Polar Science xxx (2016) 1–8

Contents lists available at ScienceDirect

Polar Science

journal homepage: http://ees.elsevier.com/polar/

# Erodibility of permafrost exposures in the coasts of Eastern Chukotka

Alexey Maslakov [a, *], Gleb Kraev [b]

[a] Faculty of Geography, Lomonosov Moscow State University, GSP-1, Leninskie Gory, 1, Moscow, 119991, Russia
[b] Center of Forest Ecology and Productivity, Russian Academy of Sciences, 14 Leninskii Avenue, Moscow, 119991, Russia

ARTICLE INFO

*Article history:*
Received 12 November 2015
Received in revised form
11 April 2016
Accepted 13 April 2016
Available online xxx

*Keywords:*
Permafrost
Coastal erosion
Erodibility
Chukotka
Lorino

ABSTRACT

Coastal retreat caused by coastal erosion decreases the territory of Russia by 50 km$^2$ annually. Erosion of the Arctic coasts composed by fine-grained permafrost turns coastlines into badlands dozens of meters wide and is harmful to the coastal infrastructure. Regional-level variations in the coastal retreat rate in the Arctic tend to follow the climate change dynamics and its consequences, mainly the shrinkage of the perennial sea ice area. This study considers the lower level local-scale variability linked to permafrost features, lithology, and morphology of the coasts in the remote region on the western shore of the Bering Sea within Lorino settlement (Chukotka, Russia). The coastal dynamics was tracked by means of geodesy and remote sensing in 2012–14, and the archival engineering survey data available since 1967. We have derived the erodibility of sediments from the conventional soil properties measured by engineers, and linked the coastal retreat rates to erodibility of the sediments, so that it could be extrapolated to other coastal areas of Eastern Chukotka with similar sediment structure.



## 1. Introduction

The shrinkage of the Arctic sea ice cover (ACIA, 2005; Comiso et al., 2008), and higher frequency of storms (Atkinson, 2005) occur synchronously with permafrost warming and rise of the active layer. These marine and terrestrial feedbacks to Arctic warming (IPCC, 2014) meet and work together in the coastal zone as factors emphasizing the coastal erosion in many locations in the Arctic (Solomon, 2001; Vasiliev et al., 2001; Streletskaya et al., 2004; Grigoriev et al., 2006; Lantuit and Pollard, 2008; SAC, 2011). Russia's land shrinks by up to 50 km$^2$ every year due to the coastal retreat (Luk'yanova et al., 2002) at the average rate of 2.2 m$\cdot$a$^{-1}$. The average rate is even higher on the Eastern Arctic sea shores, composed with the fine-grained sediments enriched with ground ice, ranging from 2 to 3.8 m a$^{-1}$ depending on lithology (Grigoriev et al., 2006).

Field-based monitoring of the Arctic coastline is challenged by its remoteness and accessibility. Therefore, no more than 1% of its length is covered with field monitoring (Lantuit et al., 2013). At the same time, remote monitoring of the Arctic coasts covers less than 25%, or 100,000 km of the Arctic coastline (Lantuit et al., 2012). Remote sensing methods have intrinsic limitations in use for extrapolation of the data from ground monitoring sites to regional scales. Despite the fact that the coastal retreat is sufficient for correlation with weather patterns and hydrological time series, it is disconnected from the physical processes of coastal destruction: coastal erosion and transport of sediments (Are, 2012). Highly variable geology and morphology of the coasts contribute greatly to the variations in coastal dynamics, which should be studied in order to raise the reliability of extrapolations and forecasts.

In this study we consider the erosional coefficient – the volume of soil eroded by the unit of water flow (or wave) energy, m$^3$ J$^{-1}$. It is one of the indicators of erodibility, the ability of soils to disaggregate under thermal and mechanical impact of water flow, as defined in Russian engineering geology literature (Pashkin et al., 2011). However, the data on erodibility of permafrost is sparse in Russian literature (Shur Yu et al., 1984; Zhestkova et al., 1985; Sovershaev and Kamalov, 1992; Aksyonov, 2008) and engineering survey materials. Maximal erodibility is typical for fine-grained ice rich soils (Are, 2012). This is a reason for the highest rates of coastal retreat typical for the Eastern Arctic coasts reported above, where the total gravimetrical ice content could exceed 60% (Romanovskii et al., 2004). The water heat energy adds on to mechanical energy when eroding such soil. Not only the ice content, but also the grain size of soils controls the erodibility (Hequette and Barnes, 1990). The higher the sand content in silty and clayey soils, the lower is the erodibility (Are, 1980). The rate and the character of coastal destruction could also be related to the width of the beach and the

* Corresponding author.
*E-mail address:* alekseymaslakov@yandex.ru (A. Maslakov).

http://dx.doi.org/10.1016/j.polar.2016.04.009
1873-9652/

height of the cliff (Are, 1980; Kachugin, 1959; Sovershaev, 1992; Vil'ner, 1955).

This study looked into the role of permafrost, lithology and coastal morphology in the coastal dynamics of the bluff in Lorino settlement (65.4978° N, 171.7247° W), located in Chukotka Peninsula on the Bering Sea shore, as shown on Fig. 1. It is most likely that in this study the role of climatic and hydrodynamic factors of coastal retreat variations would be less compared to the effect of coastal morphology and soil properties along the 750 m long coastline.

