Prepared for the Worst: The Importance of Nearshore Hydrographic Mapping Prior to Coastal Disasters

Todd Mitchell

Remote Sensing Manager, Fugro, 4820 McGrath St. #100, Ventura, CA, 93003, USA, tmitchell@fugro.com, +1(805) 952-5212

Abstract

Throughout our nation's history, disasters have been impacting the Canadian coast. Changes to the climate and continued development could increase their frequency and effects. Episodic events (tsunamis; tropical storms) commonly do not inflict significant damage, but the threat of greater impacts loom, particularly with changes to the climate escalating and increasing offshore petrochemical extraction and exportation. Ongoing coastal processes also steadily alter the coast and nearshore. It is becoming increasingly important to prepare for the possible impacts of accidents (such as a major petroleum spill) and prepare for a rapid response. However, in remote areas there is often no baseline data depicting ecological and habitat conditions.

The nearshore environment is particularly complex to map using conventional methods, yet it often serves as the primary line of flood defence for many communities. It is also likely to be the most ecologically fragile region affected by spills and other anthropomorphic actions due to being so rich in aquatic life. Airborne LiDAR bathymetry is a technique for collecting hydrographic survey data that is not adversely impacted by the inefficiencies and hazards associated with shallow water vessel operations. In addition, LiDAR bathymetry data can provide a product that is analogous to sonar back-scatter data (reflectance) which can be used for bottom classification. The technology performs optimally to encompass the water depths of most vessel drafts (typically 20 meters or less) and can also capture adjacent topographic data of the shore. This presentation will discuss the application of airborne LiDAR bathymetry for collecting baseline data in preparation for response to a natural or anthropomorphic disaster.

Introduction

The coast is home to a wealth of human infrastructure as well as precious ecology. It is the intersection of social, economic and environmental interests. However, being at such a busy intersection exposes the coast to significant risks imposed by both natural and anthropomorphic events and activity. Episodic events, such as storms, tsunamis or chemical spills, can have rapid and devastating impacts on people, infrastructure and/or the ecosystem. There is some evidence that supports increased potential risks of weather-based events due to climate change. Maritime vessel disasters have plagued Canada as far back as John Cabot in 1498 and the most devastating catastrophe being the explosion of the French vessel, Mont Blanc in Halifax harbour in 1917, which took the lives of more than 1600 people [1].

Ongoing coastal processes, such as changes in relative sea level and through human modification of the coastline (via armouring, dredging, beach nourishment, accelerated erosion, etc.) also affect the coast and its stakeholders, be they human, plant or animal.

The high risk exposure to these stakeholders requires a suitable understanding of the existing conditions, as well as a mechanism for tracking changes both over time and in response to an event. One key element to understanding these conditions is through mapping.

The Need for Baseline Mapping

Mapping to establish baseline conditions is essential in an area as dynamic as the coast. Most human infrastructure is designed to last longer than a generation, and in some instances, as long as 100 years. Similarly, our modern consensus on the environment is to ensure ecological systems are preserved and protected forever. However, assessing today's condition without historical data requires us to rely on either speculative or perhaps anecdotal evidence. Baseline mapping is a critical step in providing empirical evidence of change.

