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A MODEL TO SIMULATE BEACH PROFILE EVOLUTION INDUCED BY STORMS

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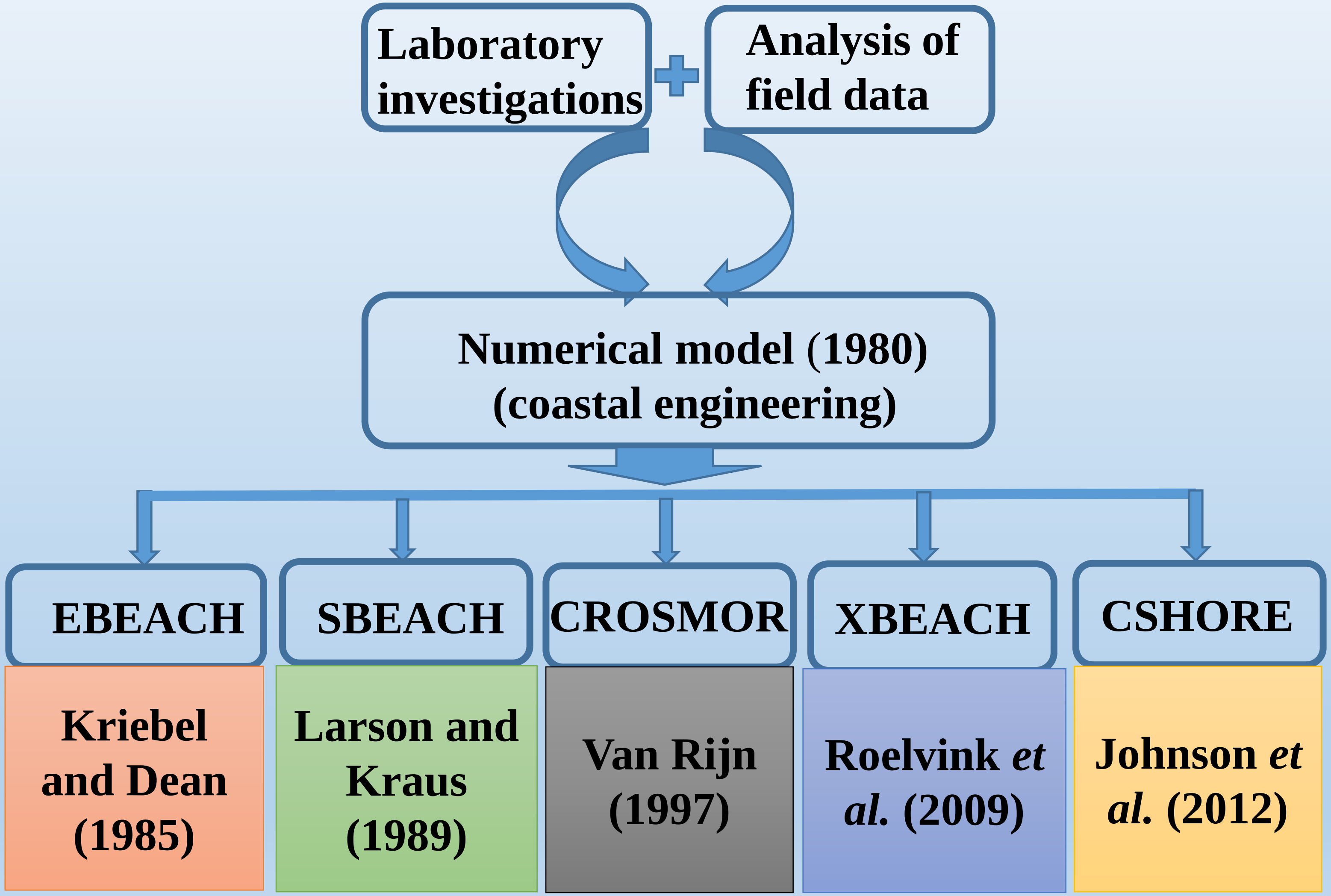
Presentation Overview

- Objectives
- Components of new model
- SUPERTANK project
- Model simulations
- Further developments
- Conclusions

