Soft Protection Approaches

Beach nourishments, dune rehabilitation and eco-engineering

Jaap van Thiel de Vries

Program

- Part I: Approaches and Technology (9:00-11:00)
  - Causes of coastal erosion
  - Soft protection approaches
  - Nourishments: The Dutch approach
  - Building with Nature
  - Mega nourishments: The Sand Engine
- Part II: Modelling event driven erosion (XBeach) (11:00-16:00)
  - Event driven erosion
  - XBeach Model concept
  - Hand on: Evaluate nourishment strategy at Kijkduin (NL) / hurricane case SantaRosa island
  - Advanced functionality: dune revetments, coral reefs, vegetation, gravel, long term simulations
- Part III: Presentation of local problems (by participants) (16:00-18:00)
  - Let participants prepare a few (=2) slides about there case

Part I

Causes of coastal erosion

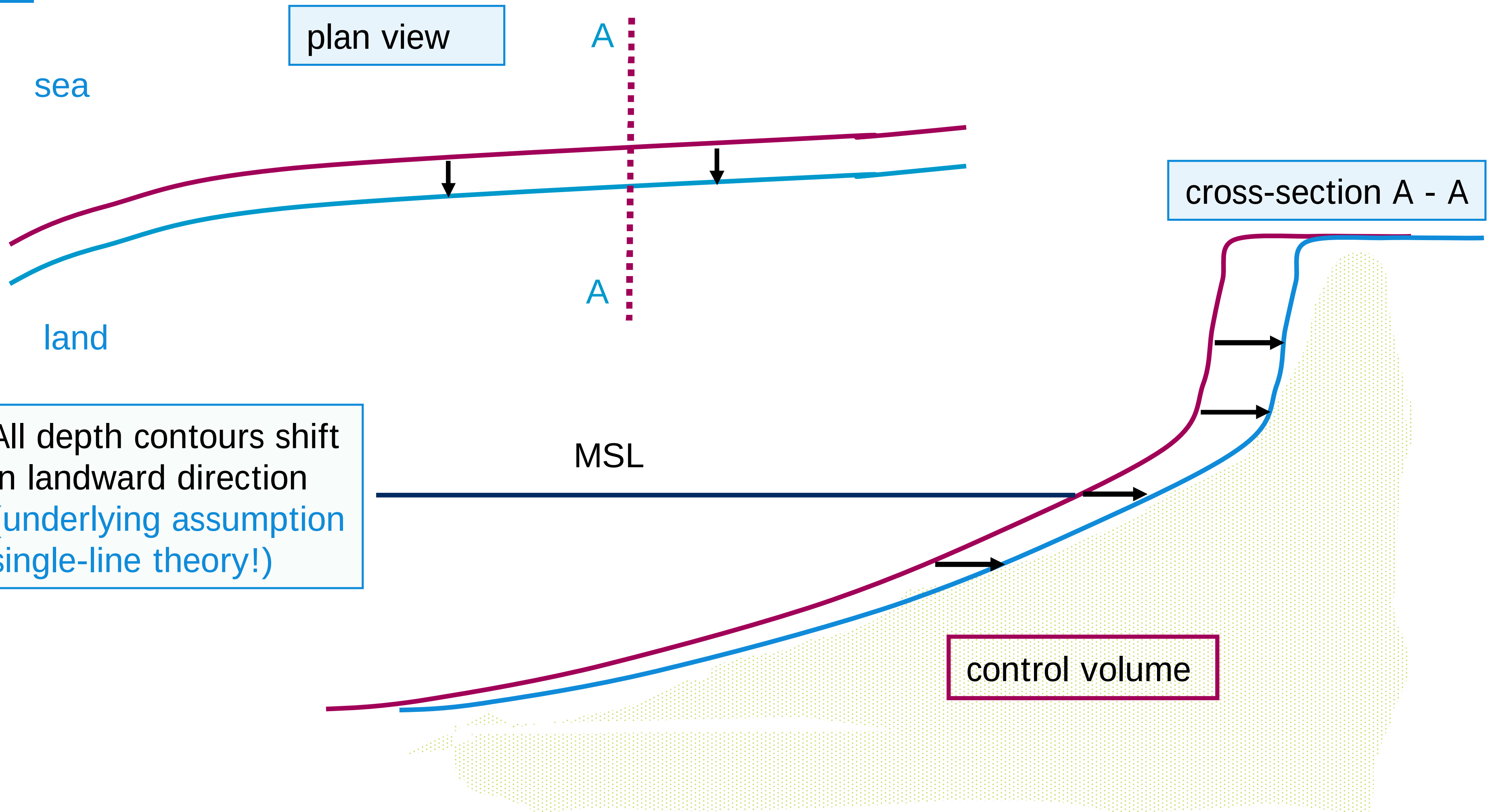
Types of coastal erosion processes

Two types of erosion

1. Structural erosion
   - long-term, gradual, due to ‘normal’ and slow processes
   - e.g. 1 m/yr or 20 m^3/m per year (if profile height is 20 m)
2. Episodic erosion, during severe storm (surge) events
   - i.e. dune erosion due to storm surge
   - fast process (hours)
   - e.g. 100 m^3/m in 6 hours or even 200 to 300 m^3/m (10 – 15 m) under design conditions

Types of coastal erosion processes

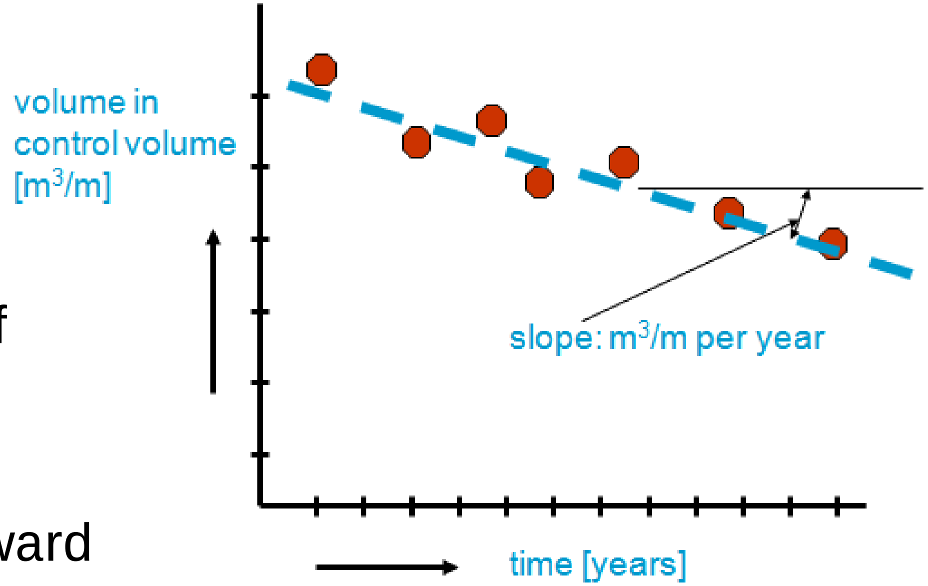
Structural erosion – control volume



All depth contours shift in landward direction (underlying assumption single-line theory!)

Types of coastal erosion processes

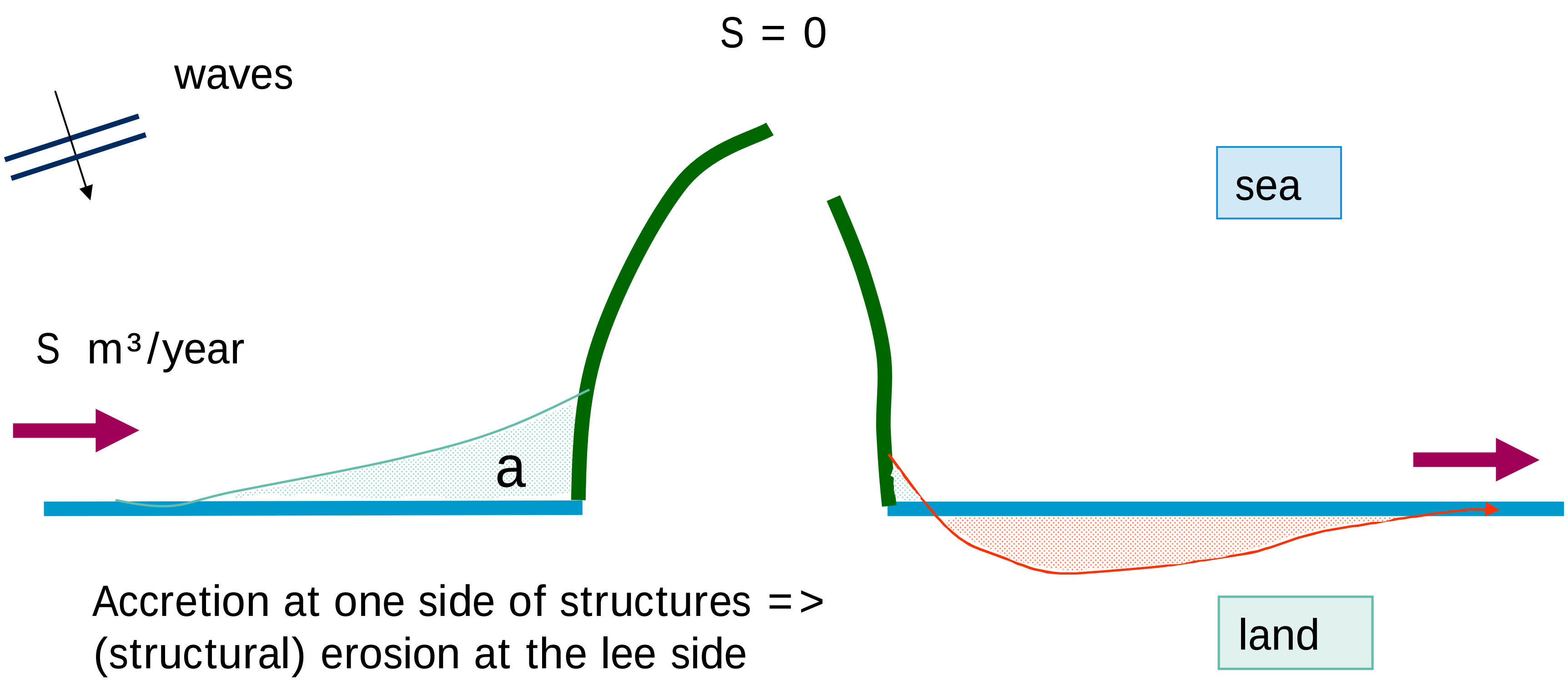
Rate of structural erosion



- Structural erosion due to loss of material out of control volume
- Permanent retreat of coast
- All depth contours shift in landward direction
- Structural erosion is often caused by gradient in longshore sediment transport

Types of coastal erosion processes

Example of structural erosion - Port



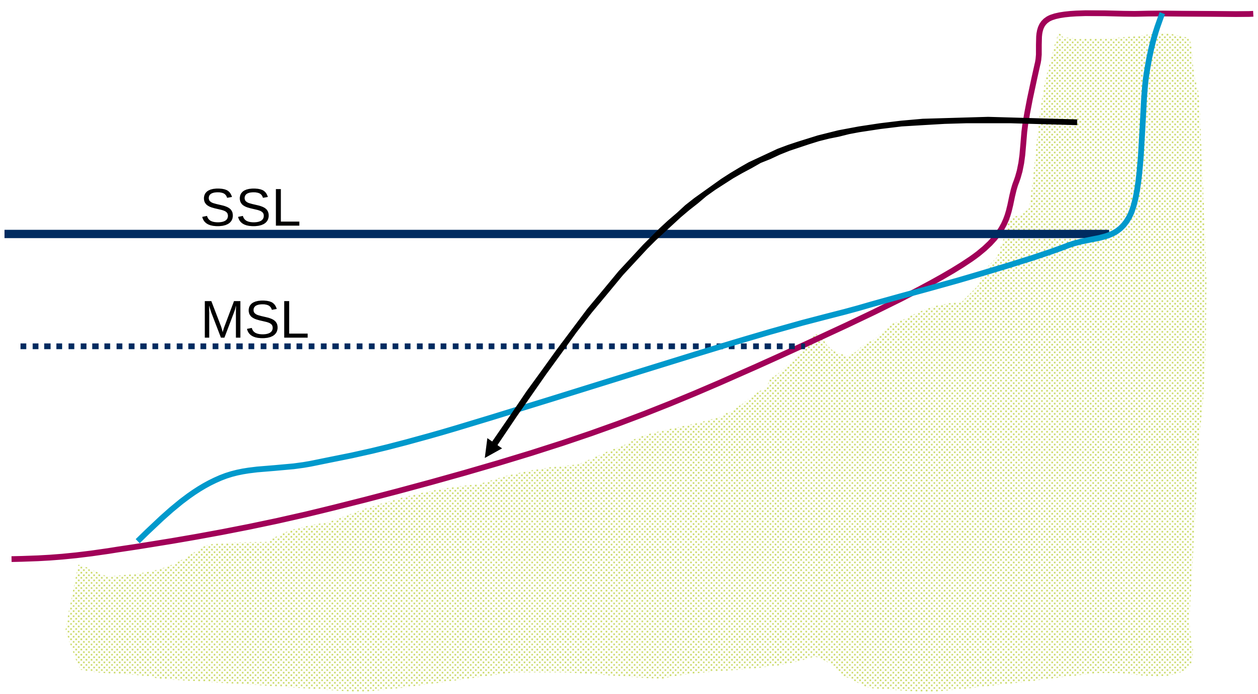
Accretion at one side of structures =>
(structural) erosion at the lee side

Types of coastal erosion processes

Dune erosion (episodic erosion)

Types of coastal erosion processes

Episodic erosion (dune erosion)



- storm event (SSL)
- redistribution over cross-shore profile
- no loss out of control volume
- return of sediments in non-storm season (in stable situations, i.e. no structural erosion)

Cyclic profile and bar behaviour

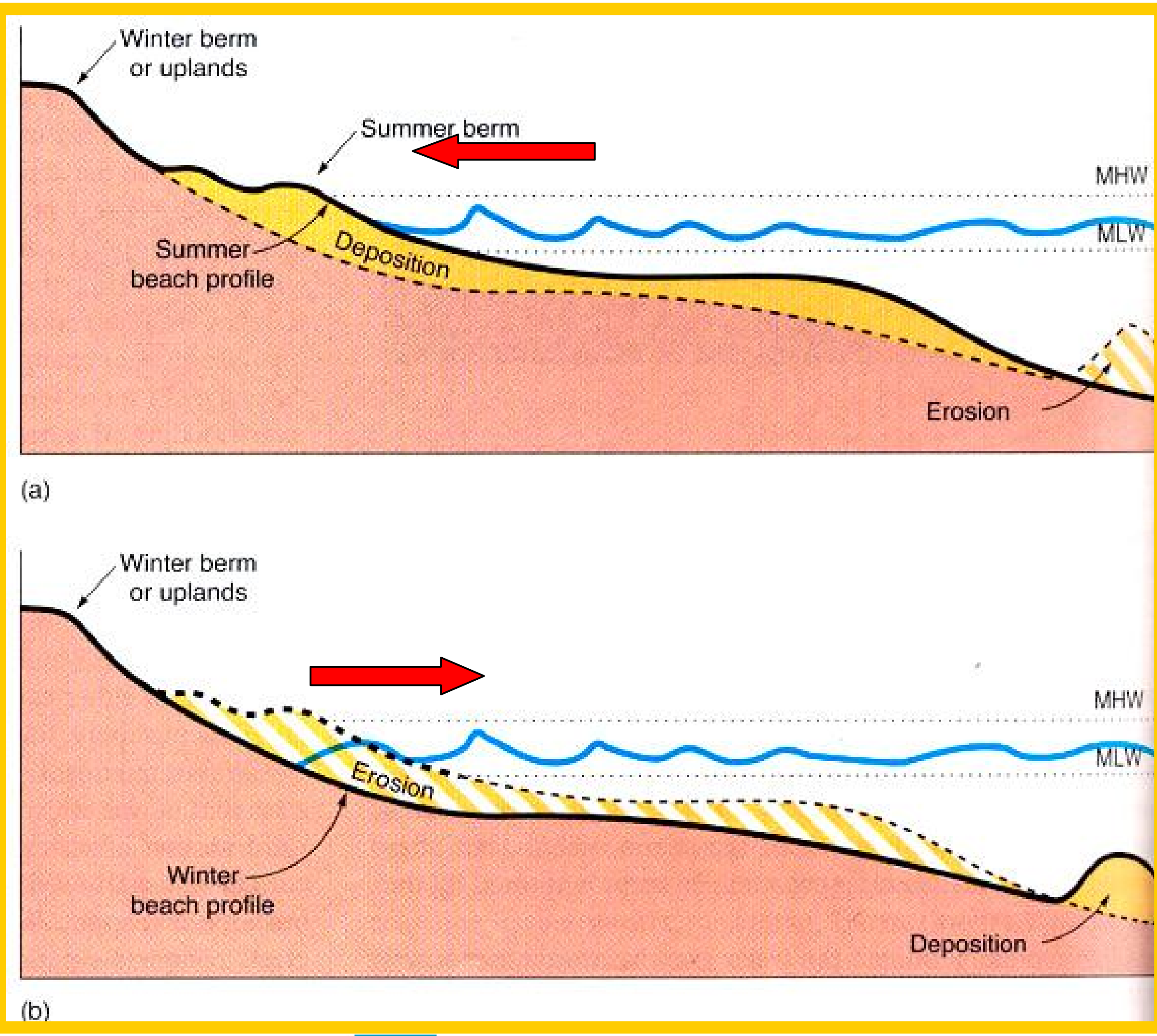
Storm and seasonal changes

Summer: beach rich in sediment

(resembling reflective beach)

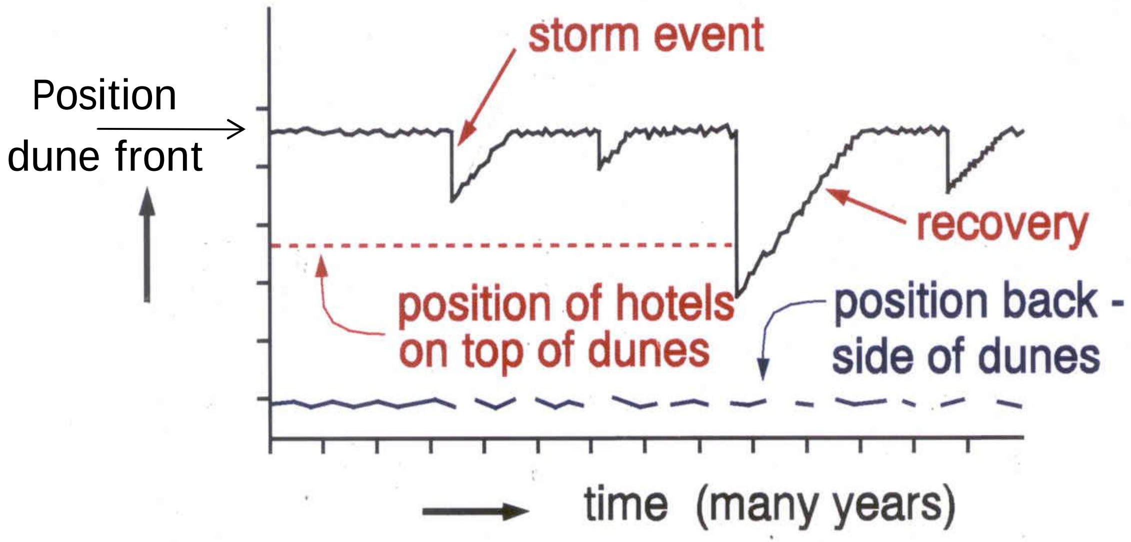
Winter and/or after storm: beach poor in sediment

(resembling dissipative beach)



Types of coastal erosion processes

Episodic erosion along a stable coast



Stable coast + storm surge events

Part I

Artificial Nourishments

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Coastal protection strategies

Selection of coastal protection method

- Important to have good insight in coastal processes
- Two basic approaches:
  1. Try to solve the cause of the erosion problem (cure the cause)
  2. Mitigate the negative effects (cure the symptoms)
- Possible solutions to mitigate coastal erosion problems:
  - "soft" (natural) measures (beach and foreshore nourishment)
  - "hard" measures (coastal structures)

Coastal protection strategies

Selection of coastal protection method

"Soft" methods: beach or foreshore nourishment

- Principle: compensate for eroded sand
- Erosion process does continue
- Must be repeated on regular basis
- If possible use sand from maintenance dredging ("make work with work")

Special "Soft" method: by-pass systems

- Re-store sediment transports from up-drift side of structure to down-drift side in an artificial way (pumping)

Coastal protection strategies

Selection of coastal protection method

"Hard" methods: groynes, offshore breakwaters, revetments, seawalls

- Principle = reduce erosion by interfering in sediment transports both alongshore and cross-shore
- But .... causes impact on down-drift coast!

Sub-division of "hard" methods

- Structures influencing longshore transport under both normal and extreme conditions (groynes, dam, detached breakwaters);
- Structures preventing erosion during extreme storm events (sea wall, revetment, sea dike).

Artificial nourishment ('soft' measures)

Introduction

- Artificial sand nourishment to:
  - Compensate structural erosion (regular basis).
  - Protect beach and dunes against storm erosion.
  - Create new beaches or reclaim new land.
- Must be repeated regularly (only treating symptoms).
- Leaves coast in natural state, without lee-side erosion.
- Flexible: scheme can be modified if results are not as expected.
- Good for coastal system: sediment is added to it.

Artificial nourishment ('soft' measures)

Introduction

- Nourishment can "never" go wrong (except for bad designed nourishment scheme, leading to damage of properties)
- Often economic solution due to its cost structure (no capital cost, only maintenance cost).

Artificial nourishment ('soft' measures)

Design aspects - Origin of sand

Borrow sand

- Land sources (river beds or sand deposits)
- Marine sources (estuaries or sea bed)
- Maintenance dredging
  (Dutch: "werk met werk maken")

Borrow pit

- At sufficiently large distance from shore
  (in NL = 20 km) to prevent erosion;
- Small and deep versus large and shallow?
  - Deep => stagnant water with poor quality
  - Large => environmental disturbance of surface layer
  - No clear recommendation. Perform environmental study

Artificial nourishment (‘soft’ measures)

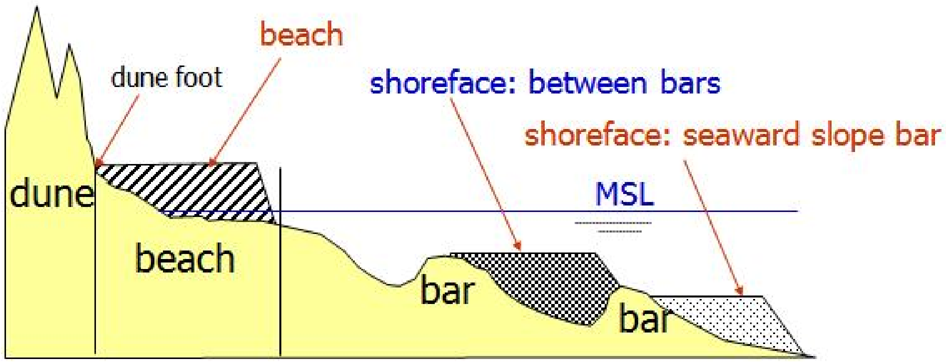
Design aspects - Quality of sand

- Use preferably borrow sand that is similar to native material (same behavior)
- Sometimes coarser material is used to reduce losses (steeper slopes).
- Borrow material contains silt (2% is normal), which may have negative impact on marine environment (during overflow).
- If necessary wash out silt before placing sand on beach.

Artificial nourishment (‘soft’ measures)

Design aspects - Location of nourishment

- Location of nourishment:
  - Landward slope of dunes
  - Seaward slope of dunes
  - Dry beach
  - Shoreface



- Sand for (landward) dune nourishment is often from land sources, because marine sand may cause salt problems for dune vegetation.
- Placing sand on beach requires dredging equipment to cross breaker zone. Rainbowing is alternative solution (shallow water).

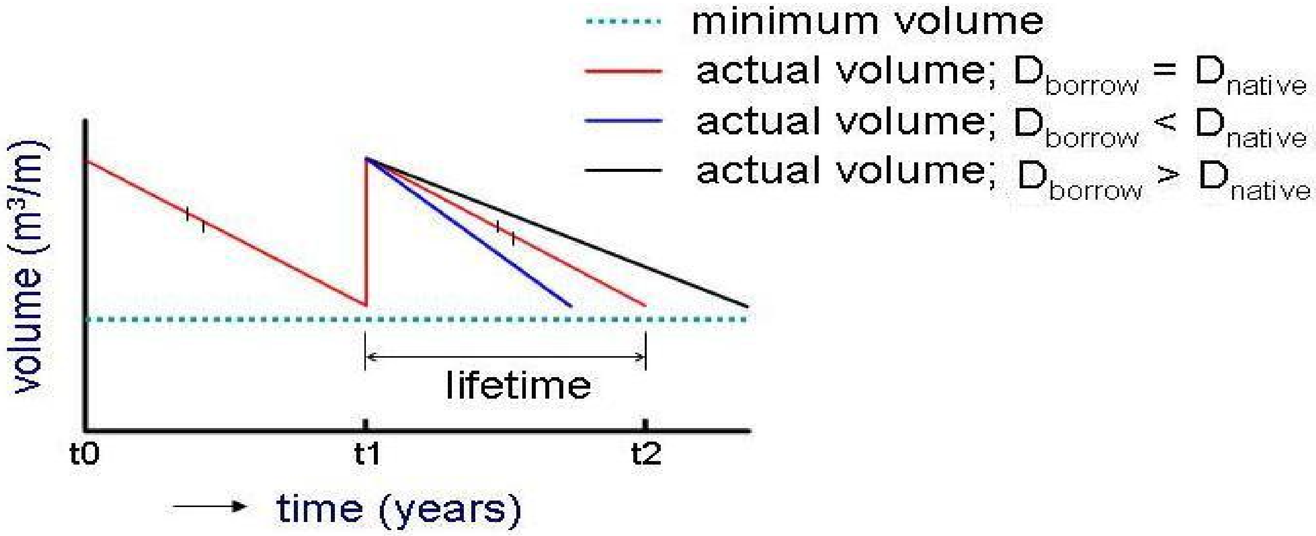
Artificial nourishment (‘soft’ measures)

Design aspects - Location of nourishment

- Shoreface nourishments are placed at the seaward edge of the surf zone where navigational depth of hopper dredger is sufficient.
- Shoreface nourishment may be more economical and recreation-friendly than beach nourishments.
- Effectiveness of beach nourishment is higher, but for higher unit cost.

Artificial nourishment ('soft' measures)

Re-nourishment for structural erosion



- Start re-nourishment at moment of minimum beach volume (t_1).
- Generally lifetime is 5 to 10 years (due to high mobilization costs).
- If borrow and native sand is the same => erosion is the same (red) => lifetime is $(t_2 - t_1) = (t_1 - t_0)$.
- Borrow sand coarser => loss decreases => lifetime increases (black)
- Borrow sand finer => loss increases => lifetime decreases (blue)

Artificial nourishment ('soft' measures)

Example nourishment project

- Assume coastline retreat is 2 m per year => sand loss over total profile height (20 m) is $\Delta V = 40\ m^3/m'$ per year.
- Assume period between nourishments is 5 year => volume to be nourished is 200 m^3/m' every 5 years.
- Assume stretch of coast is 5 km long => total volume to be nourished is 1,000,000 m^3 every 5 years.
- Volume is increased with 10% to 20% to account for additional losses of the fine fraction.
- Make "win-win" contract with contractor:
  - Long term contract
  - Control method (as built survey or hopper volume measurements)
  - Combine foreshore with beach nourishment (flexibility contractor).

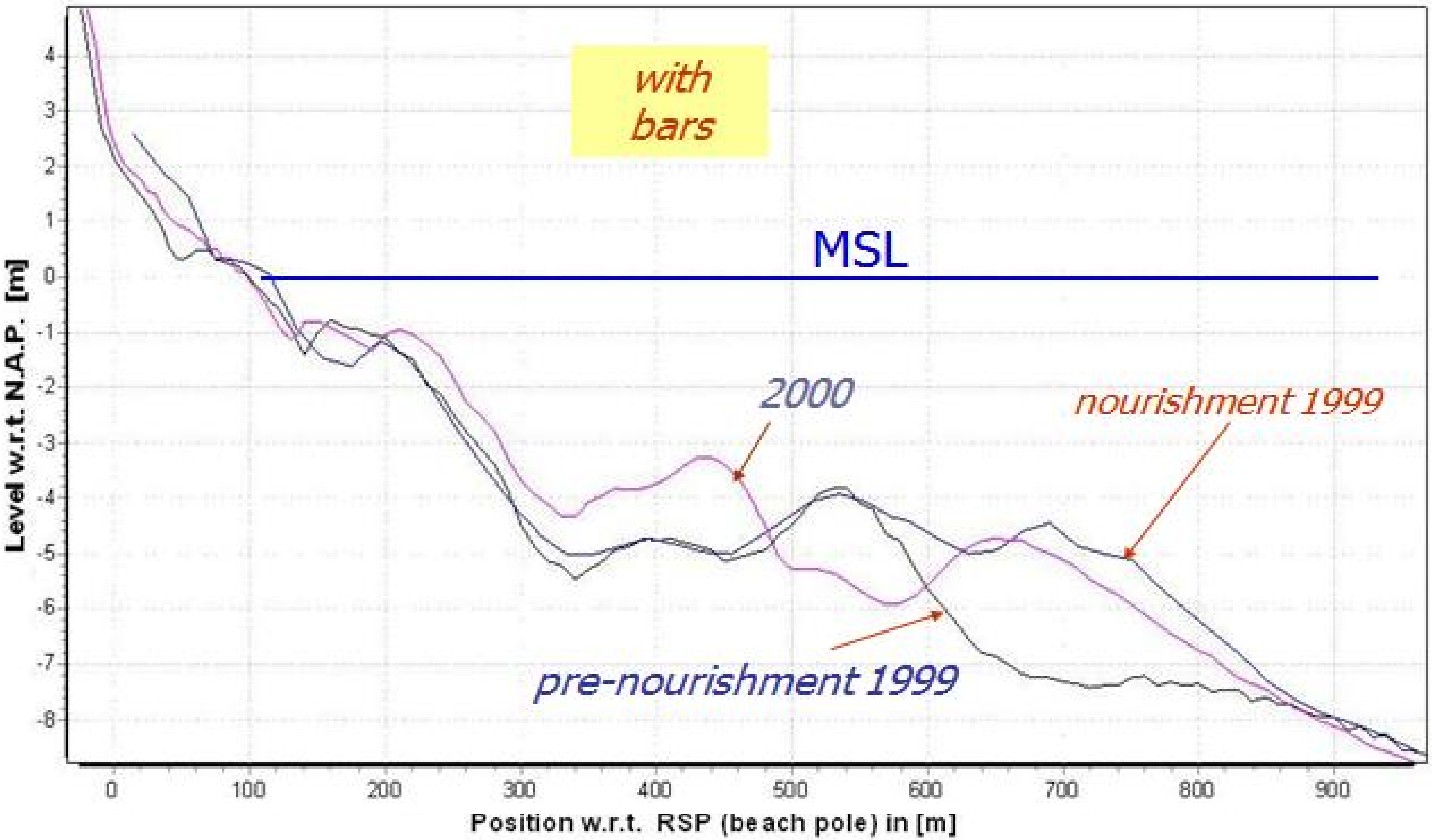
Artificial nourishment (‘soft’ measures)

Shoreface nourishment

- Nourishment volume in order of 300 to 500 m^3/m’ over alongshore distance of 2 to 5 km.
- Larger nourishment volumes are required as only 30% to 50% of nourishment volume will reach beach zone.
- Shoreface nourishments add large volumes of sand to the system.
- Costs per m^3 for shoreface nourishment are 50% to 70% less than for beach nourishment (total cost in balance?!).
- Large shoreface nourishments impact sediment transport processes (may behave like submerged breakwater, although effect diminishes in time).

Artificial nourishment (‘soft’ measures)

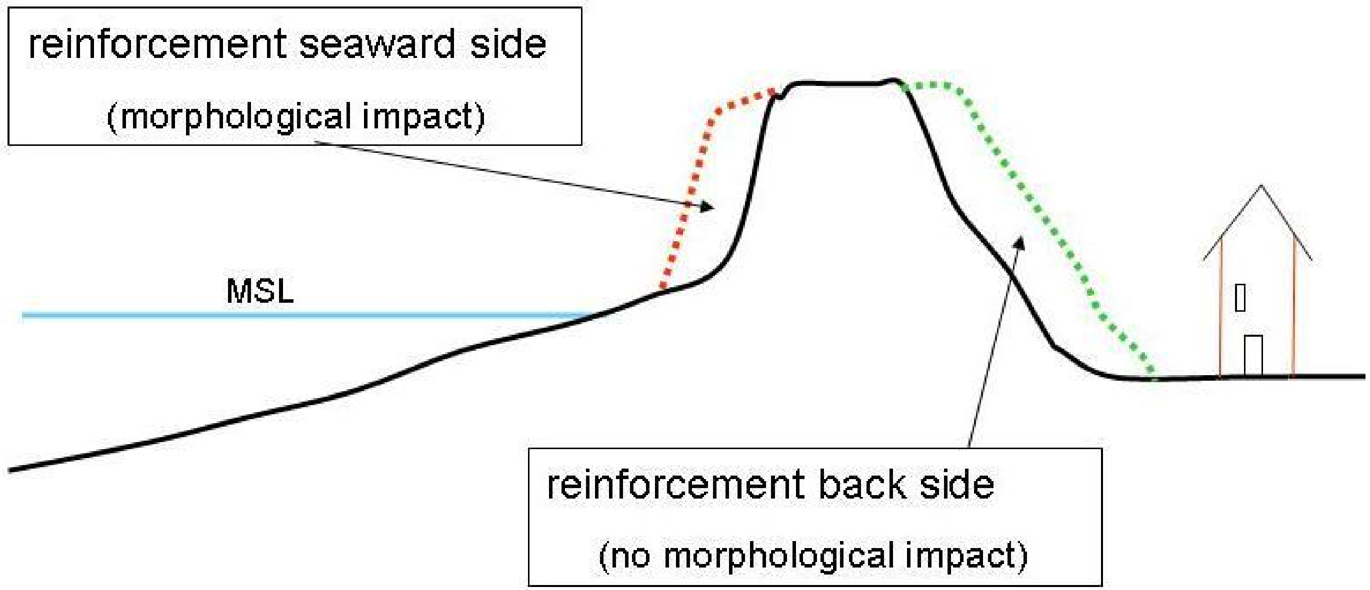
Shore face nourishment: movement of sand towards beach



Artificial nourishment (‘soft’ measures)

Dune nourishment

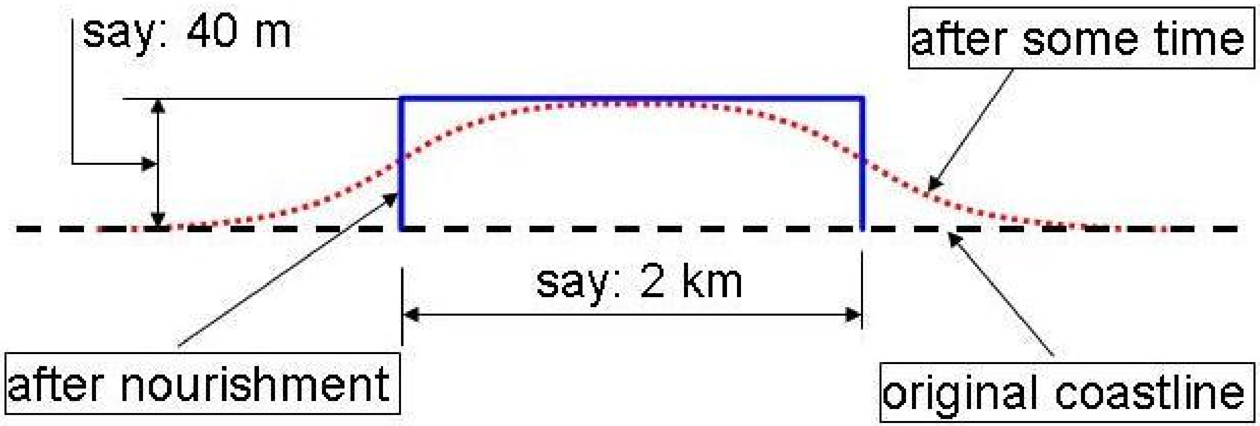
- Dune nourishment required if volume of dune is insufficient to cope with dune erosion during design storm.
- Nourishment at landward side is most effective (infrastructure?)
- Nourishment at seaward side or on top of dune interferes with the coastal dynamic system (effective but sand may be “lost” for dune)



Artificial nourishment (‘soft’ measures)

Dune nourishment: two options

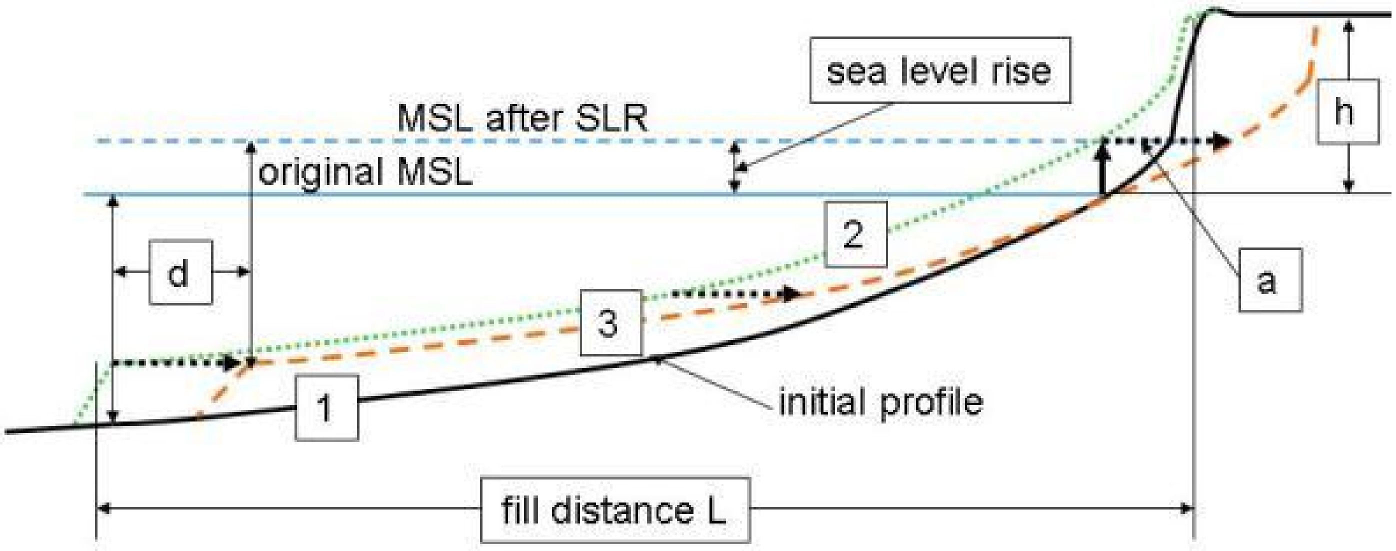
- Landward side
  - Most effective, but may be not possible due to presence of infrastructure and properties.
- Seaward side
  - Relatively large volume of sand is required to account for redistribution of the sand over the cross-shore profile, due to morphological impact.
  - So local dune reinforcement will have a relatively short life-time.



Artificial nourishment ('soft' measures)

Nourishment to counteract sea-level rise

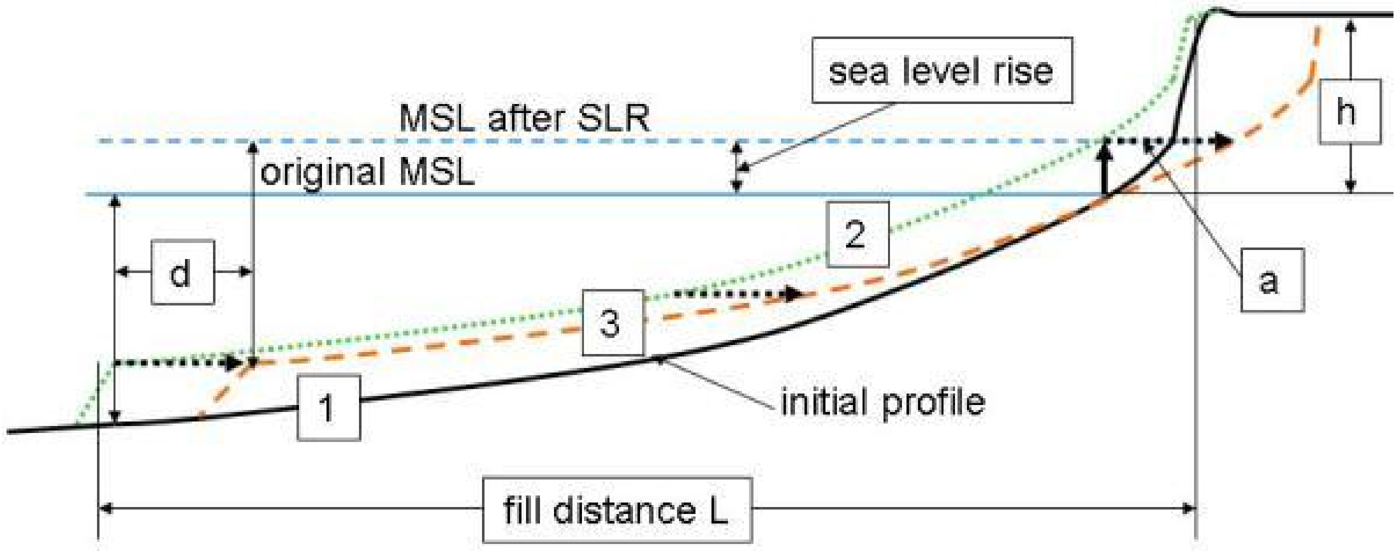
- Nourishments fills in space between profile 1 and 2 created by the sea-level rise Required volume is *SLR* x distance *L*
- E.g. *SLR* = 1.0 m per century and *L* = 1000 m, a volume of 1000 m^3/m is required in 100 yrs => 10 m^3/m per yr.
- 100 m^3/m per 10 year nourishment interval is usual number.



Artificial nourishment (‘soft’ measures)

If no nourishment is used to counteract sea-level rise?

- Without nourishment profile 3 is equilibrium coastal profile (see Chapter 7).
- Profile 3 is obtained by horizontal shift of profile 2 over distance *a*.
- $a = (SLR \times L)/(d + h)$ = (1 m/100 yr x 1000 m)/(10 m + 10 m) = 0.5 m/yr
- Result is structural coastal erosion!

