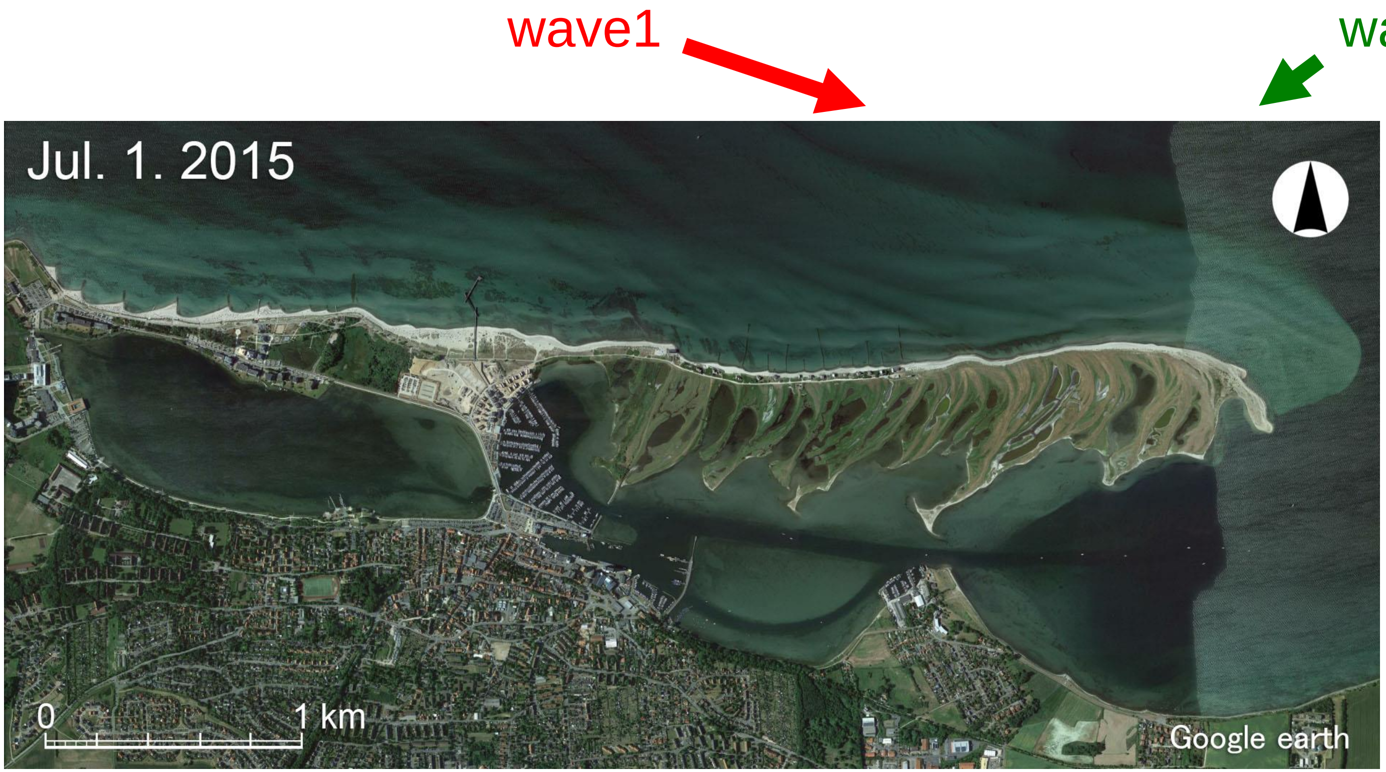
PREDICTION OF FORMATION OF RECURVED SAND SPIT USING BG MODEL

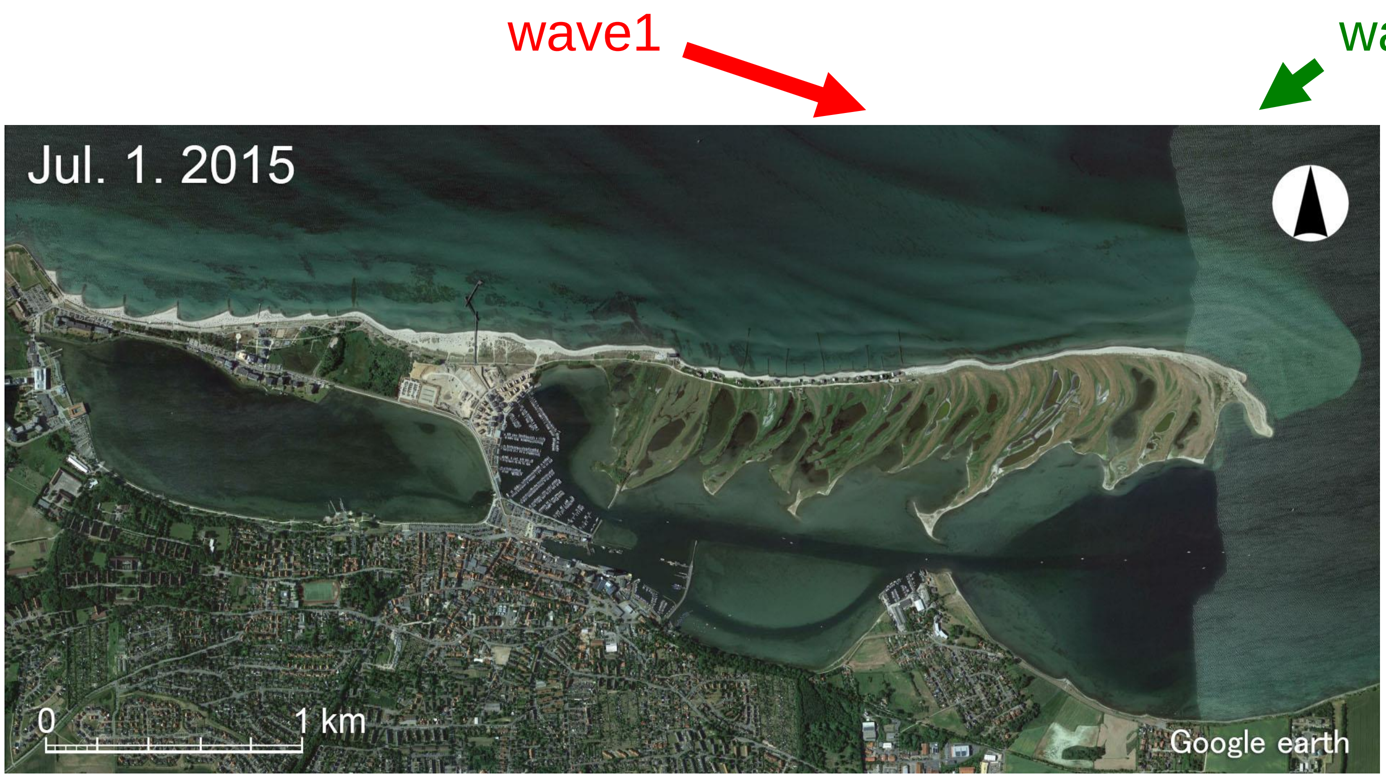
Masumi SERIZAWA Coastal Engineering Laboratory Co., Ltd.
Takaaki UDA Public Works Research Center
Shiho MIYAHARA Coastal Engineering Laboratory Co., Ltd.

INTRODUCTION

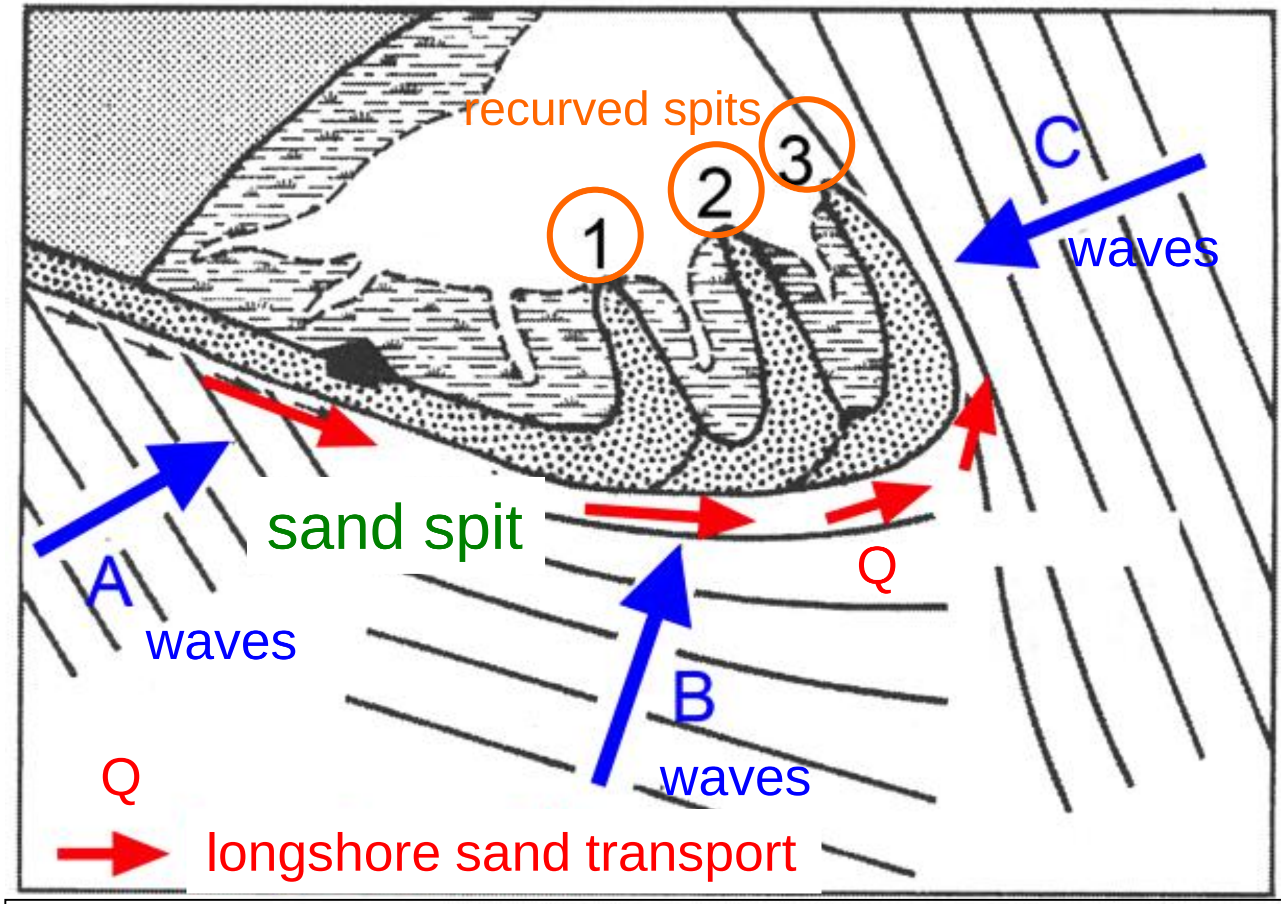
- When waves are obliquely incident at a large angle over 45° with respect to the direction normal to the shoreline, a sand spit can extend at a location with a large change in coastline orientation (Ashton et al., 2001).
- Usually, a single spit extends. However, when two sets of waves arrive from different directions, the sand spit is recurved (Bird, 2008).



- In the recurved spit, the previous shoreline often intersects at an acute angle with the overall elongation direction of the sand spit.



Schematic diagram of development of a recurved sand spit

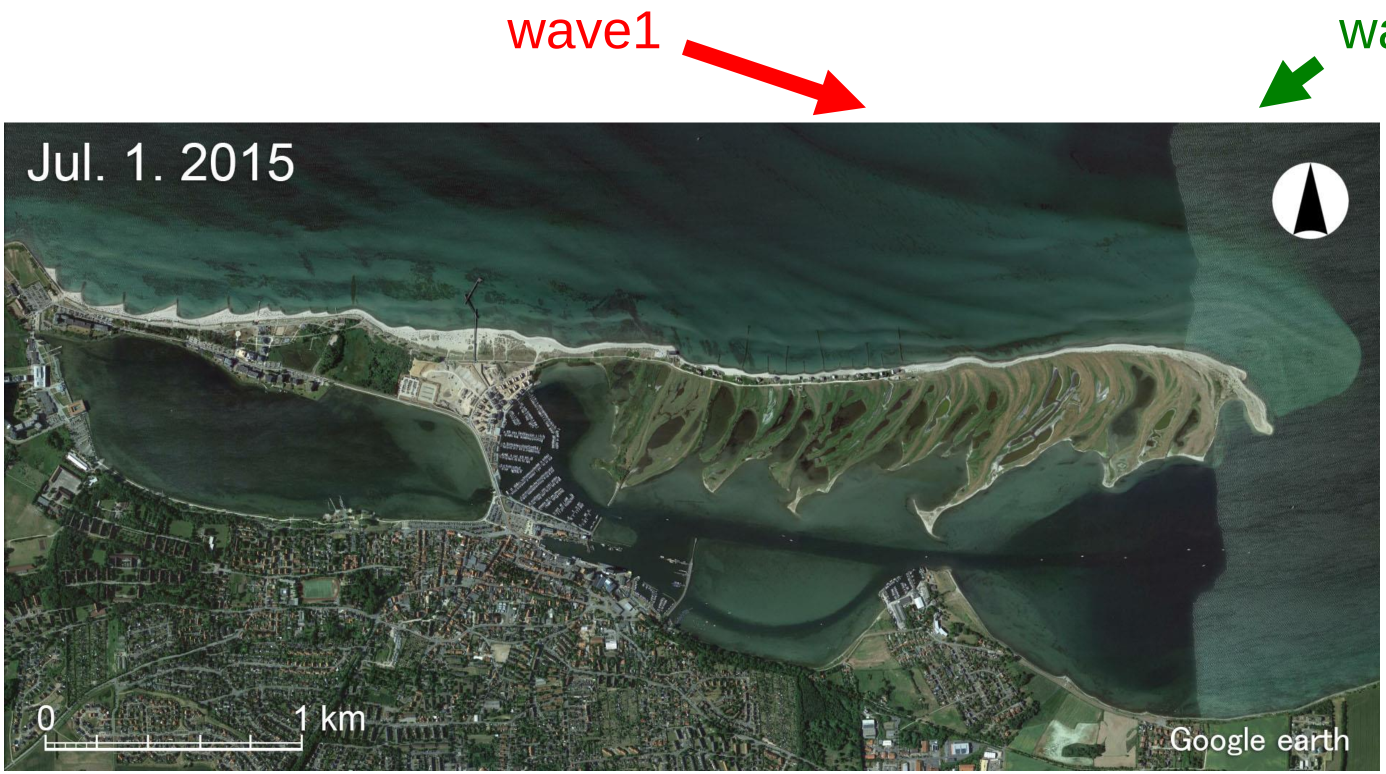


Zenkovich (1967)

- When waves are obliquely incident to the shoreline from directions A and B, longshore sand transport toward the tip of the sand spit arises, as a result, sand spit extends owing to the deposition of littoral sand.
- However, if additional waves arrive from direction C opposing to direction A, a significantly recurved spit may be formed.

