Keywords

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Summary

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References

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| State  draft  This is a draft report, intended for discussion purposes only. No part of this report may be relied upon by either principals or third parties. |

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# Introduction

Dano, Ad, Ap

# Processes and model formulation

## Domain and definitions

Dano - overnemen en nieuw plaatje curvi

## Hydrodynamics options

Dano

### Stationary mode

### Non-stationary (surfbeat) mode

### Wave resolving mode

## Short wave propagation

### Wave action balance

Kees - bezig

The wave forcing in the shallow water momentum equation is obtained from a time dependent version of the wave action balance equation. Similar to Delft University’s (stationary) HISWA model (Holthuijsen et al., 1989) the directional distribution of the action density is taken into account whereas the frequency spectrum is represented by a frequency, best represented by the spectral parameter *fm-1,0*.The wave action balance is then given by:



In which the wave action *A* is calculated as:



In *θ* represents the angle of incidence with respect to the x-axis, *Sw* represents the wave energy density in each directional bin and *σ* the intrinsic wave frequency. The wave action propagation speeds in x- and y-direction are given by:



With *uL* and *vL* the cross-shore and alongshore depth-averaged Lagrangian velocities respectively (defined below), and the group velocity cg obtained from linear theory. If wave-current interaction is turned off (*wci=0*) then the last term in either equation is not taken into account. The propagation speed in θ-space is obtained from:



In *h* represents the total water depth and in this formulation bottom refraction (first term) and wave-current interaction (last two terms) are taken into account. If wave-current interaction is turned off (*wci=0*) then the last two terms are neglected.

The wave number *k* is obtained from the eikonal equations that is described in . In this formulation the subscripts refer to the direction of the wave vector components and *ω* represents the absolute radial frequency.



The wave number is then obtained from .



The absolute radial frequency *ω* is given by . The intrinsic frequency *σ* is obtained from the linear dispersion relation. If wave-current interaction is turned off (*wci=0*) then the last two terms are not taken into account.



### Dissipation

#### Breaking

Kees - bezig

There are in four different wave breaking formulations implemented in XBeach. The formulations are coded with the keyword *break*.

1. Non-stationary waves: formulation of Roelvink (1993a)
2. Stationary waves: formulation of Baldock et al. (1998)
3. Non-stationary waves: adaptation of break=1
4. Non-stationary waves: adaptation of break=1 (Daly et al. ,2010)

For the non-stationary (surf beat) approach the total wave energy dissipation, i.e. directionally integrated, due to wave breaking is modelled according to Roelvink (1993a). This is coded as *break=1*. In *α* is applied as wave dissipation coefficient, *Qb* is the fraction breaking waves, *p* stands for the water density and *γ* is the breaker index. The total wave energy *Ew* is calculated by integrating over the wave direction per directional bin.



In a variation of , one could also use the third wave breaking formulation, presented in . This formulation is somewhat different than the formulation of Roelvink (1993a). This is coded as *break=3.*



On top of that, Daly et al. (2010) developed a formulation presented in , which states that waves are fully breaking if the wave height exceeds a threshold (*γ*) and stop breaking if the wave height fall below another threshold (*γ2*). This is coded as *break=4*.



In the stationary case Baldock et al. (1998) is applied, which is presented in . In this breaking formulation the fraction breaking waves *Qb* and breaking wave height *Hb* is calculated differently compared to the breaking formulations used for the non-stationary situation. In *α* is applied as wave dissipation coefficient, *frep* represents a representative intrinsic frequency and *y* is a calibration factor. The stationary wave breaking formulation is coded with *break=4*.



In either the non-stationary or stationary case the total wave dissipation is distributed proportionally over the wave directions with the formulation in .



