

# Erosion of Arctic permafrost coastlines

## A case study from Qikiqtaruk island

Retrogressive permafrost thaw along the Arctic coast

As the seas rise and warm owing to climate change, coastal erosion of permafrost land in the Arctic is becoming a serious problem. This article explains the processes and threats, and describes how remote sensing with drones is being used to measure and record the changes. It illustrates the interactions between climate change, coastal hazards and the carbon cycle, as well as a use of remote sensing in fieldwork

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Coastal erosion of permafrost landscapes in the Arctic is one of the most prominent and hazardous changes taking place in response to climate warming. Longer ice-free periods and sea-level rise caused by climate change are both important factors leading to coastal erosion. This article summarises the problems and presents a case study of rapid change in a permafrost shoreline in northern Canada, which is being monitored using unmanned aerial vehicles (drones). It explains how these changes can affect human activities and the carbon cycle.

### The changing Arctic

The Arctic is the most rapidly warming region on Earth. Increasing temperatures result in changes to the physical and biological processes that shape permafrost landscapes.

Degrading of permafrost due to climate change has direct and indirect impacts on natural systems and on human infrastructure and activities. One of the key ways in which permafrost is being degraded is coastal erosion, which is happening along Arctic coastlines in Siberia and western North America. Over the past few decades, Arctic permafrost cliffs have typically eroded by half a metre each year, but this may be speeding up.

### Why do permafrost coasts erode?

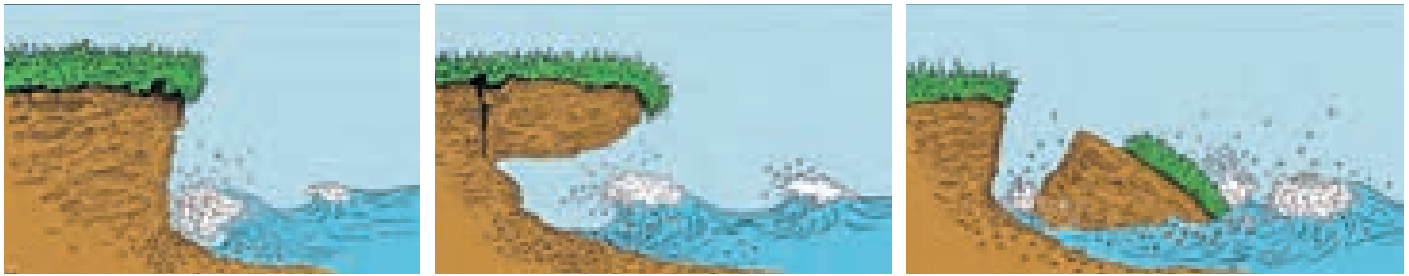
Coastal retreat and erosion of permafrost is mainly caused by **thermo-abrasion**. This is a physical process in which warmer waters, together with the mechanical energy of wave action, heat and erode permafrost. Thermo-abrasion undercuts coastal bluffs along the coastline, often creating overhanging sections that then break off into the sea as large blocks

(Figure 1). These blocks of frozen material initially protect the base of the bluff from further wave action, until they are warmed and eroded by the sea.

Variations in sea level, wave energy and sea surface temperature affect the rate of erosion, and recent research has shown the role storms can play in rapidly altering permafrost shorelines.

### Is it getting worse?

There have been reports from sites around the Arctic that the erosion of permafrost shorelines may have been increasing in recent years and decades. The evidence is not conclusive, but a speeding up of erosion would be consistent with other changes we know are happening. For example, the warming climate is causing sea ice to melt earlier in the spring and refreeze later in the autumn in nearly all



**Figure 1** Erosion of permafrost coastline by thermo-abrasional processes which lead to undercutting followed by block failure

areas. This means there are longer periods of open water when permafrost shorelines are exposed to thermo-abrasional processes.

Shoreline retreat rates can also be influenced by increasing relative sea level, caused by a combination of global sea-level

rise (**eustatic** effects) and sinking of the land in response to the melting of ice from the last ice age (**isostatic** effects).



