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Coastal dynamics of the eastern Gulf of Finland:
toward a quantitative assessment

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RSF Russian Science Foundation

1. Coastal zone geology

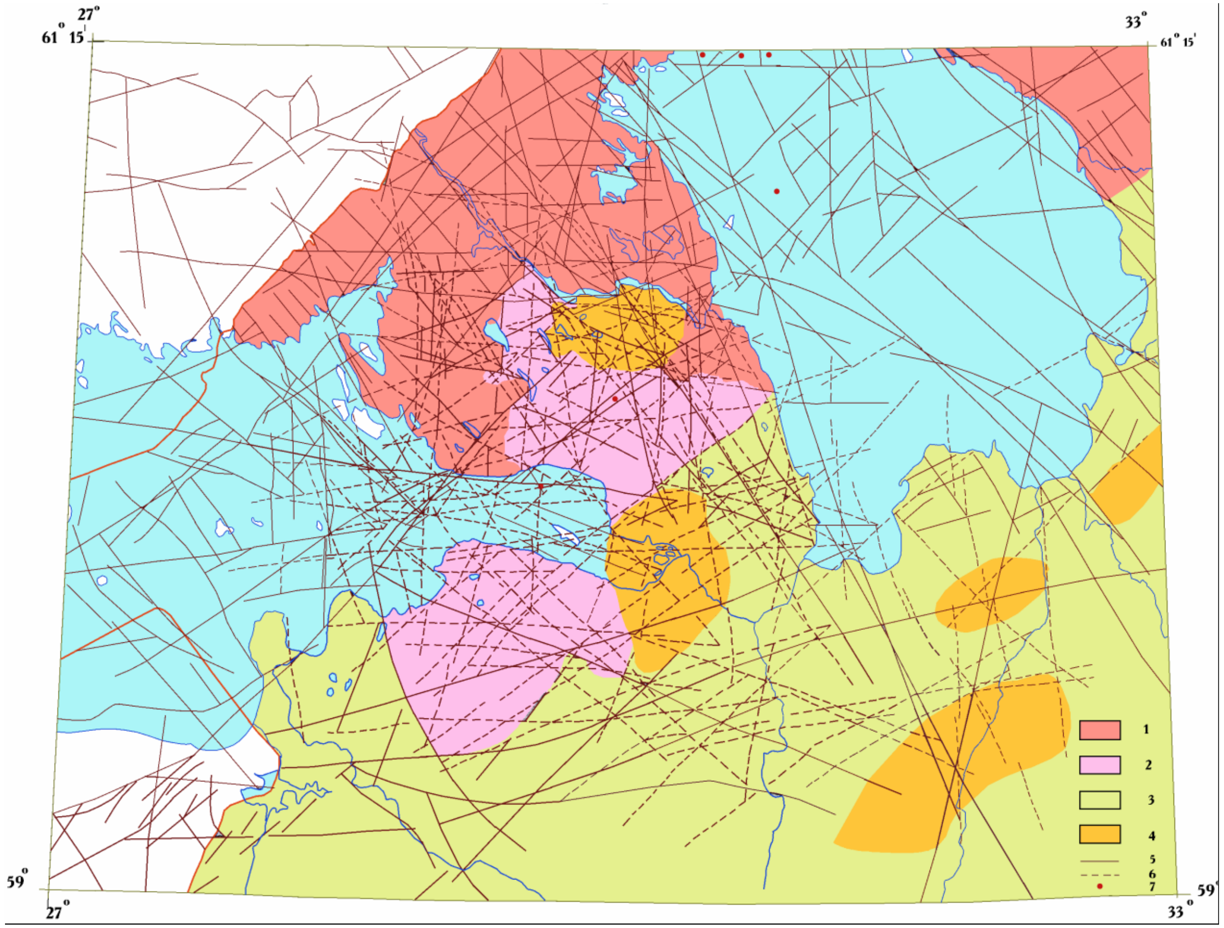
The coast of the eastern part of the Gulf of Finland is composed of loose terrigenous sediments such as sand, clay, moraine loam and sandy loam. These deposits are easily destroyed by the action of the waves.

Deficit of sand material

Effect of sediment starvation caused by deficit of sand material after boulder bench forming in moraine erosion areas.

Coastal plain shoreline of the eastern Gulf of Finland are characterized by very low rates of glacioisostatic uplift (1-3 mm/year) and a near zero rate of recent sea-level rise.

