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Future directions in hydrography using satellite-derived bathymetry

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

Christopher Parrish
University of New Hampshire, Durham

Lee Alexander
University of New Hampshire, Durham, lee.alexander@unh.edu

Chukwuma Azuike
University of New Hampshire, Durham

Andy Armstrong
University of New Hampshire, Durham

See next page for additional authors

Authors
Shachak Pe'eri, Christopher Parrish, Lee Alexander, Chukwuma Azuike, Andy Armstrong, and Maryellen Sault

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Shachak Pe'eri[1], Christopher Parrish[2, 3], Lee Alexander[1], Chukwuma Azuike[1], Andrew Armstrong[1,3]and Maryellen Sault[2]

[1] Center for Coastal and Ocean Mapping, University of New Hampshire, Durham, NH 03824, USA

[2] NGS Remote Sensing Division, NOAA/NOS, National Geodetic Survey, Silver Spring, MD 20910, USA

[3] Joint Hydrographic Center, National Oceanic and Atmospheric Administration, Durham, NH 03824, USA

Contact author: shachak@ccom.unh.edu

Summary

Satellite remote sensing provides useful reconnaissance tool for mapping near-shore bathymetry, characterizing a coastal area and monitoring any seafloor changes that may have occurred since the last hydrographic survey of the area. At the 2012 Canada Hydro conference, a study was presented on the potential use of Landsat satellite imagery to map shallow-water bathymetry in a GIS environment over three study sites. Since then, several collaborations between the current study group and various hydrographic organizations were established with the goal of implementing optically-derived bathymetry as part of their data acquiring procedure. Bathymetry over additional study sites around the world was tested. Also, different commercial software packages were evaluated to provide an affordable processing platform for hydrographic offices in developing countries. In this paper, an overview will be provided on the advances that have been achieved in the past year and an update and future directions of the study.

Satellite-derived bathometry

We presented our work at the Canadian Hydrographic Conference 2012 (CHC2012) showing that a satellite-derived bathymetry procedure can be used in a coastal location with few reference soundings (minimum two soundings) from a nautical chart. The procedure is robust and can be implemented in a variety of GIS environments, including open-source GIS software. The procedure can be used as a reconnaissance tool for investigating marine areas before a high-resolution hydrographic survey (e.g., multibeam echosounder (MBES) or airborne lidar bathymetry (ALB)) is conducted. The Landsat georeferenced imagery usually has a stated 50 m horizontal accuracy, which is suitable for mid- to small-scale nautical charting applications. The procedure does not require additional information beyond the use of satellite imagery, and a nautical chart for referencing to the vertical datum. In particular, tide-coordinated imagery is not required

The satellite-derived procedure was verified in a U.S. calibration study site (Rockport, MA) that contains a bathymetric reference dataset from an ALB survey and tidal information. In addition to the U.S. calibration study site, shallow-water bathymetry was also produced in the coastal waters of Nigeria and Belize. These two sites were selected based on the IHO publication C-55 (IHO, 2004) that identified the nautical charts as containing gaps in their hydrographic data. In Nigeria, the satellite-derived bathymetry correlated well with areas that have been recently surveyed (a commercial survey from 2004) near the entrance to Escravos River. Bathymetry derived from the procedure identified discrepancies between depths and chart soundings in the northern section of the chart over a large area (several tens of square kilometers) and in the Benin River mouth north to Escravos River. Based on the source diagram and the chart symbols, it seems that for a primary factor in this discrepancy is that the area has not been surveyed since 1913. Following the success of the initial study, we received responses from several hydrographic groups that led to the expansion of the study and collaboration with the General Bathymetric Chart of the Oceans (GEBCO) group and Integrated Ocean and Coastal Mapping (IOCM) program in National Oceanic and Atmospheric Administration (NOAA). The procedure was documented and published in the GEBCO Cookbook (http://ibis.grdl.noaa.gov/SAT/GEBCO_Cookbook/index.php). This International Hydrographic Organization/International Oceanic Commission (IHO/IOC) publication is a publically-available manual to allow user all over the world to use and produce bathymetry from archives that are available on the web (GEBCO, 2012). A follow-up study with the IOCM program began over the past year. The goals of the study were defined based on questions and comments that we received:

1. Is the procedure limited spatially or can it be applied to other geographical locations, namely the Arctic?
2. The water clarity is the main error source. Is it possible to reduce this error or at least identify the locations most affected by water clarity?
3. Would this procedure work with imagery from other satellites?

Accordingly, this paper presents the procedure results over two U.S. sites: Buck Island, U.S. Virgin Islands and Barrow Point, Alaska. Bathymetry was derived from Landsat 7 and WorldView2 (WV2) satellite imagery. The satellite-derived bathymetry from both datasets was compared to a reference ALB dataset and historic soundings.

