Ocean Sciences 2020, San Diego

Effects of Wave Breaking Formulations and Wave Nonlinearity on XBeach Performance for Onshore and Offshore Sediment Transport Event

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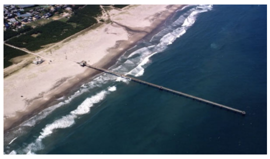

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Motivation

- Sediments are dynamically transported in on-offshore directions in the coastal area, especially in the foreshore and nearshore zones. Managing both types of sediment transport is important for coastal problems and also for recreational and leisure activities.
- Therefore, estimating the beach profile change of these zones are of paramount importance for disaster prevention for natural catastrophic events.
- Several process-based beach profile evolution models have been proposed, including, Cshore, XBeach, etc. While there is no universally accepted model.

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XBeach model

- The XBeach model predicts coastal morphological response due to the time-varying wave and water level conditions.
- As an open source model, XBeach is under continuous development, including numerical schemes for swash zone dynamics (Roelvink et al., 2018), dune erosion events, and overwash.
- In summary, there has been extensive use of XBeach for cross-shore sediment transport under a range of time scales and morphologies. However, a fair amount of tuning is required (e.g., Palmsten and Splinter, 2016).

	XBeach model evaluation								Zone			Comparison										
	2018/6/15								Fore	Near	Bar-	offshore										
	Autors	Year	Lab/Field		Qon/Qoff	Version	dis	par	dune	berm	oute	profil	WL,	Hs	veloci	volu	run	grou	over	powe	comments	title
1	Roelvink et al.	2009	Lab/Field	Maryland, US	Qoff	1D, 2D	x	x	x	x		x	x	x	x	x					dune	Modelli
2	Williams et al.	2012	Lab/Field	UK	Qoff	2D	x	x	x	x		x						x			overwash	Modelli
3	Jamal et al.	2014	Lab		Qon	1D	x		x	x		x			x only cal.						berm	Modelli
4	Berard et al.	2017	Lab		Qoff	1D			x	x		x	x		x	x					dune	Evaluat
5	Elsayed et al.	2017	Lab/Field	Santa Rosa	Qoff	2D	x	x	x			x				x					dune	Effect
6	Do et al.	2018	Lab	US	Qoff	1D	x	x	x			x				x					dune	Numer
7	McCall et al.	2010	Field	Santa Rosa	Qon	2D	x	x	x			x		x							overwash	Two-d
8	Lindemer et al.	2010	Field	US	Qon/off	2D	x		x	x		x				x					overwash	Numer
9	Vousdoukas et al.	2011	Field	Poltugal	Qoff	1D	x	x	x	x		x									beach erosion	Modelli
10	Bolle et al.	2011	Field	Belgium	Qoff	1D, 2D			x	x		x									beach erosion	APPLIC
11	Alegria-Arzaburu et al.	2011	Field	UK	Qoff	1D	x		x	x		x									overwash	APPLIC
12	Splinter et al.	2012	Field	Australia	Qoff	2D	x	x	x			x				x					dune	Modelin
13	Pender et al.	2013	Field	Australia	Qon/off	2D	x	x		x		x									swash	A statis
14	Armaroli et al.	2013	Field	Italy	Qoff	2D	x	x	x	x		x									dune	Beach
15	Cox et al.	2013	Field	US	–	2D		x		x										x	swash	An em
16	Callaghan et al.	2013	Field	Australia	Qoff		x	x	x			x				x					beach erosion	Probab
17	Verheyen et al.	2014	Field	Ghana	Qoff	1D	x	x	x	x		x									dune	Mediun
18	Stockdon et al.	2014	Field	SandyDuck	Qoff	1D, 2D			x				x				x				runup	Evaluat
19	Faraci et al.	2014	Field	Italy	Qoff	1D			x	x		x									swash&surf	Bottom
20	Dissanayake et al.	2014	Field	UK	Qoff	2D	x	x	x	x						x					dune	Modelli
21	Splinter et al.	2014	Field	Gold Coast	Qoff	V18		12	x			x				x					dune	A relat
22	Williams et al.	2015	Field	Ireland	Qon/off	1D, 2D			x			x				x					overwash	Modelli
23	Winter et al.	2015	Field	Netherlands	Qoff	2D, V19	x		x			x				x					dune	Obser
24	Winter et al.	2017	Field	Dutch	Qoff	1D, V19		22	x	x		x	x		x only cal.						dune	Sensiti
25	Roelvink et al.	2018	Field	SandyDuck	–	2D				x	x		x		x		x		x			Improv