Background

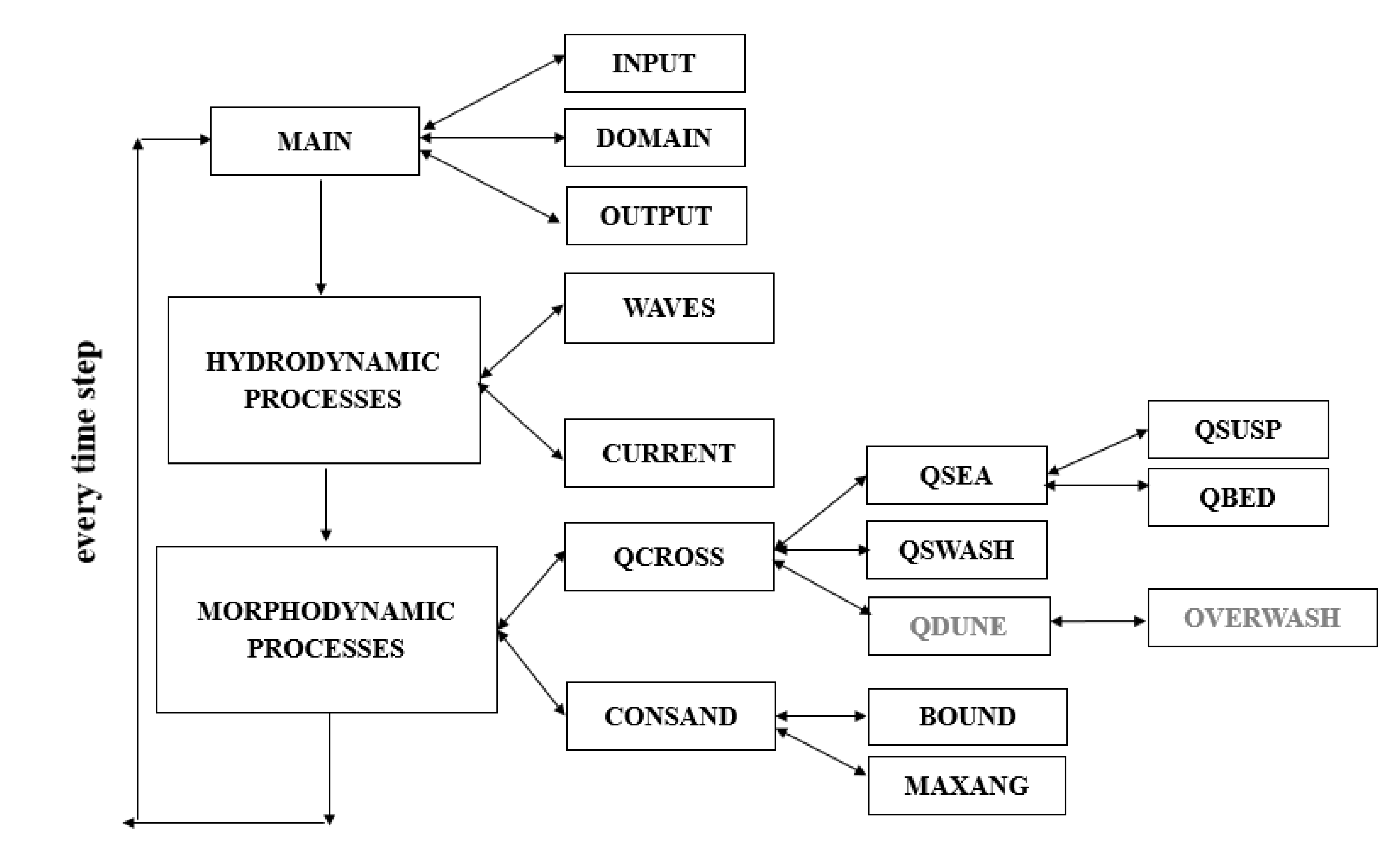

Laboratory investigations
Analysis of field data
Numerical model (1980)
(coastal engineering)
EBEACH
SBEACH
CROSMOR
XBEACH
CSHORE
Kriebel and Dean (1985)
Larson and Kraus (1989)
Van Rijn (1997)
Roelvink *et al.* (2009)
Johnson *et al.* (2012)

Objectives

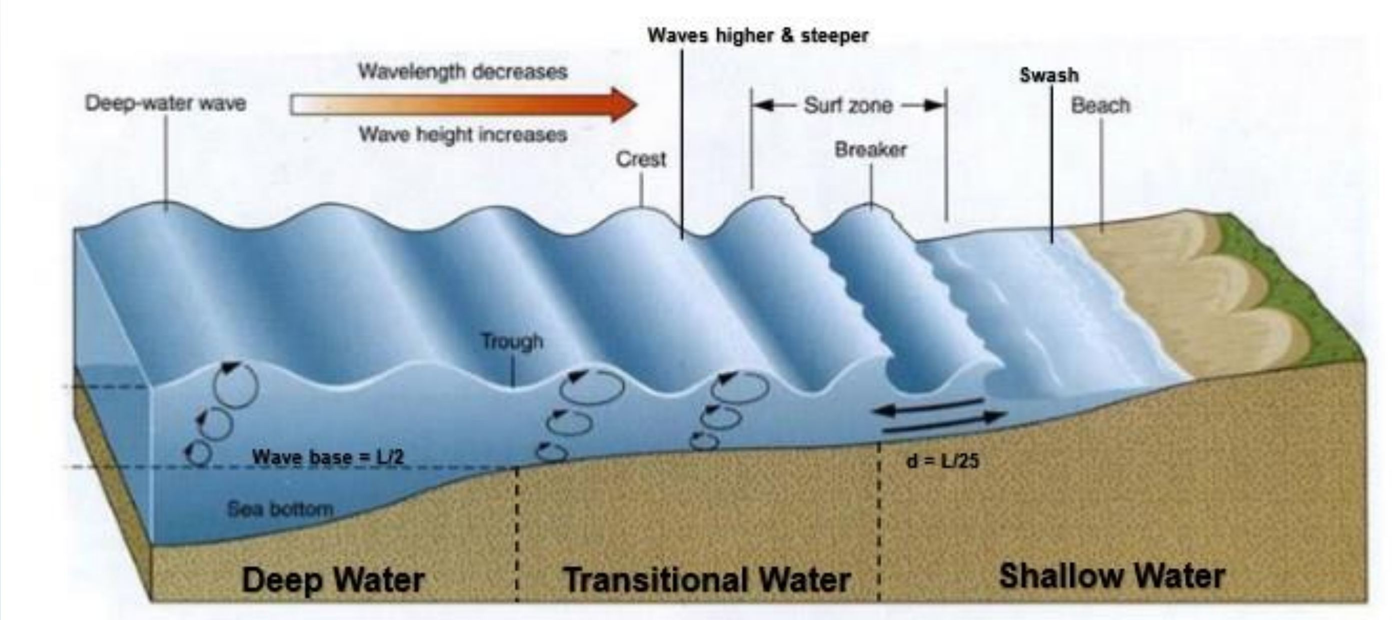
Develop a numerical model to simulate cross-shore sediment transport and beach profile evolution with focus on storm impact.

- Describe in detail the response of the **subaerial region**, including the foreshore, berm, and dune.
- Include relevant **physics** in combination with extensive empirical information.
- Validate the model based on **a variety of data** on profile evolution.

