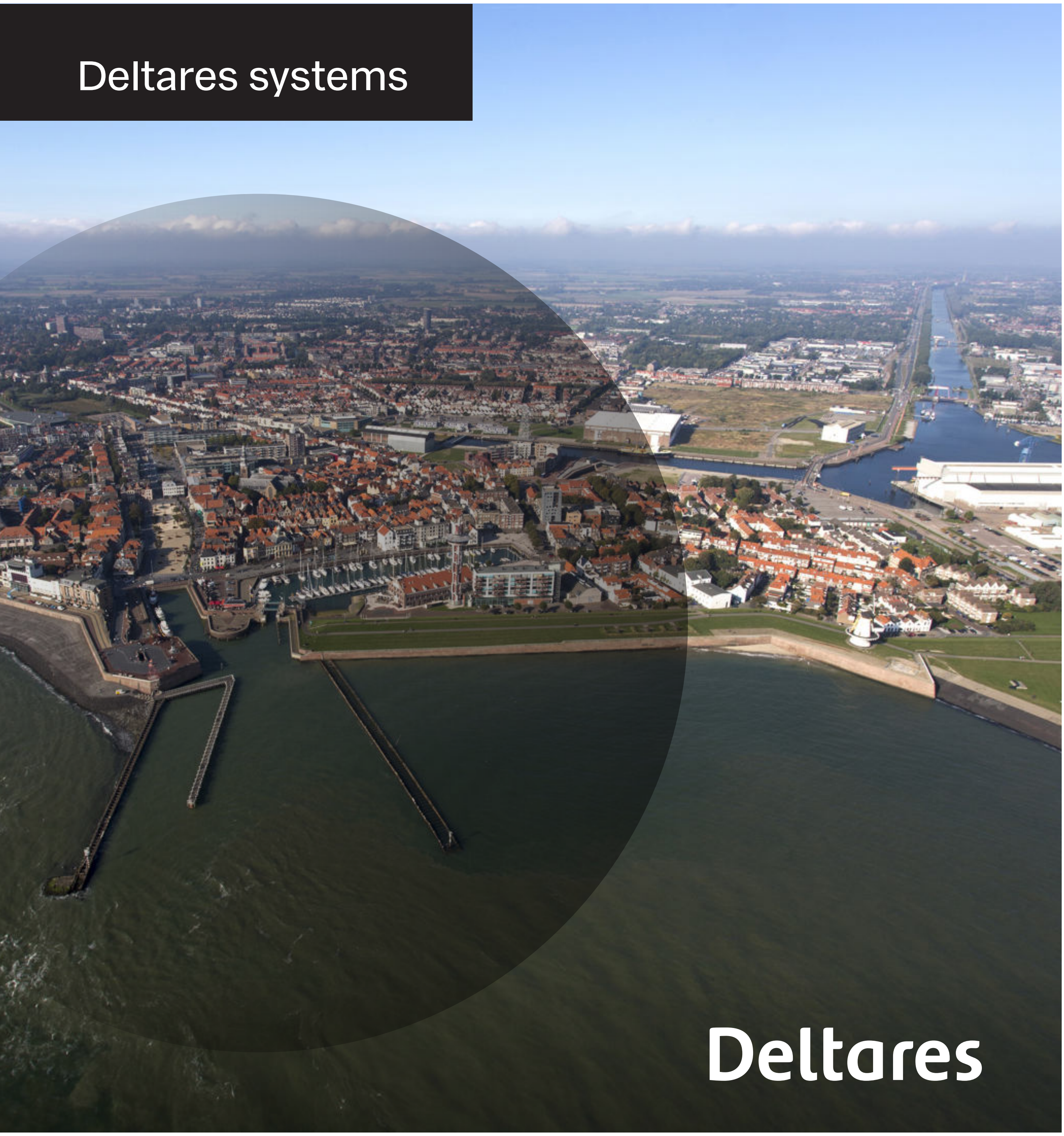
# PHAROS

Wave agitation and resonance in harbours



Deltares systems

Deltares

Wave agitation and resonance in harbours

# PHAROS

## Deltares systems

Globalisation is driving a vast increase in international trade. Consequently, the industrial and commercial centres of the world become more interconnected with each other. This puts an enormous pressure on harbours, which play an essential role in the transport of goods. Harbours therefore need to increase their throughput capacity to cope with the demand. Besides these developments, local harbours also expand to provide space for an increasing fleet of leisure ships.