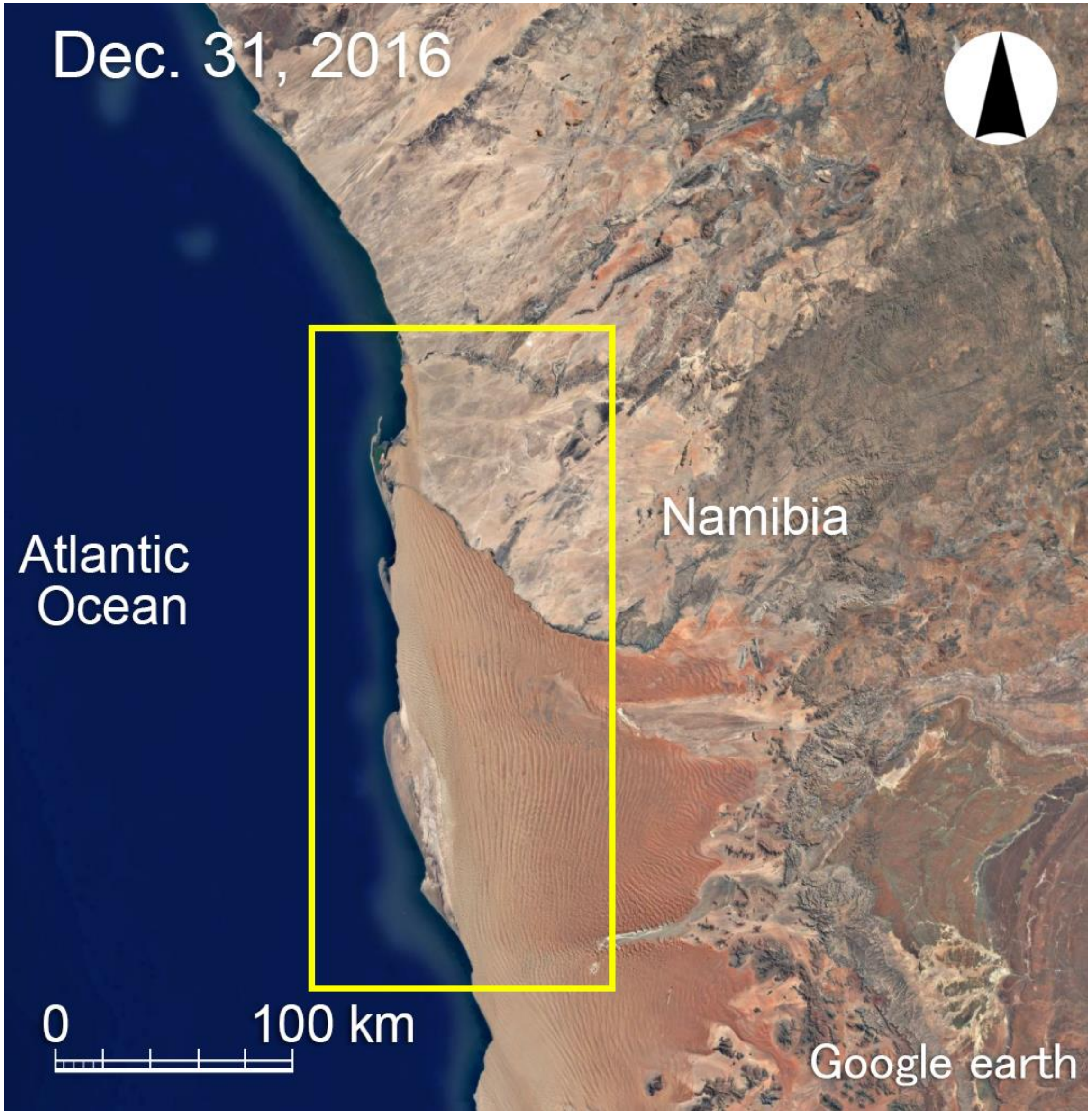
INTRODUCTION

- There are few studies on the prediction of the elongation of the recurved sand spit when waves are incident from different directions.
- In this study, the elongation of a recurved spit was predicted using the BG model (a model for predicting three-dimensional beach changes based on Bagnold’s concept) (Uda et al. 2016).



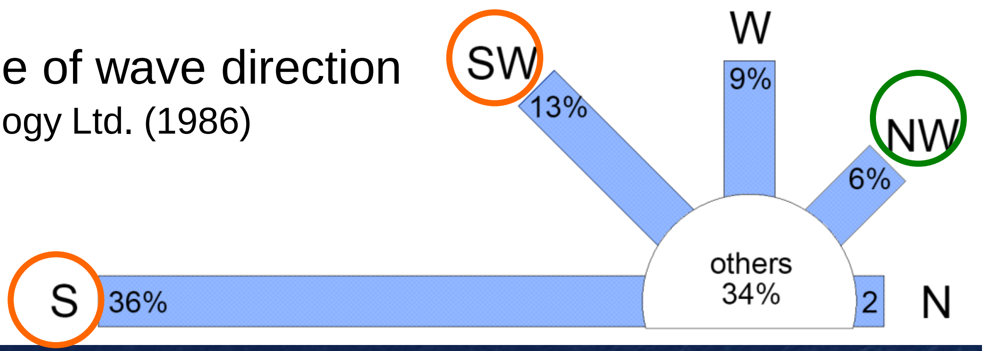
Examples of
Recurved sand spits

Example of recurved sand spit: Namibia

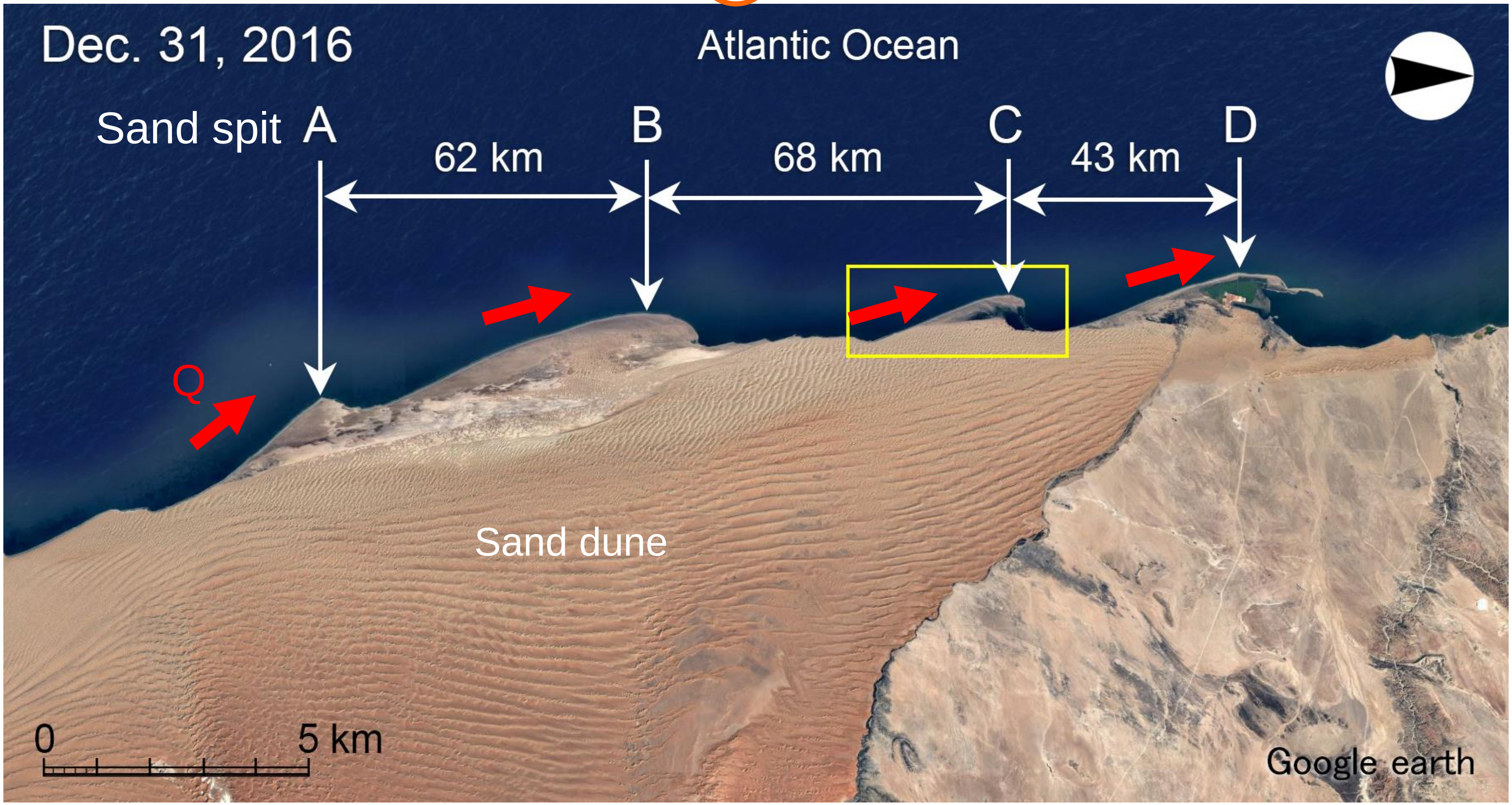


Example of recurved sand spit: Namibia

Probability of occurrence of wave direction
British Maritime Technology Ltd. (1986)



Q
longshore sand transport



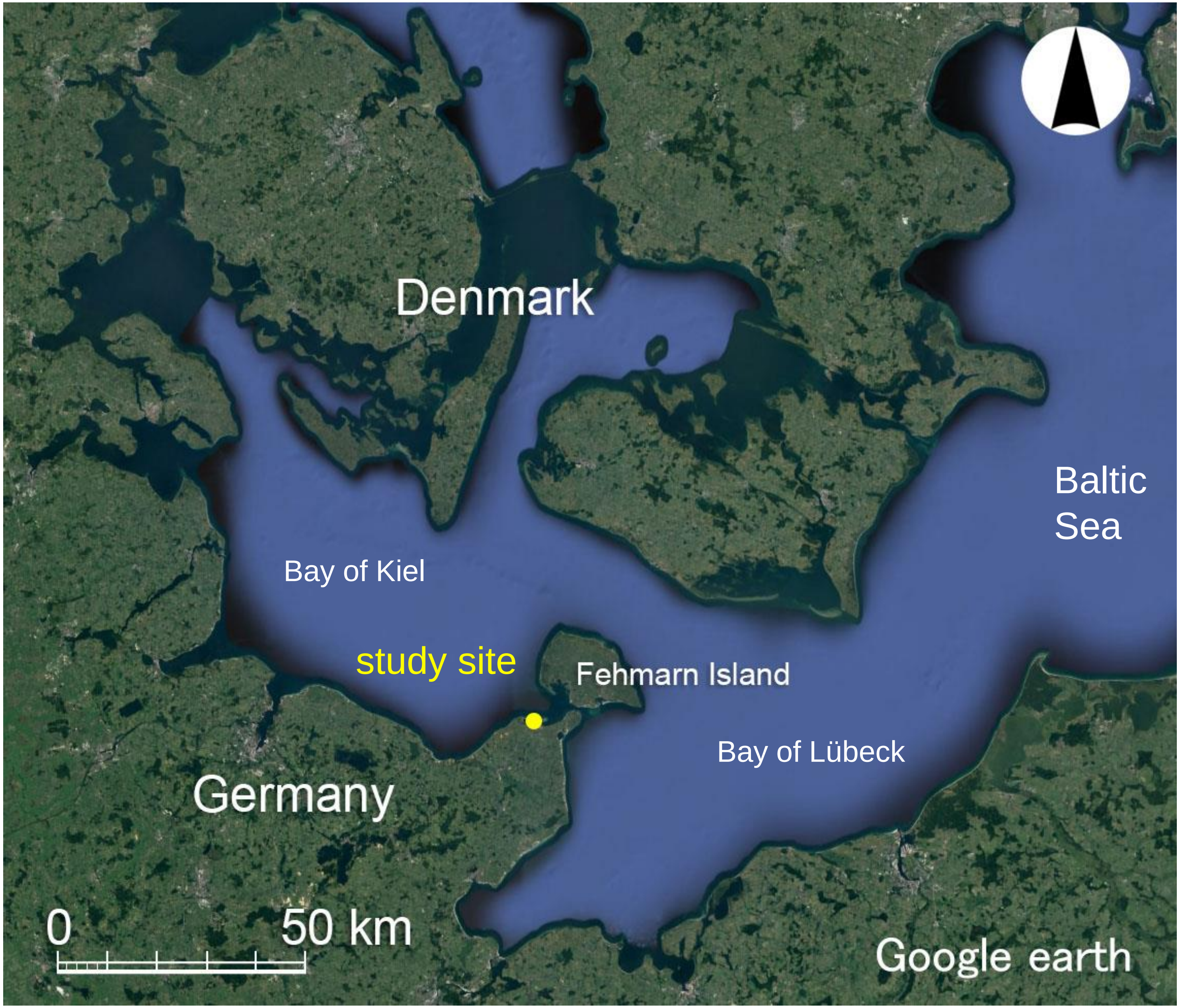
Example of recurved sand spit: Namibia

Although the sand spit extends northward, many recurved spits are superimposed.

