Generation of triangular finite element grids for coastal models

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Outline

- Concepts and theory
  - What is a finite element grid?
  - Available grid generators
  - The major steps in grid generation
- Building a FE grid with xmgredit and nicegrid
  - Introduction to Xmgredit5 software
  - Example of application

What is a finite element grid?

- Coastal processes are described by partial differential equations
- Because there are no analytical solutions for those equations, they have to be discretized to be solved numerically
- A FE grid is an approach to discretize a continuous domain
- FE discretizations offer a piece-wise continuous description of the variables, with a varying resolution
- Nodes and elements of the grid determine where equations are solved and how spatial gradients are evaluated

What is a finite element grid?

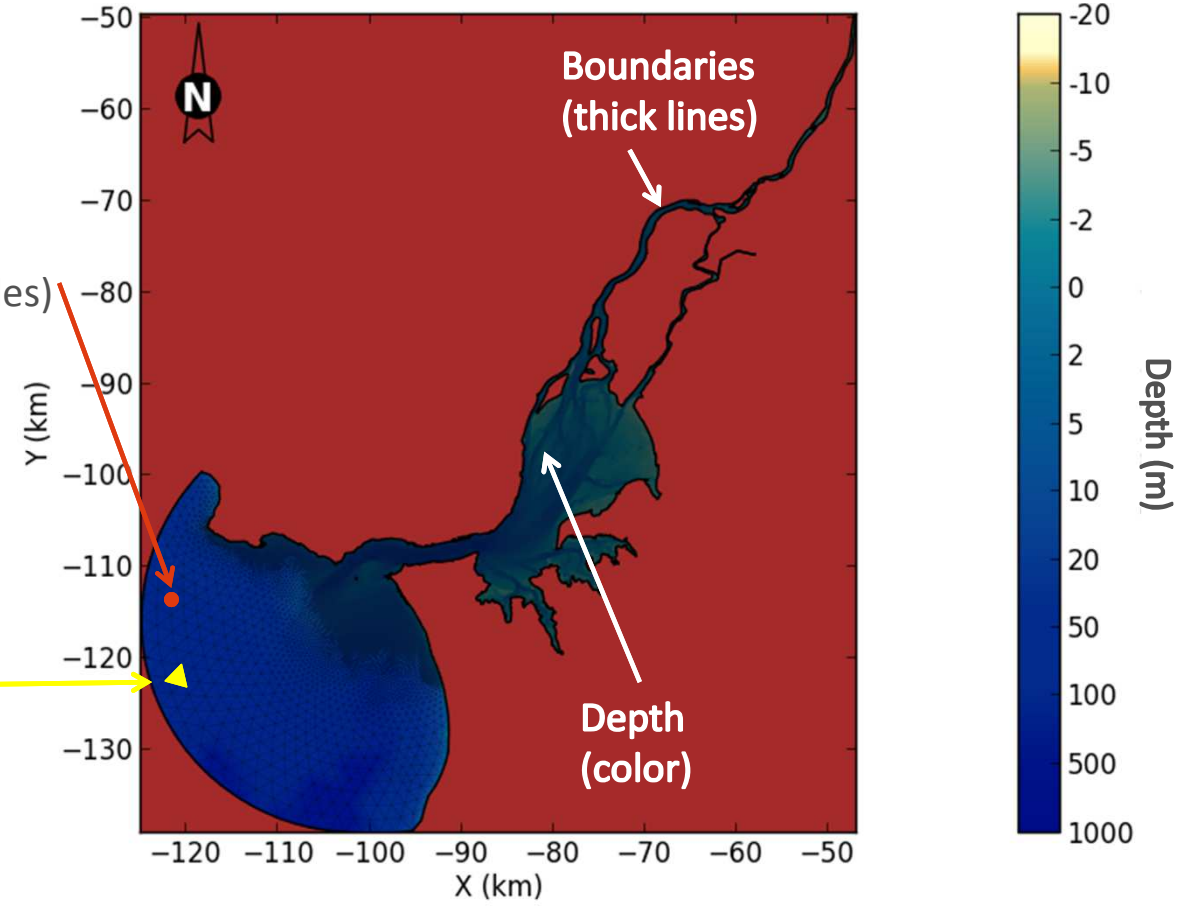
- A finite element grid includes the following information:
  - Location of the nodes
  - Depths at the nodes
  - Definition of the elements

    (ordered list of nodes that define each element)
  - Definition of the boundaries

What is a finite element grid?

Nodes
(vertices of the triangles)

Elements
(triangles)

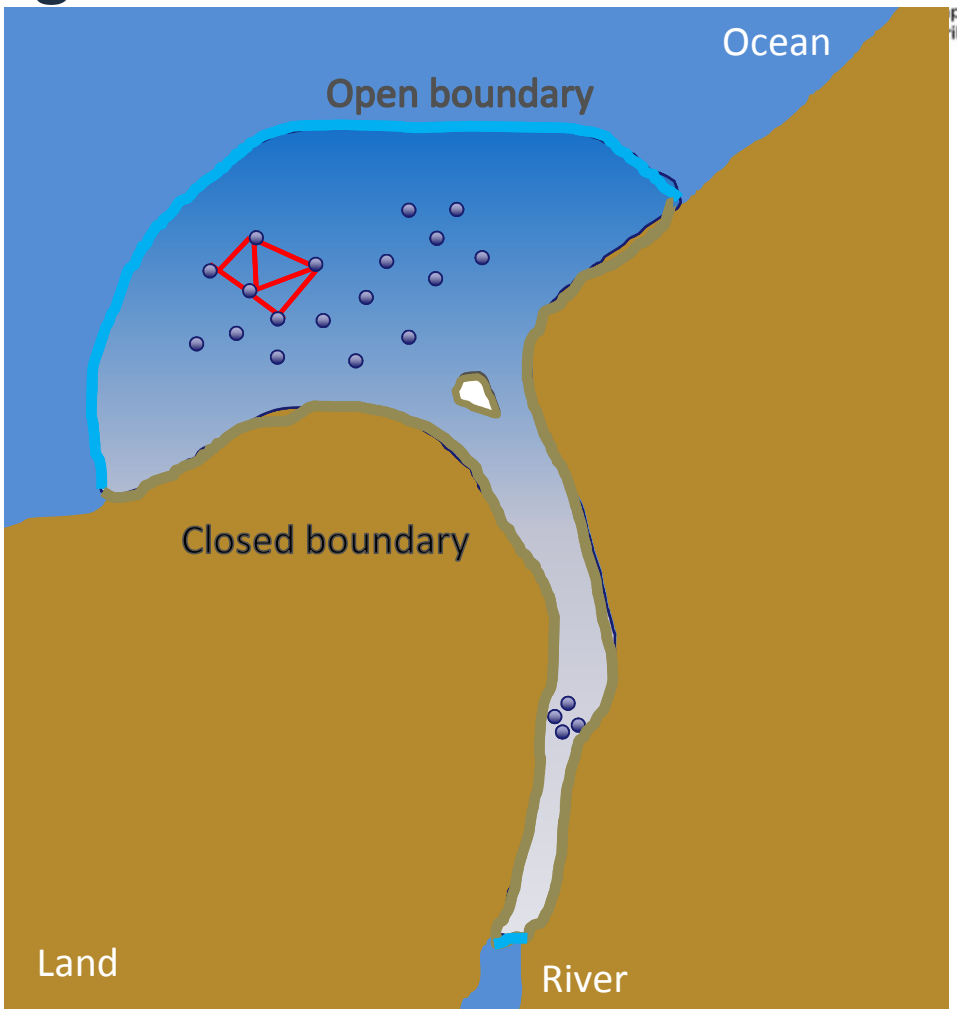


Grid generator

Name	Node placement	Triangulation	Optimization	Boundaries	Availability
xmgredit	Yes	Yes	Yes	Yes	Free
SMS	Yes	Yes	Yes	Yes	Commercial
Gmsh	Yes	Yes	Yes	Yes	Free
OceanMesh2D	Yes	Yes	Yes	Yes	Free
JIGSAW	Yes	Yes	Yes	Yes	Free
ADmesh	Yes	Yes	Yes	Yes	Free
triangle	Yes	Yes	No	No	Free
nicegrid	No	No	Yes	No	Free

Major steps in grid generation

1. Domain definition
2. Node placement
3. Definition of the triangles
4. Optimization and verification
5. Interpolate the bathymetry
6. Boundary definition



Domain definition

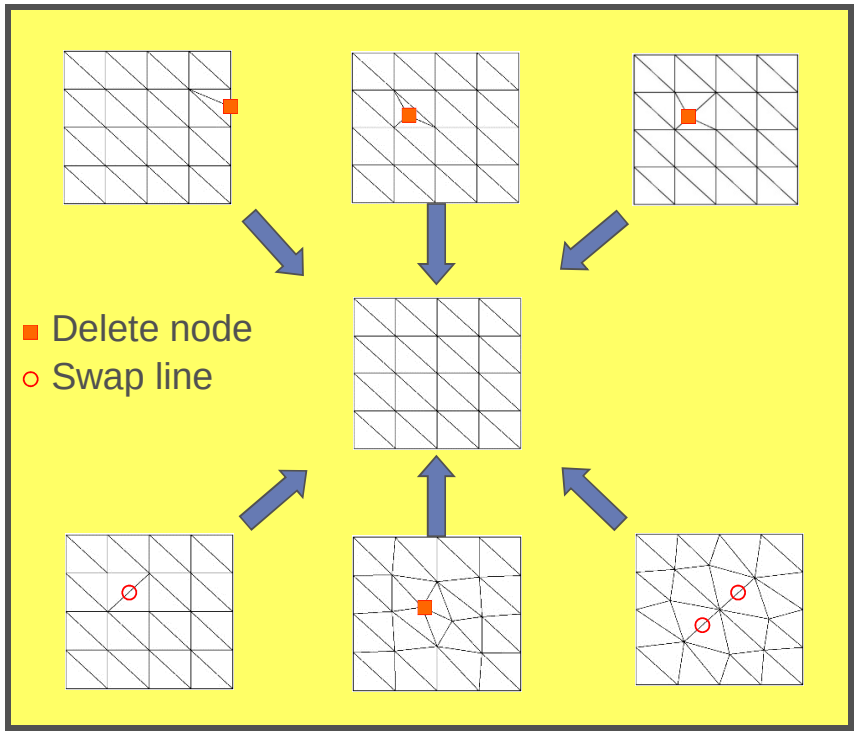
- *Upstream*
  - *Should extend beyond tidal intrusion*
  - *Often limited by the availability of bathymetry*
- *Downstream:*
  - *Extend to deep waters, where velocities are small*
  - *Avoid to place the boundary in areas where with strong velocities*
  - *Make the boundary geometrically simple*
- *Example*

Nodes placement

- *Choose node density to resolve:*
  - *Tidal wave: minimum dimensionless wavelengh > 40-60*
  - *Tidal channels must be resolved with over 4-6 nodes to guarantee the reproduction of fluxes*
  - *Sharp bathymetric gradients*
  - *Solid boundaries must be adequately resolved*
  - *Sharp velocity gradients (e.g., ebb jet from a tidal inlet)*
- *Grid resolution should vary smoothly to promote accuracy and stability*

