Using WorldView-2 Multispectral Bands for Shallow Water Bathymetric Survey near Wales, Alaska

By: Jacquelyn R. Smith[1], Nicole E.M. Kinsman[2], and Debasmita Misra[3]

[1]Graduate Research Assistant, Geological Engineering, University of Alaska Fairbanks, [2]Alaska Division of Geological & Geophysical Surveys, Fairbanks, Alaska,
[3]Department of Mining and Geological Engineering, University of Alaska Fairbanks

**This poster was presented at the 2013 American Society of Photogrammetry and Remote Sensing Conference in Baltimore, Maryland

Abstract

Coastal flooding and erosion from storm surges have been identified as imminent threats to communities along the northwest coast of Alaska. High resolution nearshore bathymetric surveys are required to properly predict landfall timing and intensity of storms, as well as to identify areas most vulnerable to overwash and inundation. To collect high-resolution, shallow-water bathymetric measurements for the vast state of Alaska, remote sensing must be employed. Bathymetric data have been derived from WorldView2 multispectral satellite imagery using the Spectral Processing Exploitation and Analysis Resource (SPEAR) Relative Water Depth Wizard in ENVI™. Using this method, in combination with ground truth values from a single beam sonar survey, we have produced a bathymetric map for a region near Wales, Alaska. Derived and measured depths have been compared using a linear regression between corresponding survey points and image pixels with an R^2 = 0.7221. Locations with potentially high suspended sediment loads were found to cause discrepancies between surveyed and derived depth values.

Processing Flow Chart

SPEAR Relative Water Depth Wizard in ENVI™ → Trial to find best color composite → RGB 431 (yellow, green, coastal blue) → Density slice output RGB at spectral reflectance intervals → Regional relative water depth map (Figure 5b)

Density slice output RGB at spectral reflectance intervals → Calibrate density slice to actual depth (based on survey) → Average pixels to 16 m resolution, to reduce noise → Cut to ~3 m depths → Bathymetric map 16 m xy resolution, 0.25 m z resolution (Figure 6)

Introduction

Remote sensing technologies provide earth scientists with many applications for geo-hazard identification and assessment that can, in certain locations, be used to improve engineered mitigation approaches. Remote sensing approaches may be especially useful in Alaska, where aerial and satellite imagery can facilitate the identification of and responses to natural hazards in areas where access can be limited by cost and remoteness. Utilizing knowledge gained from the application of remote sensing techniques could provide an efficient and cost-effective avenue for scientific analysis to help advance engineering and public safety in these remote locations of Alaska.

For the region of Wales, Alaska (Figures 1 & 2), bathymetric data are sparse, but have the potential to be derived from remote sensing techniques. Bathymetric data are important for analyzing inundation and erosion by storm surges (Figure 3). A higher spatial resolution of bathymetry in critical shallow-water areas would improve our ability to model hazards from storm surge and would support efficient engineering solutions. Bathymetric data are also important for updating navigational charts, understanding benthic environments, and for use in sediment migration studies.

One method for obtaining necessary water depth measurements that has not been thoroughly explored in Alaska uses select spectral bands on the WorldView2 sensor (coastal blue 400-450 nm and yellow 585-625nm) to measure the absolute bathymetry of coastal regions (Lee et al., 2012, Madden, 2011, Miecznik et al., 2012, Tarantino et al., 2012). If a method of bathymetric calculation through remote sensing can be successfully developed for Alaska, communities all along the Alaskan coastline would benefit immensely.

