The design of a numerical shallow water wave hindcast model

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| **Conclusion** | HISWA is a directionally decoupled parametric wave hindcast model containing bottom- and current refraction, diffraction, wave growth and dissipation. The design for this hindcast model is presented with emphasis on the system documentation of the computational program of HISWA.  
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1. INTRODUCTION

1.1 General characteristics of the model

In this report the design of a numerical shallow water waves hindcast model named HISWA is presented. This model is expected to provide realistic estimates of the wave conditions in the Oosterschelde. It is a directionally decoupled paraffetric model containing bottom refraction, wave growth, dissipation due to wave breaking and bottom friction as well as a simple representation of diffraction effects. Further the effects of currents on refraction, wind generation and bottom dissipation is included.

For the mathematical formulation of this model reference is made to Holthuijsen and Booij (1983).

Two balance equations in the parameters $A_0$ (frequency integrated wave action) and $W_0$ (mean wave action frequency), containing gradients in three dimensions $x$, $y$ and $\theta$ (wave direction), are solved:

\[
\frac{\partial}{\partial x} (C_{X0} \cdot A_0) + \frac{\partial}{\partial y} (C_{Y0} \cdot A_0) + \frac{\partial}{\partial \theta} (C_{\theta_0} \cdot A_0 + C_{\text{dif}} (C_{Y0} \cdot A_0 + C_{\text{dif}} \cdot (C_{Y0} \cdot A_0)) = S_0 - A_0 \cdot \frac{d}{dt} W_0 \tag{1}
\]

\[
\frac{\partial}{\partial x} (C_{X0} \cdot W_0) + \frac{\partial}{\partial y} (C_{Y0} \cdot W_0) + \frac{\partial}{\partial \theta} (C_{\theta_0} \cdot W_0) + C_{\text{dif}} (C_{Y0} \cdot (W_0 \cdot A_0) - C_{X0} \cdot (W_0 \cdot A_0)) = W_0 \cdot S_0 \tag{2}
\]

in eq. 1 and 2:

$C_{X0}$, $C_{Y0}$, $C_{\theta_0}$ are the components in $x$, $y$ resp. $\theta$ direction of wave action transport velocity

$S_0$ is the relative frequency

$S_0$ is the source term including wind generation, bottom friction and surf breaking

$C_{\text{dif}}$ is a diffraction coefficient

(expressions for these terms are given in chapter 3)

A numerical grid is defined in three dimensions $x$, $y$ and $\theta$ (fig. 1). The direction of wave propagation $\theta$ is defined as the angle between the wave number vector and the positive $x$-axis, measured counter-clockwise.
The computation progresses in the positive x-direction and propagation of wave energy is limited to a sector defined by \( \theta_a \) and \( \theta_b \) around the direction of the x-axis. The computations are carried out line by line with an explicit predictor-corrector scheme. The number of corrector steps is free but two steps are sufficient to obtain a stable scheme. Lines are defined parallel to the y and \( \theta \) axis.

Beside the computational grid described above two other grids are used in the model HISWA:

- a problem grid in which the user defines his problem (in x-y plane)
- a bottom grid containing the bottom topography and current field (in x-y plane)

### 1.2 Computer programs

The model HISWA consists of three computer programs:

- PREP input preparation and control part
- COMPU computational part
- OUTP output of results

Here the design of the computational part COMPU will be considered. The programs PREP and OUTP are planned to be adjusted versions of the programs PREP and UITV of the refraction/diffraction model CREDIZ of Rijkswaterstaat.

**INPUT:**

In the program COMPU instructions, definitions of grids, coefficients etc. (formulated in PREP) and arrays containing bottom topography and current field are read from a file.

**PROCEDURE:**

First the values of the frequency integrated action \( A_0 \) and
mean action frequency $W_0$ are determined at the boundary $x=0$. Further depths, currents, wave numbers and wave propagation velocity components are computed at this boundary. For every new line $(x=n\times dx)$, $A_0$ and $W_0$ are obtained through the application of the numerical scheme described in section 1.1.

**OUTPUT:**
For every line the following results are written to a file that will be read by the program OUTP:

- wave action, frequency, relative frequency, group velocity, wave number and components of wave action transport velocity (in every grid point in the $y-\theta$ plane)
- leakage of energy through the $\theta$ boundary (for every value of $y$)
- dissipation of energy due to bottom friction and surf breaking (for every value of $y$)
- the fraction of breaking waves (for every value of $y$)

### 1.3 Documentation
A description of the computer program COMPU is given in chapters 2 through 4.

In chapter 2 the structure of the program COMPU is explained. The relations between the subroutines in COMPU are shown in block diagrams. An example of a block diagram is given below.

```
A
 | --- B
 |    |
 |    | --- C
 | --- D
```

**fig. 2 block diagram**

In the program or subroutine $A$, subroutines $B$ and $D$ are called. Further subroutine $C$ is called in subroutine $B$.

The structure of a program or subroutine is presented in Nassi-Schneidermann diagrams. For convenience the conventional construction in the left part of fig. 3 is replaced by the one on the right.
fig. 3 representation of a conditional statement

Descriptions of the various subroutines are given in chapter 3. The sequence in which the subroutines are discussed corresponds with the place in the program COMPU at which the subroutine is called for the first time. Parameter lists of the subroutines are described in which input- and output parameters are denoted by (I) resp. (O).

In chapter 4 the storage of variables and arrays in common blocks and files is described. A flexible handling of computer storage, necessary for the considerable number of arrays in COMPU is obtained through the application of a Dynamic Data Pool.

