Development of a finite-element, multi-scale model of the Mahakam Delta (Indonesia)

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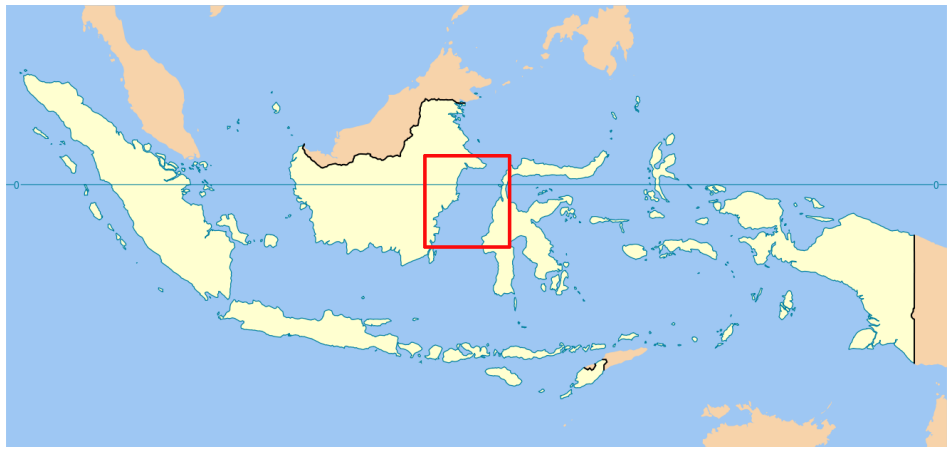

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Outline

Domain of interest: the Mahakam River

A highly multi-scaled domain

The 1D-2D SLIM model

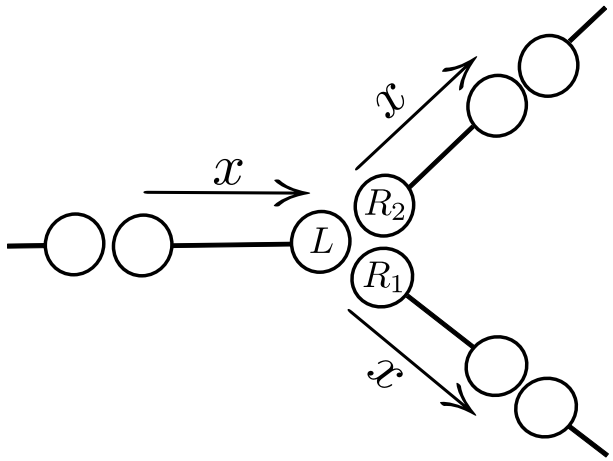
Second-generation **L**ouvain-la-Neuve **I**ce-ocean **M**odel[1]

- Shallow-water equations
  - 2D depth-averaged in the shelf and the estuary
  - 1D cross-section-averaged in the fresh tidal rivers network
- P1-Discontinuous Galerkin Finite Element Method
- Time stepping
  - Explicit ($\Delta t \approx 1$ sec) of fully implicit ($\Delta t \approx 10$ min)
  - Non-linear system solved by the Newton-Raphson
  - Estimation of the Jacobian by finite differences
- With Discontinuous Galerkin, ILU preconditioning is sufficient to ensure the convergence of GMRES (Generalized minimal residual method)
- Tracer module with flexible reaction terms

[1] `www.climate.be/SLIM`

1D model: bifurcations and connection with the 2D

- Inspired by Sherwin et al. (2003) for arterial systems
- Extension of a Riemann solver for 3 nodes
- Numerical fluxes derived from upwind variables computed assuming that
  - The caracteristic variables should take the upwind values
  - Mass is conserved
  - Momentum is conserved



- Implicit coupling between 1D and 2D elements
  - By cross-section average of the numerical fluxes

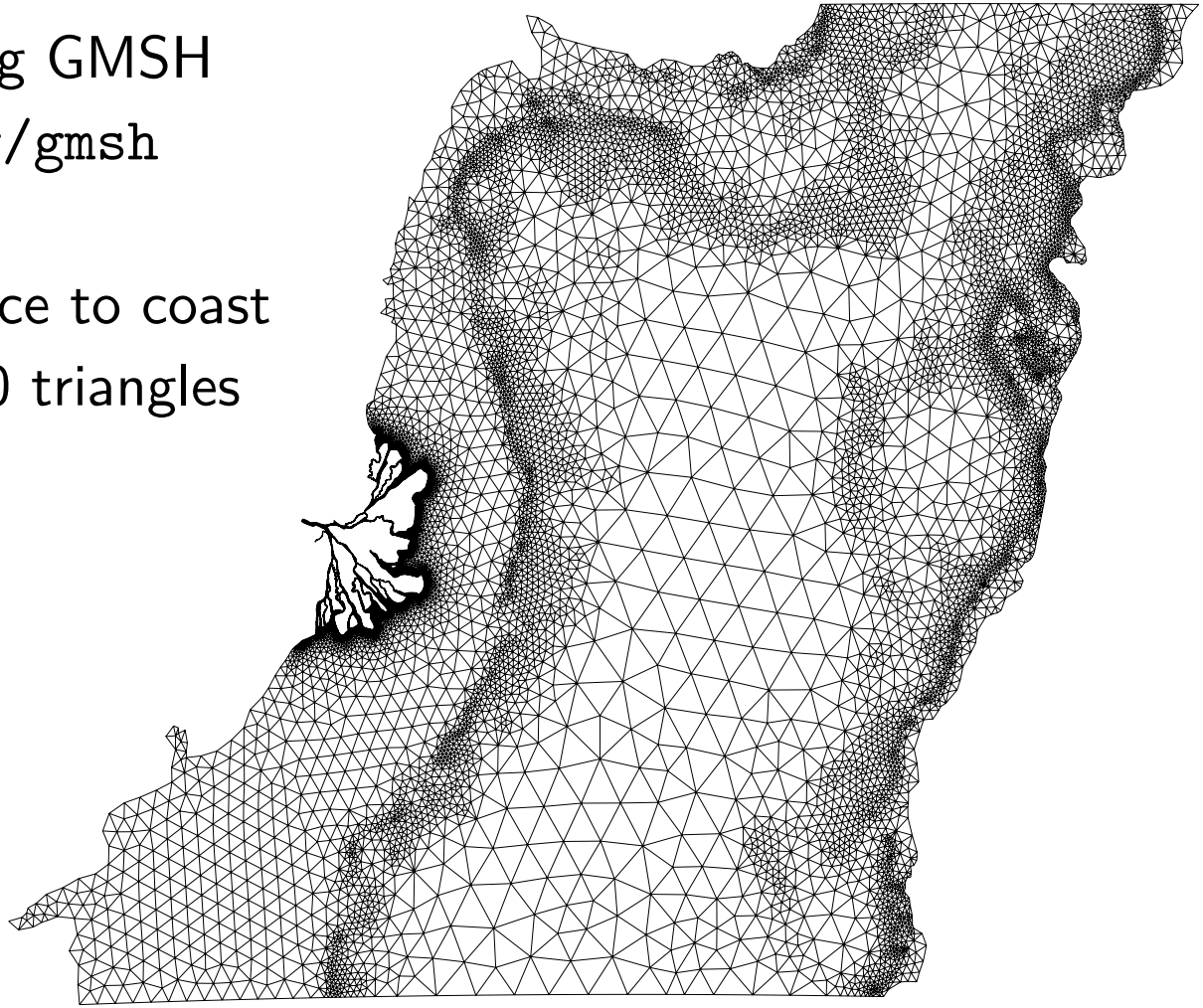
A multiscale mesh

72% of the elements are in 1.4% of the computational domain

Generated using GMSH

`www.geuz.org/gmsh`

- $\Delta \propto \sqrt{gH}$
- $\Delta \propto$ distance to coast
- $N \approx 50\,000$ triangles