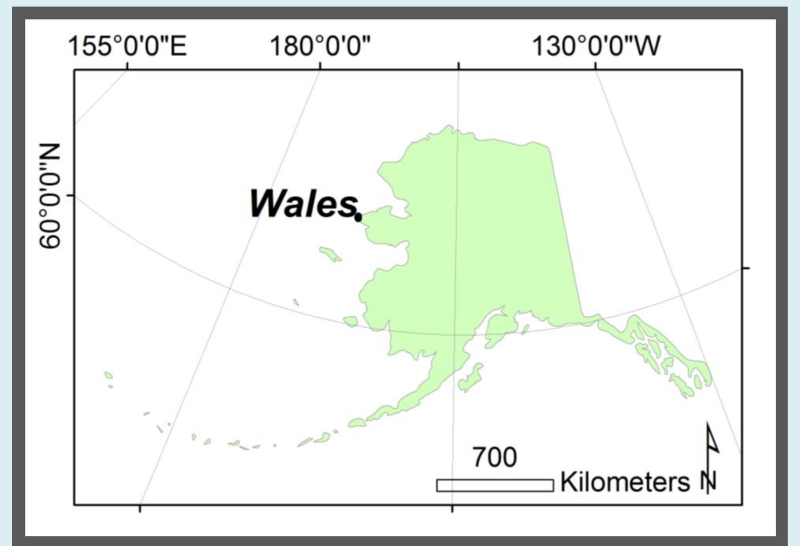


Figure 1—Location of Wales in the state of Alaska

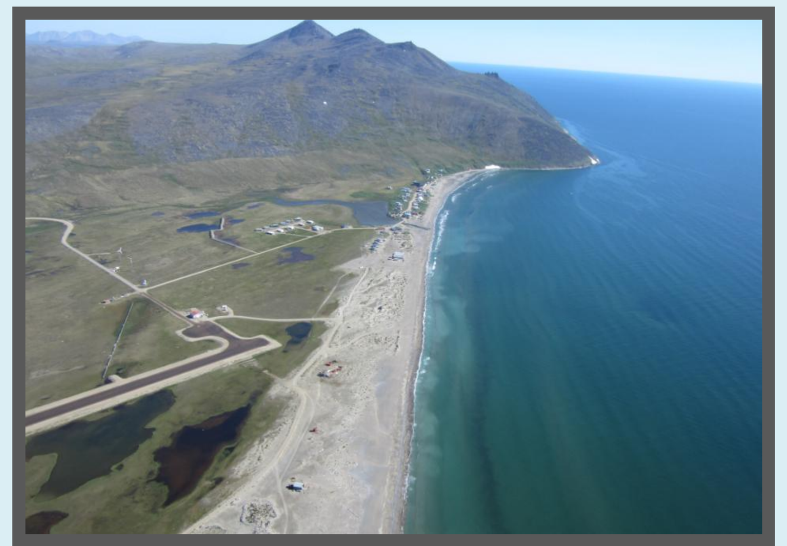


Figure 2—Oblique aerial photo of Wales, Alaska

Figure 3—Photo of storm surge at Wales, Alaska, taken November 9, 2011 by Ellen Richard

Background

The electromagnetic radiation (EM) sensed by a satellite sensor has interacted with the atmosphere, water, and land, before it reaches the sensor (Figure 4). These interactions distort the electromagnetic radiation, leading to differences in intensity that make up a satellite image. The interactions of EM radiation and these substrates can be used to measure natural phenomena in predictable ways. In this study, we have used the known reflectance characteristics of water to determine the depth of water in the nearshore environment.

The WorldView2 sensor was specifically designed to collect and record wavelengths of EM radiation that can be used to measure bathymetry. The bands of multispectral data include coastal blue (400-450nm) and yellow (585-625nm) (Digital Globe, 2011), (Table 1). The coastal blue band encompasses EM radiation that has penetrated farther into the water column than other bands in the visible spectrum, and the yellow band provides a smoother contrast to the coastal blue than other bands. WorldView2 imagery has been successfully used for bathymetric studies in tropical regions (Lee et al., 2012, Madden, 2011, Miecznik et al., 2012, Tarantino et al., 2012). However, because of differences in water temperature, sediment load and bottom albedo, it is unknown if these methods can be transferred to the Arctic.