In this report reference is made to the system documentation of CREDIZ for a detailed description, in so far as subroutines and other facilities of the system CREDIZ are implemented in the present model.
2. STRUCTURE OF THE PROGRAM COMPU

The computational part COMPU of the model HISWA is a FORTRAN program consisting of a main program and various subroutines. Input is read from a file named INSTR and output is written to a file named REKRES (section 4.3). Fig. 1 shows a diagram of the main program.

```
CALL OPENF open all necessary files
read dimension of pool and testparameter
from file INSTR
CALL INPOOL initialize the pool and fill
it with empty arrays
CALL WRCOM read common blocks and pool
arrays from file INSTR
CALL WRCOMX write common blocks and pool
arrays to file REKRES
CALL ADPOOL enlarge the dimensions of pool arrays
CALL HEAD write a title
CALL STARTB compute wave parameters on line
   x=0 and write the results to file REKRES
for every line do
   CALL NUMS compute wave parameters on this
   line and write the results to file REKRES
```

fig. 1 diagram of the main program

A block diagram showing the relations between the various subroutines of COMPU is given in fig. 2. Separate diagrams for the subroutines WRCOM,WRCOMX,WAVPA and TERMDE are included in fig. 3 through 6. The subroutines STRACE,COPYCH and MSGERR are called in various parts of the program.
COMPU

---OPENF
      |---VERSIE
      |---INPOOL
      |---REQDA
---WRCOM
      |---WRCOMX
      |---ADPOOL
      |---REQDA
---HEAD
---STARTB
      |---WAVPA
      |---WRIRE
---NUMS
      |---PREDT
      |---DISPA
      |---FRABRE
      |---TERMDE
      |---SUMDE
      |---WAVPA
      |---WRIRE

open all necessary files
a message is given at the moment
the model HISWA is generated
initialization of the dynamic data pool
expansion of the dynamic data pool
a major part of the common blocks
is written to and read from a file
ditto except for the common block UITVDA
reduction or expansion of a pool array
expansion of the dynamic data pool
a title is written above the output
computation of wave parameters at the
boundary x=0
computation of wave parameters at a line
in the computational grid
results of computations are written to a file
computation of wave parameters at a new line
wave action and frequency are computed through
linear extrapolation from the former lines
computation of parameters in source terms
the fraction of breaking waves is computed
the terms of the two balance equations
are computed in a grid point
evaluation of balance equations yields the
wave action and frequency in a grid point
computation of wave parameters at a line
in the computational grid
results of computations are written to a file

fig. 2 relations between subroutines in COMPU
WRCOM

| ---WRPOOL | a pool array is read from or written to a file

| ---ADPOOL | reduction or expansion of a pool array

| ---REQDA | expansion of the dynamic data pool

\textbf{fig. 3} relations between subroutines in WRCOM

WRCOMX

| ---WRPOOL | a pool array is read from or written to a file

| ---ADPOOL | reduction or expansion of a pool array

| ---REQDA | expansion of the dynamic data pool

\textbf{fig. 4} relations between subroutines in WRCOMX

WAVPA

| ---BOCUR | depths and currents are determined at a line

| ---INPDC | depth and current are determined in a bottom grid point

| ---ITWN | wave number and relative frequency are computed in a grid point

| ---VWPRO | propagation velocity components are computed in a grid point

\textbf{fig. 5} relations between subroutines in WAVPA

TERMDE

| ---TRSY | divergence of transport in y-direction

| ---TRST | divergence of transport in \( \theta \)-direction

| ---DIFT | diffraction terms

| ---SWIND | wind generation source terms

| ---SBOT | bottom dissipation source terms

| ---SSURF | surf breaking source terms

\textbf{fig. 6} relations between subroutines in TERMDE
3. DESCRIPTION OF SUBROUTINES

In this chapter the subroutines of the program COMPU are described. A number of these subroutines is copied from the model CREDIZ with a few adjustments in the source text. Only a short description is given of the function of these subroutines and reference is made to the documentation of CREDIZ.

3.1 Subroutine OPENF
In this subroutine all necessary files are opened in order to reserve input/output buffers. This action is taken in connection to repeated calls of the standard routine REQDA. This subroutine is copied from CREDIZ.

3.2 Subroutine VERSION
A message is printed at the moment (time and date) the model HISWA is generated.
This subroutine is copied from CREDIZ.

3.3 Subroutine INPOOL
The dynamic data pool is initialized by this subroutine. The dimension of the pool is determined from the common variable NPOOL (NPOOL * 1024). A number of empty arrays is initiated (50 in the program COMPU).
INPOOL is copied from CREDIZ with minor adjustments.

3.4 Subroutine REQDA
The standard routine REQDA, copied from CREDIZ, is used for expansion of the dynamic data pool.

3.5 Subroutines WRCOM and WRCOMX
A major part of the common blocks is written to and read from a file by the subroutines WRCOM and WRCOMX. This is necessary for the communication between the programs PREP, COMPU and OUTP. The difference between WRCOM and WRCOMX is the fact that WRCOMX doesn't read or write the common block UITVDA, containing instructions and information for the program OUTP.
WRCOM and WRCOMX are copied from CREDIZ with minor adjustments.

3.6 Subroutine WRPOOL
The subroutine WRPOOL reads or writes a pool array (unformatted) from resp. to a file.
WRPOOL is copied from CREDIZ with minor adjustments.

3.7 Subroutine ADPOOL
This routine is called by WRCOM, WRCOMX and in the main program for shrinking or expansion of an array in the dynamic data pool.
Subroutine ADPOOL is copied from CREDIZ with a few adjustments.
3.8 Subroutine WRDUMP
The contents of an array is printed by the subroutine WRDUMP.
WRDUMP is copied from CREDIZ with minor adjustments.

3.9 Subroutine HEAD

Function:
A title is printed above the output of the program COMPU.

The call of this subroutine is:
CALL HEAD(str1,str2,str3)

Parameters:
str1,str2,str3 are character strings containing a title.

3.10 Subroutine STARTB

Function:
In the subroutine STARTB the wave conditions at the boundary x=0 are determined.