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Generated using GMSH

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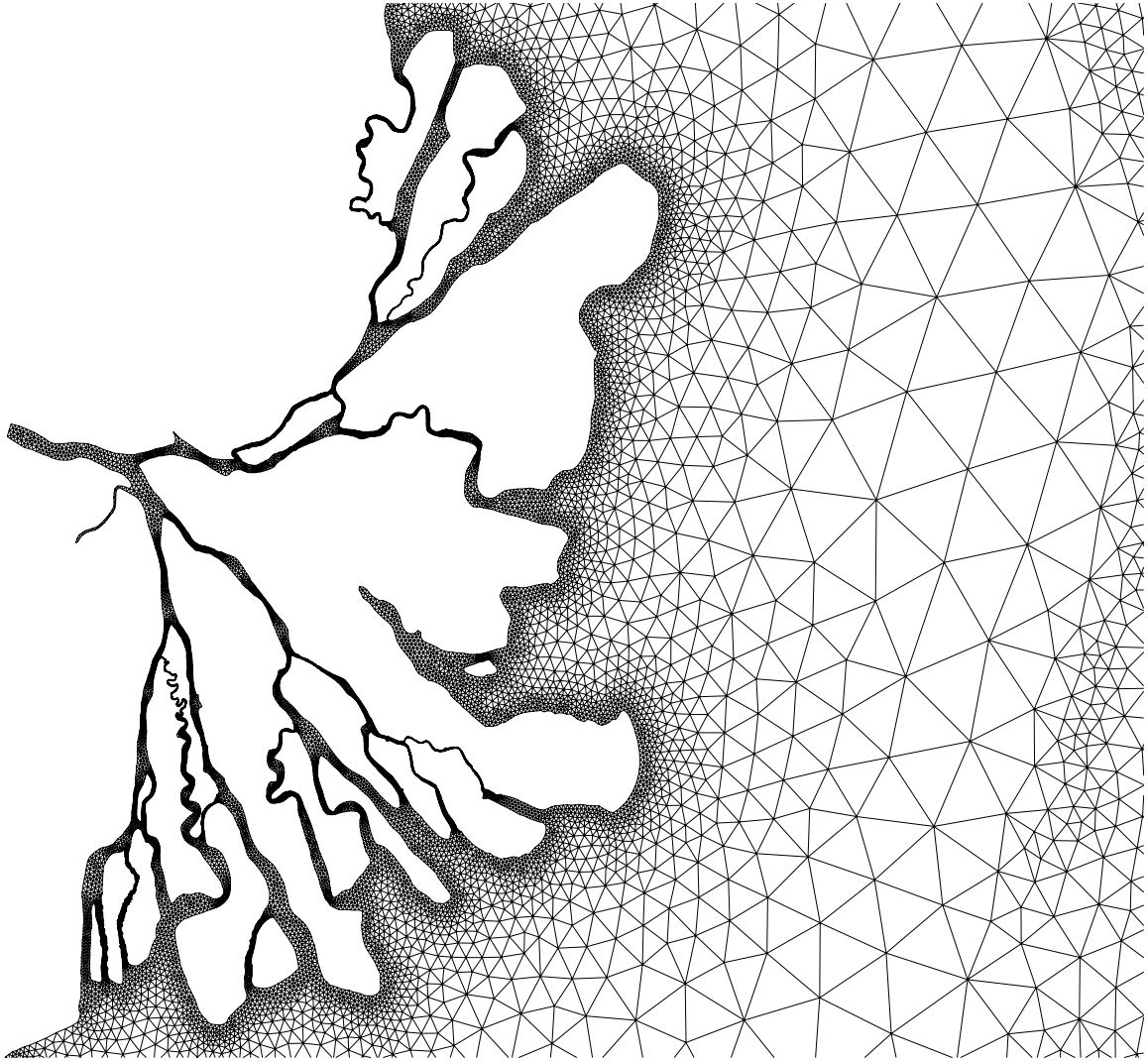
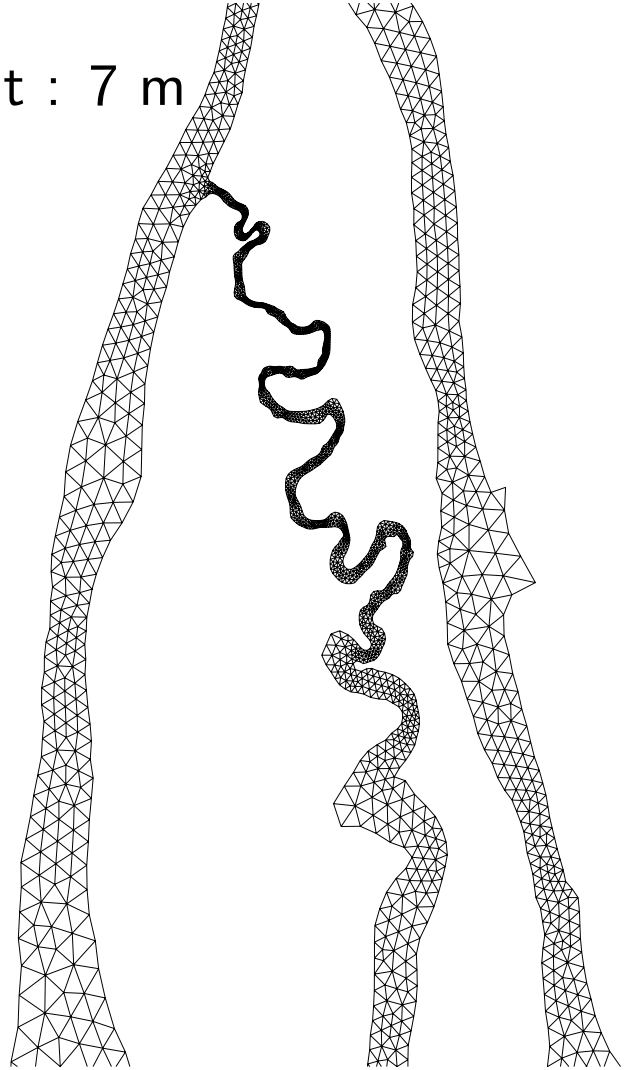
- $\Delta \propto \sqrt{gH}$
- $\Delta \propto$ distance to coast
- $\Delta \propto ||\nabla H||^{-1}$
- $\Delta \propto$ delta channels width
- $N \approx 50\ 000$ triangles