Components of new model



Wave transformation



(Plummer et al., 2001)

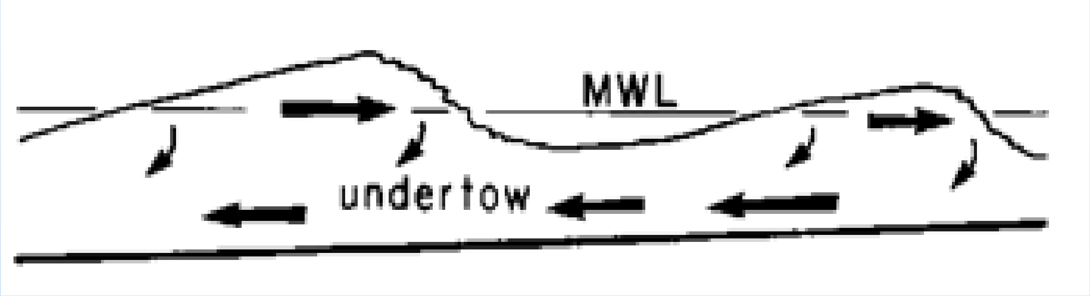
Random breaker decay model by Larson (1995):

$$\frac{d}{dx}\left(F_{rms}\cos\varphi\right) = \frac{\kappa}{d}\left(F_{rms} - F_{stab}\right)$$

$$F_{rms} = \frac{1}{8}\rho g H_{rms}^2 C_g$$

$$F_{stab} = \frac{1}{8}\rho g\left(\left(1-\alpha\right)H_n^2 + \alpha\Gamma^2 d^2\right)C_g$$

Mean cross-shore current (undertow)



Undertow model by Rattanapitikon and Shibayama (2000)

$$U_m = k_1 \frac{BgH^2}{Cd_t} + k_2 \frac{BCH}{d_t}$$

monochromatic waves

Stoke’s drift **wave breaking**

$$U_m = k_1 \frac{BgH_{rms}^2}{Cd_t} + k_2 \frac{BCH_{mean}}{d_t}\alpha$$

random waves (Larson et al., 2015)

Bed Shear Stresses

Shear stresses depend on friction factors determined by bed roughness arising from:

- Skin friction ($k_{s,g}$) → sediment grain size d_{50}
- Bed forms ($k_{s,r}$) →  
- Sediment transport motion ($k_{s,sf}$)

The bed shear is calculated from (for currents, waves, and combined) (Soulsby, 1997):

$$\tau_b = \frac{1}{2}\rho f U^2$$

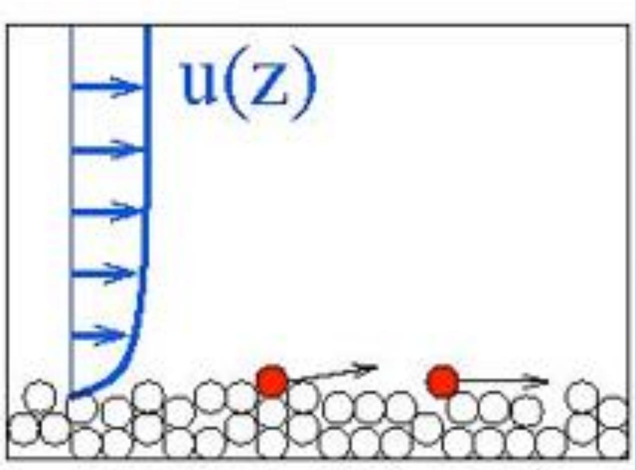
Roughnesses f_c and f_w for a current and waves respectively.
The friction factor (f_{cw}) is weighted according to f_c and f_w.

Bed load transport

Contributions from wave asymmetry (onshore) and undertow (offshore), the generalized formula developed by Larson et al. (2015).

Bed load transport due to wave asymmetry

$$q_{ba} = a_w \sqrt{\frac{f_w}{2}} d_{50} \hat{u} K_a \theta_{cw,m} \exp\left(-b \frac{\theta_{cr}}{\theta_{cw}} \right)$$



Bed load transport due to undertow

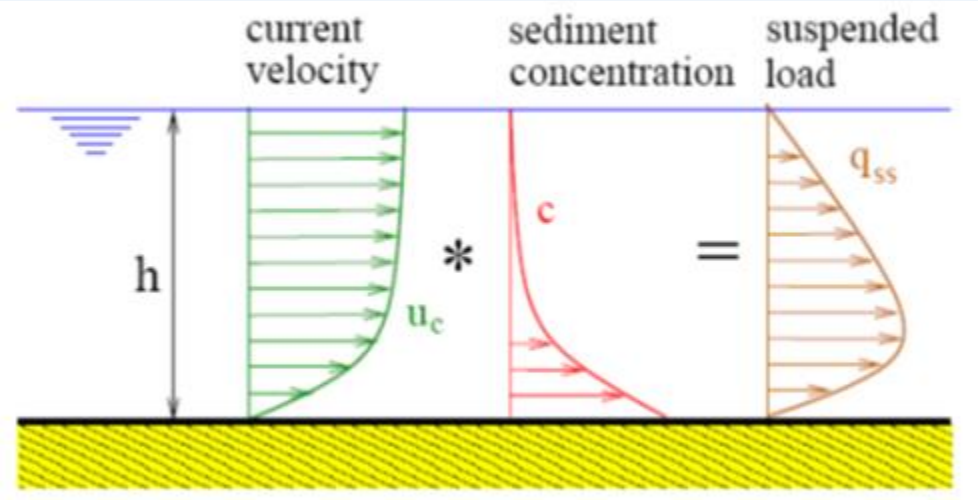
$$q_{bu} = a_c \sqrt{\frac{f_c}{2}} d_{50} U_m \theta_{cw,m} \exp\left(-b \frac{\theta_{cr}}{\theta_{cw}} \right)$$

Suspended load transport

The expressions are given in Camenen and Larson (2008)

From bed to trough level (offshore):

$$q_{su} = \int_0^{d_t} U_m c_R \exp\left(-\frac{w_s}{\varepsilon} z\right) dz = \frac{U_m c_R \varepsilon}{w_s}\left(1 - \exp\left(-\frac{w_s}{\varepsilon} d_t\right)\right)$$