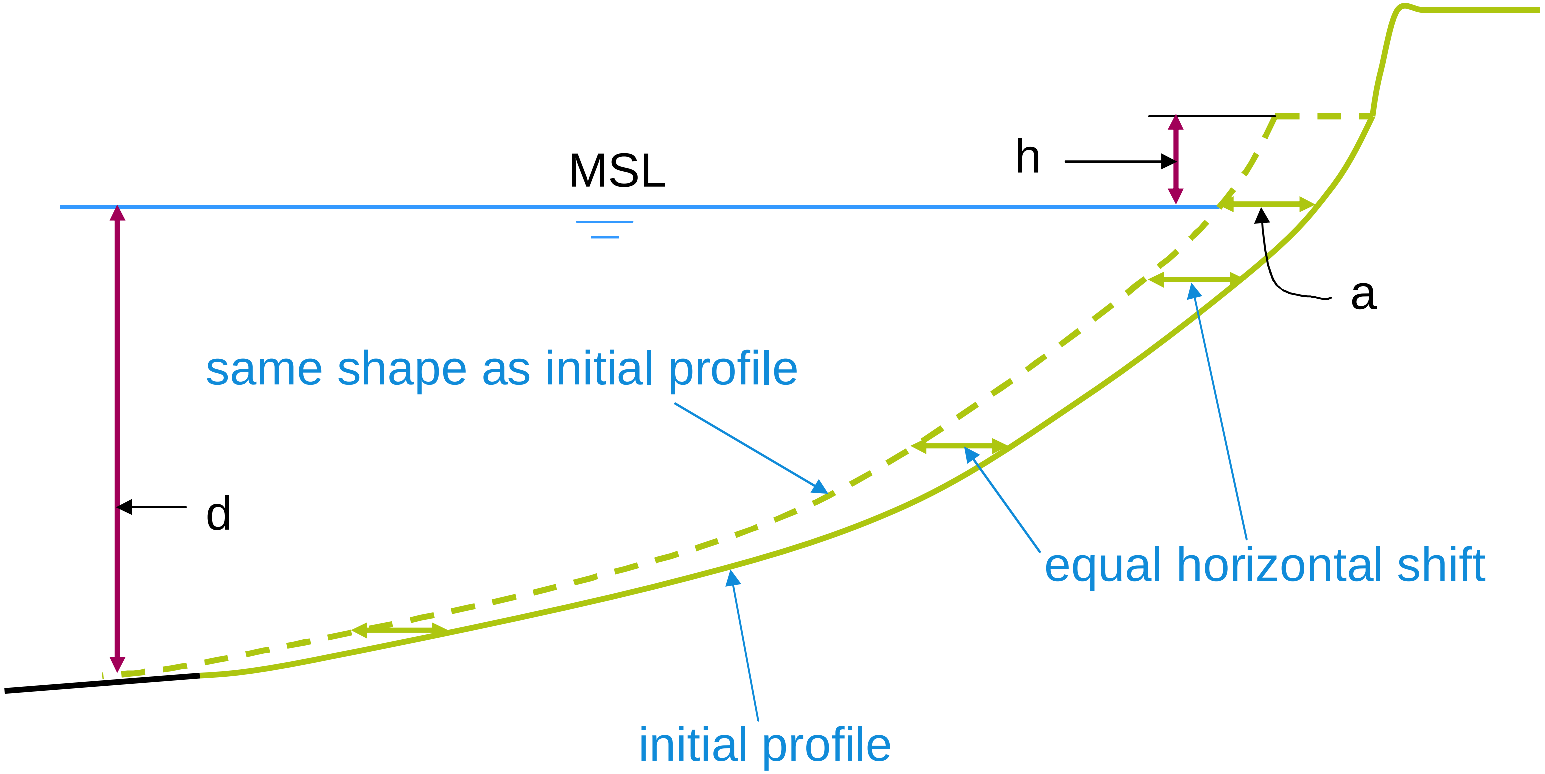


Artificial nourishment ('soft' measures)

Land reclamation

Artificial nourishment ('soft' measures)

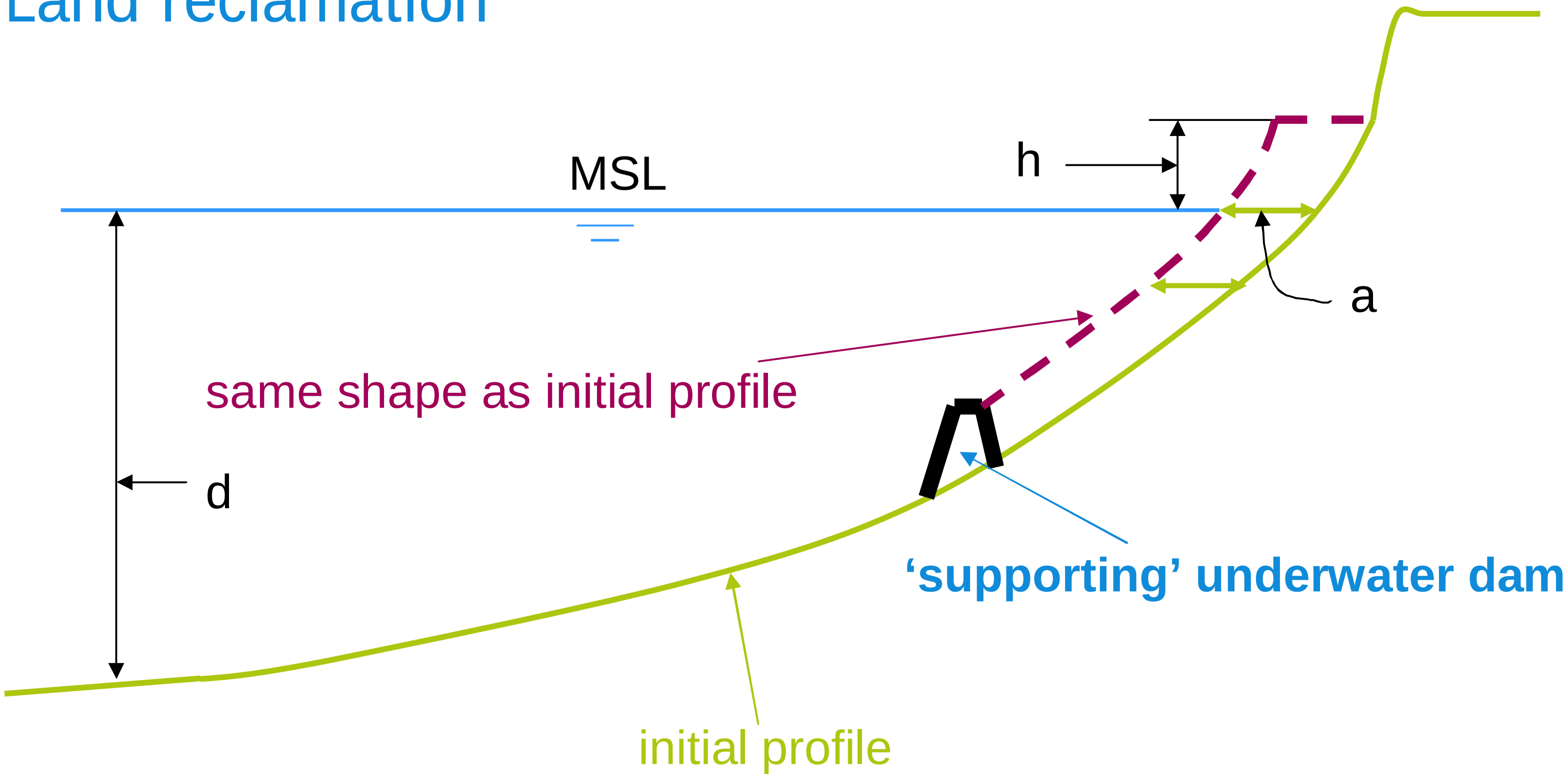
Land reclamation



d = 15 m; h = 10 m ---> 1 m^2 of 'new' land: 25 m^3; costs?

Artificial nourishment ('soft' measures)

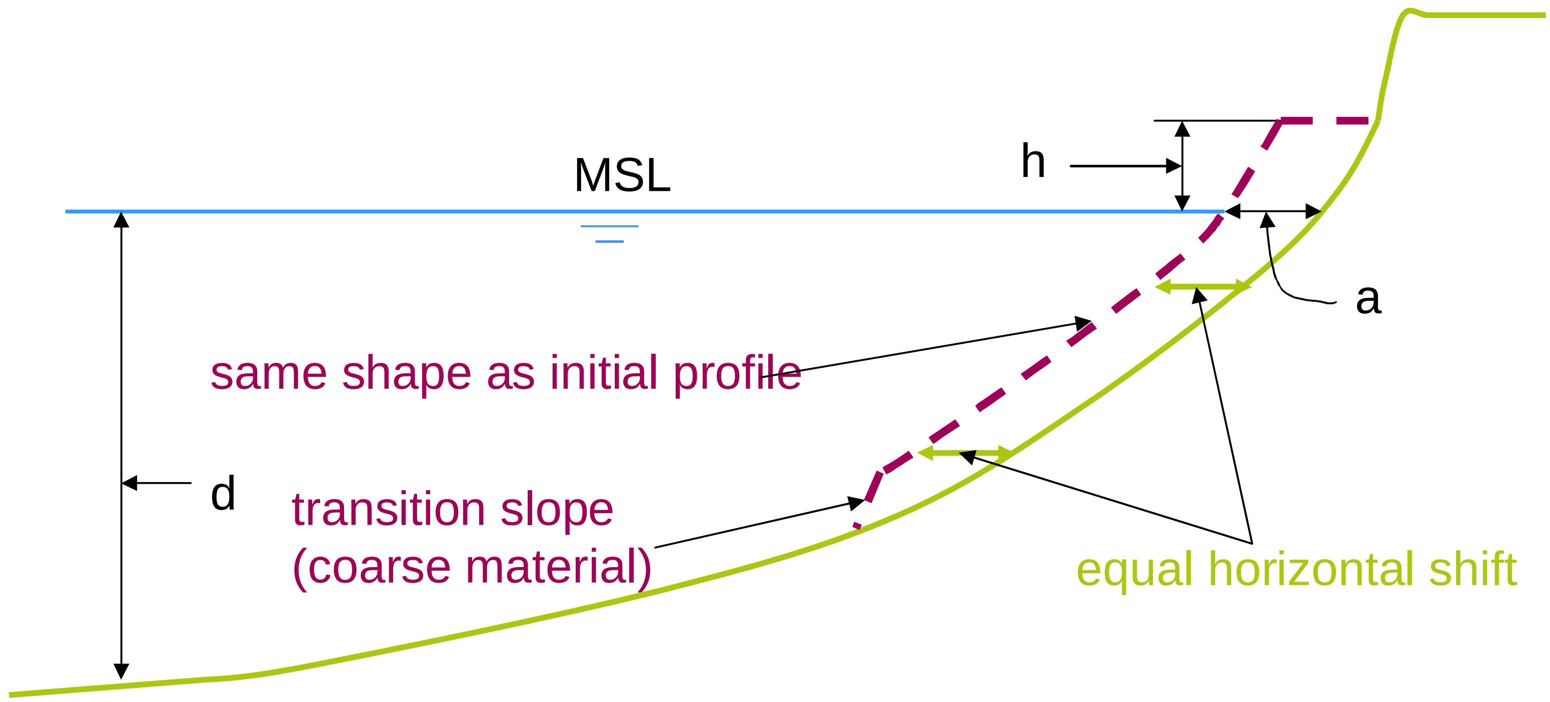
Land reclamation



"Perched" beach

Artificial nourishment ('soft' measures)

Land reclamation



Other methods?

Part I

The Dutch approach

The Dutch coast

1. Wadden
2. Holland
3. Delta

Coastal protection strategies

Coastal zone management strategies

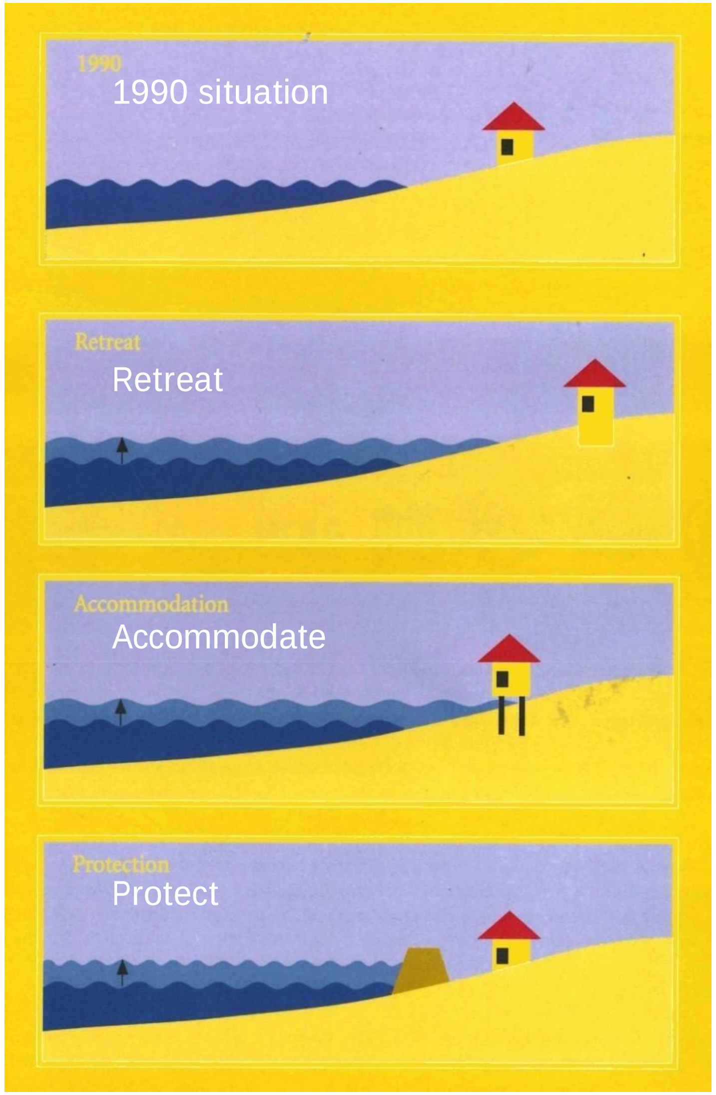
Why?

- Increased pressures on coastal zone
- Changing conditions (climate, SLR)

CZM strategies:

- Retreat (simple solutions in future?)
- Accommodate (adapt infrastructure)
- Protect (take measures)

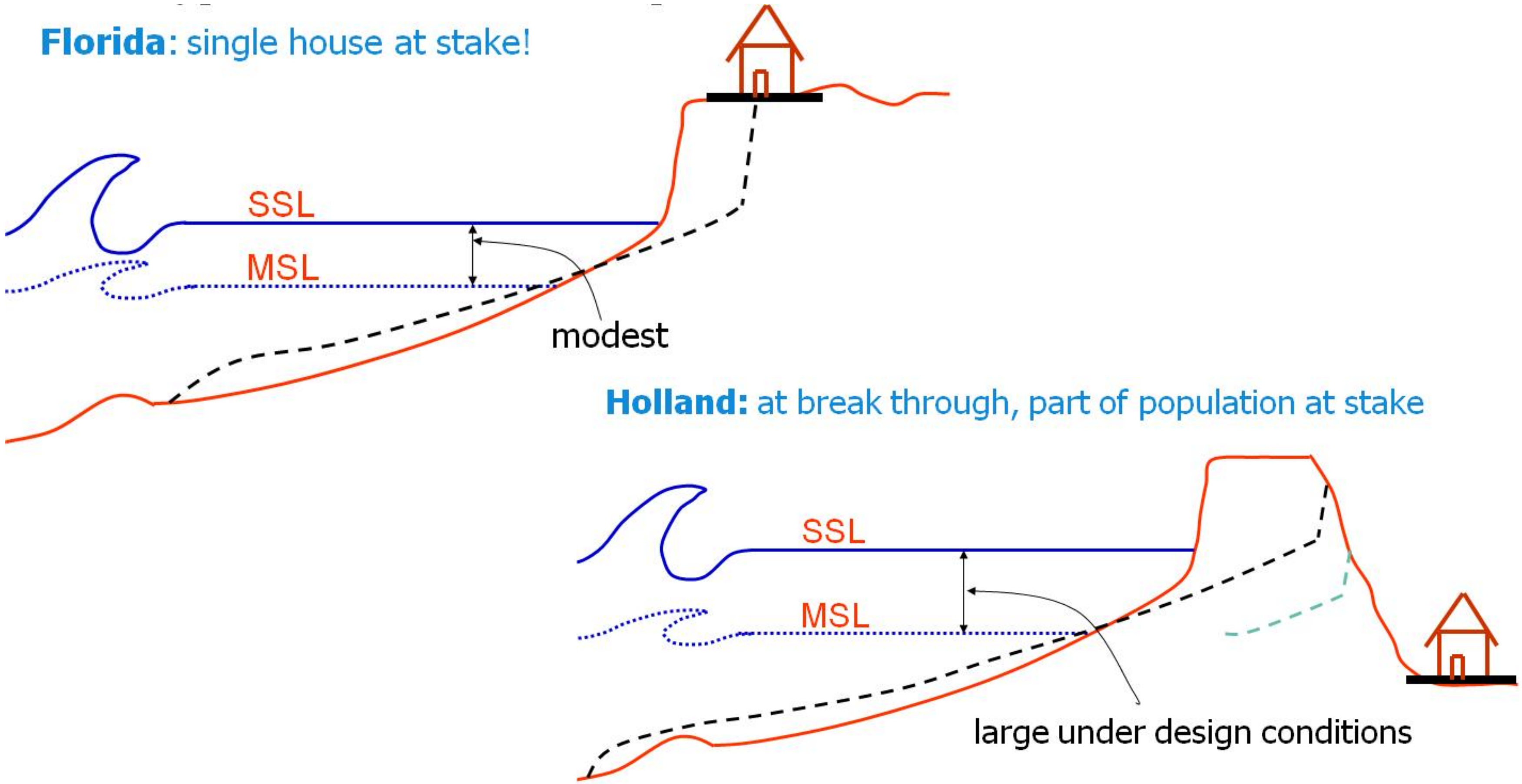
Important to define proper CZM strategy, taking into account use of the coastal zone (social, economic and cultural) in relation to the cost for protection (Chapter 11).



This lecture only deals with “Protect”.

Types of coastal erosion processes

Coastal zone management strategies



Coastal protection strategies

Coastal zone management strategies

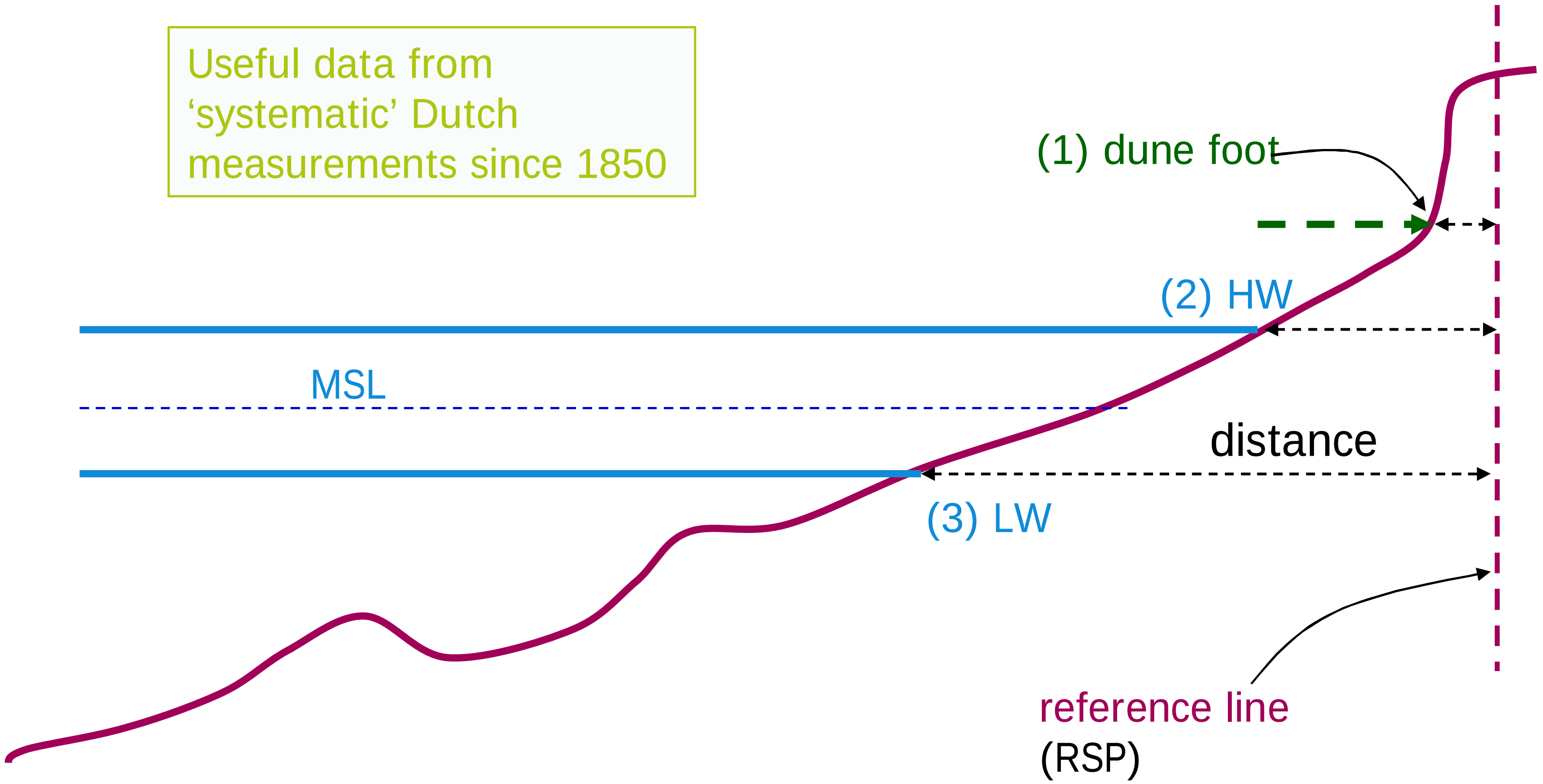
Actual Coastal Protection Strategy of Rijkswaterstaat (Dutch Ministry of Infrastructure and Environment)

- “Soft” if possible, “hard” if required.
- Nourishment at foreshore if possible, at beach if required.

Types of coastal erosion processes

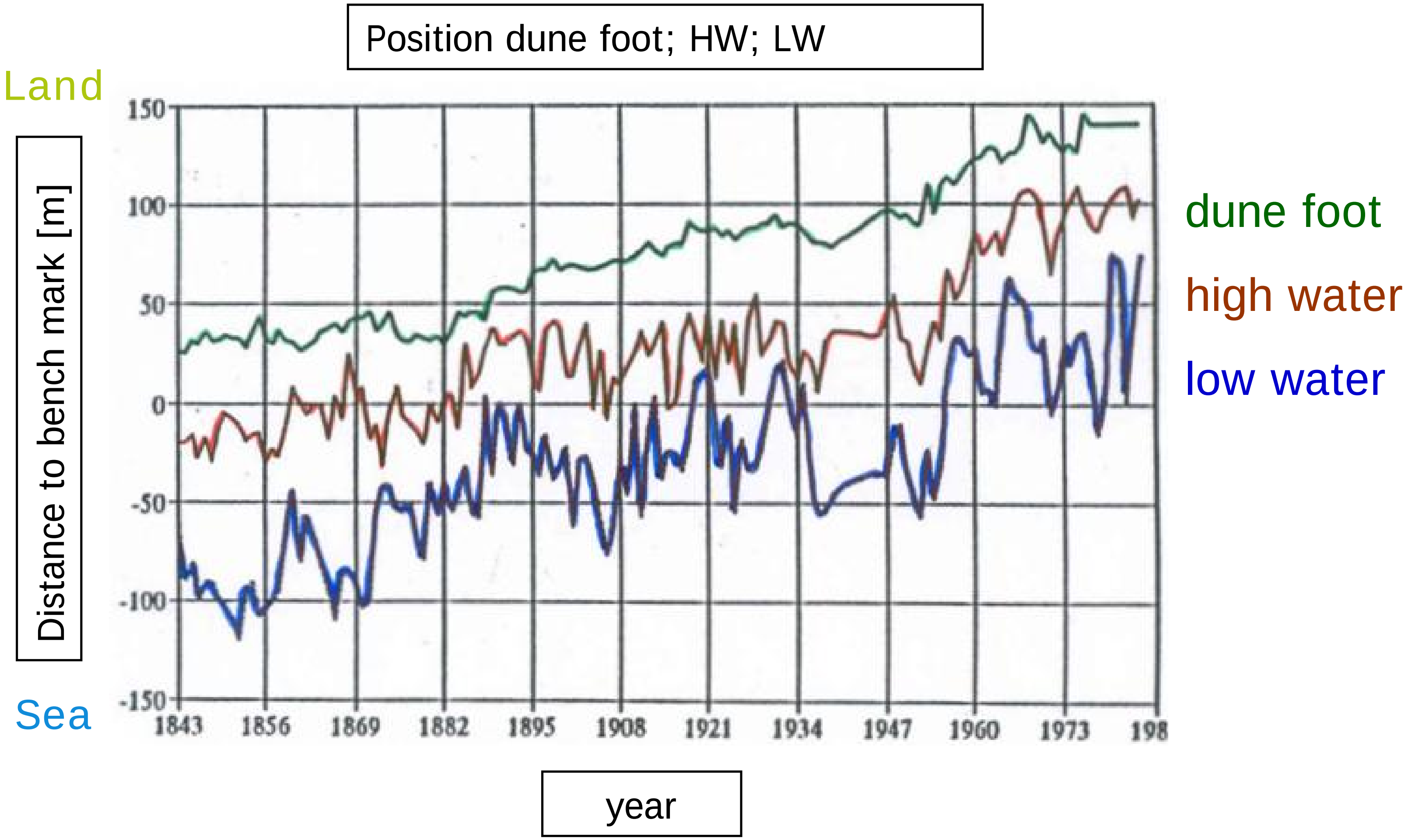
Structural erosion - data

Useful data from 'systematic' Dutch measurements since 1850



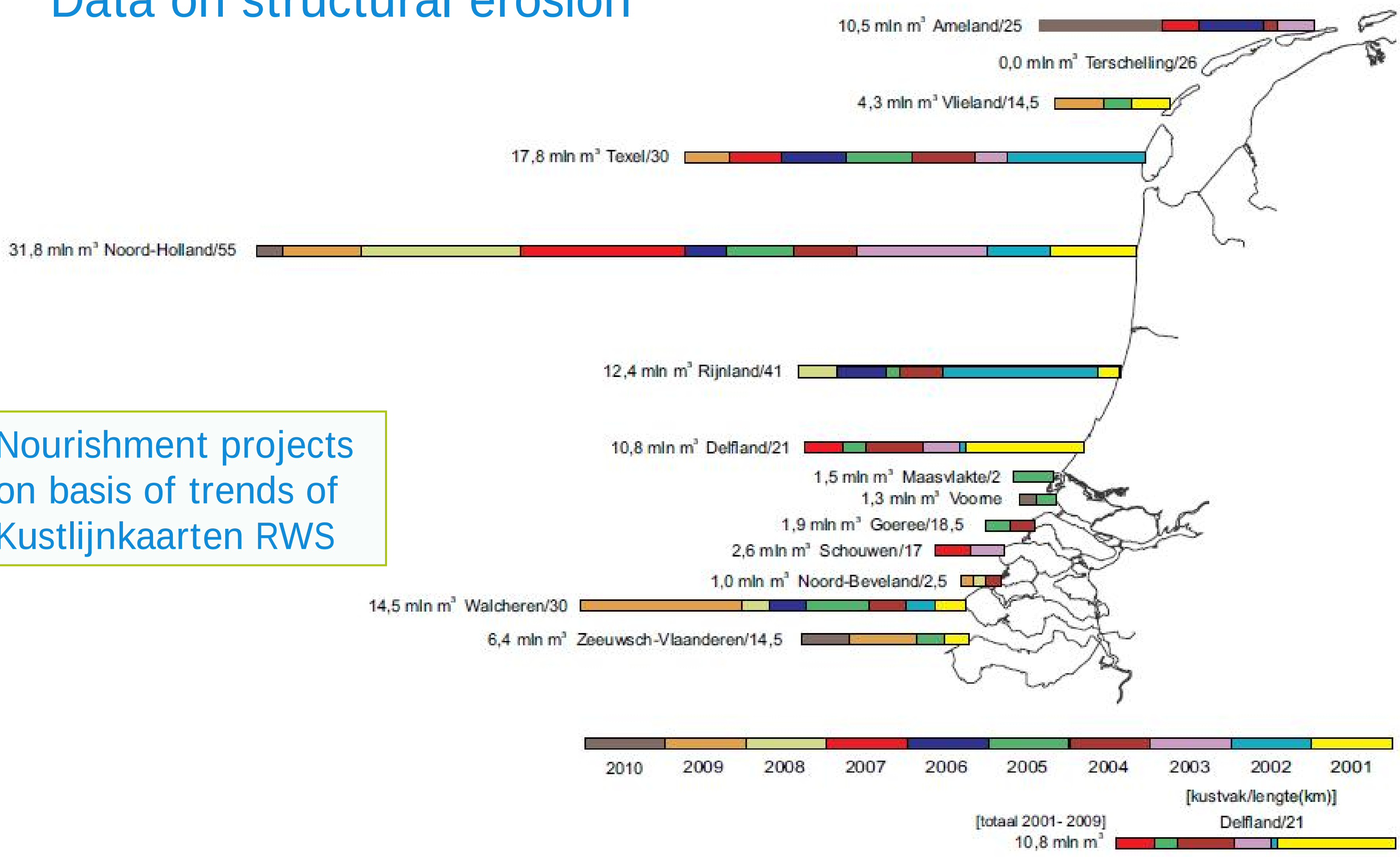
Types of coastal erosion processes

Structural erosion – data ("lightning graphs")



Types of coastal erosion processes

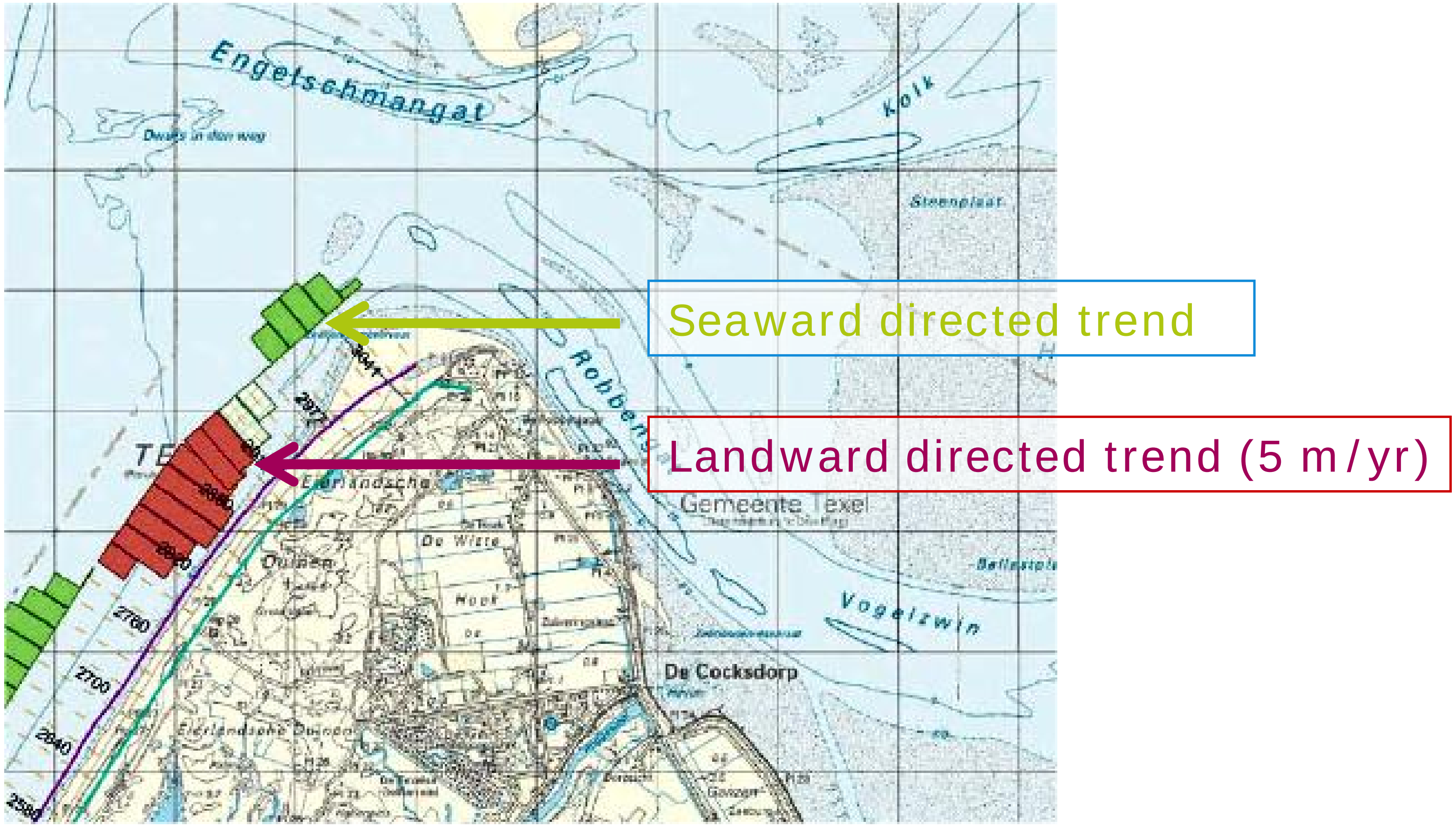
Data on structural erosion



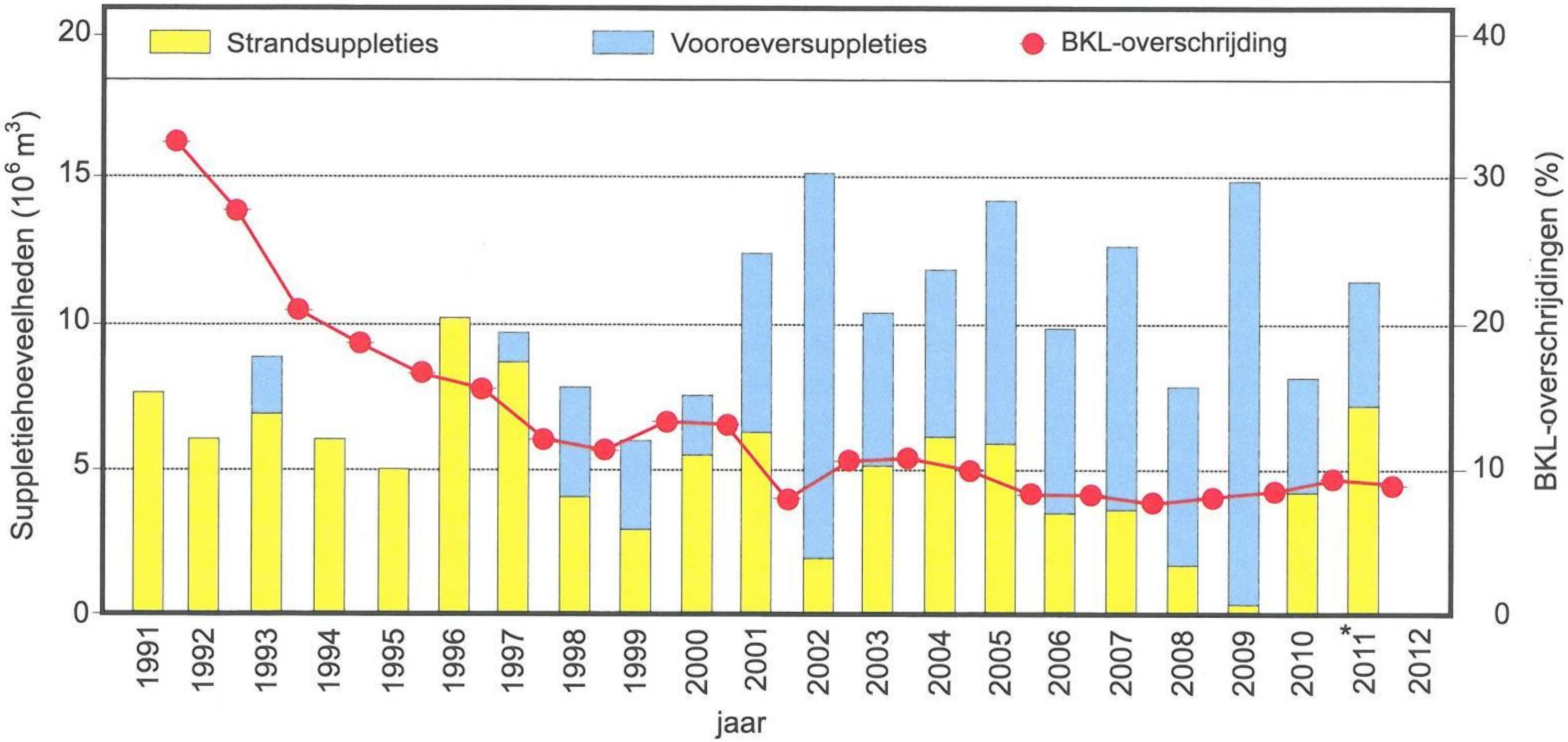
Nourishment projects on basis of trends of Kustlijnkaarten RWS

Types of coastal erosion processes

Data on structural erosion. RWS “Kustlijnkaarten 2011”



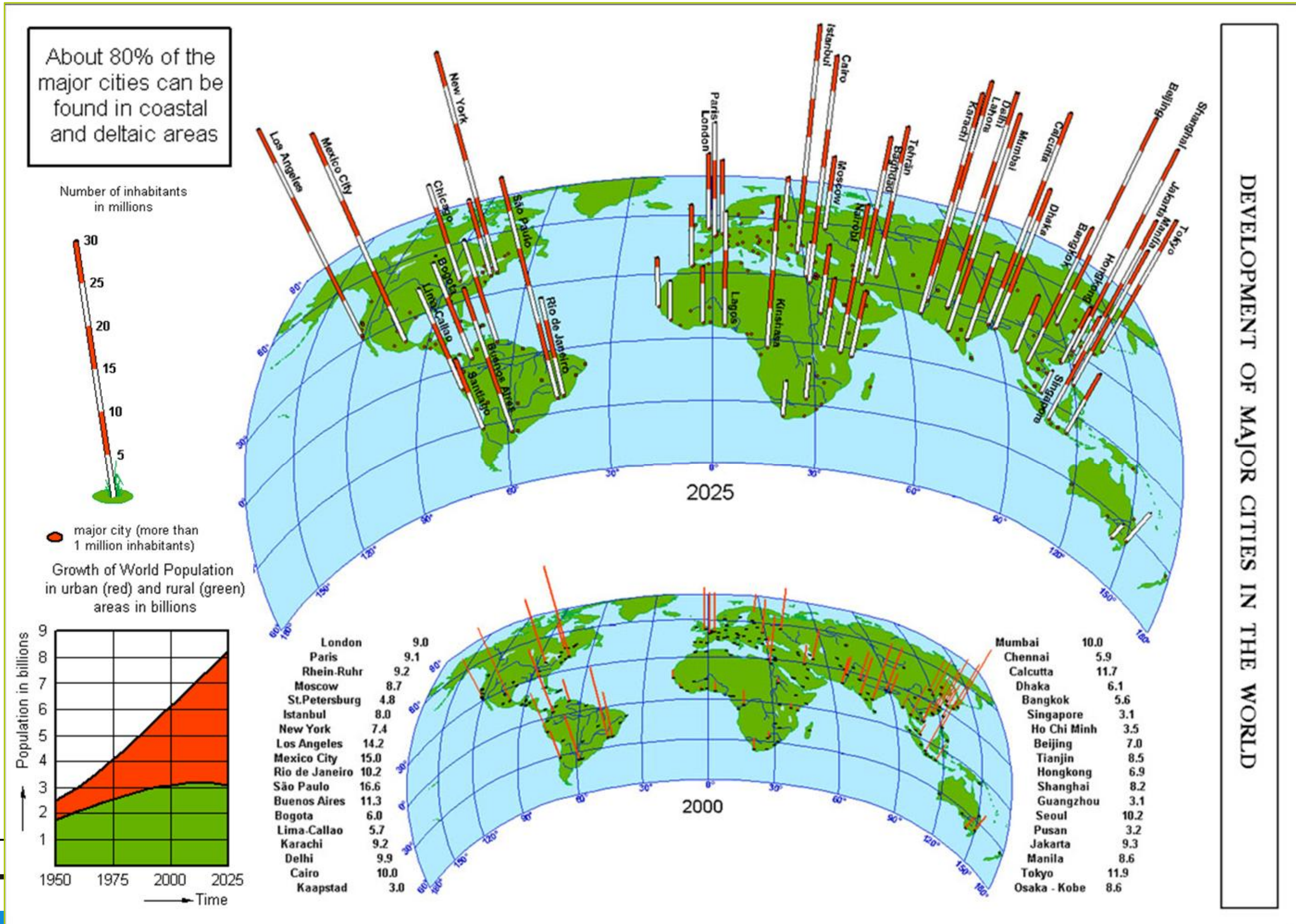
Results of 20 years of nourishing



Part I

Building with Nature

Increasing pressure on deltas worldwide



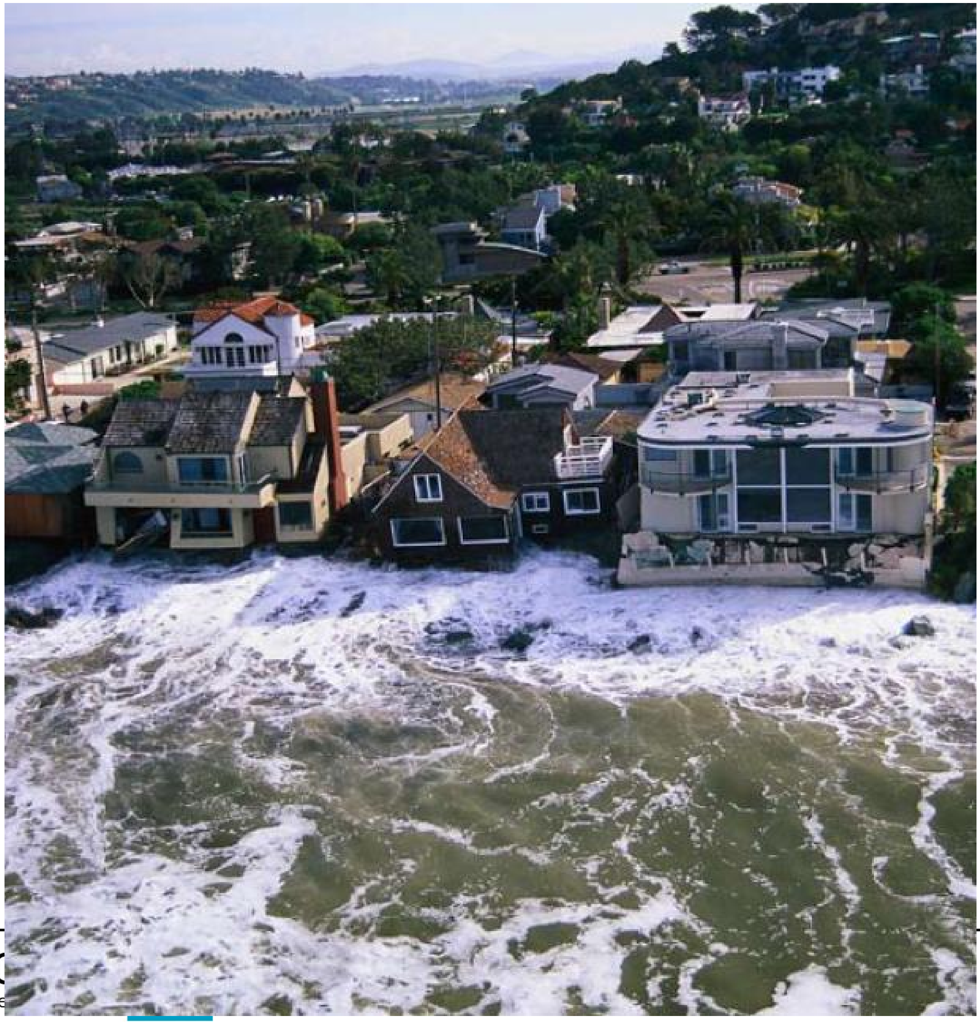
Global trade growth

Container and bulk transport boost the need for port capacity

Global energy consumption

Oil & Gas trade flows generate LNG and Offshore pipeline projects

Climate change



Pressures are reinforced by effects of climate change

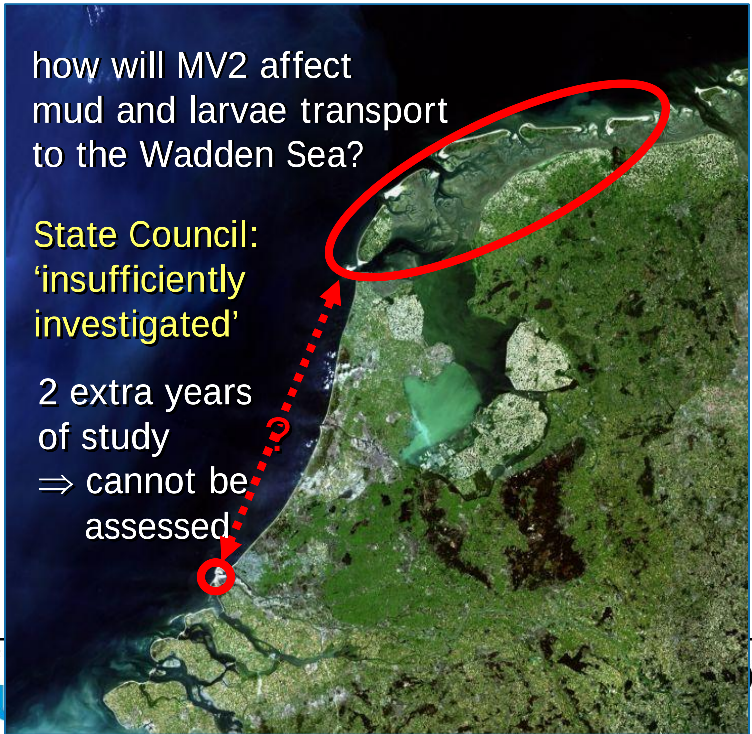
Trends:

Ongoing need for marine infrastructure development

… while at the same time …

Increasing environmental awareness

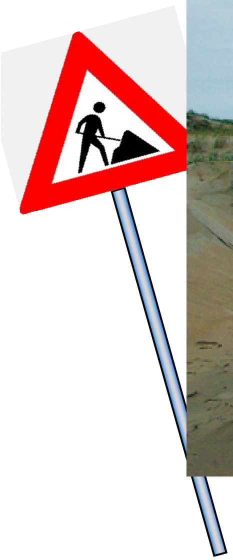
EIA Maasvlakte-2



Environmental management

Is what we do truly sustainable ???