A harbour design needs to comply with safety and operational requirements. The design of the harbour needs to be such that hydraulic conditions are reduced and downtime of the quays is minimised. As construction works are expensive, it pays off to investigate the effectiveness (in reducing hydraulic loads) of the harbour design before construction.

Within Deltares the Pharos wave model is used to compute wave agitation and resonance in harbours. The model has been applied in a wide variety of research and engineering projects all over the world. Construction measures, like extensions of breakwaters or adjustments to quays, that may reduce wave agitation or harbour resonance can be evaluated with the model in order to optimise the layout of a harbour.

### General

One of the most important aspects of harbour designs is the extent to which both long and short waves penetrate to the berthing facilities. Moored ships may respond to these waves leading to downtime in loading and unloading operations or even to damage to mooring lines or fenders. Resonant harbour response to long waves can be particularly onerous, since moored large ships may have a coinciding resonant response.

The numerical wave model **PHAROS** (**P**rogram for **HAR**bour **OS**cillations) accurately predicts the short wave penetration around coastal structures such as breakwaters and the resonant behaviour of enclosed areas to incident long waves. It therefore provides harbour developers with valuable information in the design phase of a harbour, or when optimization of an existing harbour is required.

Some typical study areas in which PHAROS is employed are:

- Assessment of the quality of a berthing location, in terms of safety or comfort,
- Comparison of mitigating measures such as different breakwater layouts or alternative quay wall designs,
- Determination whether and for which wave conditions a harbour basin will show resonant behaviour (seiching).


Westsluis, Terneuzen. Photo: beeldbank.zeeland.nl

## Theoretical background

PHAROS calculates the solution of the elliptic mild-slope equation formulated by Berkhoff (1972). This equation governs linear wave propagation over a mildly sloping bathymetry, with no restrictions to the water depth. It includes the physical processes of diffraction, shoaling and refraction due to depth variations and ambient currents, which leads to the following equation:

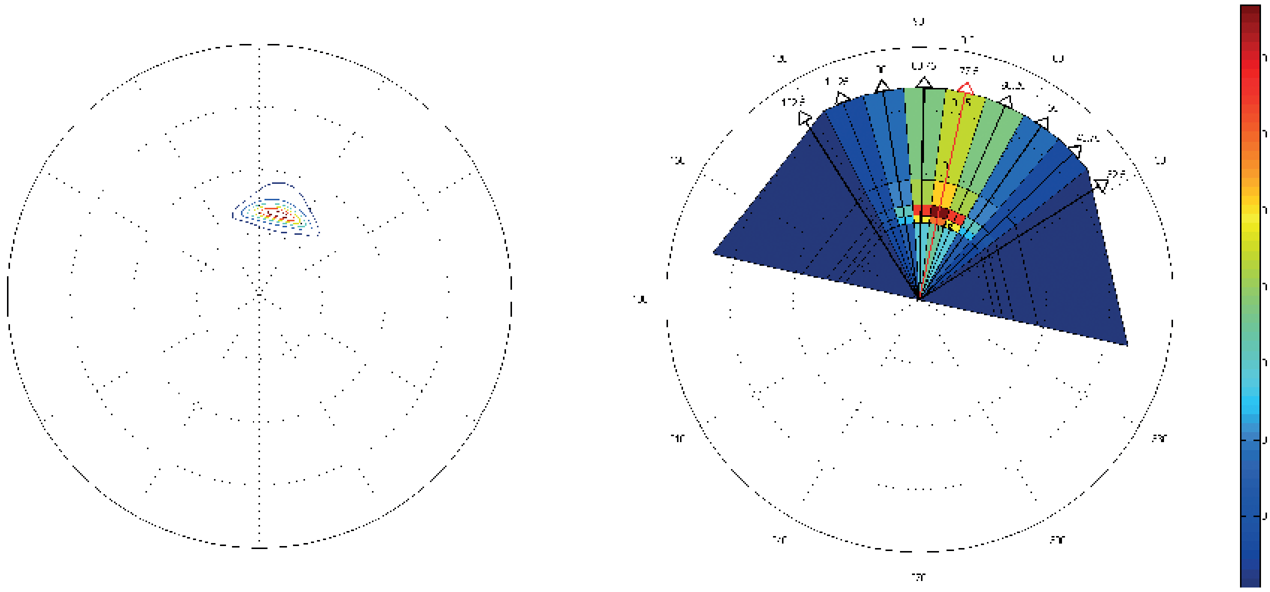
$$\nabla \cdot \left( c c_g \nabla \phi \right) + 2 i \omega \vec{U} \cdot \nabla \phi +$$
$$+ \left( k^2 c c_g + \omega^2 - \omega_r^2 + i \omega \nabla \cdot \vec{U} \right) \phi = -i \omega_r W \phi$$

