ODYSSEA

Creating products and knowledge
for the Mediterranean

FORTH
FOUNDATION FOR RESEARCH AND TECHNOLOGY - HELLAS

HYDRODYNAMICS MODELLING TRAINING
THEORY & EXERCISES

PLATFORM VALIDATION AND CAPACITY DEVELOPMENT WORKSHOP : HYDRODYNAMICAL AND WATER QUALITY MODELING BASED ON THE MARINOMICA PLATFORM

Wednesday-Thursday, 14- 15 July 2021

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What is a numerical model ?

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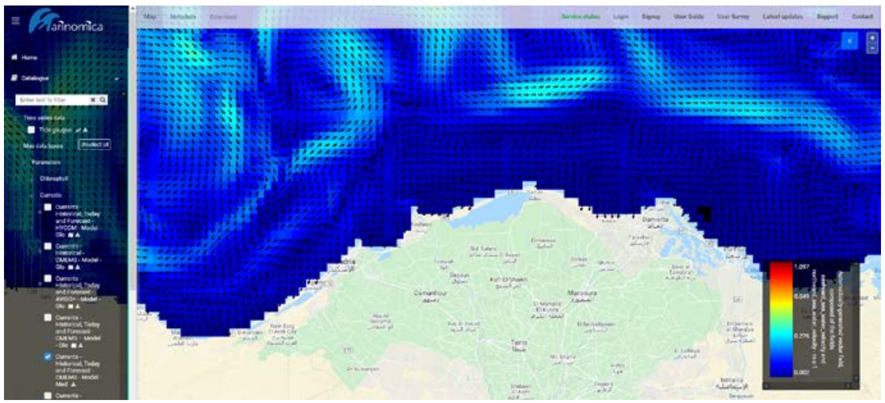
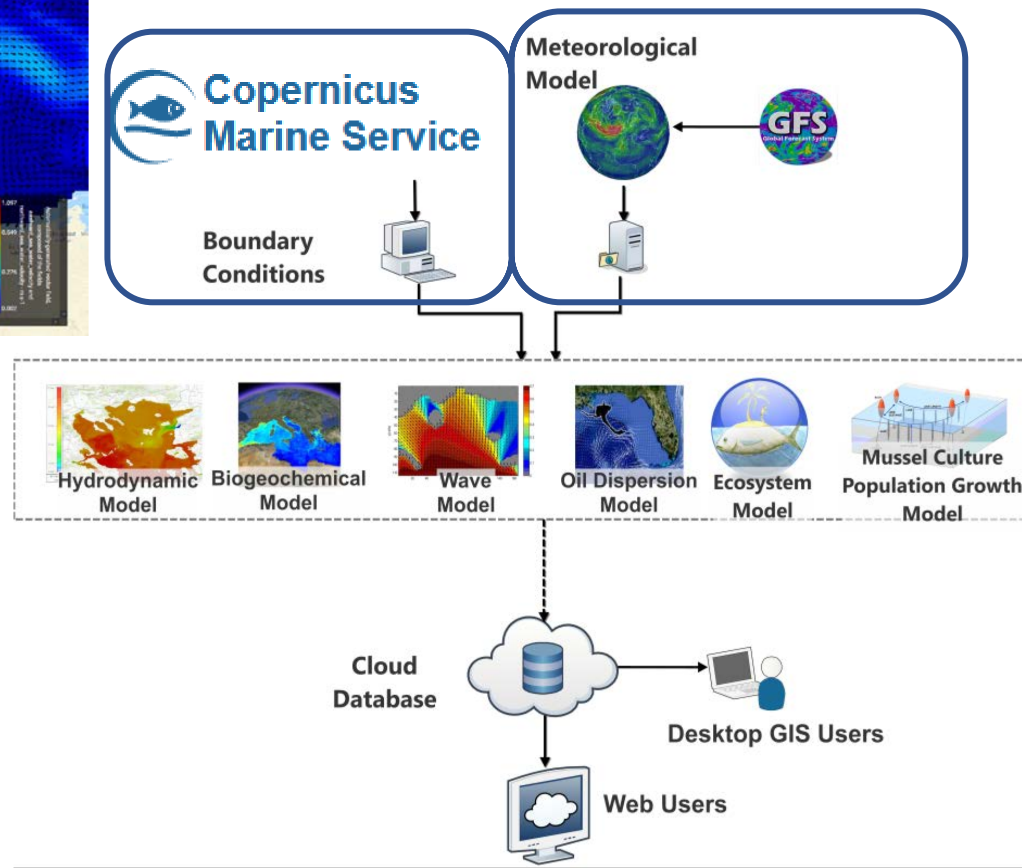
- **Mathematical description of processes/phenomena** (physics, chemistry, biology, etc.)
- **We use numerical methods to solve the resulting partial differential equations, which are discretized in time (time steps) and space (numerical grid)**

Source: EuroGOOS https://eurogoos.eu/

From regional to coastal scales

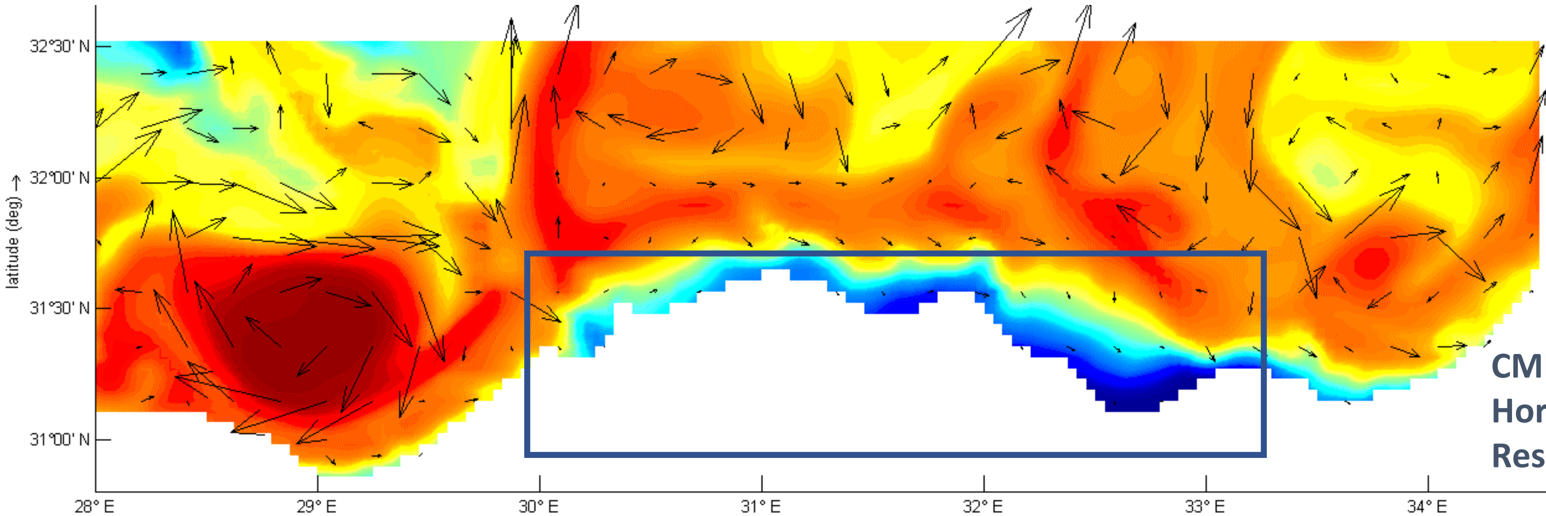
From CMEMS Med MFC products to coastal high-resolution models



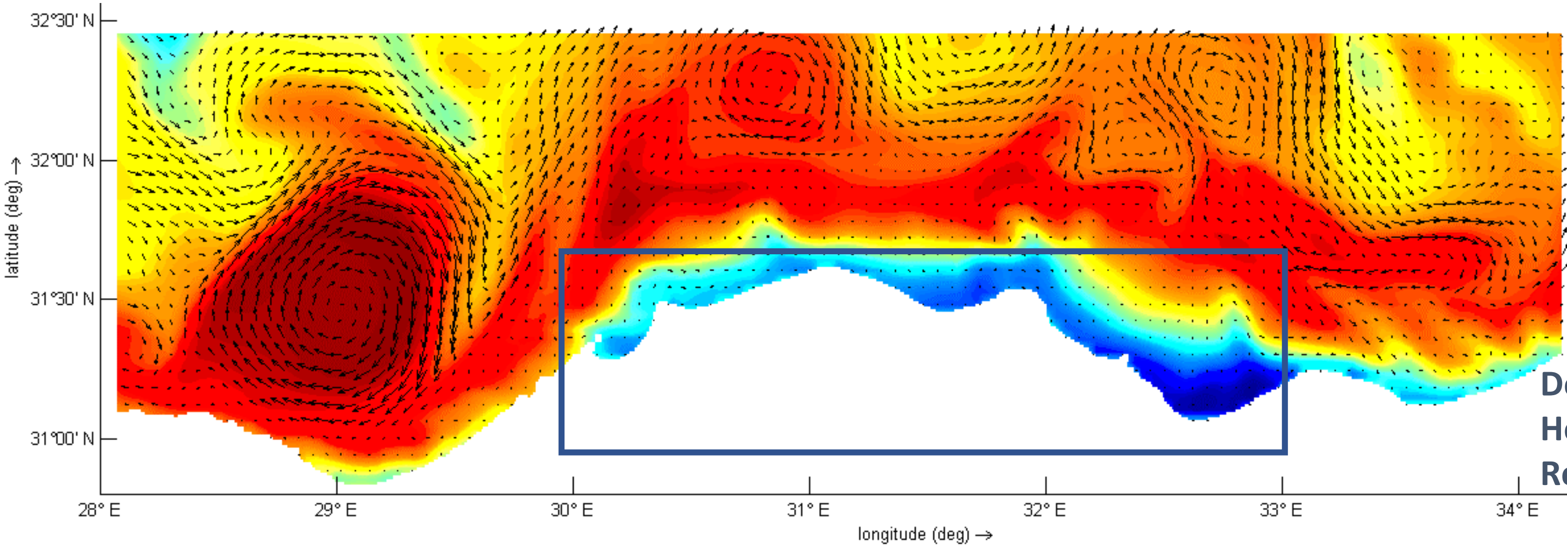


- Initial conditions/boundary conditions
- Calibration and validation
- Data assimilation

Numerical models: the horizontal resolution



CMEMS Horizontal Resolution ~ 4.2 km

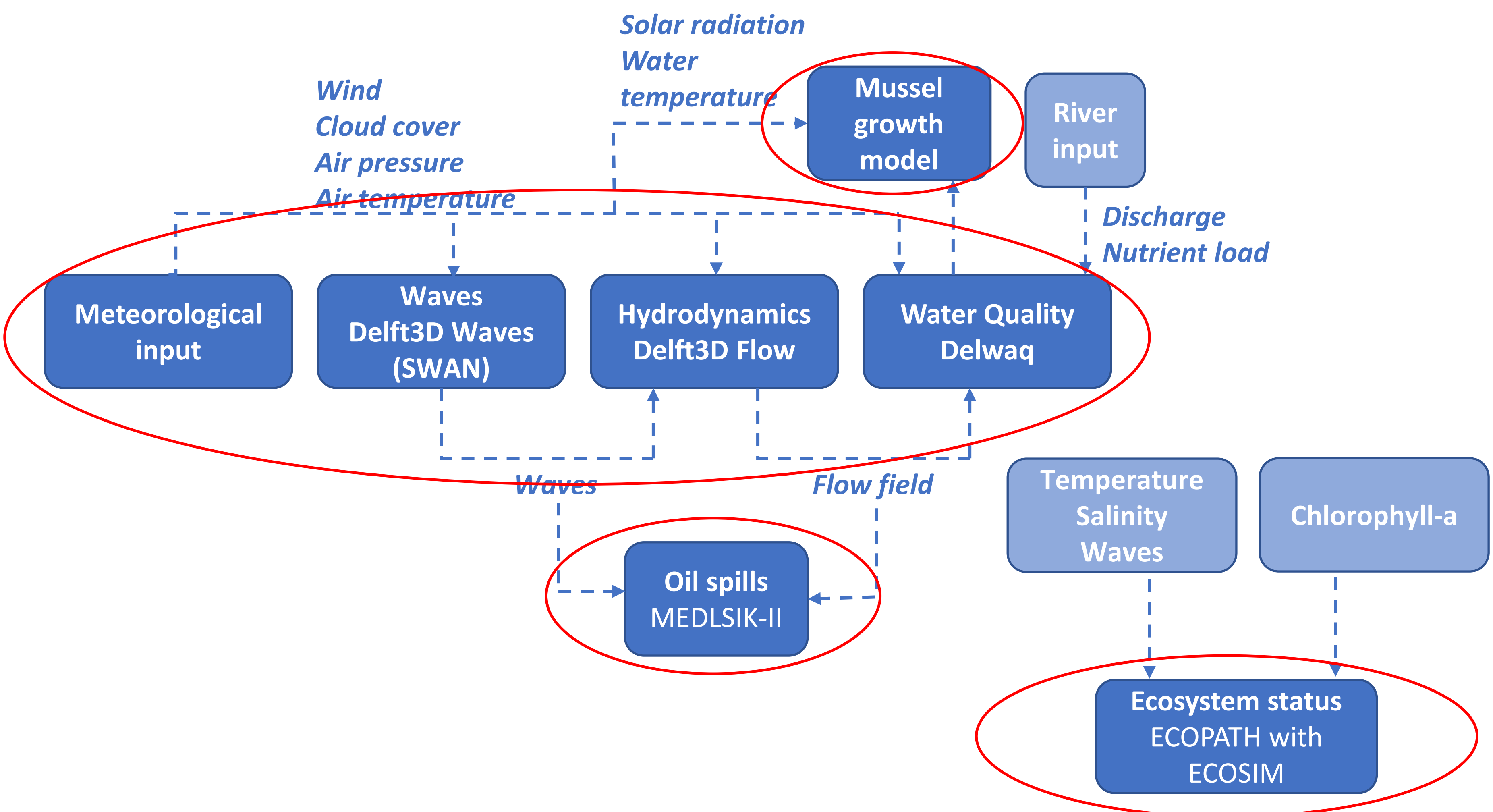


Delft3D-refined Horizontal Resolution ~ 1 km

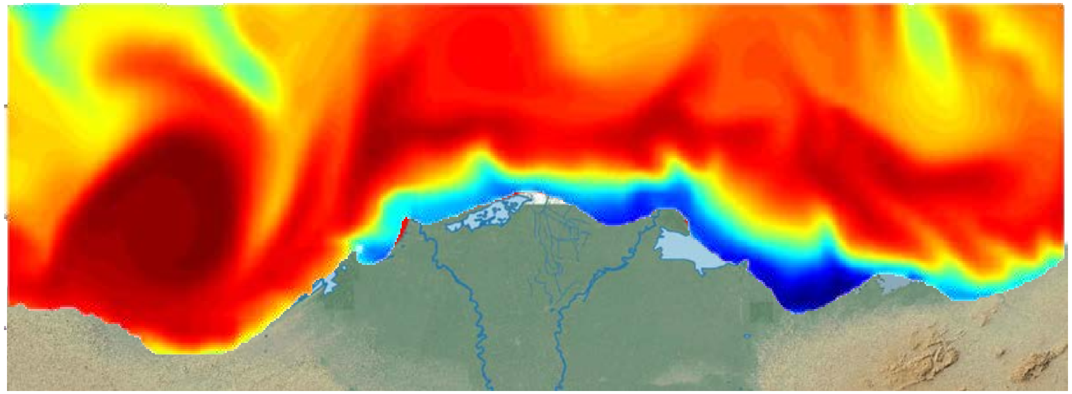
The Observatories

- ✓ A network of 9 observing and forecasting systems covering coastal and shelf zone environments,
- ✓ Diverse systems from Ecologically-vulnerable systems (MPAs) to systems with increased human pressure,
- ✓ Combine monitoring and modeling activities,
- ✓ Produce new datasets with increased spatial and temporal resolution, stored, manipulated, made accessible through Marinomica platform.