Table 1—Worldview2 Sensor Information

Sensor Name	Data	Resolution				Orbit Altitude
		Spatial	Spectral	Temporal	Radiometric	
Worldview2	Multispectral	2.00 m	**1-Coastal Blue (400-450 nm)** 2-Blue (450-510 nm) **3-Green (510-580 nm)** **4-Yellow (585-625 nm)** 5-Red (630-690 nm) 6-Red-Edge (705-745 nm) 7-NIR1 (770-895 nm) 8-NIR2 (860-1040 nm)	Less than 3.7 days at 20° off nadir	11 bits per pixel	770 kilometers
Worldview2	Panchromatic	0.5 m	450-800 nm	see above	"	"

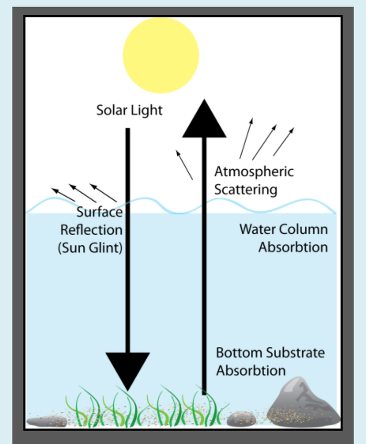
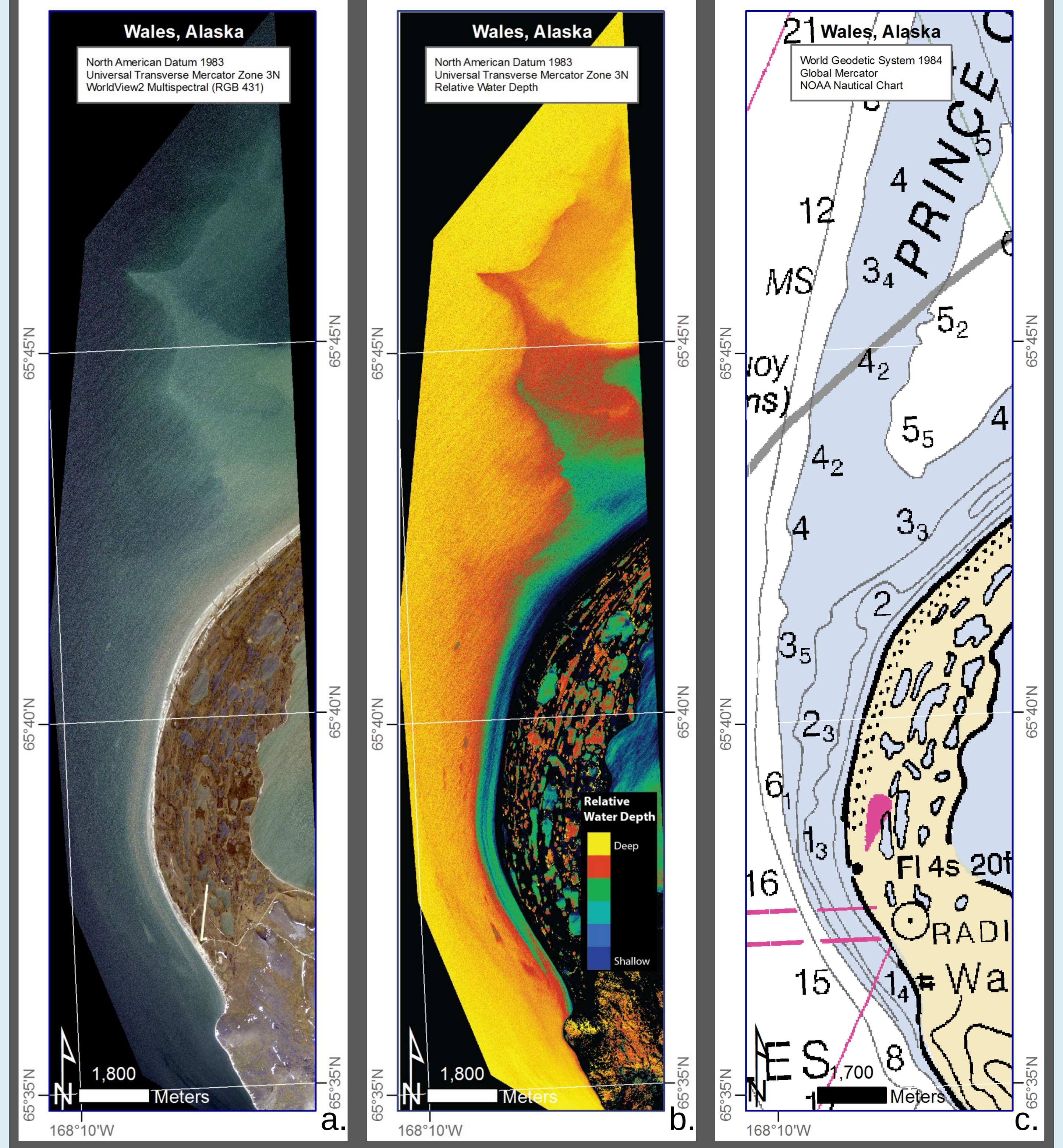