WorldView 2

One of the more recent multispectral imaging (MSI) data sources that is available for satellite-derived bathymetry is DigitalGlobe's WorldView-2 (WV-2) sensor. WV-2 provides eight multispectral bands at a resolution of about 2 m (Table 1). The spectral range of the bands is from 0.4 to 1.040 µm. According to DigitalGolbe (2012), each band is dedicated to a particular part of the electromagnetic spectrum to be sensitive to a specific type of feature on land, above or beneath water bodies, and in the atmospheric column. Although the swath width of WV-2 (18 km) is much smaller than the swath width of Landsat 7 (185 km), the WV-2 image resolution (~2m) provides the ability to identify smaller features that cannot be observed in the Landsat 7 imagery (28.5 m pixel resolution).

Band number	Band Name	Wavelength
Band 1	Coastal	0.400 - 0.450 µm
Band 2	Blue	0.450 - 0.510 µm
Band 3	Green	0.510 - 0.580 µm
Band 4	Yellow	0.585 - 0.625 µm
Band 5	Red	0.630 - 0.690 µm
Band 6	Red Edge	0.705 – 0.745 µm
Band 7	Near-IR2	0.770 – 0.895 µm
Band 8	Near-IR2	0.860 – 1.040 µm

Table 1. Band names and wavelength ranges of the multispectral WV-2 bands (Digital Globe, 2012).

Direct evaluation

The first IOCM study site was the Buck Island Reef National Monument (BUIS). The site is located northeast of St. Croix, U.S. Virgin Islands (USVI). The BUIS waters are very clear and considered as tropical/subtropical oceanic water (Jerlov oceanic waters, Case II-III). These very clear waters provide ideal conditions for a controlled evaluation of satellite-derived bathymetry over morphological features that vary in area and height above the seafloor. In addition to Landsat 7 and WV-2 imagery acquired over the BUIS study site, survey data collected from a LADS MKII ALB was used to derive reference bathymetry (Figure 1). The ALB survey was conducted on February 22, 2011 over the BUIS study site to map the protected coral habitat. Multiple band combinations of the WV-2 imagery were evaluated to determine the optimal bands for extracting bathymetry. The bathymetry was produced according to the satellite-derived procedure . The best bathymetry result was produced from band 1 (0.400 - 0.450 µm) and band 3 (0.510 - 0.580 µm). These different bathymetry grids were then compared to the reference ALB bathymetry. Bathymetry derived from Landsat 7 imagery was also produced using the same procedure. Due to resolution differences between the two satellite datasets, a comparison was conducted at the survey resolution of the reference ALB dataset (i.e., 4 m).

A horizontal shift was identified between the WV-2 imagery and the ALB dataset. This shift was corrected manually using a linear transformation. Although there might also be a horizontal shift between the Landsat 7 imagery and the ALB dataset, it was difficult to identify a shift smaller than 25-30 m because of the image resolution. The comparison results showed that the Landsat 7 imagery was less sensitive to the features on the seafloor. The areas in which both satellite imagery datasets did not perform well are in the optically-deep waters close to the extinction depth (i.e., 12 m below the MLLW) and over small coral features (< 5 m in diameter) with a large relief (> 2 m). The comparison over the areas where both datasets performed well showed similar results with up to ±2 m difference between the satellite-derived bathymetry and the reference ALB dataset.

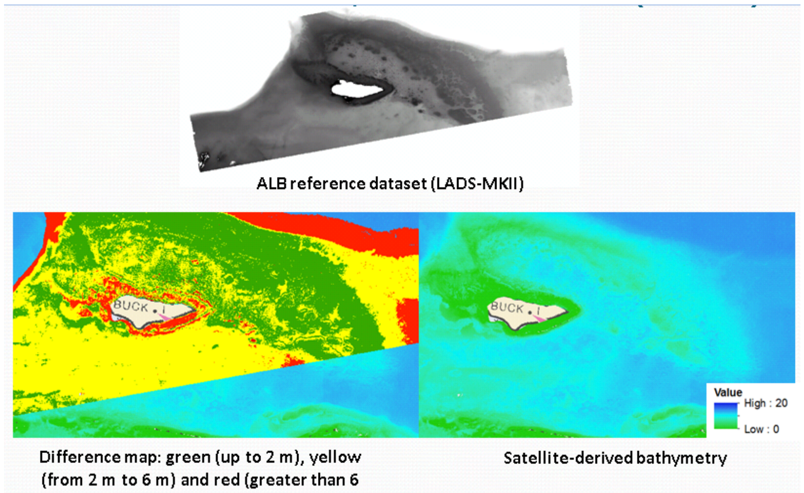

Figure 1. BUIS study site: (top) reference ALB dataset (LADS-MKII), (bottom right) satellite-derived bathymetry using WV-2, and (bottom right) difference depth map between the two bathymetric datasets..