Building with Nature



cannot we let nature do part of the work ...

while creating new new opportunities for itself?

Building with Nature solutions

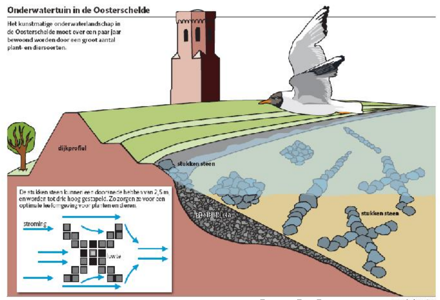
soft solutions ⟷ **hard solutions**

Temperate

Pilot Sand Engine
Delfland Coast

IJsselmeer
foreshore nourishment

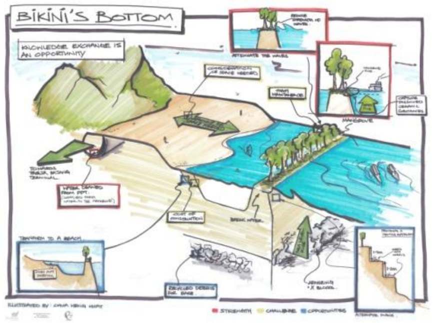
ES: oyster reefs
as shore protection



Eastern Scheldt
Underwater garden

Tropical

Coastal protection
Sea grass



BwN design Singapore
Labrador Park

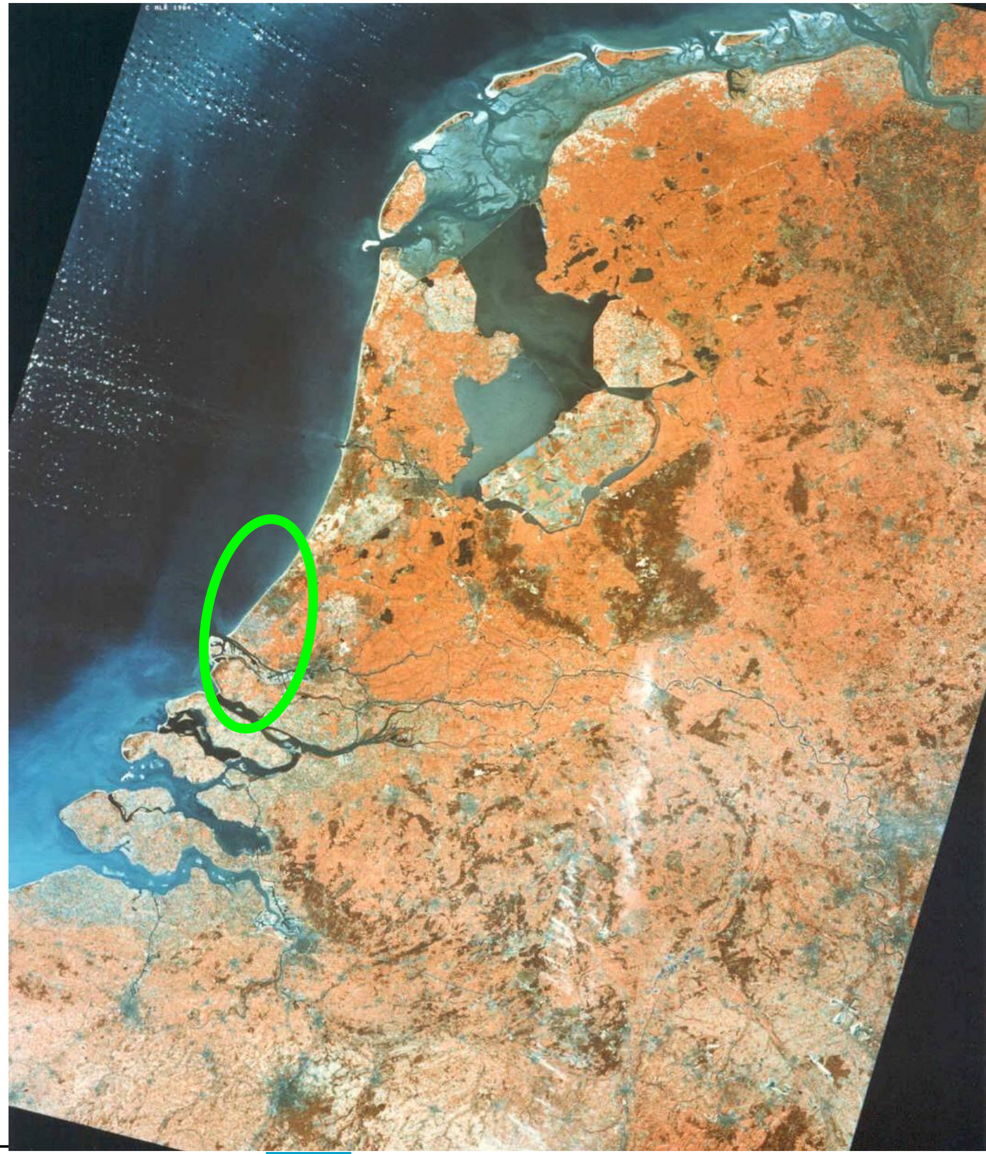
Coastal protection
Mangroves

Singapore
'rich levee'

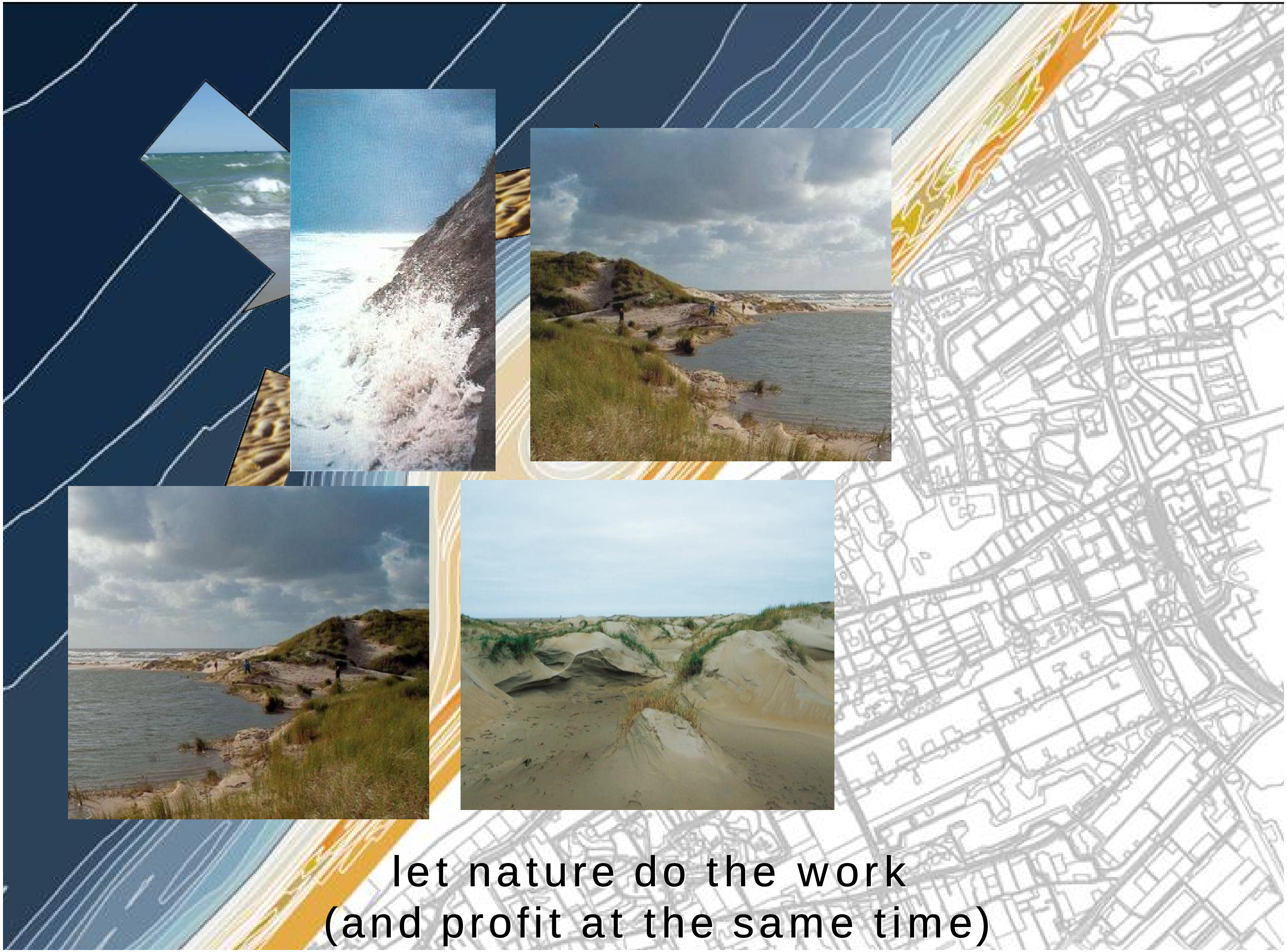
focus on ecosystem functioning ⟷ **focus on infrastructure development**

The Dutch coast

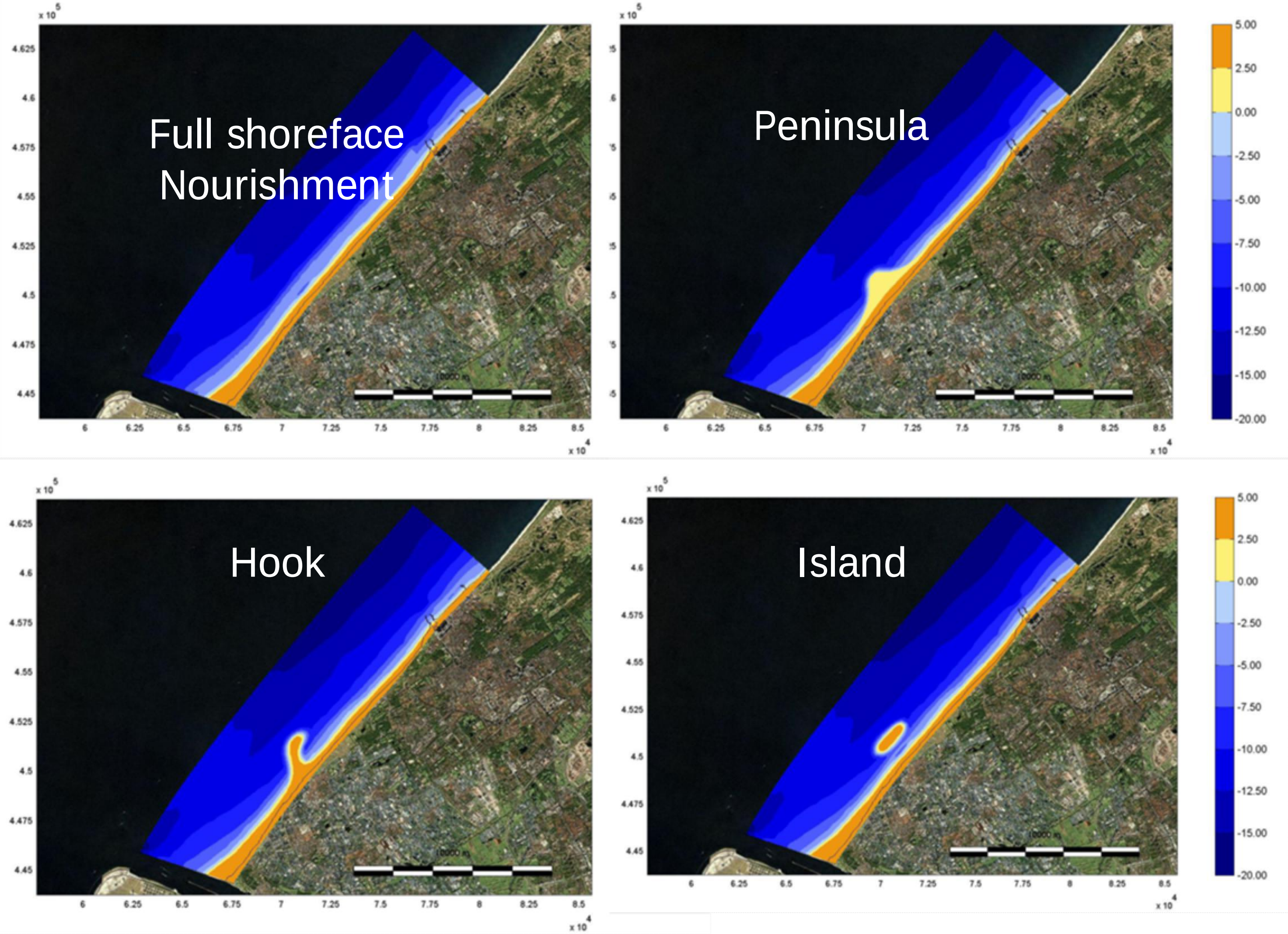
1. Wadden
2. Holland
3. Delta



Delfland Coast


let nature do the work
(and profit at the same time)

Design alternatives



Design

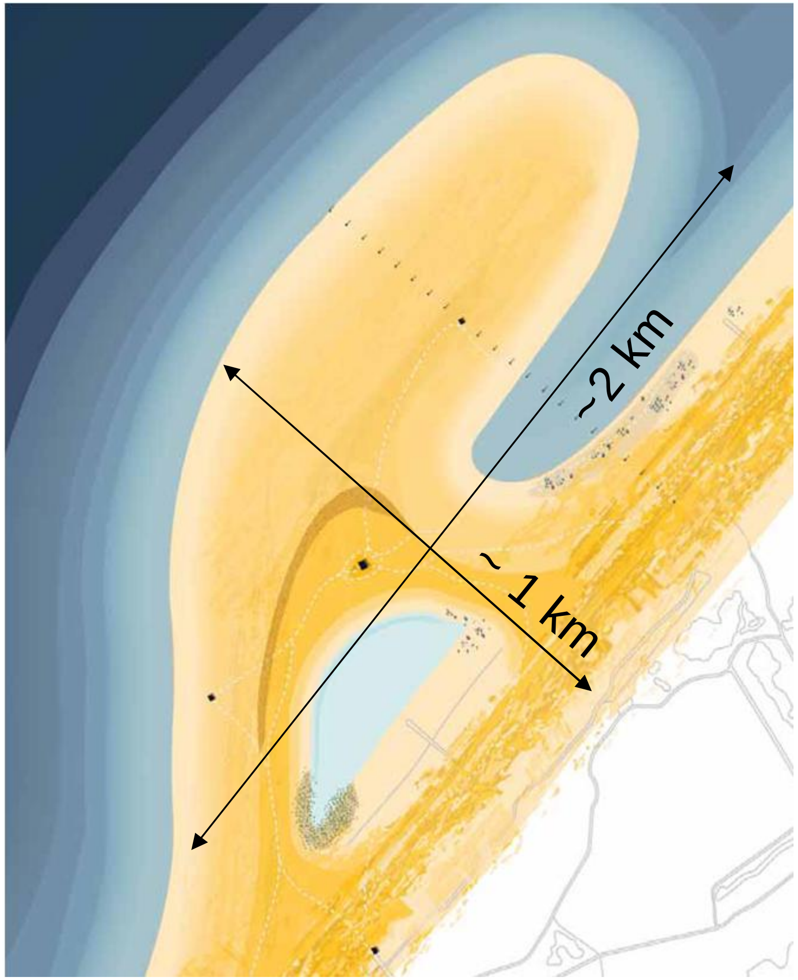
Objectives:

1. Extra Safety
2. Nature area / ‘Quality of living’
3. Innovation

‘Hook’ altenative

70 M Euro.

21 M m^3 of sand



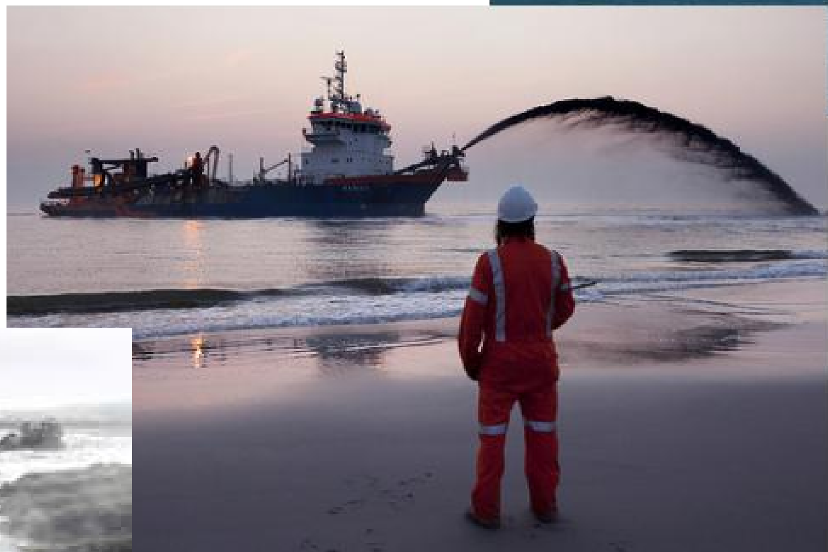
Expected advantages

- enhanced safety against flooding
  - (first: wave attenuator; later: wider dune buffer)
- cheaper per m3 compared to traditional nourishments
  - (but: costs brought forward → interest!)
- longer period between consecutive nourishments
  - more time for beach and shoreface ecosystem to recover
- ecologically interesting intermediate stages
  - beach lagoons, juvenile dunes, pioneer vegetation
- recreation potential
  - swimming, surfing, beach recreation
- wider dune area
  - increased freshwater reserve

Construction

Suction hopper:

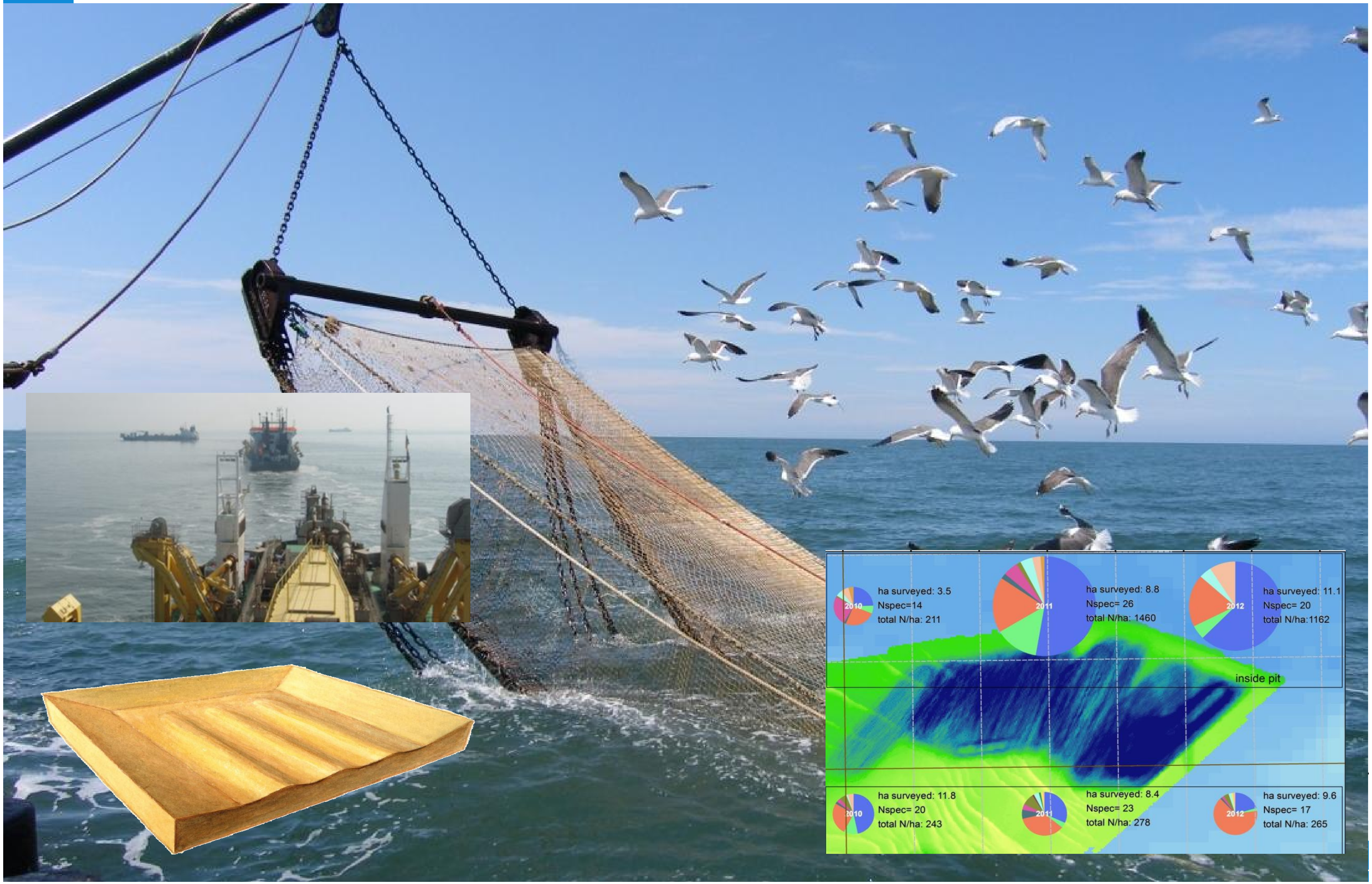
- Pumping ashore
- Bottom dumping
- Rainbowing



Van Oord

Boskalis bv

Knowledge for infrastructure projects



Construction


28-03-2011
Most western
point reached

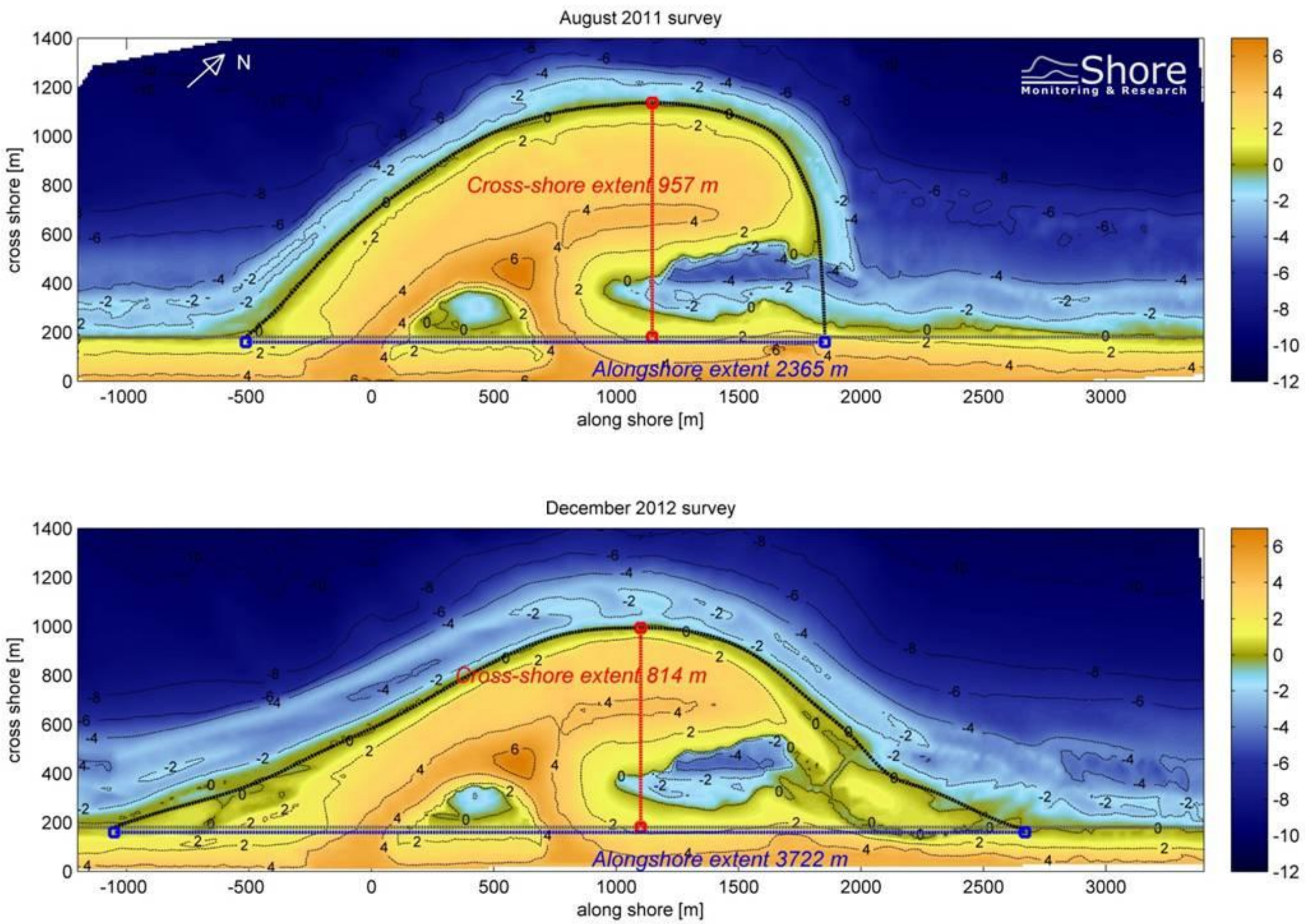

Shoreface
nourishment
Shoreface
nourishment

Recreation and Nature

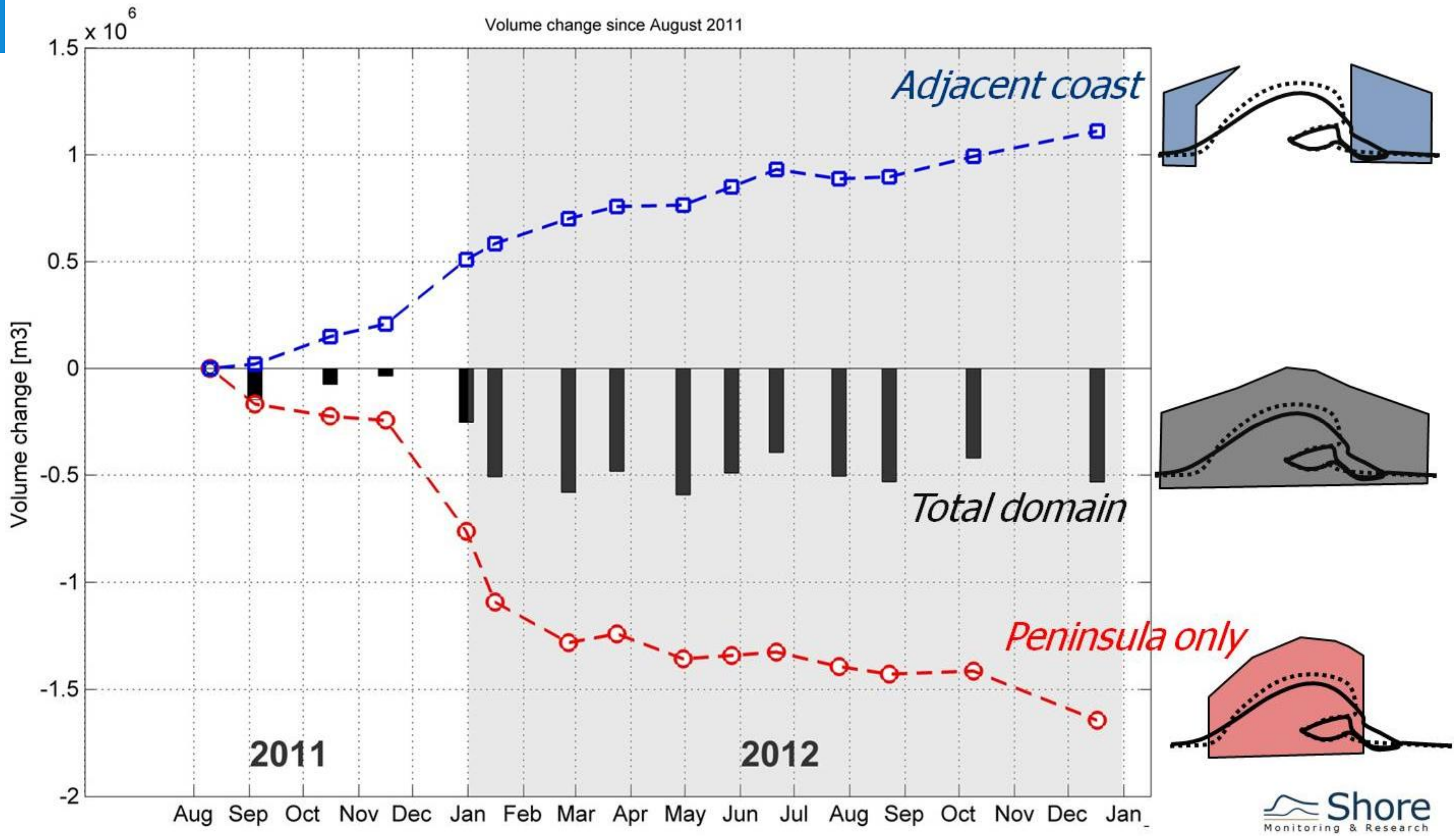


Morphology: General observations

- Erosion seaward side ('tip')
- Sedimentation southern end
- Spit and channel formation near lagoon
- Symmetry



Sediment Budget



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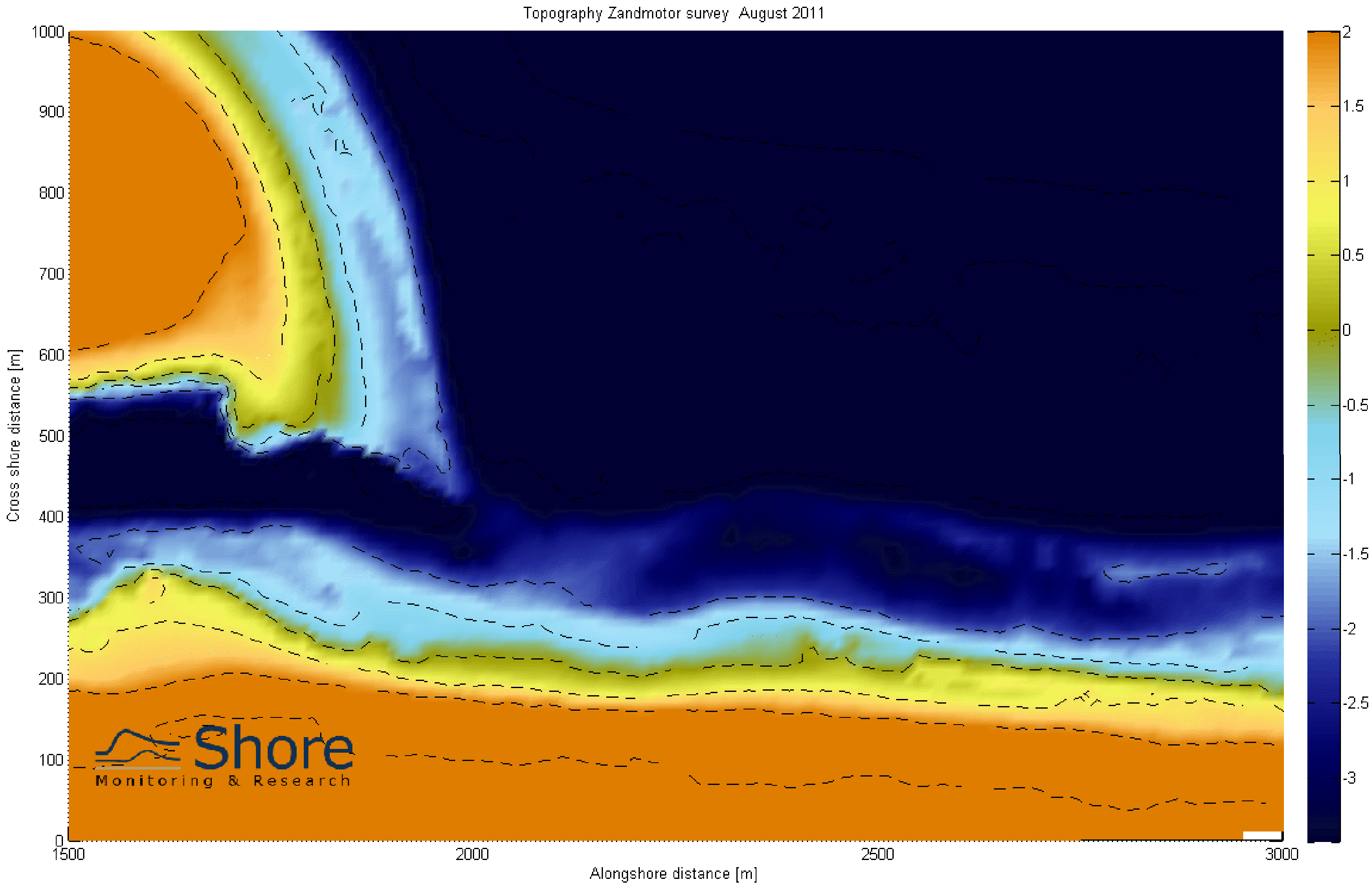
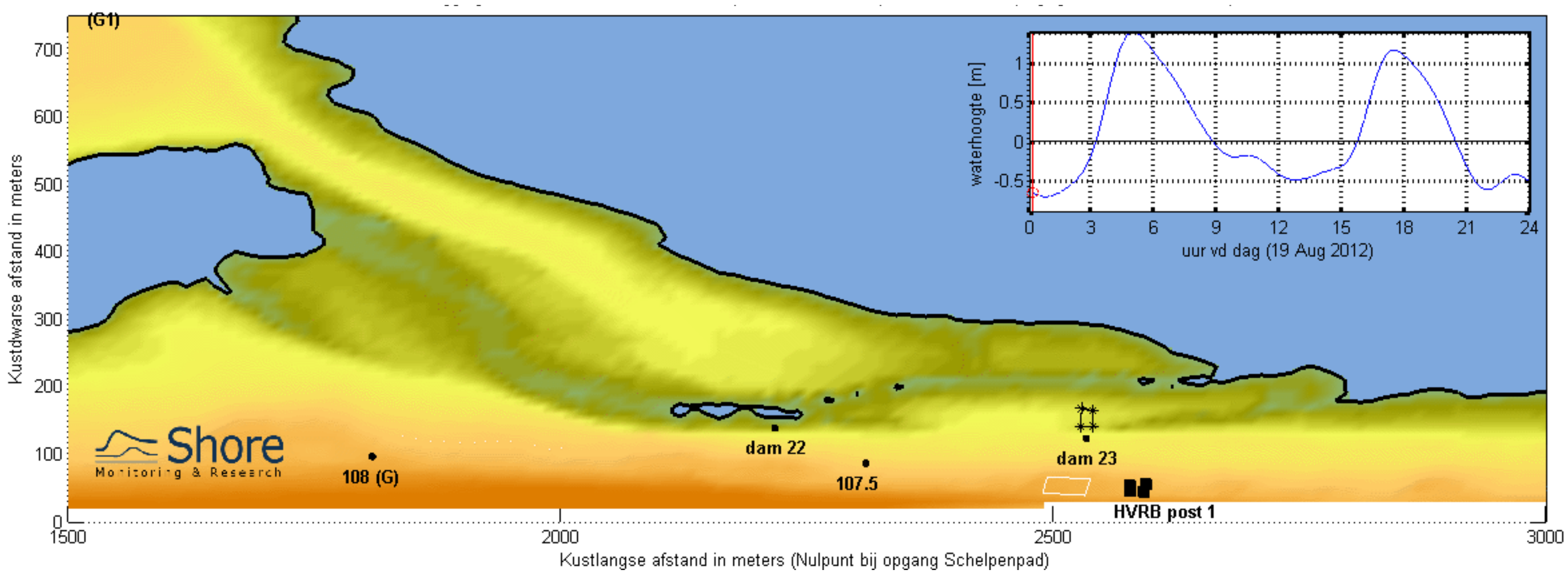
Spit and channel formation near lagoon



Vertical tide

Vertical tide



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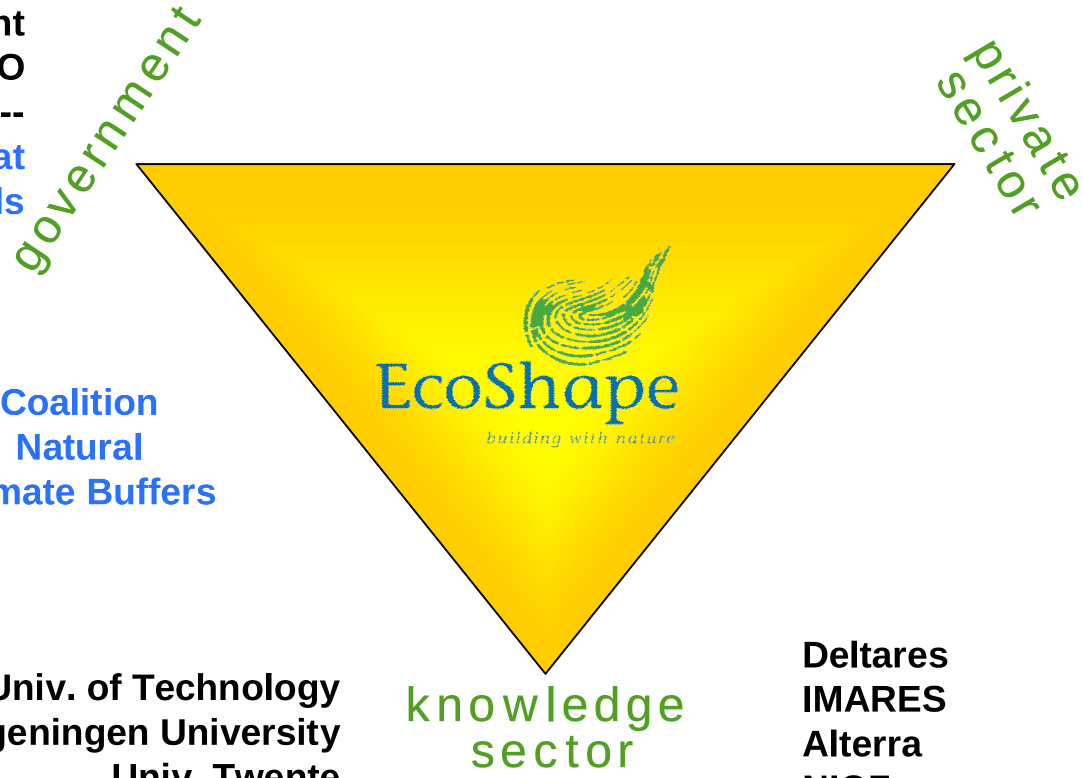
Challenging Governance

Collaboration in "GOLDEN TRIANGLE"

Ministry I&E
Municipality Dordrecht
EFRO

Rijkswaterstaat
Waterboards

Coalition
Natural
Climate Buffers



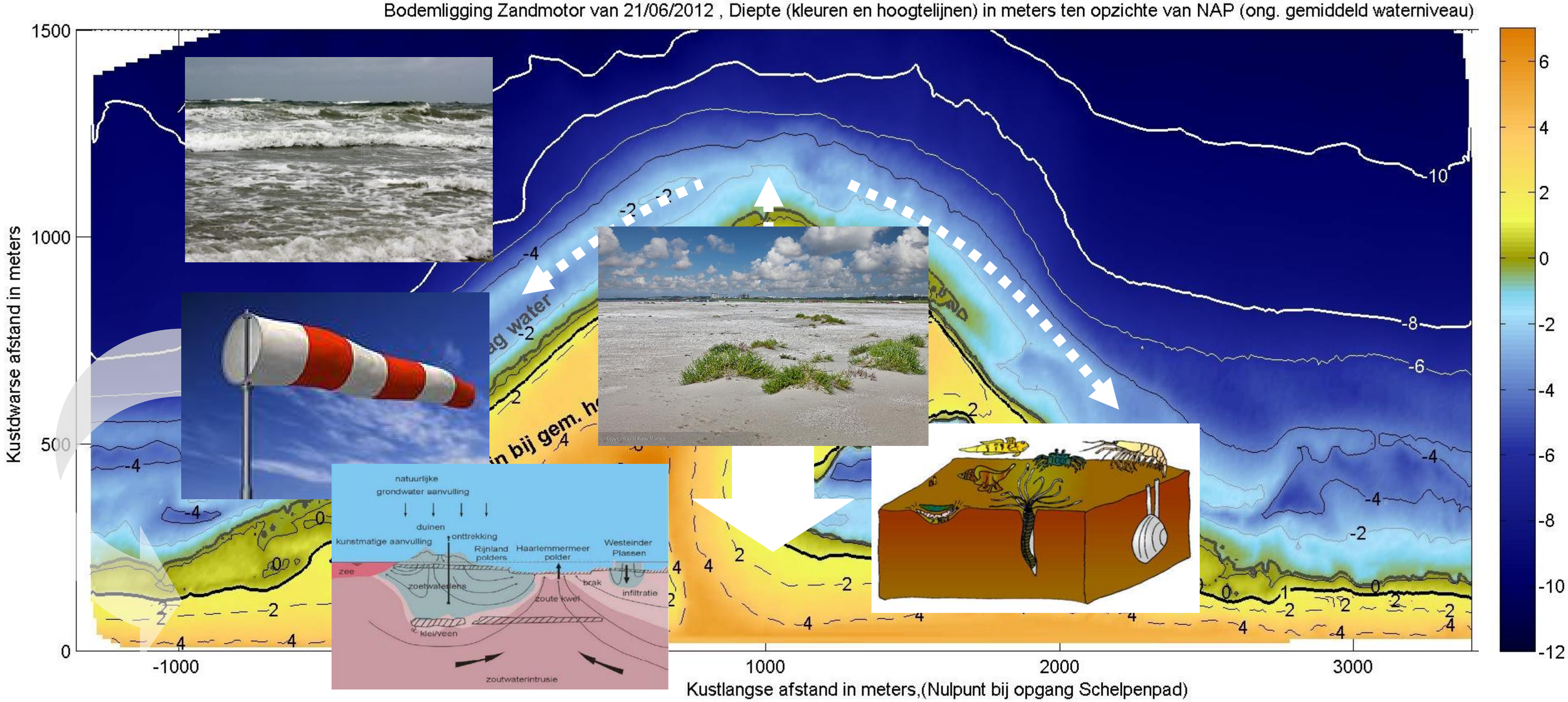
Boskalis
Van Oord
IHC
Ver. v. Waterbouwers
DHV
Witteveen + Bos
Haskoning
Arcadis
R'dam Port Auth.

