The shallow water wave hindcast model
HISWA Part II: test cases

N. Booij
L.H. Holthuijsen
T.H.C. Herbers

Report No. 7-85
The shallow water wave hindcast model
HISWA Part II: test cases

N. Booij
L.H. Holthuijsen
T.H.C. Herbers

Report No. 7-85
Project title
GEOMOR wave model (HISWA)

Project description
Development of a two-dimensional model to hindcast spectral wave parameters in an estuary with tidal flats on the basis of bottomtopography, current and wind data.

Customer
Rijkswaterstaat
Deltadienst, Afdeling Kustonderzoek
van Alkemadelaan 400
2597 AT THE HAGUE, the Netherlands

represented by
J. v. Marle

Project leader
dr.ir. L.H. Holthuijsen

work carried out by
dr.ir. N. Booij
dr.ir. L.H. Holthuijsen
ir. T.H.C. Herbers
G. Marangoni

Conclusion
Computational results of the HISWA model with default parameter values are compared with field observations in the Haringvliet and over the Galgenplaat. The results indicate that some tuning of the parameter values is required but not extensively.

Status of report
confidential, final report, part II

City/date:
Delft, February 15, 1985
## Contents

1. Introduction  
   page 1

2. Test in the Haringvliet estuary  
   page 4

3. Test in the Galgenplaat region  
   page 20

4. Computer capacity  
   page 23

5. Conclusions  
   page 24

6. References  
   page 25
1. Introduction

To demonstrate that the basic concepts of the HISWA model and the numerical implementation thereof provides realistic information in complex geophysical conditions, two tests have been carried out without turning the HISWA model. The following test should therefore be considered as "blind" tests in the sense that all coefficients in the HISWA model were either taken from literature or from arbitrary choices and that no feed-back was used from the observations in these tests to the model.

The first test was carried out for the Haringvliet (one of the branches in the river Rhine delta). This situation can be characterized as non-locally generated waves passing over a shoal where breaking and refraction (and perhaps diffraction) are dominant. Local wave generation was relevant only far behind the shoal and currents were taken to be zero.

The second test was carried out for the Galgenplaat (on extensive shoal surrounded by deep channels in one of the branches of the river Rhine delta). This situation can be characterized as local wave generation on a current with considerable current refraction. Over the top of the shoal wave breaking is dominant and behind the shoal bottom refraction is dominant.
2. Test in the Haringvliet estuary

In the mouth of the Haringvliet estuary (see fig. 1) a comprehensive measurement campaign has been undertaken which is described by Dingemans (1983). These measurements were carried out to verify the refraction-diffraction computations with the CREDIZ-model (Booij and Radder, 1981).

The computations have been carried out for a situation with low current velocities which occurred during the measurement period on October 1982 at 22.00 (M.E.T). The bottom topography on a large scale is shown in fig. 1 and the location of the area of computation is shown in fig. 2. A more detailed topography in the computation area is shown in fig. 3. The results of the computations are given in figs. 4-7.

The wave situation can be characterized as one in which waves have been generated by wind in deeper water and which penetrate the area under consideration. There the waves break on a shoal with a minimum depth of about 2 m. The wave height reduction over the shoal is considerable: from about 3 m in front of the shoal to about 0.5 m behind the shoal. The situation is obviously dominated by wave breaking over the shoal and by refraction and possibly diffraction around the shoal.

At seven locations measurements were taken (see figs. 2 and 3):

WA a pitch-and-roll buoy providing not only the significant wave height and mean wave period but also the main direction and the directional energy spreading. These measurements served as input at the upwind boundary of the model

WR1, WR2, WR3 waverider buoys in front of the shoal giving significant wave height and mean wave period

WR4, WR5, WR6 waverider buoys behind the shoal

E75 a wavestaff far behind the shoal
The results of the measurements are taken from Dingemans (1983). They are given in figs. 3 through 15 together with relevant HISWA results. It should be noted that two sets of analysis were available: one labelled "Hellevoetsluis" and the other "D.I.V.". The former is based on a statistical analysis of the observed time series, the latter is the result of a spectral analysis. Since the HISWA model is based on energy (or action) considerations the "D.I.V." results are the relevant observation results. The computations were carried out for time 22.00 hr. (M.E.T.), the observations were taken mostly at another time. The two nearest observations (nearest in time) are indicated in the figures.