<u>Time series</u>

In addition to a direct evaluation of the bathymetry, a time-series from three different WV-2 images was generated. This time-series allowed us to identify changes that might be related to either the bathymetry or the water column. In cases where the three images were acquired over a very short period (weeks to months) with no seasonal or weather-related events, the bathymetric changes between the images are most likely related turbidity in the water column. In order to test this hypothesis, the BUIS study site was used as a calibration site. A starting assumption was that bathymetry would not change much over the acquisition period between the three WV-2 images and no changes would be identified in the satellite-derived bathymetry. As expected, no bathymetric changes were noticed in the comparison between Landsat and WV-2 bathymetric datsets.

This same time-series approach was also tested over the Barrow Point, AK study site (Figure 2). Most of the waters around Barrow have not been surveyed since the early 1960's (NOAA, 2004). We expected to encounter water clarity issues in the near-shore area based on the weather conditions and the local geology. The main issue was no *a priori* knowledge on the exact locations of the local currents that can carry suspended sediments which affect water clarity. Bathymetry from three different WV-2 images was generated. The calculated extinction depths ranged from 3 to 5 m below MLLW. A comparison between the bathymetry datasets identified "stable" areas; where the water clarity was clear in all three WV-2 images and reliable bathymetry could be calculated. Most of these "stable" areas were within the Elson Lagoon (east to Point Barrow). The west side of Point Barrow was found to be too murky for deriving bathymetry.

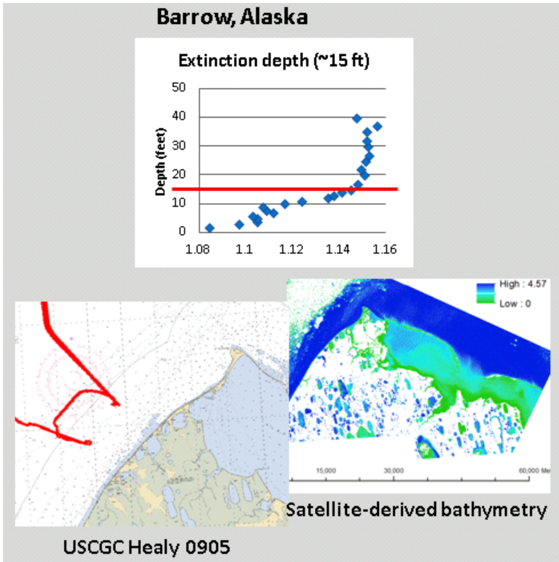

Figure 2. Point Barrow, AK

Discussion

When deriving shallow-water bathymetry, it is important to consider the environmental conditions that could degrade the estimated accuracy of the bathymetric product. Water clarity is a key factor that determines the penetration of light in water. The depth of the seafloor can only be estimated to the extent of this penetration. Turbidity will also lead to a false shoaling in most algorithms for depth retrieval from satellite imagery. Due to this limitation, it is important to regard satellite-derived bathymetry as a reconnaissance tool, and not a replacement for an acoustic (e.g., interferometric sonar or multibeam echosounders) or active remote sensing (e.g., ALB) hydrographic survey. Although the satellite-derived bathymetry was able to indicate the shallow-water bathymetry, it also mapped deeper areas and underestimated their depth values due to water clarity.

Although the focus of this follow-up study was on WV-2 imagery, it is important to note the data availability from other satellite missions. Landsat 7 has operated successfully since April, 1999. However, its operations have been marred by a faulty scan line corrector since June, 2003. This flaw has made coastal mapping with the satellite problematic. A new Landsat satellite, Landsat Data Continuity Mission (LDCM), was launched in 2013 (ldcm.nasa.gov/). In addition, satellite imagery at higher pixel resolution can be purchased from commercial companies (e.g., Ikonos and QuickBird). The substitution of Landsat 7 and WV-2 imagery with imagery from any of these other satellite is straightforward. However, it is important to identify the spectral bands that provide the best results using the procedure.

References

Digital Globe, 2012. WorldView-2 Data Sheet, last accessed Feb. 18, 2012: http://www.digitalglobe.com/downloads/WorldView2-DS-WV2-Web.pdf.

General Bathymetric Chart of the Oceans (GEBCO), 2012. GEBCO Cook Book V2.6.13: http://ibis.grdl.noaa.gov/SAT/GEBCO_Cookbook/document/CookBook.2.6.13.pdf.

International Hydrographic Organization (IHO). 2004. Publication C-55, Status of Hydrographic Surveying and Nautical Charting Worldwide, Monaco, third edition (Latest Update 27 September 2011).

National Oceanic and Atmospheric Administration (NOAA). 2004. Chart 16802: Pt Barrow and Vicinity, Scale: 1:47,943. Silver Spring, MD, U.S.A.