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Bridging The Land / Water Boundary Using SHOALS Bathymetric Lidar

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Abstract

The Optech SHOALS solution has proven to be an efficient means of providing depth information ranging from approximately 1.5 meters to 50 meters in clear water. However, the traditional depth extraction algorithm has limitations in very shallow water and/or turbid areas where lidar signals from the water surface and water bottom merge. Such limitations inhibit seamless lidar sounding at the land-water boundary and restrict a much broader application of laser bathymeters in inland environments as well as very shallow coastlines.

Historically, various approaches have been attempted towards recovering lidar points within the very shallow water region, but with limited success. However, over the past several years very promising advances in shallow water algorithms (SWA) have been made, demonstrating the depth-sounding capability of airborne lidar bathymeters in extremely shallow water as well as a seamless lidar depth solution across the land-water boundary.

A case study is presented using data collected around the Gulf of St. Lawrence in Quebec, Canada, where bathymetric lidar measurements were obtained in wetland and a network of shallow river channels. A review of the capabilities of SHOALS bathymetric lidar system in inland water environment will be presented. Particularly, the challenges of delineation of complex land/water boundaries and depth extraction in extremely shallow water will be discussed.

1. Introduction

Compared to vessel-based acoustic survey methods in water and traditional survey methods on land, airborne lidar bathymeters encompass unparalleled advantages in providing rapid and full coverage at the land/water boundaries. However, the advantages of airborne lidar bathymeters can only be fully realized when intelligent algorithms are employed that can consistently and reliably extract shallow water depths from the waveform data collected at the land/water boundary. Furthermore, due to the difference in light propagation through air and through water, meaningful water depth extraction and land elevation derivation from lidar waveforms depends on reliable discrimination between lidar returns from land surfaces and from water bottoms. Being able to reliably differentiate between these types of returns is critical to the success of delineating complex land/water boundaries and deriving both land and underwater topographies accurately.

In this paper, capabilities of the SHOALS bathymetric lidar system in both topographic mapping and bathymetric mapping will be discussed. In particular, the newly acquired ability to seamlessly extract shallow water depths at the land/water boundary will be demonstrated.

2. Overview Of The SHOALS Bathymetric Lidar System

Airborne laser bathymetric systems exploit time of flight photon echoes to determine the depths of water bodies. The Optech SHOALS system uses a combination of multiple wavelengths and scanning mirrors in order to accurately derive depths up to 50 m, with center to center horizontal resolution selectable between 2 and 5 m.

