Coastal Sediment Transport
Cross-Shore

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- Overview of problems
- Bed shear stress by waves and current
- Sediment transport by waves and current
- Longshore sediment transport
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- Dune erosion

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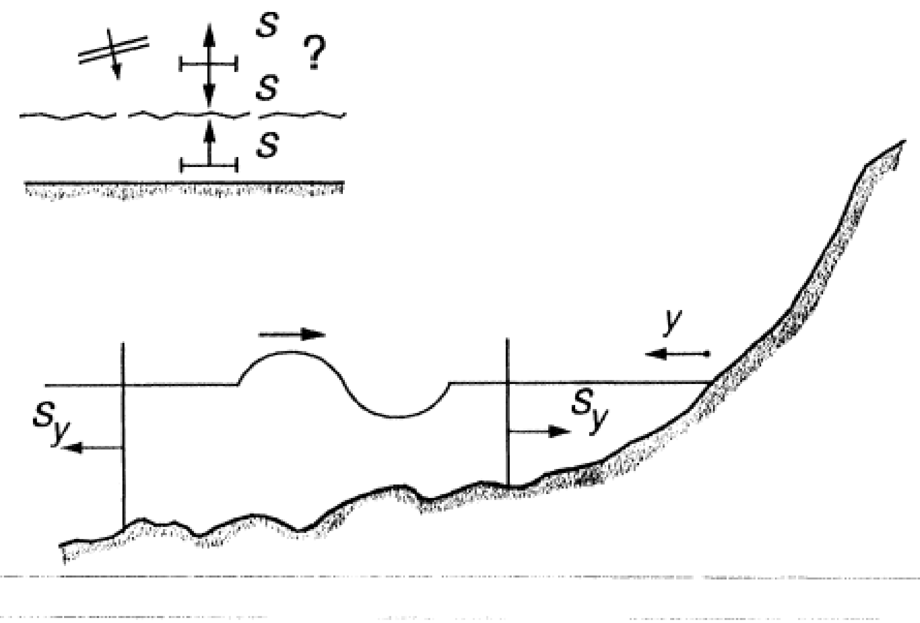
CROSS-SHORE TRANSPORT

onshore / offshore transport



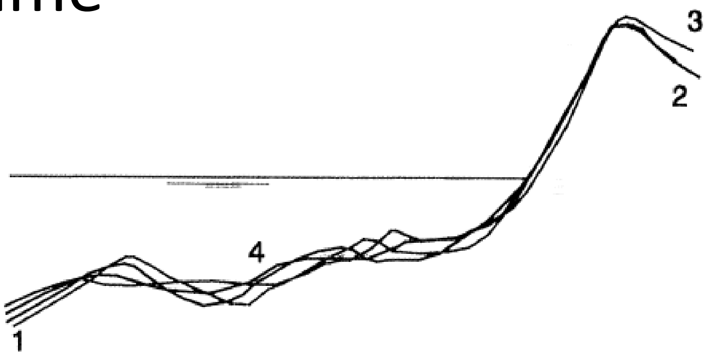
$$S_y = \frac{1}{t_0} \int_0^{t_0} \int_0^{h} v_y(z,t) \cdot c(z,t)\, \mathrm{d}z\, \mathrm{d}t$$

V_y : function of z and t (difficult) (wave period scale) (orbital motion)

C : function of z and t (impossible) (wave period scale)

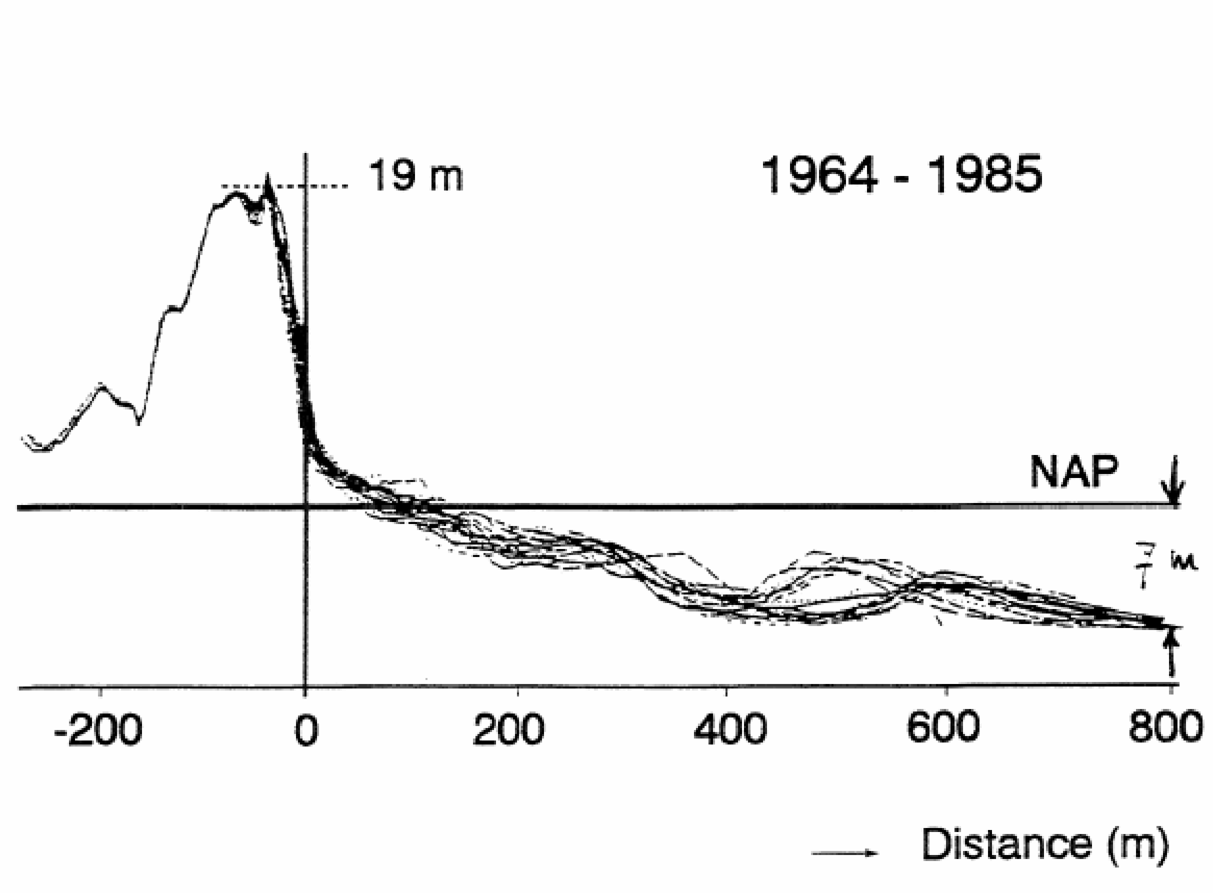
Equilibrium profile?

- Real equilibrium only for constant conditions
  - May be possible in wave flume
- In the field:
  - Varying wave conditions
  - Tidal variations



- Dynamic equilibrium: overall profile shape does not change too much

Yearly profiles North-Holland



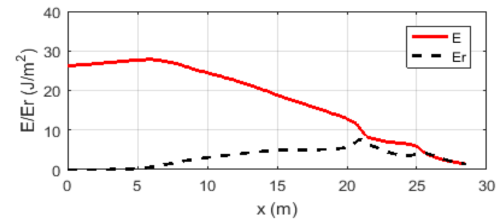
Cross-shore profile models

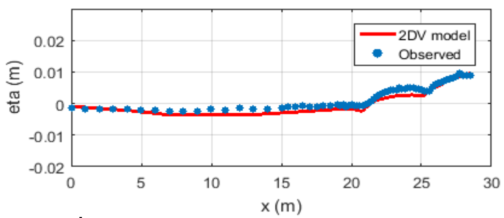
- Assumptions
  - Cross-shore processes dominate
  - Longshore variations very gradual
  - Wave-averaged
- Development since the ’80s
  - Crostran
  - Litprof
  - Unibest-TC
- Focus on behaviour of:
  - Longshore bars
  - Effect of nourishments
  - Effect of submerged breakwaters

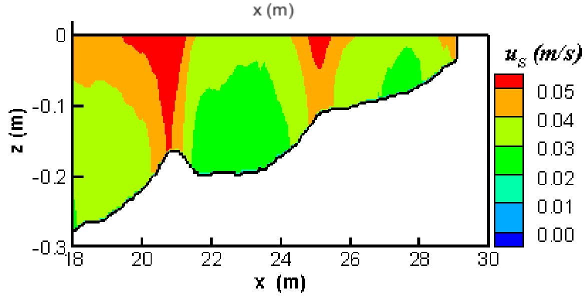
Principles of a cross-shore profile model

- wave distribution across surf zone
- roller energy
- wave setup
- longshore and cross-shore velocity profiles
- estimates of skewness, asymmetry
- sediment transport f(Hrms,u,v,...)
- profile change due to cross-shore transport
- total longshore transport for use in coastline model

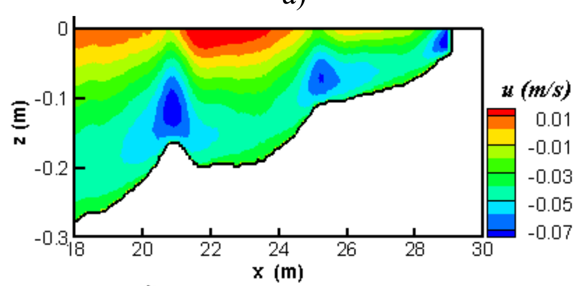
Boers test of wave heights, setup, mean current vs 2DV model (Duoc Nguyen)







a)



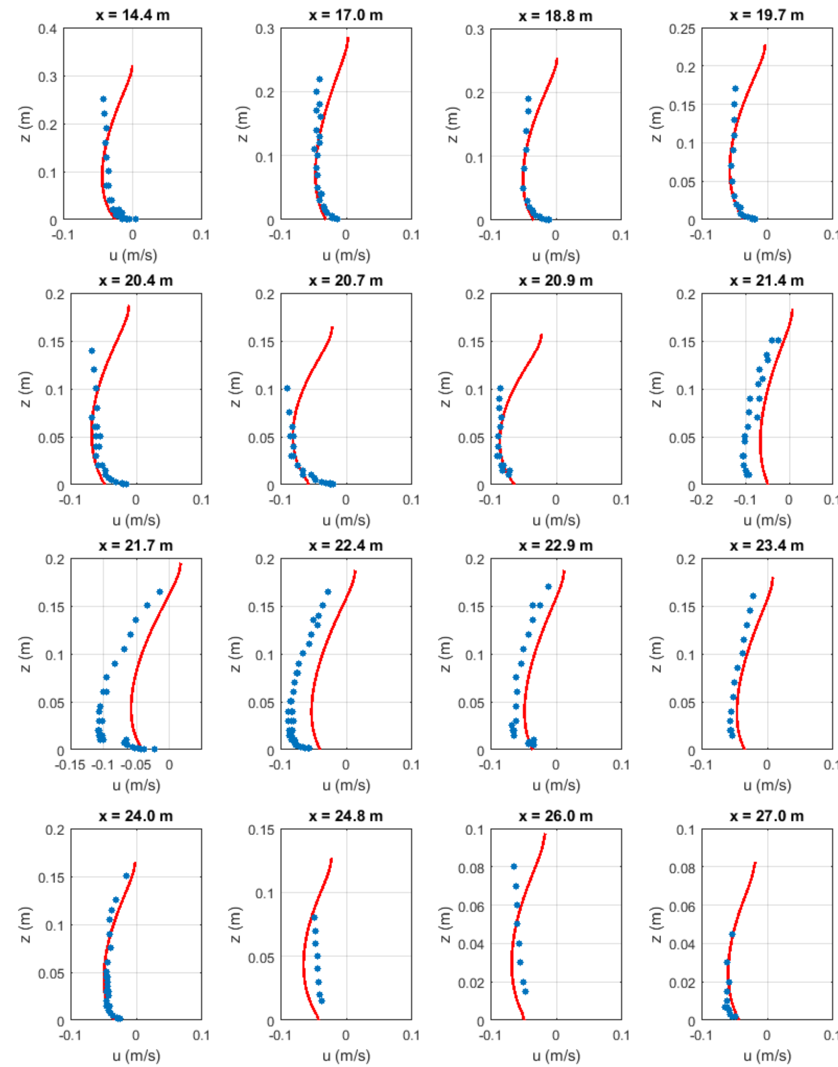


FIGURE 30. Vertical distribution of horizontal mean velocity in test 1B
Solid line: model results dots: experimental data

