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# Coastal retreat at Kharasaveyskoye gas and condensate field area, Kara Sea, Russia since 1970s

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Abstract. Changes in coastal retreat rates, both spatial and temporal, are considered at the area of Kharasaveyskoye gas and condensate field for the period before the exploration till now. In the study area, the presence of permafrost makes the erosional coasts vulnerable to rising temperatures. The increase in air temperatures contributes to the thawing of coastal sediments and their accelerated destruction. And a decrease in sea ice area potentially increases the wave fetch. The rapidly changing climate of the Arctic should influence the processes of destruction of frozen coasts. At West Yamal Peninsula near Cape Kharasavey the average coastal retreat rate is 1.1 m per year (1977-2016) for 7 km of coastline. Based on the analysis of multi-temporal aerial and space images, it has been established that the maximum retreat rates are typical of coastal segments composed of icy sediments. As for temporal variability, the maximum rate of destruction was observed in 1977-1988 (up to 6.5 m per year) immediately after the beginning of economic development of the territory. In this key site, human impact affects the rate of coastal destruction more than variations in hydrometeorological parameters.

#### 1. Introduction

The coasts of the Kara Sea are mainly represented by accumulative (about 40% of the length), rocky (about 1/3 of the length) and thermoabrasional (about 20%) types of coasts [1, 2]. Thermal abrasion is a process of frozen coasts destruction, which combines results of wave action and coastal disintegration due to permafrost thawing. The weighted average rate of coastal retreat is 0.68 m/year [2], while the rate is higher within the open coastal areas (0.8-2 m/year) and lower in narrow bays (0.2-0.7 m/year for the coasts of the Gulf of Ob and Yenisei Gulf) [1]. The coasts of Western Yamal are destroyed with average annual rates of 0.5 to 2.5 m/year [3-5]. In the vicinity of the Kharasavey settlement, one of the highest mean multiyear shoreline retreat rates - up to 2.5 m/year - was observed at the end of the XX century [5-7]. Permafrost coasts are destroyed not only by the waves, but also by the melting of underground ice at positive air temperatures, which leads to loss of rock strength and the development of landslides, floats, debris and other destructive relief-forming processes [8, 9]. Thus, the observed climatic changes (in particular, the increase in air temperature) can accelerate the rate of cliff destruction. Reduced sea ice also contributes to increased coastal erosion by increasing the wave fetch and the duration of the dynamically active period [10, 11].

The relevance of the study of the dynamics of the coasts of the Kharasaveyskoye gas condensate field (GCF) in the north of Western Yamal is also determined by the recent start of development of the gas field, the project is expected to last for 108 years [12].

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#### 2. Research area

The Kharasaveyskoye field (71°7' N, 66°47' E) is located in the Yamal Peninsula north of the Bovanenkovskoye field, predominantly onshore and partly in the Kara Sea (Figure 1). The field is classified as unique due to its enormous gas reserves, which amount to 2 trillion cubic meters. Production is scheduled to begin at the field in 2023 with a design capacity of 32 billion cubic meters of gas per year [12].



#### 2.1. Climate and permafrost

The Kharasaveyskoye field is located in the subarctic tundra zone. The frost-free period is short and winter lasts 9.5 months. The average annual air temperature is about -10°C. In shallow waters the sea is free from ice for 2-2.5 months. Landfast ice opening occurs at the end of June, and the ice formation begins at the end of October [13]. Despite the short period of open water, the rate of coastal retreat is high enough.

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## 2.2. Topography and permafrost

The Northern Yamal is a lowland consisting of different-altitude flat surfaces with maximum heights in the central part of the peninsula. The origin of deposits of these surfaces is treated as either marine, coastal-marine and deltaic [13, 14], or the participation of cover glaciation in their formation is

recognized [15-17]. In the area of the Kharasaveyskoye field the absolute surface marks are 10-20 m, increasing up to 30 m in the northern part of the field. Researchers attribute the saline sediments composing these surfaces to coastal and marine terraces [13] or glacial sediments [17].

The research area is located in the zone of continuous permafrost distribution. The permafrost temperature in the elevated areas at the depth of zero annual amplitudes is about -7.8°C [13, 18]. The permafrost thickness varies from 0 in the subaquatic part to 150-180 m [13].

#### 2.3. Coastal types

On the 20 km stretch of coast between Cape Burunny in the north and Cape Kharasavey in the south the field monitoring of coastal dynamics has been carried out since the early 1980s by the staff of the Research Laboratory of Geoecology of the North, Faculty of Geography, Lomonosov Moscow State University. The northern 11 km of coastline is represented by low accumulative (by geomorphological type) retreating coasts, the accumulative forms of which are gradually shifting towards the land. While the southern part of the studied segment of the coastline is subject to thermal abrasion.

The thermoabrasional coasts are spread over a distance of 9 km between the Cape Kharasavey in the south and the Kharasavey settlement in the north. The cliffs are 7-12 m high and are composed of permafrost sediments: sand, sandy loam and loam. The ice content in permafrost changes along the coast, reaching in some places 60% [13, 14].

