) imagery over Elson Lagoon inlet, AK.

The use of the clear water criteria allowed to remove areas that were observing scattering in the water column and extract only the areas that optically-deep for bathymetry. An example for that is provided in Figure 3, where the distribution of the depth differences between all the chart soundings to the SDB model seem to random and not correlated to depth (Figure 3a) compared to depth difference results over clear areas that show a closer distribution around the mean (Figure 3b).
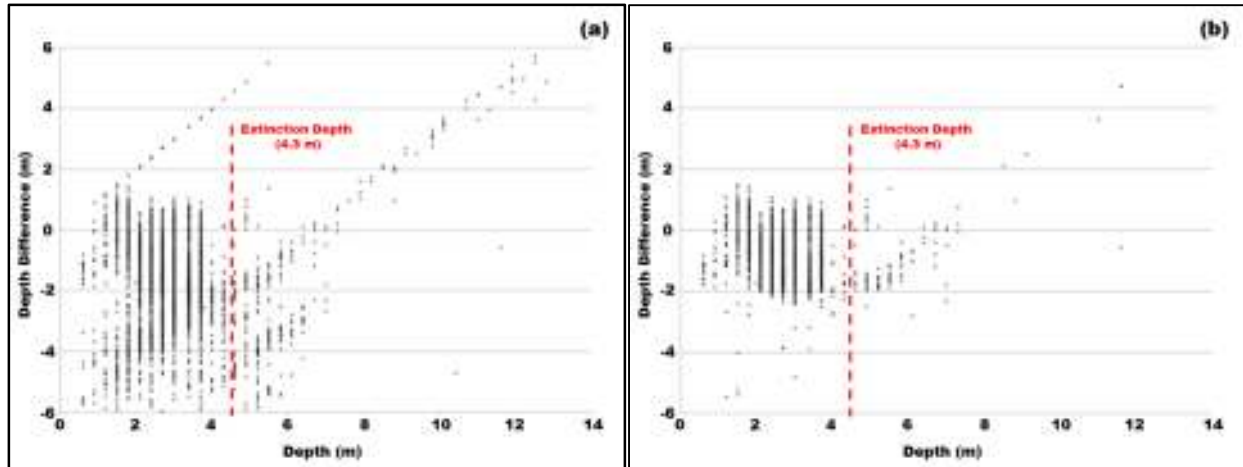
Figure 3. Depth difference results using WV-2 imagery over Elson Lagoon inlet, AK: (a) scatter plot showing the depth differences between all the chart soundings to the SDB model and (b) scatter plot using only sounding from areas that were identified as clear water conditions.

Accordingly, the multiple image SDB procedure has a few additional steps that were added to the single image SDB procedure:

Pre-processing - Ice or cloud coverage are removed from the images using a similar procedure to the water separation.

Applying the bathymetry algorithm to all images– the bathymetric model is calculated for all images available over the area of interest.

Generating depth difference maps – A difference map is calculated for each pair of SDB models. For example, four SDB models will provide six pairs (difference maps).

Histogram balancing - One difference maps is selected as the reference. The histograms of the other difference maps are matched to the histogram of the reference difference map.

Identifying the clear water areas - Only areas that contain small changes (up to 1% change) are kept. These areas are then compiled together.

Vertical referencing– A statistical analysis between the compiled clear water areas to the chart soundings references is used to reference the bathymetry to the chart datum.