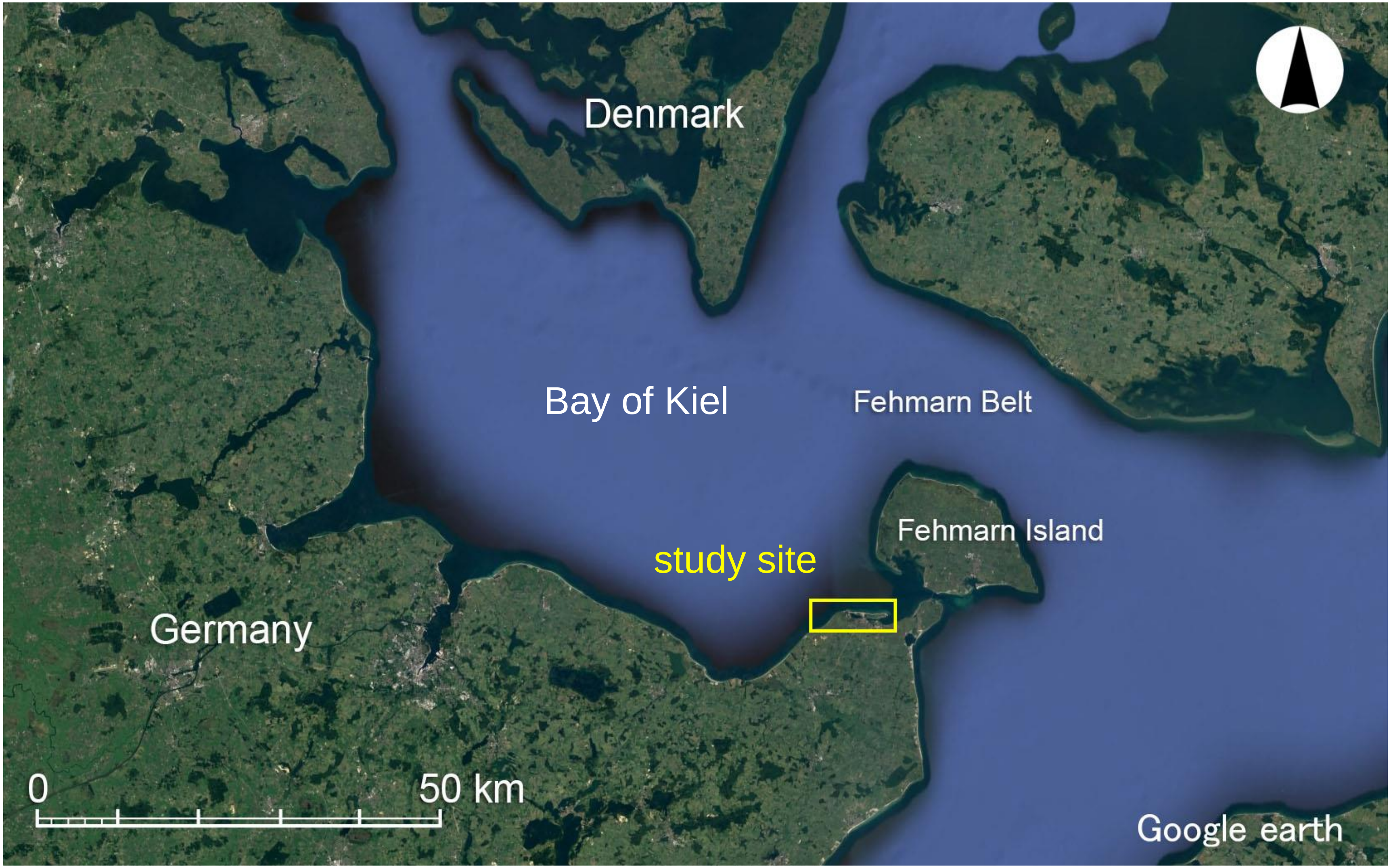
Example of recurved sand spit: Namibia

Although the sand spit extends northward, many recurved spits are superimposed.

Graswarder spit (Germany)

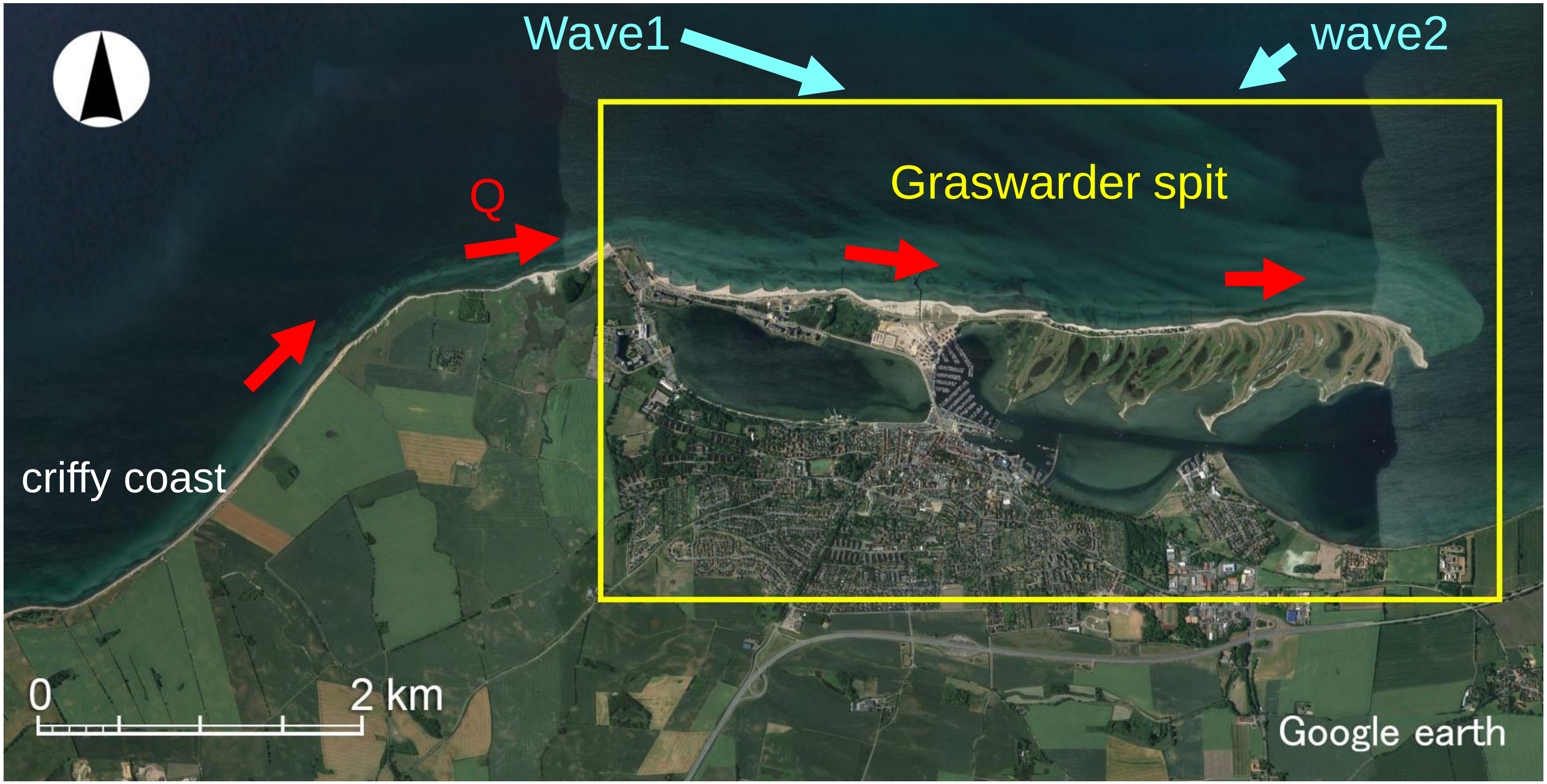


Graswarder spit (Germany)



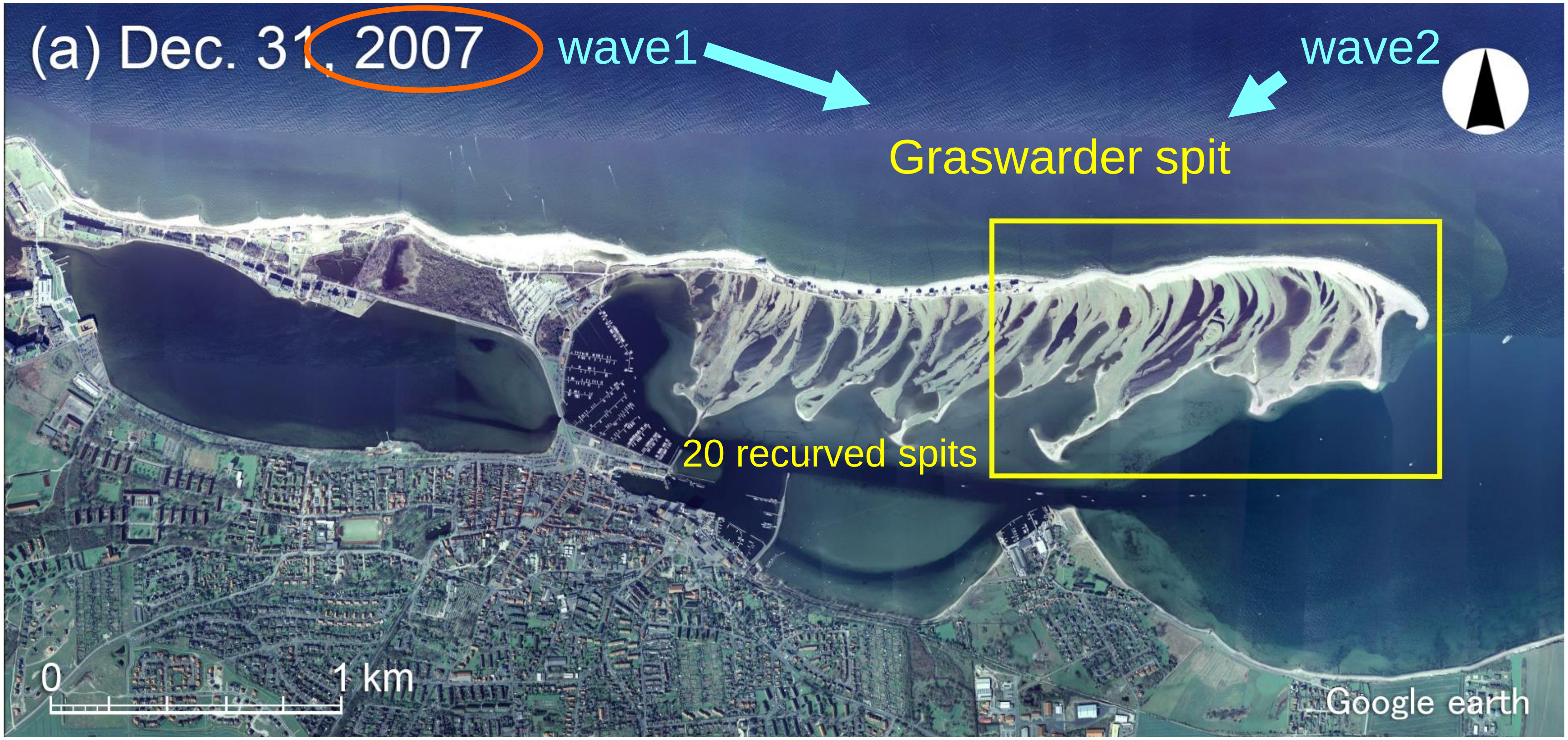
Graswarder spit (Germany)

Q longshore sand transport



The sand spit extended by eastward longshore sand transport, and a barrier island has grown eastward for about 3,000 years (Bird, 2008).

Graswarder spit (Germany)



Although the sand spit extends eastward, many recurved spits are superimposed.
20 recurved spits can be seen (Bird, 2008).

Graswarder spit (Germany)

Graswarder spit (Germany)

Graswarder spit (Germany)

Calculation of elongation of recurved sand spits

BG Model (Model for predicting beach changes based on BaGnold's concept)

Uda et al. (2016)

BG Model (Model for predicting beach changes based on BaGnold's concept)

The sand transport equation

- •equilibrium slope : Inman and Bagnold(1963)
- •energetic approach : Bagnold(1963)

$$\vec{q} = C_0 \frac{P}{\tan\beta_c} \left\{ \begin{array}{l} K_n \left(\tan\beta_c \vec{e_w} - |\cos\alpha| \overrightarrow{\nabla Z} \right) \\ + \left\{ (K_s - K_n)\sin\alpha - \boxed{\frac{K_2}{\tan\bar{\beta}} \frac{\partial H}{\partial s}} \right\} \tan\beta \ \vec{e_s} \end{array} \right\}$$

$$(-h_c \le Z \le h_R) \quad \ldots(1)$$

Ozasa and Brampton (1980)

$P =$ wave energy dissipation by breaking

$$= K\sqrt{g/h}\left[1 - (G/g)^2\right]E \quad \ldots(2)$$

P is calculated by using the results of wave field.

Calculation model of plane wave field:

energy balance equation (Mase, 2001) with dissipation term due to wave breaking (Dally *et al.,* 1984).

$\vec{q} = (q_x, q_y)$: the net sand transport flux

$Z = (x, y, t)$: the seabed elevation

n s: the coordinates of cross-shore and longshore directions,

$\vec{e_n}$: the unit vector normal to the contour lines (shoreward).

$\vec{e_s}$: parallel to a contour line

$\overrightarrow{\nabla Z} = \tan\beta \ \vec{e_n} = (\partial Z/\partial x, \ \partial Z/\partial y)$: the gradient vector of Z.

$\vec{e_w}$: the unit vector of wave direction

θ_w : the angle between the *x*-axis and the wave direction

$\tan\beta \ \vec{e_s} = (-\partial Z/\partial y, \ \partial Z/\partial x)$

$\alpha = \theta_w - \theta_n$: the angle between the wave direction and the normal to the contour line

$\tan\beta = \left|\overrightarrow{\nabla Z}\right|$: the seabed slope

$\tan\beta_c$: equilibrium slope

K_s : coefficients of longshore sand transport

K_n : cross-shore sand transport

h_c : the depth of closure

h_R : the berm height

H : the wave height at a local point

$C_0 = 1/\{(\rho_s - \rho)g(1-p)\}$

Physical meaning of BG model

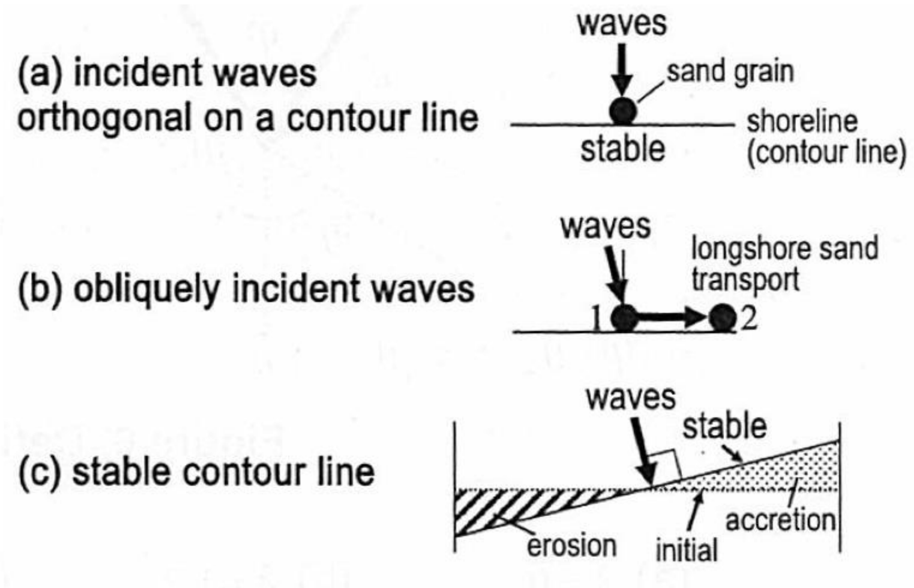


Fig. Stabilization mechanism of contour lines based on wave directions and longshore sand transport.