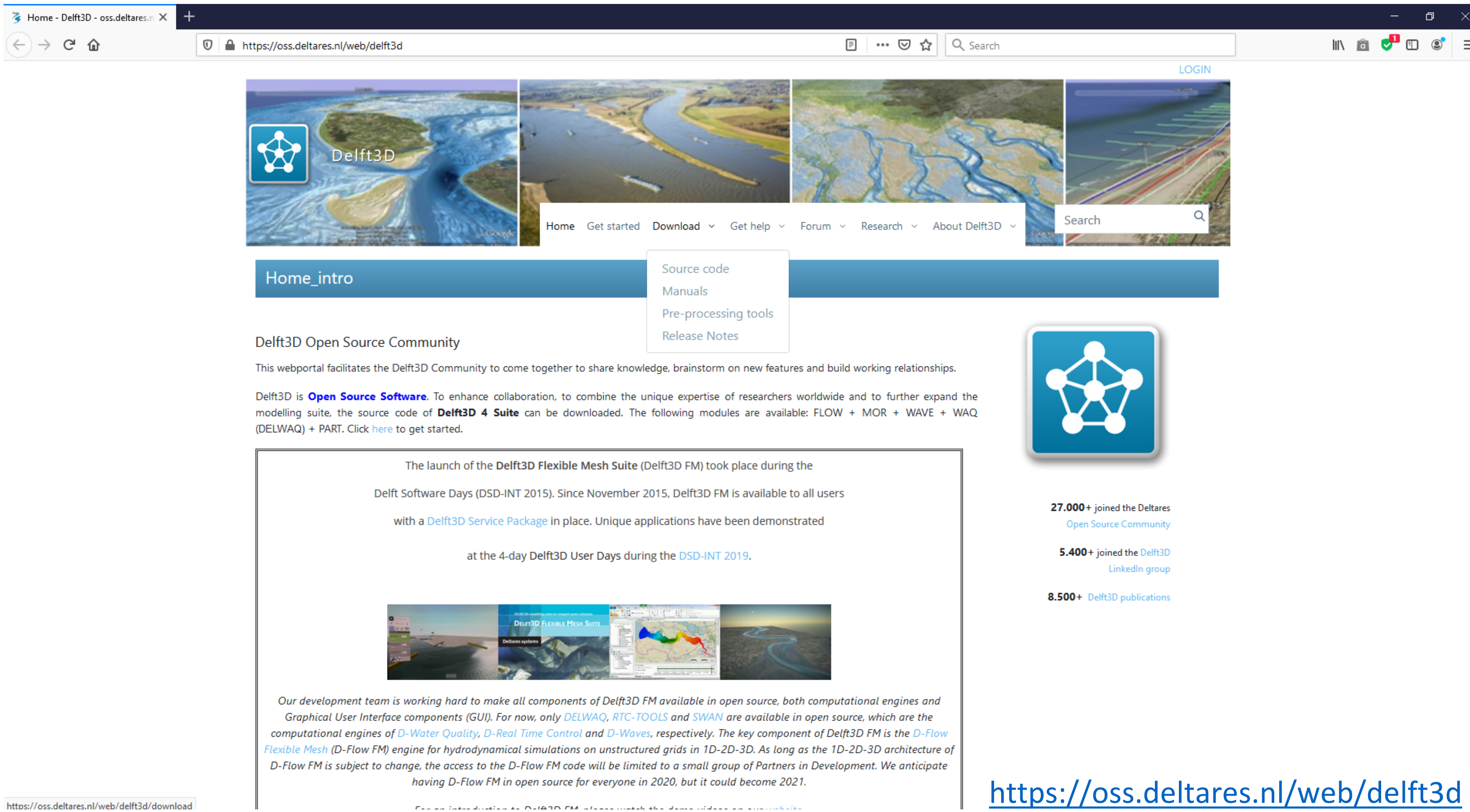
The Models in Marinomica



Delft3D system overview



Delft3D modelling suite



https://oss.deltares.nl/web/delft3d

Delft3D-Flow functionalities for coastal systems

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- Flows due to tide, wind, density gradients (3D flow models)
- Advection and dispersion of constituents
- Salinity, temperature, other constituents
- Sediment transport
- Morpho dynamics, bed level changes
- Wave-induced currents
- Online coupling to WAVE model, online/offline to WAQ, PART

Delft3D-Flow – areas of application

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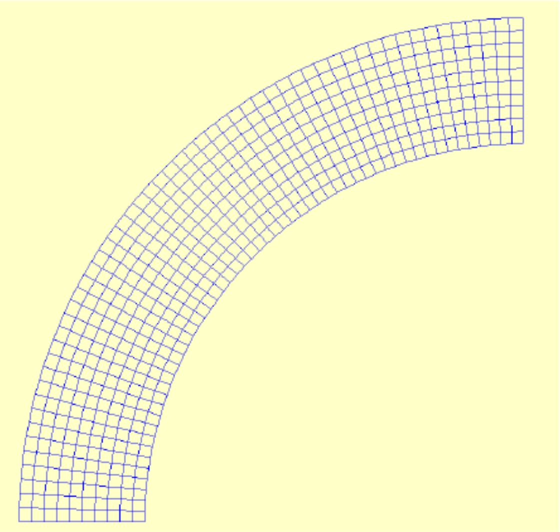
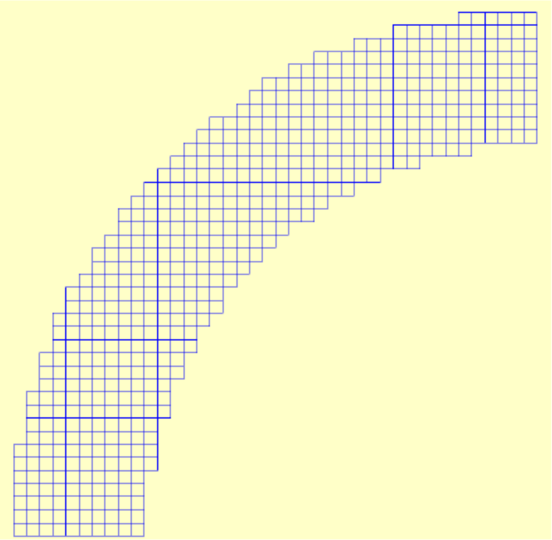
- Saltwater intrusion in estuaries
- **Fresh water discharges** in bays
- **Thermal stratification in seas**
- Cooling water intakes and waste water outlets
- Sediment transport and morphodynamics
- **Transport of dissolved material and pollutants**
- Storm surges modelling

Discretization of partial differential equations

Two horizontal co-ordinate systems (Delft3d structured)

- **metric**
- **spherical**

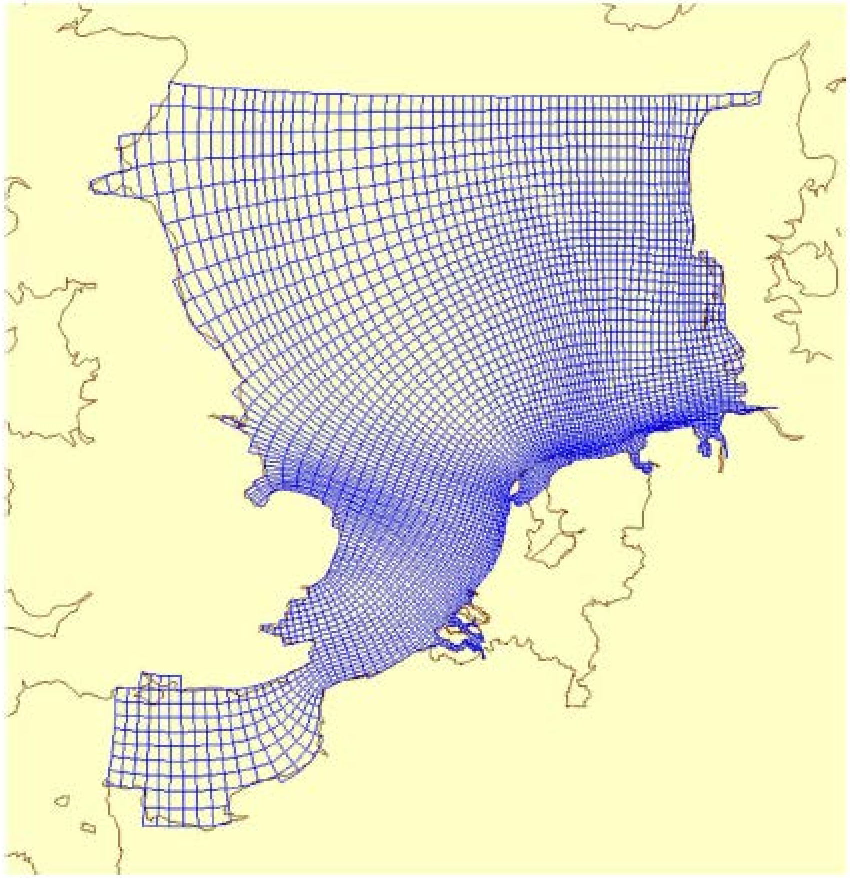




Discretization of partial differential equations

Curvilinear grid

- Local refinements where required
- Boundary fitted (no 'stair-case')
- Follows channels and shallow areas



Discretization of partial differential equations

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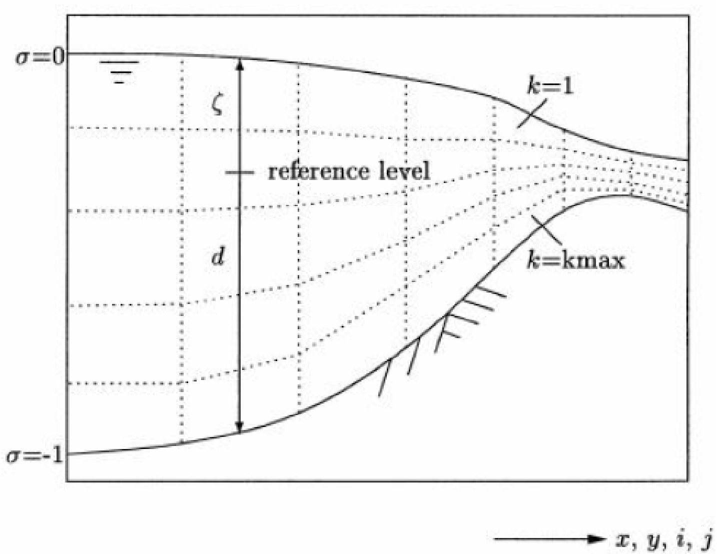
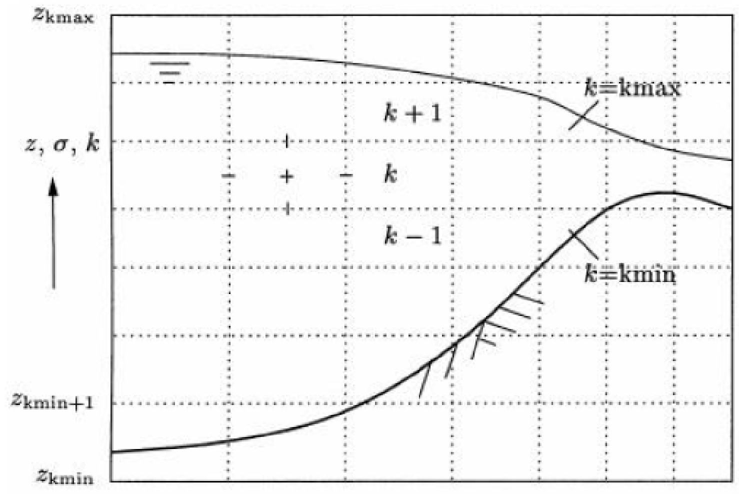
Two vertical systems

- **Surface and bottom following σ-layers**
- **Fixed horizontal z-layers**





Discretization of partial differential equations

Two vertical systems

- **Surface and bottom following σ-layers**
- **Fixed horizontal z-layers**

Shallow water equations (3D, hydrostatic)

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Assumptions

- **The shallow water assumption:** vertical accelerations are assumed to be small compared to the gravitational acceleration and are not taken into account.
- The effect of variable density is only taken into account in the horizontal pressure gradient term (Boussinesq approximation).
- The water is assumed to be incompressible
- Reynolds averaging for turbulent fluctuations
- Eddy viscosity concept

Shallow water equations (3D, hydrostatic)

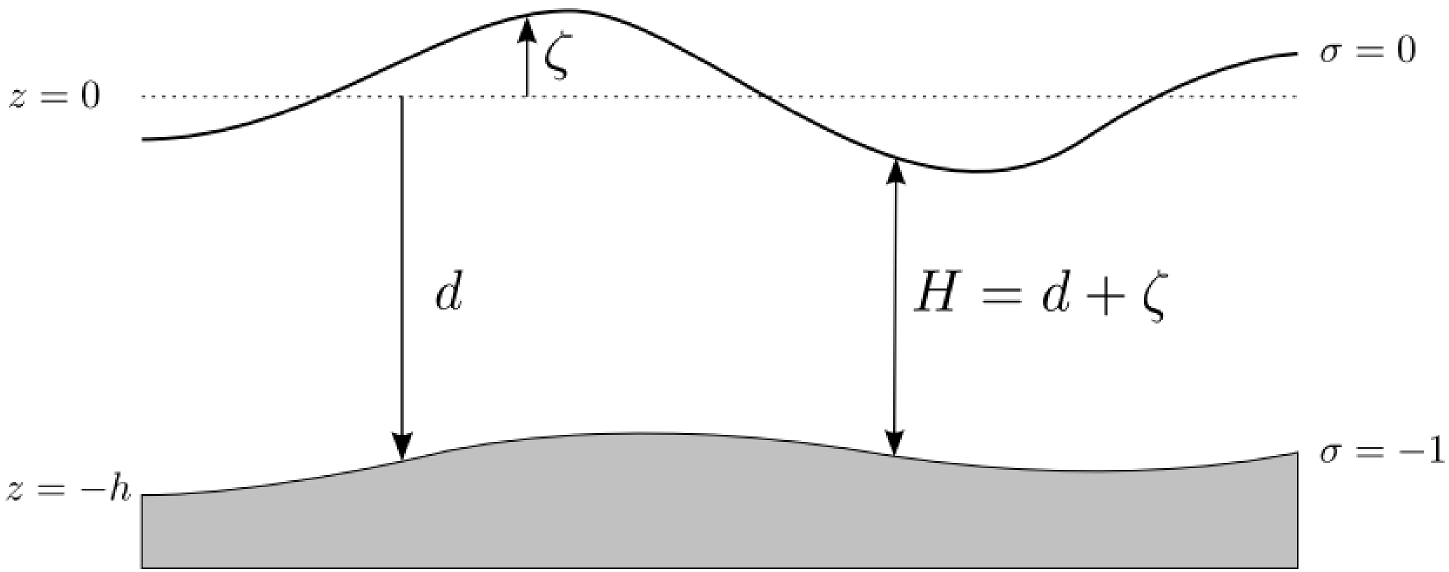


Figure 9.1: *Definition of water level (ζ), depth (h) and total depth (H).*

Shallow water equations (3D, hydrostatic)