Here, W is the source term for dissipation due to bottom friction or breaking. The dissipation by wave breaking is calculated using the formulation of Battjes and Janssen (1978), while dissipation by bottom shear stress is modelled based on the formulation by Putnam and Johnson (1949). The model computes wave propagation for a given wave period.

Dutch harbor Delfzijl. Photo: Adobestock.nl

# Wave agitation and resonance in harbours

# PHAROS



Visualization of the 2D energy spectrum (top) and the corresponding weights for each individual PHAROS computation.

### Directional and frequency spreading

The effect of directional spreading (short-crested waves) and frequency energy spreading (a spectrum) can be accounted for by combining the output of multiple computations. PHAROS includes routines that perform this operation, given a user-defined directional spreading function and/or a frequency spectrum. In the combined solution, the non-linear effects of wave breaking and bottom friction are also taken into account.

Special procedures are also available to carry out computations for a large number of long wave periods to study long-wave resonance and seiching of harbours (a 'seiching' computation).

### Boundary conditions

The boundary condition for the incoming wave signal is implemented in such a way that waves can pass and move out of the model domain without the use of sponge layers. Moreover, the shape of the incoming model boundary does not have to be circular, thus reducing the outer model area and therefore computational time. Also, boundary conditions are available for (partially) reflective and transmissive model boundaries.

### Model grid

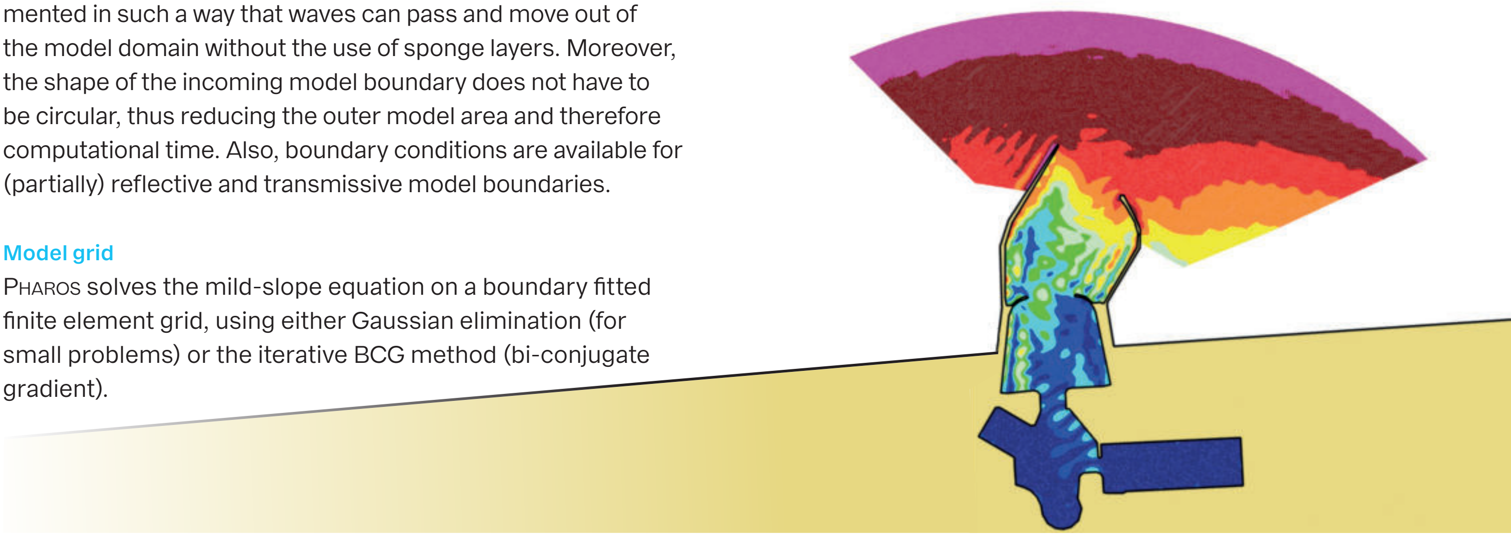
PHAROS solves the mild-slope equation on a boundary fitted finite element grid, using either Gaussian elimination (for small problems) or the iterative BCG method (bi-conjugate gradient).

