Remote Sensing of the Arctic Coast of Alaska Using Airborne Lidar Data

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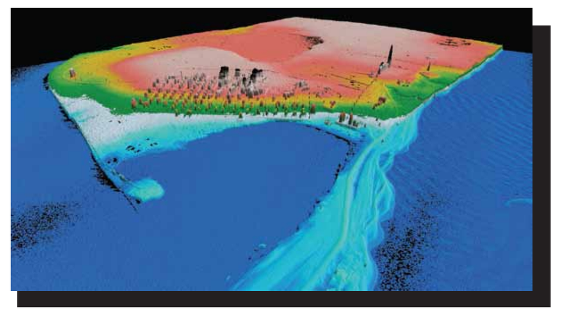
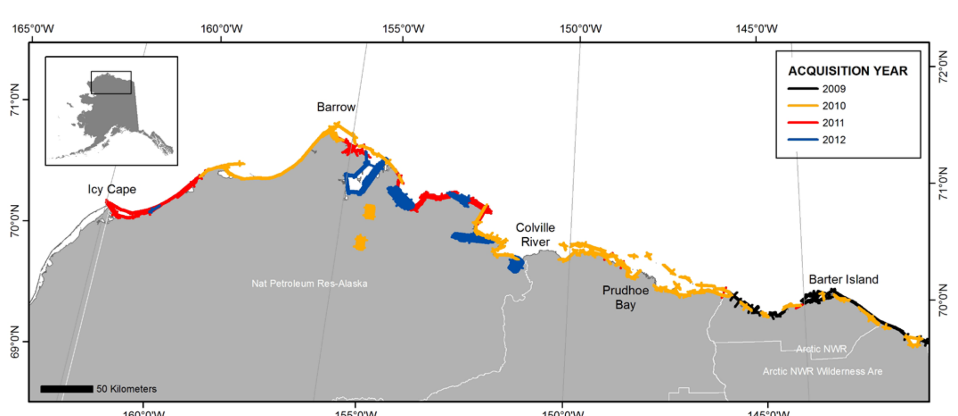
ABSTRACT



As part of a U.S. Geological Survey assessment of coastal change hazards, over 11,000 km2 of airborne lidar elevation data were collected along the Arctic coast of Alaska between 2009 and 2012. Data coverage includes the barrier islands and mainland coast between Icy Cape and the U.S.–Canadian border, from the shoreline to ~1.5 km inland. Data coverage extends further inland to around 3 km on the Barrow Peninsula and along the coast of the Teshekpuk Lake Special Area (TLSA) where coastal erosion rates are among the highest in the world (> 18 m/yr). Nominal point density is 1.5 m and vertical accuracy is better than 30 cm. Data were not collected over most river deltas or large embayments, with the exception of Admiralty Bay, Smith Bay (Ikpikpik Delta), Kogru River, and the Fish Creek portion of Colville River Delta. The primary use of the lidar data is to establish a modern shoreline position to be used for change analyses with historical shoreline positions. However, the lidar DEM provides a wealth of topographic and intensity data that can be used for morphological mapping of the remote arctic coast.

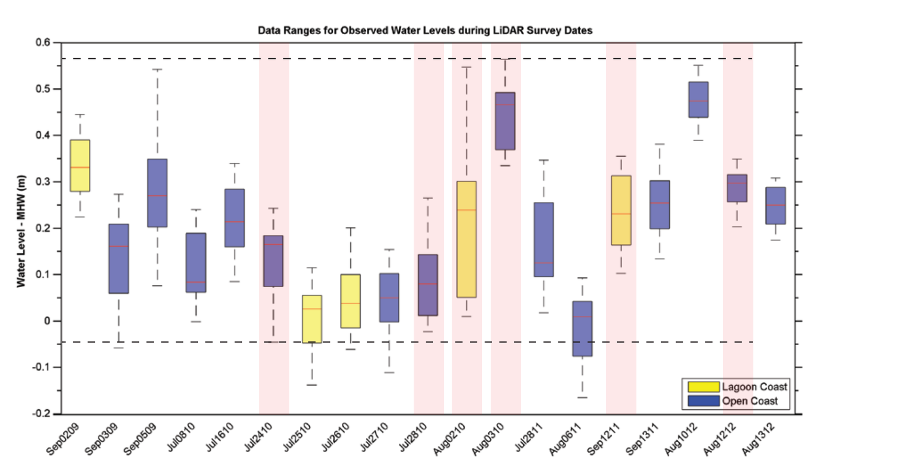
This is one of the first comprehensive lidar datasets collected in a continuous permafrost environment. Many periglacial landscape features, such as patterned ground, ice-wedge polygons, and thermokarst lakes and former lake basins (recent and relict) are discernible in the dataset. Traditional coastal landscape features including shoreline position, beach width, slope, and bluff height and morphology are also distinct. Here we present an overview of the dataset and an assessment of methodologies developed for characterizing and classifying a variety of landscape features including overall complexity, geometry and morphology of polygonal tundra (polygon spacing, high center vs. low center), coastal bluff morphology (vertical or overhanging, convex vs. concave), drainage patterns and hydrologic connectivity. We also investigate the dataset to estimate offsets between ellipsoid and sea-level elevations, which is necessary for evaluating the vulnerability of the coast to inundation associated with storm surge, sea-level rise, oil spills and other marine-associated hazards.