Figure 4—Schematic of EM radiation paths



Figures 5 a, b, c—Resultant relative water depth map(b) compared to original RGB(a) and nautical chart modified from National Oceanic and Atmospheric Administration (2004)(c)

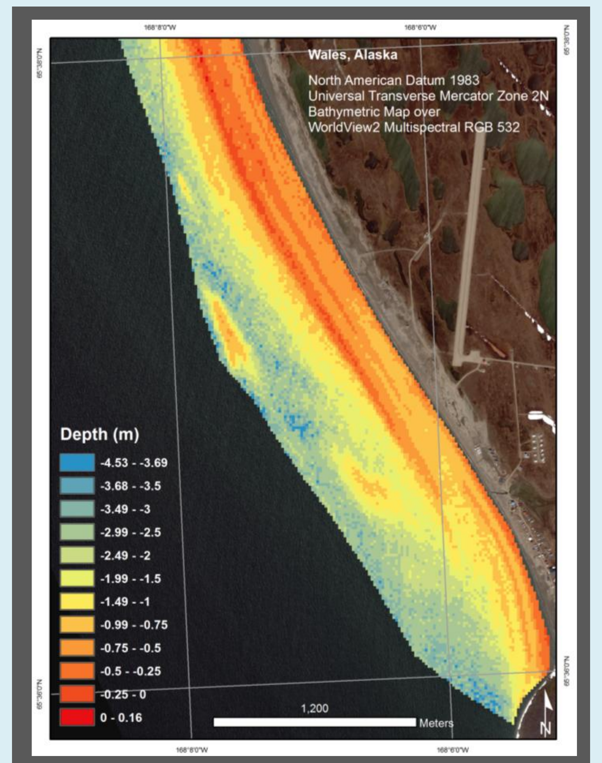


Figure 6—Calculated bathymetric map of the nearshore, image taken **June 27, 2012**

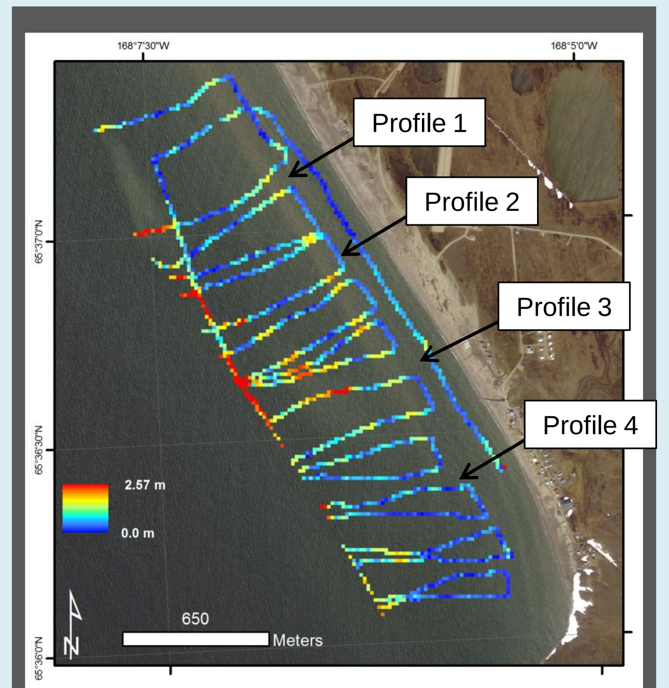


Figure 10—Absolute value of surface difference plot between surveyed and derived depths

Method

An expedited approach to calculating bathymetry from satellite imagery uses pre-existing algorithms developed for use in GIS software. One version of these algorithms requires an estimate of the local seafloor albedo, or reflection coefficient. Because the albedo was unknown for Wales, an albedo-independent method was used to derive a bathymetric map from a WorldView2 multispectral scene.