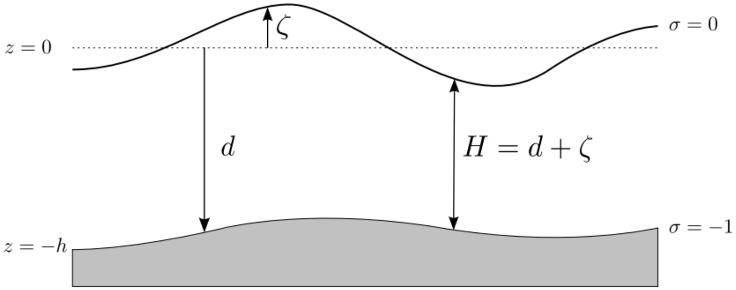
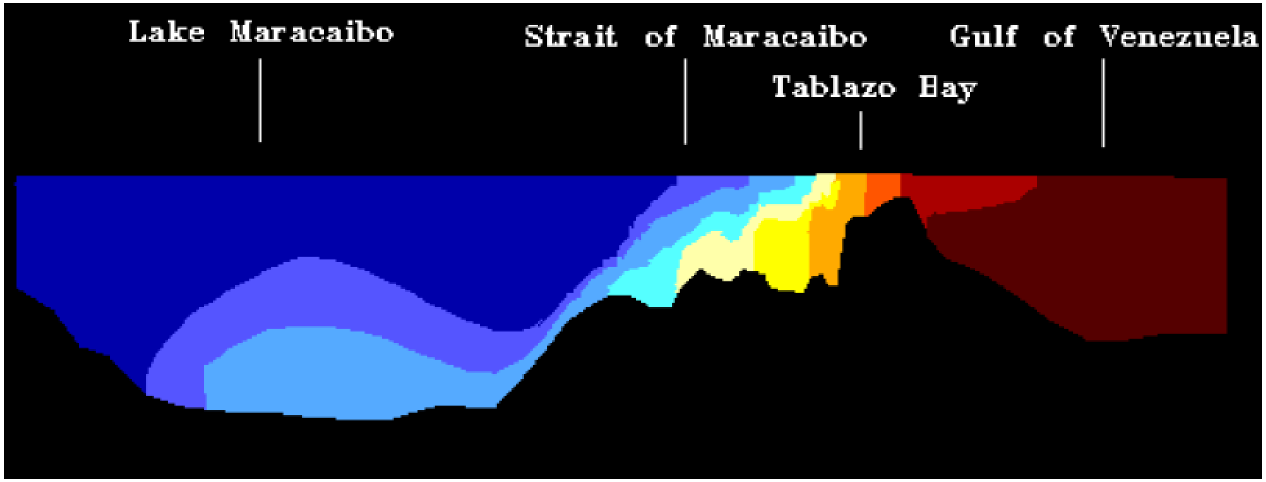


Figure 9.1: *Definition of water level (ζ), depth (h) and total depth (H).*

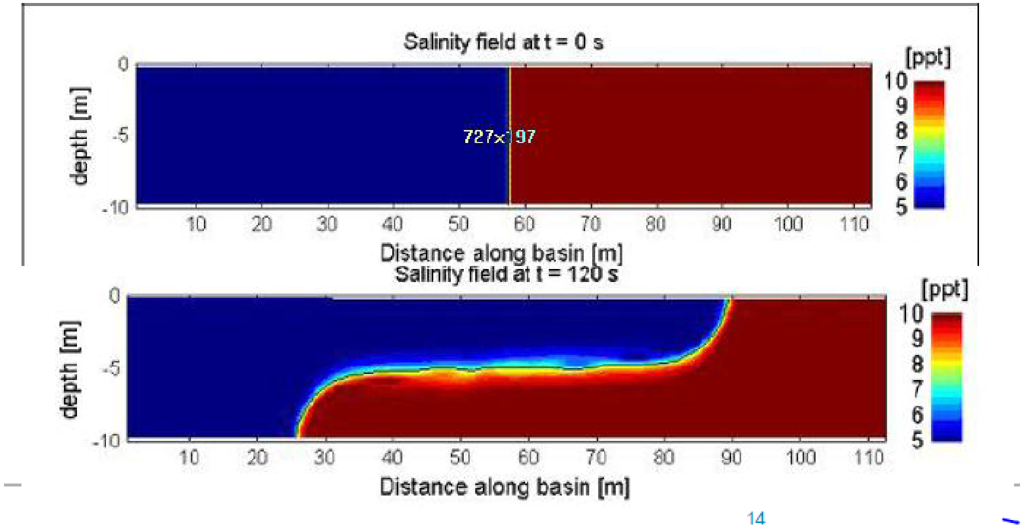
Delft3D-FLOW, 2D and 3D



- easy to switch from 3D to 2D and vice versa
- σ co-ordinates vertically, optional fixed layers
- same number of layers everywhere if σ is used
- special anti-creep approach

Delft3D-FLOW, salinity and temperature

- S- and T-stratification
- modelling re-circulation
- momentum of discharges
- several options for heat exchange atmosphere
- evaporation/precipitation



Modelling aspects and tasks

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- **Background and objective of the study – guidelines for the numerical approach**
- General orientation
- (field) data collection and analysis
- Set-up of the FLOW model
- Set-up FLOW postprocessing
- **Calibration and verification**
- **Production and reporting**

Background and objectives of the study

- **What is the actual interest of this study?**
  - Hydrodynamic, water quality, waves, morphology
- **If hydraulic, what are the problems?**
  - e.g. storm surge, flooding, construction, recirculation, stratification, flow regime
- Are different scenarios involved?
  - e.g. seasonal discharge, wind tidal ranges
- Are (accuracy) criteria set?
  - e.g. maximum water levels, velocities, temperature
- **What will be the main output, result?**

General orientation

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- **Identification problem, how to tackle**
- **Literature scan, what is known yet**
- **Characteristics of the study area**
  - Dominant currents, seasonal effects, morphological active
  - Physical phenomena to include 2D or 3D
- **Model boundaries**
  - Availability and accuracy of data
  - Tidal excursion, main flow patterns, orientation boundary
- **Specification grid, bathymetry**
  - Area of interest, channels, outfalls

(Field) data collection and analysis

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- **collecting consistent data on**
  - Coast line, bathymetry
  - water levels, currents, salinity, temperature
  - river flows, wind and pressure
- **processing, e.g.**
  - units, reference systems, format, conversion
  - erroneous data
- **analysis, e.g.**
  - Tidal constants
  - Consistency, quality assessment

Set-up of the FLOW model-1

- **model area and grid; Delft3D-RGFGRID**
  - specifications from previous steps
  - boundary fitted, orthogonal
- **bathymetry; Delft3D-QUICKIN**
  - Digitizing? Different reference levels?
  - Best data (recent, high-resolution) first
- **Dry points, thin dams, VISUALISATION AREA**
  - jetties, small islands, reclamations

Set-up of the FLOW model-2

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- **Open boundaries**
  - Water levels, velocity, discharge?
  - Number of boundary sections (variability parameter)
  - Forcing; time series; Harmonic, tidal constants
- **Physical and numerical parameters**
  - Roughness, wind, heat, drying & flooding parameters
  - Best data (recent, high-resolution) first
- **Monitoring stations, cross-sections**
  - Calibration data at inside locations
- **Sensitivity time-step**
  - Accurate results?

Set-up FLOW postprocessing

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- **QUICKPLOT**
- **what kind of plots, graphs**
  - Computed vs measured, predicted
  - time-series, 2DH, 2DV, profiles, vector, iso-lines
- **working routine for data set names/files**
  - Very efficient for postprocessing similar simulations
  - Calibration data at inside locations
- **Layout and text**
  - Well-documented
  - Self explaining

Calibration and validation

- **strategy, which data and periods**
  - accuracy criteria, wet-dry, neap-spring, wind
- **frequency and time domain**
  - tidal constants, first 2DH, always time domain
- **Calibration parameters**
  - Bathymetry, boundary conditions, roughness
  - Calibration data at inside locations
- **Log simulation and analysis results**

Production and reporting

- **final calibration, verification**
- **Report on**
  - Data used, quantity, quality
  - Model set-up
  - Process of calibration, verification
- **QA label model**
- **HD databases for WAQ, WAVE, etc. ?**
- **archive**

Delft3D-FLOW GUI

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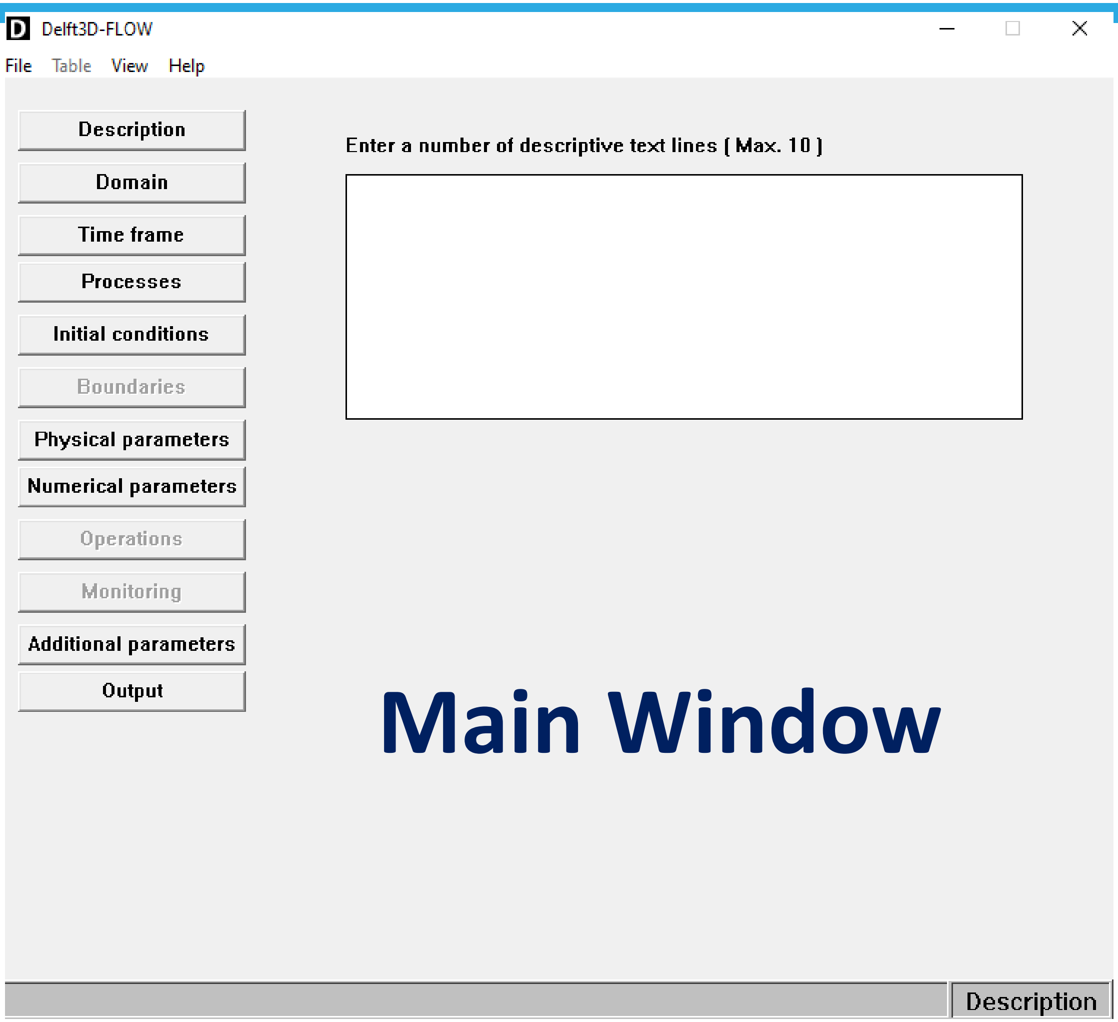
- ***One small input file* (Master Definition File, .mdf)** containing general information (time frame, etc.) and links to
- ***attribute files*** containing large data quantities (depths, boundary conditions, initial conditions, etc.)
- ***input data organised in Data Groups*** filled in by a graphical user interface