North Alaska Coastal Lidar Survey



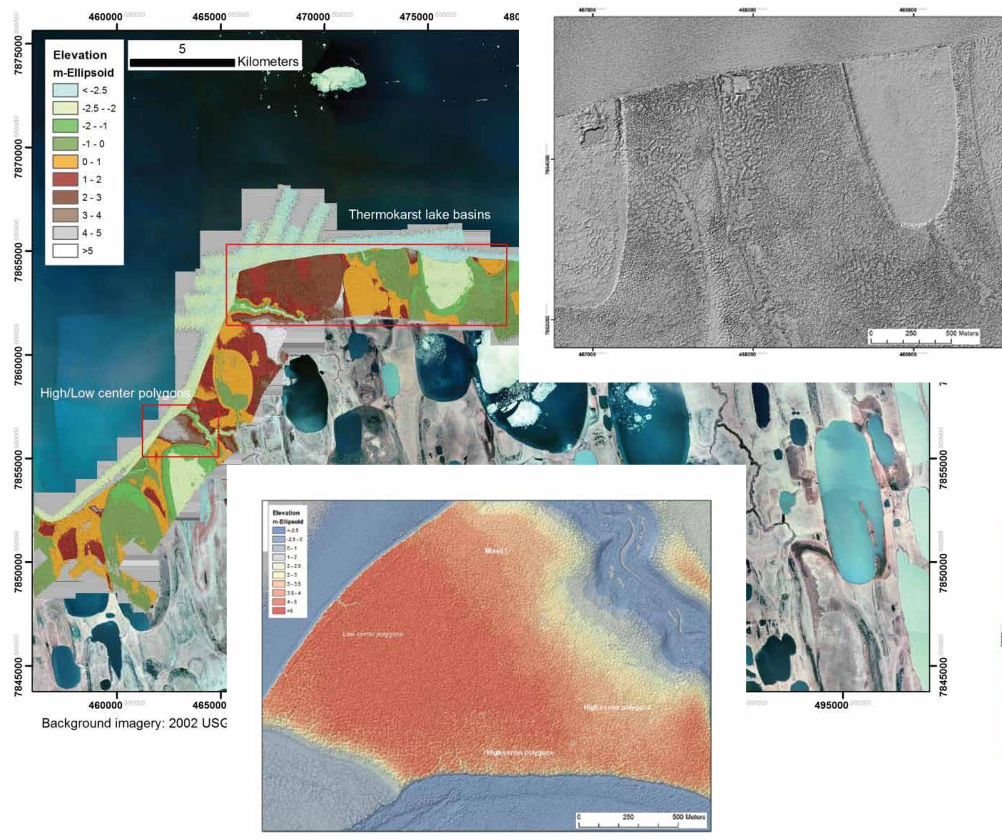
- 11,000 km2 (7,119 line-km) acquired between 2009 and 2012
- Icy Cape to the U.S.-Canadian Border
- Mainland coast and barrier islands (limited delta and estuaries)
- Waterline to approximately 1.5 km inland; 2-4 overlapping passes
- ~ 1m point spacing/30 cm vertical accuracy (0.14 RMSE)
- NAD83; Ellipsoidal elevation

