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<td>MODELLING OF WAVES AND CURRENTS IN THE BELGIAN COASTAL ZONE USING THE COUPLED HYDRODYNAMIC AND WAVE MODELS TELEMAC-2D AND TOMAWAC.</td>
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<td><strong>Autor/a</strong></td>
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<tr>
<td>ALEJANDRO QUESADA VÁZQUEZ</td>
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<tr>
<td><strong>Tutor/a</strong></td>
</tr>
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</table>
| OCTAVIO CÉSAR MÖSSO ARANDA  
JAAK MONBALIU (KU LEUVEN) |
| **Departament** |
| DEPARTAMENT D’ENGINYERIA HIDRÀULICA, MARÍTIMA I AMBIENTAL |
| **Intensificació** |
| |
| **Data** |
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Alejandro Quesada
Abstract

Nowadays, the coastal and offshore zones get a relevant importance due to the increasing economic and environmental actions towards them, for this reason the understanding of the processes taking part in this zone becomes essential.
Many studies talk about the importance of the physical effects of bottom morphology and dynamics involved in hydrodynamic and wave processes, modifying currents velocity profiles and energy content in wave field.
Therefore, two different numerical models were implemented in order to simulate the hydrodynamics flow and wave field belonging the North Sea zone, emphasizing the Belgian coast. In order to not lose details, I set up both models separately in first instance, and then the software let me coupled them afterwards to see the importance of both joint effect.
Telemac2D is the software that models the changes, through time and spatial domain, of the depth of water and the two velocity components. While Tomawac is the software that models the changes of the spectro-angular density of wave action, both in oceanic domain, in intracontinental seas as well as in shallow waters.
First of all, I needed a solvent background theory and literature regarding hydrodynamics processes and wave dynamics to deal with the different problems I would have doing the implementation of the models.
Thereafter, I started defining the new mesh, followed by the implementation of the new bathymetry file, both together forming the new geo file, and then the boundary conditions file. Once I had all of them implemented, I had the basic part of boundary conditions of both models.
Secondly was the time of the implementation separately of both models due to the differences between the files that belong to each one. Here starts the implementation of Teleamc2D: the meteorology file, the fortran file and the steering file, which together, leave the model ready to be run. Then was the turn of Tomawac following same steps.
Finally I made the changes needed to couple both and for a properly run in order to have realistic results to compare afterwards with real results extracted from the data base of 4 sea stations proving if the work is well done.
Resumen

Hoy en día, las zonas costeras y de offshore reciben una importancia muy relevante, debido a las crecientes acciones económicas y ambientales hacia ellas, por esta razón, la comprensión de los procesos que participan en esta zona se convierte en esencial.

Muchos estudios hablan de la importancia de los efectos físicos de la morfología del fondo y las dinámicas que intervienen en los procesos hidrodinámicos y de oleaje, modificando los perfiles de las corrientes de velocidad y el contenido de energía en el campo de oleaje.

Por lo tanto, se llevaron a cabo dos modelos numéricos diferentes con el fin de simular el flujo de la hidrodinámica y campo de oleaje que pertenece la zona del mar del Norte, haciendo hincapié en la costa belga. Con el fin de no perder detalles, he creado dos modelos por separado en primera instancia, y luego el software me deja acoplarlos después para ver la importancia del efecto en conjunto.

Telemac2D es el software que modela los cambios, a través del tiempo y el dominio espacial, de la profundidad del agua y los dos componentes de la velocidad. Mientras Tomawac es el software que modela los cambios de la densidad spectro-angular de la acción del oleaje, tanto en el dominio oceánico, en mares intracontinentales, así como en aguas poco profundas.

En primer lugar, necesitaba una solvente y amplia teoría y literatura, en relación con los procesos hidrodinámicos y dinámica del oleaje para hacer frente a los distintos problemas que tendría que hacer frente en la aplicación de los modelos.

A partir de entonces, empecé a definir la nueva malla, seguido de la aplicación del nuevo archivo de batimetría, los dos juntos forman el nuevo archivo geo, y luego implementar el archivo de las condiciones de contorno. Una vez que tuve todos ellos implementados, tuve la parte básica completa de las condiciones de contorno de ambos modelos.

En segundo lugar era el momento de la aplicación por separado de ambos modelos, debido a las diferencias entre los archivos que pertenecen a cada uno. Aquí comienza la ejecución de Telemac2D: el archivo de la meteorología, el archivo fortran y el archivo steering, que en conjunto, dejan el modelo listo para ser ejecutado. Luego fue el turno de Tomawac siguiendo los mismos pasos.

Finalmente hice los cambios necesarios para acoplar los dos y realizar una computación adecuada para poder tener resultados realistas para comparar éstos después con resultados reales extraídos de la base de datos de 4 estaciones marítimas que demuestren si el trabajo está bien hecho.
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List of abbreviations and symbols

- $\pi$ The number pi
- $\zeta$ Water level
- $\partial$ Partial derivative
- $g$ Standard gravitational acceleration
- $h$ The mean water depth
- $U,V$ The mean flow velocity in the two directions $x$ and $y$.
- $U$ The total velocity
- $\nu_t$ The diffusion coefficient
- $S,Q$ Source or sink terms in the dynamic equations
- $\varphi,\lambda$ The origin point of the new coordinate system (longitude, latitude)
- $R$ The radius of the Earth
- $X,Y$ Longitude and Latitude according to the Mercator projection
- $t$ The time referred to 0 hour at GMT (Greenwich Mean Time)
- $n$ The vector normal
- $A$ The amplitude
- $f$ The nodal factor
- $\omega$ The intrinsic frequency
- $G$ The phase lag behind the phase of the corresponding constituent at Greenwich.
- $V$ The uniformly changing part of the phase of the constituent at the Greenwich meridian
- $u$ The nodal adjustment of the tidal constituent.
- $\rho_{air}$ The air density
- $\rho_{\omega}$ The water density
- $a_{vent}$ The wind resistance coefficient
- $P$ The total pressure
- $P_A$ The atmospheric pressure
- $C_{fr}$ The dimensionless friction coefficient
- $\tau$ The bottom shear for 2D depth average flow
- $C_r$ The Chezy friction factor
- $\alpha$ The angle
- $H$ The wave height for a monochromatic wave
- $\omega_E$ The angular velocity of the earth
- $N$ The wave action density
- $F$ The energy density
- $c_x,c_y$ The absolute group velocities in $x$ and $y$ direction
- $c_\Omega$ The absolute frequency
- $c_\theta$ The rate of change of wave direction
- $\Omega$ The absolute frequency
- $\theta$ The wave direction relative to the north
- $k$ The wave number vector
- $\Psi_{inl}$ The linear growth
- $\Psi_{ine}$ The exponential growth
- $\beta$ The so-called Miles parameter function of the wave age and the wind profile parameter
- $\epsilon$ The ratio between air and water density
- $u_*$ The wind friction velocity
- $c$ The phase speed of the waves
- $z_{st}$ The constant allowing to offset the growth curve
- $\theta_{u*}$ The wind direction
- $\eta$ A constant given by the sea state
- $C_{dis}$ A constant given by the model
- $m_0$ The total variance
- $\kappa$ The average intrinsic frequency and wave number
- $C_f$ A constant which include several factors leading to high uncertainties in its determination
- $\Gamma$ The JONSWAP constant
- $\gamma$ The breaking index
- $H_{max}$ The maximum wave height
Chapter 1: Introduction

The aim of this thesis is modelling the dynamics within the North Sea through Telemac2D and Tomawac programs coupled. The reason is the importance to have a tool to deal with the peculiar geomorphologic location that includes this shelf sea, between ocean and shore, which contain several forces influence the flow and the bottom dynamics of it, which are currents and waves.

Tides are oceanic waves that are composed by a very long wavelength and small amplitude in deep water (astronomic tide), which is the most important factor within currents. But while the tide is approaching the shelf continent, the amplitude starts to increase causing the retard of the wave crest. This effect is associated with the enhancement of the tidal current, which becomes the main water movement in any shelf sea. Even though the tidal are modified to a greater or lesser extent, by irregular factors: atmospheric pressure, winds acting on the sea surface, limited water depth, the presence of the sea floor which is responsible for frictional effects, and others. Telamac2D is the program which I solved all this equation within tide influence.

Telamac2D is used to simulate free-surface flows in two dimensions of horizontal space. At each point of the mesh, the program calculates the depth of water and the two velocity components. [www.opentelemac.org]

Wave propagation has also an important influence that changes due to irregular factors too: wind, whitecapping, influence of the bottom, deep and interactions between waves in shallow waters. Here the program, which helps me to solve these equations, will be Tomawac.

Tomawac is used to model wave propagation in coastal areas. By means of a finite-element type method, it solves a simplified equation for the spectro-angular density of wave action. This is done for steady-state conditions (i.e. with a fixed depth of water throughout the simulation). [www.oceanide.net]

So, the set-up of this numerical model involves a series of intermediate steps which need to be carried out to reproduce the physical phenomena in the most accurate way as possible taking into account the limitation of computational resources. So they will be easier to test them separately in first instance, what is demonstrated that is a useful approach for a comparison with analytical solutions and for testing the model, and then I will try to run it together.

Also is going to be interesting to compare both models with and without the effect of the meteorology in order to know how it affects over the tides.

Finally I will see if the programs have been implemented correctly comparing the results obtained with real results of some studies and operative sea stations.
Chapter 2: Mathematical modelling procedures used by TELEMAC2D

Here is explained which mathematical equations are used and how is transcribed in the computational language.

2.1 Mathematical modelling procedures used by TELEMAC2D

Telemac-2D is a two-dimensional finite element model, which is able to solve the depth averaged Saint-Venant equations. The main results at each node of the computational mesh are the depth of water and the depth-averaged velocity components. The main application of TELEMAC-2D is in free-surface maritime or river hydraulics [Manual of Telemac]

In this section are described the equations that define the different processes used by Telamac2D, which are separately illustrated in: astronomical tides, atmospheric conditions, bottom friction, Coriolis force and turbulence.