Method:
The boundary condition is represented here by the directional integrated wave action A(y) and frequency W(y).
The distribution of A(y) over the directions is obtained by a \( \cos^m \) directional distribution. The parameter \( m \) is read from file INSTR.

\[
\begin{align*}
A_0(Y,\theta) &= c \cdot \cos(\theta - v) \cdot A(Y) \quad \text{for} \ |\theta - v| < 90 \text{ deg.} \\
&= 0 \quad \text{for} \ |\theta - v| \geq 90 \text{ deg.} \\
W_0(Y,\theta) &= W(Y)
\end{align*}
\]

(1)

\( v \) is the wind direction defined as the angle between the wind velocity vector and the positive x-axis, measured counter-clockwise.
The normalization coefficient \( c \), consisting of gamma-functions, is determined from approximations given in Abramowitz and Stegun (1965).
Depths and currents are determined at the boundary \( x=0 \).
Wave number, relative frequency, group velocity and components of propagation velocities are computed in every grid point in the Y-\( \theta \) plane.
Next these parameters are written to the file REKRES.
Other options for the representation of boundary wave conditions can be implemented.
The call of this subroutine is:
CALL STARTB

3.11 Subroutine WAVPA

Function:
In this subroutine wave numbers $K_0$, relative frequency $\Omega_0$, group velocity $C_G$, and propagation velocity components $C_{X0}$, $C_{Y0}$ and $C_{\theta 0}$ are computed at a line $IX$ in the computational grid.

Method:
In order to evaluate these parameters first the depths $D$ and current velocity components $U_X$, $U_Y$ at line $IX$ are determined.

The subroutine ITWN requires an estimate of the wave number $K_0$ as input parameter. Here the value of $K_0$ on line $IX-1$ is used as an estimate for $K_0$. At the boundary $x=0$ the following approximation of $K_0$ is applied.
\[ g \cdot K_0 = \frac{1}{2} \quad \frac{W_0}{2^{1/2}} (\tanh(W_0 \cdot D/g)) \]

Structure:

*WAVPA*

if predictor is passed or line is boundary

\[ x = 0 \text{ then} \]

if predictor is passed then

move arrays containing depths and currents

at line IX to arrays with old values

CALL BOCUR compute depths and currents

at line IX

for every \( y \) do

for every \( \theta \) do

\[ \text{give an estimate for the wave number} \]

CALL ITYN calculate wave number and relative frequency

CALL VWPRO calculate group velocity and components of propagation velocity

The call of this subroutine is:

CALL WAVPA(IX)

parameter:

IX (I) line in computational grid at which wave parameters are computed \((X = (IX-1)DX)\)

3.12 Subroutine BOCUR

Function:

In this subroutine depths \( D(Y) \) and current velocity components \( UX(Y), UY(Y) \) are determined at a line in the computational grid.

Method:

For every grid point, bottom grid coordinates are computed and depth and current velocity components are determined through bilinear interpolation.
Structure:

*BOCUR*

for every \( y \) do

- determine bottom grid coordinates of point
- CALL INPDC determine depth and current (if current is on) in point
- if current is on then
  - determine current relative to computational grid

The call of this subroutine is:

CALL BOCUR(IX)

parameter:

- IX (I) line in computational grid at which depths and currents are computed \((X=(IX-1)\cdot DX)\)

3.13 Subroutine INPDC

Function:
Depth and current velocity components are computed in a point given in bottom grid coordinates \((IB,JB)\).

Method:
A bilinear interpolation is carried out with the surrounding points in the bottom grid. If point \((IB,JB)\) is located outside the bottom grid then a constant depth and no current is assumed.
Structure:

*INPDC*

```
if point is located in bottom grid then
  compute depth
  if depth is positive and current is on then
    compute current components
  else if depth is negative and current is on then
    current is 0.
else
  depth is constant value outside bottom grid
  if current is on then
    current is 0.
```

The call of this subroutine is:
CALL INPDC

3.14 Subroutine ITWN

Function:
In ITWN the wave number $K_0$ and relative frequency $\omega_0$ in a grid point $(I_X, Y, I_T)$ is determined.

Method:
$K_0$ is computed through a Newton-Raphson iteration process, applied to eq. 1.

$$ F = W_0 - K_0 (U_X \cdot \cos \theta + U_Y \cdot \sin \theta) - (g \cdot K_0 \cdot \tanh (K_0 \cdot D)) = 0 \quad (1) $$

(the second term in eq. 1 falls off if no current is present)

For points outside the bottom grid $K_0$ is computed with eq. 2.

$$ K_0 = \frac{W_0}{g} \quad (2) $$

$\omega_0$ is calculated with eq. 3.

$$ \omega_0 = (g \cdot K_0 \cdot \tanh (K_0 \cdot D)) \quad (3) $$
If a negative depth is encountered then K0 and 00 are given the values -1.0 resp. 0.0.

Structure:

```plaintext
*ITWN*

if point is located outside bottom grid then
  compute wave number and relative frequency
else if depth is negative then
  wave number is -1., relative frequency is 0.
else
  compute function F
  for i = 1 to 50 while F > accuracy do
    compute derivative of F
    compute wave number
    compute function F
  compute relative frequency
```

The call of this subroutine is:

```
CALL ITWN(IY,IT)
```

Parameters:

- IY (I)  ) coordinates of point in computational grid
- IT (I)

3.15 Subroutine VWPRO

Function:
In subroutine VWPRO the group velocity CG0 and the components of wave action transport velocity CX0, CY0 and C00 are determined in a point (IX, IY, IT) in the computational grid.

Method:
The relations for the parameters mentioned above used in this model are:
\[ CG0 = \mathcal{O}_0 \left( \frac{1}{2K0} + \frac{D}{\sinh(2K0D)} \right) \] (1)

\[ CX0 = CG0 \cdot \cos \theta + UX \] (2)

\[ CY0 = CG0 \cdot \sin \theta + UY \] (3)

\[ \mathcal{C}0 = - \frac{\mathcal{O}_0 \partial D \partial D \partial UY \partial UX \partial UY}{\sinh(2K0D)} \partial X \partial Y \partial X \partial Y \] (4)

The terms containing current velocity components \(UX\) and \(UY\) in eq. 2 through 4 are omitted if no current is present. The term \(\mathcal{C}0\) is evaluated intermediate lines \(IX\) and \(IX+1\). Derivatives of depth and current are determined through a central difference scheme (after the predictor step). If negative depths are encountered then all velocity components are given the value 0.