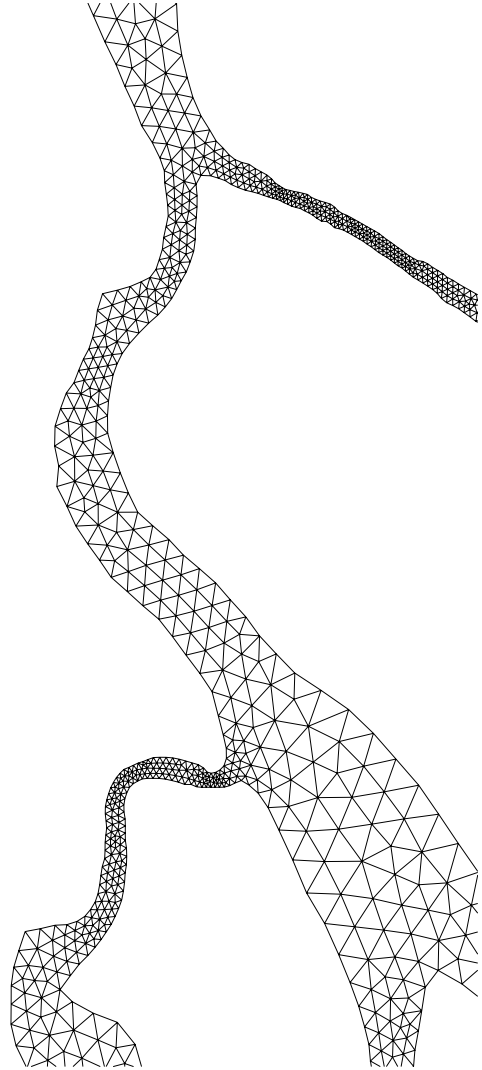


A multiscale mesh

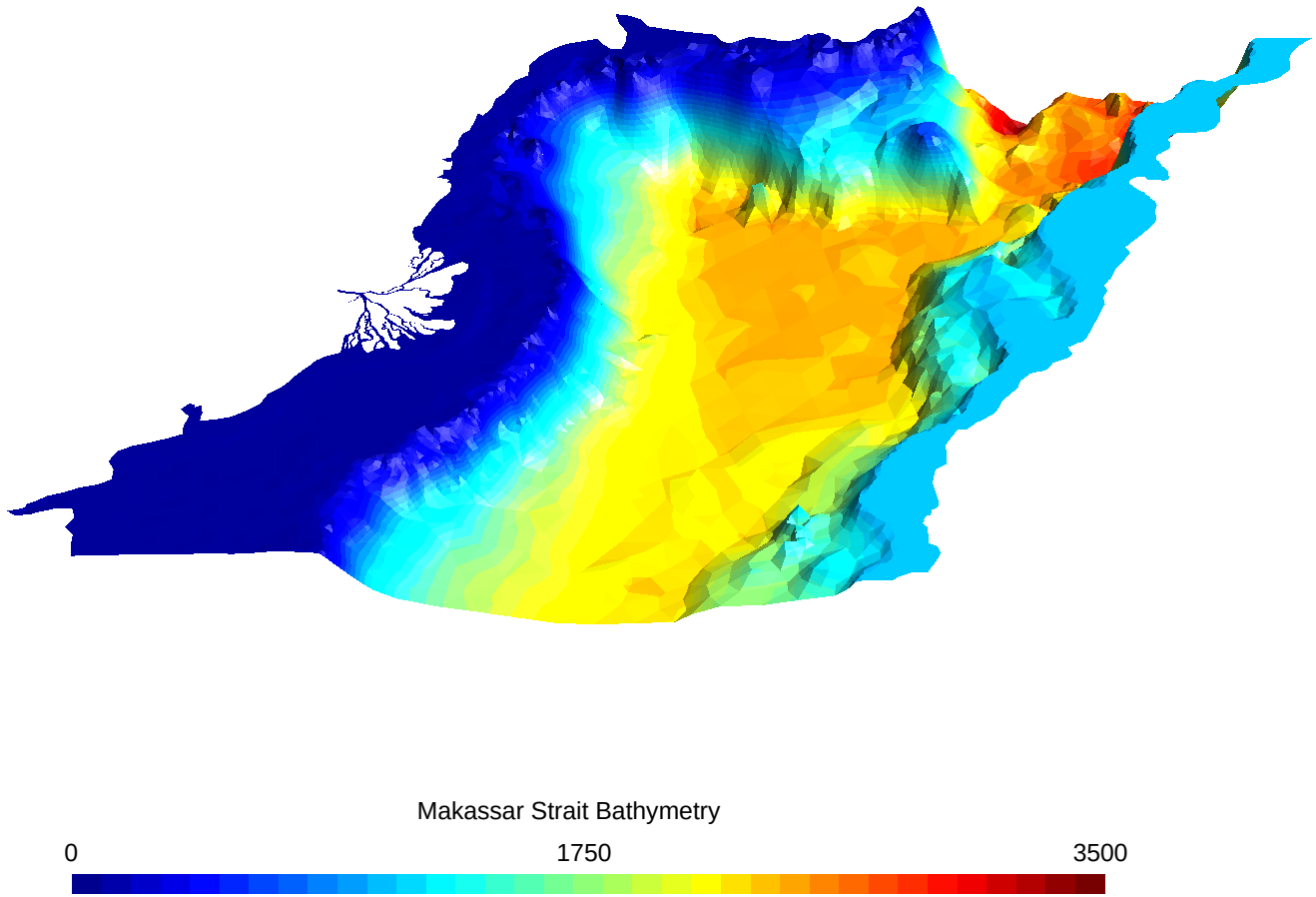
72% of the elements are in 1.4% of the computational domain

Smallest element : 7 m



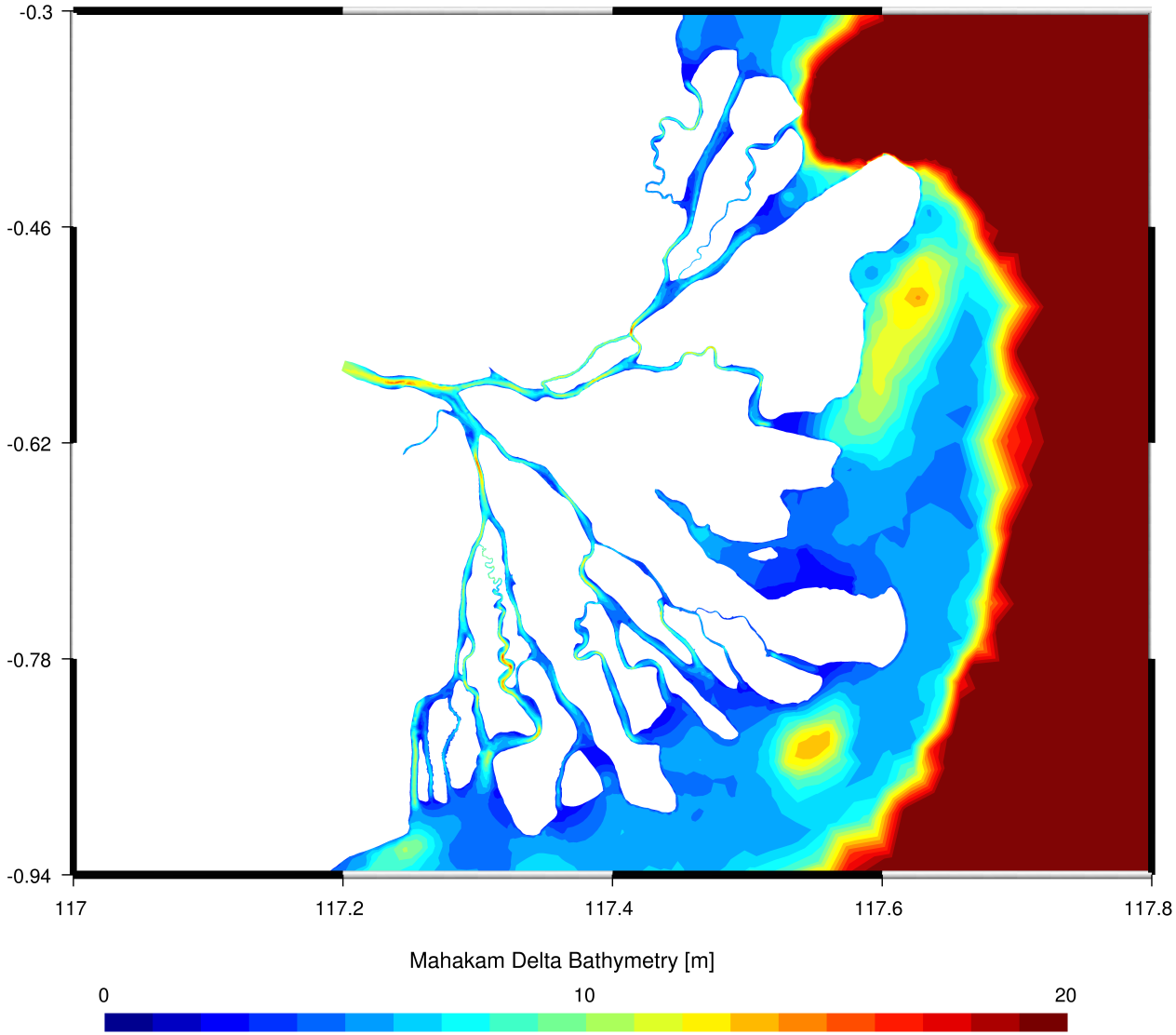


Imposing bathymetry in the Makassar Strait from GEBCO[2]