Also is described, in a subsection of each process, how Telemac2D transforms these equations to be available to the calculation through changes in the subroutines inside the Fortrain file: north_sea_scheldt. (Previously implemented by Alessio). [All the theory information of this chapter is taken from the thesis: Numerical modelling of sediment transport in shelf seas and estuaries, Alessio Giardino]

2.1.1 Shallow Water equations

These equations are represented by Navier Stokes equations. Deriving these and assuming constant density on the vertical hydrostatic pressure distribution, we obtain a continuity equation (equation 2.1), and two momentum equations (equations 2.2 and 2.3), which belong Newton’s second law for a volume of water in the two directions.

\[ \frac{\partial h}{\partial t} + \mathbb{U} \cdot \nabla (h) + h \text{div} (\mathbb{U}) = S_h \quad (2.1) \]
\[ \frac{\partial U}{\partial t} + \mathbb{U} \cdot \nabla (U) = -g \frac{\partial h}{\partial x} + S_x + \frac{1}{h} \text{div} (hv_t \nabla U) \quad (2.2) \]
\[ \frac{\partial V}{\partial t} + \mathbb{U} \cdot \nabla (V) = -g \frac{\partial h}{\partial y} + S_y + \frac{1}{h} \text{div} (hv_t \nabla V) \quad (2.3) \]
Where \( h \) is the water depth, \( g \) the gravity acceleration, \( U \) and \( V \) are the flow velocity in the two directions \( x \) and \( y \). \( S_h \) is the source or sink of fluid term. \( \bar{U} \) represents the total velocity and \( v_t \) the diffusion coefficient. Finally there are two terms, \( S_x \) and \( S_y \), which are source or sink terms in the dynamic equations representing the wind and the atmospheric pressure, The Coriolis force, the bottom friction and additional sources or sink of momentum within the domain in the two directions \( x \) and \( y \).

- **Shallow Water equations data to spherical coordinates**

First of all, as the hydrodynamic simulations are performed over a large domain, in this case the North Sea, Telemac-2D offers the chance to solve the Saint Venant equations in spherical coordinates according to the Mercator projection. So in this case we have to solve the equations in a new coordinate system \((X,Y)\), function of the spherical coordinates according to the following equations (equations 2.4 and 2.5):

\[
X = R(\varphi - \varphi_0) \quad (2.4)
\]

\[
Y = R\left[\ln \left(\tan \left(\frac{\lambda}{2} + \frac{n}{4}\right)\right) - \ln \left(\tan \left(\frac{\lambda_0}{2} + \frac{n}{4}\right)\right) \right] \quad (2.5)
\]

Where \( \varphi \) and \( \lambda \) are the origin point of the new coordinate system and \( R \) is the radius of the Earth.

To translate it into the model, two subroutines were modified previously, to perform internally in the model the change of coordinate from \( \varphi \) and \( \lambda \) to \( X \) and \( Y \) according Mercator projection (Giardino and Monbaliu 2004). These are \texttt{CORRYX.f} and \texttt{ERCGEO.f} subroutines.

2.1.2 Astronomical tides

Water level can be predicted in function of time and location with a high accuracy by a superposition of the main tidal components by the Equation 2.6. The values obtained through this, can be used to define the variable water depth in the shallow waters equations described previously, at the open boundary of the domain (Dronkers, 1964).

\[
\zeta = \sum_{n=1}^{N} f_n A_n \cos[\omega_n t - G_n + (V_n + u_n)] \quad (2.6)
\]

Where \( t \) is time referred to 0 hour at GMT (Greenwich Mean Time), \( n \) is the index of the tidal constituent and then \( A_n \) is the amplitude of the tidal constituent, \( f_n \) is the nodal factor of the tidal constituent, \( \omega_n \) is the frequency of the tidal constituent and \( G_n \) the phase lag of the tidal constituent behind the phase of the corresponding constituent at Greenwich.

The expression of \((V_n + u_n)\) means the value of the equilibrium argument of the tidal constituent, where \( V_n \) is the uniformly changing part of the phase of the constituent at the Greenwich meridian and \( u_n \) is the nodal adjustment of the tidal constituent (Yu, 1993).
• Boundary conditions data

In Telemac-2D this term is distinguished between two sorts of boundary: solid and liquid.

In the case of solid boundary, due to there is a no-flux condition, the equation 2.7 is imposed:

$$ U \cdot n = 0 \quad (2.7) $$

Where $U$ is the mean current velocity and $n$ is the vector normal to the solid boundary.

In the case of liquid boundary, a tidal elevation can be prescribed if measurements of water elevations are calculated. Equation 2.7 was programmed in order to compute a water elevation in a location and a time given. This calculation is implemented in the model through a subroutine named BORD.f and the function SL.f, following the implementation adopting in the 2D Hydrodynamic Model developed by the Management Unit of Mathematical Models of North Sea (MUMM) (Van de Eynde et al., 1995).

The simulation has to start with a prescribed water level (0 m), the same in all the points in the domain (North Sea). A linear interpolation is performed to pass from the prescribed water lever to the value calculated by Equation 2.7 (subroutine BOARD.f) at the open boundary.

2.1.3 Atmospheric conditions

In this section appear two of the different parts that compose the source terms $S_x$ and $S_y$ in the momentum equations of shallow water equations. These are the wind resistance and the atmospheric pressure.

a) Wind resistance

Can be calculated by these equations (equations 2.8 and 2.9). The free surface’s smoothness and the level above it rule the wind influence. Where the wind speed is measured conventionally is 10m above the free surface.

$$ S_{or_x} = \frac{1}{h} \frac{\rho_{\text{air}}}{\rho_{\omega}} a_{\text{vent}} U_{\text{vent}} \sqrt{U_{\text{vent}}^2 + V_{\text{vent}}^2} \quad (2.8) $$

$$ S_{or_y} = \frac{1}{h} \frac{\rho_{\text{air}}}{\rho_{\omega}} a_{\text{vent}} V_{\text{vent}} \sqrt{U_{\text{vent}}^2 + V_{\text{vent}}^2} \quad (2.9) $$

Where is established a relation between $\rho_{\text{air}}$, which is the air density and $\rho_{\omega}$, which is the water density, and depending on $a_{\text{vent}}$, which is the wind resistance coefficient and the velocity in the two components ($U_{\text{vent}}, V_{\text{vent}}$).

Is known that atmospheric pressure responds sea level according to an inverse proportional relationship (equation 2.10) (Pugh, 1987). The total pressure $P$ is the sum of the atmospheric pressure and the weight of the water above the same point.

$$ P = P_A - \rho_{\omega} g (h - \xi) \quad (2.10) $$
The sum has a negative sign because the sea level increases upwards while $h$ is negative below the water surface.

If we assume that equilibrium conditions with no currents are reached after the application of a pressure field and we neglected the influence of additional source terms and differentiating the previous equation, the term can be added to the source terms of the momentum equations as (equation 2.11):

$$ S_{or} = -\frac{1}{\rho_w} \nabla P_A \quad (2.11) $$

- **Wind and Atmospheric pressure data**

  a) Wind data

  This term is calculated in the model as the resistance of the wind through the equations 2.9 and 2.10. To achieve this, is used a bilinear interpolation to interpolate the wind field on the mesh (program `PREWIND.f`). This field is computed at the computational time by means of a linear interpolation (subroutine `METEO.f`).

  Then, for a more accurate calculation of the wind resistance, the coefficient of wind drag $a_{vent}$, can be calculated as a relationship with the wind velocity. It is done through the subroutine `PROSOU.f`, which was implemented to define this coefficient according to the formulation provided by the Institute of Oceanographic Sciences (United Kingdom):

  \[
  \begin{align*}
  &\text{if } |U_{vent}| < 5 \text{ m/s} \quad \quad \quad \quad a_{vent} = 0.565 \times 10^{-3} \\
  &\text{if } 5 < |U_{vent}| < 19.22 \text{ m/s} \quad a_{vent} = (-0.12 + 0.137 \times |U_{vent}|) \times 10^{-3} \\
  &\text{if } |U_{vent}| > 19.22 \text{ m/s} \quad a_{vent} = 2.513 \times 10^{-3}
  \end{align*}
  \]

  b) Atmospheric data

  This term is calculated through the Equation 2.12 added in the momentum equations as and additional source terms. In the model, the same subroutines are used for wind speed are used to interpolate the pressure data on the mesh at the computational time.

  $$ S_{or} = -\frac{1}{\rho_w h} \nabla P_A \quad (2.12) $$

  2.1.4 Bottom friction

  The effect that it produces is removing energy from the water motion. The main problem is to parameterize this term according to all physical parameters, which play a significant role in its definition: current field, wave field, water depth, and bottom roughness.

  The bottom shear for 2D depth average flow is represented by the following quadratic law (equation 2.13):
\[ \tau = \frac{1}{2} \rho_w C_{fr} U |U| \]  \hspace{1cm} (2.13)

Where \( C_{fr} \) is the dimensionless friction coefficient and \( U \) is the average flow velocity. \( C_{fr} \) is commonly described by the Chezy friction factor: \( C_h \) (equation 2.14):

\[ C_{fr} = \frac{2g}{C_h^2} \]  \hspace{1cm} (2.14)

Therefore, the equation that can be added to the momentum equation is (equation 2.15):

\[ S_{or} = -\frac{1}{\cos \alpha} g \frac{h}{C_h^2} U |U| \]  \hspace{1cm} (2.15)

Being \( \alpha \) the angle between the steepest slope at the bottom and the bottom friction direction.

• Bottom friction data

This term is taken into account by adding to the momentum equations and additional source terms represented by equation 2.15. We define it through a relationship between Chezy coefficient which vary as a piecewise depending of the depth through a linear function:

\[
\begin{align*}
\text{if } h &\leq 50m \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \q
Where $\omega_E$ is the angular velocity of the earth and $\lambda$ the latitude. This equation is implemented in the subroutine PROSOU.f.

2.1.6 Turbulence modelling

All the instantaneous variables that compose turbulent flows used to be decomposed into a mean and fluctuating value because mean quantities are generally more practical than instantaneous values either because these instantaneous variables need a too high resolution in space and time. At the same time of averaging these variables, the system introduces additional terms, which form the Reynolds tensor, correlating the fluctuating velocities. The resulting system is not closed so this leads to turbulence models called closure models. These models allow the calculation of the diffusion coefficient $\nu_t$ in the momentum equations.

For large scale applications is often used a constant diffusion coefficient as long as it does not require a flow with detailed resolution as in our case, tidal simulations.