Structure:

*VWPRO*

**Structure**:

---

if depth is negative then

- give velocity components and derivatives the value 0.

else

- compute group velocity

  if predictor step is passed then

  - compute depth derivatives and current derivatives (if current is on)

  - compute components of wave action transport velocity

  (\(\mathcal{C}0\) only if line \(x=0\))

---

The call of this subroutine is:

`CALL VWPRO(IX,IY,IT)`

Parameters:
3.16 Subroutine NUMS

Function:
In the subroutine NUMS wave parameters are computed at a new line IX+1 in the computational grid.

Method:
The following numerical scheme is applied:
Estimates for the wave action AO and -frequency WO at line IX+1 are obtained through a linear extrapolation from the lines IX-1 and IX (predictor step). With these estimates the other wave parameters at line IX+1 can be determined. Linear interpolation between the lines IX and IX+1 yields the wave parameters at line IX+1/2, necessary for the corrector step. The corrector step (which can be repeated several times) consists of an explicit differential scheme, applied to the two balance equations described in section 1.1.
The amount of energy lost through dissipation (FD) and leakage of energy through the boundaries θa and θb (FL) is kept.
Results of the computations are written to the file REKRES.
**Structure:**

*NUMS*

CALL PREDT predictor estimates for wave action and frequency on line IX+1

move contents of arrays with new values of wave number, relative frequency and propagation velocity components to arrays with old values

CALL WAVPA compute wave parameters at line IX+1

determine depths and currents (if current is on) intermediate lines IX and IX+1

for every corrector step do

  determine wave parameters intermediate lines IX and IX+1

  CALL DISPA compute parameters in dissipation terms

  for every y do

    if last corrector step is in progress then

      initialize leakage and dissipation in point x,y

    if depth is positive then

      for every θ do

        CALL TERMDE compute terms of the two balance equations

        CALL SUMDE determine wave action and frequency

      if last corrector step in progress then

        compute leakage and dissipation in point x,y

      CALL WAVPA compute wave parameters on line IX+1

  CALL WRIRE write results of line IX+1 to REKRES

The call of this subroutine is:

CALL NUMS(IX)
Parameter:
IX (I) wave parameters are determined at line IX+1
in the computational grid (X=IX*DX)

3.17 Subroutine PREDT

Function:
Estimates for the wave action $A_0$ and -frequency $w_0$ at line IX+1 (predictor step) are determined in this subroutine.

Method:
The predictor is a simple extrapolation procedure. $A_0$ and $w_0$ at line IX+1 are determined as follows:

$$A_0 = 2.A_0 - A_0 \quad (1)$$

$$w_0 = 2.w_0 - w_0 \quad (2)$$

If a negative depth is encountered then $A_0$ and $w_0$ are given the value 0..

Structure:

*PREDT*

if line is boundary $X=0$ then

wave action and -frequency on new line are given the values on the old line

else

for every $y$ do

if depth is positive then

for every $\theta$ do

move wave action and -frequency to arrays with old values and compute new values

else

for every $\theta$ do

move wave action and -frequency to arrays with old values and give new values the value 0.
The call of this subroutine is:
CALL PREDT(IX)

Parameter:
IX (I) wave parameters are determined at line IX+1 in the computational grid (X=IX.DX)

3.18 Subroutine DISP

Function:
In this subroutine parameters at line IX+1/2 are determined, necessary for the evaluation of the dissipation terms in the two balance equations.

Method:
The following parameters are determined:
orbital velocity at the bottom Ubot
current velocity at the bottom Ucur
wave energy density Et
local maximum wave height Hm
the fraction of breaking waves Qb

For these parameters the following relations are used:

\[ U_{\text{bot}} = \left( D\theta \sum_{\theta} g \cdot k_0 \cdot \theta_0 \cdot A_0 \right)^{1/2} \]
\[ \frac{2}{W_0 \cdot \cosh(k_0 \cdot D)} \] (1)

\[ U_{\text{cur}} = (U_X + U_Y)^{1/2} \] (2)

\[ E_t = D\theta \sum_{\theta} \theta_0 \cdot A_0 \] (3)

\[ H_m = 0.88 \cdot \theta_0^{-1} \cdot \tanh(\sqrt{\theta_0 \cdot D/0.88}), \quad \theta_0 = \sum_{\theta} k_0 \] (4)

\[ 1 - Q_b = \frac{E_t}{8.88} \] (evaluated in FRABRE) (5)

\[ \ln Q_b = \frac{1}{2} H_m \]
Structure:

*DISPA*

if bottom dissipation is on then

for every y do

compute orbital velocity at the bottom

if current is on then

for every y do

compute current velocity at the bottom

if surf breaking is on then

for every y do

compute wave energy density

compute local maximum wave height

CALL FRABRE compute fraction of breaking waves

The call of this subroutine is:

CALL DISPA

3.19 Subroutine FRABRE

Function:
In this subroutine the fraction of breaking waves in a point 
\( x,y \) in the computational grid (\( Q_b \)) is computed.

Method:
A Newton-Raphson iteration process is applied to eq. 1.

\[
\frac{E_t}{F} = 1 - Q_b + 8.85 \ln Q_b = 0 \quad \text{ (1)}
\]

\[
\frac{H_m}{2}
\]

An initial estimate of \( Q_b \) is obtained from a crude
approximation of this implicit relation between \( Q_b \) and
\( 8.85 E_t/H_m^{0.85} \). The parameters \( E_t \) and \( H_m \) in eq. 1 are
determined in subroutine DISPA.
Structure:

\*FRABRE*

```plaintext
if 8.--- \geq 1.0 then
  \frac{Et}{Hm}
  \text{fraction of breaking waves } Q_b \text{ is 1}
```

```plaintext
else if 8.--- < .15 then
  \frac{Et}{Hm}
  \text{fraction of breaking waves } Q_b \text{ is 0}
```

```plaintext
else
  \text{determine an estimate for the fraction of breaking waves } Q_b
  \text{compute function } F
  \text{for } I = 1 \text{ to } 50 \text{ while } F > \text{accuracy do}
    \text{compute derivative of function } F
    \text{compute fraction of breaking waves } Q_b
    \text{compute function } F
```

The call of this subroutine is:

CALL FRABRE(IY)

Parameter:

- IY(I) \text{ y-coordinate of point in which the fraction of breaking waves } Q_b \text{ is computed}

