Прибрежная морфодинамика и прогноз развития берега

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Nearshore morphodynamics and forecast of coastal changes

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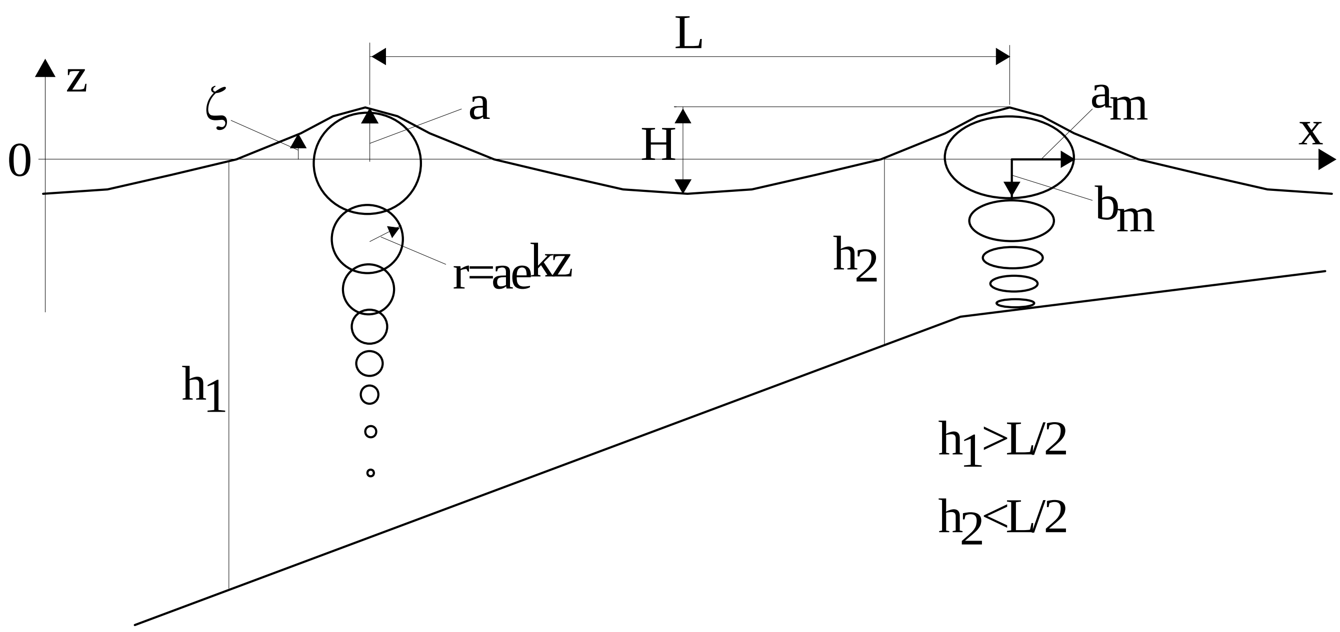
The sea coast or in more extensive comprehension, coastal zone is a border area between the sea and the land. Sea waves and currents interact here with the surface of coastal slope and accomplish the work forming the shore face and the bed relief. Result of this work depends on a number of natural factors what determine the multiplicity of existing types of coasts.

Further we shall mainly take an interest in coasts composed of sands which are easily mobilized under the action of waves and currents resulting in an active morphodynamic processes. Sandy coasts are often used as the objects of economical activit y and as the recreation centers.

Many coasts are needed in protection of which the strategy should be based on forecast of the future behavior of coast. Reliable forecast implies an appropriate level of knowledge of primary processes and mechanisms.

Further we shall outline some important aspects of nearshore morphodynamics and characterize approaches to predicting coastal evolution for different time scales.

The most of energy coming to the open sea coast is delivered by the gravitational surface waves excited by wind. Wave propagation on relatively shallow water (where depths are lesser than half wave length) is accompanied by the water particle motions along elliptic orbits. At the bottom these motions transform into the to-and-fro excursions along the bed. When orbital velocities reach 0.2-0.3 m s-1 the sand particles are mobilized and involved into the flow oscillations. These oscillations are asymmetric and accompanied by some net transport in wave direction.

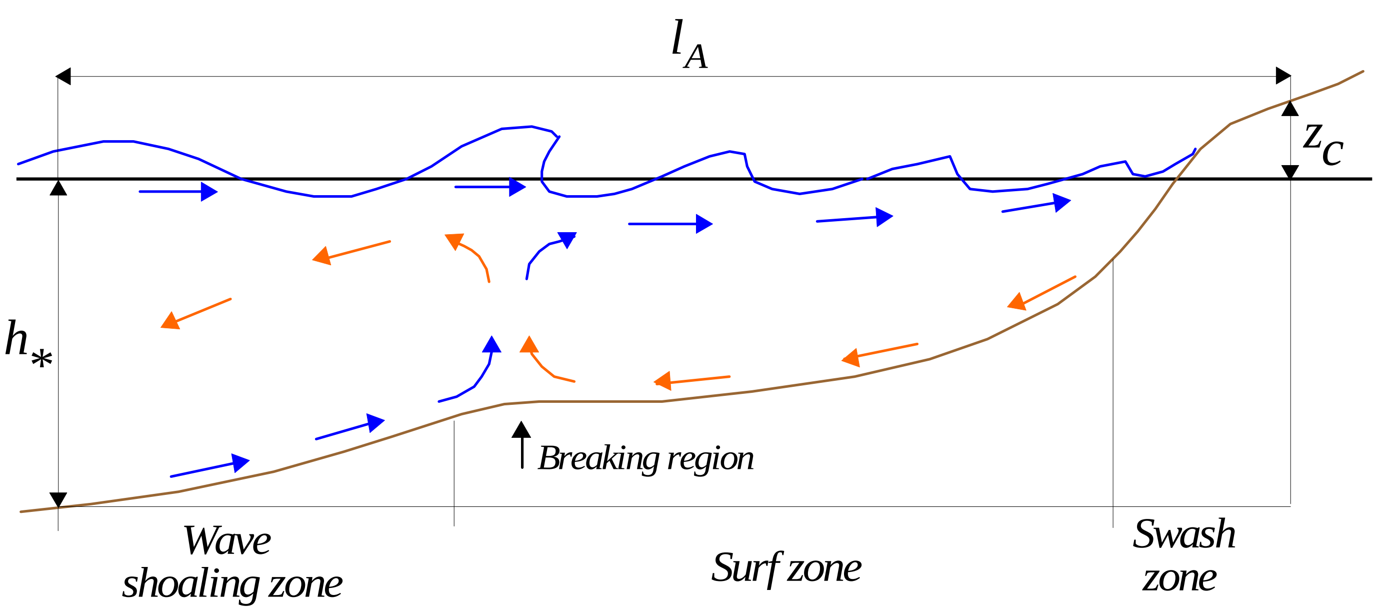


When the depth becomes comparable with the wave height the waves collapse. Intensive turbulence generated in breaking waves lifts the sediment masses into the water column. Roller arising in front of wave crest dissipates the energy and so the waves decay approaching to coast. At the shoreline the flow takes form of the swash – oscillations of tongue of water along the beach slope.

Certain portion of energy lost by waves in the surf zone transforms into the energy of wave setup (rise of water level) and various wave-induced currents.