2.2 Mathematical modelling procedures used by TOMAWAC

TOMAWAC depicts the general principles of Wave dynamics, solving the balance equation of wave action density (Action balance equation 2.19), models the changes, both in the time and in the spatial domain, of the power spectrum of wind-driven waves and wave agitation for applications in the oceanic domain, in the intercontinental seas as well as in the coastal zone. In this section is described the physical forces which drive the wave field propagation in time and space. [All the theory information of this chapter is taken from the thesis: Numerical modelling of sediment transport in shelf seas and estuaries, Alessio Giardino, and Manual of Tomawac]

The main source term $Q$ (equation 2.18), includes inputs from: Wind ($Q_{in}$), Dissipation of Whitecapping ($Q_{ds}$), Wave dissipation at the bottom ($Q_{bf}$), Depth induced breaking ($Q_{br}$), Nonlinear wave-wave interactions ($Q_{nt}$, $Q_{tr}$).

$$Q = Q_{in} + Q_{ds} + Q_{nt} + Q_{bf} + Q_{br} + Q_{tr} \quad (2.18)$$

2.2.1 Action balance equation

The wave field is used to describe as the energy density spectrum in frequency and direction, where $\omega$ is the intrinsic frequency and $\theta$ the propagation direction. However when the current is not uniform, the wave energy is not conserved because of the exchange of energy between currents and waves, due to a new quantity is introduced as wave action, which is conserved during the propagation (Phillips, 1977). So, the generalized action balance equation is given by by Komen (1994) (equation 2.19), which governs the wave evolution in Cartesian coordinates.

$$\frac{\partial N}{\partial t} + \frac{\partial (c_x N)}{\partial x} + \frac{\partial (c_y N)}{\partial y} + \frac{\partial (c_\Omega N)}{\partial \Omega} + \frac{\partial (c_\theta N)}{\partial \theta} = S_{tot}(x, y, t, \Omega, \theta) \quad \omega \quad (2.19)$$
Where $N$ is the wave action density, and is defined as (equation 2.20):

$$N = \frac{E}{\omega} \quad (2.20)$$

Being $F$ the energy density

The $t$ corresponds to time. The constants $c_x$ and $c_y$ are the absolute group velocities in $x$ and $y$ direction. While $c_\Omega$ is the absolute frequency and $c_\theta$ the rate of change of wave direction. Then $\Omega$ is the absolute frequency and $\theta$ is the wave direction relative to the north. $\Omega$ can be found through the equation 2.21:

$$\Omega = \omega + k \cdot \mathbb{U} \quad (2.21)$$

Where $k$ is the wave number vector and $\mathbb{U}$ is the velocity of the medium in which waves propagate. Finally the result $S_{tot}$ is the total source term.

2.2.2 Wind input

The main input for the growth of waves is which is produced by the wind (equation 2.22). This mechanism is considered produced by two stages: linear ($\Psi_{inl}$) and exponential ($\Psi_{ine}$) growth:

$$S_{in} = \Psi_{inl} + \Psi_{ine}F(\omega, \theta) \quad (2.22)$$

In the early stage, the small pressure fluctuations associated with turbulence in the airflow above the water induce small perturbations on the sea surface, represented on a linear growth (Phillips 1957). Once the waves have grown to a sufficient size, most of development starts affecting the air above them, and then the input from the wind at this stage depends on the size of the waves and is represented as a exponential growth (Miles 1957).

- Wind input data

Three formulations are available in Tomawac in order to calculate the wind input. Janssen formula (equation 2.23) is which is used in this thesis. The linear term growth is ignored and only the exponential energy growth is taking into account.
\[ S_{in} = \omega \varepsilon \beta \left( \frac{u_*}{c} + z_d \right) \max \left[ \cos (\theta - \theta_w); \sigma \right] F(\omega, \theta) \] (2.23)

Where \( \omega \) is the intrinsic frequency, \( \varepsilon \) is the ratio between air and water density and \( \beta \) is the so-called Miles parameter function of the wave age and the wind profile parameter. Then all of them multiply with a expression formed by \( u_* \), which is the wind friction velocity, \( c \) the phase speed of the waves, \( z_d \) the constant allowing to offset the growth curve, \( \theta \) the propagation direction of waves, \( \theta_w \) the wind direction and \( F(\omega, \theta) \) the energy density spectrum.

2.2.3 Whitecapping

The main input in deep water is the dissipation source of whitecapping. This is because the growth of the waves is limited by a point when waves reach a critical steep-ness and then they break. The mathematical description of the dissipation due to whitecapping is given by Hasselmann (1974) (equation 2.24).

\[ S_{wc} = -\eta \omega^2 F(\omega, \theta) \] (2.24)

Where \( \eta \) is a constant given by the sea state.

- **Whitecapping data**

This input is calculated according to the dissipation model of Konen and Janssen (1991) (equation 2.25), for a finite water depth.

\[ S_{wc} = -\frac{1}{2} C_{dis} \omega \kappa m_0^2 \left[ \frac{k}{\kappa} \left( 1 - \delta \right) \left( \frac{k}{\kappa} \right)^2 \right] F(\omega, \theta) \] (2.25)

Where \( C_{dis} \) and \( \delta \) are two constants given by the model, \( m_0 \) is the total variance, \( k \) the wavenumber and \( \kappa \) the average intrinsic frequency and wave number.

2.2.4 Wave dissipation at the bottom

When the sea is around shallow waters, the orbital motion induced by the surface waves extends down to the bottom. The interaction used to follow different processes and at the same time these depend on the bottom conditions. A expression for the wave energy dissipation due to the bottom friction was obtained by Komen (1994) (equation 2.26), from the linearized momentum equations for the bottom boundary layer flow

\[ S_{bf}(k) = -2C_f \frac{k}{\sinh 2kh} F(k) \] (2.26)

Several factors are included in the parameter \( C_f \) leading to high uncertainties in its determination like the bottom roughness and the interaction between waves and currents might increase the bottom friction.
• **Wave dissipation at the bottom data**

The expression used corresponds to the JONSWAP model proposed by Hasselman (1973) (equation 2.27), an empirical expression, which represents all the contributions, to wave dissipation at the bottom: percolation, friction and bottom motion.

\[ S_{bf} = -\Gamma \frac{2k}{g \cdot \sinh(2kh)} F(\omega, \theta) \]  

(2.27)

This expression corresponds to the JONSWAP model presented by Hasselman. \( \Gamma \) is a constant with a default value of 0.038 m\(^2\) s\(^{-3}\) in accordance with JONSWAP experiments.

2.2.5 Deep induced breaking

When a wave is in a shallow waters and it progresses, its crest tends to increase its speed with respect to the trough. It happens till the crest attains a sufficient speed to overtake the preceding trough, then the face of the wave becomes unstable and the crest falls along the forward face of the wave. Is possible to calculate the maximum wave height \( H_{max} \) through a function of the local water depth \( h \) (Holthuijsen, 2007) (equation 2.28).

\[ H_{max} = \gamma h \]  

(2.28)

Where \( \gamma \) is a breaking index with an average value of 0.73

• **Depth induced breaking data**

Four different expressions are implemented in TOMAWAC, in this thesis is used the first option, the Battjes and Janssen model (1978), which is based on the analogy between depth-induced breaking and hydraulic jump. \( H_{max} \) is calculated through the equation 2.28.

2.2.6 Nonlinear wave-wave interactions

The propagation of the wave energy can be affected by this kind of conditions. Then, the conditions that affect in the propagation depend on the depth. In deep water the mechanism is determined by an interaction between four wave components (Quadruplet wave-wave interactions). This mechanism transfer wave energy from the spectrum peak to lower frequencies, moving the peak frequency to lower values, where the energy is dissipated by whitecapping. The DIA method, developed by Hasselman (1985), is used for the calculation, which reduces the space to two-dimensional space where the interaction happens between two pairs of configurations. However in shallow waters only affects the mechanism of the interaction between three conditions (Triad wave-wave interactions). This mechanism is very important for steep waves, where the energy transfer can take a place over
short distances changing radically from single peaked spectra into multiple peaked spectra. In this case this conditions are negligible interaction mechanism due to the thesis is studying out-side the surf zone and the shallow zone is too little, if we had used this term, the time of computation would have been too big to be useful.

To sum up, the source term $Q_{tot}$ is given by the wind input $Q_{in}$, dissipation input $Q_{ds}$ and non-linear wave-wave interactions $Q_{nl}$. The importance of each source takes place depending on the frequency. In lower frequencies the non-linear interaction is the dominant growth agent whereas mid frequencies are dominated by the input from the wind. Finally for high frequencies the dissipation term is mostly important.
Chapter 3: Implementation of North Sea model

Before a coupling computation, I follow a scheme that the figure 1 shows, to sort out the different problems I will have during the implementation. The best choice I though was first of all do the implementation of Telemac alone, after it, do the implementation of Tomawac alone, and then once I'll have both working properly, do the implementation of the coupling model in order to at last both programs work at the same time with a correct time relation between both results.

For these computations, a set of files must be used by TELEMAC-2D as input or output. Also exist other optional files depending on the model and program used.

The obligatory input files are the following:

- The geometry file, containing the mesh, the bottom and the bathymetry data,
- The boundary conditions file, containing the description of the type of each boundary,
- The Meteo file, containing the information regarding the meteorology of the zone
- The FORTRAN file, containing the specific programming,

- The steering file, containing the configuration of the computation,

3.1 The implementation of TELEMAC2D

The following points describe the information about the needed files to work with the software Telemac-2D. All the files described below are going to be saved in Telemac folder Before explain them point by point, I have to introduce the program through I characterize the new bathymetry and boundary files and through I can plot the results I'm going to have once the model has been run. It is Blue Kenue™ that is an advanced data preparation, analysis, and visualization tool for hydraulic modellers. It provides a state-of-the-art interface, integrating geospatial data with model input and results data. Blue Kenue provides direct import of model results from TELEMAC, ADCIRC and HydroSim.[National Research Council Canada, Blue Kenue]

3.1.1 Geometry file

Main input parameters consist in a bathymetry file (given by Alessio) on which the computational mesh is built, where boundary condition are distinguished between open and closed, also wind and pressure data. Bottom friction is regarded as the main source of momentum, which is having more importance while the water depth is decreasing. The higher number of tidal constituents need to be taken into account because of the complex bathymetry in the proximity of the Belgian coast (many sand banks and gullies) and the correct representation of the wave field which requires a model able to both simulate locally wind waves and waves which have travelled a long distance from the generating area (swell), different bathymetric data were used, with a high spatial resolution of Belgian shelf, but with extension sufficiently wide for a correct representation of the hydrodynamic and wave processes. Because of it, the choice of a model based on finite element scheme was determinated by the possibility of running at once the computation over the whole domain, with the possibility to highly refine the area of interest at the same time. [Numerical modelling of sediment transport in shelf seas and estuaries, Alessio Giardino]

- The Mesh

First of all, I tried to characterize a new mesh through the North_Sea_2015 implementation folder of June 2002 implemented by Osuna, using the file Geo_NorthSea.slf, but the procedures it needed to be run, gave wrong results at the moment when I checked amplitudes and tidal phases in the time series of each node near from the coast once the model has been run before. It was because when I created the new mesh with a randomly distributions of the nodes, the boundary conditions change and then they didn’t correspond with the bathymetry data (Appendix 1). So, I chose another procedure to get a mesh with rational correct results and this one is which is explained in this part. How I didn't know how to fix it, I asked for help to
people who is working with Telemac-2D in the University of Brussels. Then they provided us information that we can build a correct mesh with a program called Gmsh™.