2. Regional tectonics



3. Hydrometeorological reasons of coastal erosion

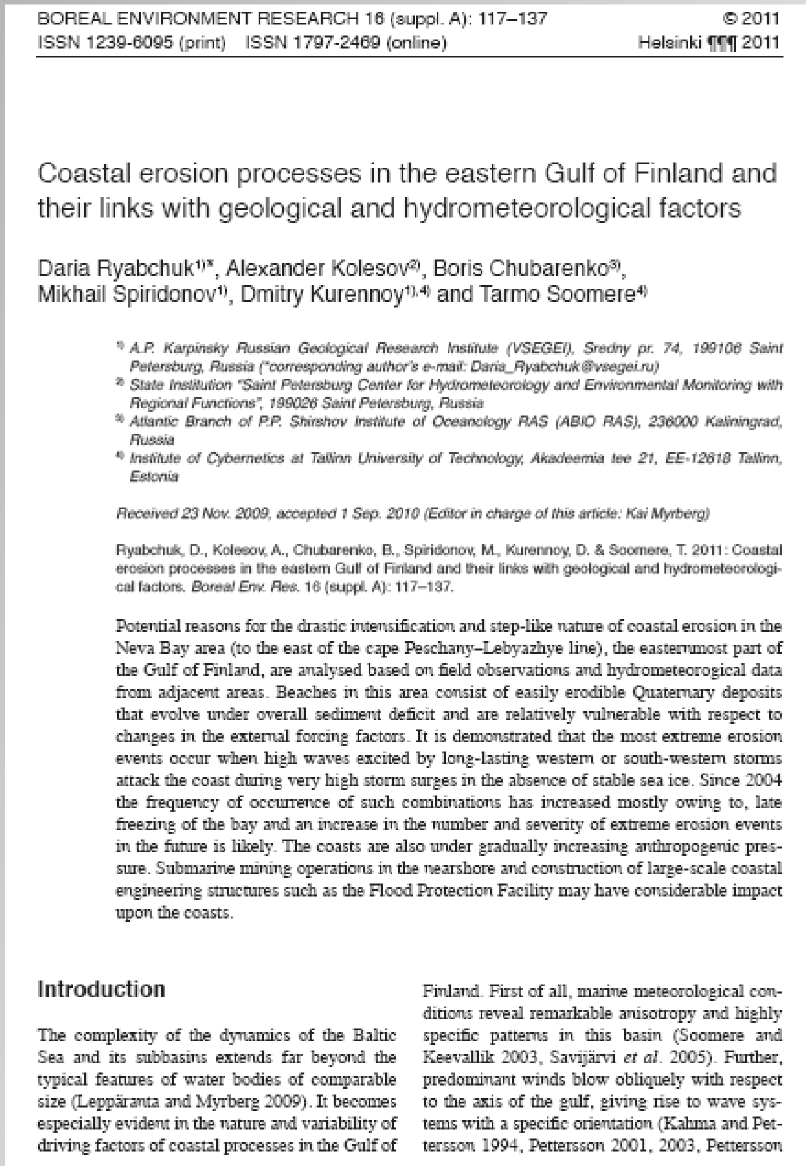
western storms

storm surge (higher 2 m)

absence of sea ice

Most severe erosion events observed in case of coincidence

Based on the results of statistics analyses of coastal monitoring and hydrometeorological data during 2004–2010, it was demonstrated that the most extreme erosional events occur within study area when three unfavourable conditions take place simultaneously: 1) long-lasting west or south-west storms; 2) high water level, and 3) the absence of stable sea ice (Ryabchuk et al. 2011). The results of coastal monitoring for 2011–2017 support this hypothesis.



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Coastal erosion processes in the eastern Gulf of Finland and their links with geological and hydrometeorological factors

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Ryabchuk, D., Kolesov, A., Chubarenko, B., Spiridonov, M., Kurennoy, D. & Soomere, T. 2011: Coastal erosion processes in the eastern Gulf of Finland and their links with geological and hydrometeorological factors. *Boreal Env. Res.* 16 (suppl. A): 117–137.

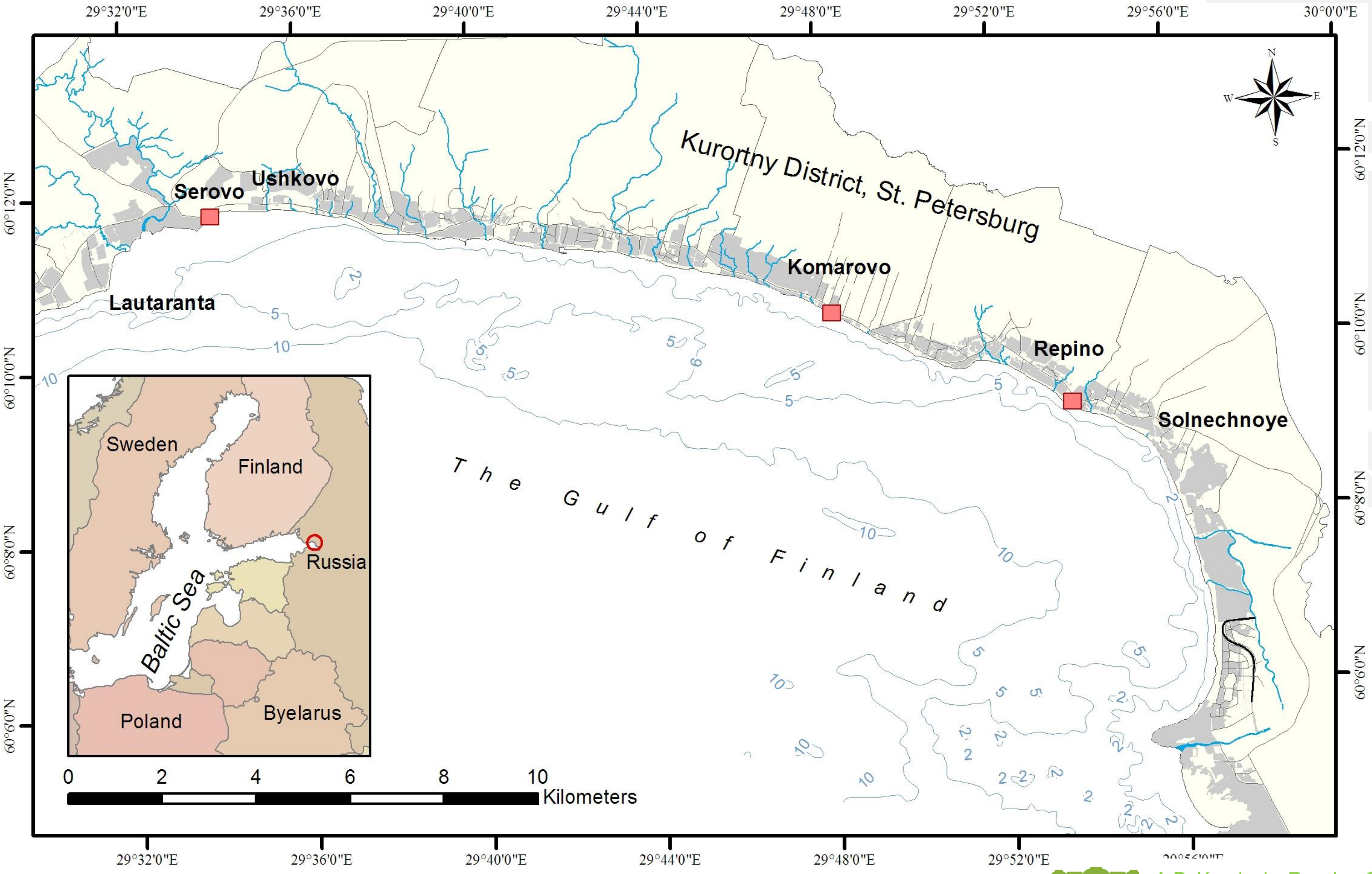
Potential reasons for the drastic intensification and step-like nature of coastal erosion in the Neva Bay area (to the east of the cape Peschany–Lebyazhye line), the easternmost part of the Gulf of Finland, are analysed based on field observations and hydrometeorogical data from adjacent areas. Beaches in this area consist of easily erodible Quaternary deposits that evolve under overall sediment deficit and are relatively vulnerable with respect to changes in the external forcing factors. It is demonstrated that the most extreme erosion events occur when high waves excited by long-lasting western or south-western storms attack the coast during very high storm surges in the absence of stable sea ice. Since 2004 the frequency of occurrence of such combinations has increased mostly owing to, late freezing of the bay and an increase in the number and severity of extreme erosion events in the future is likely. The coasts are also under gradually increasing anthropogenic pressure. Submarine mining operations in the nearshore and construction of large-scale coastal engineering structures such as the Flood Protection Facility may have considerable impact upon the coasts.