Evidence of block failure on the Arctic coast at Kaktovik, Alaska

### Why does it matter?

Around the Arctic, erosion of permafrost coastlines releases large amounts of sediment into the sea near the shore. These sediments are often rich in organic matter, and so represent a transfer of carbon from the terrestrial ecosystem into the ocean. Researchers are working to understand how these additional nutrients influence coastal ecosystems, and what happens to the carbon that enters the sea.

It matters where this carbon ends up because it is being removed from long-term storage in the permafrost.

- If it is metabolised in the ocean, releasing carbon dioxide to the atmosphere, this

represents a positive feedback: increasing greenhouse gases leading to further climate warming.

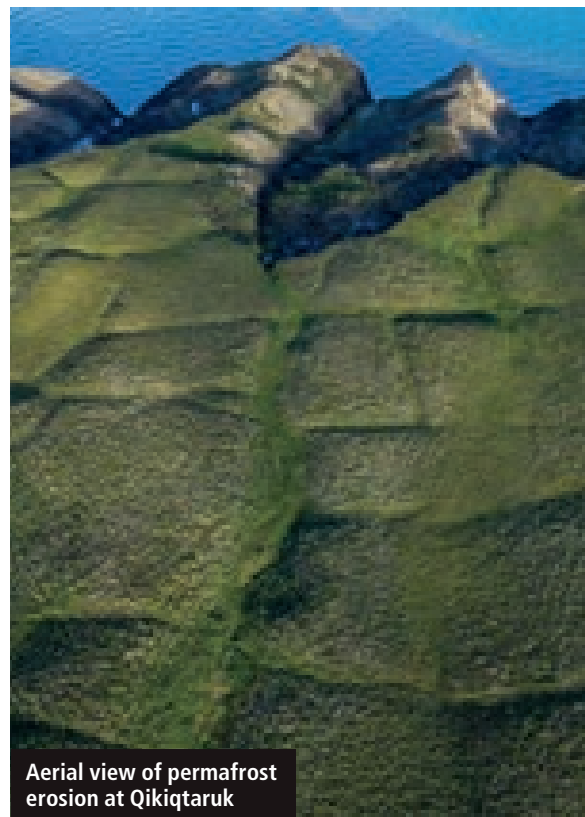
- On the other hand if the eroded carbon is buried in ocean-floor sediments it simply represents movement of carbon from one long-term store to another.

There are also direct human impacts of coastal erosion in the Arctic. Human settlements are often located in coastal areas, in the Arctic as in other parts of the world. Loss of coastline places these settlements at high risk. It threatens cultural heritage sites and damages modern infrastructure essential for local communities.

### Case study: Qikiqtaruk, Yukon, Canada

Qikiqtaruk is an island just off the north coast of the Canadian Yukon, in the western Arctic Ocean (Figure 2). It is at a latitude of 69°N, and the 110 km<sup>2</sup> area of this island consists mostly of ice-rich permafrost. The surrounding sea surface freezes solid from October to June, so there is little erosion throughout the harsh winters. Once the sea ice breaks up during the brief summers, the permafrost shoreline is subjected to thermo-abrasional erosion.

Around the whole island, the shoreline retreated by 0.45 m per year between 1970 and 2000, and by 0.68 m per year between 2000 and 2011. As



Aerial view of permafrost erosion at Qikiqtaruk



Figure 2 Map showing the study location

## Box | Measuring fine-scale shoreline change

Shoreline positions can be measured on the ground using instruments like global navigation satellite systems, such as GPS. However, such surveys are labour intensive and can be hazardous when standing at the top of crumbling bluffs.

Shorelines can also be seen in images captured by satellites, but freely available satellite images have coarse spatial resolutions and it is difficult to detect changes smaller than a pixel. This means that satellite images can usually be used only to detect relatively large changes in the position of a shoreline, of several metres or more. In addition, optical cameras in space can only see the Earth's surface when their view is not blocked by clouds in the atmosphere. Since the Arctic is often cloudy, many orbits of satellite

cameras do not capture any images of target areas. All these issues mean that satellite imagery has limitations for observing shoreline change.

