Seasonal Electrical Resistivity Surveys of a Coastal Bluff, Barter Island, North Slope Alaska

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ABSTRACT

Select coastal regions of the North Slope of Alaska are experiencing high erosion rates that can be attributed in part to recent warming trends and associated increased storm intensity and frequency. The upper sediment column of the coastal North Slope of Alaska can be described as continuous permafrost underlying a thin (typically less than 1–2 m) active layer that responds variably to seasonal thaw cycles. Assessing the temporal and spatial variability of the active layer and underlying permafrost is essential to better constrain how heightened erosion may impact material fluxes to the atmosphere and the coastal ocean, and how enhanced thaw cycles may impact the stability of the coastal bluffs. In this study, multi-channel electrical resistivity tomography (ERT) was used to image shallow subsurface features of a coastal bluff west of Kaktovik, on Barter Island, northeast Alaska. A comparison of a suite of paired resistivity surveys conducted in early and late summer 2014 provided detailed information on how the active layer and permafrost are impacted during the short Arctic summer. Such results are useful in the development of coastal resilience models that tie together fluvial, terrestrial, climatic, geologic, and oceanographic forcings on shoreline stability.

Introduction

It is now well documented that some Arctic coastlines are highly susceptible to erosion, and rates of coastal bluff retreat have increased at some sites during recent decades (Hinzman *et al.*, 2005; Osterkamp, 2005; Jones *et al.*, 2009; Wendler *et al.*, 2010). Heightened erosion may be attributed in part to increases in the duration of thaw cycles and the frequency/intensity of oceanic storm events (Rachold *et al.*, 2000; Jorgenson *et al.*, 2006). Impacts of such erosion are now affecting North Slope infrastructure, including some Native villages and petroleum exploration and production facilities (Gibbs and Richmond, 2015). As part of a combined geochemical and geophysical reconnaissance, multi-channel electrical resistivity tomography (ERT) was used to image shallow subsurface features such as permafrost, the active layer, and a coastal bluff face on Barter Island, northeast Alaska. This paper examines the utility of the ERT method to assess fine-scale nuances in active layer and permafrost dynamics over one summer thaw cycle on the North Slope of Alaska. Preliminary results suggest that ERT is a useful technique to discern subtle change in surface features, and can be used in models that address shoreline retreat, erosion, and bluff stability.

Study Site

Barter Island is located along the Beaufort Sea coast of northern Alaska in the Arctic National Wildlife Refuge (ANWR) (Fig. 1). The island is bounded to the east and west by the Jago and Hulahula Rivers, respectively. The Native Village of Kaktovik (population in 2014 was <300, http://www.alaska-demographics.com/kaktovik-demographics) is located on the northeastern shore of Barter Island. Parts of Kaktovik's infrastructure are directly impacted by shifting and retreating shorelines (Gibbs and Richmond, 2015). The coastal margin of the

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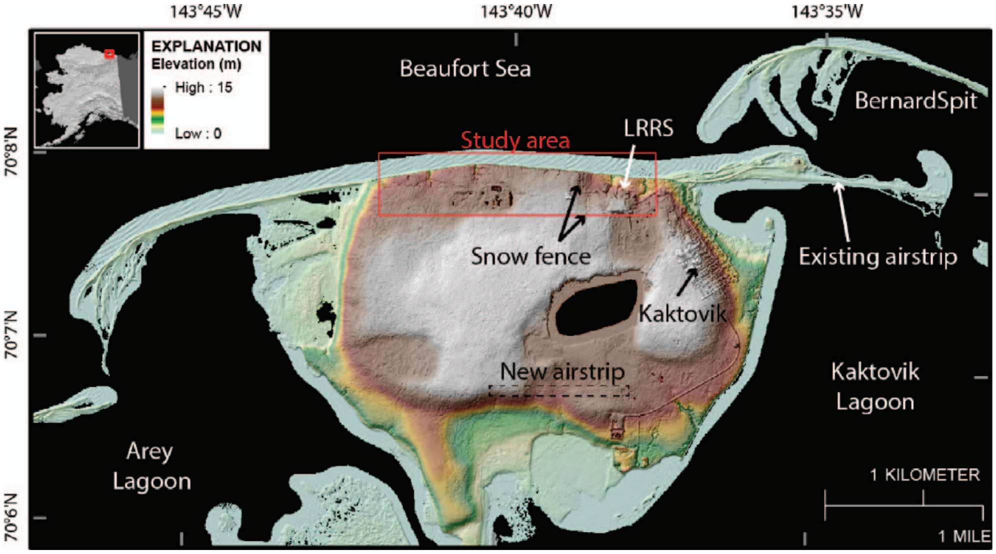