Delft Univ. of Technology
Wageningen University
Univ. Twente

Deltares
IMARES
Alterra
NIOZ

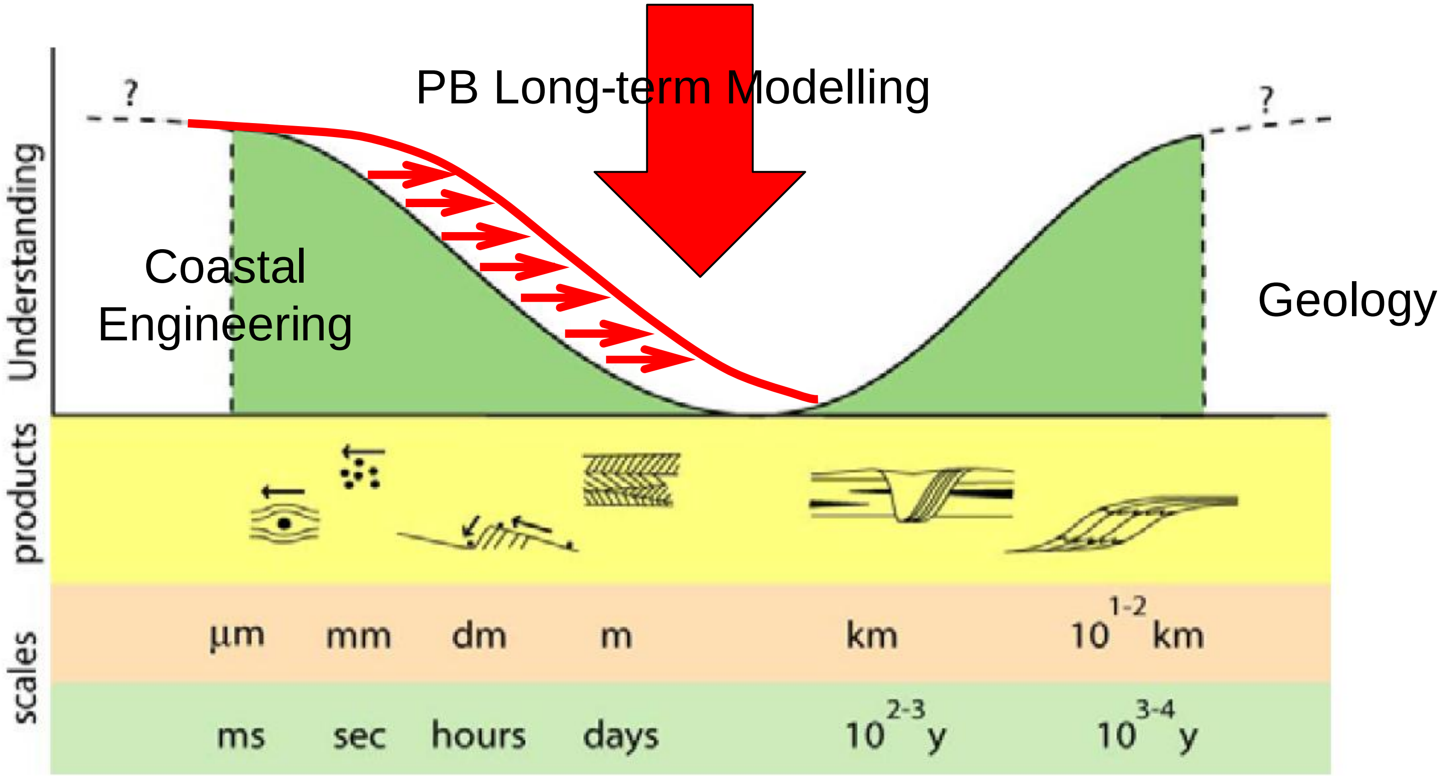
Challenging Governance

Understanding of landscape dynamics: inter-disciplinary knowledge



Universiteit Utrecht UNIVERSITEIT TWENTE. VU VRIJE UNIVERSITEIT AMSTERDAM WAGENINGEN UR For quality of life

Different time scale:



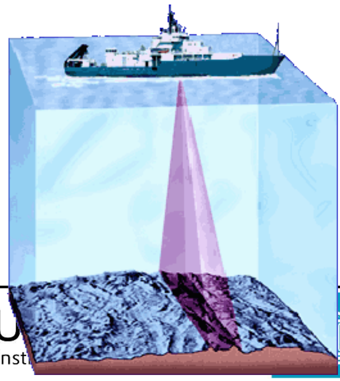
Storms et al. (2007)

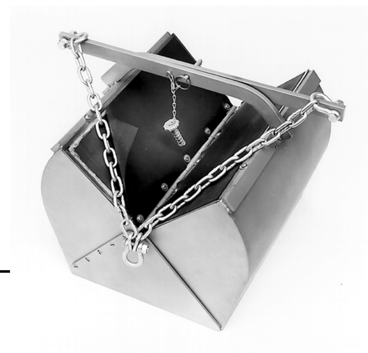
Extensive monitoring campaign

BEACH

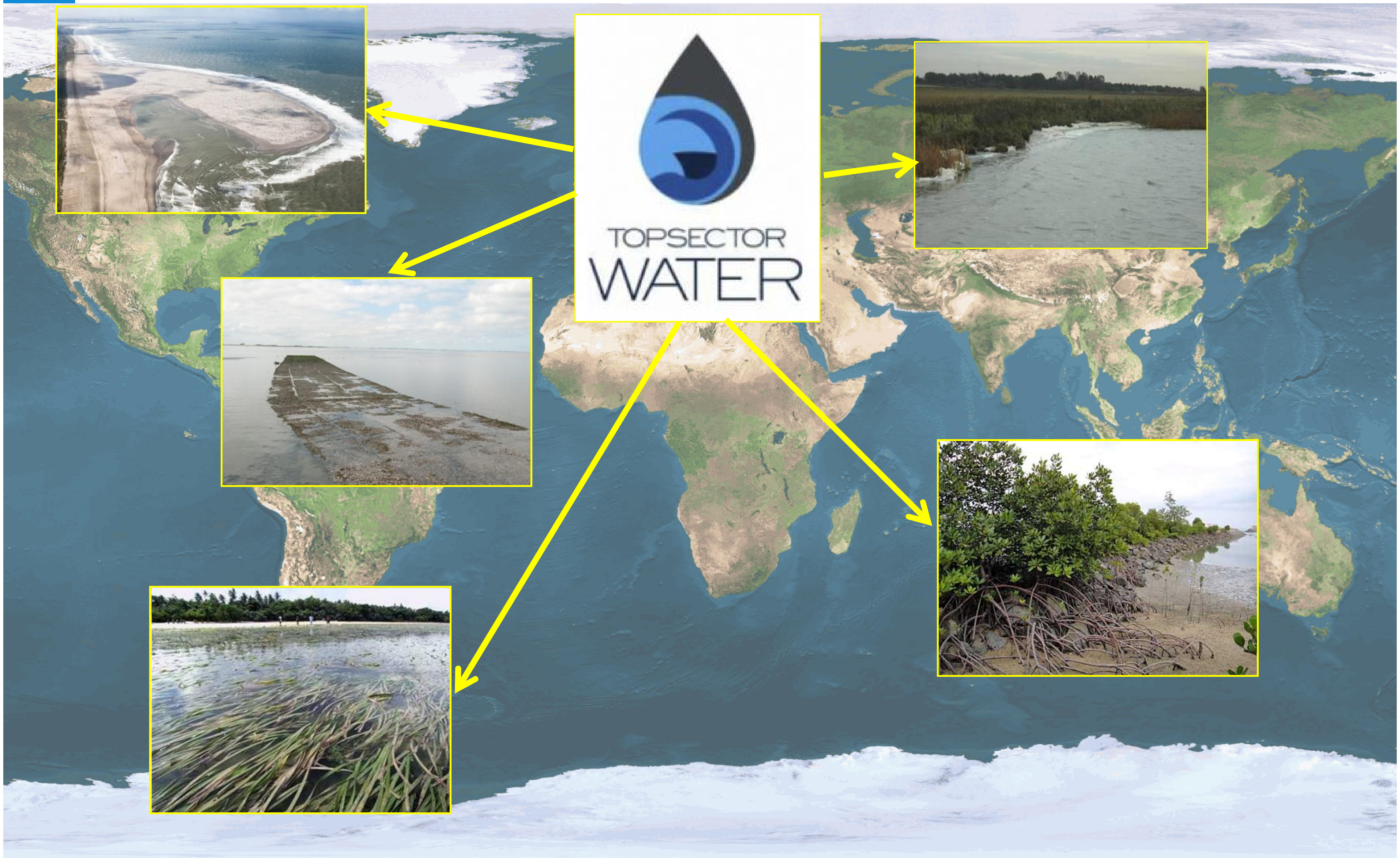
SURF

LS





Explore new applications...



Modellling event driven erosion

XBeach

Dano Roelvink, Ad Reniers, Ap van Dongeren, Jaap van Thiel de Vries, Robert McCall, Arnold van Rooijen

TU Delft Delft University of Technology

UNESCO-IHE Institute for Water Education

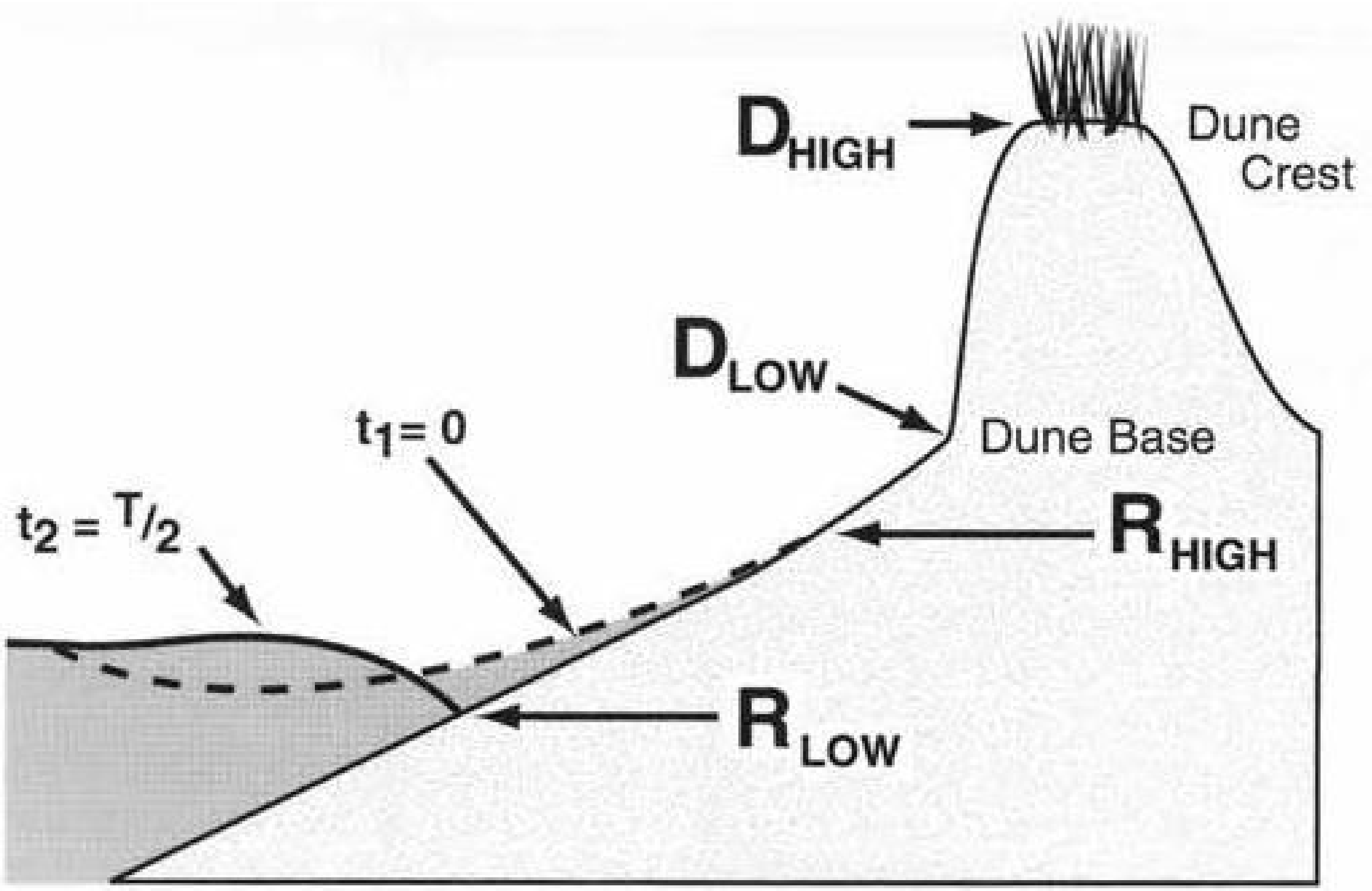
Deltares

Controlling factors in storm impact:

- Hydrodynamic boundary conditions
  - Surge properties (surge height, temporal and spatial surge level gradients)
  - Wave properties (Wave height, Wave period, Spectral shape)

- Coastal properties:
  - Crest height of dunes
  - Sediment properties
  - Vegetation
  - Longshore variation in topography and bathymetry
  - Presence of structures

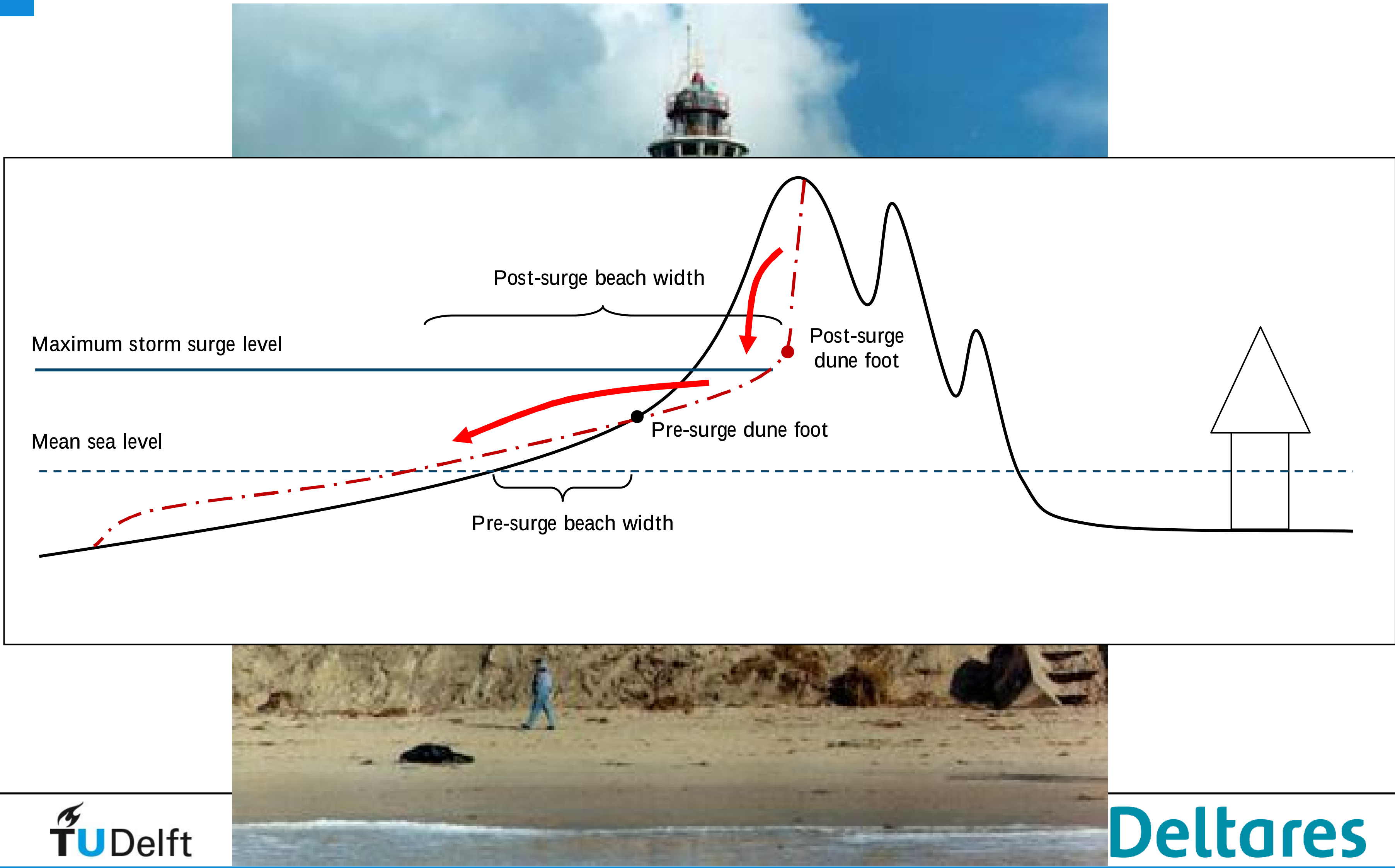
Storm regimes (Sallenger, 2000)



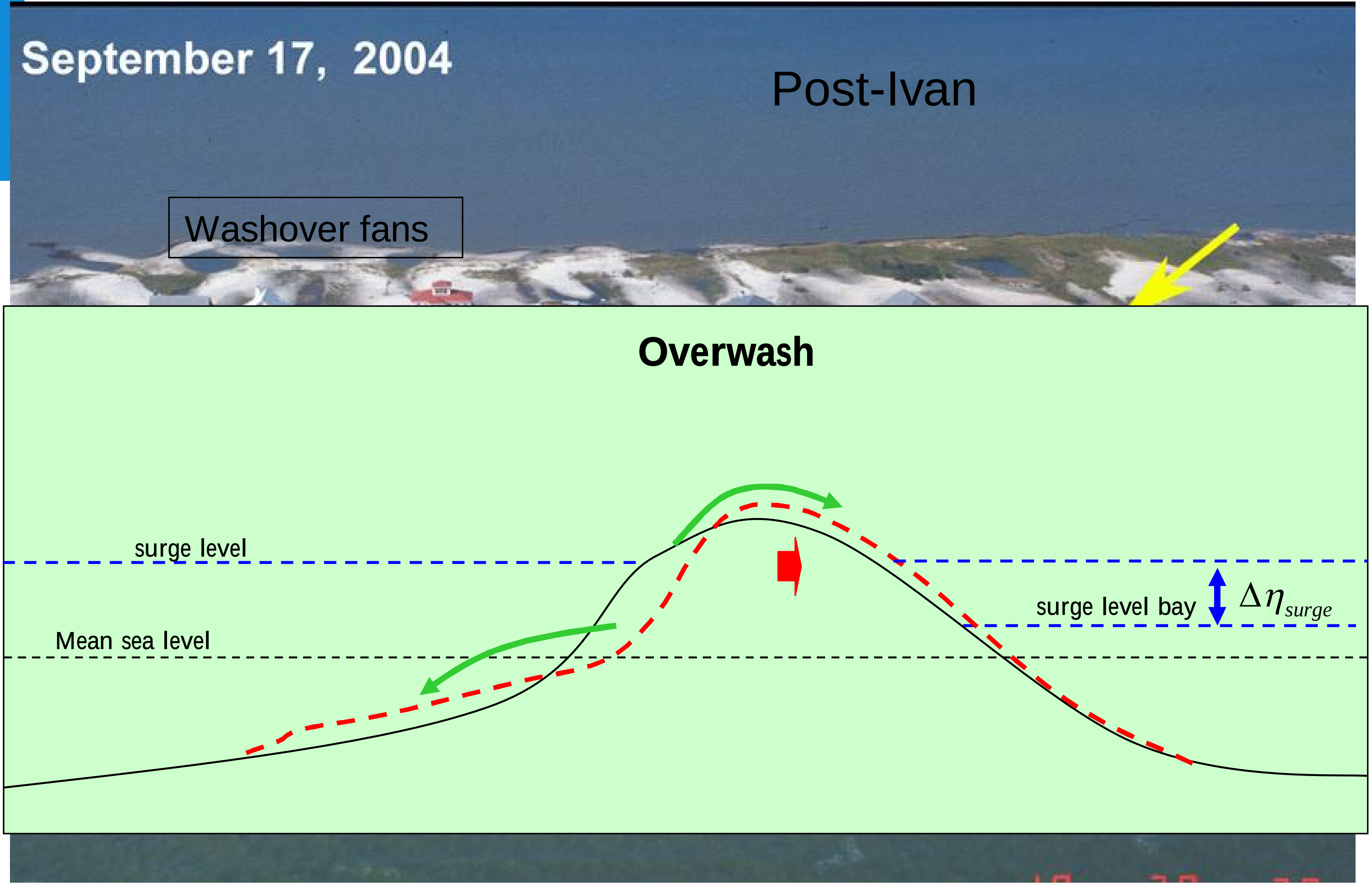
Inundation: Wave rundown above Dune Crest:

$$R_{LOW} > D_{HIGH}$$

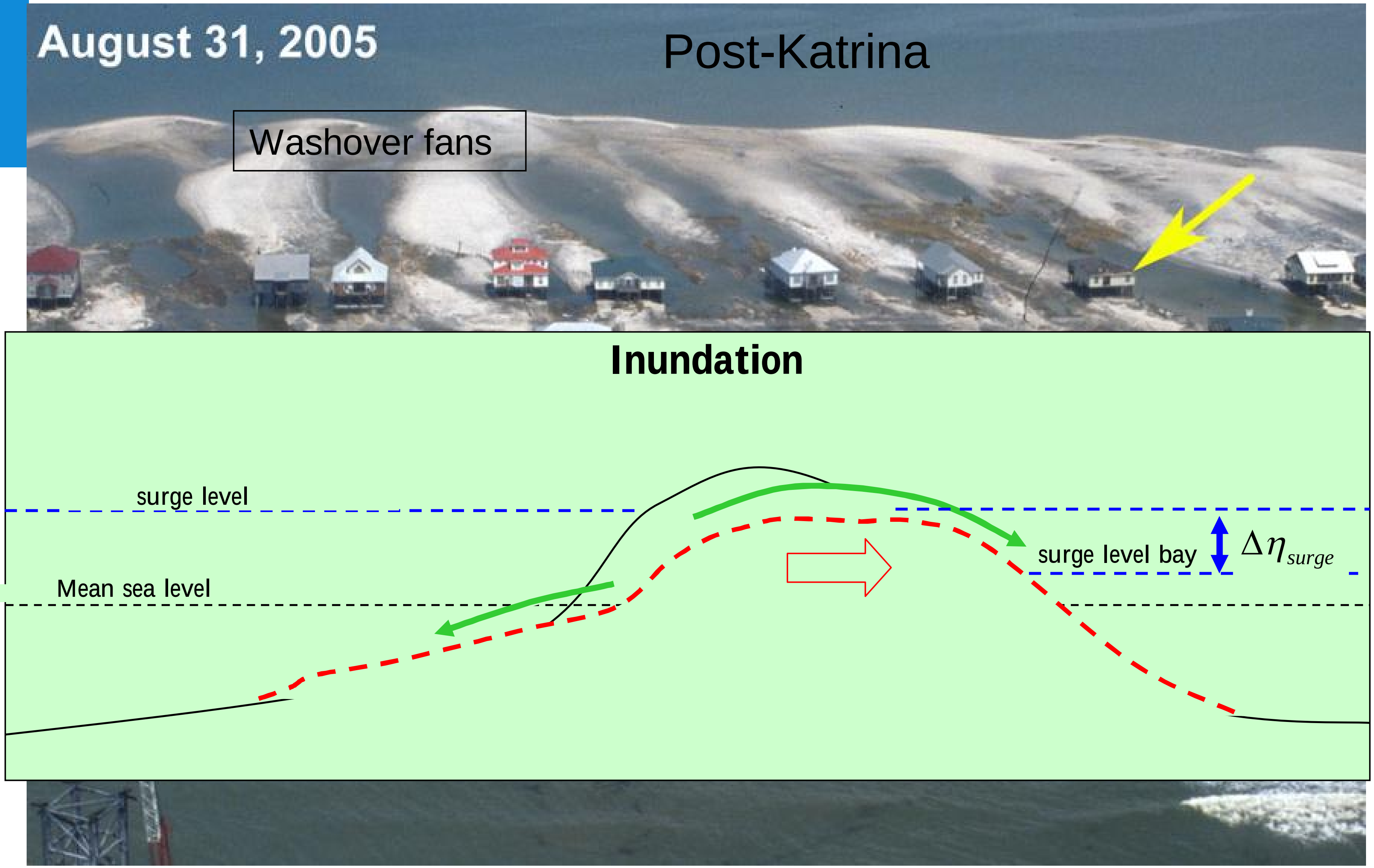
Collision / Dune Erosion



Courtesy of USGS

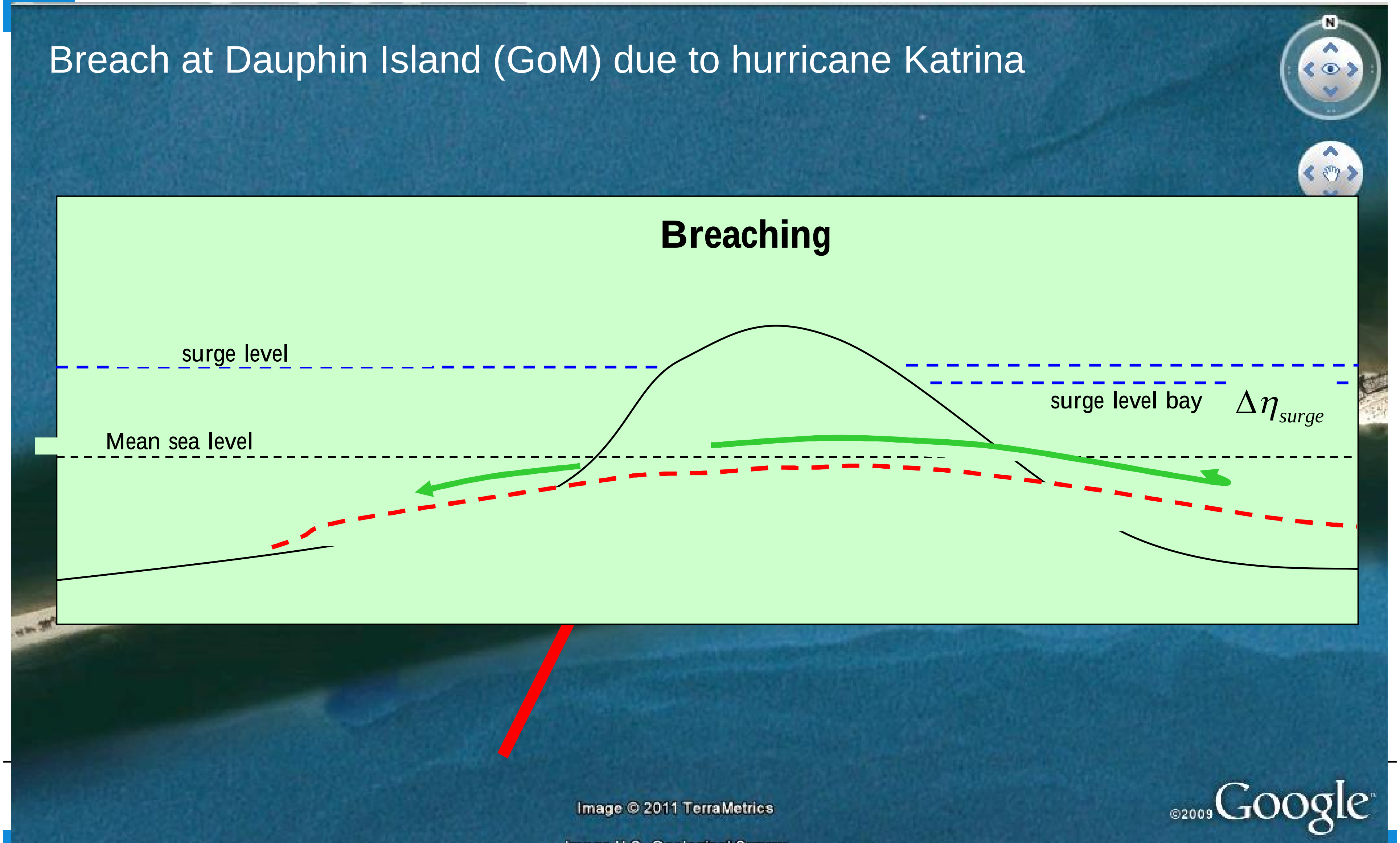


Courtesy of USGS

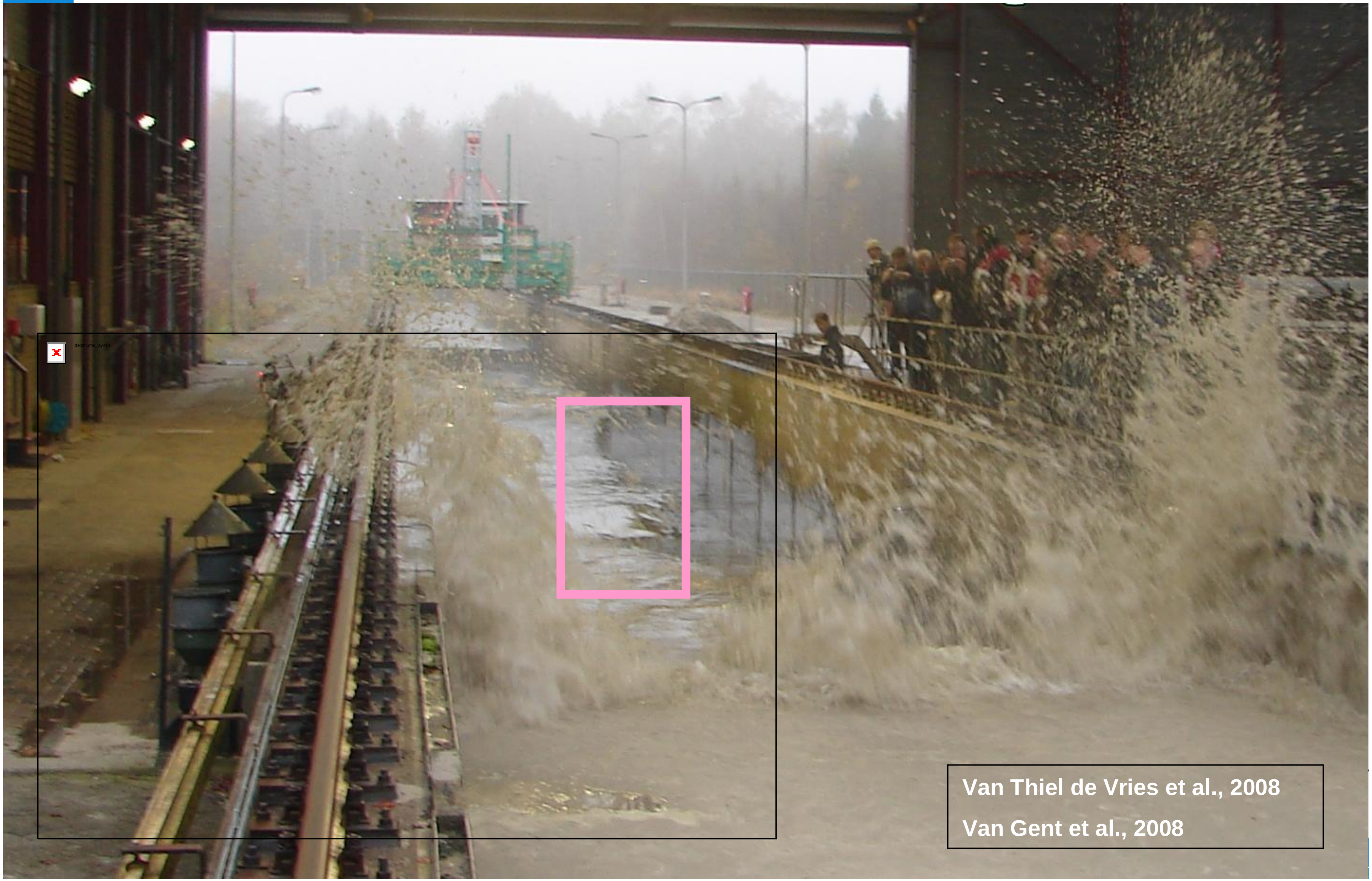


August 31, 2005
Post-Katrina
Washover fans
Inundation
surge level
surge level bay
$\Delta\eta_{surge}$
Mean sea level

Breaching

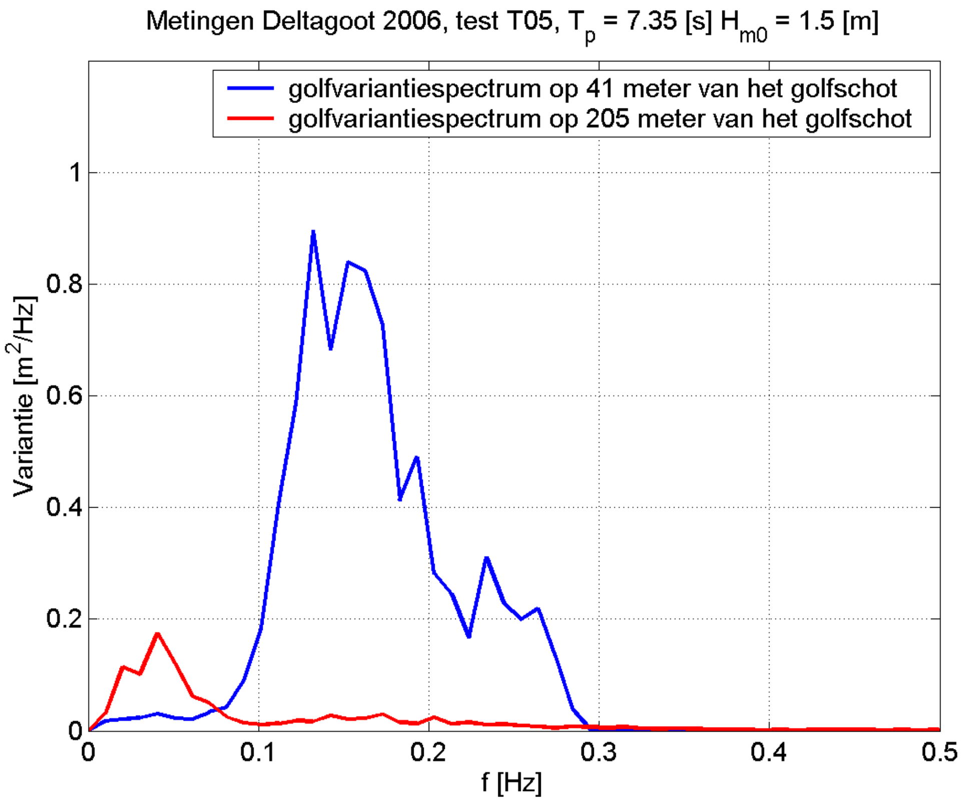

Breach at Dauphin Island (GoM) due to hurricane Katrina
Breaching
surge level
Mean sea level
surge level bay
$\Delta\eta_{surge}$
Image © 2011 TerraMetrics
©2009 Google

Near shore processes during storms

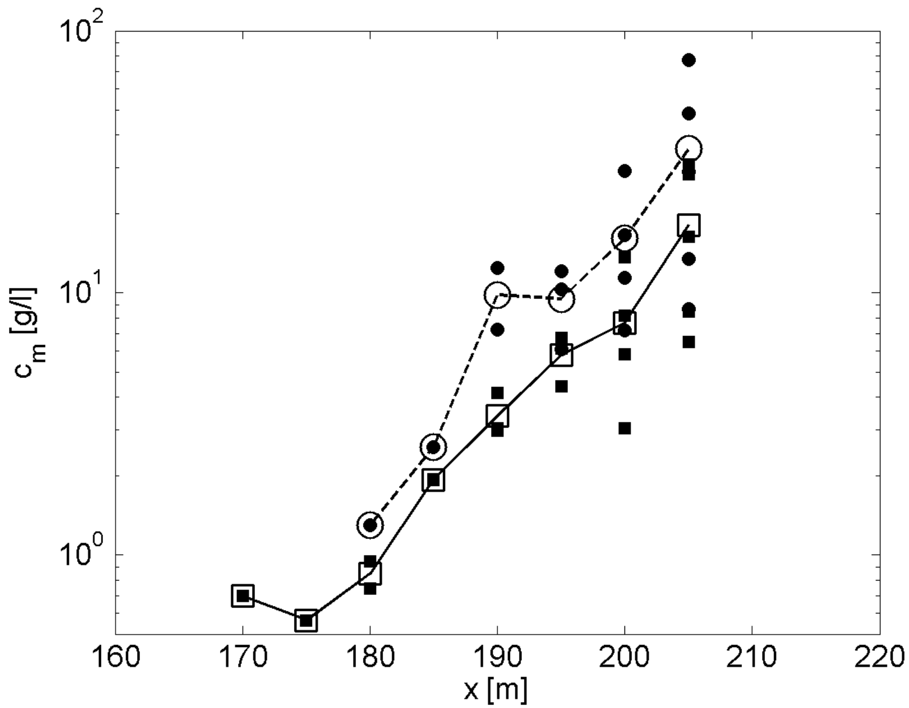


Near shore processes during storms

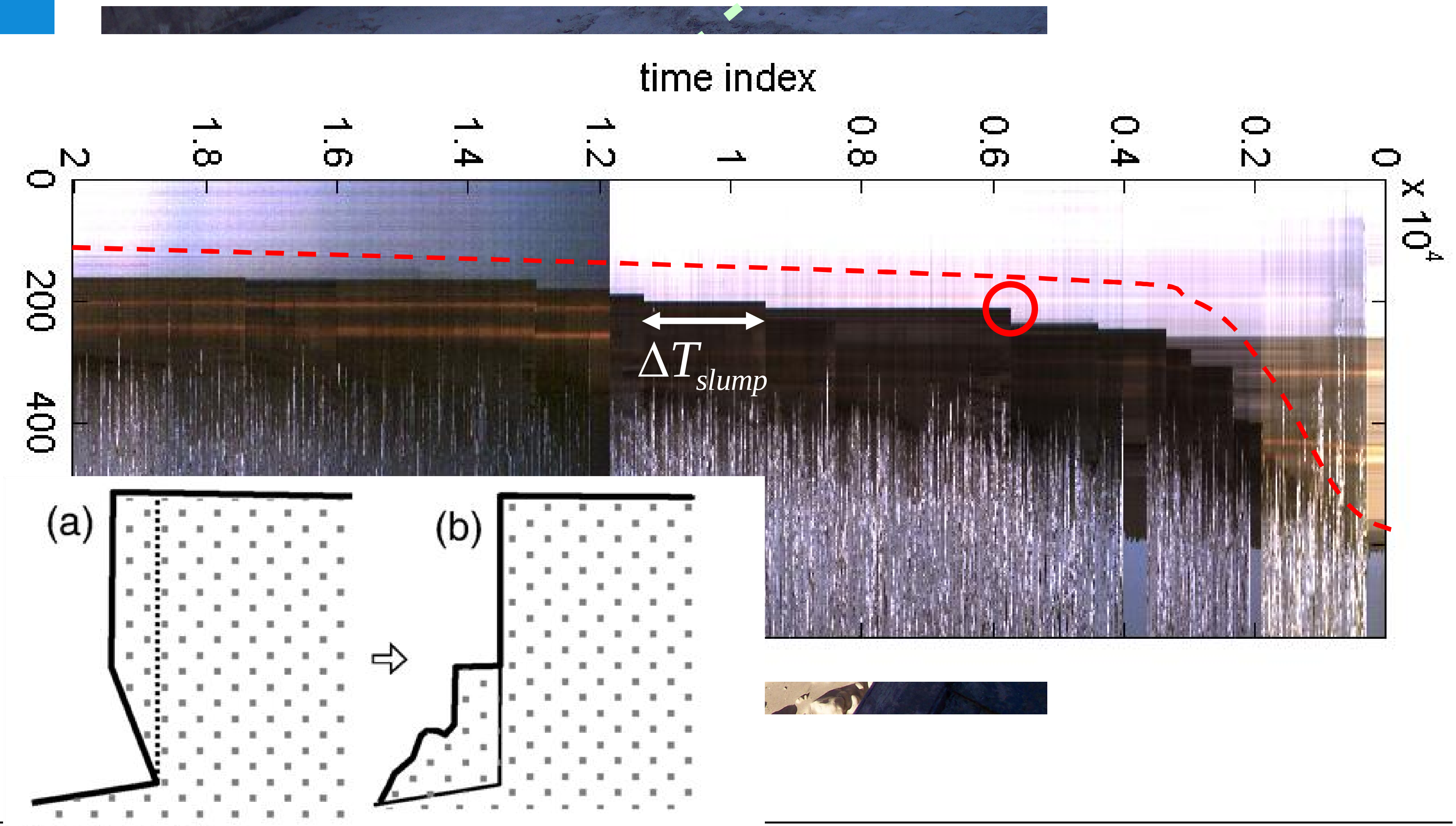
Wave spectra:



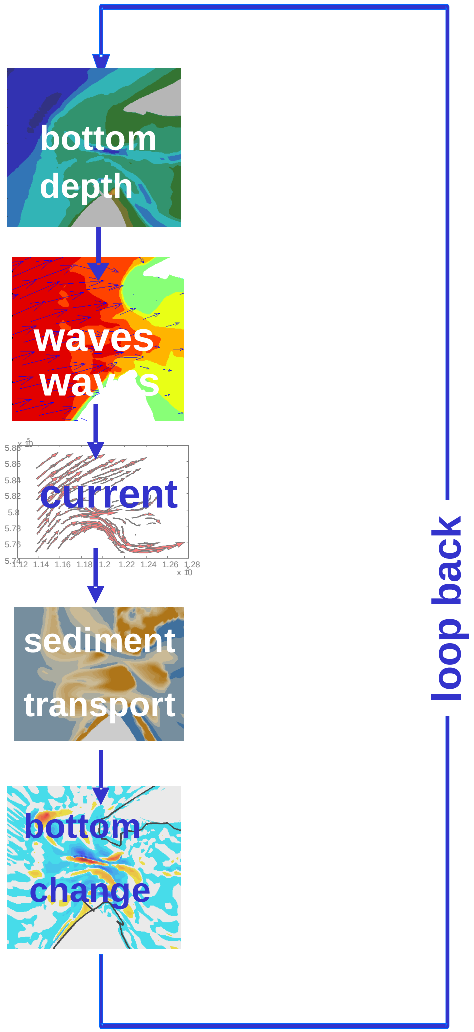
Near dune sediment suspensions:



Dune face erosion



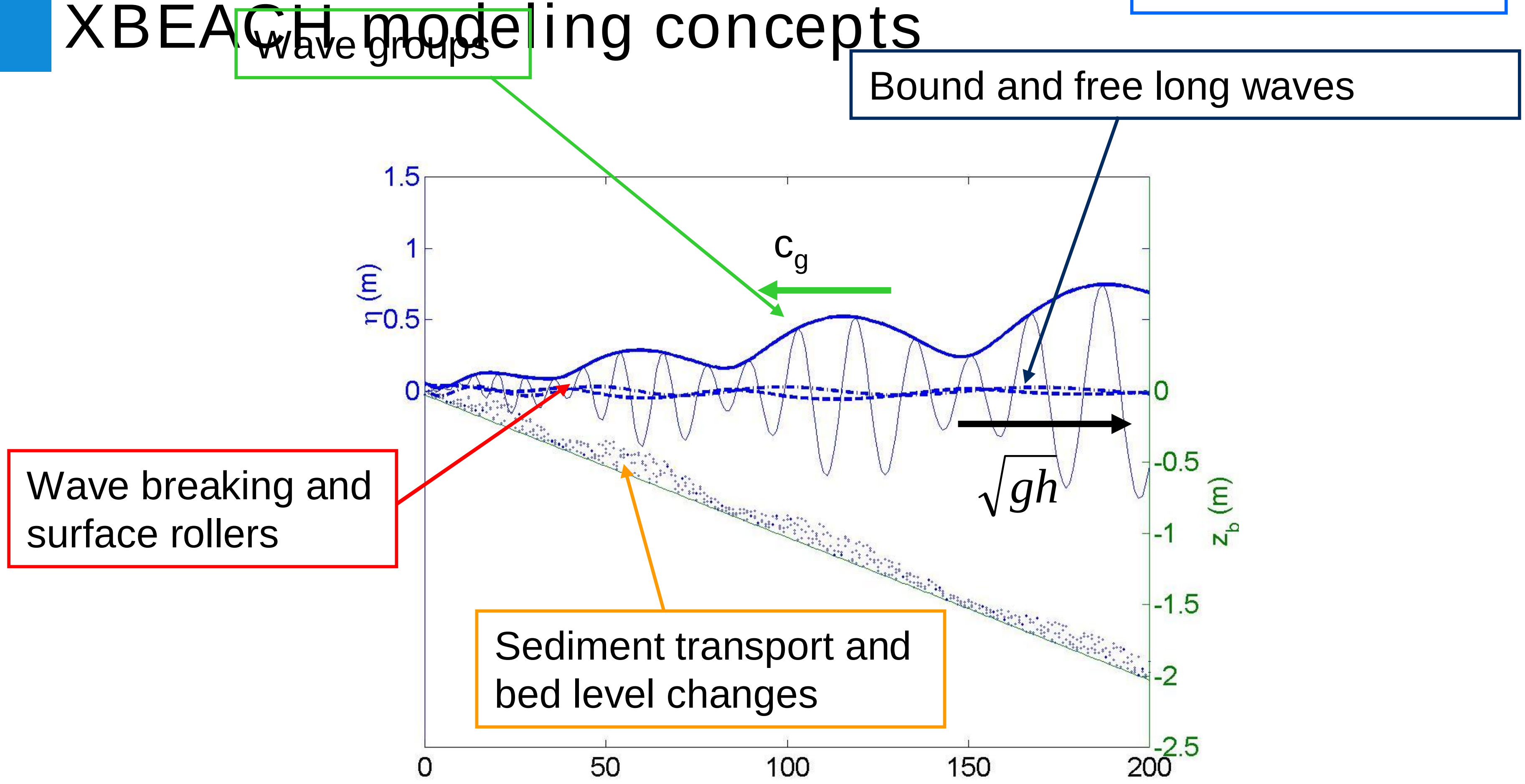
XBEACH Model set-up



XBEACH modeling concepts

Wave-flow motions time scale:

25 s <T< 250 s

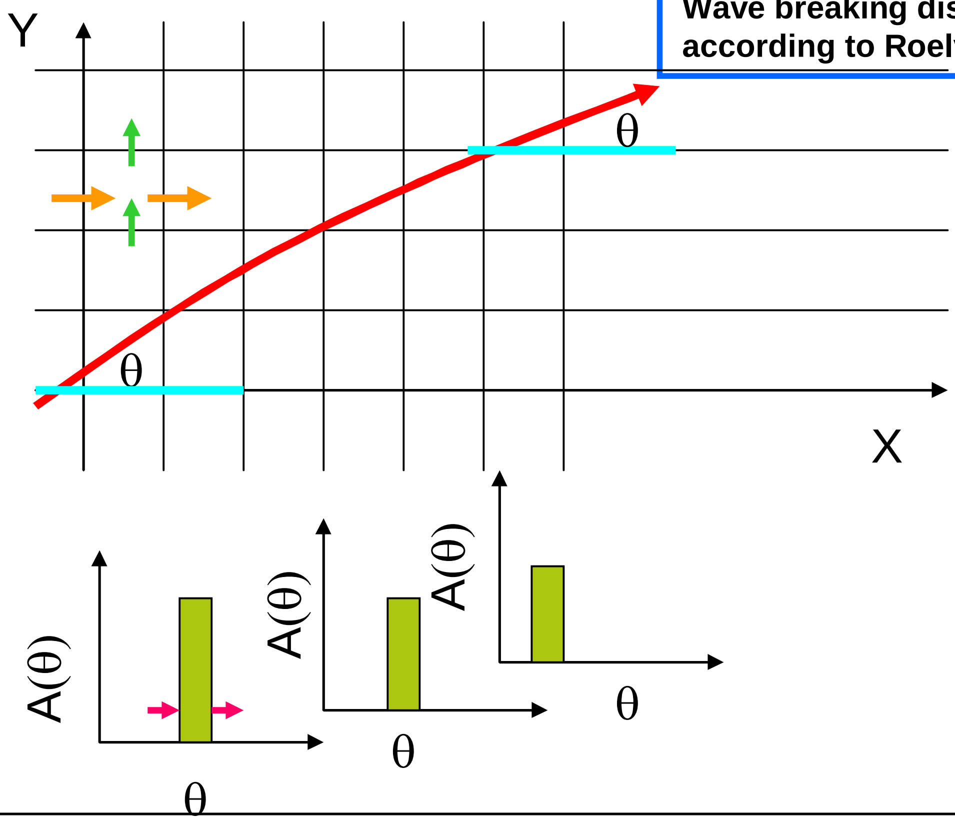


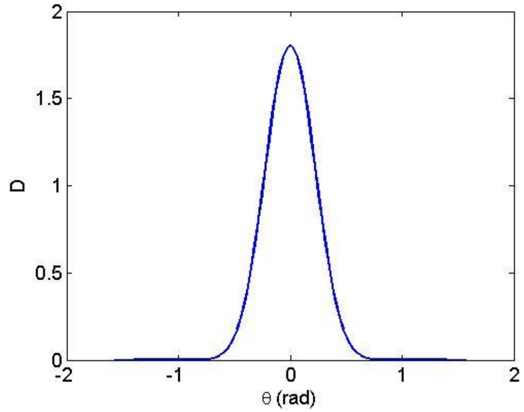
2D-wave action balance

$$\frac{\partial A}{\partial t} + \frac{\partial c_x A}{\partial x} + \frac{\partial c_y A}{\partial y} + \frac{\partial c_\theta A}{\partial \theta} = -\frac{D}{\sigma}$$

$$A(x, y, \theta) = \frac{S_w(x, y, \theta)}{\sigma(x, y)}$$

Wave breaking dissipation D according to Roelvink 1993





Propagation is resolved for wave action in each directional bin similar to HISWA (Holthuijsen et al., 1989) however retaining the non-stationarity of the wave field to allow for wave groups.

