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Reconnaissance surveying of Bechevin Bay, AK using satellite-derived bathymetry

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ABSTRACT

Recently, a remote sensing study has been conducted over Bechevin Bay Channel, Alaska as part of a collaboration project between NOAA and the U.S. Coast Guard (USCG). The goal of the study to develop a procedure to prioritize survey areas and plan the annual deployment of Aids to Navigation (AtoN) along the channel. Bechevin Bay is considered a priority for marine surveying because it constitutes the easternmost passage through the Aleutians from the Bering Sea to the Gulf of Alaska. The channel is located in a mud flat area, where every winter the passage is closed due to ice cover. As a result, the path of the channel may change after sea ice has melted. Because of the geographic location of Bechevin Bay, many resources are required in order to conduct an annual survey to map the channel's path. The surveys are typically conducted by the USCG buoy tenders using small boats and reconnaissance-style single beam lines. This paper presents the use of single-image satellite-derived bathymetry (SDB) as an economic alternative approach. The study compares the performance using different band ratios. Datasets that were used in the study included Landsat 8 and WorldView 2 (WV-2) imagery.

Key words: Arctic, Satellite-derived bathymetry, Nautical Charting, Remote Sensing, Seafloor changes

Introduction

False Pass, AK provides a passage for small- and mid-size vessels (less than 200 ft in length) from Northern Alaska to the U.S. West Coast states. The passage is considered an alternative route to Unimak Pass, AK and estimated to be shorter by 160 to 240 km (100 to 150 miles) for connecting between the Bearing Sea on Alaska to the Pacific Ocean. The pass route is located within Bechevin Bay Inlet system, a large tidal basin located at the southwestern end of the Alaska Peninsula. The depth of the natural channels at Bechevin Bay permits the passage of vessels with a draft less than 4.2 m (14 ft.). The navigability through the pass is limited due to offshore bars at the northern part of the Bechevin Bay inlet system.

The name ‘False Pass’ was given by early American mariners that considered the route to be impassable for mid-size vessels. The strong currents in the Bay and a channel that is changing on an annual basis still deters current-day mariners to use the western Passes (Unimak Pass or Dutch Harbor). False Pass is closed every winter due to sea-ice cover that freezes-up the inlet system around October-November and melts only towards the spring (around March). As a result, the path of the channel that passes through mud flats and the sandy bottom may change after the sea ice has melted. Preparation of False Pass for the next season vessel traffic during the Summer-Fall, requires many resources in a 3-month time window to identify the main channel and place buoys around it as Aids to Navigation for mariners. The surveys are typically conducted by the U.S. Coast Guard (USCG) buoy tenders using small boats and reconnaissance-style single beam lines.

Because of the geographic location of False Pass, the costs and transit time that are required to map the channel’s path on an annual basis are not cost-efficient. A potential resource for survey reconnaissance is multispectral satellite imagery, which provides repeatable coverage of remote areas that are hard to access. Satellite-derived bathymetry (SDB) has proved to be a useful reconnaissance tool in tropical and subtropical regions with clear water conditions, especially over a sandy bottom. However, it is very difficult to extract good information over the Arctic marine areas using a single satellite image because of water turbidity caused by glacial powder from land that limits the light penetration depth. This paper presents a modified single-image SDB approach to map the water currents rather than bathymetry as an economic reconnaissance survey to guide USCG buoy tenders.

Environmental Settings

Bechevin Bay is a large tidal basin located at the southwestern end of the Alaska Peninsula (Figure 1). It connects Isanotski Strait and Ikatan Bay on the south to the Pacific Ocean and opens north to the Bering Sea through a wide tidal inlet. The length and the average width of Bechevin Bay from False Pass to Cape Krenitzin are about 19 km and 10.5 km, respectively. The total surface area of the bay, including St. Catherine Cove, Traders Cove, Hotsprings Bay, and Hook Bay, is 203.8 km^2. The northern portion of Bechevin Bay is shallow and full of sand bars and mud flats. Bechevin Bay, which provides the opening of to the Bering Sea, is 2.7 km wide. Most of the inlet cross section is shallow and ranges from 0.3 to 0.9 m (1 to 3 ft) at mean lower low water (MLLW), while water depth increases to about 33.3 m (100 ft) at the eastern section near Cape Krenitzin. Bechevin Bay, and Isanotski Strait form an inlet system which separates Unimak Island from the Alaska Peninsula. There are several natural channels passing through the northern part of Bechevin Bay that converge at Isanotski Strait, a 4.8 km long channel with an average with of 0.8 km. During strength-tide conditions, the currents in the strait at peak tide are swift, ranging from 4 to 7 knots.

