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A NUMERICAL MODEL OF CROSS-SHORE BEACH PROFILE EVOLUTION: THEORY, MODEL DEVELOPMENT AND APPLICABILITY

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Presentation Outline

- Background
- Study Area and Field Measurements
- Numerical Model
- Model Setup
- Results and Discussion
- Conclusions

Background

- The knowledge on nearshore morphological processes such as prediction of sediment transport rates and beach profile evolution is still limited.

- Nearshore environment is very dynamic and complex.

- Sedimentation at Iranian ports is a major problem. The large sedimentation forced the authorities to plan a regular monitoring program of bathymetric surveys.

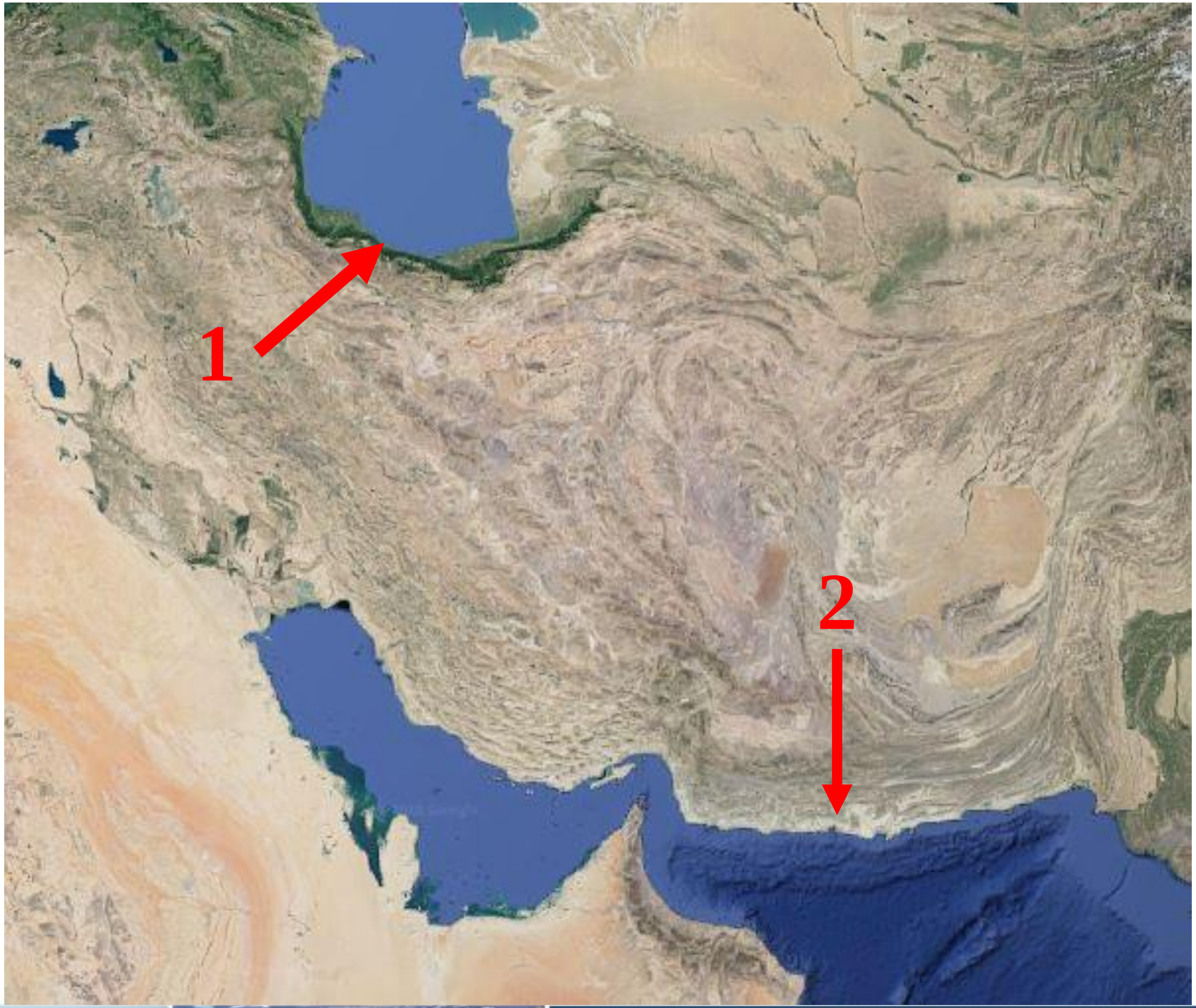
- Evaluation of bathymetric change is of importance for solving the problem. Predicting cross-shore beach profile evolution would be the first step for short term evaluation.

Study Area and Field Measurements

The study areas and field data of the present study are as follows:

1) Nowshahr

2) Zarabad

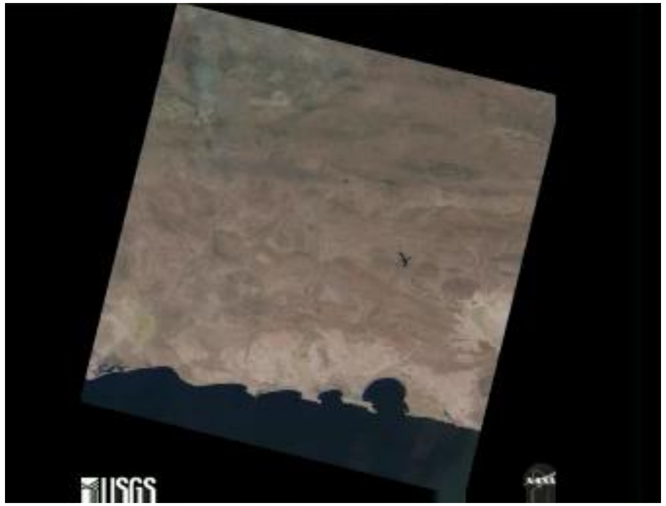


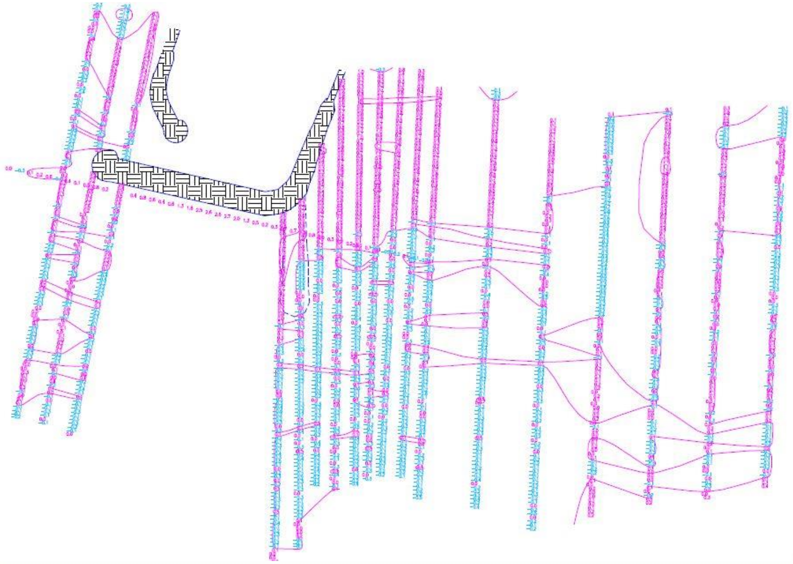
Nowshahr Coastal site

- This site is located on the south coast of the Caspian Sea.
- The field site in Nowshahr is about 13km alongshore and about 1km offshore coastal area.
- The data set consists of the measured cross-shore profiles and wave conditions for the events of 30th October 2013 to 18th January 2014.

Zarabad Site

- This site is situated south of Iran at Sistan and Balouchestan province on the Gulf of Oman.
- A field monitoring program of periodic hydrography surveys was started from 2006 to 2008.
- The field site in Zarabad is about 2km alongshore and about 1km offshore coastal area.
- The hourly time series of offshore spectral waves were adopted from 22-years' hindcast data of the Gulf of Oman.

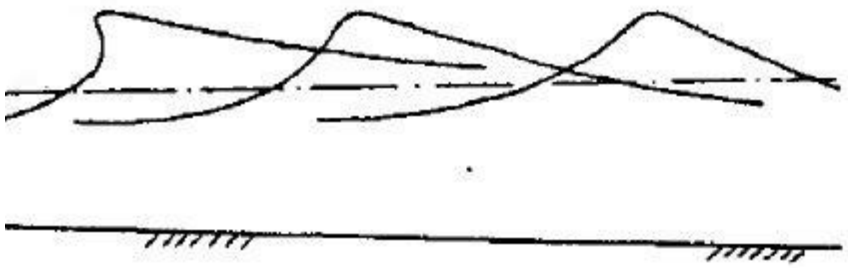


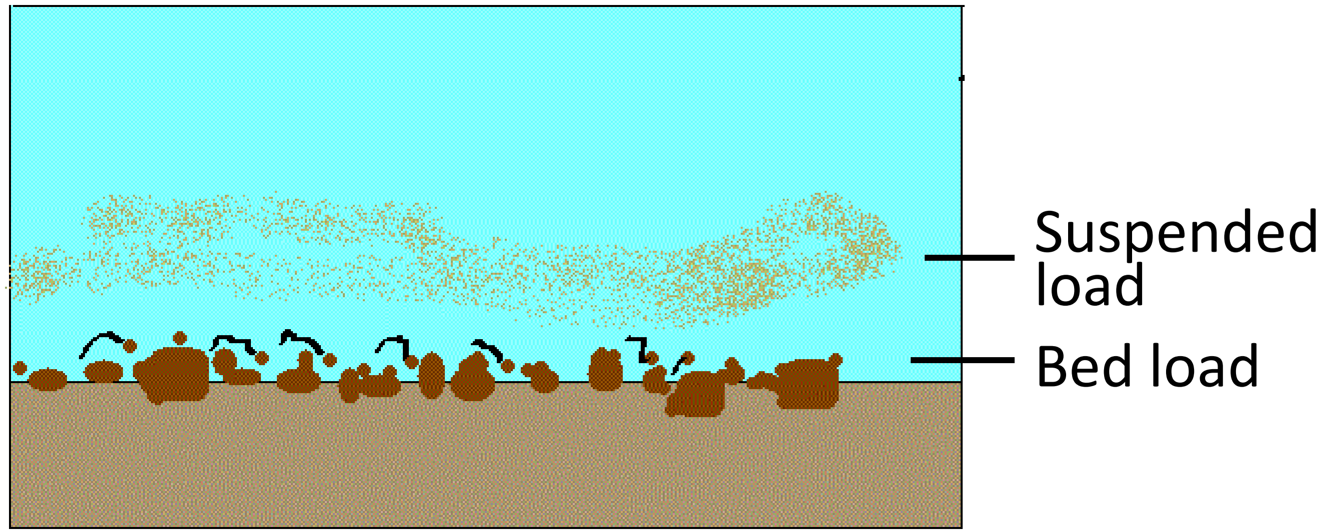


Numerical Model

A process-based cross-shore beach profile evolution model consisting of three sub-models is applied.