Delft3D-FLOW GUI



Data Group Domain

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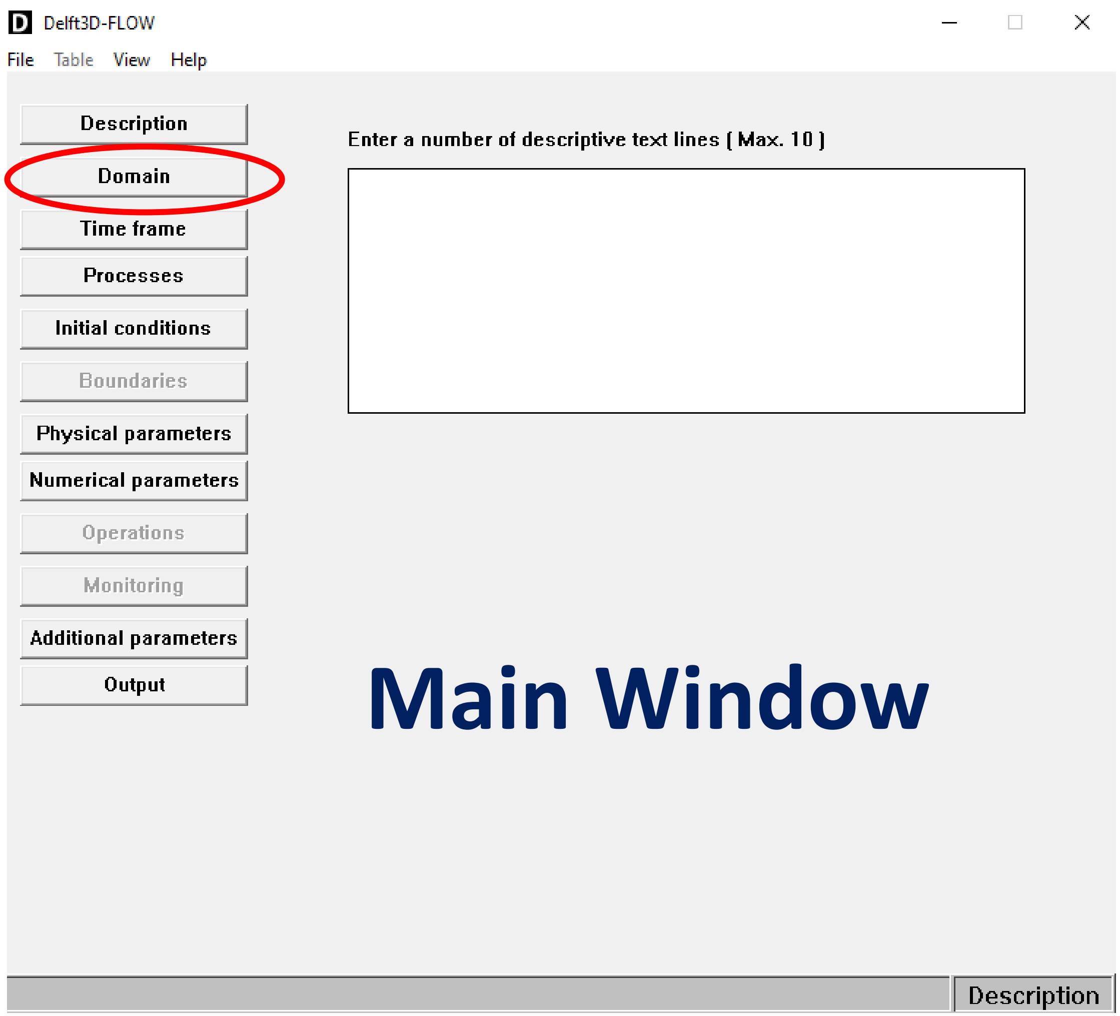
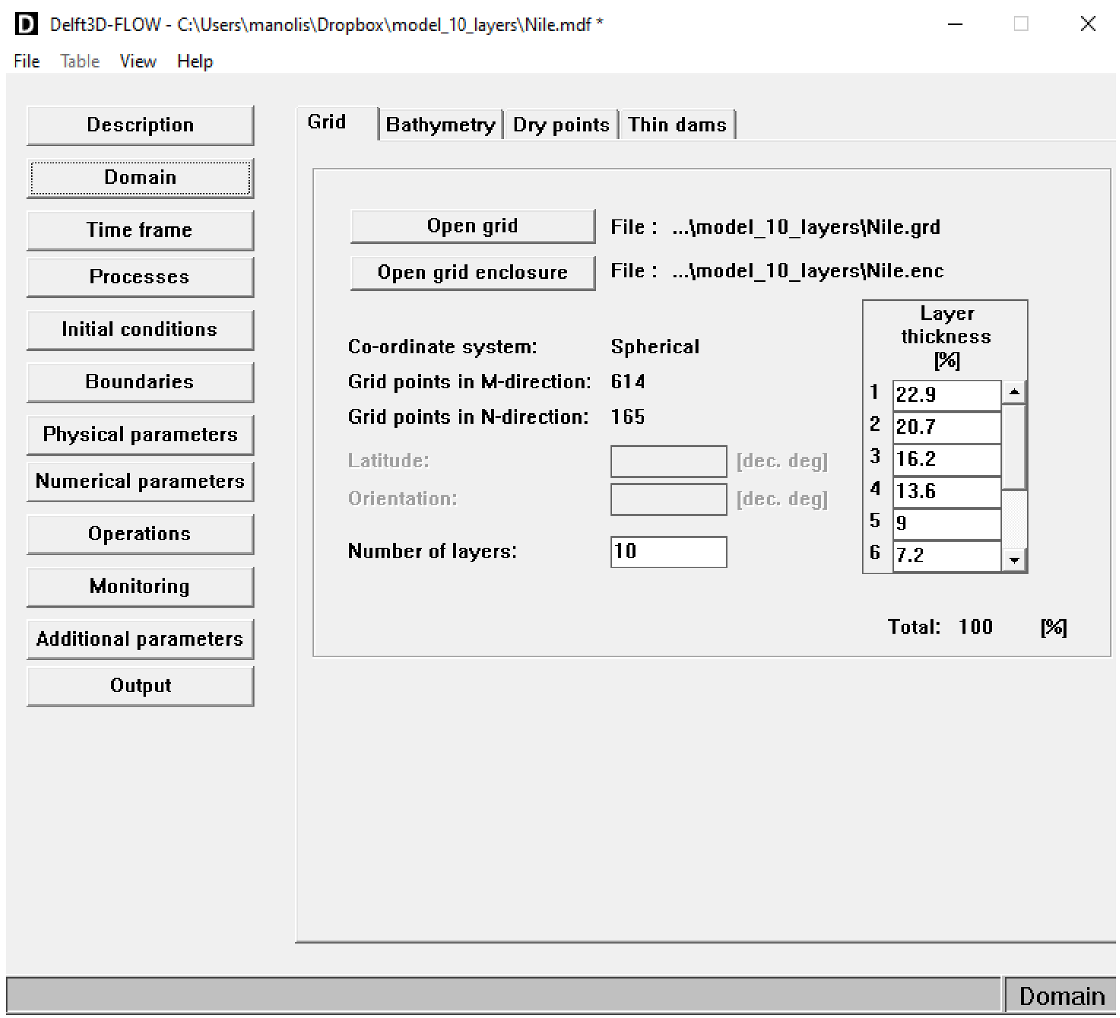
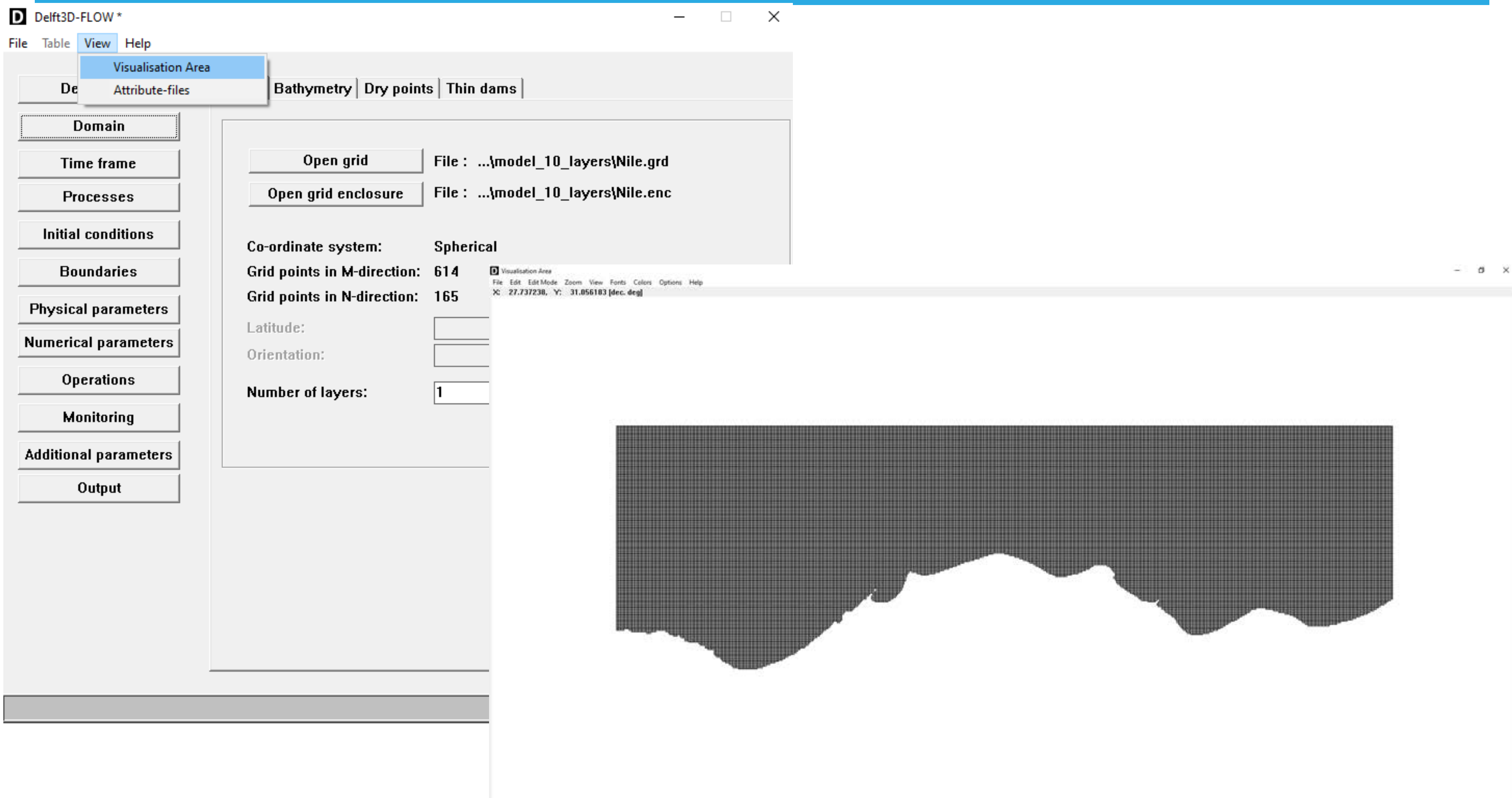


Data Group Domain

- grid (cartesian or spherical) (*.grd, and *.enc)
- number of layers and layer distribution (3D)
- latitude (Coriolis force)
- depth (uniform or from Delft3D-QUICKIN, *.dep)
- dry points and thin dams (*.dry and *.thd)
  - point-and-click in Visualisation Area



Data Group Domain



Data Group Time Frame

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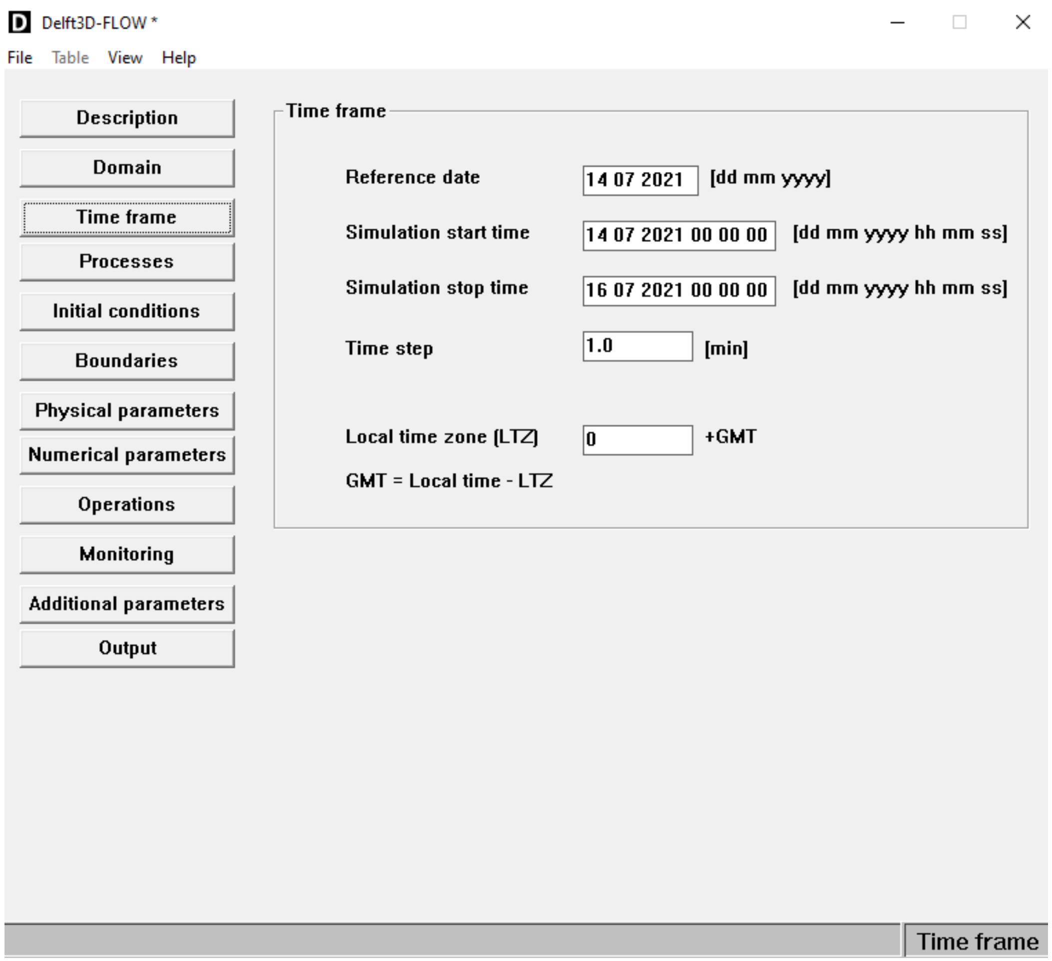
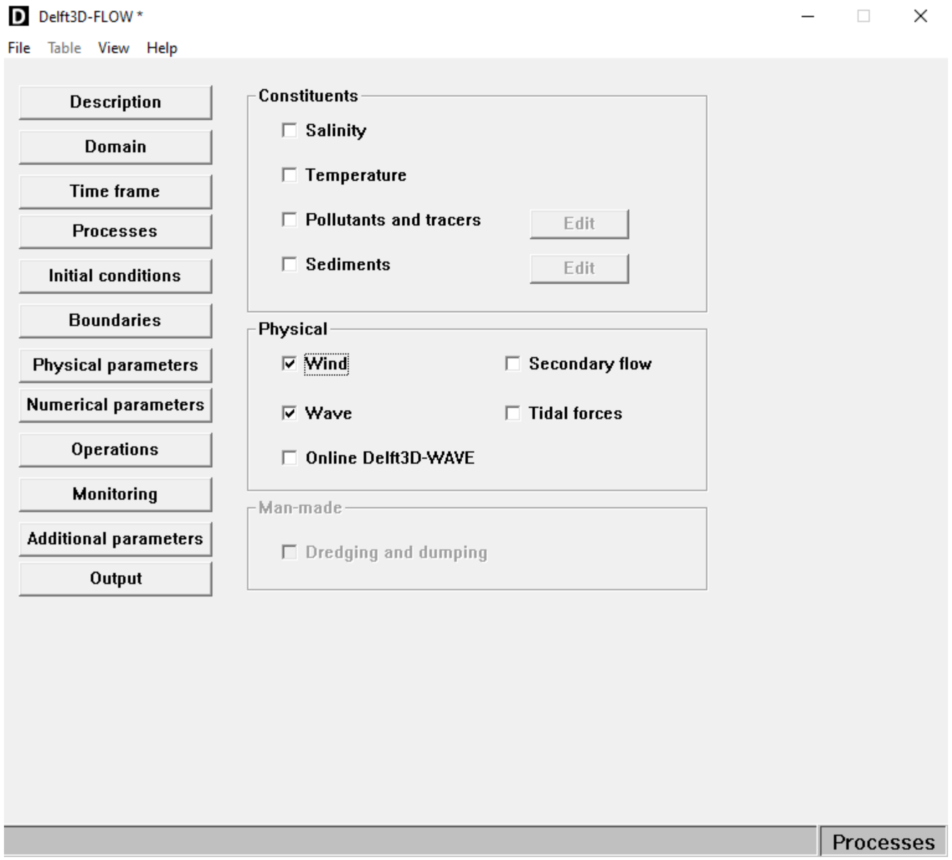
- reference time of the simulation (ddmmyyyy); relevant for astronomical BC
- start time of simulation (ddmmyyyy hhmmss)
- stop time of simulation (ddmmyyyy hhmmss)
- computational time step (min)