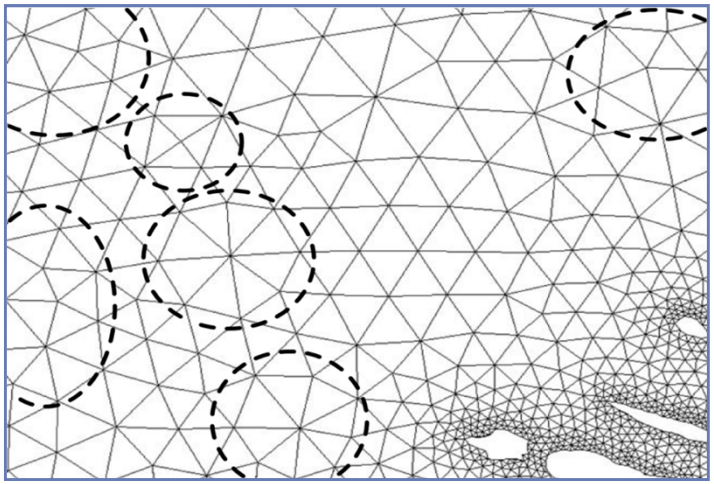
Optimization and verification

- *Objectives:*
  - *Reduce skewness*
  - *Smooth transition between elements*
  - *Prevent angles above 90º (some models)*
- *Typical operations:*
  - *Add nodes*
  - *Delete nodes*
  - *Move nodes*
  - *Swap edges*



Grids that are transformed into the one in the center

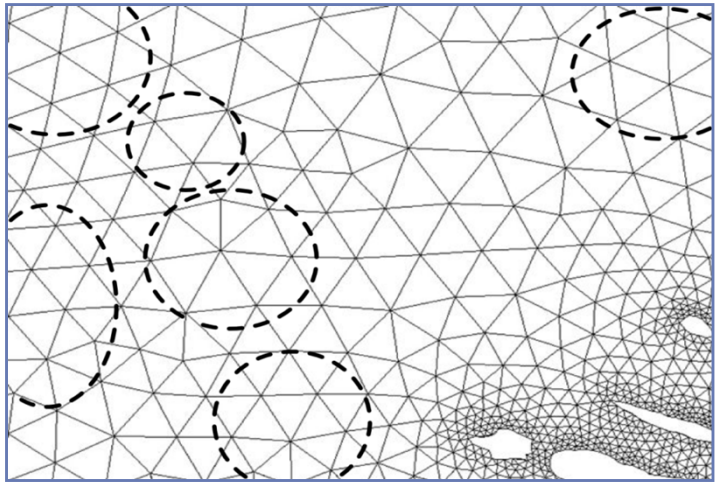
Optimization and verification



Before

(generated with *xmgredit*)…

… and after (optimized with *nicegrid*)



Automatic grid generation

With xmgredit and nicegrid

What is the xmgredit?

- FE grid generator developed for coastal modelling
- Semi-automatic grid generator
  - Node placement
  - Triangulation
  - Quality control and grid editing
  - Boundary definition
  - Bathymetry interpolation
- UNIX/LINUX based