1) Wave and current model
2) Sediment transport model
3) Bed level changes



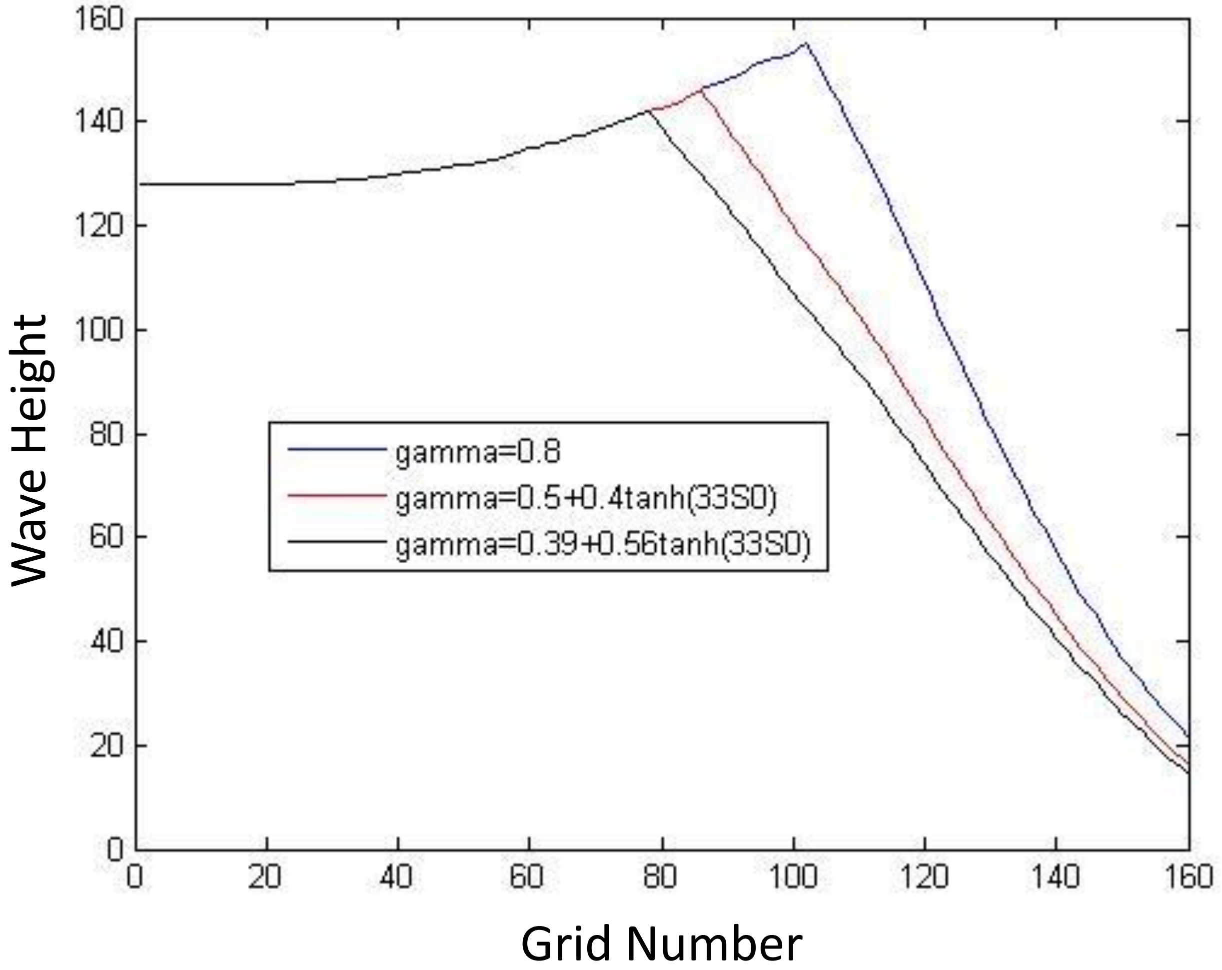


Wave and Current

- Breaker height (Battjes & Janssen, 1978)

$$H_m = \frac{0.88}{k}\tanh\left(\frac{\gamma}{0.88}kh\right)$$

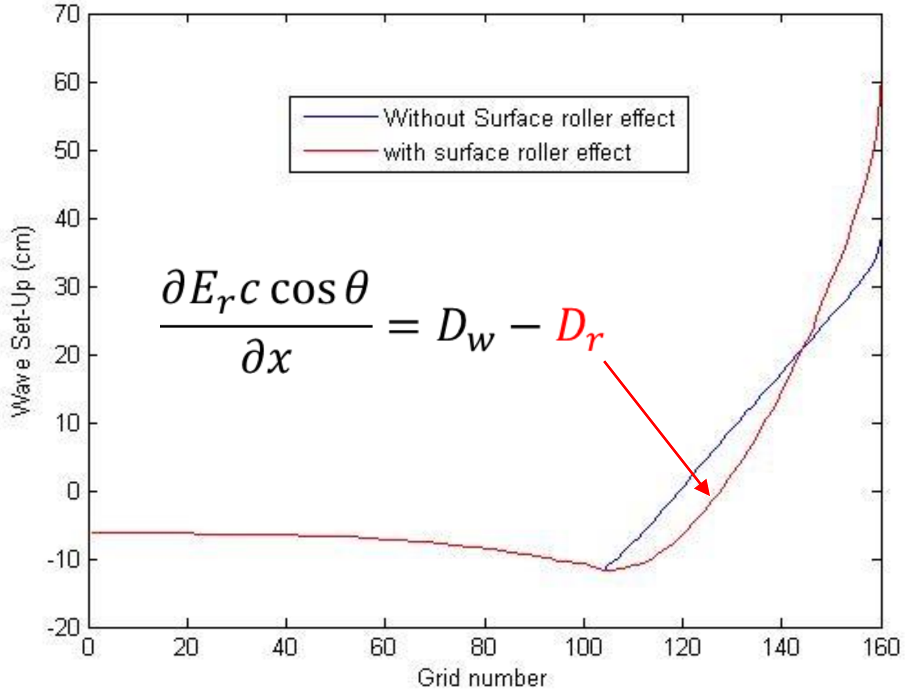
- The model contain a free parameter γ that can be tuned using different formula to provide more accurate predictions.



Wave and Current

The wave propagation sub-model computes the wave transformation including:

- Wave energy decay → $\frac{\partial E C_g \cos\theta}{\partial x} = -D_w - D_f$
- Bottom friction (D_f) → $D_f = \rho C_f \overline{|u_{rms}|^3}$
- Surface roller (D_r) → $D_r = 2\beta \frac{g}{c} E_r$ →



Sediment transport model

- Sediment concentration ($C(z)$) is predicted using a set of explicit empirical formulas developed by Jayaratne and Shibayama (2007, 2014).

1) Sediment suspension over rippled bed
2) Sediment suspension over sheet flow
3) Sediment suspension under breaking waves

- The modified bed load transport formula of Watanabe (1982) is used.

Sediment transport model — Sediment suspension over rippled bed —

For upper suspension layer ($z > 2\eta$):

