Dynamics of low-lying accumulative coasts of western Gydan Peninsula in the area of gas development

Alexander A. Ermolov[1,2], Anna V. Novikova[1], Nataliya G. Belova[1]
[1] Faculty of Geography, Lomonosov Moscow State University, Moscow, Russia
[2] AO «Institute of Environmental Survey, Planning & Assessment», Moscow, Russia

ABSTRACT

The arctic coasts, largely composed of permafrost, are dynamically active with a tendency to retreat with a mean rate of about 0.5 m/yr. In the last decades due to global climate changes and construction in the coastal zone, the rates of retreat have increased at many sites so that a large part of accumulative coasts turned to erosional. We studied a 7 km long section of the western coast of the Gydan Peninsula in the area of Salman gas field development. Based on multi-temporal satellite imagery interpretation, field geological and topography surveys, we assessed the dynamics of the coast for the periods before and after the facilities' construction.

The coast at the area of study is a low-lying (0.5-2 m high) sandy accumulative marine terrace, and before the start of construction (2012-2014) it showed low dynamics with predominantly accumulative processes: mean rate of coastline progradation was 4.1 m/yr. With the beginning of port construction, the dynamics of the coast have changed: in 2014-2017 ¾ of the coast of the studied area experienced retreat (average retreat rate -5.8 m/yr, up to 28.5 m/yr in close proximity of the constructed facilities). We propose that coastal erosion intensification results from human impacts. After 2017, the rates of coastal destruction decreased, but the trend towards retreat continued.

KEY WORDS: Arctic coastal dynamics; Accumulative coasts; Coastal erosion; Gydan Peninsula; Gulf of Ob

INTRODUCTION

The coasts of the Arctic seas are retreating at an average rate of 0.5 m/yr (Lantuit, et al., 2012). Coastal erosion rate is characterized by significant regional and local variability and is primarily determined by coastal structure (coastline shape, the presence of permafrost, ice content, coastal bluff height, etc.) and hydrometeorological conditions (air and water temperatures, wave regime, ice-free period duration, frequency and the intensity of storms, etc.). Most of the studies are focused on the dynamics of thermo-abrasional coasts with a pronounced high coastal cliff, which erosion and destruction lead to coastal retreat (Baranskaya, et al., 2021, Belova, et al., 2020, Novikova, et al., 2018, and others). However, in recent decades, due to global climate change and warming in the Arctic region, the coasts that were previously stable or accumulative, formed in the Holocene in the conditions of marine sedimentation, also began to erode. Signs of ongoing erosion are often not expressed in the morphology of these coasts, but analysis of multitemporal aerospace and field data shows that such coasts are also subject to active destruction. The investigated key site is a low accumulative coast, where land development and hydraulic engineering construction have been carried out since 2014. The study aims to quantify the rate of destruction/advancement of a low accumulative coast based on the analysis of field and remotely sensed data and to determine the impact of construction on the dynamics of this coastal section.

STUDY AREA

The study area is located on the Gydan coast of the Ob Bay, the Kara Sea (Figure 1). The coasts of the Kara Sea gulfs retreat at a rate of 0.2-0.7 m/yr (Vasiliev, et al., 2006). A 7-km section of the coast between the mouths of the Khaltsanayakha River in the northwest (71.03° N, 73.75° E) and the Nadyaipingche River in the southeast (70.98° N, 73.87° E) is studied. Before the construction, along the entire length of the section, the coast was a low modern accumulative marine terrace (laida) 0.5 km wide and with heights of 1-2 m above sea level (Figure 1). Such accumulative low-lying laida coasts are characterized by the highest environmental sensitivity to oil and oil product spills (Petersen, et al., 2002, Kara Sea..., 2016). Further inland laida borders with an older surface composed of marine sediments with heights of 30-45 m in a 2-km strip along the coast (Porter, et al., 2018).