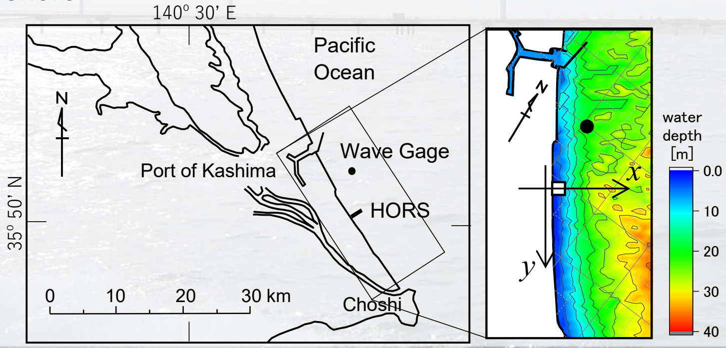
Objective

In this research, cross-shore sediment transport events are carefully selected from the field data.

Investigate the effect of wave dissipation model on spatial distribution of wave height wave, and the effect of wave nonlinearity on beach profile change

Hasaki data analysis: Outline of the field observation site /Hasaki Oceanographical Research Station (HORS), PARI

- Hasaki coast is a part of Kashima-nada coast facing the Pacific Ocean and about 7 km south from the Port of Kashima.
- The averaged sediment diameter around the site is approximately **0.18 mm**, and tidal range is around **1.8 m**.
- HORS has a 427-m-long pier and located perpendicular to the shore.



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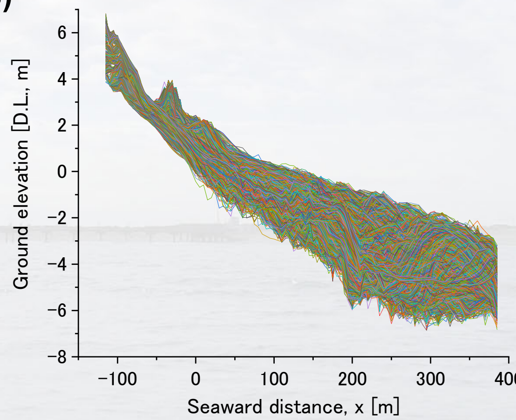
Select benchmark data of cross-shore sediment transport

- **Data duration: 1987.1-2003.12 (17 years)**

- **Beach profile**
  - **--- [every weekdays]**
- Wave (H, T) at *x* = 380 m, 145 m, 40 m
  - --- [hourly]
- Current (10 locations until x385m)
  - --- [every weekdays]
- Tide (Observed and estimated)
  - --- [hourly]
- Wind
  - --- [hourly]



Beach profile from 1987.1 to 2003.12

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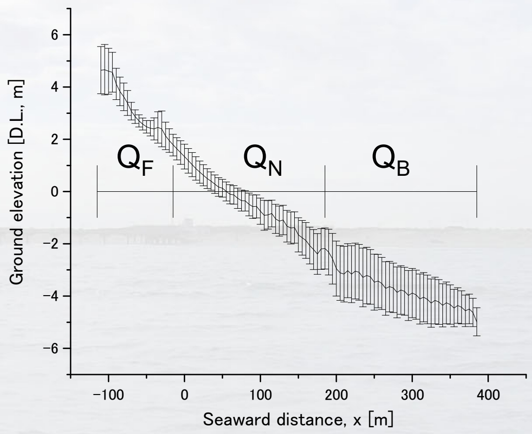
Calculation of volume change [m^3/m/m]

- Volume difference is calculated at different three sections

- Q_T (Total): x = -115 ~385m
- Q_F (Foreshore): x = -115 ~-20m
- Q_N (Nearshore): x = -15 ~180m
- Q_B (Bar-offshore): x = 185 ~385m

Q is calculated using 3days difference
= profile(t)-profile(t-3)
(from 1987/1/4 to 2003/12/31= total 6206)



Averaged beach profile and SD

Selection of cross-shore sediment transport events

<Onshore transport>	<Offshore transport>
• Total $\Sigma Q_N > 0$ → 3318cases	• Total $\Sigma Q_N < 0$ → 2888cases
• $\Sigma Qt/\Sigma\|Qt\| < 0.10$, $\Sigma Qn > 0$ → 470cases	• $\Sigma Qt/\Sigma\|Qt\| < 0.10$, $\Sigma Qn < 0$ → 605cases
• Ave 4days(|V145m|) < 0.25m/s → 285cases	• Ave 4days(|V145m|) < 0.25m/s → 346cases
• $\Sigma Q_N > 2$ → 69cases	• $\Sigma Q_N < -2$ → 101cases
• Full 4days observe data of |V145m| → **11cases**	• Full 4days observed data of |V145m| → **20cases**

Focus on nearshore sediment dynamics

Sediment dynamics closed in the pier length.

