KU LEUVEN

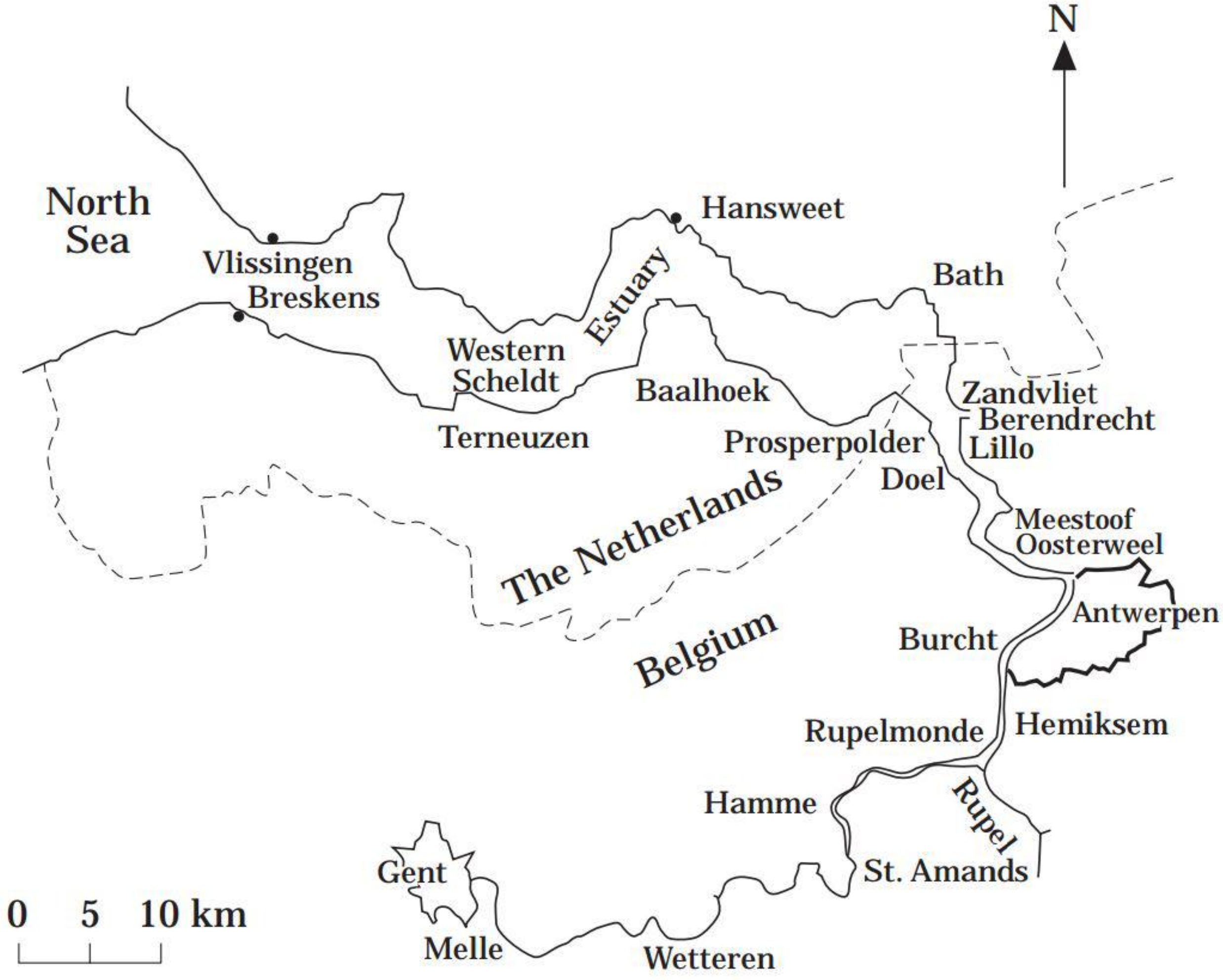
A New Sediment Transport Model for Western Scheldt