Albedo-Independent Algorithm

Lyzenga (1978, 1985) took into account the exponential relationship of light attenuation through a column of water to develop a linear transformation function that relates observed radiance with water depth. Stumpf et al. (2003) expanded Lyzenga's equation to a ratio transform function that can calculate water depth without information about seafloor albedo (Equation 1).

In the model, each band of light is attenuated depending on its wavelength. As the wavelength increases, depth to attenuation decreases. If attenuation of two bands of light are compared as a ratio, the value is proportional. This suggests that bottom albedo would not affect the ratio of the bands at similar depths. Once a value for this ratio is calculated for each pixel, the image sample can then be calibrated to actual measured depth. The ratio transform function has been pre-packaged into the SPEAR Relative Water Depth Wizard (RWDW) in the spectral menu, by ENVI™.

SPEAR Relative Water Depth Wizard

To test this method in an Arctic setting, we used the RWDW on a WorldView2 false color composite (RGB 431) of Wales, Alaska (Figure 5a). When compared to running the RWDW using band combinations of RGB 532, 531, and 432, RGB 431 had the best resolution and least visual noise, so this composite was used for the analysis. The entire scene was run to produce a map of raw relative water depths (Figure 5b) and compared to the NOAA nautical chart (Figure 5c). A subset region of interest was calibrated to actual depth around a nearshore location that was surveyed within one month of image collection (Figure 6).

The image output from the calibrated RWDW includes an RGB and density slice of relative depth reflection. This RGB was put through a more rigorous density slice to produce 8 spectral classes (compared to 4 in the RWDW). These classes were associated with specific ranges of depths based on the surveyed depth measurements. The classes were transformed into water depths using ERDAS Imagine™. To reduce noise, the image was transformed to a 16 m spatial resolution from 2 m, by using the arithmetic mean of the pixels within each 16 m². The only region with a spectral variability of 0.25 m was in nearshore depths of up to 3 m deep; the derived bathymetric map has been clipped to show only the results for depth of less than 3m.

Sonar Data

Bathymetric data were collected in the summer of 2012 by a boat-mounted, single-beam sonar system (Figure 7). Perpendicular transects were collected at a spacing of approximately 50 to 100 m alongshore, an additional two transects were collected parallel to shore (Figure 8). These measurements have been converted into elevations relative to NAVD88 and averaged at 16 m intervals to be used for calibration of the RWDW output. The total number of measurements compared was 1,480.

Equation 1 $$Z = m_1 \frac{\ln(nR_w\lambda_i)}{\ln(nR_w\lambda_j)} - m_0$$

Z=depth,
m_1= constant,
n=fixed value to ensure the logarithm will be positive and the relationship will be linear,
R_w=observed radiance,
λ_i=band i,
λ_j=band j,
m_0=offset for zero depth.