Figure 1. Barter Island, located off northeastern Alaska in the Beaufort Sea. Inset box defines the area of resistivity surveys conducted on the coastal bluffs west of Kaktovik in June and September 2014.

Beaufort Sea at Barter Island is influenced by oceanic, fluvial, and climatic processes that control sediment supply, deposition, accumulation, and erosion (Jorgenson and Brown, 2005; Reimnitz and Bruder, 1972). The source of sediment originates in upland watersheds of the Brooks Range with lesser contributions from local glacial outwash (Wiseman *et al.*, 1973; Walker, 1974; Walker and Hudson, 2003). The rivers that drain the Brooks Range are confined to the zones of continuous permafrost (Beltaos, 2000). This implies that the groundwater contribution to discharge (baseflow) is limited to short periods of summer thaw. As a consequence, geomorphic processes are essentially shut down during non-summer periods when river ice dominates (Ritchie and Walker, 1974), and many shorter Arctic rivers can experience no-flow conditions during this time. Most fluvial sediment is transported to the Beaufort Sea within a few weeks and maximum sediment values in a North Slope river often occur a few days before peak water discharge (positive hysteresis), indicating the complex role of prolonged frozen conditions on river hydrology (Reimnitz and Bruder, 1972; Kane and Carlson, 1973; Reimnitz and Maurer, 1979; Ray and Aldrich, 1996).

ANWR coastal plain sediment consists of eolian, alluvial, fluvial, and marine deposits that are complexly reworked (Short *et al.*, 1974; Rawlinson, 1993; Rachold *et al.*, 2000; Smith and Piearce, 2002). With the exception of deep lakes and incised river channels, the entire coastal plain is underlain by continuous permafrost (Jorgensen *et al.*, 1996; Jorgenson and Brown, 2005). Ice-wedge polygons are prevalent along the coast (Kanevskiy *et al.*, 2013). Seasonal thaw impacts the soil column variably to depths up to 30–40 cm in peats and to deeper depths in sands. Sediment from a borehole on Barter Island that was drilled near Kaktovik consisted primarily of silt to a depth of 150 cm, ground ice to depths that extended from 150 to 300 cm, sandy gravel from 300 to 760 cm, and very uniform clay (beyond 760 cm to 7,770 cm) (Osterkamp and Jorgenson, 2006). Barter Island experiences a prolonged winter that lasts up to 9 mo, and strong winds (mean wind speed ~5 m/s) are frequent. The mean annual air temperature is −12.4°C, while a mean precipitation rate is just under 20 cm/yr (Kanevskiy *et al.*, 2013). There is an abundance of evidence that documents recent climatic change on the Alaska North Slope (cf. Hinzman *et al.*, 2005; Osterkamp, 2005; Osterkamp and Jorgenson, 2006). Figure 2 is an example of an actively eroding coastal bluff (elevation ~8 m) on Barter Island.

Figure 2. An example of a rapidly retreating coastal bluff just west of Kaktovik, Alaska. Photo location is shown in Fig. 3. Photo credit: Tom Lorenson, USGS.