$$c_r = \frac{k_3 \Theta \upsilon}{\sqrt{(s-1)gd}(\frac{\eta}{2})}$$

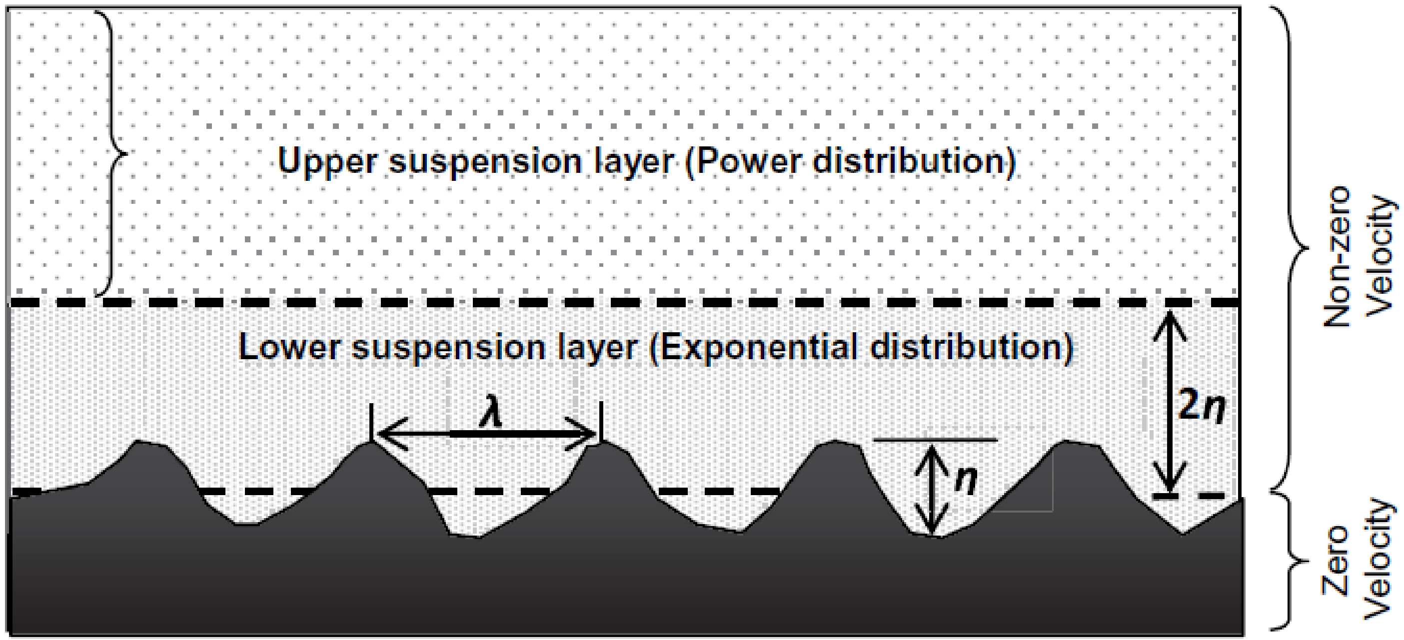
$$c(z) = c_r(\frac{z_0}{z})^{M_r}$$

For lower suspension layer ($z \leq 2\eta$)

$$c_r = \frac{k_1 \Theta \upsilon}{\sqrt{(s-1)gd}(\frac{\eta}{2})}$$

$$\varepsilon_r = k_2 u_{*wc} A_b (\frac{w_s}{u_{*wc}})^2 (\frac{\eta}{d})^{0.1} (\frac{\lambda}{d})^{0.25} d_*^{-1.5}$$

$$c(z) = c_r exp\left\{\frac{-w_s(z-r)}{\varepsilon_r}\right\}$$



Sediment transport model —Sediment suspension over sheet flow —

For suspension layer:

$$c_r = \frac{k_7 \Theta \upsilon}{\sqrt{(s-1)gd}(\frac{\eta}{2})}$$

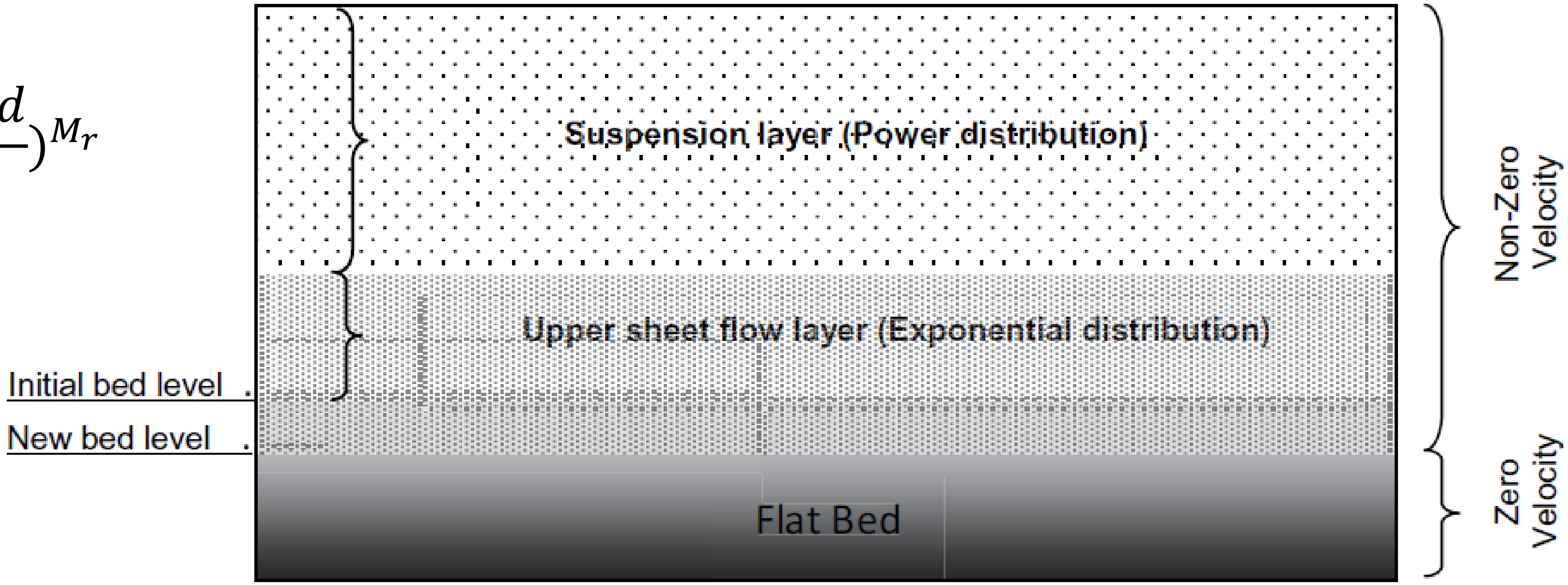
$$M_r = (\frac{w_s}{u_{*wc}})^{k8} \qquad c(z) = c_{ra}(\frac{100d}{z})^{M_r}$$

For upper sheet flow layer:

$$c_r = \frac{k_5 \psi \upsilon}{\sqrt{(s-1)gd}(\frac{\eta}{2})}$$

$$\varepsilon_r = k_6 u_{*wc} A_b (\frac{w_s}{u_{*wc}})^{1.8} d_*^{-1.5}$$

$$c(z) = c_r exp\left\{\frac{-w_s(z-d)}{\varepsilon_r}\right\}$$



Sediment transport model —Sediment suspension under breaking waves —

$$c_r = k_9(\frac{\hat{u}}{\hat{u}_b})^{1.5}\left[10^{-9} g T \frac{\hat{u}_b^{2.3}}{w_s^{3.3}}\right]$$