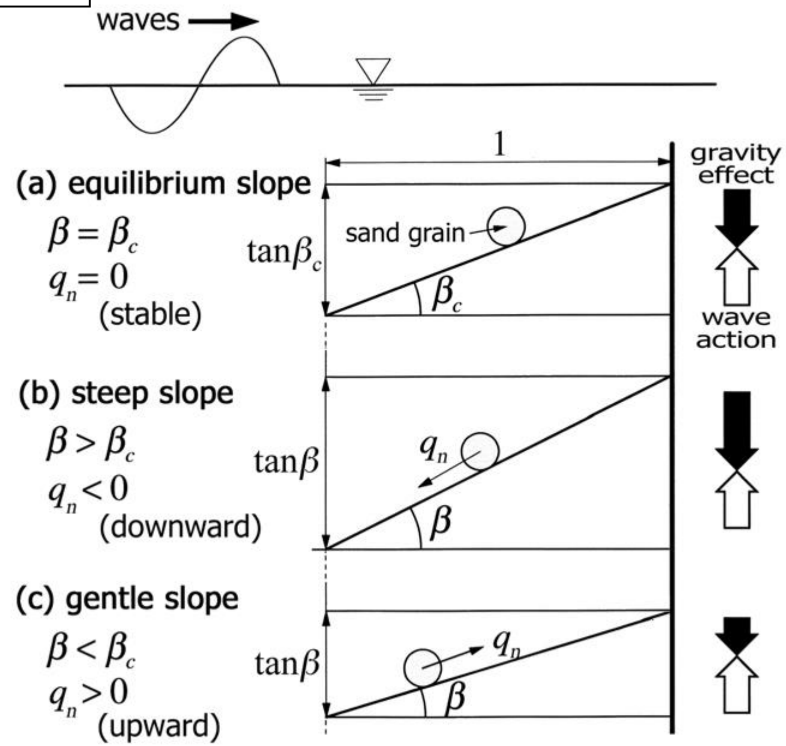
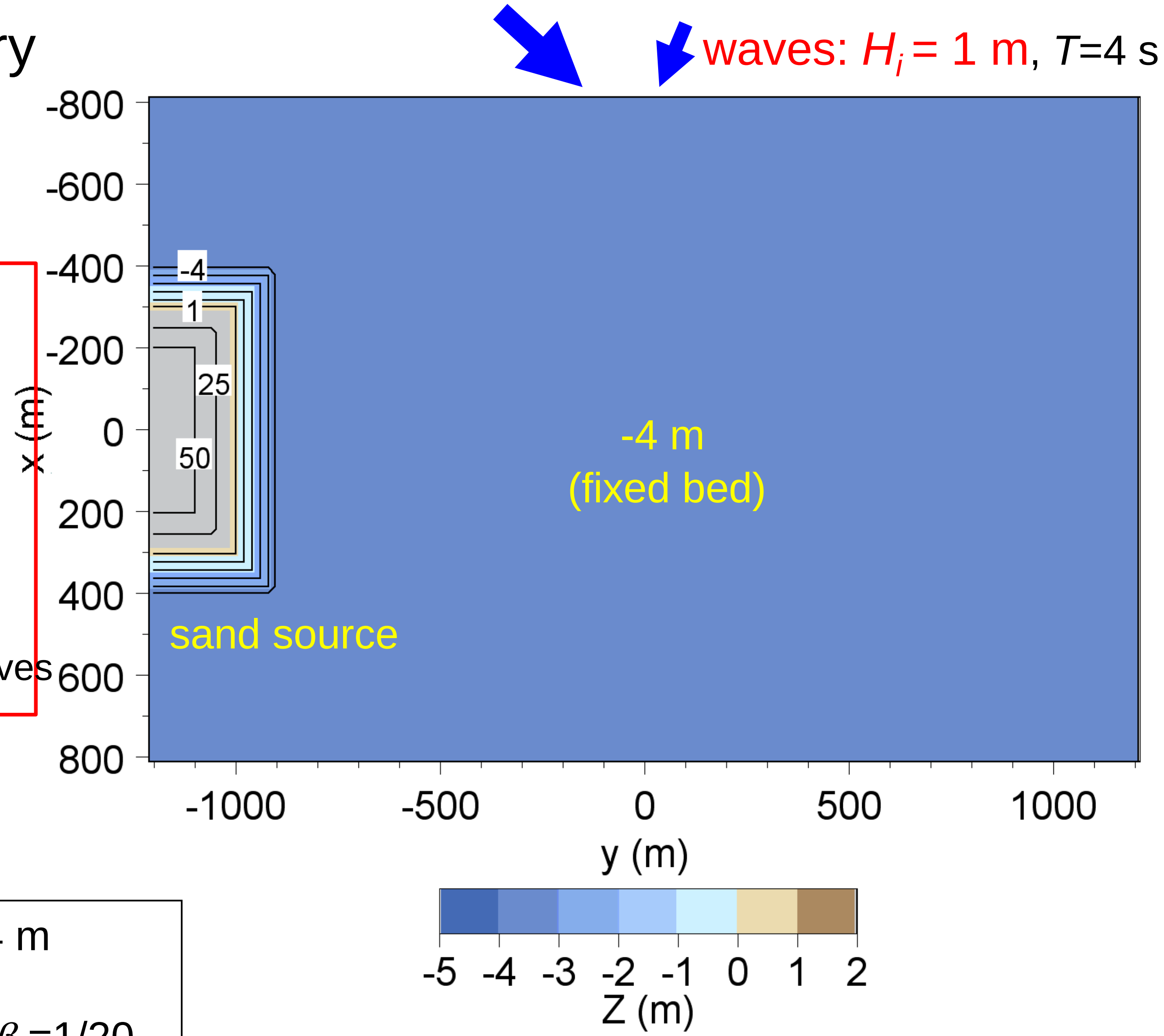


Fig. Stabilization mechanism of beach profile based on equilibrium between gravity effect and wave action.

Calculation results

Case 1: wave direction $\theta_1 = +45^\circ$, $\theta_2 = -30^\circ$

Initial bathymetry



2 waves

wave 1: 45°, P_1=0.85

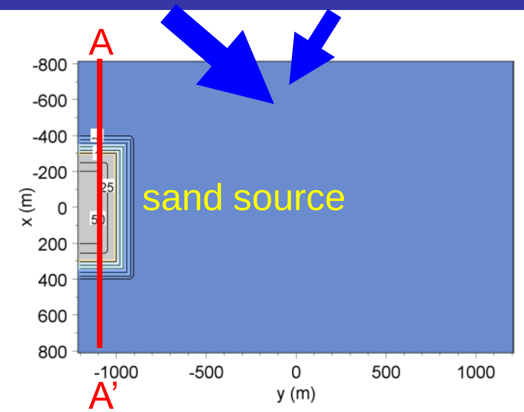
wave 2: -30°, P_2=0.15

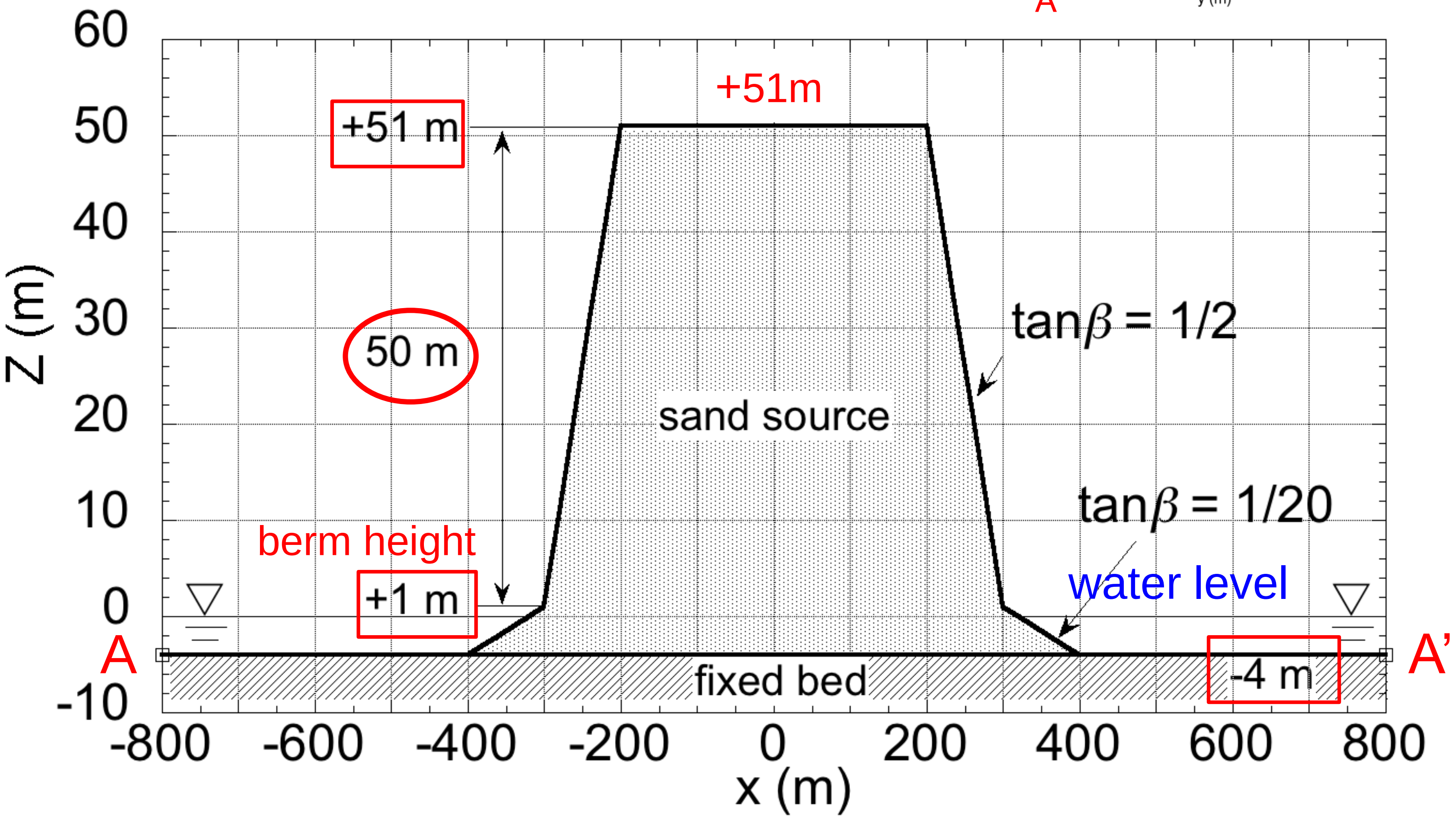
Ratio of duaration of 2 waves

Depth of closure h_c= 4 m
Berm height h_R= 1 m
Equilibrium slope: $\tan\beta_c$=1/20

Cross section of sand source.

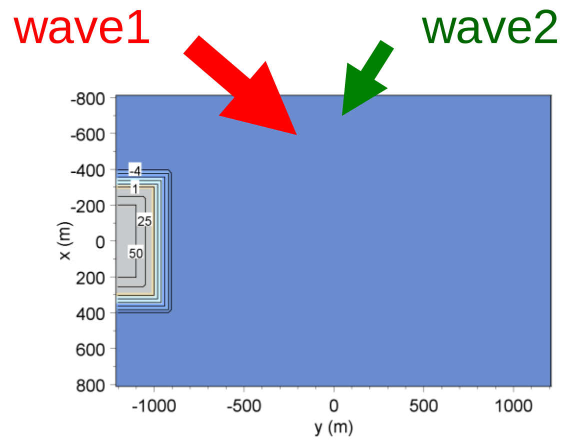
The reason for setting the high tower as the sand source was that a sufficient amount of sand for the elongation of the sand bar could be supplied.





Case 1: wave direction θ_1 = +45°, θ_2 =-30°

Incident wave condition

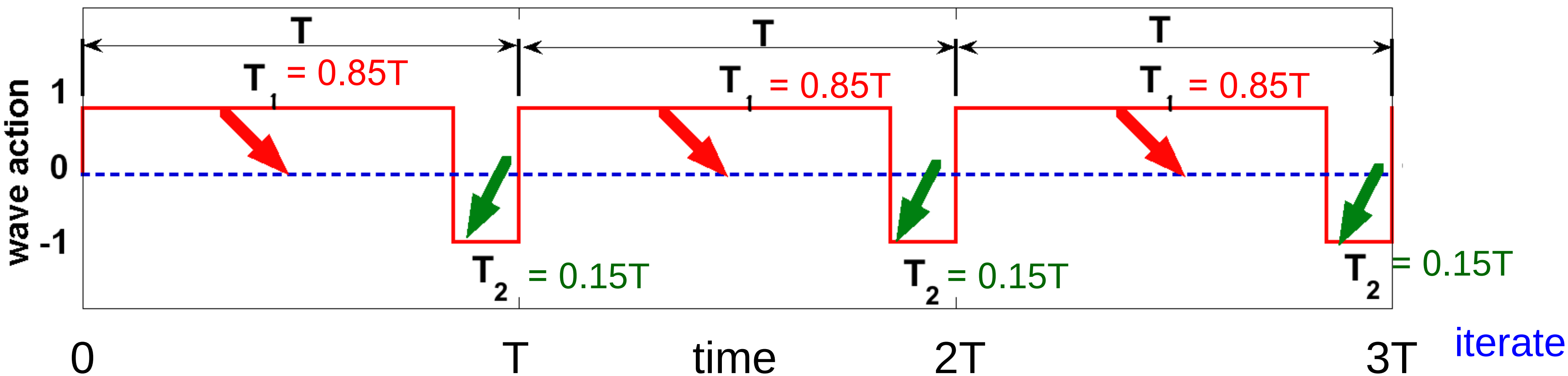


H_i = 1 m,
T=4 s

Time series of 2-wave action

wave direction 1 = +45 deg

wave direction 2 = -30 deg



iterate to 8T

One cycle of the two waves action T = 5000steps (2500hr)

Waves are incident periodically from two directions with a duration ratio of 0.85: 0.15.