Gmsh™ is a 3D finite element grid generator with a build-in CAD engine and post-processor. Its design goal is to provide a fast, light and user-friendly meshing tool with parametric input and advanced visualization capabilities. Gmsh is built around four modules: geometry, mesh, solver and post-processing. The specification of any input to these modules is done either interactively using the graphical user interface or in ASCII text files using Gmsh’s own scripting language. [Online in geuz website]

- First, I extracted the outline of the mesh from the old mesh through the Blue Kenue™ program and I made it as a text file that contains the coordinates of every point saving it as a geo file. How I did it:

  1. The figure 2 shows how I opened the old North Sea file in the Blue Kenue

![Figure 2: First step, old bathymetry file view](image)

2. Then, the figure 3 shows the following step, which was the extraction of the shorelines file of the Bottom file to redefine a new mesh with the same boundaries, so I clicked on the Tools command at the top bar -> T3 Mesh -> Extract Edges (Shorelines).
2. The figure 4 shows what was the result. Then it has to be saved as a geofile: *NorthSea_with_BC_Node.geo*.

A geo file contains information about how to load an image, and how to calibrate it so that the software can determine the lat/long of each pixel, for example in this case the points, lines, loops, surface and outlines which compose the whole map through I’ll characterize the new mesh. Also it could be define through different programs as ArcGis or Matlab.
The figure 5 shows the second step, which was open the file (NorthSea_with_BC_Node.geo) in the Gmsh and define the node density in the domain, connecting all the points which compose the outline through the tab: Modules->Geometry->Elementary entities-> Add->B-Spline, and transforming this in a whole surface in order to build the mesh through the tab: Modules->Geometry->Elementary entities-> Add->Plane Surface.

-Then the figure 6 shows the third step, which was open the Mesh tab and do one click on the 2D tab. Then can be seen the mesh inside the boundaries of the North Sea map, save to use later as the new mesh of the bathymetry file.
Once I had the mesh saved, Fourth and last step was use the matlab files provided by Dr. Olivier Gourgue (http://www.oliviergourgue.net/) to transform the .msh format to selafin format that can be used in Telemac and in a file available for Blue Kenue view and available to work with the mesh there. These files can be found in the folder Mesh Generation inside the folder Telemac with the matlab extension (.m). Running this files beside the mesh generated, I obtained the new available mesh file called: New Mesh.t3s.

- **Bathymetry file**

Once I had the mesh opened in the Blue Kenue™, the next step, which was to do the bathymetry data, which I made following these steps.
1. Open a New Selafin Object, how the figure 7 shows
2. Put the New Mesh, which I renamed BOTTOM, on the New Selafin file which is in the WorkSpace. How figure 8 shows.

![Figure 8: New mesh in Blue Kenue](image)

3. Then, how figure 9 and 10 show, click on BOTTOM (our new mesh) and click on the Tools command at the top bar -> Map Object -> click on the old BOTTOM on the list and click ok.

![Figure 9: Situation of the Map object, third step](image)
Figure 10: Connection between the old and new Bathymetry files

4. Figure 11 and 12 show the fourth step, which was do Right Click on the new BOTTOM → Properties. Then a window is opened, click on the Colour Scale section and click the command Reset and click ok. Then can be seen the bathymetry in 2D View window, through the BOTTOM file.

Figure 11: How to see the new Bathymetry file (1)
3.1.2 Boundary conditions

Each line of this file is dedicated to one point of the mesh boundary. The numbering of the boundary points is the same as that of the lines of the file. It describes first of all
the contour of the domain in a trigonometric direction, and then the islands in the opposite direction. [Manual of Telemac]
In order to the bathymetry becomes valid and the program accepts it in the calculation, I must follow a series of steps.
The figure 14 shows the first of these, which is the definition of the boundary conditions. It is done through the command File at the top bar -> New -> Boundary Conditions (Conlim)...

Figure 13: How to create a new boundary conditions file (1)

Then a new window appears, how figure 15 shows, where must be chosen the new mesh clicking on the option and clicking ok later.

Figure 14: How to create a new boundary conditions file (2)
And a new file is created in the Work Space named BOTTOM_BC. Now I put it on the 2D View window, and how the figure 16 shows, I defined the open boundary clicking on the first node of the open part (part without land limitation). Then press Shift in the keyboard and while it is pressed, click on the last node of the open part.

![Figure 15: How to create a new boundary conditions file (3)](image1)

Then the open boundary will be marked. So the figure 17 shows the next step, which is done a right click on the boundary marked and click on the Add Boundary Segment option. With this action a new window is opened.

![Figure 16: How to create a new boundary conditions file (4)](image2)
How the figure 18 shows, in this window must be changed the boundary Code to Open Boundary with prescribed H (sea level). And then click ok. The changes can be seen in the subfile (table) of the file BOTTOM-BC.

Figure 17: How to create a new boundary conditions file (5)

Now the following step is SAVE all the files in the same new folder where redirect the program when it will be calculating. In my case, how the figure 19 shows, I saved the selafin file (renamed Geo_NorthSea) and the boundary file (renamed BC_North Sea) in Telemac folder where I'm going to save all the files I will create.

Figure 18: View of the new boundary conditions file saved in the Telemac folder
3.1.3 Meteo

TELEMAC-2D can be used to simulate flow while taking into account the influence of a wind blowing on the water surface and the atmospheric pressure. First is necessary to modify the previous file given by Alessio of 2004, which is a text file called meteoJun2004 that contains a register of the meteo during 18 days of March 2004. The new file was characterized by Prewind code due to the new boundary and bathymetry files.

- **Prewind Code**

The following step, how the figure 20 shows, is to modify the Prewind program to fit it in the new mesh. So first of all I searched it in the North Sea folder. Once found the prewind.f file, double click to open it.

![Figure 19: Situation of the prewind.f file](image)

The figure 21 shows how it is opened it in a Visual program as a Matlab implementation done by Alessio Giardino in 2004. There I changed the number of nodes and elements for the new ones I checked in the properties of the New Mesh in Blue Kenue program. It was: Nodes=12760/ Elements= 24584.
• **New Meteo File**

To create a new meteo file, it is done through the prewind file modified. First I opened the Intel Composer XE 2013™ program, how the figure 22 shows:

![Figure 21: View of the Intel Composer XE 2013 program opened](image)

The commands must be written are the commands can be seen in the following lines and which the figure 23 shows at the beginning:

1.) `>cd c:\NorthSea`
2.) `>ifort -o prewind.exe prewind.f`
Then the program calculates a new application saved in the North Sea folder with the name of prewind.exe.

Figure 22: View of written commands in the Intel Composer XE 2013

Then I copied this file and pasted it in Telemac folder. Once did it, I did a double click on the new application prewind.exe, and a new Intel composer window is opened, how the figure 24 shows.

Figure 23: The new window of Intel Composer XE 2013, opened through the new application prewind.exe
The application is going to formulate three questions, how the figure 25 shows. In the first one I put the name of the new mesh file (Geo_NorthSea.sfl). In the second one it asks about the name of the windfile, it is meteo-Jun2004.txt in North Sea folder, so I copied it to the new and I answered the question with the name od the file. The last one asks about the name of the output wind file. I called it as meteo_jun_2004.slf.

Finally, when is clicked the last Enter, it does the calculation of the output file, which appears in Telemac folder with the name we wrote before in the program.

3.1.4 Fortran file

The FORTRAN file contains all the TELEMAC-2D subroutines modified by the user and those that have been specially developed for the computation. This file is compiled and linked so as to generate the executable program for the simulation. [Manual of Telemac]
In this step I had to change some subroutines inside de fortran file north_sea_scheldt. So first of all, I copied the file from North Sea folder to Telemac folder. Then I opened it. Once it was open, I searched the subroutine Bord () at the top on the right side of the calculation paper, the subroutines command has a pictures as a pink rectangle before the name of the subroutine.
Once I had the correct subroutine, how the figure 26 shows, I searched the line 1877 where I had to change the number of the nodes, which form the open boundary in the new mesh. First could be seen this: IF((K.GE.1 .AND. K.LE.15) .OR. (K.GE.2169 .AND. K.LE.2298)). But in the new mesh it changes, and then checking the table of the boundary file BC_NorthSea in the Blue Kenue, I changed it for:

![Figure 25: Changed lines in the fortran file (1)]:

Once this are changed, I had to changed the subroutine to Meteo().
Then, how the figure 27 shows, here has to be changed the number of nodes and elements which acting in the model. I found it at line 177. As a step before I put the same numbers: Nodes= 12760 and Elements= 24584.

Figure 26: Changed lines in the fortran file (2)

And then save the file.
3.1.5 Steering file

This is the last step to finally have all fixed in order to have the program able to calculate the new model. First of all I searched the steering file June_2002_new in the North Sea folder, I copied it and pasted in Telemac folder. Then I opened it in a text editor and I changed the files I was going to use in the new implementation of the model. The steering file finally is:

(The symbol “/” in front of the input means that it is turned off and the information no indicated can be imposed as default of the software. [Definitions from the: Manual of Tomawac]

/ COMPUTER INFORMATION
BOUNDARY CONDITIONS FILE (Bc_NorthSea.cli): it describes the contour of the domain trigonometrically
GEOMETRY FILE (Geo_NorthSea.slf): This file contains all the information concerning the mesh
RESULTS FILE (res_north_sea): This is the file in which TELEMAC-2D stores information during the computation
FORTRAN FILE (north_sea_scheldt.f): This file contains all the TELEMAC-2D subroutines modified by the user
FORMATTED DATA FILE 1 (csm_newcoa_reorg.bnd): This file can be used to provide data to the program, with the user of course managing reading within the FORTRAN file (given by Alessio)
BINARY DATA FILE 2 (meteo_mar_2004.slf): This file contains the meteo data
/FORMATTED RESULTS FILE : (informations.txt)
/PARALLEL PROCESSORS = 16 Command for divide the work in different processor to do shorter the computation time.