## Applications

PHAROS can be applied for every harbour layout imaginable, from simple to very complex. It combines high quality computations with relatively low computational costs, enabling harbour developers to assess the quality of various harbour layouts. The two main areas of application are short wave agitation and long wave resonance (seiching).

### Short wave agitation

PHAROS is mostly used to assess wave agitation in harbours. Once the basic grid has been prepared, changes in the geometry (for example the extension of a breakwater), bathymetry or reflection properties are easily implemented. By repeating simulations for the modified layout, the effects



Wave penetration into the harbour of Scheveningen (Netherlands)

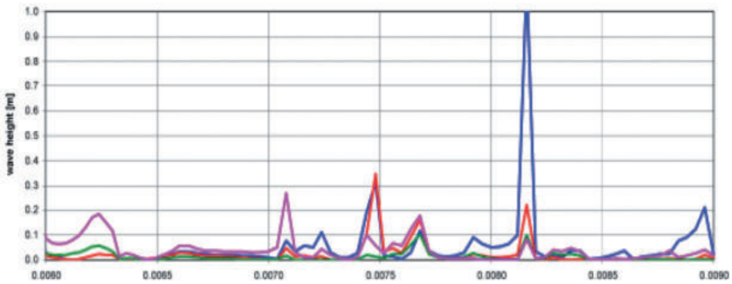
Deltares

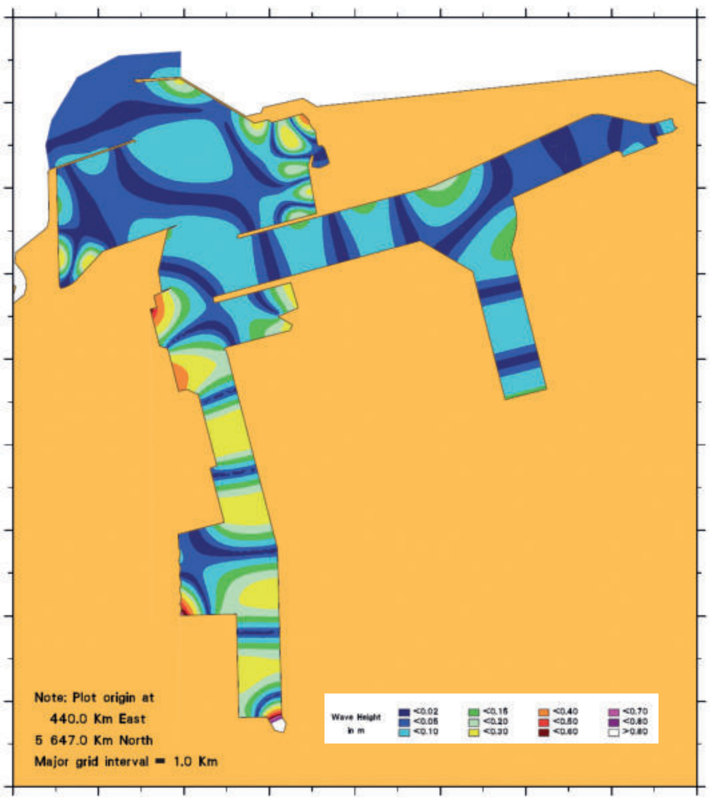
of these changes on the wave heights in the harbour can be evaluated rapidly. In this way, the design of the harbour can be optimised, for example by estimating the consequences for the downtime at the berths.