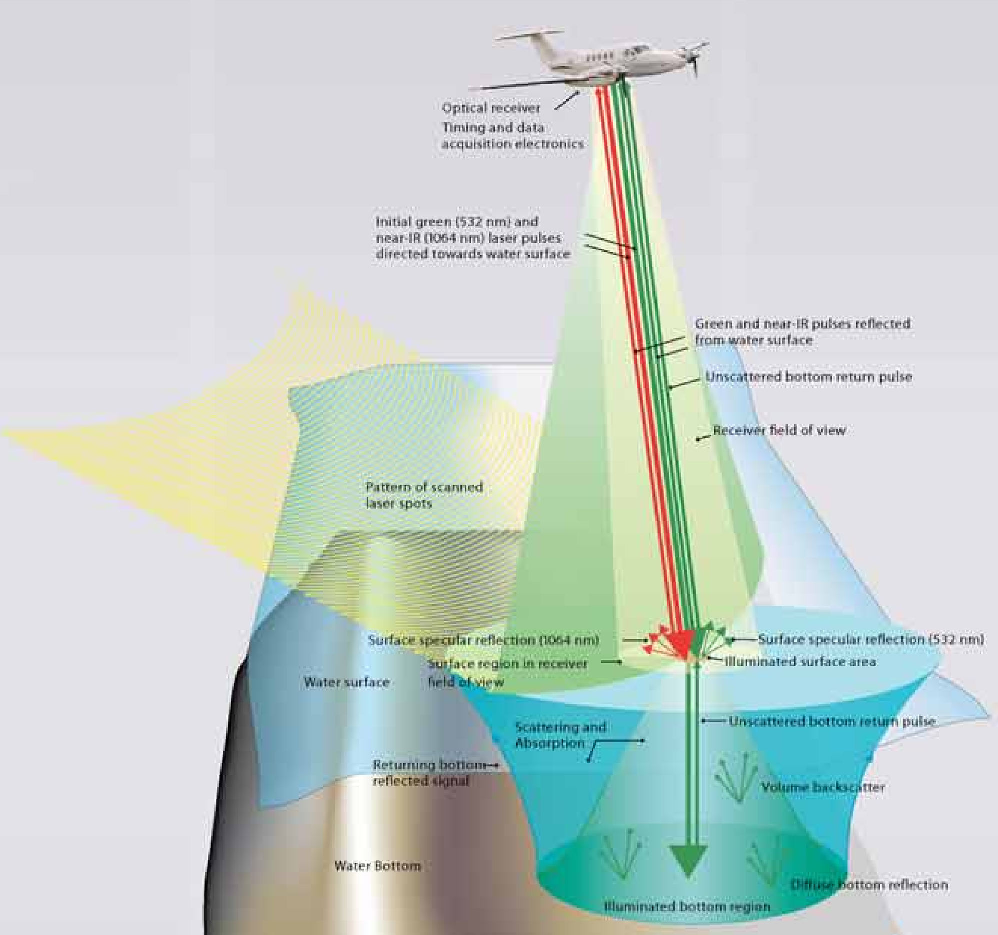

Figure 1: SHOALS Principle of Operation

Figure 1 illustrates the bathymetric principal of operation. Two arrows, red and green, are shown propagating from the aircraft and represent two wavelengths, at 1064 and 532 nm respectively. The infrared (IR) wavelength at 1064 nm is used to obtain a strong surface signal, triggering the data collection. The green wavelength at 532 nm penetrates and propagates through the water surface and is used for the depth sounding. Due to the scattering properties of water, the spot size within the water column flares out in a trumpet horn shape. The light propagates to the bottom of the water body, at which time it is reflected back to the airborne instrument and by means of its round trip time recorded as a depth sounding. In order to collect swaths of depth data along the flight path, the beam is scanned across the surface of the water as the aircraft is in flight. However, in order to ensure that the beam characteristics, such as beam spot size, are consistent, the entry angle into the water is held constant. For this reason, the bathymeter scanner slews in an arc, maintaining a constant nadir entry angle for the light, rather than a simple back-and-forth pattern.