From trough to crest level (onshore):

$$q_{sb} = \int_{d_t}^{d_c} U_b c_R \exp\left(-\frac{w_s}{\varepsilon} z\right) dz = \frac{U_b c_R \varepsilon}{w_s} 2\sinh\left(\frac{H w_s}{2\varepsilon}\right) \exp\left(-\frac{w_s h}{\varepsilon}\right)$$

The net transport due to suspended load is q_{su} - q_{sb}

Swash zone transport

The net sediment transport in the swash zone is given by Larson et al. (2004):

$$q_{bs} = K_c \frac{\tan\phi_m}{\tan^2\phi_m - (dh/dx)^2} \frac{u_o^3}{g} \left(\frac{dh}{dx} - \tan\beta_e \right) \frac{t_o}{T}$$

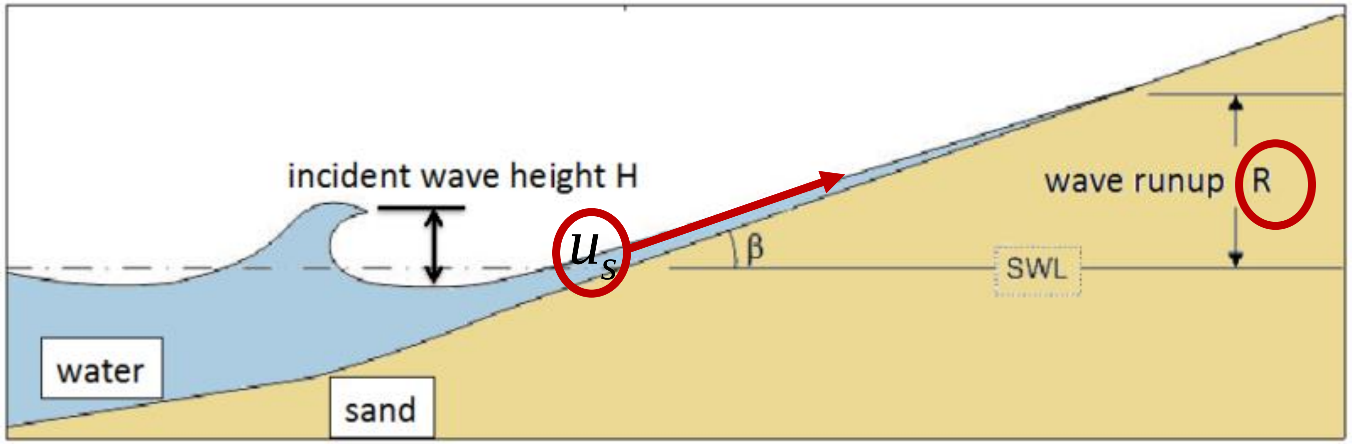
Self-similar velocity variation:

$$u/u_o = \Gamma\left((t - t_s)/t_o\right)$$

Ballistics theory is employed to determine the velocity and duration

$$u_o/u_s = \sqrt{1 - h/R}$$

$$t_o/T_s = \sqrt{1 - h/R}$$



Influence of Long Waves on Swash-Zone Transport

The effects of long waves are described through an enhanced runup height obtained based on a probabilistic approach:

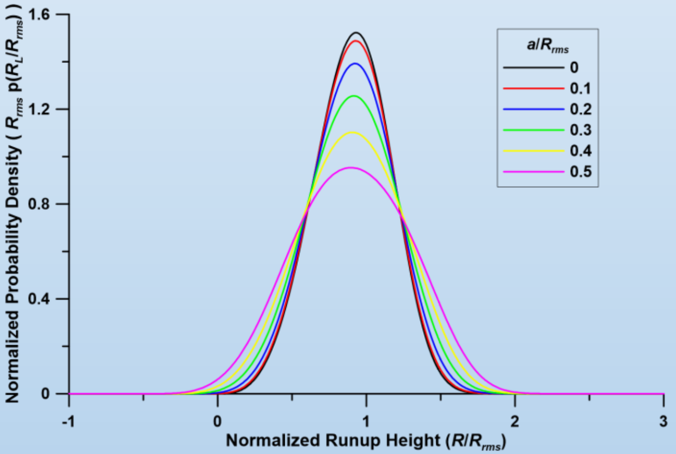
- **pdf for runup height (R) based on a transformed Rayleigh distribution (Hunt formula)**
- **pdf for water elevation at shoreline (η) uniform with a constant amplitude (*a*)**

Combined pdf for $R_L = R + \eta$:

$$p_{R_L}(R_L)=\frac{1}{2a}\left(1-\exp\left(-\frac{(R_L+a)^4}{R_{rms}^4}\right)\right) \qquad -a \le R_L \le a$$

$$p_{R_L}(R_L)=\frac{1}{2a}\left(\exp\left(-\frac{(R_L-a)^4}{R_{rms}^4}\right)-\exp\left(-\frac{(R_L+a)^4}{R_{rms}^4}\right)\right) \qquad R_L > a$$

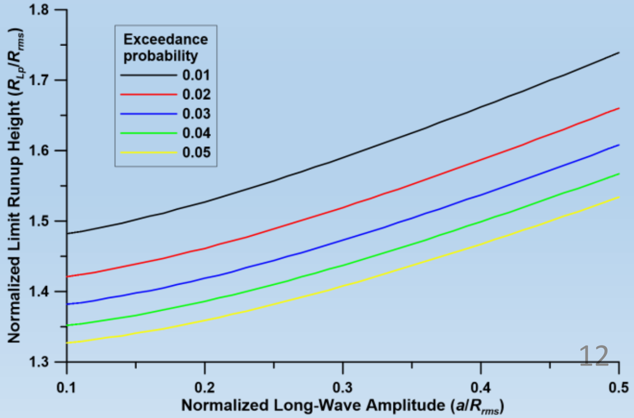
Combined pdf for different a/R_{rms}



Limit R_{Lp} for certain exceedance probability (p):