[2] https://www.bodc.ac.uk/data/online_delivery/gebco/

Imposing bathymetry in the Mahakam delta

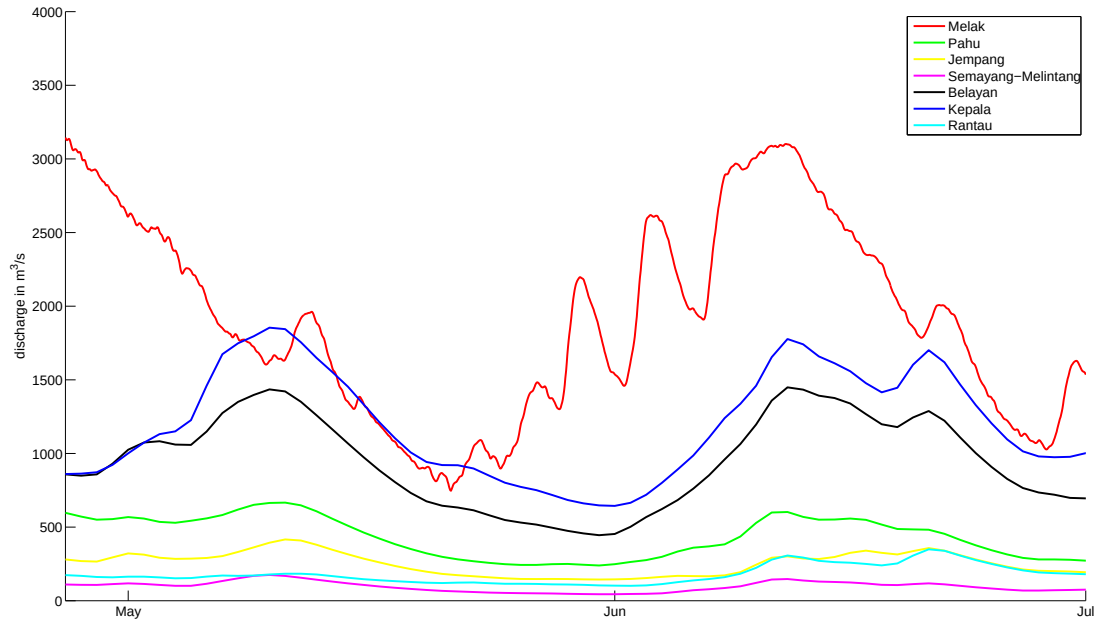


Imposing open boundary conditions

Difficult near the delta

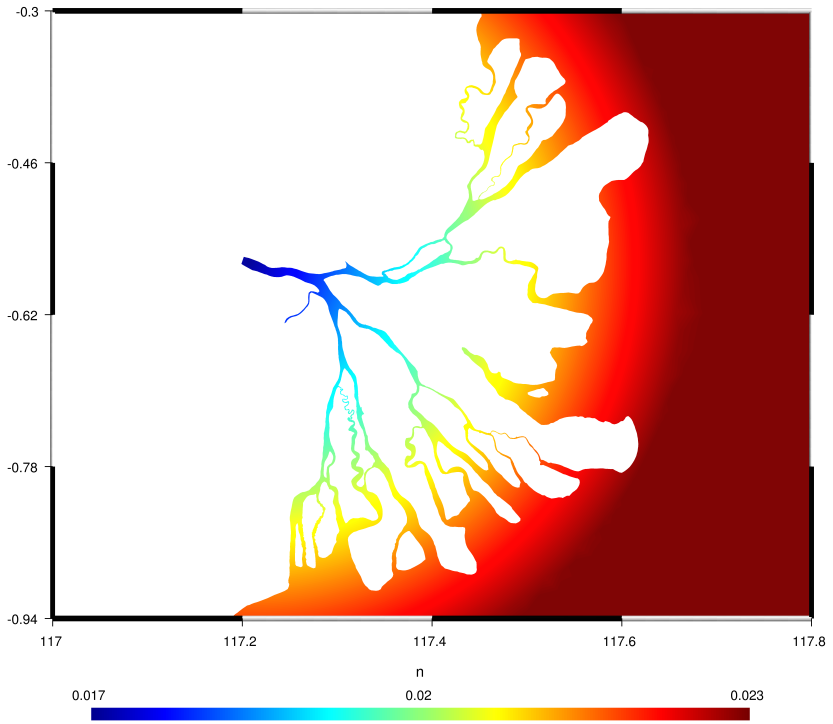
→ Extending of the computational domain:

- Downstream to the Makassar Strait
  - Open boundary conditions provided by a global ocean tidal model
  - Meteorological forcings imposed as a surface stress (wind + atm pressure)
- Upstream to the limit of the tidal dominance and for the tributaries
  - Velocity imposed from measured discharges



Parametrisations

- The slope in the 1D part of the domain : $\frac{3m}{365000m}$
- The Chézy coefficient linked to the bottom friction : $C = \frac{R^{1/6}}{n}$ where
  - R is the hydraulic radius fixed to H in the 2D part and to Section/Wet Perimeter in the 1D part.
  - n results in an optimisation for this application and ranges between 0.023 in the outer delta and 0.017 in the rivers.

