Arctic Coastal Dynamics under Changing Relative Sea Level and Environmental Forcing, Canadian Arctic Archipelago

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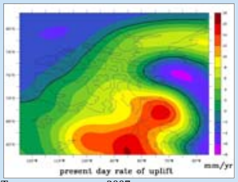
Abstract

Changes in climate variables and relative sea-level (RSL) are ongoing in the Canadian Arctic Archipelago (CAA). These regional changes threaten to modify the nature and timescale of arctic coastal processes. Further local variables such as bathymetry, sediment source and exposure to fetch alter the response of coastal systems to changing climate and RSL. Increased sediment erosion, transport and deposition will create a more dynamic coastline. Arctic communities need an assessment of the sensitivity of their coastline for decision-making and adaptation planning.

Facts: changing environment

The CAA is currently subject to significant changes in relative sea-level, sea-ice extent, thickness and duration, storm frequency and intensity and air temperature. These changes are illustrated below.

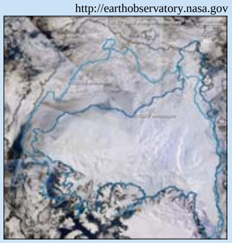


RSL is rising in the western and eastern CAA and falling in the central Arctic.

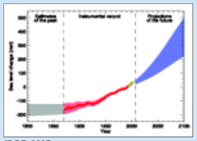
Tarasov, pers. comm. 2007

The rate and direction of RSL change results from the interaction between two components: the vertical motion of the earth crust (above) and global sea-level change (below).

http://earthobservatory.nasa.gov

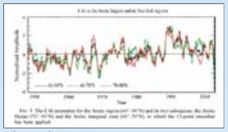


Satellite data point towards alarming reduction in sea-ice extent, thickness (Rothrock & Zhang, 2005) and duration (NSDIC, 2007). The extent of sea-ice minima in 2007 is contoured in medium blue, the previous record low from 2005 in light blue and the long-term average in gray (above).



Global sea-level is predicted to rise at a faster pace in the future.

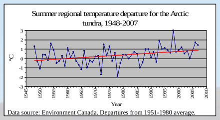
IPCC, 2007



The number, intensity and duration of cyclones in the Arctic have increased during the second half of the twentieth century (Zhang et al. 2004).

Zhang et al. 2004

Air temperature is rising over the CAA.



Theory: coastal dynamics

Changing RSL

Even though RSL is in itself a passive control, the rate and direction of RSL change is of great significance to beach evolution since it constrains the reach of wave processes. RSL rate and direction of change is a determining factor in the access to sediment source and in the rate of sediment supply (Forbes et al., 1995). For example, a higher rate of RSL change results in higher rates of sediment supply.

Changing air temperature

Warmer air temperature contributes to the deepening of the active layer. Under the same wave conditions, an unfrozen gravel berm erodes up to 10 times faster than a frozen gravel berm (Cox & Monde, 1985).

Changing sea-ice conditions

Sea-ice protects the shoreline by reducing the potential for wave generation and propagation (Forbes & Taylor, 1994). Longer and more extensive open water season exposes the shoreline to more energy by increasing the intensity and the number of wave events.

Changing wave climate

Lower sea-level pressure and increased number, intensity and duration of cyclones result in more numerous and more extreme wave events, flooding and storm surges at the coast. Wave climate also dictates the ratio between overtopping and overwashing processes therefore controlling the rate of coastal retreat (Orford et al. 1995).

Reality: observed changes

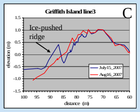
The rate and direction of RSL change, the storm climate and the duration and extent of open water are useful regional parameters to gauge the sensitivity of a coastline to climate change. However, local factors such as bathymetry or sediment source often override the influence of regional parameters in coastal dynamics.

The following case studies illustrate the changing balance between regional and local factors and the morphological outcomes of such a dynamic balance.

1. From flying spits to fringing barriers in 50 years, Griffith Island.

Although arctic coasts are thought to be low energy, they sometimes evolve very rapidly. The SE coast of Griffith Island has experienced significant changes since 1958, evolving from a series of discontinuous flying spits to continuous fringing barriers.

This rapid evolution necessitates a supply in sediment which is not readily available from the modern coast. Recent field observations suggest that sea-ice plays a dominant role in the supply of sediment by pushing sediment from the nearshore to the foreshore. This sediment is subsequently reworked by waves.

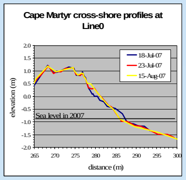


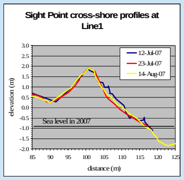
(A)Ice-pushed ridge with an ice core (circled) on the shoreface of GI3 on 07/16/2007. Arrow shows field book for scale.
(B) Same location on 08/17/2007 after significant wave activity. Boulders are left on the lower shoreface as a lag deposit while finer gravel was transported and sorted onshore by waves.
(C) The shoreface prograded by up to 2.2m in 4 weeks.

2. The impacts of a storm on emerging gravel beaches, Cornwallis Island.

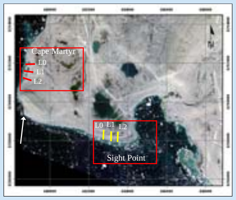
On July 20-22 2007, a deep cyclone produced strong easterly winds sustained over a 48 hour period. With negligible sea ice present in the region, maximum open-water fetch occurred and winds generated significant wave activity at the coast. Numerous cross-shore profiles were surveyed before, immediately after, and three weeks after the storm event.

Relatively sheltered west-facing sites (right) experienced accretion during the storm.





At Sight Point (left) the foreshore slope was eroded by up to 1.3 m. Minimal beach changes was observed at both sites by mid-August.

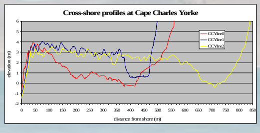


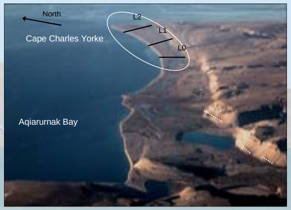
Locations of the Cape Martyr and Sight Point study sites and profile lines. The location of a newly formed ridge is indicated by an arrow.

Erosion of the south-facing beaches combined with a westward sediment transport likely provided material for the development of a new beach ridge (dashed line).

3. Rising RSL and prograded coastline, northern Baffin Island.

Cape Charles Yorke consists of a series of prograded gravel ridges deposited under rising RSL as indicated by the increasing crest elevation seaward (below). The morphology of the foreland suggests continuous progradation. In contrast, truncation of relict ridges by the modern shoreline suggests a regime shift to predominantly erosion. The reasons for this shift are currently being investigated.





The Cape Charles Yorke site illustrates how a coastal system may respond to changes in forcing. For instance, the system may be responding to changes in sediment supply or accommodation space (i.e. nearshore bathymetry).

Implications

The arctic coastline is a dynamic environment that is likely to become even more dynamic as sea-ice recedes, permafrost thaws and storm activity increases. Normal coastal processes such as sediment erosion, deposition and transport are likely to intensify in the future. The capacity for arctic communities to adapt to an increasingly dynamic coast relies on a thorough understanding of the coastal system at both regional and local scales.

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