Bagnold/Bailard approach

- cross-shore transport is function of velocity moments
- these result from interactions between
  - orbital velocity and superharmonics
  - orbital velocity and mean flow
  - wave groups and associated long waves
- can be estimated using e.g. Stokes theory and other local models
- simplification makes cross-shore transport computation ‘doable’
- not very accurate

Skewness and asymmetry

- Skewed Asymmetric

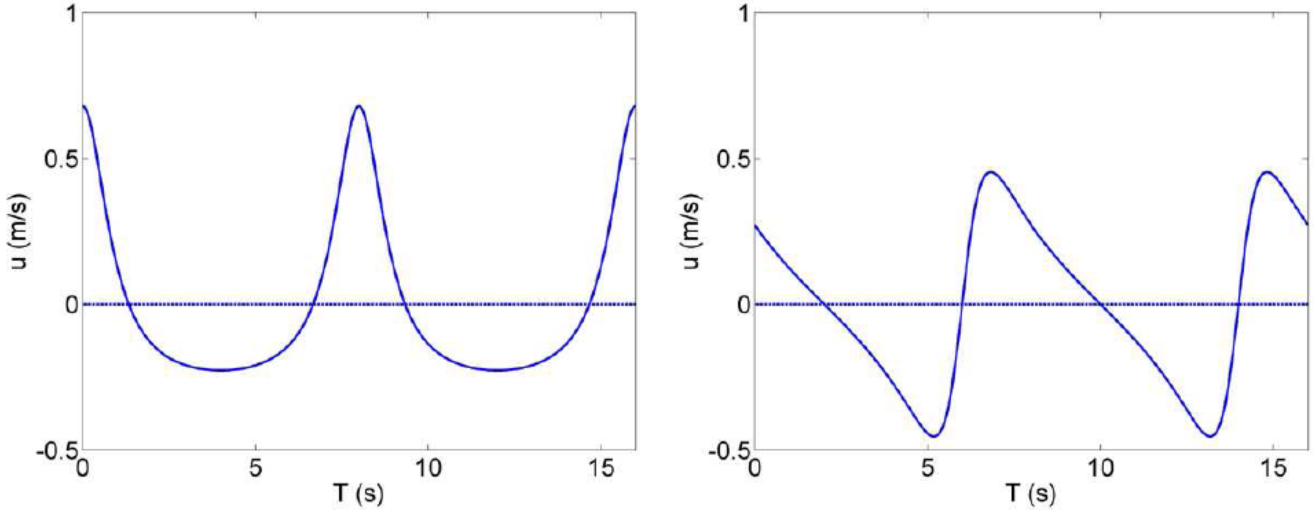


Fig. 4.2 Left panel: Stokes like free stream velocity generated with eq. (4.26) for Tp = 8 s, $\sigma(u_\infty)$ m/s, N=10 and $\Phi = 0$. Right panel: Similar but for a saw tooth shape free stream velocity obtained with $\Phi = 90^o$

Skewness and asymmetry

- Outside the breakerzone, waves are typically skewed (onshore velocity > offshore velocity)
- Important when transport is related to u^n
- Inside breakerzone, waves are more asymmetric (sawtooth-shaped)
- Important when transport is related to acceleration
  - Pressure gradient induced (Hoefel and Elgar)
  - Boundary layer thickness (Nielsen and Callaghan)
  - Phase lags in concentration (e.g. Ribberink and Chen)

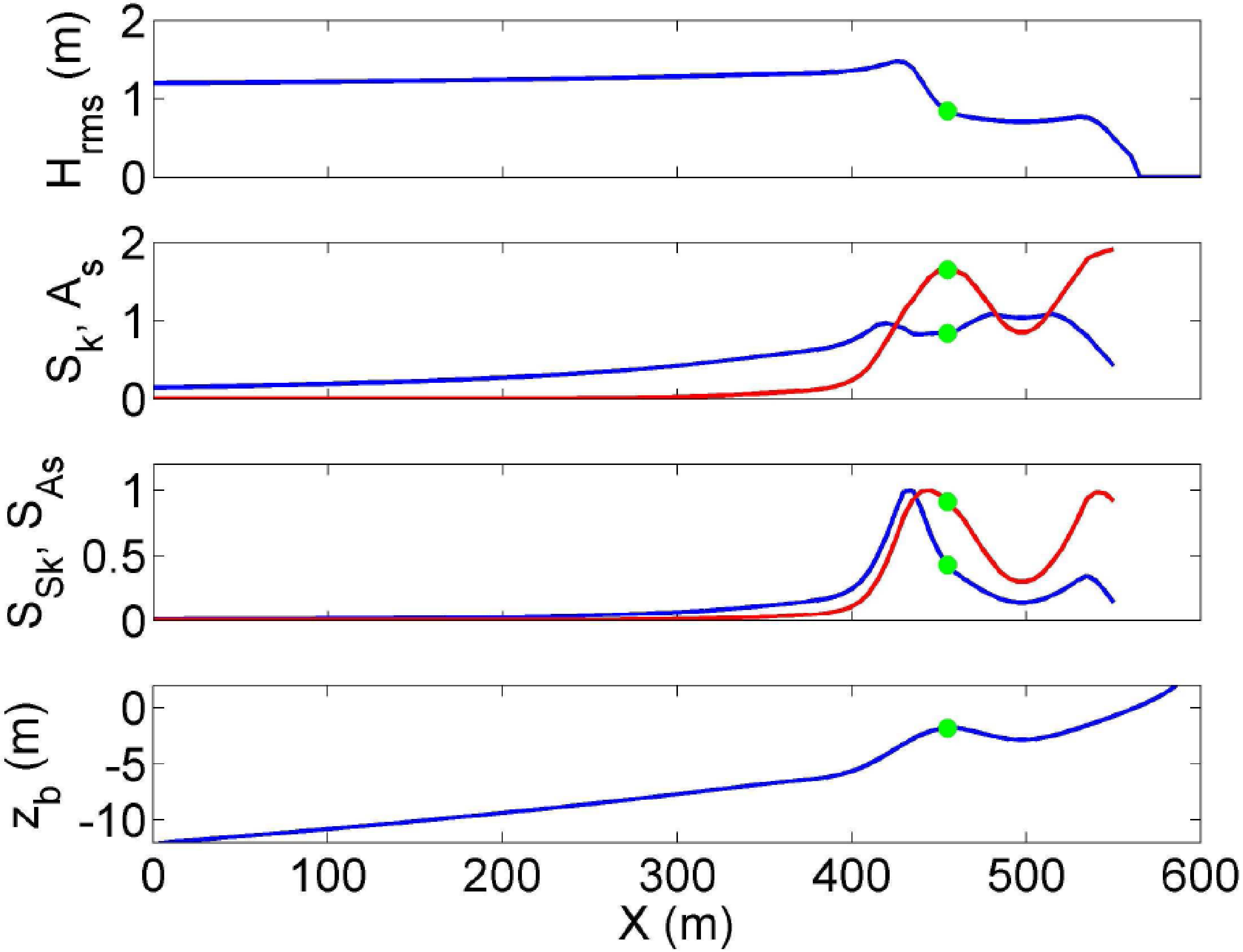


Fig. 4.5 Upper panel: Cross-shore wave height distribution. 2nd panel: corresponding S_k (blue) and A_s (red) obtained from tabulated data (see Figure 4.4). 3rd panel: Skewness (blue) and asymmetry-related (red) sediment transports (normalized by their respective maxima). Lower panel: Single barred bottom profile and position of the bar crest indicated by green dots.

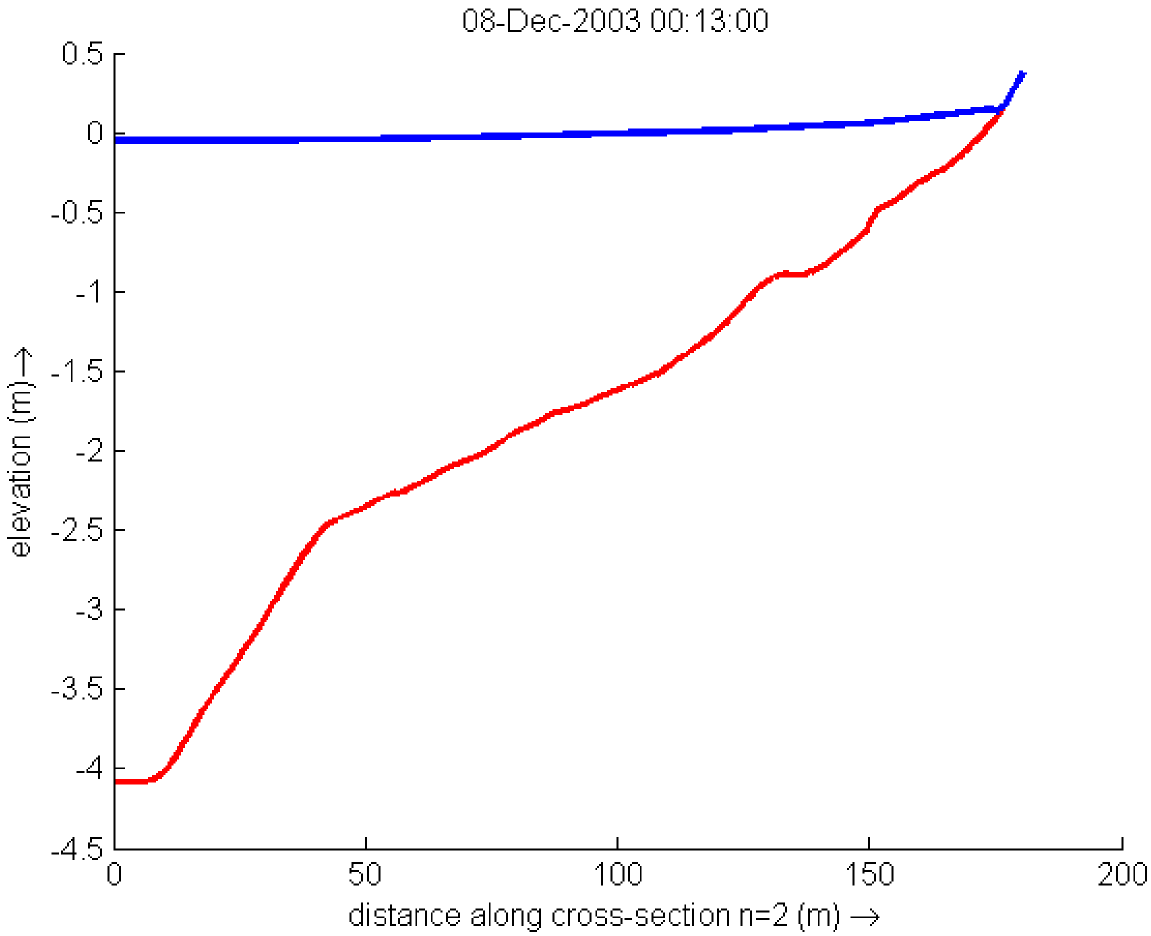
Wave flume example

- Example comparison Delft3D with Delta Flume test
- Hs= 1.4 m, Tp = 5 s
- Barred profile
- Lots of measurements
- Prototype conditions