Weak longshore current

Large onshore/offshore sediment transport

The beach profile change of some events are not clear…

Selected cross-shore sediment transport

- Overall, 4 events are selected from 17 years data.

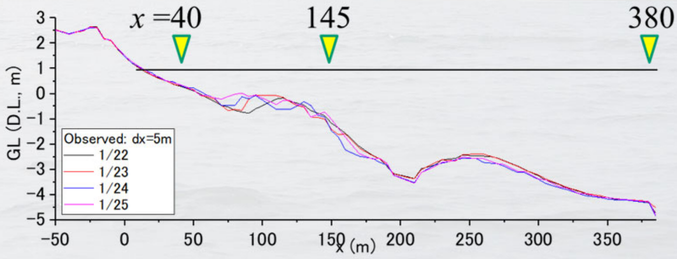
ID	Date		ΣQ_F m²/m	ΣQ_N m²/m	ΣQ_B m²/m	ΣQ_T m²/m	$\frac{\Sigma Q_T}{\Sigma \lvert Q_T \rvert}$	$\langle \lvert v_{145m} \rvert \rangle$ [m/s]	Comments
1	**1996/1/22–24**		**–0.06**	**2.87**	**–2.75**	**0.06**	**0.006**	**0.058**	Onshore
2	1999/1/4–6		0.17	2.28	–2.82	–0.37	–0.020	0.079	On-offshore
3	2001/2/5–7		–0.23	–2.78	4.35	1.34	0.009	0.060	On-offshore
4	1990/10/15–17		0.10	–9.70	12.98	0.76	0.032	0.108	Offshore
Full data	1987/1/1– 2003/12/31	**Ave**	**0.012**	**0.0056**	**–0.006**	**0.012**	**0.050**	**0.246**	
		std	0.346	4.44	6.01	8.30	0.415	0.138	
		Max	1.89	23.3	36.89	47.6	0.960	0.963	
		Min	–4.84	–29.3	–52.0	–59.5	–0.980	0.004	

- Effects of wave dissipation models on the spatial and temporal distributions of water level and wave height
- Effects of wave nonlinearity on beach profile change

Effects of wave nonlinearity on the spatial and temporal distributions of wave height

- **Water level**, **wave height**
- Instantaneous spatial output, Time-averaged spatial output, Fixed point output
  → x = 40m, 145m, 380m

XBeach wave input: Jonswap
- H_{mo}, T_p at x =380m
- Wave angle = angle at x =380m
- Morfac= 5 (morphology acceleration parameter)