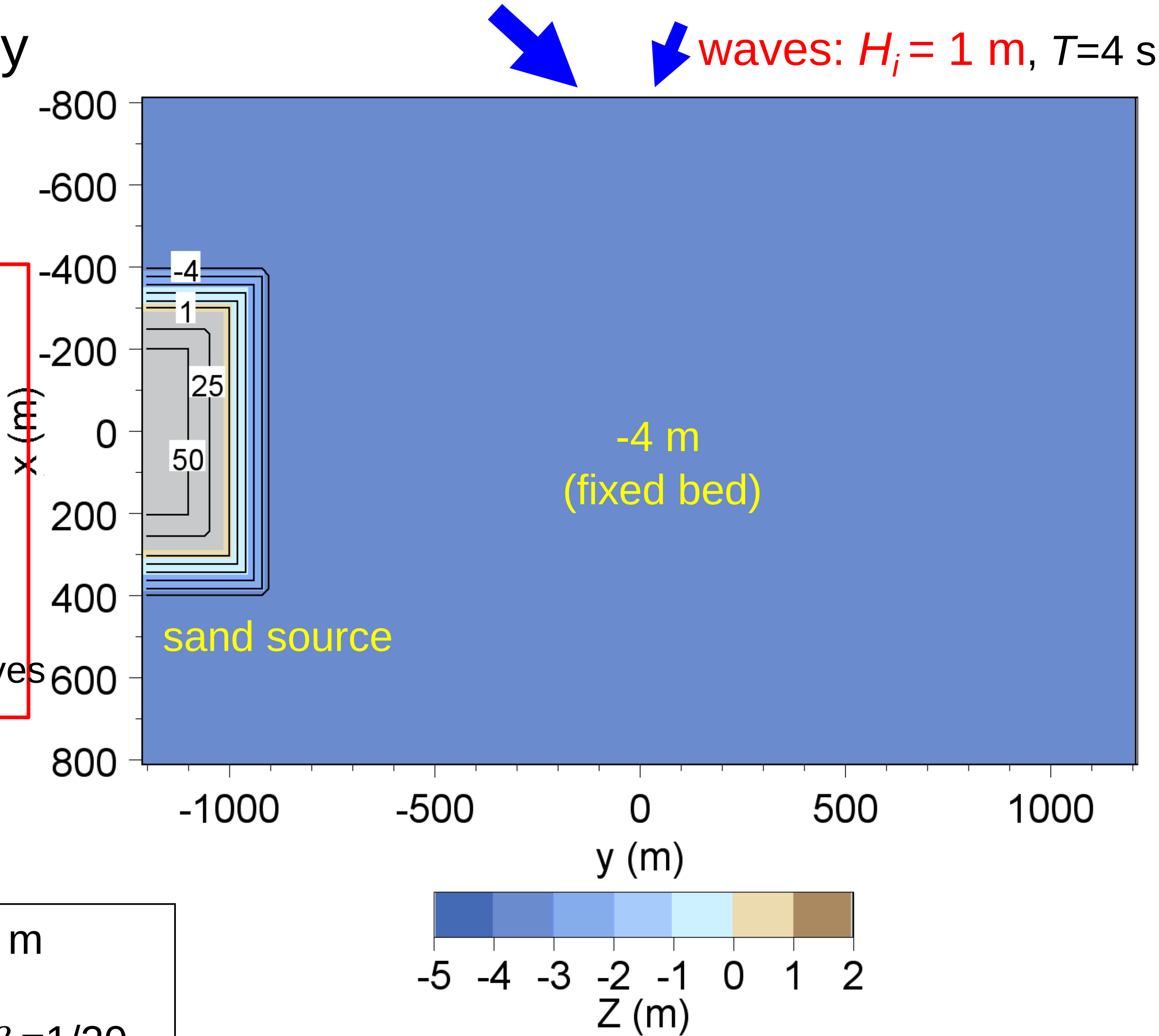
Ratio of duaration of 2 waves

$P_1 = T_1/T = 0.85$

$P_2 = T_2/T = 0.15$

Case 1: wave direction θ_1 = +45°, θ_2 =-30°

Initial bathymetry



2 waves

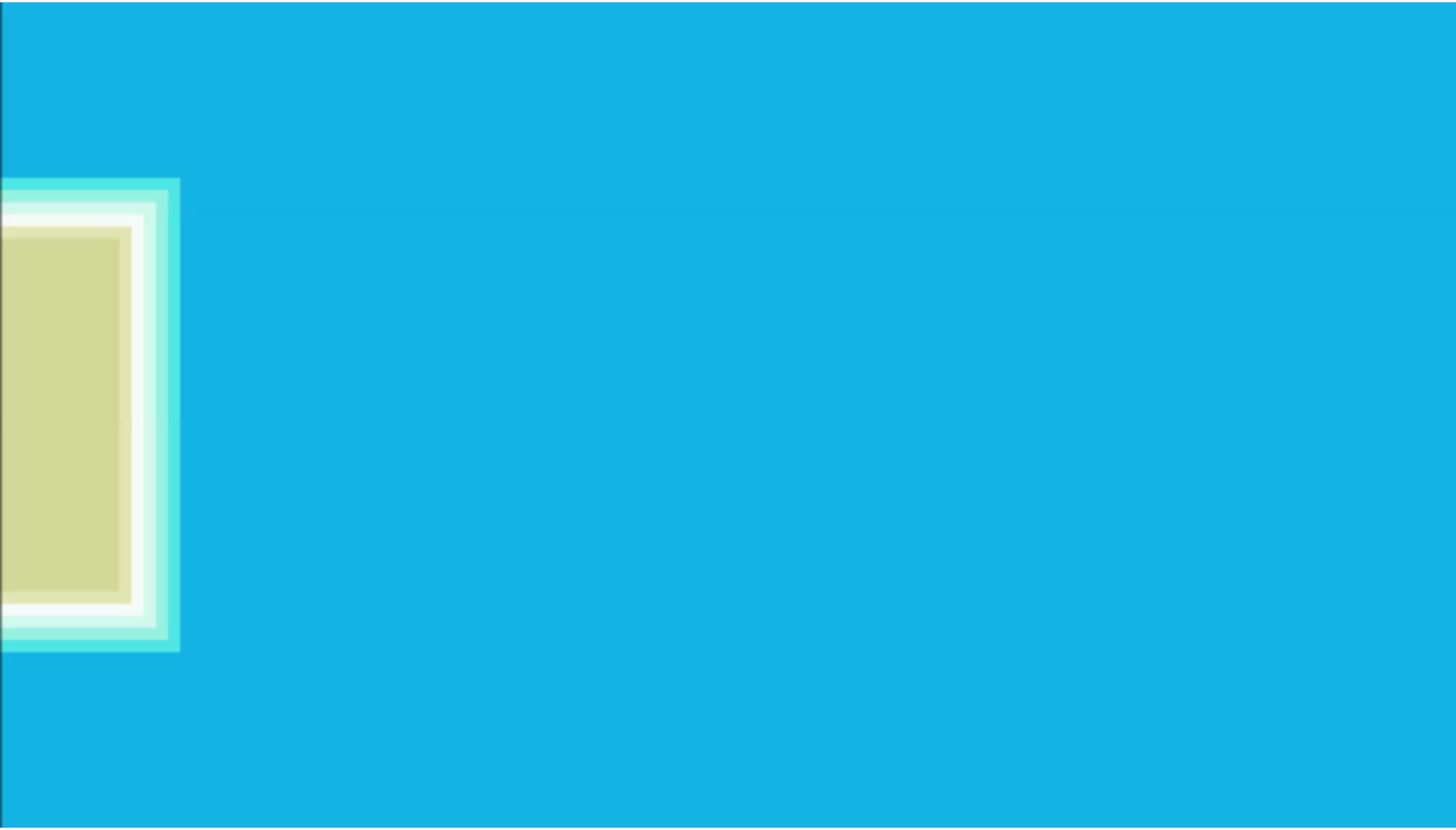
wave 1: 45°, P_1=0.85

wave 2: -30°, P_2=0.15

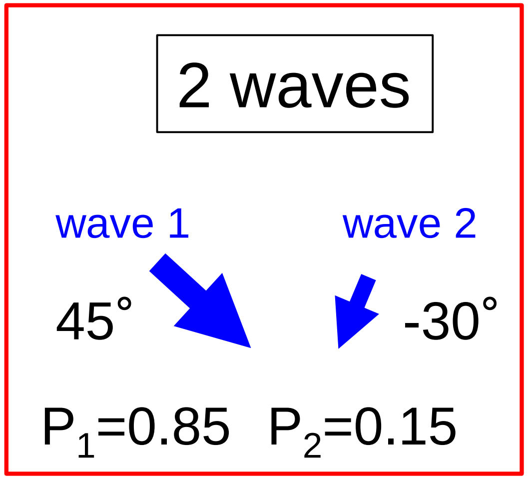
Ratio of duaration of 2 waves

Depth of closure h_c= 4 m
Berm height h_R= 1 m
Equilibrium slope: $\tan\beta_c$=1/20

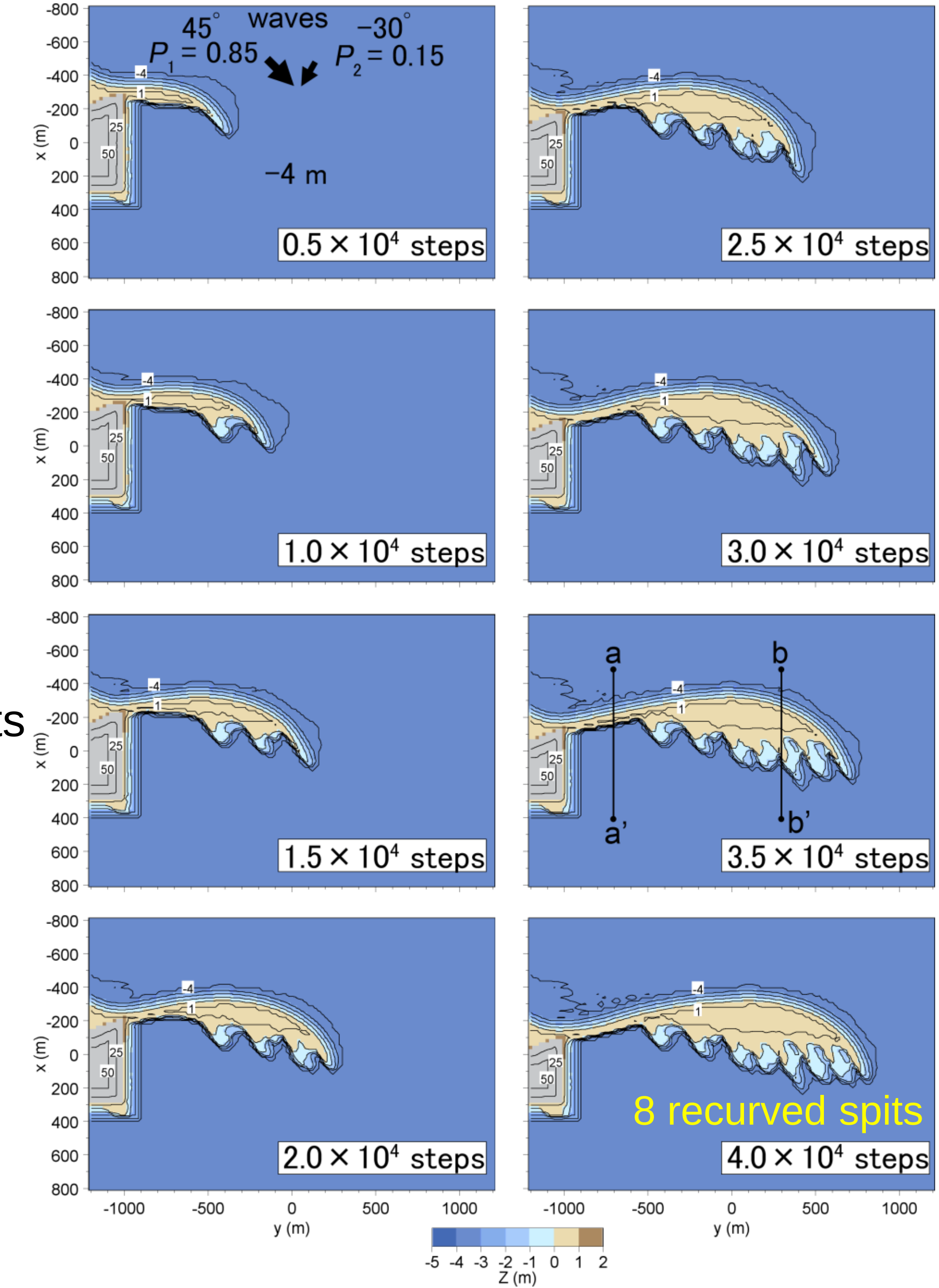
Case 1: wave direction $\theta_1 = +45^\circ$, $\theta_2 = -30^\circ$



Case 1: wave direction $\theta_1 = +45^\circ$, $\theta_2 = -30^\circ$



The number of the recurved sand spits corresponds to the number that the wave direction was changed from 45° to -30°.