Flow modeling

$$\frac{\partial \eta}{\partial t}+\frac{\partial hu}{\partial x}+\frac{\partial hv}{\partial y}=0$$

Bottom stress / Wave forcing / Water level gradient

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{\tau_{sx}}{\rho h}-\frac{\tau_{bx}}{\rho h}-g\frac{\partial \eta}{\partial x}+\frac{F_x}{\rho h}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=+\frac{\tau_{sy}}{\rho h}-\frac{\tau_{by}}{\rho h}-g\frac{\partial \eta}{\partial y}+\frac{F_y}{\rho h}$$

$$u=u^E+u^S$$

$$v=v^E+v^S$$

GLM description (Walstra et al., 2000)

Wave forcing

$$F_x=-\left(\frac{\partial S_{xx}}{\partial x}+\frac{\partial S_{xy}}{\partial y}\right)$$

$$F_y=-\left(\frac{\partial S_{xy}}{\partial x}+\frac{\partial S_{yy}}{\partial y}\right)$$

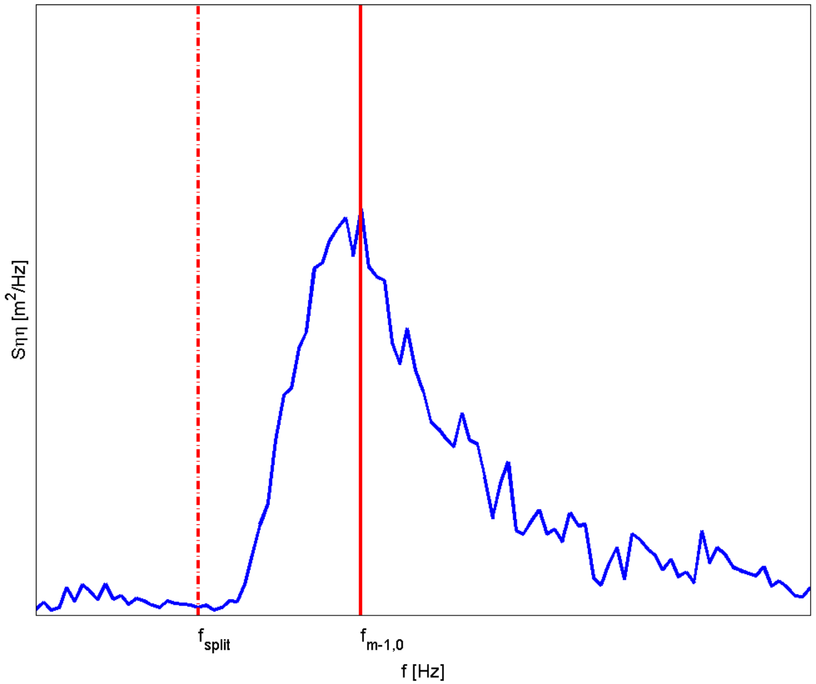
Radiation stresses

$$S_{xx}=\int\left(\frac{c_g}{c}\left(1+\cos^2\theta\right)-\frac{1}{2}\right)S_w d\theta$$

$$S_{xy}=S_{yx}=\int\sin\theta\cos\theta\left(\frac{c_g}{c}S_w\right)d\theta$$

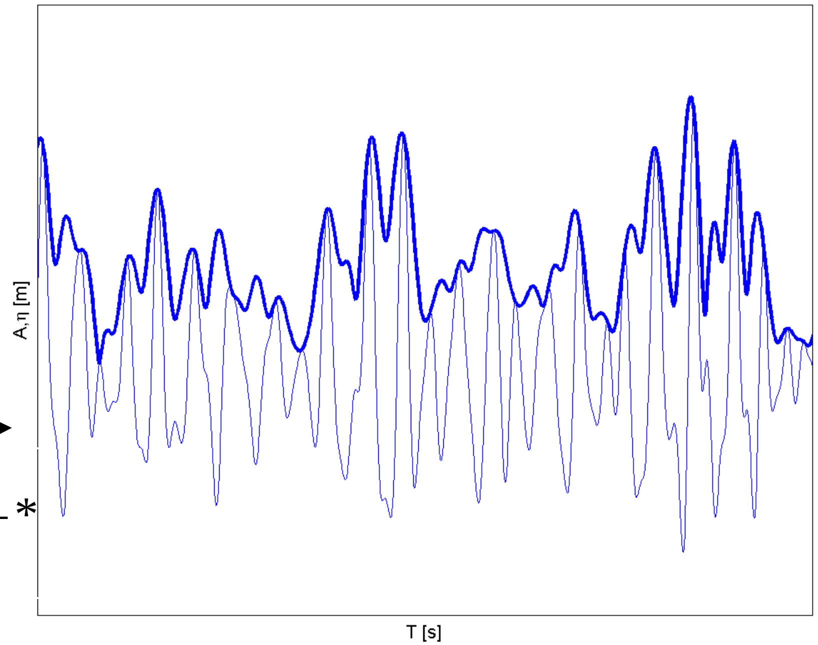
$$S_{yy}=\int\left(\frac{c_g}{c}\left(1+\sin^2\theta\right)-\frac{1}{2}\right)S_w d\theta$$

Surf Beat: Boundary Conditions



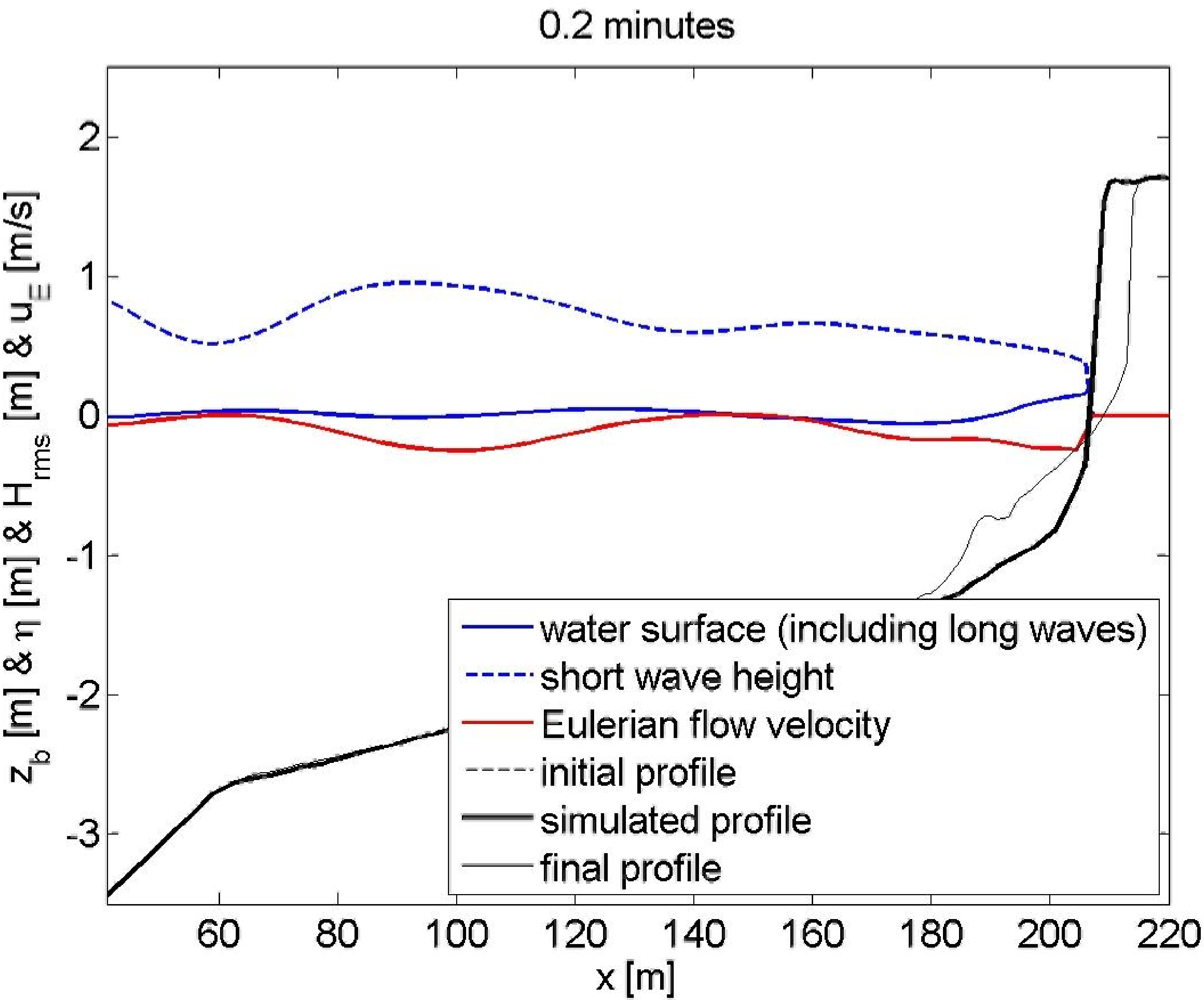
$$E_w(x,t) = \frac{1}{2}\rho g \,|\, A_{low}(x,t)\,|^2$$

Hilbert Transform



$$\eta(x,t) = \sum_{j=N_{split}+1}^{N} \hat{\eta}_j e^{i(\sigma_j t - k_{x,j}x + \phi_j)} + *$$

$$\eta(x,t) = \sum_{j=1}^{N_{split}} \hat{\eta}_j e^{i(\sigma_j t - k_{x,j}x + \phi_j)} + *$$



0.2 minutes
z_b [m] & η [m] & H_rms [m] & u_E [m/s]
x [m]
2
1
0
-1
-2
-3
60
80
100
120
140
160
180
200
220
water surface (including long waves)
short wave height
Eulerian flow velocity
initial profile
simulated profile
final profile

Sediment transport

$$\frac{\partial hC}{\partial t}+\frac{\partial hCu^E}{\partial x}+\frac{\partial hCv^E}{\partial y}+\frac{\partial}{\partial x}\left[D_h h\frac{\partial C}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_h h\frac{\partial C}{\partial y}\right]=\frac{hC_{eq}-hC}{T_s}$$

Eq. 6.52 CD1

$$C_{eq}=\frac{A_{sb}+A_{ss}}{h}\left(\left(|u^E|^2+0.018\frac{u_{rms}^2}{C_d}\right)^{0.5}-u_{cr}\right)^{2.4}(1-\alpha_b m)$$

Soulsby-van Rijn, 1996

avalanching

Bottom update:

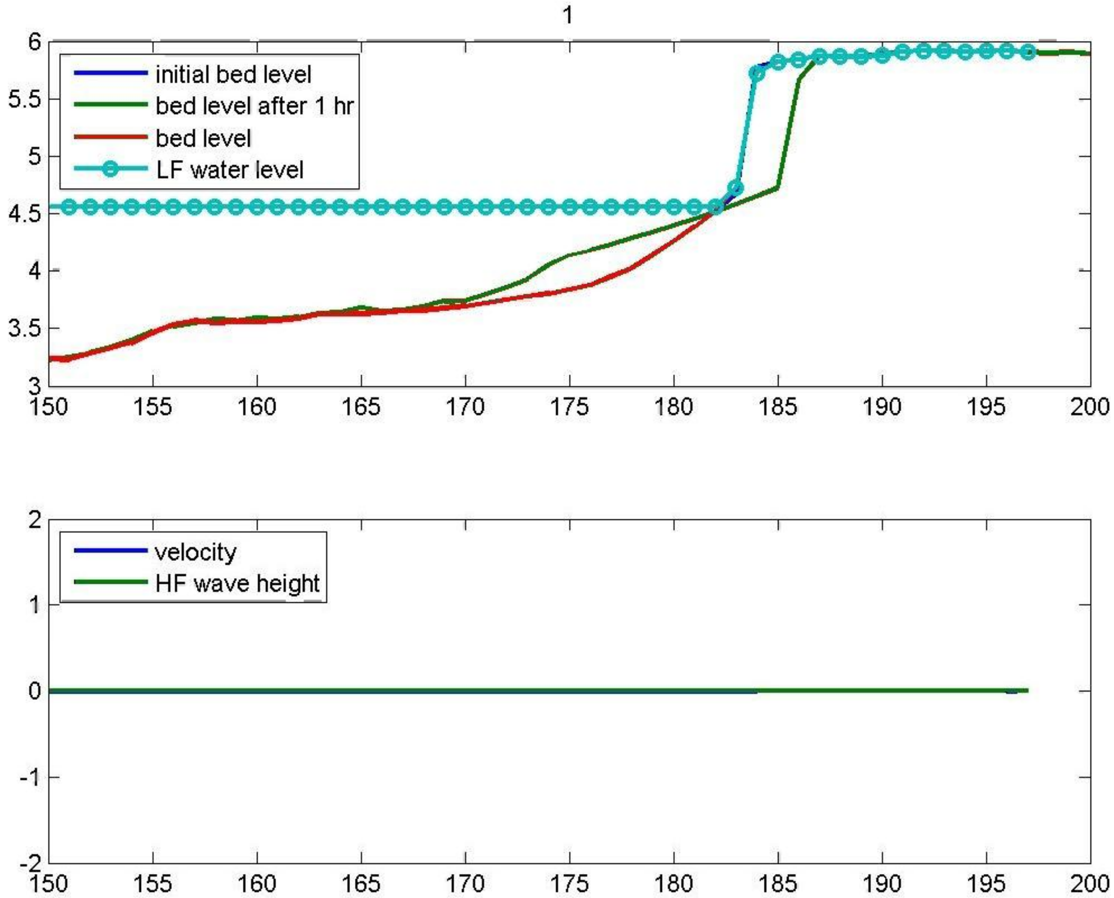
$$(1-p)\frac{\partial z_b}{\partial t}+\frac{\partial S_x}{\partial x}+\frac{\partial S_y}{\partial y}=0$$

Eq. 6.14 CD1

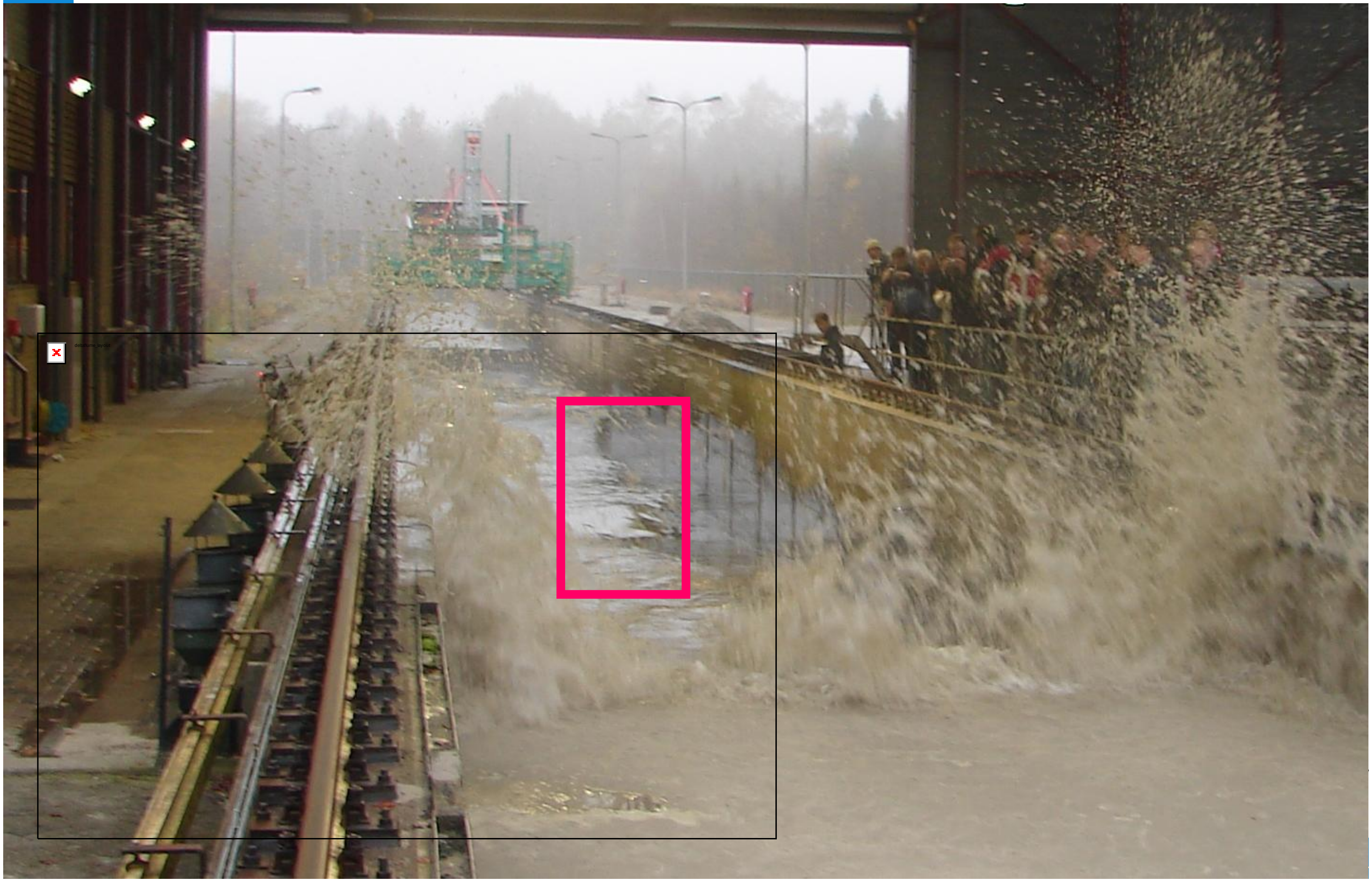
$$\Delta z_b=\min\left(\Delta t\left(\left|\frac{\partial z_b}{\partial x}\right|-m_{cr}\right)\Delta x, 0.005\right)\quad ,\frac{\partial z_b}{\partial x}>0$$

$$\Delta z_b=\max\left(-\Delta t\left(\left|\frac{\partial z_b}{\partial x}\right|-m_{cr}\right)\Delta x, -0.005\right)\quad ,\frac{\partial z_b}{\partial x}<0$$

Avalanching

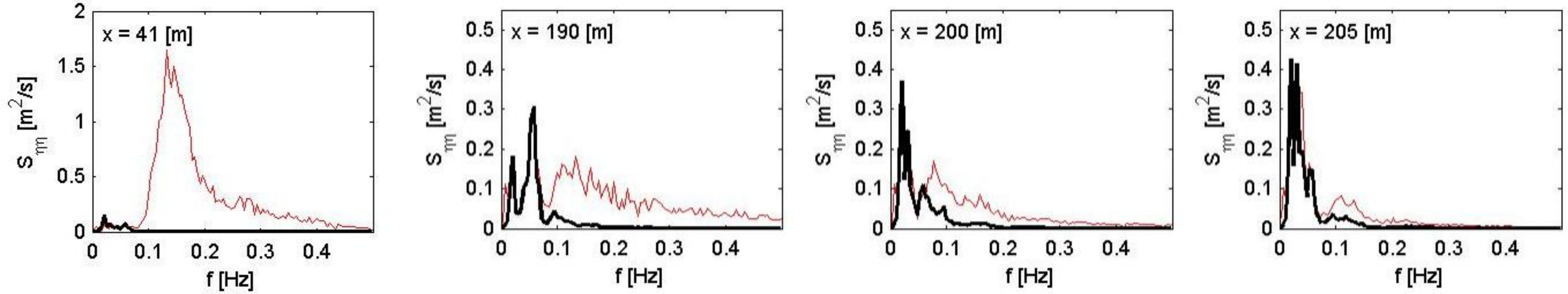


Large scale dune erosion tests

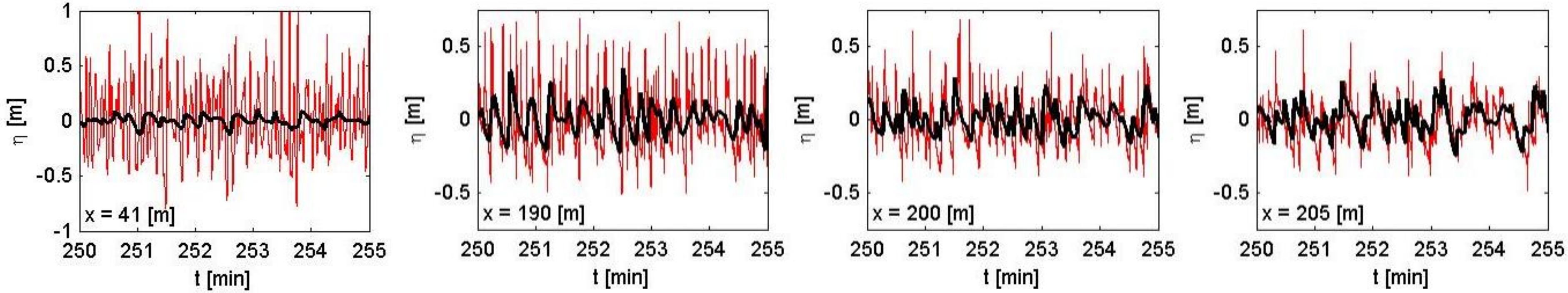


Dune erosion case: Deltaflume test

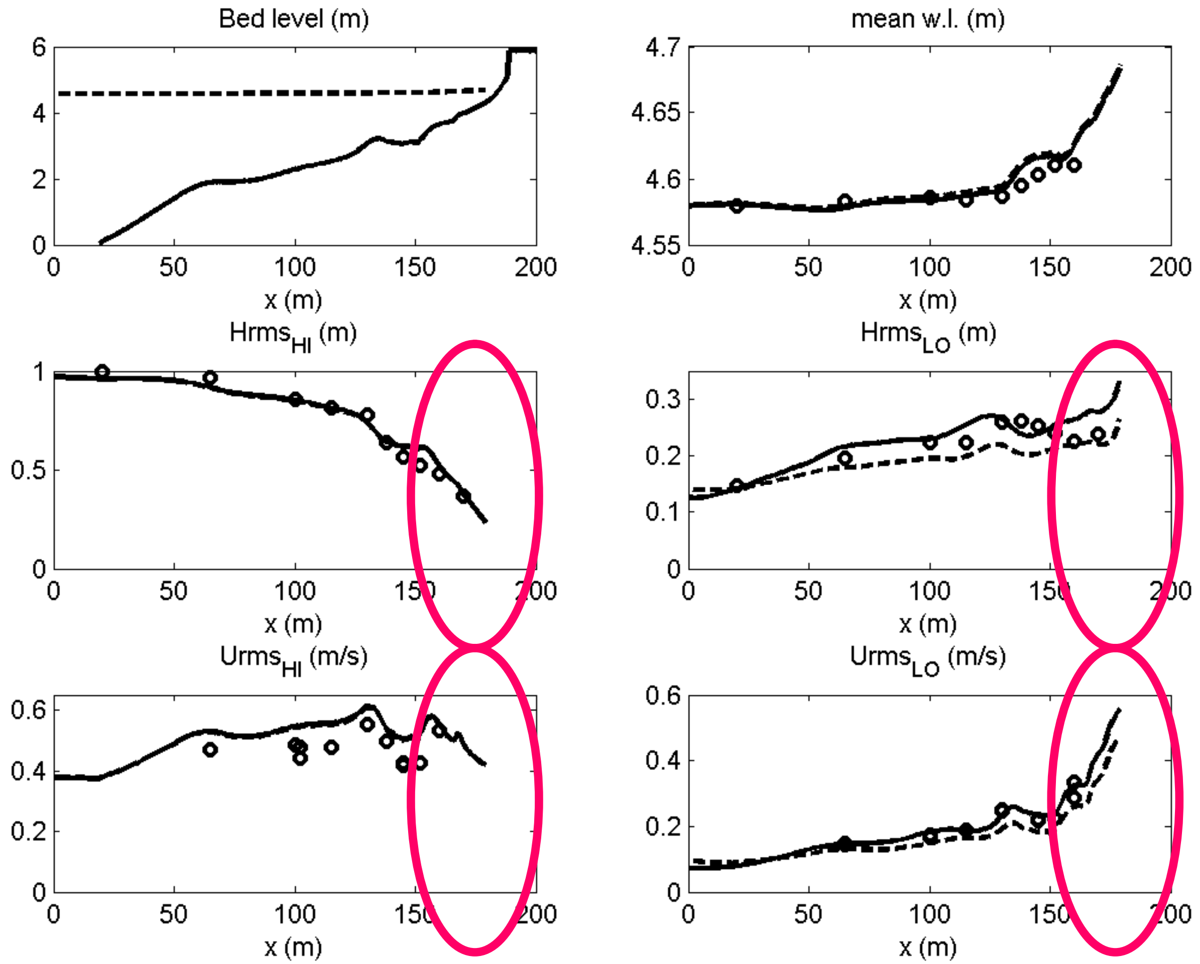
Wave spectra



Water surface elevation time series

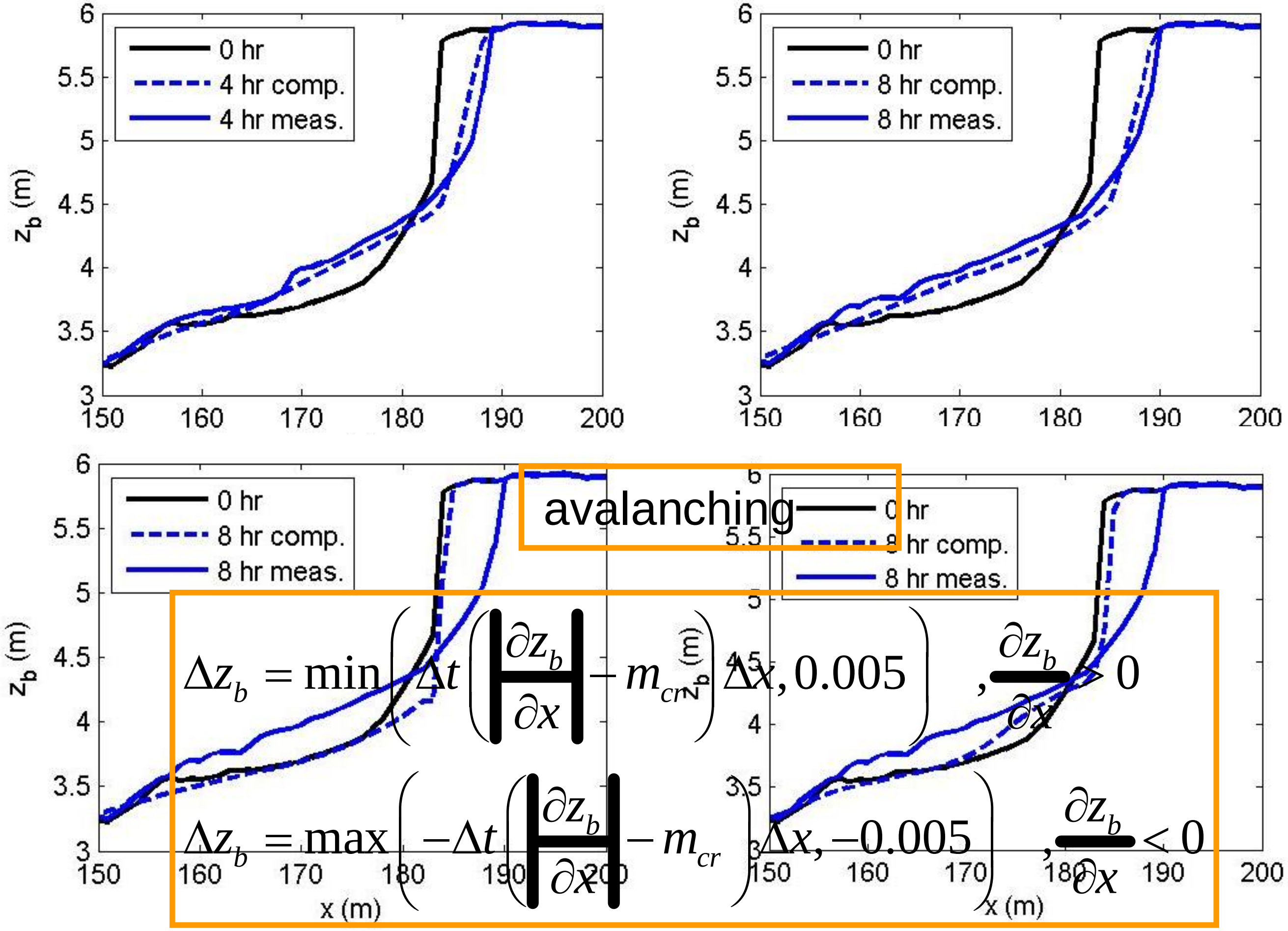


Hy



Roelvink et al., 2010

Du



$$\Delta z_b = \min\left(\Delta t\left(\left|\frac{\partial z_b}{\partial x}\right| - m_{cr}\right)\Delta x, 0.005\right), \quad \frac{\partial z_b}{\partial x} > 0$$

$$\Delta z_b = \max\left(-\Delta t\left(\left|\frac{\partial z_b}{\partial x}\right| - m_{cr}\right)\Delta x, -0.005\right), \quad \frac{\partial z_b}{\partial x} < 0$$