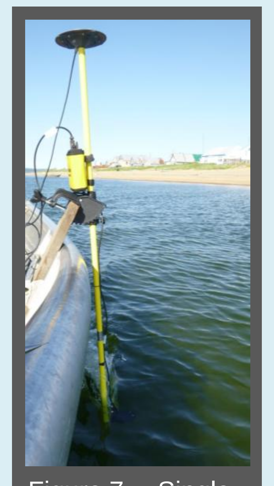


Figure 7— Single beam sonar system

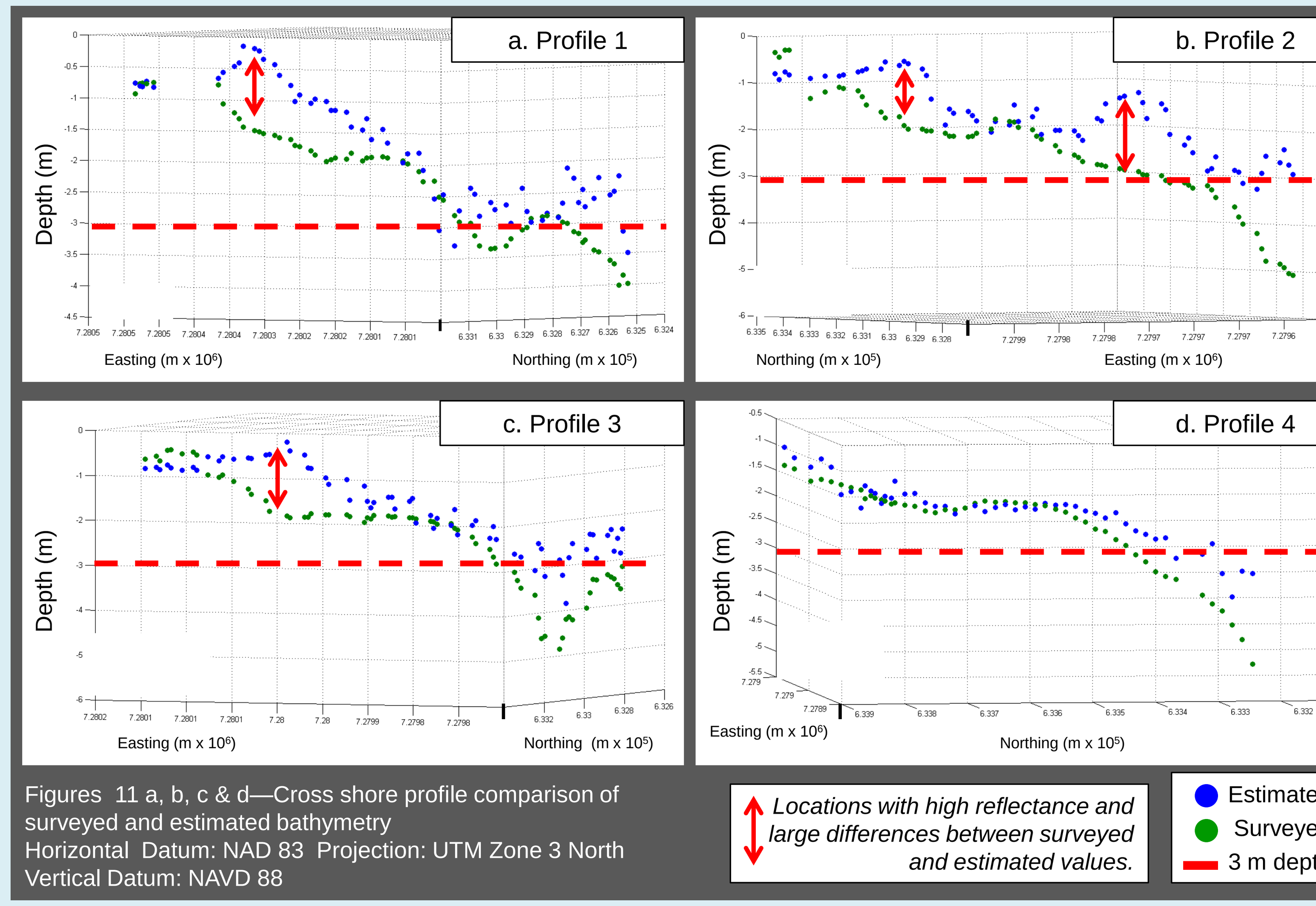
Figure 8—Bathymetric survey points collected **July 29, 2012**

Discussion

The coastal blue, green, and yellow bands of Worldview2 multispectral imagery, processed with the RWDW, provide bathymetric data for Wales at a more continuous sampling rate than surveyed data and data available on current nautical charts (Figure 5c). The nearshore region was mapped at 0.25 m contour intervals up to 3 m depth and when compared to survey data, produced an R^2 value of 0.7221. Shallow-water bathymetry (~3 m deep) is useful for storm surge studies and other applications. However, inconsistencies between shore-normal profiles in the datasets reveal a sensitivity of this analysis to possible suspended sediment. Although the image was taken a month before the survey, the differences in shore-normal profiles indicate significant increases in elevation above surveyed troughs that are unlikely the result of natural, seasonal shifts in the seafloor, which may have been explained by sandbar migration. More likely, the alongshore trough, located at a distance of approximately 200 m from shore, may act as a location of high sediment transport, giving rise to increased reflectance at this location and producing false returns in the derived depth map.

