Delineation of lakes and channels in the Mackenzie Delta, NWT using airborne LiDAR

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Abstract A terrain based method using locally adaptive thresholds that adjust to slope and orientation of banks was tested to delineate lake and channel banks in the Mackenzie Delta, NWT. Results will contribute to an improved understanding of the local hydrology, the development of a hydraulic model and studies on subsidence impacts of planned natural gas extraction projects in the area. In addition to prevalent terrain-based methods that use point elevations alone, an approach based on using a water mask was tested. Water masks can improve the accuracy of terrain-based bank delineation by: a) suppressing the effect of low signal-to-noise areas; and b) prioritizing regions around existing water bodies that are most likely to contain sill points.

Key words LiDAR, river channel delineation, digital terrain analysis

INTRODUCTION

LiDAR is a useful mapping tool in remote environments due to its ability to rapidly generate digital earth surface point coordinate locations that can be readily manipulated using terrain analysis tools. Hollaus *et al.* (2005) and Mandlburger and Briese (2007) demonstrated the applicability of LiDAR for improved hydraulic modelling over large remote alpine environments. LiDAR has also been used to identify lake and channels (e.g. Song *et al.*, 2002, Mason *et al.*, 2006), and to study floodplain geomorphology (e.g. Lohani and Mason 2001, Lindsay *et al*., 2004, Notebaert *et al*., 2009). However, many previous LiDAR terrain analysis models have dealt with areas of substantial relief and might not be directly transferrable to low-relief deltas.

PURPOSE OF STUDY

The calculation of water storage capacity within a hydrodynamic system is a critical step to solving mass and energy balance equations at hydraulic nodes (ASCE, 2000). By delineating banks of lakes and channels and extracting associated maximum bank heights from LiDAR based elevation models of a hydrodynamic system, the basis for the calculation of storage capacity can be established for subsequent studies. While manual digitizing of lakes and channels offers the highest accuracy of results, this is a labour and time intensive process for a large area such as the Mackenzie Delta. The purpose of this paper is to evaluate automated approaches to channel delineation for improved hydraulic modelling.

STUDY AREA

The study area is located within the Mackenzie Delta where the Mackenzie River flows into the Beaufort Sea. The LiDAR survey polygon shown in Fig 1 is one of six polygons surveyed across different reaches of the Mackenzie Delta in August, 2008. The delta is dominated by nearly 50000 lakes and complex networks of channels (Emmerton *et al.,* 2007). Furthermore, it is estimated that close to 33% of the lakes are perched (Marsh *et al.*, 1999) and set within a geologically young and evolving landscape (Hill *et al*., 2001). The analysis presented in this paper is limited to a single 2 km x 2 km area highlighted in Fig. 1.