Acquired by Aerometric, Alaska; Funded by USGS National Geospatial Program, Coastal and Marine Geology Program, Alaska Science Center; U.S. Fish and Wildlife Service, Arctic Landscape Conservation Cooperative; U.S. Bureau of Land Managment

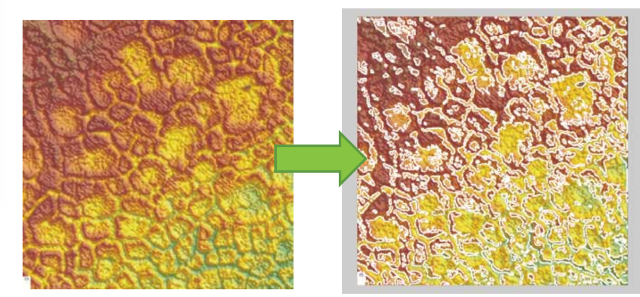


Water levels measured at Prudhoe Bay varied by as much as 0.75 m during the four years of lidar acquistion and about 0.62 m during acquistion in UTM Zone4 (red bars)

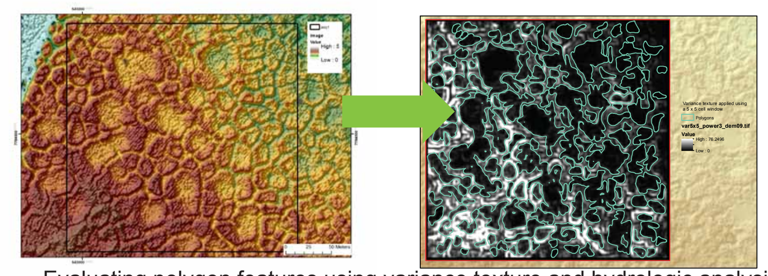
Evaluating Morphometrics
Surface Complexity, Polygon Geometry, Drainage Patterns



The lidar data set is rich with information on the morphology of the Arctic landscape. We are actively investigating a number of analytical techniques such as edge detection, topographic position index, and hydrologic variance functions to explore the metrics of a variety of features.



Evaluating polygon features using edge extraction code (Canny method)



Evaluating polygon features using variance texture and hydrologic analysis

Challenges with the Vertical Datum and Shoreline Extraction

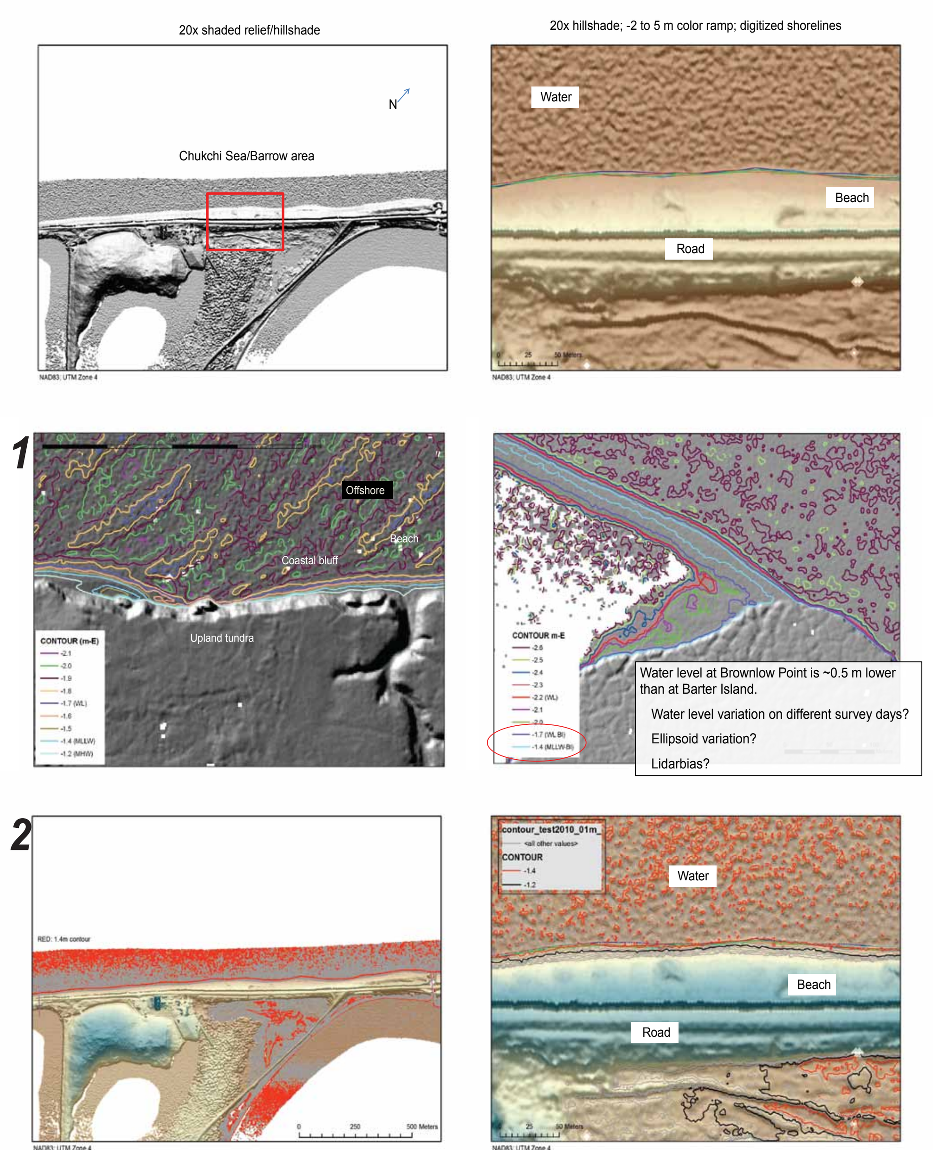
Converting ellipsoidal elevations to orthometric or tidally referenced elevations is difficult in northern Alaska.
- The current GEOID model is not accurate
- There are few tide stations (4 total; 1 continuous)
- The tidal range on the north slope is small, 0.21 m range, but large wind driven set up/down can elevate water levels by 2-3 meters.