Qilong Bi & Erik Toorman

Hydraulics Laboratory,
Civil Engineering Department
University of Leuven

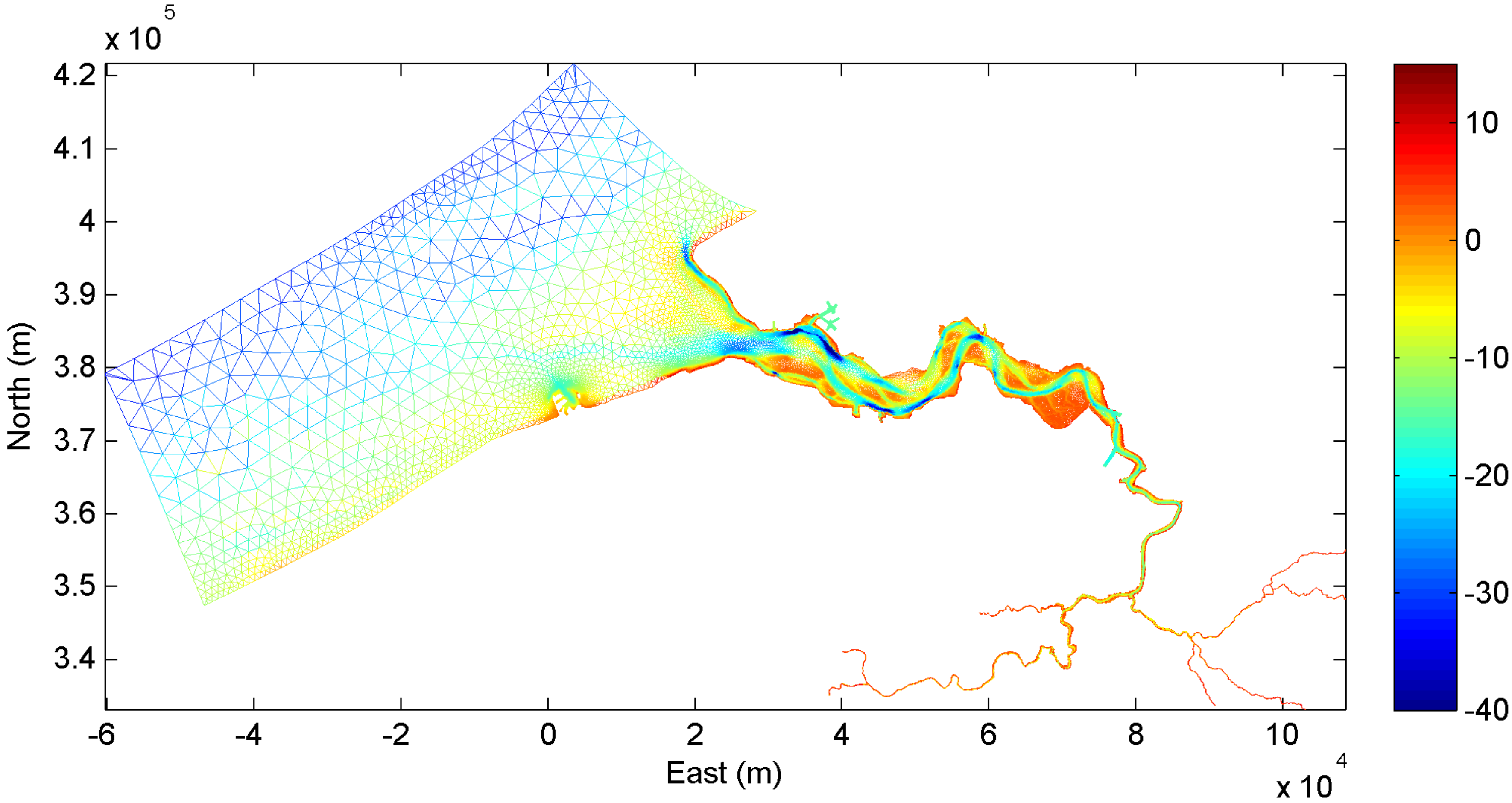
JONSMOD 2014 · Brussels · 14th May

The Scheldt Estuary



(from Fettweis et al., 1998)

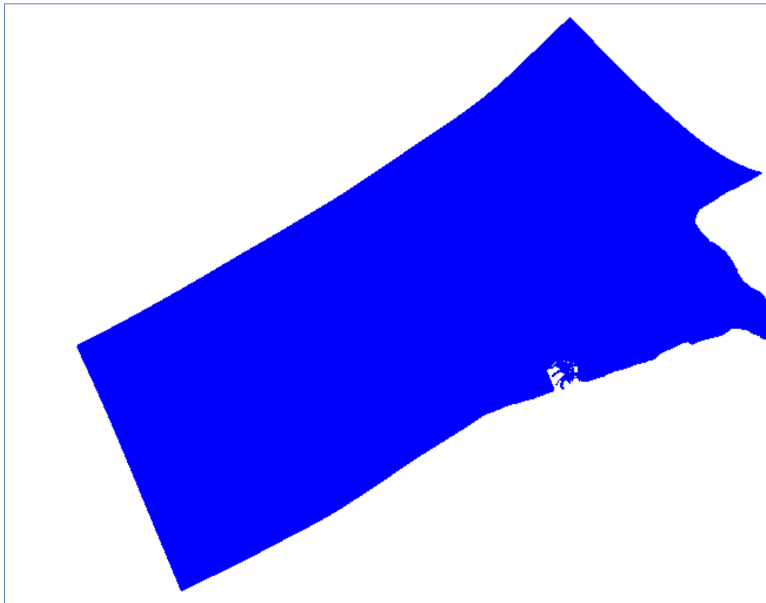
Hydrodynamic Model



(Mesh and bathymetry of the Scheldt model)