The first well at the Kharasaveyskoye field was drilled in 1974. Since then, preparations have begun for the development of the field. A port was built at the mouth of the Kharasavey River and a settlement 9 km to the north. At that time the pressure on the environment has increased considerably. However, in the XX century the project was frozen, as it was not profitable to transport gas by sea at that time. Today,

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after the construction of the pipeline from the Bovanenkovo field, Kharasaveyskoye's gas can be transported by land.

#### 3. Methods

It is not enough to analyze data averaged over long time intervals or for large areas of the coast to identify the factors that determine the rate of coastal erosion. In order to study the spatial and temporal variability of the retreat rates, multi-temporal airborne and space images were analyzed for the work area. Previous publications have used aerial photographs of 1977 (21.07.1977) and 1988 (05.08.1988), space images of 2006 (ALOS PRIZM 16.07.2006, resolution 2 m) and 2016 (WorldView-2, 15.07.2016, resolution 0.5 m, space images provided by the ©Digital Globe Foundation) [5, 7].

This work also analyzed the aerial survey of 1972, performed before the discovery of the field in 1974 and before the first attempts to begin exploration of the field. The images were orthorectified using TandemX 90m DEM and were linked to the most recent and detailed image of 2016. The rate of retreat was determined by the change of position in the coastal bluff edge.

#### 4. Results

In 1972-1977, only a 600 m long stretch of coastline, 2 km north of Cape Kharasavey, was actively retreating (Figure 2); it was characterized by a rate of 2.5-5 m per year. In 2008 the shoreline also retreated due to thermo-erosional niches formation and subsequent block failure (Figure 3) at the coastal segment located ~0.5 km to the north (Figure 4, northern part). For the rest of the coast, the rates were insignificant and close to the accuracy of the method (Table 1). It is not correct to calculate the speeds for 1972-1977 on the most part of the coastline length, because taking into account the resolution of the images and the accuracy of the binding only significant speeds will be reliable (more than 2 m/year, which corresponds to the total deviation of more than 10 m/year during this period).



**Figure 2.** Block failure at the coast to the north from Kharasavey Cape, 1976 [19, 20]. Note absence of the beach indicating high erosion rates



**Figure 3.** Block failure at the coast to the north from Kharasavey Cape, 2008. Person for scale

Table 1.	Coastal	retreat rate	calculated	for the	segments	with	different	coastal	sediments

Profiles of	Coastal bluff sediments	Segment . length, km	Retreat rate for different the periods, m/yr						
monitoring network			1972- 1977	1977- 1988	1988- 2006	2006- 2016	1977- 2016		
P7-P9	icy loams	0.9	<1.5	0.5	0.6	1.4	0.8		
P10-P12	loams	0.6	~2	0	0.8	0.7	0.6		
P22-P25	icy loams	0.8	<1	3.5	1.8	2.7	2.5		
P26-P35	sands	2.1	~1.5	2.4	1.3	1.5	1.7		

IOP Conf. Series: Earth and Environmental Science 324 (2019) 012027 doi:10.1088/1755-1315/324/1/012027



**Figure 4.** Coastal bluff retreat from 1972 to 2006, 2 km north of Cape Kharasavey. 1 – field monitoring network profiles; position of coastal bluff edge defined based on aerial and space images, in 2 - 1972, 3 - 1977, 4 - 1988, 5 - 2006, 6 - 2016

Previous studies have shown that the maximum rates at the 9-km section of the studied coastline were observed in 1977-1988 (maximum rate up to 6.5 m/year, weighted average for 6.8 km of active drifting shore 1.3 m/year). Coasts retreated significantly, but after all slower in 2006-2016 (maximum rate up to 3.7 m/year, weighted average for 6.8 km of actively retreating coast 1.2 m/year). Minimum rates were observed in 1988-2006 (maximum rate up to 2.3 m/year, weighted average for 6.8 km of actively retreating coast 0.9 m/year).

#### 5. Discussion

To characterize the hydrometeo-rological conditions, the wind wave energy flow and the duration of the ice-free period for 1979-2014 were previously calculated; freezing and melting indices were calculated for the entire period covered by the images [5, 7]. The maximum rates of retreat were observed in the area of the Kharasaveyskoye GCF in the period 1977-1988, when the parameters of both wave and thermal impact were at the level of average values. During the period of increasing hydrometeorological potential of coastal destruction (2006-

2016), the retreat rates increased compared to the previous period, but did not reach the level of 1977-1988. The increase in erosion during this period can be explained by both the peculiarities of the coastal zone structure (destruction of more icy deposits due to high spatial variability of sediment types) and the economic development that began in the mid-1970s.

#### 6. Conclusions

The example of the Kharasaveyskoye GCF shows that changes in hydrometeorological parameters (climatic changes) for the coasts of Western Yamal are not directly proportional to the rate of cliff destruction.

The coasts in the area of the Kharasaveyskoye gas condensate field were retreating with maximum rates in the period of the beginning of development (1977-1988 and earlier), characterized by reduced hydrometeorological load on the shore. The retreat rates were up to 6.8 m per year with the average values of 1.3 m per year. The increase in the rate of retreat in 2006-2016 is due to both changes in the hydrometeorological regime and human impact. Any technogenic changes in the coastal zone lead to the disturbance of the coastal lithodynamic system. As a result, some areas are becoming more eroded, while others may begin to accumulate sediments. Forecasting and accounting of these processes is necessary when planning the development of fields in the coastal zone of the Arctic seas.

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