Introduction

The complexity of the dynamics of the Baltic Sea and its subbasins extends far beyond the typical features of water bodies of comparable size (Leppäranta and Myrberg 2009). It becomes especially evident in the nature and variability of driving factors of coastal processes in the Gulf of Finland. First of all, marine meteorological conditions reveal remarkable anisotropy and highly specific patterns in this basin (Soomere and Keevallik 2003, Savijärvi *et al.* 2005). Further, predominant winds blow obliquely with respect to the axis of the gulf, giving rise to wave systems with a specific orientation (Kahma and Pettersson 1994, Pettersson 2001, 2003, Pettersson

Location map of the study areas of terrestrial laser scanning (red squares)

along the eastern coast of the Gulf of Finland within the Kurortny District of St. Petersburg.



Ivan Shishkin. 1891. AFTER STORM.

Merihovi (Kuokkala)

Saint Juda hurricane,
29 October, 2013

AFTER STORM 05.12.2015

Repino village

Komarovo village

01.12.2011

28.12.2011

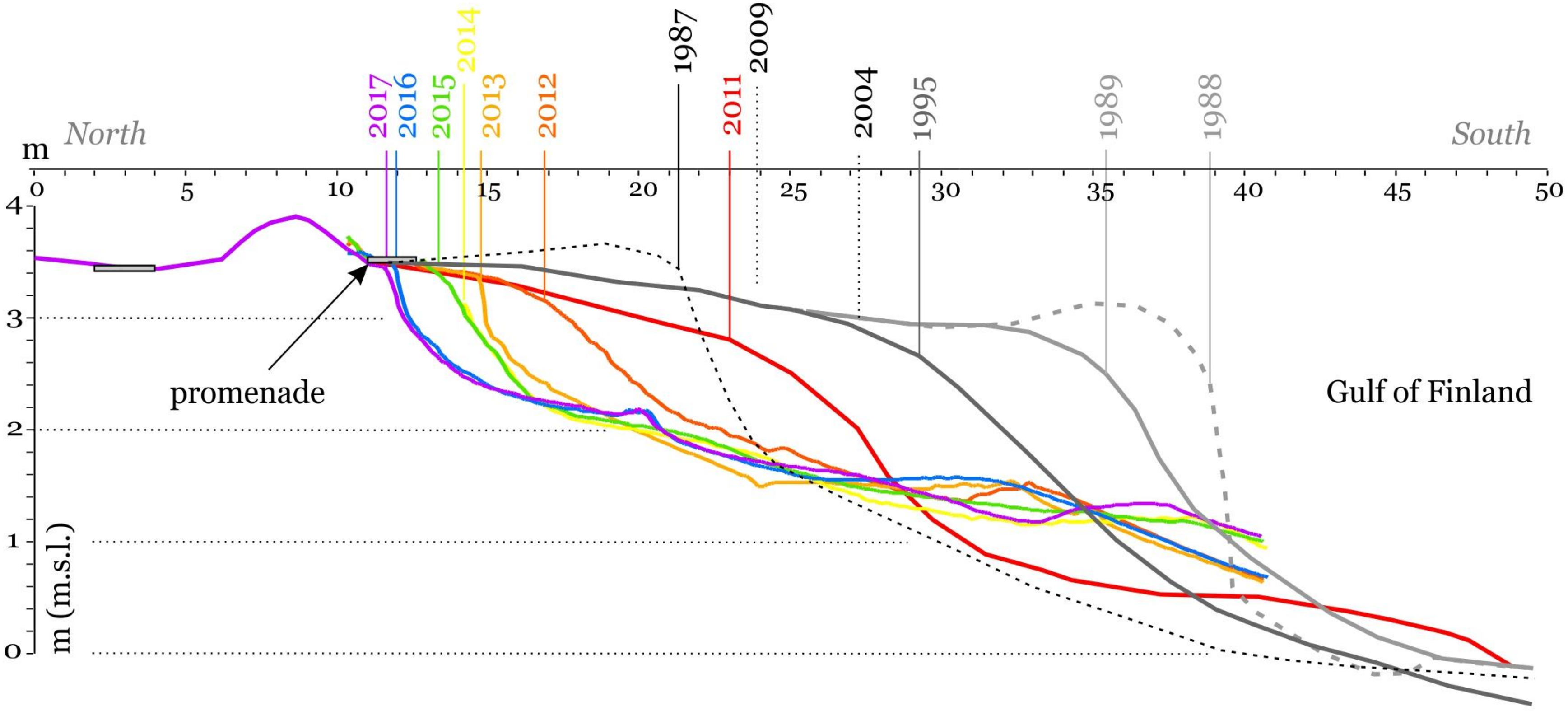
2014

Artificial beach in Komarovo village, 1988

(courtesy by prof.Kaarel Orviku)

Current situation on the beach

Dynamics of beach erosion by Levelling



Dynamics of beach erosion in the area of artificial beach backfilling performed in 1988 in Komarovo village. Levelling profiles from 1987 to 1995 according to K. Orviku data, from 2011 according to VSEGEI data.