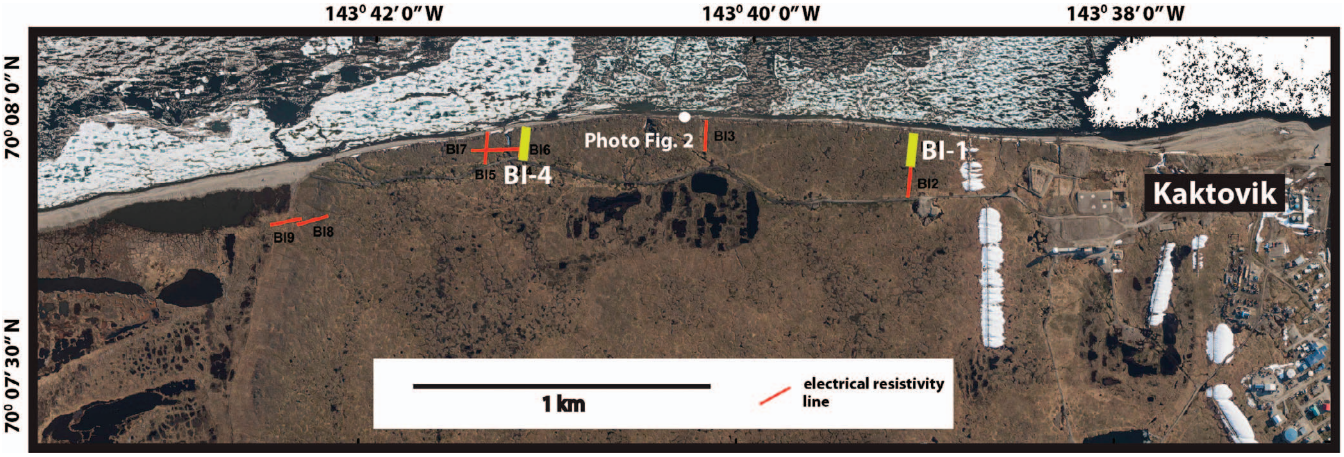

Figure 3. Electrical resistivity survey lines collected perpendicular and parallel to the coastal bluffs west of Kaktovik, Alaska in June and September 2014. Lines BI-1 and BI-4 are the thick gray lines.

Methods

Two identical sets of nine shore-parallel and shore-perpendicular ERT surveys were conducted on a coastal bluff west of Kaktovik on Barter Island in June and September 2014 (Fig. 3). The timing of these surveys was intended to capture winter (June) and end-of-summer (September) conditions so that the cumulative effects of one summer thaw cycle could be examined in the paired ERT data. The paired ERT surveys were conducted using an AGI R8 multi-channel SuperSting receiver powered by two 12v DC marine batteries. Current was routed by an external switch box to a land-based cable that consists of 56 electrodes spaced 2 m apart. Electrical resistivity measurements were conducted by injecting current into the ground through two electrodes and then measuring the resulting potential field at various positions using additional pairs of potential electrodes down cable. Up to eight simultaneous pairs of electrodes can be measured for each current injection point for the 56 electrodes on the line. Contact resistance was lowered to increase signal levels versus noise by driving in 50-cm stainless steel electrode spikes into the ground. A contact resistance test was preformed prior to each ERT survey. A dipole-dipole array was used on all nine survey lines during both June and September. Each ERT survey line pair was processed identically using AGI EarthImager software. Inversion model goodness of fit was determined using the root mean square (RMS) error between the measured apparent resistivity and the calculated apparent resistivity. In general, iterations less than six are desired, with lower iterations preferred. Inversion model RMS of less than 10% is typically acceptable for noisy environments. Inversions on this project typically required less than 5 iterations to attain an RMS error of less than 5%. The shallow subsurface (0.5–2 m) was also manually ground-truthed along each survey line using either electrode spikes (June 2014) or a probing probe (September 2014).