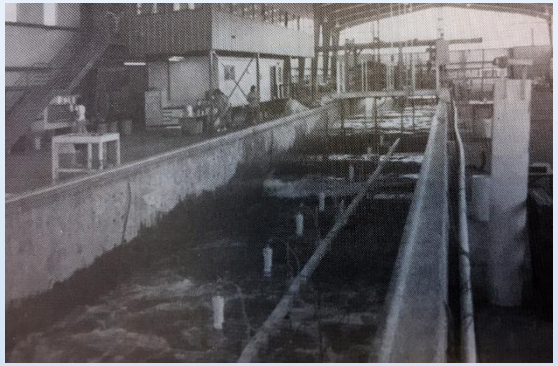
$$\frac{R_{rms}}{8a}\left(\Gamma\left(\frac{1}{4},\frac{(R_{Lp}-a)^4}{R_{rms}^4}\right)-\Gamma\left(\frac{1}{4},\frac{(R_{Lp}+a)^4}{R_{rms}^4}\right)\right)=p$$

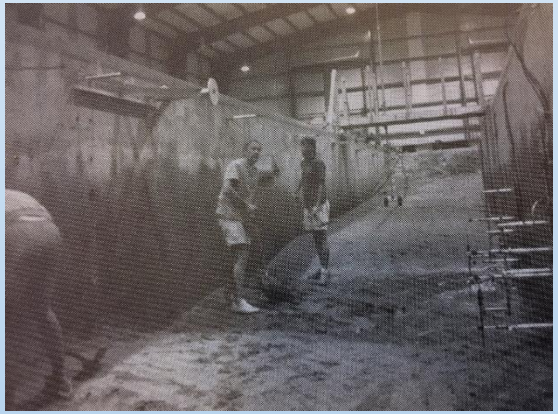
R_{Lp}/R_{rms} versus a/R_{rms} for different p



SUPERTANK data collection project

(Kraus and Smith, 1994)





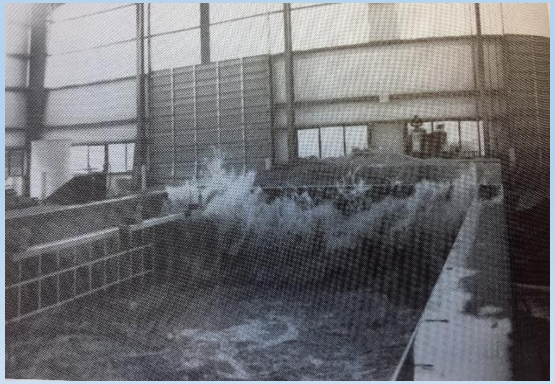


Table 1-1
Summary of SUPERTANK Tests

Test Number	Description	Date	Representative Significant Wave Height, m	Representative Significant Wave Period, sec
ST_10	Erosion toward equilibrium, random waves	8/05 – 8/09	0.8	3.0
ST_20	Acoustic profiler tests (random, monochromatic)	8/11 – 8/13	0.2-0.8	8.0-3.0
ST_30	Accretion toward equilibrium, random waves	8/14 – 8/16	0.4	8.0
ST_40	Dedicated hydrodynamics	8/19 – 8/21	0.2-0.8	8.0-3.0
ST_50	Dune erosion, Test 1 of 2	8/22	0.5-0.8	6.0-3.0
ST_60	Dune erosion, Test 2 of 2	8/23	0.5-0.7	6.0-3.0
ST_70	Seawall, Test 1 of 3	8/26	0.7-1.0	4.5
ST_80	Seawall, Test 2 of 3	8/27	0.7	4.5
ST_90	Berm flooding, Test 1 of 2	8/28 a.m.	0.7	3.0
ST_A0	Foredune erosion	8/28 p.m.	0.7	3.0
ST_B0	Dedicated suspended sediment	8/29 – 8/30	0.3-1.0	10.-3.0
ST_C0	Seawall, Test 3 of 3	9/02	0.4-0.8	8.0-3.0
ST_D0	Berm flooding, Test 2 of 2	9/03 a.m.	0.7	3.0
ST_E0	Laser Doppler velocimeter, Test 1 of 2	9/03 p.m.	0.2-0.8	3.0
ST_F0	Laser Doppler velocimeter, Test 2 of 2	9/04 a.m.	0.2-0.7	8.0
ST_G0	Erosion toward equilibrium, mono. waves	9/04 p.m.	0.8	3.0
ST_H0	Erosion, transition toward accretion, mono. waves	9/05 a.m.	0.5-0.8	4.5-3.0
ST_I0	Accretion toward equilibrium, mono. waves	9/05 – 9/06	0.5	8.0
ST_J0	Narrow-crested offshore mound	9/09 – 9/11	0.5-0.7	8.0-3.0
ST_K0	Broad-crested offshore mound	9/12 – 9/13	0.5-0.7	8.0-3.0