Sand nourishment

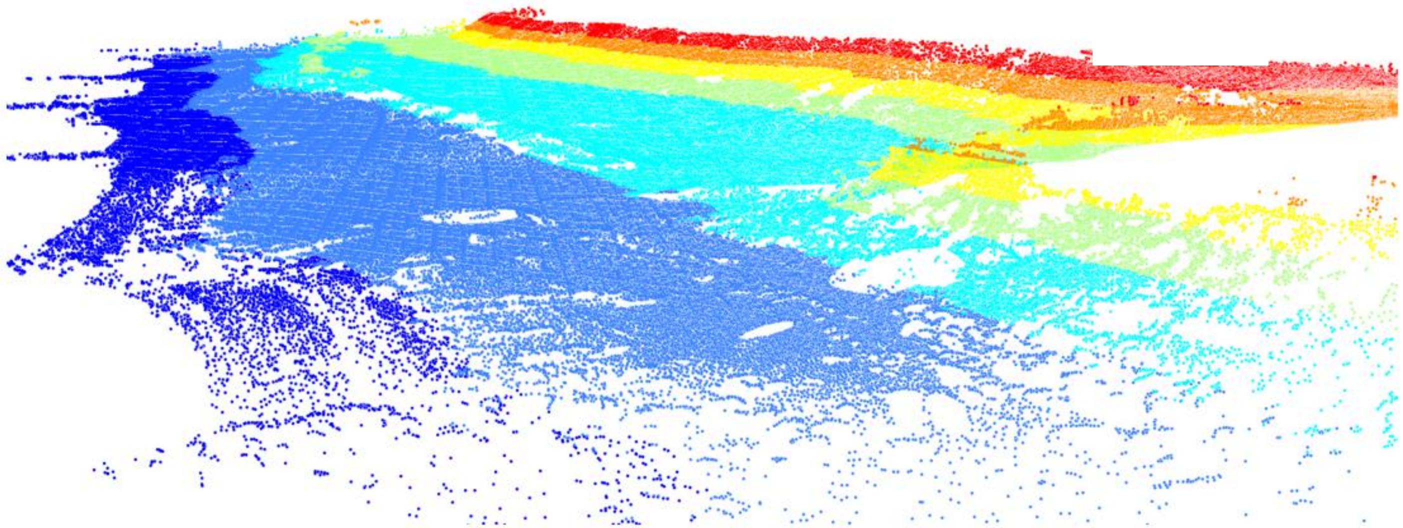
In 1988, the beach-face escarpment moved seaward **17.5** m

Annual rate

The average annual rate of retreat of the terrace scarp was **0.86** m/year

Maximum

The maximum rate of shore erosion was recorded in the 2011–2012 storm season and reached **6.5** m/year



Terrestrial laser scanning

4

Device

TLS was carried out by “Alpha-Morion ltd.” using the terrestrial laser scanner “RIEGL VZ-400” (Austria)

Periods

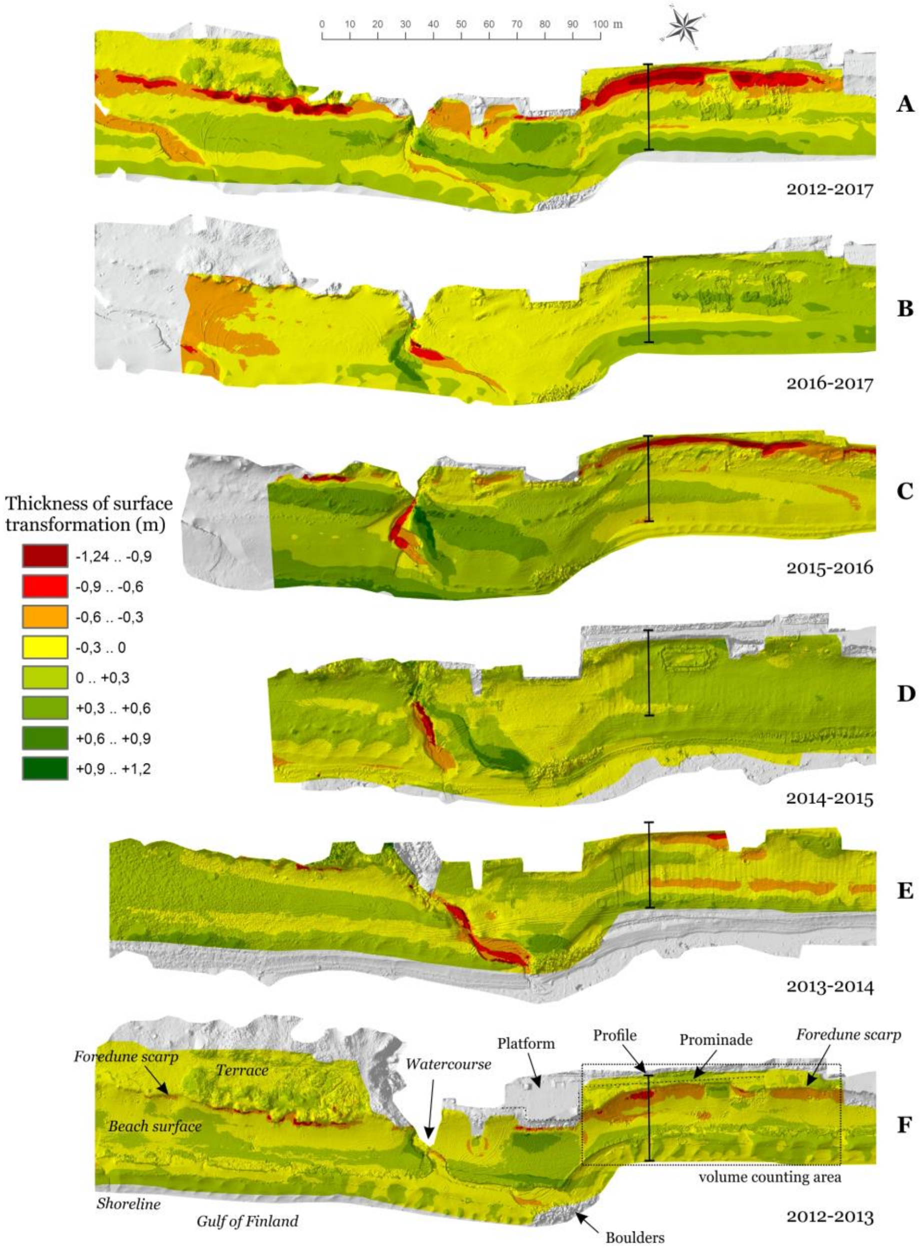
October 2012, November 2013, every summer from 2012 to 2017