Factors Contributing to Inaccuracies:

- False shallow returns because of potential sediment transport zones.
- The image was taken one month before the survey was performed. The nearshore environment is constantly changing, even within the same season. Because of this, bathymetric features could have shifted during storm events or with currents, which necessitates further survey and understanding.
- Noise in the water reflectance arising from sun-glint patterns that cannot be systematically removed because of their irregularity.
- Noise in surveyed data because of boat movement during collection.



Figures 11 a, b, c & d—Cross shore profile comparison of surveyed and estimated bathymetry
Horizontal Datum: NAD 83 Projection: UTM Zone 3 North
Vertical Datum: NAVD 88

Results

A direct comparison between the derived depth value of each pixel and the corresponding sonar measurements was made using a linear regression, shown in Figure 9. The linear regression resulted in an R^2 value of 0.7221 between the data (N=1,480). The absolute difference between the sonar measurements and the corresponding derived depth values are shown in Figure 10. Figure 10 illustrates the increased correlation between measured and derived values as depth decreases, however, consistent differences can be observed across locations of high spectral reflectance. From the plotted cross-sections of derived and measured data points (Figure 11a-d), the locations with high spectral reflectance are shown to be locations of troughs by the surveyed data. Without the presence of high reflectance zones, the measured and derived values of depth are very similar until about 3m, where the plots begin to diverge (Figure 11d).

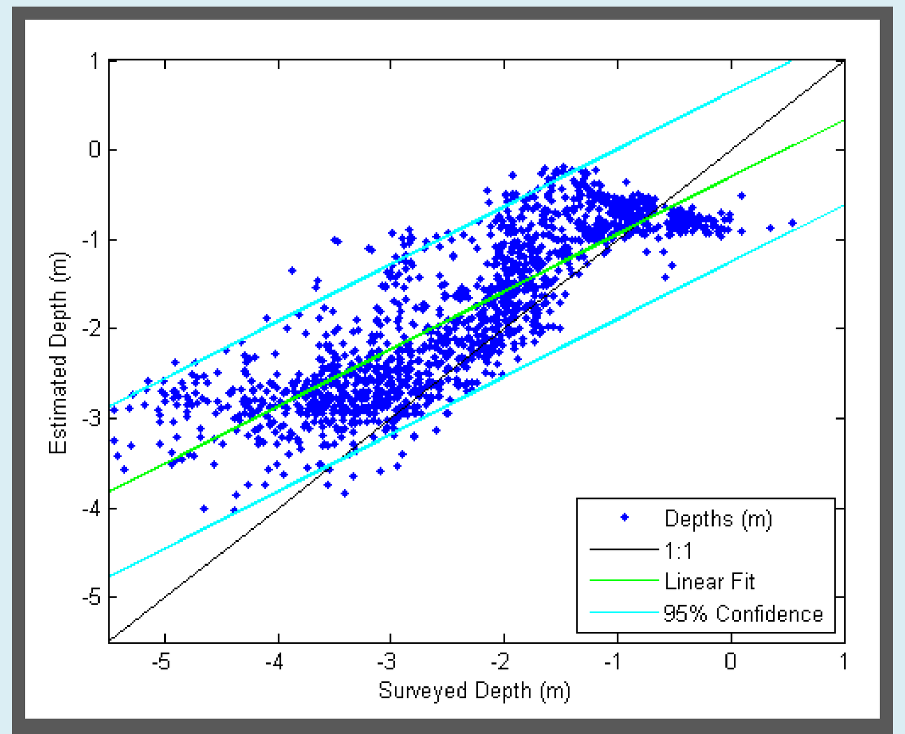


Figure 9—Linear regression between surveyed and estimated data with 95% confidence interval

Future Research

For regions with less sediment laden water, this method may be appropriate for estimating bathymetry up to about 3 meters depth. Other methods discussed by Bramante et al. (2013) such as the linear band model may increase bathymetric resolution in sediment laden waters; however, depth limitations will still exist.