#### Bottom friction

Kees

#### Vegetation

Arnold

### Roller energy balance

Dano

## Shallow water equations

Kees

## Nonhydrostatic pressure correction

Robert

## Groundwater flow

Kees/Robert

## Bedload transport

Kees + Lodewijk

## Suspended load transport

Kees + Lodewijk

## Bottom updating

### Due to sediment fluxes

Kees

### Avalanching

Kees + Pieter

### Bed composition

Bas

# Numerical implementation

Dano behalve 3.4,3.8

## Grid types

### 1D

### Rectilinear

### Curvilinear

## Grid setup

The new implementation utilises a curvilinear, staggered grid where depths, water levels, wave action and sediment concentrations are given in the cell centres (denoted by subscript z) and velocities and sediment fluxes at the cell interfaces (denoted by subscript u or v). In Figure 1 the z, u, v and c (corner) points with the same numbering are shown. The grid directions are named s and n; grid distances are denoted by and , with subscripts referring to the point where they are defined. A finite-volume approach is utilized where mass, momentum and wave action are strictly conserved. In the middle panel of Figure 1, the control volume for the mass balance is shown with the corresponding grid distances around the *u-* and *v-*points. The right panel explains the numbering of the fluxes *Q* and the volume *V*.



Figure Location of staggered grid points (left panel); definition of grid distances (middle) and terms in volume balance (right)

## Shallow water equations

### Mass balance equation

The mass balance reads as follows:



This is discretized according to:



Here, *Az* is the area of the cell around the cell centre, *zs* is the surface elevation, *uu* is the u-velocity in the u-point, *hu* the water depth in the u-point and *vv* the v-velocity in the v-point. The indices *i,j* refer to the grid number in u resp. v direction; the index *n* refers to the time step.

### Momentum balance equation

Second, we will outline the derivation of the u-momentum balance. The control volume is given in . It is centered around the u-point. We now consider the rate of change of the momentum in the local u-direction as follows:



where V is the cell volume, u the velocity in local grid direction, Q the fluxes, the density, g acceleration of gravity,  the bed shear stress, wind shear stress and wave force in u-direction. We consider that the outgoing fluxes carry the velocity inside the cell, *u* and that *uin* is determined at each inflow boundary by interpolation, reconstructing the component in the same direction as *u*.

The volume balance for the same volume reads:



By multiplying the volume balance by *u*, subtracting it from the momentum balance and dividing the result by *V*  we arrive at the following equation:



where *A*  is the cell area and *hum* is the average depth of the cell around the *u*-point. The procedure for the second term (the others are straightforward) now boils down to integrating (only) the incoming fluxes over the interfaces and multiplying them with the difference between *u* in the cell and the component of velocity in the same direction at the upwind cell.



**Figure 2 Control volume u-momentum balance and definition of fluxes**

In equations and and the procedure for computing the u-momentum balance is outlined. The discharges in the u-points are computed by multiplying the velocity in the u- or v-point by the water depth at that point. These discharges are then interpolated to the borders of the control volume around the u-point. The difference in grid orientation between the incoming cell and the u-point is computed and used to compute the component of the incoming velocity in the local u-direction, from the left and right side of the control volume.



The same is done for the top and bottom of the control volume, based on the discharges in v-direction:



Finally, the advective term in the momentum balance is given in equation .



### Time integration scheme

The time integration of the mass and momentum balance equations is combined in an explicit leap-frog scheme, as depicted in . The velocities (in the '-' points) are updated using the momentum balance, the water levels are updated using the mass balance. The water level gradients influence the momentum balance and the velocities and derived discharges affect the mass balance. Because of the leap-frog scheme these influences are always computed at the half time step level, which makes the scheme second order accurate.



**Figure 3 Leap-frog time integration scheme**

Using this straightforward finite volume approach, complicated transformations of the equations are avoided and the solution scheme remains transparent. It is also completely compatible with the original rectilinear implementation and is even slightly more efficient.

## Nonhydrostatic pressure correction

Robert

## Wave action balance

### Nonstationary solver

The time-varying wave action balance solved in XBeach is as follows:



Where *E* is the wave energy or wave action, Cg is the group velocity, the refraction speed in theta-space and *Sink* refers to effects of wave breaking and bottom friction.