3.20 Subroutine TERMDE

Function:

In this subroutine the terms of the two balance equations are evaluated in the point IX+1/2, IY, IT. The source terms S0 and d\(\bar{W}_0/dT\) are split up in components of wind generation, bottom- and surf dissipation.
Structure:

*TERMDE*

```
CALL TRSY compute transportation terms in y-direction
CALL TRST compute transportation terms in θ-direction
if diffraction is on then
  CALL DIFT compute diffraction terms
else
  give diffraction terms the value 0.
if wind generation is on then
  CALL SWIND compute wind generation terms
else
  give wind generation terms the value 0.
if bottom dissipation is on then
  CALL SBOT compute bottom dissipation terms
else
  give bottom dissipation terms the value 0.
if surf breaking is on then
  CALL SSURF compute surf breaking terms
else
  give surf breaking terms the value 0.
```

The call of this subroutine is:
CALL TERMDE(IY,IT)

Parameters:

IY (I)  coordinates of point in computational grid
IT (I)  

3.21 Subroutine TRSY
Function:
The transportation terms of the two balance equations in y-direction:

\[
\frac{\partial}{\partial y} (C_{Y0,A0}) \quad \text{and} \quad \frac{\partial}{\partial y} (C_{Y0,W0,A0})
\]

are determined in this subroutine.

Method:
A conservative central difference scheme is applied:

\[
\frac{\partial f}{\partial y} = \frac{f_{IX+1/2,IY+1,IT} - f_{IX+1/2,IY-1,IT}}{2dY}
\]

Energy entering the computational region through the boundaries \(Y=0\) and \(Y=LY\) is not taken into account. At these boundaries somewhat different schemes are used.

Structure:

The call of this subroutine is:

\[
\text{CALL TRSY(IY,IT)}
\]

Parameters:

- \text{IY (I)} \quad \text{coordinates of point in computational grid}
- \text{IT (I)}

3.22 Subroutine TRST

Function:
The transportation terms of the two balance equations in \(\theta\)-direction:

\[
\frac{\partial}{\partial \theta} (C_{\theta0,A0}) \quad \text{and} \quad \frac{\partial}{\partial \theta} (C_{\theta0,W0,A0})
\]
are determined in this subroutine.

Method:
A conservative central difference scheme is applied:

\[ \frac{\partial f}{\partial \theta} = \frac{f_{IX+1/2,IY,IT+1} - f_{IX+1/2,IY,IT-1}}{2.d\theta} \]  

(1)

Energy entering the computational region through the boundaries \( \theta=\theta_a \) and \( \theta=\theta_b \) is not taken into account. At these boundaries somewhat different schemes are used. The leakage through these boundaries \( |C\theta 0| \cdot A0 \cdot 00 \) is kept.

Structure:

*TRST*

if point is located on boundary and wave energy is entering the computational region then

| give transportation terms in \( \theta \)-direction the value 0. |

else

| compute transportation terms in \( \theta \)-direction |

if point is located on boundary then

| compute leakage of wave energy |

The call of this subroutine is:

CALL TRST(IY,IT)

Parameters:

IY (I)  
coordinates of point in computational grid

IT (I)

3.23 Subroutine DIFT

Function:
The diffraction terms in the two balance equations:

\[ \frac{\partial}{\partial \theta} \left( \text{Cdif} (CYO \cdot \frac{\partial}{\partial X} A0 - CX0 \cdot \frac{\partial}{\partial Y} A0) \right) \quad \text{and} \]

\[ \frac{\partial}{\partial \theta} \left( \text{Cdif} (CY0 \cdot \frac{\partial}{\partial X} (W0 \cdot A0) - CX0 \cdot \frac{\partial}{\partial Y} (W0 \cdot A0)) \right) \]
are determined in subroutine DIFT.

Method:
Derivatives in x, y and \( \theta \) direction are approximated by central difference schemes:

\[
\frac{\partial f}{\partial x} = \frac{f_{x+1,y,t} - f_{x,y,t}}{dx}
\]

(1)

\[
\frac{\partial f}{\partial y} = \frac{f_{x+1/2,y+1,t} - f_{x+1/2,y-1,t}}{2dy}
\]

(2)

\[
\frac{\partial f}{\partial \theta} = \frac{f_{x+1/2,y,t+1} - f_{x+1/2,y,t-1}}{2d\theta}
\]

(3)

At the boundaries in the y-\( \theta \) plane somewhat different schemes are applied.

The call of this subroutine is:

\texttt{CALL DIFT(IY,IT)}

Parameters:

- \texttt{IY (I)}
  - coordinates of point in computational grid
- \texttt{IT (I)}

3.24 Subroutine SWIND

Function:
In this subroutine the wind generation components

\[ S_0 \quad \text{and} \quad \frac{d}{dt}w_0 \]

wind \quad \text{and} \quad \text{wind}

of the source terms in the two balance equations are determined.

Method:
The following relations are used for the terms mentioned above:

\[
S_0 = \frac{3}{\text{wind}} \frac{U_{10}^3}{g} \prod \frac{(E/B)}{a} \left\{ \frac{1 - \left( \frac{E/B}{a} \right)^2}{b} \right\} \left\{ \frac{1}{\text{atanh} \left( \frac{E/B}{d} \right)} \right\} \frac{c^{-1}}{c}
\]

(1)
\[ \frac{d W_0}{dt} = \frac{g^2 a_2}{2} \left( \frac{S_0}{u_0} \right) \left( \frac{W}{u_0} \right)^2 \]

\[ \text{wind} \quad u_10 \quad u_10 \]

with

\[ E \] is the dimensionless wave energy density \[ E_0 = \frac{E_0}{u_10} \]

\[ B \] is the directional distribution of waves, \[ E_0(Y, 0) = B(0) \cdot E_t(Y) \]

\[ u_10 \] is the wind velocity at 10m elevation relative to the current velocity

\[ a, b, c \] and \[ d \] are coefficients derived from literature

\[ a_2, b_2 \] are coefficients to be determined empirically.

Eq. 1 and 2 hold only for growing waves \( E < aB \). In the case \( E > aB \) then the wind generation terms are assumed to be 0.

