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Validation of wave propagation on curvilinear grids in SWAN

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Validation of wave propagation on curvilinear grids in SWAN

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TITLE: Validation of wave propagation on curvilinear grids in SWAN

ABSTRACT:

The numerical coastal wave model SWAN can perform computations on a regular rectangular grid or on a curvilinear grid. The performance of the SWAN model using the regular rectangular grid has extensively been tested (with success). This grid is therefore, at present, widely used by many SWAN-users and is relatively free of model errors. The performance of SWAN using a curvilinear grid is at present only tested in a very limited number of test cases. In some of these test cases some unexpected model behaviour has been observed. As a result, curvilinear grids are presently not frequently used. So, some validation of the procedure for wave propagation on curvilinear grids in SWAN is to be called for.

The aim of the present study is to validate wave propagation on curvilinear grids in SWAN. To this end a number of computations have been carried out in highly idealised situations and in more complex field cases using both regular rectangular grids and curvilinear grids. The SWAN model results of this validation study are presented in this report.

On the basis of the results presented in this study it is concluded that the implemented procedure seems to work well. However, in the more complex field case of the Western Schelde significant differences in significant wave height (up to 0.3 m or even more) were found between the model results (considering wave propagation only; source terms de-activated) using a regular rectangular grid and a curvilinear grid. The observed differences are (presumably) attributed to the numerical first-order scheme in SWAN, which is rather diffusive for waves propagating (nearly) parallel to the coast, and to the way in which the coast line is modelled using a curvilinear grid (boundary fitted co-ordinates) or a regular rectangular grid.


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KEYWORDS

SWAN wave model, curvilinear grids, wave propagation.

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PROJECT IDENTIFICATION: H3306.20
List of symbols

Roman letters

\[ \begin{align*}
\text{d} & \quad \text{water depth} \\
\text{f} & \quad \text{frequency} \\
\text{f}_{\text{low}} & \quad \text{lowest discrete frequency in SWAN} \\
\text{f}_{\text{high}} & \quad \text{highest discrete frequency in SWAN} \\
\text{F} & \quad \text{wave force} \\
\text{H}_s & \quad \text{significant wave height (defined as } H_s = 4 \sqrt{m_0}) \\
\text{H}_{s,\text{el}} & \quad \text{significant wave height as computed on a curvilinear grid} \\
\text{H}_{s,\text{rr}} & \quad \text{significant wave height as computed on a regular rectangular grid} \\
\text{m0, m1} & \quad \text{zero-order moment and first order moment of the energy density spectrum} \\
\text{S}_{xx} & \quad \text{wave stress} \\
\text{T}_{m01} & \quad \text{mean wave period} \\
\text{T}_{m-2-1} & \quad \text{wave period} \\
\text{T}_{m-2-1,\text{el}} & \quad \text{wave period as computed on a curvilinear grid} \\
\text{T}_{m-2-1,\text{rr}} & \quad \text{wave period as computed on a regular rectangular grid} \\
\text{T}_p & \quad \text{peak period} \\
\text{u} & \quad \text{current velocity} \\
\text{U}_{10} & \quad \text{wind speed at 10 m height} \\
\text{x, y} & \quad \text{x-, y-coordinate}
\end{align*} \]

Greek symbols

\[ \begin{align*}
\sigma_0 & \quad \text{standard deviation in directional-space} \\
\sigma_\omega & \quad \text{standard deviation in frequency-space} \\
\gamma & \quad \text{peak enhancement factor} \\
\theta & \quad \text{mean wave direction (cartesian convention)} \\
\theta_{\text{wind}} & \quad \text{mean wind direction (cartesian convention)} \\
\theta_{\text{i}} & \quad \text{incident mean wave direction (cartesian convention) at up-wave boundary} \\
\Delta x, \Delta y & \quad \text{increment in x- and y-direction, respectively} \\
\Delta f, \Delta \theta & \quad \text{increment in frequency- and directional-space, respectively}
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1 Introduction

1.1 General

By letter dated May 6, 1998, the National Institute for Coastal and Marine Management (hereafter to be called RIKZ) commissioned WL | DELFT HYDRAULICS (hereafter to be called WL) to carry out a validation study on the curvilinear grid of SWAN. In the proposal of WL (reference is made here to the letter of April, 22, 1998) a number of three test cases were specified in order to validate the curvilinear grid of SWAN:

1. validation of the curvilinear grid in academic situations in which wave propagation is investigated in highly idealised conditions;
2. validation of the curvilinear grid in a case in which waves refract around a barrier island;
3. validation of the curvilinear grid in a realistic complex field case: the Westerschelde estuary, the Netherlands.

The validation of wave propagation on curvilinear grids in SWAN CYCLE 2 wave model in these three cases is the subject of this study.

1.2 The wave model SWAN

SWAN, which is an acronym for Simulating WAVes Nearshore, is a spectral non-stationary third-generation wave model (see e.g. Booij et al., 1998; Ris, 1997). The SWAN model is fully spectral (in all directions and frequencies) and computes the evolution of random, short-crested waves in coastal regions with shallow water and ambient currents. The SWAN model accounts for (refractive) propagation and represents the processes of wind generation, dissipation due to whitecapping, bottom friction and depth-induced wave breaking and non-linear wave-wave interactions (both quadruplets and triads) explicitly with state-of-the-art formulations.

The SWAN model can compute the wave propagation on a regular rectangular grid or on a curvilinear grid. The regular rectangular grid is fairly well tested and is presently widely used. The curvilinear grid is also available in SWAN, but is has not extensively been tested. So, some validation of this curvilinear grid is therefore to be called for. This validation of the curvilinear grid is the subject of this study.

The wave computations in this study are carried out with the stationary mode of SWAN CYCLE 2, version 30.75, using the default options as mentioned in the user manual (Ris et al., 1997).
1.3 Outline

This report is organised as follows. The results of the validation of the curvilinear grid in the academic test cases are presented in Chapter 2. The performance of SWAN using the curvilinear grid in the test case of the barrier island is the subject of Chapter 3. The validation of the curvilinear grid in the realistic complex field case of the Westerschelde is described in Chapter 4. A discussion with conclusions and recommendations is given in Chapter 5.

The project was carried out between June 1, 1998 and October 1, 1998 at WL as under project H3306.20. The work was performed by dr R.C. Ris and ir N. Doorn. We thank dr N. Booij and dr L.H. Holtuijsen of Delft University of Technology (hereafter to be called TUD) for their help and advice during this project and for providing us with the numerical wave ray model REFRAC.
2 Academic test cases

2.1 Introduction

Using a curvilinear grid - instead of a regular rectangular grid - may have an effect on wave propagation. In order to investigate this, we firstly consider highly idealised cases in which wave propagation is dominant. To this end, the physical processes of wave generation, dissipation and non-linear wave-wave interactions are deactivated in SWAN. If the SWAN model performs well in these cases, source terms will be activated.

To test wave propagation on a curvilinear grid, several different curvilinear grids have been used. Although the curvilinear SWAN grid does not necessarily have to be orthogonal (the only requirement is that the grid is well structured), it seems wise to draw a distinction between an orthogonal quadrangular grid and an irregular quadrangular grid. Therefore use has been made of four different computational grids:

1. a regular rectangular grid;
2. an orthogonal curvilinear grid;
3. a horizontally jagged curvilinear grid;
4. a vertically jagged curvilinear grid.

The computational grids are shown in Fig. 2.1.1. The difference between the third and the fourth grid lies in the direction of the irregular gridline: in the third grid the direction of the x-gridline is irregular, whereas in the fourth grid the y-gridline is the irregular one (see Fig. 2.1.1). The positive y-axis is taken in the mean direction of the waves of normal incidence. The length of the up-wave boundary is equal to 20,000 m whereas the travel distance of the waves of normal incidence (perpendicular to the x-axis) is 2,400 m.

Computations on the four grids are made for the following situations:

1. propagation in deep water (constant depth) without source terms;
2. propagation in shallow water with bottom friction activated;
3. propagation in deep water with a slanting current;
4. propagation towards an infinitely long plane beach (shoaling and refraction) test.

In all situations waves propagating from a uniform up-wave boundary are considered. The amount of incoming energy density and the shape of the spectrum are determined by a JONSWAP-spectrum with a significant wave height of \( H_s = 1 \) m, a peak wave period of \( T_p = 7 \) s and a \( \cos^2(\theta) \) directional distribution (with a corresponding directional spread \( \sigma_\theta = 24.9^\circ \)). The directional resolution is taken equal to \( \Delta \theta = 3^\circ \). The frequency resolution is equal to \( \Delta f = 0.12f \) between 0.07 Hz and 1.0 Hz (MSC = 24).
To validate the transfer of wave action from one quadrant to another and to investigate the effect of oblique incident waves on a curvilinear grid, both waves of normal incidence ($\theta_0 = 90^\circ$; Cartesian convention) and waves with an incident wave direction of $60^\circ$ (Cartesian convention) are considered.

In the centre of the computational area a curve parallel to the y-axis (at $x = 10$ km) is defined (see Fig. 2.1.1 for the location of the curve). Along this curve output for the following physical quantities is generated: the significant wave height ($H_s$), the mean absolute wave period ($T_{\text{m} \theta}$), the mean wave direction (DIR), the transport of energy (TRANSPORT) and the wave-induced force per unit surface area (FORCE) (for definitions see SWAN manual; Ris et al., 1997).

The latter two variables are related to the geographical gradient of the energy density. On the curvilinear grid the gradient of the energy density between neighbouring grid points can not be calculated in the same way as on a regular rectangular grid. Therefore the geographic distribution of the energy density between each three neighbouring grid points is approximated with a flat triangle, (see SWAN manual for details). To test this approach, the two gradient-based output variables TRANSPORT and FORCE are considered along the curve in this study.