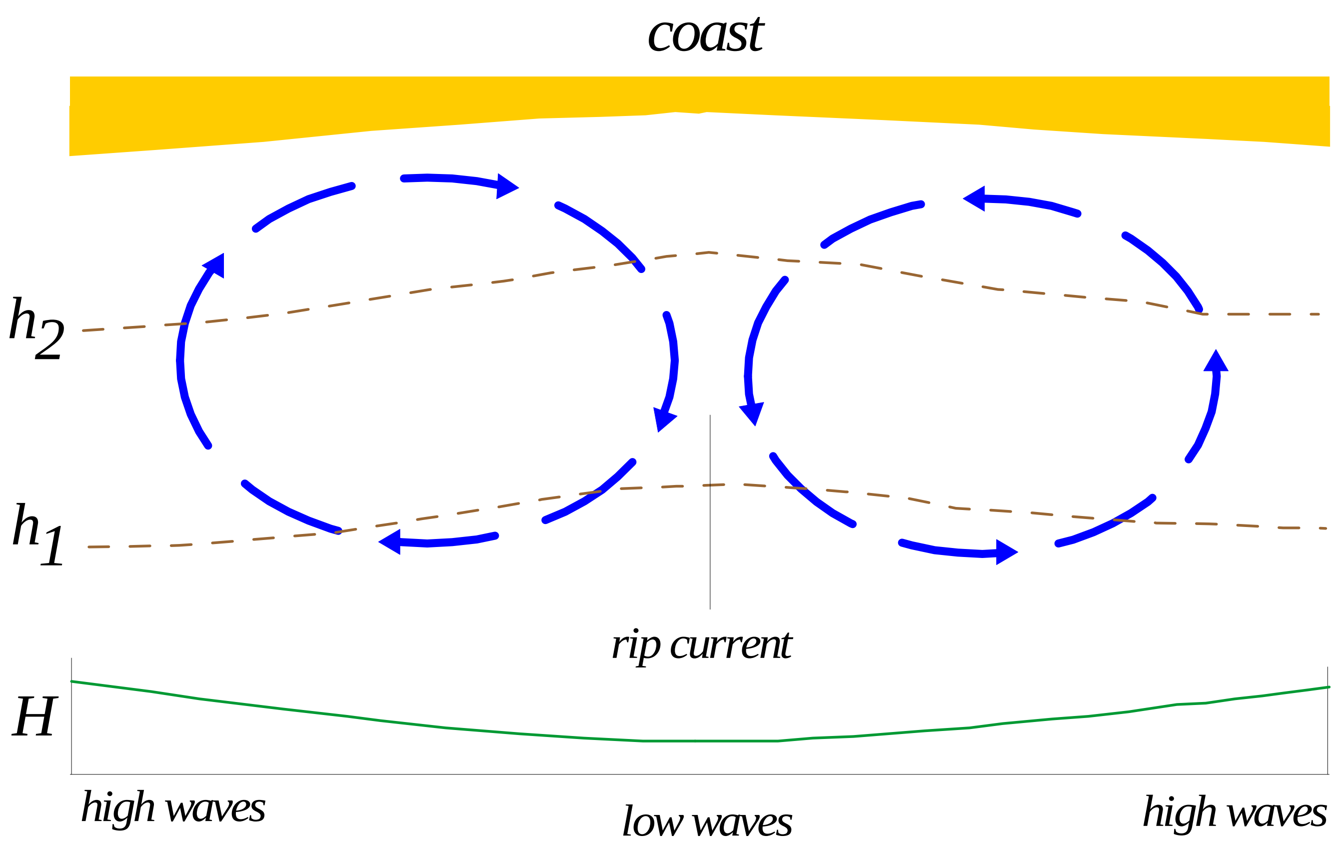
Especial role of the undertow and the longshore current should be emphasized.

Undertow is a seaward flow balancing the landward mass transport caused by broken wave crests and carrying suspended material away from coast. Longshore current is generated by obliquely incident waves and creates the sediment flux along the coast.



If the bottom topography and heights of incident waves are non-uniform along the shore then the local horizontal circulations can develop. Those superimpose on the vertical-plane circulation considered before and produce more complex flow patterns.

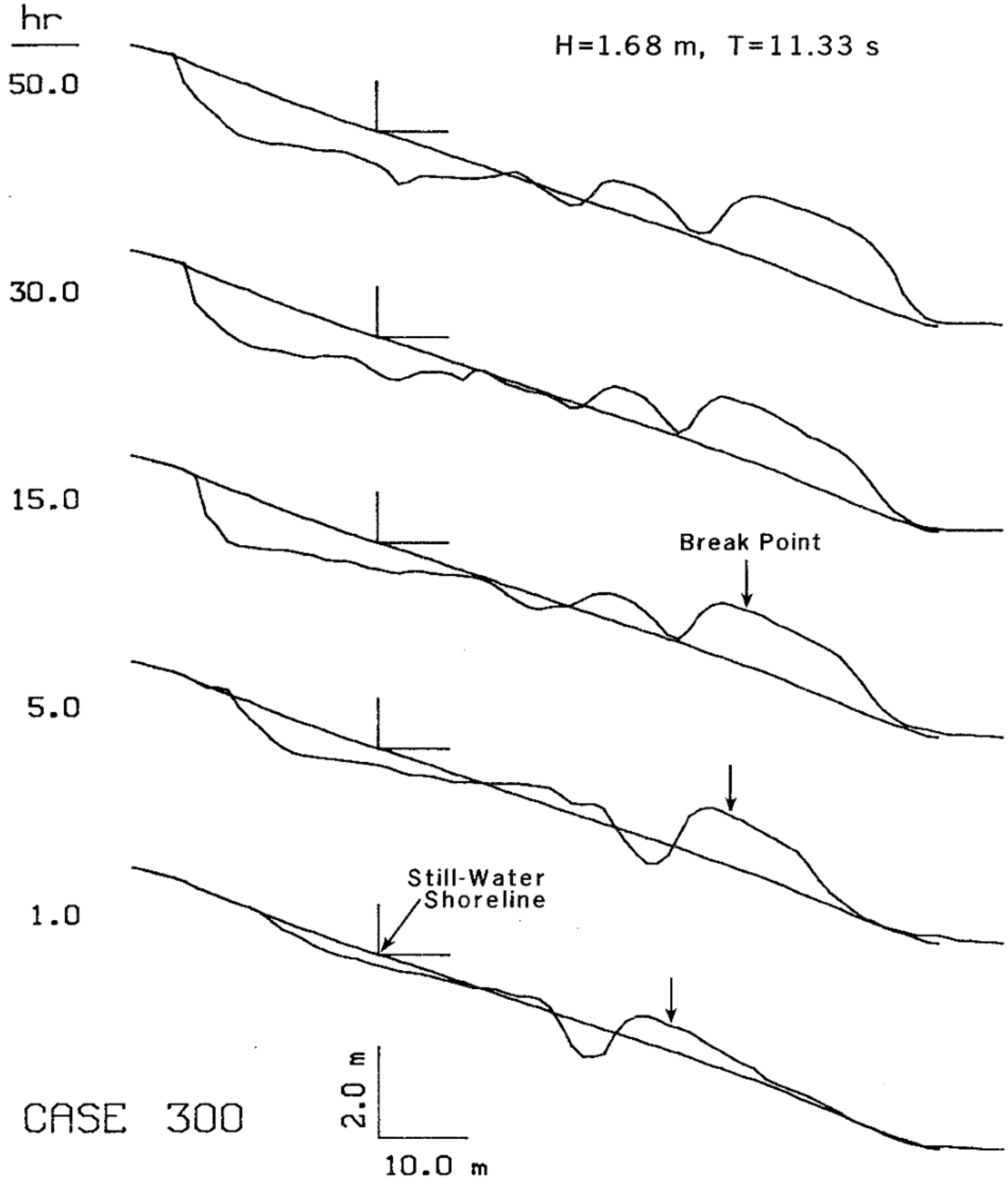
The outflow from shore in some cases takes the form of rip current (with velocities are of the order of 1 m s^{-1}) concentrating in sections of relatively low waves.



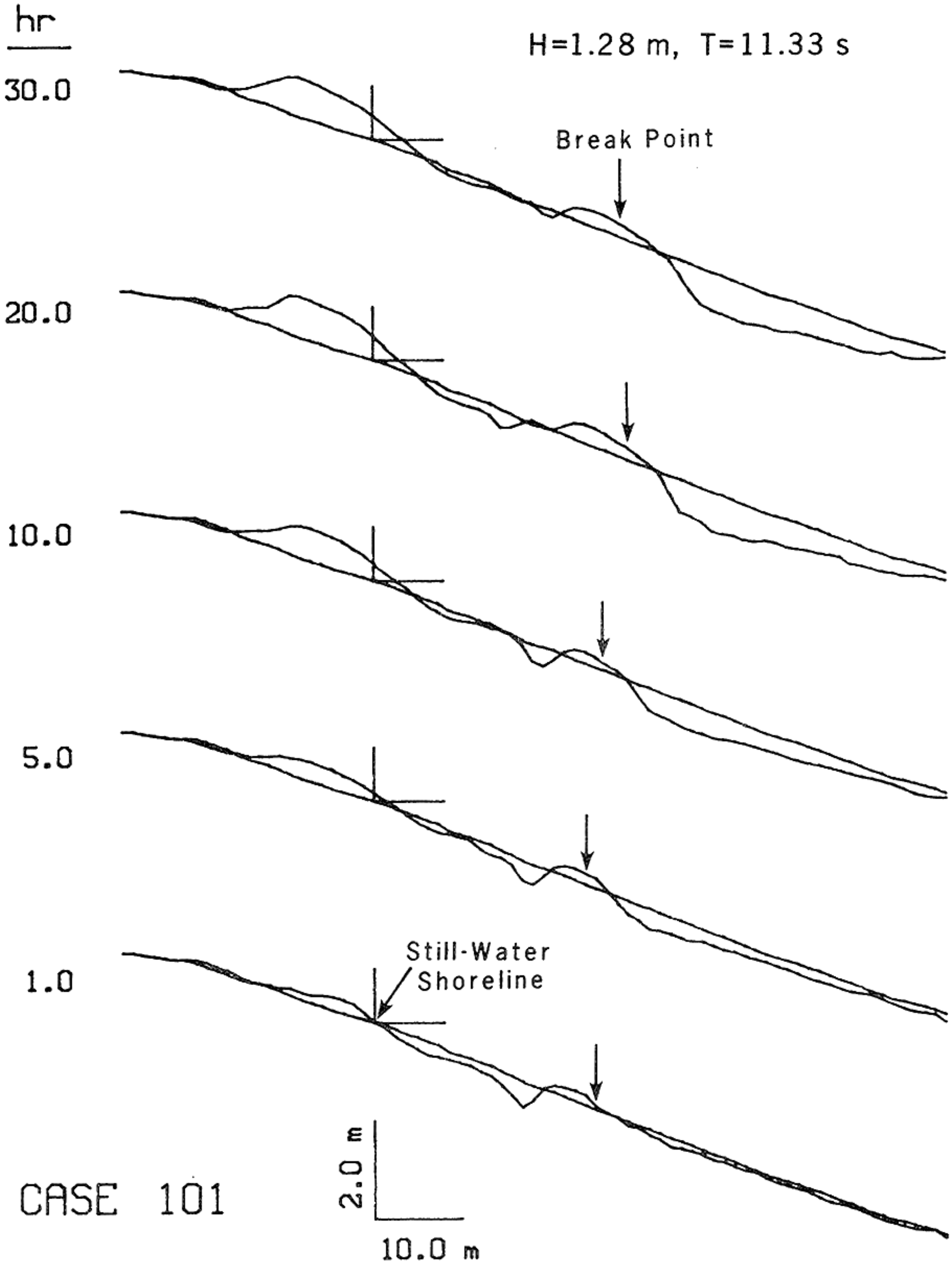
Together with gravity waves mentioned above also the infragravity waves (with periods exceeding 20-30 s) of different genesis occur in a coastal zone. Those influence the nearshore currents, sediment transport and morphological response. Infragravity waves, in particular, contribute to forming of beach cusps – rhythmic shoreline undulations with spatial step of several meters to hundred meters. Comparatively small beach cusps can be observed on photo.