Due to the methodological approach used in this study, we were unable to determine the minimal number of survey transects necessary to establish accurate depth intervals. Determination of the minimal number of survey transects that will not compromise accuracy of the derived bathymetric map may be possible with a classification system based on training areas rather than a density slice. A valid option would use support vector machines or maximum likelihood classification with differing percentages of training pixels (Oommen, et al., 2007).

Conclusions

- The WorldView2 satellite imagery was used to derive a bathymetric map for shallow-water less than 3 m deep near Wales, Alaska. A linear regression between measured and derived values of absolute depths resulted in an R^2 of 0.7221.
- The coastal blue and yellow bands of the WorldView2 sensor enhanced the spectral separation for this study.
- Potentially sediment laden waters disrupted the seafloor reflectance in WorldView2 multi-spectral imagery.

Acknowledgments

This research is funded, in part, with qualified outer continental shelf oil and gas revenues by the Coastal Impact Assistance Program, U.S. Fish and Wildlife Service, U.S. Department of the Interior. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the U.S. Government. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Government.

Completion of the nearshore bathymetric survey was funded, in part, by the Western Alaska Landscape Conservation Cooperative.

This research was also funded, in part, by the Alaska Space Grant Graduate Research Fellowship.

We would like to thank our boat operator, Amos Oxereok, for his contributions to the July 2012 bathymetric survey.

We would also like to thank Scott Huang for participating in the graduate advisory committee for this research.

References

Bramante, James F., Raju, Durairaju Kumaran , and Sin, Tsai Min, (2013), Multispectral derivation of bathymetry in Singapore's shallow, turbid waters: International Journal of Remote Sensing, vol. 34, no. 6, p. 2070-2088.

Digital Globe, October, 2011, Bathymetry Data Sheet: *Digital Globe*, 2 p.

Lee, Krista R., Oslon, Richard C. and Kruse, Fred A., May 1, 2012, Using multi-angle WorldView-2 imagery to determine ocean depth near the island of Oahu, Hawaii, *Proc. SPIE* 8390, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XVIII, 83901I.

Lyzenga, D.R., 1985, Shallow-water bathymetry using combined lidar and passive multispectral scanner data: *International Journal of Remote Sensing*, vol. 6 p. 115-125.

Lyzenga, D.R., 1978, Passive Remote Sensing techniques for mapping water depth and bottom features: *Applied Optics*, vol. 17.

Madden, C.K., 2011, Contributions to Remote Sensing of Shallow Water Depth with the WorldView-2 Yellow Band [Thesis]: Department of Physical Oceanography and Meteorology, Naval Postgraduate School, Monterey, California.

Miecznik, Grzegorz and Grabowska, Dorota., May 1, 2012, WorldView-2 bathymetric capabilities, *Proc. SPIE* 8390, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XVIII, 83901I.

National Oceanic and Atmospheric Administration, October 4, 2004, Norton Sound to Bering Strait 1:400,000: NOAA National Ocean Service Coast Survey, no. 16200.

Oommen, Thomas, Misra, Debasmita, Twarakavi, Navin K.C., Prakash, Anupma, Sahoo, Bhaskar, and Bandopadhyay Sukumar, 2007, An objective analysis of support vector machine based classification for remote sensing: *Math Geosci.*, no. 40, p. 409-424.

Stumpf, Richard P., Holderied, Kristine, and Sinclair, Mark, 2003, Determination of water depth with high-resolution satellite imagery over variable bottom types: *Limnology and Oceanography*, no. 41(1, part 2), p. 547-556.

Tarantino, Cristina, Adamo, Maria, Pasquariello, Guido; lovergine, Francesco, Blonda, Palma, Tomaselli, Valeria, 2012, 8-Band Image Data Processing of the Worldview-2 Satellite in a Wide Area of Applications: *Earth Observation*, Rustam B. Rustamov and Saida E.Salahova (Ed.), ISBN: 978-953-307-973-8, InTech.