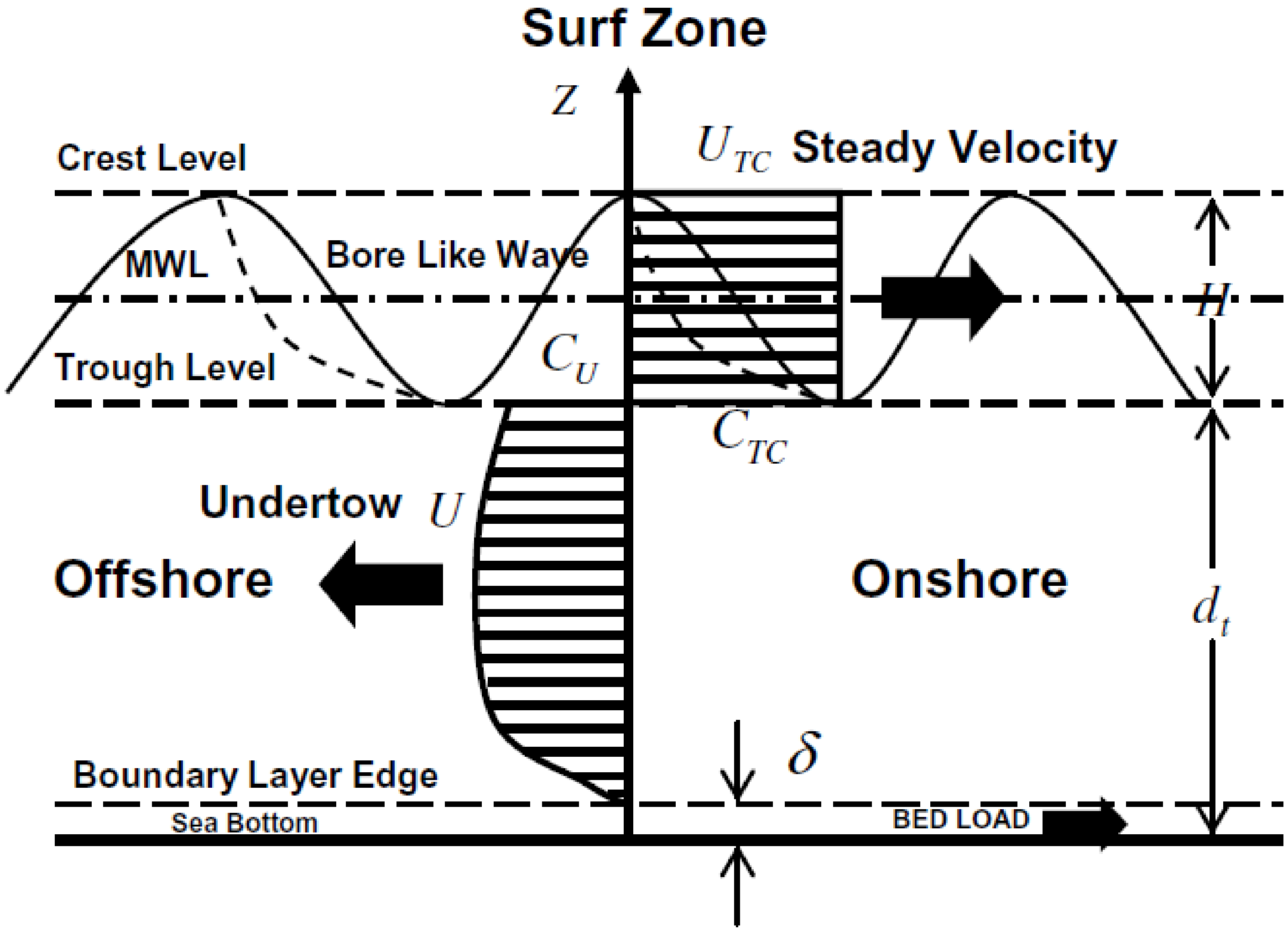
$$k_9 = \begin{cases} 0.45 & T \leq 6\ s \\ 0.34 & 6\ s < T \leq 10\ s \\ 0.25 & T > 10\ s \end{cases}$$

$$\varepsilon_r = \left[k_{10} u''_{*wc} + k_{11}(\frac{D_B}{\rho})^{1/3}\right] z$$

$$k_{11} = k_{12}\left[0.3 + 0.7\frac{(x_b - x)}{(x_{b-} x_t)}\right]$$

$$M_r = \frac{w_s z}{\varepsilon_r}$$

$$c(z) = c_r(\frac{100d}{z})^{M_r}$$



Model Setup

- A computer program was written and performed in MATLAB software.