### Long wave resonance

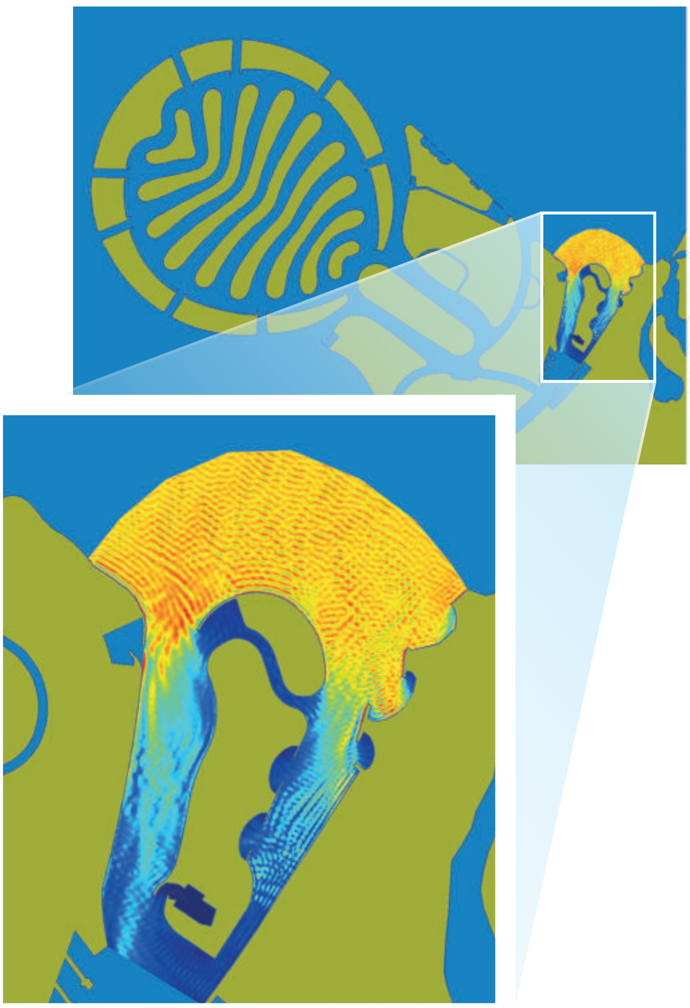
Another important application of PHAROS is harbour resonance (seiching) studies. In several harbours around the world, long waves are known to be a cause for problems either in the form of excessive motions of moored ships in apparently calm wave conditions.

This occasionally leads to breaking of mooring lines, or strong oscillating flows in the harbour entrance. Long wave energy outside the harbour due to e.g. wave grouping, can be amplified for certain frequencies by the geometry of the harbour basin.




Example of harbour resonance simulation for the Port of Dunkerque: amplification at selected points as a function of the frequency (insert) and wave height pattern for the highest peak.



Wave height pattern resulting from a PHAROS directional spreading computation. Palm Deira, U.A.E

The seiching module of PHAROS allows to determine possible resonance of long waves in the harbour for a range of frequencies. This enables the user to determine the relevant wave periods for resonance and seiching. By evaluating the amplification of the wave height or the water velocity at critical positions in the port, possible risks for moored ships can be determined and possible mitigating measures evaluated.

# Wave agitation and resonance in harbours

# PHAROS

## Model organisation

Setting up a PHAROS model is straightforward and the process is well explained and documented in the extensive User's Manual. The following modules are used in the process of setting up a model, running it and visualizing the results:

- user interface,
- graphical grid editor,
- computational modules for long or short crested waves (with or without frequency spreading) as well as a module for seiching,
- Visualization package Delft3D-QUICKPLOT,
- Post-processing tool for wave directions.

The PHAROS user interface is the starting point for all steps in the modelling process. It opens windows to prepare input, start the other modules and provides support for case management. The graphical grid generator automatically generates the finite element grid, using the contour of the area to be modelled and the depth values in that area. The dimensions of the cells will vary in size according to the local wave length to obtain an optimal resolution of the grid. Various options are available to check the quality and consistency of the grid.