This presents problems when trying to extract shorelines and model current and future coastal inundation extents based on elevation.

Shoreline Extraction Methods

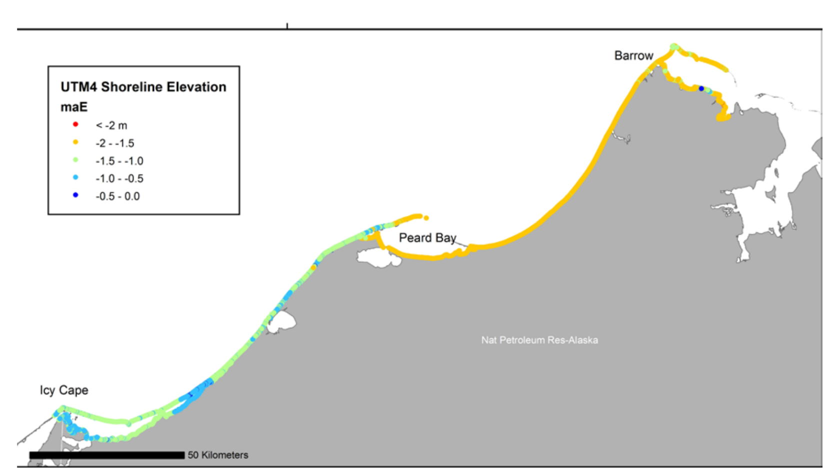
Heads-up digitizing:
Morphological features, such as the land/water interface or top/base of buff, are easily identified on exaggerated hillshades of the lidar data. The process is time intensive, qualitative, subject to analyst interpretation bias/error, and highly dependent on absolute water level at the time of the survey.