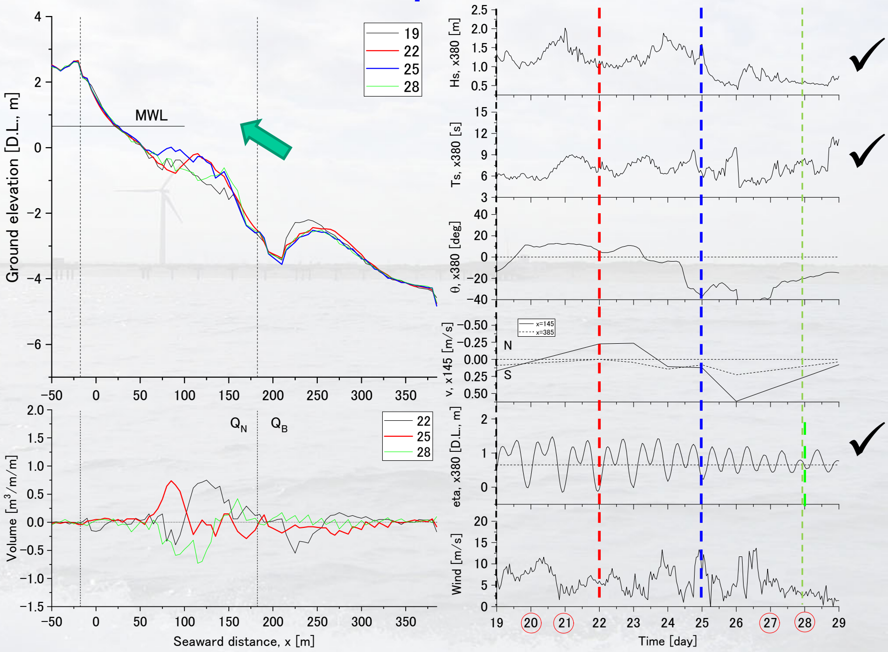


Onshore dominant sediment transport event: ID1

- 1996/1/22-26
- Q_N=2.87

- H: high
- T: const.
- Ave|V|: 0.174m/s
- Tide: Spring→ Neap

Inner bar onshore-ward



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Wave dissipation

- Wave breaking: Dw
- Bottom friction: Df
- Vegetation: Dv

Wave breaking

- Roelvink (1993) [roelvink1]
- Roelvink (1993) extended [roelvink2--- Default]
- Daly et al. (2010) [roelvink_daly]

(keyword: *gamma*). In the formulation for H_{rms} the ρ represents the water density and g the gravitational constant. The total wave energy E_w is calculated by integrating over the wave directional bins.

Roelvink1

α (1.0) …[0.5-2.0]
n (10) …[5-20]
γ (0.55) …[0.4-0.9]

$$\bar{D}_w = 2\frac{\alpha}{T_{rep}} Q_b E_w$$

$$Q_b = 1-\exp\left(-\left(\frac{H_{rms}}{H_{max}}\right)^n\right), \quad H_{rms} = \sqrt{\frac{8E_w}{\rho g}}, \quad H_{max} = \gamma \cdot (h + \delta H_{rms}) \qquad (2.11)$$

Fraction breaking waves

$$E_w(x,y,t) = \int_0^{2\pi} S_w(x,y,t,\theta)\, d\theta$$

In variation of (2.11), one could also use another wave breaking formulation, presented in (2.12). This formulation is somewhat different than the formulation of Roelvink (1993a) and selected using keyword *break=roelvink2*. The main difference with the original formulation is that wave dissipation with *break=roelvink2* is proportional to H^3/h instead of H^2.

Roelvink2

$$\bar{D}_w = 2\frac{\alpha}{T_{rep}} Q_b E_w \frac{H_{rms}}{h} \qquad (2.12)$$

Alternatively the formulation of Daly et al. (2010) states that waves are fully breaking if the wave height exceeds a threshold (γ) and stop breaking if the wave height fall below another threshold (γ_2). This formulation is selected by *break=roelvink_daly* and the second threshold, γ_2, can be set using keyword: *gamma2*.

Roelvink_daly

γ_2 (0.3) …[0-0.5]

$$\begin{cases} Q_b = 1 & if \quad H_{rms} > \gamma h \\ Q_b = 0 & if \quad H_{rms} < \gamma_2 h \end{cases} \qquad (2.13)$$

Reduce wave heights in very shallow water

[XBeach Manual]

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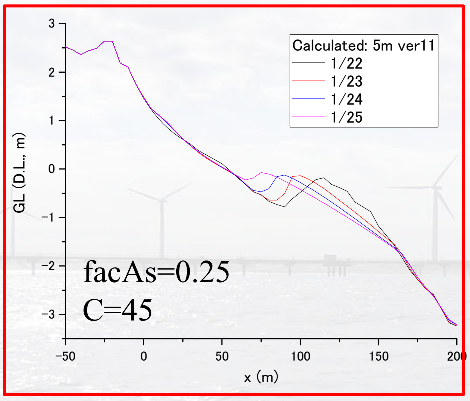
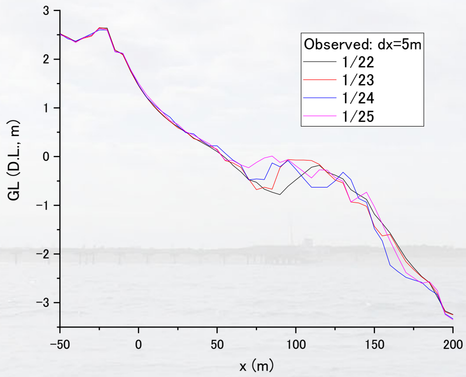
Beach profile change using Roelvink2 (default)





