ICCE 2018
36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018
Baltimore, Maryland | July 30 – August 3, 2018
The State of the Art and Science of Coastal Engineering

INFLUENCE OF WAVE TRANSFORMATION PROCESSES ON EVOLUTION OF UNDERWATER BEACH PROFILE

Yana Saprykina, PhD, Senior Researcher

Olga Kuznetsova, PhD student

Shirshov Institute of Oceanology of Russian Academy of Sciences, Moscow, Russia




Outline

- Motivation and main aim
- Field experiments
- Wave parameters and method of evaluation of underwater profile deformations
- Discussion of results
  - Dependence of profile deformations on
    - Initial wave parameters (height, period, steepness)
    - Empirical numbers : Ursell , Iribarren numbers and Dean parameter
    - Processes of wave transformations:

    - nonlinearity – scenario of evolution of nonlinear wave harmonics

    - wave breaking - type of wave breaking (spilling and plunging)
- Conclusions

Motivation and main aim

Sea level change → **Underwater beach profile deformation** ← Currents

Waves ↓

Numerical models

Many options of initial and boundary conditions
Empirical parameterizations included
xBeach, Delft3D, MIKE21

Empirical models

Equilibrium profile (Dean, 1991)
Input – grain size only
No hydrodynamics
No bottom features

Engineering models

Integral estimations;
Based on wave energy conception
Empirical formulas and parametrizations,
No irregular wave structure
No physical processes of wave transformations description

Different results! What to choose? How to tune? How to control results? What is important?

AIM: Estimation of influence of wave parameters and wave transformation processes on underwater beach profile deformation based on field data

Limitation: normal wave direction , cross-shore wave induced sediment transport, time scale 1-2 storms

Field Experiments: Shkorpilovtsy 2007 and 2016 (Black Sea):

synchronous measurements waves and depth deformations along special pier (220 m)

Wave s: 15 wire digital gauges : 7 resistance + 8 capacity type along pier; 65 wave records, 20 min -1 hour, sampling frequency 5 - 200 Hz. (2007) ; 20 wire digital gauges : antenna of 4 resistance at the end of pier + 16 capacity type, along pier; 53 wave records, 20 min - 24 hours, sampling frequency 5 - 50 Hz (2016)

Depth deformations: every day 1-3 profile (spatial step = 2 m), length of measured profile depends on storm conditions (special marced lot or spinning rod), GPS (on 10 profiles, 500 m along shoreline) 1 per day in storm.

Visual observations, photo, video – type and position of **wave breaking**

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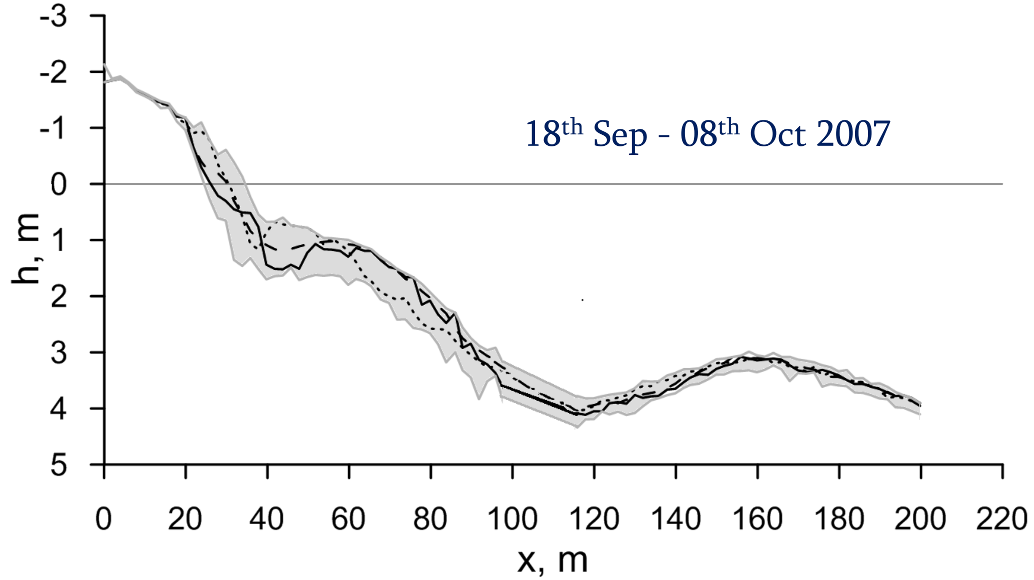
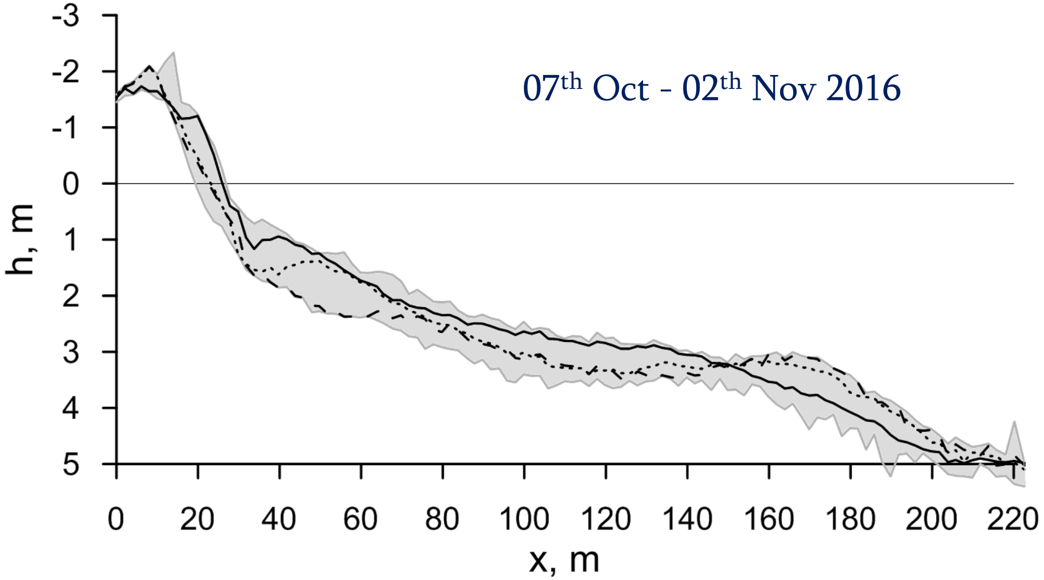
Underwater profile deformation parameters and evaluation methods





Minimal, maximal and mean (dotted) deformation of underwater profile, grey – dynamical layer.

	2007	2016
Mean wind speed	3.2 m/s	4 m/s
Max. wind speed	10 m/s	15 m/s
Wave height	0.6 –1.7 m	0.7 – 2.4 m
Wave period	4.5 – 7 s	6 – 9 s
Number of cross-shore profiles	36	53
Profile features	Stable bar, depth 3-4 m, temporal bar 1-2 m	Temporal bars, depth 1-2, 3-4 m

Size grain of sand 0.2-0.5 mm

Speed of shoreline movement m/h

$$Sh = (x0_{t_2} - x0_{t_1})/(t_2 - t_1)$$

where *xo* - location of 0 m isobath, t1 and t2 -time of surveys;