Additional information regarding the wind and the computation parameters are given on the next page.

For convenience of comparison the following list gives the time-interpreted observations at 22.00 hours M.E.T. and the corresponding HISWA results.

<table>
<thead>
<tr>
<th>location</th>
<th>D.I.V. observation</th>
<th>HISWA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hs (m)</td>
<td>Tmean (s)</td>
</tr>
<tr>
<td>WA</td>
<td>3.23</td>
<td>T = 8.3</td>
</tr>
<tr>
<td>WR-1</td>
<td>3.30</td>
<td>6.3</td>
</tr>
<tr>
<td>WR-2</td>
<td>2.36</td>
<td>6.3</td>
</tr>
<tr>
<td>WR-3</td>
<td>2.56</td>
<td>5.9</td>
</tr>
<tr>
<td>WR-4</td>
<td>0.61</td>
<td>2.6</td>
</tr>
<tr>
<td>WR-5</td>
<td>0.99</td>
<td>3.7</td>
</tr>
<tr>
<td>WR-6</td>
<td>1.47</td>
<td>5.1</td>
</tr>
<tr>
<td>E-75</td>
<td>0.89</td>
<td>2.8</td>
</tr>
</tbody>
</table>
TEST: HARINGVLIET OCT. 14, 1982, at 22.00

bottom grid: 21750 m x 29000 m
              87 x 116

computational grid: 15000 m x 15000 m x 120°
                   225 x 60 x 15

boundary values
incoming waves:

$H_s = 3.285$ m, per 8.3 s, dir. 5.5°, $\cos^2$ distr.

wind:
$U_{10} = 16.5$ m/s dir = 5.5°

breaking on/eff frequency on/eff
bottom friction on/eff frequency on/eff
diffraction off
numeric diffusion on/eff (upstream scheme)
wave blocking on/eff

notes: in wind, breaking and friction only standard coefficients were used.
Fig. 1 Bathymetry of Haringvliet estuary, contourlines in m, interval is 2.0 m.
Fig. 2 Location of computation area in Haringvliet area shown in fig. 1 with buoy locations.
Fig. 3 Detailed bathymetry in area of computation. Contour lines in m, interval is 2.0 m.
Fig. 4 Significant wave height in m, contour line interval is 0.5 m.
Fig. 5 Mean wave period in s, contour line interval is 1.0 s.
Fig. 6 Energy transport vectors in \( \text{m}^3/\text{s} \).
Fig. 7 Wave induced stress in $m^2/s^2$. 

土地

$10^{-3} m^2/s^2$

WR3

WR4

WR2

WR5

WR6

E-75

土地
Fig. 8 Measurements at location WA.

Hs = significant wave height
Tp = peak period
SPR = standard deviation of directional energy distribution
SENSOR: WR-1

MEASUREMENTS:

Time: 21.00

<table>
<thead>
<tr>
<th>Time</th>
<th>Hs(m)</th>
<th>Tm(s)</th>
<th>D.I.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hellevoetsluis</td>
<td>3.22</td>
<td>6.1</td>
<td>2.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Time: 22.30

<table>
<thead>
<tr>
<th>Time</th>
<th>Hs(m)</th>
<th>Tm(s)</th>
<th>D.I.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hellevoetsluis</td>
<td>4.81</td>
<td>6.5</td>
<td>3.71+</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6.4+</td>
</tr>
</tbody>
</table>

+from Hellevoetsluis measurements with same ratios as at 21.00

HISWA:

Time: 22.00

<table>
<thead>
<tr>
<th>Time</th>
<th>Hs(m)</th>
<th>Tm(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.02</td>
<td>7.8</td>
</tr>
</tbody>
</table>

Hs = significant wave height

Tm = mean wave period

Fig. 9 Measurements at location WR-1.
SENSOR: WR-2

14-October-1982

MEASUREMENTS:

Time: 21.00
Hellevoetsluis         D.I.V.
Hs(m)    Tm(s)        Hs(m)    Tm(s)
2.89     6.2           2.27     6.1

Time: 22.30
Hellevoetsluis         D.I.V.
Hs(m)    Tm(s)        Hs(m)    Tm(s)
3.57     6.5           2.40     6.4

HISWA:
Time: 22.00
Hs(m)    Tm(s)
2.58     7.0

Hs = significant wave height
Tm = mean wave period

Fig. 10 Measurements at location WR-2.
 time: 21.20

Hellevoetsluis   D.I.V.

<table>
<thead>
<tr>
<th>Hs(m)</th>
<th>Tm(s)</th>
<th>Hs(m)</th>
<th>Tm(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.54</td>
<td>5.9</td>
<td>2.53+</td>
<td>5.9+</td>
</tr>
</tbody>
</table>


Time: 22.50

Hellevoetsluis   D.I.V.

<table>
<thead>
<tr>
<th>Hs(m)</th>
<th>Tm(s)</th>
<th>Hs(m)</th>
<th>Tm(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.61</td>
<td>5.8</td>
<td>2.60</td>
<td>5.8</td>
</tr>
</tbody>
</table>

+ from Hellevoetsluis measurements with same ratios as at 22.50

HISWA:

Time: 22.00

<table>
<thead>
<tr>
<th>Hs(m)</th>
<th>Tm(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.52</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Hs = significant wave height

Tm = mean wave period

Fig. 11 Measurements at location WR-3.
SENSOR: WR-4

14-October-1982

MEASUREMENTS:

Time: 21.40
Hellevoetsluis

D.I.V.

<table>
<thead>
<tr>
<th>Hs(m)</th>
<th>Tm(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.58</td>
<td>2.1</td>
</tr>
<tr>
<td>0.58</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Time: 22.50
Hellevoetsluis

D.I.V.

<table>
<thead>
<tr>
<th>Hs(m)</th>
<th>Tm(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.61</td>
<td>3.2</td>
</tr>
<tr>
<td>0.64</td>
<td>3.2</td>
</tr>
</tbody>
</table>

HISWA:

Time: 22.00

<table>
<thead>
<tr>
<th>Hs(m)</th>
<th>Tm(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.46</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Hs = significant wave height
Tm = mean wave period

Fig. 12 Measurements at location WR-4.
SENSOR : WR-5

14-October-1982

MEASUREMENTS :

Time: 21.40

Hellevoetsluis

<table>
<thead>
<tr>
<th>Hs(m)</th>
<th>Tm(s)</th>
<th>Hs(m)</th>
<th>Tm(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.86</td>
<td>3.6</td>
<td>0.87</td>
<td>3.6</td>
</tr>
</tbody>
</table>

D.I.V.

Time: 22.30

Hellevoetsluis

<table>
<thead>
<tr>
<th>Hs(m)</th>
<th>Tm(s)</th>
<th>Hs(m)</th>
<th>Tm(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.10</td>
<td>3.6</td>
<td>1.12</td>
<td>3.8</td>
</tr>
</tbody>
</table>

D.I.V.