Launching xmgredit

- *With an existing grid:*

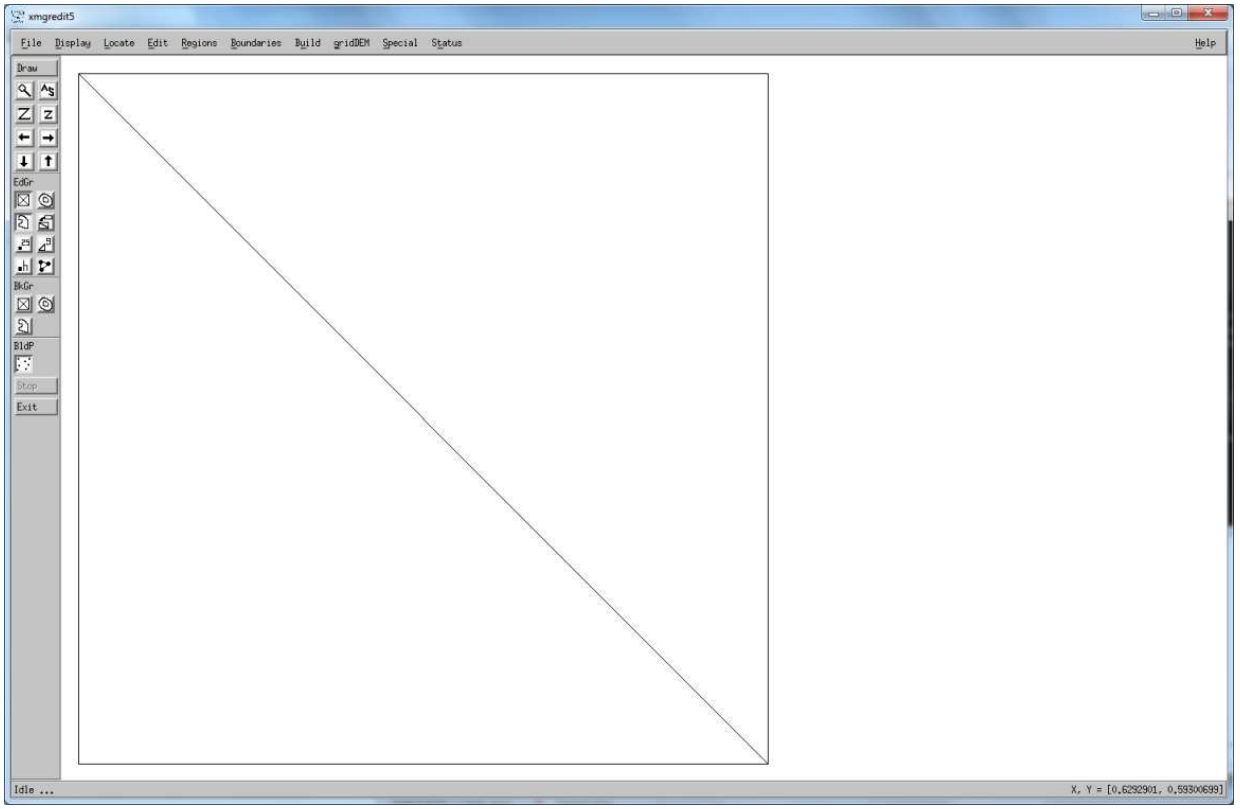
  xmgredit5 hgrid.gr3

- *With an existing points file:*

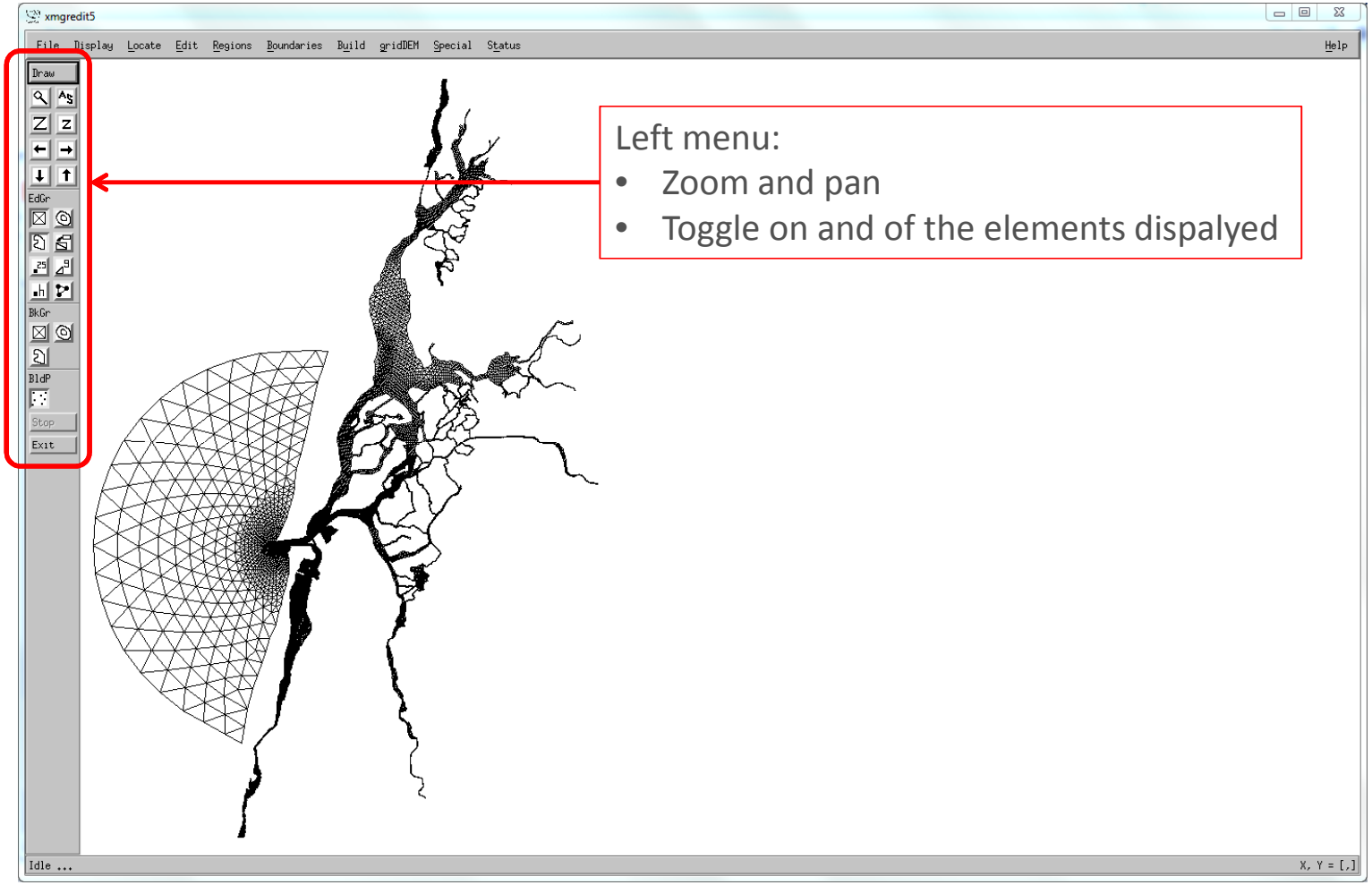
  xmgredit5 –b points.bpt –w

- *Without any file:*

  xmgredit5 –W 0 0 1 1



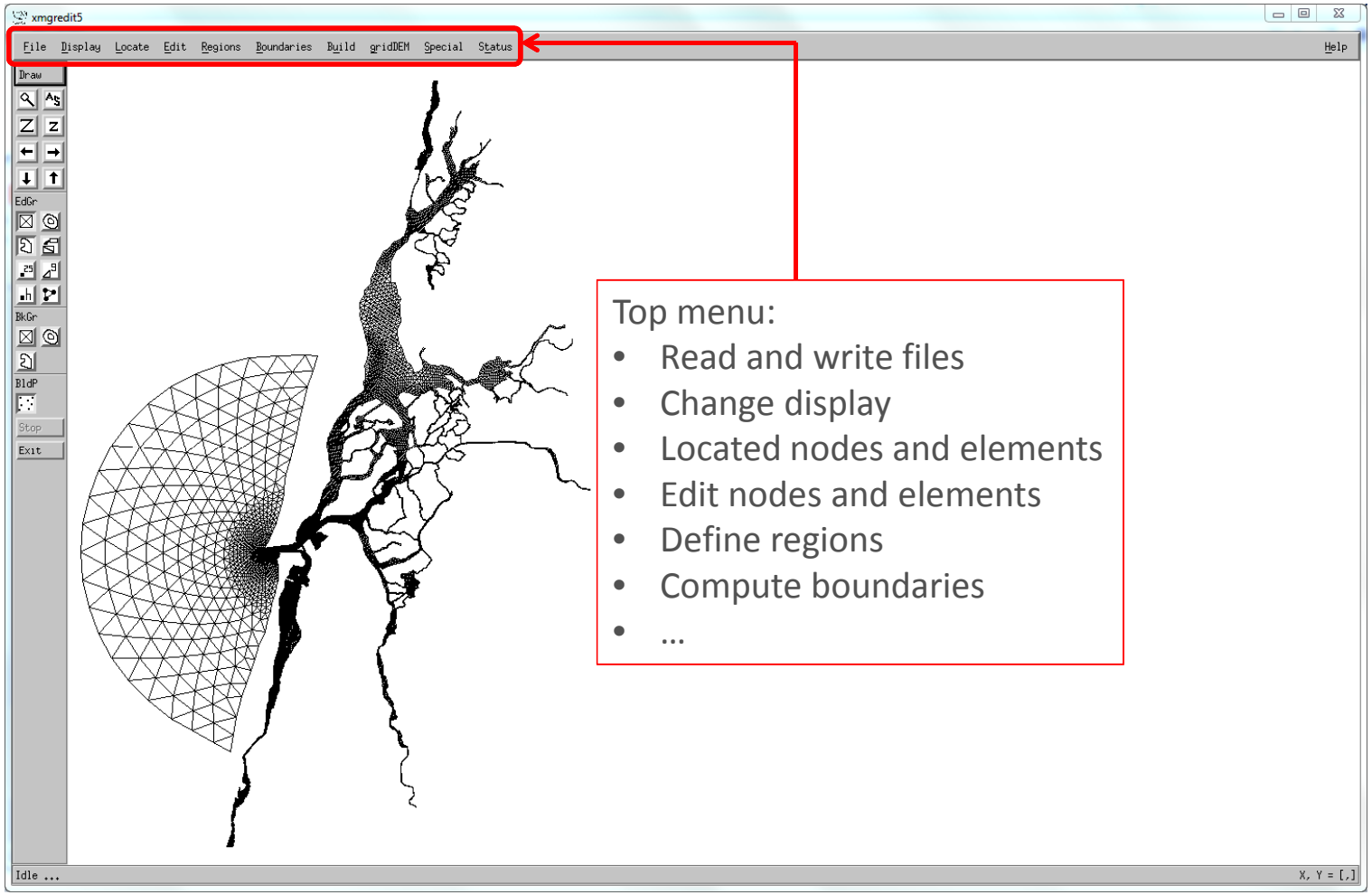
The working environment



Left menu:

- Zoom and pan
- Toggle on and of the elements dispalyed

The working environment

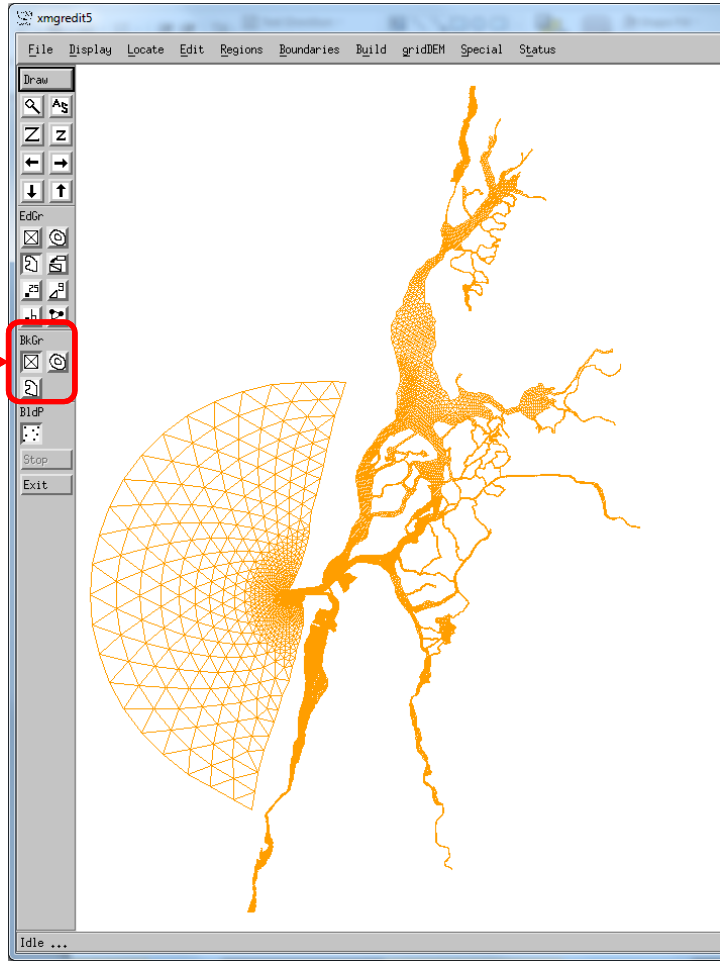


Top menu:

- Read and write files
- Change display
- Located nodes and elements
- Edit nodes and elements
- Define regions
- Compute boundaries
- …

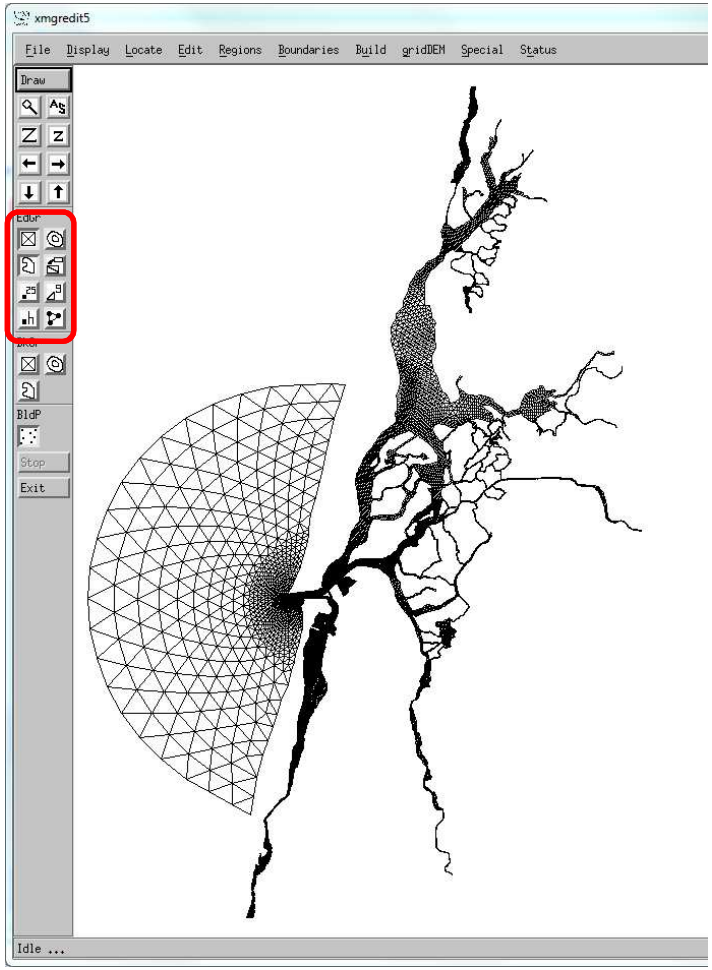
The components

- *The background grid*
  - *Cannot be edited*
  - *Usually contains the bathymetry*
  - *Represented in orange*



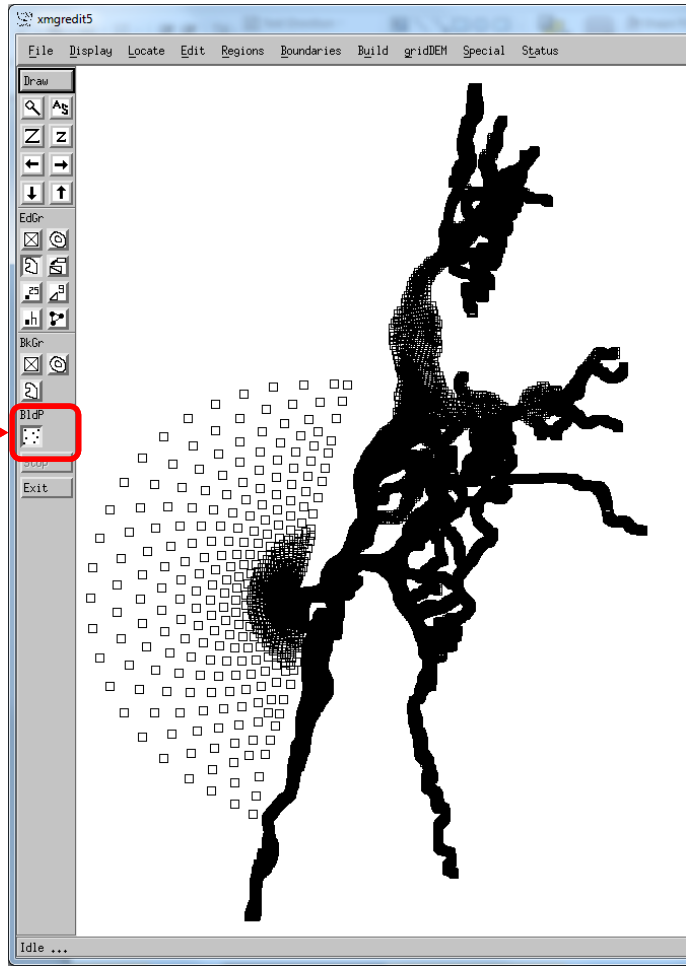
Os componentes

- *The edit grid*
  - *Can be edited*
  - *Represented in black*



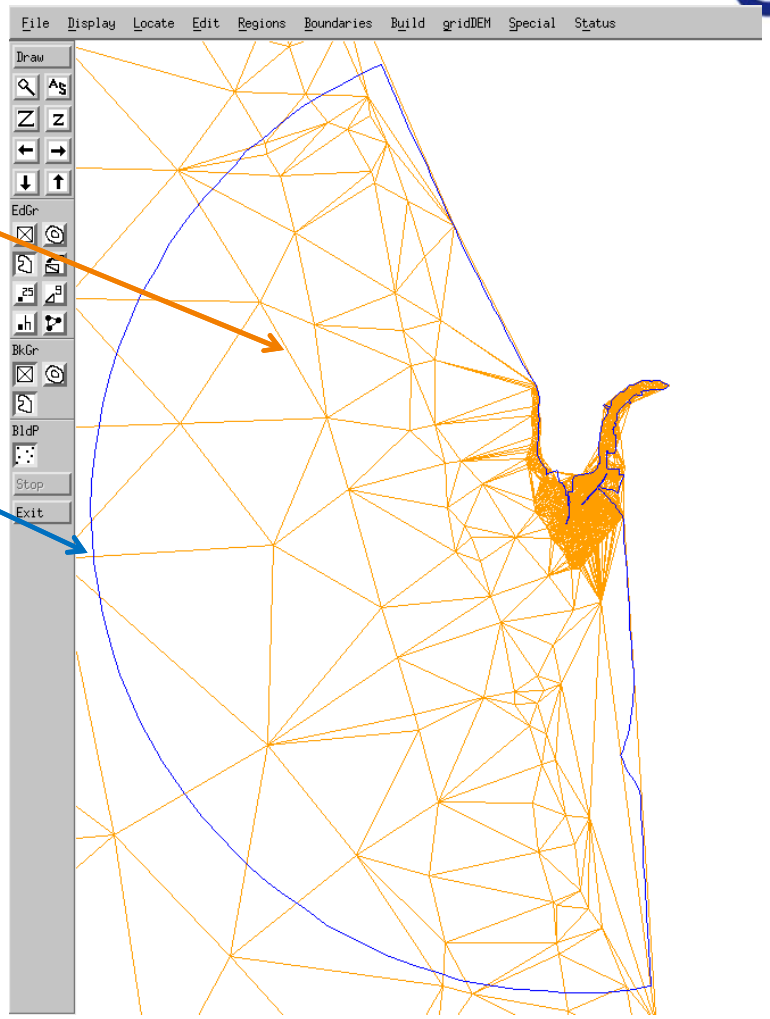
Os componentes

- *The build points*
  - *Can be added, moved, deleted*
  - *Represented as black squares*