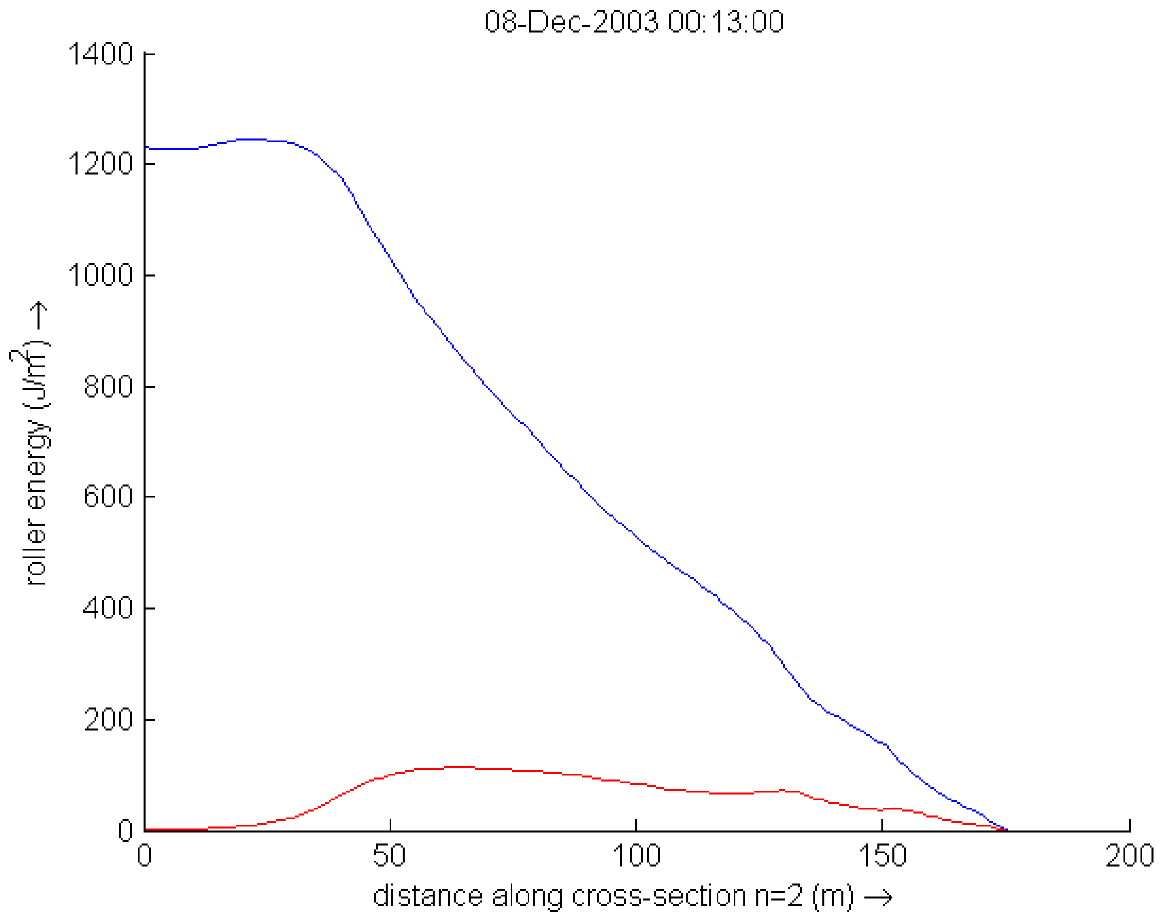
Delft3D

- Process-based model
- 2Dh, 2DV or 3D
- This application 2DV
- Based on wave and roller energy balance, 3D shallow water equations, 3D advection-diffusion equation
- Hydrodynamics and concentrations reasonably well modelled
- Sediment transport rate difficult