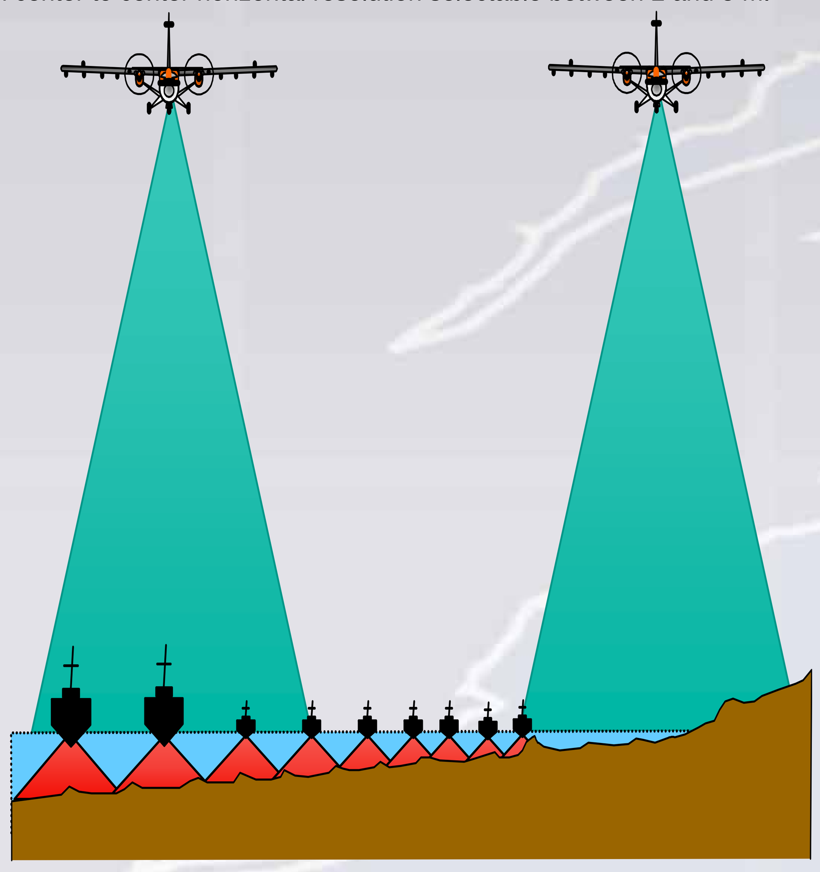

Figure 2: Advantages of SHOALS over SONAR in Coastal Water Sounding

The advantages of coastal water airborne bathymetry over SONAR are described in Figure 2. The swath detected from the aircraft is shown in comparison to the soundings taken from large surface vessels to the left of the cartoon and smaller surface vessels towards the shore. Given the smaller footprint of the surface vessels and their much slower speed, the advantages of airborne laser bathymetric systems are immediately apparent. It takes hours to provide depth charts for airborne systems as opposed to weeks for surface vessels. Also note that the bathymeter is capable of retrieving depth information in extremely shallow water where it is difficult and sometimes impossible for small surface vessels to access. The bathymeter is also capable of retrieving land elevations.

Although the SHOALS bathymetric lidar system has mostly been used in coastline mapping, its capability in simultaneously capturing land elevation and underwater bottom topography provides unparalleled application opportunities in the inland water environment. Traditional methods for bathymetric measurements and land surveys are labor intensive and very time consuming for riverine surveys, whereas terrestrial-oriented airborne lidar sensors have limitations in acquiring underwater coverage. The bathy-enabled SHOALS system, on the other hand, is capable of obtaining full coverage production rates of up to 70 km^2 per hour with complete bottom coverage at densities up to 2 m x 2 m, under such amalgamated inland water mixtures. Studies carried out by Woolpert and Fugro two years ago to map shallow rivers for the United States Bureau of Reclamation using the SHOALS bathymetric lidar system have initiated the inland water applications of lidar bathymetry, which also presented a challenge for capable algorithms to extract shallow water depths consistently and accurately. Our latest accomplishments in the development of SWA are aimed to answer such challenges and to provide a seamless solution at the land/water boundary.

3. Challenges at the land/water boundary

One of the advantages of using airborne bathymetric lidar is its efficiency in acquiring full data coverage at the land/water boundary, regardless of the complex environmental conditions underneath. However, there are a few challenges to achieve accurate lidar measurements at the land/water boundary, owing to the peculiarities of lidar bathymetry. Unlike vessel-based acoustic methods and traditional land survey methods, lidar measurement relies on proper differentiation of laser returns from either water or land in order to correctly evaluate the laser sounding. This is because laser propagation differs in the air and in the water and thus requires a different mathematical model to compute the accurate position of a lidar sounding according to its land/water identification. At complex land/water boundaries, such as in riverine environment, it is very important for robust and consistent discrimination between land returns and water returns. As well, accurate measurement of the air/water interface is of great significance.

As indicated earlier, our traditional depth extraction algorithm is not capable of extracting depth information from the waveforms generated from shallow water areas. This is because the traditional algorithm requires clear identification of bottom return signals for bottom timing measurement, whereas waveforms generated in extremely shallow water areas are merged waveforms without apparent distinction among various components of the combined laser return signal. For the past few years we have made significant progress in developing algorithms to reliably extract depths from the merged shallow water waveforms and greatly enhance the capability of the SHOALS bathymetric lidar system to seamlessly map across the land/water boundary.

Figure 3: Complex inland water environment

Figure 3 illustrates a camera image mosaic of a shallow water network at the entrance around the Gulf of St. Lawrence in Quebec, Canada, which was covered by a demo survey during the summer of 2006, using SHOALS bathymetric lidar. Achieving full data coverage in a complex terrain consisting of land and shallow water like the one illustrated in Figure 3 poses a challenge for any conventional survey method. However it is an ideal case to demonstrate the capability of SHOALS airborne bathymetric lidar systems for inland water mapping.

4. Advances in shallow depth extraction and case studies

Since 2004, Optech has been making progressive improvements to the SWA. One of the key challenges to continually improving the extraction of shallow water depths is being able to adapt the algorithm to the varying types of shallow water signatures produced by the varying shallow water conditions. Factors affecting the waveform shape are optical water properties, bottom reflectance, wind conditions, etc. Although these conditions produce many variants of shallow water waveforms, they are mostly single-peaked waveforms without clear separation between surface and bottom returns as illustrated in Figure 4. As previously mentioned, the traditional algorithm is only capable of extracting depth from a waveform where the bottom and surface return peaks can be clearly distinguished as in Figure 5.

Additional challenges are posed when dirty water is encountered as these signatures very closely resemble shallow water signatures as illustrated in Figure 6.