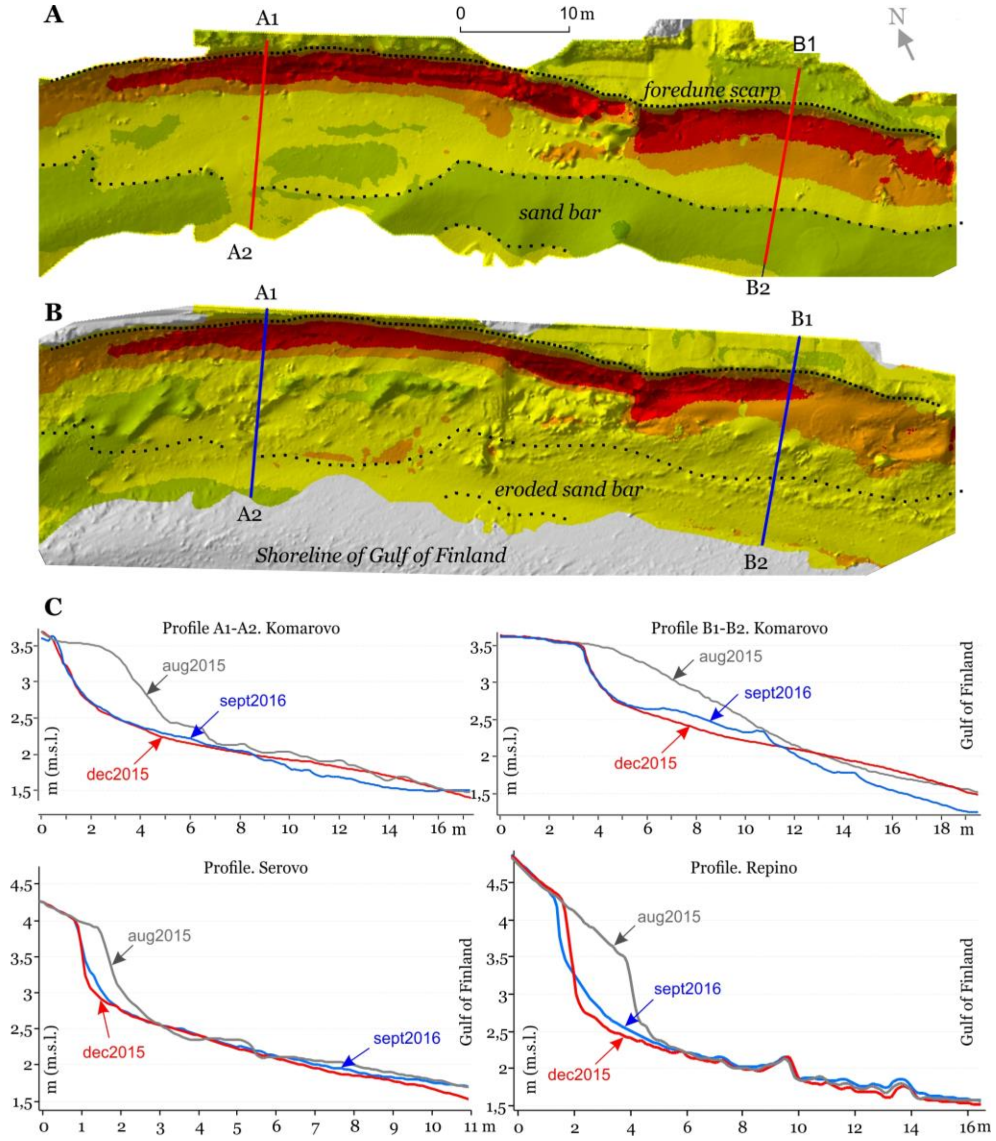
4

Locations

Coastline scanning is about 400 m in Komarovo village, 190 m in Repino village and 150 m in Serovo village

The thickness of the deformation layer of the beach and foredune surfaces in Komarovo village from 2012 to 2017 according to the TLS. 2012–2017 (A). 2016–2017 (B). 2015–2016 (C). 2014–2015 (D). 2013–2014 (E). 2012–2013 (F).