- facAs: 0.25 (default 0.1)
- Chezy paramater: 45 (default 55)
- BSS(x=-15~180) 0.81(Jan23), 0.51(Jan24), 0.51(Jan25)

How about wave transformation??

morphology: $\Delta z = 0.1$

$$BSS = 1 - [\langle(|z_{b,c} - z_{b,m}| - \Delta z_{b,m})^2\rangle / \langle(z_{b,0} - z_{b,m})^2\rangle]$$

van Rijn et al. (2003)

Table 2.2
Qualification of e

Qualification	Morphology; BSS
Excellent	1.0–0.8
Good	0.8–0.6
Reasonable/fair	0.6–0.3
Poor	0.3–0
Bad	<0

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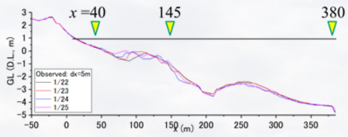
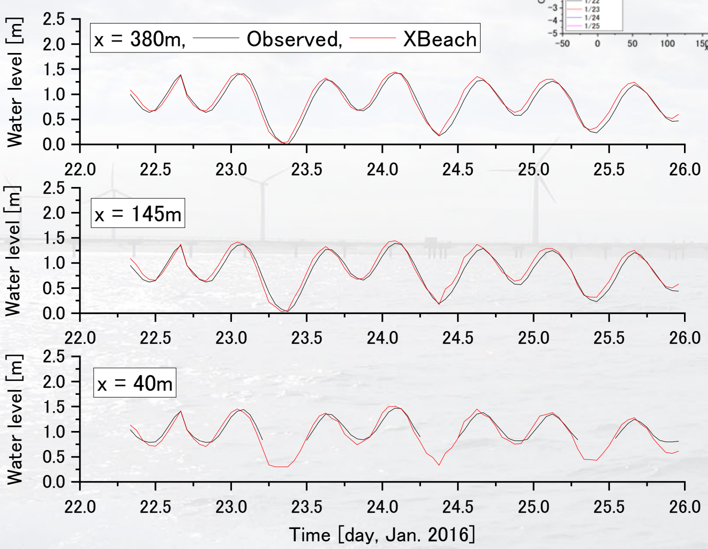
Water level





- RMAE

x =380, 145, 40m
=0.093, 0.100, 0.117 →good-reasonable

wave height: van Rijn et al. (2003)

$$RMAE = \langle |H_c - H_m| - \Delta H_m\rangle / \langle H_m\rangle$$

$\Delta H = 0.0$

Table 2.2
Qualification of error ranges of pro

Qualification	Wave height; RMAE
Excellent	<0.05
Good	0.05–0.1
Reasonable/fair	0.1–0.2
Poor	0.2–0.3
Bad	>0.3

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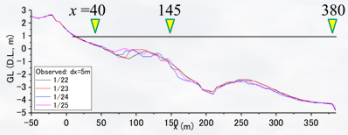
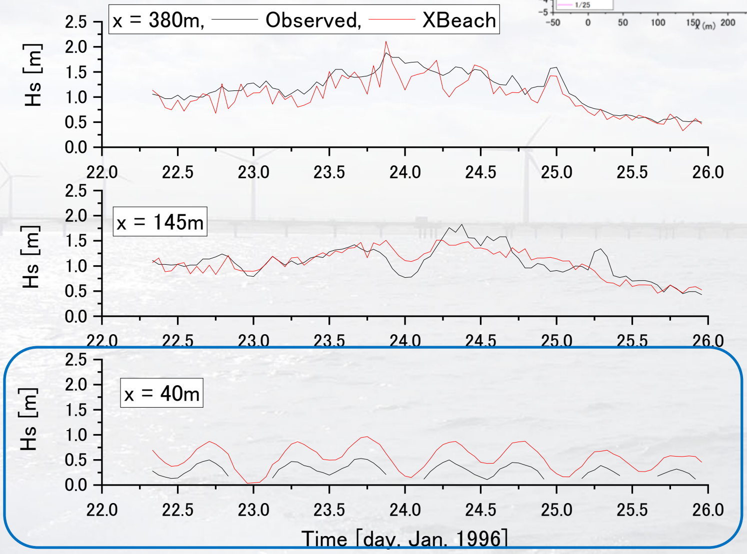
Wave height: hourly Hs