Behavior of coast can be mainly controlled by tides. This is a typical for closed estuarine coasts. Outside the coastal zone tidal currents can form the large-scale sand waves on the sea bed. Slowly moving sand waves result in undulations in shoreline and bottom relief.

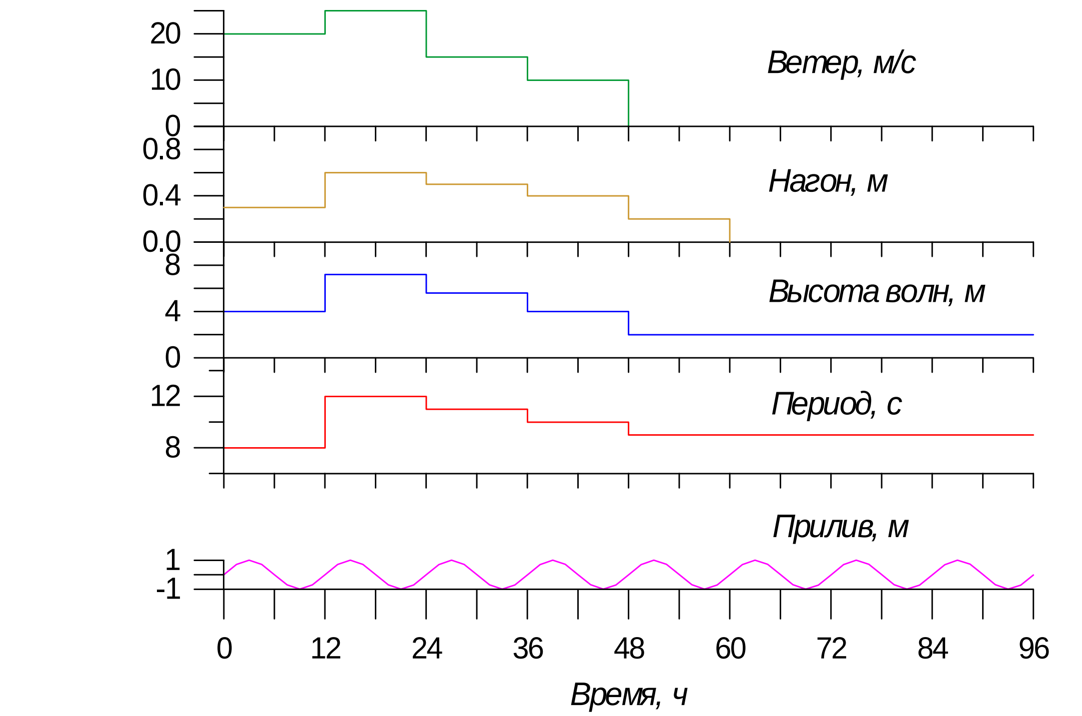
Finally, combined action of wind and waves creates a storm surge resulting in appearance of outflow transporting sediment particles away from coast. Besides, the wind causes the lost of beach material due to Aeolian sand transport toward the land.



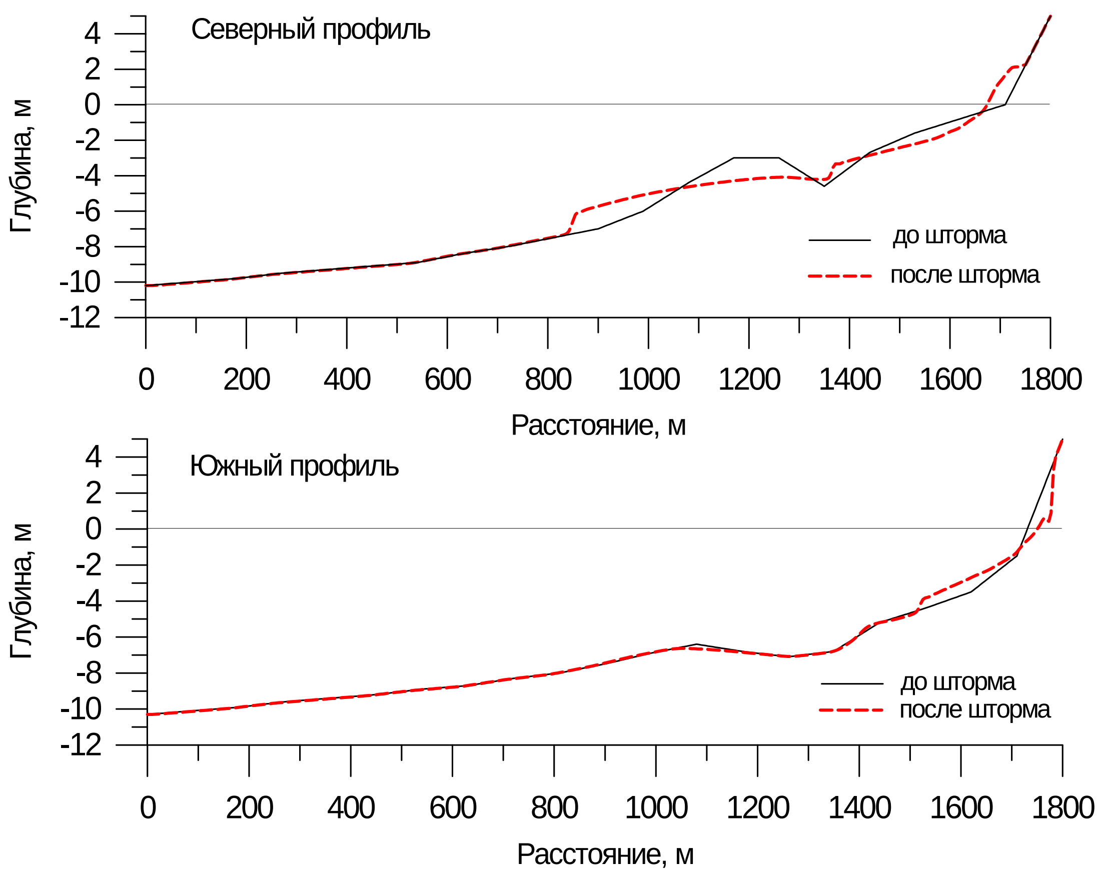
Deformations of sand-composed coastal slope attacked by steep stormy waves.



