Topographic LiDAR – providing a new perspective in the Mackenzie Delta

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Topographic LiDAR is used to map flooding hazards along the Beaufort Sea coast, in particular on the outer Mackenzie Delta. Flooding can be caused by storm surges anywhere along the coast and by high river discharge or backwater at spring breakup or later in summer and fall on the delta. Airborne scanning laser altimetry using LiDAR enables the generation of geospatial information with decimetre level resolution in the form of digital elevation models (DEMs) representing the ground surface, digital surface models (DSMs) including trees and structures, and signal intensity returns to represent the surficial features and materials. LiDAR data are ideal for feature recognition and quantification, providing small-scale geomorphological and depositional details within a larger-scale context. The identification and formation of coastal and river levees, crevasses, secondary channels, and floodplain topography can be useful in determining flooding thresholds, inundation pathways, and drainage patterns. Indicators of past flooding events such as lines of driftwood debris, dead vegetation patterns and the accumulation of alluvial material inland can also be detected through the topographic LiDAR data. Due to the relatively flat nature of much of the low-lying modern Mackenzie Delta, slight increases in water levels can produce extensive additional flooding inland. Flood-simulation models based on LiDAR DEMs can show the potential for inland flooding for a given storm-surge water level at the coast.

Keywords: LiDAR, flooding, Mackenzie Delta, storm-surge

Introduction

Topographic LiDAR has been widely used for a number of applications in the coastal zone such as: coastal elevation mapping and studies on flood zone and storm surge extents, coastal erosion/accretion, natural vegetation line identification and habitat classification (Gutierrez et al, 2001). The recent resurgence of activity by the oil and gas industry in the Mackenzie Delta region has sparked a need for a better understanding of these potential hazards and new interest in detailed topographic mapping. This paper discusses applications of the LiDAR systems that are becoming common practice in the south, as well as new applications specific to the Northern landscape, citing examples from the coastal regions of the Mackenzie Delta which include Nellice Island (north of Ellice Island and the town of Aklavik which is located ~100 km inland.

The Geological Survey of Canada has recently acquired topographic LiDAR from a number of locations in the outer Mackenzie delta (Figure 2) to map the potential extent of flooding due to storm surges along the Beaufort Sea coast in Yukon and the Northwest Territories. This study will focus on the LiDAR flown in 2004, however new LiDAR (2008) is now available and will be the focus of later work and comparison. The main objective of this paper is to study overland flooding extents in areas of the Mackenzie delta where topographic LiDAR is present. In order to do this the relationship between the water and land surface must be calculated. Using water level gauge information provided by Water Survey Canada flood overland extents can be measured at specific locations. However in some cases the location of the gauge does not correlate with the location of the desired region. In such cases assumptions were made on the hydraulic slope and water level of the LiDAR data during time of acquisition. The use of RTK-GPS, satellite information, land morphology and locations of water transported debris (driftwood) are used to validate the maximum flood extent predictions discussed in this paper.

Study Area

The Mackenzie Delta is the largest arctic delta in North America. Bording the Beaufort Sea the delta is located on the northwestern coast of continental North America in the Northwest Territories, Canada (Figure 1). The area is dominated by new and old deltaic channels numerous lakes, ranging in elevation from the the low-relief areas of the delta (0-2 m elevation) to high-relief areas of the adjacent upland tundra region (3-30 m elevation). The region is underlain by continuous permafrost and features such as ice-wedge polygons, pingos, massive ground ice, and thermokarst products. Vegetation consists of sparse to dense ground cover with sporadic patchs of willows along channel levees in the delta and in the valleys in the upland tundra regions. Coastal regions of the Beaufort Sea are ice-covered 8-9 months a year, with freeze-up beginning in October and break-up occurring in late May to June. The Mackenzie delta is the most hydrologically active (Marsh & Hey 1989) between the May 1st – June 15th where snow melting and increased discharge rates from the Mackenzie river in combination with ice jamming (Marsh & Hey 1989) can increase water levels significantly and cause large areas of the outer Mackenzie Delta to flood. During the open-water season, the coastline is exposed to strong northwest winds and frequent summer storms in the the months of August and September (Harper et al 1988).