PHAROS has four modules to carry out the actual computations:

- one for a single, long crested run
- one for simulations including directional spreading
- one for simulations including directional and frequency spreading
- one for harbour resonance computations.

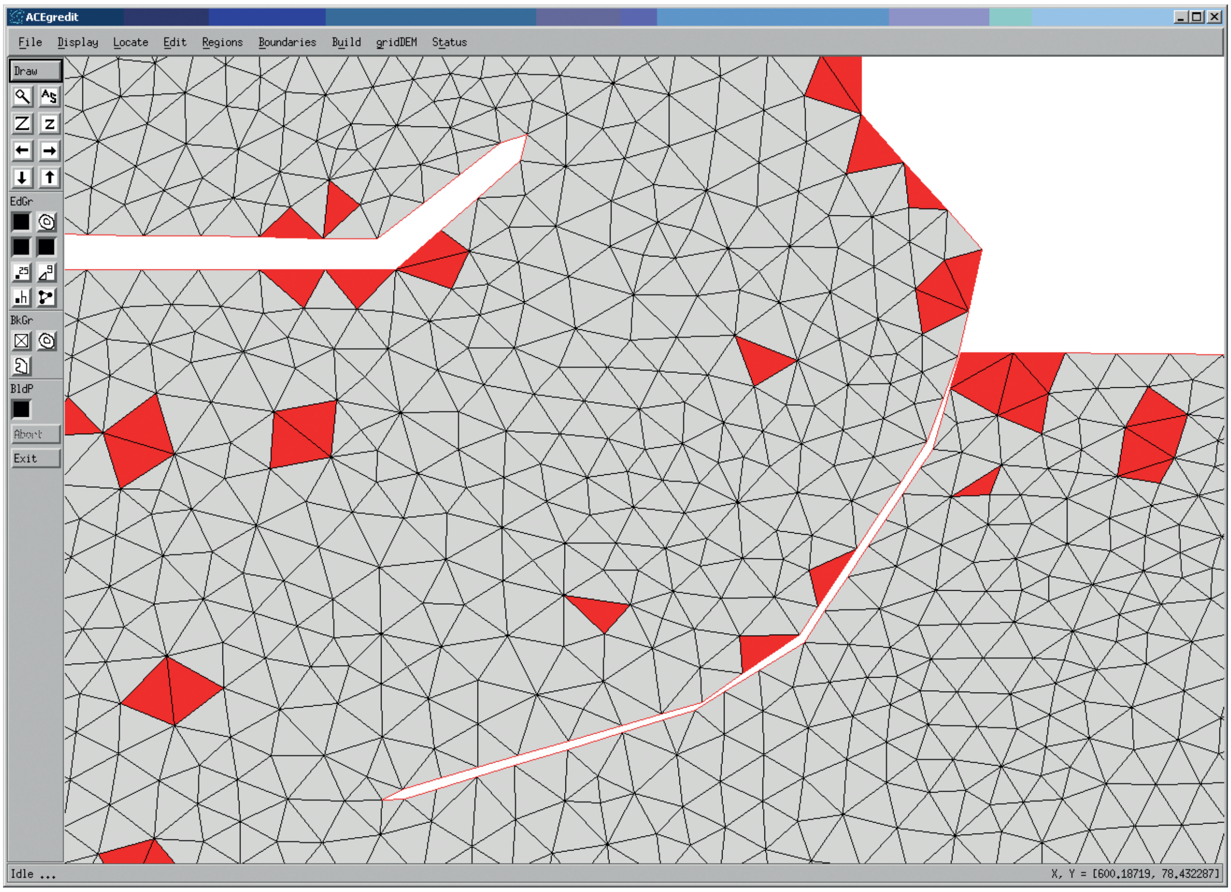
Visualisation tools are available for the presentation and analysis of the computation results.

For this, the program DELFT3D-QUICKPLOT is coupled to PHAROS.

The PHAROS model software also contains a tool to derive wave directions from the wave output fields of PHAROS computations. It can, for example, be used to identify incident and reflected wave components, see De Jong and Borsboom (2012).