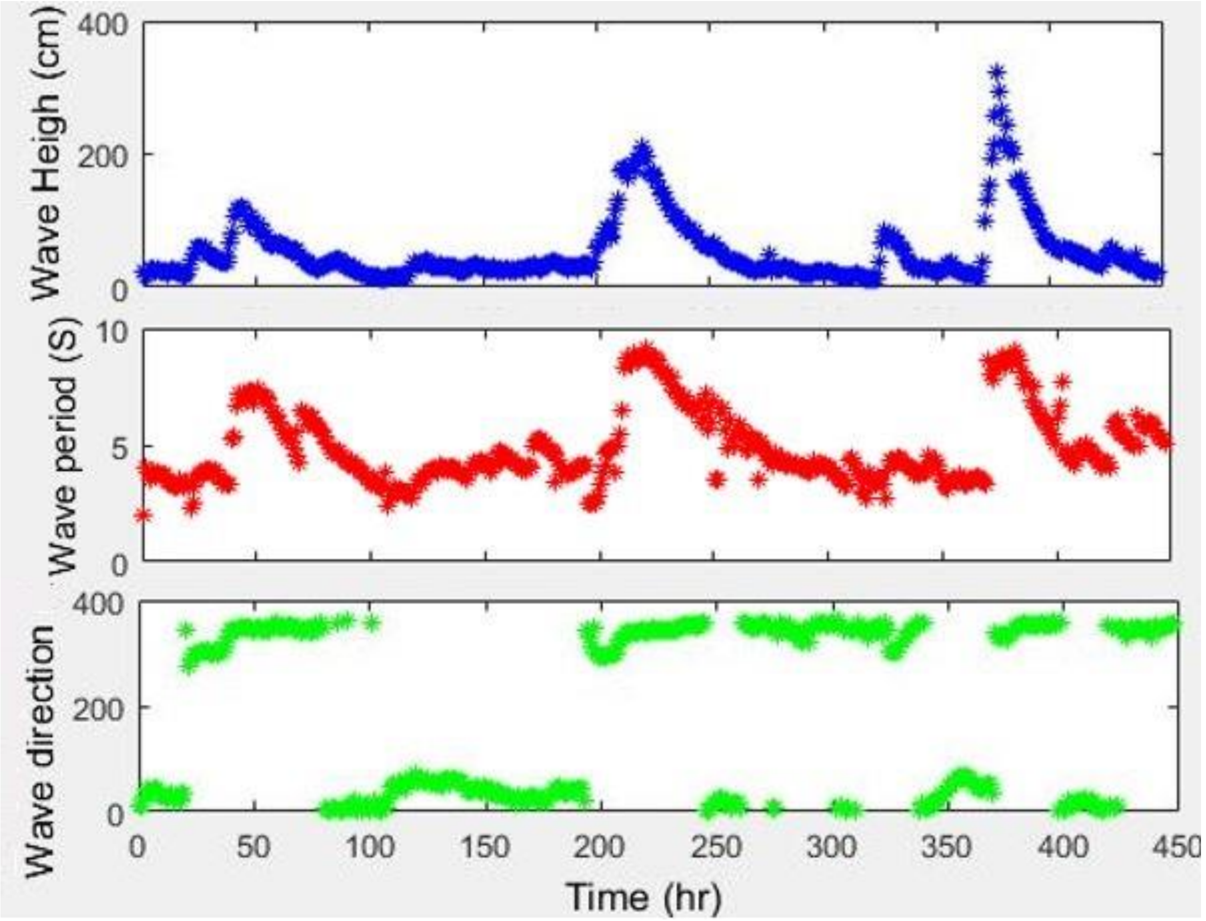
- The initial bed profile introduced to the program and a regular grid with constant spacing ($\Delta x = 0.5$ m) was employed.

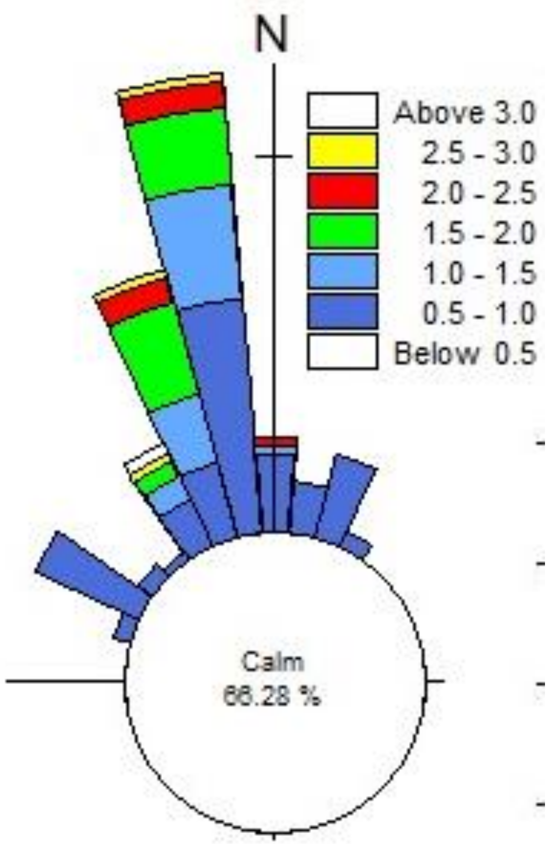
- Calibration parameters such as: breaker index (γ), roller coefficient index (β), reference concentration constants (k_n), The values of $m_{cr,w}$ and $m_{cr,d}$ were changed for each test case.

Nowshahr Simulation

- Profile 8 was selected to reduce the effect of longshore sediment transport.