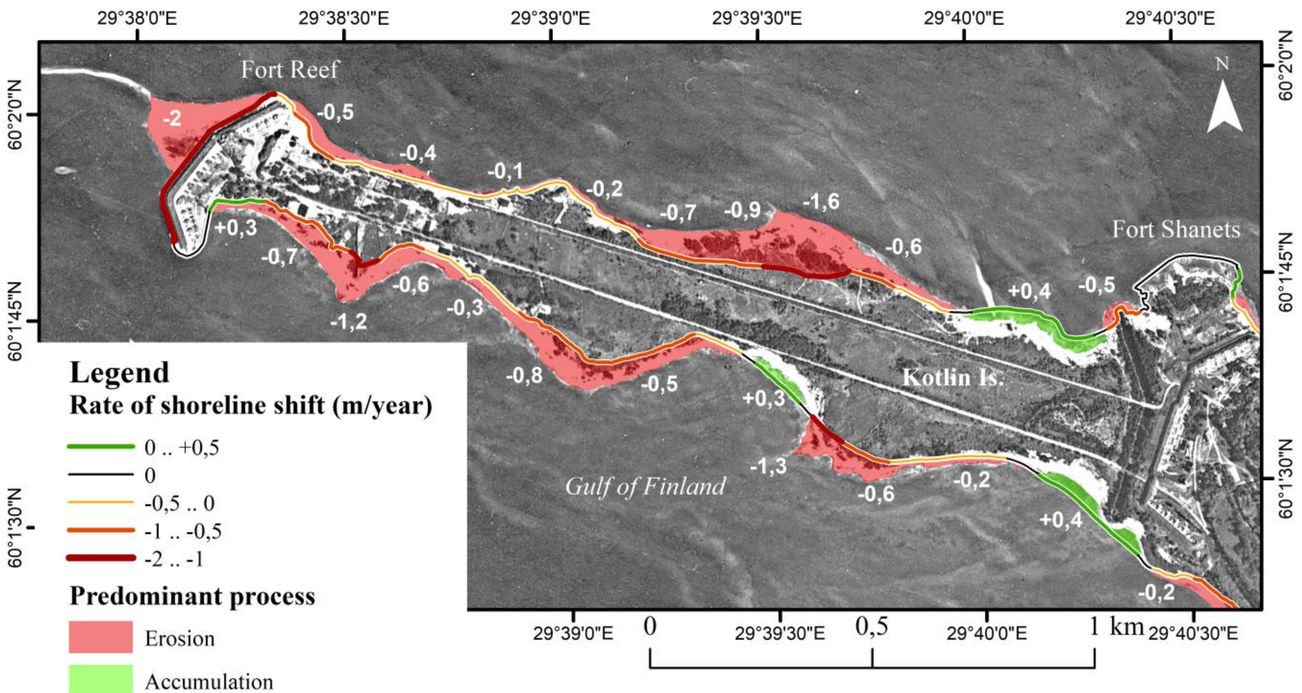
Changes in beach sand thickness according to TLS data. For digital elevation model (DEM) before the storm in August and after the December 2015 storm (A). For DEM after the December 2015 storm and in August 2016 (B). Deformation of the beach and foredune profiles in Komarovo, Serovo and Repino villages (C).

Volumes of sand material displaced in the beach zone of Komarovo village according to TLS data from 2012 to 2017

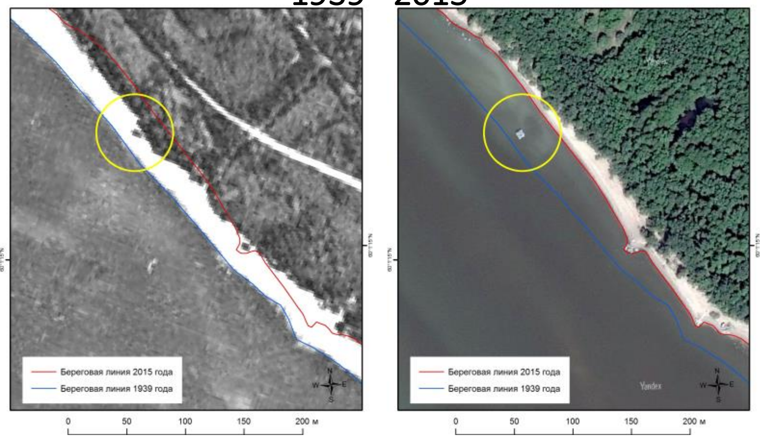
(a shore segment (91 m longshore length, 2800 m2))

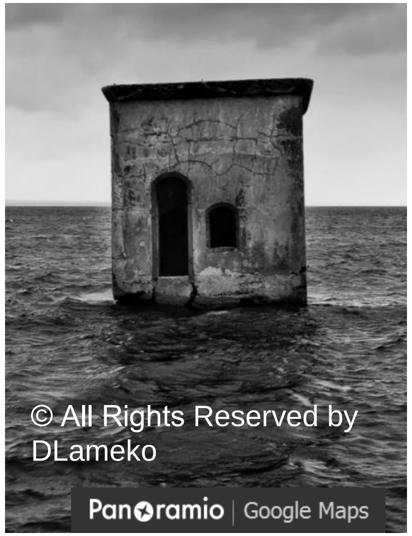
Period	Sand accum. (m^3)	Sand loss (m^3)	Budget (m^3)	Area of sand accum. (m^2)	Area of sand loss (m^2)	Budget of linear meters (m^3 m^{-1})
2017-2012	176.84	589.9	–413.06	1032	1844.83	–4.5
2017-2016	304.83	64.17	240.66	1992.58	843.1	2.6
2016-2015	60.71	451.79	–391.08	672.66	2165.64	–4.3
2015-2014	226.07	23.9	202.17	1916.75	528.59	2.2
2014-2013	114.82	318.84	–204.02	831.42	1607.3	–2.2
2013-2012	60.72	299.07	–238.35	1001.83	1896.78	–2.6

The main features of coastal dynamics of the western Kotlin Island. **1939 - 2015**