Speed of profile deformation, m²/h

$$Q = (V_{t_2} - V_{t_1})/(t_2 - t_1)$$

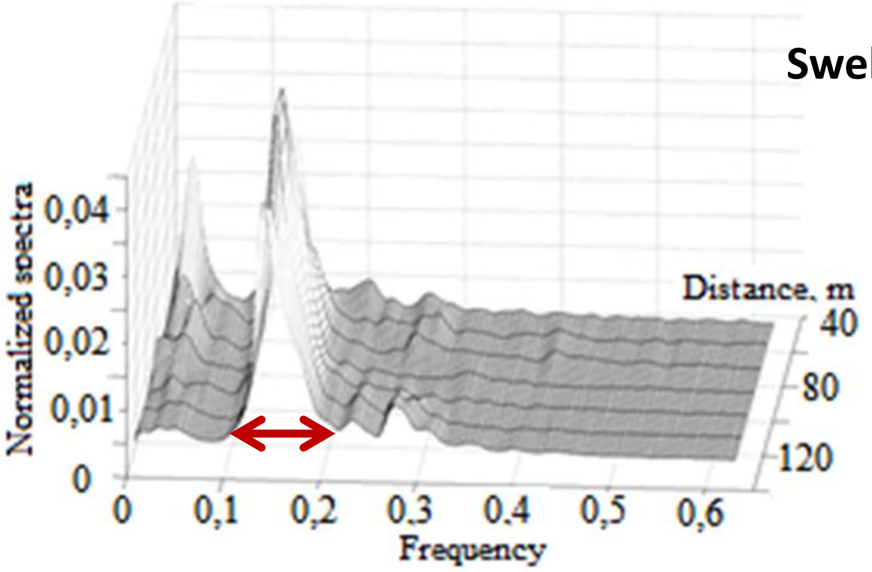
where V - specific sediment volume, m³/m

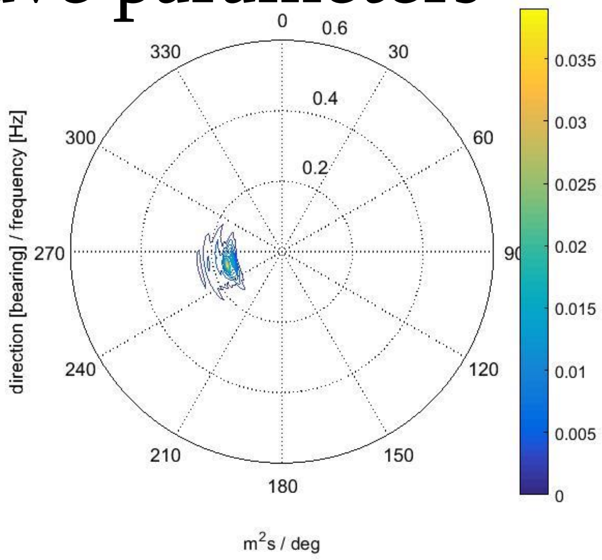
$$V = \int (h - h_{mean})dx$$

h_{mean} - mean profile depth, x - cross-shore coordinate.