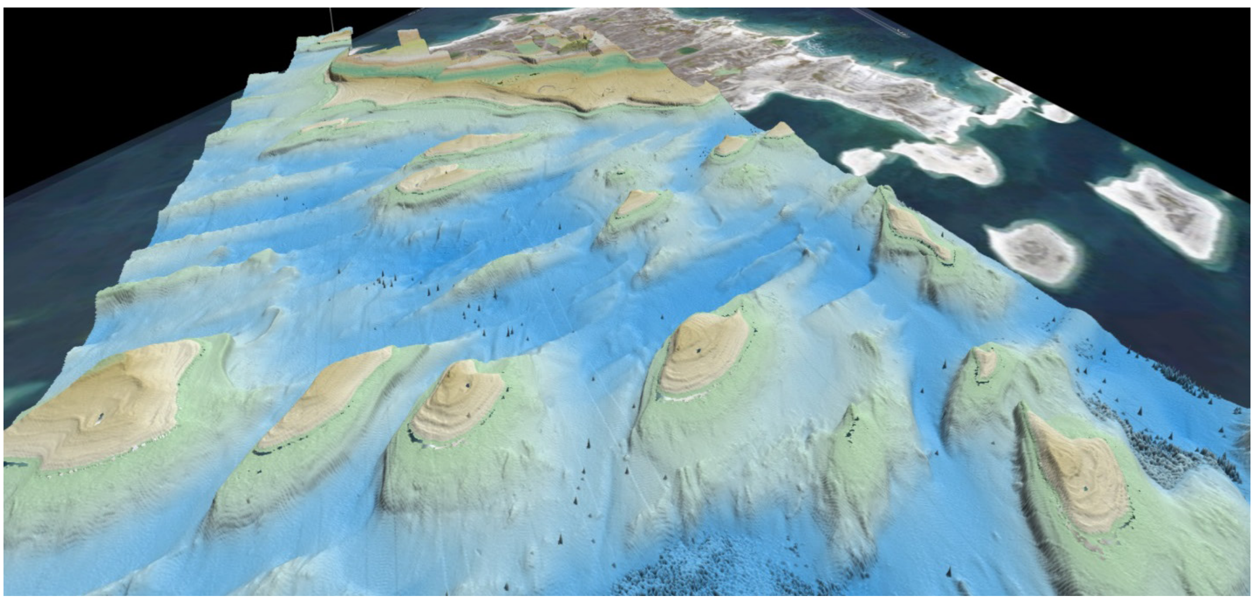

Figure 1: Baseline mapping data is essential for knowledge of existing (pre-event) conditions, improved hazard mitigation, change detection and disaster response.

The Need for Charting

Canada has the longest coastline in the world [2]. However, much of that coast is in unutilized, unpopulated and often icebound regions that have not merited the production of navigational charts for safe vessel operation. Yet the lack of human utilization or population does not necessarily mean that these coasts are not exposed to human impact. On both the Pacific and Atlantic coasts, Canada transports chemical goods (including more than 80 million tonnes of oil per year [2]) over water. The nation also develops offshore oil in the Arctic and Atlantic. With the continuing reduction of Arctic sea ice, vessel traffic through the Arctic is increasing and this in turn is exposing the cartographic limitations of the region on which the conduct of safe passage by vessels is heavily reliant.

At any time, a vessel containing oil, fuel or chemicals or an offshore oil field extraction program could result in an incident that would produce a large toxic chemical spill into the ocean. Similarly, marine vessel operation could require emergency response. In either case, with the vast extent of uncharted Canadian coastal waters, performing clean-up and/or search-and-rescue operations could provide significant safety risks to those vessels involved.

Therefore, modern, fit-for-use navigational charts are necessary in all of the Canadian coastal waters and indeed throughout the Arctic region.

Limitations of Conventional Acoustic Mapping

General definitions of “the coast” are naturally expansive as the term is commonly applied to refer to a region. Thus the area of consideration is typically quite large, particularly from the perspective of vessel-based bathymetric surveying.

In many areas, existing mapping and charting data is insufficient for adequately tracking changes wrought by a coastal disaster and/or to safely respond to it. This is partly due to the complexity of the nearshore environment, which can also be hazardous to map using conventional acoustic survey technologies. The lack of data is further compounded by the vast extent of area to map in Canada and limited usage of most of it. The economic situation for federal, provincial and local government agencies cannot readily support a comprehensive coastal mapping campaign – nor can these entities secure long-term funding for tracking change. Disasters do not wait for ideal funding scenarios, however, so it is a great advantage to identify methodologies that are economically advantageous, can capture data at a regional level and that can be performed in a time-efficient manner. Airborne and satellite remote sensing technologies can often offer an option to meet all three goals, although these techniques rely upon suitably clear water to do so.