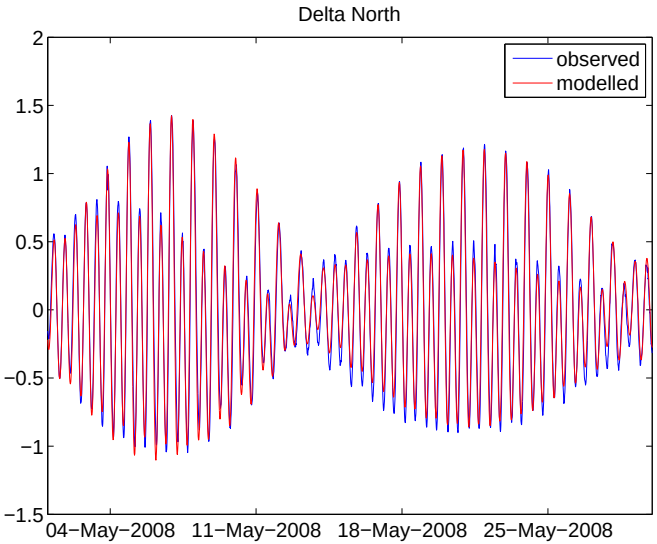


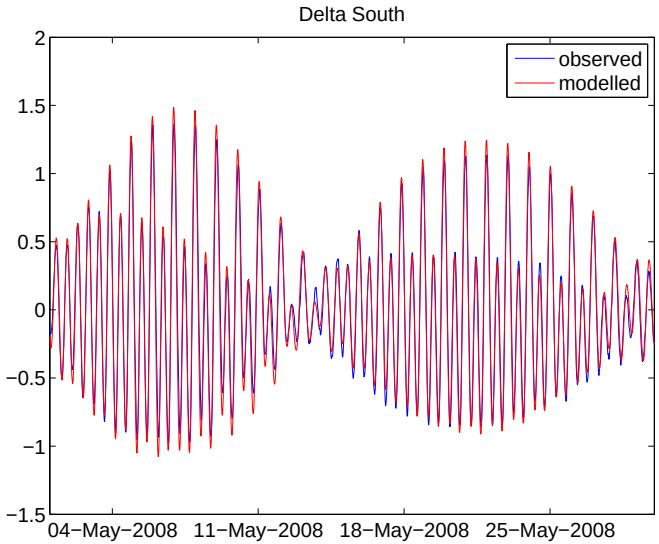
Validation of Water Levels

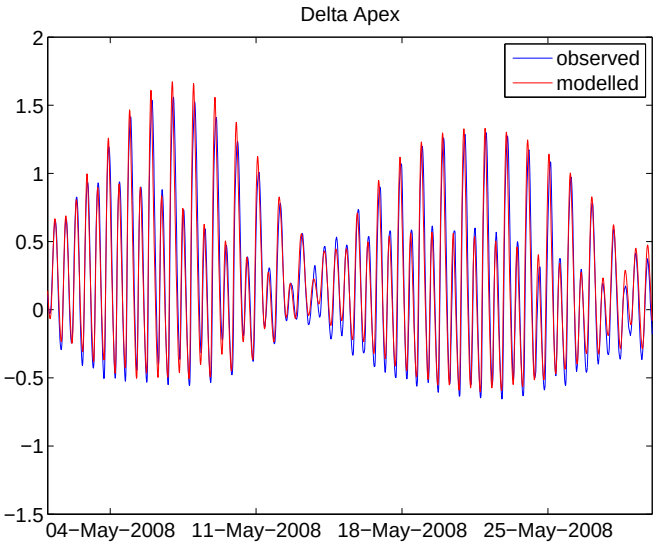
Location of the stations

Validation of Water Levels

Time series comparison

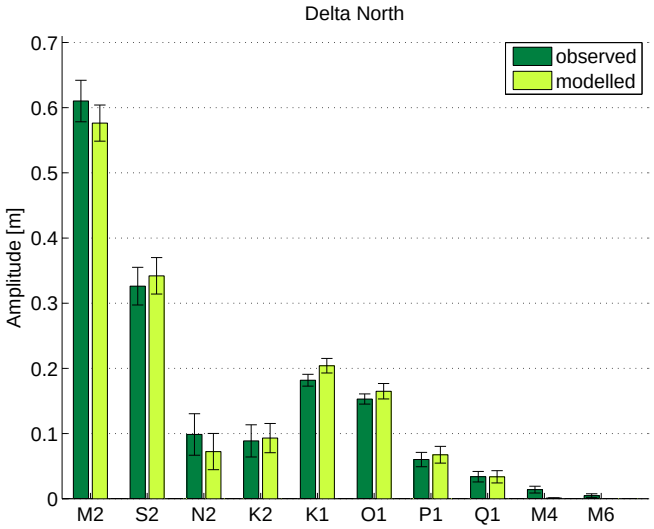


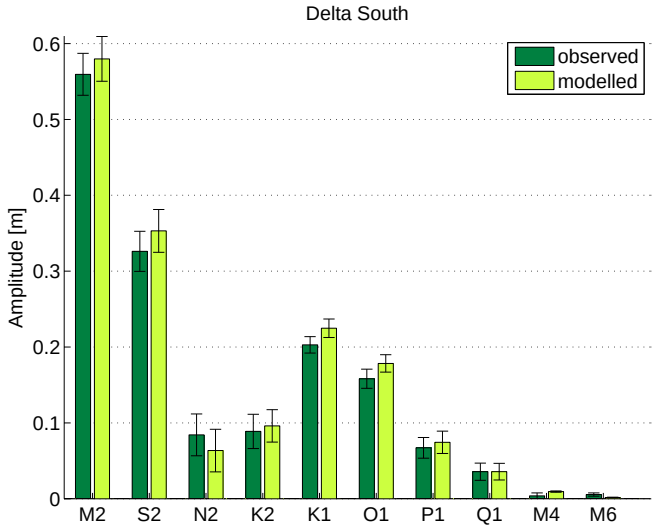


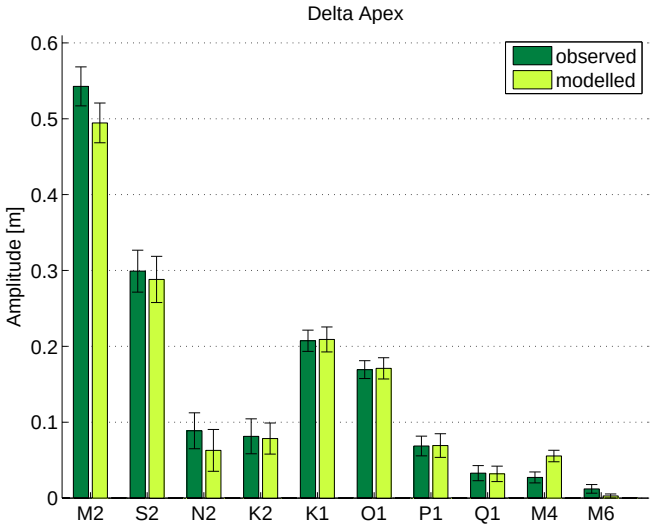


Validation of Water Levels

Amplitude comparison