HISWA :

Time: 22.00

<table>
<thead>
<tr>
<th>Hs(m)</th>
<th>Tm(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.04</td>
<td>4.2</td>
</tr>
</tbody>
</table>

\[ Hs = \text{significant wave height} \]
\[ Tm = \text{mean wave period} \]

Fig. 13 Measurements at location WR-5.
SENSOR: WR-6

14-October-1982

MEASUREMENTS:

Time: 21.40
Hellevoetsluis D.I.V.
Hs(m) Tm(s) Hs(m) Tm(s)
1.36 5.1 1.37 5.1

Time: 23.10
Hellevoetsluis D.I.V.
Hs(m) Tm(s) Hs(m) Tm(s)
1.79 5.7 1.79 5.7

HISWA:
Time: 22.00
Hs(m) Tm(s)
1.34 4.6

Hs = significant wave height
Tm = mean wave period

Fig. 14 Measurements at location WR-6.
SENSOR : E-75

14-October-1982

MEASUREMENTS :

Time: 22.00
Hellevoetsluis D.I.V.

Hs(m) Tm(s) Hs(m) Tm(s)
0.90 2.8 0.89 2.8

Time:
Hellevoetsluis D.I.V.

Hs(m) Tm(s) Hs(m) Tm(s)

HISWA :

Time: 22.00

Hs(m) Tm(s)
0.77 3.6

Hs = significant wave height
Tm = mean wave period

Fig. 15 Measurements at location E-75.
3. Test in the Galgenplaat region

The Galgenplaat is located in the Oosterschelde estuary. The Galgenplaat is a shoal surrounded by deep channels, with depths up to 50 m.

In contrast with the Haringvliet test, measurements are scarce. Wave gauges were installed in two places, indicated in fig. 16 as 'GALA' and 'GAHO'. The test was carried out for a situation on March 30, 1983, at 13:00 (M.E.T.).

The wind was coming from the South-West, so the waves were primarily locally generated. Thus wave frequencies are rather high, and the velocities of the currents around the Galgenplaat cannot be neglected in this test. Current velocities were determined by the 2-dimensional unsteady flow model WAQUA. The station can be characterized as local wave generation on a current upwind from the shoal, wave breaking over the shoal and refraction around the shoal. At the location of observation the situation seems to be dominated by the breaking of locally generated waves.

Details of the parameters of the computations are on the next page. The following figures are provided:

- fig. 16: Location of the area.
- fig. 17: Depths and current vectors in parts of the computational region.
- fig. 18: Significant wave height and energy transport vector in the same region.
- fig. 19: Mean wave period in the same region.

The results of the mean wave period were unreliable in part of the area (the shaded region in fig. 19). It is the region downwave of a dry part of the shoal, where the action densities are small; the mean wave period is there obtained as the ratio of two small quantities, so that small errors deteriorate the results.

Because the wave gauge 'GAHO' was not flooded at the time of observation, comparison with measurement can only be based on the gauge 'GALA'. These measurements are: $H_s = 0.33$ m, and $T_{\text{mean}} = 1.82$ sec; the computation gave: $H_s = 0.15$ m and $T_{\text{mean}} = 2.2$ sec.
The differences are considerable, but it must be stressed that
1) the model has been run with default parameter values which have not
been tuned;
2) the current field was not observed but has been computed, thus
introducing differences between the actual situation and the input
current field for the HISWA model;
3) the significant wave height and period are very low in the
measurements. The effects of instrument noise and the reliability
of these measurements is not known to the present authors. Some
caution seems to be called for considering the quality of some of
the observations in the tests described in the previous section
(Haringvliet).

To estimate the effect of the spatial resolution of the computation
grid, the computations were repeated for a sub-region of the region
considered above with a mesh of 50 m x 124 m and with a directional
resolution of 8°. The result at the location GALA is for the signifi­
cant wave height 0.15 m and for the mean wave period 2.6 s. This is
slightly better than the results of the large grid computations
compared with the observations. Possible causes for the discrepancies
between observations and computational results are
a) wave generation on a current is too slow
b) wave dissipation on a current is too high
c) up-stream boundary effects penetrate deep into the area under
consideration
d) breaking at the shoal is overestimated
e) wave set-up is not taken into account
TEST: GALGENPLAAT MARCH 14, 1983

bottom grid:

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>7950 m x</td>
<td>12400 m</td>
</tr>
<tr>
<td>159 x</td>
<td>248 x</td>
</tr>
</tbody>
</table>

computational grid:

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>7950 m x</td>
<td>12400 m x</td>
<td>120°</td>
</tr>
<tr>
<td>100 x</td>
<td>50 x</td>
<td>8°</td>
</tr>
</tbody>
</table>

boundary values
incoming waves: absent

\[ H_s = 0 \text{ m}, \quad \text{per} = - s, \quad \text{dir.} = - \quad \text{dspr.} = - \]

wind: South-West
\[ U_{10} = 9. \text{ m/s} \quad \text{dir} = 0° \]

breaking on/eff frequency on/eff
bottom friction on/eff frequency on/eff
diffraction off
numeric diffusion on/eff
wave blocking on/eff

notes: in wind, breaking and friction only standard coefficients were used.
Fig. 16 Location of the Galgenplaat shoal in the Oosterschelde tidal basin.
Fig. 17 Bathymetry and current pattern in the area of the Galgenplaat. Contour lines are in m, interval is 10.0 m.
Fig. 18 Contour lines of significant wave height and energy transport vectors in the Galgenplaat area; values are in m, interval is 0.1 m. Wind is south-west, 9 m/s; direction as indicated above.
Fig. 19 Contour lines of the average wave period. Values are in seconds, the interval is 0.5 s. In the shaded area the results are truncated at 3.0 s.
4. Computer capacity

The computer capacity required for running HISWA is estimated from some runs with the Galgenplaat model.

As a general rule it can be stated that the amount of CPU-time required for a HISWA computation is roughly proportional to the total number of points in the computational grid, i.e. the product of $N_x$, the number of points in $x$-direction, $N_y$, the number of points in $y$-direction, and $N_\theta$, the number of points in $\theta$-direction. This is illustrated by table 2.

<table>
<thead>
<tr>
<th>Part of Region</th>
<th>$N_x \times N_y \times N_\theta$</th>
<th>CPU-time UNIVAC 1100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part of region</td>
<td>6000</td>
<td>44 sec</td>
</tr>
<tr>
<td>Whole Galgenplaat region</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Region (coarse grid)</td>
<td>40000</td>
<td>319 sec</td>
</tr>
</tbody>
</table>

Table 2. Relation of grid size and computer time for the Galgenplaat test.

The computer storage required is a more complicated matter; this depends on the number of points in the bottom grid and on the number of points in the computational grid. If $M_x \times M_y$ is the number of points in the bottom grid, the number of data to be stored during the preparation phase is a few thousand $+ 3 \times M_x \times M_y$ if currents are taken into account, or $M_x \times M_y$ if currents are absent. During the computational phase the number of data is roughly $30 \times N_y N_\theta$; $N_x$ does not influence the required storage because a stepping procedure is employed in $x$-direction.
5. Conclusions

The HISWA model has been run in two regions: the Haringvliet and the Galgenplaat without any tuning.

The agreement between the observations and the computational results is fair for the Haringvliet situation with differences in significant wave height of typically 5%-20% (HISWA results too low) and in mean period of 10%-30% (HISWA results too high) over a range of 0.5-3.0 m and 6-2 s respectively.

The agreement between the observations and the computational results is not good for the Galgenplaat situation. The difference is about -50% for the observed significant wave height of 0.33 m and about +20% for the observed mean wave period of 1.82 s.

Other wave parameters produced by the HISWA model, such as the directional energy distribution or the radiation stress gradient have not been observed and the HISWA results could therefore not be validated for these parameters.

The main conclusion is that the HISWA model produces realistic values for the wave field in complex geophysical situations but some tuning is required especially in the presence of a current.
6. References


Booij, N. and A.C. Radder, CREDIZ, a refraction-diffraction model for sea waves. DIVISIE, Data Processing Division of Rijkswaterstaat, 1981.

Dingemans, M.W., Verification of numerical wave propagation models with field measurements; CREDIZ verification Haringvliet. Delft Hydraulics Lab., report W488 part 1, 1983.