Figure 1. Research area (at the right) and typical low-lying laida coast (at the left)

The climate of the region is polar marine. Average annual temperature is about -8°C according to the data on the nearest weather stations Seyakha and Gyda (Weather timetable, 2021). During winter winds blow from the land to the sea and have the southern direction predominantly, during summer direction is opposite. Wind rates does not vary significantly, annual amplitude does not exceed 1-3 m/sec. The highest mean rates of wind (up to 7-8 m/sec) are observed during autumn and winter. The range of water level fluctuations in the Gulf of Ob in this area is about 1.3 m, depending on tides and surges. The maximum calculated annual sea level of repeatability 1 time in 50 years exceeds the average level by about 1.5 m, that is, the flooding of laida during high surges is possible. This part of the Kara Sea is covered by ice during 7-8 months per year, from November to June-July. During the last decades there is a tendency to rise of the summer temperatures, prolongation of sea ice free period duration, increase of storm frequency, related to global climate change.

In 2014, the construction of port facilities and ground infrastructure facilities began within the study area as part of the Arctic LNG 2 project of PAO Novatec. According to the project schedule, the explored 7 km of the coast between the mouths of the rivers Khaltsinneyyakha and Nyadaypinche will be almost completely occupied by the port, plant, and infrastructure facilities.

MATERIALS AND METHODS

The study is based on field lithological, geomorphological, and geodetic works, as well as on multitemporal remotely sensed data.

Field work

The fieldwork was carried out in September 2020 and included a description of the lithology and morphology of the coast and a geodetic survey of the coastline position and shoreface profile of the coastal zone using GNSS (Global Navigation Satellite System) receivers. Data on the composition and structure of beach and laida sediments was obtained. Technogenic impacts and natural lithodynamic processes were recorded.

Remotely sensed data

The analysis of the coastline dynamics was carried out using multitemporal satellite images. The position of the coastline on the accumulative coasts changes significantly even during the day. To characterize lithodynamic processes, two geomorphological indicators were considered: 1) the shoreline (the boundary of the water surface and land), and 2) dense vegetation boundary. The shoreline, as a rule, is easier to mark out at the image, nevertheless, its position on accumulative low-lying coasts varies significantly (up to the first tens of meters laterally) during the season and even during the day due to tidal, surge and storm fluctuations of the sea level. The boundary of dense vegetation is the upper boundary of the coastal zone (similar to the cliff edge at the erosional coasts) - this is the upper boundary of the wave run-up, averaged over recent years. Thus, this boundary is more stable than the coastline and its movement can better represent coastal dynamics. However, its position is difficult to trace on satellite imagery due to wind-blown sand from the beach deposited on laida, causing blurring of this border. Dense vegetation boundary can also shift due to man-made activities. According to the results of our calculations for a given section, the shoreline and vegetation boundary movement show similar trends. In the paper, we present data on coastline retreat.

We used space images WorldView-2 and GeoEye-1, purchased from Maxar Technologies, with a spatial resolution of up to 0.5 m (panchromatic channel), taken on August 23, 2012, June 29, 2014 and July 13, 2014 (mosaic), July 14, 2017 and July 24, 2020. All images were processed by the pan-sharpening operation to improve the spatial resolution of multispectral images. To improve the image georeferencing, they were orthorectified using freely distributed DEM ArcticDEM R.7 (Porter, et al., 2018) with 10 m resolution, in the WGS84 coordinate system, UTM zone 43N. To improve the accuracy of the results, images were manually referenced using at least 10 points for each set of images in ArcGIS using the 2nd Order Polynomial function for the 2014 and 2020 images and a 3rd Order Polynomial function for the 2012 image (all linked to the 2017 image). The final image referencing accuracy amounted: for images of 2017 and 2020 – 0.4 m, 2014 and 2017 – 0.5 m, 2012 and 2017 – 1.0 m.

Images were processed and interpreted using ArcGIS 10.5 software (ESRI Inc., Redlands, CA, USA). The coastline was digitized at a scale of 1: 500. The calculation of the rates of coastlines movement was carried out using the ArcGIS Digital Shoreline Analysis System (DSAS) 5.0 extension (Himmelstoss, et al., 2018). The program automatically builds transects normal to the general direction of the coastline (baseline) with an optional spacing along the baseline (50 m in our case). A date is assigned for each coastline. Thus, for each transect, the rate for a specific time period is calculated by dividing the distance between the coastlines by that time period.