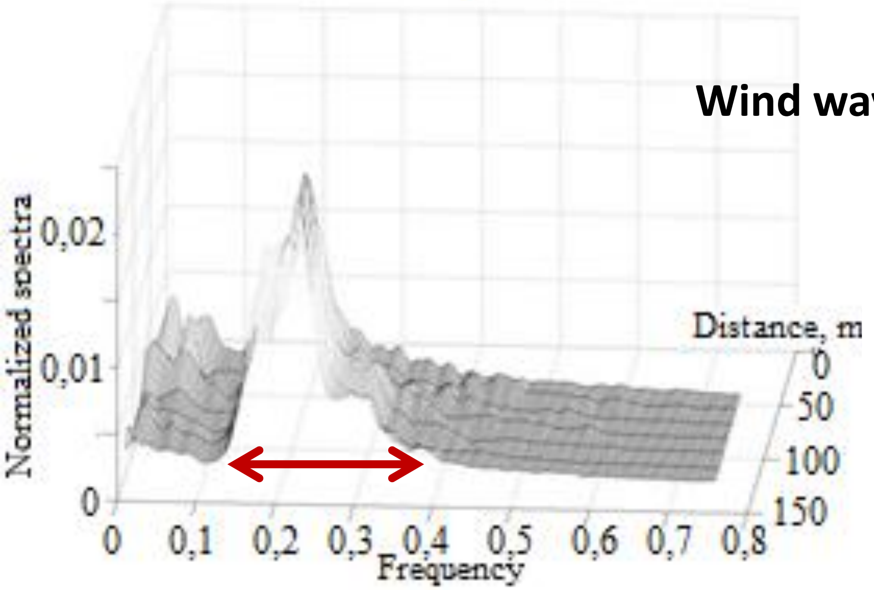
Wave parameters

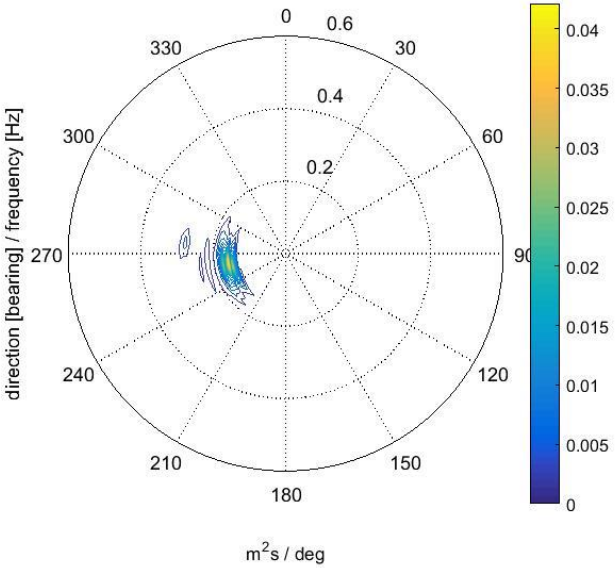
Swell





Wind waves





Significant wave height, m

$$H_S = 4 \cdot \sqrt{m_0}$$

$$m_0 = \int_0^{\infty} S(\omega)\, d\omega$$

Spectrum peak period T_p, sec

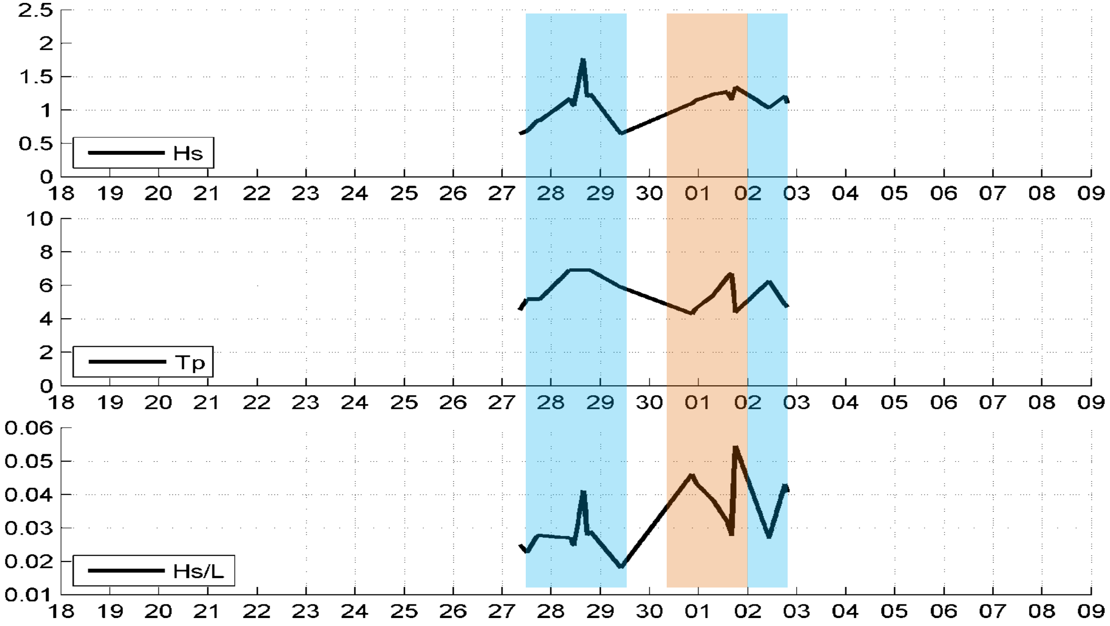
Wave steepness

$$\lambda = H_S / L$$

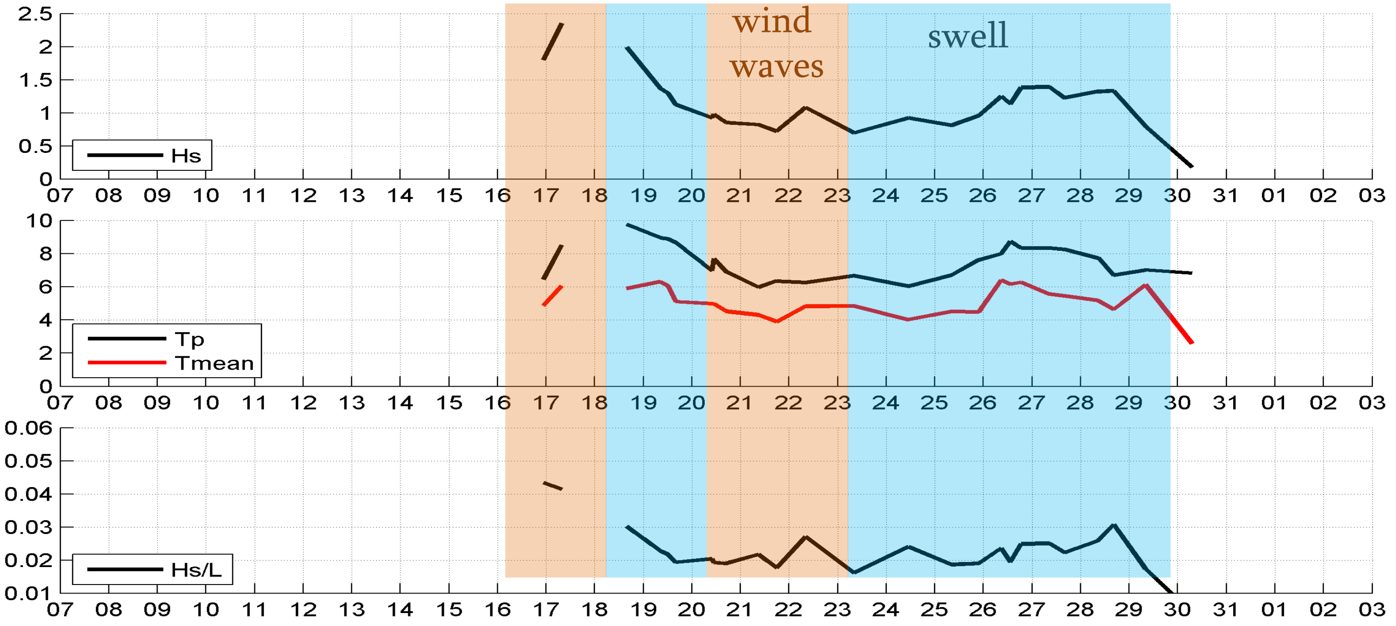
Records with predominant normal main wave direction and without or with minimal along shore sediment flux were chosen to estimate cross-shore underwater profile deformations, ; wave parameters at the entrance of coastal zone were calculated for the distance 200-220 m (the end of pier)

Discussion of results

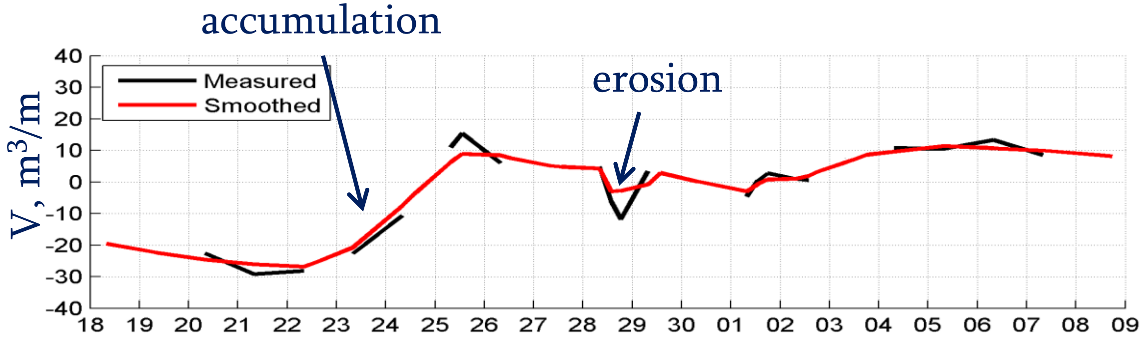
A few cycles of erosion-accumulation were observed. Increasing of Hs can lead to erosion; but Tp, H/L?