Currently the SWA yields reliable depth measurements that covers a broad range of shallow water waveforms. As well, the SWA can accurately discriminate and reliably reject waveforms from dirty water as it encompasses the intrinsic response functions of the system and applies such information to accurately determine the air/water interface and decompose the compound shallow water waveforms for depth extraction.

Combined with reliable algorithms for land/water discrimination, the SWA is capable of producing seamless deep to shallow to land results as illustrated in Figure 7 and Figure 8.

Figure 7 displays an overview of data coverage collected at a river network around the Gulf of St. Lawrence, Quebec. The deeper water area (towards the lower left corner) in the data coverage is part of the shoreline around the Gulf of St. Lawrence, whereas the mixture of land and water at the upper right corner reveals a complex river network connected to the Gulf of St. Lawrence. The depth range in this coverage is from 0 meter to about 6.5 meters, whereas most of the river channels are less than 2 meters deep.

Figure 8 shows a snapshot of lidar point clouds captured from the data coverage of Figure 7, which demonstrates details of the lidar point coverage at the complex shallow water river network outlined in Figure 3. The shallow water algorithm extracts all of the shallow water depths in the river networks.

5. Conclusion

The Optech Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) bathymeter has been widely recognized as an accurate, cost-effective, rapid, safe and flexible method for providing depth solutions from near shore up to 50 meters in clear water. Until now, most of the SHOALS applications have been for coastal mapping and for various bathymetric survey projects around the shoreline areas. However, the SHOALS bathymeters have the capability of simultaneously collecting dry-land topographical measurements as well as depth measurements under complex environmental conditions, which are usually difficult for conventional survey methods. With the continuous improvements in SWA, along with the capability of shot-by-shot land/water discrimination and seamless solution at the land/water boundary, the SHOALS bathymeters have demonstrated their suitability for inland water mapping making it a complete mapping tool from land to sea.