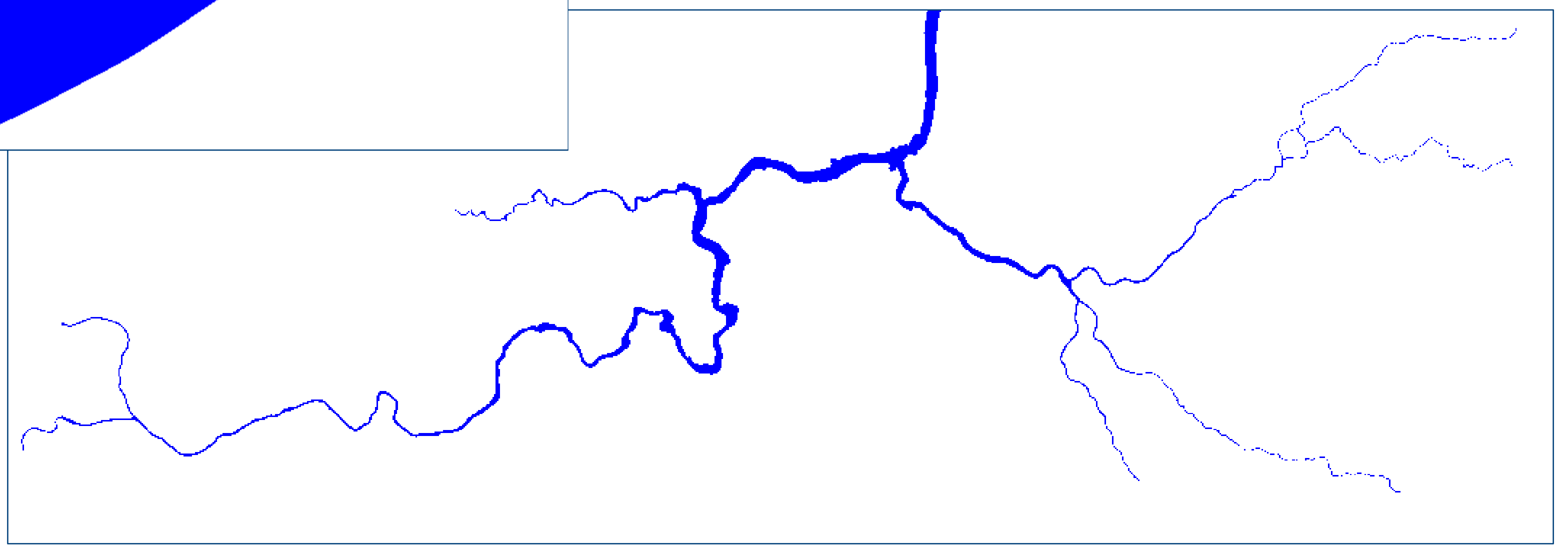
KU LEUVEN

Hydrodynamic Model



Upstream: constant fresh water inflow from tributaries

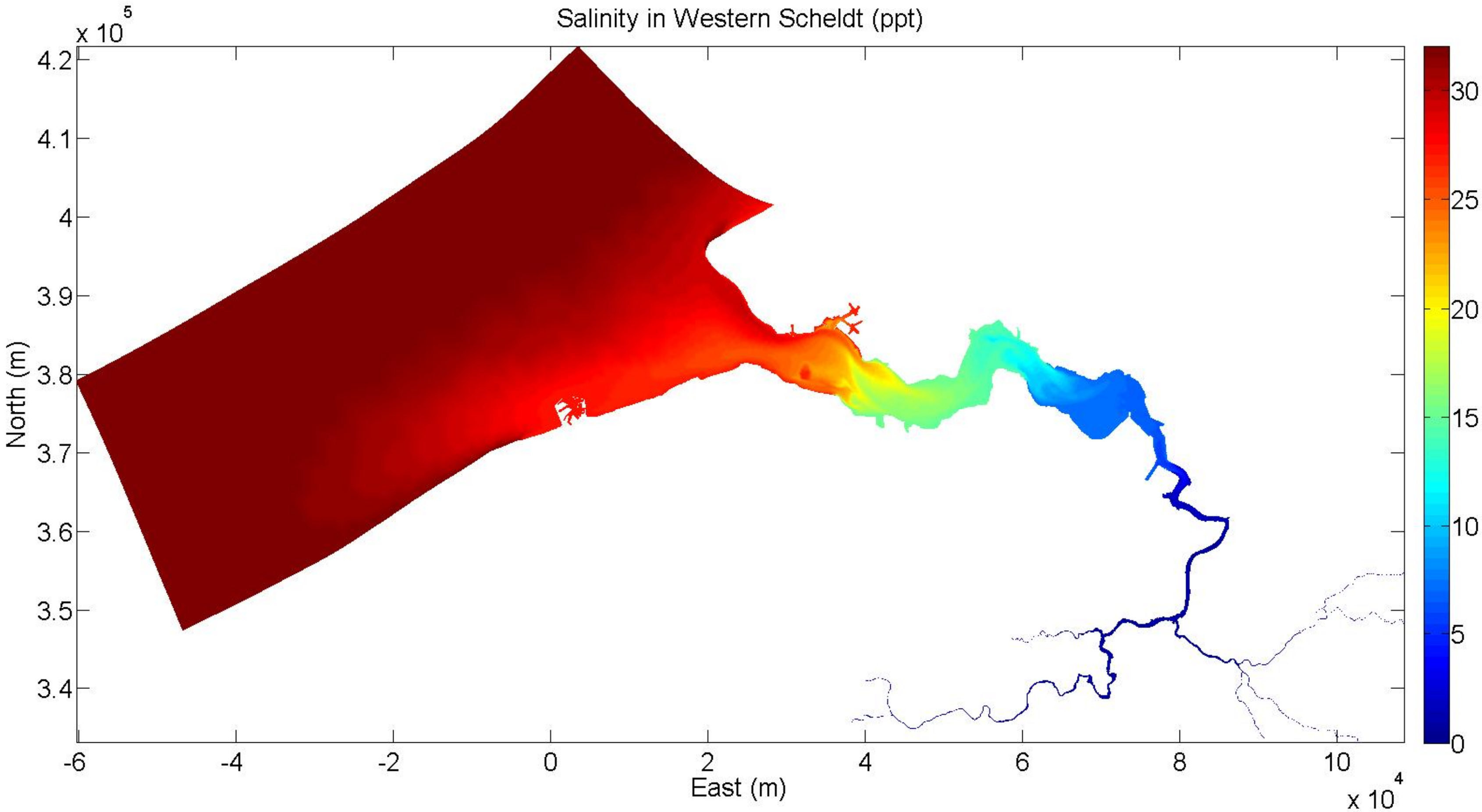
Downstream: imposed tidal elevations and salinity data



(Liquid boundaries)

KU LEUVEN

Hydrodynamic Model



(Initial salinity)

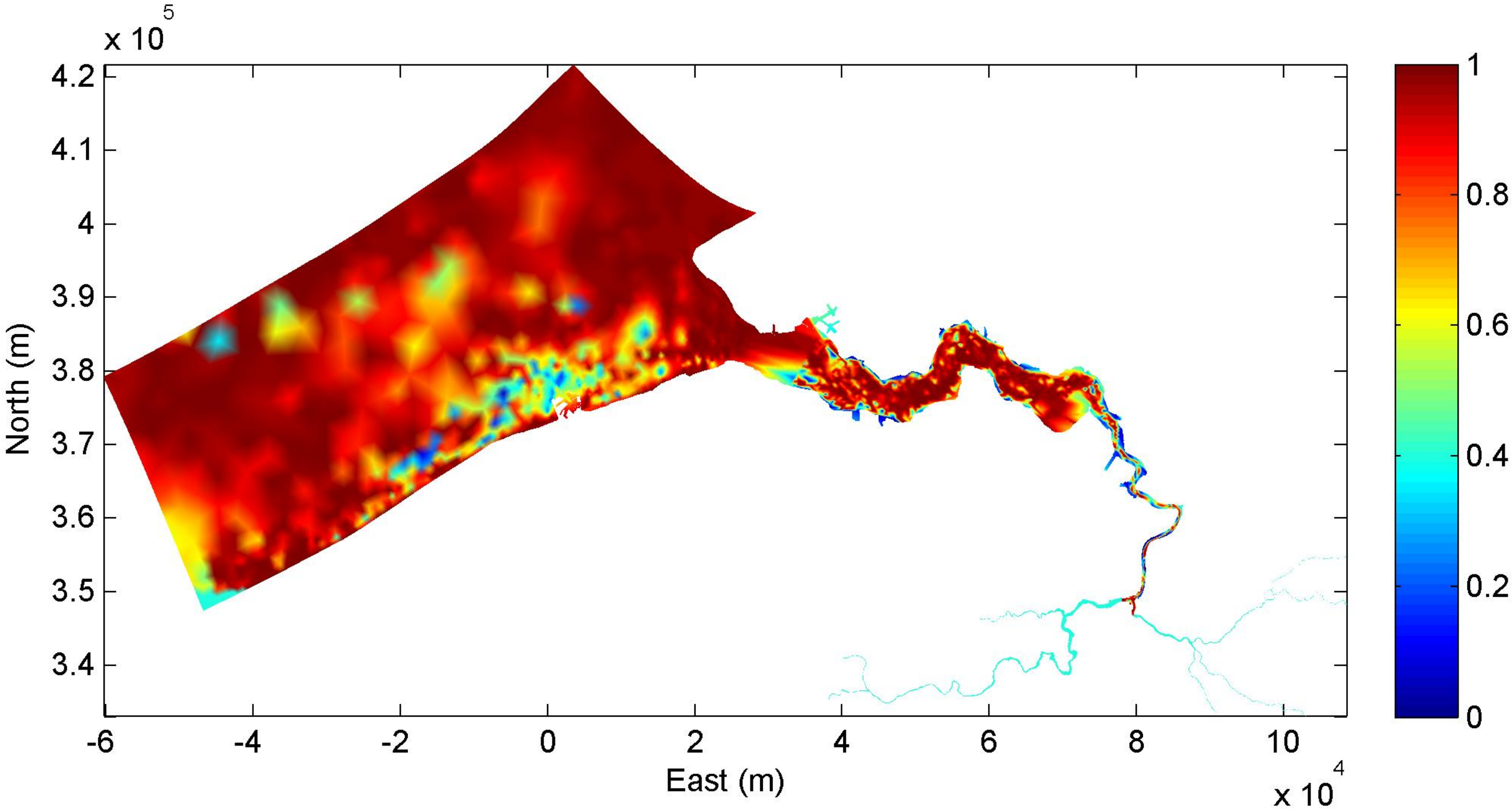
KU LEUVEN

Hydrodynamic Model

Other settings

- Law of bottom friction : Chézy formula
- Turbulence model : k-epsilon model
- Treatment of tidal flats :
  equations solved everywhere with correction on tidal flats
- Coriolis force considered
- Coupled with SISYPHE