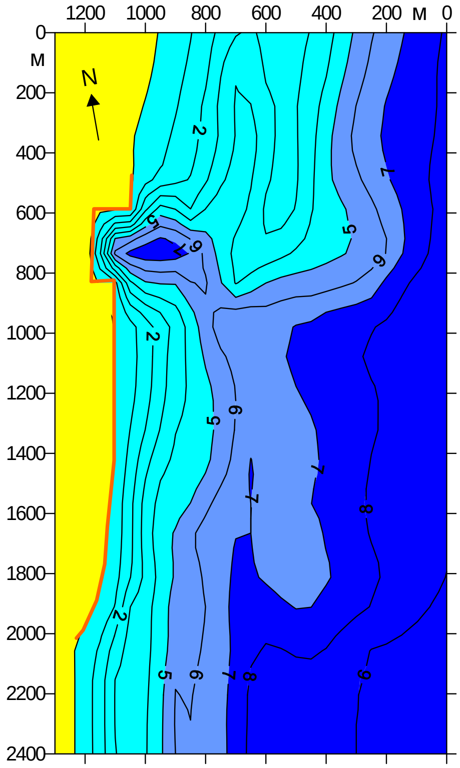
Deformations of sand-composed coastal slope under the action of gentle waves of swell

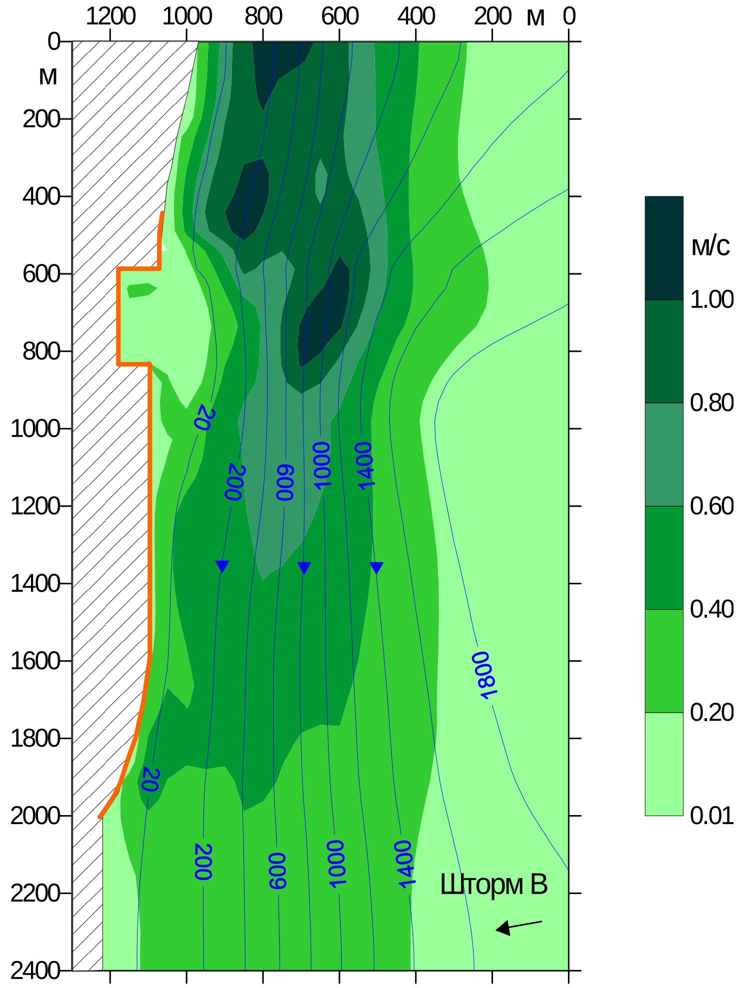


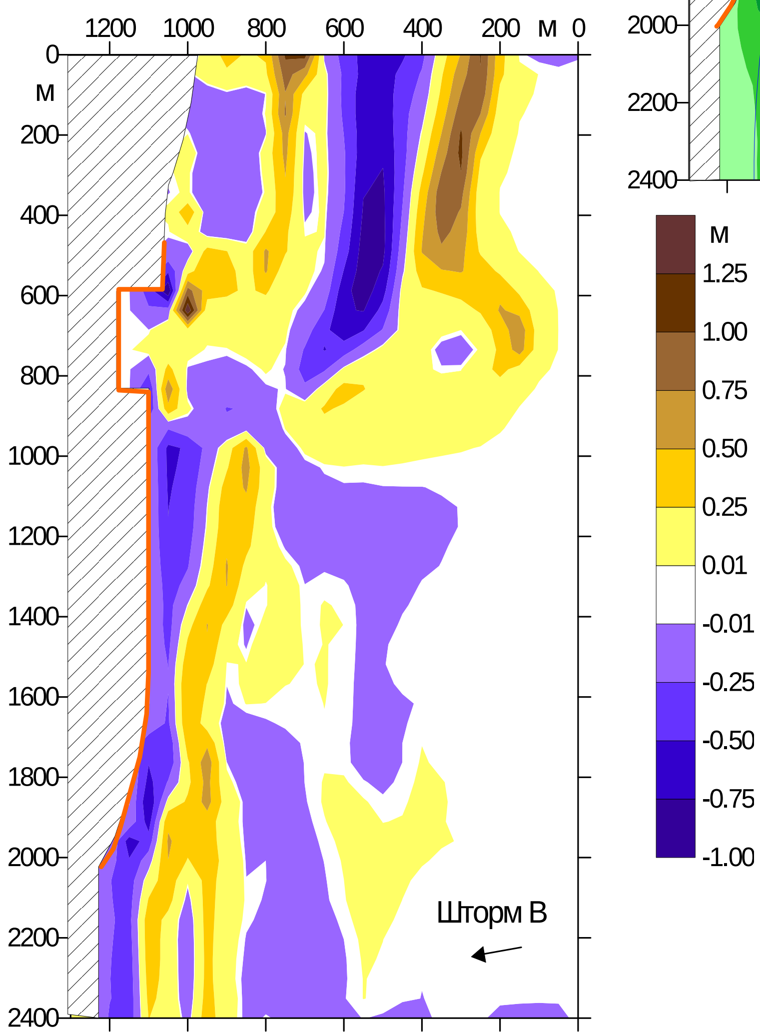
Scenario of severe storm



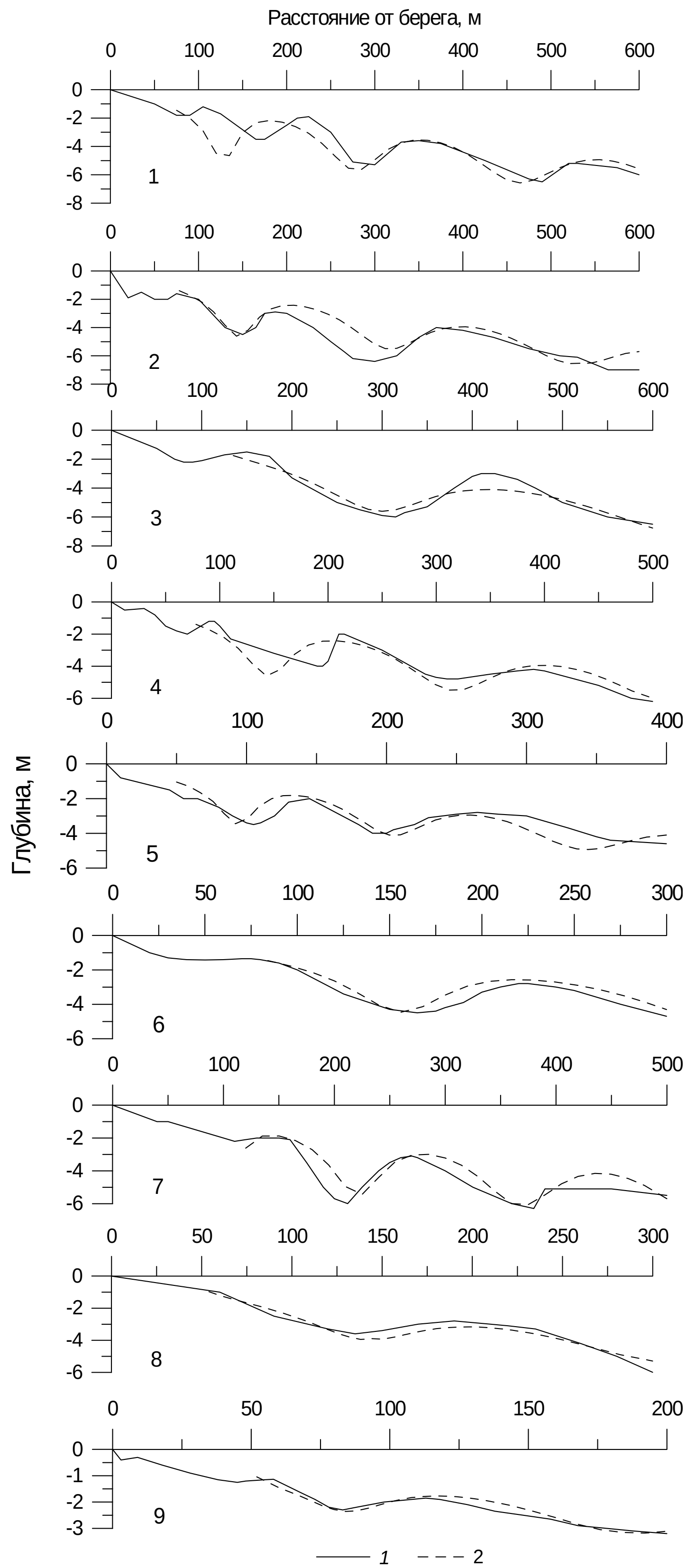
Cross-shore profile modeling







Coastal area modeling



Multiple bar systems on sand-composed gentle coastal slopes

A number of hypothesis is proposed to explain the appearance of sand bars. Part of those assume that bar generation is due to wave breaking process.