All computations have been carried out with a rather strict accuracy criterion in order to achieve model convergence. In the present study the following criteria have been used:

a) less than 1.e-5 (relative) or 1.e-5 m change in significant wave height from one iteration to the next, and
b) less than 1.e-5 (relative) or 1.e-5 s change in mean wave period from one iteration to the next, and
c) the conditions a) and b) are fulfilled in more than 99.5% of all wet grid points.

An example of the SWAN-input file is presented in appendix A.

2.2 Constant depth (deep water)

The first test case deals with waves propagating in deep water of constant depth ($d = 1.000$ km). Since all source terms have been disabled, and hence no wave dissipation occurs, the outgoing waves at the down-wave boundary should be the same as those at the up-wave boundary. (It is assumed that the numerical diffusion introduced by the numerical schemes is negligible considering the total travel distance of the waves.)

In Fig. 2.2.1 a contour plot of the significant wave height for all four grids is shown. In Fig. 2.2.2 a contour plot in terms of difference in significant wave height relative to the computed wave height on the regular rectangular grid (grid n° 1) is shown. In the centre of the computational area the differences between the results are negligible. At the lateral boundaries of the second and fourth grid small differences occur. These are the grids in which the irregular gridlines have the same orientation as the direction of wave propagation. It is seen that since the differences are not symmetrical (see grid 4), that the differences are due to the orientation of the gridlines at the lateral boundary.
The output along the curve is shown in Fig. 2.2.3.a and Fig. 2.2.3.b. The computed wave conditions ($H_w$, $T_{m0}$, DIR and TRANSP) in all the panels of Fig. 2.2.3.a correspond exactly with each other, indicating a correct wave propagation. Figure 2.2.3.b shows the computed wave force ($F_x$, $F_y$ and its absolute value $F$). Considering the constant depth and the absence of source terms the computed wave force should be equal to zero, which is not the case (see Fig. 2.2.3.b). However, the change in significant wave height corresponding to these values for the computed wave force is order of magnitude $10^{-4}$ m per grid point. Subsequently, these oscillations in the wave force should therefore be considered as numerical noise.

The computation is repeated for obliquely incident waves. In this case the incident wave direction is $\theta = 60^\circ$ (Cartesian convention). The model results are shown in Figures 2.2.4.-2.2.6.b. Here it is seen that the differences with grid 1 are relatively large for the second and fourth grid (see Fig. 2.2.5). It seems that at the lower left corner of these two computational grids an erroneous boundary condition propagate into the computational area.

The agreement between the computed wave conditions along the output curve is good (see Fig. 2.2.6.a). Note that the mean wave direction is not constant but that its value slightly increases with fetch due to the short crestedness of the waves. Due to this short crestedness, the energy of the incident waves which are propagating at an angle of about $1^\circ$ to $5^\circ$, say, cannot reach the inner area (at $x = 10.000$ m) of the computational grid and thus affect the mean wave direction in this area. It is again noted that the differences in the wave force ($F_x$, $F_y$, and $F$; see Fig. 2.2.6.b) correspond to very small changes in the significant wave height (order of magnitude $10^{-6}$ m per grid point).

### 2.3 Bottom friction (shallow water)

The tests are repeated for waves in shallow water with the bottom friction activated. The (default) JONSWAP-formulation for bottom friction is used with the friction coefficient set equal to $C_{FJON} = 0.067\text{m}^2\text{s}^{-3}$. The water depth has been chosen such that the significant wave height along the output curve reduces with a factor of about 2. This results in a water depth equal to 2.5 m.

The results of the computations with waves of normal incidence are presented in Figures 2.3.1 to 2.3.3.b. The four contour plots of the computed significant wave height show a good agreement. The differences at the lateral boundaries of the second and fourth grid seem somewhat smaller than in the case of a constant bottom depth (deep water).

The agreement of the results along the curve is even better than in the foregoing situations. Both jagged grids (grid 3 and grid 4) and the regular rectangular grid (grid 1) give similar results (see Fig. 2.3.3.a). At the up-wave side of the second grid the computed wave force shows a small deviation from the wave force computed on the other grids, as can be seen from Fig. 2.3.3.b. The change in significant wave height corresponding to these values for the computed wave force is rather small (of the order of magnitude $10^{-3}$ m per grid point).
The same holds for the test with obliquely incoming waves for which the results are shown in Figures 2.3.4 to 2.3.6.b. Note that as in the other test cases the mean wave direction increases with fetch. The main reason for this is given in section 2.2. In this particular test case, however, the mean wave direction is also affected by dissipation by bottom friction. The longer the travel distance of the waves the more the waves are affected by the bottom friction. This results in more energy dissipation at the ‘lower frequency side’ of the directional spectrum.

2.4 Refraction and shoaling

In this test case the wave refraction and shoaling are tested. To this end, all the physical processes (such as depth-induced wave breaking, bottom friction etc.) have been deactivated. The same waves as the foregoing tests are considered, propagating from a uniform up-wave boundary (at a water depth of 10 m) towards an infinitely long plane beach (parallel depth contours in x-direction). The travel distance of the waves towards the shore is 2,400 m. Note that the depth at $y = 2.400$ m has been chosen equal to 0.5 m (instead of 0 or -1 m) to avoid boundary effects and interpolation errors near the shore line (where $d = 0$ m) if different curvilinear grids are used.

The results of the computations with waves of normal incidence are presented in Figures 2.4.1 to 2.4.3.b. At the lateral boundaries of the fourth grid and at the second and third grid there is a little difference between the results, see Fig. 2.4.2. The differences occur at the boundaries which have the same orientation as the irregular gridline: on the horizontally jagged grid (grid 3) the differences occur at the down-wave boundary and on the vertically jagged grid (grid 4) the differences occur at the lateral boundaries. It seems that the $H_s$ roughly follows the pattern of the grid lines, as is evident in Fig. 2.4.1.

Figures 2.4.3.a and 2.4.3.b show that the output along the curve is almost identical for grid 1, 3 and 4, except for grid 2. It is surprising to see that the results from the non-orthogonal curvilinear grids (i.e. grid 3 and grid 4) give a better agreement with those of the regular rectangular grid (i.e. grid 1) than the orthogonal curvilinear grid (i.e. grid 2) since the grid lines of the latter grid are more even.

Note that due to shoaling effects of the (discrete) low frequency wave components, the mean frequency shifts towards the lower frequencies (thus slightly increasing the mean wave period).

The results of the computation with obliquely incoming waves are shown in Figures 2.4.4 to 2.4.6.b. For these cases the agreement with the results of the regular rectangular grid are comparable with that of the 90° incident wave direction.

In addition, it has been verified (results not presented here) that the 2 dimensional wave spectra as computed by SWAN at three locations (for these locations see SWAN input file: Appendix A) are identical for the four grids considered.
2.5 Slanting current (deep water)

To investigate the performance of SWAN (using curvilinear grids) in the presence of a current, the same waves are considered as above, travelling in a current with velocity that increases in the down-wave direction. The current velocity at the up-wave boundary is 0 m/s (the waves start to travel from quiescent water) and gradually increases with a rate of 0.0008 m/s/m in the direction of the positive y-axis. A plot of the current field is given in Fig. 2.5.3.b. The depth in this case has been taken constant and is equal to 1000 m.

The results of the computations with waves of normal incidence are presented in Figures 2.5.1 to 2.5.3.b. Except for the differences at the lateral boundaries the agreement between the contour plots is reasonably well. However, the wave direction as computed on the fourth grid slightly deviates from the other three grids and the regular rectangular grid as can be seen in Fig. 2.5.3.a. The differences between the computed wave force on the four grids are considerable (factor of about 2). However, the change in significant wave height corresponding to these values for the computed wave force is only order of magnitude $10^{-6}$ m per grid point. The observed differences should therefore again be considered as numerical noise.

For obliquely incoming waves (incident wave direction equal 60°) the influence of the lateral boundaries propagates far into the computational area, as can be seen in Fig. 2.5.4. The differences between the results as shown in Figures 2.5.5 to 2.5.6.b are approximately the same as those in the foregoing situation (i.e., incident wave direction equal 90°). It is surprising to see that the oscillations in the wave force as computed by SWAN have disappeared (see Fig. 2.5.6.b).

2.6 Model convergence

Although all computations show model convergence, the required number of iterations strongly depends on the grid type as can been seen in Table 2.1:

<table>
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<th>case</th>
<th>computation</th>
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<th>grid 2</th>
<th>grid 3</th>
<th>grid 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>2</td>
<td>5</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>constant depth; obliquely incoming waves</td>
<td>2</td>
<td>7</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>friction; perpendicular waves</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>9</td>
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<tr>
<td>4</td>
<td>friction; obliquely incoming waves</td>
<td>2</td>
<td>6</td>
<td>12</td>
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<tr>
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<td>refraction; perpendicular waves</td>
<td>5</td>
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<td>refraction; obliquely incoming waves</td>
<td>5</td>
<td>8</td>
<td>11</td>
<td>10</td>
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<td>7</td>
<td>slanting current; perpendicular waves</td>
<td>5</td>
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<tr>
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<td>slanting current; obliquely incoming waves</td>
<td>7</td>
<td>7</td>
<td>7</td>
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</tr>
</tbody>
</table>

Table 2.1 Number of iterations required to obtain model convergence.

