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Enabling Delta Life

DSD 2016: XBeach course - Morphodynamic modelling during storm conditions

Kees Nederhoff & Ellen Quataert

28 oktober 2016

Program of today

Time	Topic
09:15	**Theory**: the different modes of XBeach (stationary, surfbeat, non-hydrostatic)
09:30	**Practical**: general setup
09:45	**Hands-on**: Santa Rosa (2DH)
12:00	**Theory**: background information formulations
12:30	**Lunch**
13:30	**Practical**: advanced applications
14:00	**Hands-on**: Boscombe beach, UK or own case
16:45	**Practical**: numerical tips & tricks
17:00	**Closure** & **drinks**

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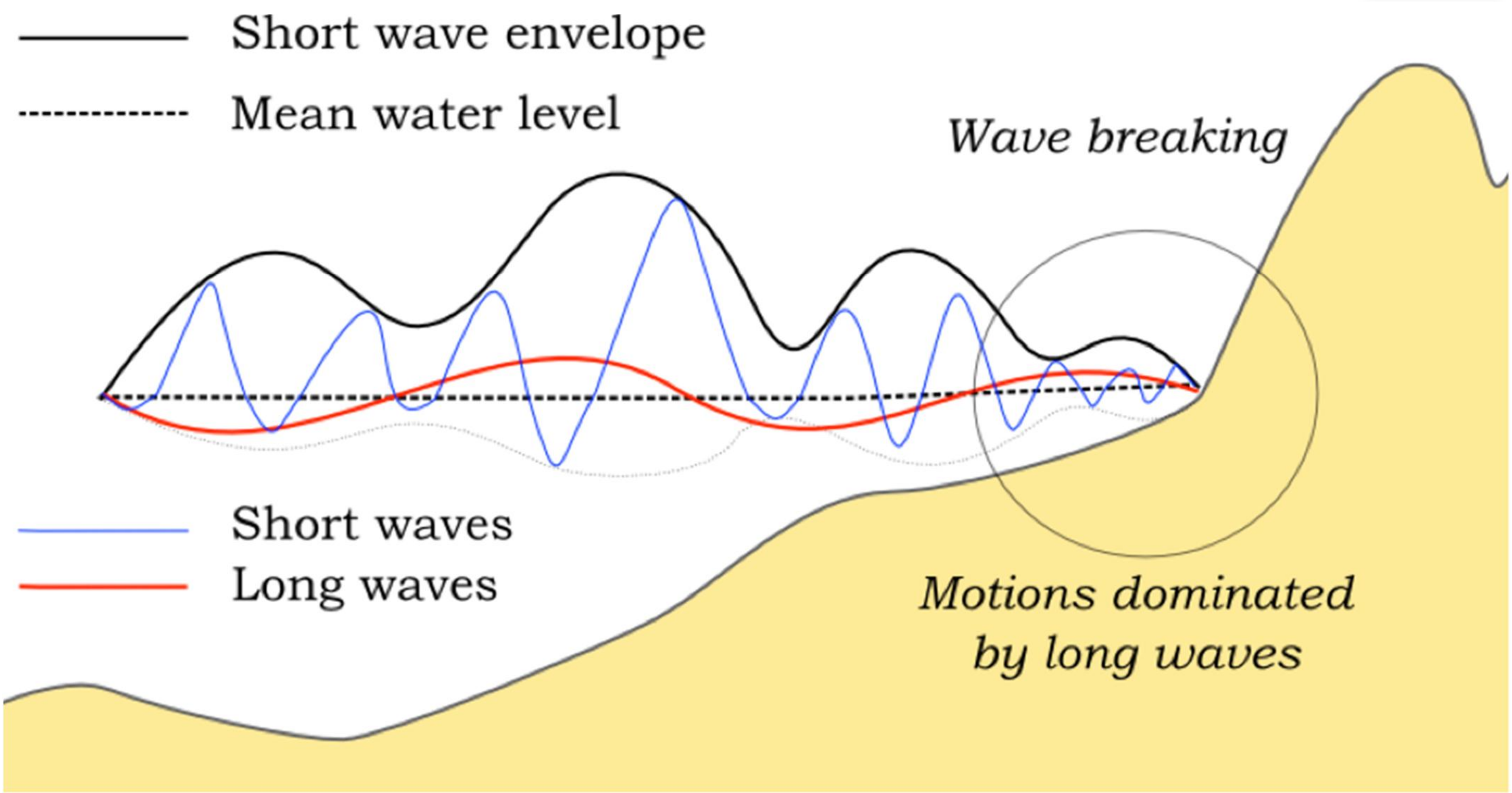
Part 1A. Theoretical background

THE DIFFERENT MODES OF XBEACH (STATIONARY, SURFBEAT, NONHYDROSTATIC)

Motivation to develop XBeach

Impact Hurricane Matthew. At Vilano Beach FL, 10/9, video credit Tom Kane
Source: https://twitter.com/StuOstro/status/785532989497368576?s=02

Relevant wave processes



Nederhoff (2014). Modelling the effets of hard structures on dune erosion and overwash. Hindcasting the impact of Hurricane Sandy on New Jersey with XBeach

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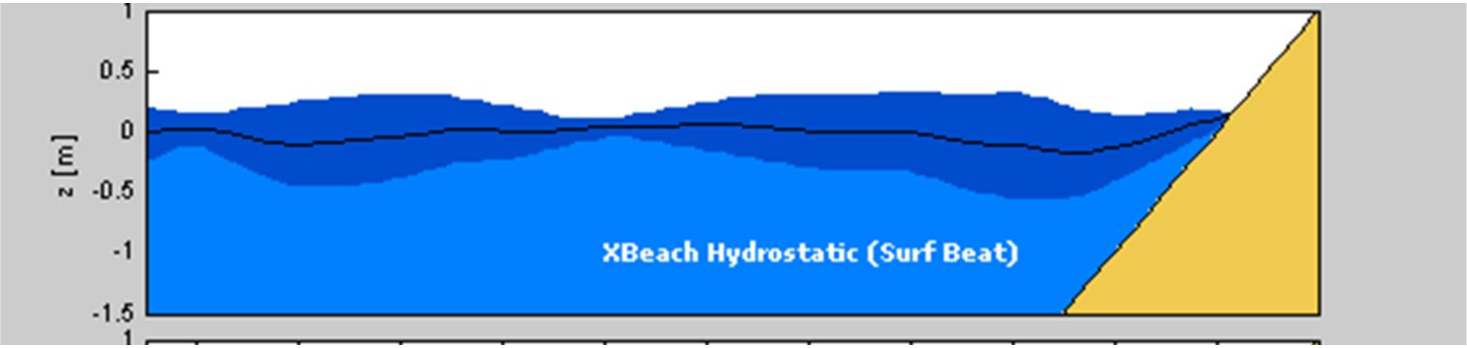
Different XBeach hydrodynamic modes



surfbeat mode
Wave conditions vary on wave group scale, IG waves resolved

Governing equations in surfbeat mode

Long waves

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-\nu_h\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)=-\frac{\tau_{bx}}{\rho h}-g\frac{\partial \eta}{\partial x}+\frac{F_x}{\rho h}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+\nu_h\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)=-\frac{\tau_{by}}{\rho h}-g\frac{\partial \eta}{\partial y}+\frac{F_y}{\rho h}$$

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

Wave forcing

Short waves

And

Rollers

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

$$\frac{\partial S_r}{\partial t}+\frac{\partial c_x S_r}{\partial x}+\frac{\partial c_y S_r}{\partial y}+\frac{\partial c_\theta S_r}{\partial \theta}=-D_r+D_w$$