1. **Flow convergence at the breaking point**.
2. **Vortices generated by passing bor.**
3. **Diffusion of sediment suspension**

Alternative viewpoint do not connect the bar formation with the wave breaking.

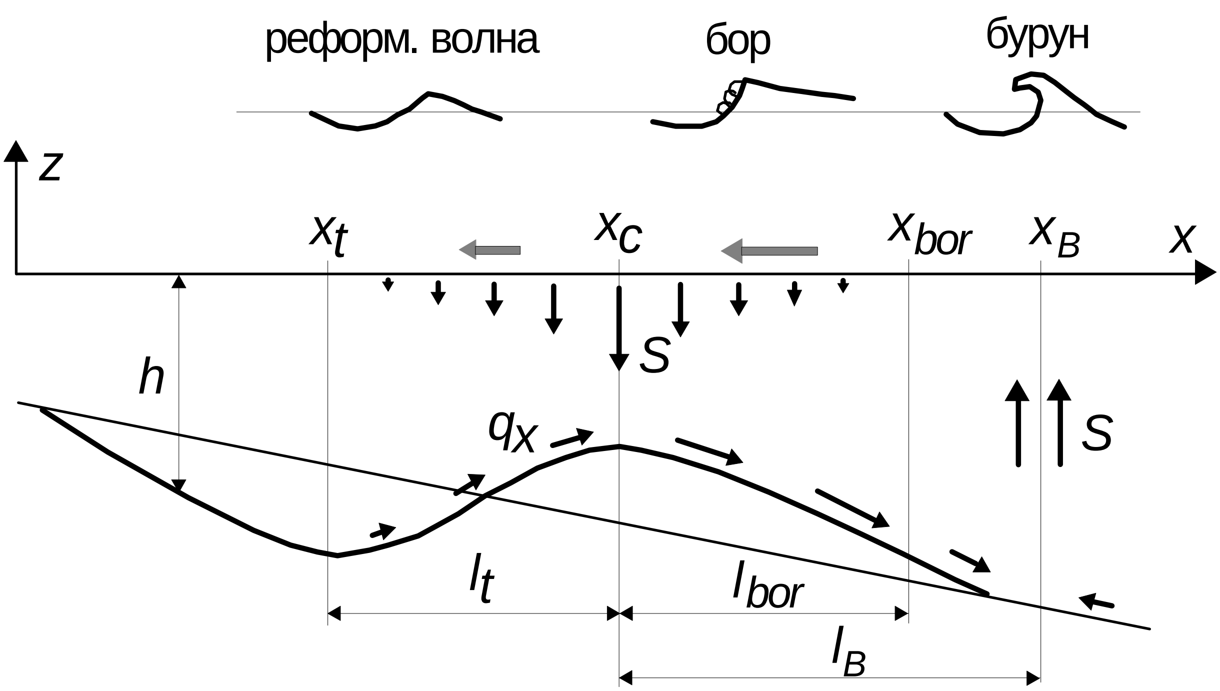
4. **Non-linear interaction of harmonics in shallow-water waves**.
5. **Infragravity oscillations**.

6. Spatial undulation of short-wave energy dissipation due to infragravity waves.

This concept reconciles the two known viewpoints on the nature of bars and explains this phenomenon as a result of the short-wave energy dissipation influenced by weak infragravity oscillations of water level. A quite pronounced bar system arises even with the ratio of long-wave energy to short-wave energy of only about 10-2. The equation of the equilibrium profile obtained allows reproduction of the principal features of profiles observed on various natural sandy seashores. The period of infragravity oscillations determining the spatial step of the multiple bar system is found to be consistent with the period of short-wave groups

7. Balance of horizontal and vertical sediment fluxes . A cloud of suspension lifted up in the wave-break point is transported toward the shore and simultaneously deposited creating the vertical sediment flux to the bed, -*S* . At the same time, the undertow generates a horizontal flux of suspended sediment in seaward direction, *qx*. Under these conditions the sediment balance is determined by the equality of flux S and gradient dqx/dx :

$$\frac{dq_x}{dx} = -S$$



Suggested mechanism is revealed in different manner in the inner and outer sections of coastal zone. In the inner section, the horizontal extent of bar is controlled by the length of short wa ves (induced by wind), while in the outer section it is determined b y length of infragravity waves associated with short-wave groups.

Energetic principle determining the properties of coastal profile

Version of such a principle formulated by Dean (1991) is: *under equilibrium conditions the rate of energy dissipation per unit volume of the water column is uniform.*

$$\frac{1}{h}\frac{d}{dx}\left(EC_g\right) = \varepsilon = const$$

Only monotonic profile is possible in this case.

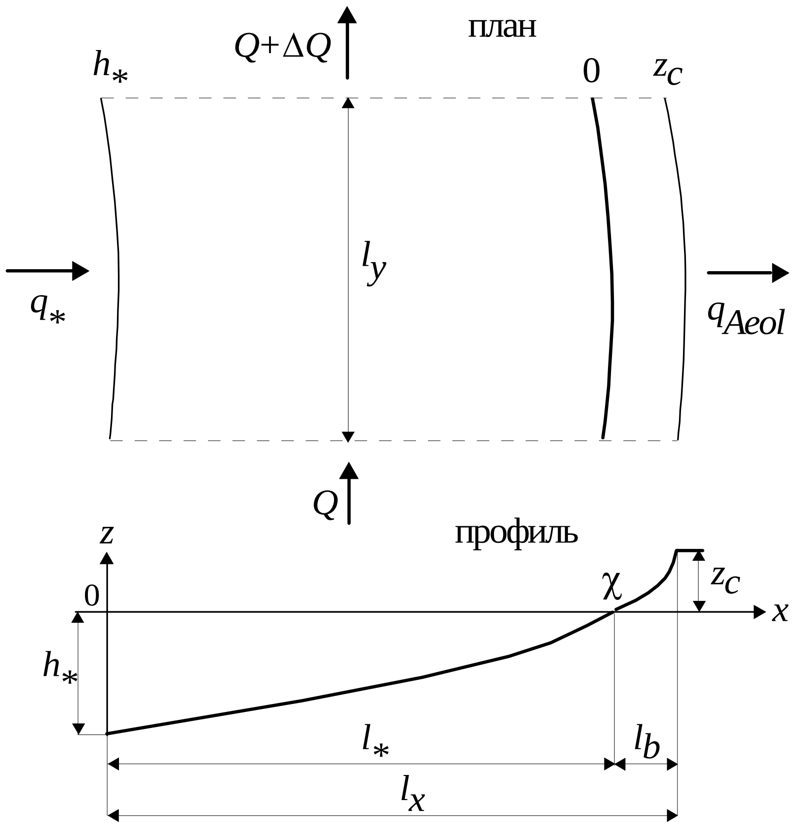
Version by Leont'yev (2004) is: *the rate of energy dissipation is directly proportional to the energy itself* .

$$\frac{d}{dx}\left(EC_g\right) = \varepsilon_* \frac{E}{h}$$

This allows both the monotonic and the bar-trough equilibrium profiles.