Sediment Transport Model

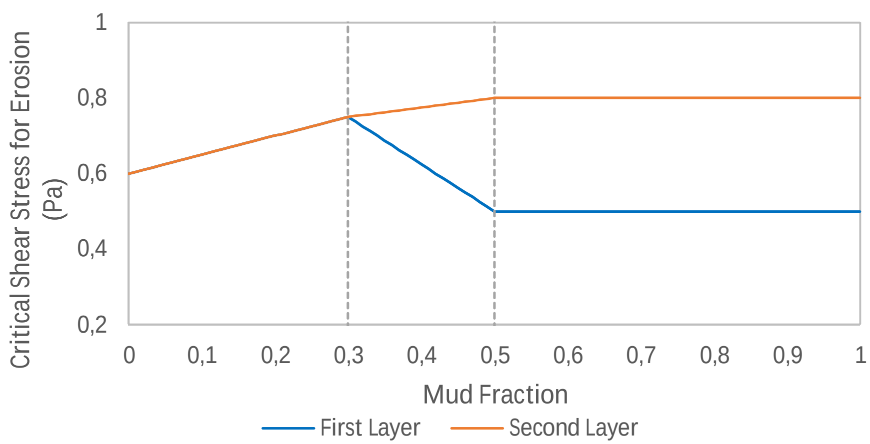


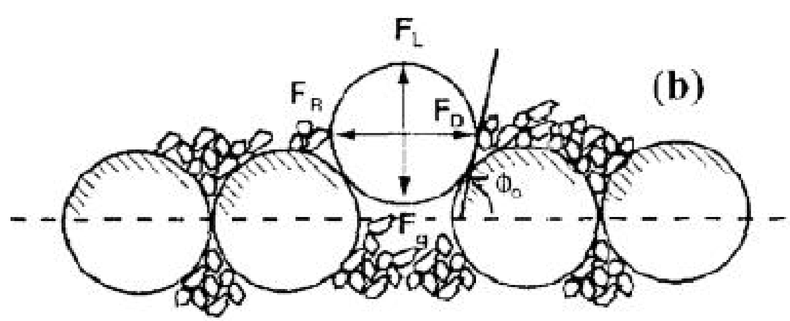
(mixed-sediment: sand faction distribution map)

Sediment Transport Model

Sediment properties (two-layer bed model)

Type of Sediment	Diameter	Density	Settling Velocity	Critical Shear Stress for Erosion (first layer)	Critical Shear Stress for Erosion (second layer)
Non-cohesive (Sand)	300 µm	2560 kg/m^3	1.0E-02 m/s	0.6 Pa	0.6 Pa
Cohesive (Mud)	60 µm	1600 kg/m^3	1.0E-03 m/s	0.5 Pa	0.8 Pa





(Waeles, 2005)

KU LEUVEN

Sediment Transport Model

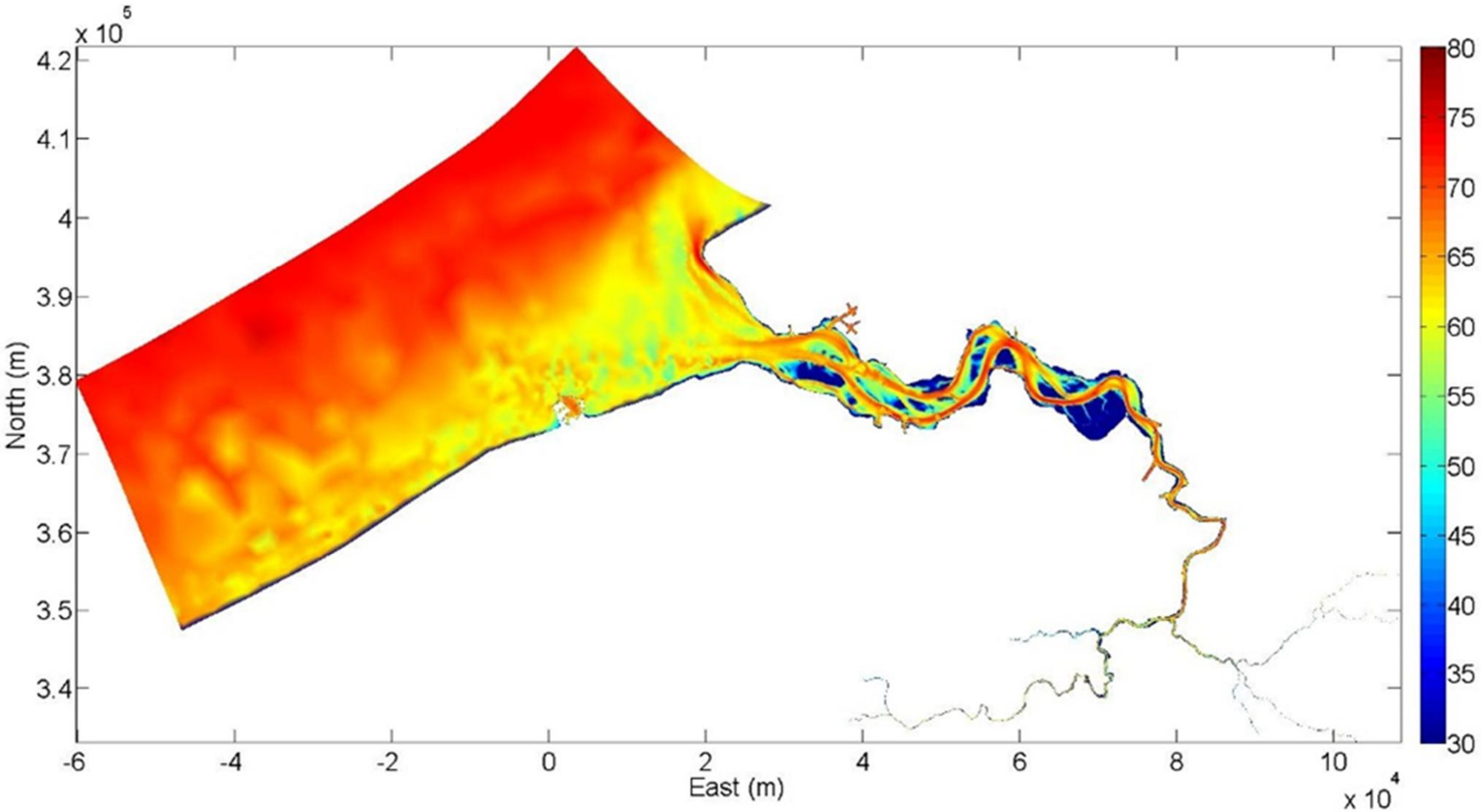
- The new bottom friction Law based on GML theory
  - General case (*laminar – transient – turbulent*):