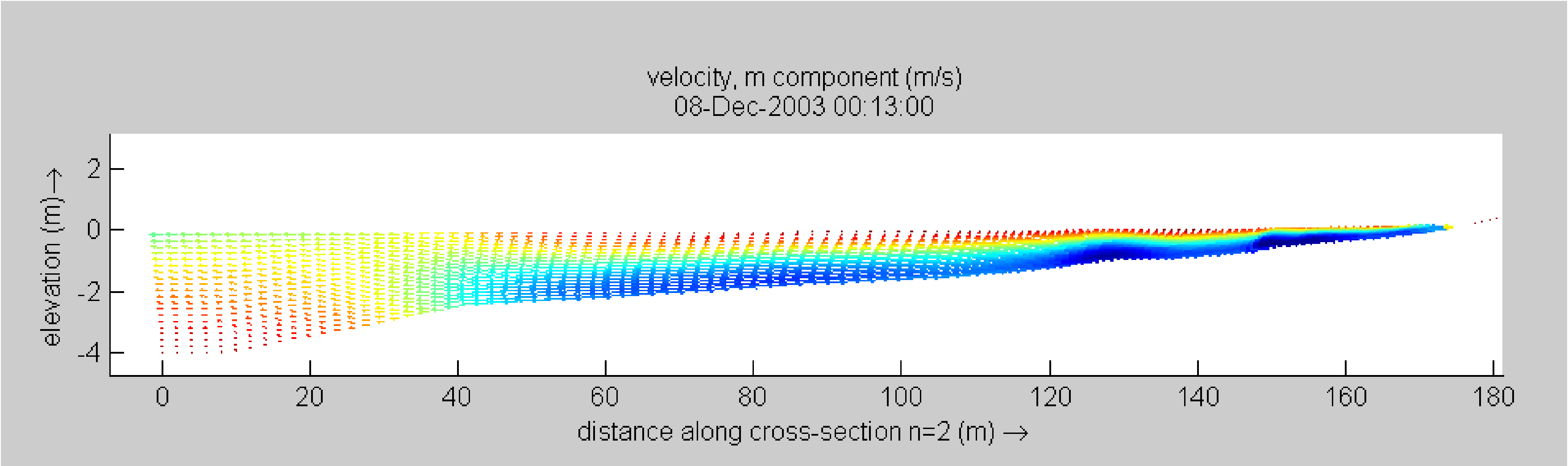
Initial profile

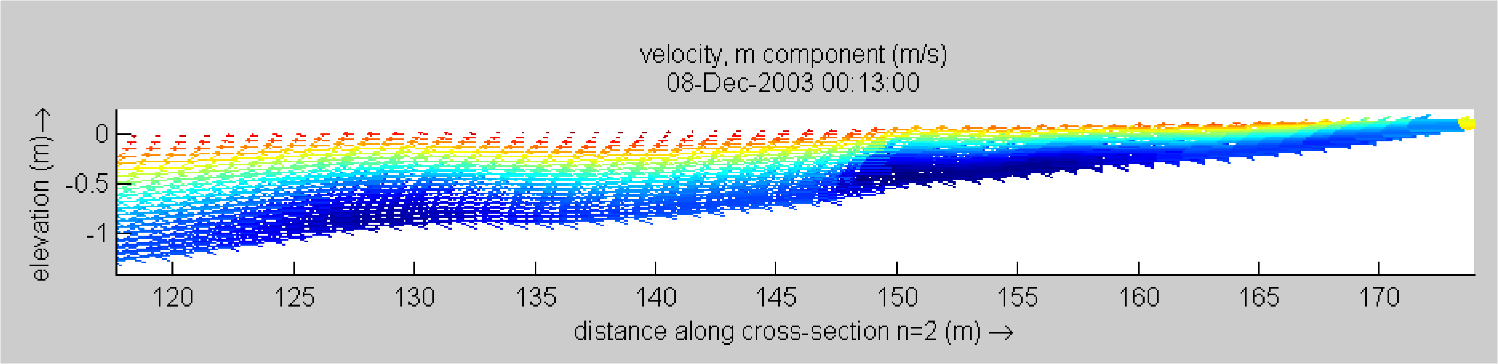


Wave and roller energy

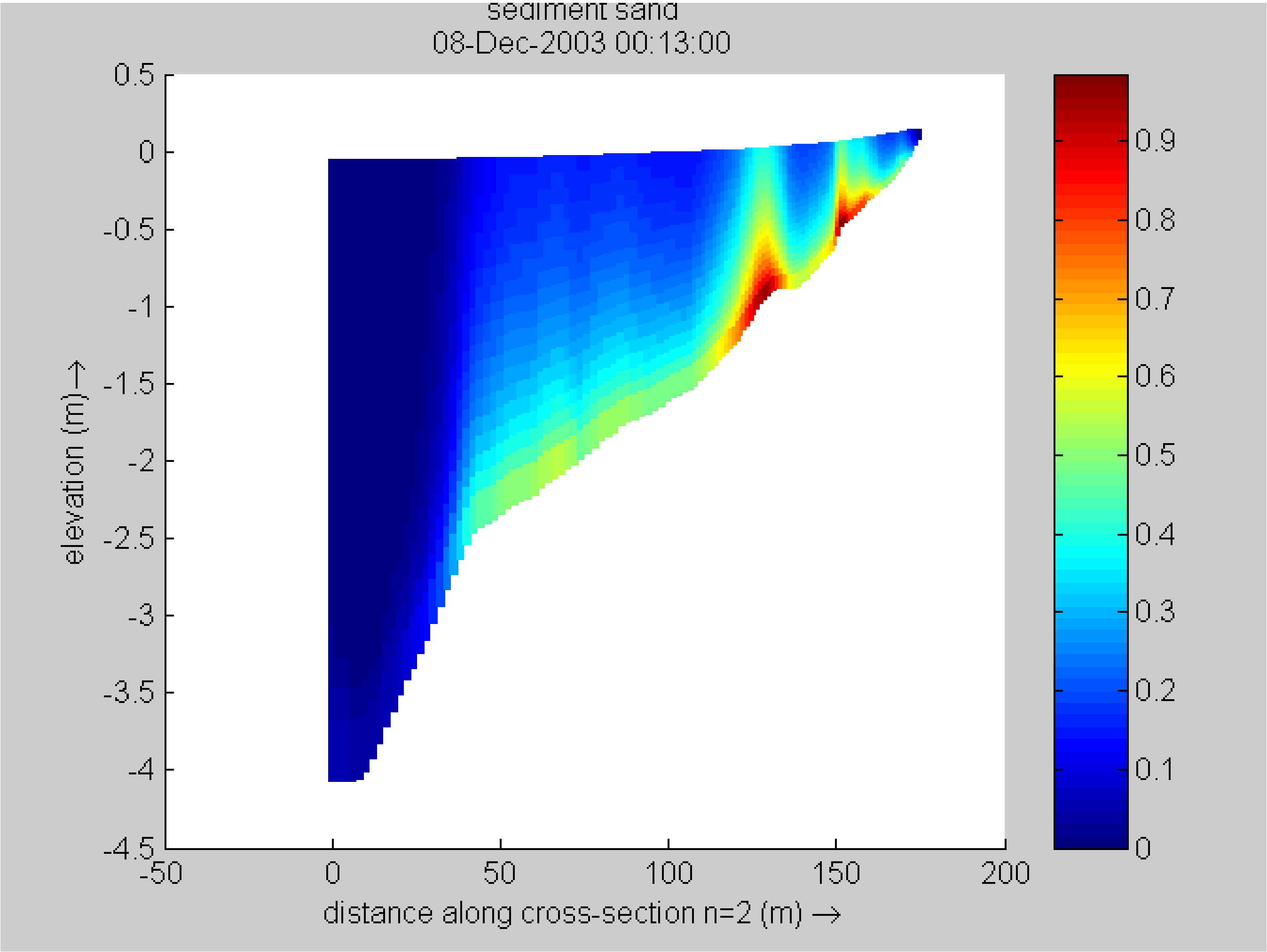


Velocity

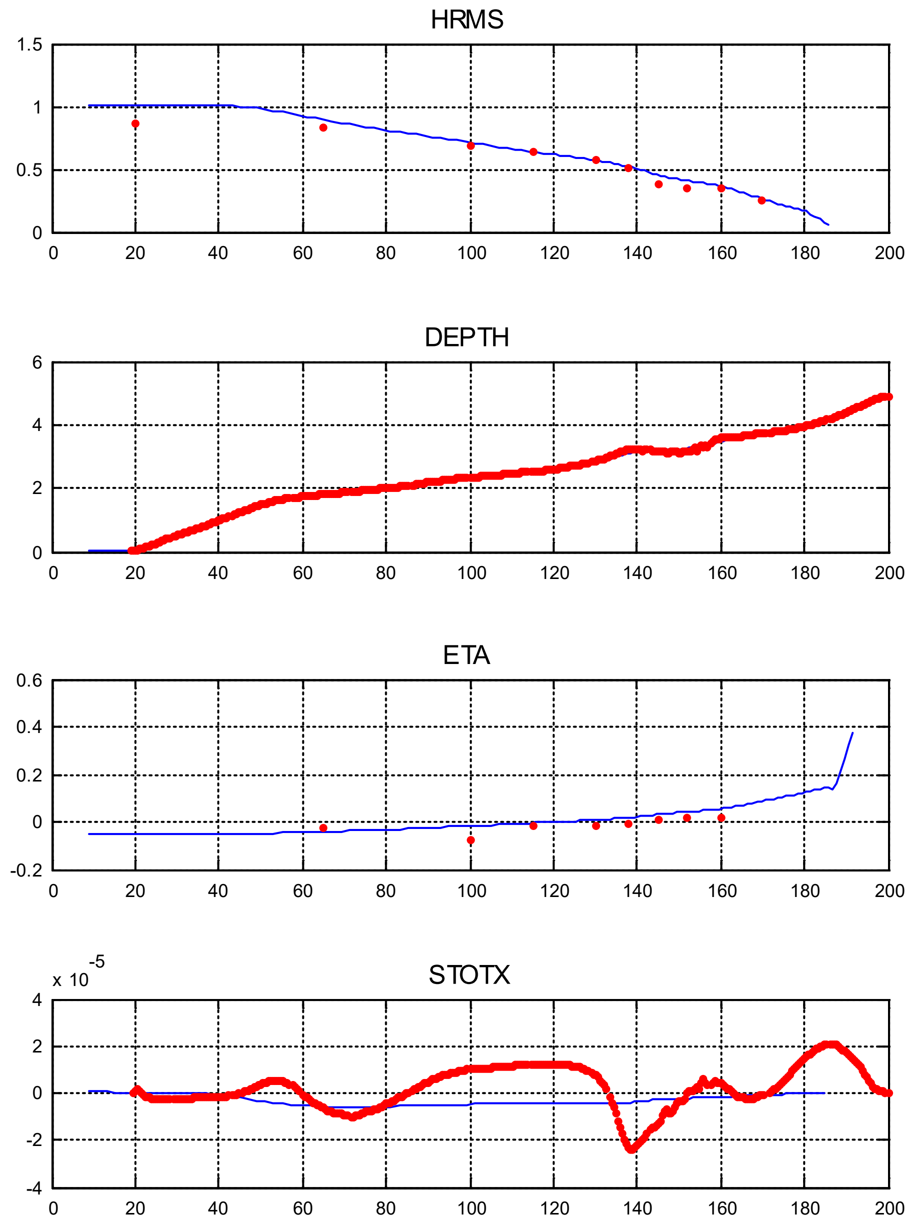

velocity, m component (m/s)
08-Dec-2003 00:13:00
elevation (m) →
2
0
-2
-4
0
20
40
60
80
100
120
140
160
180
distance along cross-section n=2 (m) →


velocity, m component (m/s)
08-Dec-2003 00:13:00
elevation (m) →
0
-0.5
-1
120
125
130
135
140
145
150
155
160
165
170
distance along cross-section n=2 (m) →

Sediment concentration



Example: hindcast of Delta Flume test with Delft3D



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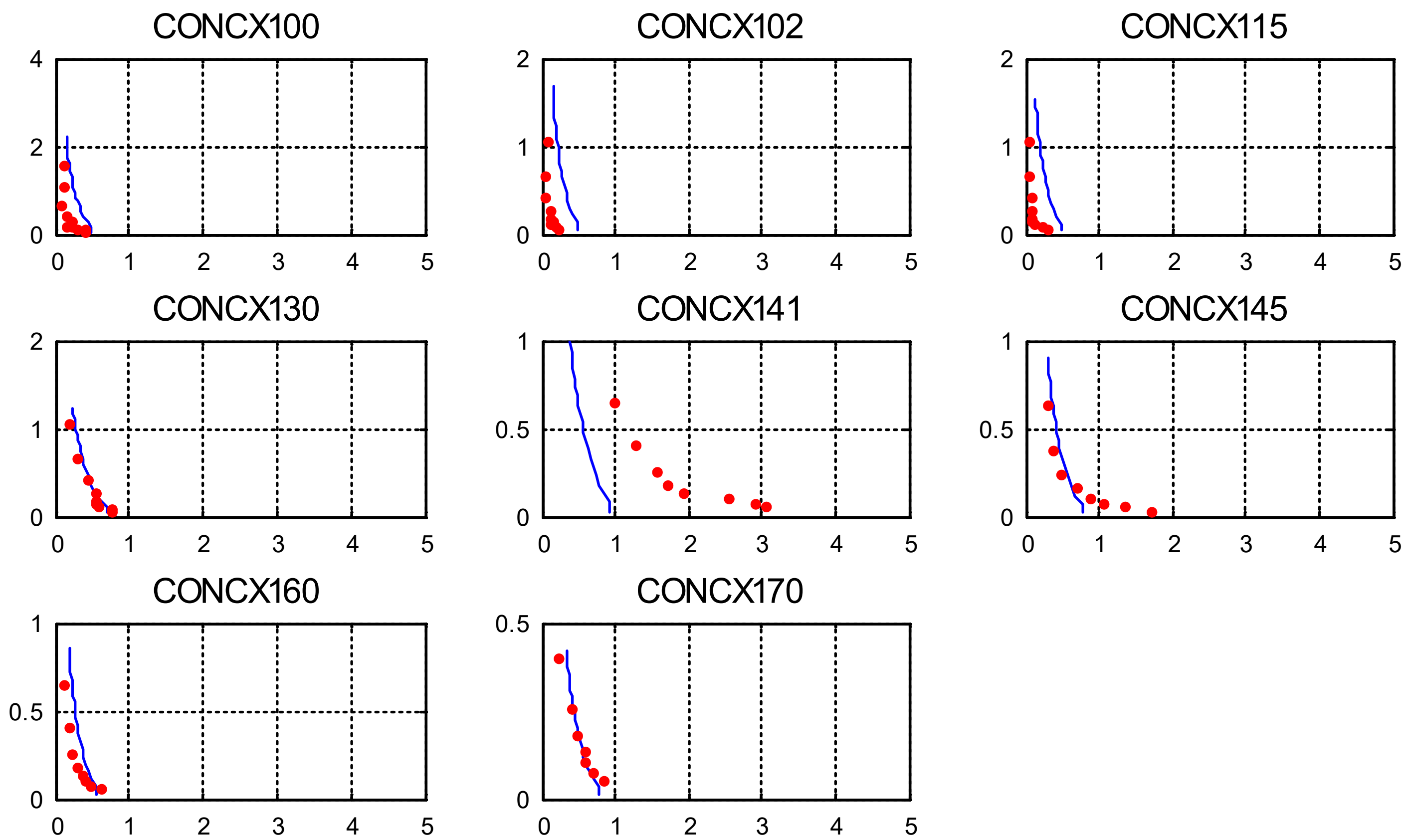
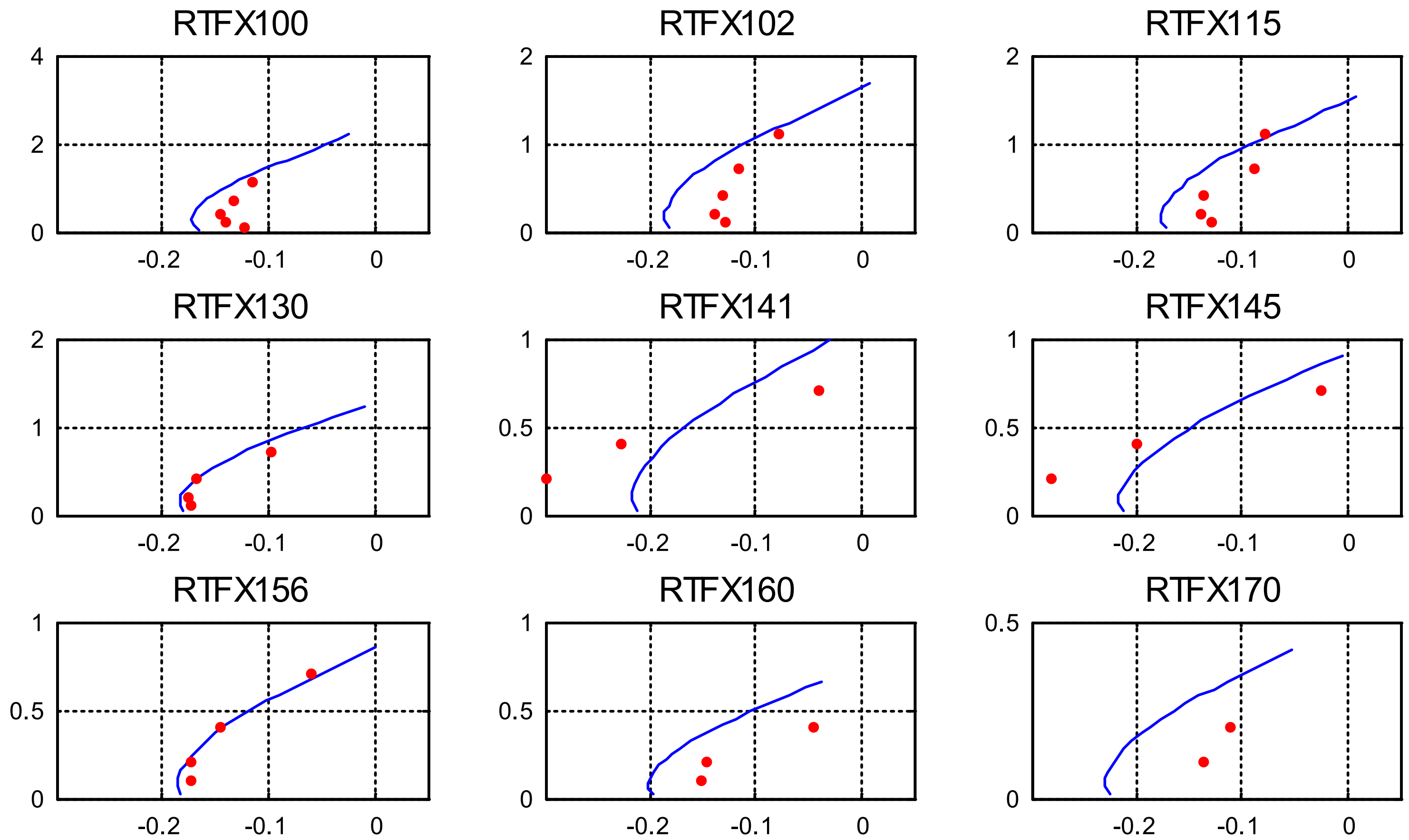
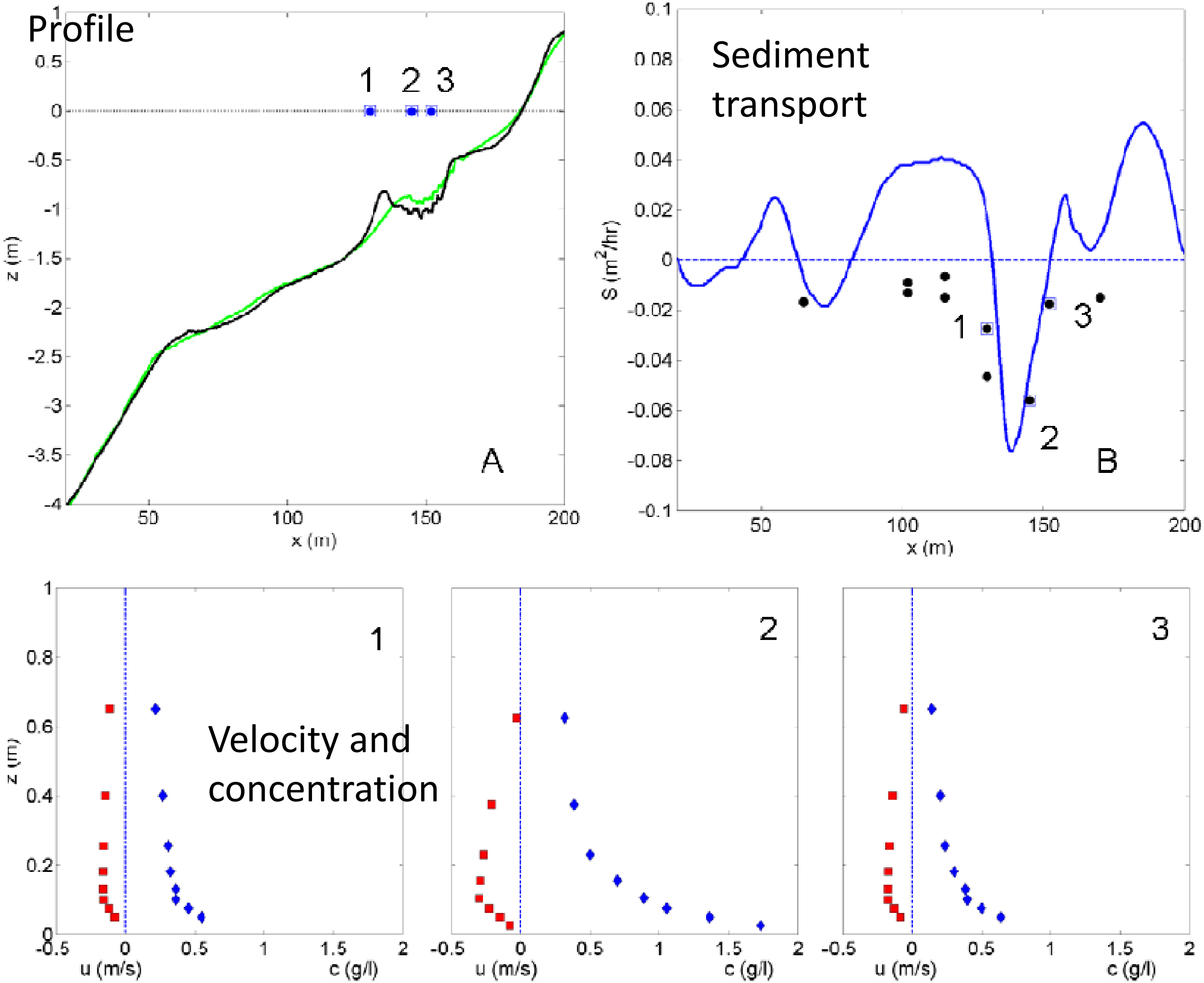
Concentration profiles