Local Time Zone



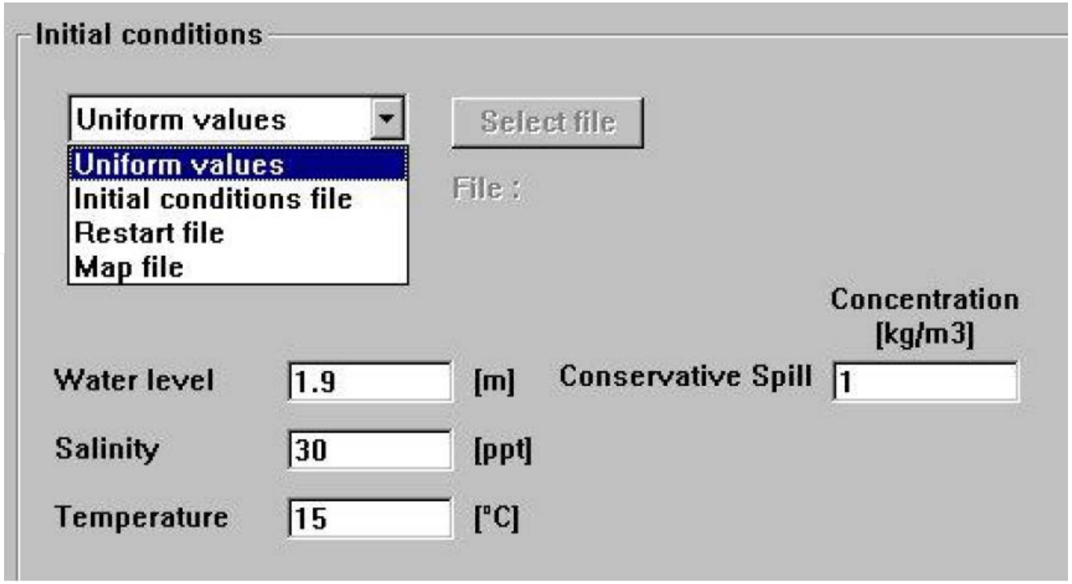
Data Group Processes

- salinity
- temperature
- passive tracers (constituents)
- sediments (cohesive and non-cohesive)
- wind
- tide generating forces
- include effects of (short) waves on flow
- include spiral motion (rivers, 2DH)
- dredge and dump



Data Group Initial Conditions

uniform
attribute file (*.ini)
from previous computation (restart file tri-rst.<runid>.<date>,<time>)
map-file



Data Group Boundaries – Flow BC

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- *Open boundaries are virtual "water-water" boundaries.*
- They are introduced to obtain a limited computational area and so to reduce the computational effort.
- In nature, waves can cross these boundaries unhampered and without reflections.
- At an open boundary the water level, the normal velocity component or a combination should be prescribed to get a well-posed mathematical initial-boundary value problem.
- The data needed for the boundary conditions can be obtained from measurements, tide tables or from a larger model, which encloses the model at hand (nesting).

Data Group Boundaries – Flow BC

- *If we do not prescribe exactly the incoming waves at an open boundary, the outgoing waves will reflect at the boundary and propagate as a disturbance into the area.*
- To reduce the reflections at the open boundary (Verboom and Slob, 1984; Verboom and Segal, 1986) derived a so-called zero and first order weakly reflecting boundary condition based on the work of Engquist and Majda (1977, 1979).
- Assuming zero flow along the boundary, the zero order boundary condition may also be obtained using the so-called Riemann invariants for the linearised 1D equation normal to the open boundary: $R = U \pm 2\sqrt{gH}$.

Data Group Boundaries – Flow BC

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- The two Riemann invariants are two waves moving in opposite direction with propagation speed R.
- *Riemann invariant is a combination of water level and current. The Riemann type of boundary is used to simulate a weakly reflective boundary. The main characteristic of a weakly reflective boundary condition is that the boundary up to a certain level is transparent for outgoing waves, such as short wave disturbances. Outgoing waves can cross the open boundary without being reflected back into the computational domain as happens for the other types of boundaries.*

Data Group Boundaries – Flow BC

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- *In the computational part, the following type of boundary conditions are distinguished (for the sake of simplicity only a description for the U-direction is given here):*

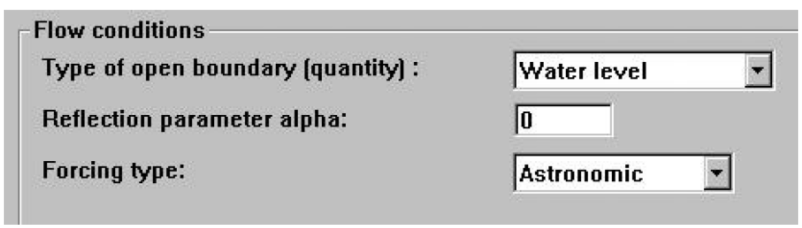
  - Water level: $\zeta = F_\zeta(t) + \delta_{atm}$,
  - Velocity (in normal direction): $U = F_U(t)$,
  - Discharge (total and per cell): $Q = F_Q(t)$,
  - Neumann $\frac{\partial \zeta}{\partial \vec{n}} = f(t)$,
  - Riemann invariant $U \pm \zeta\sqrt{\frac{g}{d}} = F_R(t)$.

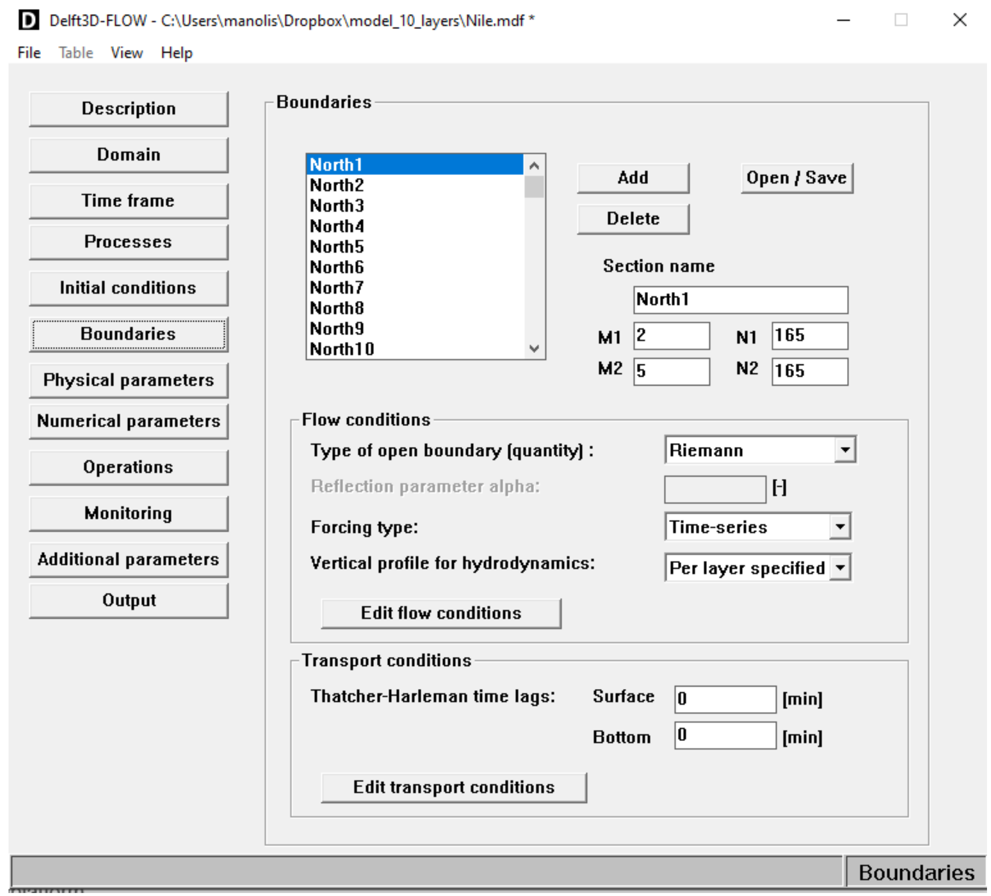
Data Group Boundaries – Flow BC

boundary sections, using Visualisation Area (*.bnd)

for each segment

- boundary forcing type
  - > water level, velocity, Neumann, discharge, Riemann
  - > reflection coefficient (not for Neumann and Riemann)
- boundary forcing data type (*.bca, *.bch resp. *.bct resp. *.bcq)
  - > astronomical (tidal constituents, amplitudes, phases)
  - > harmonic (frequencies, amplitudes and phases)
  - > time-series (uniform, linear, logarithmic or per layer)





Astronomical Tides

Astronomical tide = sum of harmonic constituents (k):

$$H(t) = A_0 + \sum_{i=1}^{k} A_i f_i \cos\left(\omega_i t + (V_0 + u) - G_i\right)$$

$H(t)$ = water level
A_0 = mean value
A_i = tidal amplitude component i
F_i = nodal amplitude factor for component i
ω_i = angular velocity / frequency component i
V_0+u = astronomical argument of component i
G_i = local phase lag component i

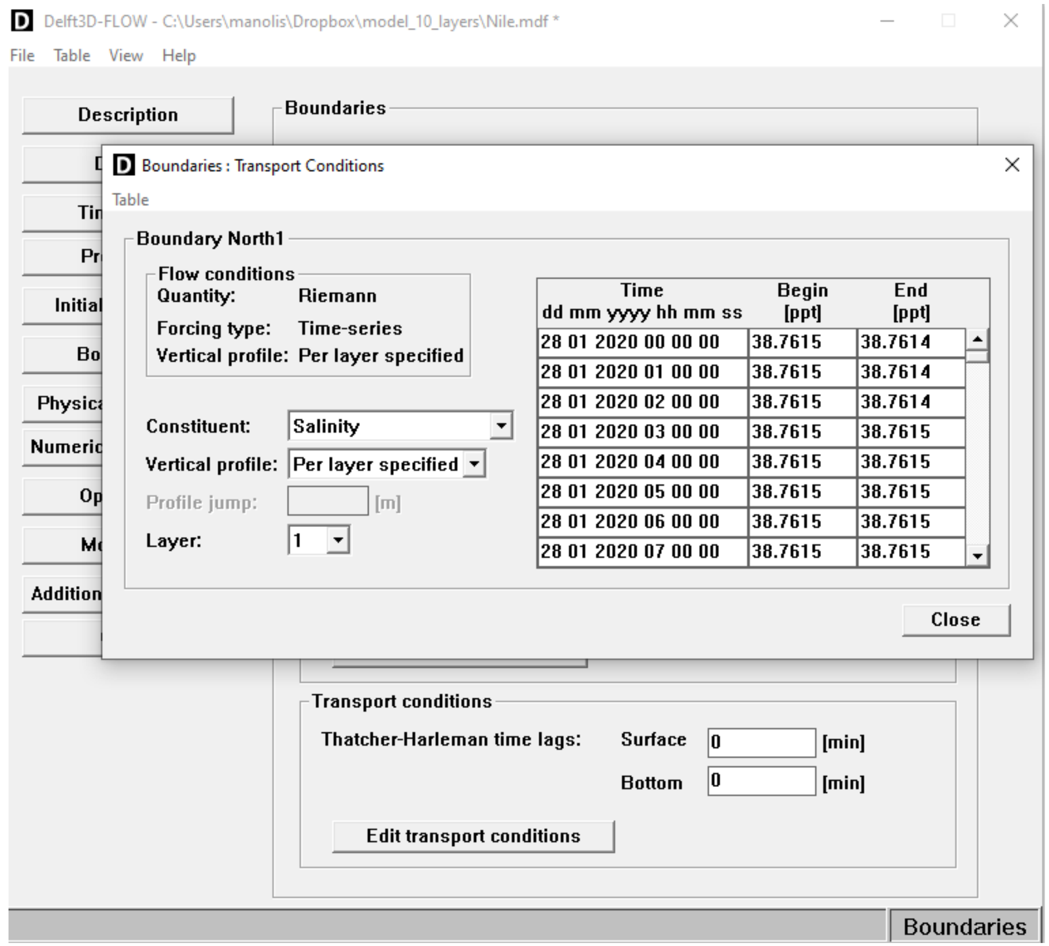
Data Group Boundaries - Transport BC

for salinity, temperature and tracers (*.bcc)

specify “concentrations”

- uniform
- linear, between surface and bed
- step (‘2-layer’ system)
- per computational layer

Thatcher Harleman time lags (inflow)



Data Group Physical Parameters

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constants (gravity, water and air density, wind stress coefficients, background salinity and temp)

roughness (Manning, Chézy, White Colebrook or Z0) and partial slip condition (*.rgh)

horizontal and vertical viscosity (hydrodynamics) and diffusivity (transport) (*.edy)

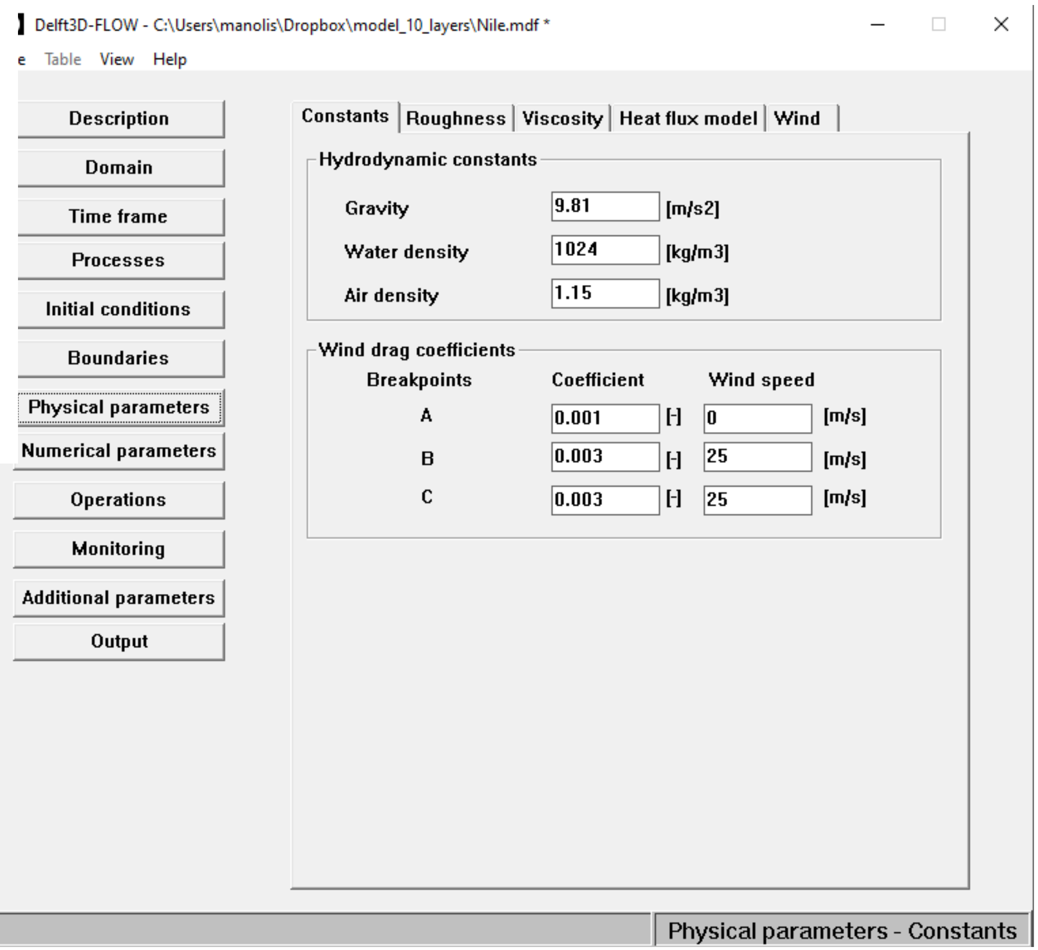
model for 2D turbulence (HLES)

turbulence closure model (k-eps recommended for stratified conditions)