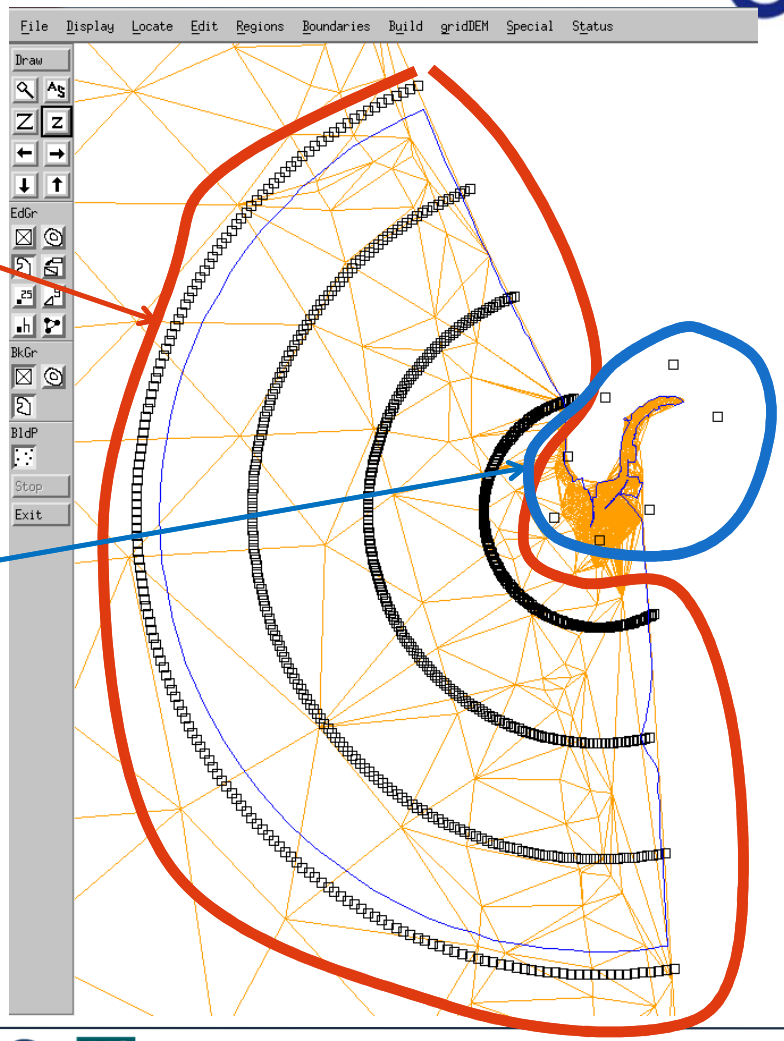
Required information

- *Background grid*
- *Coastal boundary*



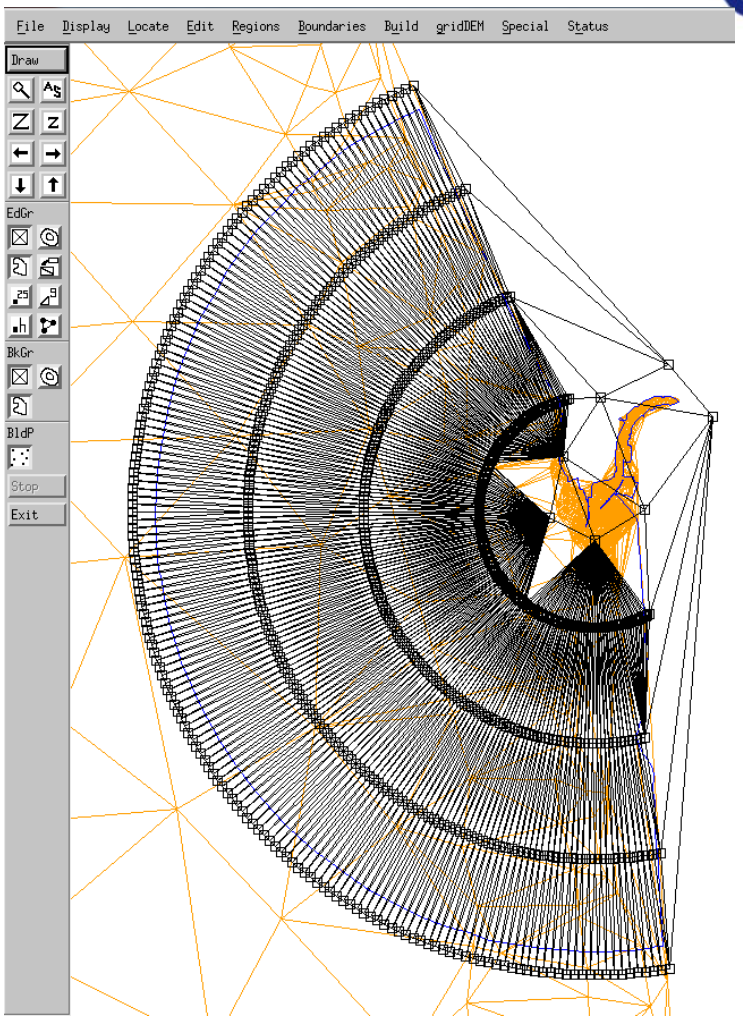
Define grid spacing (1)

- *Generate build points using build / circular spread*
- *By-hand placement of build points using build / place build points*



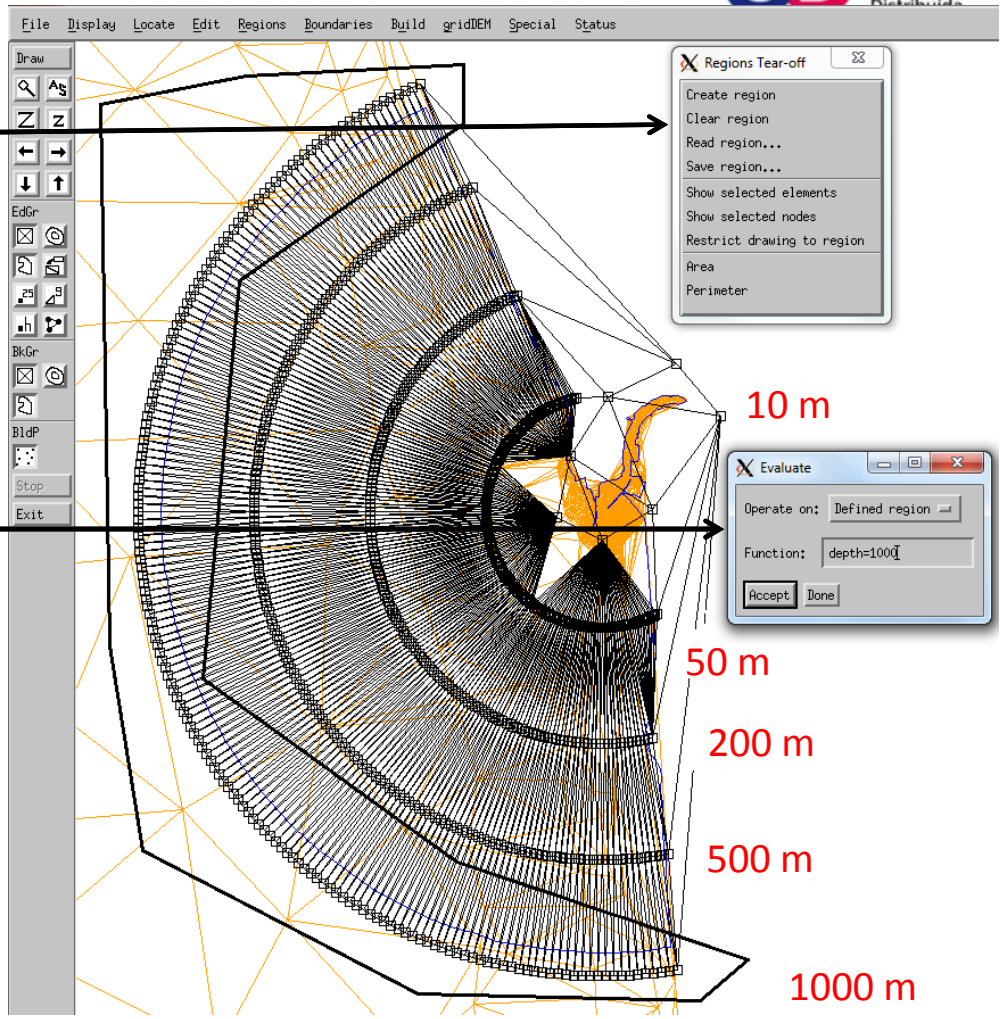
Define grid spacing (2)