Structure:

```
if current is on then
    determine wind speed relative to current
    compute dimensionless wave energy density E
if E < aB then
    compute wind generation terms
else
    give wind generation terms the value 0.
```

The call of this subroutine is:

```
CALL SWIND(IY,IT)
```

Parameters:

- \( IY (I) \) coordinates of point in computational grid
- \( IT (I) \)

**Subroutine SBOT**

Function:

The bottom dissipation terms
The following relations are applied:

\[ S_0 = -W \cdot \sigma_0 \cdot A_0 \]  
\[ \frac{dW_0}{dt} = W_0 \cdot a_3 \left( g \cdot W_0 \cdot W \cdot \sigma_0 \cdot A_0 \right) \]  
\[ W = \frac{g \cdot K_0 \cdot C_0}{2 \cdot \pi \cdot W_0 \cdot \cosh(K_0 \cdot D)} \]  

The second term in eq. 3 is omitted if no current is present. In this formulation the effects of currents on bottom dissipation are included in the same way dissipation due to wave orbital velocities is determined. The same procedure with somewhat different relations is applied in the model CREDIZ.

The terms are determined in point IX+1/2, IY, IT in the computational grid. The wave action A0 in the linear term S0bot is included implicitly in the two balance equations (section 3.27).

The coefficients Cfw, Cfc, a3 and b3 have to be determined, by the user, empirically.

The call of this subroutine is:

CALL SBOT(IY, IT)

Parameters:

IY (I)  
IT (I)  

coordinates of point in computational grid

3.26 Subroutine SSURF

Function:

The terms representing dissipation of wave energy due to surf breaking
SO and \( \frac{\partial W_0}{\partial t} \) are determined in this subroutine.

**Method:**
Relations for these terms applied in this model are:

1. \[ SO_{\text{surf}} = -W_0 \cdot \sigma_0 \cdot A_0 \] (1)
2. \[ \frac{dW_0}{dt_{\text{surf}}} = W_0 \cdot a_4 \cdot (g \cdot W_0 \cdot W \cdot \sigma_0 \cdot A_0) \] (2)

with
\[ W = \frac{2}{H_m} \]
\[ \sigma_0 = \frac{1}{2} \cdot Q_b \cdot W \cdot W \cdot W \cdot T \] (3)

The terms \( W \) and \( \frac{dW_0}{dt_{\text{surf}}} \) are determined in point \( IX+1/2, IY, IT \) in the computational grid. The wave action \( A_0 \) in the linear term \( SO_{\text{surf}} \) is included implicitly in the two balance equations (section 3.27).

The coefficient 1 is of order 1 while the coefficients \( a_4 \) and \( b_4 \) should be determined empirically.

The call of this subroutine is:
\[ \text{CALL SSURF(IY,IT)} \]

**Parameters:**
- \( IY (I) \)
- \( IT (I) \) coordinates of point in computational grid

3.27 Subroutine SUMDF

**Function:**
In this subroutine, the wave action \( A_0 \) and frequency \( W_0 \) in the grid point \( IX+1, IY, IT \) are determined.

**Method:**
The two balance equations 1 and 2 are solved.
\[-(\text{transportation+diffraction terms}) + \frac{1}{\alpha_0} \cdot \frac{d\omega}{dt} \]
\[-\left(\frac{\omega + \omega}{2}\right) \cdot \omega \cdot \alpha_0 \]

For brevity the transportation- and diffraction terms as well as the source term \(\frac{d\omega}{dt}\) have not been written in full in eq. 1 and 2.

The numerical scheme applied to these equations is:

\[
\begin{align*}
IX+1,IY,IT & \quad IX+1,IY,IT \\
IX,IY,IT & \quad IX,IY,IT \\
\alpha_X & \quad \alpha_X \\
\frac{f}{f} & \quad - CX0 \\
\frac{dX}{dX} & \quad \frac{dX}{dX} \\
H & \quad IX+1,IY,IT \\
& \quad IX,IY,IT \\
& \quad IX,IY,IT \\
& \quad G - \frac{(f + f)}{2} \\
\end{align*}
\]

with:
- \(f\) represents the terms \(\alpha_0\) (eq.1) or \(\omega_0 \cdot \alpha_0\) (eq.2)
- \(G\) contains the non-linear terms of eq. 1 and 2
- \(H\) contains the linear terms of eq. 1 and 2

Further the dissipation of wave energy \((\omega_{\text{bot}} + \omega_{\text{surf}}) \cdot \alpha_0 \cdot 0.00 \cdot d\theta\) is determined in point IX+1/2,IY,IT in the computational grid.

Structure:

*SUMDE*

<table>
<thead>
<tr>
<th>determine wave action and frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>if last corrector step is in progress then</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

The call of this subroutine is:

CALL SUMDE(IY,IT)
Parameters:

IY (I)  coordinates of point in computational grid

IT (I)

3.28 Subroutine WRIRE

Function:
In the subroutine WRIRE arrays containing wave parameters at a line in the computational grid are written to the file REKRES.

Structure:

*WRIRE*

:----------------------------------------------------:

| if line ≠ boundary x=0 then |
| write leakage of energy EL, dissipation of energy ED, fraction of breaking waves QB and the wave action transport velocity component C00 |
| to the file REKRES |

:----------------------------------------------------:

| write depth D, current velocity components UX, UY (if current is off then fill arrays with 0), wave action AO, -frequency W0, relative frequency Ω0, wave number K0, group velocity CG0 and wave action transport velocity components CX0, CY0 to the file REKRES |

:----------------------------------------------------:

The call of this subroutine is:

CALL WRIRE (IX)

Parameter:

IX (I) results of line IX in the computational grid are written to the file REKRES

3.29 Subroutine STRACE

This subroutine, called at the start of every subroutine and the main program, provides a message of the entry of this subroutine resp. program. STRACE is copied from the model CREDI2.

3.30 Subroutine MSGERR

The subroutine MSGERR, called when an error is encountered during the execution of the program COMPU, provides an error message. MSGERR is copied from CREDI2.