It is striking that the required number of iterations to obtain model convergence with a curvilinear grid is about 2 to 3 times higher (except for case 7 and 8) and thus 2 to 3 times more computer time expensive. The reason for this is probably due to the four-sweep technique (personal communication with dr Booij, 1998) and the way in which wave components are propagated in a sweep. A curvilinear grid can be such organised that a
wave component (with a constant direction of propagation) falls within sweep 1 at a certain grid point (i, say) whereas at an adjacent grid point (grid point i,+1) it falls within sweep 2 (the directional sectors can significantly differ between adjacent grid points). It seems that more iterations are required to obtain model convergence for such (grid) configurations.
3  Barrier Island

3.1  Introduction

A standard test case for curvilinear grids, used at Delft University of Technology, is the test case of a barrier island. This test case is also used in the present study. The computational meshes and the model resolutions are shown in Fig. 3.1.1. Figure 3.1.2 shows the bathymetry of the area. The waves propagate from a uniform up-wave boundary (at a water depth of 10 m) towards the island. The depth contours are parallel to the contours of the island (see Fig. 3.1.2) and the travel distance of the waves from the up-wave boundary towards the shore is 7000 m. The incident significant wave height is 2 m and the peak period is 6 s. The curved segments at the boundary of the computational grid are provided with boundary conditions. The mean incident wave direction of approach is 90° (Cartesian convention). The coefficient MS is set equal to 4, which corresponds to a directional spread of the waves of 24.9°. The computations are carried out with a directional resolution of Δθ = 5°. The spectral grid in frequency space is defined by a minimum and maximum frequency of f_{low} = 0.1 Hz and f_{high} = 1 Hz respectively and a resolution Δf = 0.10* f (MSC = 24).

The results of the computations on the curvilinear grid (i.e. the top panel in the figures) are compared with results of computations on a regular rectangular grid (usually the bottom panel in the figures). The latter grid has a resolution in geographical space of Δx=Δy=500 m. The computations on a regular rectangular grid are repeated with a nested run, for which the boundary conditions are obtained from the computation on the curvilinear grid. Note that a very strict accuracy criterion has been chosen to terminate the iterations (the same accuracy criterion as in the academic test cases has been used here; see Section 2.1)

An example of the SWAN-input file is presented in appendix B.

3.2  Situation without currents

A first test is done for a situation without currents. The model results in terms of significant wave height are shown in Fig. 3.2.1. The top panel shows the results of the computation on the curvilinear grid; the bottom panel shows the results of the computation on the regular rectangular grid. In Fig. 3.2.2 the results of the computation on the curvilinear grid are shown (top panel) whereas the bottom panel shows the difference in significant wave height relative to the computed wave height on the regular rectangular grid.

At the head and just behind the head of the barrier island and at the lower right corner of the computational grid there are significant differences between both results. Generally, the computed wave heights on the curvilinear grid seem to be somewhat higher near the coast line and the up-wave boundary, whereas the opposite is true for a small area (the ‘red’ areas) behind the barrier island. The differences just near the coast (the ‘green’ areas) can
partly be explained by interpolation errors due to the different resolutions of the computational grids. The same holds for the boundaries of the curved segments. It seems that an erroneous lateral boundary condition at the lower right corner is transported into the computational area.

In order to test the nest option, a computation is made with a nested run. The boundary conditions for the grid shown in the bottom panel of Fig. 3.2.3 are obtained from the curvilinear grid. The spatial step in the nested run is equal $\Delta x = \Delta y = 250$ m. The top panel in Fig. 3.2.3 shows the results of the curvilinear grid, the bottom panel shows the results of the nested computation. The results of the nested grid (i.e., a regular rectangular grid) are compared with the results of the computation on the curvilinear grid (see Fig. 3.2.4). Note that the differences in significant wave height at the head and just behind the barrier island have (largely) disappeared due to the higher model resolutions that have been used in the nested grid. It is striking that the results of the curvilinear grid give slightly higher significant wave heights just in front of the barrier island compared to the results obtained with the nested grid.

### 3.3 Situation with currents

To determine the effect of currents, the same computations for the coarse grids have been carried out with currents activated. The current direction is parallel to the coast line (thus westwards at the up-wave side of the island and eastward at the down-wave side). A vector-plot of the current is presented in Fig. 3.3.1.

It appeared that it is not possible that the current field for the curvilinear mode of SWAN was given in terms of curvilinear co-ordinates (note that this is also true for the bottom and other grids). Therefore, the current field for the curvilinear grid is based on a regular rectangular grid. The current field has been generated using the numerical program Excel.

The results of both computations are shown in Fig. 3.3.2 (top panel; curvilinear grid, bottom panel; regular rectangular grid). The differences between the model results as computed on the curvilinear grid and the regular rectangular grid are shown in Fig. 3.3.3. It is clearly seen that nearly the same pattern is present as in the situation without currents (compare Fig. 3.3.3 with Fig. 3.2.2).

### 3.4 Comparison with wave ray model

In the test case without currents short crested waves were considered (see Section 3.2). In order to compare the mean wave direction (as computed on a curvilinear grid) with analytical solutions for wave propagation, a third test is carried out with longcrested, monochromatic waves. The results are compared with the TUD-model results of the model REFRAC. In REFRAC the starting point and the starting direction of a wave ray and the frequency of the wave should be given. The model computes the wave propagation along the ray on the basis of Snell's law.
The wave propagation along a number of 45 curves are computed with the model REFRAC. The incident wave field is specified by a significant wave height of $H_s = 2\,\text{m}$ and a peak period $T_p = 6\,\text{s}$.

In the SWAN computations the monochromatic wave is simulated with a Gaussian shaped frequency spectrum with a standard deviation $\sigma_o$ equal to $\sigma_o = 0.025\,\text{rad/s}$. The frequency resolution is equal to $\Delta f = 0.05*f$ between 0.125 Hz and 0.25 Hz. The longcrested character of the waves is approximated with a $\cos^{300}(\theta)$ directional distribution and a directional resolution of $1^\circ$ is used. All physical processes are deactivated.

In Fig. 3.4.1 the SWAN-results (wave propagation on a curvilinear grid) and REFRAC-results are shown. The vectors correspond to the SWAN-results and the solid lines to the REFRAC-results. The agreement between both wave propagation directions is fairly reasonable.
4 Westerschelde field case

4.1 Introduction

In the test cases described in the previous two chapters the curvilinear grid has been tested in a number of relatively idealised situations. To test the curvilinear grid in a more complex realistic case, the field case of the Westerschelde (the Netherlands), is used. The Westerschelde is an estuary of approximately 60 km by 10 km in the Southwest of the Netherlands with significant two-dimensional variations in bathymetry and tidal flow.

This area has been subject of earlier studies in which computations have been made on a regular rectangular grid and on a curvilinear grid covering the estuary of the Westerschelde. The differences between the results of these computations (using different grids) were significant (personal communications with experts of RIKZ, 1997). One of the possible clarifications for these differences was the location of boundaries of the grids. Since the bathymetry shows considerable variations great care is required in defining (the location of) the boundaries. In order to be able to make a correct comparison between a curvilinear grid and a regular rectangular grid, the boundary conditions for the regular rectangular grid are obtained from the SWAN computation on the curvilinear grid. By this, differences in the model results that are caused by differences in the boundary conditions, are avoided.

The bathymetry is provided by RIKZ (file: ws.z). The depth contours over the modelling area and the location of the nested grid (bottom panel) are shown in Fig. 4.1.1. Both panels show an almost identical bathymetry. This can more clearly be seen in Fig. 4.1.1.a, which shows a close up of the bathymetry at an area located at the southern coast of Walcheren. Note that the computational grid does not cover the whole Westerschelde area but only the western area. The reason for this is that the resolution of the regular rectangular grid and the curvilinear grid for this area just match the maximum available computer capacity of the Hp 9000/735 work-station. The selected area has been chosen such that both swell propagation (outer area) and the regeneration of waves by wind effects (in the inner area) are present. The curvilinear computational and bottom input grid are presented in Fig. 4.1.2 (curvilinear grid) and Fig. 4.1.3 (regular rectangular grid). The locations are defined in the Paris co-ordinate system. The origin of the output frame is (9500.0 m, 381100.0 m) and the x-axis is oriented 105° clockwise from the north direction.

In order to investigate the performance of SWAN (using different grids) in the Westerschelde the following (fourteen) test cases are considered:
Table 4.1  Processes activated in the test cases for the Westerschelde case.

The first test case deals with wave propagation in geographical space only (depth-induced shoaling), whereas in the second test case refraction has been activated. The third test case is identical to the first test case but now depth-induced wave breaking has been activated. In test case four both refraction and depth-induced wave breaking have been activated. In order to obtain complete model convergence, a rather strict criterion has been used to terminate the computations in these four test cases. The following criterion has been used:

a) less than 1.e-5 (relative) or 1.e-5 m change in significant wave height from one iteration to the next, and
b) less than 1.e-5 (relative) or 1.e-5 s change in mean wave period from one iteration to the next, and
c) the conditions a) and b) are fulfilled in more than 99.5% of all wet grid points.

The computation of test case four has been repeated with the standard accuracy criterion in order to demonstrate the performance of SWAN if this standard criterion (with a maximum number of six iterations) is used. This is test case five.

In these five test cases the incident wave direction at the up-wave boundary is equal to 315° (Cartesian convention). These five test cases have been repeated but with a different incident wave direction equal to 10° at the up-wave boundary (for description of boundary conditions see below) in order to investigate the performance of SWAN if the incident waves are propagating in a different direction. These cases correspond to test cases 6 to 10.

Test case 11 (strict accuracy criterion) and 12 (default accuracy criterion) are identical to that of test case five but now all physical processes have been activated in SWAN and a uniform wind field \( (U_{10} = 35 \text{ m/s}, \theta_{\text{wind}} = 280^\circ) \) has been applied. The latter two test cases (13 and 14) are identical to test case 11 and 12, respectively, but now a current is present.