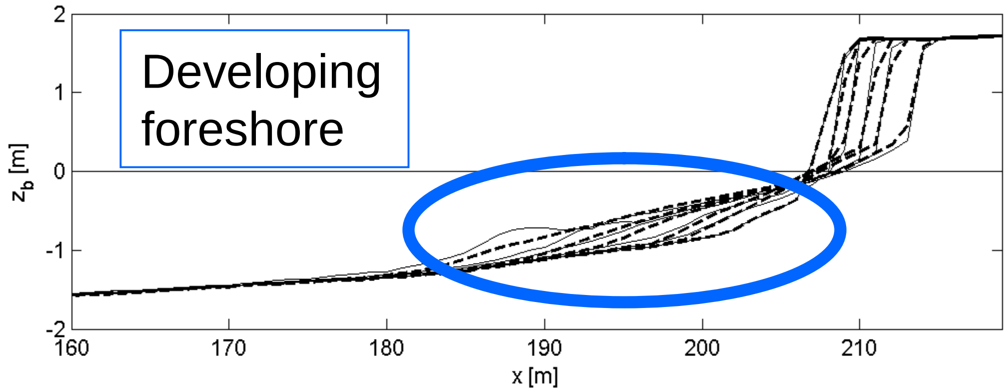
No avalanching

No wave groups

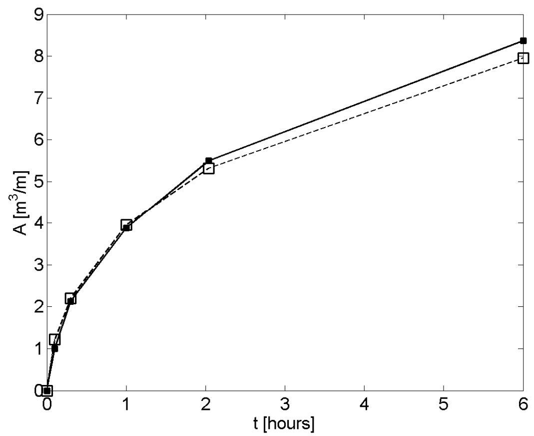
Roelvink et al., 2010

Temporal evolution

Developing foreshore



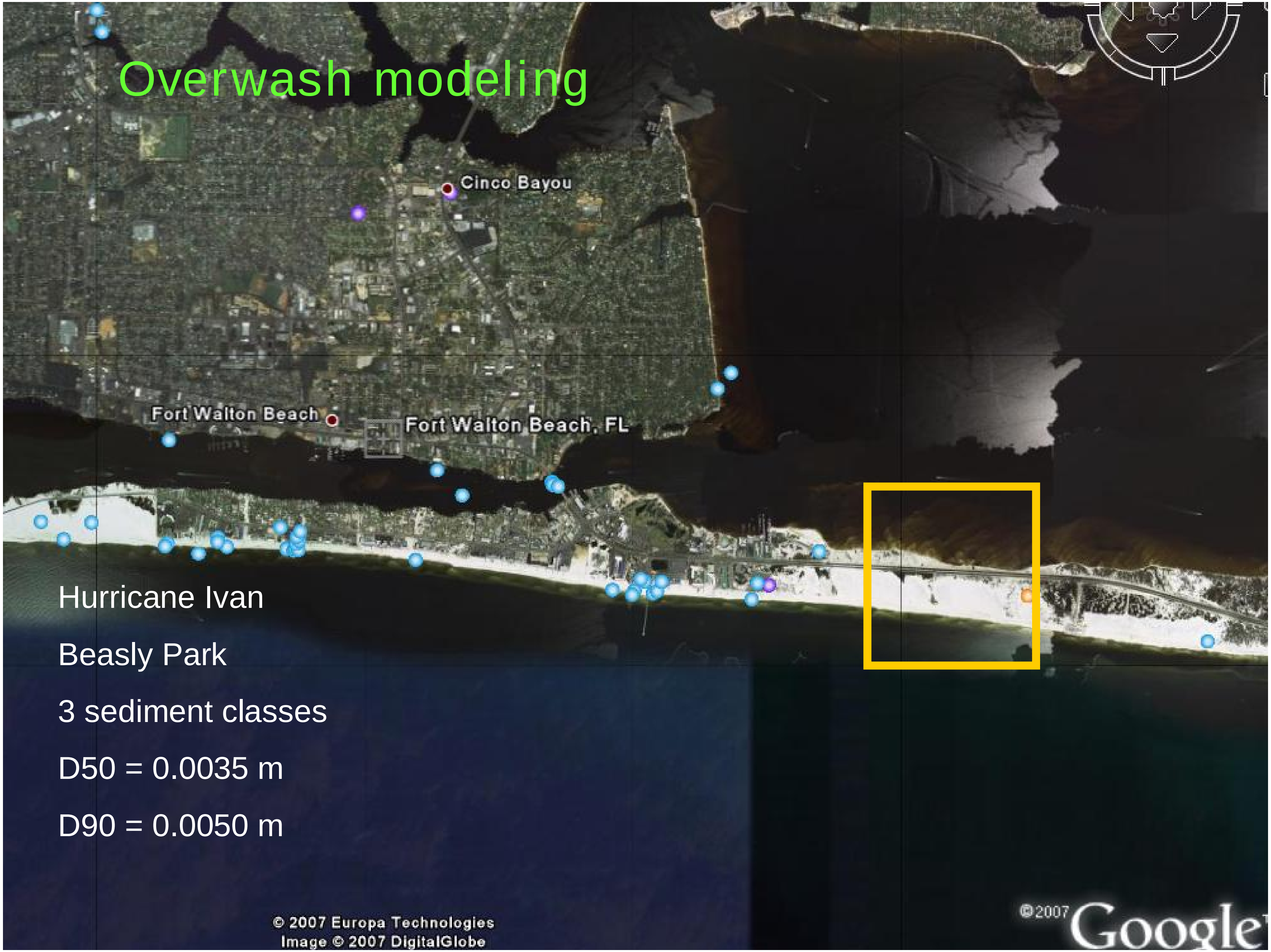
Decreasing dune erosion rate



Van Thiel de Vries et al., 2008
Van Gent et al., 2008

Section 7.3.5 CD1

Overwash modeling



Hurricane Ivan

Beasly Park

3 sediment classes

D50 = 0.0035 m

D90 = 0.0050 m

Ivan

η_{max}>2.0m

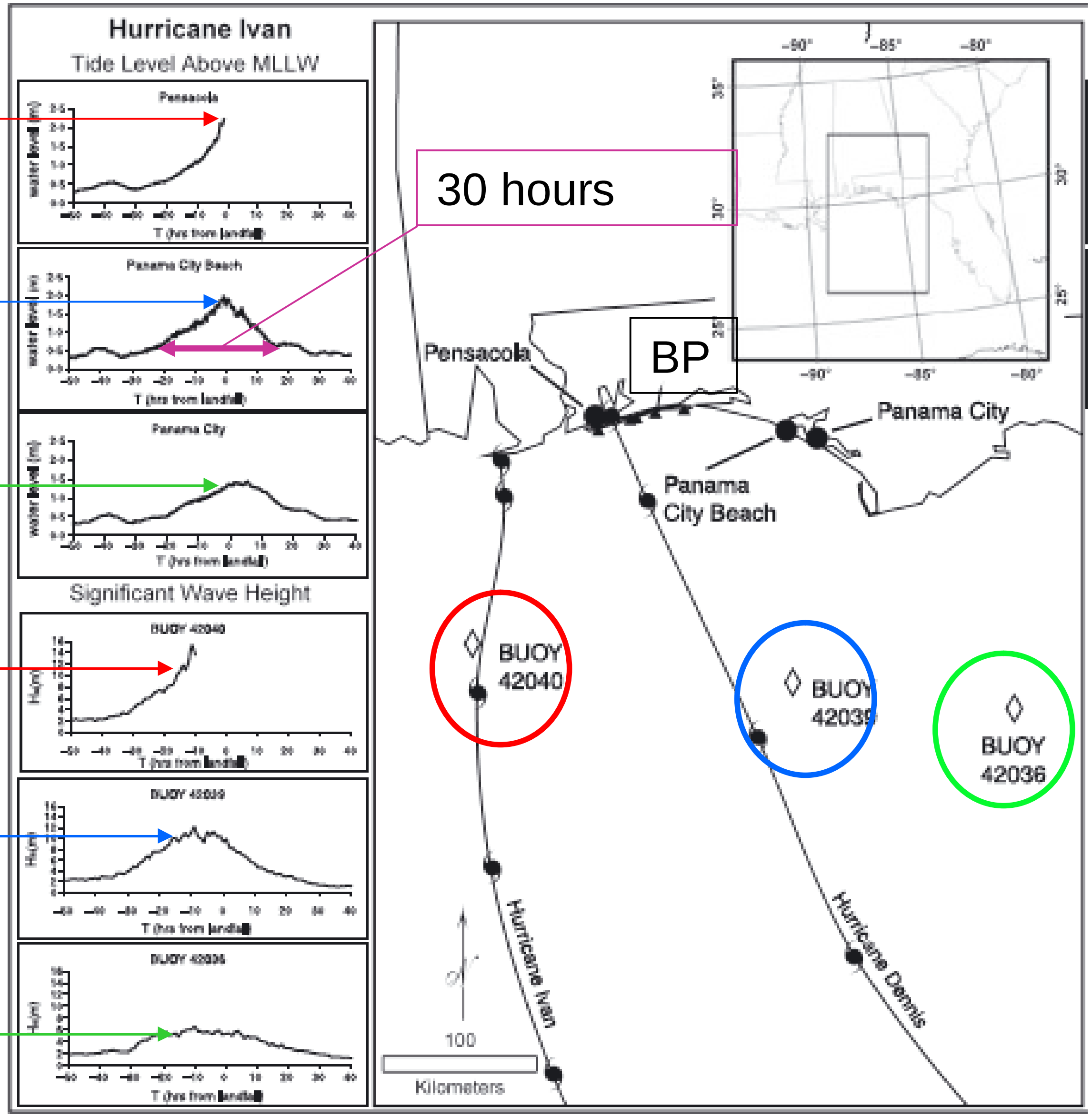
η_{max}~1.9m

η_{max}~1.5m

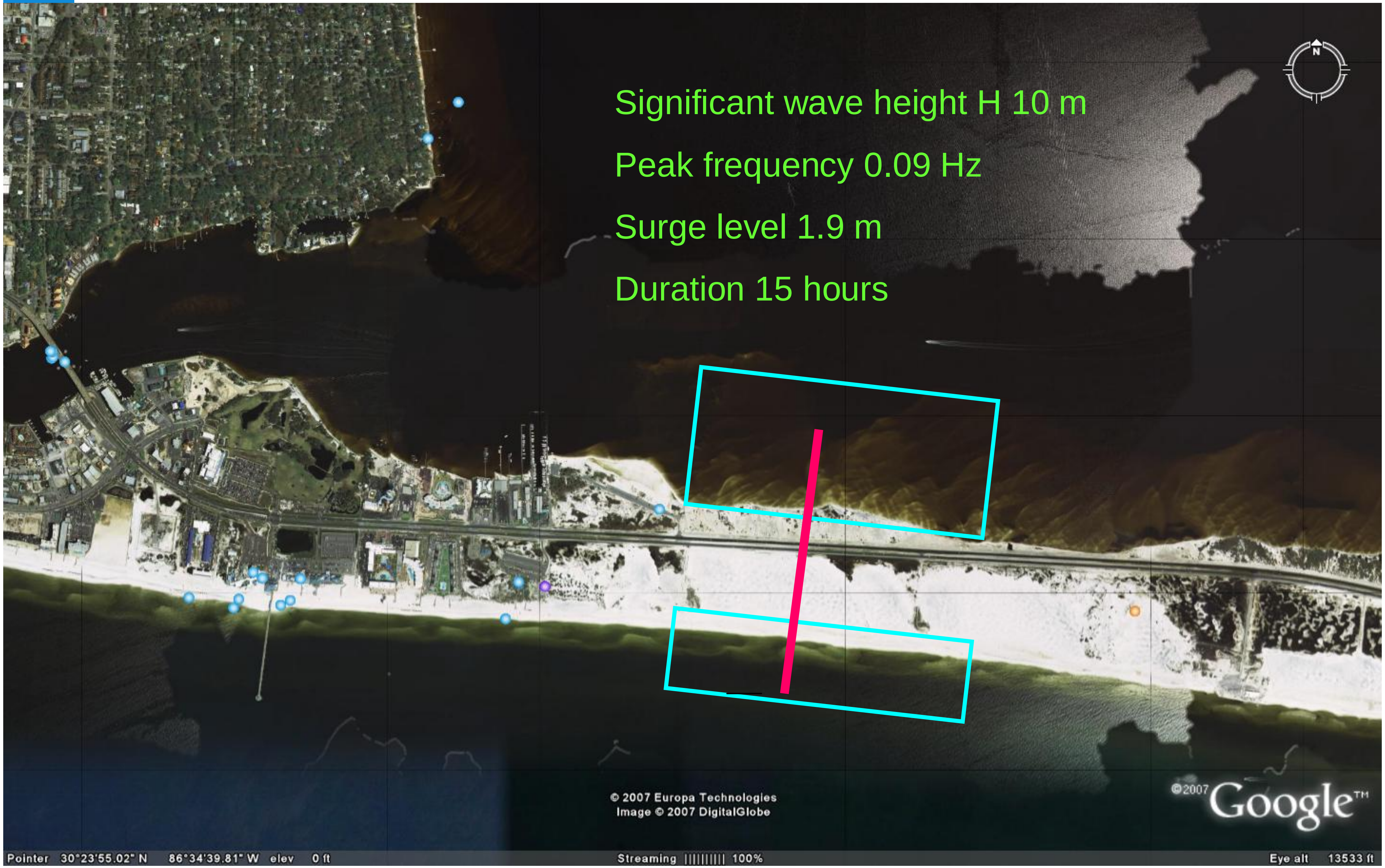
H_s>14m

$H_{s,max}$~10m

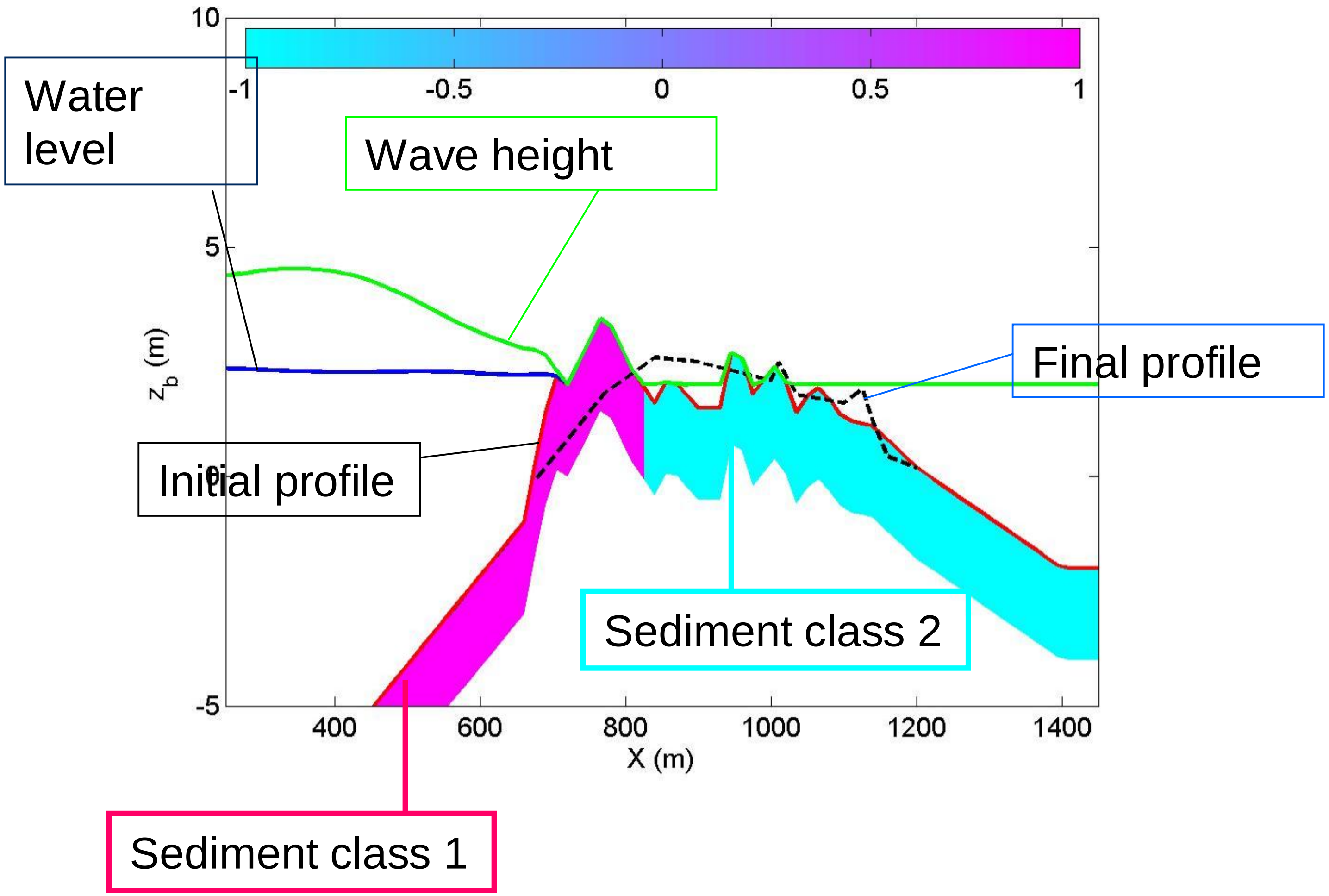
$H_{s,max}$~6m



1D Model setup

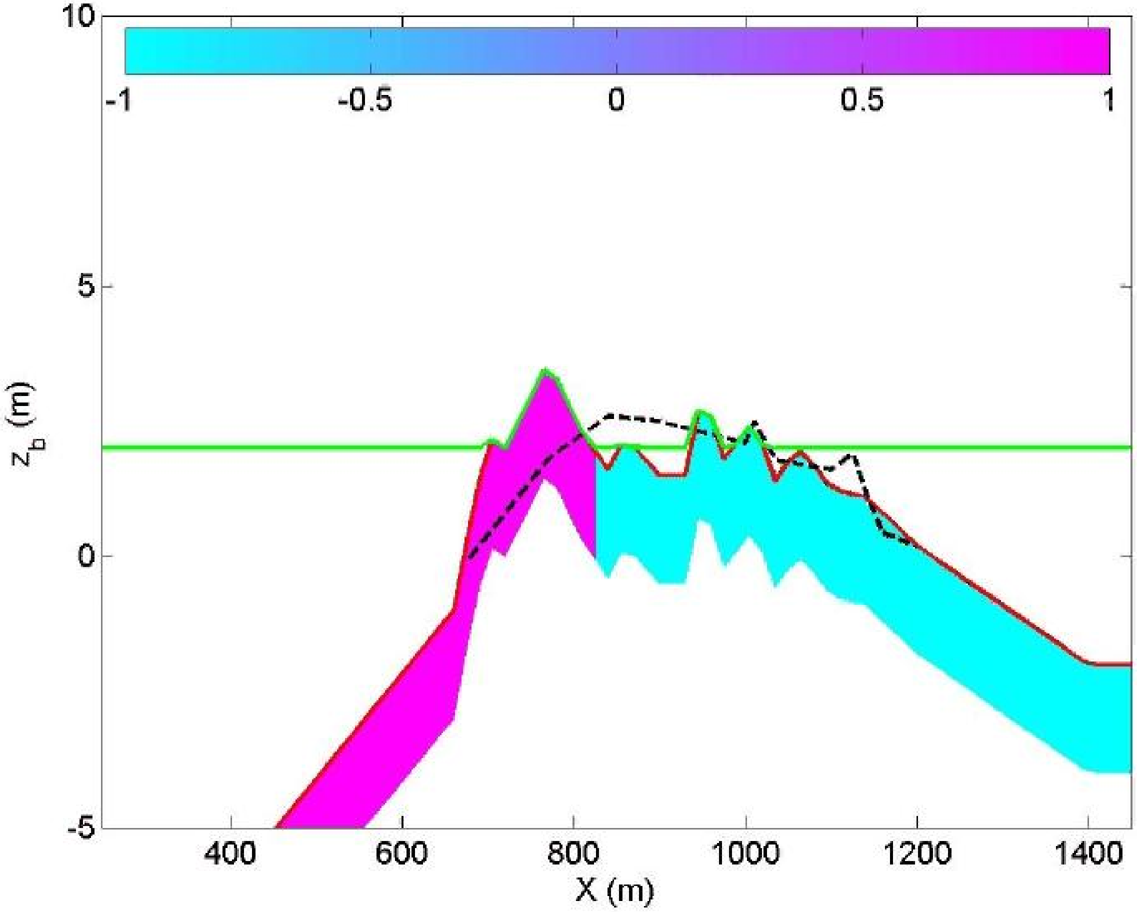


Overwash modeling

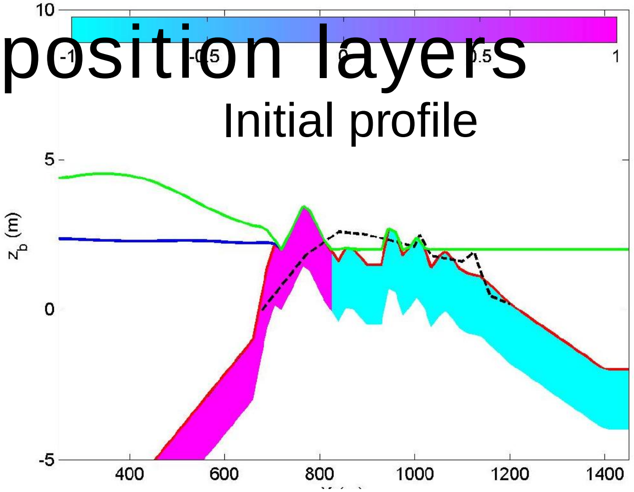


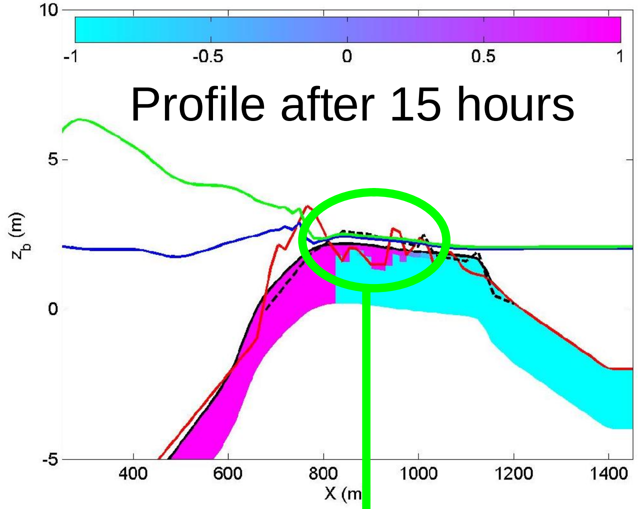
Initial and final profile from Wang and Horwitz, 2006

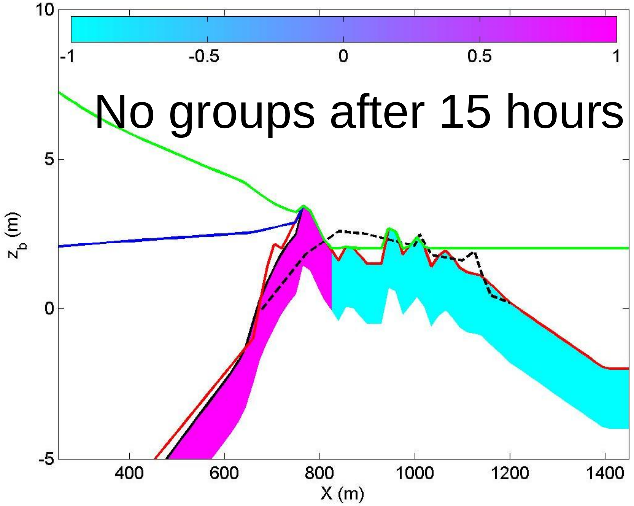
Simulation

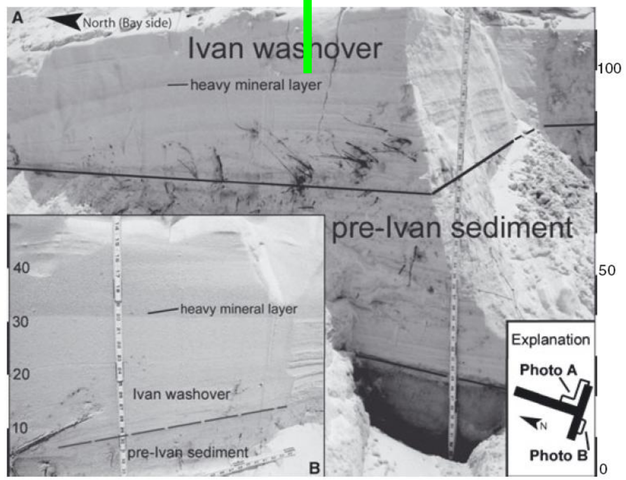


Deposition layers



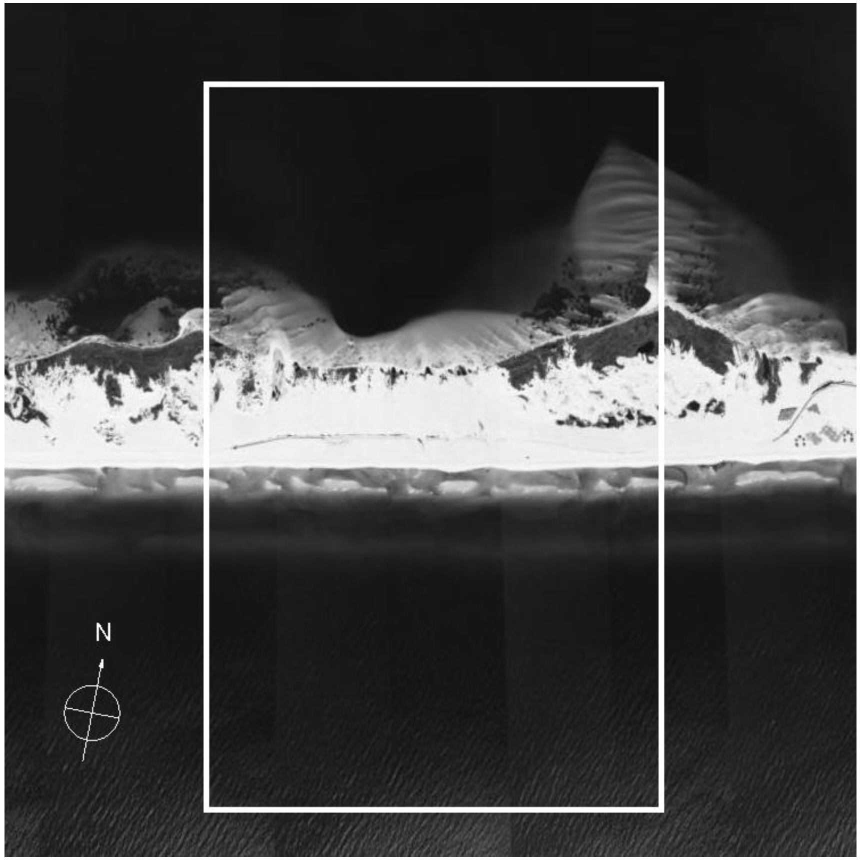


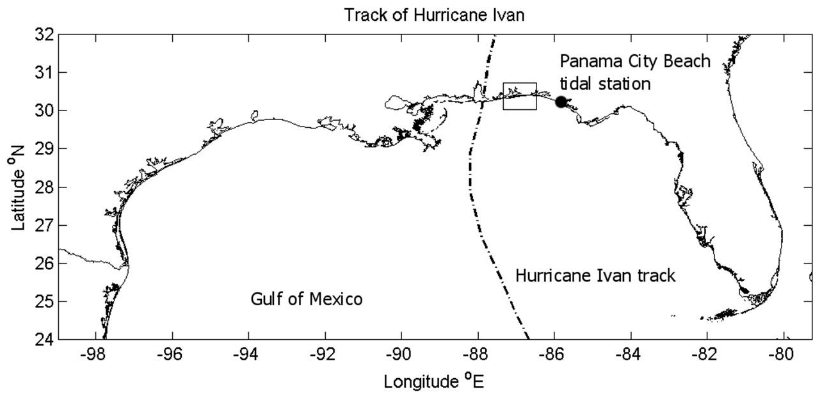


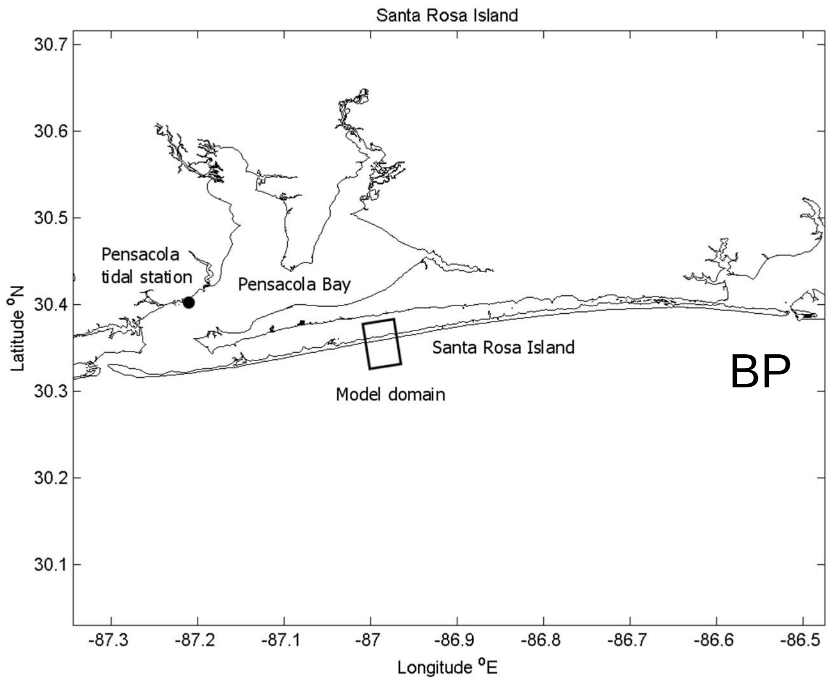


Courtesy of Wang and Horwitz, 2006

Alongshore variation

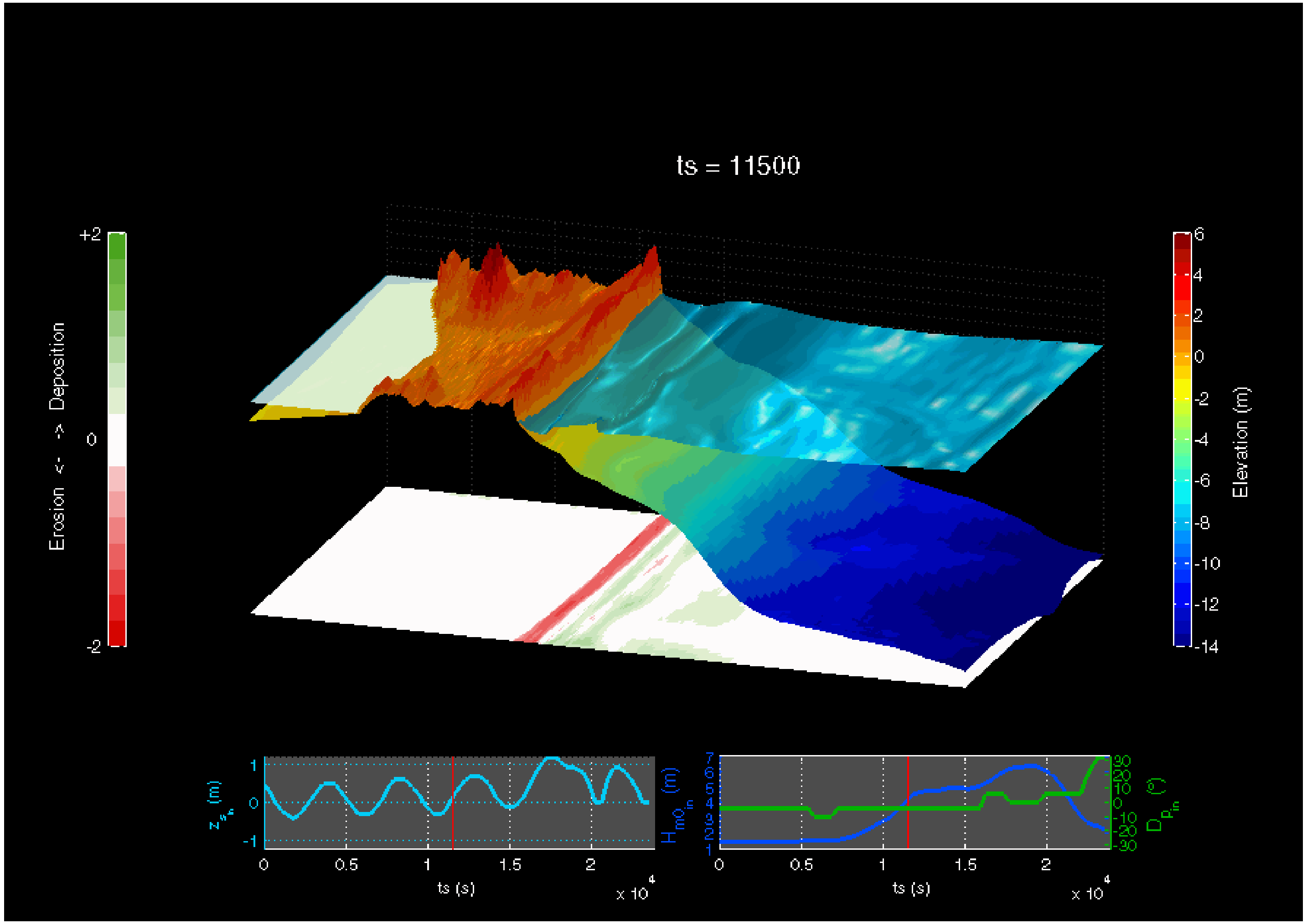






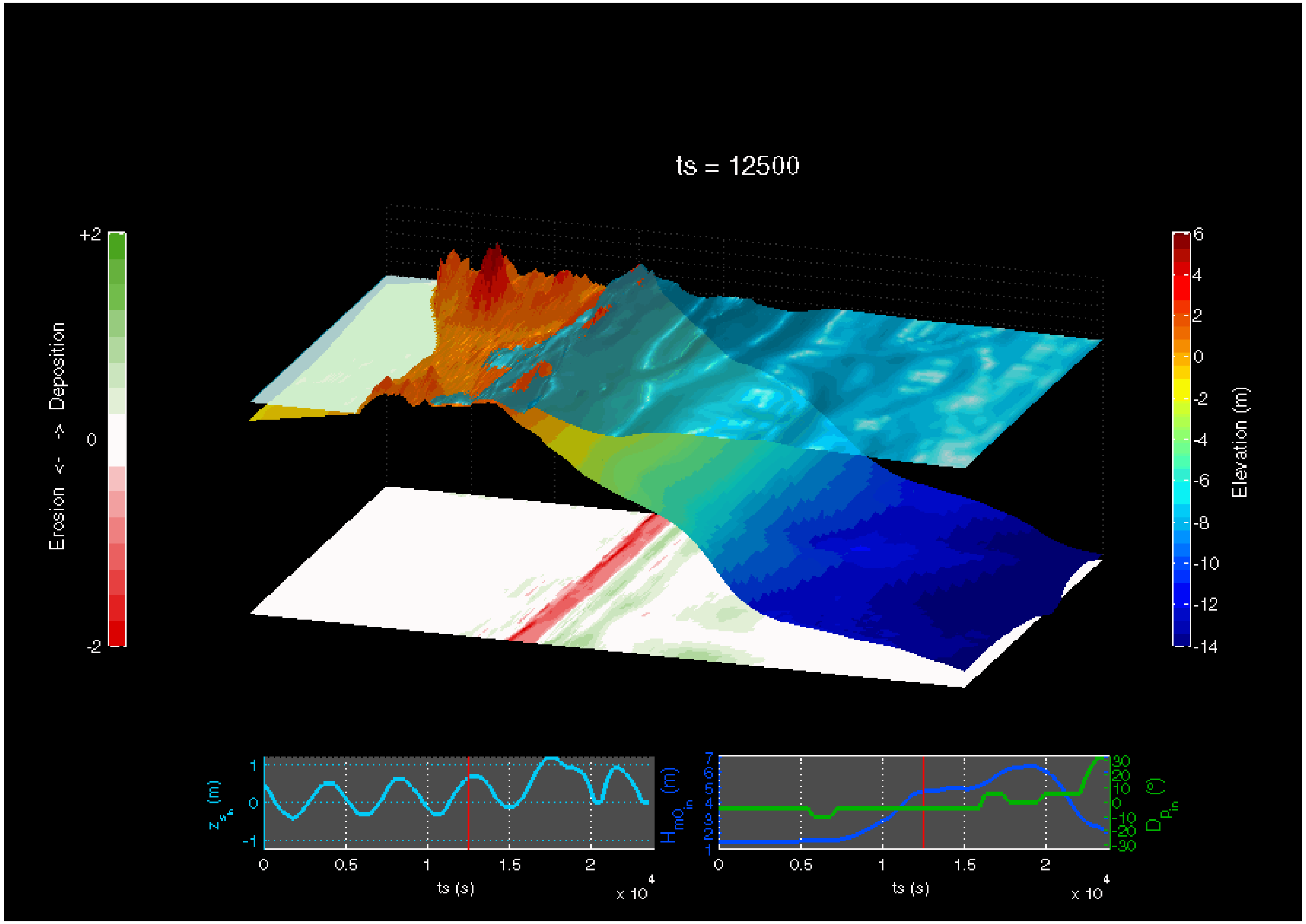
McCall et al., 2010

Collision → Overwash



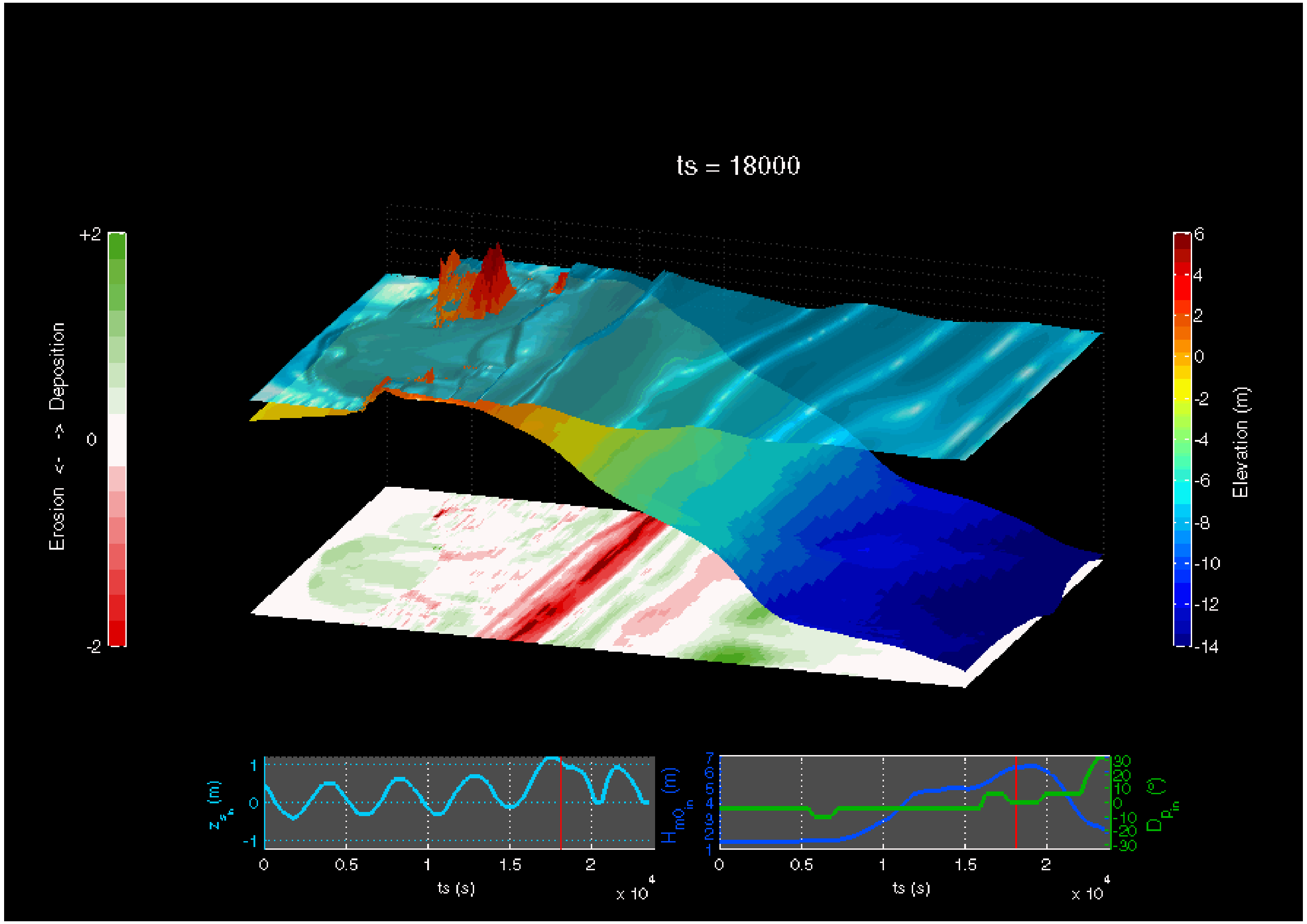
XBEACH simulations by Dave Thompson, USGS

Overwash



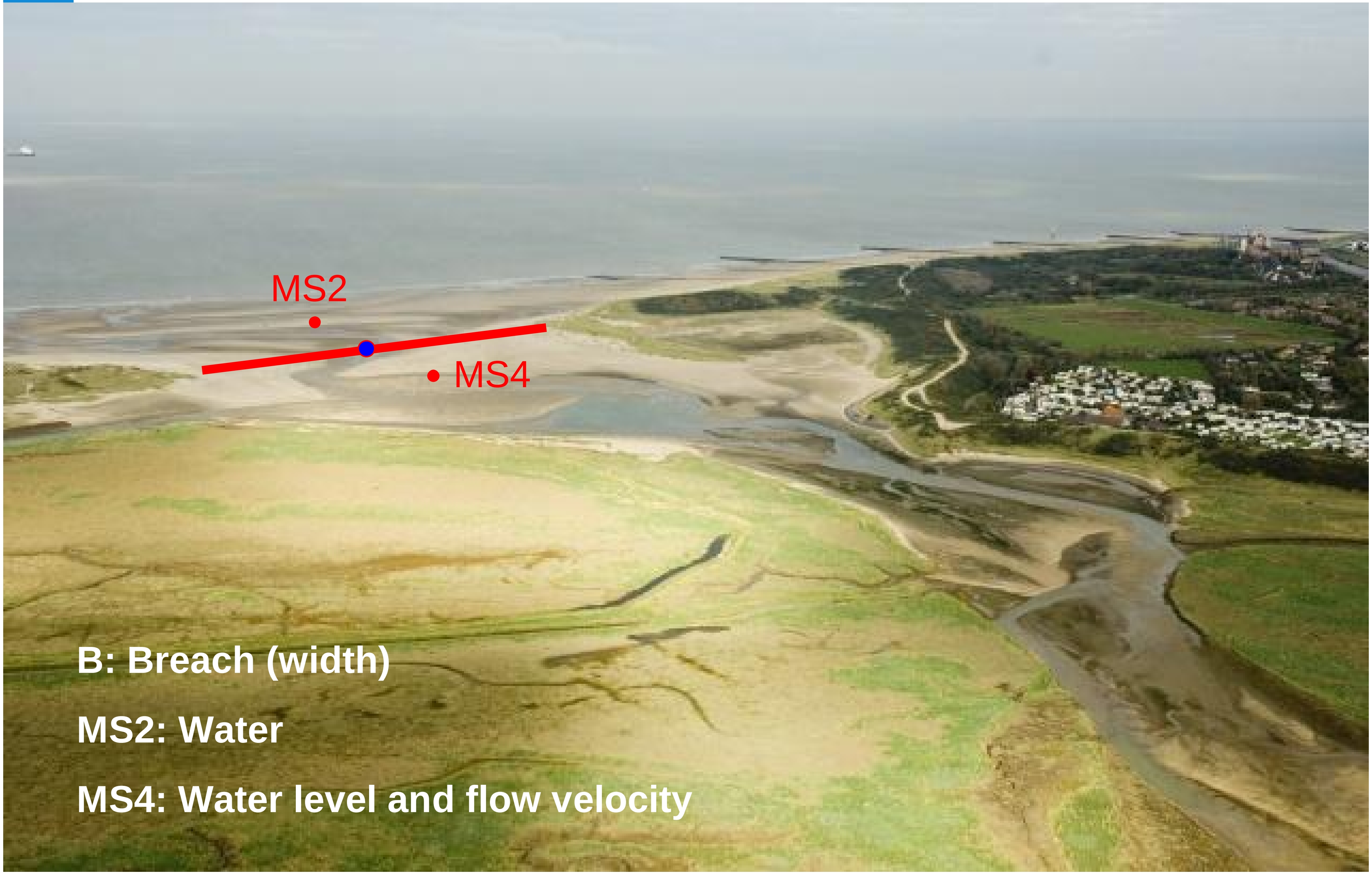
XBEACH simulations by Dave Thompson, USGS

Peak of the Storm: Inundation

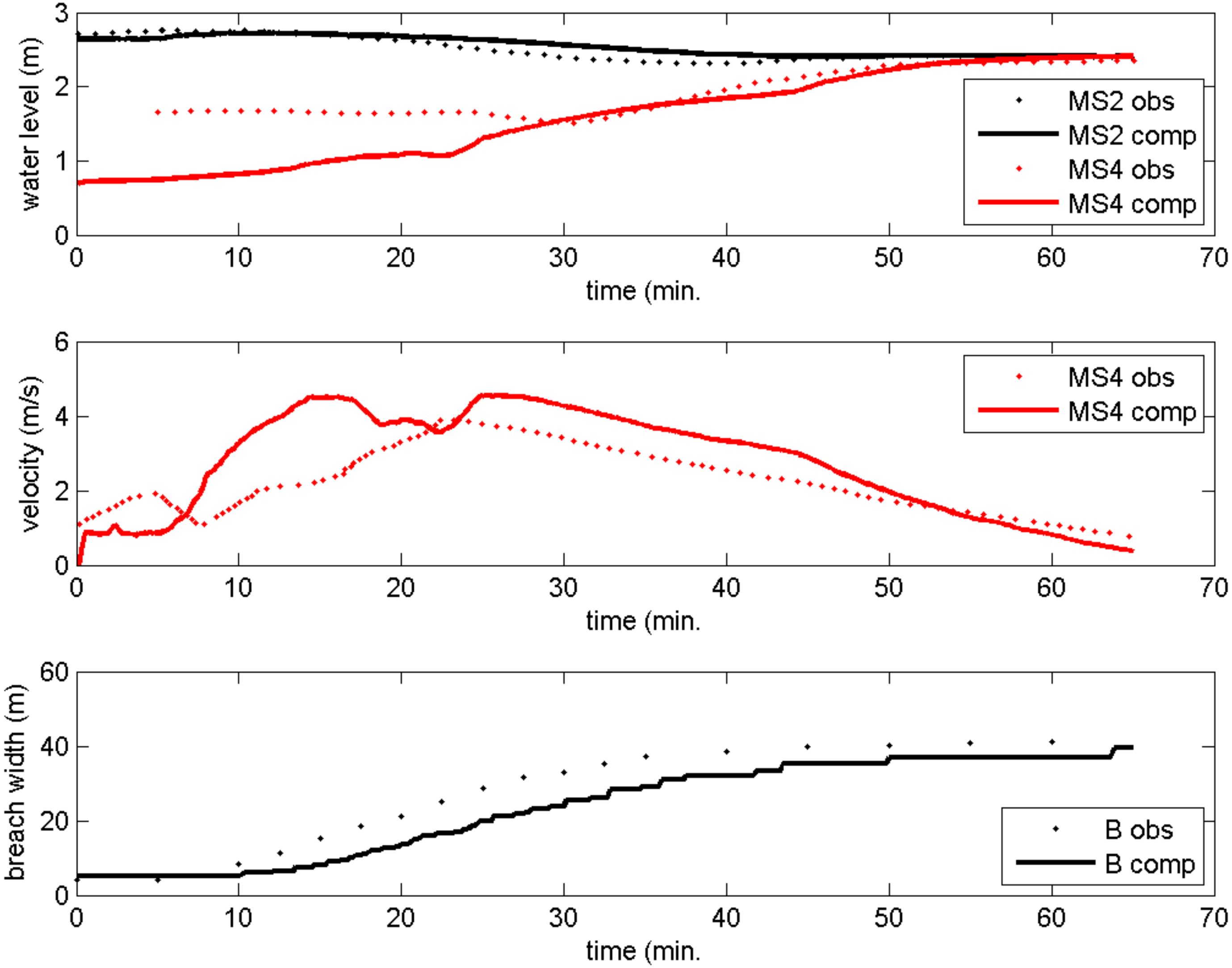


XBEACH simulations by Dave Thompson, USGS

Breaching Case: Zwin

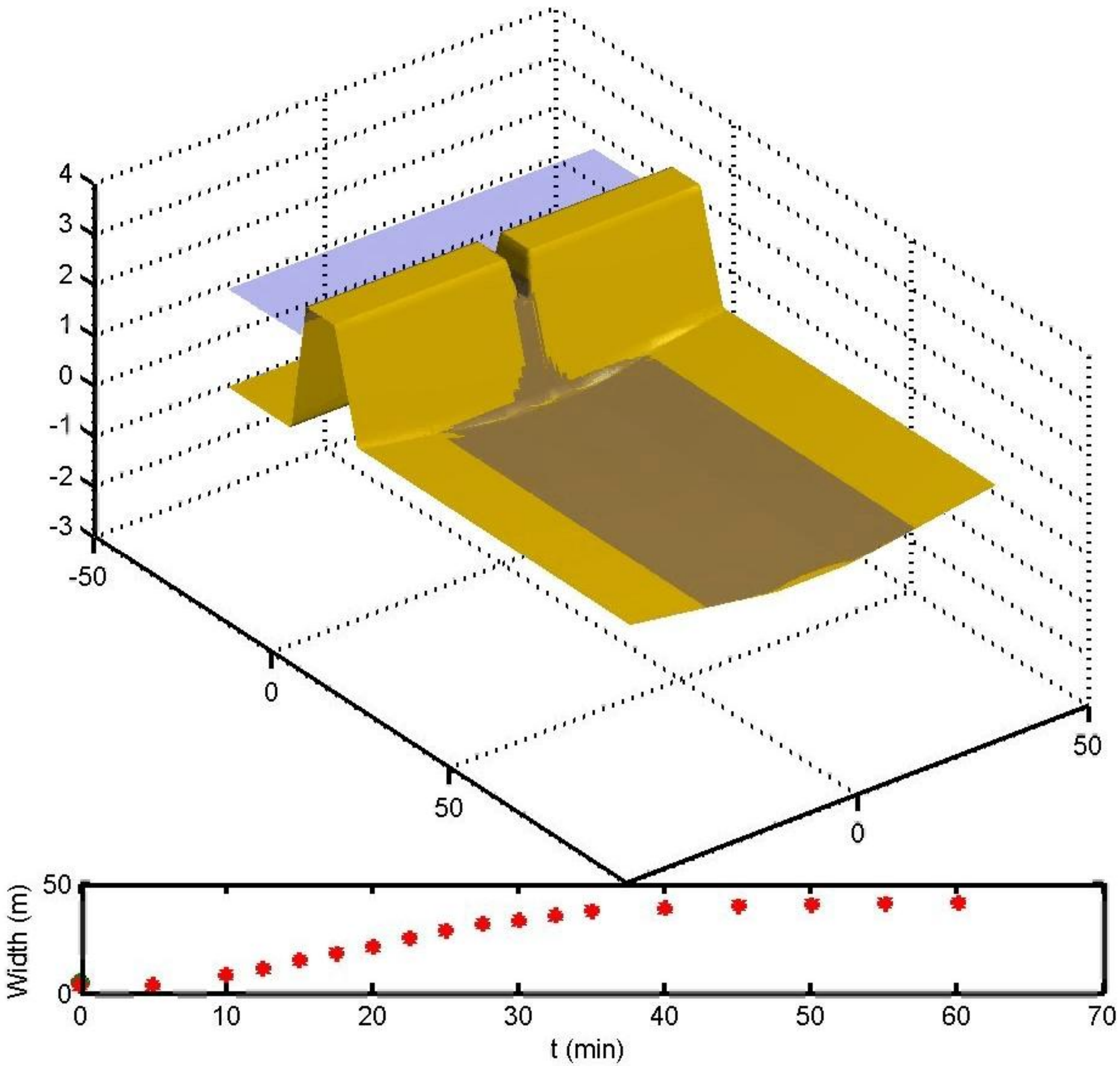


Breaching Case: Zwin



Deltares

Breaching Case: Zwin

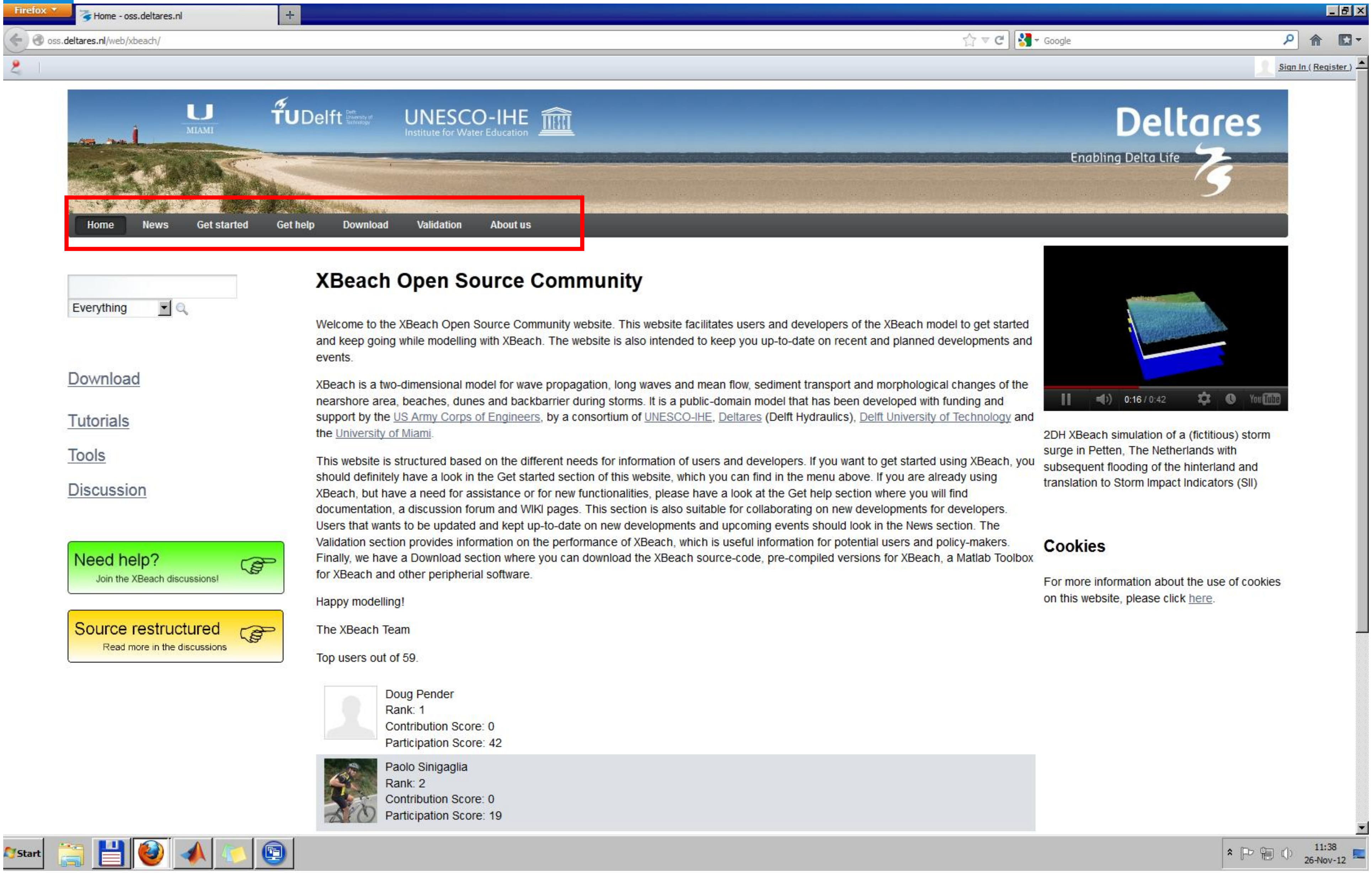


Part II

Hands on: Modelling Event Driven Erosion

TUDelft UNESCO-IHE Institute for Water Education Deltares

XBeach.org (accessible via oss.deltares.nl)



Running XBeach:

1. Simulation folder where you collect the following files:
2. XBeach executable
3. Params.txt file
4. Depth file

Additional Files:

- Grid file(s): In case you work with non-equidistant grids
- Wave input files: This can be a list of (irregular) wave conditions
- Waterlevel input files: In case you want to apply varying tide and surge conditions
- Files related to additional functionality: i.e. to specify structure, ground water flow, tracers, river discharge.