RESULTS

Field work

In September 2020, the morphology and sediments of the laida and the beach at the key site were investigated, lithodynamic processes and technogenic impacts were recorded. The laida with heights 0.5 to 2 m a.s.l. is formed by a series of longshore barriers up to 25-40 m wide, separated by swales with a relative depth of 0.7 m and a width of 20-50 m, swampy or occupied by shallow lakes (Figure 2). The beach and laida are composed of fine, homogeneous sands (sands and loamy sands in USDA classification system). Aeolian processes are active in a 100 m width strip of the backshore: sandy material is transferred from the beach surface to the adjacent part of the laida, which makes it difficult to use the vegetation line as a coastal boundary proxy. The width of the beach is from 2 to 30 m, in some places a low cliff is formed in laida sediments, indicating recent erosion. To the north-west of the terminal, there is a 0.9 km long strip of longshore bars in the nearshore zone which become almost completely submerged in high tide and located 30-80 m from the coastline.

Remotely sensed data

During the last 8 years (2012-2020) the investigated coast experienced erosion at an average rate of -2.7 m/yr (Table 1, Figure 2), i.e. over 8 years, the coastline has shifted landwards by more than 20 m. The maximum retreat rate of 12 m/yr was observed in the area to the south of the terminal, where the total retreat for 8 years was 60-90 m. Against the background of this general trend, there are segments where the coastline in certain periods shifted towards the sea.

We considered three time periods that differ in the direction and intensity of lithodynamic processes:

2012-2014 is a period of relative stability/accumulation before the start of construction. ¾ of the coastline length shifted seawards. The entire coast aggraded at an average rate of 4.1 m/yr.

Table 1. Coastline position changes at the 7-km section of the eastern coast of the Gulf of Ob in 2012-2020

Time period	Coastline retreat rate, m/yr*	Coastal type, % of the total length (7 km)

	Mean	Max	Min	Retreating	Aggrading	no data (incl. technogenic coasts)
2012-2020	**-2.7**	**4.6**	**-12.0**	**50**	**20**	**30**
2012-2014	4.1	21.6	-3.4	17	77	6
2014-2017	-5.8	5.8	-28.5	77	16	7
2017-2020	-3.8	3.9	-13.9	65	10	25

* negative values indicates coastal retreat, positive – accumulation processes

It is inappropriate to extrapolate this value to a longer time interval, because it was obtained for a short two-year period. Nevertheless, it represents a tendency towards stability or coastal build-up before the beginning of the construction.

2014-2017 – a period of sharp intensification of erosion at the initial stage of construction. The situation became opposite in comparison with the previous period – erosion was observed on ¾ of the coast. The coastal retreat rate averaged 5.8 m/yr (i.e. coastal retreat >17 m during 3 years). The most intensively retreating section was the 2-km long coastal segment in the middle part of the study area on both sides of the constructed terminal (see Fig. 2). Average erosion rates here were more than 15 m/yr, up to 28.5 m/yr (total coastal retreat of 45 and 85.5 m during 3 years, respectively). Within this area the traces of sediment removal from the beach and the tideflat are visible on the space images. During this period, to the northwest of the constructed terminal the chain of longshore bars formed in the nearshore zone at the site of the 2014 coastline.

2017-2020 is a period of continued erosion with lower rates of retreat. Erosion was observed on the ⅔ of the coast; the average along all the coast rate of retreat amounted 3.8 m/yr. The erosion rate decreased in the most intensively retreating area between the projected northern ice protection structure and the constructing LNG plant, which indicates a relative stabilization of the lithodynamic system state after intensive impact at the previous stage. However, this is the area where coastal erosion threatens infrastructure facilities. In September 2020, the actively used road turned out to be at a distance of up to 13 m from the coastline, which necessitates coastal monitoring, limiting dredging and material excavation from the beach, and artificial beach nourishment if erosion continues.

So, the maximum rates of retreat were observed during the years of intensive technogenic restructuring of the coastal zone (2014-2017) and in the areas with dredging in the adjacent part of the nearshore zone and at the segments with sediment excavation from the beach and tideflat in a 100-m width strip along the coast.

Forecast

The construction of the southern of two ice protection structures (see Figure 2) began in 2020. These structures will partially protect a 4.5 km section of the coast from waves. However, erosion can be expected at the segments where the ice protection structures approach the coast because currents velocities there will increase.