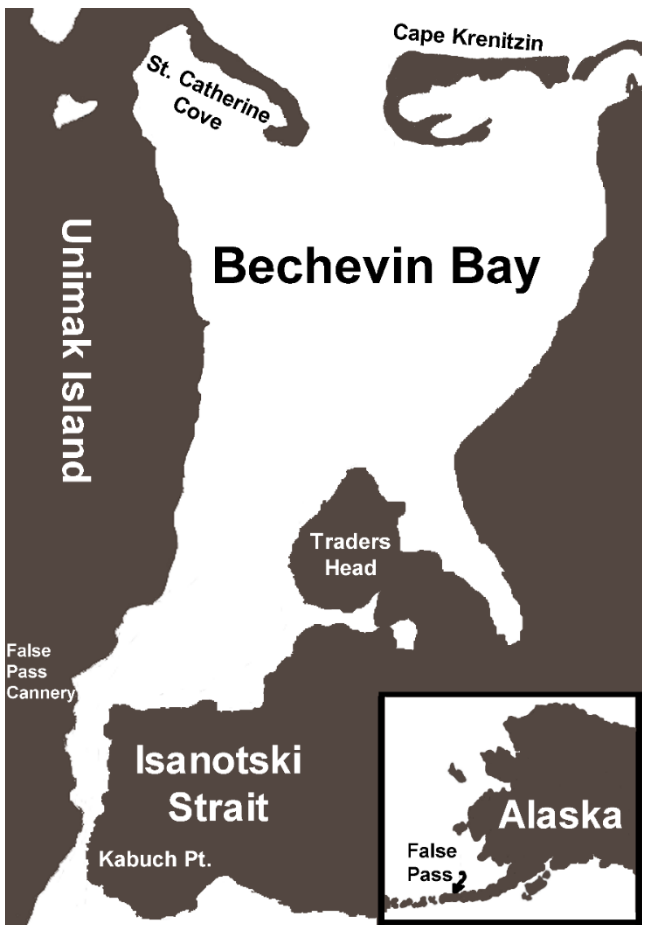

Figure 1. Bechevin Bay Inlet System.

Turbidity Mapping using SDB

The ability to derive bathymetry from multispectral satellite imagery is a topic that has received considerable attention in the scientific literature. Using the blue and green bands from satellite imagery, it is possible to estimate the water depths. The bathymetry is referenced to a chart datum using soundings from a recent hydrographic survey in the area of interest. The key steps in a single-image SDB 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.
- **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 bathymetry for Bechevin Bay, AK (the northern part of False Pass) was calculated using WorldView-2 (WV-2) imagery. As expected, the turbid waters limited the depth penetration (Figure 2). In many areas in the bay, sediment plumes generated false bathymetry in the results. As a result, it was hard to separate between true-bottom detection representing the bathymetry and water-column detection representing the sediment plume. Multi-temporal approach using multiple images to identify sediment plumes cannot be conducted. The window of opportunity is only a 3-month (March to May) that limits the number of available images to one or two images that can be used to calculate the bathymetry in Bechevin Bay.

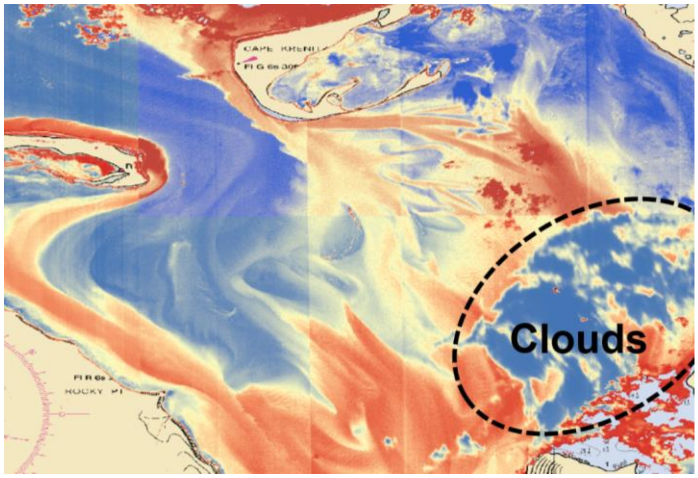

Figure 2. Bathymetric model using a WV-2 single-image SDB overlaid on NOAA Chart 16535. Blue areas represent shallow areas and sediment plumes.

Based on the currents generated by Isnaotski Strait, it is possible to use the water turbidity to map the channels within the bay. Assuming that most of the surface turbidity will be concentrated in the strongest currents, then mapping the water surface layer (shallow water-depth penetration) will provide the horizontal location of the channel. Based on the optical properties of the water, it is possible to the use of the red band instead of the blue band and restrict the light penetration to only the top layer of the water. Preliminary results using WV-2 imagery were able to detect the channels and also alternative channels in the bay (Figure 3). Similar results were obtained using Landsat 8 imagery.