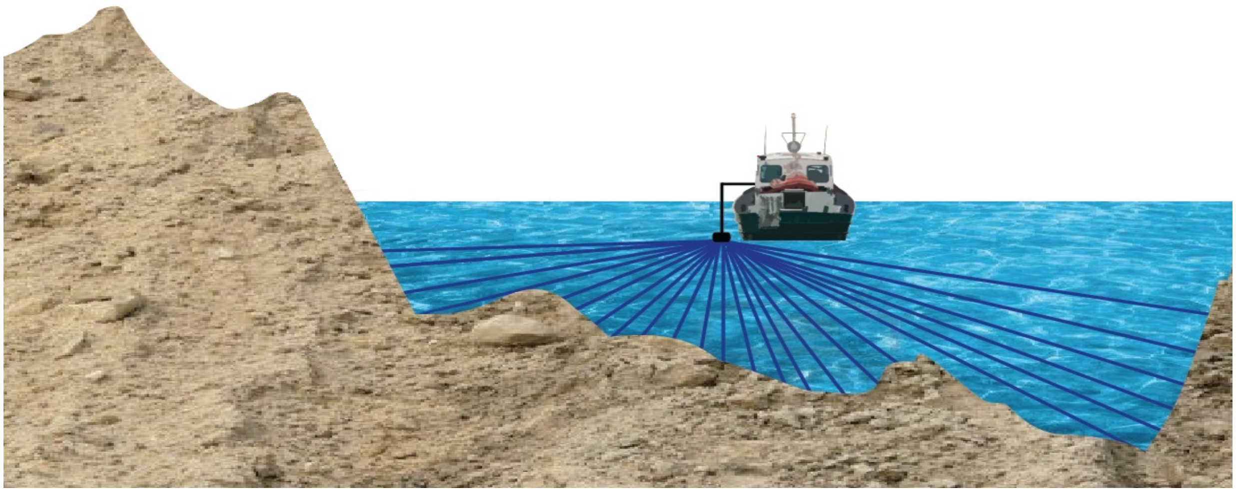

Figure 2: Conventional hydrographic survey methods are less efficient and more hazardous in shallow water.

Airborne LiDAR Bathymetry (ALB)

Airborne LiDAR bathymetry (ALB) is a technique for collecting hydrographic survey data that is not adversely impacted by the inefficiencies and hazards associated with operating a vessel within shallow water. In addition, ALB data can provide a product that is analogous to sonar back-scatter data (reflectance) which can be used for bottom classification. The technology performs optimally to encompass the water depths beyond that of most vessel drafts (given suitable water clarity) and can also capture adjacent topographic data of the shore.

Multispectral Satellite Imagery (MSSI)

Although colour satellite imagery is very useful for many applications and is the most easily interpreted by the human eye, it is relatively limited in its effectiveness in seafloor investigations . Multispectral satellite imagery (MSSI) adds several additional discrete colour bands to the captured image, where each band captures different spectral reflectance characteristics of the land and seafloor. In addition, and more importantly, each spectral band has different characteristics for passing through the water medium to reach and reflect from the seabed [3]. Where water conditions are sufficiently clear for light to penetrate to the seafloor, the shorter wavelengths (e.g. aerosol/coastal, blue, green and yellow bands) can be expected to have the best penetration characteristics. The near infra-red band(s) will be almost completely reflected by the water. The differential in reflectance characteristics of different colour bands is one of the primary techniques for deriving bathymetric depth calculations from MSSI.

Work by a number of researchers, public sector agencies and private sector firms are advancing the techniques for using MSSI for deriving bathymetry and seabed classification. Stakeholders have the option of choosing free, relatively recent imagery at low resolution, such as

LANDSAT-8 with 28.5 metre ground sample distance (pixel size) or may employ imagery captured by DigitalGlobe's WorldView-2 satellite, which captures hyperspectral images two orders of magnitude more detailed at 2.5 meter resolution – albeit at a cost.

Although there is limited research available on the subject, higher resolution imagery does deliver better spatial resolution of the bathymetry observations and should also improve the accuracy where a gradient in the terrain might skew the calculated result.

Currently, the reliability and consistency of the resulting data products has not reached the point of unilateral acceptance, particularly for charting uses. However, the field continues to advance rapidly.