3.31 Subroutine COPYCH
In subroutine COPYCH character strings are copied to real variables and back. It is copied from CREDIZ.
4. STORAGE OF DATA

4.1 Dynamic data pool

As in CREDIZ a dynamic data pool is used to obtain an efficient and flexible storage of arrays. With the subroutine ADPOOL the dimension of an array can be extended or reduced. The structure of the pool is the same as in CREDIZ.

An element of an array A is found by:

\[ A(I) = \text{POOL}(IA+I), \text{IA is the adresse of array A} \]

A two-dimensional array is stored row by row:

eg.: array \( B(1:n,1:m) \)

storage in pool:

\[ B(1,1), \ldots, B(n,1), B(1,2), \ldots, B(n,2), B(1,m), \ldots, B(n,m) \]

thus \( B(k,1) = \text{POOL}(IB+(1-1)n+k) \), \( IB \) is the adresse of array \( B \)

For more detailed information on the structure of the dynamic data pool, reference is made to the system documentation of CREDIZ.

The following arrays of the program COMPU are included in the pool:

<table>
<thead>
<tr>
<th>number</th>
<th>name</th>
<th>adresse</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DEP</td>
<td>IDEP</td>
<td>depths</td>
</tr>
<tr>
<td>2</td>
<td>VX</td>
<td>IVX</td>
<td>x-component current velocity</td>
</tr>
<tr>
<td>3</td>
<td>VY</td>
<td>IVY</td>
<td>y-component current velocity</td>
</tr>
<tr>
<td>4</td>
<td>WAO</td>
<td>IWAO</td>
<td>wave action (old line)</td>
</tr>
<tr>
<td>5</td>
<td>WFO</td>
<td>IWFO</td>
<td>wave frequency (old line)</td>
</tr>
<tr>
<td>6</td>
<td>WKO</td>
<td>IKWO</td>
<td>wave number (old line)</td>
</tr>
<tr>
<td>7</td>
<td>RFO</td>
<td>IRFO</td>
<td>relative frequency (old line)</td>
</tr>
<tr>
<td>8</td>
<td>CGO</td>
<td>ICGO</td>
<td>group velocity (old line)</td>
</tr>
<tr>
<td>9</td>
<td>CXO</td>
<td>ICXO</td>
<td>x-component wave action</td>
</tr>
<tr>
<td></td>
<td>CYO</td>
<td>ICYO</td>
<td>y-component wave action</td>
</tr>
<tr>
<td>10</td>
<td>WA</td>
<td>IWA</td>
<td>transport velocity (old line)</td>
</tr>
<tr>
<td>11</td>
<td>WF</td>
<td>IWF</td>
<td>wave action (between old and new line)</td>
</tr>
<tr>
<td>12</td>
<td>WK</td>
<td>IKW</td>
<td>wave frequency (between old and new line)</td>
</tr>
<tr>
<td>13</td>
<td>RF</td>
<td>IRF</td>
<td>relative frequency (between old and new line)</td>
</tr>
<tr>
<td>14</td>
<td>CG</td>
<td>ICG</td>
<td>group velocity (between old and new line)</td>
</tr>
<tr>
<td>15</td>
<td>CX</td>
<td>ICX</td>
<td>x-component wave action transport</td>
</tr>
<tr>
<td></td>
<td>CY</td>
<td>ICY</td>
<td>y-component wave action transport</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>ICT</td>
<td>( \theta )-component wave action transport</td>
</tr>
<tr>
<td>19</td>
<td>WAN</td>
<td>IWAN</td>
<td>wave action (new line)</td>
</tr>
<tr>
<td>20</td>
<td>WFN</td>
<td>IWFN</td>
<td>wave frequency (new line)</td>
</tr>
<tr>
<td>21</td>
<td>WKN</td>
<td>IKWN</td>
<td>wave number (new line)</td>
</tr>
<tr>
<td>22</td>
<td>RFN</td>
<td>IRFN</td>
<td>relative frequency (new line)</td>
</tr>
<tr>
<td>23</td>
<td>CGN</td>
<td>ICGN</td>
<td>group velocity (new line)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>CXN</td>
<td>ICXN</td>
<td>x-component wave action</td>
</tr>
<tr>
<td>25</td>
<td>CYN</td>
<td>ICYN</td>
<td>y-component wave action</td>
</tr>
<tr>
<td>26</td>
<td>DD</td>
<td>IDD</td>
<td>derivatives in bottom geometry</td>
</tr>
<tr>
<td>27</td>
<td>DC</td>
<td>IDC</td>
<td>derivatives in current field</td>
</tr>
<tr>
<td>28</td>
<td>HM</td>
<td>IHM</td>
<td>local maximum wave height</td>
</tr>
<tr>
<td>29</td>
<td>QB</td>
<td>IQB</td>
<td>fraction of breaking waves</td>
</tr>
<tr>
<td>30</td>
<td>ET</td>
<td>IET</td>
<td>directionally integrated wave energy</td>
</tr>
<tr>
<td>31</td>
<td>FD</td>
<td>IFD</td>
<td>dissipation of wave energy</td>
</tr>
<tr>
<td>32</td>
<td>FL</td>
<td>IFL</td>
<td>leakage of wave energy</td>
</tr>
<tr>
<td>33</td>
<td>UBOT</td>
<td>IUBOT</td>
<td>orbital velocity near the bottom</td>
</tr>
<tr>
<td>34</td>
<td>UCUR</td>
<td>IUCUR</td>
<td>current velocity near the bottom</td>
</tr>
<tr>
<td>35</td>
<td>DEO</td>
<td>IDEO</td>
<td>depths (old line)</td>
</tr>
<tr>
<td>36</td>
<td>UXO</td>
<td>IUXO</td>
<td>x-component current velocity (old line)</td>
</tr>
<tr>
<td>37</td>
<td>UYO</td>
<td>IUYO</td>
<td>y-component current velocity (old line)</td>
</tr>
<tr>
<td>38</td>
<td>DEM</td>
<td>IDEM</td>
<td>depths (between old and new line)</td>
</tr>
<tr>
<td>39</td>
<td>UXM</td>
<td>IUXM</td>
<td>x-component current velocity (between old and new line)</td>
</tr>
<tr>
<td>40</td>
<td>UYM</td>
<td>IUYM</td>
<td>y-component current velocity (between old and new line)</td>
</tr>
<tr>
<td>41</td>
<td>DEN</td>
<td>IDEN</td>
<td>depths (new line)</td>
</tr>
<tr>
<td>42</td>
<td>UXN</td>
<td>IUXN</td>
<td>x-component current velocity (new line)</td>
</tr>
<tr>
<td>43</td>
<td>UYN</td>
<td>IUYN</td>
<td>y-component current velocity (new line)</td>
</tr>
</tbody>
</table>