Velocity profiles



Delta Flume test 1B

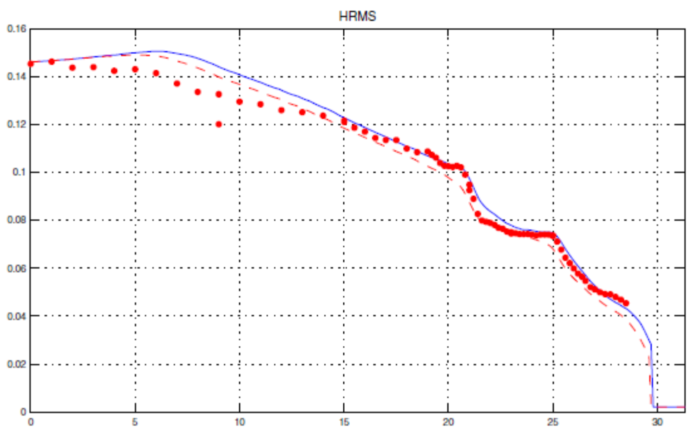


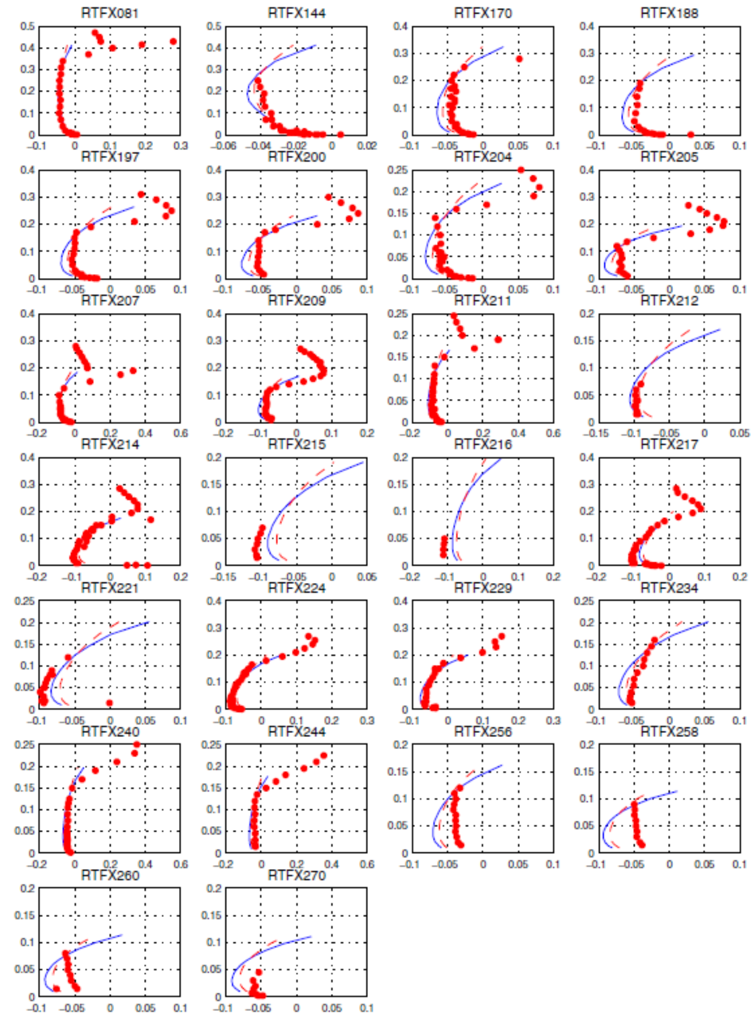
UNIBEST-TC

- Developed at Deltares
- Profile model for cross-shore behaviour
- Includes 1DV return flow model
- Has effect of skewness
- Infragravity waves effect schematized
- Well calibrated for profile behaviour

Test bank for model validation
Boers case 1B

- Flow profiles
- Wave height distribution





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Work by Ruessink, Walstra et al

- Massive calibration of Unibest-TC against profile data at Egmond (NL), Duck (US), Hasaki (Japan)
- Found settings with minor changes between sites
- Skill over weeks to years

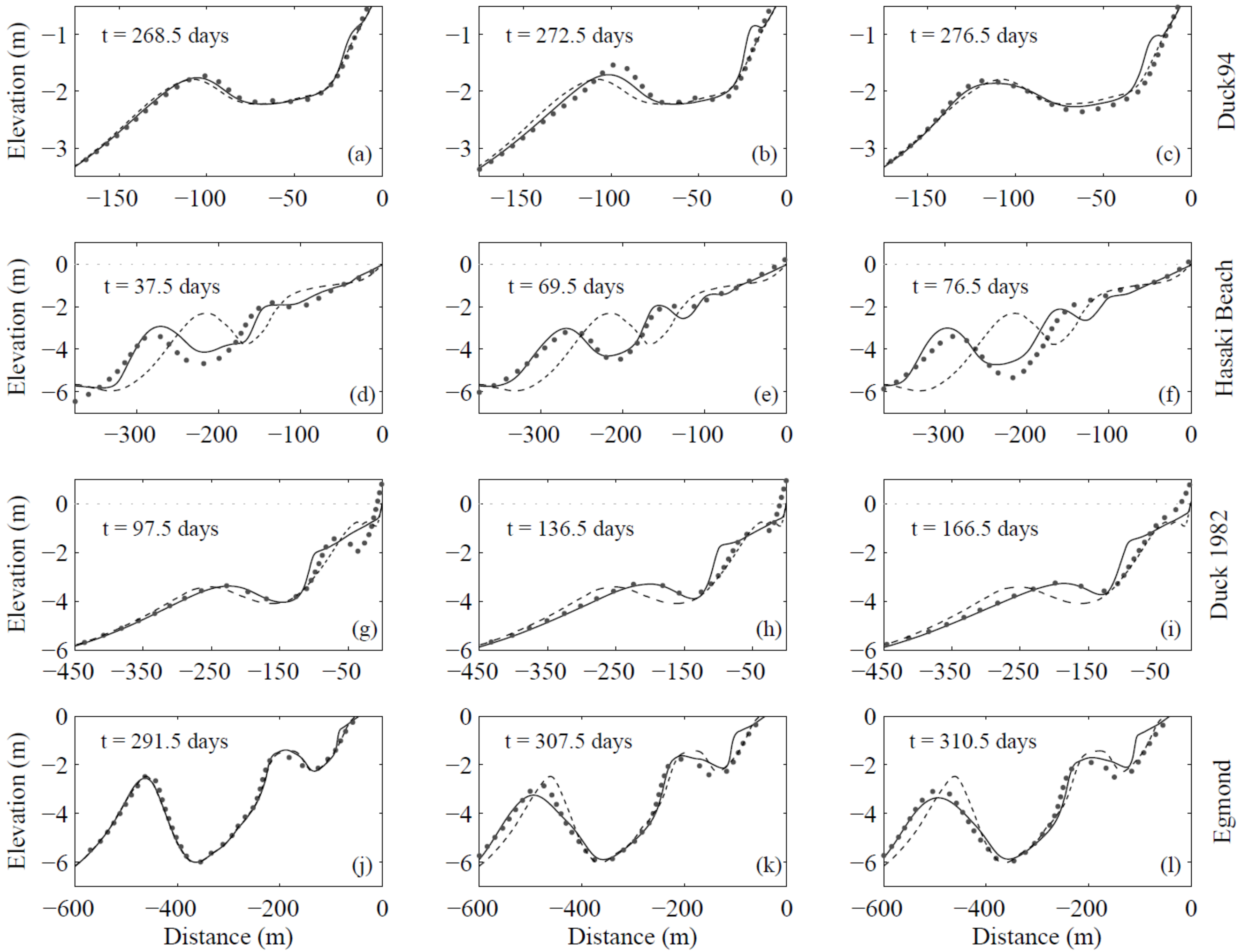
Ruessink et al, 2007

Duck94

Hasaki

Duck82

Egmond



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Summary

- Profile behaviour depends on a lot of competing processes
  – Return flow
  – Wave skewness and asymmetry
  – Bed slope effect
  – Streaming
  – Long wave-short wave interaction
- Bar growth or decay depends on location of transport peak relative to bar crest
  – Onshore transport: peak seaward of crest leads to growth
  – Offshore transport: peak landward of crest leads to growth
- Bar migration depends on mean transport direction