/ GENERAL OPTIONS
TITLE = 'TELEMAC 2D : OB FILE TEST 2_2'
VARIABLES FOR GRAPHIC PRINTOUTS : 'U,V,S,H': This is used to specify the list of variables to be stored in the results file. Each variable is identified by a symbol, these are listed in the description of this keyword in the Reference Manual.
TIME STEP = 5.: This defines the time separating two consecutive instants of the computation in seconds
NUMBER OF TIME STEPS =311040: The total duration of the computation is supplied by the number of time steps, which is 311040 because multiply by time step, the result is 18 days as the meteo file.
NUMBER OF FIRST TIME STEP FOR GRAPHIC PRINTOUTS : 0: This is used to determine at what time step information is first to be stored
GRAPHIC PRINTOUT PERIOD : 120: This fixes the period for outputs so as to avoid having an excessively large file
LISTING PRINTOUT PERIOD : 120:This fixes the period between time step editions
/FOURIER ANALYSIS PERIODS : 44712
MASS-BALANCE = YES : Different options of print out
INFORMATION ABOUT SOLVER : YES for the output information.

INITIAL TIME SET TO ZERO : YES
/ WIND AND PRESSURE TERMS
WIND : YES
AIR PRESSURE : YES
COEFFICIENT OF WIND INFLUENCE : 2.57D-6
/ PHYSICAL PARAMETERS : Physical parameters calculated and given by the Alessio’s thesis,
LAW OF BOTTOM FRICTION = 2 : Chézys law is applied how the hydrodynamic theory said.

FRICITION COEFFICIENT = 65 : The value of the coefficient chosen.
TURBULENCE MODEL : 1 : For a constant viscosity.
LATITUDE OF ORIGIN POINT :
47.8333 : Necessary to define the spherical coordinates.
CORIOLIS = YES
CORIOLIS COEFFICIENT = 1.078E-4
TIDAL FLATS : YES : Recommended when there are tidal flats in our domain.
OPTION FOR THE TREATMENT OF TIDAL FLATS : 2
INFORMATION ABOUT SOLVER : YES
/ NUMERICAL PARAMETERS: Different parameters to characterize the hydrodynamic simulation, describing the initial and boundary conditions of the North Sea.
INITIAL CONDITIONS : 'CONSTANT ELEVATION' : This initialises the free surface elevation at the value supplied by the keyword INITIAL ELEVATION in meters.
INITIAL ELEVATION : 0 : The model starts to run at 0m
ADVECTION = YES :
TYPE OF ADVECTION : 1;5
ADVECTION OF H : YES : To take into account the advection of depth,
ADVECTION OF U AND V : NO : For the advection of velocity components
DIFFUSION OF VELOCITY : NO : To take into account the diffusion of velocity
SOLVER : 1 : For solving the hydrodynamic propagation step, 1: Conjugate gradient method
SOLVER OPTION : 3 : For hydrodynamic propagation 3: Conjugate gradient on normal equation method,
SUPG OPTION : 1;1
MASS-LUMPING ON H : 1. : The value 1 indicates maximum mass-lumping (the mass matrices are diagonal)
PRESERVED ELEVATIONS : 0.
PRECONDITIONING: 2: Concerns the propagation solution step, 2: Diagonal preconditioning (default value)
SPHERICAL COORDINATES : YES : If a simulation is being performed over a large domain, TELEMAC-2D offers the possibility of running the computation with spherical coordinates
SPATIAL PROJECTION TYPE: 2 : necessary for the spherical coordinates
SOLVER ACCURACY : 1.E-6: Defines the accuracy required during solution of the propagation step
MATRIX STORAGE : 3 : 3: edge-based storage method (default and recommended value).
MATRIX-VECTOR PRODUCT : 1 : 1: multiplication of a vector by a non-assembled matrix (default and recommended value),
DISCRETIZATIONS IN SPACE : 12;11
INITIAL GUESS FOR H : 1  
INITIAL GUESS FOR U : 1
IMPLICITATION FOR DEPTH : 0.55
IMPLICITATION FOR VELOCITY : 0.55

Default values, 1: Initial value of DH equal to the value of DH at the previous time step
Default values of Alessio

Finally save, and the it's done to start the calculation of the model.
3.1.6 The Run of TELEMAC model with and without Meteo.

In this part I wanted to make a comparison with the results I could obtain when I run two times the program, once with meteorology and the other without it in order to know in what way the meteorology affects the results. The meteorology is activated through the steering file June_2002_New I had saved in Telemac folder in the step before. When it is opened, how the figure 28 shows, what has to be changed are two terms from line 38 (Wind and Air Pressure). Normally it will be always activated (YES), if I wanted to run the model without meteorology, I would change the state of both terms from YES to NO. Later If I had wanted the meteorology activated, I would have to change it another time from NO to YES.

Figure 27: Situation of the meteo commands inside de Steering file in order to enable or disable the effect of this

Once the terms before have been changed in the way I wanted the results, with or without meteorology, now there were specific steps to follow correctly to run the model. First of all I opened the Intel composer program and I wrote the following lines how the figure 29 shows:

1) >cd c:\Telemac
2) >runcode.py telemac2d -c wintels -s steeringFile_June_2002.txt
Once I wrote it, I pressed enter and the program calculated the model each step until it is intended to. In this case, I let the program calculating until it arrives to 7days, I will be enough to see the increase of the tide. But if the number of time steps in the steering file is changed, it can be calculated during all time we want. The program stops when we press the keyboard key: ctrl+c or when it has calculated all time steps for which it is programmed, it stops itself. Once the both models were calculated, I opened them in Blue Kenue through the file TD2RES inside the new folder created by the program I found in the folder Telemac or through res_north_sea file between other input files, how the figure 30 shows.
Then when the results file was opened in Blue Kenue™, I could check all different outputs I ordered to calculate in the steering file at the command “VARIABLES FOR GRAPHIC PRINTOUTS”. To check this outputs I put each one in the 2Dview and then I animated which was necessary to observe the result depends on the time. I also changed every scale to have more accurate results and I loaded the colour scale in the 2D View window of each output. Now I show an example of every output at the end of the computation, but it could be shown at the time we prefer through the 7 days computed.
• **Velocity UV:**
The figure 31 shows the component along X and Y axis of the marine flow velocity vector through the whole domain.

![Figure 30: View of Velocity UV results in Blue Kenue](image)

• **Water Depth:**
The figure 32 shows the water depth of the whole domain.

![Figure 31: View of the Water Depth results in Blue Kenue](image)
- **Free Surface:**
  The figure 33 shows the elevation of the sea through the whole domain.

![Image of Free Surface results](image1)

**Figure 32: View of the Free Surface results in Blue Kenue**

- **Comparison between the model with meteo and the model without it.**

When I had both results files of both models opened in the Blue Kenue, and I followed the different steps that the figure 34 shows. I put both FREE SURFACE files, in different 2D View windows. There I searched a node, which interested me at both 2DView, which was the node number 1978, because it is near from the Belgian Coast and is where I the study was interested to know the behaviour of the model.

![Image of Node selection](image2)

**Figure 33: Node selected in Blue Kenue in order to extract the Time series file**
Once it is selected, I did a right-click on the node and then I click on Extract Timeseries, and a file will be opened under the Free Surface file. Then when I had extracted both time series, I renamed them for NoMeteo and Meteo, how the figure 35 shows, so that they could be differentiable and they can be seen in the 1DView together.

![Figure 34: Followed steps to extract the Time series file (1)](image)

![Figure 35: Followed steps to extract the Time series file (2)](image)

Seen this extract in the figure 36, can be observed than the amplitude during a cycle vary between less than four meters, also can be observed in the figure 37 that the tidal
high is slightly higher without a meteorology affecting always over the sea than with it. Although amplitude and frequency are the same in both cases.

Figure 36: Comparison between the model with and without meteorology

3.2 The implementation of TOMAWAC

The implementation of the Tomawac in this point is easier than all done in the telemac's implementation, because some files that tomawac needs are the same done in the telemac in the previous step. All the files of this implementation are going to be saved in the Tomawac Folder. Tomawac needs the same geometry file and boundary file, therefore this files don’t need any other changes to fit it to the new tomawac’s implementation.

3.2.1 Meteo

In this case was necessary to create a new meteo file, because we found problems in the implementation of tomawac with the same meteo file of telemac, because tomawac doesn’t use the atmospheric pressure in the computation, so I had to create a new meteo file specific to tomawac with only the influence of a wind blowing.

The first step is to modify the prewind fortran file implemented previously to telemac.

So, I had to open it and then change and write:

- **Line 106, change by:** WRITE(LUSEL) 2, 0
- **Line 115, change by:** ! WRITE(LUSEL) TEXTE(1)
- **Line 269, change by:** IF (IVAR.GT.1) WRITE(LUSEL) (TAB_EF(IP),IP=1,NPOIN)

(Change of the number of variables from 3 to 2 (remove the variable 1: pressure). The other two are wind in X and Y)

Once the change was done, the procedure to get the new meteo file to tomawac is the same as telemac. Look at the paragraph New Meteo file of in Telemac implementation
Chapter. When I followed this steps I saved all the files in the Tomawac folder as: the same name as the previous file_tomawac, to differentiate this files from the telemac's file, it helps us not to have any confusion when all the files must will be in the same folder in the Coupled model. In this case this file was called prewind_tomawac and the meteo file resulting meteo_jun_2002_tomawac.sif.

3.2.2 Fortran file

As the meteo file was changed, the Fortran file has to be changed too, as a different fortran file for the tomawac model. But in this case the modification of the file would be more noticeable. In fact, what I did is erase some subroutines of the telemac's fortran file and maintains some others which are this subroutines: CORRXY, ERCGEO, WRITE_MESH. It will be saved as north_sea_scheldt_tomawac.

Only inside the subroutine WRITE_MESH there were some changes:

- **Line 1420**: USE DECLARATIONS_TOMAWAC, ONLY:NPOIN2,X,Y
- **Line 1453**: DO I=1,NPOIN2
- **Line 1456**: DO I=1,NPOIN2

(These changes were in order to change the call from Telemac program to Tomawac program.)