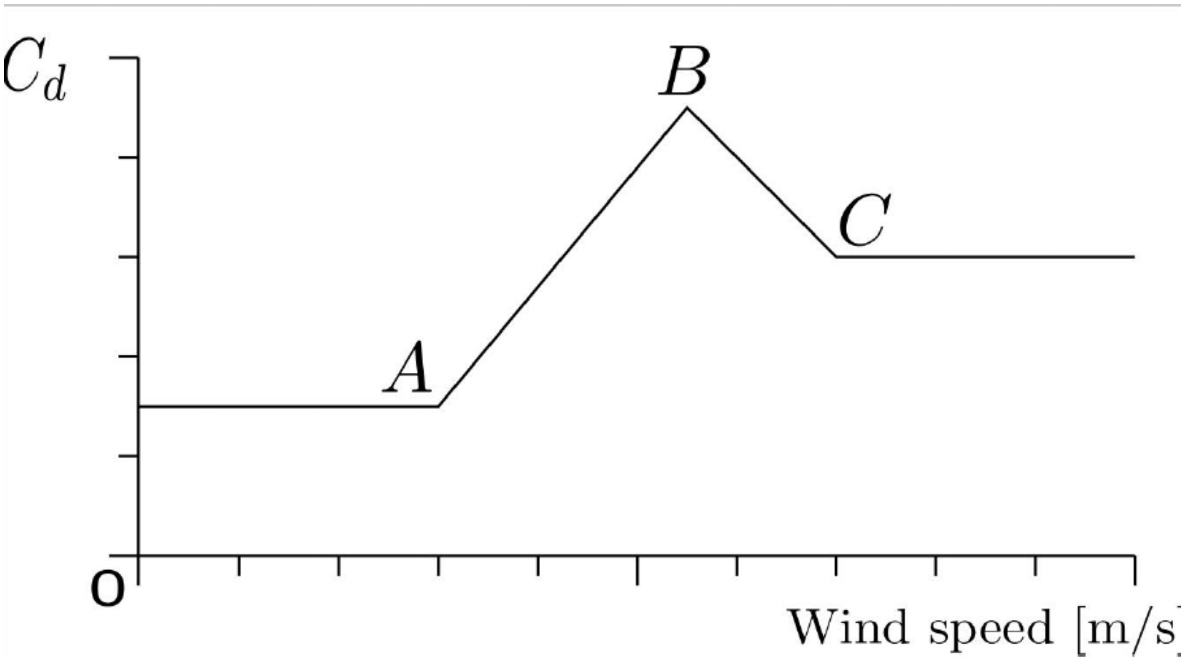
heat flux model (*.tem, exchange at water surface)

sediment and morphology

wind forcing (speed and direction, *.wnd, *.svw)



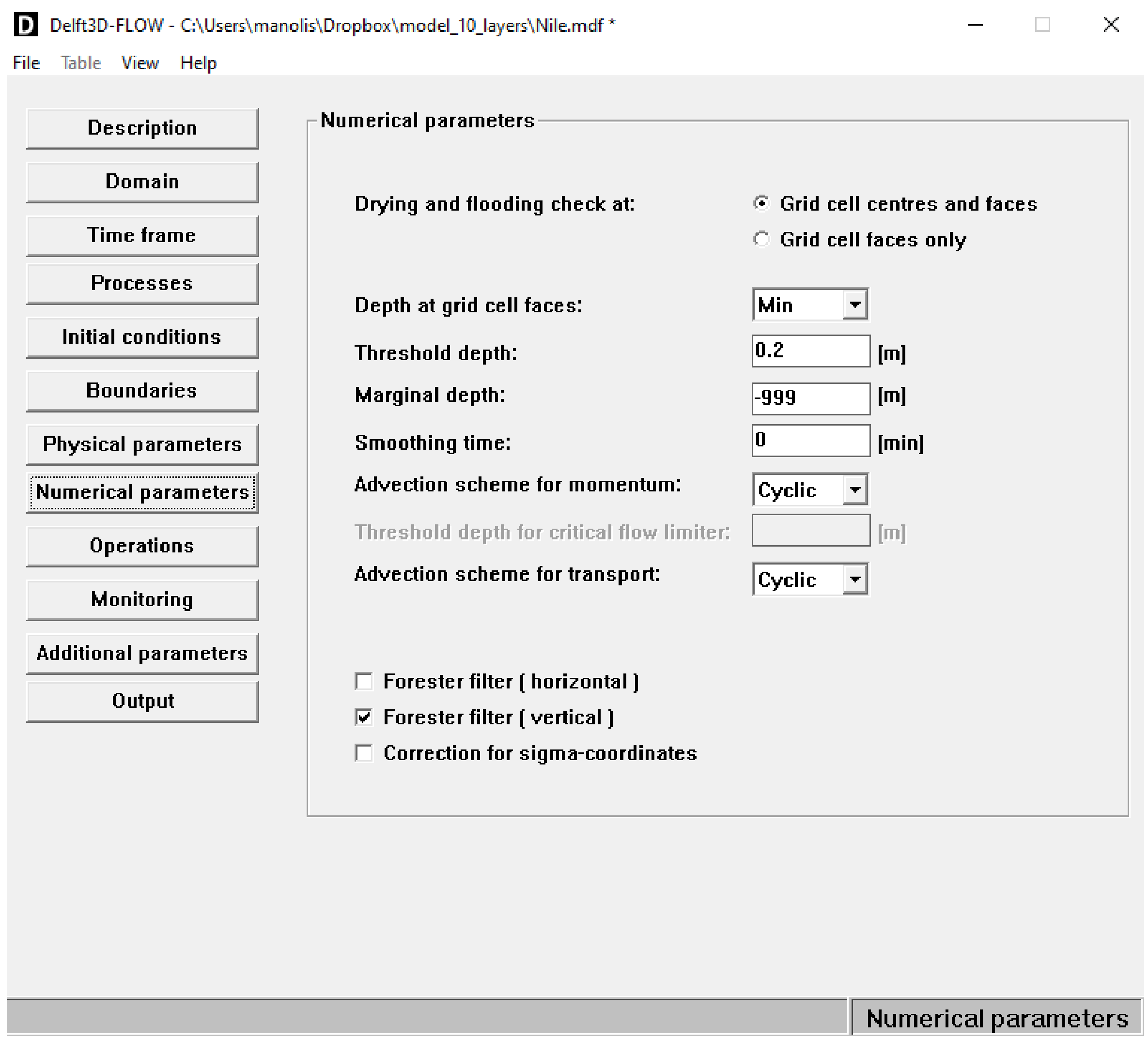
Data Group Physical Parameters



Cd_A at W_A
Cd_B at W_B
Cd_C at W_C

Data Group Numerical Parameters

- extra drying and flooding procedure and parameters
- smoothing time
- numerical scheme for momentum
- numerical scheme for transport (salinity, temperature and/or tracers)
- filter to avoid overshoot undershoot concentrations
- correction sigma co-ordinates (anti-creep)



Data Group Operations

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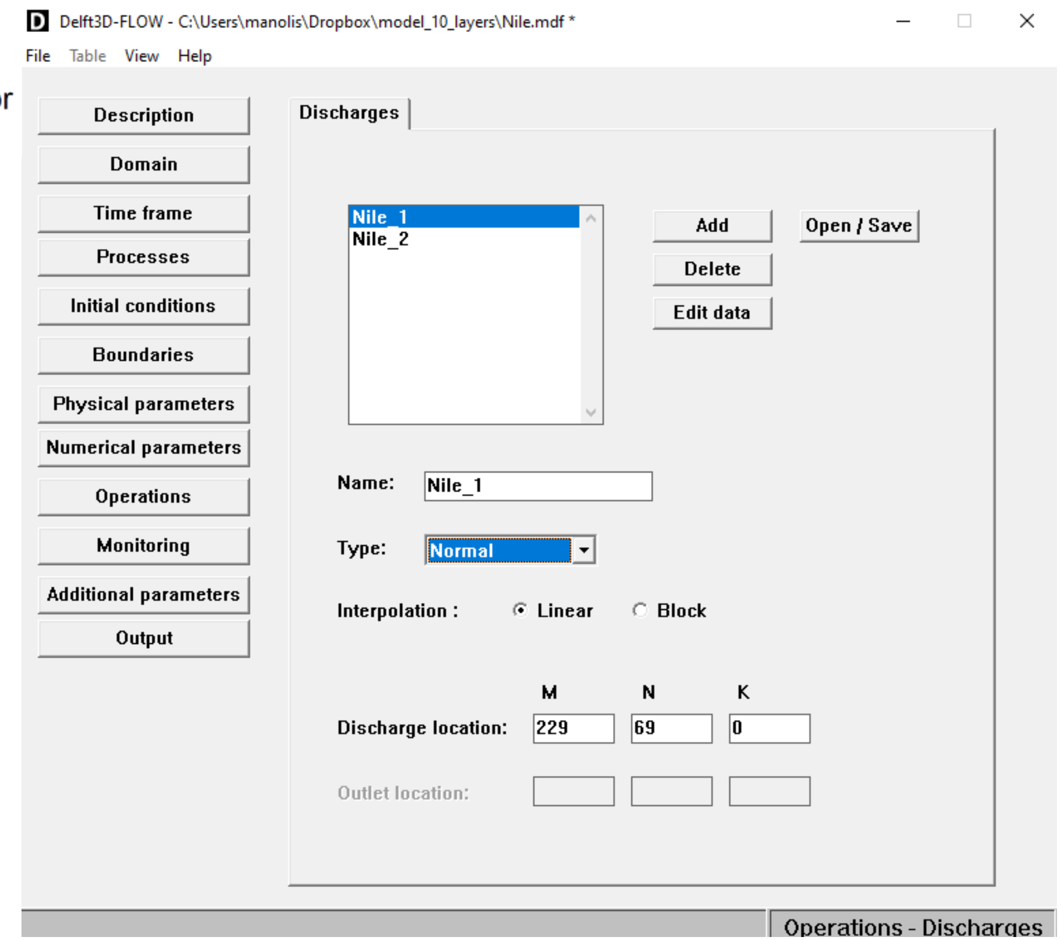
discharge location (small rivers, outfalls) either in the Visualisation Area or by attribute file (*.src)

for each discharge: flow (m3/s), salinity, temperature or tracer concentration (*.dis)