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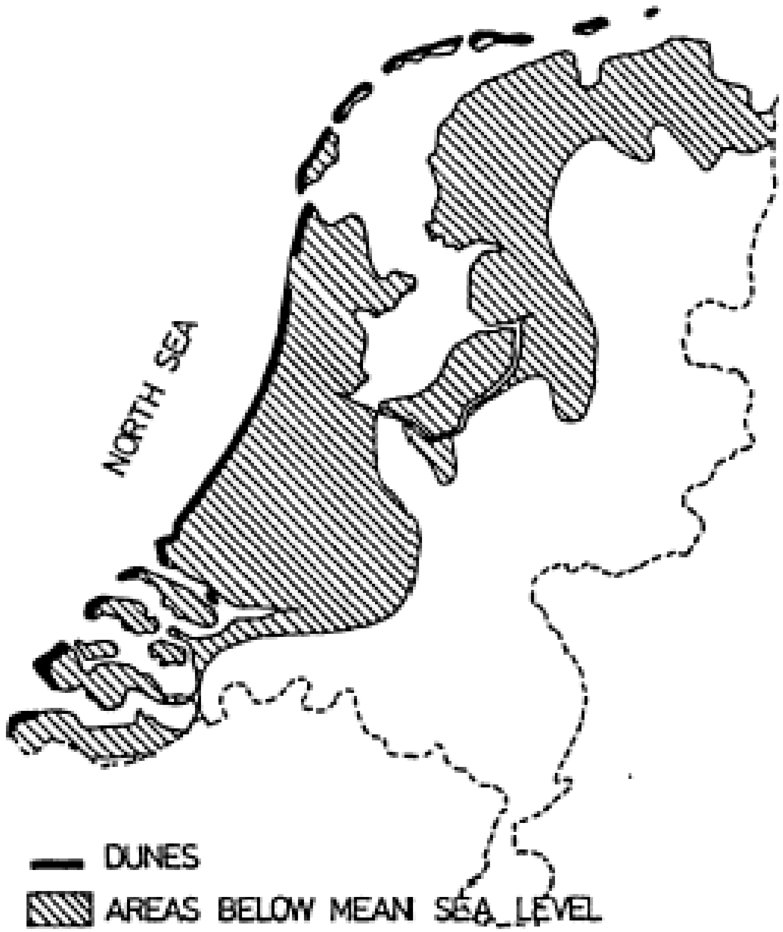
Dunes as coastal protection



Dune erosion

- Fast process
- Dominated by undertow that brings sand offshore
- Development of steep 'scarp'
- Undercutting by waves followed by slumping of scarp
- Eventually rather flat equilibrium profile

Dune erosion behaviour

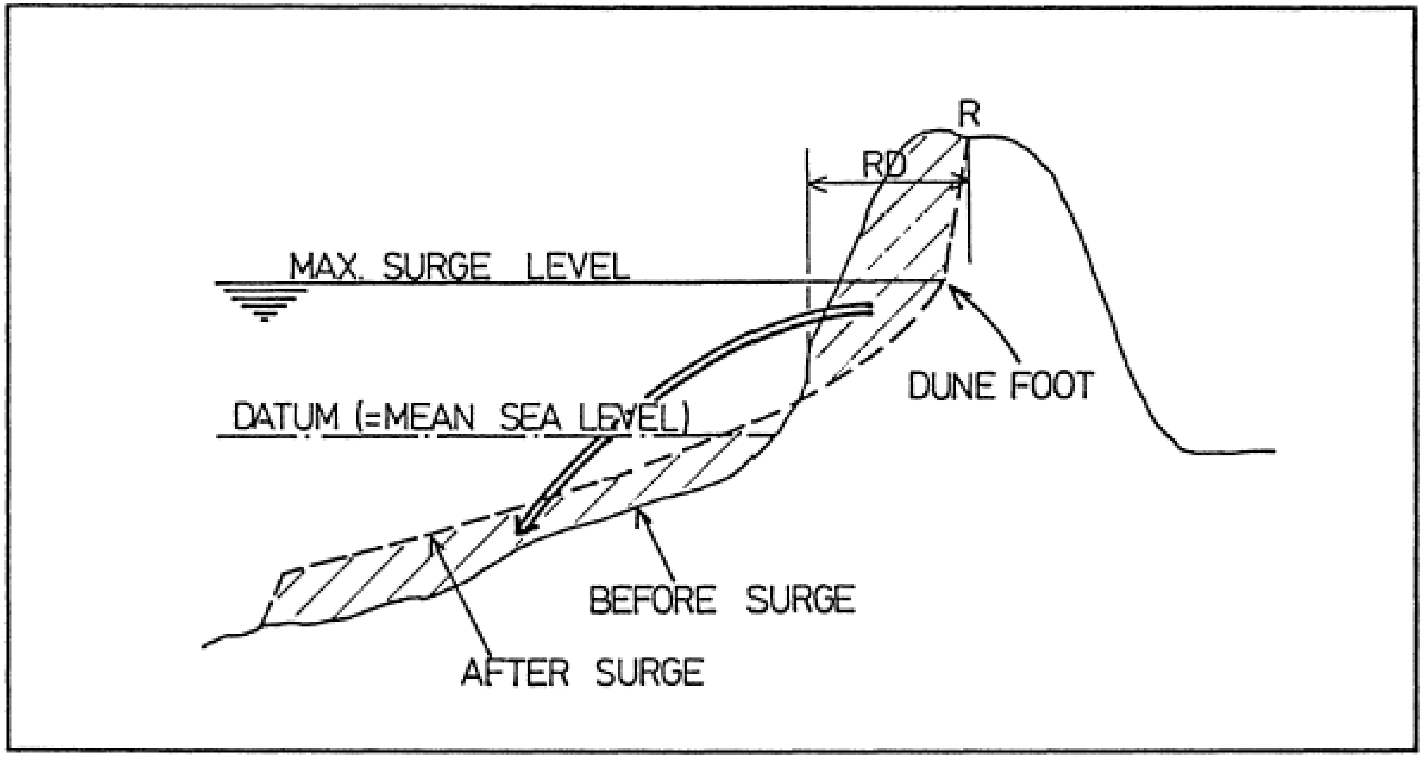
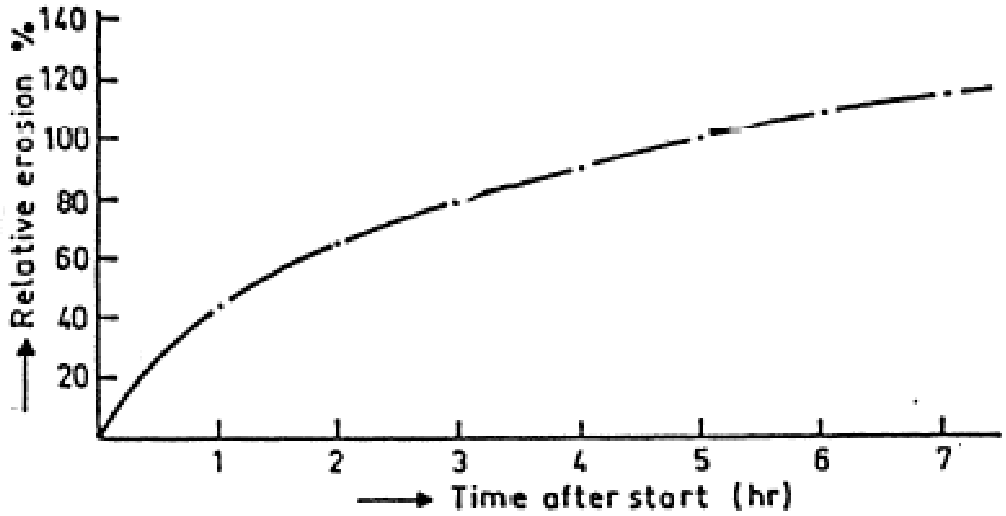


Fig.8.2.1 Schematic cross section of dunes in the Netherlands.

Behaviour in time



Equilibrium profile Vellinga

$$\left[\frac{7.6}{H_{o\ sig}}\right] y = 0.47 \left\{ \left[\frac{7.6}{H_{o\ sig}}\right]^{1.28} \left[\frac{w}{0.0268}\right]^{0.56} x + 18 \right\}^{0.5} - 2.00 \quad 8.4.1$$

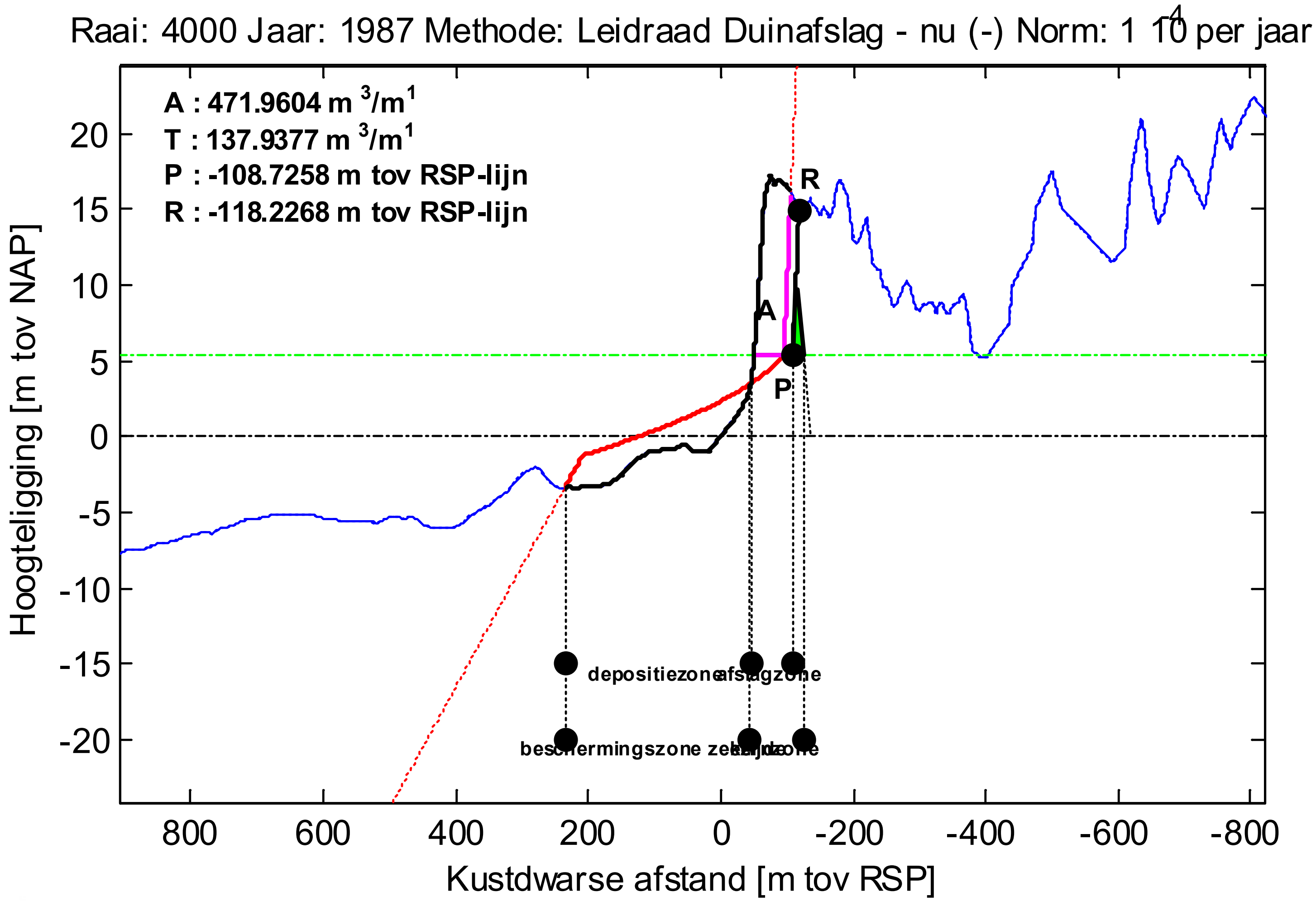
$H_{o\ sig}$: prototype significant 'deep' water wave height
w : fall velocity of bottom particles (= 0.0268 m/s; D_{50} = 225 μm)
x : distance from the new dune foot
y : depth below maximum storm surge level