Running XBEACH: Tips and Tricks

- Setting up a Grid:
  - Grid resolution should be sufficient to describe long wave
  - Vary grid resolution based on Courant condition
  - Near water line, grid resolution based on expected morphological changes
- Define Depths:
  - Offshore boundary at sufficiently deep water for realistic long wave boundary conditions (n < 0.8)
  - Uniform coast (three cells) near lateral boundaries and offshore boundary
- Settings:
  - Use defaults as much as possible (especially when you start)
- REMARK: Tricks for robuust model set-up are implemented in Toolbox

Getting Started (1)

1. All will receive hardcopy assignments and a USB stick that contains model software, documentation and software.
2. Copy all data to a local folder on your laptop and wait for further instructions.
3. Go to folder Documents → Exercises and follow the instructions in Install_Delft3Dsoftware.doc
4. Work on the following examples:

Part II

Advanced applications

Contents

- Situations with hard elements
  - Dune revetments r1
  - Coral reefs
- Situations with vegetation (mangroves)
  - Mangroves
- Non-hydrostatic model and ground water flow
  - Gravel beaches
- Long term simulations

r1 dit kan weg?
rooijen; 26-11-2012

Part II

Situations with hard elements:

- Dune revetments
- Coral reefs

Hard layers

• Hard structures substantially affect the morphodynamic evolution during a storm in both cross-shore and longshore direction

Hondsbosche en Pettemer sea defense

Coral reef Australia: Great Barrier Reef

oostende sea defense

Hard Elements

- Implementation:
- You specify the sediment thickness on top of a hard layer.
- In case the sediment thickness on top of the layer becomes sufficiently small the sediment source term is limited:

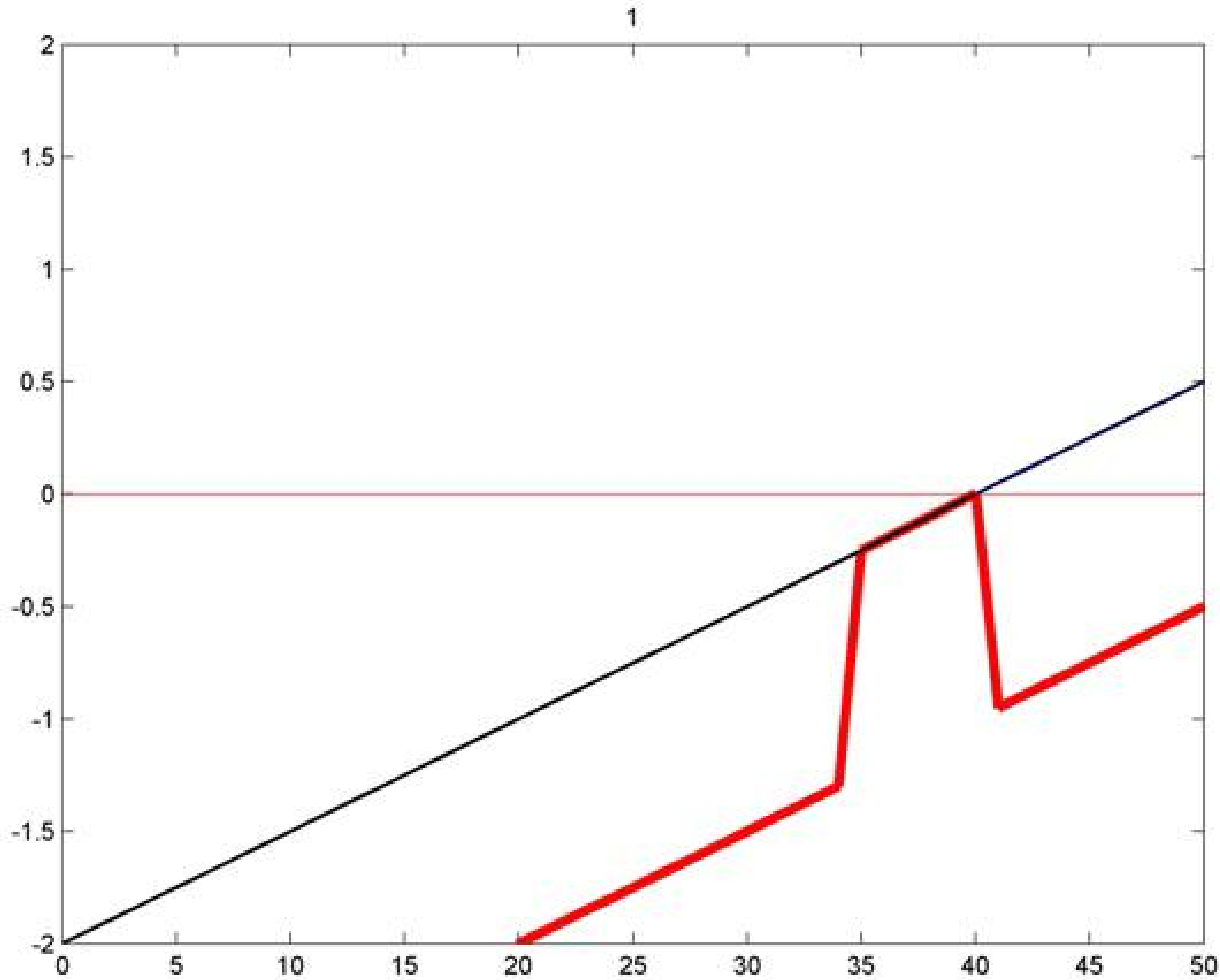
$$\frac{\partial hC}{\partial t}+\frac{\partial hCu^E}{\partial x}+\frac{\partial hCv^E}{\partial y}+\frac{\partial}{\partial x}\left[D_h h\frac{\partial C}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_h h\frac{\partial C}{\partial y}\right]=\min\left(S_{\max},\frac{hC_{eq}-hC}{T_s}\right)$$

- In which

$$S_{\max}=(1-p)\frac{dz_{remain}}{dt}$$

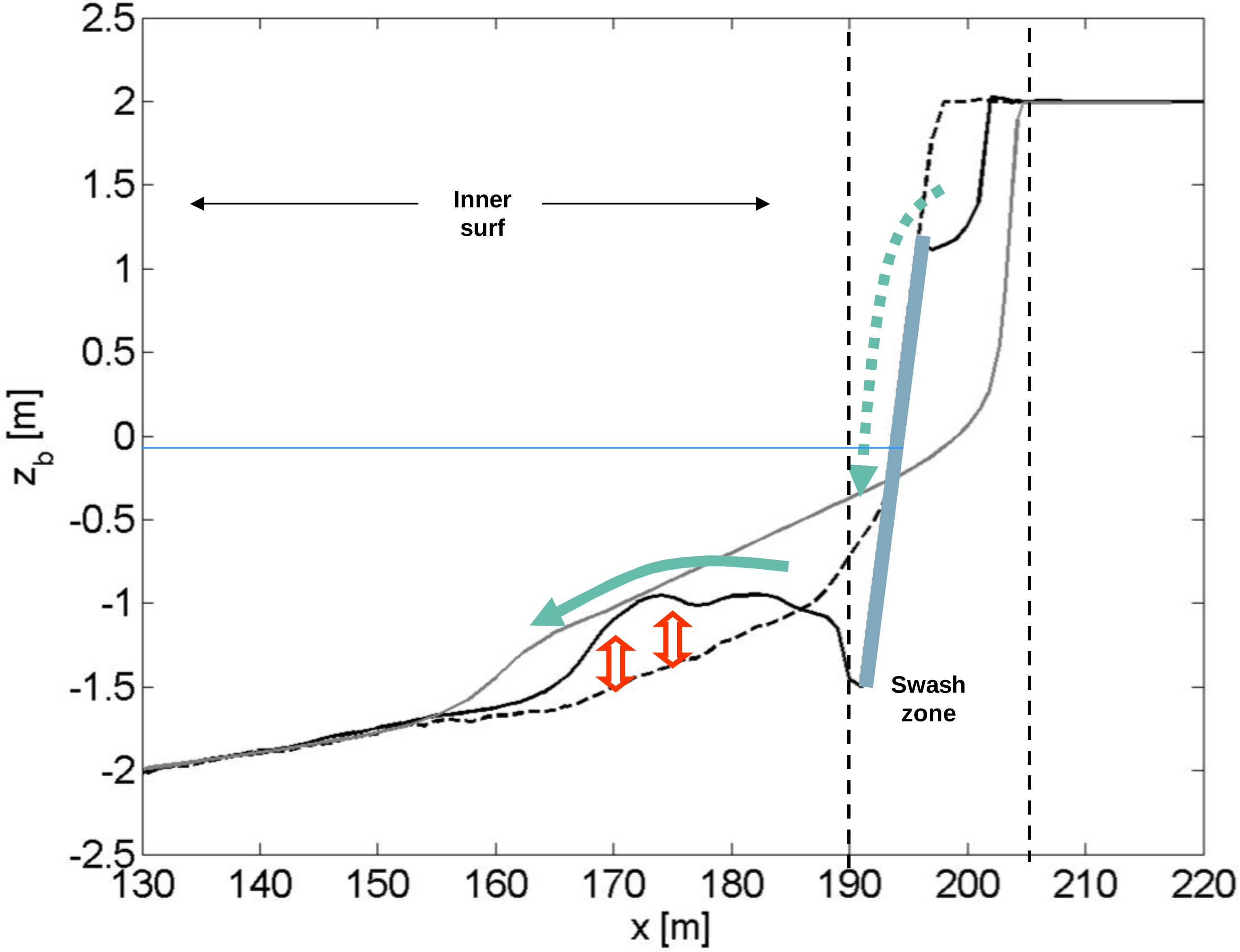
Hard Layers

- To setup a model with a hard layer two additional keywords need to be specified in params.txt:
  - struct: struct =1 in case of a hardlayer and struct = 0 (default) in the abscence of hardlayer.
  - ne_layer: ne_layer is a filename that contains the thickness of the sediment layer on top of the hardlayer.



1
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
5
10
15
20
25
30
35
40
45
50

Dune erosion with revetment

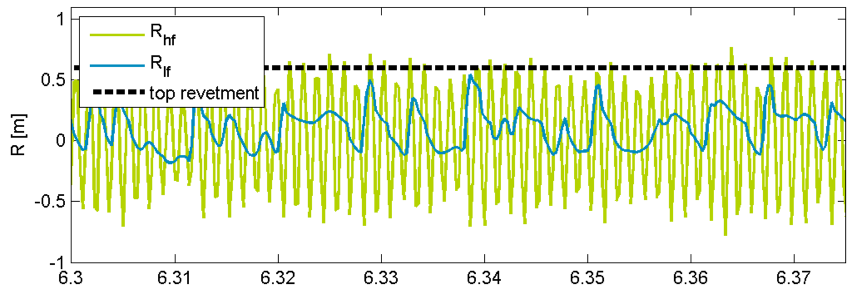


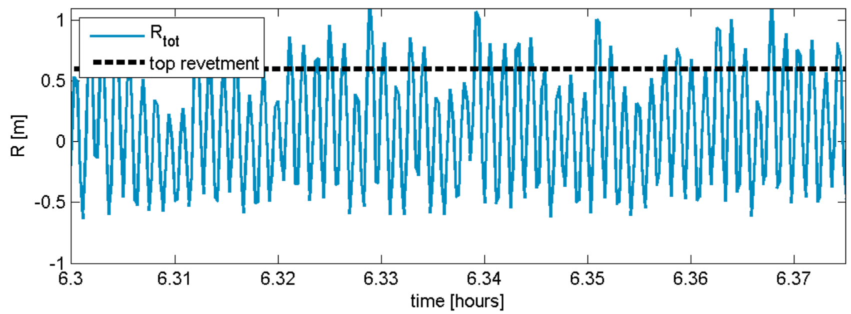
XBeach: Including short wave run-up

- Include short wave run-up to simulate erosion above revetments:
  - Compute short wave run-up elevation at base of revetment from short wave height time series.
  - Simulate distribution of short wave run-up (without swash swash interactions):
    - concept of equivalence (Saville 1962; Battjes 1974)

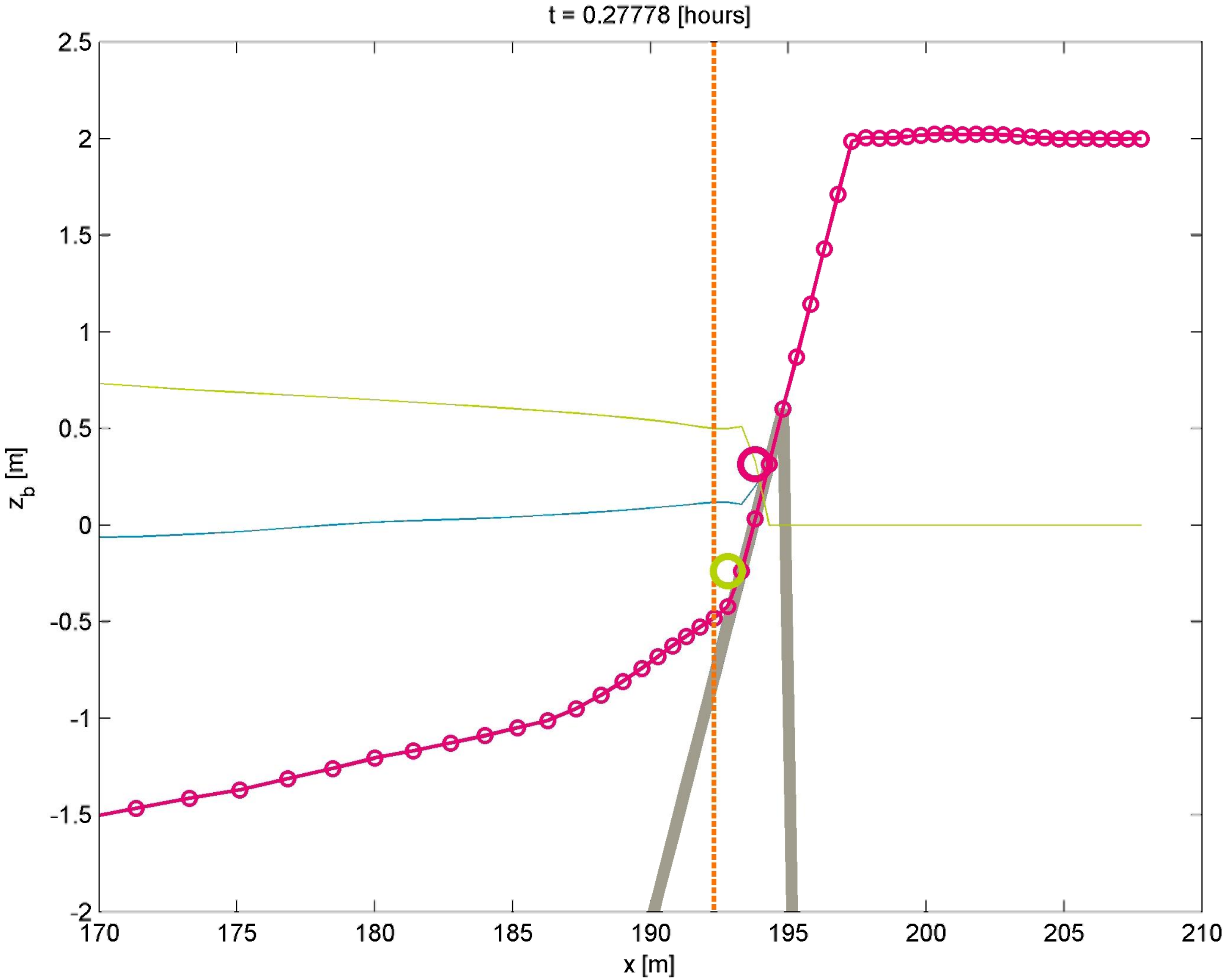
$$R = \gamma_{runup} H_{rms} \min(\xi, 2.3) \cos(\omega t)$$

$$\eta_{tot} = \eta_{wl} + R$$



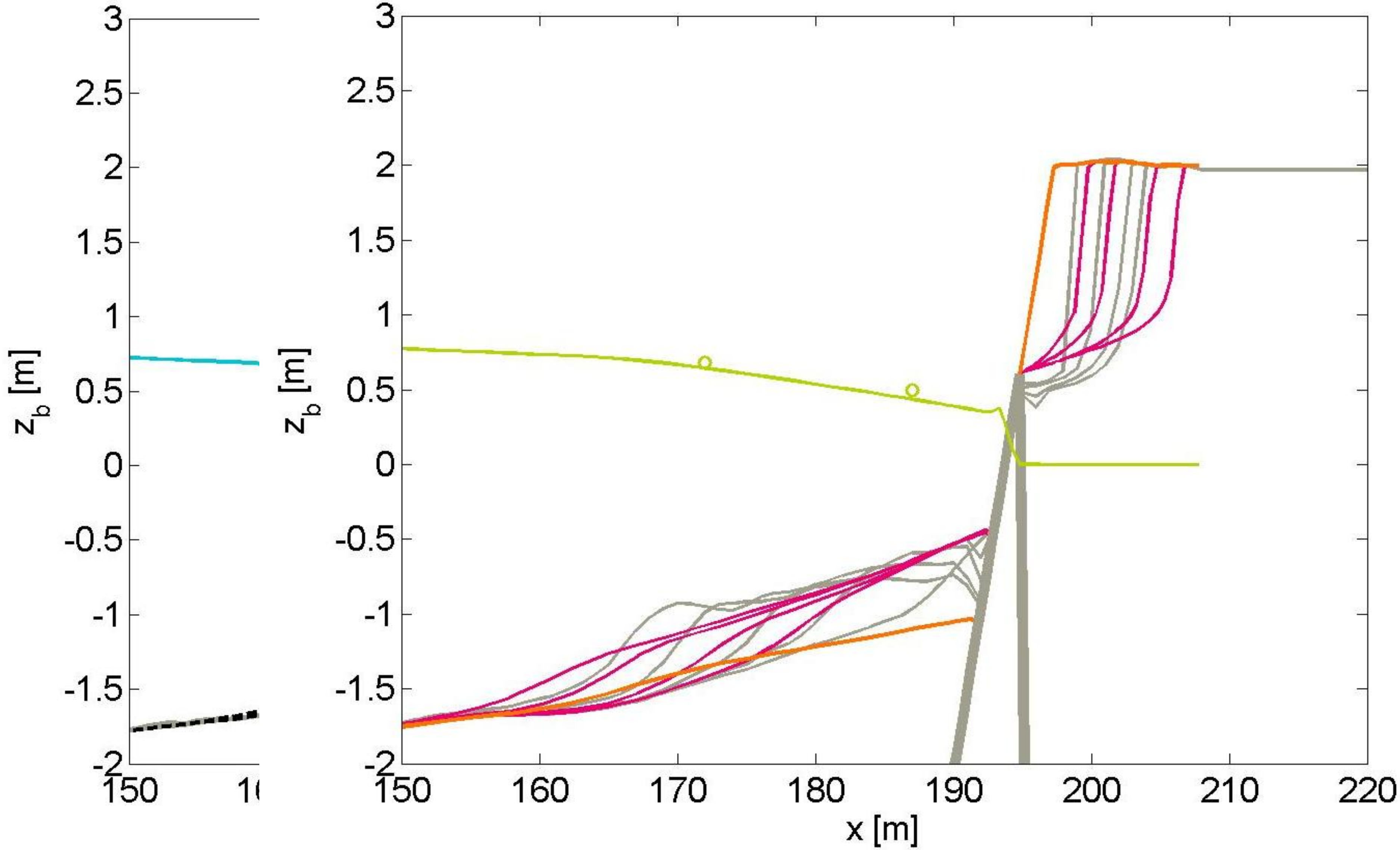


XBeach: Including short wave run-up

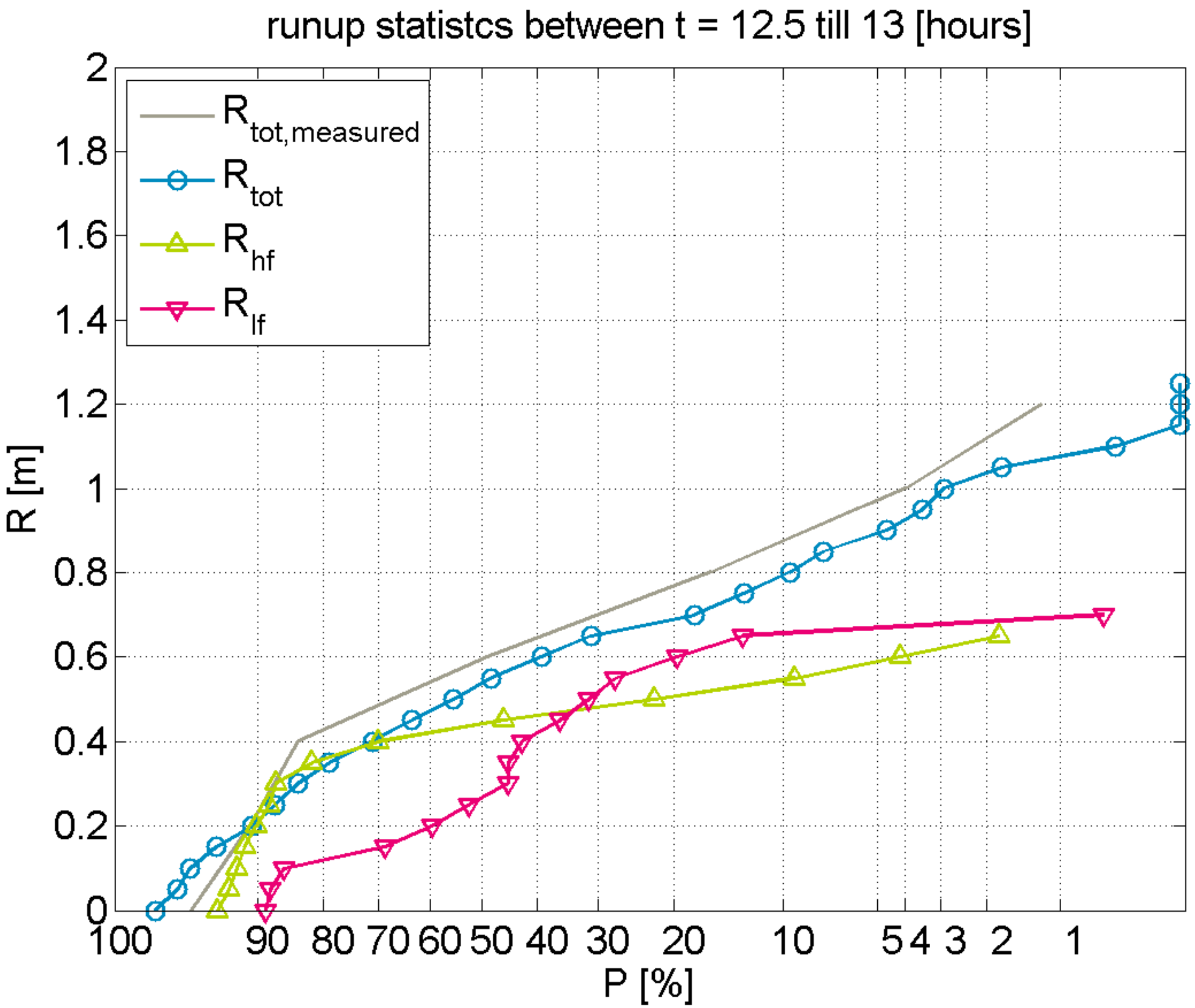


es

Results: Profile evolution



Runup statistics



.ares

Hard Layers

- To setup a model with a hard layer two additional keywords need to be specified in params.txt:
  - struct: struct = 1 in case of a hardlayer and struct = 0 (default) in the abscence of hardlayer.
  - ne_layer: ne_layer is a filename that contains the thickness of the sediment layer on top of the hardlayer.
  - swrunup: swrunup = 1 to account for short wave runup (default swrunup = 0)
  - facrun: facrun = 0.8 runup calibration factor (default facrun= 1)
  - jetfac: jetfac = 0.1 scout parameter (default facrun = 0)

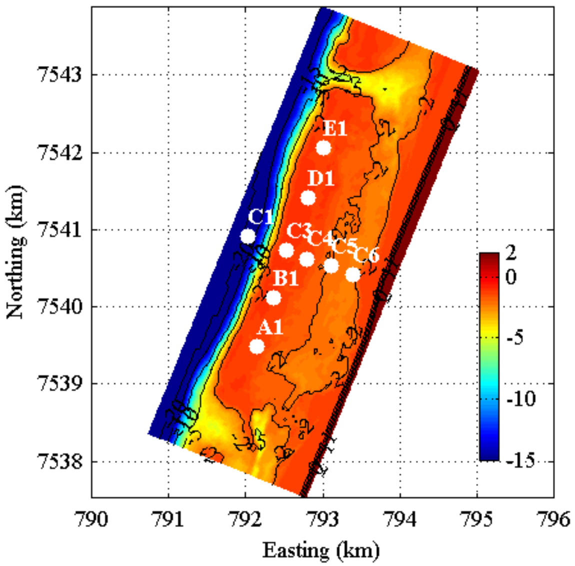
Wave modelling in coral reef environments

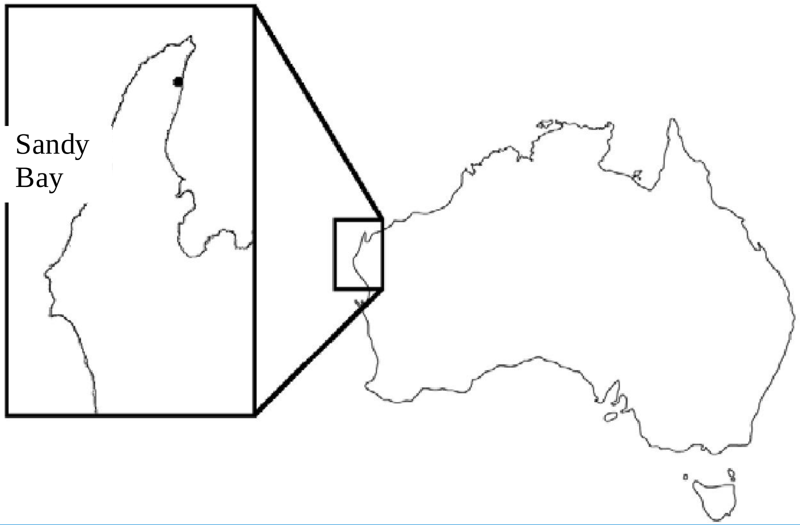
- Coral reef systems are
  - present along large parts of tropical coastlines
  - protect the coast from storm impacts
  - form habitat for great number of species

- Waves and wave-induced currents are important to reef systems, drive
  - Sediment transports
  - nutrient dynamics,
  - Uptake by benthic communities
  - Wave run-up and overtopping of the main land or atoll.

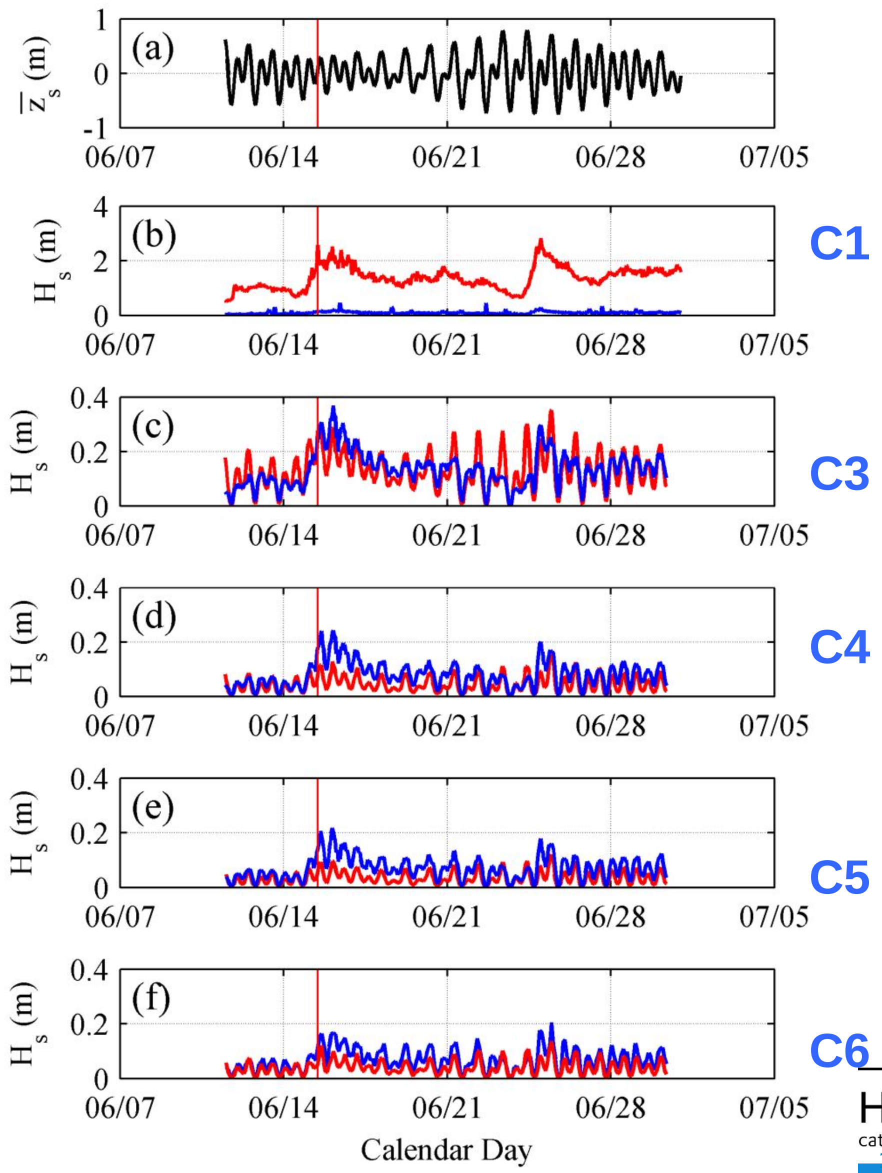
Ningaloo Reef Observations

- Ningaloo Reef extends 250 km along the North-West Cape of Australia
- Hundred individual reef-lagoon-channel circulation systems with gaps (channels) occurring in the reef every few kilometers.
- Swells from the South-West (roaring 40's).
- Field data by Ryan Lowe (U. of Western Australia) in 2009

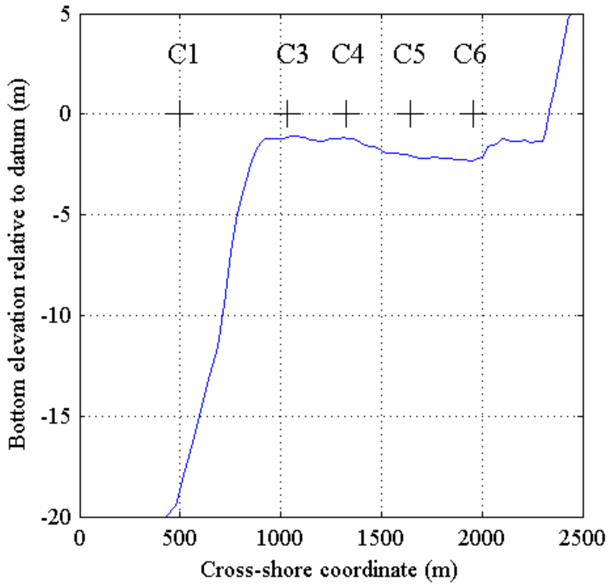




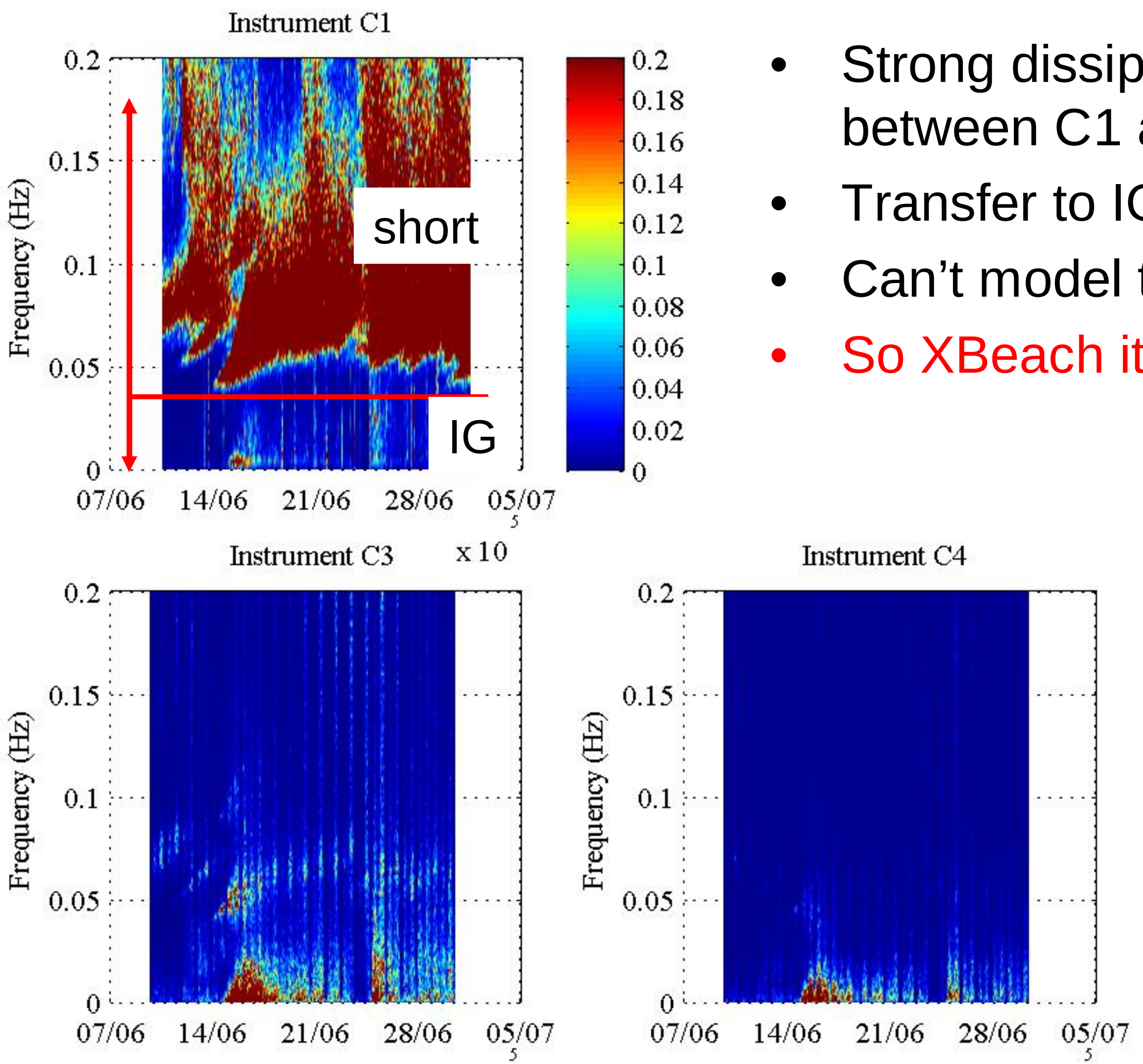
Short wave and IG wave heights



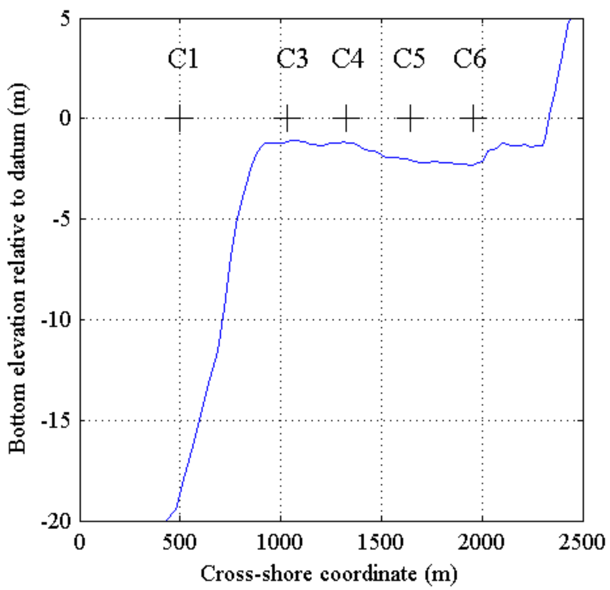
- Low frequency IG signal dominant in the lagoon
- Short waves decay
- Clear tidal signature of IG and short waves



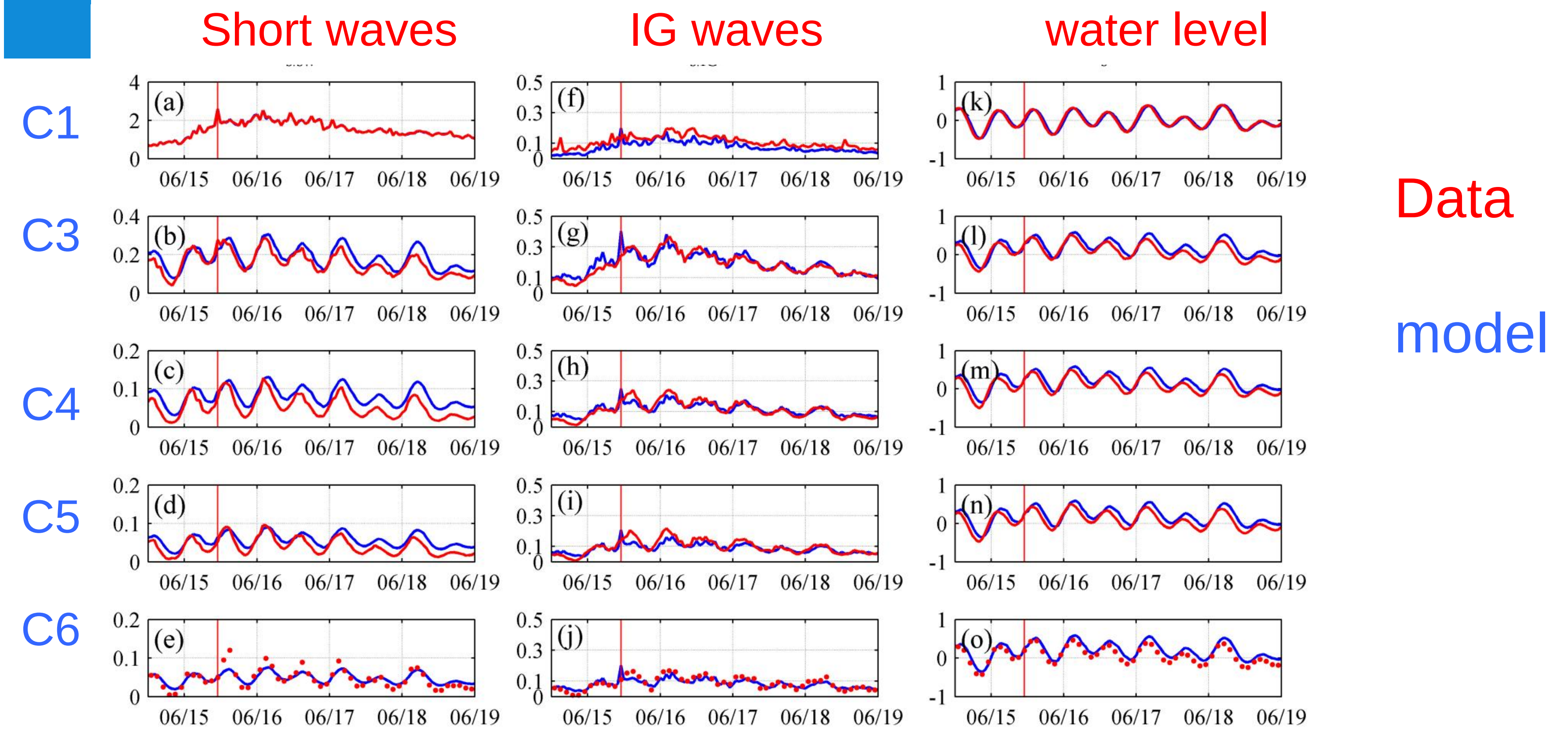
Observations of spectra



- Strong dissipation of short waves between C1 and C3
- Transfer to IG wave frequencies
- Can't model this with SWAN!
- So XBeach it is

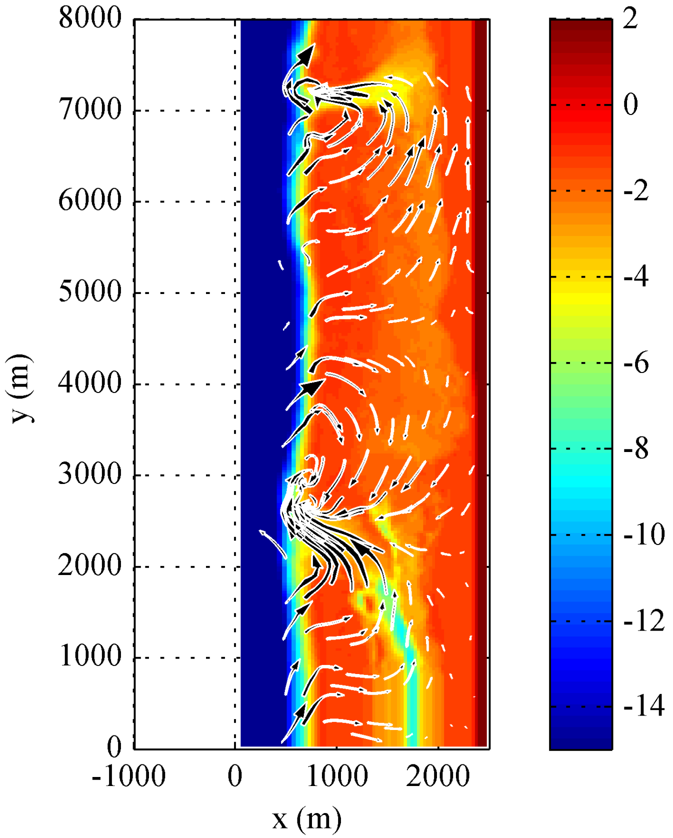


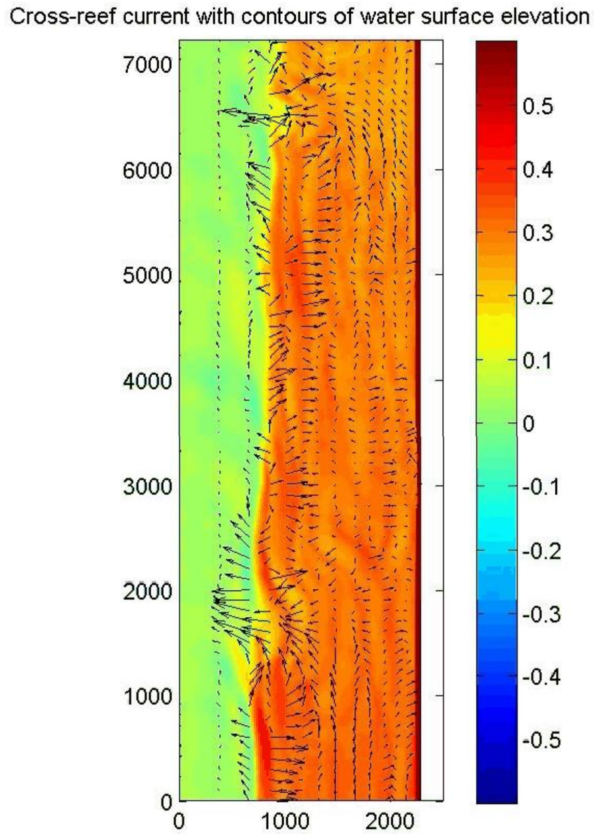
Results for storm duration 1D



- Short waves slightly overpredicted
- Water levels slightly overpredicted
- Short waves and Infragravity wave displays tidal signature

Now to 2D





Note: need recalibration, not discussed here today.

Modification of equations

- Wave action equation including bottom friction dissipation

$$D_f = \frac{2}{3}\rho\pi f_w \left(\frac{\pi H}{T_{rep}\sinh kh}\right)^3$$

- With free parameter f_w

- We use default settings, except calibration of short wave friction f_w and
- unsteady current (IG) friction c_f.

Part II

Vegetation:

- Mangroves

Vegetation: Mangroves

- Mangroves are usually mildly sloped and are therefore dissipative

- Due to the dissipative character we hypothesize that wave group generated long waves play an important factor in mangrove morphodynamics and erosion

- We hypothesize that this effect is enhanced due to the presence of mangrove vegetation.