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

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

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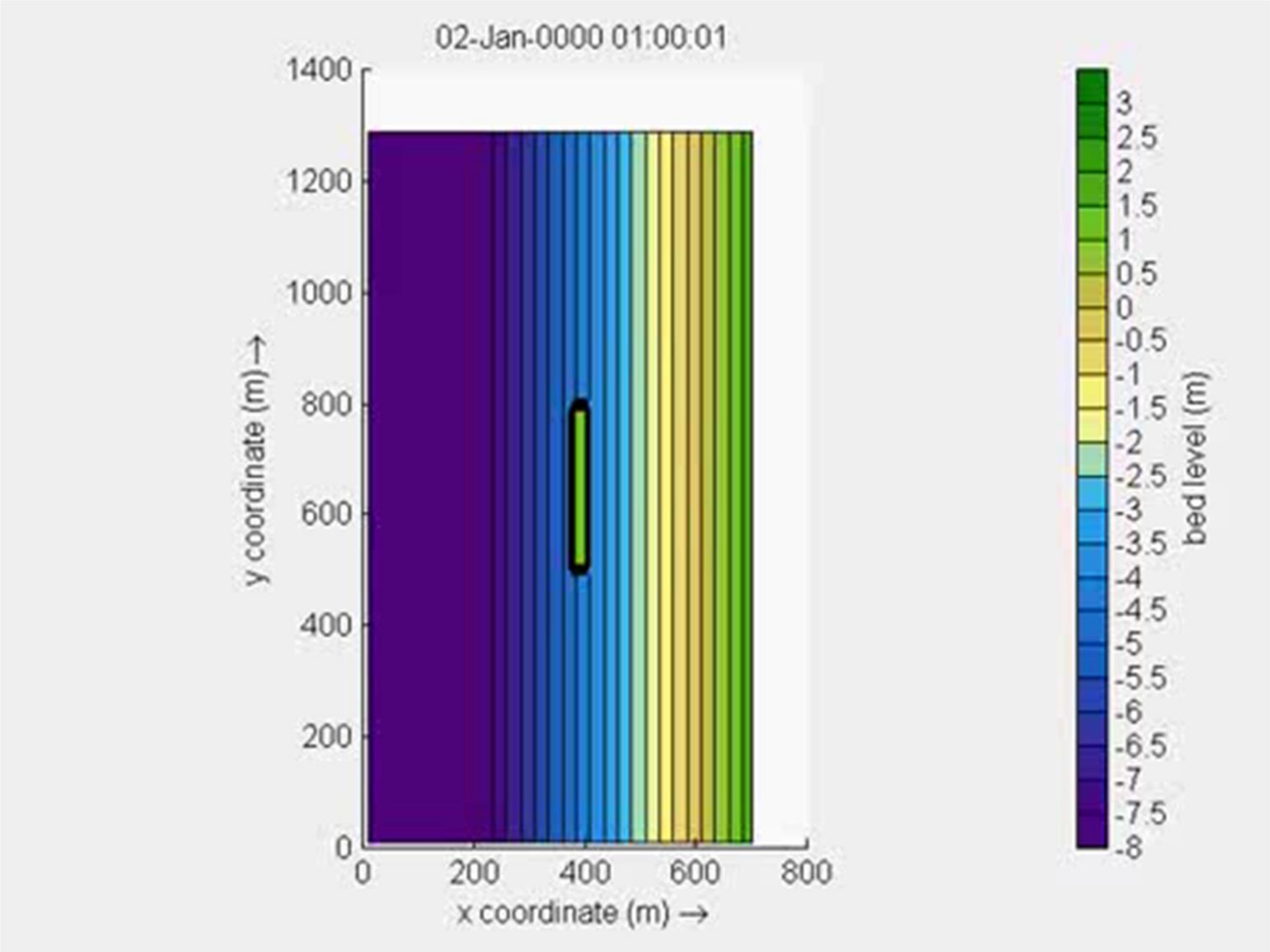
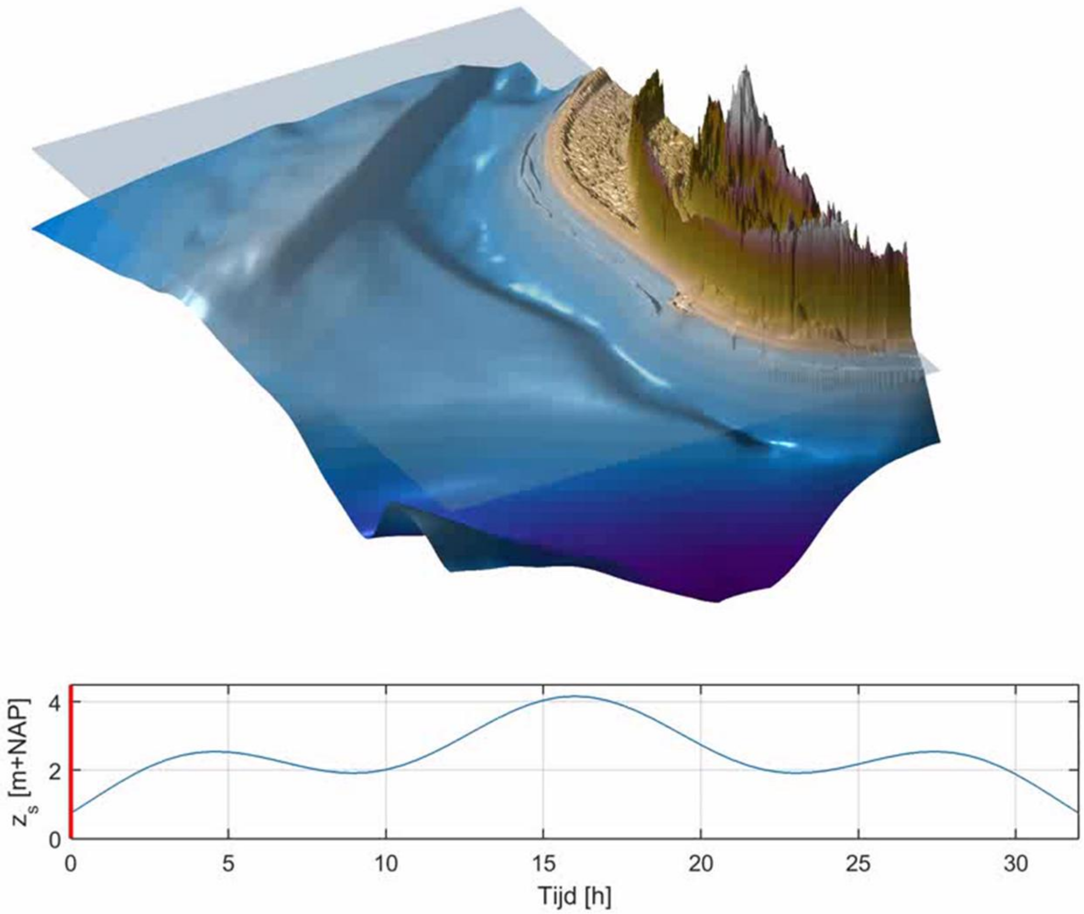
Example of XBeach-stationary



XBeach simulation of the offshore breakwater case described in Nicholson, J., I. Broker, J.A. Roelvink, D. Price, J.M. Tanguy, L. Moreno. Intercomparison of coastal area morphodynamic models. Coastal Engineering 31(1997) 97-123. Simulation using stationary wave solver, approx. 3 months simulation time.