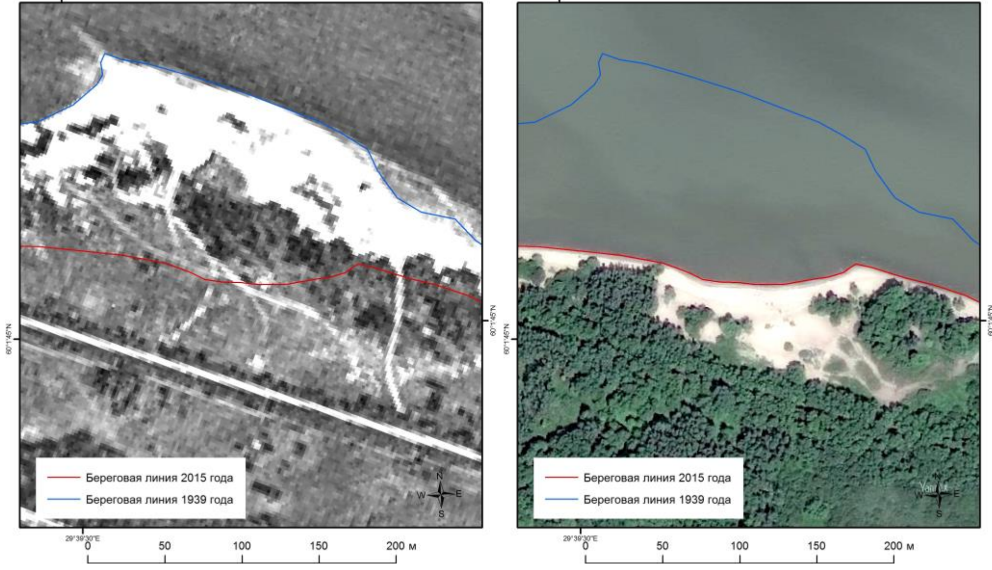
1939 - 2015



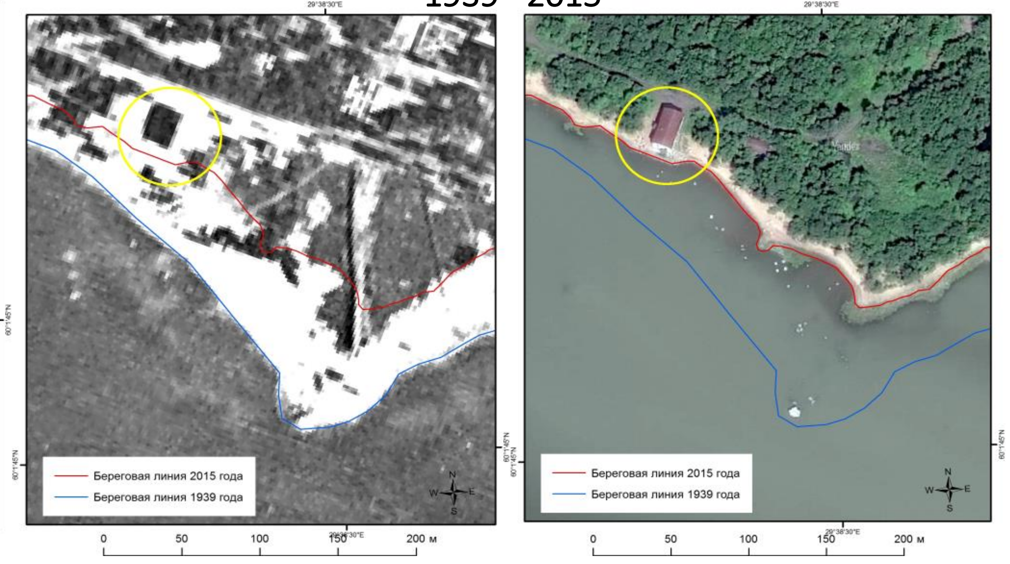


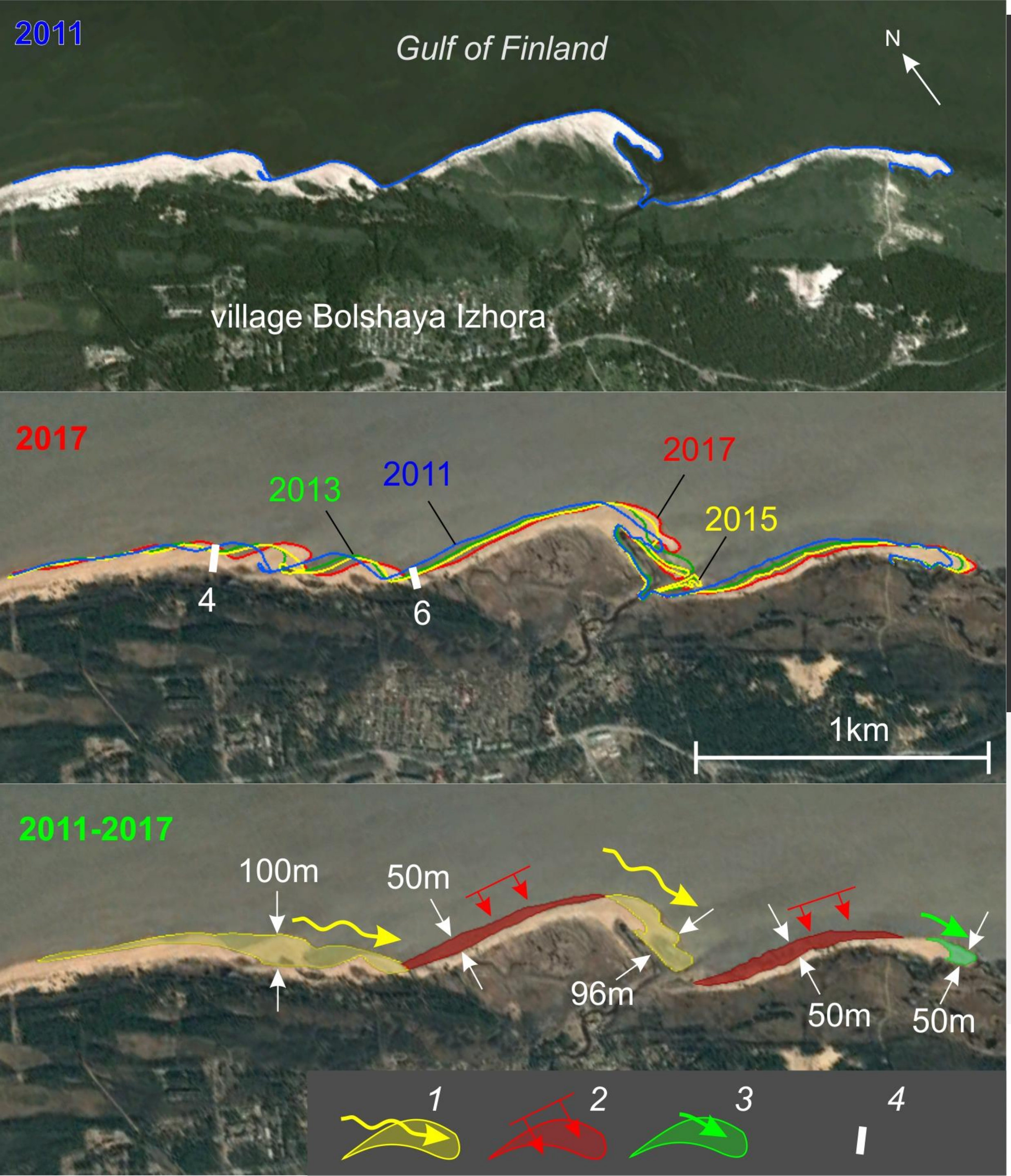
High rate coastal erosion on the Kotlin Island's shores in the Gulf of Finland