The sediments exposed in the Lorino bluff comprise the stratotype section for Beringia. This implies that the results of the study could be applied to a wider area using the data on erodibility together with the different external environmental factors that drive erosion, like the wave energy under different wind directions and number of storms, or the climate change decreasing the stability of permafrost. This might be practically applied in the design of transcontinental transport corridor across the Bering Strait, planned for 2030 (LUPS, 2008).

## 2. Materials and methods

### 2.1. Climate and hydrodynamics

According to the Köppen-Geiger updated classification (Kottek et al., 2006) the climate in Lorino is typical for the polar tundra, with the mean annual air temperature of −6.1°C (based on Lavrentia weather station, 35 km East of Lorino), and the 130-day-long period with above-zero temperatures, having the mean temperature of 4.4°C (http://aisori.meteo.ru/ClimateR; Kobysheva, 2001). The mean annual wind speed is 6.4 m $s^{-1}$ blowing dominantly northward and southward during the warm period (June–September). The mean annual number of days with stormy weather (wind speed more than 15 m $s^{-1}$) during the warm period is 24, of which over two-thirds occur during autumn (Atkinson, 2005; Zimich, 2002). Century-scale observations in Uelen (66.1600° N, 169.0816° W; WMO index 25399) and Provideniya (64.4286° N, 173.2172° W; WMO index 25594) show weak warming trend of 0.09–0.17°C per decade for 1929–2009 (http://aisori.meteo.ru/ClimateR). No trends in precipitations were detected.

Currently there is no permanent ice cover in the Bering sea. It is free of ice for about 4–5 months per year (June–October). The situation has changed significantly since 1980, when the summer ice cover occupied about 2 mln. $km^2$ (http://www.aari.ru/projects/ECIMO/index.php; Volkov et al., 1985), as shown on Fig. 2. Increases in the open water area and duration destabilized the areas affected by the Arctic air masses, which increased storm frequency (Atkinson, 2005). Autumn storms (southern, southeastern and eastern winds) recently occurred during the open water period, eroding the coasts, and causing harm to coastal infrastructure. The range of flood and ebb lies within the 0.3–0.4 m, and does not affect the coast compared to winds.

### 2.2. Permafrost, lithology, and morphology of the coasts

The coast in Lorino forms a straight line of northeastern direction with homogenous offshore bathymetry (TSL, 1992). We studied the 750-m-long erosion scarp of the remnant of a 22–25-m-high

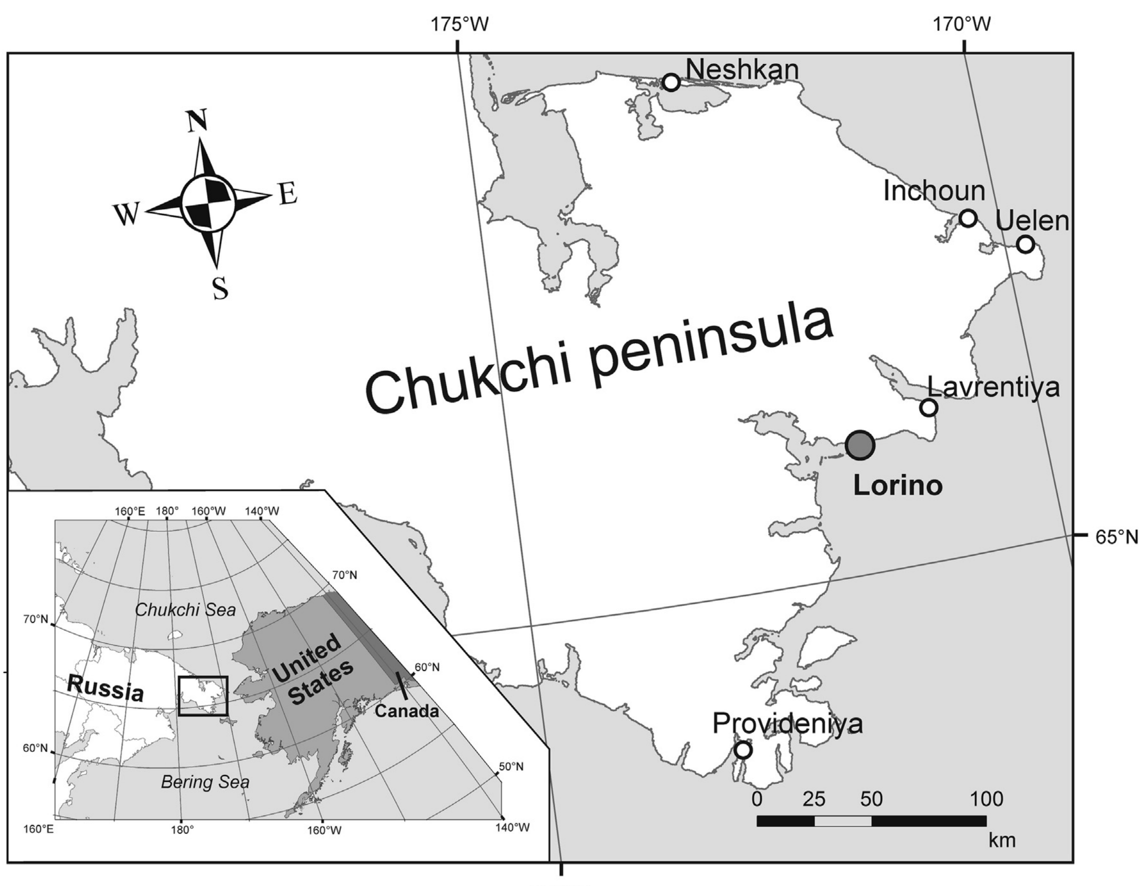


Fig. 1. Study location.