**Table 1 arrays in dynamic data pool**

### 4.2 Common blocks

A number of common blocks are defined in which principal data for the model HISWA is included. Each of these blocks contains a certain category of information:
<table>
<thead>
<tr>
<th>name</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITEL</td>
<td>title</td>
</tr>
<tr>
<td>DEPROS</td>
<td>location and dimensions of bottom grid</td>
</tr>
<tr>
<td>REKROS</td>
<td>location and dimensions of computational grid</td>
</tr>
<tr>
<td>TRANSF</td>
<td>transformation coefficients between different grids</td>
</tr>
<tr>
<td>NUMS</td>
<td>information on the numerical scheme</td>
</tr>
<tr>
<td>TERMDE</td>
<td>terms of the balance equations</td>
</tr>
<tr>
<td>TESTDA</td>
<td>information for output control</td>
</tr>
<tr>
<td>FYSPAR</td>
<td>physical parameters</td>
</tr>
<tr>
<td>UITVDA</td>
<td>information for the program OUTP</td>
</tr>
<tr>
<td>REFNRS</td>
<td>data set reference numbers</td>
</tr>
<tr>
<td>LEESDA</td>
<td>information for reading data</td>
</tr>
<tr>
<td>POOL</td>
<td>references to arrays in the dynamic data pool</td>
</tr>
</tbody>
</table>

Table 1: Description of common blocks

Most of the common blocks are copied from the model CREDIZ. In the following only the changes with regard to the common blocks in CREDIZ are discussed. For more information reference is made to the system documentation of CREDIZ.

**TITEL** as in CREDIZ

**DEPROS** the elements AKX, CCGX and WKX are omitted

**REKROS** the following elements are added:
- MTR number of grid points in \( \theta \)-direction
- TETAA
  - boundaries of computational grid in \( \theta \)-direction
- TETAB
  - DT grid size in \( \theta \)-direction

**TRANSF** as in CREDIZ

**NUMS** contains the following elements:
- NCOR number of corrector steps
- IPRE indicator of predictor step
- ICOR indicator of corrector step
- IOBW option for the representation of the boundary condition at \( x=0 \)
- ICUR switch for the introduction of current
- IDIF switch for the introduction of diffraction
- IBOT switch for the introduction of bottom dissipation
- ISURF switch for the introduction of surf breaking
- WDIP wind direction relative to problem grid
- WDIC wind direction relative to computational grid
U10 wind velocity at 10 m. elevation
U10C wind velocity at 10 m. elevation relative to current
ADIR coefficient for directional distribution of waves
AT(300) wave action at boundary x=0
WT(300) wave frequency at boundary x=0
BDIR(300) directional distribution of waves
CDIF diffraction coefficient
PWIND(10) parameters of wind generation (a,b,c,d,a2,b2)
PBOT(5) parameters of bottom dissipation (Cfw,Cfc,a3,b3)
PSURF(5) parameters of surf breaking (1, a4, b4)

TERMDE contains the following elements:
FYA ) transportation terms in y-direction
FYF FTA ) transportation terms in θ-direction
FTF DIFA ) diffraction terms
DIFF WINDA ) wind generation terms
WINDF WBOT ) bottom dissipation terms
BOTF WSURF ) surf breaking terms
SURFF TDIS dissipation of wave energy
TLEAK leakage of energy

TESTDA as in CREDIZ

FYSPAR the following elements are omitted:
IM, DEP1, DEP2, DEP3, UX1, UX2, UX3, UY1, UY2, UY3,
AK1, AK2, AK3, CCG1, CCG2, CCG3, WKC1, WKC2, WKC3,
ISTA1, ISTA2, ISTA3, SIGMA1, SIGMA2, SIGMA3,
SINH1, SINH2, SINH3, AMPL1, AMPL2, AMPL3
the following elements are added:
DEP depth in a point in the bottom grid
UXC ) current velocity components relative to computational grid
UYC WNU wave number

UITVDA as in CREDIZ (for the time being)

REFNRS the elements HULPF1 and HULPF2 are omitted

LEESDA as in CREDIZ

POOL this block will be adjusted to the new construction
In the model HISWA a number of files are used that serve as communication tools between the programs PREP, COMPU and OUTP. Two of these files are used by the program COMPU:

a) **INSTR**

This file contains instructions formulated in PREP and data necessary for the computations carried out in the program COMPU.

**Contents:**
- NPOOL number of pool arrays
- ITEST test parameter
- **Common blocks:**
  - TITEL, DEPROS, REKROS, TRANSF, NUMS, FYSPAR, REFNRS, UITVDA, TESTDA
- **Arrays:**
  - DEP, VX, VY, OUTREQ, OUTDA

b) **REKRES**

In file REKRES the results of the computations carried out in the program COMPU are stored. This file will be read by the program OUTP.

**Contents:**
- **Common blocks:**
  - TITEL, DEPROS, REKROS, TRANSF, NUMS, FYSPAR, REFNRS
- **Arrays:**
  - DEP, VX, VY
  - DEN, UXM, UYN, WAN, WFN, RFN,
  - RFN, WKN, CGN, CXN, CYN
  - FL, FD, QB, CT

Each array in the files described above is preceded by the dimension of the array. The same conventions as described under 4.1 are applied with regard to the storage of two-dimensional arrays. Files are read and written unformatted.
REFERENCES


CREDIZ01 system documentation, 1984 (in Dutch)

Holthuijsen, L.H. and Booij, N., 1983, Selection and formulation of a numerical shallow water wave hindcast model, Delft University of Technology, Report no 1783