- *Triangulation of build points using*
  build / triangulate build points



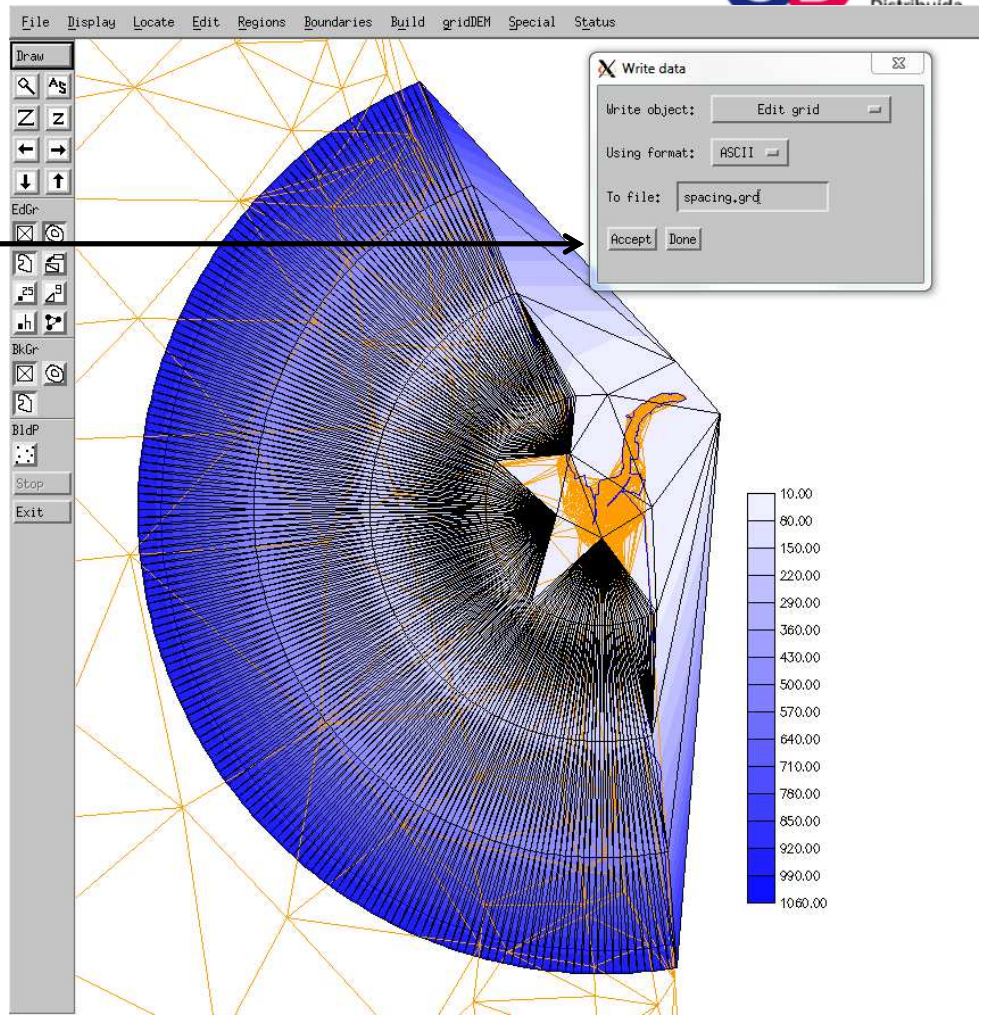
Define grid spacing (3)

- *Define regions using regions / create regions*
  - *Define desired spacing in each subset of nodes using edit / edit over grids or regions / evaluate / depth = XXX*



Define grid spacing (4)

- *Save the grid using*
  file / save / edit grid



Define auxiliar bathymetry (1)

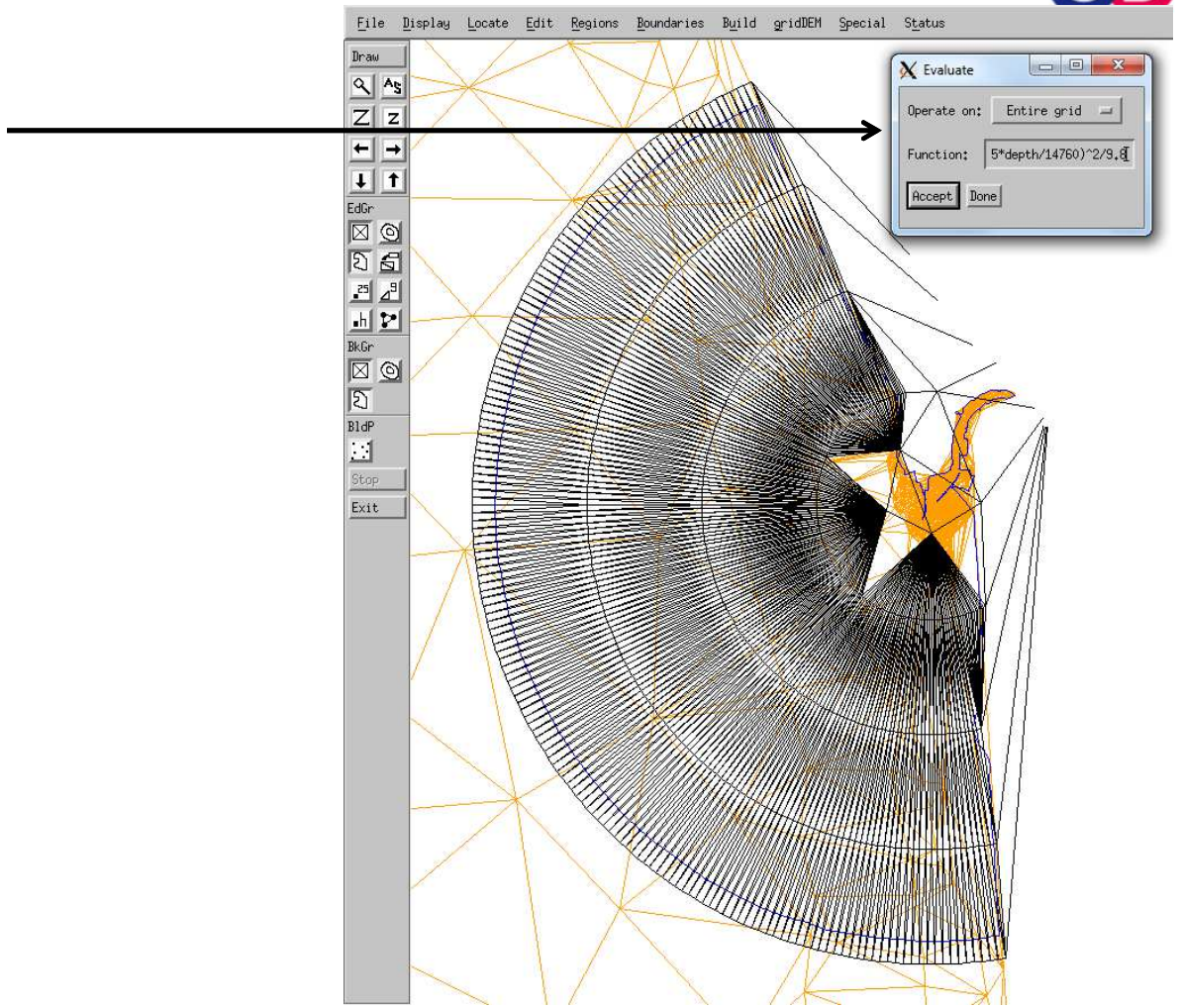
- Xmgredit automatically places build points based on the dimensioneless wavelength
- Generate a fake bathymetry to get the grid spacing that we want:

$$\text{Depth} = 1/g\ (\alpha\ s\ /\ T)^2$$

- where
  - g is gravity(9.8 m/s^2)
  - s is the desired grid spacing previously defined
  - α is a dimensionledd wavelength
  - T is a wave period

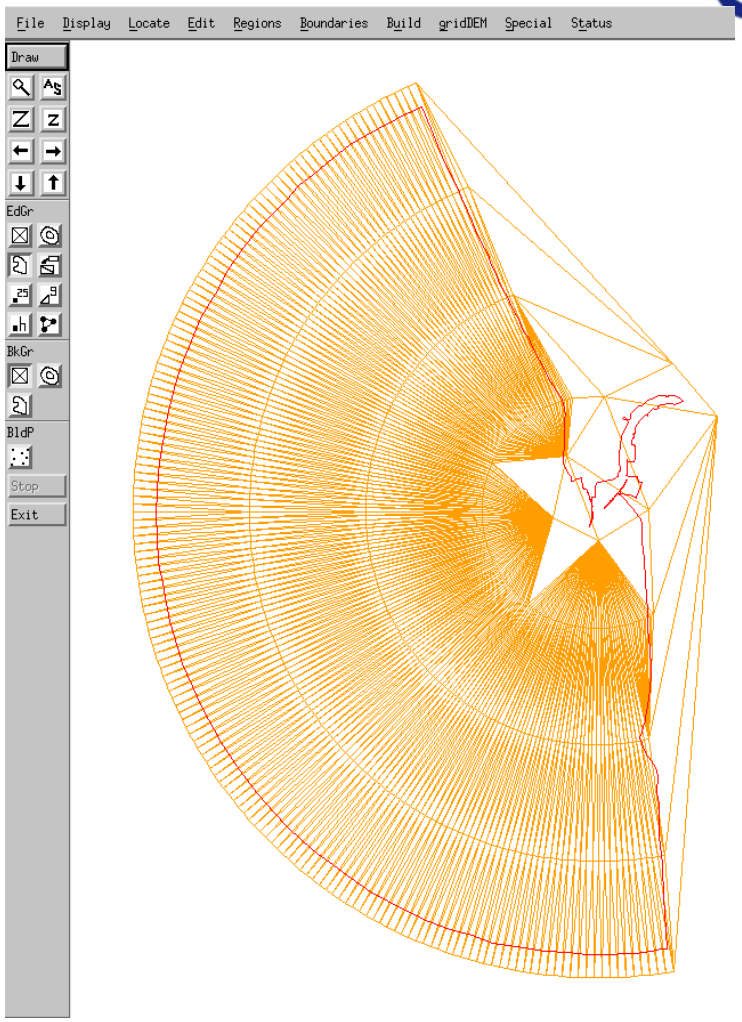
Define auxiliar bathymetry (2)

- *Change the bathymetry using edit/ edit over grids – regions/ evaluate*
- *We use:*
  - *α=25*
  - *T=14760 s*
- *Save the grid using file / save / edit grid (aux.grd)*



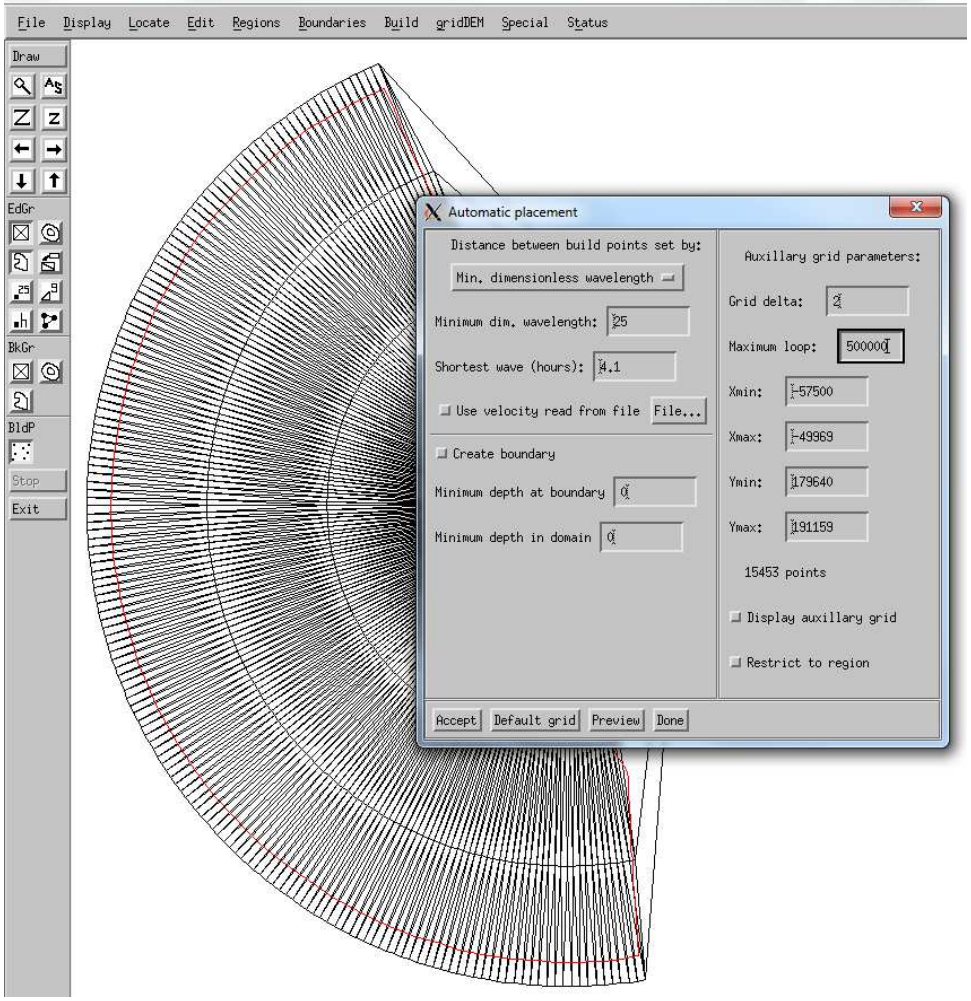
Generate build points (1)