A given coast is usually subdivided on several morphodynamic systems with inherent energy, sediment transport, morphology and other properties. The limits of systems are determined, in particular, by the coastline prominences or the river mouths. Using the principle of mass conservation and the equilibrium profile concept one can derive the following equation of sediment balance in morphodynamic system:

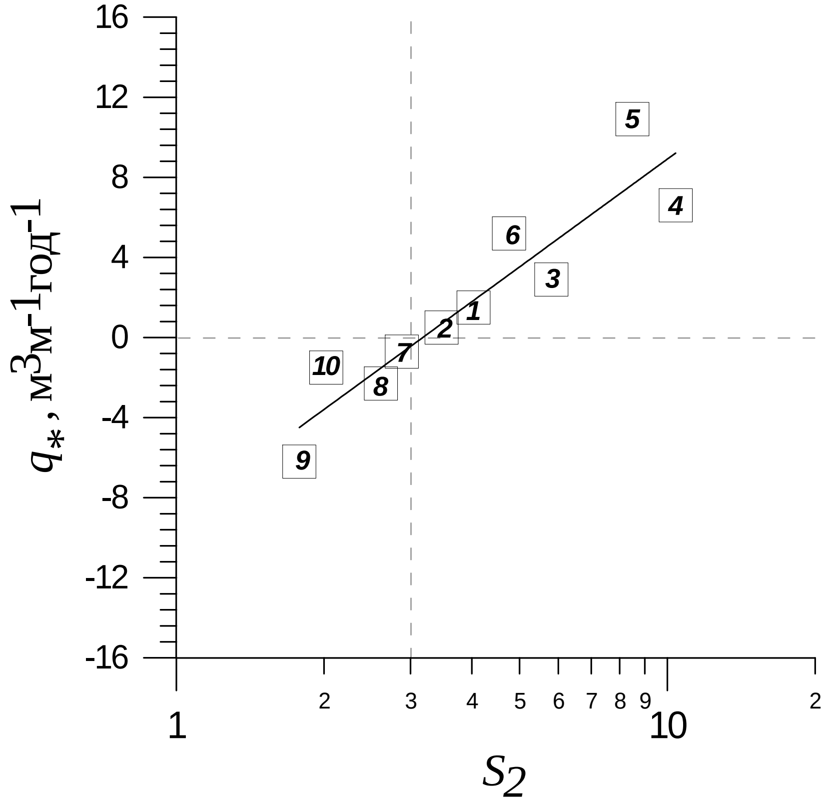
$$\frac{\partial \chi}{\partial t} = \frac{1}{h_* + z_c}\left(\frac{\partial Q}{\partial y} + q_{Aeol} - q_* + wl_X - \Omega\right)$$



When sediment fluxes passing a given system remain unchanged or the changes in cross-shore and longshore fluxes neutralize each other, the sediment balance equation transforms into the well known Bruun rule establishing direct proportion between sea level change and displacement of coastline.

Sediment budget components may by due to both the natural processes and man-caused impact.

Sediment balance equation can be used to predict the behavior of coast over period of tens and hundred years. Principal problem is to estimate correctly the sediment budget components. This problem, in principle, is solved on the base of long-term observations of the behavior of a given coast. But the relevant data required are far from always available and only indirect evaluating methods can help in the majority of cases.
In particular, to determine the cross-shore sediment flux q* at the lower limit of coastal zone one can use the empirical relationship established by Leont’yev (2008). Flux q* can be positive (directed shoreward) or negative depending on some parameter S2.

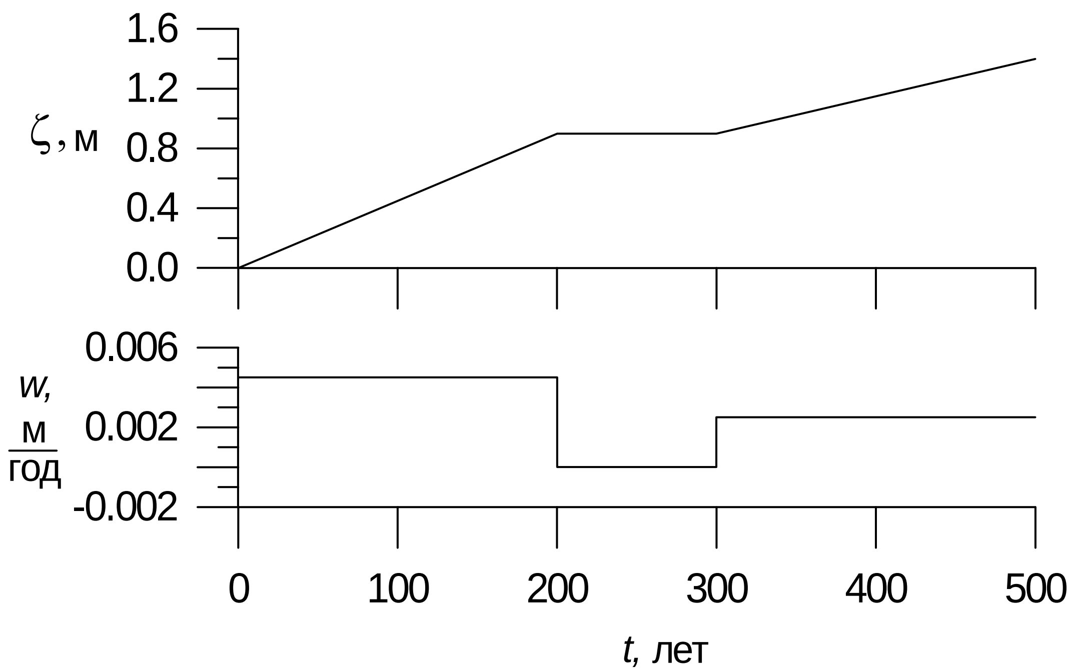


$$q_* = 7.76 \ln S_2 - 8.97$$

$$S_2 = 10^5 \beta_* d_s T_{4\%}^2$$

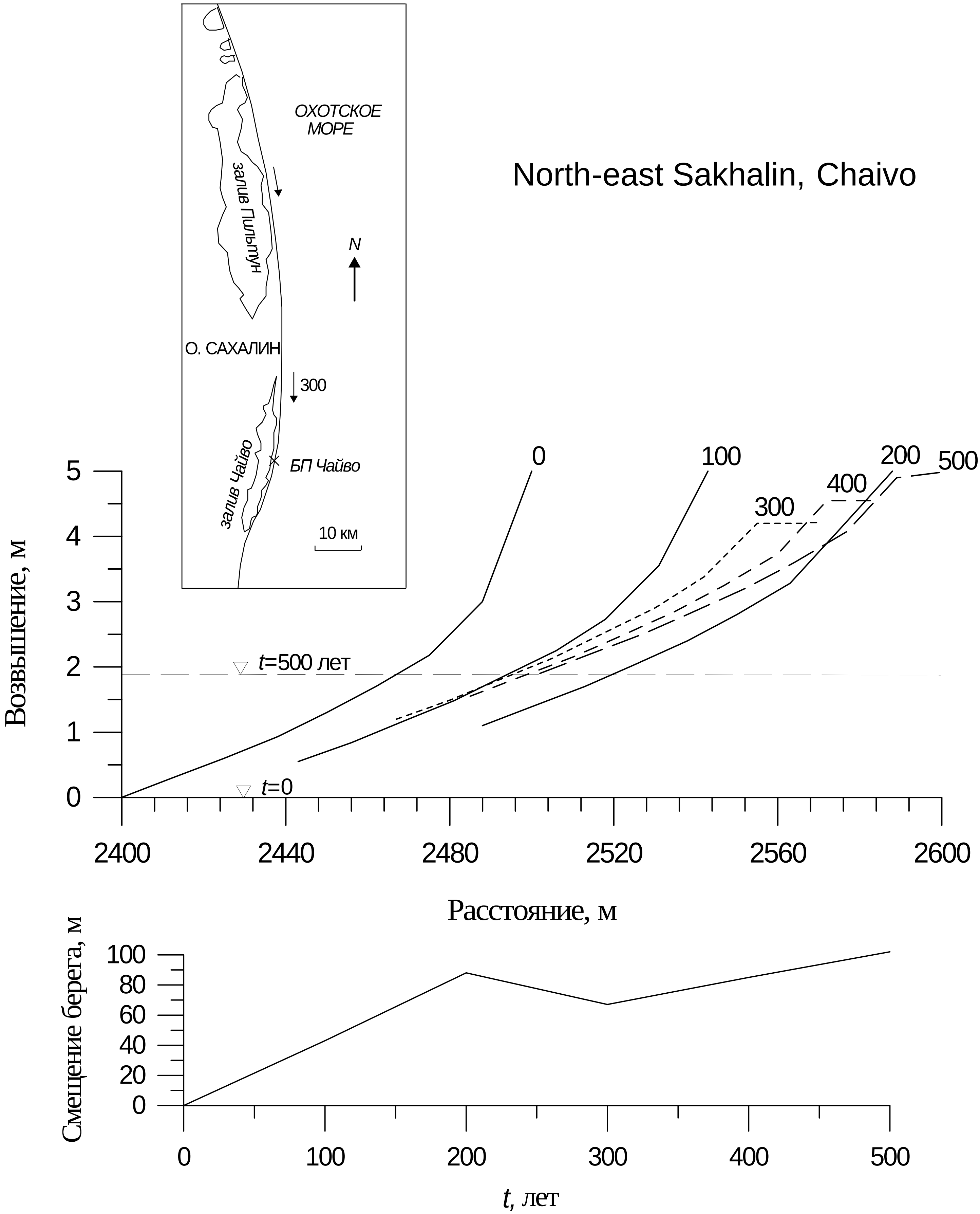
For S2<3 the flux q* is negative. This is the case of very gentle bed slope and rather short waves, what is typical, in particular, for many Arctic coasts.

Serious problem making difficulties for prediction of coast behavior is the developing of reliable scenario of future change s in sea level. Different researchers represent various viewpoints on even the sea level changes over the nearest century. Predominate estimation assumes the sea level rise on about 0.5 m to the end of nearest century. Further we follow scenario developed by Pavlidis shown schematically below.