Source: https://www.youtube.com/watch?v=-BV-8ReVfX4

Example of XBeach-surfbeat



Nederhoff, Elias, Vermaas (2016). Erosion on Ameland Northwest. Modelstudie with Delft3D and XBeach simulations. Number: 1503-0080. In Dutch.
Source: https://www.youtube.com/watch?v=F44-1QVsmjE&feature=youtu.be

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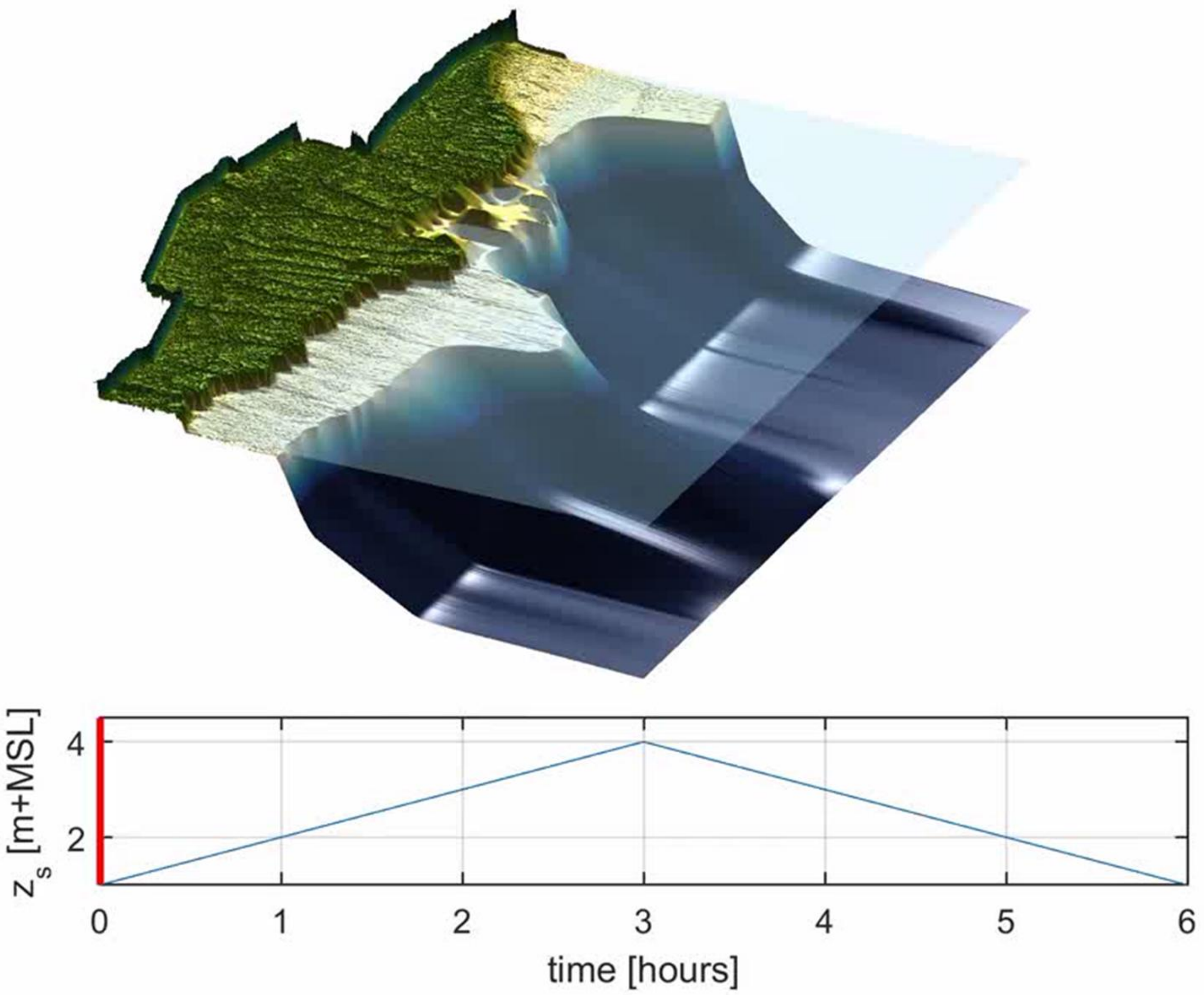
Example of XBeach-nonh



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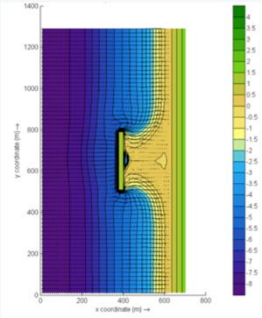
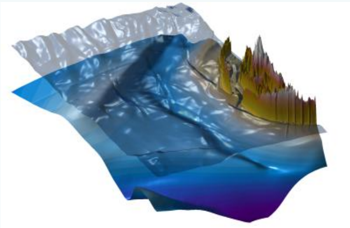
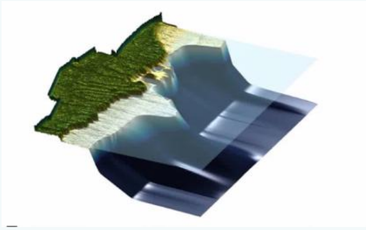
Overview different hydrodynamic modes

Type	Stationair	Surfbeat	Nonh
Goal	Schematic short waves	Fully resolve long waves	Propagation of individual waves
Hydrodynamics	no	yes, but only for long waves	yes, for all waves
Morphodynamics	moderate wave conditions	extreme conditions (e.g. hurricanes)	*under development*
Computational time	Short	Medium	Long
Time-scale	Long-term	Short to medium	Short
Example			

Part 1B. Practical information

HOW TO SET UP A XBEACH MODEL?

XBeach model setup

Simulation folder containing:

File	Function	Essential file	Additional file
xbeach.exe	XBeach executable	x	
params.txt	File defining all model parameters	x	
Depth file (.dep)	Model bathymetry	x	
Grid file (.grd)	Model grid	x	
Wave input files	One or a list of (irregular) wave conditions		x
Water level input files	to apply varying tide and surge conditions		x
Files for additional functionality	e.g. hard layers, ground water flow, tracers, river discharge, spatially varying roughness …		x

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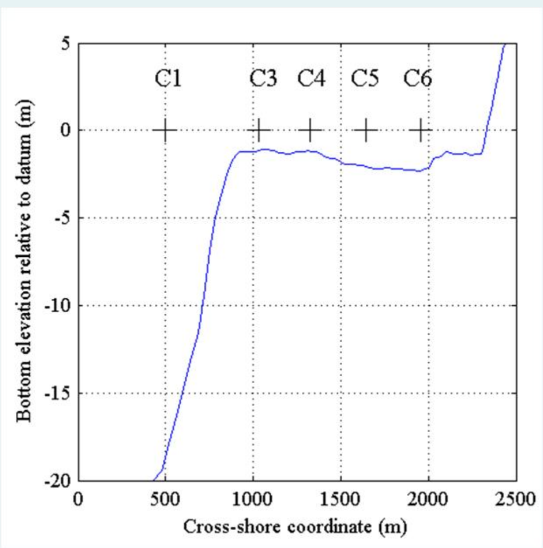
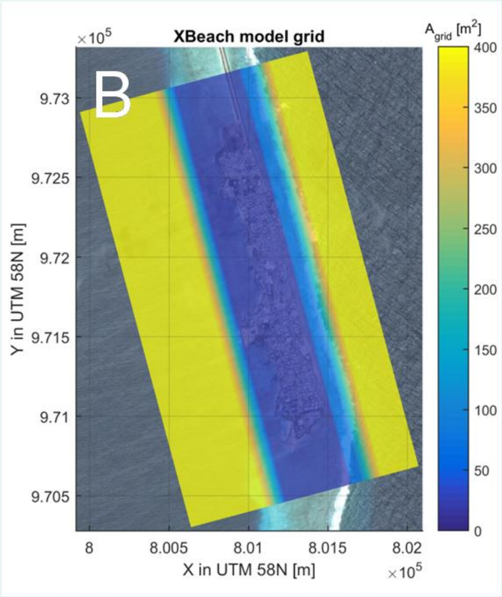
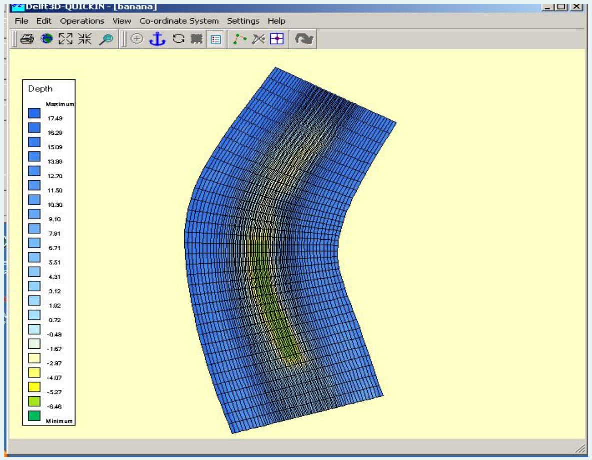
Computational grid

Grid types:

1-Dimensional (Cross-shore profile)	2-Dimensional rectilinear (depth averaged/2DH)	2-Dimensional curvilinear (depth averaged/2DH)
		

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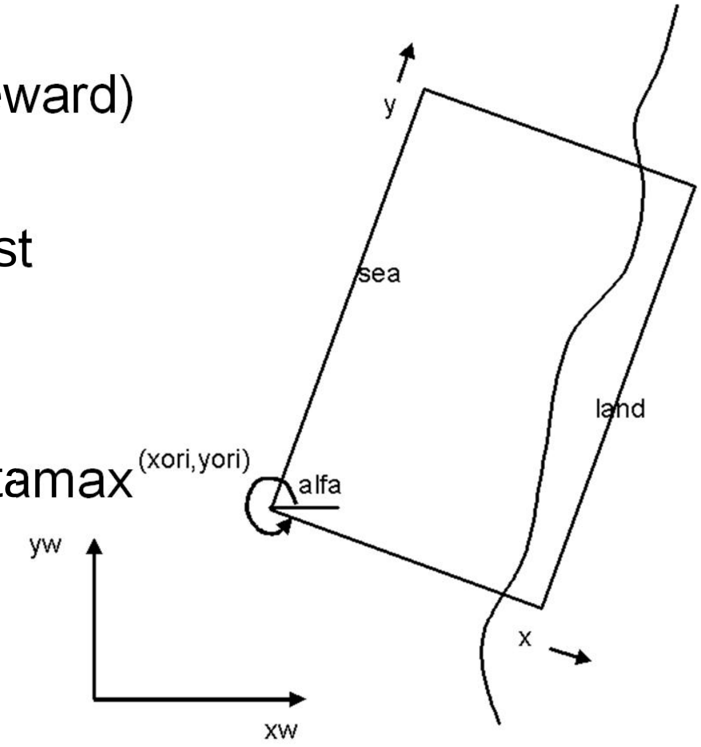
Computational grid

- XBeach coordinates refer to local coordinate system (in meters)

- Local coordinate system
  - Origin on offshore boundary
  - x-axis in cross-shore direction (+ shoreward)
  - y-axis in along-shore direction
  - ‘alfa’ angle counter-clockwise w.r.t. East

- Wave grid
  - Bins of dtheta between thetamin & thetamax
  - Either thetanaut = 1 (nautical conv.)
    or 0 (w.r.t. x-axis)



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Files for additional functionality	e.g. hard layers, ground water flow, tracers, river discharge, spatially varying roughness …		x

XBeach model setup

Params.txt example:

keywords

value or filename

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% XBeach parameter settings input file
%%%
%%% date:     17-Aug-2011 22:07:19
%%% function: xb_write_params
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%% Bed composition parameters %%%%%%%%%%%%%%%%

D50          = 0.000200
D90          = 0.000300

%%% Flow boundary condition parameters %%%%%%%%

front        = abs_2d
back         = abs_2d

%%% Flow parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%

C            = 55

%%% Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%

depfile      = bed.dep
posdwn       = 0
alfa         = 0
thetamin     = 200
thetamax     = 300
dtheta       = 20
thetanaut    = 1
gridform     = delft3d
xyfile       = xy.grd
```


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XBeach output options

```
%%% Output variables %%%%%%%%%%%%%%%%%%%%

outputformat = netcdf
tintg        = 1
tintm        = 3600
tintp        = 1
tstart       = 0