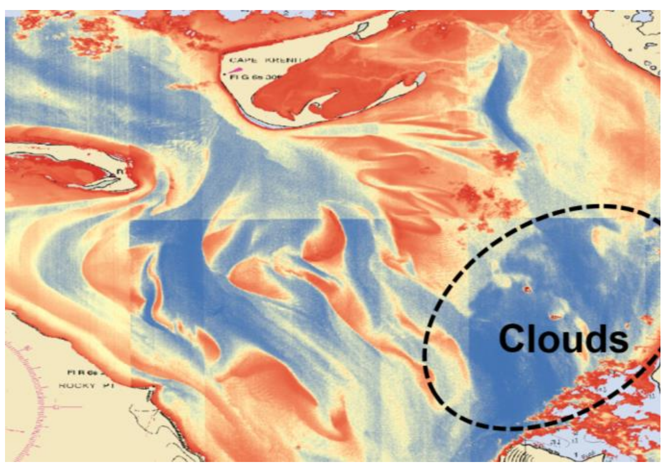

Figure 3. Turbidity map using a WV-2 single-image SDB (green and red bands) overlaid on NOAA Chart 16535. Red areas represent clearer water and blue areas represent turbid areas.

Discussion and Conclusions

As part of the annual channel inspection of Bechevin Bay, AK, the USCG Cutter SPAR conducted a single-beam hydrographic survey in May, 2014. Cutter SPAR surveyed of the channel and the surrounding areas to best mark the navigable channel through Bechevin Bay. The USCG results were very similar to the SDB measurement inside the bay, including the identification of a shifting bar rising to 3.6 m (12 feet) at Mean Lower Low Water (MLLW) located east to the current channel near buoy '19' (Figure 4). The USCG has observed this shoal moving annually and recommends repositioning the buoys marking this shoal every one to three years. An additional shoal was identified at the entrance to Bechevin Bay, northwest to Cape Krenitzin. However, this shoal was not detected by the SDB approach. Possibly because of weak currents surrounding the shoal.

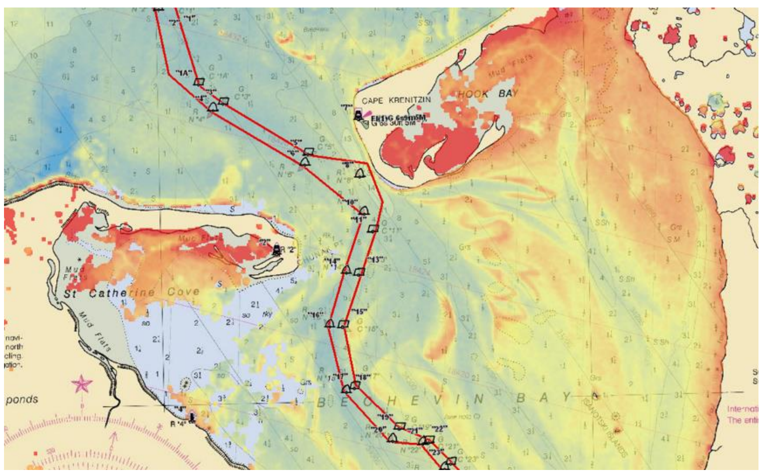

Figure 4. Turbidity map using a Landsat 8 single-image SDB (green and red bands) overlaid on NOAA Chart 16535. Red areas represent clearer water and blue areas represent turbid areas.

The formal incorporation of SDB into NOAA's workflows are still to be determined. NOAA's Hydrographic Survey Division (HSD), the group tasked with identifying and addressing the survey priorities throughout the United States, has already found SDB to be useful as both a reconnaissance and planning tool – assisting with determining the accuracy of existing charted data and assessing the anticipated level-of-effort associated with a given project. In addition to the above, survey conducted by the USCG, HSD contracted Terrasond Limited to conduct a full bathymetric survey of Bechevin Bay and False Pass, AK. The SDB result (Figure 4) was passed on to the field party to improve their surveying efficiency by focusing their efforts on the potential navigable channels, while simultaneously avoiding areas where they may risk grounding their vessel. Initial reconnaissance survey lines were planned based on the charted 4-meter contour limits and compared well to the channels suggested by the SDB. Interestingly, the SDB turbidity map was validated the possibility for a secondary channel through Bechevin Bay (Figure 5) that is characterized with fewer turns (thus being easier to navigate), and potentially being more geologically stable than the presently demarcated channel which is known to shift annually.