It is assumed that 200 years later the sea level rises on about 0.9 m. After 100-years pause, the level continues to increase and at the end of 500-years period it attains the mark 1.4 m.

Tectonic motions are also should be taken into account.


North-east Sakhalin, Chaivo
ОХОТСКОЕ МОРЕ
залив Пильтун
N
О. САХАЛИН
300
залив Чайво
БП Чайво
10 км
0
100
200
300
400
500
t=500 лет
t=0
Возвышение, м
0
1
2
3
4
5
2400
2440
2480
2520
2560
2600
Расстояние, м
Смещение берега, м
0
20
40
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80
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100
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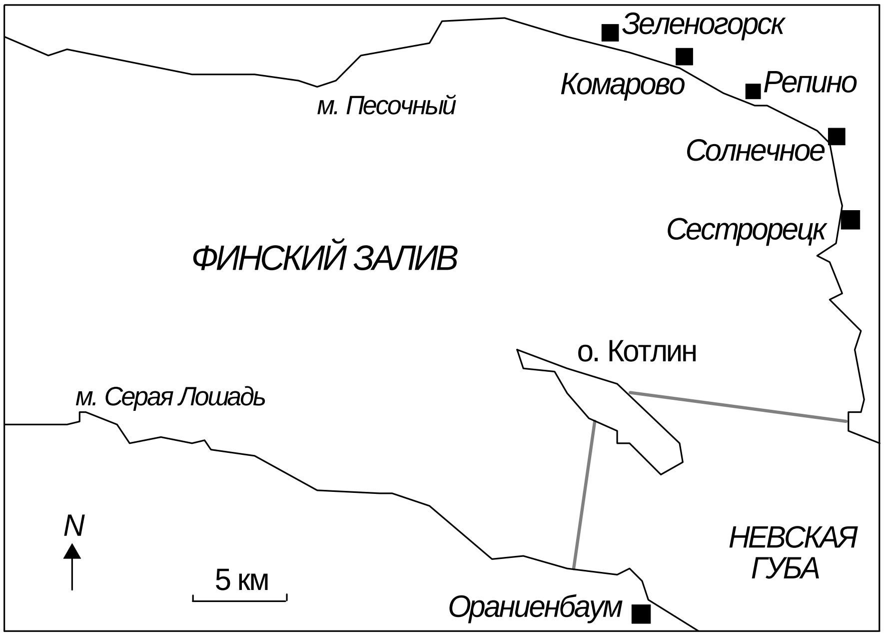
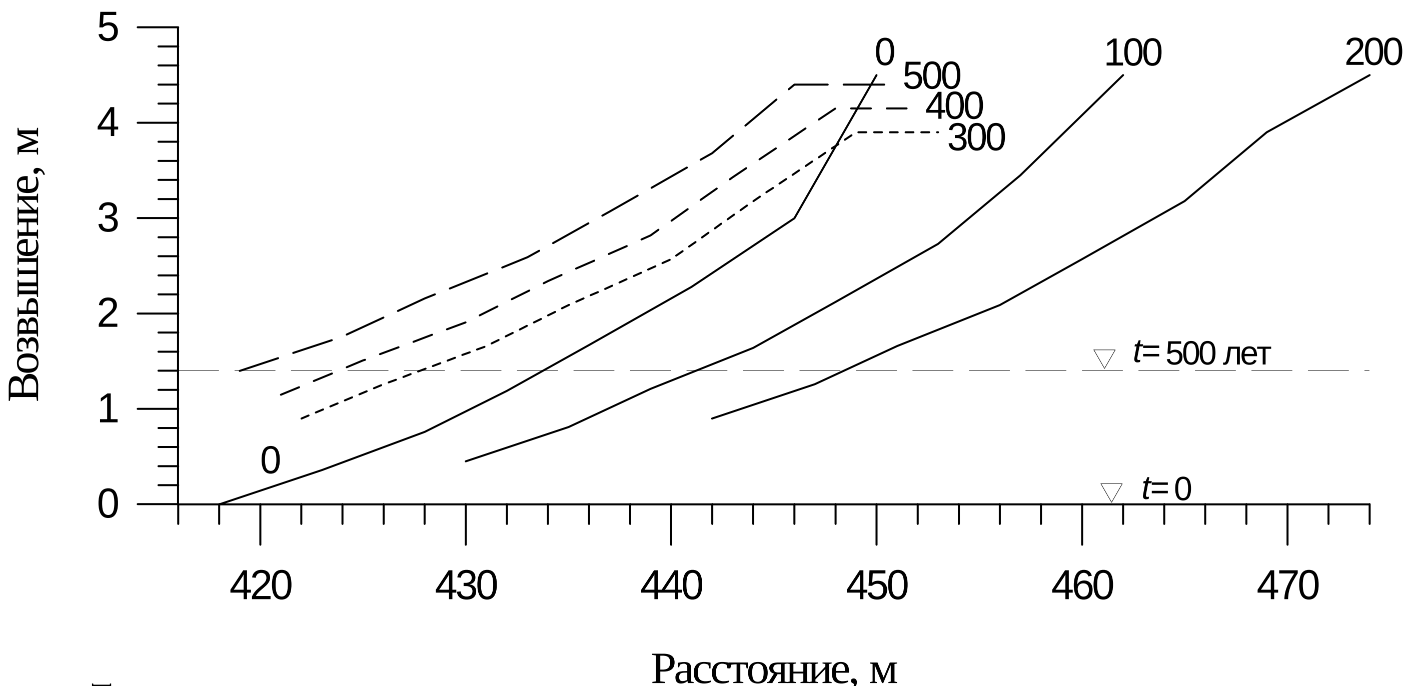
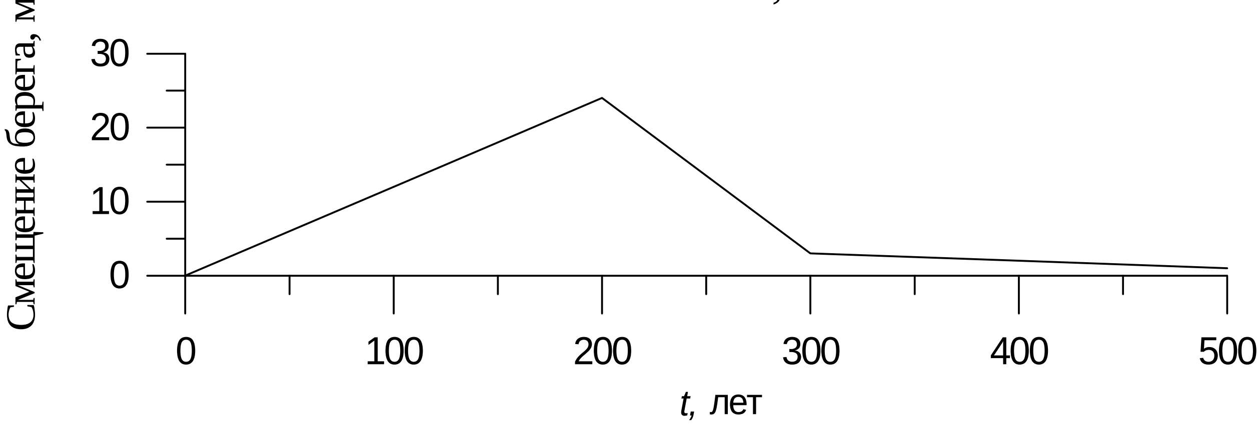
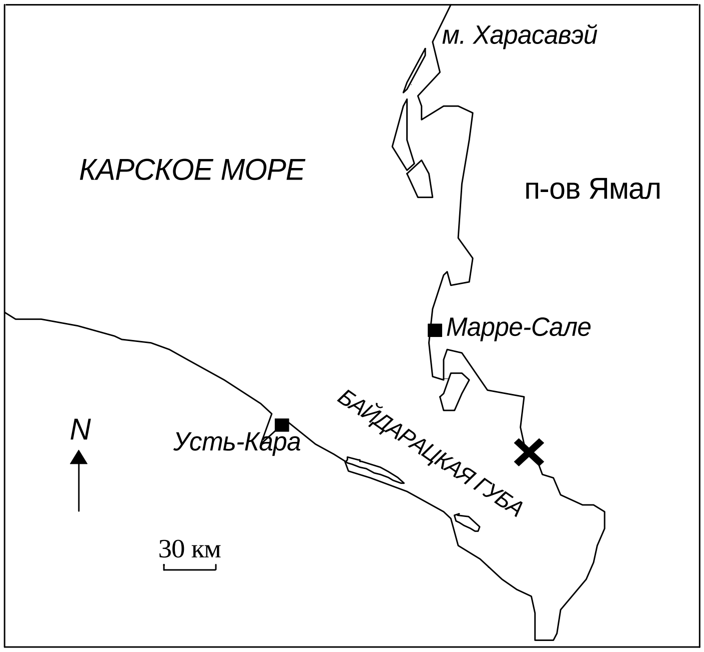
t, лет