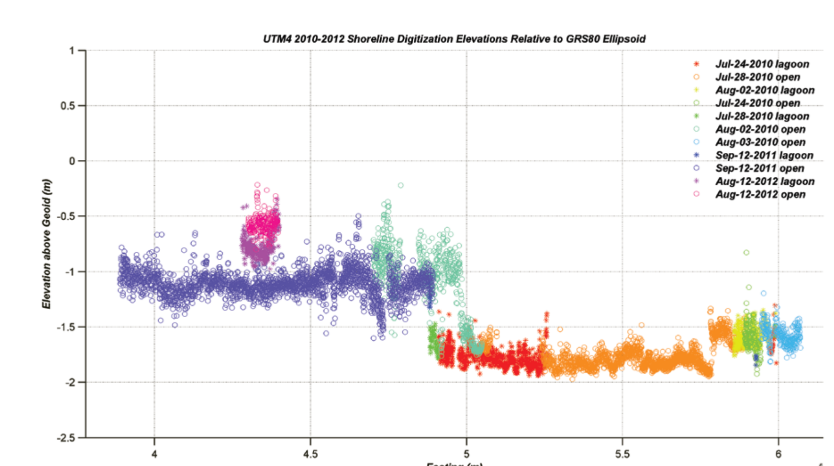
Semi-automated contour extraction:
Using this method we define the shoreline as the most seaward, continuous, smooth contour generated from (1) the lidar data or (2) an elevation based on some variation (in this case 20 cm) from the mean offshore water level calculated from the lidar data. This methodology is more analytically intensive than the method above, but requires limited analyst interpretation. Similar to heads-up digitizing, the absolute elevation of the shoreline delineated is dependent on water level at the time of the survey and varies with time and across the study area.



Lidar Derived Shoreline Elevations

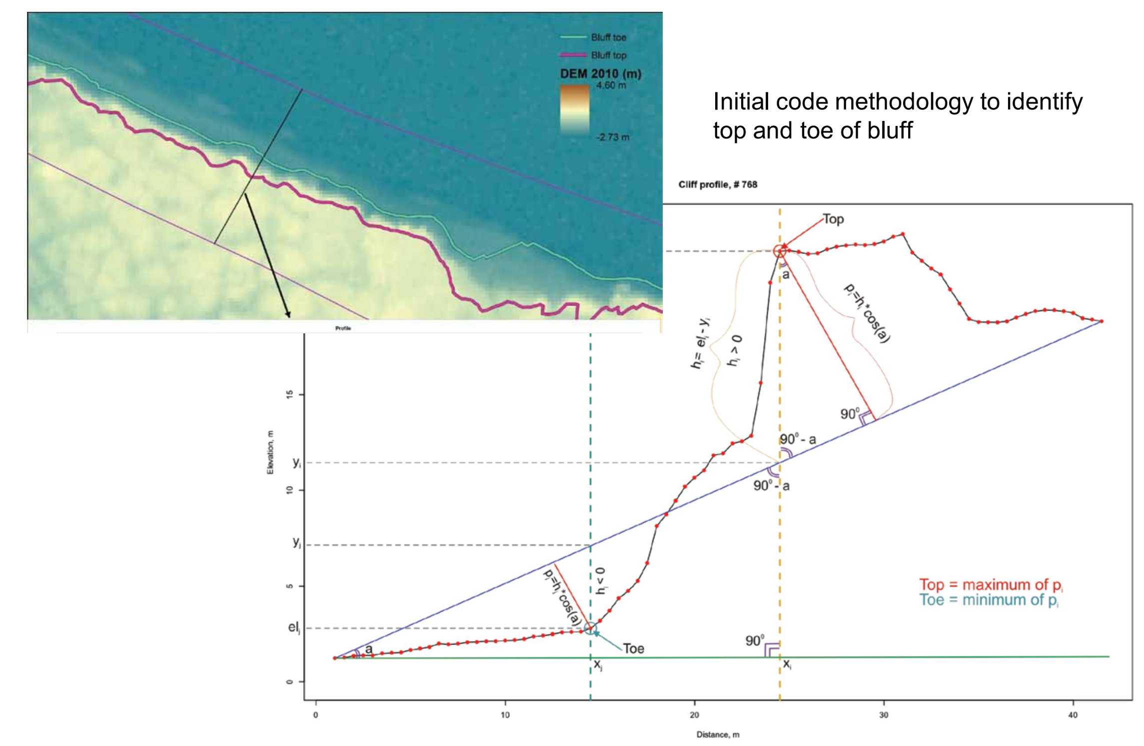
Shoreline elevations derived from lidar data in UTM Zone 4 indicate relative differences of nearly 2 m, whereas water levels measured at Prudhoe Bay (more than 300 km to the west) during survey acquisiton vary by only 0.6 m. The figures below show that derived shoreline elevations using the methods above may reflect lidar acquisiton errors or bias, exposure to winds and waves, and/or local oceanographic conditions that may result in elevated total water levels on the beaches, realtive to the measured water levels.