- Based on lots of large-scale tests in wave flumes
- Specific for Dutch circumstances

Applying method

- Put equilibrium profile over existing profile
- compute area eroded and area accreted
- if eroded>accreted: shift seaward
- if accreted>eroded: shift landward
- find location where eroded=accreted

Dune erosion computation

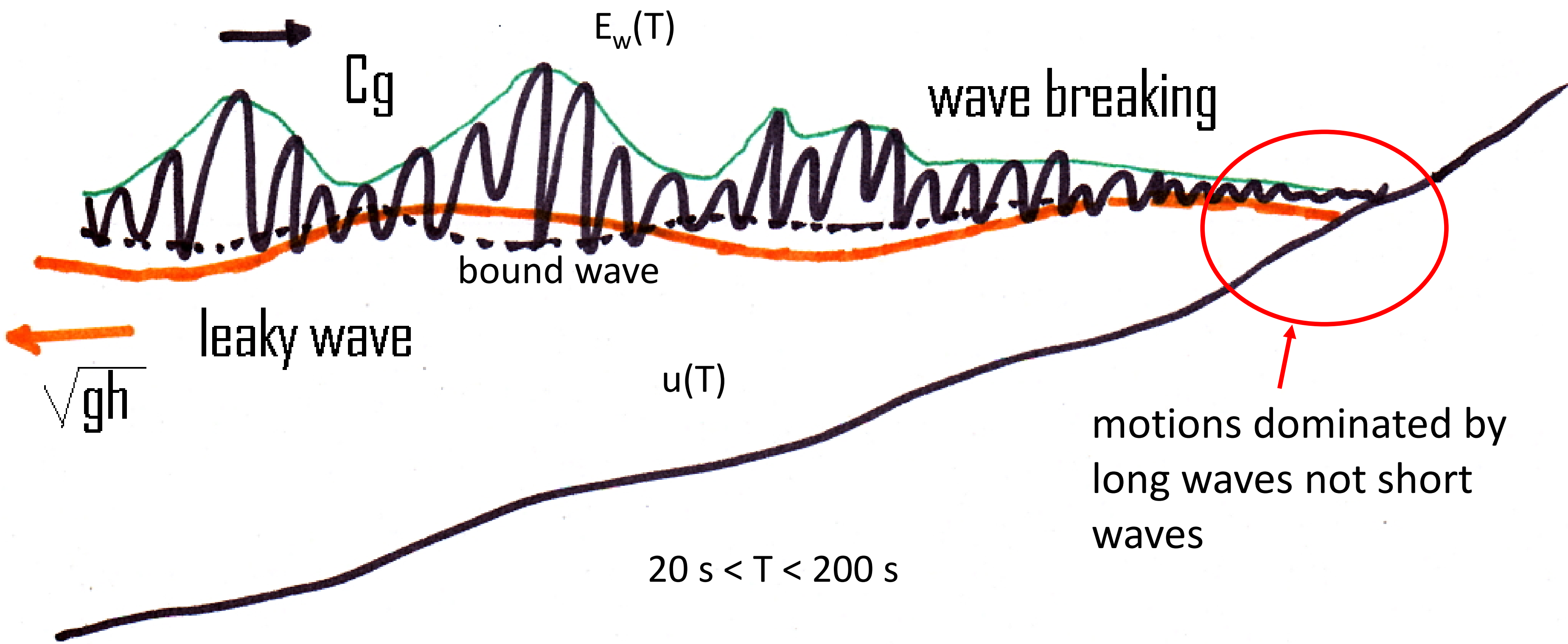


XBeach - approach

- open source code available for free on internet (xbeach.org)
- easy to use

- Short-wave averaged but long-wave resolving modeling of waves, flow and morphology change in time-domain
- Swash and overwash motions
- Dune erosion, overwashing, breaching and full inundation
- Domain from outside surfzone to backbarrier
- Driven by boundary conditions from surge and spectral wave models

Principle sketch - physics



Formulations

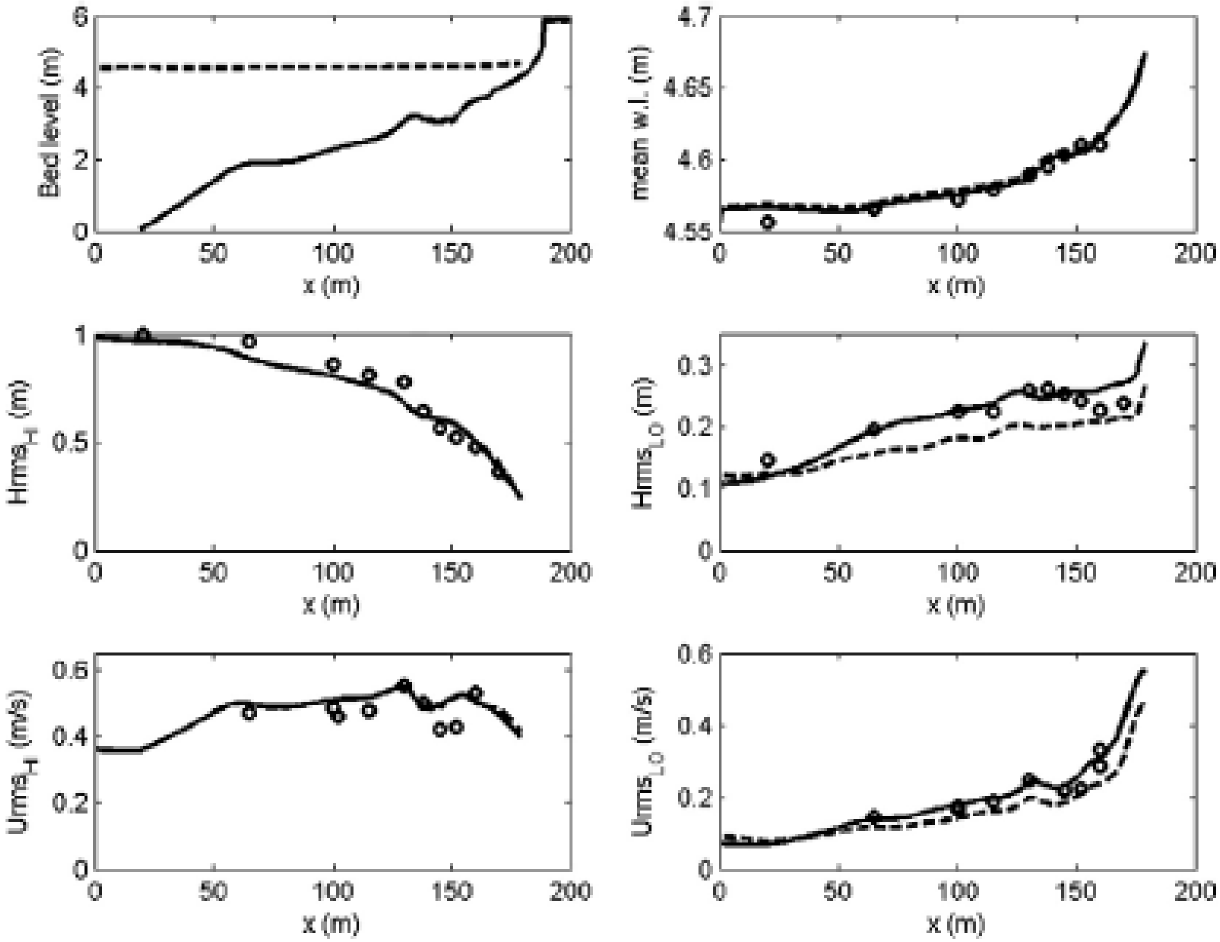
- Wave action balance
- Shallow water equations
- Advection-diffusion equation sediment
- Bed load transport
- Bed updating including avalanching