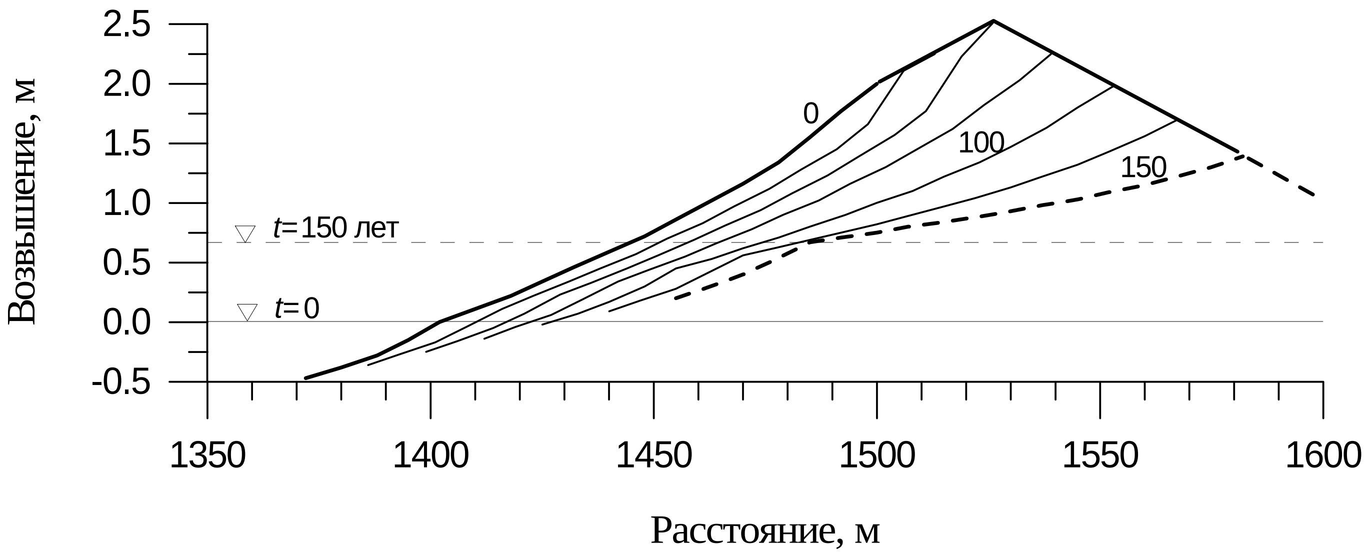
Finnish Bay,
Komarovo

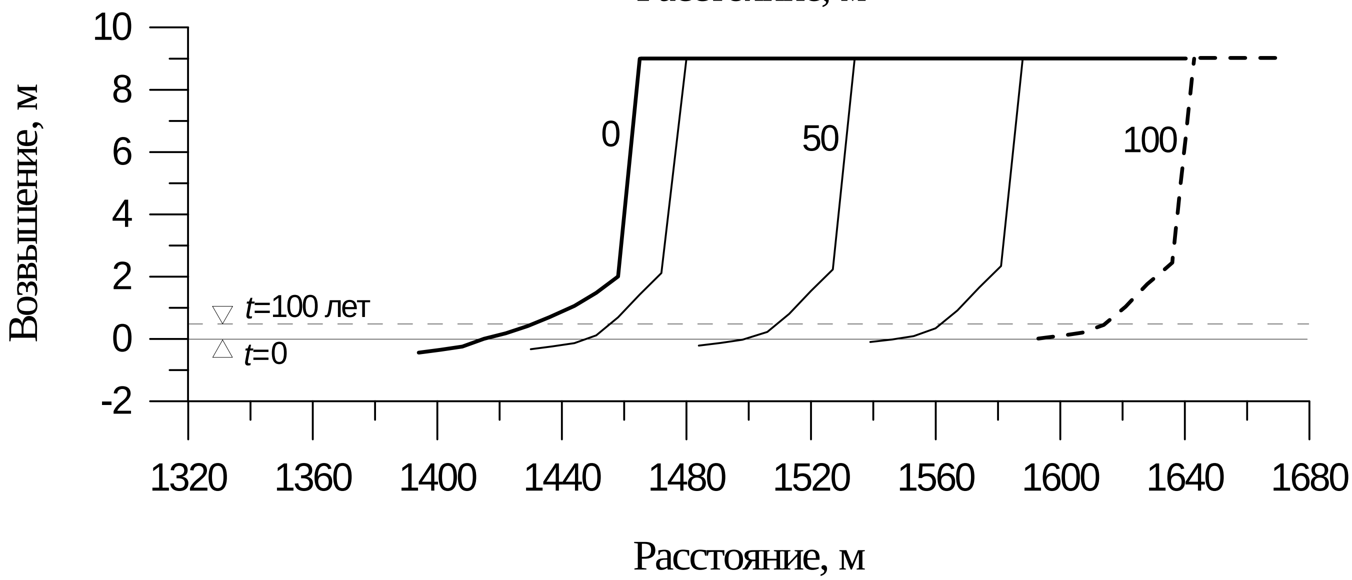


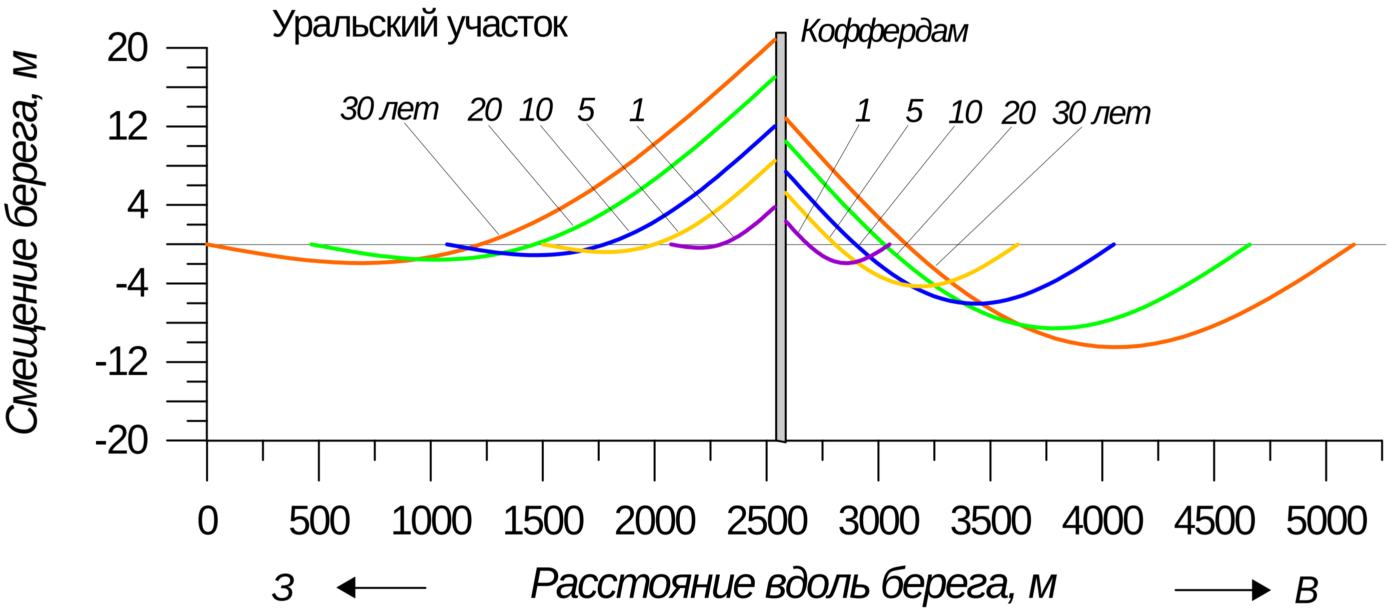




Baidaratskaya Bay,
East coast







Shoreline changes due to cross-shore structure

Results obtained manifest at least three types of evolution . Despite the differences in coasts of Sakhalin and Finnish Bay sites there is a common feature: sediment budget in both sites i s almost in balance. Hence the main factor of future development here is the sea level change resulting in oscillations of shorel ine position. Radical changes in coast behavior are not expected.

In other circumstances moderate sea-level rise is able to change radically sediment budget and trigger destructive processes, in particular, thermal abrasion of cliff (the case of Baydaratskaya Bay).

And finally, effect of sea level change can have no influence on coast behavior in case of significant imbalance in sediment budget. Such a situation is typical for coasts subjected to ther mal abrasion or man-caused impact.