Advances in drone technologies are allowing scientists to observe changing environments in new ways. Off-the-shelf consumer drones can be used to collect fine-resolution photographs recording shoreline positions, flying beneath clouds when necessary. Drones can be used to collect measurements as often as required (when the weather allows), sometimes every few days, recording small changes in shoreline positions. These changes can then be related to factors like meteorological conditions, sea level and sea-surface temperature, to learn more about the controls on shoreline change.

### GLOSSARY

**Episodic** Consisting of a series of separate irregular events.

**Eustatic** Changing sea level due to an altered volume of water in the oceans.

**Isostatic** Changing sea level due to a rise or fall in the movement of land masses.

**Permafrost** A sub-surface layer of ground that remains below freezing point for 2 or more years.

**Thermo-abrasion** Erosion of permafrost through the combined mechanical and thermal action of sea water.

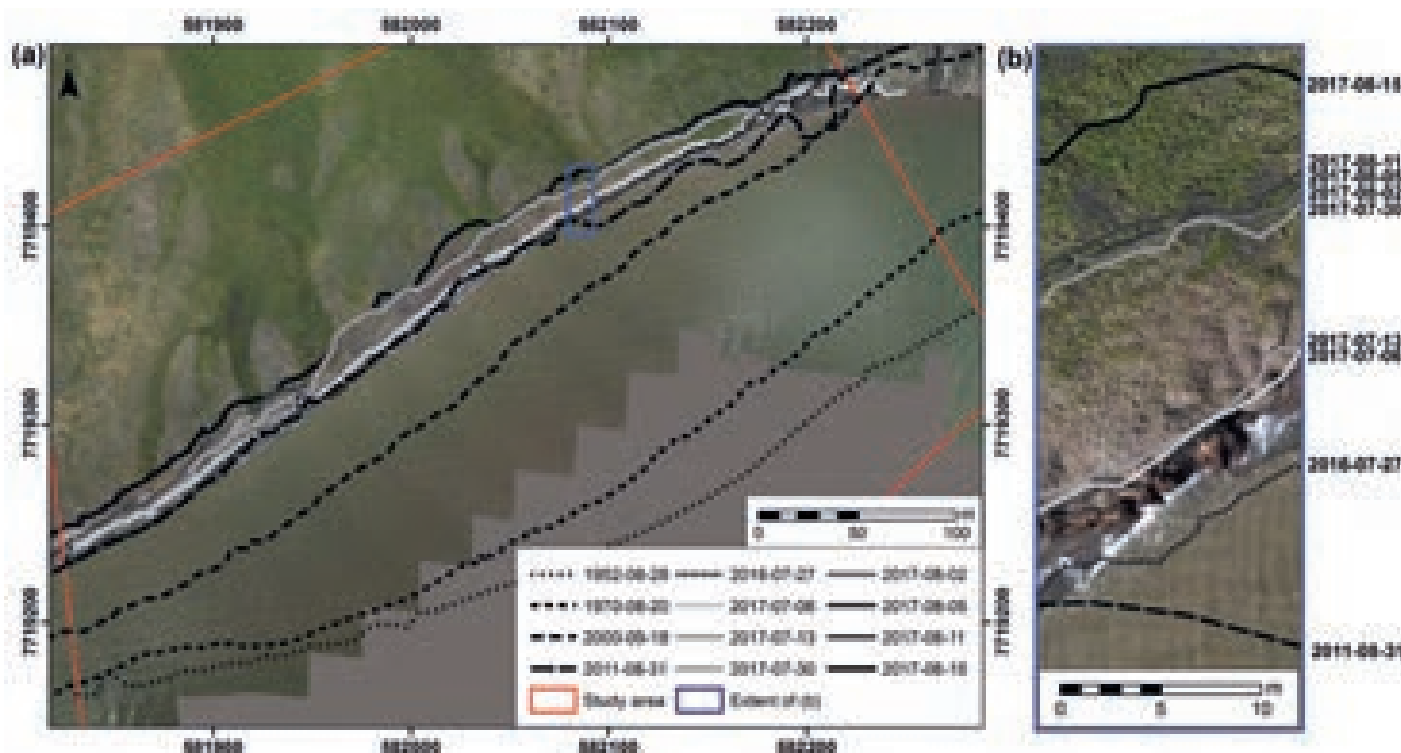
the climate warms, the sea ice melts earlier and freezes later each year, allowing more opportunity for the ocean to warm and for storms to batter the coast with waves.