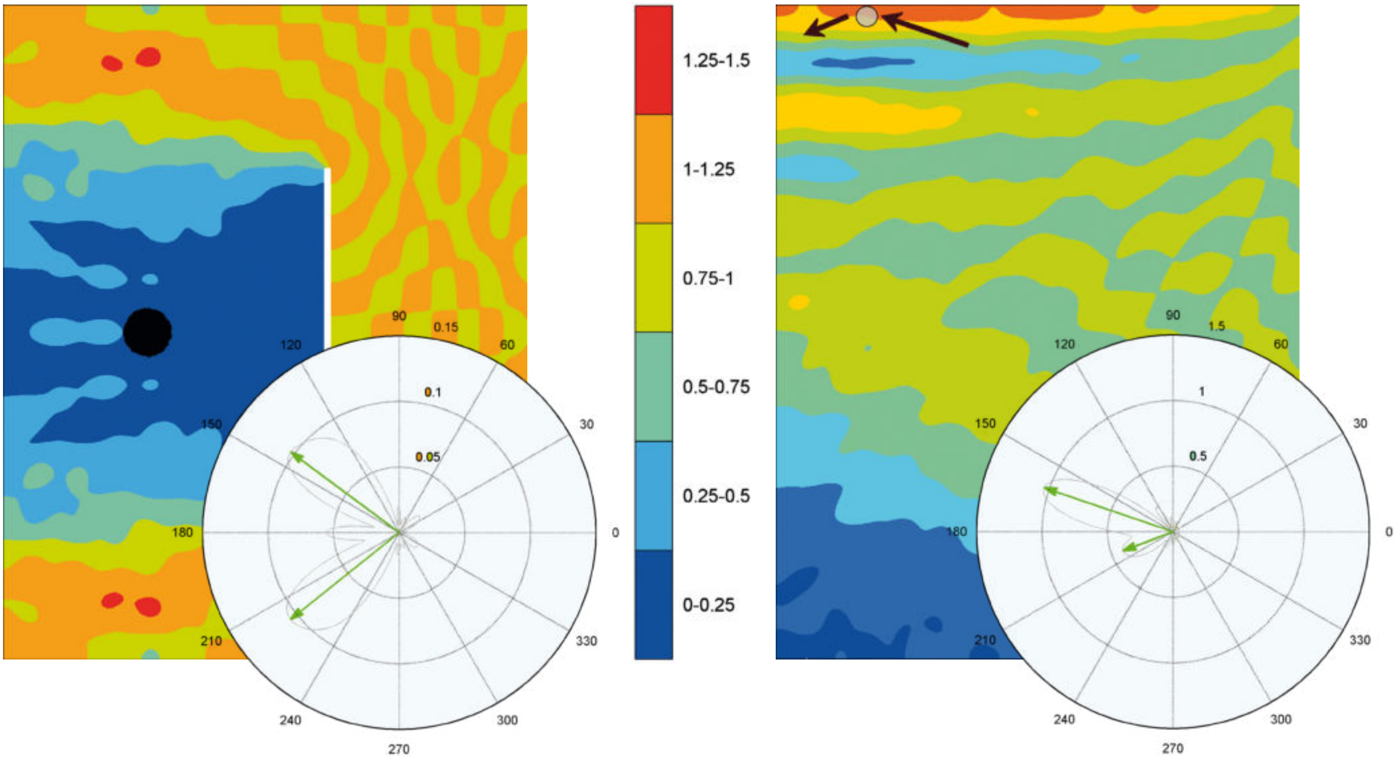
## Manual

PHAROS comes with a digital User & Technical manual, which contains all necessary information to use the program and understand the underlying model. This manual is available in pdf-format.




Detail of a PHAROS computational grid. In red the computational elements that are too large for the local wave length.