$$u_*^{\,2} = f_A u_{*turb}^{\,2} + u_{*lam}^{\,2}$$

$$u_*^{\,2} = f_A \left(\frac{\kappa U}{\ln(h/z_0) - 1 + z_0/h} \right)^2 + \left(\sqrt{\left(z_0 \frac{U}{h} \right)^2 + 2\frac{U}{h}\nu} - z_0 \frac{U}{h} \right)^2$$

  - with: $z_0 = \frac{k_s}{30} + \beta\phi h$

Sediment Transport Model

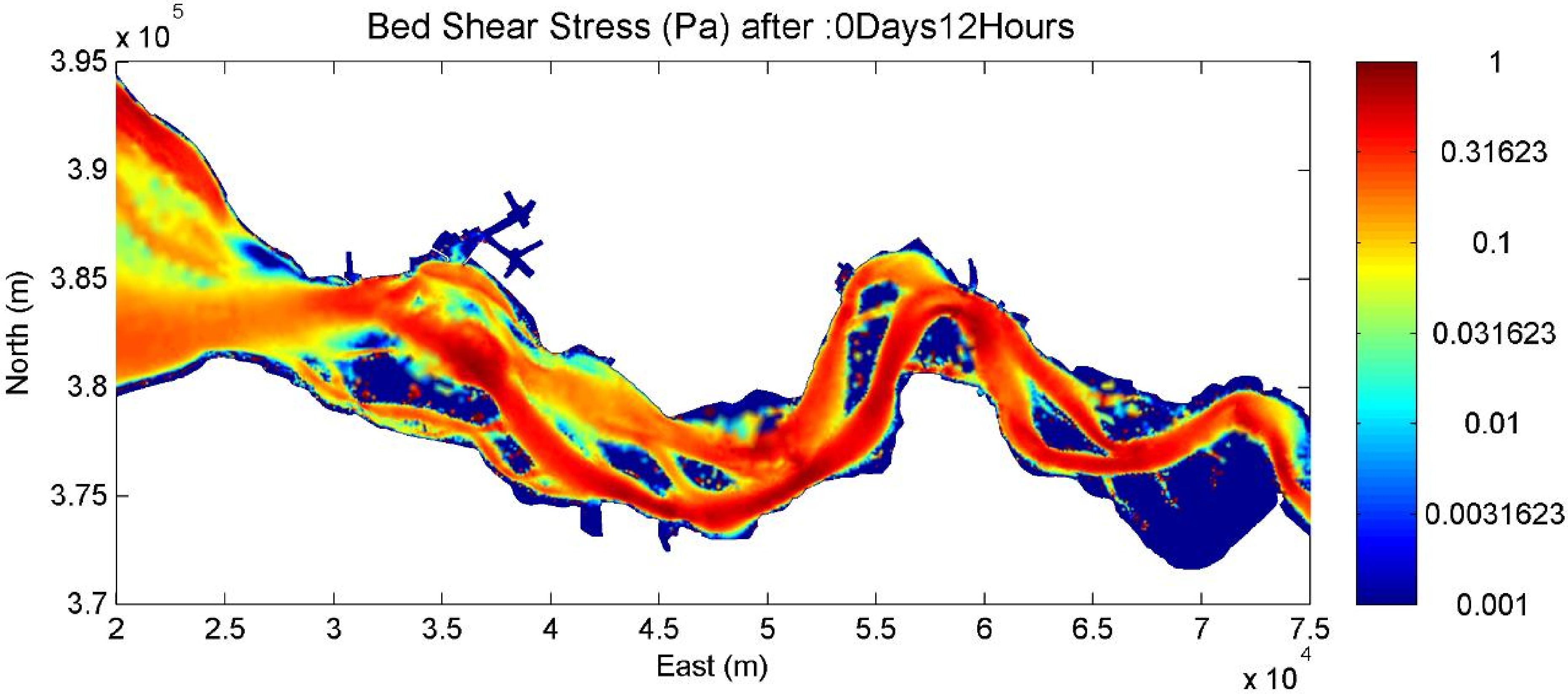


(Chézy coefficient obtained from the new bottom friction law)