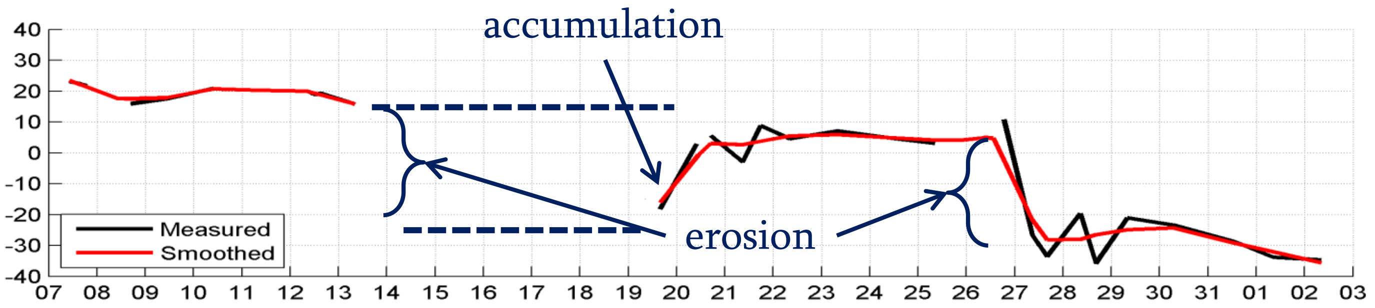


September-October 2007

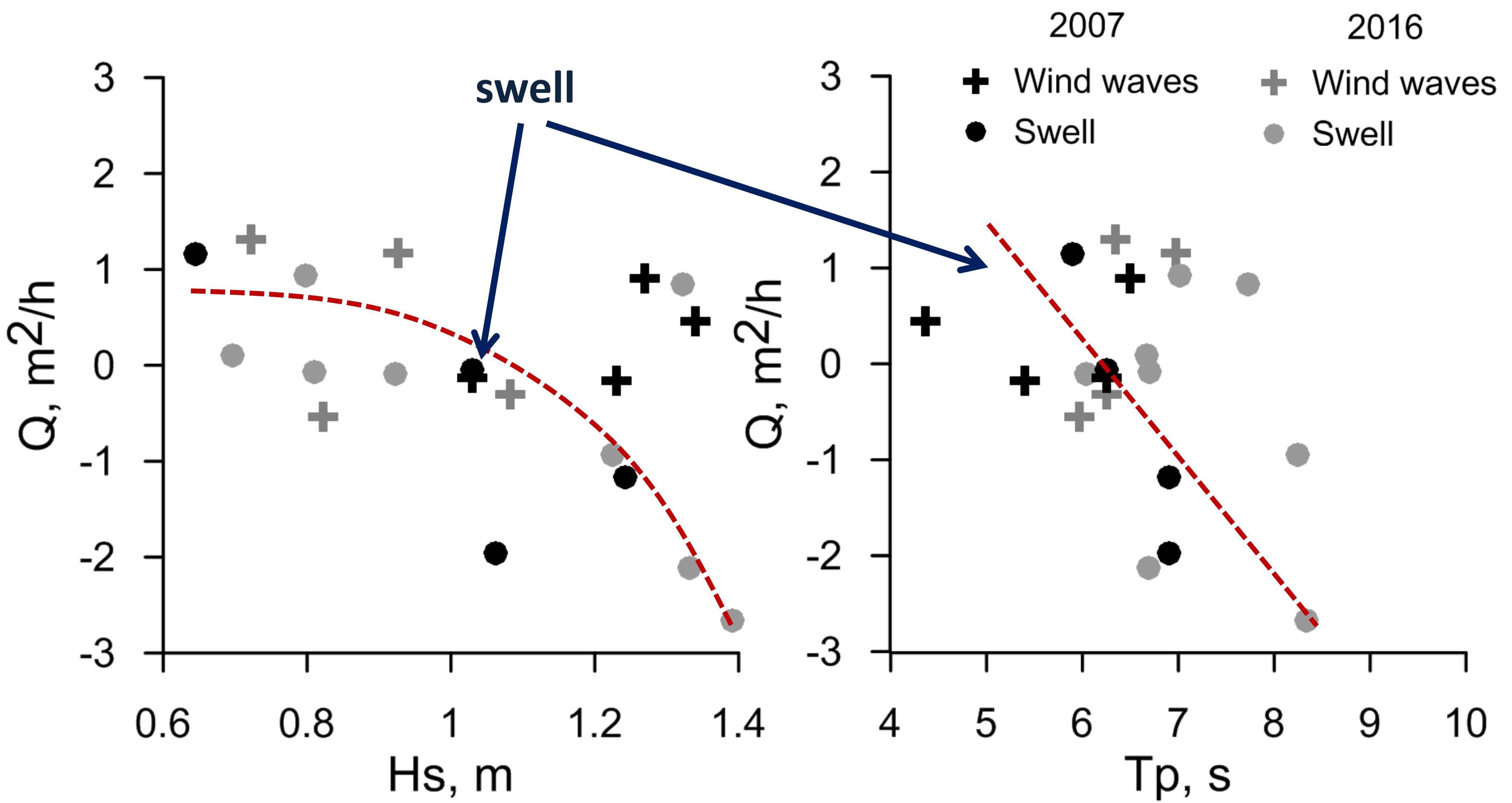


October -November 2016





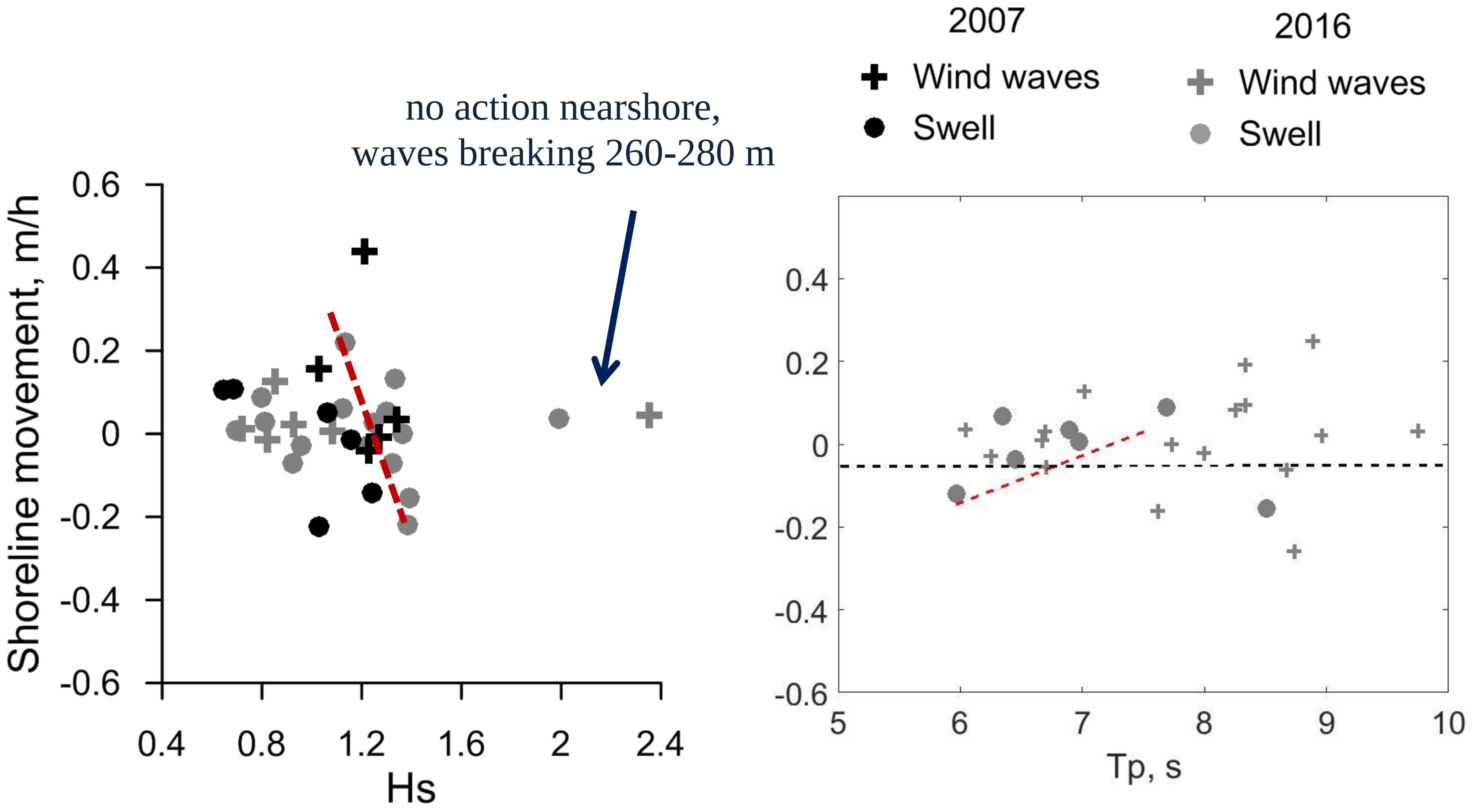
Influence of wave height and peak period on speed of profile deformation



No clear dependence.