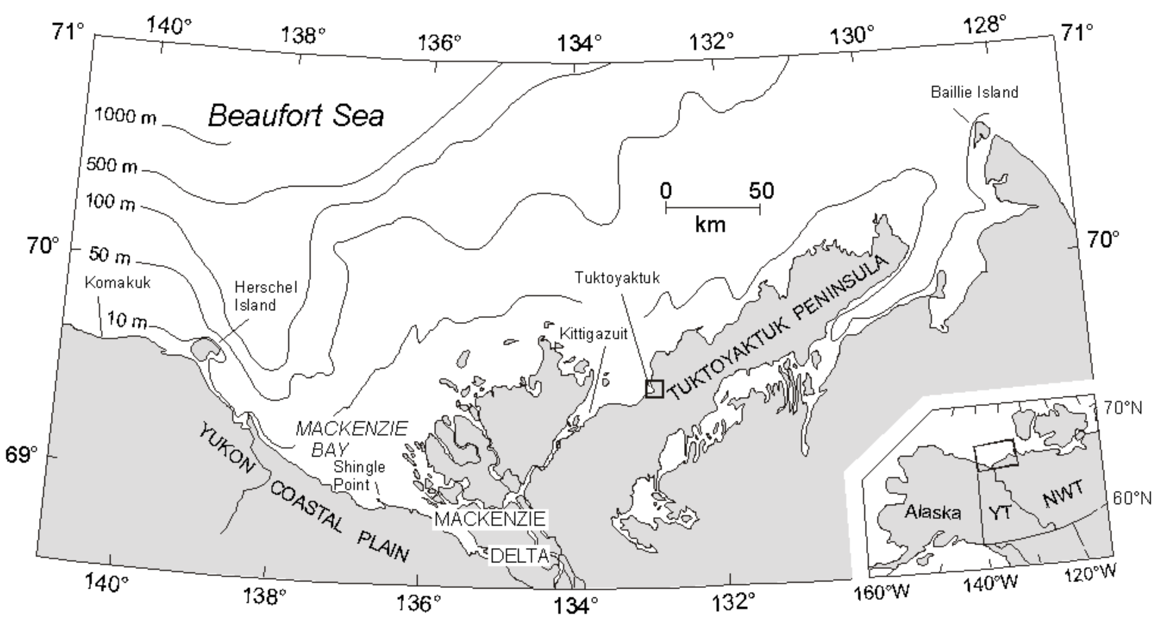

Figure 1: Map showing the 2004 LiDAR acquisition by the Geological survey of Canada in the outer Mackenzie delta.

Coastal Flooding

Coastal storm surge flooding is caused by strong northwesterly winds during the open-water season of late summer and fall. The impact of these storms depends on wind speed, direction and ice free open water. Maximum storm-surge elevation is about 2.5 m along much of the Beaufort Sea coastline (Solomon 2005). Flooding affects wildlife habitat and associated hunting activities and constrains the design of infrastructure built for support of hydrocarbon exploration and development.

The relationship between land and water

To obtain an accurate representation of coastal flooding, the relationship between mean water level (MWL) and the surface elevation must be known. The representation of flood levels for any area involves relating the water levels (relative to a local chart or gauge datum) to the low-relief topography (ellipsoidal elevations converted to orthometric elevations using a particular geoid model). The limited number of water level measurements (tide gauge at Tuktoyaktuk and gauges in the outer delta) and precise geodetic control has posed challenges for simulation of flooding levels in the study area (Véronneau 2006). Control and validation surveys and additional water level measurements have been undertaken to alleviate these difficulties. LiDAR elevations have been converted to the orthometric height values as defined on the Canadian Geodetic Vertical Datum of 1928. (CGVD28). For this study all water level data has been converted to represent height values above CGVD28.

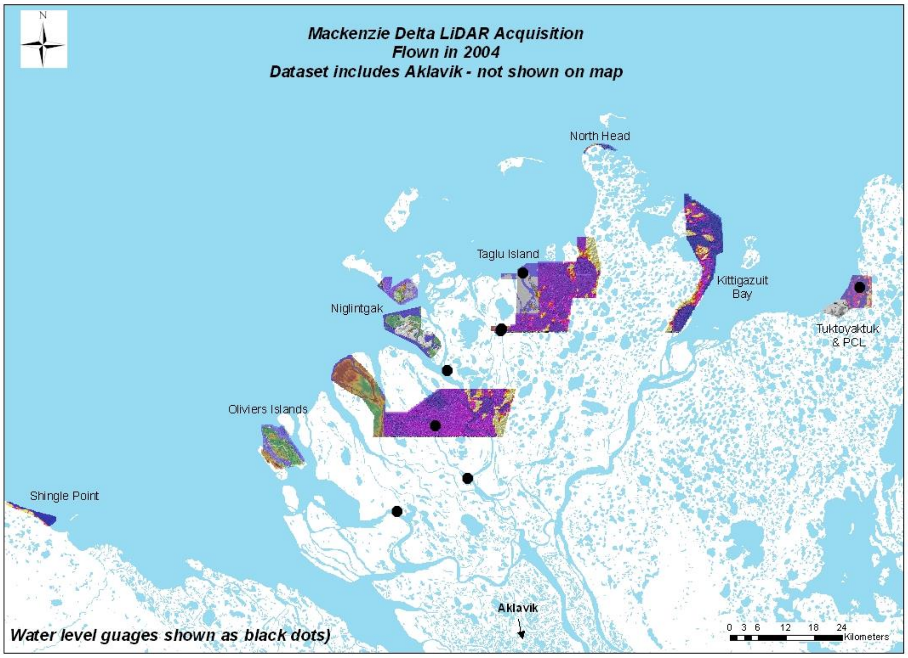

Figure 2: Map showing the relationship of the 2004 LiDAR and the water level gauges in the outer Mackenzie Delta.