type of discharge

- normal
- inclusion of momentum
- walking
- Intake - outlet

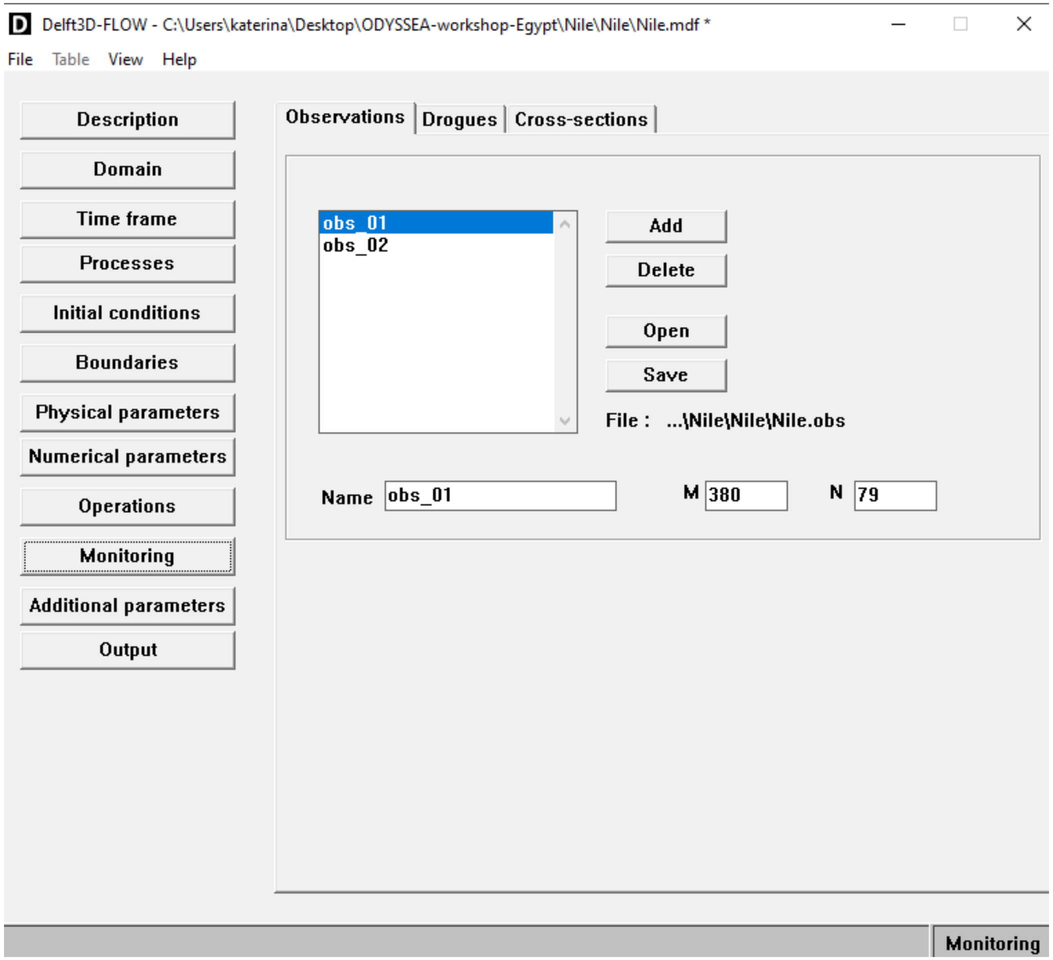


Data Group Monitoring

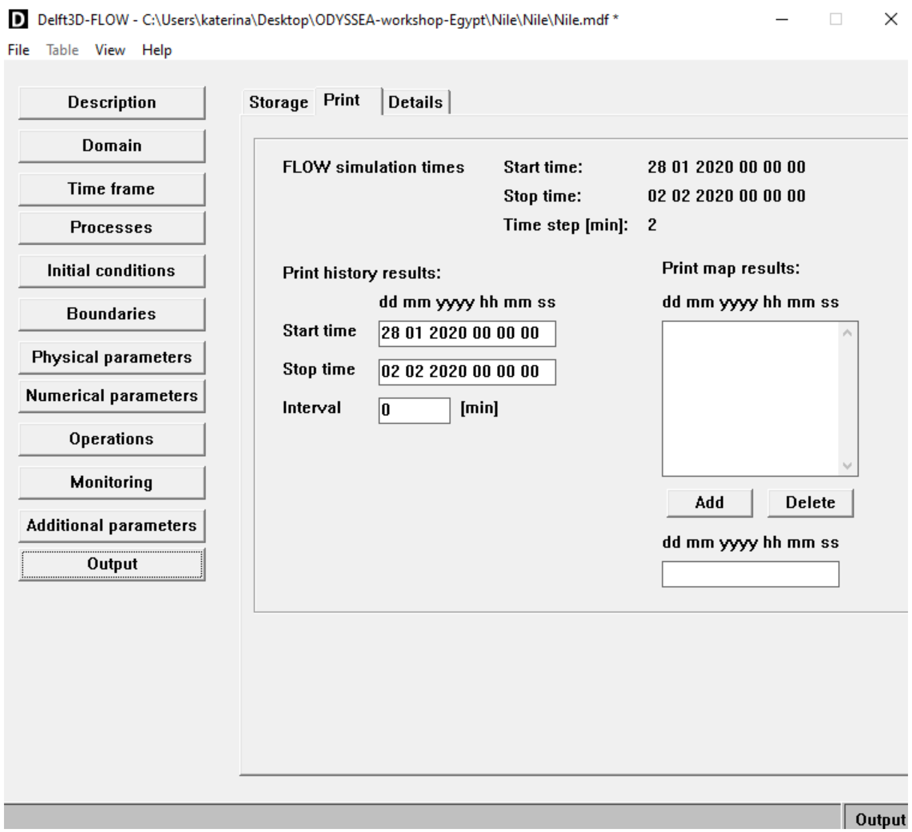
observation points (stations for history output, *.obs))

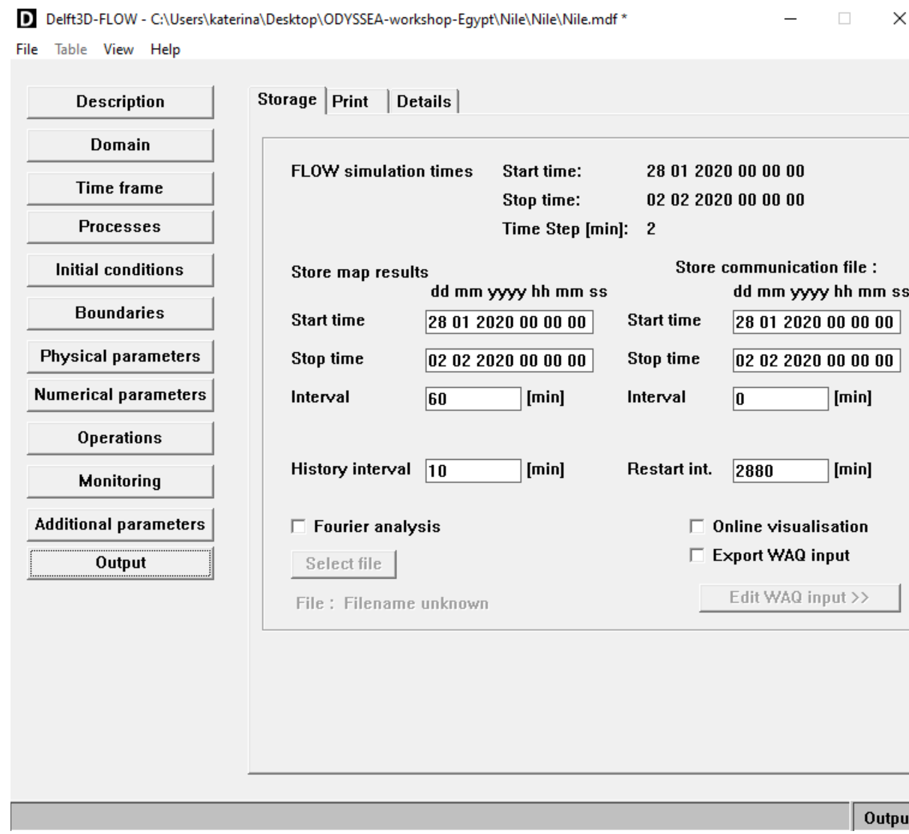
drogue track release and recovery points (f.I. tidal excursion), *.par

cross-sections (history output of momentary and accumulated fluxes, *.crs)



Data Group Output Options





Data Group Output Options

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times for map output (each grid point)

interval for history output

times for output to be used by other programs (communication file used by Delft3D-WAVE, WAQ, PART, etc)

sub-selection of parameters

FOURIER analysis (*.fou)

storage and print output timings

online visualisation

online coupling

GUI - Exercises

Creating a sample model- Delft Dashboard

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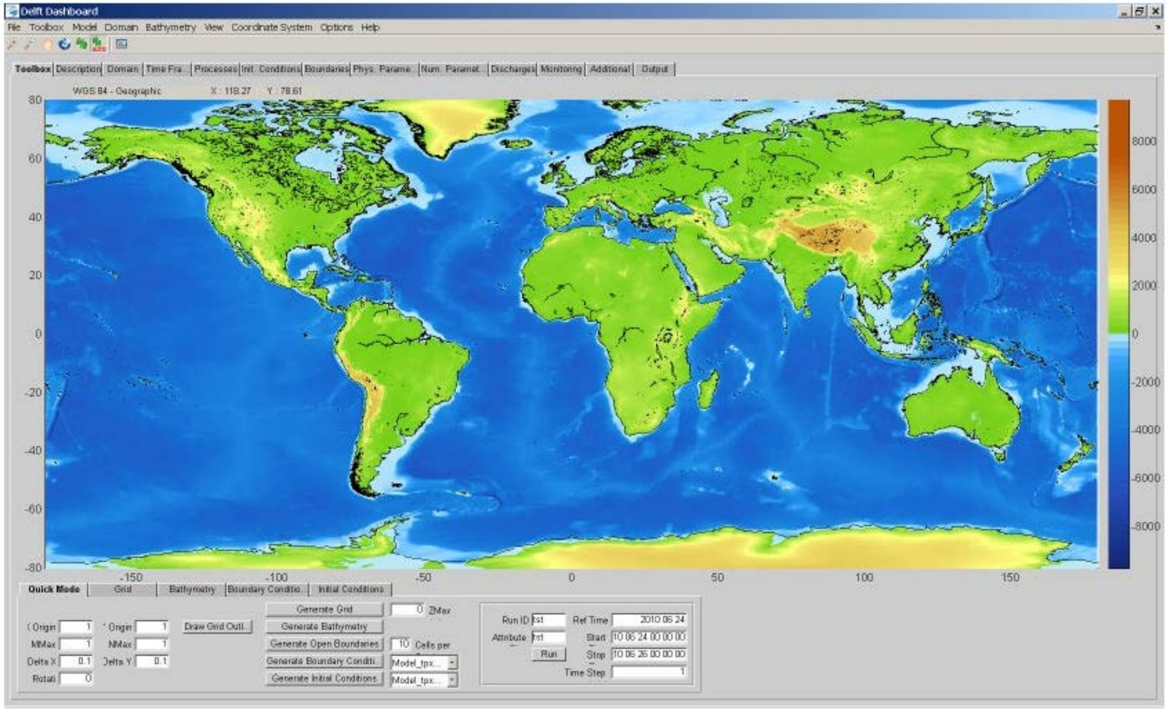
Delft Dashboard

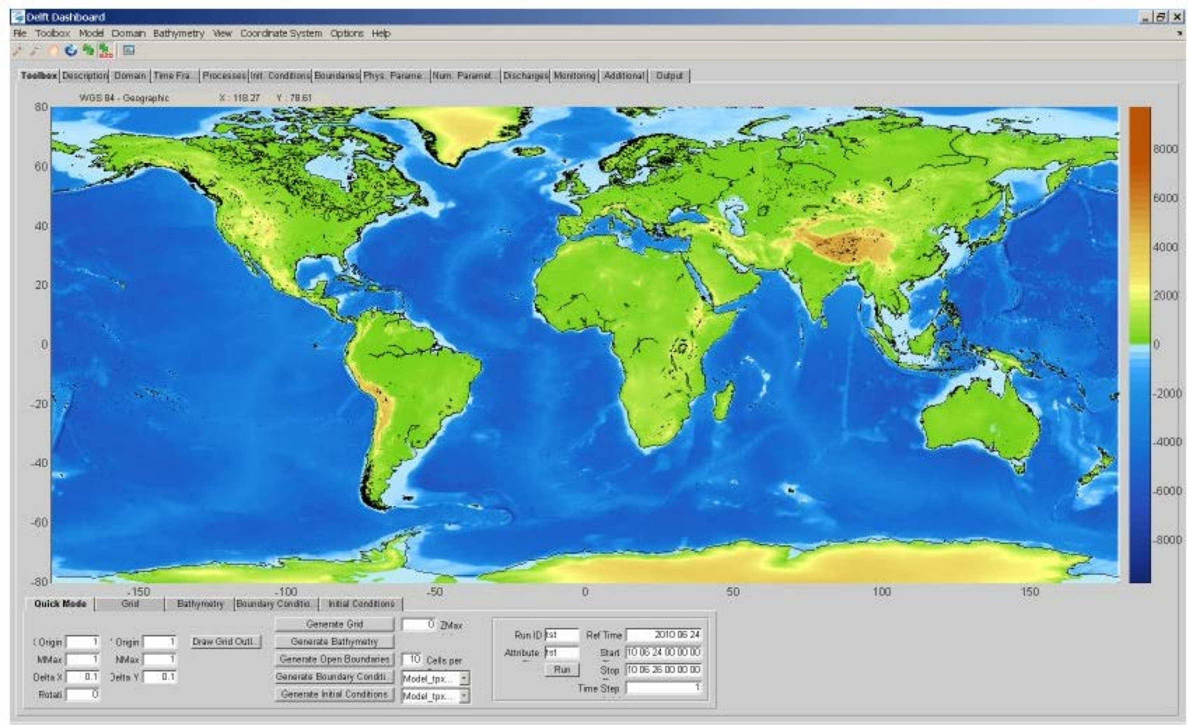
Delft Dashboard is a standalone Matlab-based graphical user interface (i.e. GUI) which supports modellers in setting up new and existing models. Delft Dashboard employs a large number of coupled toolboxes for fast and easy model input generation. For any location in the world a model can now be set up in a matter of minutes, an operation which used to take weeks of work until a short time ago!

The Delft Dashboard interface includes all the options related to hydrodynamics, waves, morphodynamics and water quality that are also available in the Delft3D modelling suite. Yet, the range of application reaches beyond a standard Delft3D model set up, as the interface also offers toolboxes for e.g. advanced tidal analysis, wind speed simulations, pressure drop estimations for tropical cyclones and tsunami generation/propagation analysis.



Creating a sample model- Delft Dashboard

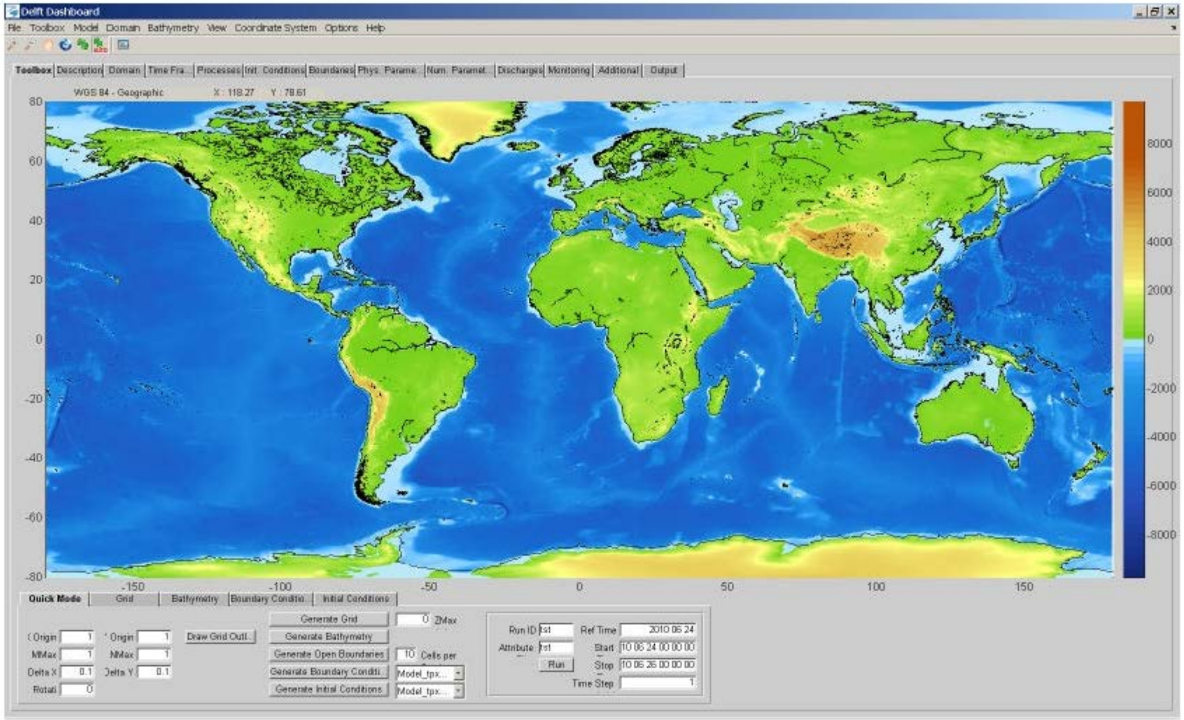
*The **Top menu** describes the most generic functions such as toolboxes, bathymetries, coordinate systems and saving options for files that are generated during your Delft Dashboard working session. The Top menu also includes features to Zoom in, Zoom out, Pan and Refresh the Map View.*