- *Load the auxiliar grid as background grid*
- *Load coastal boundary as edit boundary*



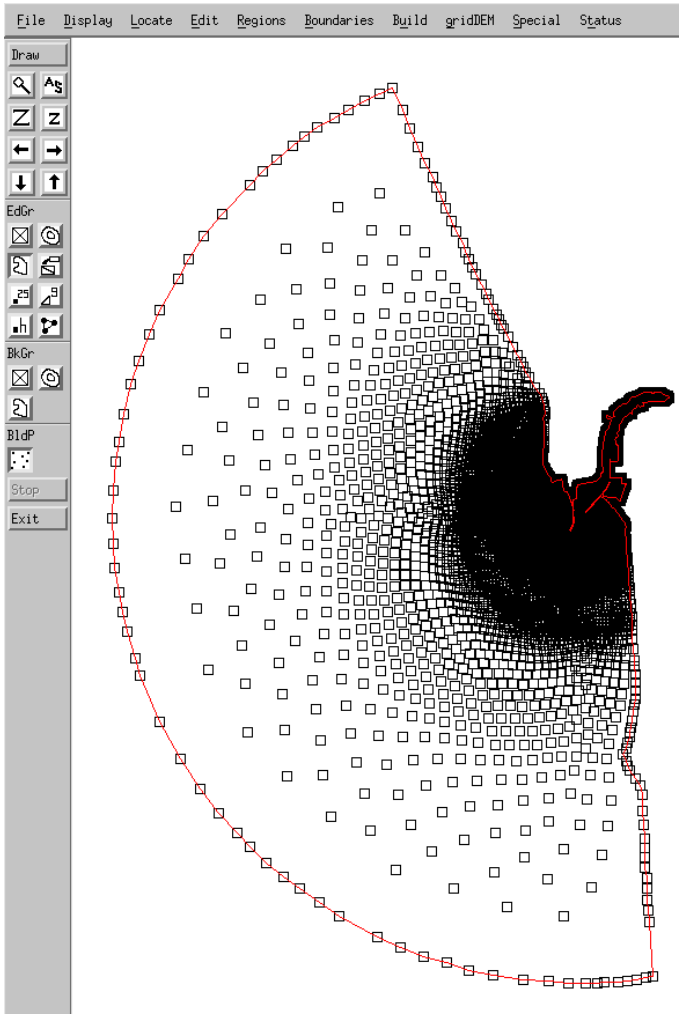
Generate build points (2)

- *Generate a new set of build points using build / automatic placement*
- *Use the same values of α and T used previously*



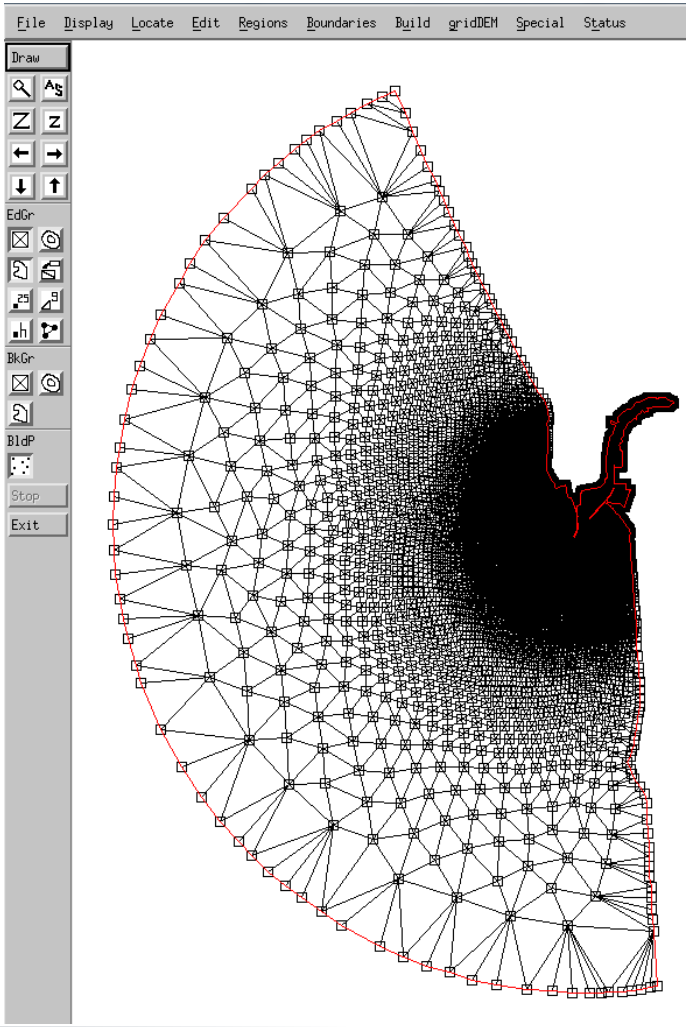
Generate build points (3)

- *A set of build points is created in the domain that obeys the desired grid spacing*



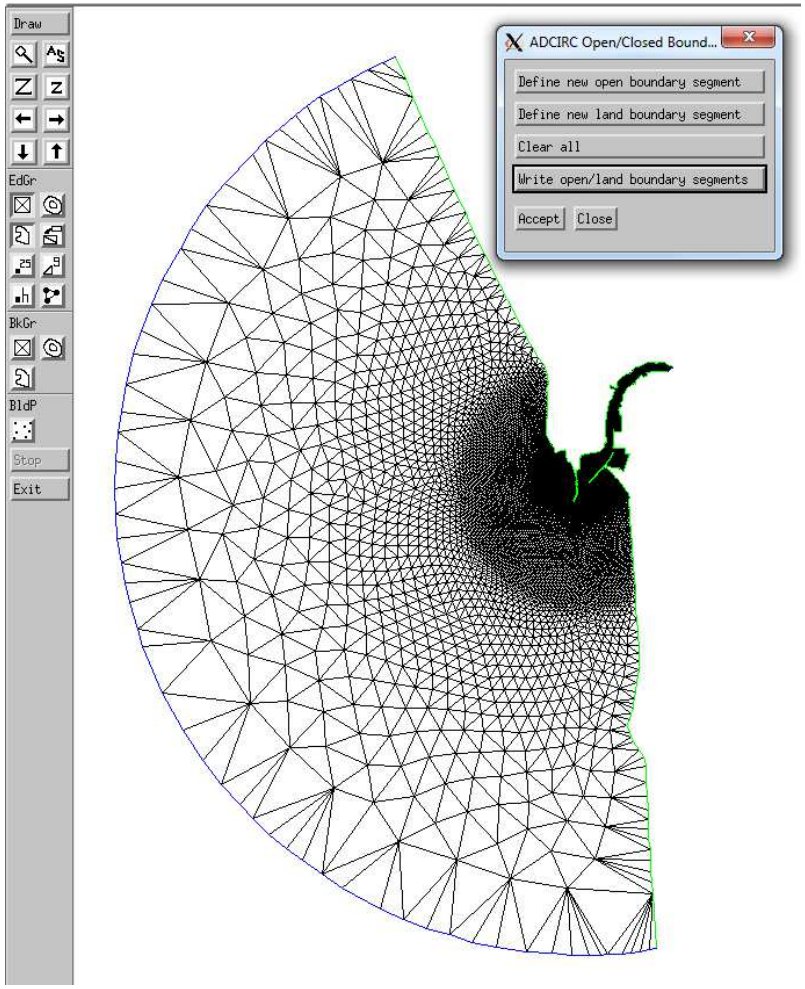
Triangulate build points

- *Triangulate build points using build / triangulate*
- *A computational grid is generated, but with some quality problems*



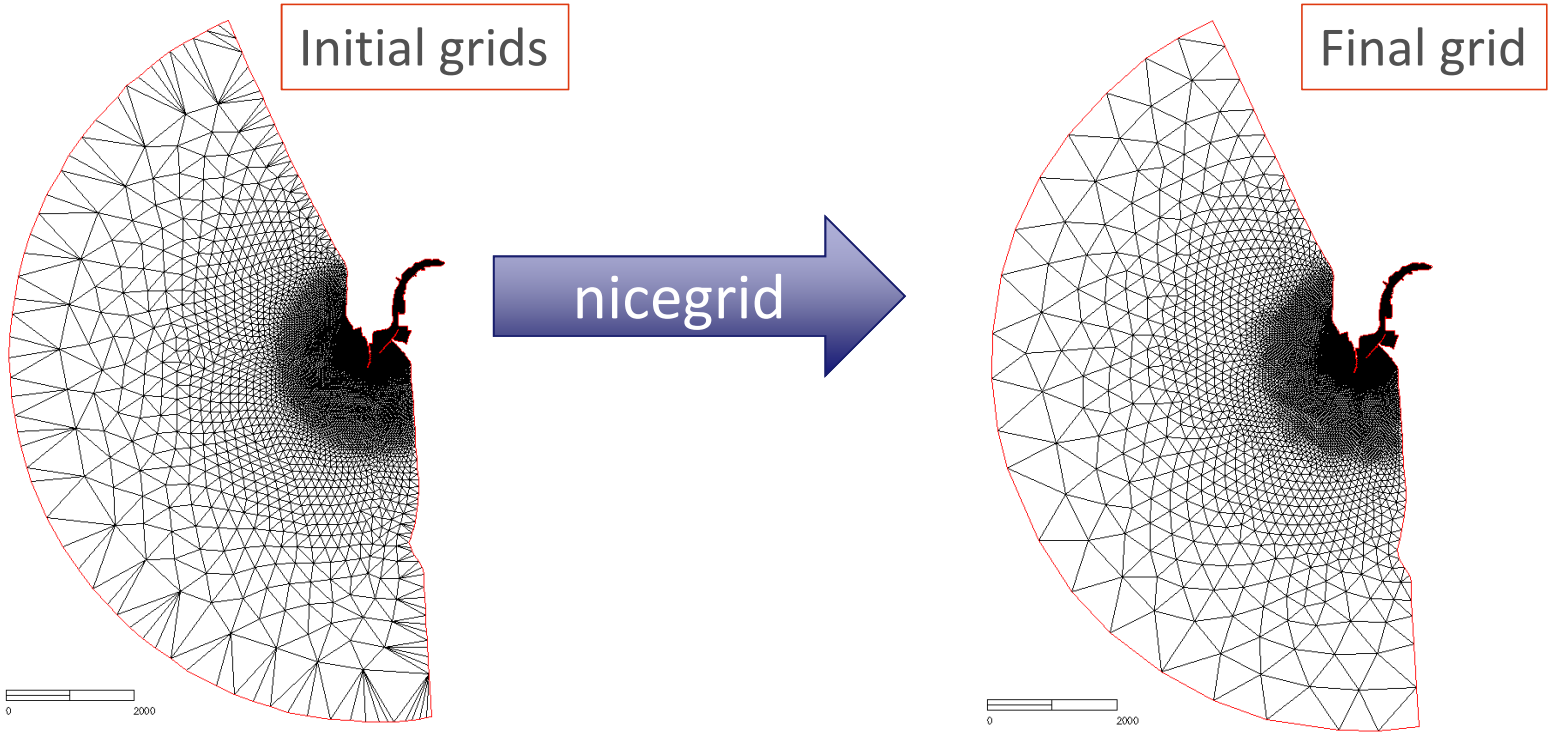
Define open and land boundaries

- *Define exterior boundaries using boundaries / compute boundary, then gridDEM / create open - land boundaries*
- *Save the grid and the boundary and concatenate the two files*