Then I had to create new subroutines specifics for tomawac found in Tomawac's Manual. These subroutines are CONDIW and SEMIMP. These can be checked in the tomawac’s fortran file.

**CONDIW:**

Specific initial conditions (stationary current) can be prescribed directly for the directional spectrum of wave action using the condiw.f subroutine, which configuration can be found in north_sea_scheldt_tomawac file. This subroutine initialises the arrays with physical parameters. Provided by F.Marcos (LNH) 01/02/95. [Appendix 3]

**SEMIMP:**

This subroutine solves the integration step of the source terms using a scheme with variable degree of implicitation, provided by M. Benoit 26/03/95. The subroutine’s configuration can be found in north_sea_scheldt_tomawac file. [Appendix 3]

Then the Fortran file of tomawac is ready to work correctly.

3.2.3 Steering file

In this case the steering file I used for the tomawac computation is different than the telemac's steering file. I called it Tomawac_Internal_Coupled_2D_ClosedUpstream.

What I did is modify the tomawac's steering file provided by Alessio in his thesis, I copied it and pasted in Tomawac folder. Then I opened it in a text editor and I changed the files I was going to use in the new implementation of the model. The steering file finally is: (explained the files not explained before).

(The symbol “/” in front of the input means that it is turned off and the information no indicated can be imposed as default of the software. [Definitions from the: Manual of Tomawac]
/ FILES
GEOMETRY FILE  (Geo_NorthSea.slf)
BOUNDARY CONDITIONS FILE (Bc_NorthSea.cli)
FORTRAN FILE (north_sea_scheldt_tomawac.f)
WINDS FILE FORMAT  (3) The format is 3 means it is a TELEMAC result file of the SERAFIN standard. It is a binary file and its name should be assigned to the keyword: BINARY WINDS FILE.
BINARY WINDS FILE  (meteo_mar_2004_tomawac.slf) This is the file from which TOMAWAC reads the information about the wind fields.
/2D RESULTS FILE  (Result2D_WesternScheldt_WAC.slf)
/FORTRAN FILE
/REFERENCE FILE
DEBUGGER= 0 If this command is 1, calls of subroutines will be printed in the listing
/DIVERS ENTREES-SORTIES
VALIDATION= NO  Must be True if the computation is a validation.
TITLE = NORTH SEA MODEL WAVES
TIME STEP= 600. I chose 600 because a time step of 10 min is enough large to obtain good computation results
NUMBER OF TIME STEP= 2592 I chose this number because multiplied by Time Step, the result is the 18 days long of the wind file.
PERIOD FOR GRAPHIC PRINTOUTS= 3
VARIABLES FOR 2D GRAPHIC
PRINTOUTS=HM0,DMOY,TPR5,ZF,WD,FX,FY,UX,UY,VX,VY  These are Codes of the variables the user wants to write into the 2D RESULTS FILE which can be found in Tomawac's Manual at page 52.
PERIOD FOR LISTING PRINTOUTS= 600
/DEBUGGER = 1
/DISCRETISATION: (Default Alessio's values)The spectral discretisation is defined by the following 5 keywords.
MINIMAL FREQUENCY= 0.04 Define the minimal frequency in Hz. The discretised frequencies are computed from the FREQUENTIAL RATIO r and the NUMBER OF FREQUENCIES NF by the relation f=f0*r^(k-1) k=1,NF.
FREQUENTIAL RATIO= 1.1007 Define the ratio between 2 successive discretised frequencies
NUMBER OF FREQUENCIES= 25 It defines the number of wave propagation frequencies
NUMBER OF DIRECTIONS= 12 It defines the number of wave propagation directions. The propagation directions are evenly distributed from 0 to 360 degrees.
SPECTRUM TAIL FACTOR= 5 Used to consider in the computations the contribution of the non-discretised high frequencies, 5 is the default value.
/ CONDITIONS INITIALES  (Default Alessio's values)
TYPE OF INITIAL DIRECTIONAL SPECTRUM = 6 If it ranges from 1 to 7, a JONSWAP (or TMA)-typed spectrum is specified at these points as a function of the initial wind field and/or of the values of the following keywords
INITIAL STILL WATER LEVEL= 0. Parameter used in the computation of the initial water DEPTH: DEPTH=ZREPOS-ZF
/INITIAL SIGNIFICANT WAVE HEIGHT = 0.5 It is part of the set of constants used for computing the boundary directional spectrum as a function of the wind field.

/INITIAL PEAK FREQUENCY = 0.250 It is part of the set of constants used for computing the boundary directional spectrum as a function of the wind field.

/INITIAL PEAK FACTOR = 3.3 It is part of the set of constants used for computing the boundary directional spectrum as a function of the wind field.

/INITIAL ANGULAR DISTRIBUTION FUNCTION = 1 It is part of the set of constants used for computing the initial directional spectrum. 1: model en $\cos^2 s(T-T0)$; $T$ dans $[T0-pi/2;T0+pi/2]$

INITIAL WEIGHTING FACTOR FOR ADF = 1.0 It is part of the set of constants used for computing the boundary directional spectrum as a function of the wind field.

INITIAL MAIN DIRECTION 1 = 270. It is part of the set of constants used for computing the boundary directional spectrum as a function of the wind field.

/INITIAL DIRECTIONAL SPREAD 1 = 3 It is part of the set of constants used for computing the boundary directional spectrum as a function of the wind field.

/INITIAL MEAN FREQUENCY = 0.586

/ CONDITIONS AUX LIMITES (Default Alessio's values)

TYPE OF BOUNDARY DIRECTIONAL SPECTRUM = 6 If it ranges from 1 to 7, a JONSWAP (or TMA) -typed spectrum is specified at these very points as a function of the initial wind field and/or of the values of the following keywords

BOUNDARY SIGNIFICANT WAVE HEIGHT = 0.202 It is part of the set of constants used for computing the boundary directional spectrum as a function of the wind field.

BOUNDARY PEAK FREQUENCY = 0.530 It is part of the set of constants used for computing the boundary directional spectrum as a function of the wind field.

BOUNDARY PEAK FACTOR = 3.3 It is part of the set of constants used for computing the boundary directional spectrum as a function of the wind field.

BOUNDARY MAIN DIRECTION 1 = 270. It is part of the set of constants used for computing the boundary directional spectrum as a function of the wind field.

BOUNDARY DIRECTIONAL SPREAD 1 = 32. It is part of the set of constants used for computing the boundary directional spectrum as a function of the wind field.

BOUNDARY DIRECTIONAL SPREAD 2 = 32

/ OPTIONS DU CALCUL (Default Alessio's values)

MINIMUM WATER DEPTH = 0.01 It defines the minimum water depth below which bottom elevations are regarded as dry.

INFINITE DEPTH = NO It indicates if an infinite depth is assumed. If so, bottom friction is inhibited.

CONSIDERATION OF TIDE = NO It indicates whether a current is taken into account.

CONSIDERATION OF A STATIONARY CURRENT = NO It indicates whether a stationary current is taken into account.

CONSIDERATION OF SOURCE TERMS = YES It indicates whether the source terms are taken into account or not.

CONSIDERATION OF A WIND = YES It indicates whether a wind is taken into account.

STATIONARY WIND = NO It indicates if the wind evolves temporally and requires to be updated.

LINEAR WAVE GROWTH = 1 Possibility to add a linear wave growth term to the wind generation source term. If its value is 0, the linear wave growth is ignored; if its value is
1, it is added to the source term, as in the formula of Cavalieri and Malanotte-Rizzoli (1981). 

**WIND GENERATION = 1** Selection of the type of modelling of the wind generation source term. If its value is 1, it is integrated in accordance with the WAM cycle 4 formula.

**WHITE CAPPING DISSIPATION = 1** Selection of the modelling type of the white capping source term. If its value is 1, it is integrated in accordance with a formula that is similar to that of WAM cycle 4.

/WIND VELOCITY ALONG X = -10.0 Wind velocity along X axis, if we want it constant and homogeneous.

/WIND VELOCITY ALONG Y = -10.0 Wind velocity along Y axis, if we want it constant and homogeneous.

/WIND DRAG COEFFICIENT = 1.2875E-3 Constant used in the wind source term (WAM cycle 4 model).

**BOTTOM FRICTION DISSIPATION = 1** Selection of the modelling type of the bottom friction source term. If its value is 1, it is integrated in accordance with a formula that is similar to that of WAM cycle 4.

/BOTTOM FRICTION COEFFICIENT = 0.042 Bottom friction coefficient.

**NUMBER OF BREAKING TIME STEPS = 5** Number of time steps for the breaking source term. These time steps are in a geometric progression.

**DEPTH-INDUCED BREAKING DISSIPATION = 1** Selection of the modelling type of the bathymetric-induced breaking dissipation source term.

/DEPTH-INDUCED BREAKING 1 (BJ) COEFFICIENT ALPHA = 1
/DEPTH-INDUCED BREAKING 1 (BJ) COEFFICIENT GAMMA1 = 0.88
/DEPTH-INDUCED BREAKING 1 (BJ) COEFFICIENT GAMMA2 = 0.8

**SPHERICAL COORDINATES = YES** It indicates whether the coordinates are spherical (unit = degree) or cartesian (unit = meter).

**CONSIDERATION OF PROPAGATION = YES**

**NON-LINEAR TRANSFERS BETWEEN FREQUENCIES = 1** Used the DIA method, which is a discrete parameterization of the exact computation operator as proposed by Hasselmann.

Finally save, and then it's done to start the calculation of the model.

Where is written Alessio’s values results means these values have been compared and tried, checking that are available for my implementation, surely Alessio find them using the Literature of the conditions of the zone and through trials, concerning the model refer to Hervouet 2007, Osuna 2002 and Pugh 1987 (Alessio’s Thesis). Also some of them are recommended in the Manual of Tomawac where can be checked. I took some of them after some trials with other settings and after having some problems in the results I have through the Manual recommendations, these finally did that made sense.

This keywords are disable because they aren’t needed if it's used defaults values.
3.2.4 The run of TOMAWAC model

Now is moment to run the model due to this is correctly set. First of all I opened the Intel ComposerXE 2013™ and then I wrote the following commands, how the figure 38 shows:

1) >cd c:\Tomawac
2) >runcode.py tomawac -c wintels Tomawac_Internal_Coupled_2D_ClosedUpstream

And pressing enter it started to run. The model is going to stop when the computation arrives to the number of time steps for which the model is set that it is 7 days, because the meteo file is implemented for 7 days as in Telemac2D.