nglobalvar   = 5
zb
zs
u
v
H

npoints      = 2
0 100
1000 100

npointsvar   = 2
zs
H

nrugauge     = 2
20 50
40 50

nmeanvar     = 4
zs
u
v
H
```

→ Two output formats: netCDF or .*dat

→ Global output variables at time interval tintg

→ Point output locations at time interval tintp

→ Point output variables at time interval tintp

→ Runup output locations at time interval tintp

→ Mean, min, max, var output variables at time interval tintm

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Model generation

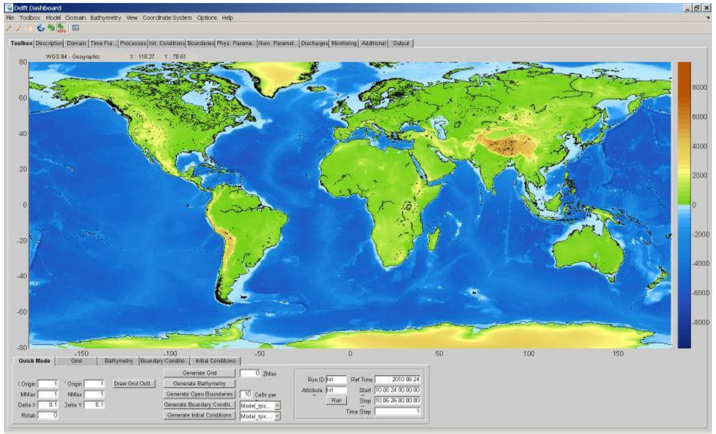
1. Own scripts for pre- and post-processing

2. Matlab Toolbox provides:

This course

- scripts to set-up and run XBeach models;
- functions to read and analyze model output.

3. Delft Dashboard



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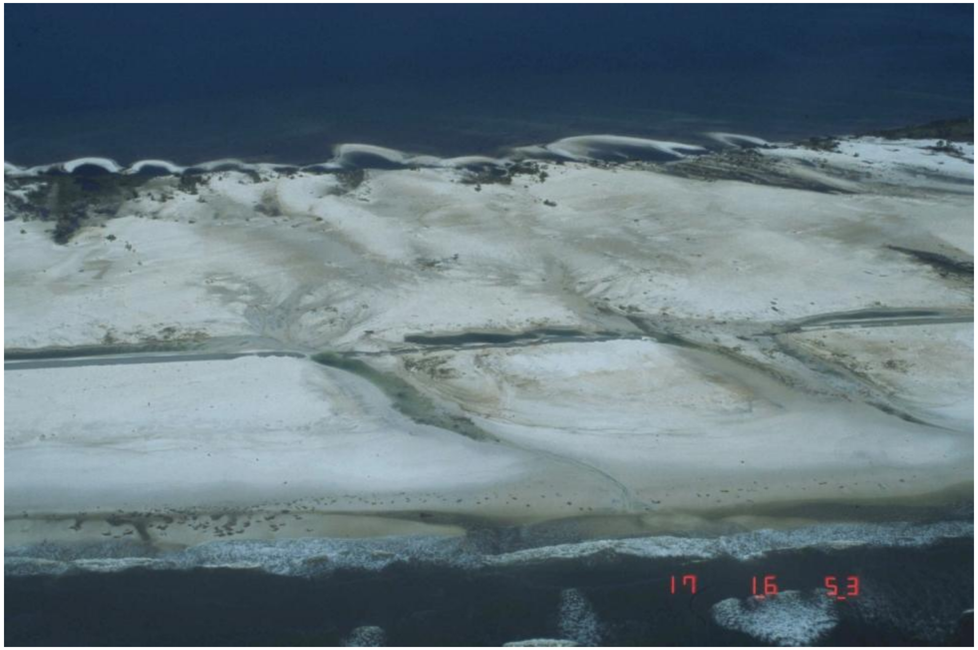
Part 1C. Hands on

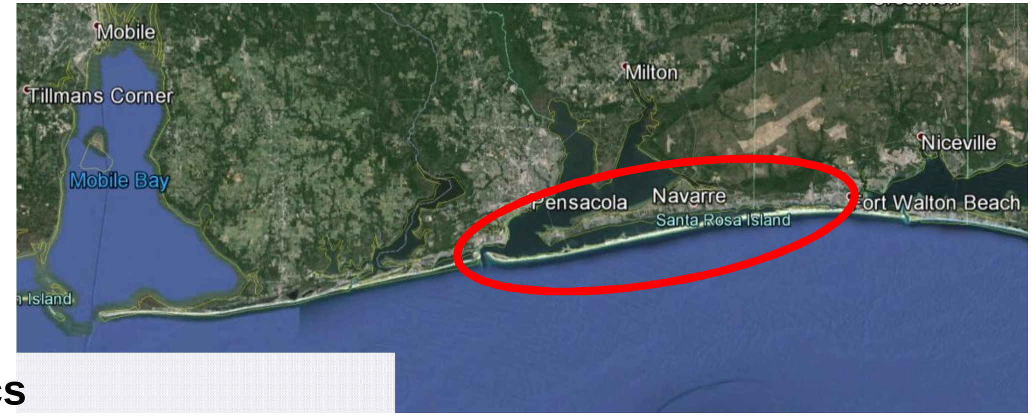
SANTA ROSA

Santa Rosa Island, USA (2D)

Hurricane Ivan, 16 Sept. 2004

- Modelling overwash on typically very narrow Gulf of Mexico barrier islands
- Large sediment deposits on the island and back barrier bay





Focus: physics

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Part 2. Theoretical background

GOVERNING EQUATIONS AND BOUNDARY CONDITIONS

Waves: governing equations

- **Short wave action balance**
  - Similar to HISWA (Holthuijsen et al., 1989)
  - Relative simple energy field as driver for long waves

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

- **Dissipation (possible) due to:**
  - wave breaking — keyword: break (default=roelvink2)
  - wave friction — keyword: fw (default = 0)
  - vegetation — keyword: vegetation (default = 0)

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Waves: boundary conditions

Form	Type	Keyword: instat =
Spectral	Parameterized	jons or jons_table
	SWAN spectrum	swan
	Other type spectrum	vardens
Non-spectral	Stationary	stat or stat_table
	Time series	ts_1, ts_2, ts_nonh
Other forms	Biochromatic	bichrom
	No waves	off
	Reuse previous	reuse

Flow: governing equations

- **Generalized Lagrangian Mean (GLM) formulation**
  - Momentum & continuity are formulated in **Lagrangian** velocity, see Walstra et al. (2000) for more info

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

$$u^S = \frac{E_w \cos\theta}{\rho h c}$$

- **Definition per symbol:**
  - **uL** is the distance a water particle travels in one wave period divided by that period
  - **uE** is the short-wave averaged velocity observed at a fixed point
  - **uS** is the stokes drift

Flow boundary conditions

Offshore & bayside flow boundary conditions (keyword: ‘front’ & ‘back’)

keyword	Effect
wall	no-flux
abs1d / abs2d (default)	long wave can enter/leave
waterlevel	a constant water level

Lateral flow boundary conditions (keyword: ‘left’ & ‘right’)

keyword	Effect