Model simulations

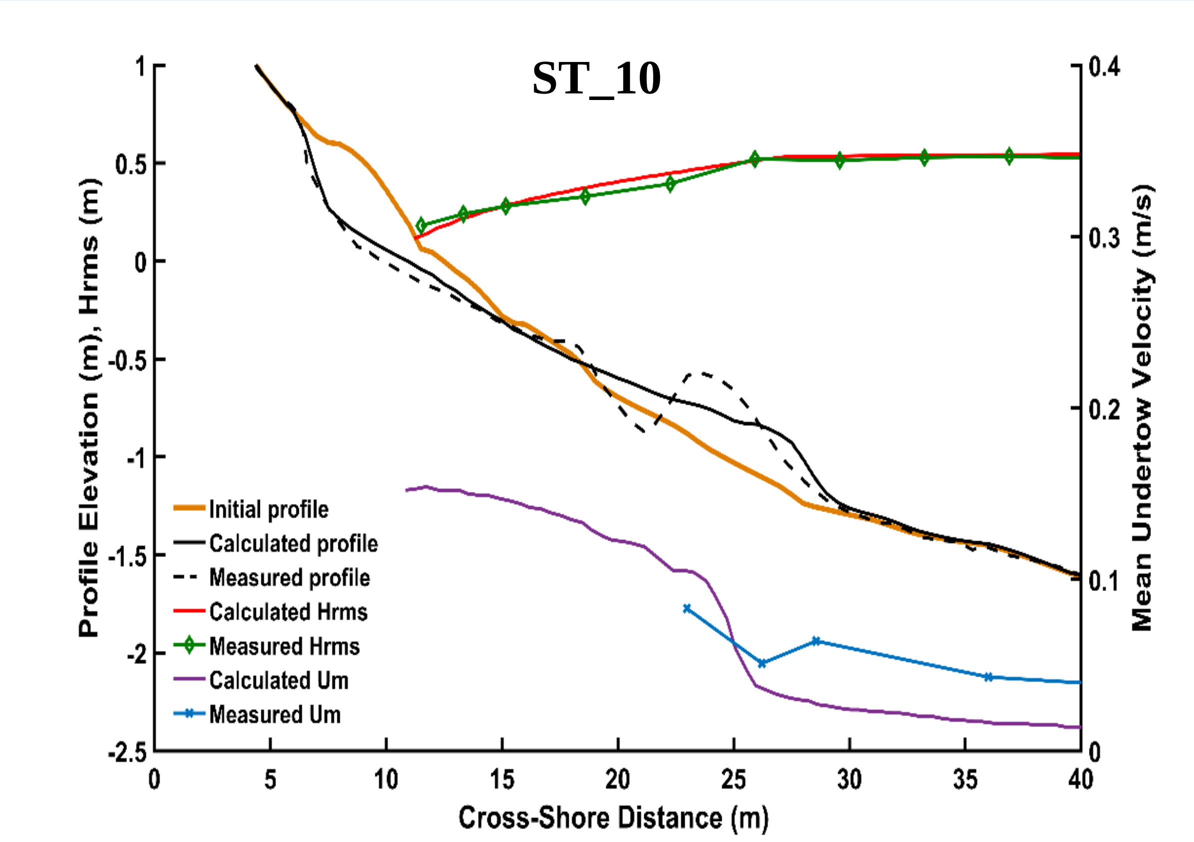
The computational region: 60 m
Grid size Δx : 0.5 m
Time step Δt : 60 s.
The still-water level: 3.0 m
Median grain size D_{50}: 0.22 mm.

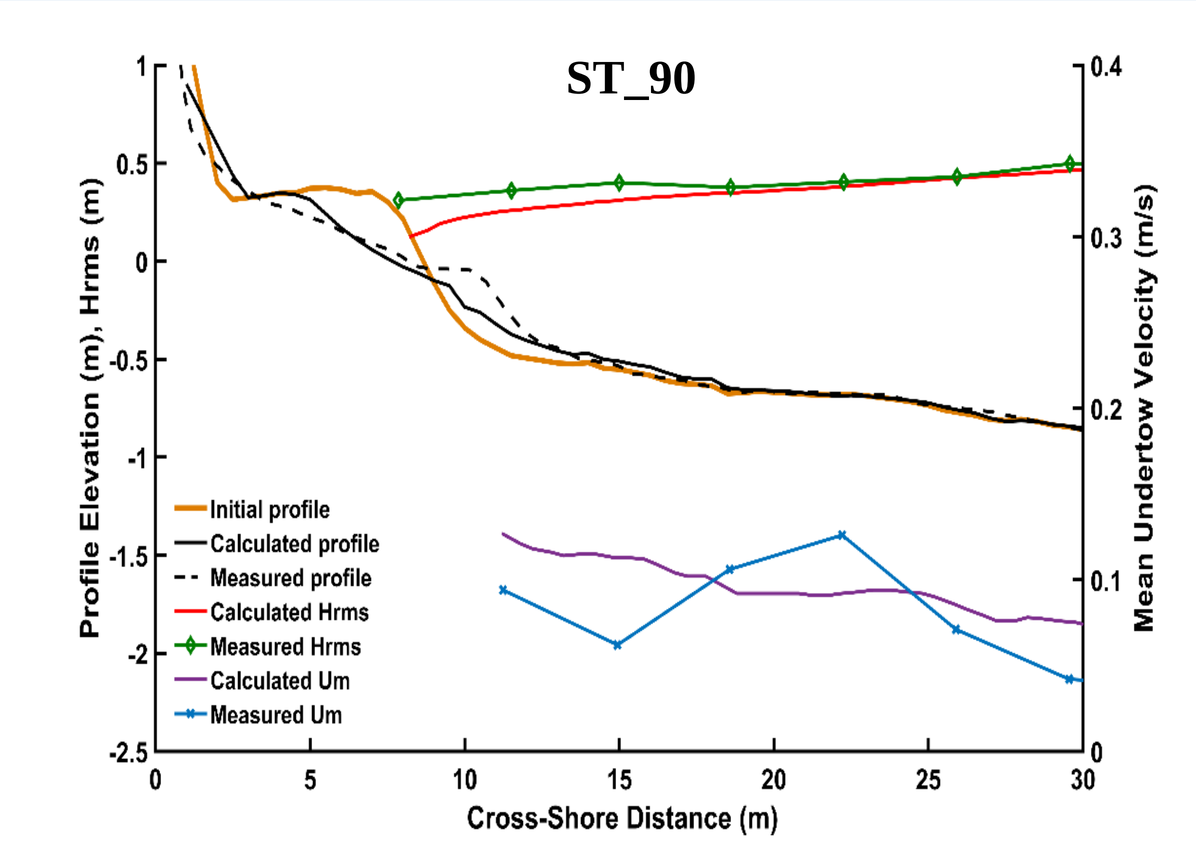
Calibrated coefficients:

- related to sediment transport
- the effects of long waves

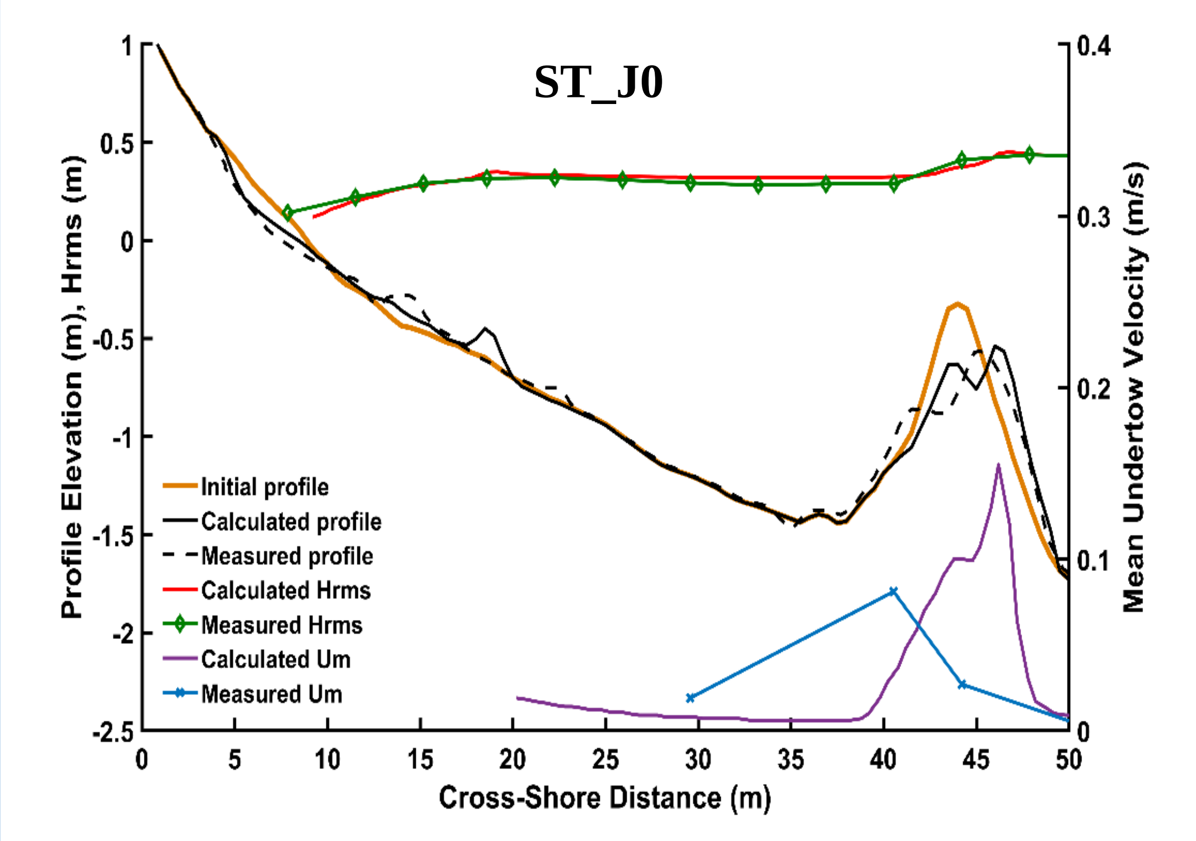
Case	Rms wave height (m)	Mean wave period (s)	Duration (min)
ST_10	0.50-0.81	2.5-3.1	270
ST_90	0.48-0.53	2.4-2.5	50
ST_J0	0.45-0.46	2.4-2.5	150
ST_K0	0.46-0.47	2.5	220

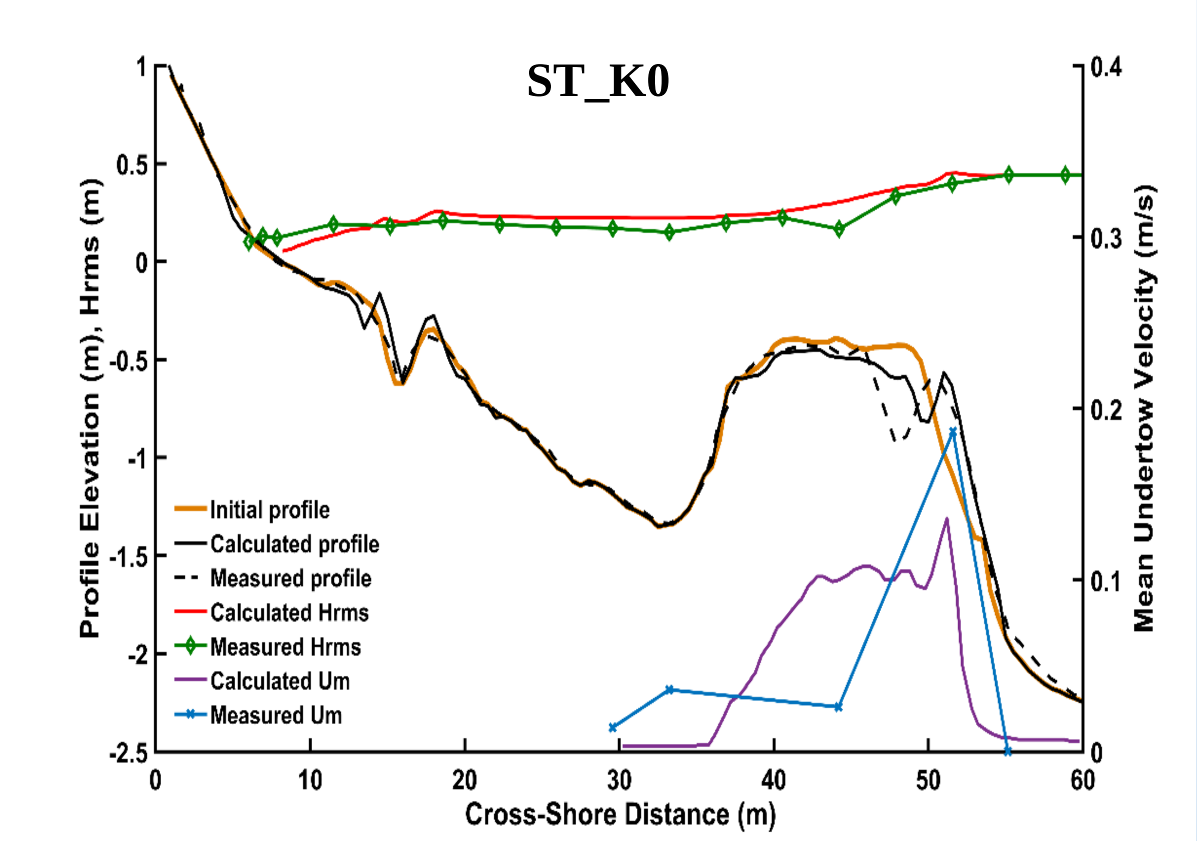
Model simulations





Model simulations





Model simulations

Model agreement with data is described by the rms error (RMSE) and the Brier Skill Score (BSS)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_{mi} - y_{ci})^2}{n}}$$