In order to investigate the effect of each process separately, the same boundary conditions have been used for all the cases (except for the test cases 6 to 10 where the incident wave
directions has been chosen different). The boundary at sea side is provided with the following uniform wave boundary condition: a JONSWAP spectrum with a significant wave height \( H_s = 4 \text{ m} \) and a peak period \( T_p = 12 \text{ s} \). The coefficient of directional spread \( MS = 4 \), which corresponds to a directional spread of the waves of \( 24.9^\circ \). The mean incident wave direction has been taken equal to \( 315^\circ \) (Cartesian convention), except for test case 6 to 10 where the incident wave direction is equal to \( 10^\circ \). The computations are carried out with a directional resolution of \( \Delta \theta = 10^\circ \). The spectral grid in frequency space is defined by a minimum and maximum frequency of \( f_{\text{low}} = 0.03 \text{ Hz} \) and \( f_{\text{high}} = 0.8 \text{ Hz} \) respectively and a resolution \( \Delta f = 0.12^*f \) (MSC = 30).

Note that the size of the meshes in geographical space has been chosen such that the resolution of the regular rectangular grid is about the same as the resolution of the curvilinear grid in the narrow part of the Westerschelde. This resulted in a mesh size of 200 m in x-direction and 40 m in y-direction.

In order to demonstrate the performance of SWAN the same procedure as in the previous chapters has been used: the results of the computation on the curvilinear grid are compared with the results of the nested computation. The nested grid is identical to the output frame (used in the curvilinear grid: see Appendix C).

The results of all the test cases are presented in the Figures 4.2.1 - 4.4.3. The top and middle panel in the figures (except for Fig. 4.2.11.a and 4.2.11.b) represent the SWAN results as computed on a curvilinear grid and a regular rectangular grid, respectively. The bottom panel in the figures (except for Fig. 4.2.11.a and 4.2.11.b) shows the differences - in terms of significant wave height \( H_s \) or in wave period \( T_{m-2,1} \) - between the model results (using a curvilinear grid and a regular rectangular). The difference \( \Delta H_s \) and \( \Delta T_{m-2,1} \) are defined as follows:

\[
\Delta H_s = H_{s,\text{cl}} - H_{s,\text{rr}} \tag{4.1}
\]

and

\[
\Delta T_{m-2,1} = T_{m-2,1,\text{cl}} - T_{m-2,1,\text{rr}} \tag{4.2}
\]

The differences between the model results - in terms of significant wave height - have also been presented in terms of relative difference for the cases 1, 3, 4 (see Fig. 4.2.11.a) and 6, 8 and 9 (see Fig. 4.2.11.b). Here, the relative difference \( \Delta H_{s,\text{rel}} \) is defined as:

\[
\Delta H_{s,\text{rel}} = (H_{s,\text{cl}} - H_{s,\text{rr}}) / H_{s,\text{cl}} \times 100 \%
\tag{4.3}
\]

where the subscripts \( cl \) and \( rr \) refers to the curvilinear grid and the regular rectangular grid, respectively.

An example of a SWAN-input file is presented in appendix C.
4.2 Model results

4.2.1 Idealised conditions, incident wave direction 315° (case 1 - 5)

The results of the SWAN computations - in terms of significant wave height - for test case 1 (only wave propagation in geographical space) are shown in Fig. 4.2.1. Although the agreement between the model results (using a curvilinear grid and the regular rectangular grid) seems to be reasonable at first sight, the difference plot (bottom panel) shows significant differences of even more than 30 cm in significant wave height in the shallow areas. These differences correspond to a relative difference of about 20% (in the inner area) up to 40% near the coast (see top panel Fig. 4.2.11.a). These differences are rather high considering that only wave propagation is taken into account here. Since refraction is deactivated, a refractive shadow zone is found in the inner area of the Westerschelde area.

The nest-option seems to work well, although the wave conditions at the western boundary of the SWAN grids (compare top panel and middle panel of Fig. 4.2.1) are not similar for both grids. The narrow dark line seems to indicate wave conditions corresponding to a negative depth (H_s = -10.0), which is expected to be due to interpolation errors between the bottom grid and the output grid. (This has recently been confirmed by dr Booij of TUD). (It is noted here that although differences are visible at the up-wave boundary between the two grids, the actual wave boundary conditions (i.e., the two-dimensional wave spectrum at the up-wave boundary) in the nested run are correct.)

Figure 4.2.1.a shows a close up of the computed significant wave height near the southwest coast of Walcheren. Again significant differences in the significant wave height are found, especially just near the coast line. Note that these differences are present in a well-defined area. It seems that these differences in the inner area are due to differences that are present in grid points which are located just near the coast (most southern land point).

The model results in terms of significant wave height for the situation with refraction activated (i.e. test case 2) are shown in Fig. 4.2.2. It was found for this particular test case that the SWAN model became unstable, resulting in significant wave heights of order of magnitude $10^7$ m. The computations have been repeated using a more robust first-order upwind difference scheme in directional space (taking the numerical diffusion coefficient CDD equal to 1; see SWAN manual). Although this up-wind scheme had a positive influence on the model stability, it was not enough to obtain a stable model solution.

The computed patterns of the significant wave height if depth-induced wave breaking is activated (test case 3) are shown in Fig. 4.2.3 (top and middle panel). It is clearly seen that these patterns of the significant wave height are nearly identical to the patterns computed if depth-induced wave breaking is de-activated (compare with Fig. 4.2.1). The agreement between the model results seems to be slightly better than in test case 1. However, the relative differences in significant wave height are still rather large - of the order of 20% - near the coast (see middle panel of Fig. 4.2.11.a).
Activating both refraction and depth-induced wave breaking (test case 4) resulted in a wave height pattern as shown in Fig. 4.2.4. The bottom panel of Fig. 4.2.4 clearly shows that the differences in significant wave height are scattered in the inner area of the Westerschelde area (there is no clear shadow zone visible). Moreover, it is seen that the relative differences in significant wave height are larger for this case (see bottom panel of Fig. 4.2.11.a) compared to the cases 1 and 3 (see top and middle panel of Fig. 4.2.11.a).

Note that for test case 4 additional output in terms of $T_{m2-1}$ has been generated. The results are shown in Fig. 4.2.4.a. and Fig. 4.2.4.b (area near the south-west coast of Walcheren). In the outer area the agreement between the model results (using a curvilinear grid and a regular rectangular grid) is good (differences less that 0.025 s; see Fig. 4.2.4.a), however, just near the coast the differences are larger (differences of up to 0.30 s are found; see Fig. 4.2.4.b). Note that the maximum differences in $T_{m2-1}$ do not necessarily occur at the same locations as where the $\Delta H_1$ has its maximum.

Since the SWAN model is often applied in a default mode (i.e. with a maximum of 6 iterations and standard values for the absolute and relative accuracy criterion) it is also investigated to what extend the model results would have been converged if this criterion is used and what the differences are between the two grids (curvilinear and regular rectangular). This is done in test case 5 (see Table 4.1). The model results are presented in Fig. 4.2.5. From this figure it follows that the differences after six iterations are significantly larger than after 50 iterations (compare with see Fig. 4.2.4). It is clearly seen from Fig. 4.2.5 that the significant wave height as computed on the curvilinear grid is significant higher (compared to the nested (regular rectangular) grid) in the inner area of the Westerschelde.

### 4.2.2 Idealised conditions, incident wave direction 10° (case 6 - 10)

In order to investigate if the SWAN model results are sensitive to the incident wave direction at the up-wave boundary, repeated computations for test case 1 to 5 have been carried out but with an incident wave direction of 10° at the up-wave boundary. In this section the model results of these test cases 6 to 10 are presented (see Table 4.1).

The computed significant wave height pattern for test case 6 (wave propagation in geographical space only) is shown in Fig. 4.2.6. These results are comparable to the results shown in Fig. 4.2.1 (315° incident wave direction). It is again clearly seen (bottom panel of Fig. 4.2.6) that there are two clear areas (starting at a land tip) where the differences between the two grids are significant (note that these differences are even larger than those found in test case 1; see Fig. 4.2.1). At some distance from the coast the differences vary from 0. cm to 20 cm. The relative differences are up to 20% in the inner area and up to 50% just near the coast (see top panel of Fig. 4.2.11.b).

Activating refraction in the computation (i.e., test case 7) resulted again in an unstable model behaviour (see Fig. 4.2.7).

In Fig. 4.2.8. the model results are shown for the case in which breaking is activated (i.e., test case 8). The computed significant wave height pattern is in accordance with the results
presented in Fig. 4.2.3. The differences in significant wave height between the two grids are up to 20 cm at some distance from the coast and more than 30 cm near the coast (see bottom panel Fig. 4.2.8). The pattern of the computed relative differences in significant wave height is shown in the middle panel of Fig. 4.2.11.b. At some areas the relative difference are of about 20%.

The model results in terms of significant wave height with refraction and depth-induced wave breaking activated (test case 9) are presented in Fig. 4.2.9. It is seen (with a bird's-eye view) that the significant wave height as computed on the curvilinear grid is generally larger than that computed on a regular rectangular grid (see bottom panel of Fig. 4.2.9). It is noted that the relative differences for this case are of the order of about 20% in the inner area. The differences in the computed wave period $T_{m2}$ are less pronounced and vary between 0.5 s and 0.3 s in the inner area, as is evident from Fig. 4.2.9.a. Just near the coast the differences are up to 0.3 s (see Fig. 4.2.9.b).

Figure 4.2.10 shows the computed significant wave height pattern if the default criterion is used (test case 10). It is again striking to see that with the default criterion the significant wave height as computed on the curvilinear grid is significantly larger (generally more than 0.3 m) than the significant wave height as computed on the regular rectangular grid.