wall	no-flux
neumann (default)	long wave can enter/leave
no_advec	a constant water level
cyclic	

Sediment transport

$$\underbrace{\frac{\partial hC}{\partial t}+\overbrace{\frac{\partial hC\left(u^E-u_a\sin\theta\right)}{\partial x}+\frac{\partial hC\left(v^E-u_a\sin\theta\right)}{\partial y}}^{=S_x}+\frac{\partial}{\partial x}\left[D_h h\frac{\partial C}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_h h\frac{\partial C}{\partial y}\right]}_{=S_y}=\frac{hC_{eq}-hC}{T_s}$$

- Depth-integrated advection-diffusion equation
- Equilibrium sediment concentration determined by extended Van Rijn 2008 formulation or Soulsby-Van Rijn formulation
- Sediment advection velocity includes seaward return flow *(u_e)*
- Nonlinear effects taken into account with asymmetric velocity *(u_a)*
- T_s is adaptation time scale

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Morphology: bed updating

- ***Sediment transport gradients**:*

$$(1-\varepsilon)\frac{\partial z_b}{\partial t} + f_{mor}\left(\frac{\partial S_x}{\partial x} + \frac{\partial S_y}{\partial y}\right) = 0$$

- ***Avalanching** (to simulate interaction with dry dune):*

$$\frac{\partial z_b}{\partial x} > m_{cr} \quad \text{or} \quad \frac{\partial z_b}{\partial y} > m_{cr}$$

- *Different critical slopes (mcr) for dry and wet points*
- *Default values are above water (~ 1.0) and below water (~ 0.10-0.3)*
- *Avalanching is carried out in both x- and y- direction*

Morfological acceleration factor (morfac)

- Multiplies the bed level change with morfac (ranging from 1-10)

Two different implementations

- morfacopt = 1 (default)
  - All time series divided by morfac (so accelerated tidal cycle)
  - e.g. tstop = 5hrs with morfac = 10 simulates 30min of hydrodynamics & 5hrs bed level change
- morfacopt = 0
  - Time series aren't compressed
  - e.g. tstop = 5hrs with morfac = 10 simulates 5hrs of hydrodynamics & 50hrs bed level change

- **Be careful! Too high morfac can lead to unrealistic results!**

Morphological calibration

1. **For swash and dune erosion**
   - Vary the wave asymmetry and skewness together (keyword: facua; range 0.0 to 0.5)
   - Vary the wave asymmetry and skewness separate (keywords: facAs and facSk)

$$u_a = (facSk \cdot S_k - facAs \cdot A_s) u_{rms}$$

2. **For overwash and inundation (e.g. sheetflow barrier islands)**
   - Increase roughness on barrier (Manning *n*: 0.04 $m^{1/3}/s$ versus 0.02 $m^{1/3}/s$ for the rest of the model domain). *Bulk parameter.*

More information XBeach manual and Nederhoff et al. (2015). Modeling the effects of hard structures on dune erosion and overwash - a case study of the impact of Hurricane Sandy

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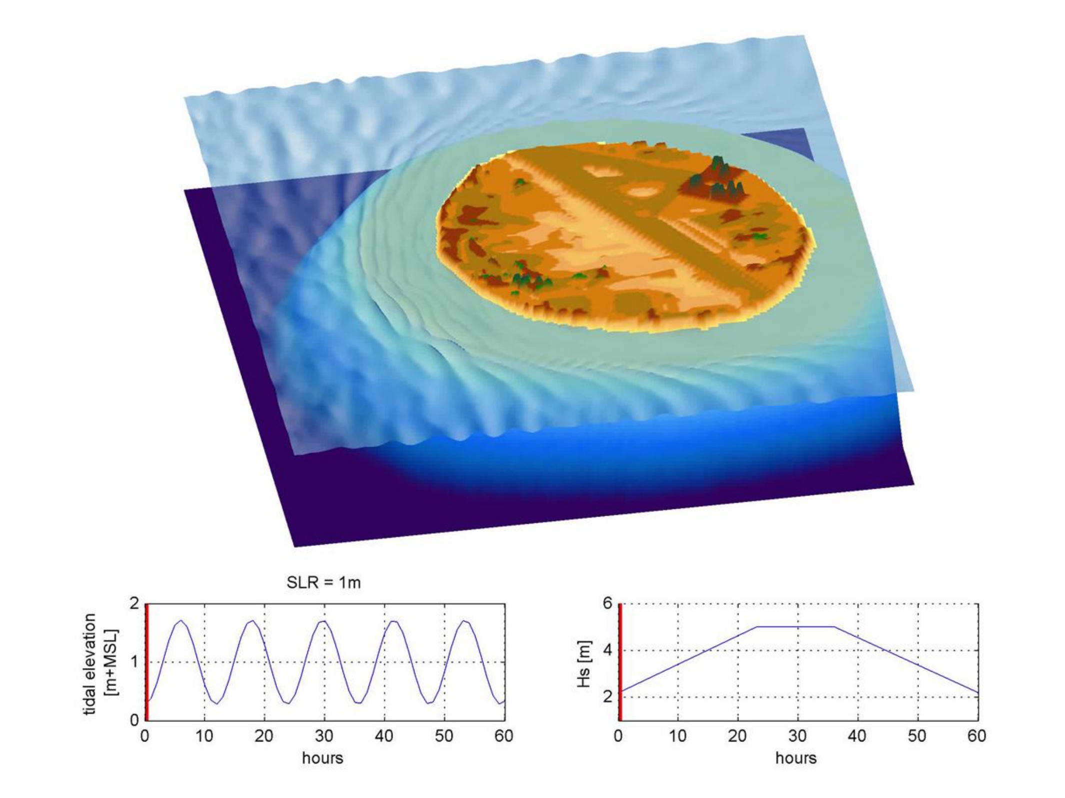
Part 3A. Practical background

ADVANCED APPLICATIONS

Coral reef environments