Vegetation in XBeach

- Approach of Mendez and Losada (2004)
- Short wave attenuation by vegetation (wave action balance):

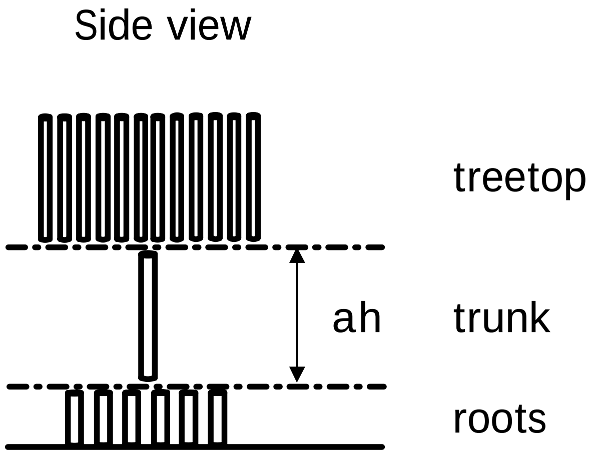
$$D_{veg} = -\frac{1}{2\sqrt{\pi}} \rho C_D b_v N_v \left(\frac{k}{2\sigma}\right)^3 \left(\frac{\sinh^3 k\alpha h + 3\sinh k\alpha h}{3k\cosh^3 kh}\right) H_{rms}^3$$

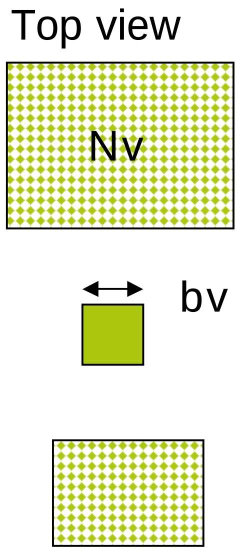
- Long wave attenuation by vegetation (momentum equation):

$$F_{veg} = 0.5 C_D b_v N_v \frac{\alpha h}{h} u|u|$$

Vegetation in XBeach

- Vertical structure of vegetation is accounted for





- Different species can be specified:
  - With different properties:
    - Section heights (ah)
    - Drag coefficient (Cd)
    - Number of plants per unit area (Nv)
    - Plant area per unit height (bv)

Breaking uni-directional waves

Short waves (Blue)

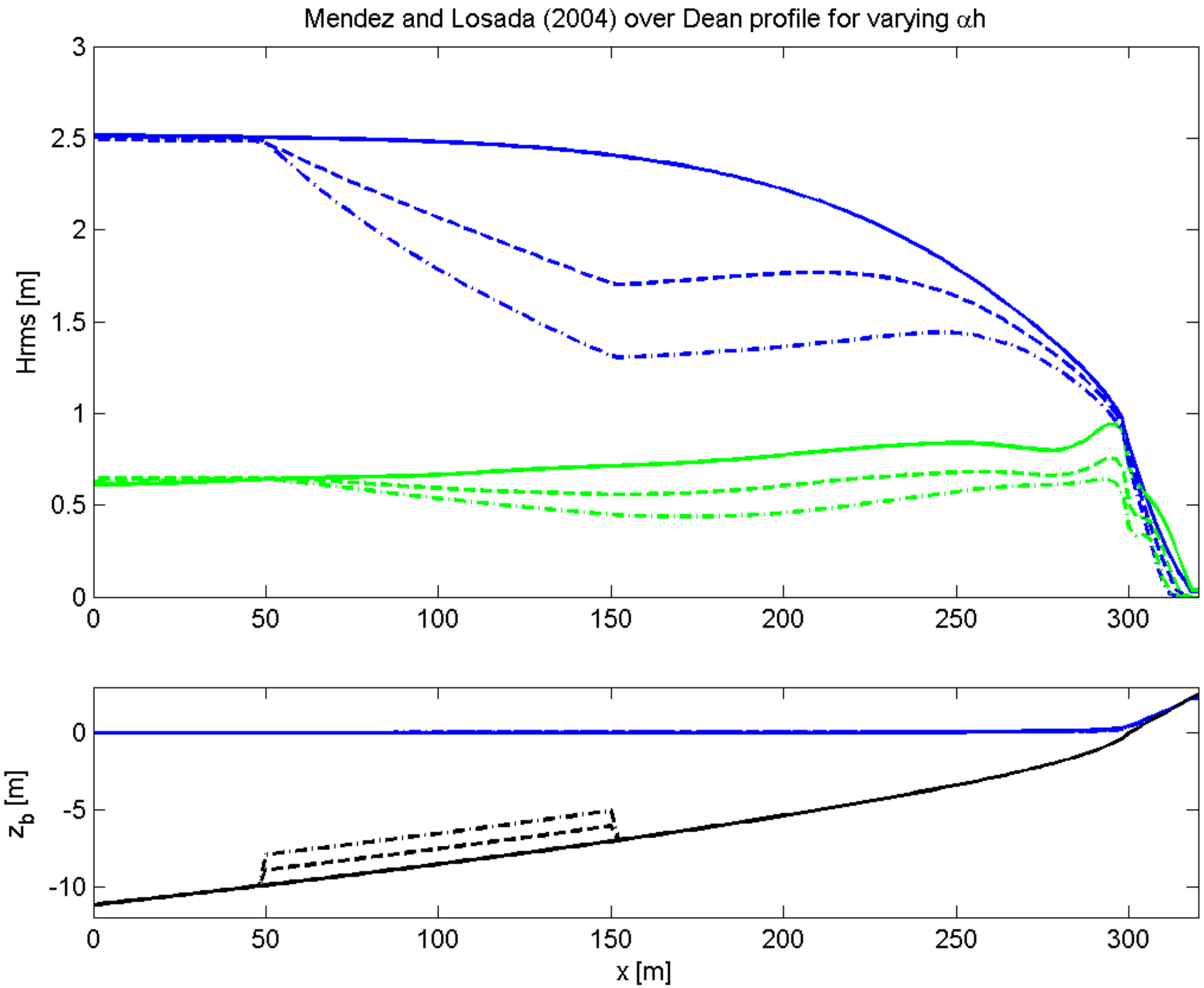
Long waves (Green)

Set-up (Blue)

Three vegetation heights:

- 0 [m] (solid)
- 1 [m] (dashed)
- 2 [m] (dashed-dotted)

Width vegetation patch is 100 m



Breaking uni-directional waves (Stationary)

Short waves (Blue)

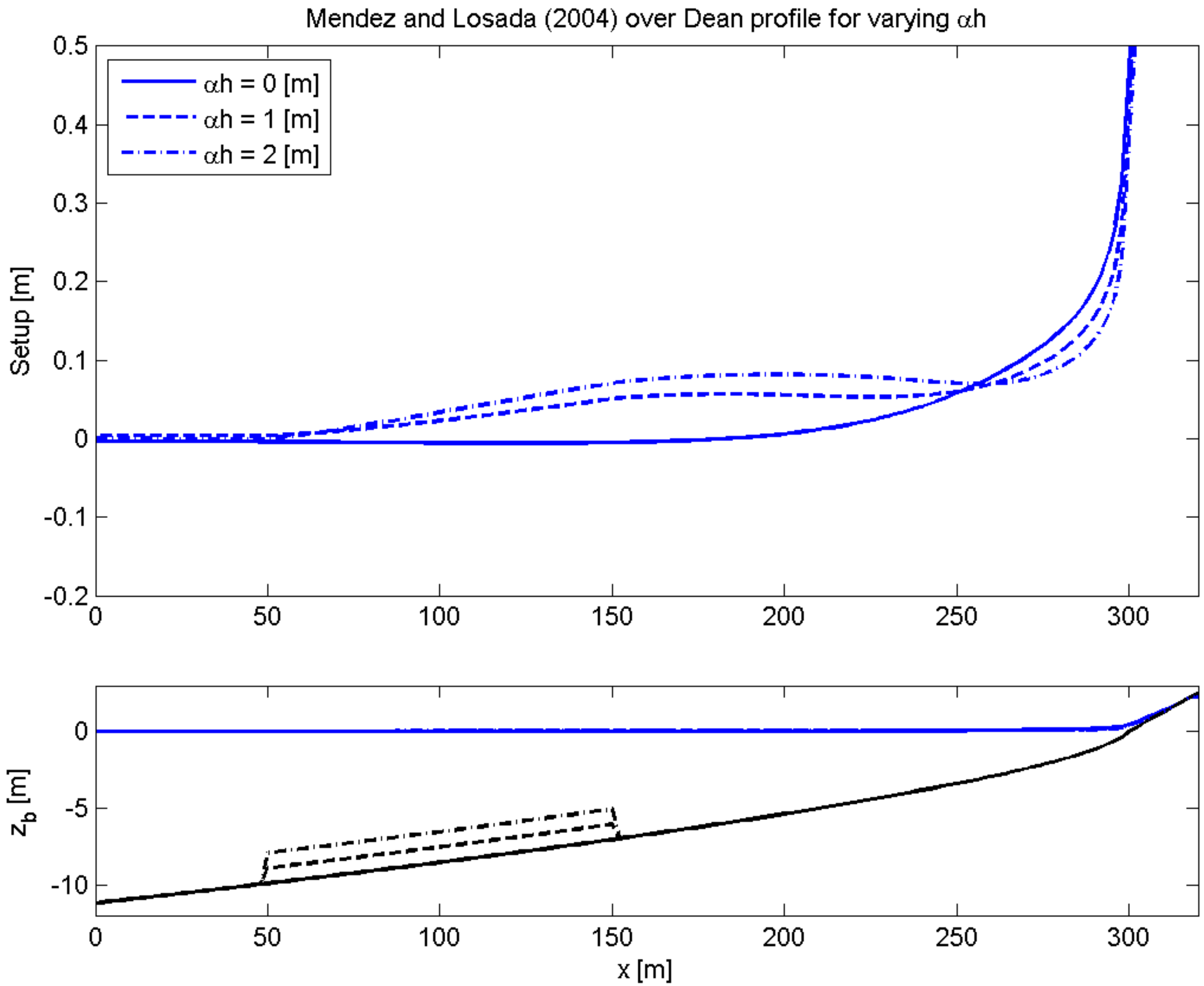
Long waves (Green)

Set-up (Blue)

Three vegetation heights:

- 0 [m] (solid)
- 1 [m] (dashed)
- 2 [m] (dashed-dotted)

Width vegetation patch is 100 m



Next steps

- Include cohesive fractions
- Compare to field observations
- Work on wave set-up in vegetation fields
- Explore erosion meganism (PhD Student Linh Phan Khanh

Part II

Non-hydrostatic model and ground water flow:

- Gravel beaches

Gravel beaches, PhD work Robert McCall

- Gravel beaches occur in many high-lattitude areas around the world (Northern Europe, Russia, North America, Australia & NZ, Argentina and Chile)
- Considered sustainable forms of coastal defence due to ability to absorb large amounts of wave energy

- Little knowledge of processes occurring on gravel beaches, particularly during storms

- Few (if any) tools available to coastal managers of gravel beaches to assess flood risk

Porlock Bay

Gravel beaches differ from sandy beaches:

	Sand	Gravel
Waves	Large dissipative surf zone	Waves break at shoreline,
	Dominance of infragravity waves at shoreline	Incident band and iG energy at shoreline

	Sand	Gravel
Groundwater	Low infiltration rates,	High infiltration rates, leading to large swash asymmetry and onshore transport
	Groundwater level unimportant	Groundwater level can influence zones and magnitudes of erosion and deposition

Gravel beaches differ from sandy beaches:

	Sand	Gravel
Sediment transport	in surf zone and swash	swash zone
	Suspended transport	Bed load and sheet flow
	Limited effect of grain interactions	Large spread in grain size leads to exposure and hiding effects. Saltation of casts

	Sand	Gravel
Morphology	Time scale of storm and response similar	Time scale of response (~minutes) shorter than storm.
	beach flattening	often beach steepening
	High energy event leads to longshore uniform morphology	High energy event may increase or develop longshore rhythmicity

Model development

- Development of groundwater model to account for infiltration and exfiltration on gravel beaches
  - ✓ Completed. Results presented McCall et al, ICCE 2012

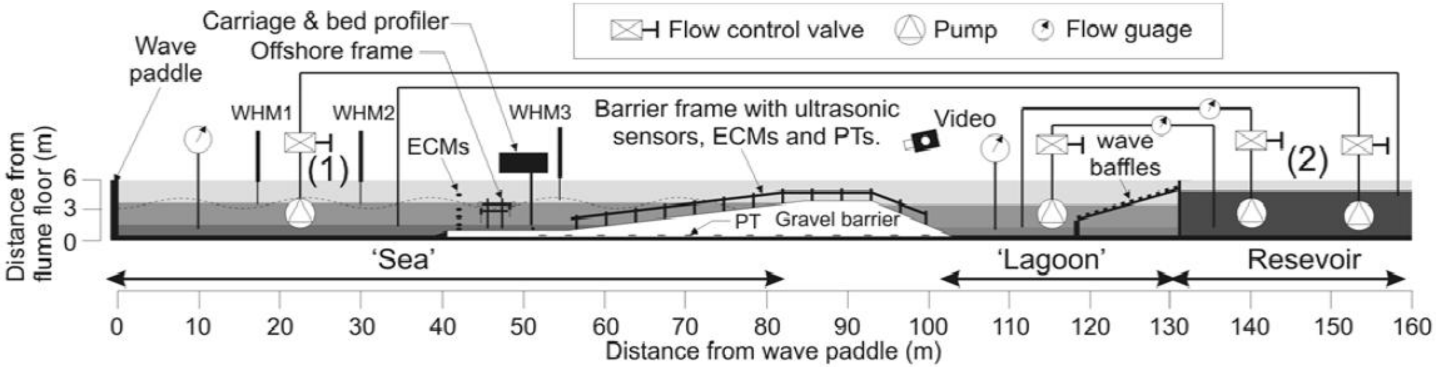
- Validation of phase-resolving wave model (similar to TUDelft SWASH model) for steep, reflective gravel beaches
  - ✓ Almost complete. McCall et al. Journal publication in prep.

- Development of gravel sediment transport and morphology processes in XBeach
  - x To be done 2013-2014

- Development of practical coastal management tools
  - ✓ First steps taken. Presented at McCall et al., ICS 2013

Model validation

- Gravel barrier dynamics experiment in Delta Flume (BARDEX, Hydralab)
- 4m high, 50 m wide permeable gravel barrier
- Varying wave conditions and water levels
- Large dataset of swash and overwash hydrodynamics and morphodynamics



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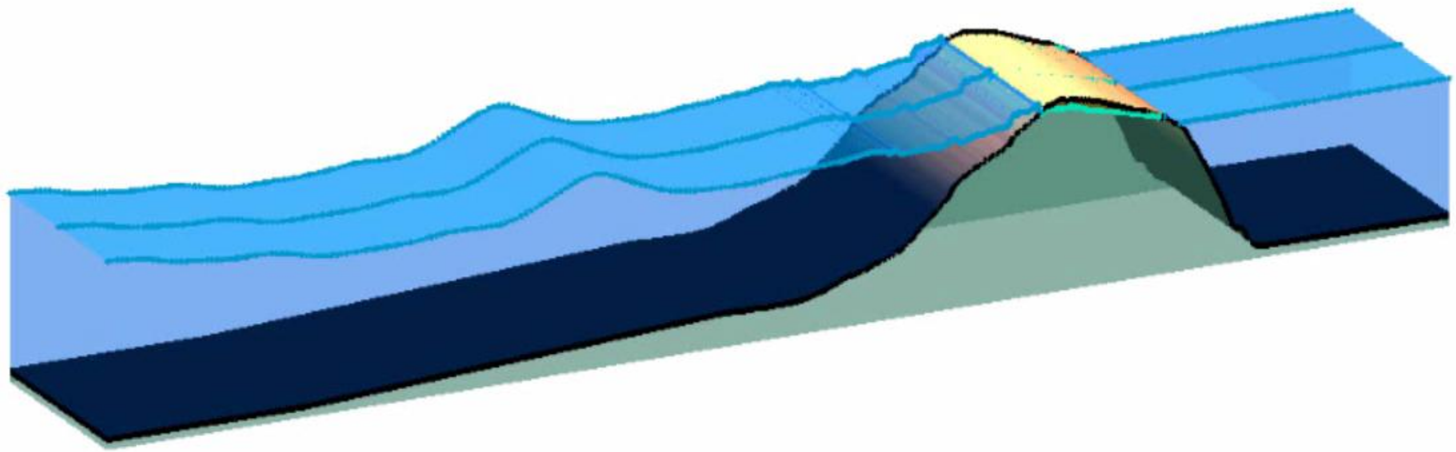
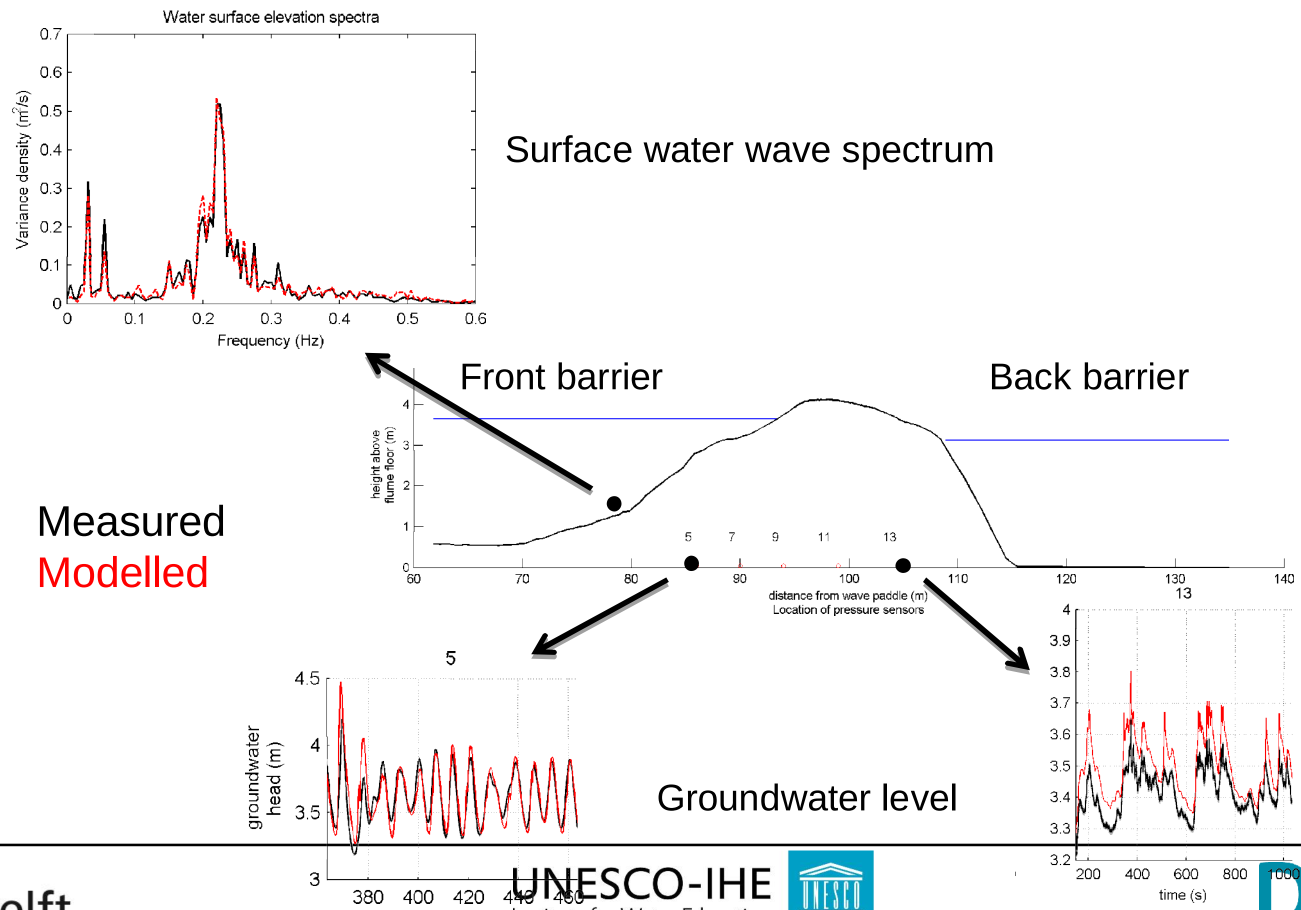
474.8 seconds



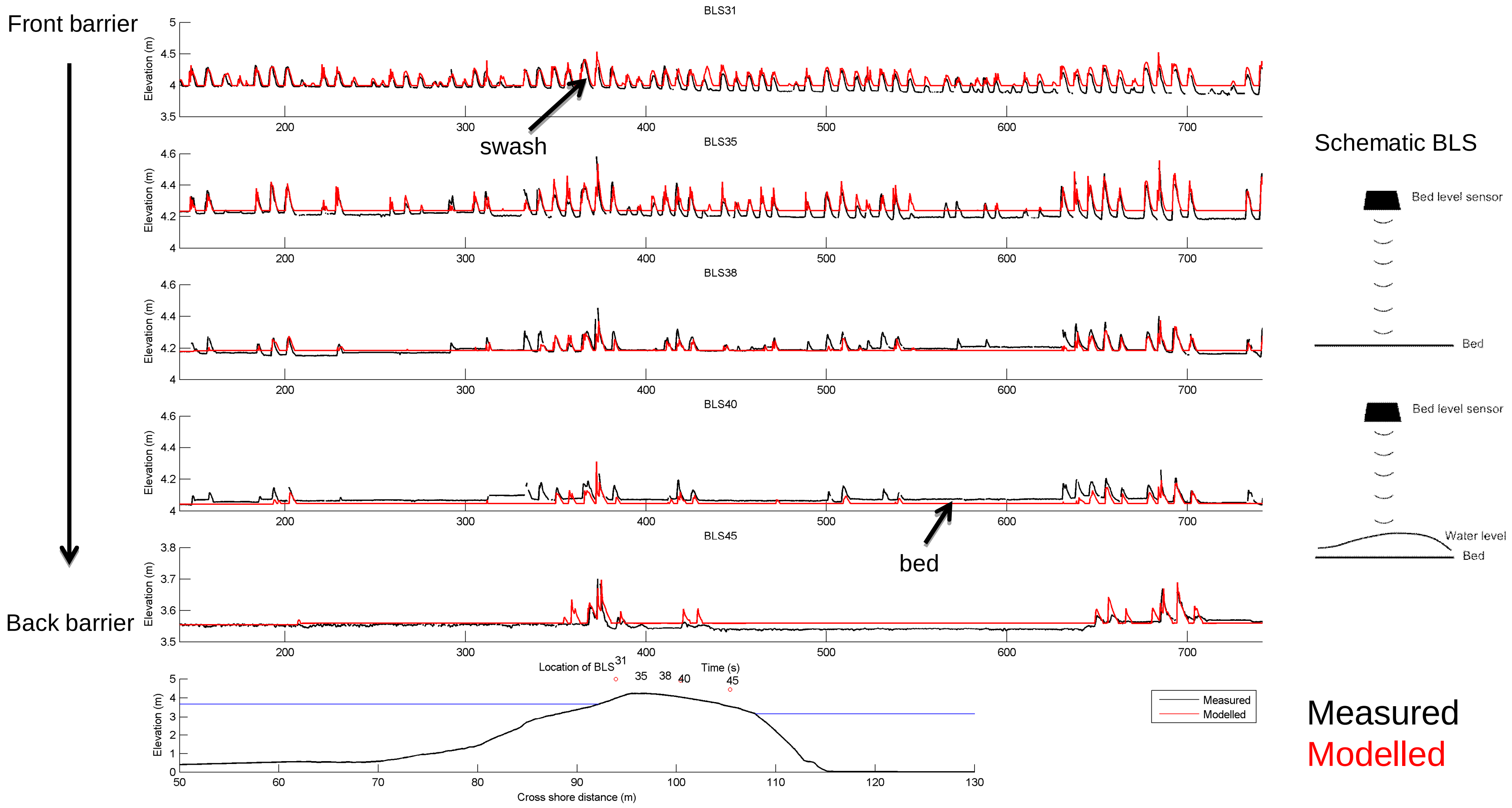
Model validation

- Good reproduction of groundwater level variations
- Transformation of waves towards gravel barrier modelled well



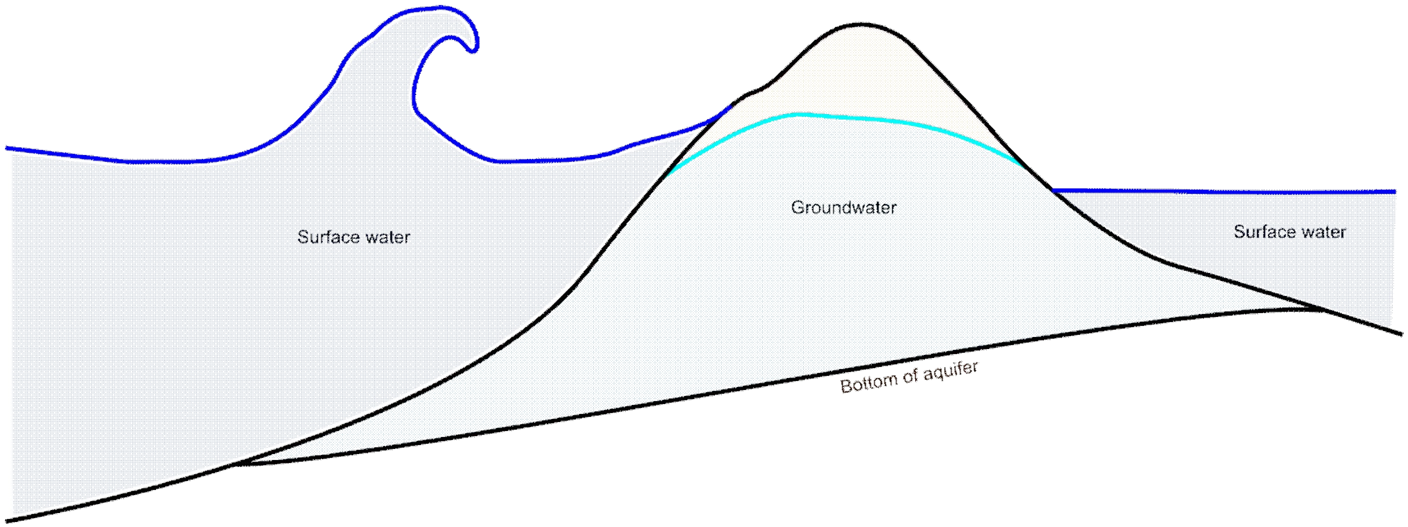
Model validation

- Very good reproduction of overwash events
- Inclusion of infiltration essential in correct modelling of overwash



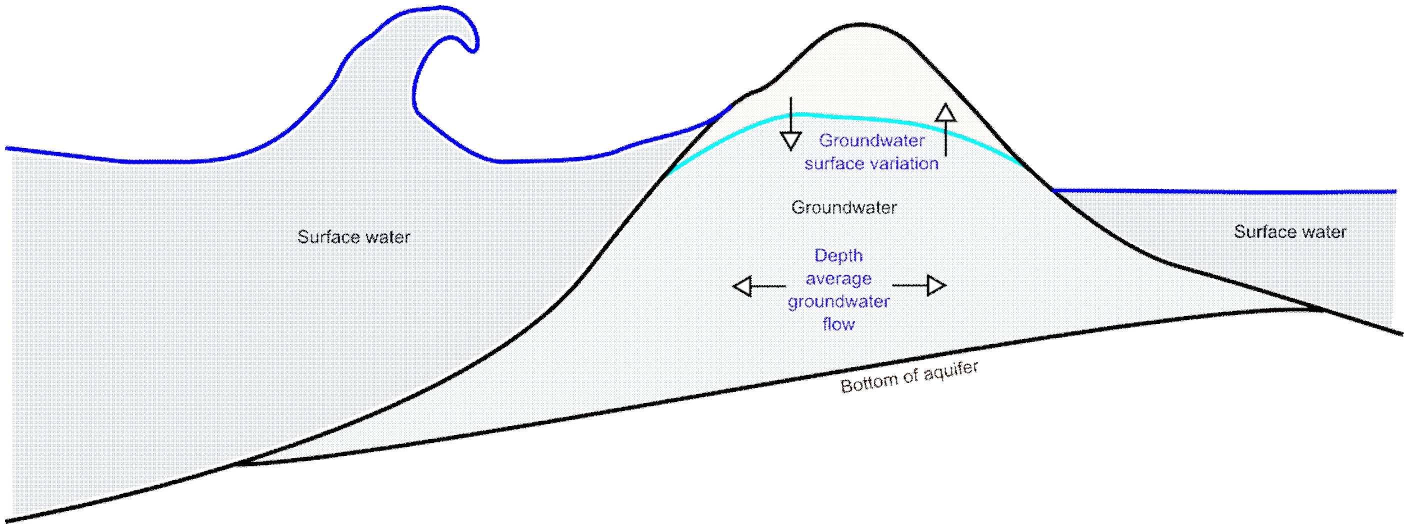
Groundwater extension to XBeach

- Separate surface water regime and groundwater regime



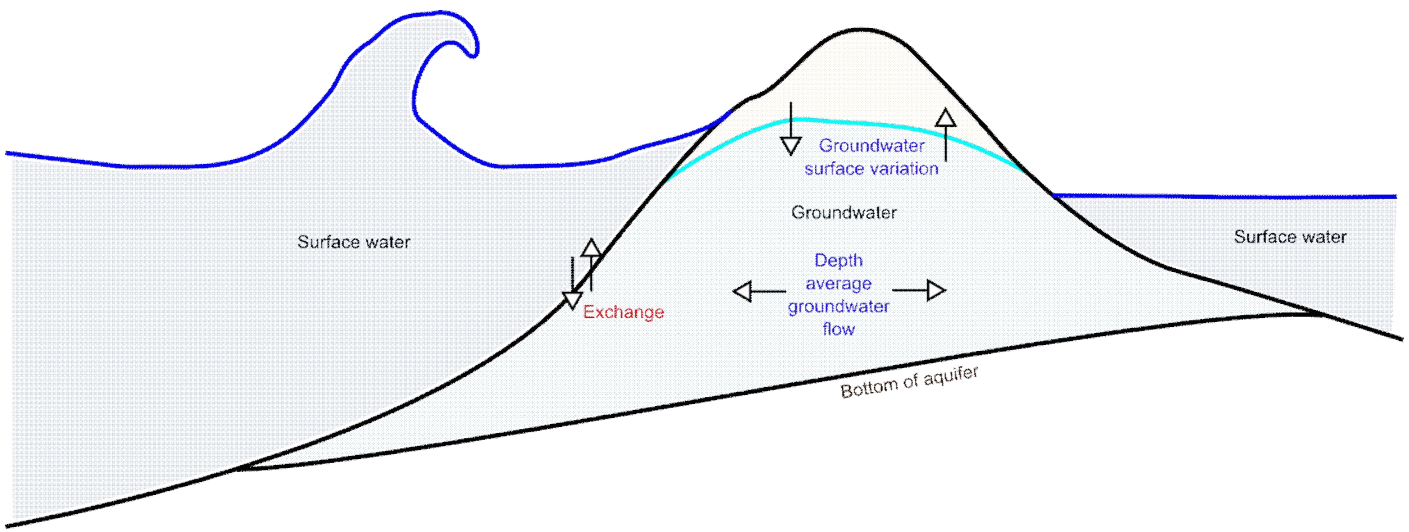
Groundwater extension to XBeach

- Separate surface water regime and groundwater regime
- Darcy-type depth average horizontal groundwater flow



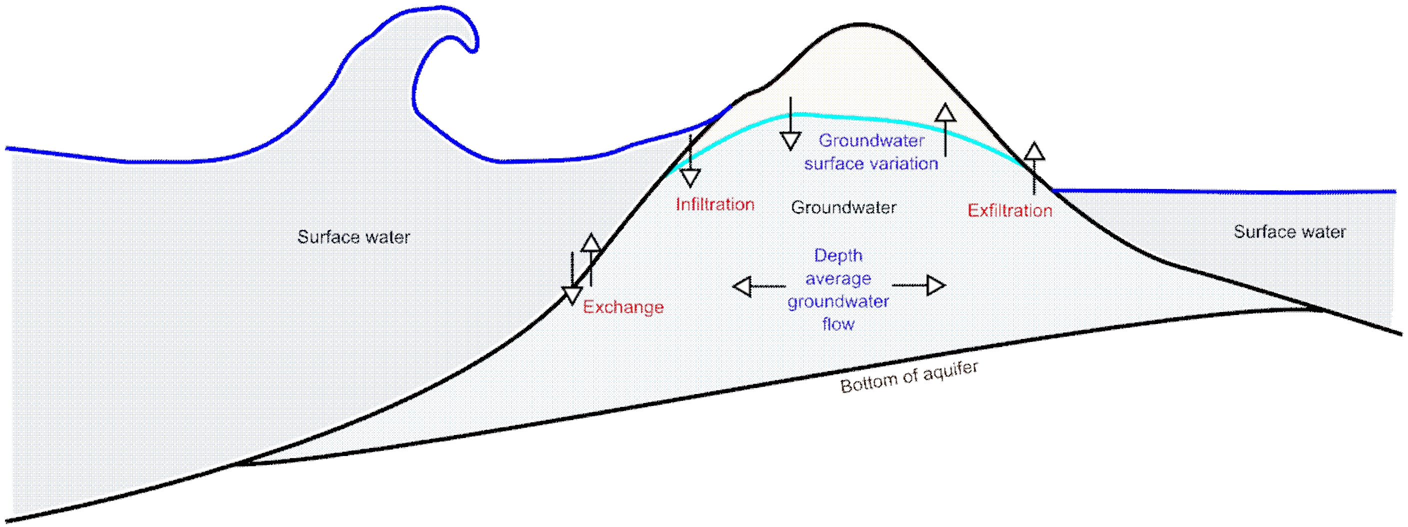
Groundwater extension to XBeach

- Separate surface water regime and groundwater regime
- Darcy-type depth average horizontal groundwater flow
- Vertical exchange of water using estimate of vertical head gradient



Groundwater extension to XBeach

- Separate surface water regime and groundwater regime
- Darcy-type depth average horizontal groundwater flow
- Vertical exchange of water using estimate of vertical head gradient
- Infiltration and exfiltration where regimes are unconnected



Central equations

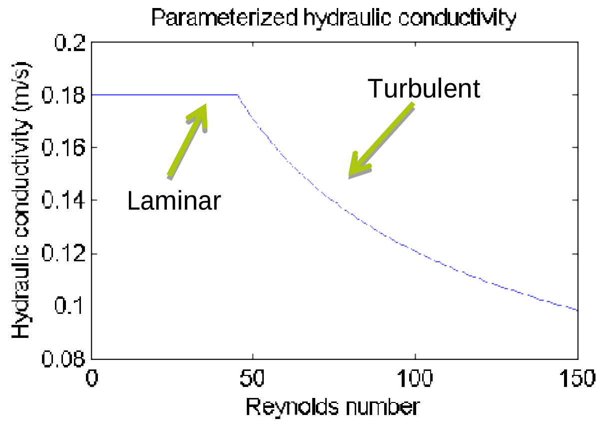
- Continuity $\nabla \vec{U} = 0$ $\vec{U} = \begin{bmatrix} u \\ w \end{bmatrix}$

- Equation of motion $K \nabla H + \vec{U} = 0$ $H = z + \frac{p}{\rho g}$

- Parametric inclusion of turbulent groundwater flow (Kuniansky et al., 2008; Shoemaker et al., 2008)

$$K = \begin{cases} K_{lam} \sqrt{\frac{Re_{crit}}{Re}} & Re > Re_{crit} \\ K_{lam} & Re \leq Re_{crit} \end{cases}$$

$$Re = \frac{|u| D_{50}}{\nu} \qquad Re_{crit} \sim 1 - 100$$



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Non-hydrostatic equations in XBeach

- 1D equations:

$$\frac{\delta\zeta}{\delta t} + \frac{\delta hu}{\delta x} + S = 0$$

$$\frac{\delta u}{\delta t} + u\frac{\delta u}{\delta x} - \upsilon_h \frac{\delta^2 u}{\delta x^2} = -\frac{1}{\rho}\frac{\delta(\bar{q} + \rho g\zeta)}{\delta x} - c_f \frac{u\,|u|}{h}$$

Non-hydrostatic model (2)

Waves model input (described in draft nonhydrostatic report):

- Use XBeach nonhydrostatic model
    - parameter 'nonh' turns on nonhydrostatic pressure correction

- Wave boundary conditions for nonhydrostatic model
    - parameter 'wbcversion = 3' uses the most advanced wave boundary condition generation scheme
    - parameter 'nonhspectrum = 1' sets XBeach to generate individual random waves from a spectrum
    - parameter 'instat' sets the type of spectrum file to be read (parameterised, SWAN, or 2D variance density table)
    - parameter 'front = nonh_1d' sets the offshore boundary condition to (1D) absorbing/generating for nonhydrostatic wave simulations
    - other parameters can be the same as described in the XBeach manual

Non-hydrostatic model (3)

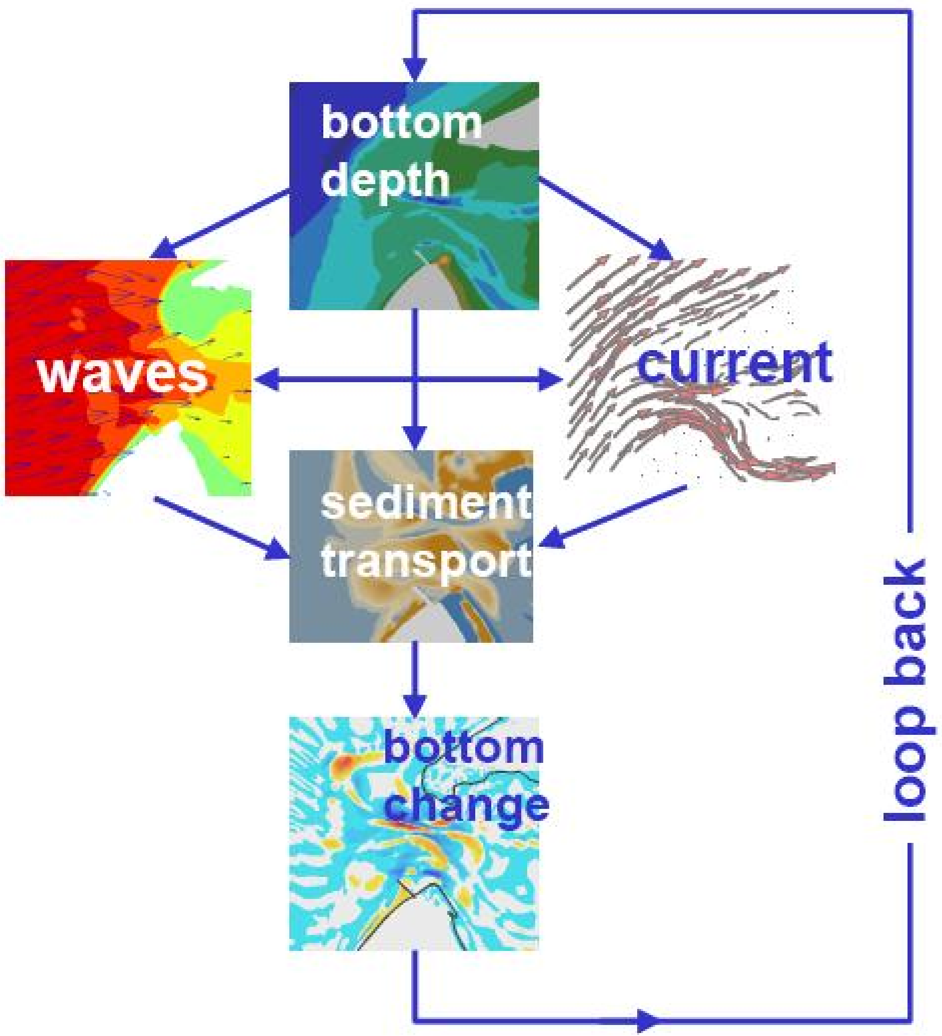
Waves model input (described in draft nonhydrostatic report):

- Numerical parameters
  - parameter ‘solver=2’ uses a fast nonhydrostatic pressure solver that can only be used in 1D simulations, else use slower ‘solver=1’
  - set parameter ‘Topt’ to the dominant wave period in your simulation

Long term stationary solutions

1 year – 1000 years	Climate change impact on profile behaviour	Evolution of tidal inlets, including climate change impacts	Evolution of tidal basins Large-scale coastline evolution
1 day – 10 years	Cyclic bar behaviour Effect of shoreface nourishments Evolution of beach states Effects of small-scale coastal structures	Impact of harbour extensions, land reclamations Mega nourishments	Longshore spreading of nourishments Coastal realignment in response to wave climate variability (El Niño, La Niña)
1 hour – 10 days	Dune erosion (1D) Reset events Dune erosion, overwashing and breaching (2D)		
Time scales	1 m- 1 km	10 m – 10 km	100 m – 100 km
Space scales			

Morphodynamic loop



- Bottom changes are fed back into bathymetry after each time step
- Bottom changes are multiplied by morphological factor MORFAC
- Difference between hydrodynamic time scale and morphodynamic timescale

Morfac options

- We can either:
  - Specify morphological time and adjust hydrodynamic time, or
  - Specify hydrodynamic time and adjust morphological time
- In the first option (morfacopt=1):
  - All input times are divided by morfac
  - Time series of boundary conditions are shortened
  - Tidal dynamics may be distorted
  - Time series of wave energy may get too short
- In the second option (morfacopt=0):
  - Hydrodynamic time series are untouched
  - Tidal dynamics are preserved
  - Effects of changes within tidal cycle are exaggerated

Morfacopt

Options for using morfac:

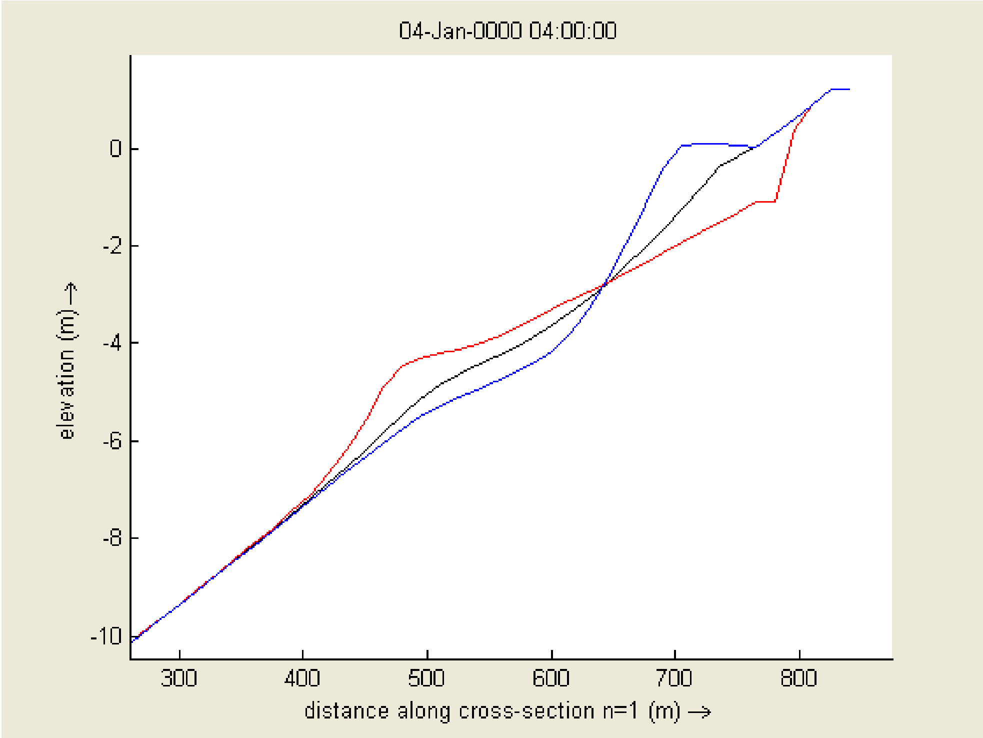
Morfacopt=0	Morfacopt=1 (default)
Times are specified as hydrodynamic times	Times are specified as morphological times
Hydrodynamics of tidal cycle are not disturbed	All times divided by Morfac Tidal variation is accelerated

Differences in approach / Considerations

- Need to calibrate longer-term profile behavior
- More attention to onshore processes
  - facua or facsk, facas
- During moderate conditions, infragravity waves much less important
- Stationary approach possible if infragravity waves can be neglected
- Higher morphological factor for moderate conditions

Example profile evolution

- River outflow case turned into 1D model of straight beach, to calibrate profile behaviour
- Facua (=facsk=facas)= 0.0, 0.2,0.4
- Which is which?
- More subtle calibration is possible using separate values for facas and facsk
- facas effects shoreline
- facsk effects surfzone



Stationary wave solver

- First, the wave and roller balances are iterated per longshore line until no change; screen output tells how many iterations

Short waves And Rollers

$$\left.\begin{aligned}\frac{\partial A}{\partial t}+\frac{\partial c_x A}{\partial x}+\frac{\partial c_y A}{\partial y}+\frac{\partial c_\theta A}{\partial \theta}&=-\frac{D_w}{\sigma}\\ \frac{\partial S_r}{\partial t}+\frac{\partial c_x S_r}{\partial x}+\frac{\partial c_y S_r}{\partial y}+\frac{\partial c_\theta S_r}{\partial \theta}&=-D_r+D_w\end{aligned}\right\}$$

- Then wave and roller forces are computed

$$F_x=-\left(\frac{\partial S_{xx}}{\partial x}+\frac{\partial S_{xy}}{\partial y}\right)$$

$$F_y=-\left(\frac{\partial S_{xy}}{\partial x}+\frac{\partial S_{yy}}{\partial y}\right)$$

- NO WAVE GROUP FORCING
- Stationary run repeated every *wavint* seconds

Running stationary waves

- Instat = stat or stat_table
- Break = 2
  - Baldock formulations meant for wave-averaged simulations, other formulations meant for simulations varying on wave group scale
- Hrms =
  - Watch out: Hrms not Hm0
- Trep =
  - Representative period = Tp
- Dir0 =
  - Mean wave angle (nautical convention)
- Wavint = <interval of repeating wave simulation (s)>
  - Note: take into account morfac!

Presentation of local problems

by participants

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