### Remote-sensing research

In the summer of 2017, a 500 m section of Qikiqtaruk's coastline was repeatedly surveyed with lightweight drones (Box 1). The aerial photographs were processed to generate composite images and the shorelines were manually traced (Figures 3 and 4). This shoreline retreated by 14.5 m in just 40 days, a rate more than six times faster than

the long-term average rate of 2.2 m per year (from 1952 to 2017). Over a metre per day of shoreline was being lost during some periods, and over the 40 days of the survey approximately 19,000 m<sup>3</sup> of permafrost material was eroded from the coastal bluffs.

Repeat drone surveys revealed that the erosion was highly **episodic**, rather than being constant through time (Figures 3 and 4). During the intense storms that occurred almost weekly, strong winds influenced sea levels and wave energy, speeding up thermo-abrasional erosion processes and undercutting the permafrost bluffs (Figure 1). These findings



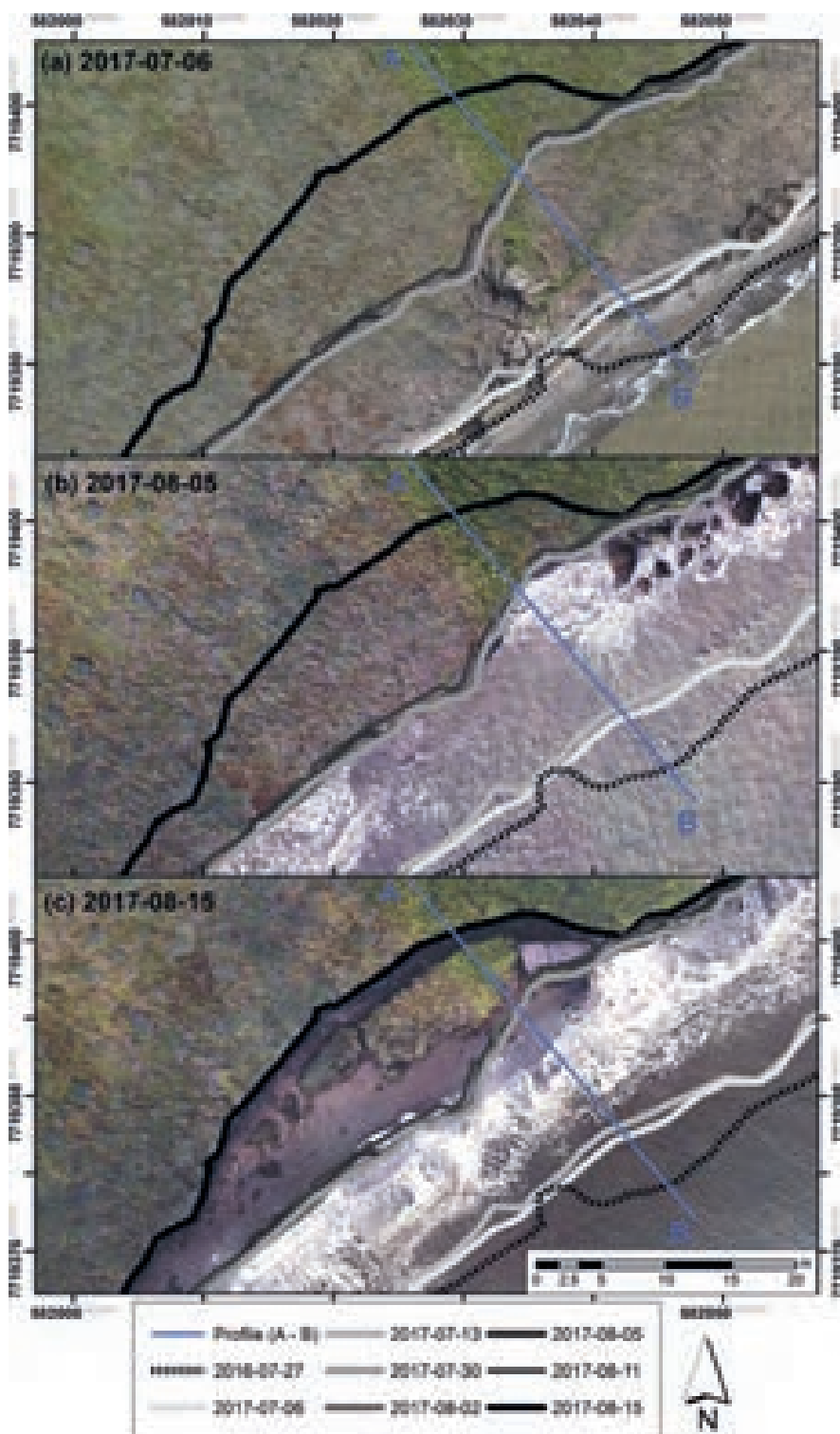
Source: Cunliffe et al. (2019) *The Cryosphere*, DOI:10.5194/tc-13-1513-2019