The most actively eroded section (for 2012-2020 period) is located directly opposite the entrance to the inner water area of the port between two ice protection walls under construction. The configuration of the ice protection structures provides probable erosion of this section of the coast under southwesterly winds wave action. Also, in the study area, it is the southwestern winds that contribute to the surge phenomena. Therefore, despite the decrease in the intensity of waves in the inner water area of the port, coastal processes are included in the monitoring program. Special attention should be paid to the areas most vulnerable to erosion, and, if necessary, beach nourishment should be performed.

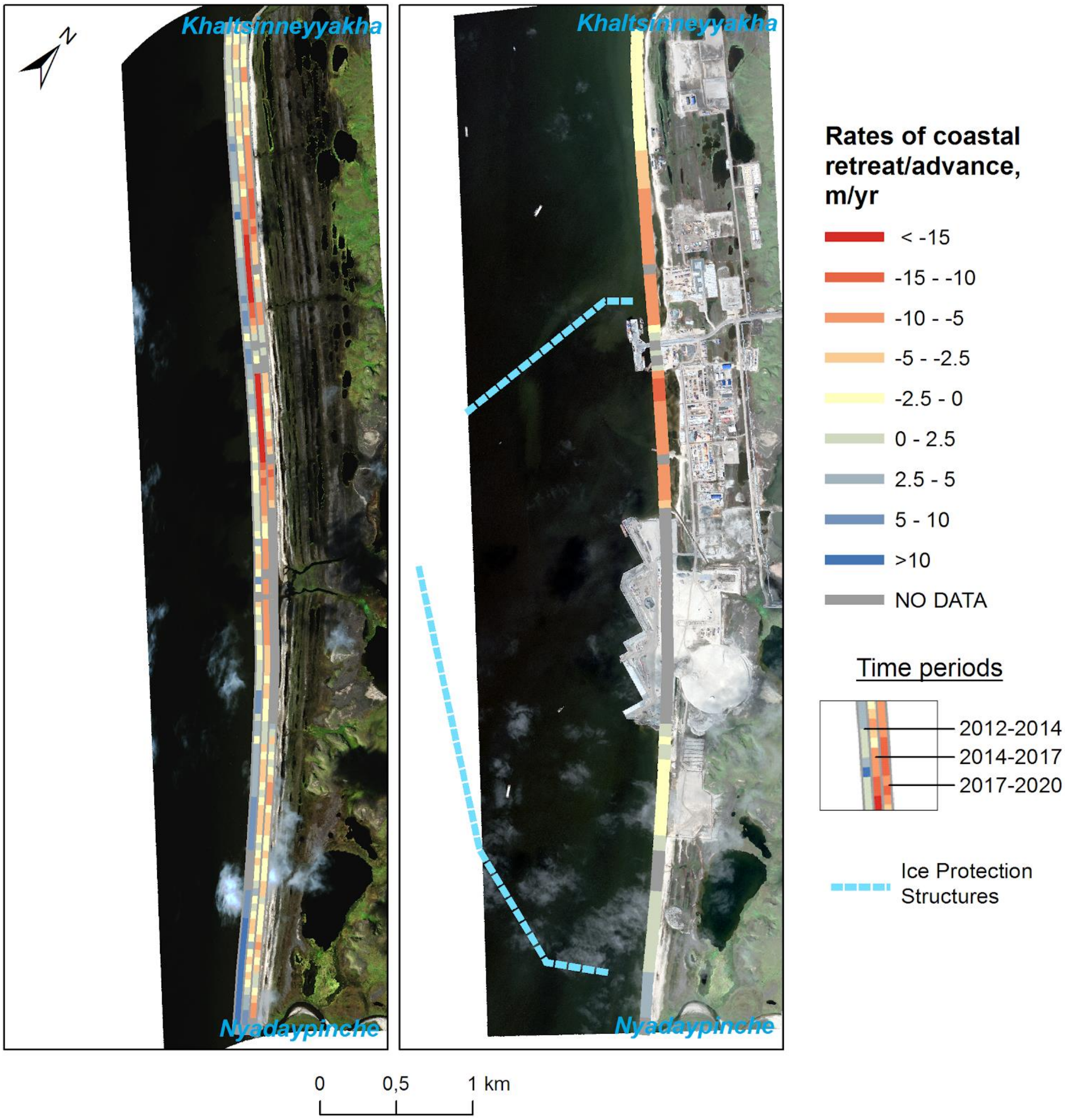

Figure 2. Rates of coastline movements: on the left – for different periods, on the right – for the 2012-2020 period. Background: WorldView-2 image of 2012 on the left, GeoEye-1 image of 2020 on the right