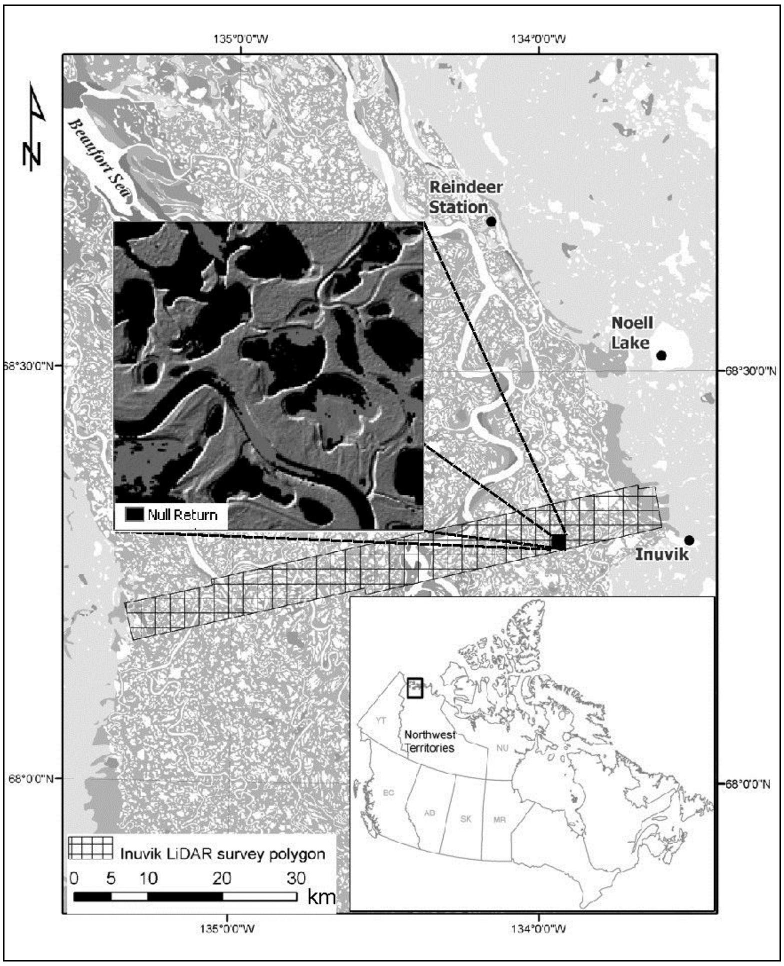

Figure 1. Study area and available datasets. Study area shown is a 2 km x 2 km digital elevation model of a test area within the larger survey polygon shown near Inuvik, NWT.

METHODS

Generating water mask and digitizing banks

A low resolution elevation and intensity model of the area was used as a general guide to locate water features. At a finer scale, vectors representing bank and the waterline locations were digitized within a moving cross-section view of the point cloud. Bank nodes were identified in a cross section view by following areas around water features with maximum slope.

Flat water surfaces behave like a specular reflector to incident laser pulses. Therefore, recorded LiDAR return intensities are either extremely high along near-nadir angles, or, very low along higher scan angles. Consequently, a large number of LiDAR pulses are lost over water either due to reflection away from the sensor or absorption within the water column. From these known properties, waterlines could digitized based on visible changes in data density and intensity, and subsequently gridded for use as a water mask.

Bank delineation using adaptive thresholding

Adaptive thresholding is a slope-based channel and lake bank delineation technique that searches for linear features on a digital elevation model (DEM). The technique was developed by Lohani and Mason (2001) and later modified by Mason *et al.* (2006) to identify tidal channels in a macrotidal environment. However, terrain properties exploited by this method are similar to deltaic environments and therefore with some modification can be applied to the Mackenzie Delta.

As a pre-processing step, a ground classification routine was applied to a georeferenced LiDAR point cloud. Ground points were gridded to generate a bare earth DEM and examined for artefactual pits and peaks.

Identifying banks

Bank identification is a four step process as illustrated in Fig 2. First, areas of high slope were classified using a study area wide slope threshold of 10% (Fig 2a-c). The threshold may vary under different terrain conditions; however, for this study area, the selection of 10% was based on visual estimation of samples distributed throughout the delta and its success with identifying the general layout of banks (areas above the dotted line Fig 2c). Areas above this threshold were extracted to a temporary working mask for subsequent processing. Second, using a 5x5 axial direction weighted filter, linear features from the temporary slope mask were weighted higher than “noisy” peak-like features (Fig 2d). Third, on assigning calculated weights to the original DEM, steep linear features like banks were adaptively raised above the original DEM (circle in Fig 2e). In the final step, banks were identified as any areas that were raised above the original DEM to produce the result as shown in Fig 2f.