Nowshahr Simulation

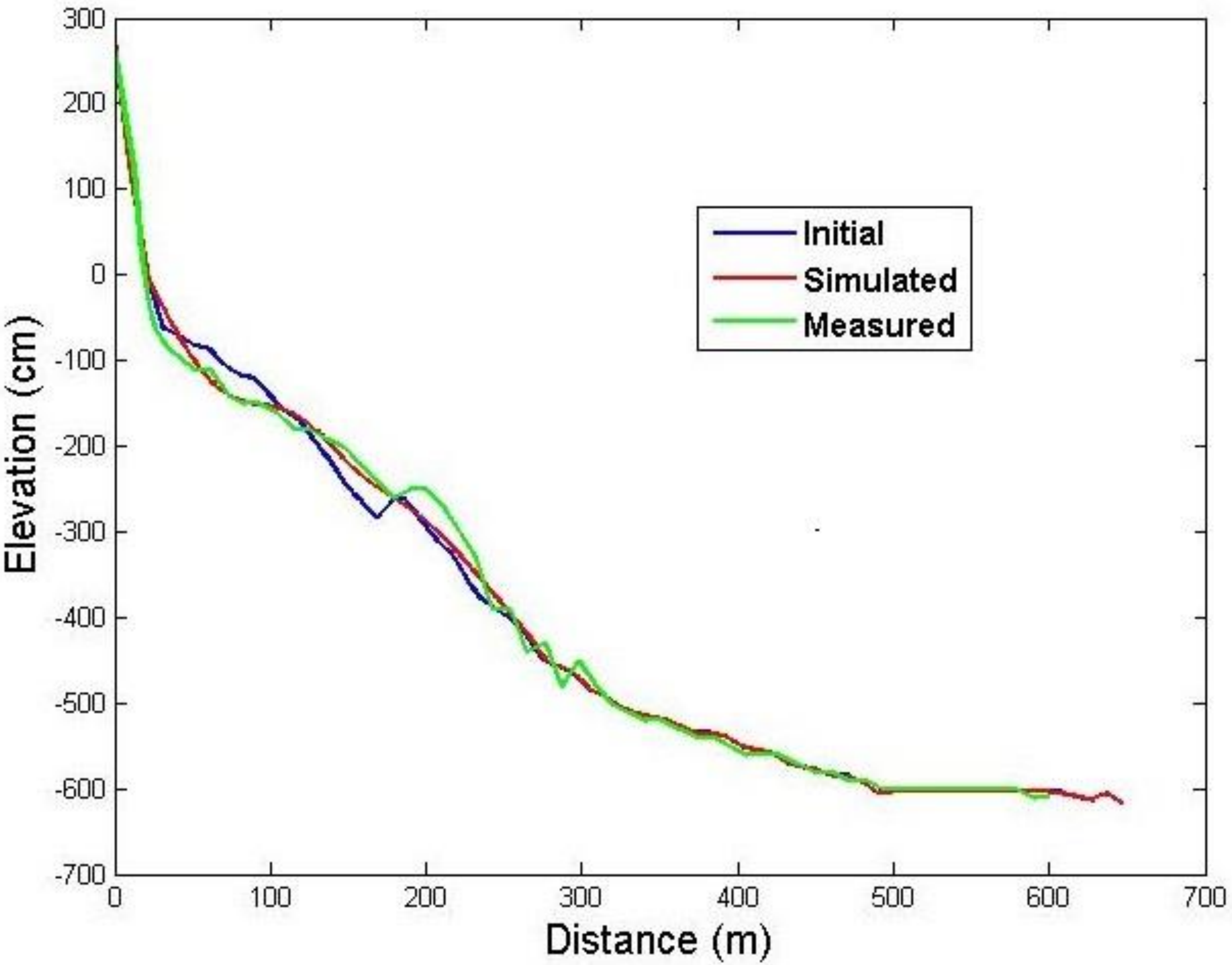




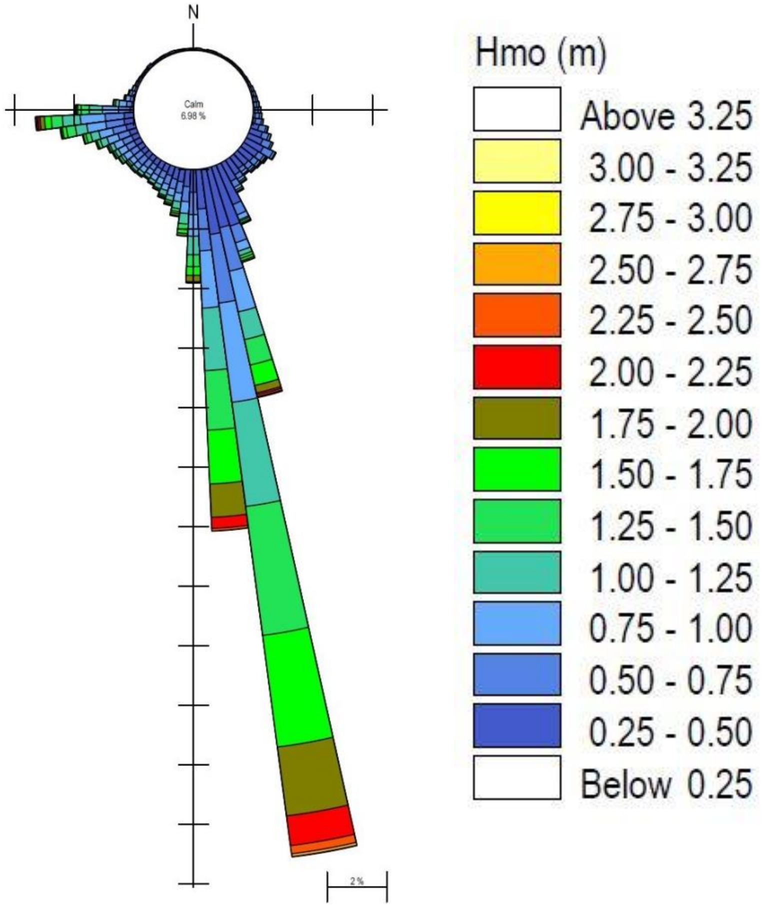
Nowshahr (2013): Hmax=3.32m, T=9.45s

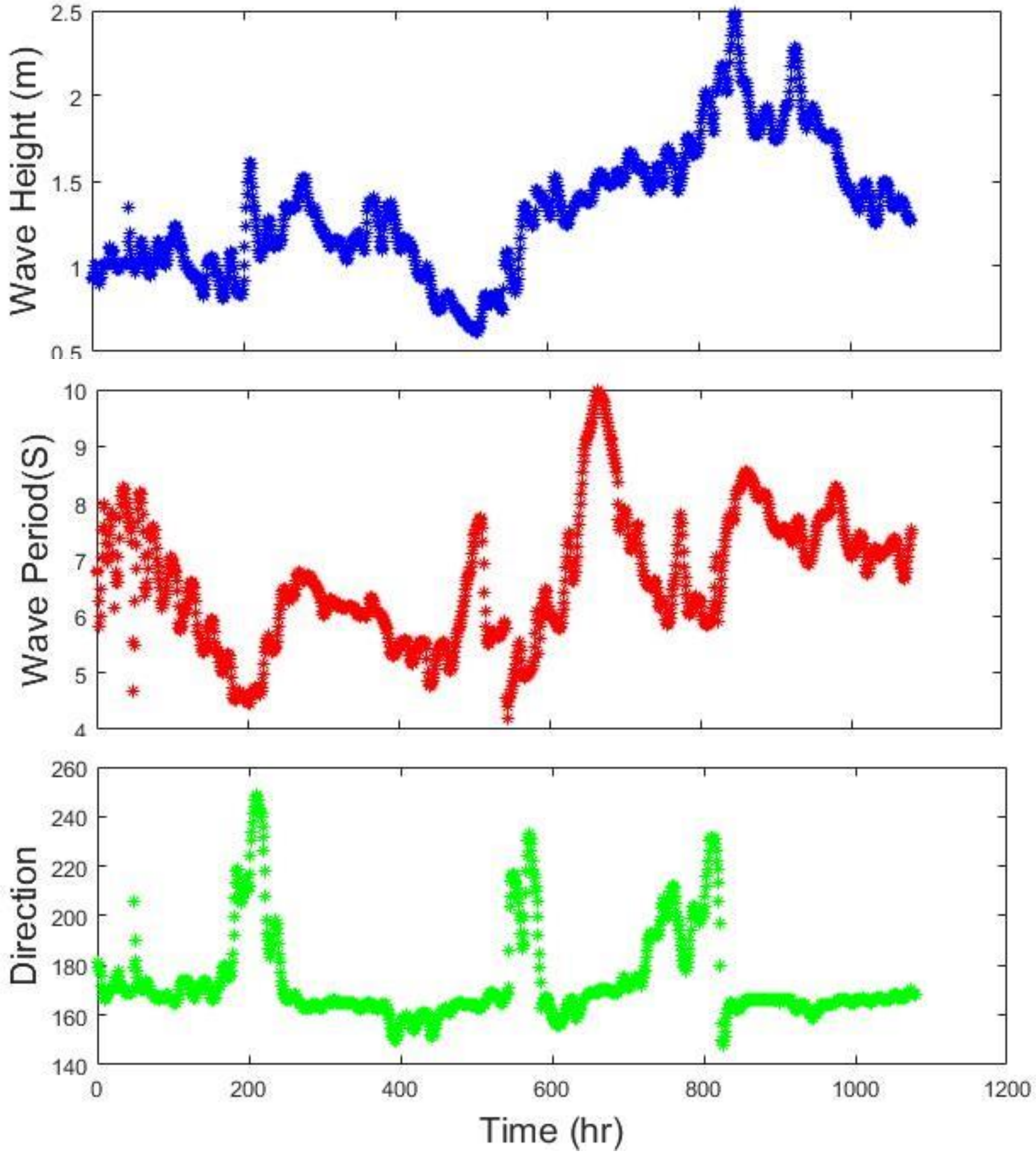
Nowshahr Simulation

D_{50}	0.02 (cm)
Slope	0.015
Δx	50 cm
γ	0.55-0.65
β	0.1-0.2
$m_{cr,w}$	0.1
$m_{cr,d}$	1
BSS	0.71



Zarabad Simulation

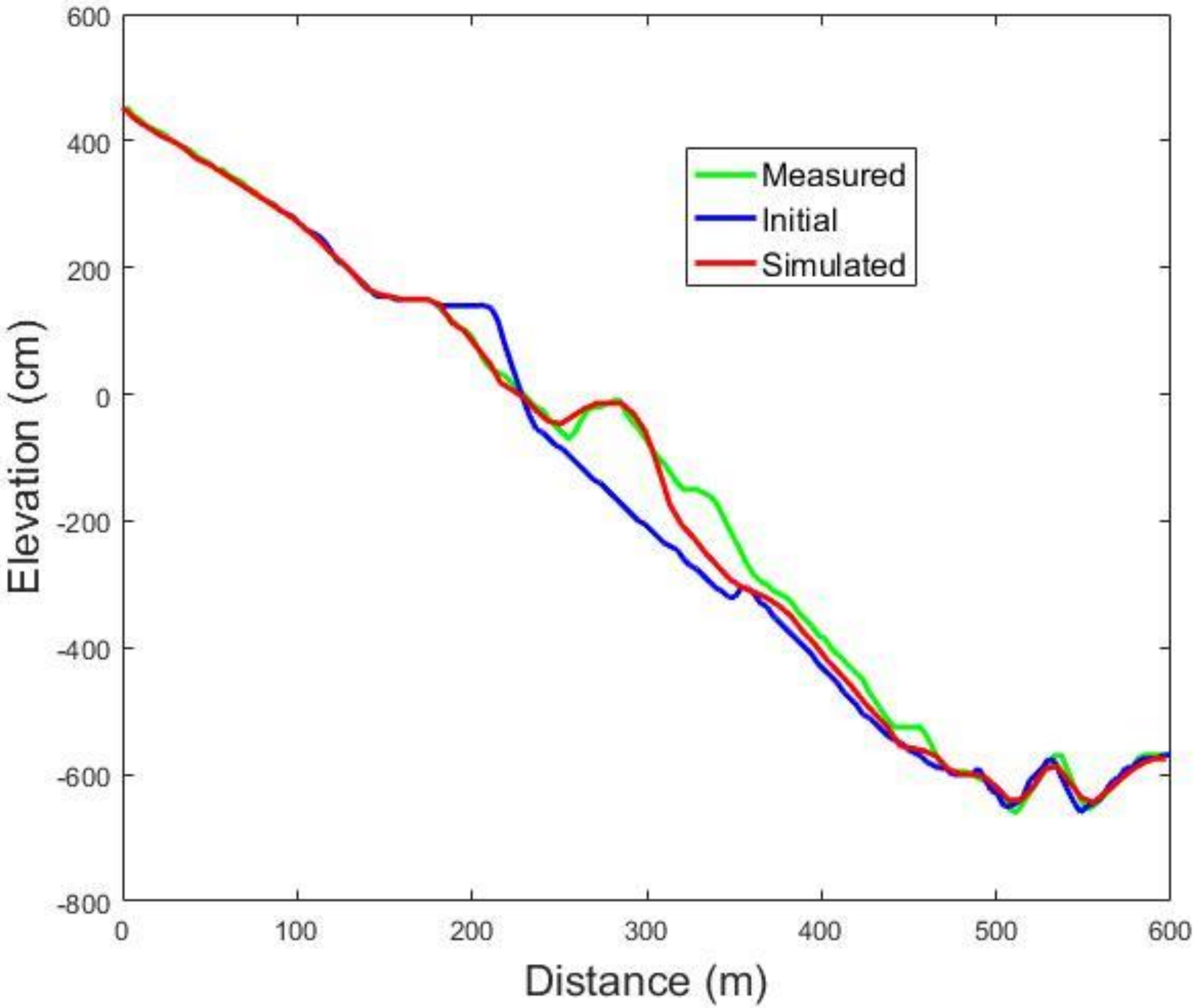




Zarabad (2007): Hmax=3.24 m , T=7.75s.

Zarabad Simulation

D_{50}	0.015 (cm)
Slope	0.02
Δx	50 cm
γ	0.75-0.8
β	0.1-0.2
$m_{cr,w}$	0.1
$m_{cr,d}$	1
BSS	0.78



Discussion and Conclusion

- The proposed model is sensitive to hydrodynamic and avalanching calibration parameters.

- Free parameters in reference concentration formulae have shown that they had effective influence on offshore sand bar formation.

- Although longshore currents and littoral drift affect the local sediment transport and the sedimentation at up-drift, one of the profile was selected as far as possible from the port to reduce the effect of longshore sediment transport.

- Numerical simulations of Zarabad and Nowshahr beaches were carried out using the proposed model and proved to be a useful practical tool to predict beach profiles on the time scales from a week to months.

Thank you!