CONCLUSIONS

The 7-km section of the West Gydan coast was classified as stable or accumulative until 2014. The construction of port facilities and the LNG plant, which began in 2014, led to changes in the lithodynamic system. In 2014-2017 the coastline shifted landwards at an average rate of 5.8 m/ yr, in 2017-2020 – 3.8 m/yr. The retreat of the coast is caused chiefly by sediment excavation from beach and tideflat, and by dredging in the nearshore zone.

The construction of ice protection structures is planned in the project. This will allow to decrease the retreat rates in the southern part of the investigated coast , except for the areas where ice protection structures approach the coast.

The following steps can help to reduce coastal erosion:

1. The limitation of material withdrawal from the beach and tideflat at the most intensively retreating parts of the coast. They include the section to the northwest of the port which will not be protected from waves by the ice protection structures; segments where ice protection structures approach the coast; the most intensively eroded area between the northern ice protection structure and constructing LNG plant.

2. Continuous lithodynamic monitoring (which is now included in monitoring program) with special attention to the intensively retreating coastal sections.

3. If necessary, beach nourishment should be undertaken in the areas where the infrastructure facilities are located near the coastline (for example, the most intensively eroded area between the northern ice protection structure and constructing LNG plant).

ACKNOWLEDGEMENTS

The research was carried out within the framework of the project "Integrated studies of the ecological state of the Ob Bay in the area of the potential impact of the Arctic LNG 2 project and in the adjacent water area" funded by LLC "Arctic LNG 2". Remotely sensed data processing has been supported by RFBR project 19-35-90116. The work was done within the framework of the state budget theme AAAA-A16-116032810055-0.

REFERENCES

Baranskaya, A., Novikova, A., Shabanova, N., Belova, N., Maznev, S., Ogorodov, S., & Jones, B.M. 2021. The role of thermal denudation in erosion of ice-rich permafrost coasts in an enclosed bay. *Frontiers in Earth Science* 8.

Belova, N.G., Novikova, A.V., Günther, F., & Shabanova, N. N. 2020. Spatiotemporal variability of coastal retreat rates at western Yamal Peninsula, Russia, based on remotely sensed data. *Journal of Coastal Research* 95, pp. 367–371.

Himmelstoss, E.A., Henderson, R.E., Kratzmann, M.G., & Farris, A.S., 2018. Digital Shoreline Analysis System (DSAS) version 5.0 user guide: U.S. Geological Survey Open-File Report 2018–1179, 110 p., https://doi.org/10.3133/ofr20181179.

Lantuit, H., Overduin, P.P., Couture, N. et al. 2012. The Arctic Coastal Dynamics Database: A New Classification Scheme and Statistics on Arctic Permafrost Coastlines. *Estuaries and Coasts* 35, pp.383–400.

Novikova, A., Belova, N., Baranskaya, A., Aleksyutina, D., Maslakov, A., Zelenin, E., Shabanova, N., & Ogorodov, S. 2018. Dynamics of permafrost coasts of Baydaratskaya Bay (Kara Sea) based on multi-temporal remote sensing data. *Remote Sensing* 10, 1481.

Petersen, J., Michel, J., Zengel, S., White, M., Lord, C. & Plank, C. 2002. Environmental sensitivity index guidelines. Version 3.0. NOAA Technical Memorandum NOS OR&R, 11.

Porter, C.; Morin, P.; Howat, I.; Noh, M.; Bates, B.; Peterman, K., et al. 2018, “ArcticDEM”, https://doi.org/10.7910/DVN/OHHUKH, Harvard Dataverse, V1, [Accessed 17.02.2021].

Kara Sea. Ecological Atlas. 2016. Arctic Scientific Center LLC: Moscow.

Weather timetable, 2021. Weather archive at Seyakha weather station [Online] (Updated 9 May 2021) Available at: https://rp5.ru/Архив_погоды_в_Сеяхе [Accessed 9 May 2021]