Seabed and Habitat Classification

Seabed characteristics can be mapped using the characteristics of the reflective properties of the different materials and vegetation. Both MSSI and ALB capture measure the strength of the reflected signal.

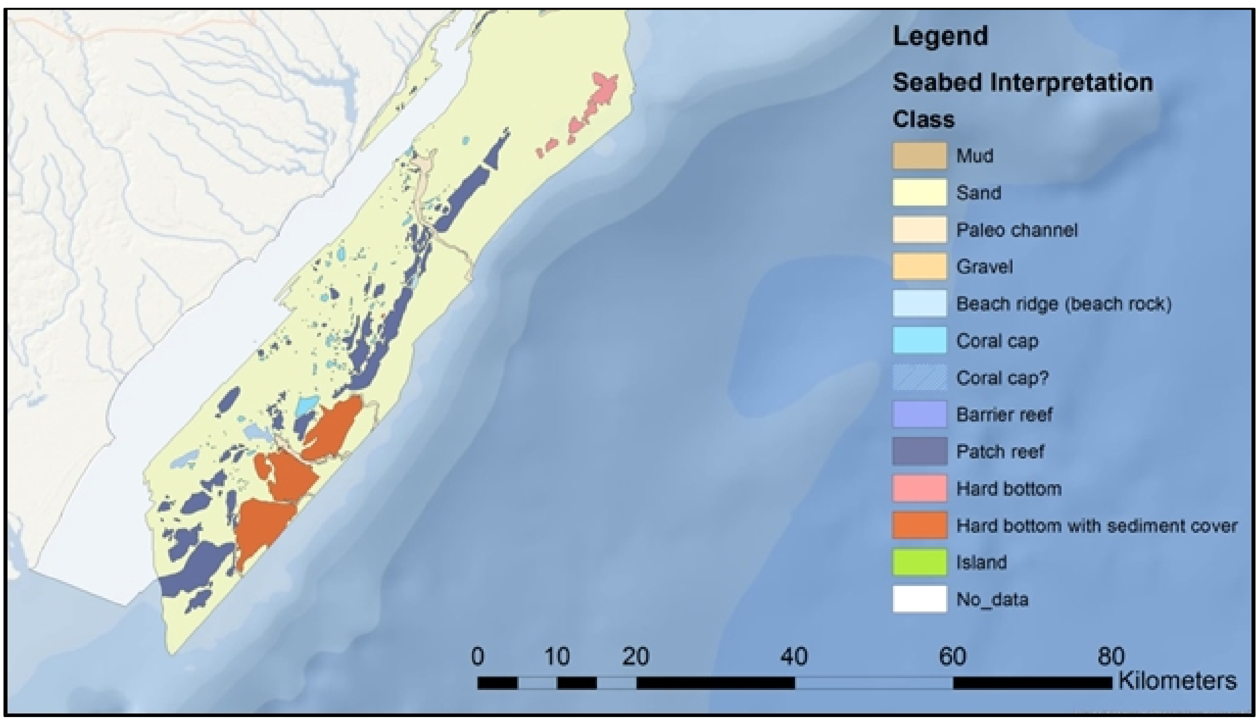

Figure 3: Seabed classification can be performed using remote sensing data.

In order to fully utilize MSSI for habitat classification, seafloor elevation is required in order to correct the imagery for the effects of water depth and turbidity on the reflectance of the seafloor material. This may be derived from the MSSI and ideally validated with field observations. After calibration/correction, the resulting imagery will be a measure of seafloor reflectance for each spectral band. Each band adds a layer of detail for the process of habitat classification. Not surprisingly, academic studies have demonstrated that higher resolution imagery from the WorldView-2 satellite is a significant improvement over previous generation MSSI for bottom classification and new methods continue to be developed.

ALB data captures seabed reflection for the single frequency of the laser (in the green light band). It also produces seafloor bathymetry data which can be used to identify an important characteristic for seabed classification – rugosity (or sea-bottom roughness). Rugosity is a measure of the variability of the seabed. Barren seafloor terrain is often relatively smooth, having a low rugosity co-efficient. Marine growth, including coral and vegetation, generally has a higher rugosity due to its inconsistency in shape. Other valuable bathymetric data that can be useful in the classification process includes depth and slope.