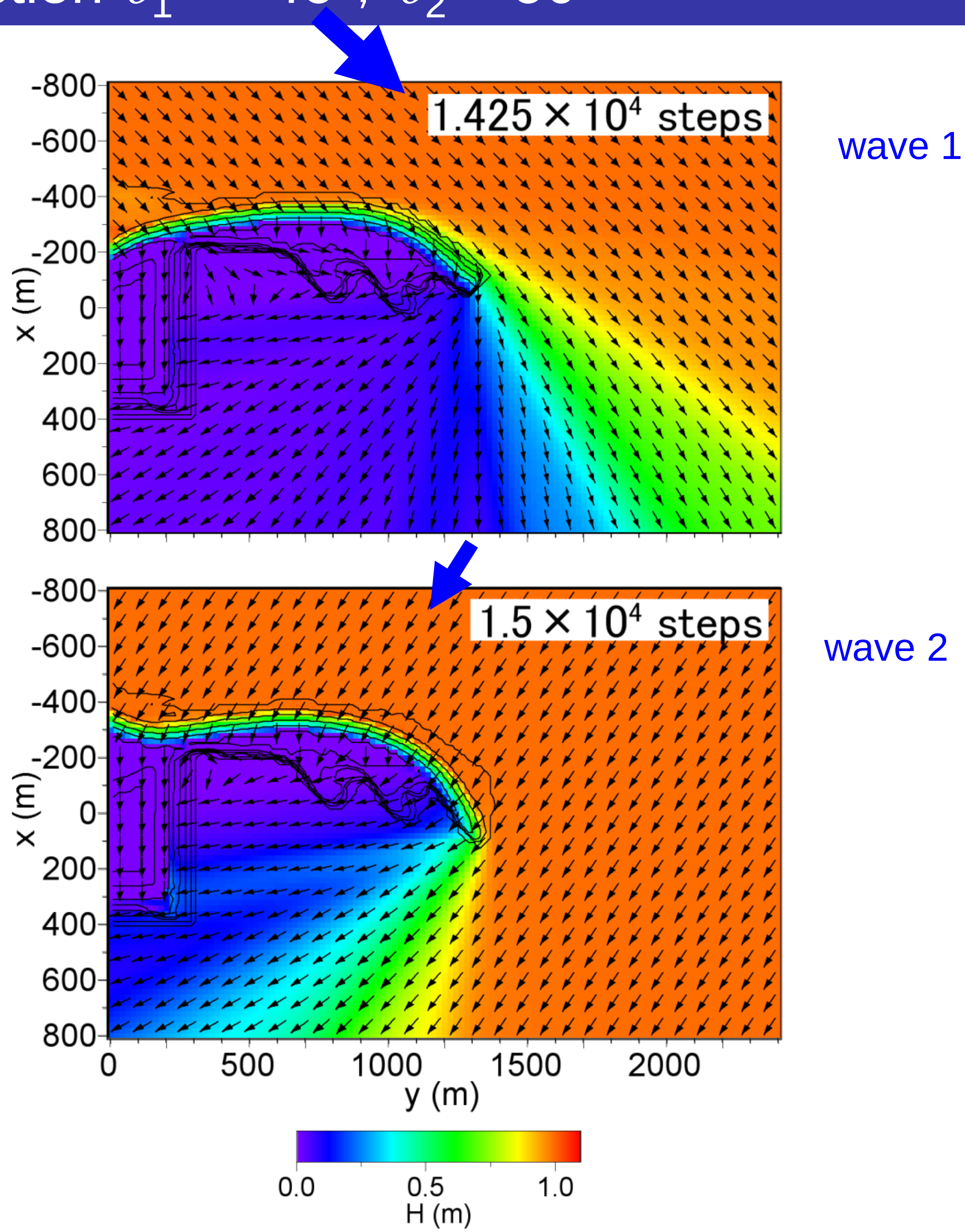


Case 1: wave direction θ_1 = +45°, θ_2 =-30°

2 waves

wave 1 — 45° — P_1=0.85

wave 2 — -30° — P_2=0.15



wave height and wave direction

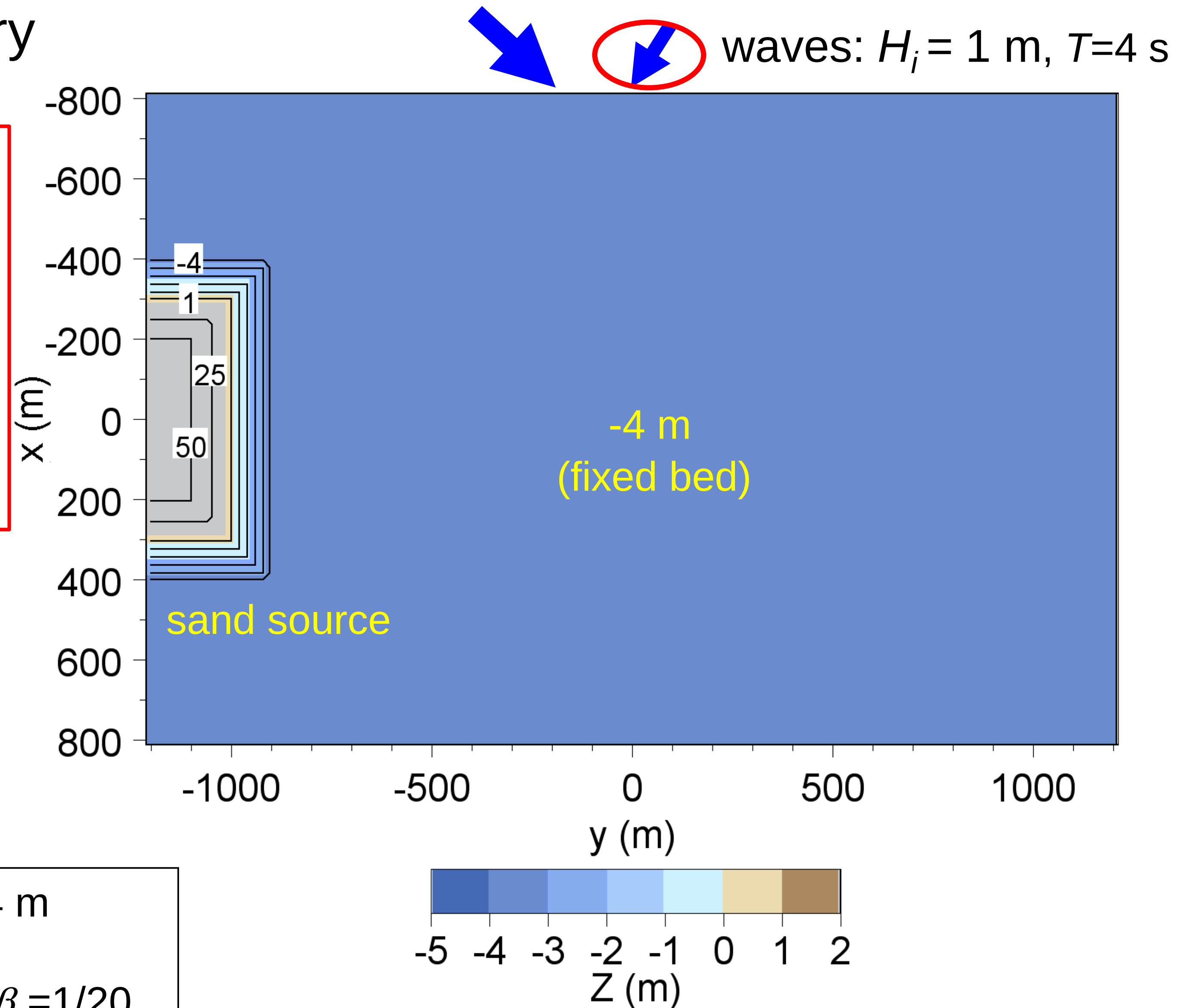
Case 2: wave direction $\theta_1 = +45^\circ$, $\theta_2 = -45^\circ$

Initial bathymetry

2 waves

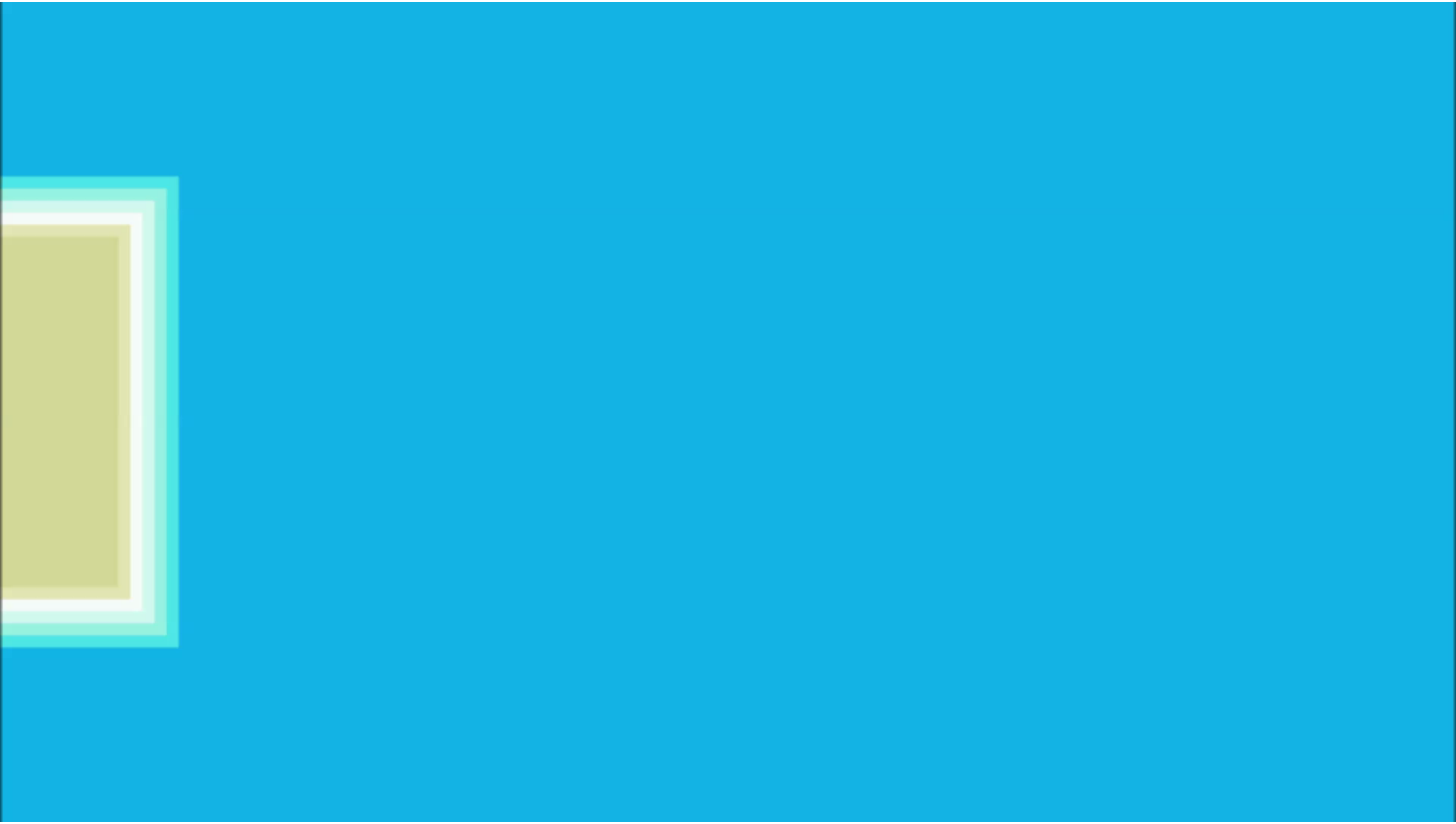
wave 1 — 45° — P_1=0.85

wave 2 — -45° — P_2=0.15

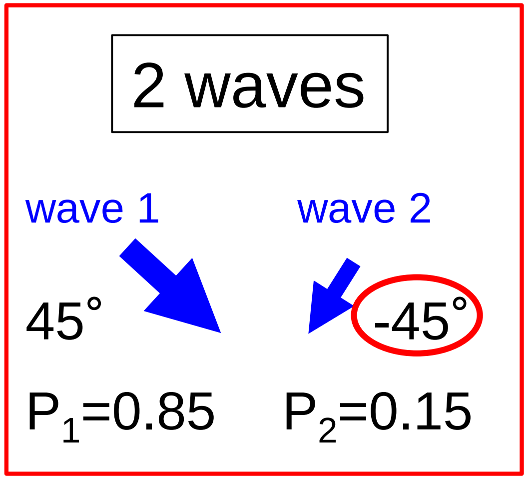


Depth of closure h_c= 4 m
Berm height h_R= 1 m
Equilibrium slope: $\tan\beta_c$=1/20

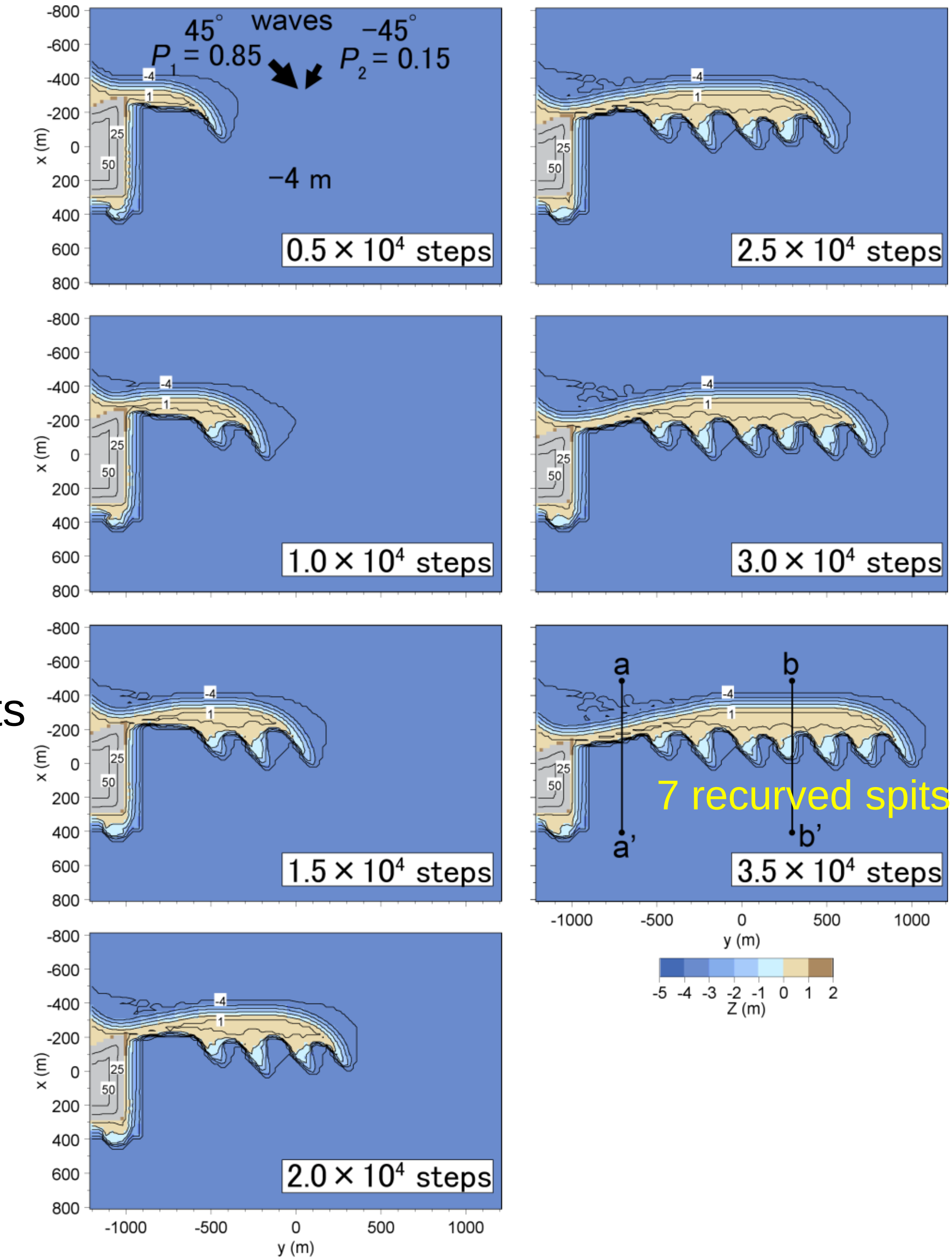
Case 2: wave direction $\theta_1 = +45^\circ$, $\theta_2 = -45^\circ$



Case 2: wave direction θ_1 = +45˚, θ_2 =-45˚



The number of the recurved sand spits corresponds to the number that the wave direction was changed from 45˚ to -45˚.