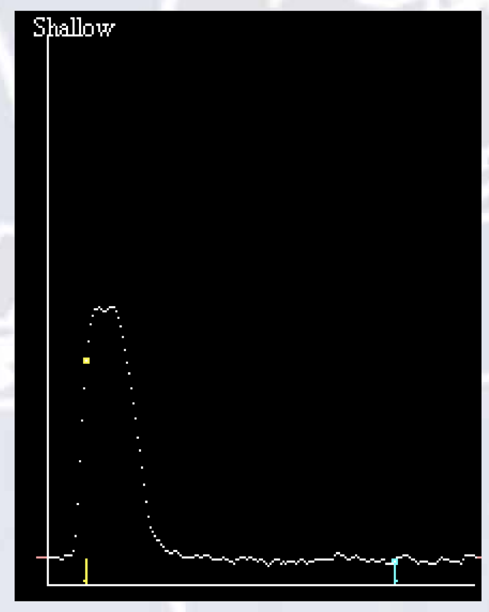

Figure 4: Sample waveform for shallow water algorithm

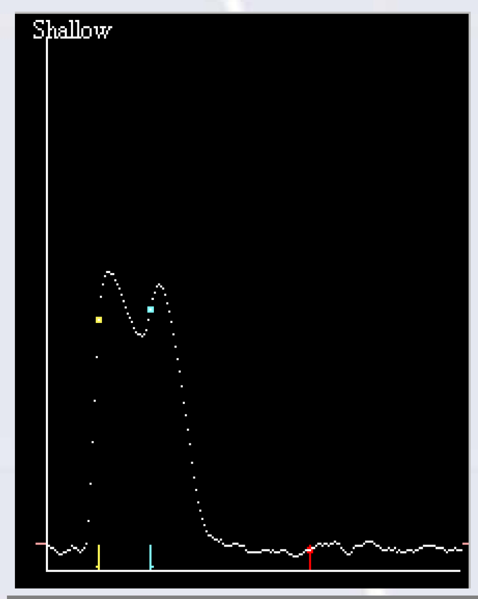

Figure 5: Sample waveform for traditional algorithm

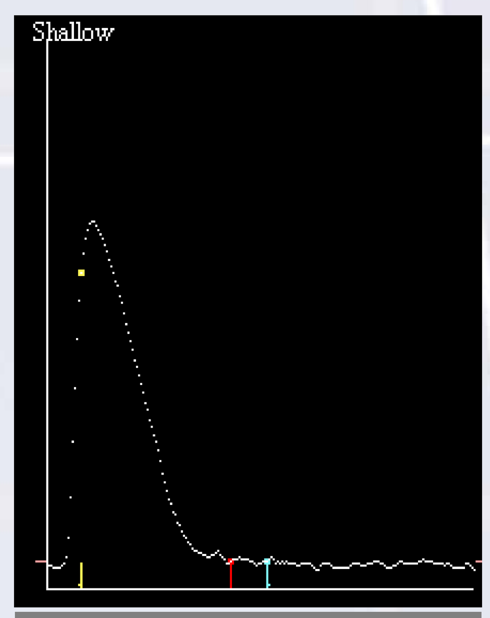

Figure 6: Dirty water waveform

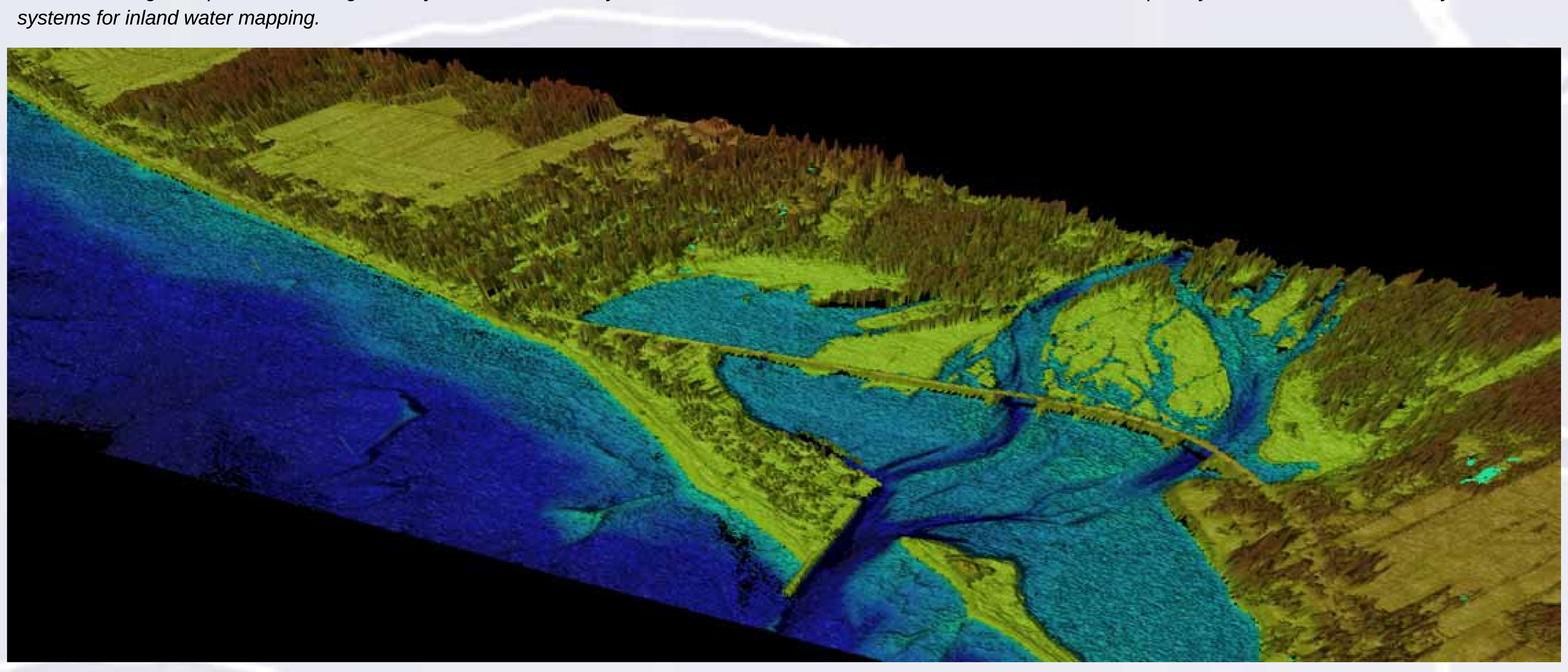

Figure 7: 3D visualization of lidar coverage around the Gulf of St. Lawrence, Quebec