- RMAE

x =380, 145, 40

=0.054, 0.046, 0.70

Overestimated at x =40m

wave height: van Rijn et al. (2003)

$$\mathrm{RMAE} = \langle |H_c - H_m| - \Delta H_m \rangle / \langle H_m \rangle$$

ΔH =0.0

Table 2.2
Qualification of error ranges of pro

Qualification	Wave height; RMAE
Excellent	<0.05
Good	0.05–0.1
Reasonable/fair	0.1–0.2
Poor	0.2–0.3
Bad	>0.3

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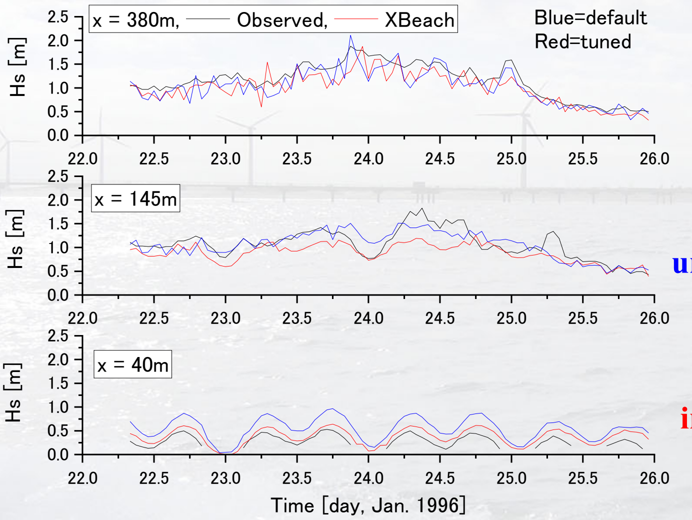
Wave height: roelvink2

Blue: roelvink2(default)
Red: roelvink2(adjusted)
Gamma=0.55 → 0.4



underestimate

improved

- RMAE

x =380, 145, 40m

=0.054, 0.046, 0.70

=0.067, 0.100, 0.123

wave height: van Rijn et al. (2003)

$$\mathrm{RMAE} = \langle |H_c - H_m| - \Delta H_m \rangle / \langle H_m \rangle$$

ΔH =0.1

Table 2.2
Qualification of error ranges of pro

Qualification	Wave height; RMAE
Excellent	<0.05
Good	0.05–0.1
Reasonable/fair	0.1–0.2
Poor	0.2–0.3
Bad	>0.3

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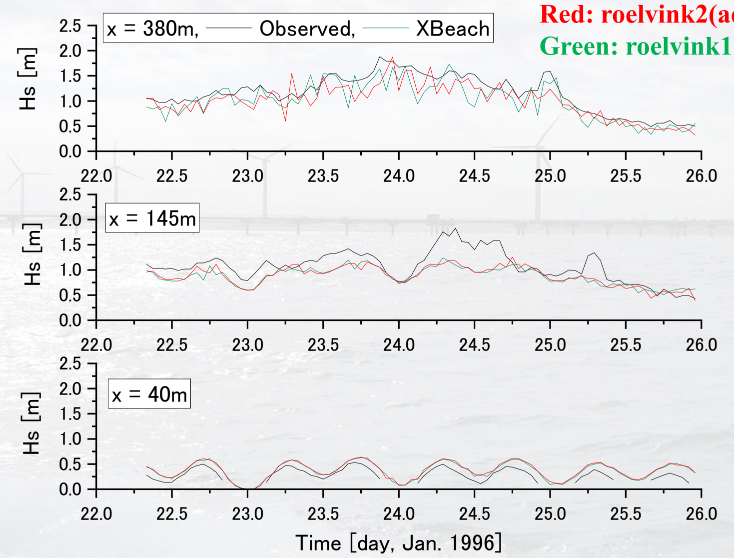
Wave height: roelvink1

(2 trials) Overall: alpha= 1.0, gamma= 0.4, n= 10



Red: roelvink2(adjusted)
Green: roelvink1(adjusted)

- RMAE

x= 380, 145, 40m

= 0.067, 0.100, 0.123

= 0.063, **0.107, 0.093**

Both are almost the same

van Rijn et al. (2003)

wave height:

$$\mathrm{RMAE} = \langle |H_c - H_m| - \Delta H_m \rangle / \langle H_m \rangle$$