Results and conclusions

Preliminary processing of the multiple SDB approach was conducted over the Arctic North Slope (Figure 4). The areas were processed in five footprint areas based on the images coverage (Landsat imagery is typically acquired over same footprints during the satellite's life cycle). Each footprint area contained between three to five images from periods ranging from 1999 to 2013. The calculated extinction depth was between 4 m to 6 m, depending on the acquisition date of the imagery. The results showed success to derive bathymetry near Point Barrow, AK and some areas in the center of the Arctic North Slope. Further work is conducted to evaluate the procedure.
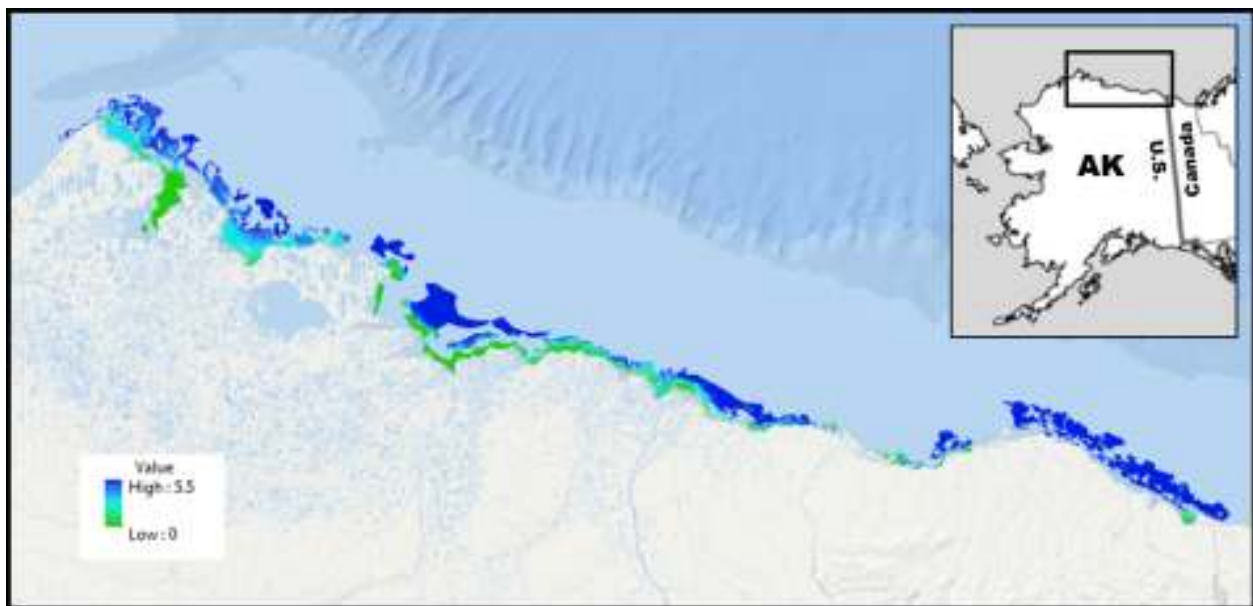

Figure 4. Preliminary results from the multiple imagery SDB approach over U.S. Arctic North Slope using Landsat imagery.

References

Dierssen, H. M., R. C. Zimmerman, R. A. Leathers, T. V. Downes, and C. O. Davis. 2003. Ocean color remote sensing of seagrass and bathymetry in the Bahamas Banks by high-resolution airborne imagery. *Limnol. and Oceanogr.* 48:444–455.

NOAA, 2010. *Bering Sea: Chart 16006*. U.S. Coast Pilot, Alaska: Cape Spencer to Beaufort Sea, Washington, DC.

Pe'eri, S., Madore, B., Alexander, L., Parrish, C., Armstrong A., Azuike, C., and Tetteh, E. (2013). LANDSAT 8 Satellite-Derived Bathymetry, *In: The IHO-IOC GEBCO Cook Book, Edition 11.1.13* (*Editor: Marks, K.*), International Hydrographic Office (IHO)/ International Ocean Commission (IOC), Monaco, Monaco Cedex, Monaco IHO Publication B-11 and IOC Manuals and Guides, 63, p. 243-304. url: http://www.gebco.net/data_and_products/gebco_cook_book/

Pe'eri, S., Parrish, C., Azuike, C., Alexander, L., and Armstrong, A., (accepted), Satellite Remote Sensing as a Reconnaissance Tool for Assessing Nautical Chart Adequacy and Completeness, Marine Geodesy.

Philpot, W.D., C.O. Davis, W.P. Bissett, C.D. Mobley, D.D.R. Kohler, Z. Lee, J. Bowles, R.G. Steward, Y. Agrawal, J. Trowbridge, R.W. Gould, Jr., and R.A. Arnone. 2004. Bottom characterization from hyperspectral image data. *Oceanography* 17(2):76–85, http://dx.doi.org/10.5670/oceanog.2004.50.

Stumpf, R. P., K. Holderied, and M. Sinclair. 2003. Determination of water depth with high-resolution satellite imagery over variable bottom types, *Limnol. Oceanogr.* 48:547–556.