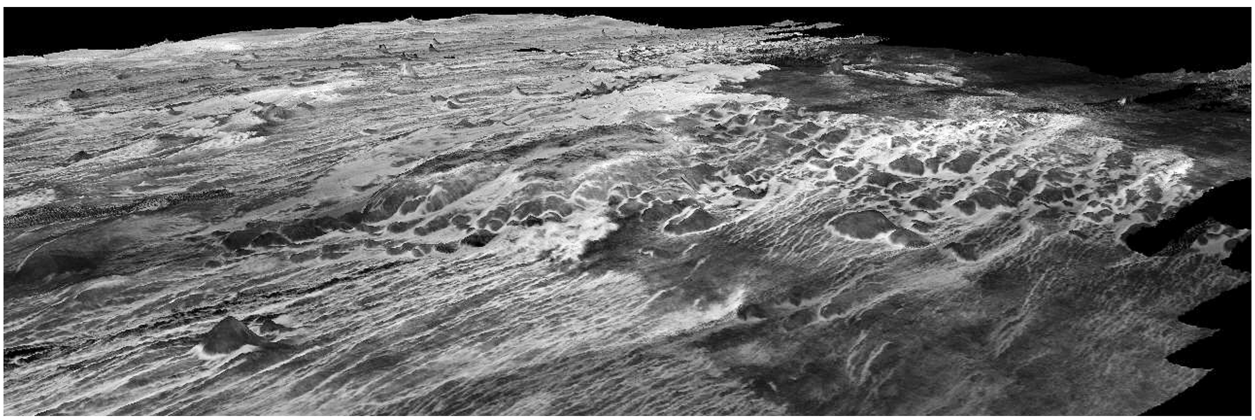

Figure 4: ALB seabed reflection map of the green-light wavelength of the laser.

The integration of the reflectance signatures and the ALB derivative data (bathymetric rugosity, slope and depth) can be analysed with automated raster techniques (unsupervised and supervised) to identify a number of seabed types, e.g. hard bottom, rock outcrop, bright soft bottom, linear reef, coral heads, sand, mud, etc. The output of such an automated classification system can be assessed by seafloor habitat experts and through consideration of the various geological, morphological, and biological attributes of features, can allow further classification into discrete habitat classes.

Screening and the Hybrid Methodology

Perhaps the most effective methodology is a hybrid of both remote sensing techniques. Whereas LANDSAT-8 data is freely available and calculating bathymetric measurements is highly automated, the cost of this step is relatively inexpensive [3]. However, this can play a highly valuable role in determining the effectiveness of utilizing more expensive, high-resolution MSSI and/or performing surveys with airborne LiDAR bathymetry. It can also help identify areas where a vessel may be the only effective option. In the case of disaster response, although MSSI derived bathymetry is not ready for chart-quality mapping, it could be used to distinguish between safe, unsafe and marginal operating areas for vessels. This hybrid approach allows site screening by technology and more effective determination of what method will be most successful in a given location resulting in the most effective reduction in overall program costs.