Table 2.2 ΔH =0.1

Qualification of error ranges of pro

Qualification	Wave height; RMAE
Excellent	<0.05
Good	0.05–0.1
Reasonable/fair	0.1–0.2
Poor	0.2–0.3
Bad	>0.3

Could not tune the wave height using Roelvink 1 and 2 models

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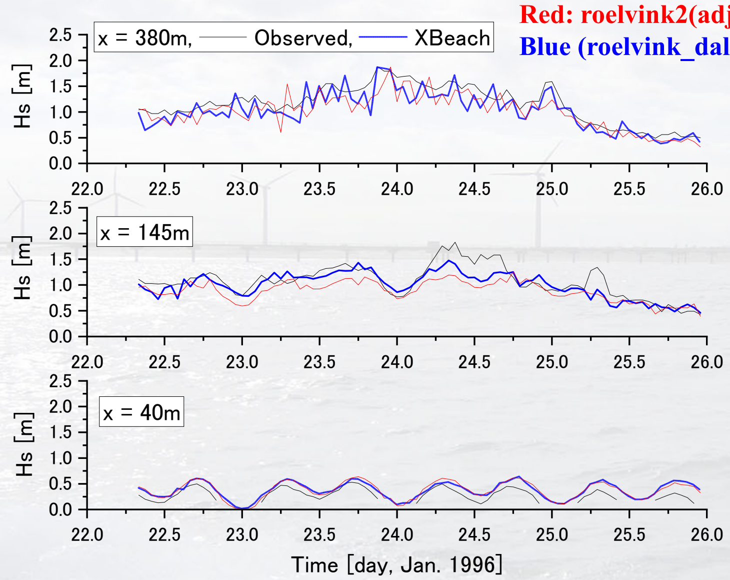
Wave height: roelvink_daly



Red: roelvink2(adjusted),
Blue (roelvink_daly)

- RMAE:

x =380, 145, 40m

= 0.063, 0.107, 0.093

=0.059, **0.034,** 0.058

Better than before

van Rijn et al. (2003)

wave height:

$$\mathrm{RMAE} = \langle |H_c - H_m| - \Delta H_m \rangle / \langle H_m \rangle$$

Table 2.2 ΔH =0.1

Qualification of error ranges of pro

Qualification	Wave height; RMAE
Excellent	<0.05
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Bad	>0.3

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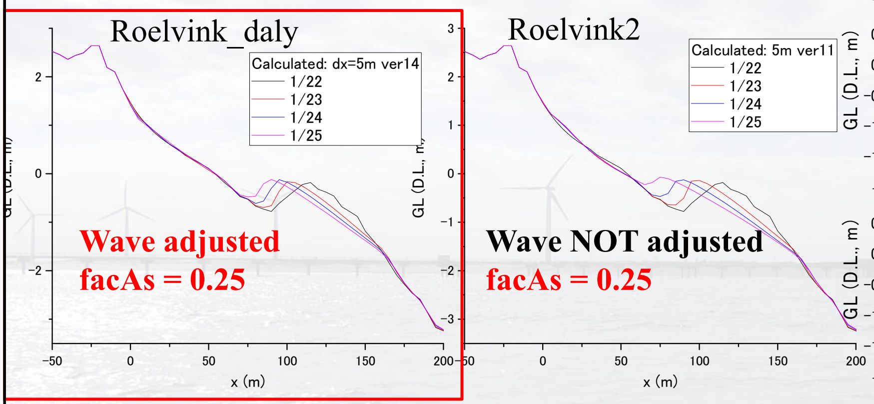
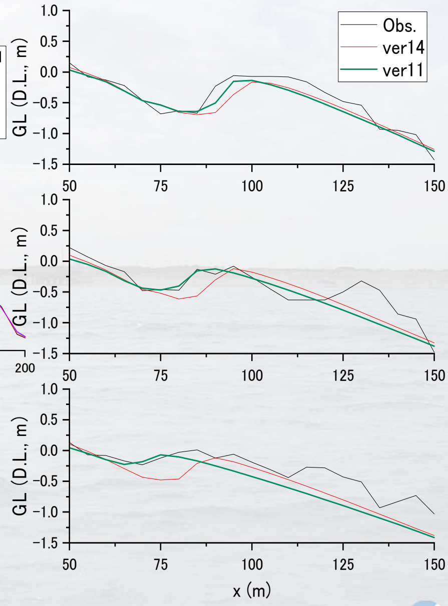
Wave nonlinearity effects on beach profile change