### 4.2.3 Wave propagation with wind (case 11 and 12)

In order to demonstrate the performance of SWAN in a more realistic case - using a curvilinear grid and a regular rectangular grid - wind has been activated in test case 11 and 12. A uniform wind field ($U_{10} = 35$ m/s, $\theta_{\text{wind}} = 280^\circ$) has been applied. The computations have been carried out in a third-generation mode (i.e., all physical processes in SWAN have been activated by default). In test case 11 and 12 the strict criterion and the default criterion have been used, respectively to terminate the computations. The wave conditions at the up-wave boundary (i.e., the up-wave boundary conditions) are similar to the boundary conditions as used in the test cases 1 to 5.

The model results for case 11 are shown in Fig. 4.3.1 (using a strict criterion). The influence of the wind is clearly visible. Again differences of more than 30 cm in significant wave height are found. In general the computed wave heights on the regular rectangular grid seem to be somewhat lower than those computed on the curvilinear grid.

Figure 4.3.2 shows the results for test case 12 in which the default criterion is used to terminate the computation. The differences in significant wave height vary considerably in the inner area (no clear pattern is visible) and are up to 0.3 m (and -0.3 m) at different areas.

### 4.2.4 Wave propagation with wind and currents (case 13 and 14)

To test the effect of currents on the wave conditions in the Westerschelde computations are performed for a realistic current condition. This is done in the test cases 13 and 14. The data for the current field (i.e., file: west_uv.dat) has been provided by RIJKZ (it should be noted here that the current field has been generated by Van Vledder, 1998). The input
current field is prepared at ebb flow on a uniform mesh of 100 m. A vector plot of the current is presented in Fig. 4.4.1.

The wind field and the wave boundary conditions are identical to those described in the previous section.

The results obtained with the strict accuracy criterion (case 13) are shown in Fig. 4.4.2. The smoothing effect of the current field results in a slightly better agreement between the contour plots (compared to the previous two test cases), which can be seen in the bottom panel of Fig. 4.4.2. The (absolute value of the) differences in significant wave height rarely exceed the value of 30 cm.

The same computation has been carried out but now the iterative procedure is terminated after 6 iterations (which is the default value for SWAN). The results of these computations are shown in Fig. 4.4.3. The differences between both plots are considerable (the (absolute) differences are even more than 30 cm at certain areas) indicating that the required default number of iterations for this complex situation should be increased to obtain model convergence.

### 4.3 Computing time and model convergence

On the basis of the computations carried out in the field case of the Westerschelde it has been found that - with the selected model resolutions - the computing time required to perform one iteration was about 2-3 minutes (for both the curvilinear and the regular rectangular grid). So, the total computing time was about 2 hrs to 3 hrs, say, for the specified 50 iterations. The postprocessing procedure for the curvilinear grid, however, took about 2 hours (whereas it took about 20 min for the regular rectangular grid). This makes the total computing time required for a curvilinear grid rather large (about 4 - 5 hrs). Note that the computing time for the postprocessing becomes proportionally large compared to that of the computational part of SWAN in practical applications since the total number of iterations for such situations is usually significantly smaller than 50 (usually 15 iterations, say, are required resulting in a computing time of about 40 min). The computing time required for the postprocessing procedure remains obviously the same (2 hrs, say).

It has been found that the computing time required for the postprocessing procedure significantly increases if output is requested on a FRAME (i.e., a command of SWAN) which is partly located outside the curvilinear computational grid. The reason for this sudden increase in computing time is ascribed to the numerical procedure in SWAN. For each output-point the requested variables are obtained by bilinear interpolation of the values in the neighbouring points on the computational grid. If the output points are located outside the computational grid all computational grid points are checked on their location. This procedure is followed for each output variable.

We checked the postprocessing procedure of the WL-model TRISULA, in which curvilinear grids are used as well. In this model the user must provide the boundaries of the computational grid. On the bases of these boundaries the model checks whether a point is
inside or outside the computational grid. This procedure in TRISULA is not very computing time expensive (compared to that of SWAN). In order to avoid the time consuming postprocessing procedure in SWAN, it is should therefore be investigated if this numerical procedure of TRISULA can be adapted for SWAN.
5 Conclusions and recommendations

The experiences gained from this project in the use of curvilinear grids in SWAN are summarised in this section. In addition, some recommendations are given.

5.1 Conclusions

Academic tests

On the basis of the academic tests the following conclusions can be drawn:

- no real errors in the propagation scheme were found;
- the area affected by erroneous boundaries seems to be much larger in the case of a curvilinear grid, particularly if the grid is oriented such that the irregular gridlines have the same orientation as the direction of wave propagation;
- computations on a curvilinear grid with a current field defined on a regular rectangular grid seem to work well;
- the number of iterations required to achieve model convergence increases significantly (with a factor of about 3) when a curvilinear grid is used.

Barrier island

On the basis of the test case of the barrier island the following conclusions can be drawn:

- difficulties occurred when the input grids of variables, such as bottom level (BOTTOM), current (CURRENT), bottom friction coefficient (FRICTION) and wind velocity (WIND), are curvilinear as well. They cannot be used in the nested computations since the use of curvilinear input grids is only allowed if the computational grid is curvilinear as well;
- the number of iterations required to achieve model convergence increases (as in the academic cases) significantly when a curvilinear grid is used;
- when using a curvilinear grid, the problem co-ordinates system is defined by the $x'$- and $y'$-components along the directions of the grid lines of the curvilinear grid (see user manual). Therefore special attention should be paid to the orientation of vector variables, such as current and wind, when they are read from a curvilinear input grid;
- the agreement between the mean wave direction as computed with SWAN (on a curvilinear grid) and with the REFRAC model is reasonable.

Westerschelde field case

On the basis of the test case of the Westerschelde field case the following conclusions can be drawn:
• The differences between the model results in terms of significant wave height using a curvilinear grid and a regular rectangular grid are significant for all the test cases that have been considered. When only wave propagation is considered the observed relative differences are up to 20% in the inner area (corresponding to differences of about 0.3 m in significant wave height). It is not clear why these differences are relatively large since it was found from the idealised cases that wave propagation on a curvilinear grid is comparable to that on a regular grid (hardly any differences in the model results).

It is striking that the significant wave height for the curvilinear grid is usually higher than for the regular rectangular grid. It is speculated here that the observed differences between the two grids are due to the use of a first-order upwind scheme in SWAN, which is rather diffusive for waves propagating (nearly) parallel to the coast (personal communication with Dr N. Booij, 1998), and to the way in which the coastline is represented in the curvilinear grid (boundary fitted co-ordinates) and the regular rectangular grid. It is noted here that the effects of a first order up-wind scheme on wave propagation near a coast line has recently been described in a paper by Cavalieri and Sclavo (1998). Reference is made to this paper for more information;

• the SWAN model gives unstable model results (significant wave heights of the order of 10^7 m) if only refraction is activated;

• the nest-option seems to work well although the values of the integral wave parameters at the up-wave boundary are incorrect (if the nested grid is rotated). At these up-wave boundaries the integral wave parameters are equal to the exception values which are produced by SWAN for negative values of the depth. The two-dimensional spectrum (which is used in the computation), however, is correct so the observed error does not affect the wave computation;

• the addition of a current field seem to smooth the wave field; in this case the differences between the wave height computed on a curvilinear grid and on a regular rectangular grid decrease;

• when output is requested on a frame which is partly located outside the curvilinear computational grid the postprocessing can take several hours which is inconvenience in practical applications;

5.2 Recommendations

On the basis of the experiences gained from this project we recommend:

• to investigate the effect of the numerical first-order upwind scheme on wave propagation near a coast in a realistic field case using a curvilinear grid (with boundary fitted co-ordinates) or a regular rectangular grid;

• to use lateral wave boundary conditions to reduce the area in which the erroneous boundary conditions propagate into the computational region;

• to implement a numerical procedure in SWAN which allows for a curvilinear input grid (for the bottom, wind, current and friction) in combination with a regular rectangular computational grid;
• the implementation of a subroutine in SWAN to define whether output points are inside or outside the computational grid in order to avoid the time consuming postprocessing procedures;
• to increase the default maximum number of iterations when the computations are carried out on a curvilinear grid.
References


Cavaleri, L. and M. Sclavo, 1998: Characteristics of quadrant and octant advection schemes in wave models, Coastal Engineering, 34, 221-242

Ris, R.C., 1997: Spectral modelling of wind waves in coastal areas, Ph.D.-dissertation, Delft University of Technology, Department of Civil Engineering, The Netherlands


Vladder, G. van, 1998: Golfberekeningen Westerschelde 2, Alkyon Report A224R0r0, Emmeloord, The Netherlands
Figures
grid 1: regular rectangular grid

output curve

grid 2: orthogonal curvilinear grid

grid 3: horizontally jagged curvilinear grid

grid 4: vertically jagged curvilinear grid

<table>
<thead>
<tr>
<th>Computational grids</th>
<th>Case I</th>
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<td>scale 1: 125.000</td>
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</table>

WL|delft hydraulics

H3306 | Fig. 2.1.1.
Significant wave height (m) computed by SWAN

$H_w = 1.0 \text{ m}, \ T_p = 7.0 \text{ s}, \ Dir = 90^\circ$

Constant Depth (depth = $1 \times 10^3 \text{ m}$)

WLdelft hydraulics

<table>
<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>H3306 Fig. 2.2.1.</td>
</tr>
</tbody>
</table>
Top panel: $H_s$ (m) as computed on a regular rectangular grid

Lower panels: difference in $H_s$ (m), where $\Delta H_s$ is defined as

$$\Delta H_s = H_{s,cl} - H_{s,ir}$$

**Case I**

<table>
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**WLIdelft hydraulics**