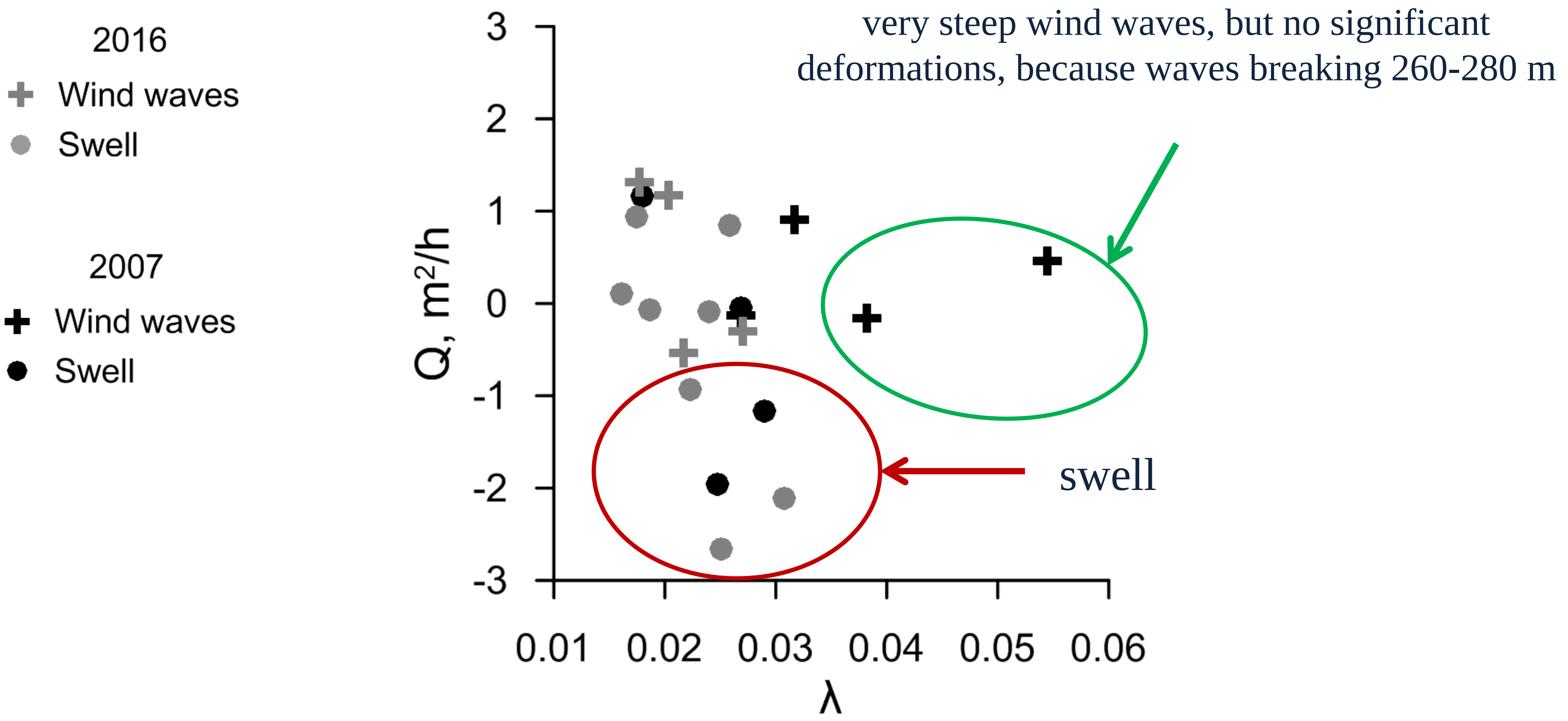
Tendency: for swell waves speed of erosion increases with increasing H_s and T_p

Influence of wave height and peak period on speed of shoreline movement



No clear dependence. Main influence of wave transformations processes?

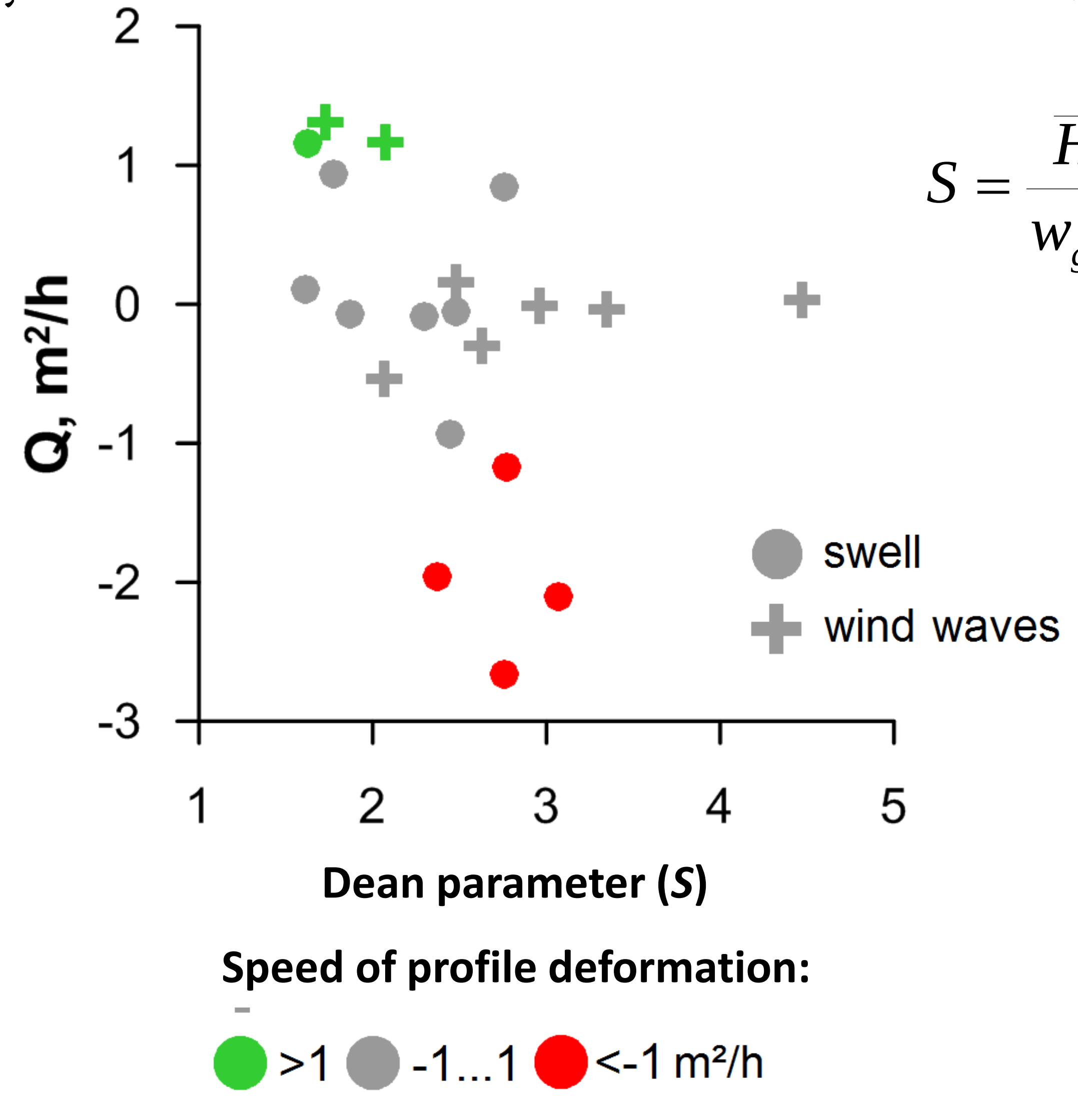
Influence of wave steepness on speed of profile deformation



Tendency:
increasing of wave steepness leads to increasing of speed of erosion (for swell).

Influence of wave steepness on speed of profile deformation: empirical relations

In engineering models according to Dean parameter steep waves create erosive underwater profile, but gently sloping waves – accumulative profile (Larson, Kraus, 1989)



$$S = \frac{\overline{H_\infty}}{w_g Tp}$$

$$\begin{cases} < 2 \rightarrow accumulation \\ \geq 2 \rightarrow erosion \end{cases}$$

In general the criterion is correct, especially for narrowband spectrum waves (swell)

Influence of processes of non-linear wave transformations on speed of profile deformation: empirical relations