Once the computation is done, the results file could be opened it the Blue Kenue™ to be plotted and see the results with images. The results file is Result2D_WesternScheldt_WAC.slf, saved how the figure 39 shows.
Then when the results file was opened in Blue Kenue™, I could check all different outputs I ordered to calculate in the steering file at the command “VARIABLES FOR 2D GRAPHIC PRINTOUTS”. To check this outputs I put each one in the 2Dview and then I animated which was necessary to observe the result depends on the time. I also changed every scale to have more accurate results and I loaded the colour scale in the 2D View window of each output. Now I show an example of every output at the end of the computation, but it could be shown at the time we prefer through the 7 days computed.

- **Wave Heigh HM0:**
  The figure 40 shows the spectral significant wave height $H_{mo}$:

\[
H_{mo} = 4\sqrt{m_0}
\]
• **Mean Direction:**
  The figure 41 shows the mean wave direction with respect to the North or to the X axis depending on the adopted choice.

Figure 40: View of Mean Direction results in Blue Kenue

• **Bottom:**
  The figure 42 shows the sea bottom elevation of the whole domain.

Figure 41: View of Bottom results in Blue Kenue
• **Water Depth:**
The figure 43 shows the water depth of the whole domain.

![Figure 42: View of Water Depth results in Blue Kenue](image)

• **Velocity UV:**
This term is provided for Telemac computation, so this term is not plotted.

• **Wind Along XY:**
The figure 44 shows the component along X and Y axis of the wind velocity vector through the whole domain.

![Figure 43: View of Wind Along XY results in Blue Kenue](image)
• **Force FXY:**
  
The figure 45 shows the component along X and Y axis of the radiation force due to waves through the whole domain.

![Figure 45: View of Force XY results in Blue Kenue](image)

• **Peak Period TPR5:**
  
The figure 46 shows the peak period computed by the Read method of order 5.

\[ T_{PR5} = \frac{1}{f_{PR5}} \]

![Figure 46: View of Peak Period TPR5 results in Blue Kenue](image)
Chapter 4: Coupling between TELEMAC2D and TOMAWAC

Once both programs are implemented correctly and they work with reasonable results alone, is time to prepare both to work together. Therefore there are many changes I had to do to find the properly running. The most of these changes were done because of the incompatibility between the implementation of both programs, which can be order different things over the same thing. All of these changed files will be saved in the Coupled folder.

4.1 Changes in the fortran file

- north_sea_scheldt.f

At Telemac’s fortran file, the changes which I did are some changes in it in order to sort out the problems of incompatibility it has with Tomawac’s coupling. Most of these changes were in the subroutine METEO (202 to 377) and BORD (1677 to 1917), and a little change in SL(2177).

- **Line 202, add:**
  ```fortran
  OPEN (T2DBI2,FILE='..\meteo_mar_2004.slf',CONVERT='BIG_ENDIAN',
  & FORM='UNFORMATTED',STATUS='OLD')
  ```

- **Line 249, change by:**
  ```fortran
  AT1=TEMPS
  ```

- **Line 266, change by:**
  ```fortran
  VX=VAR1X(MESH%KNOLG%I(N))
  VY=VAR1Y(MESH%KNOLG%I(N))
  VAR1X(MESH%KNOLG%I(N))=SQRT(VX*VX+VY*VY)
  VAR1Y(MESH%KNOLG%I(N))=ATAN2(VY,VX)
  ```

- **Line 275, change by:**
  ```fortran
  AT2=TEMPS
  ```

- **Line 291, change by:**
  ```fortran
  DO N=1,NPOIN
  VX=VAR2X(MESH%KNOLG%I(N))
  VY=VAR2Y(MESH%KNOLG%I(N))
  VAR2X(MESH%KNOLG%I(N))=SQRT(VX*VX+VY*VY)
  VAR2Y(MESH%KNOLG%I(N))=ATAN2(VY,VX)
  ```

- **Line 341, change by:**
  ```fortran
  VAR1X(MESH%KNOLG%I(N))=VAR2X(MESH%KNOLG%I(N))
  VAR1Y(MESH%KNOLG%I(N))=VAR2Y(MESH%KNOLG%I(N))
  VAR1P(MESH%KNOLG%I(N))=VAR2P(MESH%KNOLG%I(N))
  ```
Line 347, change by: AT2=TEMPS
Line 362, change by: VX=VAR2X(MESH%KNOLG%(N))
VY=VAR2Y(MESH%KNOLG%(N))
VAR2X(MESH%KNOLG%(N))=SQR(VX*VX+VY*VY)
VAR2Y(MESH%KNOLG%(N))=ATAN2(VY,VX)
Line 377, change by: DTET=VAR2Y(MESH%KNOLG%(N))-VAR1Y(MESH%KNOLG%(N))
IF (DTET.GT.PI) DTET=DTET-DEUPI
IF (DTET.LT.-PI) DTET=DTET+DEUPI
VIT=VAR1X(MESH%KNOLG%(N))+(VAR2X(MESH%KNOLG%(N)) & -VAR1X(MESH%KNOLG%(N)))*ALFA
TET=VAR1Y(MESH%KNOLG%(N))+DTET*ALFA
WINDX(N)=VIT*COS(TET)
WINDY(N)=VIT*SIN(TET)
PATMOS(N)=VAR1P(MESH%KNOLG%(N))

Line 1677, add:
OPEN (T2DFO1,FILE='..\csm_newcoa_reorg.bnd', & FORM='FORMATTED',STATUS='OLD')
Line 1688, change by:
! reads which components are taken into account (0 = not taken into account; 1 yes)
READ(T2DFO1,END=1500,FMT=*)(KREF(NC),NC=1,NHARM)
!WRITE(T2DRFO,FMT='(9I8)')(KREF(NC),NC=1,NHARM)
READ(T2DFO1,END=1500,FMT=*)(O(NC),NC=1,NHARM)
!WRITE(T2DRFO,FMT='(9F8.3)')(O(NC),NC=1,NHARM)
READ(T2DFO1,END=1500,FMT=*) NCOMP
!WRITE(T2DRFO,FMT='(I8)') NCOMP
READ(T2DFO1,END=1500,FMT=*) (NHUS(NC),NC=1,NCOMP)
!WRITE(T2DRFO,FMT='(9I8)')(NHUS(NC),NC=1,NCOMP)
READ(T2DFO1,END=1500,FMT=*)(AMPC(NC),NC=1,NCOMP)
!WRITE(T2DRFO,FMT='(9F8.4)')(AMPC(NC),NC=1,NCOMP)
READ(T2DFO1,END=1500,FMT=*)(PHAC(NC),NC=1,NCOMP)
!WRITE(T2DRFO,FMT='(9F8.0)')(PHAC(NC),NC=1,NCOMP)
READ(T2DFO1,END=1500,FMT=*) NELOB
!WRITE(T2DRFO,FMT='*') 'NUMBER OF TIDAL BOUNDARY POINTS'
!WRITE(T2DRFO,FMT='*') NELOB

Line 1750, change by:
!IWRITE(T2DRFO,FMT='*') 'INITIAL TIME'
!IWRITE(T2DRFO,FMT='*')TARRAY(1),TARRAY(2),TARRAY(3),TARRAY(4),
& TARRAY(5),TARRAY(6)
Line 1865, change by: !WRITE(T2DRFO,FMT='*') 'PHASE ANGLE AT TIME ZERO + NODAL ANGLE (V+u)'
!IWRITE(T2DRFO,FMT='*') PHII(K),K=1,NHARM
!IWRITE(T2DRFO,FMT='*') 'NODAL FACTOR (fn)'
!IWRITE(T2DRFO,FMT='*') (FC(NH),NH=1,NHARM)

Line 1885, change by: DO NE=1,145
IF (BOUNDARY COLOUR%(K).EQ.POINTNUM(NE)) THEN
! PRINT *, K, NE,BOUNDARY COLOUR%(K), POINTNUM(NE)
End If
Line 1894, change by: ! NE=1

Line 1907, change by: Z = SL(NUMLIQ(K),NBOR(K),K,O,FC,AMP,PHA,PHI,NE)
• Line 1917, add: **ENDDO**
• Line 2197, change by: **I CONT=CONT+1**

• **north_sea_scheldt_tomawac.f**

At the Tomawac's fortran file, I deleted the subroutines which I had problems because when the program call them when it was running, there was an incompatibility due to there were two fortran files (Telemac and Tomawac) where the subroutine could be call to. Therefore I deleted them from tomawac's fortran file because the coupling is done from Telemac's steering file. These subroutines are:

• CORRXY
• ECRGEO
• WRITE_MESH

The accompanying text remembers to keep paragraphs long enough, but make sure the sentences are not too long. A paragraph contains a train of thought and so will always contain a couple of sentences. Do not write a paragraph that consists of only one line.

4.2 Changes in the steering file

• **steeringFile_June_2002**

Inside the steering file is necessary to change some parameters to find the way to run properly the coupled model. These changes were:
  1. Disable the files (/):

    /FORMATTED DATA FILE 1 : csm_newcoa_reorg.bnd /FORT.26
    /BINARY DATA FILE 2 : meteo_jun_2002.slf
    (the meteo is disable because is used the tomawac's file)

  2. Introduce more variables:

    VARIABLES FOR GRAPHIC PRINTOUTS : 'U,V,X,Y,S,H'

  3. Change the number of time steps and print outs to match both programs in the same space of time calculation obtaining coupled results:

    NUMBER OF TIME STEPS = 133920
    GRAPHIC PRINTOUT PERIOD : 120
    LISTING PRINTOUT PERIOD : 120
4. Introduce necessary coupling commands:

```
FOR COUPLING TOMAWAC
/Coupling TOMAWAC
COUPLING WITH = 'TOMAWAC'
COUPLING PERIOD FOR TOMAWAC = 120
TOMAWAC STEERING FILE =
Tomawac_Internal_Coupled_2D_ClosedUpstream.txt
WAVE DRIVEN CURRENTS = YES
```

(The coupling period means that each 120 seconds of Teleamac's computation, it will be 1 Tomawac's computation. Then I had to indicate with which program Telemac will be coupled and which is its steering file. The keyword WAVE DRIVEN CURRENT is used to include wave-induced currents by recovering the information calculated by the wave propagation modules.)