Example: LIP11D Delta Flume tests

Beach profile

Short wave height

Short wave orbital velocity



Wave setup

Long wave height

Long wave orbital velocity

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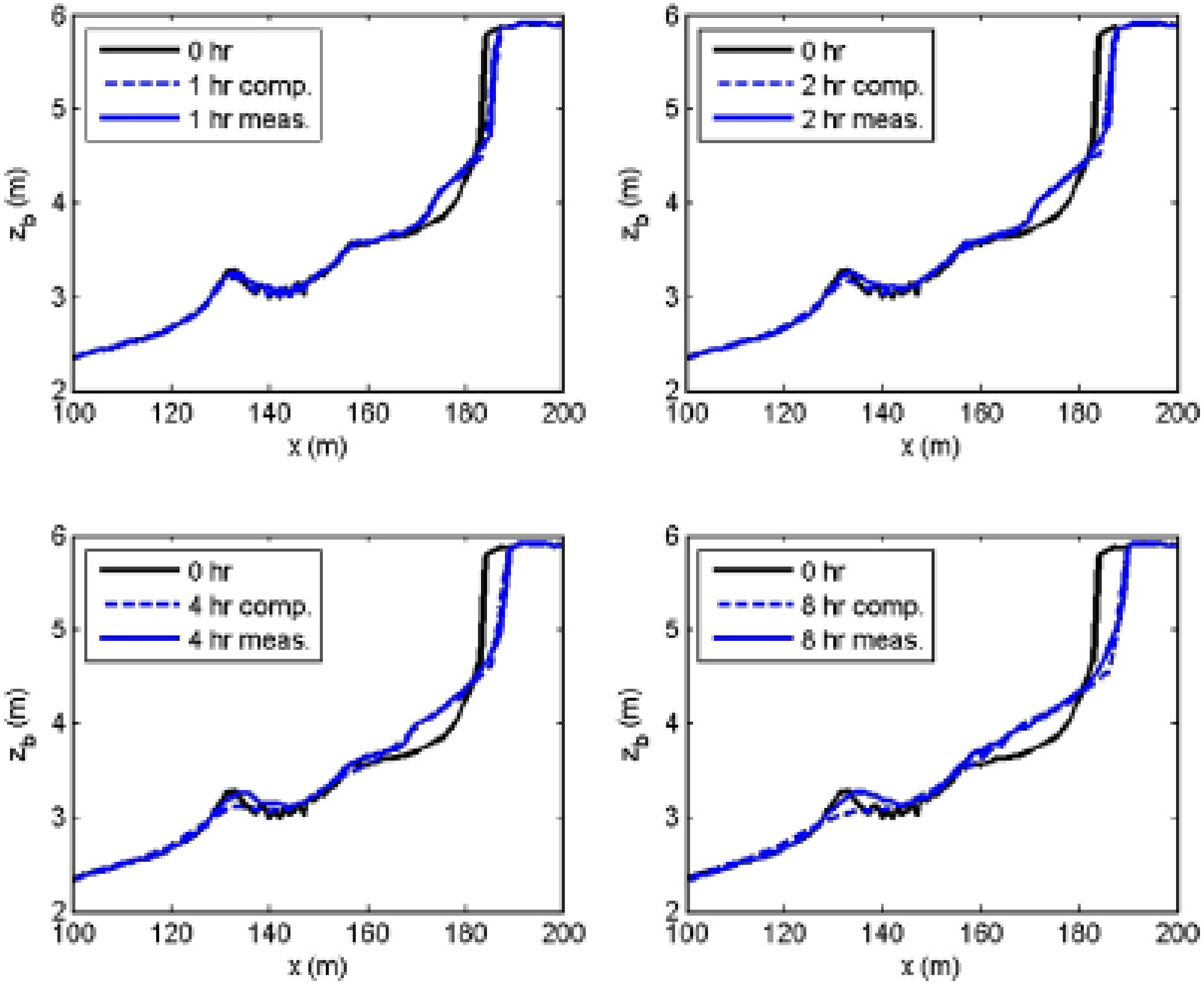
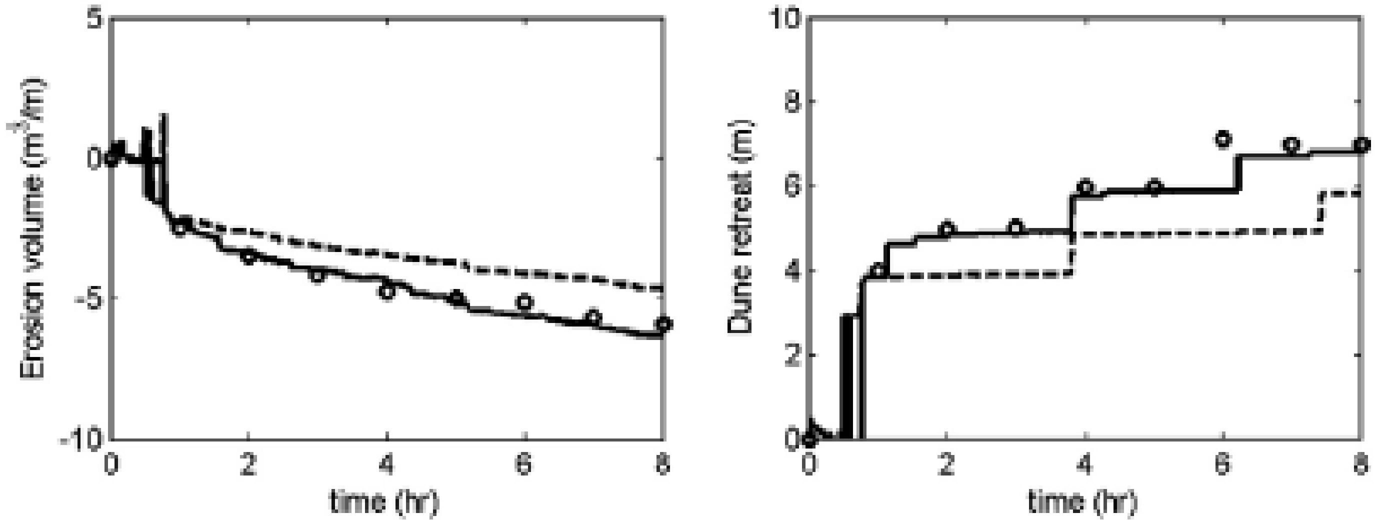
Profile development

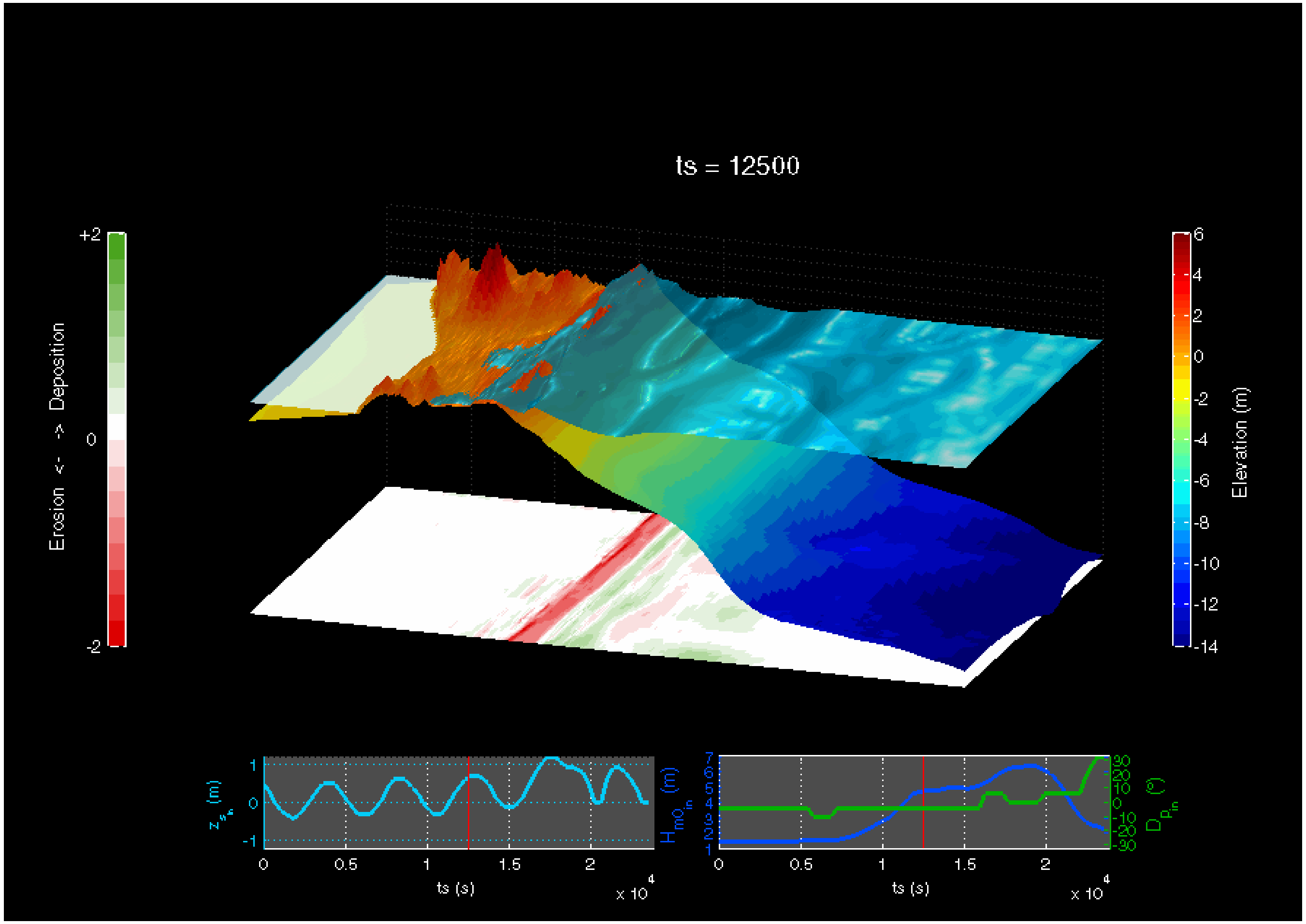


Erosion volume and dune retreat

Erosion volume and dune retreat



Overwash case: Santa Rosa Island

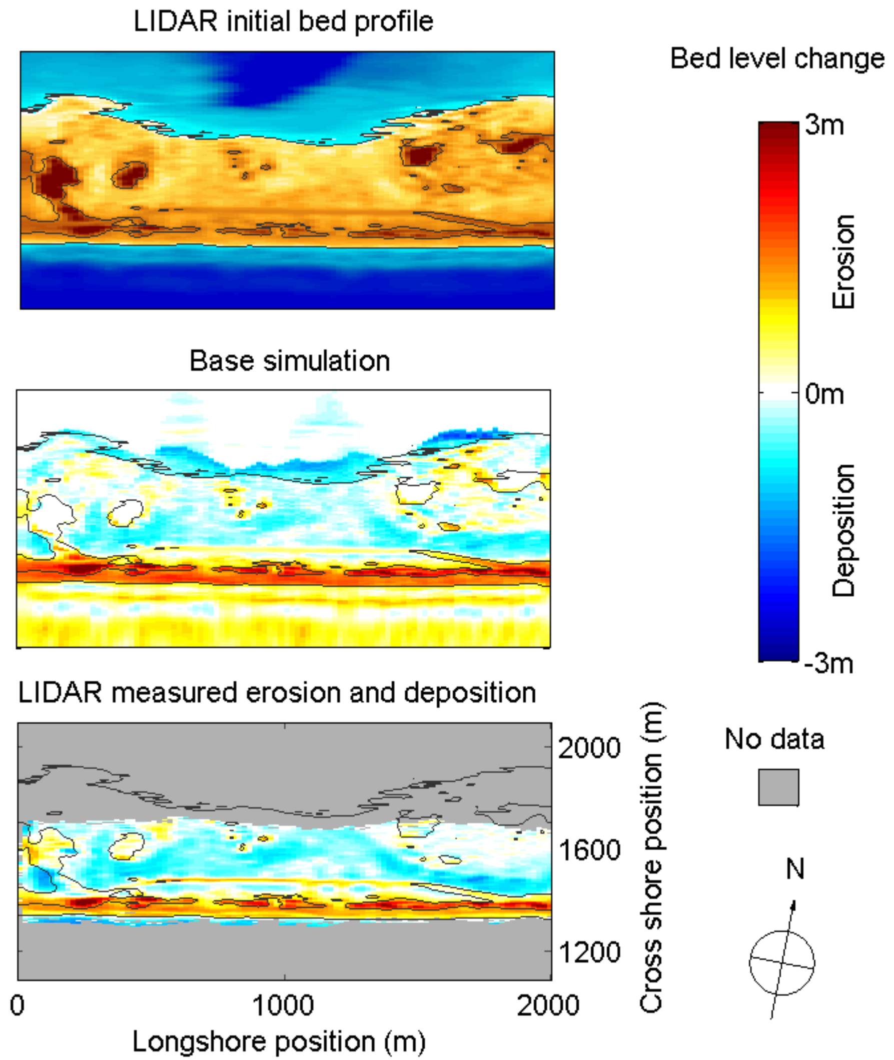


courtesy Dave Thompson, USGS

Overwash case: Santa Rosa Island

Similar erosion and deposition patterns:

- erosion of dune face
- deposition on island



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XBeach status

- Widely applied worldwide for storm/hurricane/cyclone impacts
- Prepared for official use in safety standards Dutch dunes
- Extended with wave-resolving model
- Find out more at xbeach.org