Results and Discussion

Multi-channel electrical resistivity has proven to be a useful geophysical technique to examine active layer/permafrost dynamics as it is highly sensitive to a change in the ionic strength of pore fluid, mineralogy, and the phase change between liquid water and ice (Hauck, 2002; Overduin *et al.*, 2012; Dafflon *et al.*, 2013). Using a land-based, multi-electrode resistivity cable, the underlying lithology, pore space, and hydrologic parameters are all held constant, so a change in resistivity can be attributed solely to a change in ice content, temperature, or porosity (Kneisel *et al.*, 2008; Lewkowicz *et al.*, 2011). Another attribute that makes ERT particularly useful for permafrost studies is that the resistivity of frozen sediment, ground ice, or permafrost can reach values up to 1×10^6 ohm-m, yielding a strong resistivity signal relative to other earthen materials (*e.g.*, clay = 1–100 ohm-m, and organic matter = up to 300 ohm-m; Duguay, 2013). In all ERT model outputs, the upper range of modeled resistivity values extended to 10,000 ohm-m.

The processed ERT images show dramatic changes in both the shallow and deeper features from June to September 2014. For example, a shore-perpendicular survey line conducted in September on top of the bluff reveals a thawed active layer that was still frozen in June (Figs. 4 and 5). During June, when the upper active layer was still completely frozen, many ERT images show pronounced vertical features that are either subdued or not present

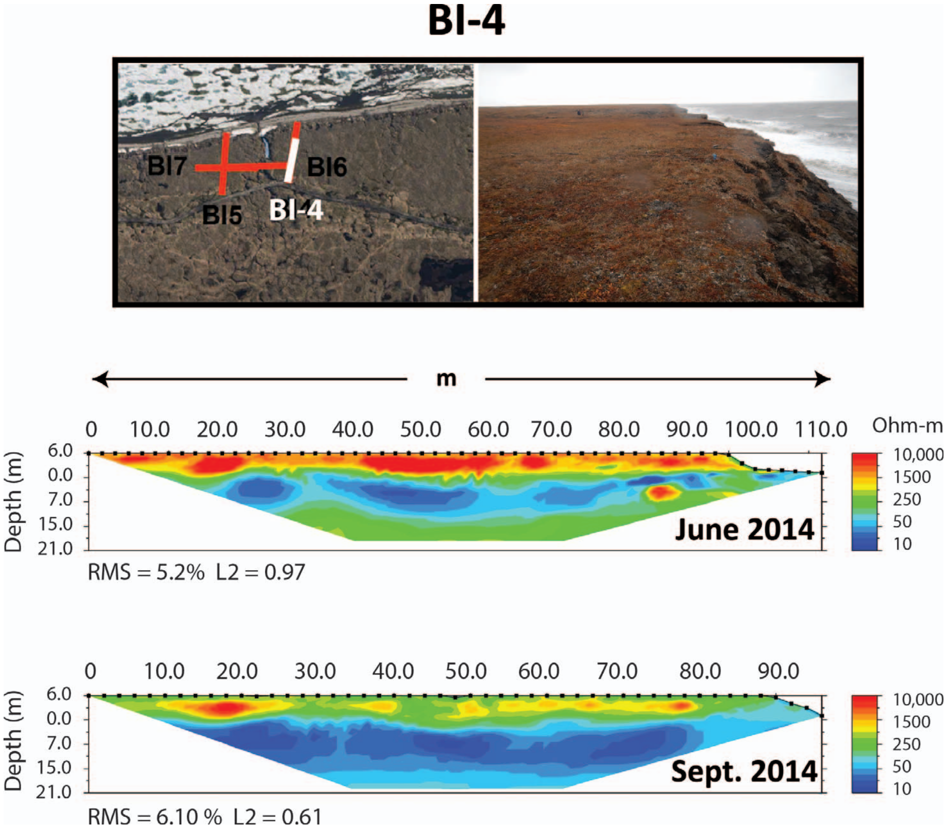

Figure 4. Paired multi-channel ERT for transect BI-4 that runs shore perpendicular and down the beach face. The structure of the active layer and underlying permafrost has clearly changed from June to September 2014. Photo shows a side view of the bluff face over which the end of the resistivity cable was draped. Photo credit: Tom Lorenson, USGS.