Irribaren number

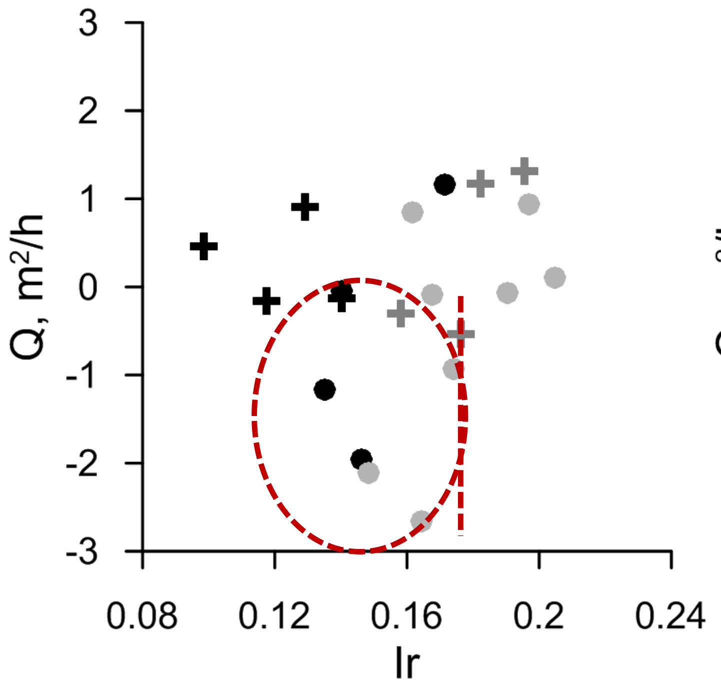
Nonlinear wave transformation features on sloping bottom tan(a)

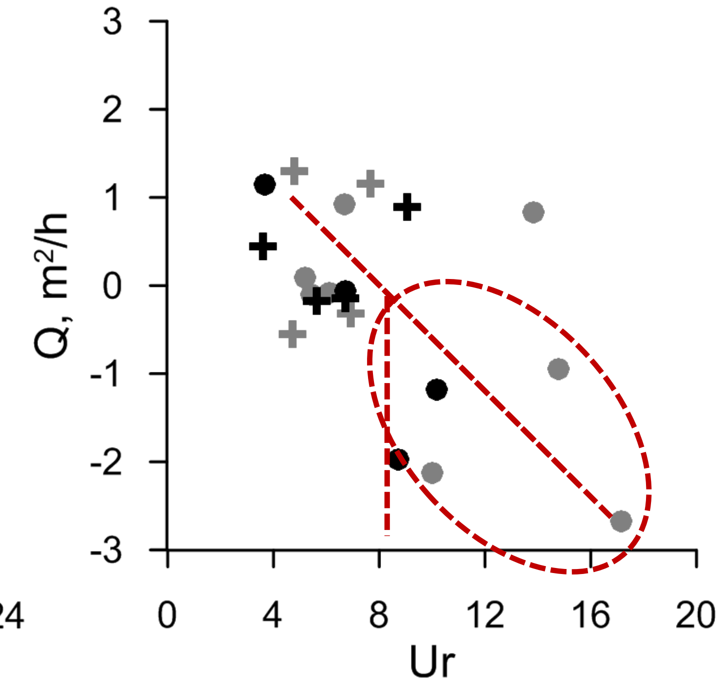
$$Ir = \tan(\alpha)\cdot(Hs/L)^{-1/2}$$

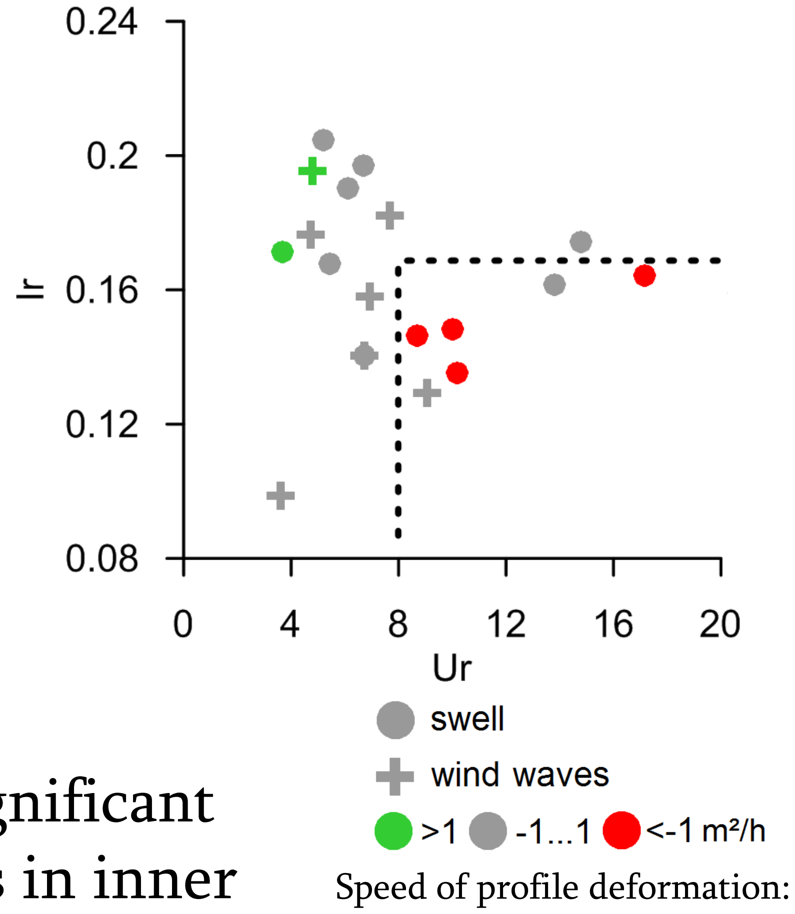
Ursell number

Relation between non-linearity and dispersion

$$Ur = 1/2\cdot(Hs/h)\cdot(L^2/h^2)$$

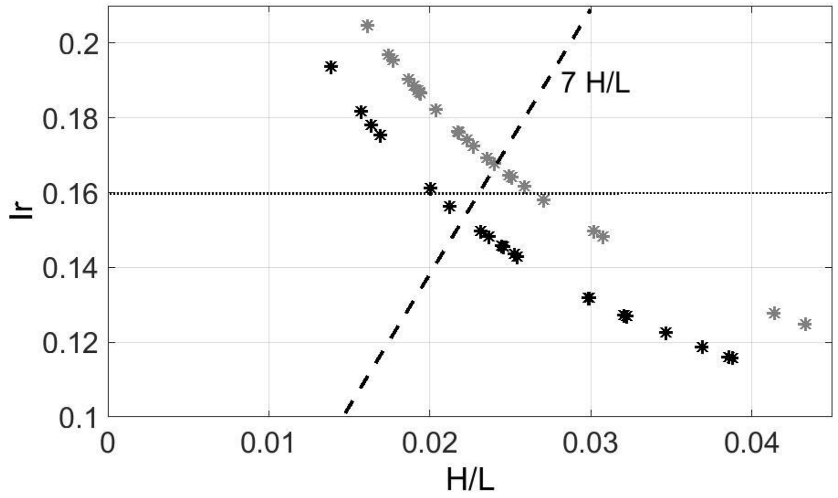


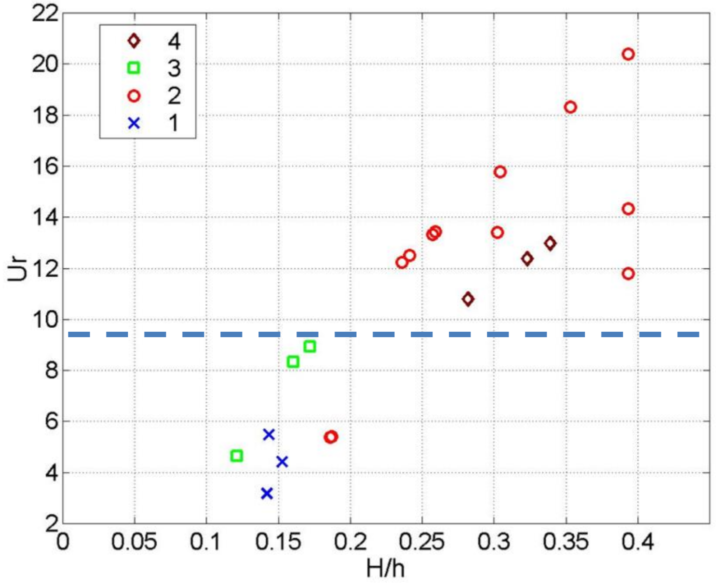




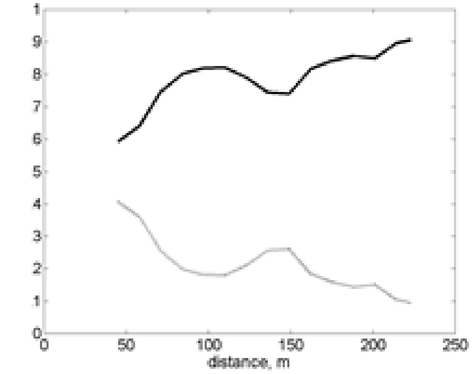
Increasing of erosion Ir<0.16 and Ur≥9, when at nonlinear wave transformation there are significant (maximal) amplitudes of second nonlinear harmonics in inner part of coastal zone (Saprykina et al, 2013))