1939 - 2015



1939 - 2015





The main features of coastal dynamics of the Bolshaya Izhora 2011 - 2017

1 - zone of movement of the longshore sand wave;

2 - coastal erosion zone;

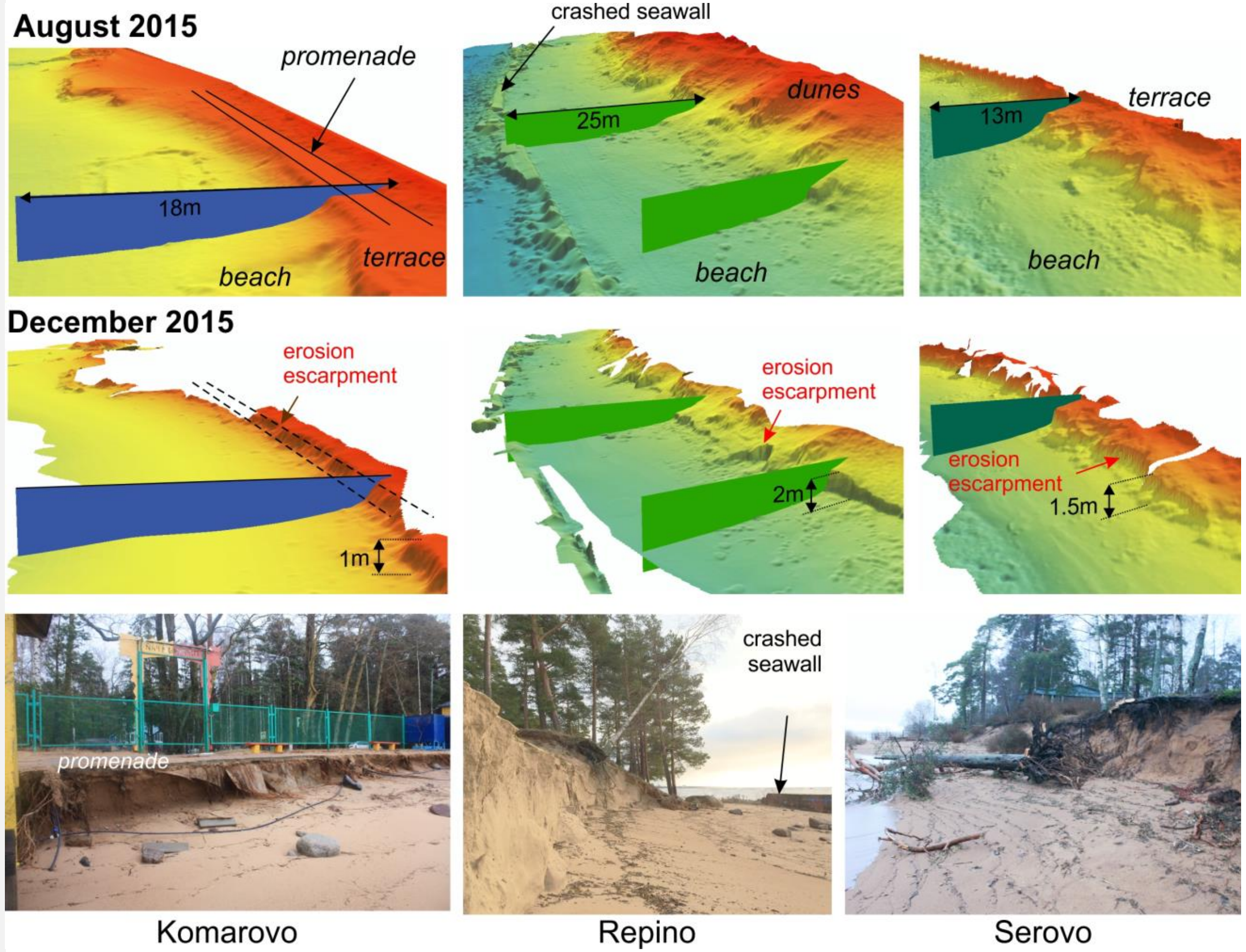
3 - coastal accumulation zone;

4 - position of leveling profiles.

Examples of storm damage in Kurortny District after storm events of December 2015

Results and Conclusions

According to the results of levelling, the rate of annual coast retreat is uneven. It is less than 0.5 m/year during low storminess periods, whereas for stormy years it is 3.3 m/year. So the infrequent events of structural erosion occurring in relation to certain extreme events give rise to a clearly pronounced step-wise manner of coastal development in this area. An important feature of annual beach transformation is recent acceleration of annual coastal escarpment retreat, which has been 0.56 m/year in 1989–2009 and reached 1.45 m/year in 2009–2017.



Results of TLS

Photos of last storm effects and 3D numerical model of beach areas with cross-section for August 2015 and December 2015

Results and Conclusions

Results of TLS data analyses allowed quantification of the volumes of sedimentary material that is eroded, transported, and redeposited as a result of extreme storms. Detailed 3D GIS models of coastal relief, compiled based on high-resolution geodesic surveys, allowed establishment of a highly reliable database of beachface transformation under the extreme storm impact and quantitative assessment of erosion volumes and sediment loss. In the stormy years, pronounced degradation of the foredune and coastal escarp was accompanied by a sharp reduction in the thickness of sand deposits by 0.6–1.2 m in a narrow strip of the backshore. The surface of the beach in turn undergoes less noticeable transformations, mainly with sediment thickness decreasing in the upper and lower parts of the beach to 0.3 m, and increasing to 0.3–0.6 m in the central and shoreline zone in the form of a discontinuous bar.

Thank you for your attention!

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