H3306  
Fig. 2.2.2.
Wave parameters along curve as computed by SWAN

$H_s = 1.0 \text{ m}, \quad T_p = 7.0 \text{ s}, \quad \text{Dir} = 90^\circ$

Constant Depth (depth = $1 \times 10^6 \text{ m}$)
Wave parameters along curve as computed by SWAN

\[ H_s = 1.0 \, \text{m}, \, T_p = 7.0 \, \text{s}, \, \text{Dir} = 90^\circ \]

Constant Depth (depth = 1 \times 10^6 \, \text{m})
Top panel: $H_s$ (m) as computed on a regular rectangular grid
Lower panels: difference in $H_s$ (m), where $\Delta H_s$ is defined as
$\Delta H_s = H_{s,cl} - H_{s,rr}$

Case I

scale 1: 1250

WLIdelft hydraulics

H3306 Fig. 2.2.5.
Wave parameters along curve as computed by SWAN

$H_s = 1.0 \text{ m}, \quad T_p = 7.0 \text{ s}, \quad \text{Dir} = 60^\circ$

Constant Depth (depth $= 1 \times 10^6 \text{ m}$)

WL|delft hydraulics

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<td>H3306</td>
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</table>

Fig. 2.2.6.a
Wave parameters along curve computed by SWAN

$H_s = 1.0 \text{ m}, T_p = 7.0 \text{ s}, \text{ Dir} = 60^\circ$

Constant Depth (depth $= 1 \times 10^6 \text{ m}$)

WL\text{delft hydraulics}

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<td>H3306</td>
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</table>

Fig. 2.2.6.b
Significant wave height (m) computed by SWAN

$H_w = 1.0 \text{ m, } T_p = 7.0 \text{ s, } \text{Dir} = 90^\circ$

Friction (depth = 2.5 m)

**Case I**

scale 1: 1250

**WLIdelft hydraulics**

H3306  Fig. 2.3.1.
Top panel: $H_s$ (m) as computed on a regular rectangular grid
Lower panels: difference in $H_s$ (m), where $\Delta H_s$ is defined as
$\Delta H_s = H_{s,cl} - H_{s,rr}$

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<tr>
<td>H3306</td>
<td>Fig. 2.3.2.</td>
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Wave parameters along curve as computed by SWAN

\[ H_b = 1.0 \text{ m}, \ T_p = 7.0 \text{ s}, \ Dir = 90^\circ \]
Friction (depth = 2.5 m)
Wave parameters along curve as computed by SWAN

$H_b = 1.0 \text{ m, } T_p = 7.0 \text{ s, Dir } = 90^\circ$

Friction (depth = 2.5 m)

WL\_delft hydraulics

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<tr>
<td>Fig. 2.3.3.b</td>
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</table>
Significant wave height (m) computed by SWAN

$H_s = 1.0 \text{ m}, T_p = 7.0 \text{ s}, \text{ Dir} = 60^\circ$

Friction (depth = 2.5 m)

**Case I**

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**WLIdelft hydraulics**

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<th>H3306</th>
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**Fig. 2.3.4.**
Top panel: $H_a$ (m) as computed on a regular rectangular grid
Lower panels: difference in $H_a$ (m), where $\Delta H_a$ is defined as
$\Delta H_a = H_a,cl - H_a,rr$

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<td>scale 1: 1250</td>
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<td>H3306</td>
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</table>
Wave parameters along curve as computed by SWAN

\( H_s = 1.0 \text{ m}, \ T_p = 7.0 \text{ s}, \ \text{Dir} = 60^\circ \)

Friction (depth = 2.5 m)
Wave parameters along curve as computed by SWAN
H₅ = 1.0 m, Tₚ = 7.0 s, Dir = 60°
Friction (depth = 2.5 m)

WL [delft hydraulics]

Case I

H₀ = 0.0

Fig. 2.3.6.b
Significant wave height (m) computed by SWAN

$H_s = 1.0 \text{ m}, T_p = 7.0 \text{ s}, \text{Dir} = 90^\circ$

Refraction

**WLIdelft hydraulics**

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<tr>
<td>H3306</td>
<td>Fig. 2.4.1.</td>
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</table>
Top panel: $H_a$ (m) as computed on a regular rectangular grid
Lower panels: difference in $H_a$ (m), where $\Delta H_a$ is defined as

$$\Delta H_a = H_{a,dl} - H_{a,rr}$$

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WLIdelft hydraulics

H3306 Fig. 2.4.2.
Wave parameters along curve as computed by SWAN

$H_s = 1.0 \text{ m}, \ T_p = 7.0 \text{ s}, \ Dir = 90^\circ$

Refraction

WL\textit{d}elft hydraulics

<table>
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<th>Case I</th>
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H3306

Fig. 2.4.3.a
Wave parameters along curve as computed by SWAN

$H_s = 1.0 \text{ m}, \quad T_p = 7.0 \text{ s}, \quad \text{Dir} = 90^\circ$

Refraction

WL|delft hydraulics
Significant wave height (m) computed by SWAN

$H_b = 1.0 \text{ m}, T_p = 7.0 \text{ s}, \text{Dir} = 60^\circ$

Refraction

scale 1: 1250

WLdelft hydraulics
Top panel: $H_b$ (m) as computed on a regular rectangular grid
Lower panels: difference in $H_b$ (m), where $\Delta H_b$ is defined as
$\Delta H_b = H_{b,ct} - H_{b,cr}$

Case I

scale 1: 1250

WLidelt hydraulics

H3306  Fig. 2.4.5.
Wave parameters along curve as computed by SWAN
Hₚ = 1.0 m, Tₚ = 7.0 s, Dir = 60°
Refraction

WL|delft hydraulics

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H3306   Fig. 2.4.6.a
Wave parameters along curve as computed by SWAN

\[ H_s = 1.0 \text{ m}, \quad T_p = 7.0 \text{ s}, \quad \text{Dir} = 60^\circ \]

Refraction

**WL|delft hydraulics**

Case I

H3306  
Fig. 2.4.6.b
Significant wave height (m) computed by SWAN

$H_s = 1.0 \text{ m}, T_p = 7.0 \text{ s}, \text{Dir} = 90^\circ$

Slanting current (depth $= 1 \times 10^6 \text{ m}$)

**Case I**

scale 1: 1250

**WLI delft hydraulics**

H3306

Fig. 2.5.1.
Top panel: \( H_\text{a} \) (m) as computed on a regular rectangular grid

Lower panels: difference in \( H_\text{a} \) (m), where \( \Delta H_\text{a} \) is defined as

\[ \Delta H_\text{a} = H_{\text{a,cl}} - H_{\text{a,rr}} \]

<table>
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<tr>
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<td>H3306</td>
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</table>
Wave parameters along curve as computed by SWAN

$H_s = 1.0 \text{ m}, T_p = 7.0 \text{ s}, \text{Dir} = 90^\circ$

Slanting Current (depth = $1 \times 10^6 \text{ m}$)

WL|delft hydraulics
Wave parameters along curve as computed by SWAN

\( H_s = 1.0 \text{ m}, \ T_p = 7.0 \text{ s}, \ \text{Dir} = 90^\circ; \) Slanting Current

Bottom panel: Current field

WL|delft hydraulics

| Case I | H3306 | Fig. 2.5.3.b |
Significant wave height (m) computed by SWAN

$H_s = 1.0 \text{ m}, \ T_p = 7.0 \text{ s}, \ Dir = 60^\circ$

Slanting current (depth $= 1 \times 10^5 \text{ m}$)

**Case I**

scale 1: 1250

WLIdelft hydraulics

H3306 | Fig. 2.5.4.
Top panel: \( H_a \) (m) as computed on a regular rectangular grid
Lower panels: difference in \( H_a \) (m), where \( \Delta H_a \) is defined as
\[ \Delta H_a = H_{a,cl} - H_{a,rr} \]
Wave parameters along curve as computed by SWAN

\( H_s = 1.0 \, \text{m} \), \( T_p = 7.0 \, \text{s} \), \( \text{Dir} = 60^\circ \)

Slanting Current (depth = \( 1 \times 10^6 \, \text{m} \))

WL|delft hydraulics
Wave parameters along curve computed by SWAN

\( H_s = 1.0 \text{ m}, \ T_p = 7.0 \text{ s}, \ \text{Dir} = 60^\circ; \)

Slanting Current (depth = \( 1 \times 10^6 \) m)

WL\texttt{\textbackslash d}elft hydraulics

Case I

H3306

Fig. 2.5.6.b
Computational grids
panel a: Regular rectangular grid
panel b: Curvilinear grid

WLdelft hydraulics

Case II
scale 1: 2000

H3306 Fig. 3.1.1
Significant wave height (m) computed by SWAN

$H_s = 2.0 \text{ m}, \ T_p = 6.0 \text{ s}, \ \text{Dir} = 90^\circ$

Barrier Island; no current

**Curvilinear grid**

**Regular rectangular grid**

**Case II**

scale 1: 1800

**WLIdelft hydraulics**

H3306  Fig. 3.2.1
Difference in significant wave height (m) defined as
\[ \Delta H_s = H_{s,cl} - H_{s,rr} \]
Barrier island; no current

Case II

scale 1: 1800

WLIdelft hydraulics

H3306 Fig. 3.2.2.
Curvilinear grid

Significant wave height (m)

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<td>Below</td>
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X-axis (km)

Y-axis (km)

Nested (regular rectangular) grid

Significant wave height (m) computed by SWAN

Case II

scale 1: 1800

WLIdelft hydraulics

H3306 Fig. 3.2.3.
Difference in significant wave height (m) defined as
\[ \Delta H_s = H_{s,cl} - H_{s,rr} \]
Barrier island; no current