Deltares




Applications of the PHAROS wave direction post-processing tool. (Left: Sheltering behind a breakwater; Right: Partial reflection)

## System requirements

See below the system requirements for using PHAROS:

| | Minimal |
|---|---|
| **Operating System** | Windows 10 (20H2) |
| **Processor** | i5-5300u CPU 2.3GHz or higher |
| **RAM** | 16 GB or higher |
| **Harddisk** | 250 GB HDD (for saving model output) |

## License

For this software package, node locked and floating licences can be issued. For more information on how to purchase this package please contact: software@deltares.nl or visit our website: www.deltares.nl/software

## Support

Deltares systems tools are supported by Deltares. A group of 70 people in software development ensures continuous research and development. Support is provided by the developers and if necessary by the appropriate Deltares experts. These experts can provide consultancy backup as well.

## References

*Battjes, J.A., and J.P.F.M. Janssen, 1978. Energy loss and set-up due to breaking random waves. Proc. 16th Int. Conf. Coastal Engineering, pp. 569-587.*

*Berkhoff, J.C.W., 1972. Computation of combined refraction-diffraction. Proc. 13st Int. Conf. on Coastal Engineering, Vancouver. ASCE, New York, pp. 471-490.*

*De Jong, M.P.C. and M.J.A. Borsboom (2012), A practical method to obtain design wave parameters from wave model output, 8th International Conference on Coastal and Port Engineering in developing countries, PIANC-COPEDEC 2012, IIT Madras, Chennai, INDIA. 20-24 Feb. 2012.*

*Hurdle, D.P., J.K. Kostense and P. van den Bosch, 1989. Mild-slope model for the wave behaviour in and around harbours and coastal structures in areas of variable depth and flow conditions. In: Advanced in water modeling and measurement.*

*Kostense, J.K., K.L. Meijer, M.W. Dingemans, A.E. Mynett and P. van den Bosch, 1986. Wave energy dissipation in arbitrarily shaped harbours of variable depth. Proc. 20st Int. Conf. on Coastal Engineering, Taipei. ASCE, New York, pp. 2002-2016.*

*Kostense, J.K., M.W. Dingemans and P. van den Bosch, 1988. Wave-current interactions in harbours. Proc. 21st Int. Conf. on Coastal Engineering, Malaga. ASCE, New York.*

*Putnam, J.A. and J.W. Johnson, 1949. The dissipation of wave energy by bottom friction. Trans. Am. Geophysics Union, 30, 1, pp. 67-74.*

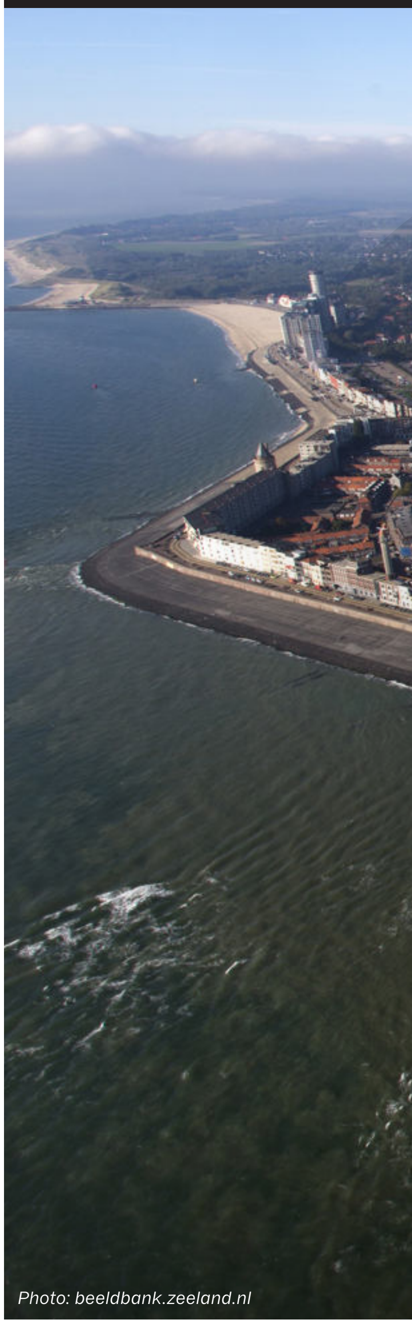


Photo: beeldbank.zeeland.nl

enabling delta life


Deltares systems

PO Box 177
2600 MH Delft
Boussinesqweg 1
2629 HV, The Netherlands

31(0)88 335 8188
software@deltares.nl
www.deltares.nl/software