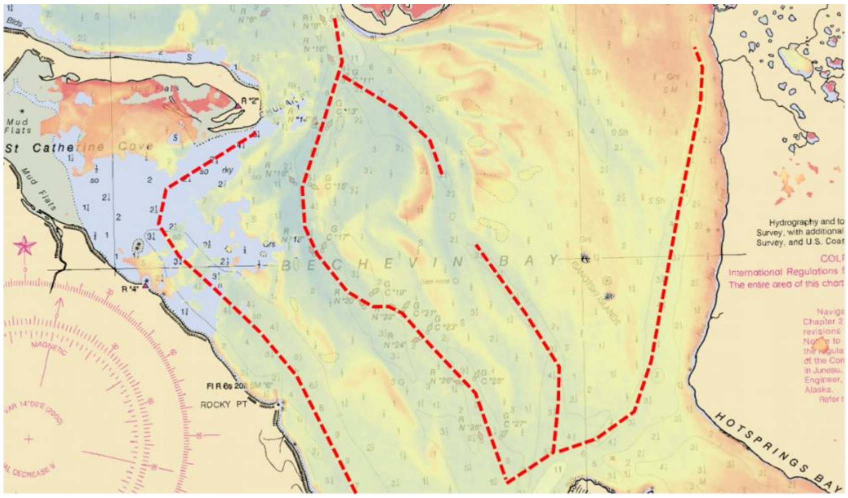

Figure 5. Initial reconnaissance survey lines based on 4-meter contour overlaid on turbidity map and NOAA Chart 16535.

With the reconnaissance lines validating the channels suggested in the SDB turbidity map, the field party was then able to strategically plan out the remainder of the survey, emphasizing and delineating all the deeper channels, while skirting around the shoal, non-navigationally significant waters. Executing the survey in this way is both more efficient and safer than the traditional methods for searching navigable waters using a single beam sonar or half-stepping with a multibeam sonar. Ultimately, an alternative channel was identified; however, the depths were not as deep as those within the presently demarcated channel (Figure 6). That written, this alternate channel does exist and can provide a navigation route for vessels with a shallower draft. The alternate would not have been mapped by the field party if the SDB turbidity map was not available.

To summarize from the perspectives of both field acquisition and office planning, the SDB turbidity map has successfully demonstrated its value. The field can execute a more efficient survey plan, reducing time spent down navigational dead-ends and focusing on surveying deeper waterways. Meanwhile, the office has a remote sensing tool for assessing currency and historic datasets. Thus, the expensive undertaking of deployment of field units can be focused only on those areas in greatest need of updated bathymetric data. It is evident that SDB has a key role to play in the future of the survey planning and determination of survey priorities.

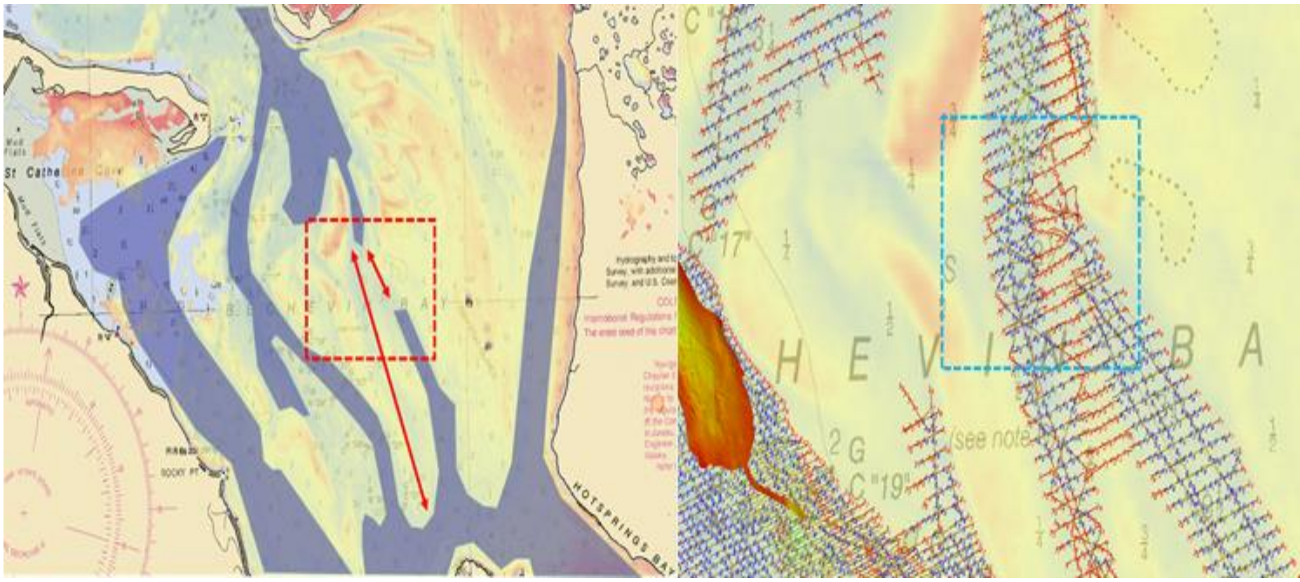

Figure 6. Terrasond investigation area (left) and completed sounding set (right) overlaid on Turbidity map and NOAA Chart 16535.

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