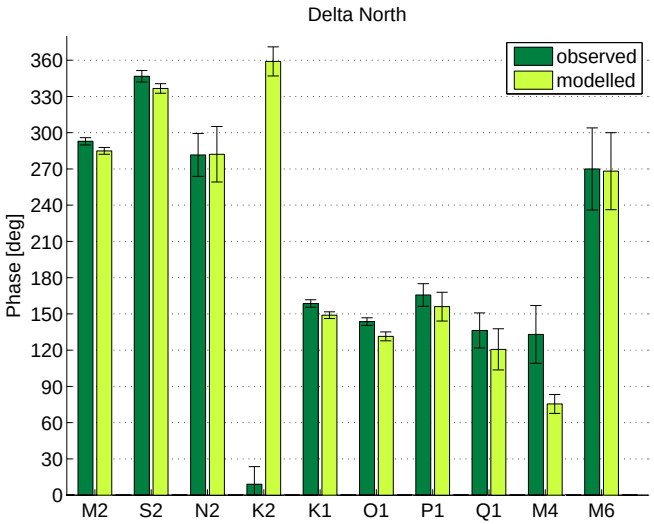


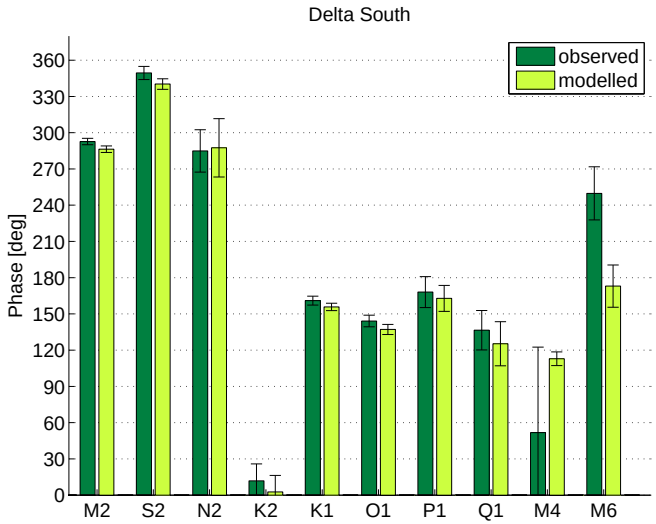


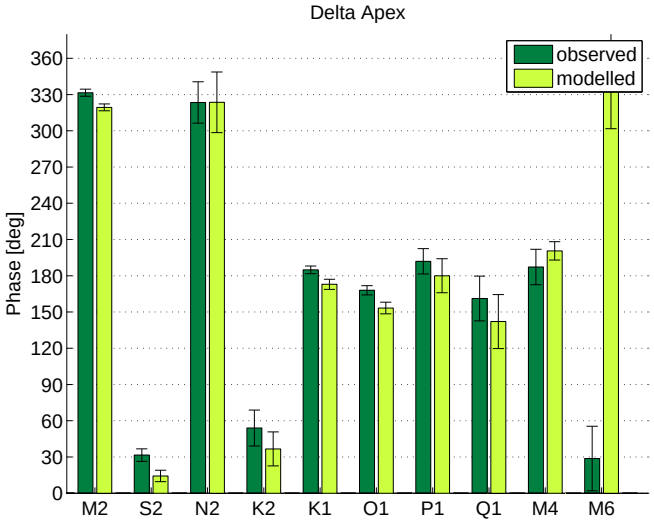


Validation of Water Levels

Phase comparison

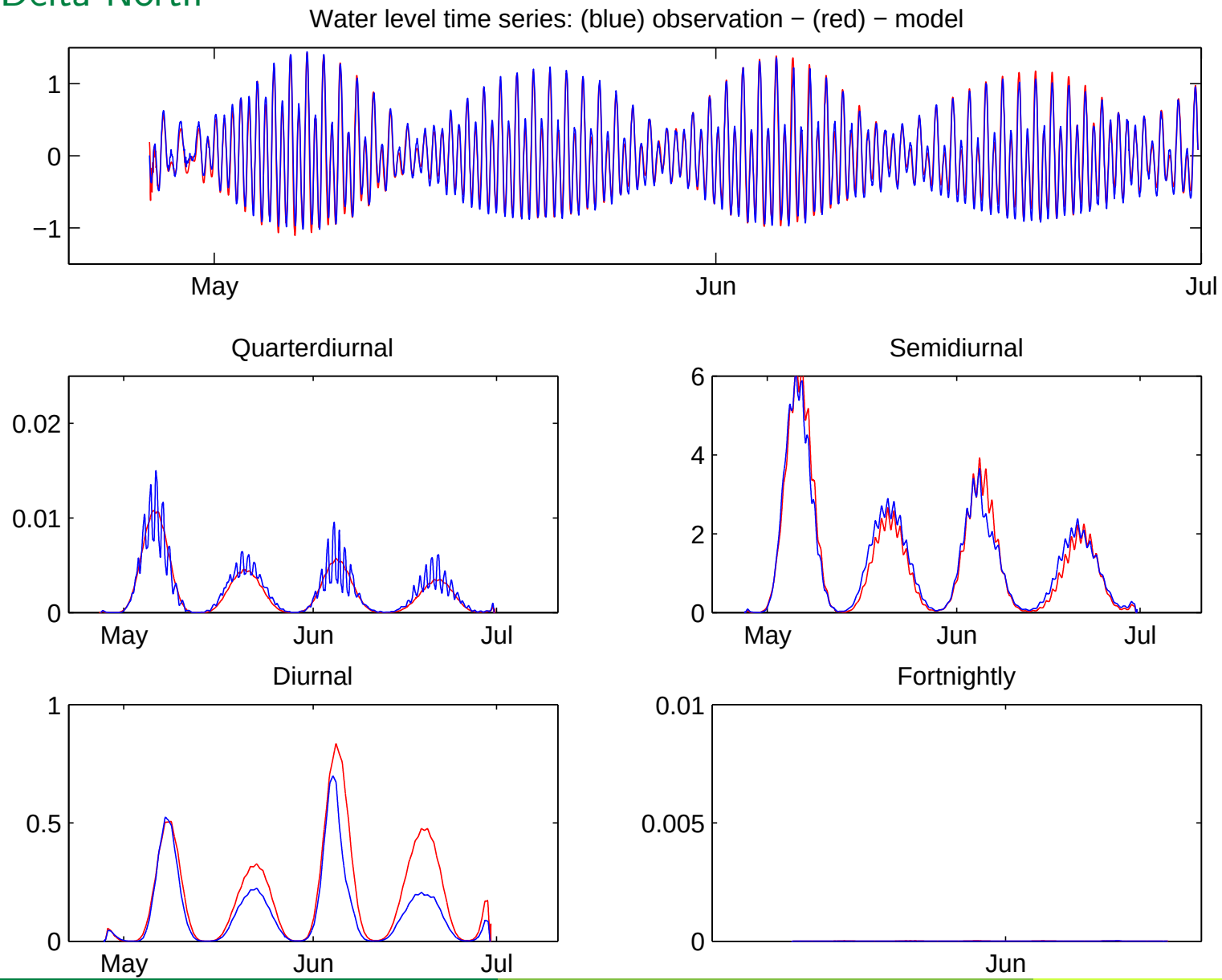






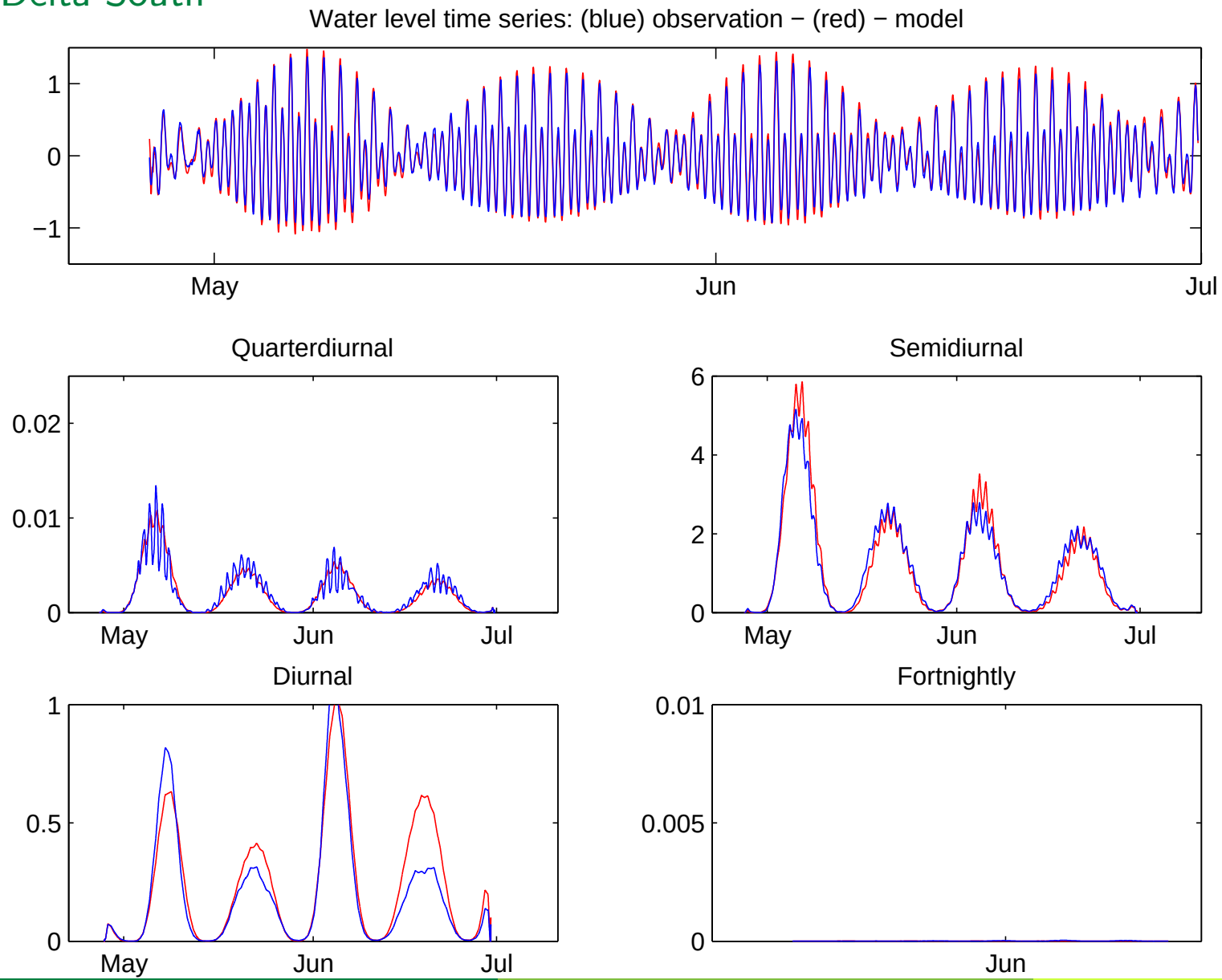
Wavelet analysis

Delta North



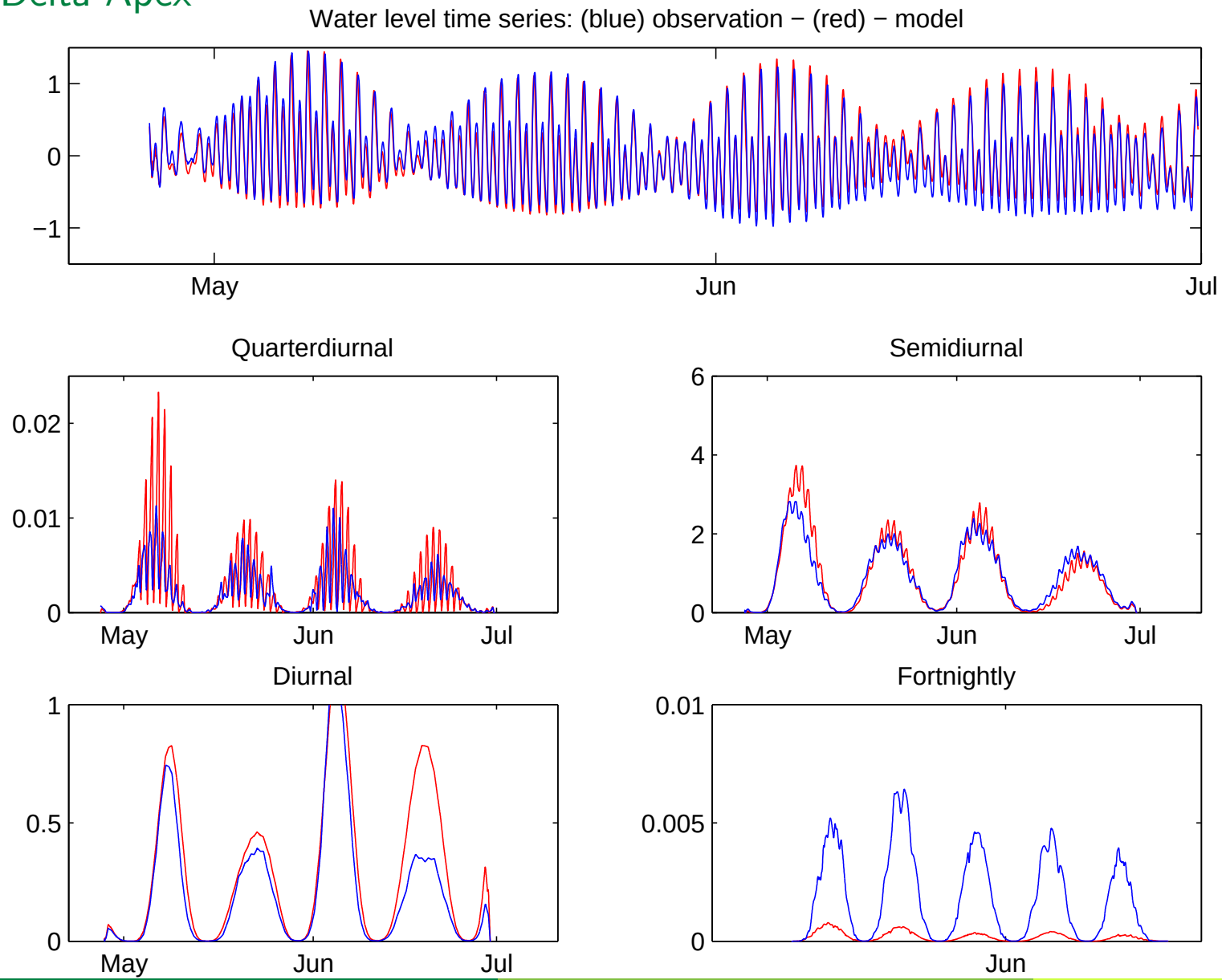
Wavelet analysis

Delta South

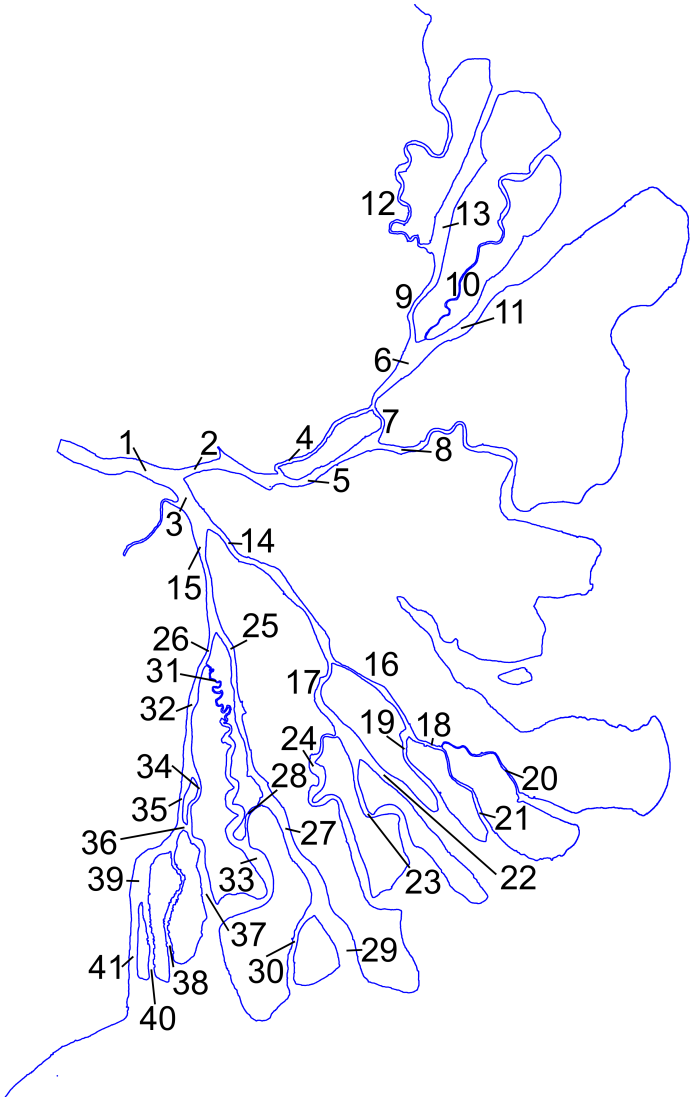


Wavelet analysis

Delta Apex