- Reproduction of complex hydrodynamics
- Surfbeat and non-hydrostatic XBeach with varying roughness



More info:
Van Dongeren et al. (2013), Numerical modeling of low-frequency wave dynamics over a fringing coral reef.
Quataert et al. (2015), The influence of coral reefs and climate change on wave-driven flooding of tropical coastlines.

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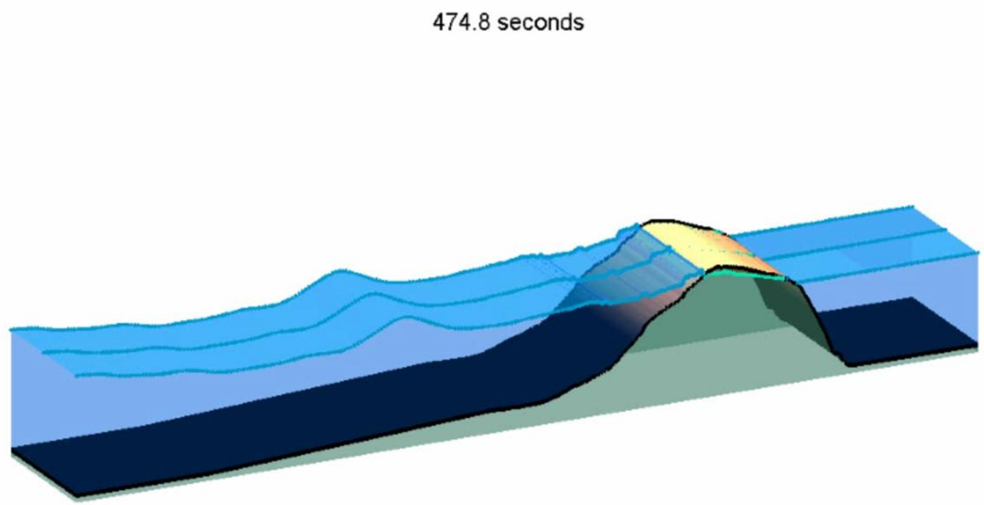
Gravel beaches and groundwater flow

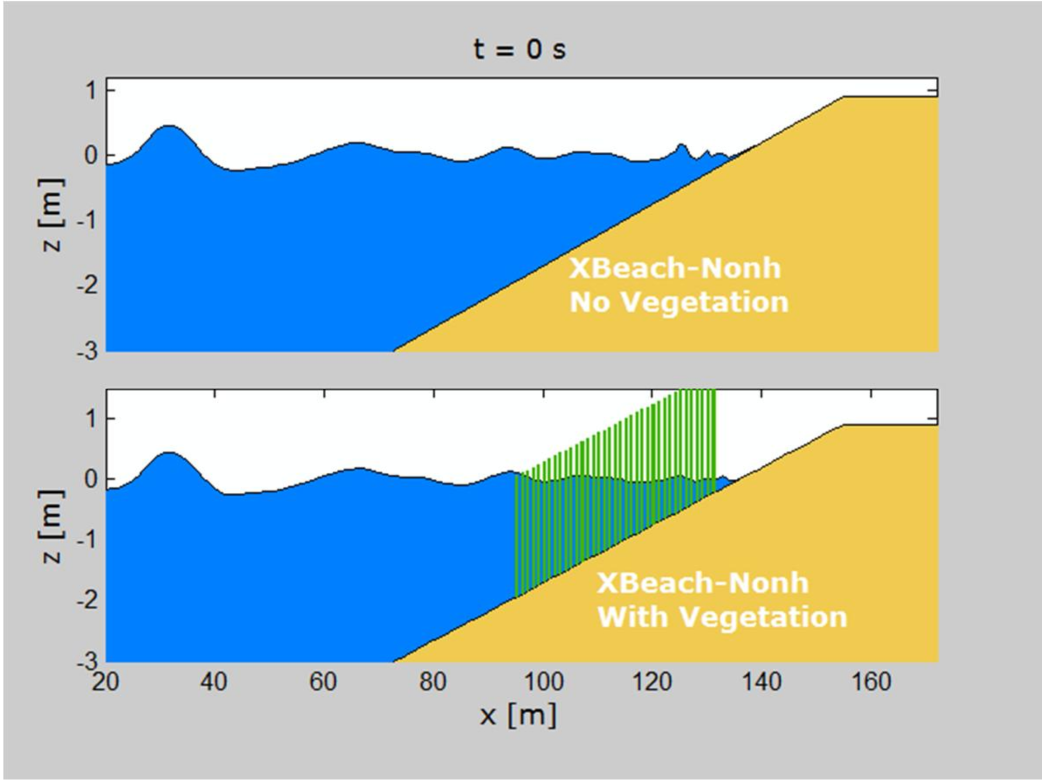
- High infiltration and exfiltration rates affecting swash processes
- Non-hydrostatic + groundwater module
- XBeach-G capable in reproducing hydro- and morphodynamics



More info:
McCall et al. (2014), Modeling storm hydrodynamics on gravel beaches with XBeach-G

Wave attenuation by vegetation

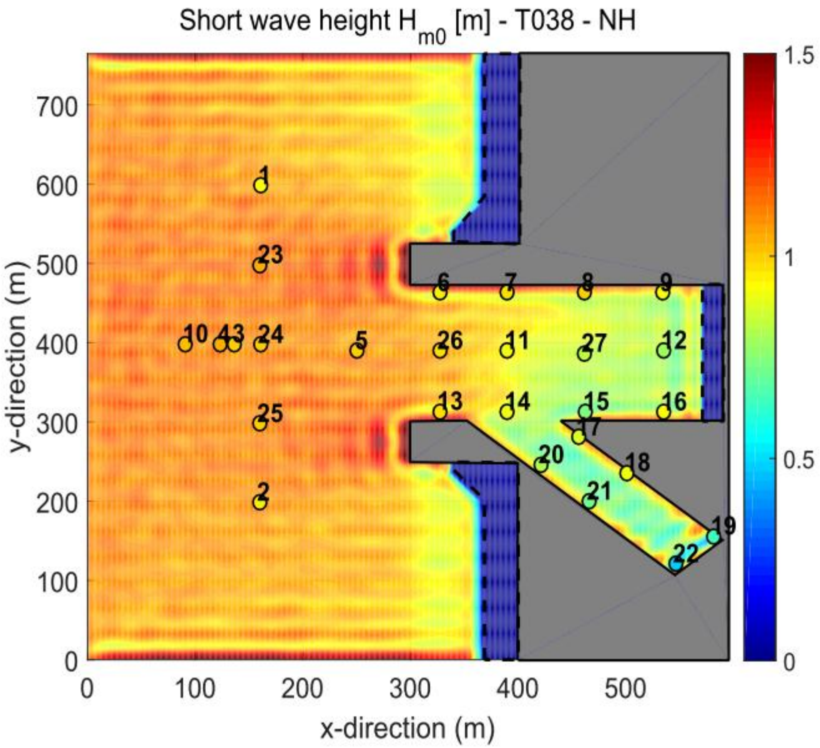
- Wave attenuation by several vegetation parameters
- Reproduction of complex hydrodynamics.
- Surfbeat and non-hydrostatic XBeach

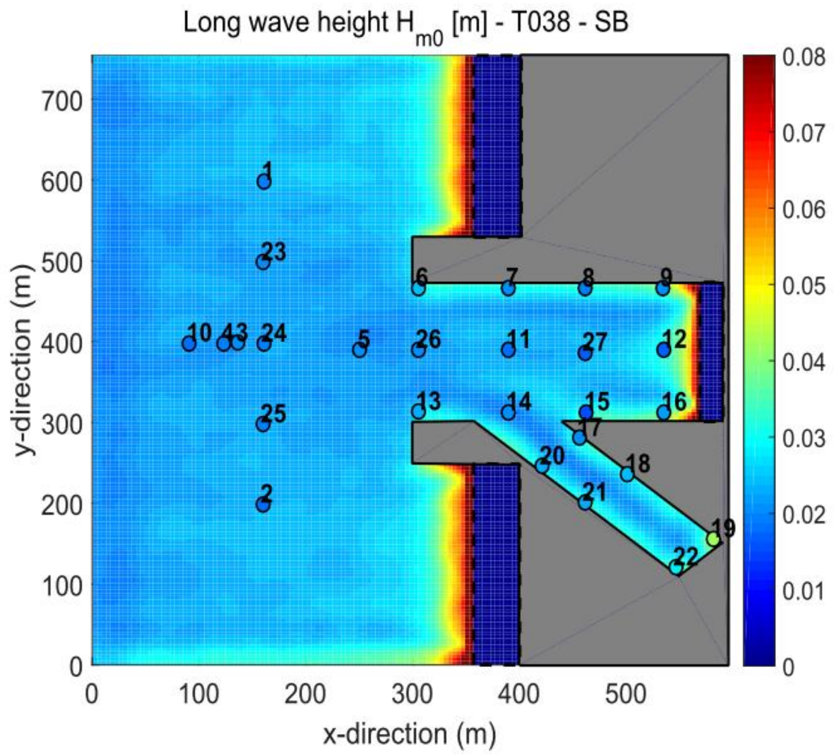


More info:
Van Rooijen et al. (2016), Modeling the effect of wave-vegetation interaction on wave setup.

Ports

- Wave penetration and basin resonance reproduced
- Surfbeat and non-hydrostatic XBeach





More info:
Wong, A.L.Z. (2016). Wave hydrodynamics in ports – numerical model assessment of XBeach. MSc thesis Delft university of Technology. Available via http://repository.tudelft.nl/

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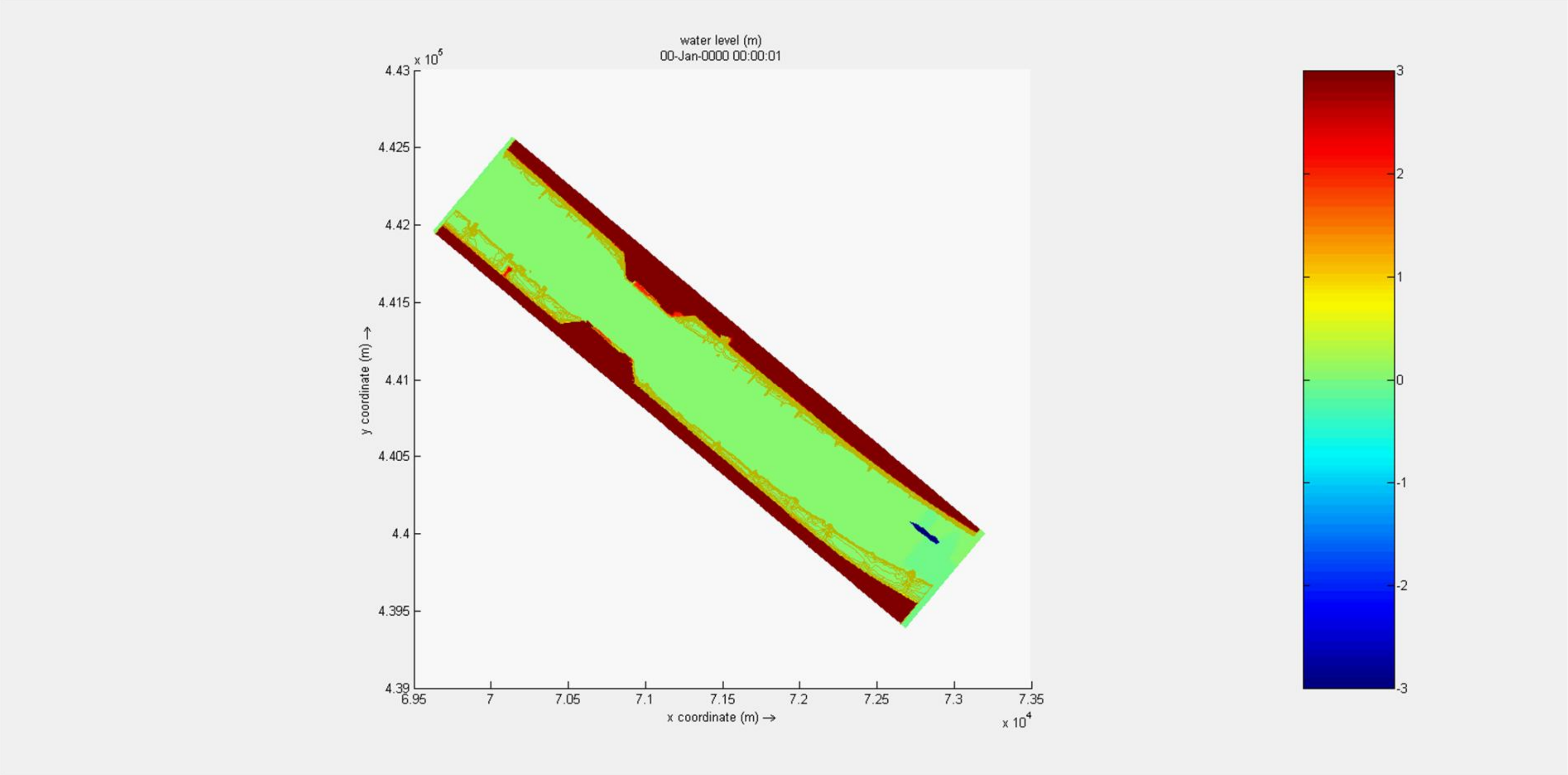
Ship-induced waves

- Non-hydrostatic module



More info:
Zhou et al. (2013), Study of Passing Ship Effects along a Bank by Delft3D-FLOW and XBeach.
De Jong et al. (2013). Numerical modelling of passing ship effects in complex geometries and on shallow water

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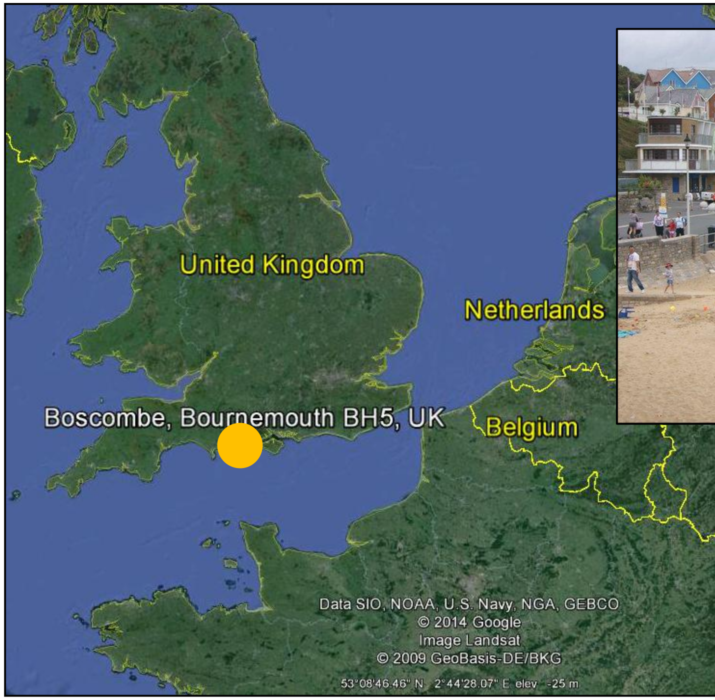
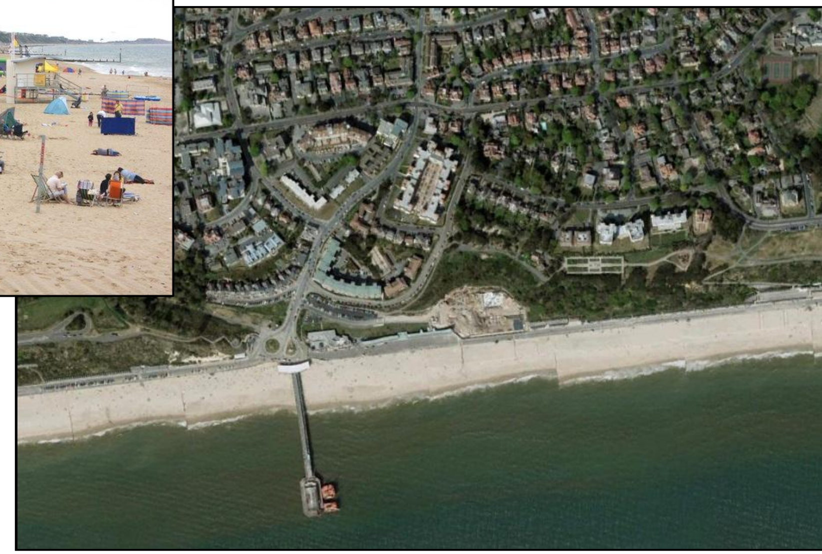
Part 3B. Hands on

BOSCOMBE BEACH CASE

Boscombe beach case





Boscombe Beach (South coast U.K.)
Popular beach: tourism, recreation

Buildings are located very close to the beach (not natural dune)
No natural dune system left: coast is protected by a sea wall

But is this sufficient? What kind of storm impact can we expect?
You will setup an XBeach model from scratch to answer these questions!

Focus: model generation

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Part 4. Practical: numerical tips and tricks

www.xbeach.org

Home | Get started | Download | Get help | Forum | Validation | XBeach-G | About

WEB CONTENT DISPLAY

Delft Software Days
Edition 2014
27 October – 7 November
DSD

XBeach Open Source Community

Welcome to the XBeach Open Source Community website. This website facilitates users and developers of the XBeach model and intends to keep you up-to-date on developments and events.