Onshore movement reduced, because of the lower wave height

- BSS(x=-15~180)
- Jan23) 0.71 0.81
- Jan24) 0.53 0.51
- Jan25) 0.59 0.51

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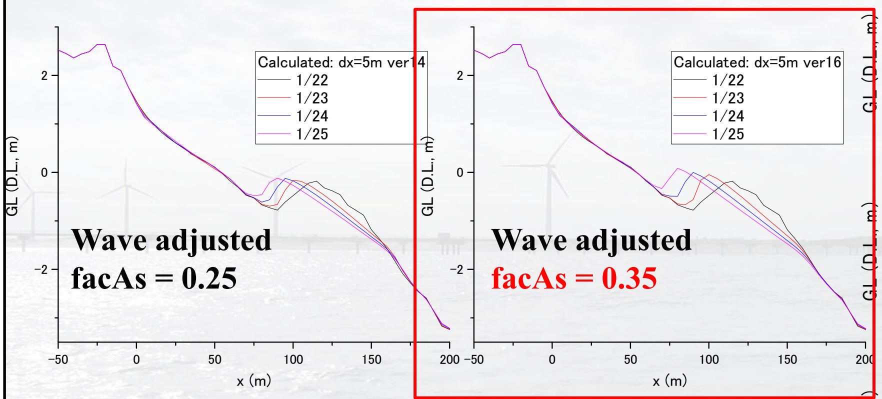
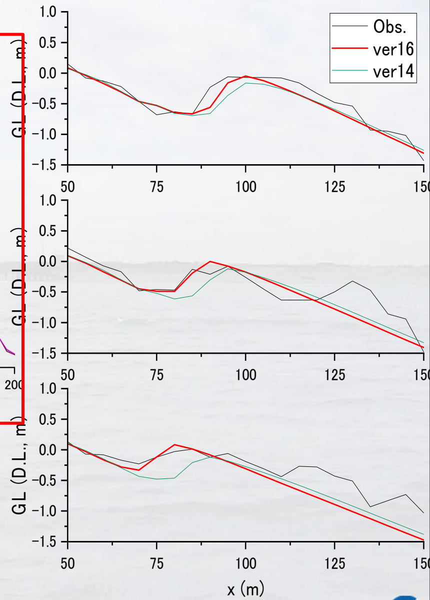
Wave nonlinearity effects on beach profile change





Onshore movement reduced, because of the lower wave height

- BSS(x=-15~180)
- Jan23) 0.78 0.71
- Jan24) 0.58 0.53
- Jan25) 0.52 0.59

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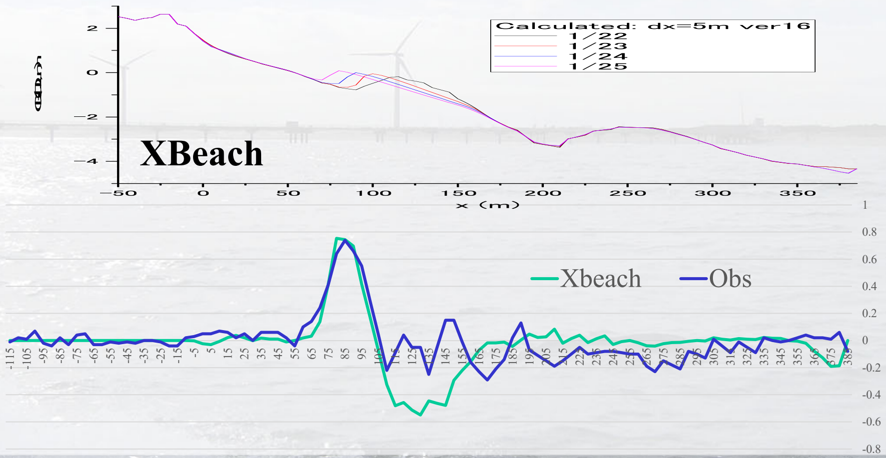
Comparison of volume change

- Inner bar onshore movement is well calculated.
- Inner bar area, erosion is overestimated.



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Summary

- Water levels are well calculated by the XBeach.
- For the wave height, wave dissipation models are not sensitive for bar-offshore and surf zone (x=145m, 380m), but sensitive for nearshore zone (x=40m).
- For the beach profile change, XBeach could tune the model to adjust the profile whether wave formation is calibrated or not.

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