Sediment Transport Model

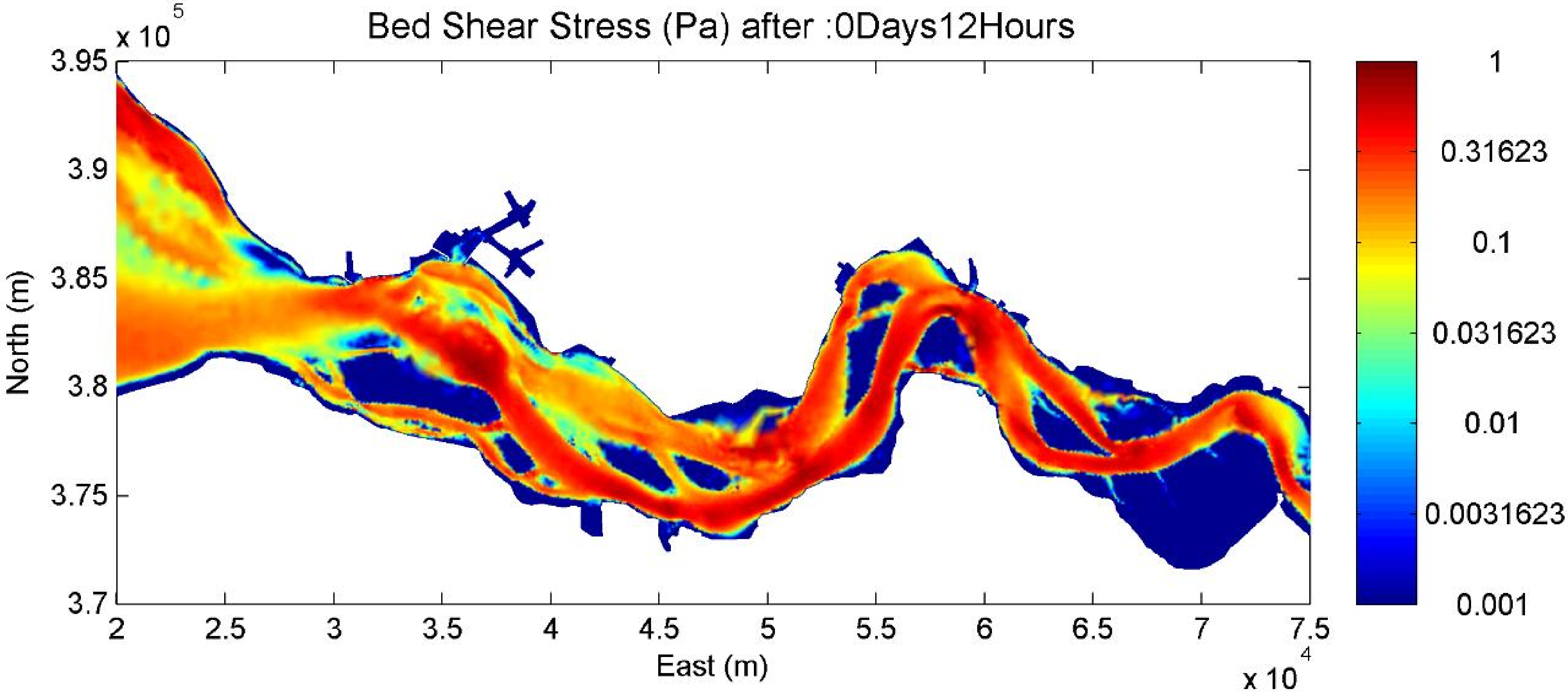
- Advantages of the new bottom friction law
  - More physically based, more accurate
  - Allows reduction of inundation threshold to roughness height (1mm in current model)
  - Improves bed shear stress computation in very shallow areas (intertidal flats)

Sediment Transport Model



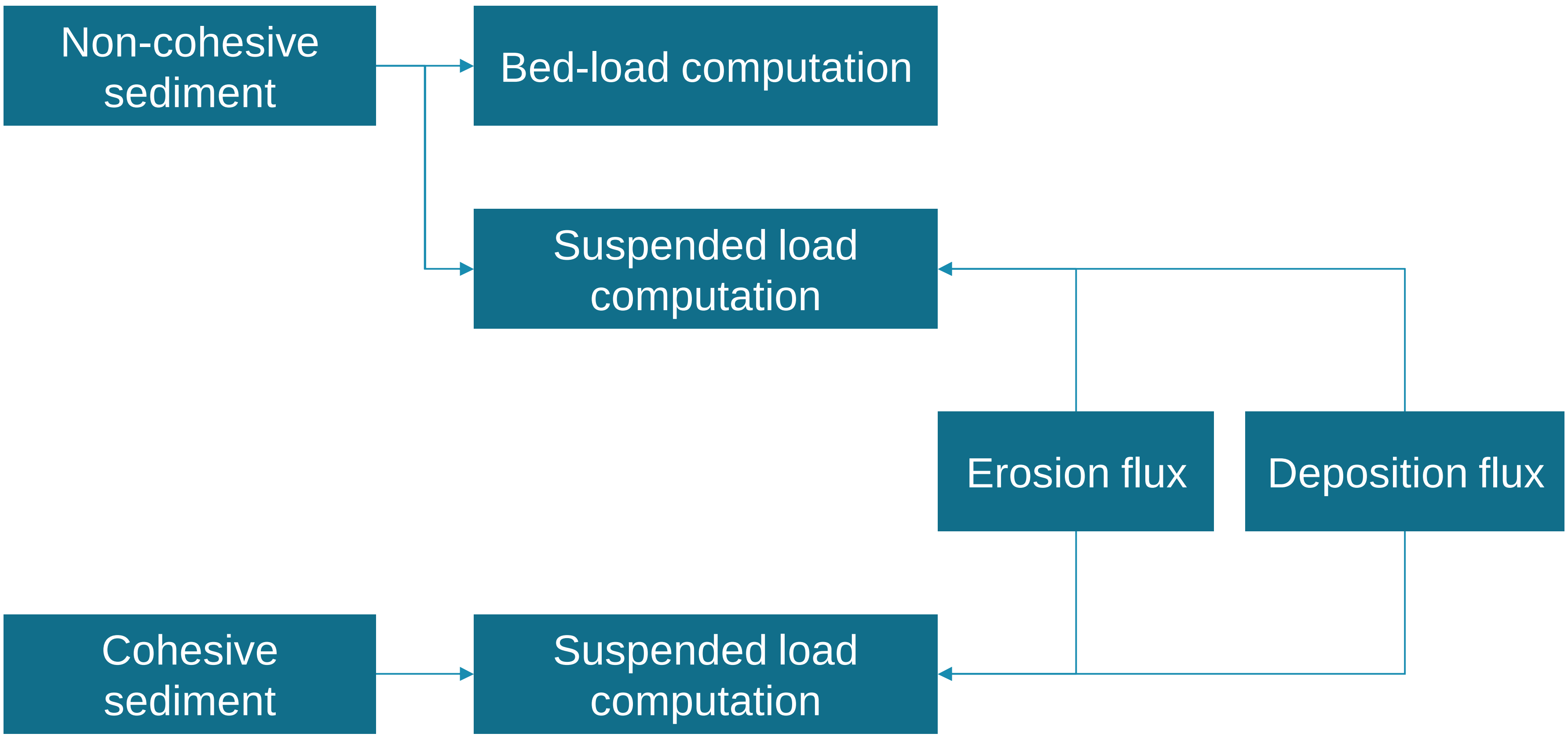
In dry areas, velocity *U* tends to be zero → $u_* = \sqrt{C_D / 2U}$

Sediment Transport Model



In dry areas, *u** is limited to zero by the new friction law

Sediment Transport Model



KU LEUVEN

Sediment Transport Model

- Bed-load:
  the formula from Van Rijn (1984) $q^* = \frac{0.053}{d^{*0.3}} \left(\frac{\tau^*}{\tau^*_{crit}} - 1 \right)^{2.1}$