Again, the advection terms are the only ones affected by the curvilinear scheme so we will discuss their treatment in detail. The control volume is the same as for the mass balance. In equation the procedure to compute the wave energy fluxes across the cell boundaries is outlined. All variables should also have an index *itheta* referring to the directional grid, but for brevity these are omitted here.

The component of the group velocity normal to the cell boundary, at the cell boundary, is interpolated from the two adjacent cell center points. Depending on the direction of this component, the wave energy at the cell boundary is computed using linear extrapolation based on the two upwind points, taking into account their grid distances. This second order upwind discretization preserves the propagation of wave groups with little numerical diffusion.



The other three fluxes are computed in a similar way; for brevity we will not present all formulations.

The time integration is explicit and the same as in the original implementation. The advection in u- and v-direction is computed simply by adding the four fluxes and dividing by the cell area. This procedure guarantees conservation of wave energy.



The procedure for the roller energy balance is identical to that for the wave energy balance and will not be repeated here.

### Stationary solver

In the stationary solver the wave energy and roller energy balances are solved line by line, from the seaward boundary landward. For each line the automatic timestep is computed and the quasi-time-dependent balance according to equation is solved until convergence or the maximum number of iterations is reached, after which the solver moves to the next line.

The iteration is controlled by the parameters *maxiter*  and *maxerror.*

## Advection-diffusion equation for sediment

The advection-diffusion equation for suspended sediment is the basis for the sediment transport computations in XBeach. The partial differential equation to solve is:



Here *c* is the depth-averaged concentration, *ceq* the equilibrium concentration, *Ts* a typical timescale proportional to water depth divided by fall velocity. As is often done to increase robustness, we treat the erosion term explicitly but take an implicit scheme for the sedimentation term:



This can be rewritten as:



The sediment transport gradient is discretized in a similar way as the mass balance:



The sediment transports in the u- points contain an advective term, a diffusive term and a bed slope term:



Here *urep,s* is a representative velocity for suspended transport, which contains contributions due to return flow, wave skewness and wave asymmetry; *Dc* is a horizontal diffusion coefficient and *fslope* a coefficient. In discretized form the expression for the suspended transport in the u-point is:



The concentrations in the u-points are computed with a -method, where  means a fully upwind approximation, and  a central scheme. In practice, we mostly use the upwind approximation for its robustness.



The erosion and deposition terms, which may also be used in the bed updating, are finally computed from:



The evaluation of the bedload transport takes place in the same way as in the previous versions of XBeach, except for the fact that the directions are taken in local grid direction, and will not be repeated here.

## Bottom updating schemes

Two alternative formulations are available for the bed updating: one where the bottom changes are computed based on the gradients of suspended and bed load transport, equation , and one where the changes due to suspended transport are accounted for through the erosion and deposition terms, equation .





In both cases *MF*  is the morphological factor used to accelerate morphological changes. In the first case, the sediment in the bottom is conserved in all cases, but changes in the amount of sediment in the water are not considered; one can also say that the sediment in suspension is added to the bottom sediment. In the second case, the storage of sediment in the water is accounted for, but will be distorted in cases of high *MF*. Since under most circumstances the real effect of the storage in the water phase is small we prefer the first formulation which guarantees mass conservation in the bottom.

## Avalanching

## Bed composition

Bas

# Boundary conditions

## Waves

### Time series

Kees, Ap review

### Spectra

Kees, Ap review

### Lateral boundary conditions

Dano

## Shallow water equations

### Absorbing-generating

Ap met appendix

### River and point discharge

Bas

### Ship motion

Dano

### Lateral boundaries

Kees

### Tide and surge

Kees

## Sediment transport

Dano

# Input description

Bas - params en attribute files

## General

## Grid and bathymetry

## Wave input

## Tide and surge input

## Water level (dam break)

## Wind input

## Sediment input

## Output selection

## Time parameters

## Model coefficients

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# Tutorial

Nog niet verdeeld. Later nog in te vullen.

## 1-D profile model

Delfland Deltagoot

## 2-D area model

Ocean bay park: getij+surge, baai, duin, nonerodible, overwash, collision,

## Langsgetij + riveroutflow

getijmodel + rivier + stationair.