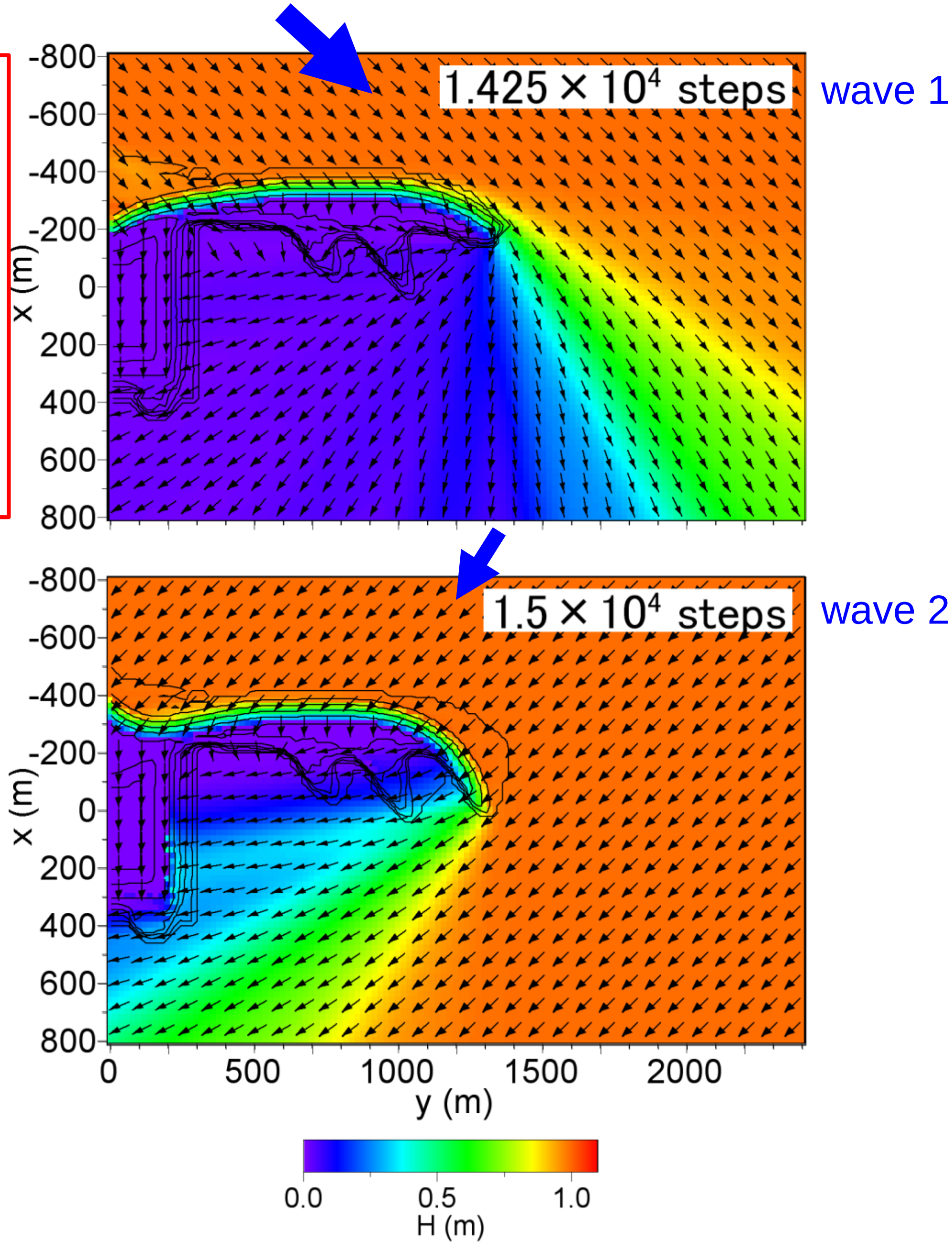


Case 2: wave direction θ_1 = +45°, θ_2 =-45°

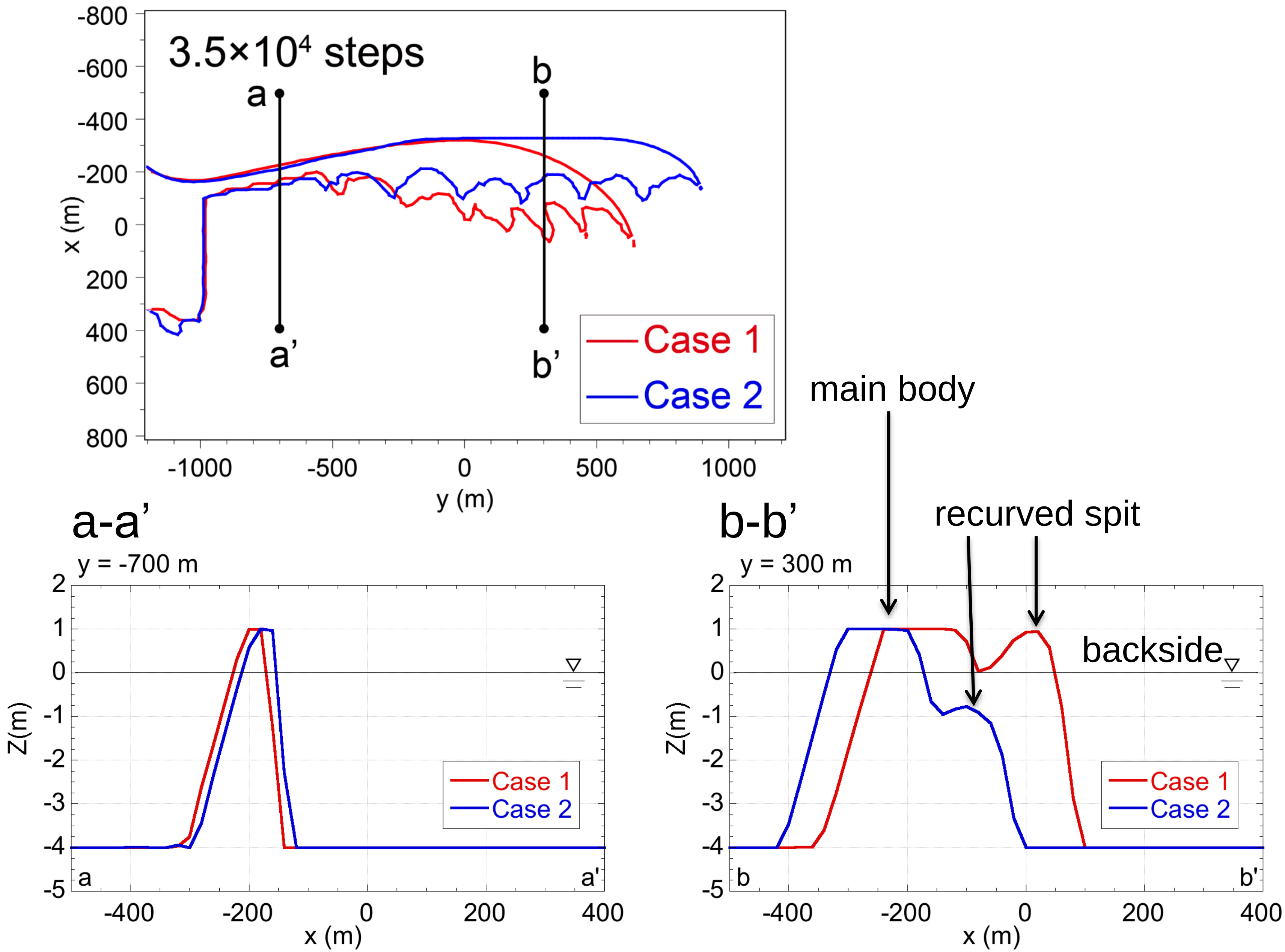
2 waves

wave 1 | wave 2
45° | -45°
P_1=0.85 | P_2=0.15

wave height and wave direction



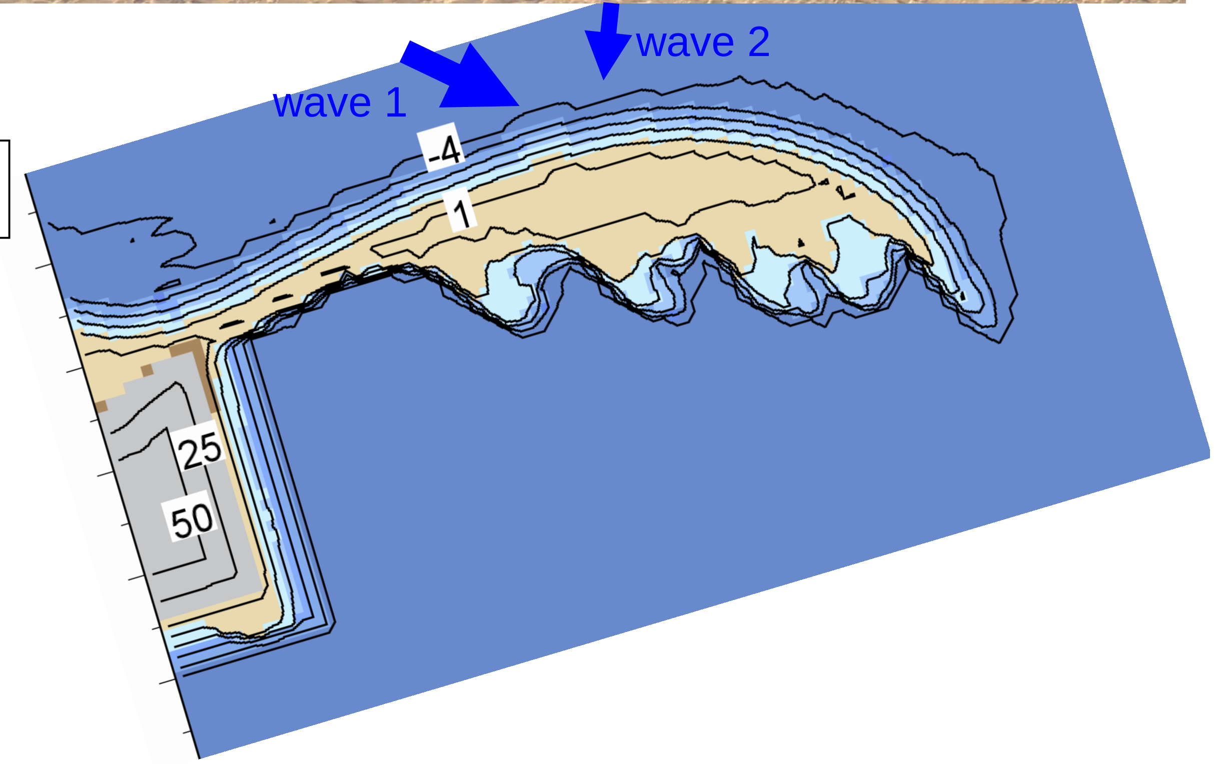
Shoreline configurations / Longitudinal profiles in Cases 1 and 2



Comparison with site observation

Site observation

Calculation



Case 1

wave direction

θ_1 = +45°, θ_2 =-30°

P_1=0.85, P_2=0.15

Comparison with site observation

Site observation

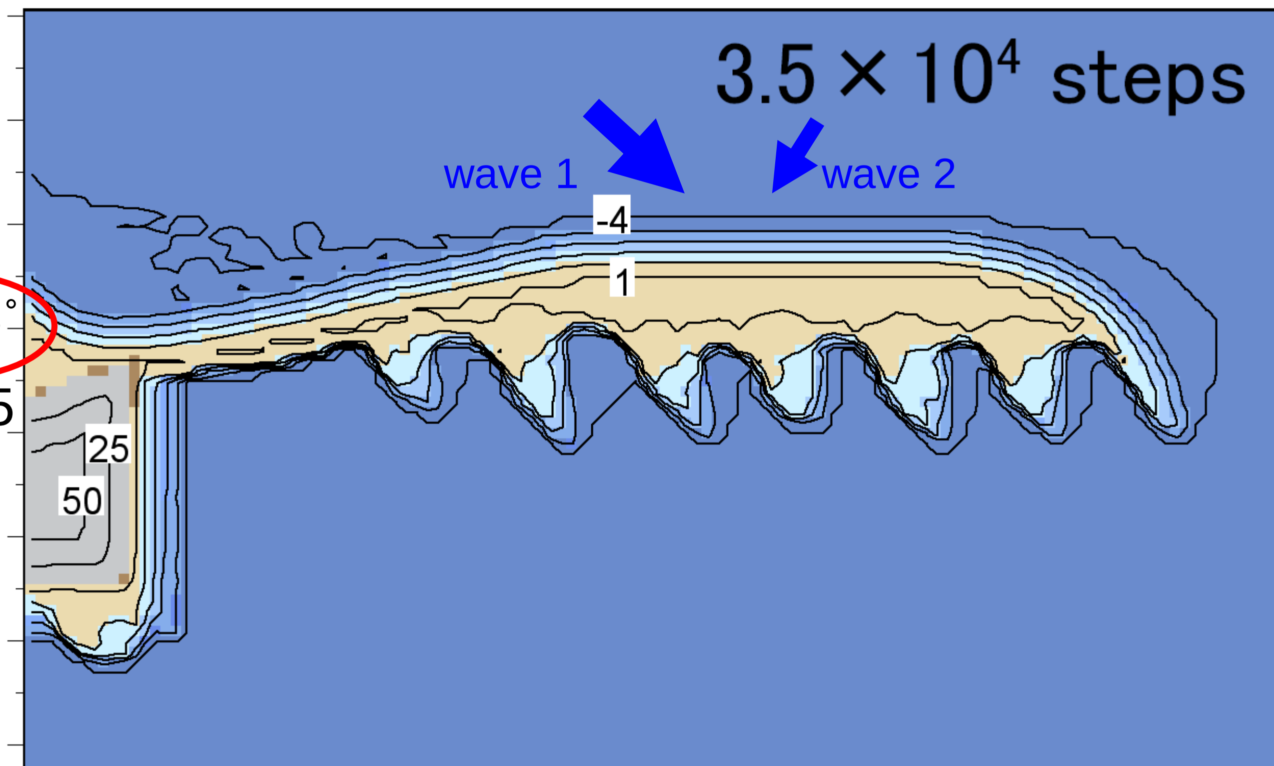
Calculation

Case 2

wave direction

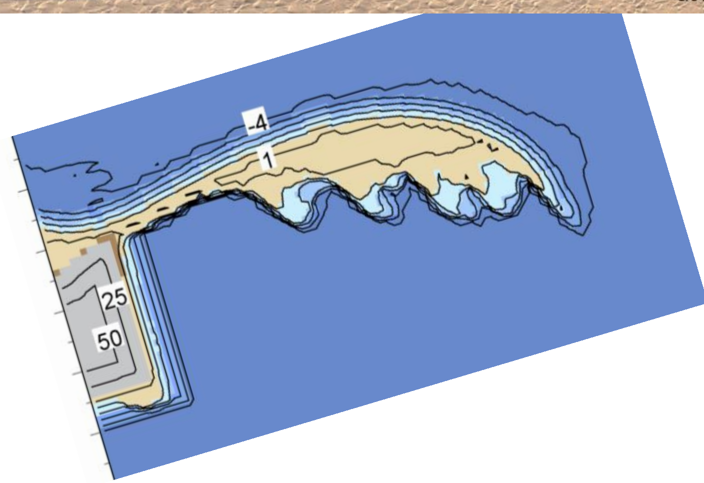
$\theta_1 = +45^\circ$, $\theta_2 = -45^\circ$

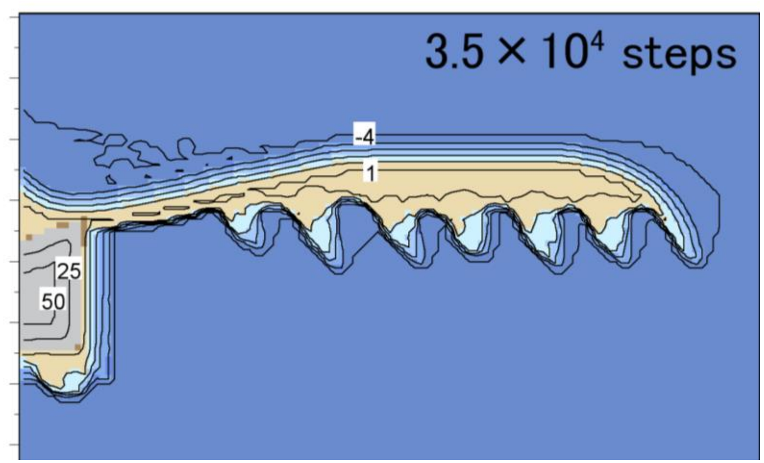
$P_1=0.85$, $P_2=0.15$



CONCLUSIONS

- In this study, the elongation of the recurved spits was predicted using the BG model.
- It was confirmed that when two sets of waves arrive from different directions, a recurved sand spit can be formed. The measured and calculated characteristics agreed well.