**Figure 3** (a) Overview of the 500 m study area, illustrating all 12 shoreline positions since 1952 overlaid on a 6 July 2017 orthomosaic. (b) A 10-fold magnification, illustrating the episodic nature of the shoreline changes at this location within the area of the blue bounding box depicted in (a)



highlight the episodic nature of shoreline change and the important role storm events can play, both of which are poorly understood along permafrost coastlines.

These high-frequency observations by drone transform the way researchers and communities can observe coastal changes to really understand them.



Source: Cunliffe et al. (2019) *The Cryosphere*, DOI:10.5194/tc-13-1513-2019

**Figure 4** Shoreline positions between 2016 and 2017 overlaid on three orthomosaics for a part of the 500 m study reach. The blocks shown in (c) were detached from the bluff, with water moving freely behind during periods of higher water level

## Questions for further discussion

- 1 What might happen to the organic-rich material that is eroded from permafrost coastlines into the ocean? How could this impact the carbon cycle?
- 2 How might the height of the coastal bluffs influence shoreline retreat rates?
- 3 How can we learn more about the controls on erosion processes in permafrost coastlines?
- 4 What are the advantages and disadvantages of drone-based surveying compared to satellite imagery or ground data collection?

## FURTHER READING

Videos of the eroding coastline of Qikiqtaruk: [www.tinyurl.com/y9k5wjml](http://www.tinyurl.com/y9k5wjml), <https://av.tib.eu/media/40250>

Video illustrating the Greening Arctic: <https://vimeo.com/342808200>

Article from Gizmodo about the erosion of Qikiqtaruk: [www.tinyurl.com/y2pc2bh4](http://www.tinyurl.com/y2pc2bh4)

Research blog from Team Shrub: <https://teamshrub.com/lab-blog/>

## KEY POINTS

- Erosion of permafrost shorelines in the Arctic is natural, but human-induced climate change appears to be accelerating this erosion.
- Erosion of permafrost shorelines happens through thermo-abrasional processes, often resulting in undercutting of coastal bluffs and 'block failure'.
- Eroding shorelines can be hazardous to coastal communities, and deliver carbon and nutrients into the coastal zone.
- Recent studies have started to reveal more about how storm events can drive abrupt erosion in permafrost coastlines, but understanding these processes will require more research.

Dr Andrew Cunliffe is a research fellow at the University of Exeter. He uses drones to measure changing ecosystems around the world, and lived and worked on Qikiqtaruk in the summers of 2016 and 2017. Dr Jo Snöälöv is a research fellow at Cranfield University. She has researched biogeochemical cycling of carbon in aquatic systems, and has spent several field seasons working in the Arctic.