- Suspended load: depth-averaged advection-diffusion equation

$$\frac{\partial hC}{\partial t} + \frac{\partial (hUC)}{\partial x} + \frac{\partial (hVC)}{\partial y} = \frac{\partial}{\partial x}\left(h\varepsilon_s \frac{\partial C}{\partial x} \right) + \frac{\partial}{\partial y}\left(h\varepsilon_s \frac{\partial C}{\partial y} \right) + E - D$$

- Erosion: Waeles (2005)

Non-cohesive regime f_m<30%

$$E_s = (1 - f_m) \cdot E_{0s} \cdot T^a$$
$$E_m = f_m \cdot E_{0s} \cdot T^a$$

linear interpolation →

Cohesive regime f_m>50%

$$E_s = (1 - f_m) \cdot E_{0m} \cdot T$$
$$E_m = f_m \cdot E_{0m} \cdot T$$

Sediment Transport Model

- The new deposition criterion
  Critical shear stress for deposition:

$$\tau_{cd,s} = \frac{\left(1-\rho_w/\rho_s\right)gh}{Rf_L}\frac{w_s C_s}{U} \qquad \tau_{cd,m} = \frac{\left(1-\rho_w/\rho_m\right)gh}{Rf_L}\frac{w_m C_m}{U}$$

  Deposition probabilities

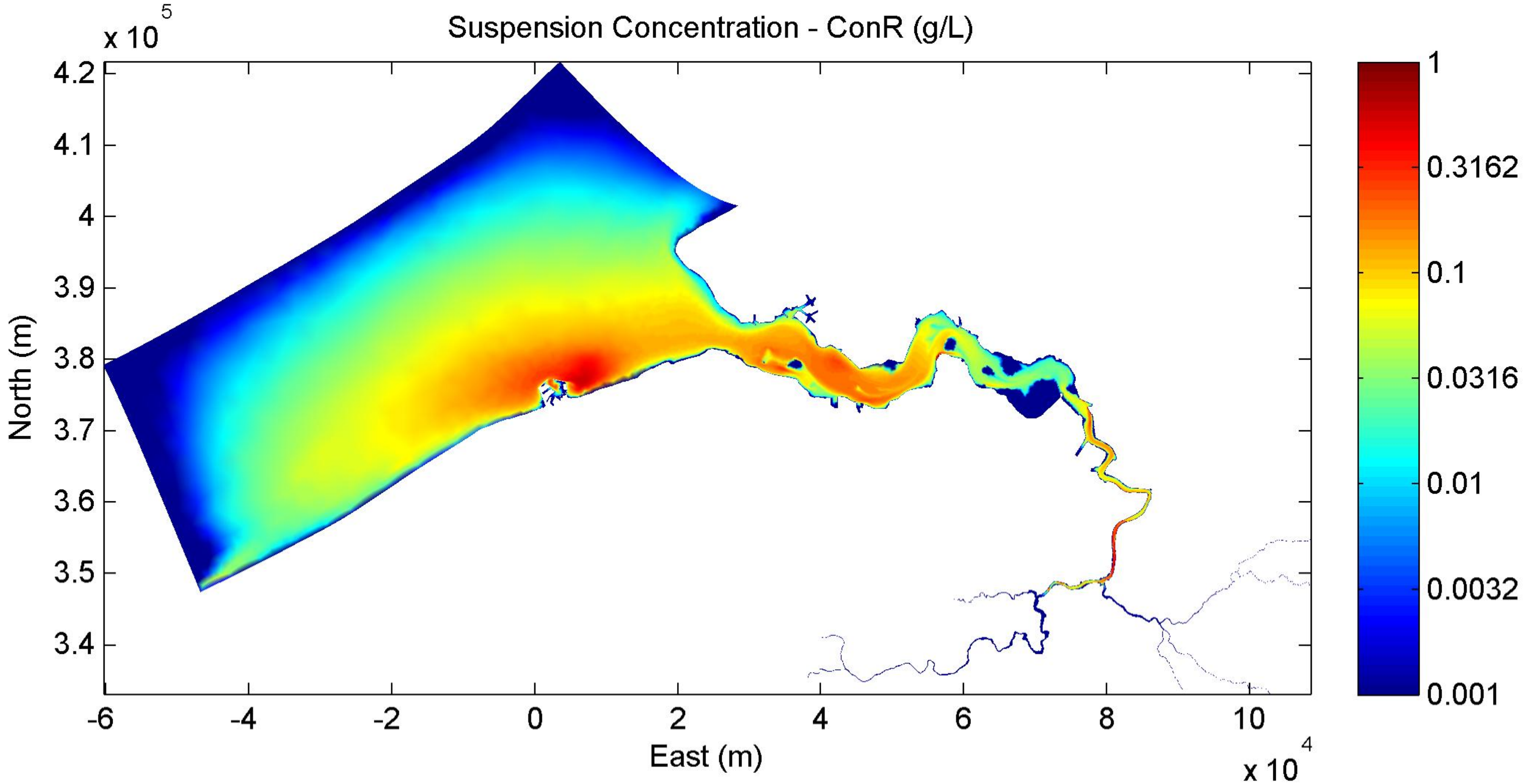
$$p_s = \max\left[1-\frac{C_s}{C_s+C_m}\frac{\tau}{\tau_{cd,s}},0\right] \qquad p_m = \max\left[1-\frac{C_m}{C_s+C_m}\frac{\tau}{\tau_{cd,m}},0\right]$$

- Krone's deposition law

$$D_s = \left(w_s C_s\right)\cdot p_s \qquad D_m = \left(w_m C_m\right)\cdot p_m$$