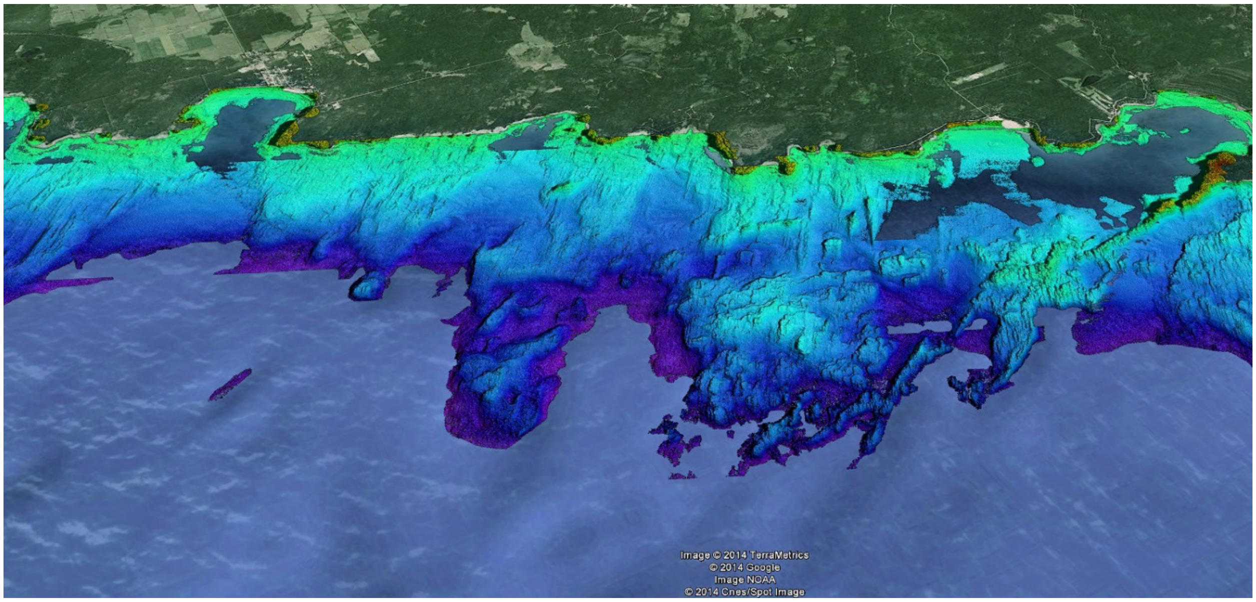

Figure 5: Remote sensing techniques can be used to screen complex, shallow coastlines for safe navigation of vessel-based acoustic hydrographic surveys as well as for chart production (image rendered in Google Earth – imagery via TerraMetrics, Google, NOAA, Cnes/Spot).

Conclusion

Our coasts play a critical role in the environment and in the social and economic interest of society. They are may be highly populated, heavily developed and/or a critical source of trade, tourism, food and/or energy. They may also be critical habitat for marine plant and animal life. The coast is also a region that is exposed to considerable risk. Regional scale coastal mapping and habitat classification is required for identifying change but is particularly challenging to perform with conventional methods.

Satellite and/or aerial multispectral imagery as well as airborne LiDAR bathymetry can play a valuable role in providing efficient regional mapping and charting data in the shallow water and coastal zones. These techniques significantly reduce human exposure to the hazards of mapping in shallow water and can perform vastly more efficiently than vessels. Thus the argument can be effectively made that aerial remote sensing may often be the most viable option, provided water clarity allows for data capture.

References

[1] The Canadian Encyclopedia website: http://www.thecanadianencyclopedia.ca/en/article/disasters/ accessed June 25, 2014.

[2] Transport Canada website: http://www.tc.gc.ca/eng/marinesafety/menu-4100.htm accessed April 22, 2014.

[3] Jerlov, N.G. 1976. Marine Optics, New York, NY, Elsevier Scientific Publication.

[4] Pe'eri, S, Parrish, C., Azuike, C., Alexander, L. and Armstrong, A. "Satellite Remote Sensing as a Reconnaissance Tool for Assessing Nautical Chart Adequacy and Completeness",

Biography of the Author

Todd Mitchell is the Remote Sensing Manager for Fugro in Ventura, California, USA. With more than thirteen years of experience, he consults clients on the applicability of various remote sensing technologies to project requirements in multiple industries. Mr. Mitchell has received certifications from the American Society of Photogrammetry and Remote Sensing (Certified Mapping Scientist), Association of State Floodplain Managers, the Association of Engineering Technologists of Alberta, GIS Certification Institute, is a member of the Canadian Remote Sensing Society and holds a Survey and Mapping diploma and Bachelors of Science degree.

Acknowledgements

Thanks are due to H. Gary Greene and Moss Landing Laboratories, EO Map, DigitalGlobe, IHO, NOAA, USGS and CHS.