Residual discharge in the delta averaged on May-June 2008



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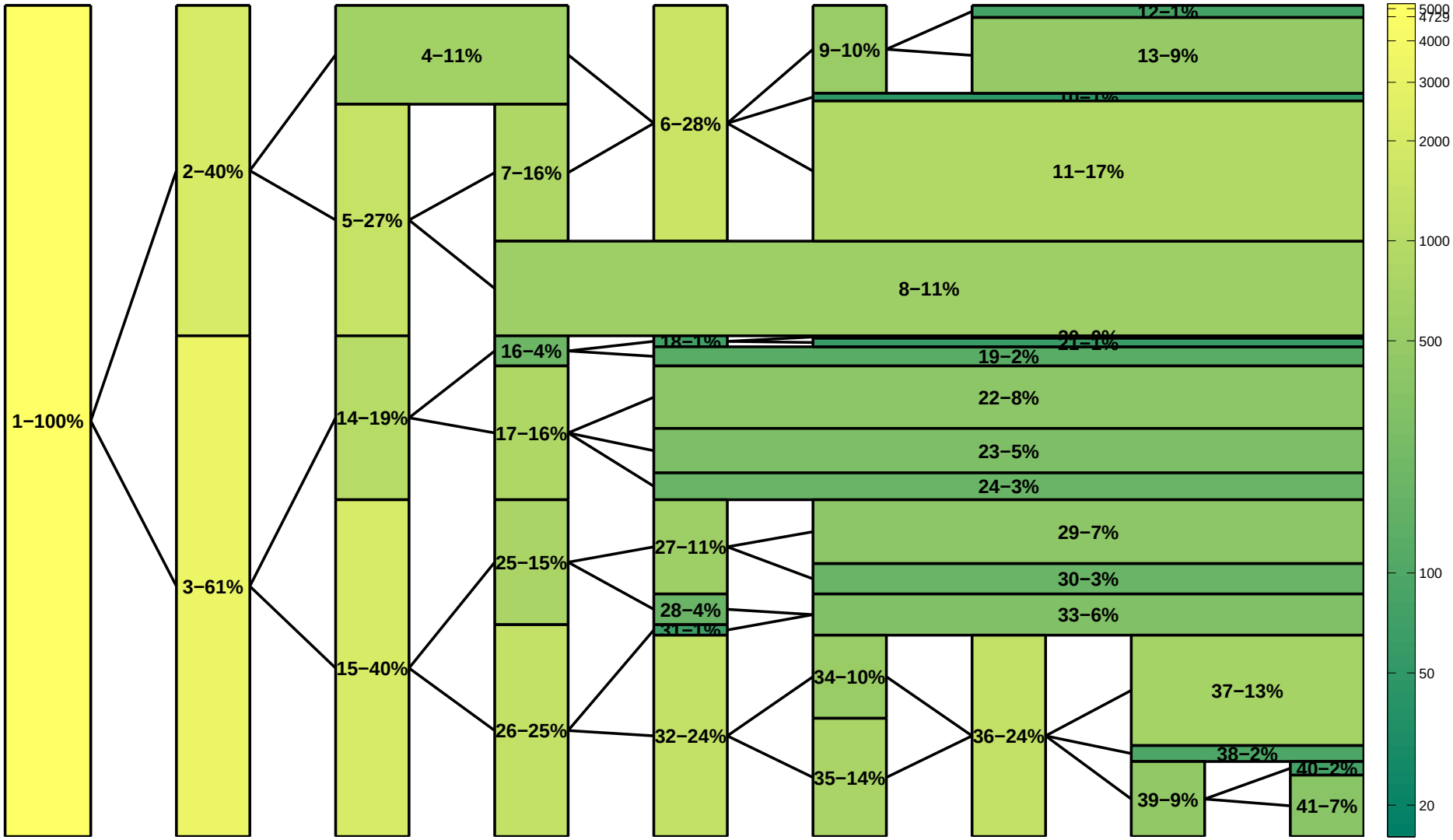
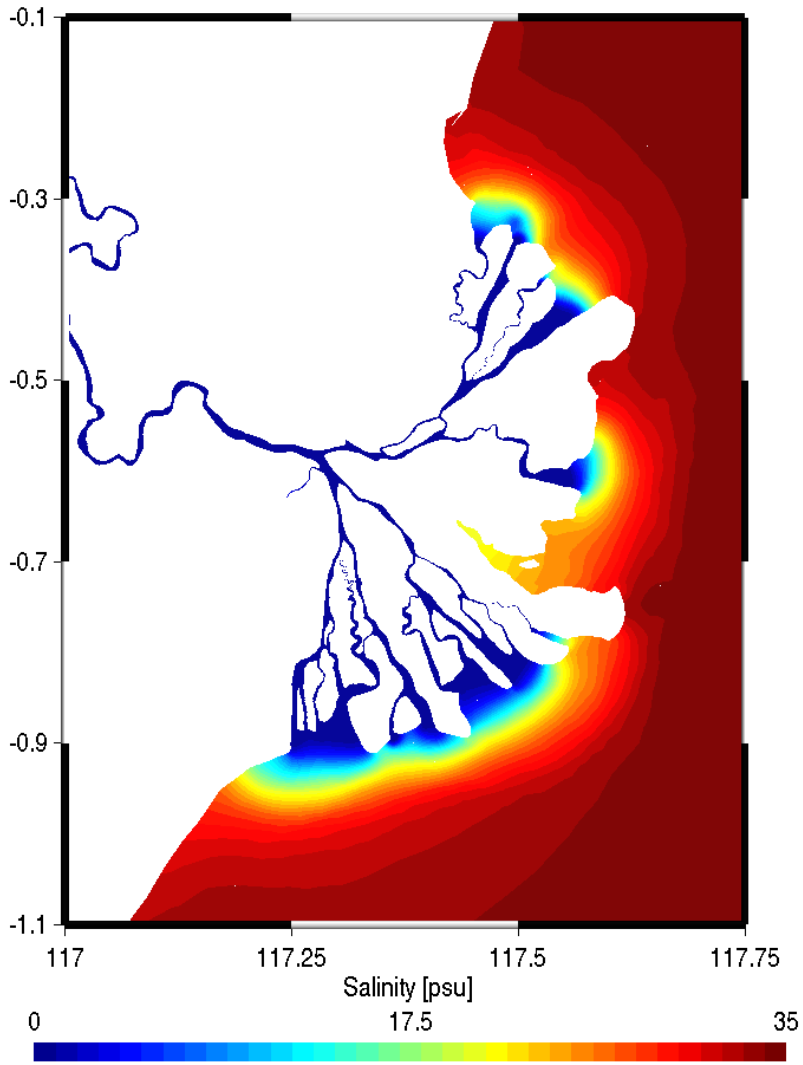


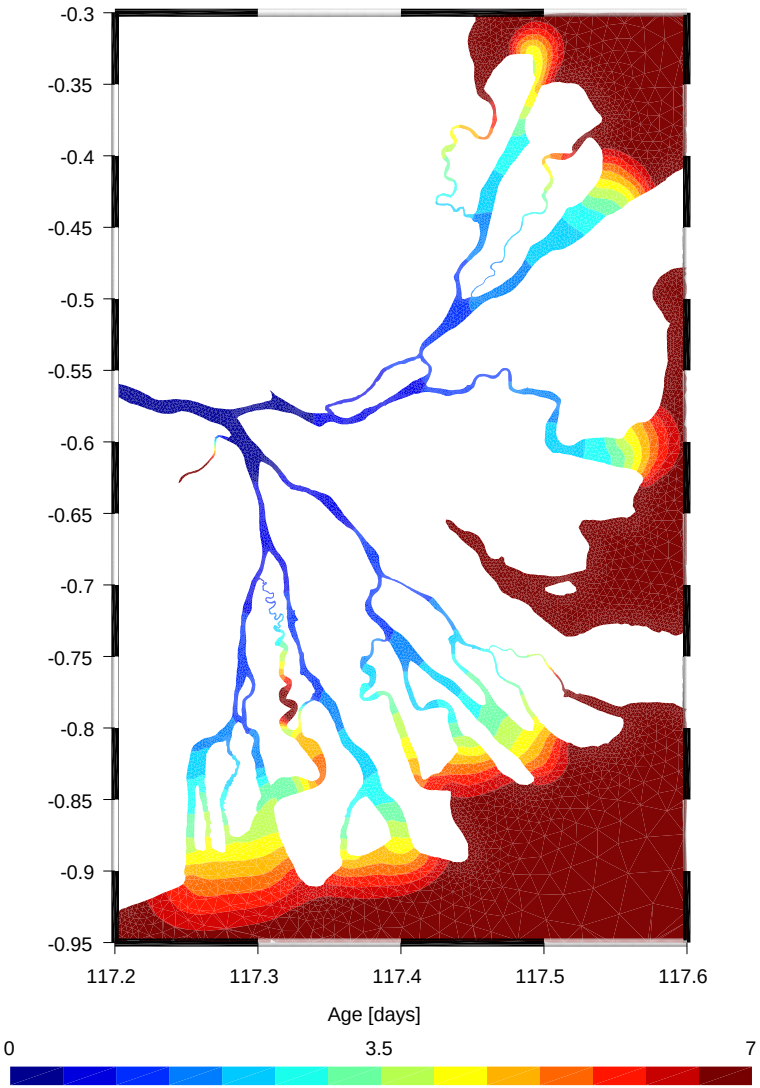
Modeling the salinity

Towards a 3D structure ?



Age

Water coming from the delta apex takes no longer than 7 days to reach the strait



Conclusion

- A multiscale model describing the Mahakam Land-Sea continuum is implemented from the Makassar Strait to the limit of the tidal influence
  - Implicit DG FEM
  - 2D (lakes-delta-strait) and 1D (the river and its tributaries)

- Perspectives
  - The validation is still in process and we need to perform validation with flow measurements.
  - Further numerical developments are required to take into account the particular ecosystem in the lakes area.