Case II

Scale 1: 1800

WLIdelft hydraulics

H3306  Fig. 3.2.4.
Current direction
\( u = 1 \text{ m/s} \)

Case II

scale 1: 1000

WLIdelft hydraulics

H3306

Fig. 3.3.1
Curvilinear grid

Significant wave height (m) computed by SWAN

H_s = 2.0 m, T_p = 6.0 s, Dir = 90°

Barrier Island; current

Regular rectangular grid

Case II

scale 1: 1800

WLIdelft hydraulics

H3306 Fig. 3.3.2
Difference in significant wave height (m) defined as
\[ \Delta H_s = H_{s,cl} - H_{s,rr} \]
Barrier Island; current

**Case II**

scale 1: 1800

WLIdelft hydraulics

H3306 Fig. 3.3.3.
Comparison REFRAC / SWAN (curvilinear computational grid)
Monochromatic waves; $T = 6\ s$

Case II

scale 1: 125.000

WL\delft hydraulics

H3306 Fig. 3.4.1.
panel a: Bathymetry Westerschelde on curvilinear grid
panel b: Bathymetry Westerschelde on nested grid
Paris Coordinates system

scale 1:360,000

WLIdelft hydraulics

H3306 Fig. 4.1.1.
panel a: Bathymetry Westerschelde on curvilinear grid
panel b: Bathymetry Westerschelde on nested grid
Paris Coordinates system

scale 1: 90,000

WLdelft hydraulics

H3306  Fig. 4.1.1.a
Westerschelde field case
Regular rectangular computational grid
panel a and b: $H_g$ in (m) as computed by SWAN (no source terms)
Bottom panel: difference in $H_g$ (m), where $\Delta H_g$ is defined as
$\Delta H_g = H_{g,cl} - H_{g,rr}$ (Dir = 315°)

Case III
scale 1:450,000
WLIdelft hydraulics

H3306  Fig. 4.2.1.
panel a and b: $H_s$ in (m) as computed by SWAN (no source terms)

Bottom panel: difference in $H_s$ (m), where $\Delta H_s$ is defined as

$\Delta H_s = H_{s,cl} - H_{s,fr}$ ($\text{Dir} = 315^\circ$)

**Case III**

scale 1:112.500

**WLIdelft hydraulics**

H3306 Fig. 4.2.1.a
panel a and b: $H_s$ (m) as computed by SWAN (only refraction)

Case III

scale 1:450,000

WLIdelft hydraulics

H3306  Fig. 4.2.2.
panel a and b: $H_s$ in (m) as computed by SWAN (only breaking)

Bottom panel: difference in $H_s$ (m), where $\Delta H_s$ is defined as

$$\Delta H_s = H_{s,cl} - H_{s,rr}$$  (Dir = 315°)

Case III

scale 1:450,000

WLIdelft hydraulics

H3306  Fig. 4.2.3.
panel a and b: $H_g$ (m) as computed by SWAN (breaking and refrac.)
Bottom panel: difference in $H_g$ (m), where $\Delta H_g$ is defined as
$\Delta H_g = H_{g,cl} - H_{g,ff}$ (Dir = 315°; strict conv. crit.)

<table>
<thead>
<tr>
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<tbody>
<tr>
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</tr>
<tr>
<td>H3306</td>
<td>Fig. 4.2.4</td>
</tr>
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</table>
panel a and b: $T_{m-2-1}$ (s) as computed by SWAN (breaking and refraction)

Bottom panel: difference in $T_{m-2-1}$ (s), where $\Delta T_{m-2-1}$ is defined as
$\Delta T_{m-2-1} = T_{m-2-1,dr} - T_{m-2-1,rr}$ (Dir =315°; strict convergence criterion)

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WLdelft hydraulics

H3306  Fig. 4.2.4.a
panel a and b: $T_{m-2-1}$ (s) as computed by SWAN (breaking and refraction)

Bottom panel: difference in $T_{m-2-1}$ (s), where $\Delta T_{m-2-1}$ is defined as

$$\Delta T_{m-2-1} = T_{m-2-1,c} - T_{m-2-1,r} \quad \text{(Dir =315°; strict convergence criterion)}$$

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WLIdelft hydraulics

H3306  Fig. 4.2.4.b
panel a and b: $H_b$ (m) as computed by SWAN (breaking and refrac.)
Bottom panel: difference in $H_b$ (m), where $\Delta H_b$ is defined as $\Delta H_b = H_{b,cl} - H_{b,rr}$ (Dir = 315°; mild conv. crit.)

WLIdelft hydraulics

Case III

scale 1:450.000

H3306  Fig. 4.2.5.
panel a and b: $H_s$ in (m) as computed by SWAN (no source terms)
Bottom panel: difference in $H_s$ (m), where $\Delta H_s$ is defined as $\Delta H_s = H_{s,cl} - H_{s,fl}$ (Dir = 10°)

**Case III**

scale 1:450,000

WLI/delft hydraulics

H3306  Fig. 4.2.6.
Panel a and b: $H_s$ (m) as computed by SWAN (only refraction)
panel a and b: $H_b$ in (m) as computed by SWAN (only breaking)
Bottom panel: difference in $H_b$ (m), where $\Delta H_b$ is defined as
$\Delta H_b = H_{b,cl} - H_{b,fr}$ (Dir = $10^5$)

WLIdelft hydraulics

Case III

scale 1:450,000

H3306  Fig. 4.2.8.
panel a and b: $H_s$ (m) as computed by SWAN (breaking and refrac.)

Bottom panel: difference in $H_s$ (m), where $\Delta H_s$ is defined as

$\Delta H_s = H_{s,cl} - H_{s,tr}$ (Dir = $10^5$; strict conv. crit.)

Case III

scale 1:450.000

WLI 1:1 hydraulics

H3306  Fig. 4.2.9.
panel a and b: $T_{m-2.1}$ (s) as computed by SWAN (breaking and refraction)
Bottom panel: difference in $T_{m-2.1}$ (s), where $\Delta T_{m-2.1}$ is defined as
$\Delta T_{m-2.1} = T_{m-2.1,cl} - T_{m-2.1,fr}$ (Dir = 10°; strict convergence criterion)

Case III

scale 1:450,000

WLIdelft hydraulics

H3306 Fig. 4.2.9.a
panel a and b: $T_{m-2-1}$ (s) as computed by SWAN (breaking and refraction)
Bottom panel: difference in $T_{m-2-1}$ (s), where $\Delta T_{m-2-1}$ is defined as $\Delta T_{m-2-1} = T_{m-2-1,cl} - T_{m-2-1,rr}$ (Dir = $10^\circ$; strict convergence criterion)

<table>
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<td>H3306</td>
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</table>
panel a and b: $H_b$ (m) as computed by SWAN (breaking and refrac.)
Bottom panel: difference in $H_b$ (m), where $\Delta H_b$ is defined as
$\Delta H_b = H_{b,ct} - H_{b,ref}$ (Dir = 10°; mild conv. crit.)
CASE: no source terms

CASE: breaking only

CASE: breaking and refraction only

<table>
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<tr>
<th>Panel a: rel. dH₃ in (%) as computed by SWAN (case 1)</th>
<th>Case III</th>
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<tbody>
<tr>
<td>Panel a: rel. dH₃ in (%) as computed by SWAN (case 3)</td>
<td>scale 1:450,000</td>
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<tr>
<td>Panel a: rel. dH₃ in (%) as computed by SWAN (case 4)</td>
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WLIdelft hydraulics

H3306 Fig. 4.2.11.a
CASE: no source terms

CASE: breaking only

CASE: breaking and refraction only

panel a: rel. $dh_0$ in (%) as computed by SWAN (case 6)
panel a: rel. $dh_0$ in (%) as computed by SWAN (case 8)
panel a: rel. $dh_0$ in (%) as computed by SWAN (case 9)

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WLI Delft hydraulics

H3306  Fig. 4.2.11.b
panel a and b: $H_s$ in (m) as computed by SWAN (Wind; dir=280°)
Bottom panel: difference in $H_s$ (m), where $\Delta H_s$ is defined as
$\Delta H_s = H_{s,cl} - H_{s,fr}$ (strict convergence criterion)

<table>
<thead>
<tr>
<th>Case III</th>
<th>H3306</th>
<th>Fig. 4.3.1.</th>
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<tbody>
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</table>
panel a and b: $H_s$ in (m) as computed by SWAN (Wind: dir=280°)
Bottom panel: difference in $H_s$ (m), where $\Delta H_s$ is defined as
$\Delta H_s = H_{s,ol} - H_{s,lr}$ (mild convergence criterion)

**Case III**

scale 1:450,000

**WLIdelft hydraulics**

H3306  Fig. 4.3.2.
panel a and b: $H_s$ in (m) as computed by SWAN (Wind and current)
Bottom panel: difference in $H_s$ (m), where $\Delta H_s$ is defined as
$\Delta H_s = H_{s,cl} - H_{s,fr}$ (strict convergence criterion)

<table>
<thead>
<tr>
<th>Case III</th>
</tr>
</thead>
<tbody>
<tr>
<td>scale 1:450,000</td>
</tr>
</tbody>
</table>

WLIdelft hydraulics

H3306 Fig. 4.4.2.
panel a and b: \( H_s \) in (m) as computed by SWAN (Wind and cucoent)

Bottom panel: difference in \( H_s \) (m), where \( \Delta H_s \) is defined as
\[
\Delta H_s = H_{s,cl} - H_{s,ref} \quad \text{(mild convergence criterion)}
\]