$$BSS = 1 - \left[\left(\frac{\sum_{i=1}^{n}\left(|y_{ci} - y_{mi}| - \Delta y_m\right)^2}{n} \right) \Big/ \left(\frac{\sum_{i=1}^{n}(y_{0i} - y_{mi})^2}{n} \right) \right]$$

BSS	Qualification
1.0-0.8	Excellent
0.8-0.6	Good
0.6-0.3	Reasonable
0.3-0	Poor
<0	Bad

Case	RMSE	BSS
ST_10	0.058	0.841
ST_90	0.044	0.779
ST_J0	0.062	0.689
ST_K0	0.073	0.622

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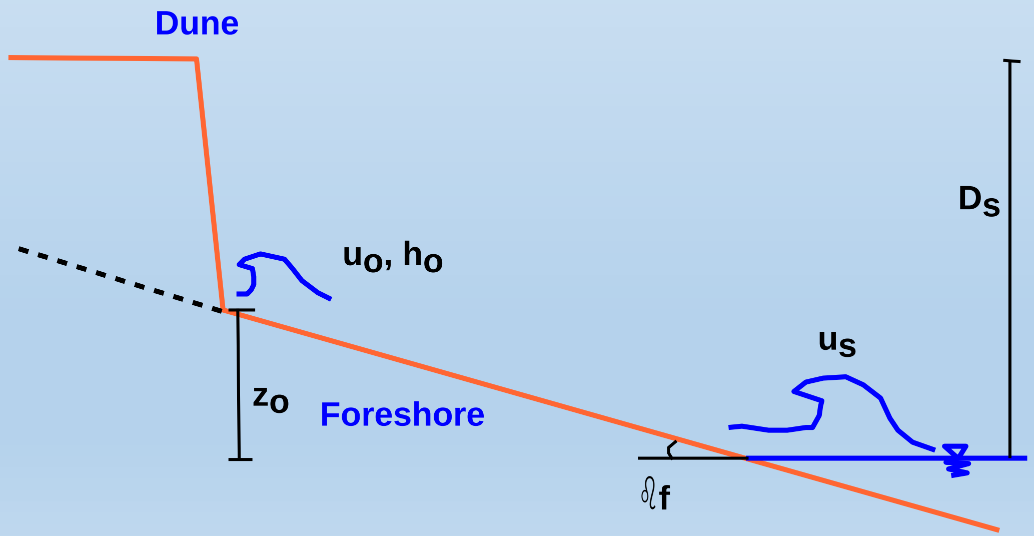
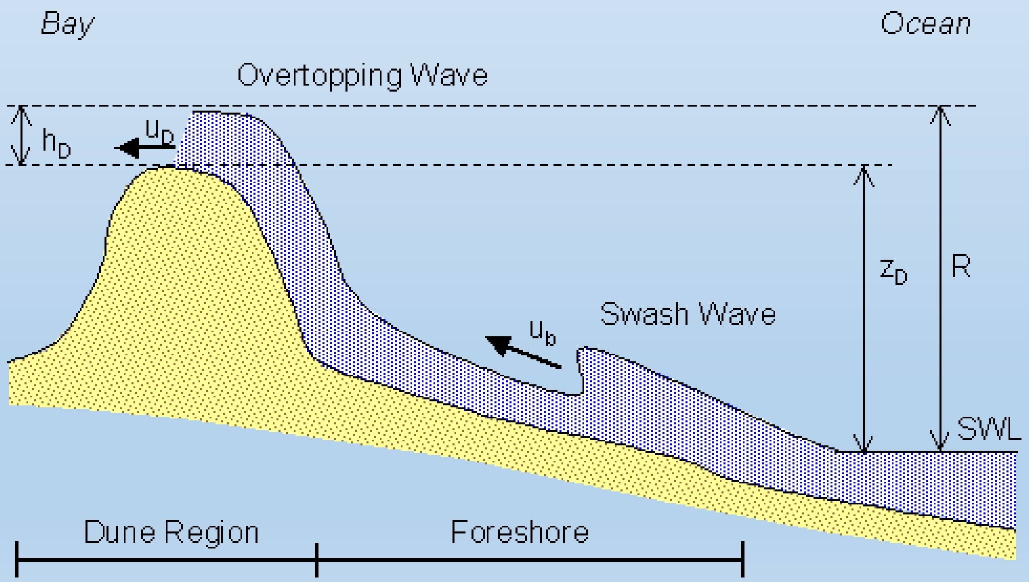
Further developments

- Include dune erosion and overwash
- Improve description of long wave effects
- Include other transport mechanisms
- Validate with field data





Conclusions

- **A numerical model of beach profile evolution with emphasis on describing subaerial change was developed.**
- **Simulations were performed for a wide range of experimental cases from the SUPERTANK data collection project to validate the model.**
- **The results obtained by the model are in good agreement with the measured data indicating that the model is robust and reliable in simulating beach profile evolution for the cases studied.**

❖ **Dune erosion and overwash should be included in the model**

❖ **Extensive model validation with field data is required**

❖ **The description of long waves and their effects on profile evolution needs further consideration**

Thank you!