XBeach is a two-dimensional model for wave propagation, long waves and mean flow, sediment transport and morphological changes of the nearshore area, beaches, dunes and backbarrier during storms. It is a public-domain model that has been developed with funding and support by the US Army Corps of Engineers, by a consortium of UNESCO-IHE, Deltares (formerly WL|Delft Hydraulics), Delft University of Technology and the University of Miami.

Happy modelling!

The XBeach Team

7500+ joined the Deltares Open Source Community

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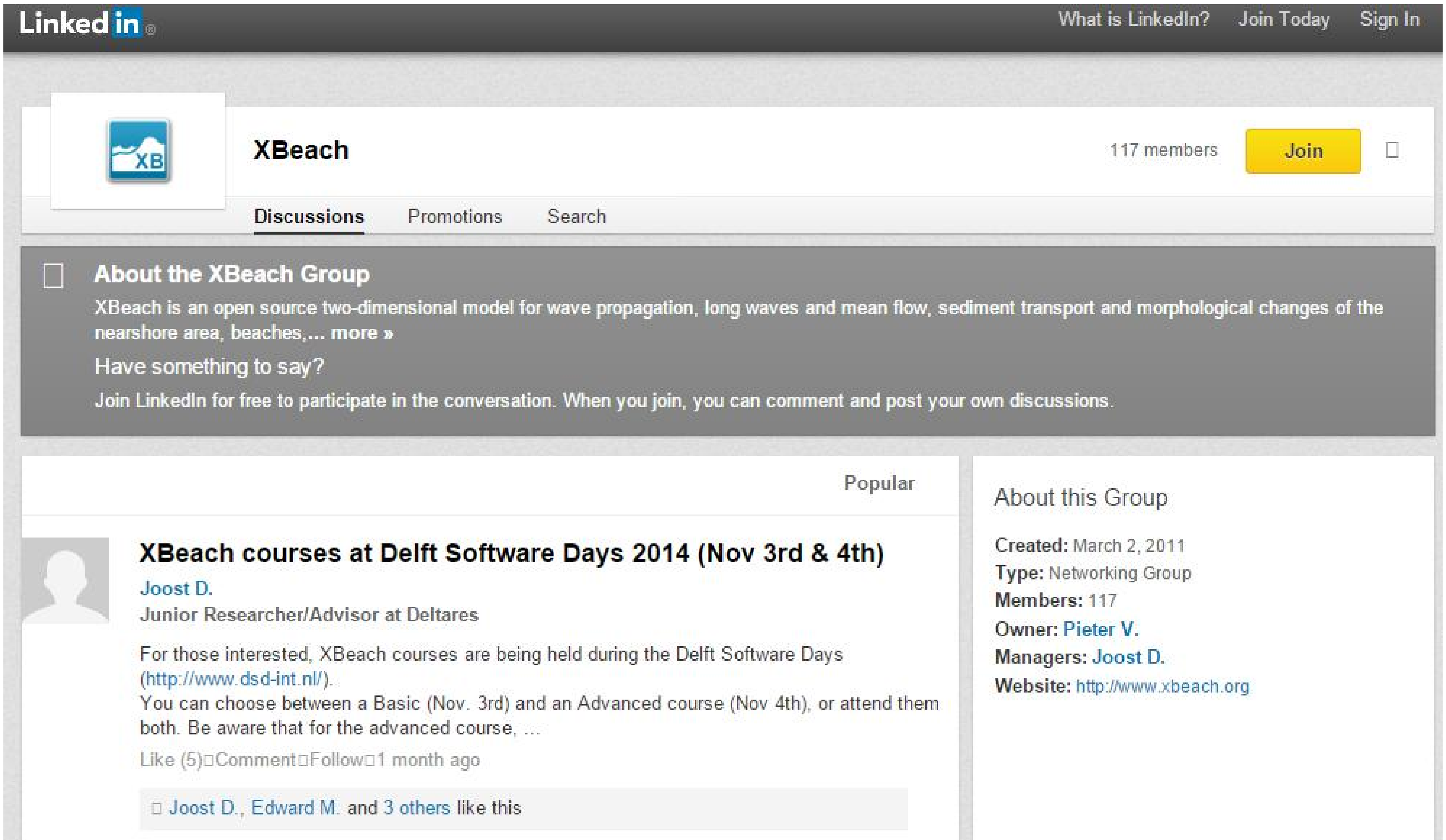
Join our LinkedIn group



Tips and tricks (1/2)

Setting up a numerical grid

- resolution should be related to length scale of features of interest
  - 5-10 grid cells per feature (e.g. dune crest of 20 meter)
  - 10-20 grid cells per wave length to be modeled
    - short wave length: +/- 100m
    - long wave length: +/ 1000m
- varying grid resolution based on Courant condition

- **Rule of thumb for surbeat**: varying grid size with dxmax = 50 meter and dxmin = 2 meter

REMARK: Tricks for robust model set-up are implemented in the Matlab Toolbox of XBeach

Tips and tricks (2/2)

Define Depths:

- Offshore boundary at sufficiently deep water for realistic long wave boundary conditions ($n < 0.8$)
- Uniform coast (three cells) near boundaries

Settings:

- Use defaults as much as possible (especially when you start)

Reducing computational time

- Run XBeach on multiple cores/nodes (MPI executable needed)

- Reduce the number of grid cells
- Reduce the number of wave bins (thetamin, thetamax, dtheta)
  - Wave grid resolution needed varies per situation
  - In 1D case, investigate using ‘Snells = 1’

- Disable unnecessary physical processes
  - When only interested in hydrodynamics, turn off morphology and sediment transport (morphology = 0, sedtrans = 0)

- Apply morphological acceleration factor (morfac)
- Only use one sediment layer

Troubleshooting

- Always check the log/warning file for any hints!
- Examine the last output results: velocities, water levels, bed levels
- Boundary conditions often problematic: try different conditions
  - Lateral: left = wall or left = no_advec
  - Backshore: back = wall or abs_1d
- Try reducing morphological acceleration factor
- Ask your question on the XBeach forum

Important rules for numerical modeling

1. **Start with the question:** ***what are you trying to do?***

2. **Start simple and build up complexity**

3. **A complex model is never a reason not to understand your model results.** Check for example: time step, morfac, wave growth due to wind

4. **Use descriptive filenames, run simulations in a separate folder, write a logbook of the different model versions**

5. **Spend enough time to make nice figures**

6. **Use Total Commander and Textpad**