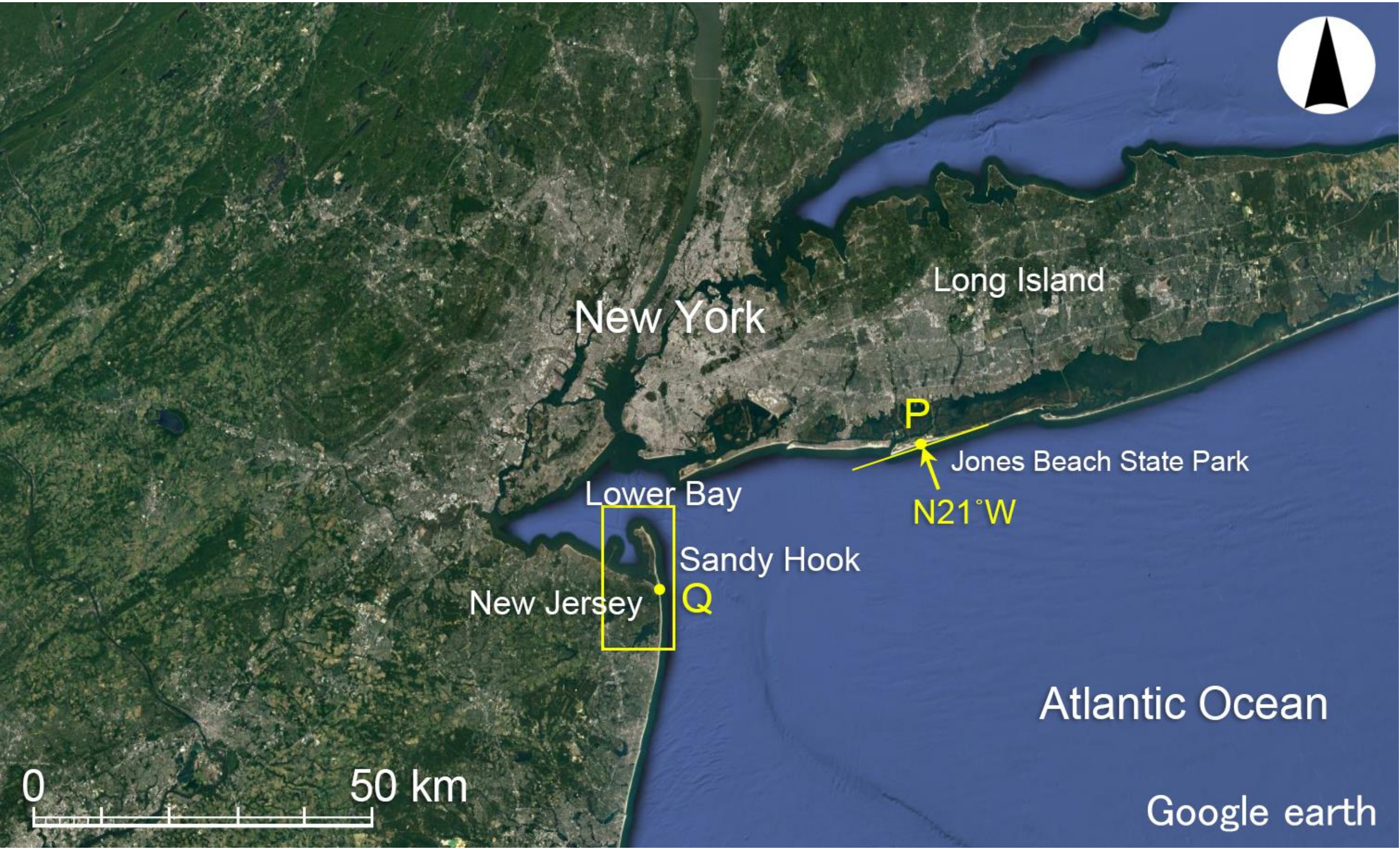




Calculation conditions

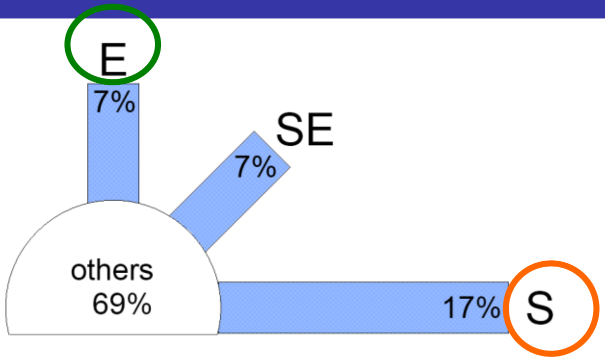
Wave conditions	Incident waves: $H_I = 1$ m, $T = 4$ s, wave direction $\theta_I = 45°$ and -45° (Case 1), $\theta_I = 45°$ and -30° (Case 2) with a duration ratio of 0.85: 0.15 Duration of one cycle: 2.5×10^3 hr (5×10^3 steps)
Berm height	$h_R = 1$ m
Depth of closure	$h_c = 4$ m
Equilibrium slope	$\tan\beta_c = 1/20$
Coefficients of sand transport	Coefficient of longshore sand transport $K_s = 0.2$ Coefficient of Ozasa and Brampton (1980) term $K_2 = 1.62K_s$ Coefficient of cross-shore sand transport $K_n = K_s$
Mesh size	$\Delta x = \Delta y = 20$ m
Time intervals	$\Delta t = 0.5$ hr
Duration of calculation	2×10^4 hr (4×10^4 steps)
Boundary conditions	Shoreward and landward ends: $q_x = 0$, right and left boundaries: $q_y = 0$
Calculation of wave field	Energy balance equation (Mase, 2001) • Term of wave dissipation due to wave breaking: Dally et al. (1984) model • Wave spectrum of incident waves: directional wave spectrum density obtained by Goda (1985) • Total number of frequency components N_F =1 and number of directional subdivisions $N_\theta = 8$ • Directional spreading parameter $S_{max} = 25$ • Coefficient of wave breaking $K = 0.17$ and $\Gamma = 0.3$ • Imaginary depth between minimum depth h_0 (0.5 m) and berm height h_R • Wave energy = 0 where $Z \geq h_R$ • Lower limit of h in terms of wave decay due to breaking: 0.5 m

Location of Sandy Hook on US East Coast

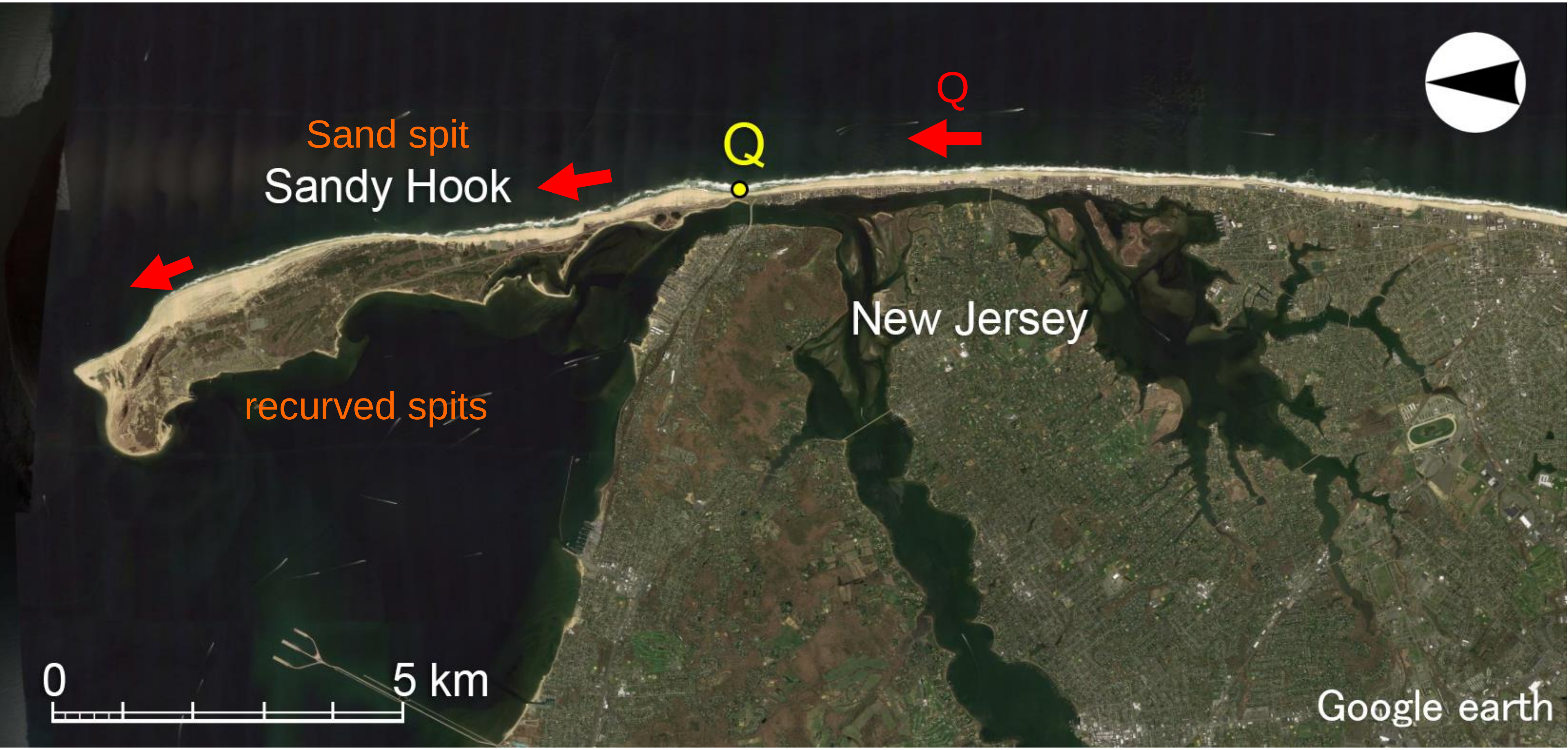


Sandy Hook

Probability of occurrence of wave direction
British Maritime Technology Ltd. (1986)



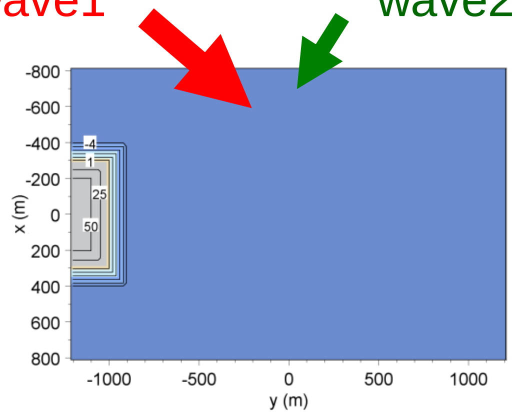
Q
longshore sand transport



Case 2: wave direction $\theta_1 = +45^\circ$, $\theta_2 = -45^\circ$

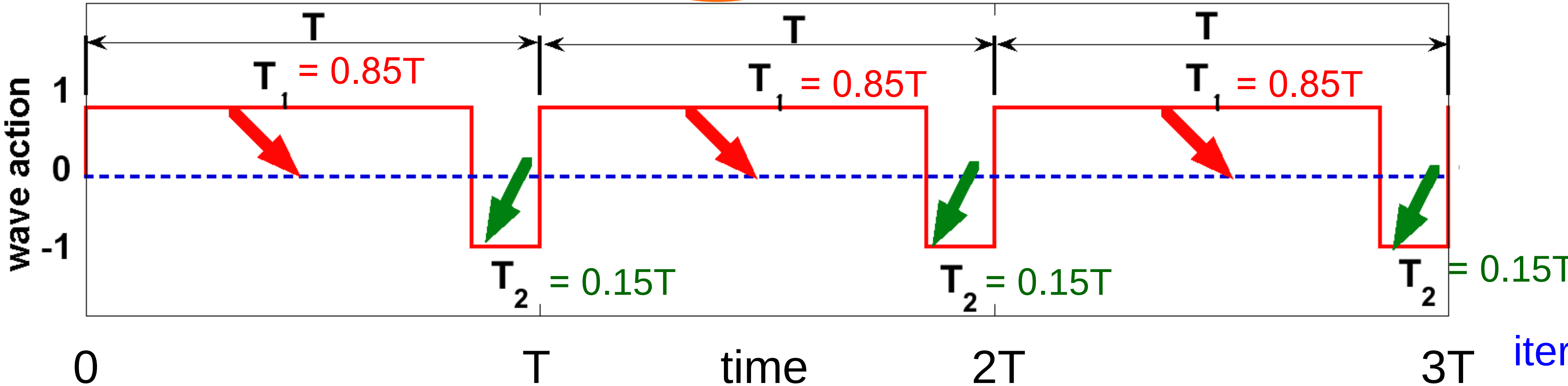
Time series of 2-wave action

wave1 wave2



wave direction 1 = +45deg

wave direction 2 = -45deg



iterate to 7T

One cycle of the wave action T = 5000steps (2500hr)

Waves are incident periodically from two directions with a duration ratio of 0.85: 0.15

Ratio of duaration of 2 waves

$P_1 = T_1/T = 0.85$

$P_2 = T_2/T = 0.15$