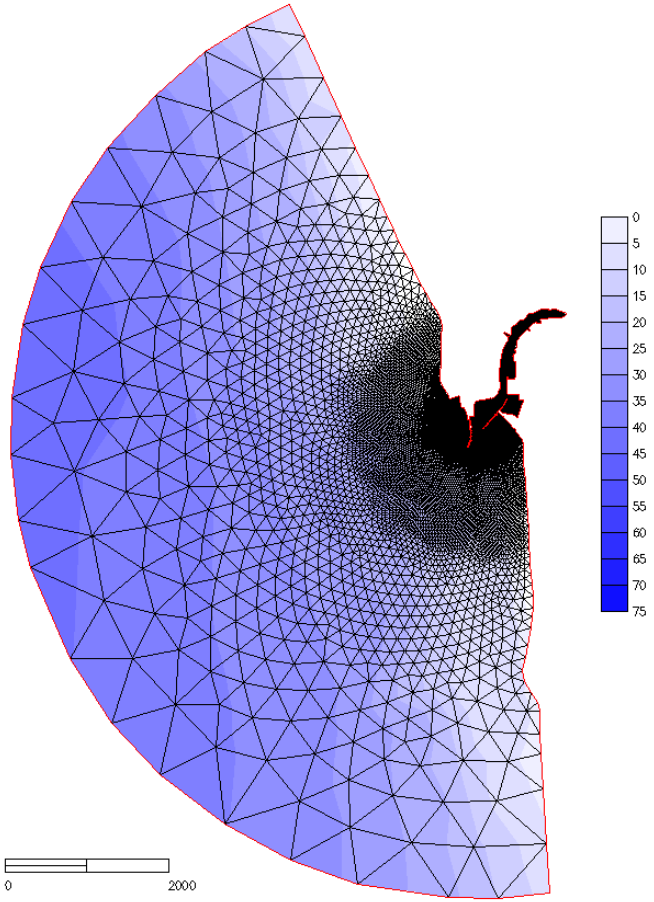
Grid optimization

- *Oprimizing the grid with xmgredit is very time consuming. nicegrid is command line code that does that automatically*



Interpolate bathymetry

- *Load the background grid using File / read / background grid*
- *Interpolate the bathymetry using gridDEM / load bathymetry*



Thank you for your attention!

Questions?

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Downloading the codes

- xmgredit5 and nicegrid2 are available through the SCHISM platform:
- Download SCHISM (including xmgredit5):

http://ccrm.vims.edu/schismweb/schism_manual.html

- Xmgredit user's manual

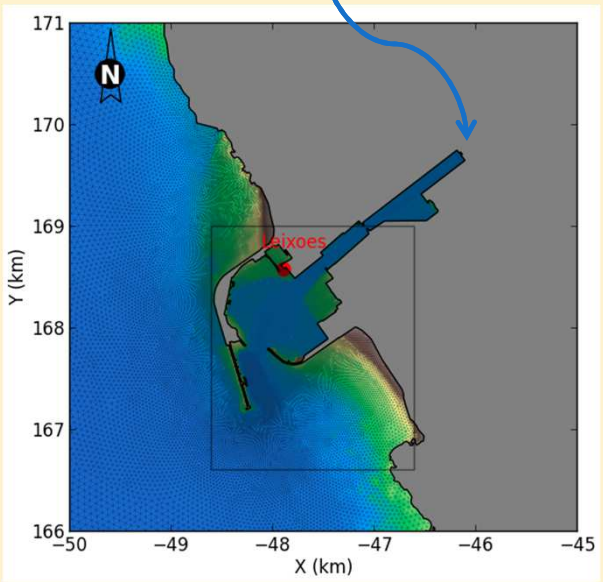
http://ccrm.vims.edu/schismweb/ACE/gredit/index.html

- nicegrid2 code (fortran source code)

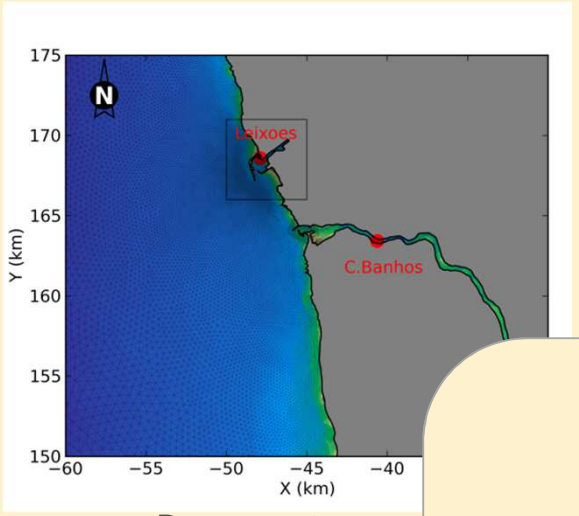
http://ccrm.vims.edu/w/index.php/Share_your_tools

Domain definition: example

Upstream boundary limited by data availability



Study region (Leixões harbor)