Creating a sample model-Delft Dashboard

Model menu

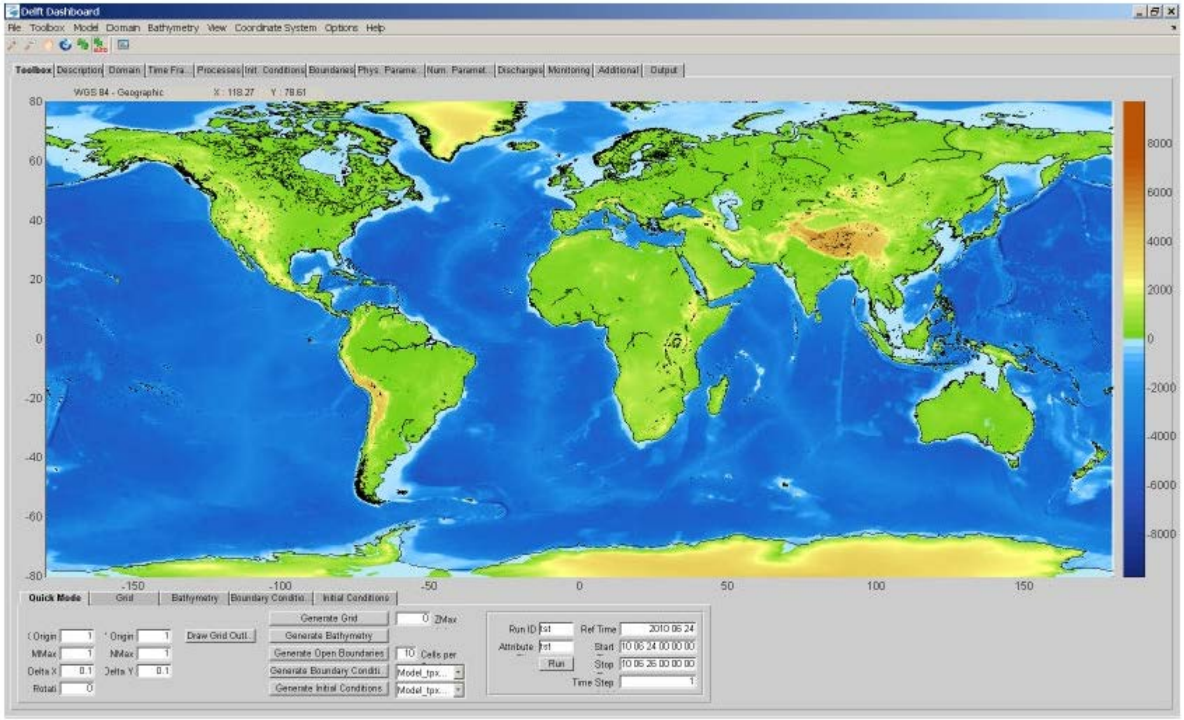
The Delft3D-FLOW menu in Delft Dashboard resembles the interface of the Delft3D-FLOW modelling suite. This menu can be used to edit the Delft3D-FLOW steering file (i.e. MDF-file) and thus gives the opportunity to e.g. include or exclude physical processes, define physical and numerical parameters, or to add monitoring stations. The main difference with respect to the Delft3D-FLOW interface is the Toolbox Tab, which does not exist in Delft3D-Flow.



Creating a sample model- Delft Dashboard

Map view

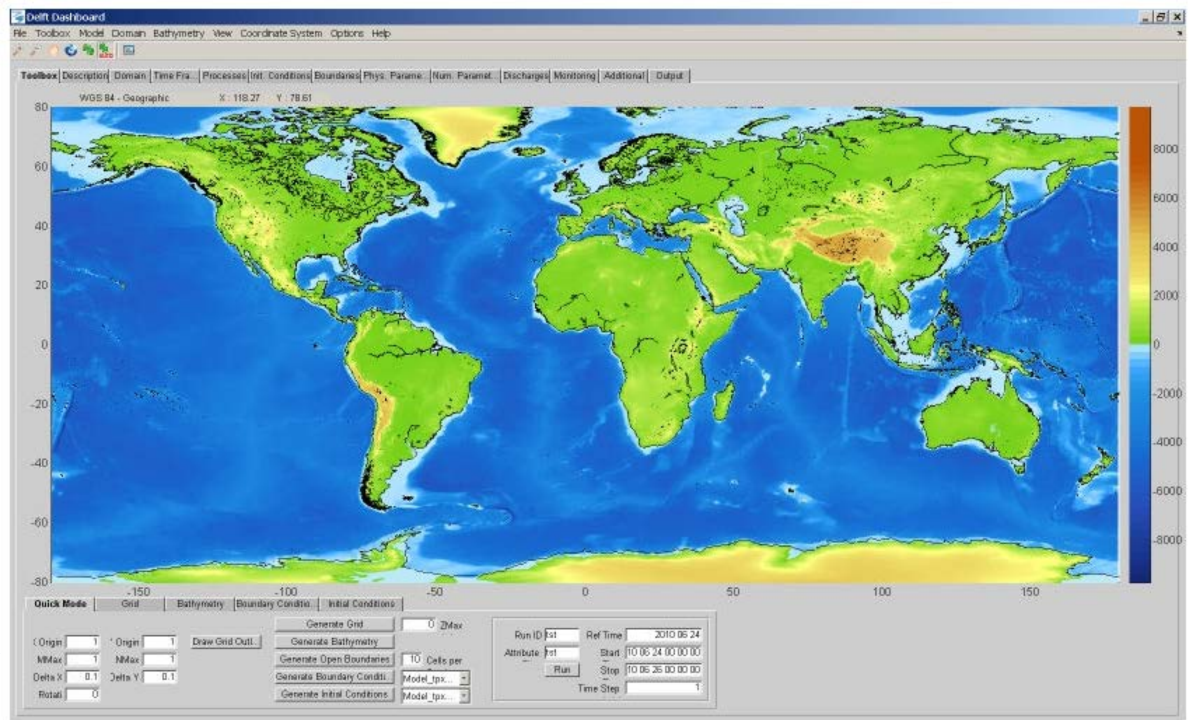
The Map View window visualizes the map with the bathymetry and/or topography used to construct the model. As a default, Delft Dashboard starts up with the GEBCO 2008 world bathymetry in the background.



Creating a sample model- Delft Dashboard

Working space

The editing of the steering file, as well as the definition of grid extension, resolution and set-up of the model bathymetry happens within the Working space, at the bottom of the Delft Dashboard home page. The items that are displayed, depend on the active tab in the Model menu, e.g. Toolbox, Initial conditions or tabs for other settings in the model input files.



Creating a sample model- Delft Dashboard

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Delft3D-FLOW

The Delft3D menu in Delft Dashboard resembles the interface of the Delft3D-FLOW modelling suite. More information can be found in the Delft3D-FLOW manual.

Button	Description
Toolbox	To perform a number of operations according to the Toolbox selected from the *Toolbox* tab in the Top Menu. For all the supported models the startup toolbox is the quick mode of the model maker. In case of Delft3D-FLOW also the possibilities to (1) combine several sources of bathymetry and (2) to define a variable roughness are implemented.
Description	To add a description to the communication file (i.e. MDF file) about the purpose of the present model.
Domain	The data Group Domain contains the following sub-data groups in the Working Space: *Grid, Bathymetry, Dry Points, Thin Dams, 2D Weirs, Structures*. • *Grid* is used to "Open a grid" file (.grd) and "Open a Grid enclosure " file (.enc). The "number of layers" on the vertical is also defined, as well as their vertical spacing in percentage with respect to the total depth. Both, "Sigma layers" and "Zeta layers" are supported. In case of Sigma layers it is moreover possible to specify the thickness (in m) of the top and bottom layer ("Z top" and "Z bottom"). The "Latitude" of the grid used to compute the Coriolis force. "Orientation" defines the grid orientation as the angle between the true North and the y-axis of the Cartesian co-ordinate system. • *Bathymetry* loads an existing depth file or can be used to define a bathymetry with a uniform water depth. • *Dry Points* is used to define points that will be permanently dry during a computation, regardless of the local water depth. Add dry points (*.dry) to the model using the mouse or load it from an external file. • *Thin Dams* are used to represent small obstacles (e.g. breakwaters, dams) in the model prohibiting flow between cells adjacent to them. Add thin dams (*.thd) to the model using the mouse or load it from an external file. • *2D Weirs* are used to represent hydraulic structures (e.g.spillways) in the model resulting in energy loss. • *Structures* are not implemented yet
Time Frame	Defines the relation between the time axis of the real world (absolute time) and that of the simulation (relative time). "Reference Date" defines the arbitrary time t = 0 for all the time series computed by the simulation. "Start Time" and "Stop Time" defines start time and end time of the simulation. "Time Step" defines the Time step (in minutes) used in the computation. "Time Zone" defines the time difference between local time and GMT time and is used to determine the phases in the local time of the tidal components in case tide generating forces are included in the simulation.

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Processes	The data Group Processes contains the following sub-data groups in the Working Space: *Constituents, Physical, Anthropogenic*. • *Constituents*: to include "Salinity", "Temperature", dispersion of "Pollutants and tracers" and transport of cohesive and/or non-cohesive "Sediment" in the simulation. For "Pollutants and tracers" and "Sediment" processes the names of the constituents need to be added. • *Physical*: to include the effect of Wind, Waves, Tidal forces and Secondary Flows. • *Anthropogenic (Dredging and Dumping)*. Not yet implemented.
Initial Conditions	To specify the initial values the computation will start with. Initial conditions are required for all processes specified under the Tab Processes. A number of options can be selected: "Uniform Values" to impose a constant value, "Initial Condition File", "Restart File", and "Map File" to impose a value from the external file.
Boundaries	To define the open boundaries, their location, type and other parameters describing them. Boundary conditions are stored in the ".bnd" file. The following "Type" of boundary conditions are available: "Water level", "velocity", "Neumann" (water level gradient), "discharge" or flux (total or per grid cell), "Riemann" (or weakly reflective boundary). Each boundary is identified by its "Name", start and end coordinates ("M1", "N1"; "M2", "N2"), reflection coefficient ("Alpha") and type of forcing ("Astronomic", "Harmonic", "Time-series", "Q-H relation"). Moreover, the vertical profile for hydrodynamics can be prescribed as: "Uniform", "Logarithmic", "Per Layer". The latter option applies neither to "Water Level" or "Neumann" boundary sections nor depth-averaged simulations.
Physical Parameters	To select or specify a number of parameters related to the physical conditions of the model area. The data Group Physical parameters contains the following sub-data groups in the Working Space: *Constants, Roughness, Viscosity, Sediments, Morphology, Heat Flow, Wind*. The tabs for *Constants, Roughness* and *Viscosity* are always visible. The other tabs are only visible if the associated processes are switched on. • *Constants*: to define values for: "Gravity", "Water Density", "Air Density". • *Roughness*: to specify the bottom roughness and the roughness of the side walls. • *Viscosity*: to specify values for background horizontal and vertical eddy viscosity and diffusivity. Viscosity and diffusivity calculated with the Horizontal Large Eddy Simulation ("HLES") can be added to it. For a 3D simulation, the vertical turbulent eddy viscosity and diffusivity which are added to the background value, are computed by one of the following models: "Constant", "Algebraic", "k-L", "k-epsilon" • *Sediments*: to specify sediment characteristics, in case you have "Sediment" switched on among the Processes. Sediment characteristics can be read from or saved to the "*.sed" file. • *Morphology*: to specify parameters for bed-update and to carry out a full morphodynamic simulation. • *Heat Flux*: not yet implemented in Delft Dashboard. • *Wind*: to add a wind field in case you have "Wind" switched on among the Processes. A wind field can be saved to a "*.wnd" file. • *Tidal forces:* with this option, the direct local influence of the tide-generating forces inside the modelling domain is taken into account.
Numerical Parameters	To specify parameters related to drying and flooding and some other advanced options for numerical approximations.

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Discharges	To add localized discharges (e.g. rivers, intake stations, waste water outfalls). Location and discharge rates are respectively saved to a ".src" and ".dis" file.
Monitoring	To monitor the simulation during certain times on a higher temporal resolution than the rest of the grid points, by specifying the number of *Stations*, *Cross sections* or *Drogues*. Drogues can be released anywhere in the grid and the patch of the particle movement with the flow can be followed.
Output	To specify "Start Time", "Stop Time", "Time Step" at which output data will be stored in the Map output File. In case of simulation run with coupling, "Start Time", "Stop Time" and "Time Step" at which data will be saved in the communication file can be specified. Moreover, the "History Time Step", defining the time step at which information is stored for the observation points, can be specified. "Online visualization" is used to inspect results during the computation. "Online coupling" is available when you store results to the communication file.

Questions

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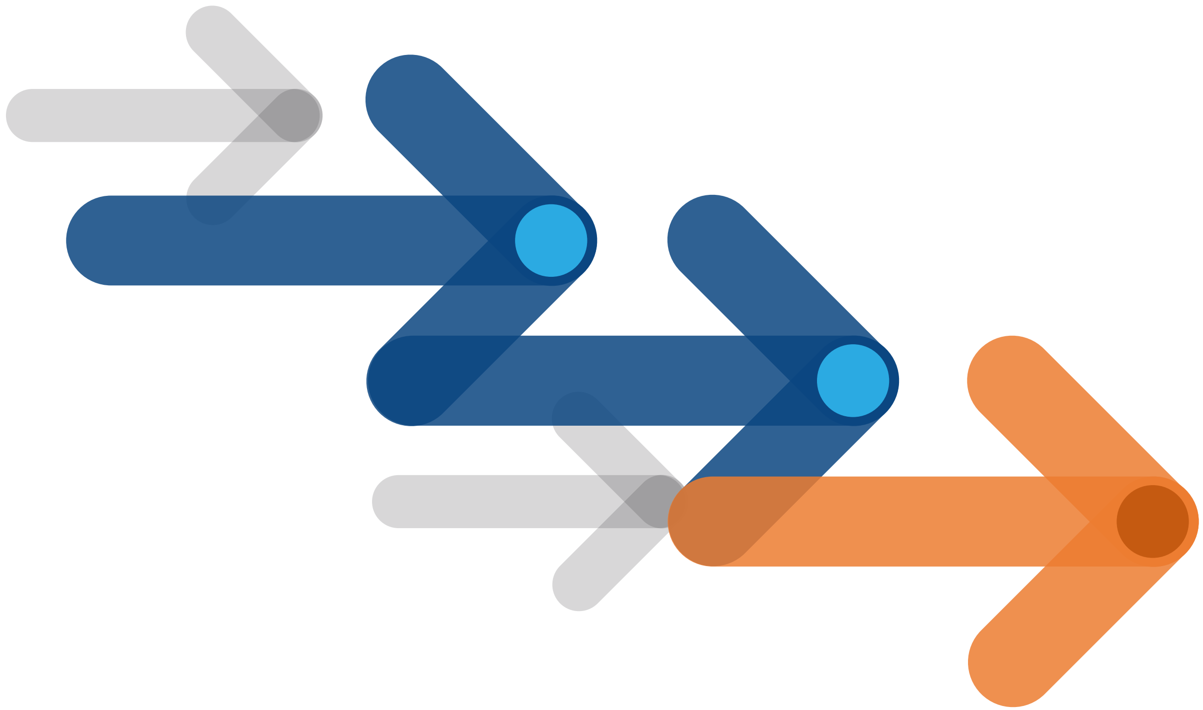

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THANK-YOU

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