Flood Indicators

Change mapping using composite Radarsat imagery taken 18 hours after the peak of a storm-surge in August 2000 is able to show areas where water has not receded after the storm. Although little is known of water levels from this storm in the outer delta region, the ponded water in depressions from Nellice Island (north of Ellice Island) reveal a definite extent of flooding. Similar flooding extent can be determined over the LiDAR DEM after a 1 m (re CGVD28) rise in sea level. As a result it can be determined that during the 2000 storm surge water levels exceeded 1 m in the outer delta (figure 3). Previous studies have revealed that the identification of debris such as driftwood that have been pushed up the coastlines of the Beaufort Sea can be good indicators of increased water levels during storms (Harper 1985). Due to the lack of vegetation these log lines are clearly visible on the LiDAR digital surface model and can be related to past flooding maximums (Whalen 2005). This concept can also be applied to the remote areas of the Mackenzie Delta where the patches of dead vegetation appear to be orientated as swash lines giving some indication of transport by sea water. Large areas of dead vegetation have been identified with air photos and field observations. The use of reflective intensity returns from the LiDAR system to identify these areas is still on going. Although this phenomenon can occur upwards of 10 km inland of the coast, the LiDAR DEM indicates that it only occurs at elevations of 1.5 m or higher. This maximum elevation is exactly what is expected from the past storm surge events of 1999 and 2000.

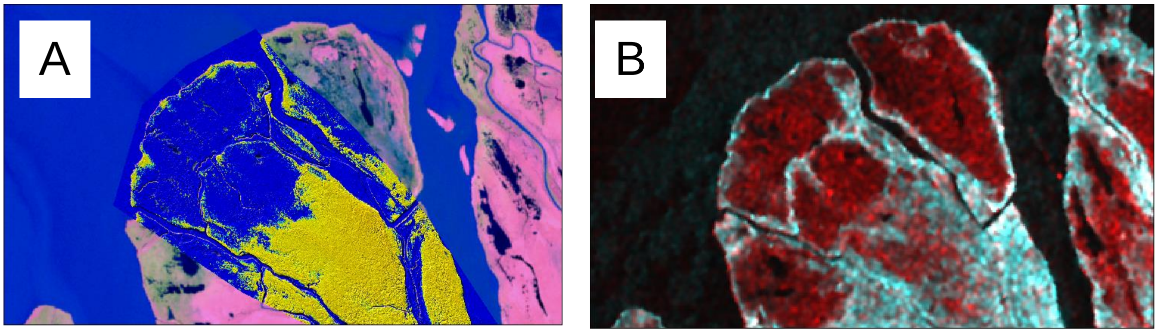

Figure 3: Radarsat imagery (image B) captured 1 day after the August 2000 storm surge show the area of ponded water (in red). A flooding surface can be generated over the LiDAR DEM and compared with the Radarsat image to validate the minimal water levels that were required to transport the water to this area.

Aklavik is located 110 south of the arctic coastline. This area of the Mackenzie delta is not susceptible to storm surge flooding, but high Spring flows and major ice jams can cause widespread flooding of the inland area. Aklavik is prone to periodic flooding during Spring Break-up which can sometimes be quite extensive. Water Survey Canada has published the water levels from the gauge on the Peel River near Aklavik since 1982. The graph below shows the water level trend as based on daily maximums between 1982 and 2008. During this time period the town has been evacuated twice in 1992 and in 2000 when water levels rose above 16 m or 6 m (re: CGVD28). This is close to 1.5 m above the normal high for this time period. To evaluate the actual flood extent during this period flood simulation models are created using the LiDAR DEM. As a further validation RTK-GPS are used to validate surface elevations and observed water level limits. The LiDAR flood simulation confirms that the airport was not over topped and some streets remained open while many of the main arteries were cutoff. A total of 98% of the land surface was covered during these maximum events. Airborne photography of both flood events also correlates with the LiDAR flood simulation of the town.