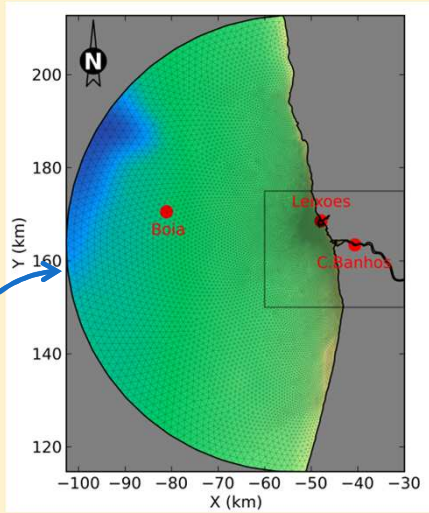


Upstream boundary determined by dam

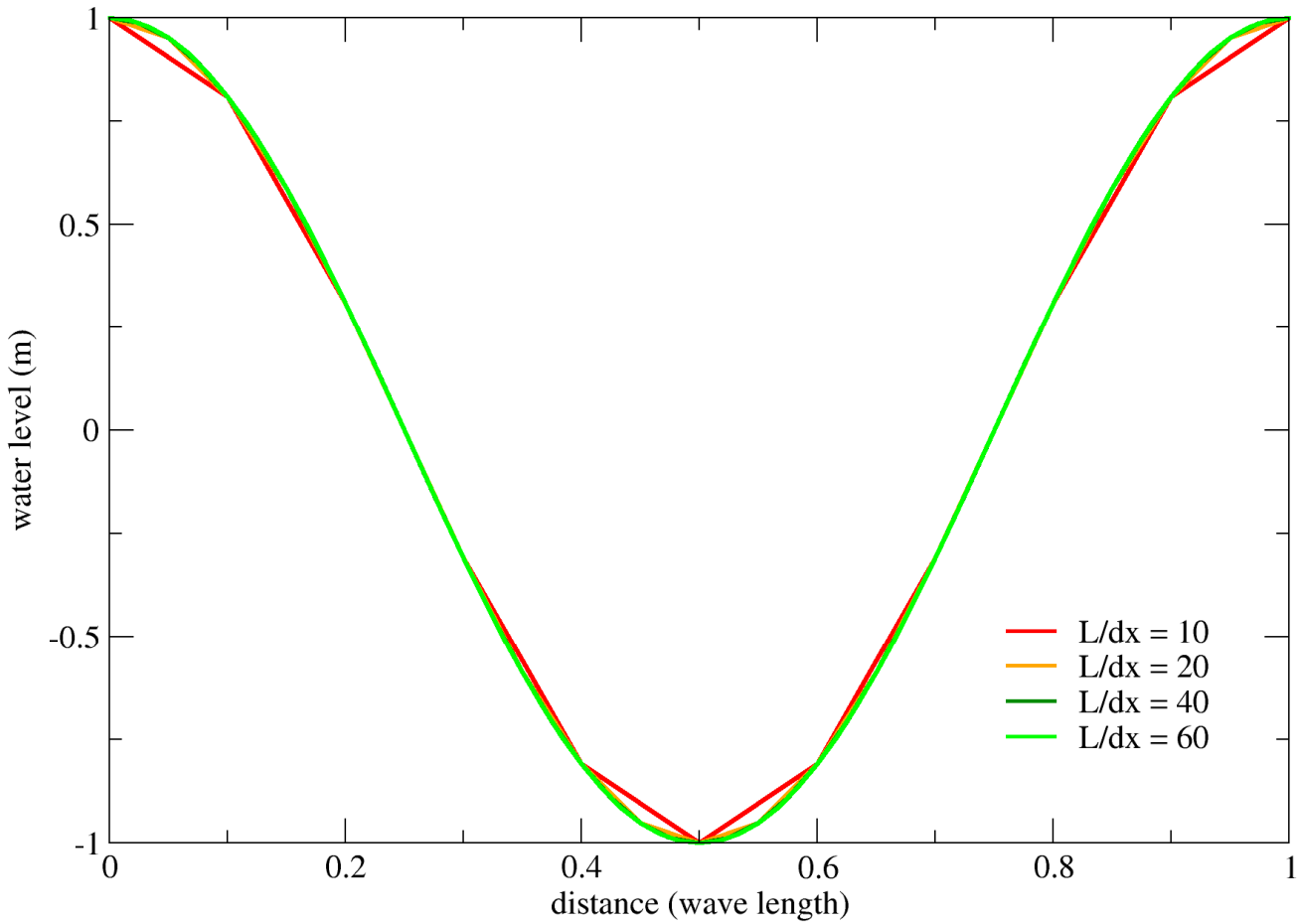
Douro estuary

Full model domain

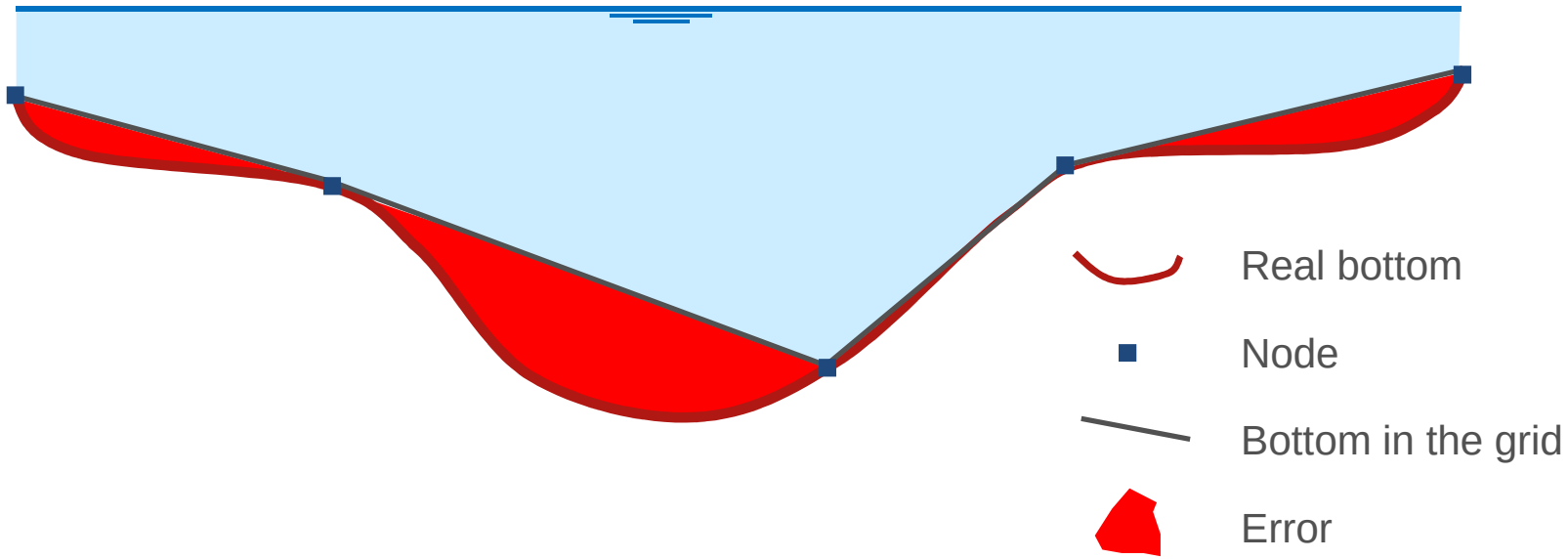
Ocean boundary away from the tidal jet and allows the inclusion of wave data in the domain



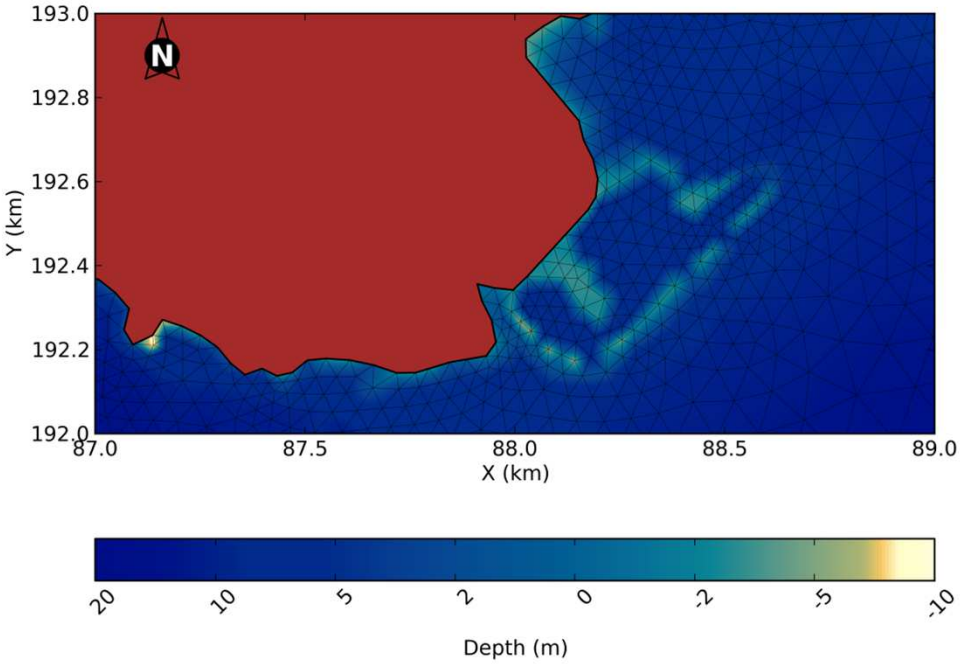
Minimum dimensionless wave length

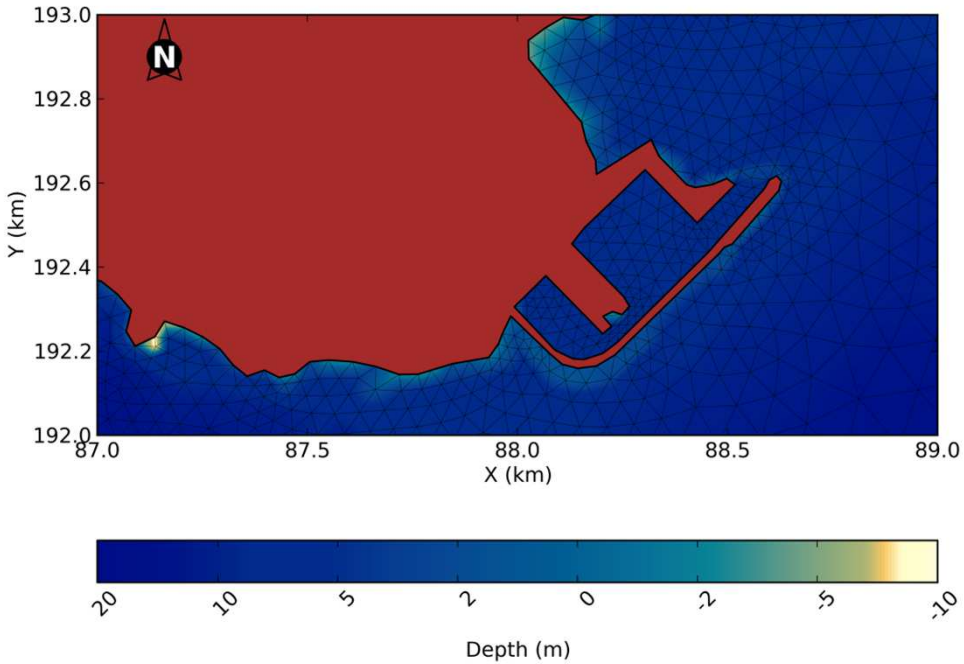


Poorly resolved channel

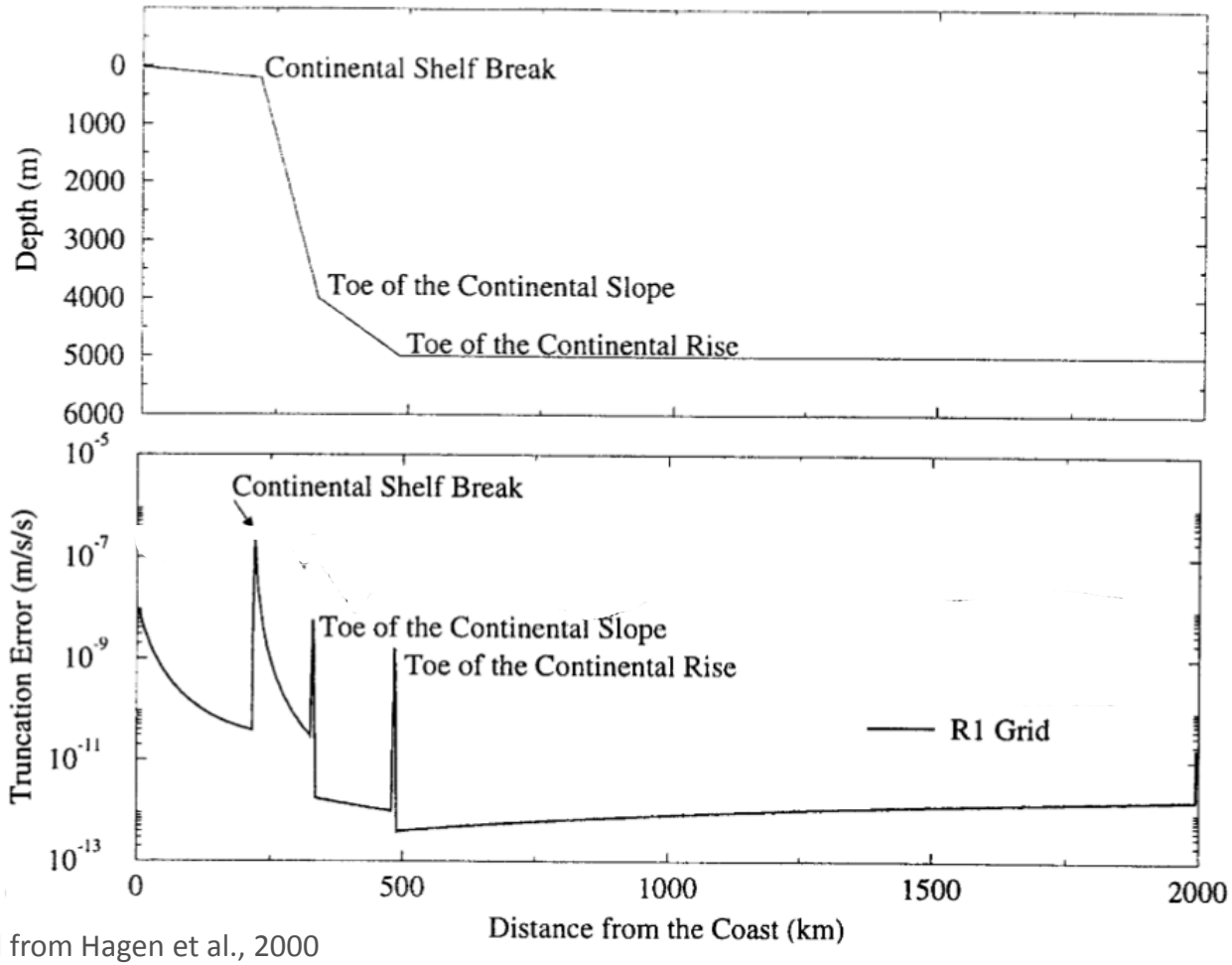


Poorly resolved marina





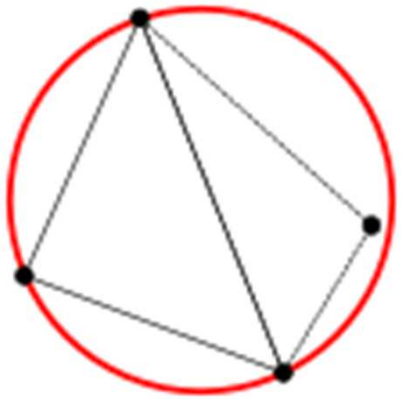
Truncation errors along a shelf slope



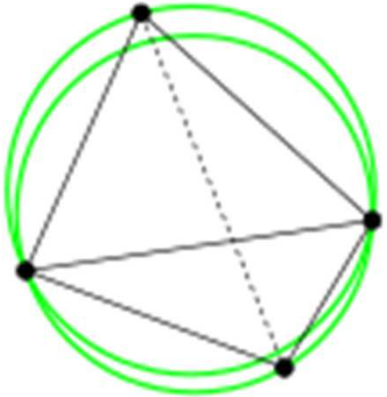
Adapted from Hagen et al., 2000

Triangulation of a set of points

- Delaunay triangles: no node is inside the circumcircle of any triangle



Triangles that do not meet the Delaunay criterion



Triangles that meet the Delaunay criterion

Figures from wikipedia