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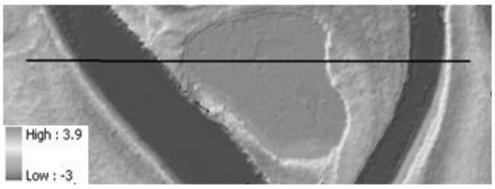
<td>
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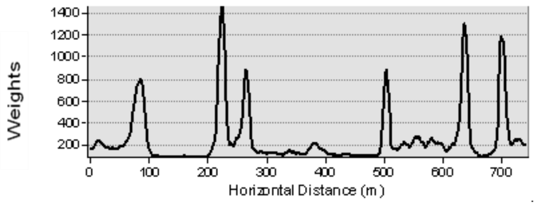
<td>
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<td>(a) Clipped sample area of ground-classified DEM. Line shown is 700 m long and represents the cross-section profile line</td>
<td>(d) Cross-section profile after weighting slopes. Peaks are better defined than in (c) due to noise suppression.</td>
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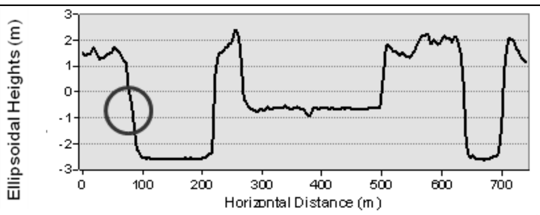
<td>
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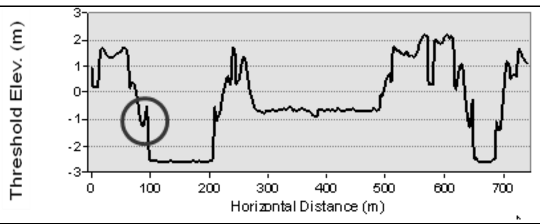
<td>
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<td>(b) Cross-section profile along DEM. Circle marks a sample area interest as a potential bank location</td>
<td>(e) Cross-section profile with weights from (d) applied to the original DEM shown in (b).Circle marks the area identified in (b).</td>
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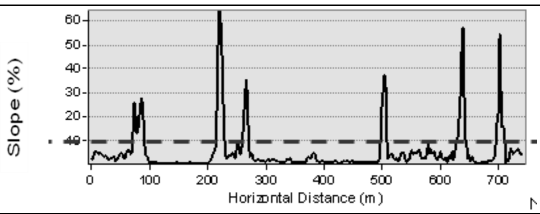
<td>
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<td>(c) Cross-section profile representing slope. Dashed line represents selected global slope threshold (9%).</td>
<td>(f) Estimated bank locations. Lines represent areas where the weighted DEM has been raised above the original location.</td>
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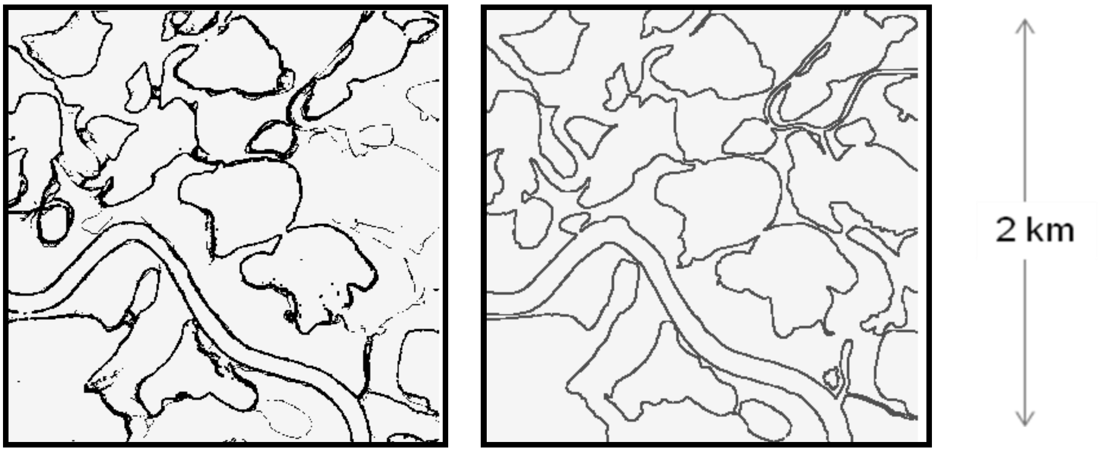
Figure 2. Bank extraction procedure using adaptive thresholding, modified from Lohani and Mason (2001).

Connecting fragments

Unconnected bank fragments are connected along a weighted Euclidean distance surface. Areas in the vicinity of manually digitised water masks and with slopes exceeding the 10% slope threshold were weighted higher than those further away. Therefore, the ideal paths for connecting bank locations were those with maximum accumulated weights and were most likely to represent steep areas near water bodies.

RESULTS

Figure 3 illustrates the results of the adaptive thresholding algorithm when applied to the 2km x 2km tile identified in Fig 1. It can be seen that shapes of delineated hydrologic features shown in Fig. 3a are well represented when compared to the manually delineated banks outlined in Fig 3b. After connecting fragments, 86% of identified banks (Fig. 3a) were found to lie within 15 m of their expected location (Fig. 3b).



(a) Identified banks after adaptive treshholding and connecting bank fragments

(b) Manually identified banks

Figure 3. Results of bank delination by adaptive thresholding over study area

CONCLUSION

Using methods presented here, LiDAR derived heights can be used to automate the process of bank delineation in the Mackenzie Delta study area. Besides manual digitization, few existing methods have demonstrated the ability to automatically delineate banks in a low relief northern delta. With further refinement the proposed process will offer a non-subjective solution to bank delineation. Based on these results, ongoing studies on water level estimation and bank height extraction using LiDAR will test the suitability of feature and elevation extraction methods for stochastic selection of hydraulic nodes in complex hydrodynamic models.

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