Non-linear wave transformation: typical scenarios

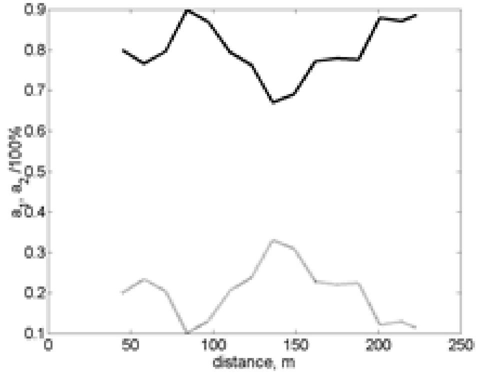




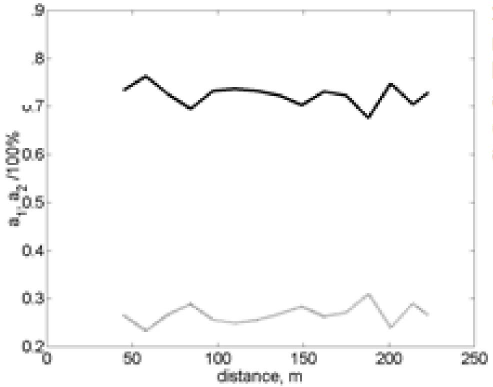
4 typical scenarios of nonlinear transformation of waves, distinguished in 23 examined records of field experiment



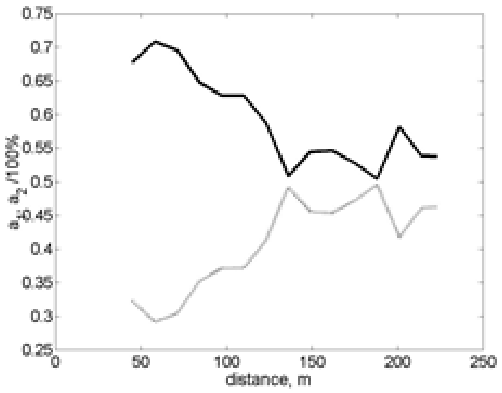
1. Amplitude of 2nd harmonic grows only near the shore, 1,5 – 2 periods of energy exchange



2. 2nd harmonic reaches its maximum within coastal zone, 1 period of energy exchange



3. No obvious maximum of 2nd harmonic, its amplitude changes a little in all coastal zone.



4. Amplitude of 2nd harmonic is high on the entrance of coastal zone and decreases to the shore, about ½ of period of energy exchange.

3

If *Ir>7*H/L* – amplitude of 2[nd] harmonic is small and decreases only near shore;

If *Ir<7*H/L* amplitudes of 2[nd] harmonic have maximum in inner part of coastal zone

4 scenarios determine different spatial structure of wave component of sediment flux

Read more: Saprykina Ya.V., et.al. 2013. Scenarios of nonlinear wave transformation in the coastal zone. Oceanology 53(4): 422-431