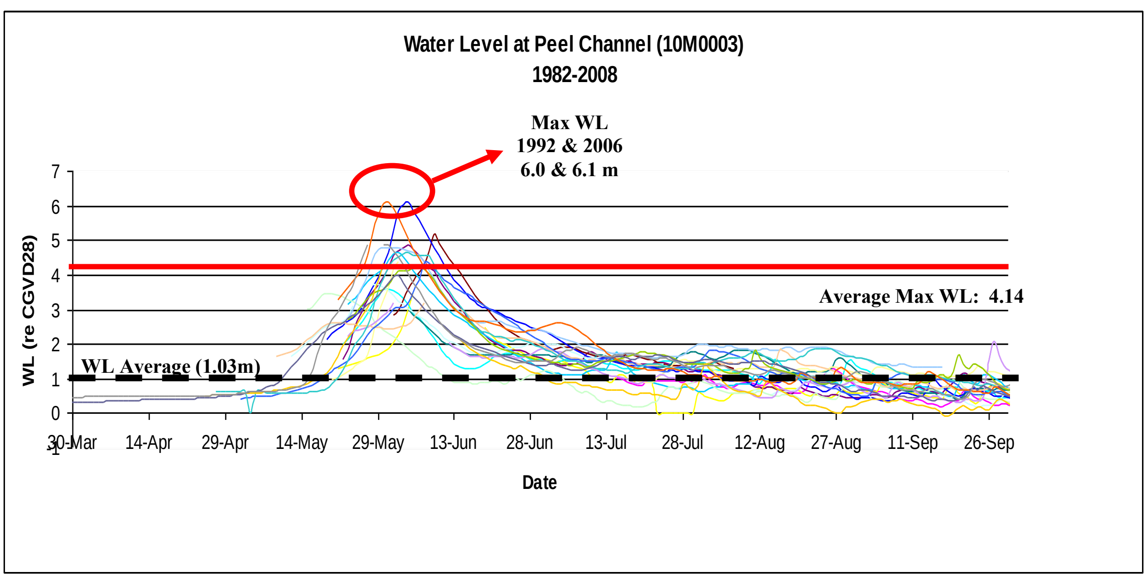

Figure 4: Graph shows water levels from the Peel River (near Aklavik) that span the last 25 years. Each year is represented by a colored line.

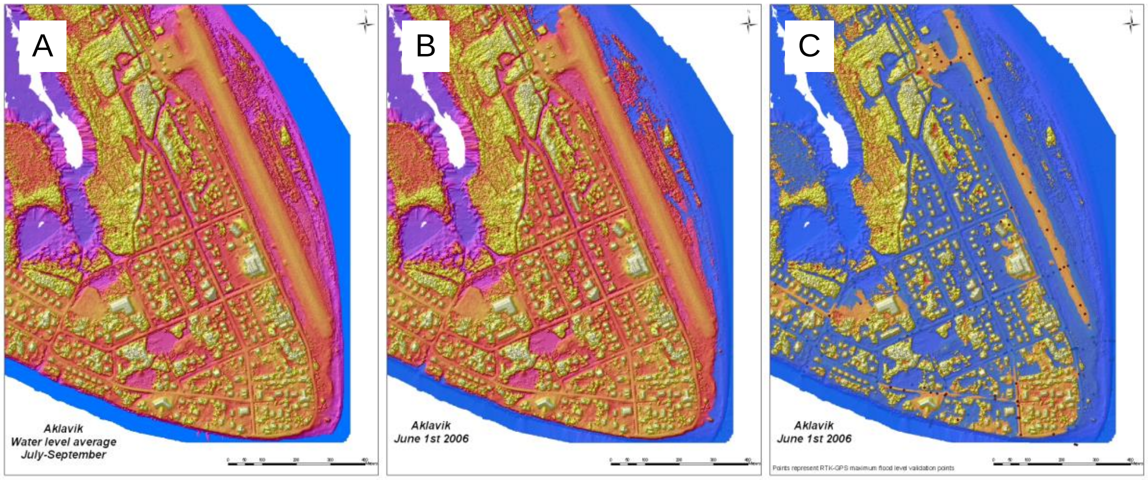

Figure 5: Geographical representation of the flooding extents as determined from the water level heights. The three images show average summer water levels (image A), average maximum water levels during Spring break-up (image B) and the flooding extents (image C) of the maximum water level recorded for this region.

Conclusions

Coastal flood modeling using LiDAR DEMs is possible in the outer Mackenzie Delta with the aid of accurate water level gauges. However the accuracy of the flood predictions may depend on the location of the gauge with respect to the coastline and LiDAR dataset. RTK-GPS surveys, identification of artifacts that have been transported inland by water and satellite imagery collected near storm events have proven to be appropriate methods of flood extent validation in this region. The intensity and severity of coastal flood hazards in this region are expected to increase over the next century due to climate warming, land subsidence, accelerated sea-level rise, and a possible reduction in sea ice. In this context, it is important to develop a better understanding of flood hazards under present conditions. DEMs and DSMs derived from LiDAR datasets provide a new perspective for this poorly mapped region, which will ultimately help to better understand the effects of global climate change and constraints on industrial development in a high-latitude deltaic and coastal setting.

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