- **Tomawac_Internal_Coupled_2D_ClosedUpstream**

Inside the steering file is necessary to change some parameters to find the way to run properly the coupled model. These changes were:

Change the keyword “CONSIDERATION OF A STATIONARY CURRENT” to “NO”

When running Tomawac alone, the keyword “CONSIDERATION OF A STATIONARY CURRENT” should be “YES” if “CONSIDERATION OF TIDE” is set to “NO”, or vice versa. But in the coupled model the keyword “CONSIDERATION OF A STATIONARY CURRENT” must be “NO” because the current is provided by Telemac.
Chapter 5: Analysis of the results

In this chapter I show the results I obtained about wave height and water depth in the coupled model of TELEMAC2D and TOMAWAC, at different important points next to the Belgian coast, which is the interesting zone of my study because is where the behaviour of the sea gets importance for the section of the university I work with and where it has more unpredictable values because of the geology of the sea bottom. Then I compare these results with real results obtained from five different measuring stations located through the Belgian coast, through the web: http://www.kustdata.be/ which are: GMT Akkaert, GMT Bol van heist, GMT Trapegeer, GMT Nieuwpoort and GMT Oostende Oosterstaketsel.

5.1 How to obtain the program results

Firsts of all, I needed the coordinates of the four measuring stations in order to find the relevant node in the Telemac map, where I have to extract the time series file. I obtained them from (web), where it contains the coordinates of each one and the results obtained of every year it has been working. The date I searched is the first 18 days of March 2004, which is the same date of the meteo file I work with in the implementation of the both programs. These are the coordinates of each one:

- GMT Akkaert à 51° 25' 08'' N – 2° 48’ 06'' E
- GMT Trapegeer à 51° 08’ 15”N - 2° 34’ 58”E
- GMT Bol van heist à 51° 23’ 22”N - 3° 11’ 55”E
- GMT Oostende Oosterstaketsel à 51° 14’ 01”N - 2° 55’ 25”E
- GMT Nieuwpoort à 51° 09’ 02”N - 2° 43' 41”E

Once I downloaded all this information, I opened the geo file Geo_NorthSea.slf in the program Blue Kenue. When the file is opened, the file Bottom has to be seen in the 2D view window. Then knowing the coordinates, I had to search them directly in the map using the measuring grid of the 2D view. The nodes I related with each station are:
1. The figure 47 shows the position of GMT Akkaert: node → 4629

![Figure 46: View of GMT Akkaert](image1)

2. The figure 48 shows the position of GMT Trapegeer: node → 7554

![Figure 48: View of GMT Trapegeer](image2)
3. The figure 49 shows the position of GMT Bol van heist: node → 1399

Figure 49: View of GMT Bol van heist

4. The figure 50 shows the position of GMT Oostende Oosterstaketsel: node → 10670

Figure 50: View of GMT Oostende Oosterstaketsel
5. The figure 51 shows the position of GMT Nieuwpoort: node → 5013

Once I knew each node related to each sea station, I opened the TELAMAC2D results file res_north_sea, and TOMAWAC results file Result2D_WesternScheldt_WAC.slf in Blue Kenue to get the results. I need the results of wave height of the nodes belonging to the stations GMT Trapegeer and GMT Bol van heist (which are buoys) from the TOMAWAC results file WAVE HEIGHT HM0, and the water depth of the nodes GMT Oostende Oosterstaketsel and GMT Nieuwpoort (at the port) form the TELEMAC2D results file WATER DEPTH.

How I did it is first take the results of the buoys, putting the file WAVE HEIGHT HM0 in the 2D View window. Once the map is visible, I found the two nodes of the buoys in the map knowing the situation of each related node searched before. When the node is found, then right click and Extract the Time series. Then a new 1D file is created with the name of the node and the coordinates, which through the 1DView window can be seen a graphic of the wave height during 7 days. As I want a table of results in order to compare them with the tables I obtained before through the web, I did I right click over the new file and then I clicked the option Show Attribute Table and the I obtained the table with results every 30 min. The figure 52 shows every window opened in order to obtain the table of attributes.
Figure 52: View of How to get the Tomawac's table of results

The procedure to obtain the results of water depth is the same, changing the file in the 2D view, which will be the file WATER DEPTH, and then change the nodes we need in each case.
5.2 Results

The results have been organized in two parts, first with the Water depth results and in second instance the Wave height results with an explanation about what is seen.

5.1.1 Water depth

The figure 53 shows the comparison between measurements and results on GMT Oostende Oosterstaketsel location: node → 10670

![Oostende](image1)

**Figure 53: View of Water depth results at GMT Oostende Oosterstaketsel**

The figure 54 shows the comparison between measurements and results on GMT Nieuwpoort location: node → 5013

![Neuwpport](image2)

**Figure 53: View of Water depth results at GMT Nieuwport**
What I could observe is that the Telemac 2D data haven't an exact result comparing with the reality, but is enough similar and the pattern is totally reasonable. In Oostende can be seen an overestimation and in Neuwport an underestimation less than 50cm. These little differences could be produced by little errors in wind file or by a non-accurate implementation of boundary or initial conditions or the mesh. Maybe with a several number of trials and with some changes in these conditions, could be possible get more accurate results.

5.1.2 Wave Height

The figure 54 shows the comparison between measurements and results on GMT Akkaert location: node → 4636

![Figure 54: View of Wave Height results at GMT Akkaert](image_url)

The figure 55 shows the comparison between measurements and results on GMT Trapegeer location: node → 7554

![Figure 55: View of Wave Height results at GMT Trapegeer](image_url)
The figure 56 shows the comparison between measurements and results on GMT Bol van Heist location: node → 1399

The conclusions I could extract of each comparison graphic of the wave heights is that the TOMAWAC data is underestimated, having lower results of wave height, and it is out of phase over time, in Tomawac the increasing and decreasing happen before the real data. After many trials and changes in the initial and boundary conditions, these results are the more realistic I could get. The reason probably is that the wind file I received was implemented incorrectly because The pattern is quite similar comparing with the measurements graphic shows, taking in account the out of phase in time. So, The most probably is that with this implementation settings and with a correct wind file regarding the real measurements, could be possible to get realistic results through the coupled model of Tomawac, with few differences. Also I recommend running the model with longer period wind files if it is possible because it would give more information about the accuracy and what is happening if there is some problems in the implementation settings. In my case there isn’t one longer than which I worked.
Chapter 6: Conclusion

After all the settings I set up in both programs and the different simulations I did during the implementation of them, separately and coupled, I have found some points to be considered while working with Telemac2d and Tomawac. The first thing is taking in to account that is totally important to be careful with paying attention in every condition or parameter you want to use, because a minuscule change could give you a good result or not, according to my current experience during the programing.

To deal with these problems, the interpretation is very important to find the solution in every wrong result or some others errors in during the programming that you don’t understand. But before get the chance to sort a problem out through the own interpretation, is necessary to obtain a previous background reading the recommended literature and checking the manuals of each program while you are working with the program. A third opinion by someone with more experience is also helpful.

Also the experience is obtained making errors, and through it you can take many conclusions. Luckily, during running the program used to give you which is the error or a clue of what could be wrong. However it doesn’t happen always.

First errors you can find is while you are trying to run a model alone and it doesn’t start due to errors of misunderstanding. You have to make sure that you have implemented the fortran file correctly, the program should give you the reason of the misunderstood. The error could be due to the uncompleted implementation of some empirical equations that rule the hydrodynamic or wave model. Also the relation between files must be correctly written in the steering file and in the fortran file, and if are implemented all necessary subroutines in the steering file. In the manual you can check each one, also there are the recommended subroutines that are usually used.

Once the model run till the end, if you find numerical errors, the first thing you have to do is check if you have implemented a correct space (mesh), and it is correctly connected with the other files as boundary conditions file, bathymetry file (geometry file) as same nodes, elements, etc., that can give you unreasonable results. If all seem correct, the problem can come from the size you applied to the domain, the size of the space or the time implemented is important due to how sensitive are the results with this input. A little grid or time step gives more accurate results, although the time calculation will be bigger

In Telemac2D for example, the numerical problems can come from unreasonable results regarding the phase and amplitude of the tide. Also when you want to compare them with the real measurements, you have to make sure that the units and the reference level are the same, for example the models used to give you the reference level in MSL, but the
measurements of a sea station used to be in the reference level TAW, which the relation
between them are of 2.33m
In Tomawac is also important a correct spectral discretisation (direction and frequency), that
affects directly in the action balance equation, in order to have a reasonable results
spectrum, which later must be fitted through other physical changes. The best way to detect
all these problems is plotting the results while the programs are running, both programs let
us do it, and when is detected one error, make the change and get back to run the model till
obtain what we are looking for. Also through the different results outputs, you can do an
interpretation of what is happening. When you charge the results file, you can see between
which values are each output, and here you can find out some unreasonable values, for
example Mean direction has to be between 0 and 360, because is the direction I degrees.
Then when you plot each one, if you see unexpected peaks in graphs, it may also be due to
wrong implementation of physical parameters. This was one of my worst problems, the
wave height had some unexpected peaks and the results are too overestimated, and I had to
check old thesis and literature and make several runs till find the boundary and initial
conditions which fit to the model better. To arrive at this point you have to compare each
result you compute with the measurements till you find a pattern similar to real one. For this
reason is better to pay attention onto the behaviour near the boundaries of the mesh,
because is where you can find better how is affecting an erroneous values in boundary
conditions due to the enhancement of the effect there.
Moreover you have to take into account that the results can’t be exactly the same, because
of the uncertainty of some physical parameters you can’t control, for example the empirical
terms which compose the dissipation input and the rather simplified non-linear energy
transfer term. So you should just try to find the results more close to the reality. To achieve
this you can do some trials switching each one off by parts and the run the model, if the
model shows better, it can continue been disabled.
Finally, how happens to me, you can find that some files are not previously implemented
correctly. In my case I have concluded that the meteo file of 2004 is not correctly
implemented comparing it with the measurements. So you should arrive to the point where,
with the experience you have been getting, results in hand after several trials and the
knowledge get before, you should know that the trouble doesn’t come from an own
implementation critical error, if not from a file error.
So my recommendations regarding my experience are if you want a most representative
results about wave height or water depth, is better to count with a longer wind file, at least
of 1 month, the longest I found was of 18 days. And then check that the wind data
corresponds with the measurements of it taking those days.
Bibliography