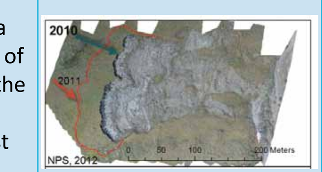




Lidar and Bluff Morphology

Bluff profiles are extracted from the lidar data at 1-m spaced crossshore transects along the coast. A series of algorithms coded in the freely available R environment have been developed for partial quantification of bluff morphology. Bluff parameters of particular interest are those that assist with the identification of failure mode and associated failure mechanisms, for example bluff height, bluff slope (convexity), beach width, proximity of ice wedges.

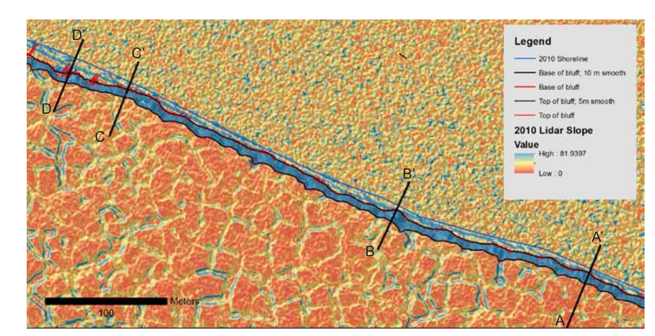


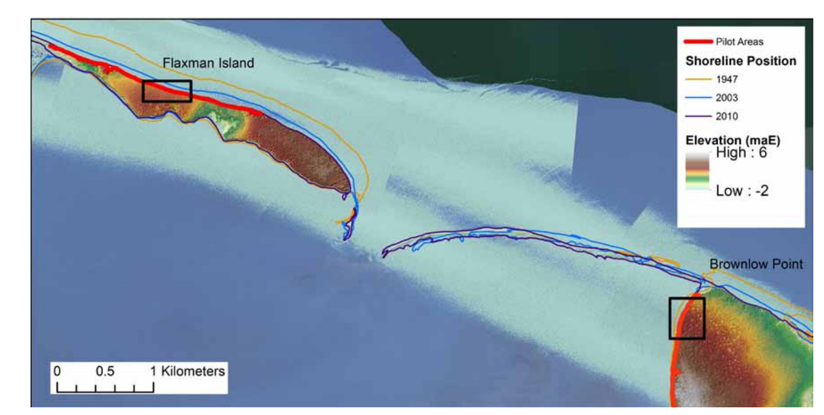
	Failure mode	Example	Parameters extracted from lidar data that are relevant for determination of failure modes and mechanisms
1	**Block failure** topples of segregation ice and ice-wedge bounded sediment; cantilevered ice-bonded peat and clay tundra blocks.	 Photo by Ben Jones	Ice wedge locations; bluff height; bluff slope; foreshore width
2	**Translational-shear ice-thaw** Culmann-style, steeply inclined block slides	 Photo by Li Erikson	Bluff height; bluff slope; foreshore width; scarp length; failure shape
3	**Retrogressive thaw slumps** Back-wasting slope retreat leaving a concave slide plane due to thawing of ice-rich permafrost and erosion at the foot of the bluff; often associated with cliffs>8m high and thermokarst lakes.		Bluff height; scarp heights; scarp length; failure shape
5	**Surface wash** Erosion by way of mechanical abrasion of surface run-off (gullying) or melting of ice-wedges as it comes in contact with warmer surface run-off or exposure to warmer air temperatures.	 Photo by Ann Gibbs	Drainage patterns; thermokarst lake proximity