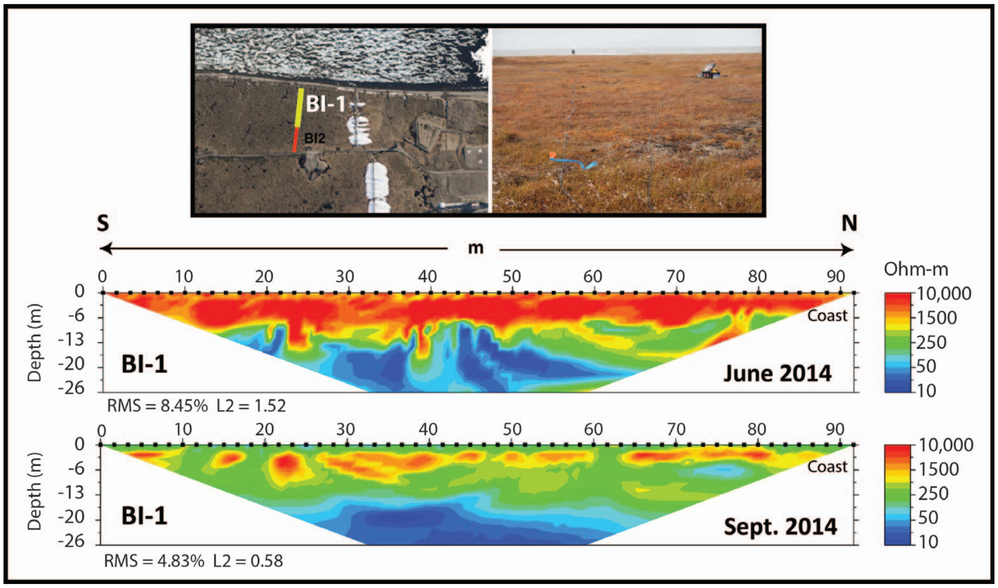

Figure 5. Paired ERT for transect BI-1, which is also a shore-perpendicular line on top of the coastal bluff. Remnants of a snow fence and the outskirts of Kaktovik are visible just east of BI-1. Photo credit: Tom Lorenson, USGS.

at all during the September surveys. These features may represent ubiquitous ice-wedge polygon boundaries that are developed by unique freeze-thaw cycles. Some ERT surveys were conducted directly across the bluff face and onto the adjacent beach (Fig. 5). A June-September comparison of such a survey line suggests that ERT effectively captured the frozen structure of an exposed bluff face and can yield information on how the bluff face and adjacent bluff surface changed during one summer thaw cycle. Shallow manual frost probe ground-truthing of the resistivity survey lines showed that the upper surface of the active layer is consistently frozen in June to depths less than 10 cm and in September to depths ~20–90 cm. Future work is needed to more quantitatively validate these geophysical observations and explore how this technique can provide new information on water content and drainage effectiveness of North Shore bluff landscapes. These electrical geophysical methods provide new insights into how subsurface features can change over one summer, with obvious implications to coastal bluff stability and material efflux to the atmosphere and coastal ocean.

Concurrent with these findings our group is i) using advanced mapping techniques to measure coastal change and bluff retreat, ii) developing complex models that merge oceanic and climatic datasets to better predict sediment transport and erosion under changing regimes, iii) quantifying associated material efflux (nutrients, carbon, sediment) to the coastal waters and atmosphere, and iv) using genomic microbial techniques to evaluate the role of freeze/thaw cycles on greenhouse gas production and emissions. Together, such results will support models that refine our understanding of how North Slope ecosystems are adapting to a changing climate.

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