**Case III**

scale 1:450,000

WLIdelft hydraulics

H3306  Fig. 4.4.3.
Appendices
Appendix A  SWAN-input file case I

$**************************HEADING******************************
$
$ FILE: accdpr2.swn
$
PROJ 'Const. depth (90)' 'gr_2'
$
$
$**************** MODEL INPUT **********************
$
$CGRID 0. 0. 0. 20000. 2400. 80 10 CIRCLE 120 0.07 1.0 24
$
GRID CURV 80, 10, CIRCLE 120, 0.07 1.0, 24
READ COOR 10. 'grid2.crd' 3, nhedvec=1
$
INPGRID BOTTOM 0. 0. 0. 1 1 20000. 2400.
READINP BOTTOM 1. 'deep.bot' 1 0 FREE
$
$
BOU STAT SIDE LOW Y JON PAR 1. 7. 90. 4
$
NUM ACCUR 1e-5 1e-5 1e-5 99.5 15
$
GEN3
OFF QUAD
OFF WCAP
OFF BREAK
$
$**************** OUTPUT REQUESTS **********************
$
$ definitions of output points, curves and frames
$
POINT 'points' 10000. 0., 10000. 1200., 10000. 2400.
POINT 'point1' 10000. 0.
POINT 'point2' 10000. 1200.
POINT 'point3' 10000. 2400.
CURVE 'curve1' 10000. 0., 24, 10000., 2400.
FRAME 'frame2' 0. 0., 0., 20000. 2400., 160 20
$
$ ****************************
$ 2d-output
$
PLOT 'COMPGRID' FILE 'accdpr2.plt' 'Hsign' ISO HS &
   VEC TRANS 0.1 2 LOC
PLOT 'COMPGRID' FILE 'accdpr2.plt' 'Tm01' ISO TM01
PLOT 'COMPGRID' FILE 'accdpr2.plt' 'Force' VEC FORCE 2. 2
PLOT 'COMPGRID' FILE 'accdpr2.plt' 'Current' VEC VEL 0.2 2
PLOT 'COMPGRID' FILE 'accdpr2.grd' CMESH
$
$
$ ******************************************************************************$
$ tabular output
$
TABLE 'curvel' NOHEAD 'accdpr2.tbl' XP YP DIST DEP VEL &
   HS TM01 RTM01 RTP DIR &
   TDIR DSPR TRANS DISS FORCE &
   DHS DRTM01
$
$ ******************************************************************************$
$ plot spectra
$
PLOT 'point1' FILE 'accdpr21.spc' 'point1' SPEC
PLOT 'point2' FILE 'accdpr22.spc' 'point2' SPEC
PLOT 'point3' FILE 'accdpr23.spc' 'point3' SPEC
$
$ ******************************************************************************$
$ output in tekal-format
$
TABLE 'COMPGRID' NOHEAD 'accdpr2.xyz' XP YP DEP HS DIR &
   TM01 FORCE TRANS DISS
$
$
$ ******************************************************************************$
$ output in tekal-format
$
TABLE 'frame2' NOHEAD 'accdpr2.frm' XP YP DEP HS DIR &
   TM01 FORCE TRANS DISS
$
$
$ ******************************************************************************$
$ numerical spectral output
$
$ 1D spectra
SPEC 'points' SPEC1D ABS 'accdpr2.abs'
$
$ 2D spectra
SPEC 'point1' SPEC2D ABS 'accdpr2a.ab2'
SPEC 'point2' SPEC2D ABS 'accdpr2b.ab2'
SPEC 'point3' SPEC2D ABS 'accdpr2c.ab2'
$
$
TEST 0,0
POOL
COMPUTE
STOP
$
Appendix B  SWAN-input file case II

$********** HEADING ***********************************************
$ File: iscu_c2.swn
$
PROJ 'Curvilin. grid' 'C2'
$
$ Test curvilinear computational and bottom grid.
$
$********** MODEL INPUT ***********************************************
$
MODE STA TWOD
$
SET LEVEL = 0.
SET DEPMIN = 0.
$
SETUP
$
CGRID CURVILINEAR 54 14 CIRCLE 72 0.1 1. 24
READ COOR 1. 'isla_cur.cor' 4 0 FREE
$
INPGRID BOTTOM CURV 0. 0. 54 14 EXCVAL -10.
READ BOT 1. 'isla_cur.bot' 4 0 FREE
$
INPGRID CURRENT 0. 0. 0. 36 36 500. 500.
READINP CURRENT 1. 'stroming.txt' 1 0 FREE
$
$ SEGMENT GRIDINDEX command
 BOU STAT SEG GRIN 1 1 23 1 JON PAR 2. PEAK 6. 90. 4.
$
NUM ACCUR 1.e-5 1.e-5 1.e-5 99.5 15
$
GEN3
BREAK
FRIC JON
TRIAD
OFF QUAD
$
$*****************************************************************************
$ output locations
$
POINT 'points' 11500. 4500. 11500. 9000. 11500. 13500.
POINT 'point1' 11500. 4500.
POINT 'point2' 11500. 9000.
POINT 'point3' 11500. 13500.
CURV 'curve1' 11500. 4000. 20 11500. 14000.
FRAME 'frame1' 0. 0.0 18000. 18000. 90 90
FRAME 'frame2' 5000. 4000. 0. 10000. 10000. 50 50
$
table output

```
TABLE 'points' NOHEAD 'iscu_c2.pnt' XP YP DEP SETUP HS TM01 &
    TM02 RTP DIR DSPR DISS FORCE

TABLE 'curve1' NOHEAD 'iscu_c2.tbl' XP YP DEP SETUP HS TM01 &
    TM02 RTP DIR DSPR DISS FORCE

TABLE 'frame1' NOHEAD 'iscu_c2frm' XP YP DEP SETUP HS TM01 &
    TM02 RTP DIR DSPR DISS FORCE

2d-output

PLOT 'COMPGRID' FILE 'iscu_c2.plt' 'Depth' ISO DEP LOC
PLOT 'frame1' FILE 'iscu_c2.plt' 'Depth' ISO DEP LOC
PLOT 'frame1' FILE 'iscu_c2.plt' 'Hsign' ISO HS &
    VEC TRANS
PLOT 'frame1' FILE 'iscu_c2.plt' 'Tm01' ISO TM01
PLOT 'frame1' FILE 'iscu_c2.plt' 'Force' VEC FORCE 2. 2
PLOT 'frame1' FILE 'iscu_c2.plt' 'Current' VEC VEL 0.2 2

PLOT 'frame2' FILE 'iscu_c2.plt' 'Hsign' ISO HS &
    VEC TRANS
PLOT 'frame2' FILE 'iscu_c2.plt' 'Tm01' ISO TM01
PLOT 'frame2' FILE 'iscu_c2.plt' 'Force' VEC FORCE 2. 2

PLOT 'COMPGRID' FILE 'iscu_c2.grd' CMESH LOC
PLOT 'frame1' FILE 'iscu_c2.grd' CMESH LOC

spectra

PLOT 'point1' FILE 'iscu_c2a.plt' SPEC
PLOT 'point2' FILE 'iscu_c2b.plt' SPEC
PLOT 'point3' FILE 'iscu_c2c.plt' SPEC
SPEC 'points' SPEC1D 'iscu_c2.spl'

spectra

nested grid

NGRID 'nest1' 0. 0. 0. 18000. 18000. 72 72
NEST 'nest1' 'iscu_n2.bnd'

TEST 0.0
POOL
COMPUTE
STOP
```
Appendix C

\textbf{SWAN-input file case III}

\$**************************HEADING******************************
\$
\$ FILE: wsc_0001.swn
\$
PROJ 'SWAN wschelde' '0001'
\$
SWAN berekeningen in de Westerschelde.
\$ curvilinear bottom and computational grid
\$ waterlevel uniform (NAP+6.m)
\$ no source terms
\$
\$************************** MODEL INPUT ******************************
\$
SET LEVEL=6. DEPMIN=.05 MAXERR=3 POWER=-1
\$
READ COORD 1., 'ws.xy' IDLA=5 NHEDVEC=1 FREE
\$
INP BOTTOM CURVILINEAR 0,0,178,504 EXCE -99.
READ BOTTOM 1. 'ws.bot' IDLA=5 NHEDF=1 FREE
\$
BOU STAT SEG GRIN 1 46 1 140 JON PAR 4. PEAK 12. 315. 4.
\$
\$
GEN3
OFF QUAD
OFF REFRAC
OFF WCAP
OFF BREAK
$
NUM ACCUR 0.00001 0.00001 0.00001 99.5 50
$
\$************************** OUTPUT REQUESTS ******************************
\$
\$ definitions of output points, curves and frames
\$
\$ resolutie frame1: 500x500
\$ resolutie frame2: 200x 40
\$
frame 'frame1' 0. 374000. 0. 46000. 28000. 92 56
frame 'frame2' 9500. 381100. -15. 30000. 15000. 150 375
$
\$************************** OUTPUT REQUESTS ******************************
\$ 2d-output
$
\$
PLOT 'frame1' FILE 'wsc_0001.plt' 'Hsign' ISO HS &
   VEC TRANS 0.1 2 LOC
PLOT 'frame1' FILE 'wsc_0001.plt' 'Tm01' ISO TM01
PLOT 'frame1' FILE 'wsc_0001.plt' 'Current' VEC VEL 0.2 2
$
$
$*****************************************************************************$
$ output in tekal-format$
$
TABLE 'frame2' NOHEAD 'wsc_0001.xyz' XP YP DEP HS PER TM01
$
$
$*****************************************************************************$
$ nested grid (resolutie 200x 30)$
$
NGRID 'nestl' 9500. 381100. -15. 30000. 15000. 150 375
NEST 'nestl' 'wsn_0001.bnd'
$
$
$*****************************************************************************$
$
POOL
COMPUTE
STOP