Pilot Areas

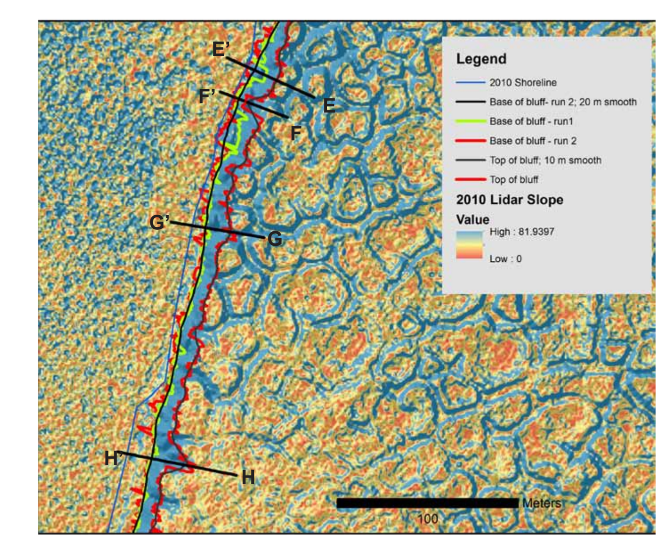
The bluff edge extraction method was tested at two pilot locations: Flaxman Island (open coast) and Brownlow Point (protected coast). Overlaying the calculated (red and green) and smoothed (black) top/base of bluff positions on a slope map of the lidar data shows that the bluff top and base were generally very well-identified using the basic parameters of the methodology. Problems arose when gullies, large thaw slump deposits, or talus deposits were present. In these cases running multiple iterations of the code with slight variation in parameters, and smoothing of the output across multiple transects, generally improves the results.

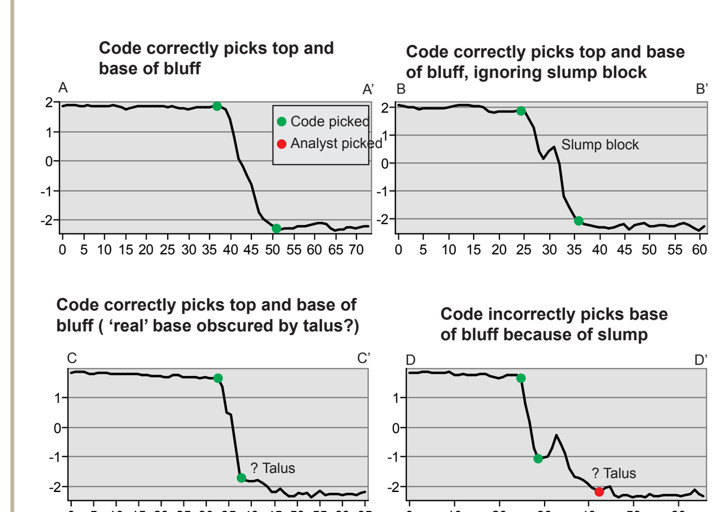
Flaxman Island





Brownlow Point

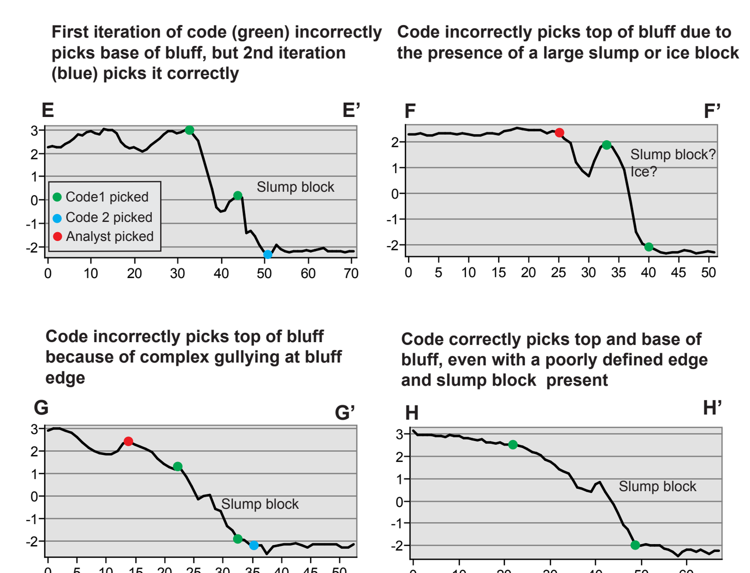




On Flaxman Island, where erosion rates, bluff elevations, and incident wave energies are high, the top of the bluff is almost always correctly picked by the code. Identification of the base of the bluff is more problematic due to the presence of slump blocks and talus at the base of the slope.

Flaxman Island

Brownlow Point



On the lagoon side of Brownlow Point, where bluff elevations are similar to Flaxman Island but erosion rates and incident wave energies are low and slump blocks and gullying are common, the method had more difficulty identifying the top and base of the bluffs.