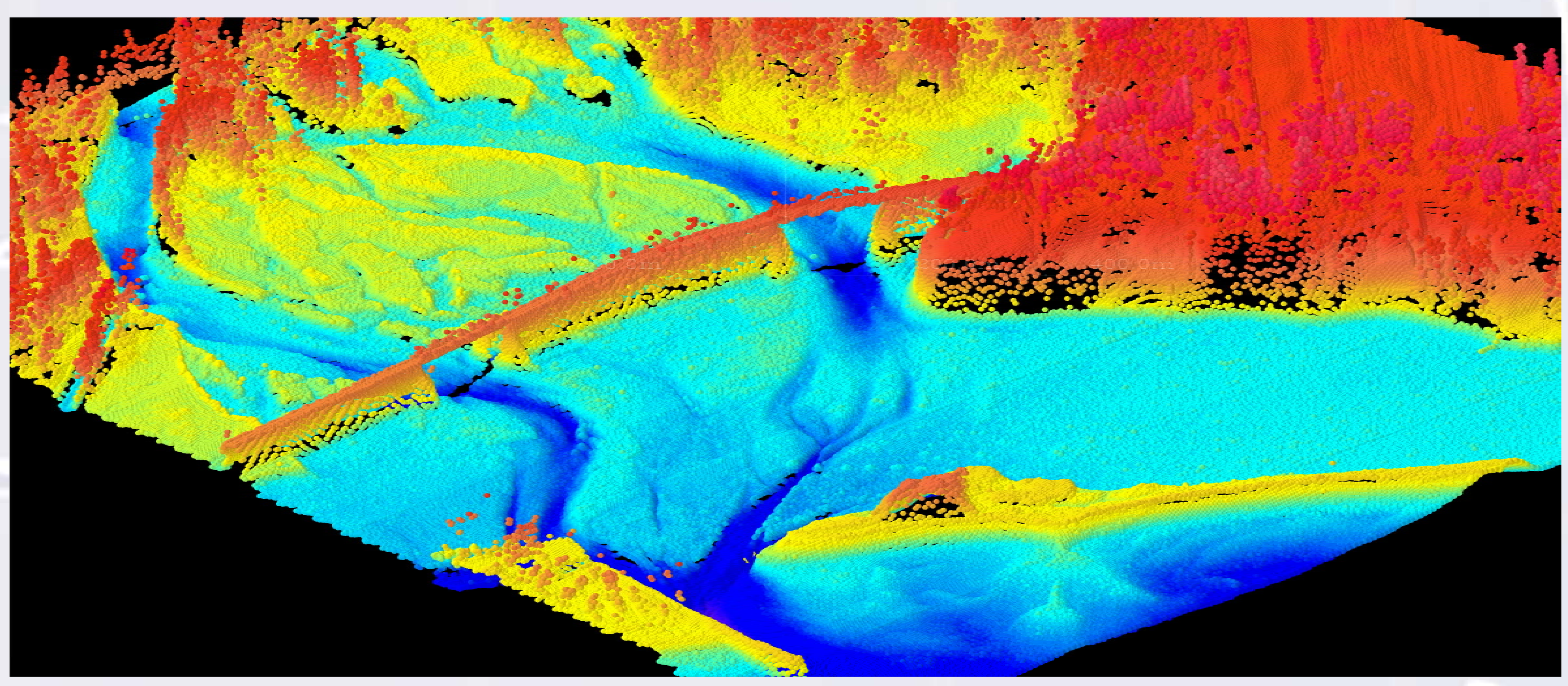

Figure 8: 3D lidar point cloud of shallow river network

BIOGRAPHY

Eric Yang - Is a scientist in the field of airborne lidar bathymetry. His latest research interest is in algorithm development, including lidar waveform analysis, spatial analysis, and lidar point classification. Eric received his BSc in physics from Peking University, China and his MSc. in geological sciences from McMaster University, Canada. He also spent three years of Ph.D. study at McMaster University in applied physics.

Michael Sitar - Is a product manager for Optech Incorporated's Airborne Survey Products business group. He has worked extensively in the mapping industry as a flight operations supervisor, field operations coordinator and glacial hydrologist. He received a MSc. in Physical Geography (spatial analysis) at the University of Waterloo in 2004, with undergraduate degrees and diplomas in Environmental Science and Environmental Biology.

Wenbo Pan - Has worked on software development, data processing and analysis, and technical support of the Shoals Airborne Laser Bathymeter Systems at Optech for over six years. She received a MSc. degree in Physical and Environmental Oceanography in China and a MSc. in Computational Science in Canada.

Karen Francis - Has been involved in software design, development, fielding testing and management of lidar systems at Optech Incorporated for over 18 years. In her current role as Software Team Manager, she oversees all software within the company. A graduate of Sir Sanford Fleming College with a diploma in Geographic Information Systems, Karen is an active member of the Project Management Institute.

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