Influence of wave breaking on profile deformation: type of breaking is important

Plunging

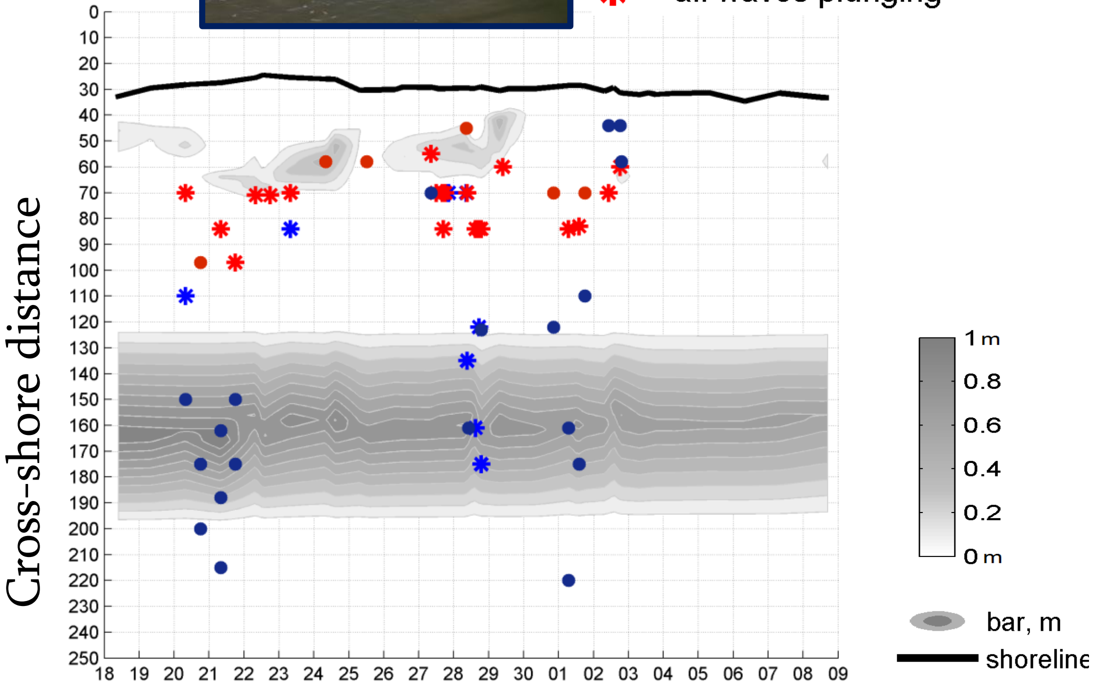
As<0
Sk≈0
symmetry

Spilling

As≈0
Sk>0
symmetry

big waves plungigng
all waves plunging

big waves spilling
all waves spilling



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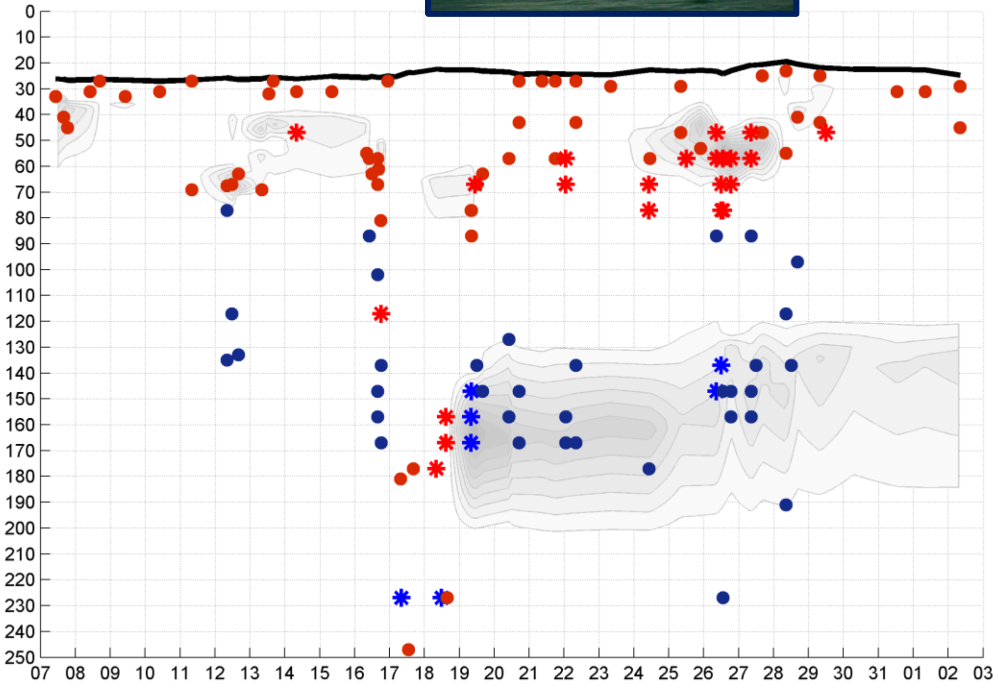
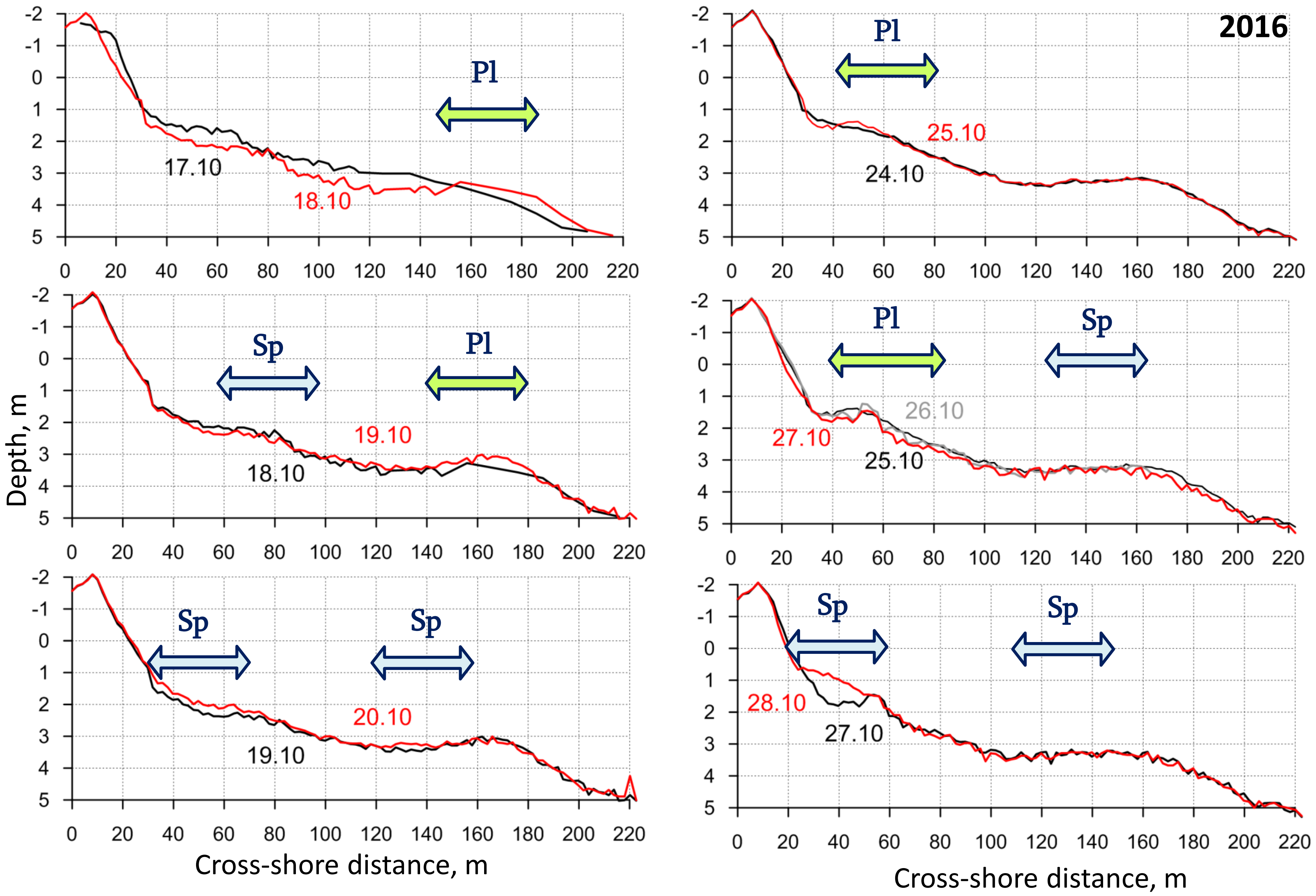


October – November 2016

Plunging breaking: increasing of negative specific sediment volume and to formation of underwater bars;

Spilling breaking: smoothing of underwater profile and bars

Influence of wave breaking type on evolution of bars during storm



Plunging breaking waves form underwater bars, move sediments seaaward and "support" existence of bars.

Spilling breaking waves move sediments to the shore and smooth out underwater bars

Influence of wave breaking type on cross-shore sediment transport

$$q = \frac{1}{2} \cdot f_w \rho \left(\frac{\varepsilon_b}{tg\phi} \overline{u|u|^2} + \frac{\varepsilon_s}{W_s} \overline{u|u|^3} \right)$$

(Bailard, 1981)

$$\overline{u|u|^3} \approx u_1^3 u_2 \cos\varphi$$

(Stive, 1986)

$$\overline{u|u|^2} \approx u_1^2 u_2 \cos\varphi$$

u=u(t) - instantaneous near bottom velocity

$$u_i = \frac{a_i \omega}{sh(kh)}$$

a_i – amplitue of *i* nonlinear harmonic

ω - angular frequency, k - wave number

Nonlinear waves in simple form:

$\xi(t,x)=a_1(x)*\cos(\omega t-kx)+a_2(x)*\cos(2\omega t-2kx+\varphi)$,

φ - shift of phases between a_1 and a_2

q depends on a_1 and a_2 and φ.

Plunging breaking waves are asymmetrical on vertical axis (As<0), $\varphi \to -\pi/2$ and $q \to 0$,

Spilling breaking waves are near symmetrical on vertical axis (As≈0), $\varphi \to 0$ and $q \to$ to maximum value.

Taking into account an undertow, the sediments will move to the sea at plunging breaking and to shore at spilling breaking

More: details Kuznetsov, S. and Saprykina Ya. DEPENDENCIES OF BREAKING TYPE, BREAKING CRITERIA AND ENERGY DISSIPATION ON AMPLITUDE-PHASE FREQUENCY STRUCTURE OF WAVES, ICCE2018 Thursday, August 2, 2018, 1:20 PM – 1:40 PM

Conclusions

- It was confirmed that the main wave parameters for cross-shore sediment transport at the entrance to the coastal zone are the wave height, spectral peak period and wave steepness. The most significant is the wave height. In general, an increase of these parameters leads to erosion. Waves with narrowband spectrum (swell) more affect on underwater profile.
- For a qualitative assessment of the processes of erosion/accumulation, the Dean parameter, the Ursell and Iribarren numbers are suitable.
- However, it is impossible to predict deformations of the underwater bottom relief on the base only wave parameters and empirical numbers, because the physical processes of wave transformation play an important role. The most significant of these are nonlinear wave transformation and wave breaking (especially the type of wave breaking). This should be taken into account for an adequate estimation of sediment transport.
- According to field observations, the concept that the wave breaking is a mechanism for the formation of underwater bars is confirmed, and it is clarified that the type of wave breaking in this case is plunging.