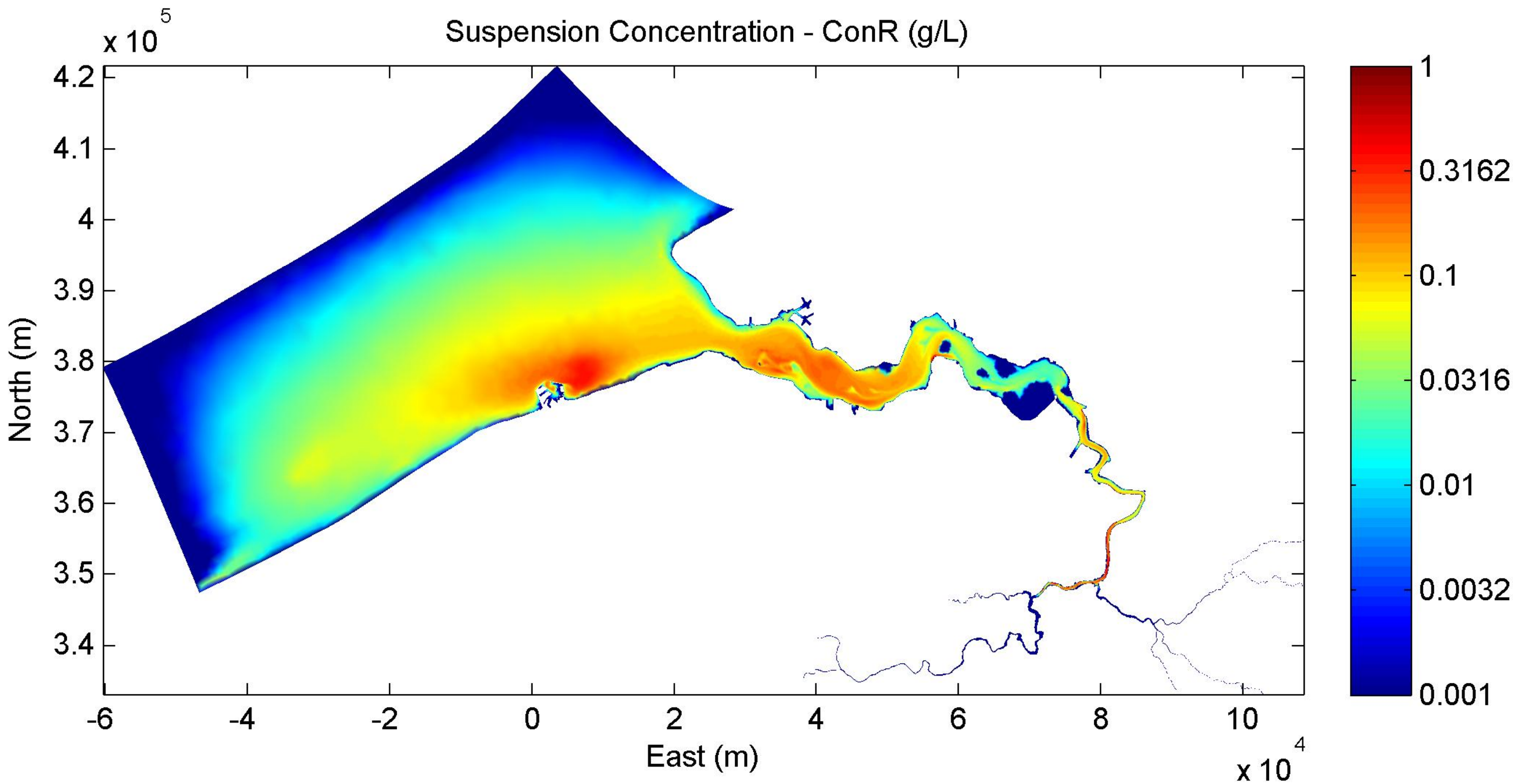
KU LEUVEN

Model Performence



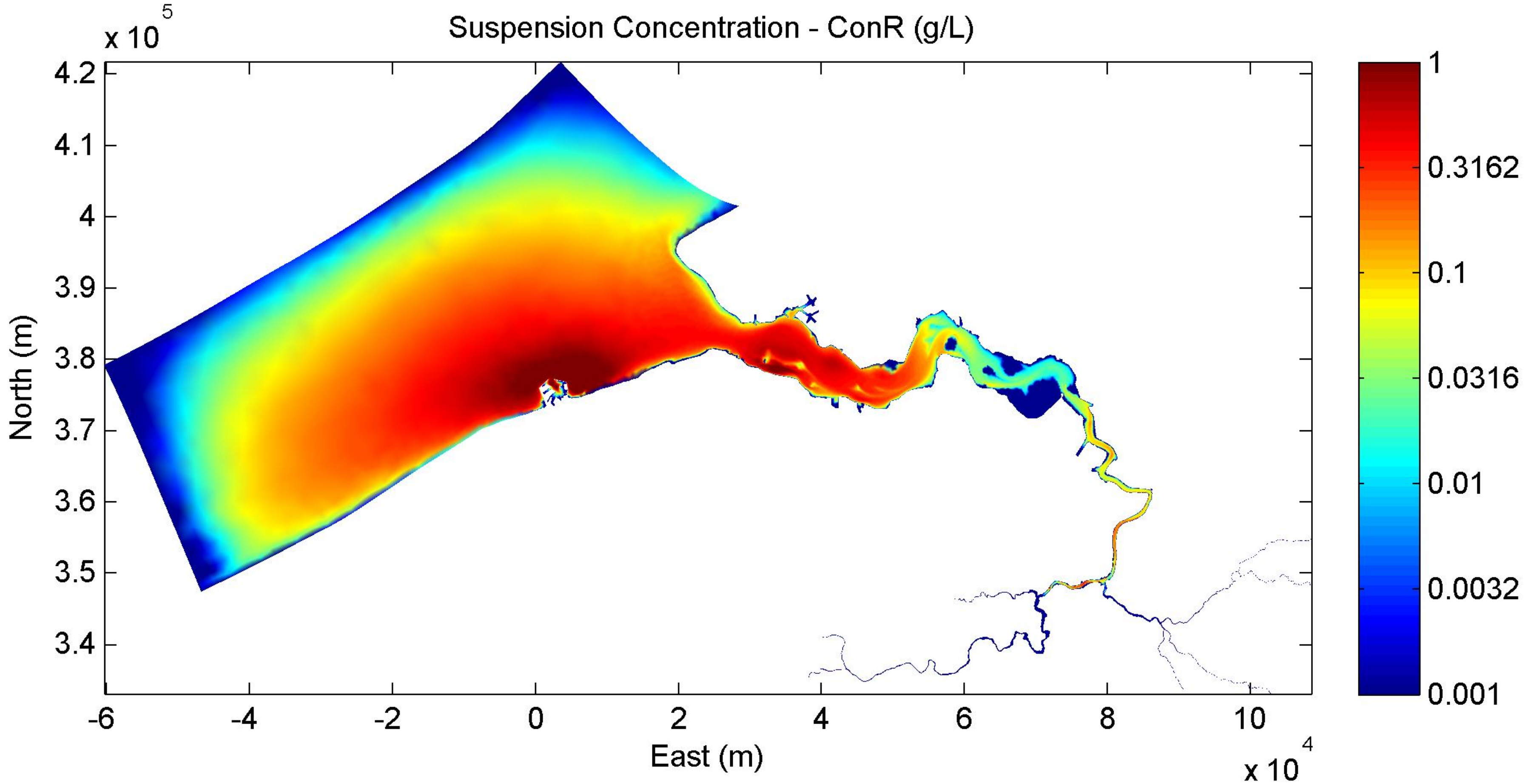
Suspension concentration at step 7000

Model Performence



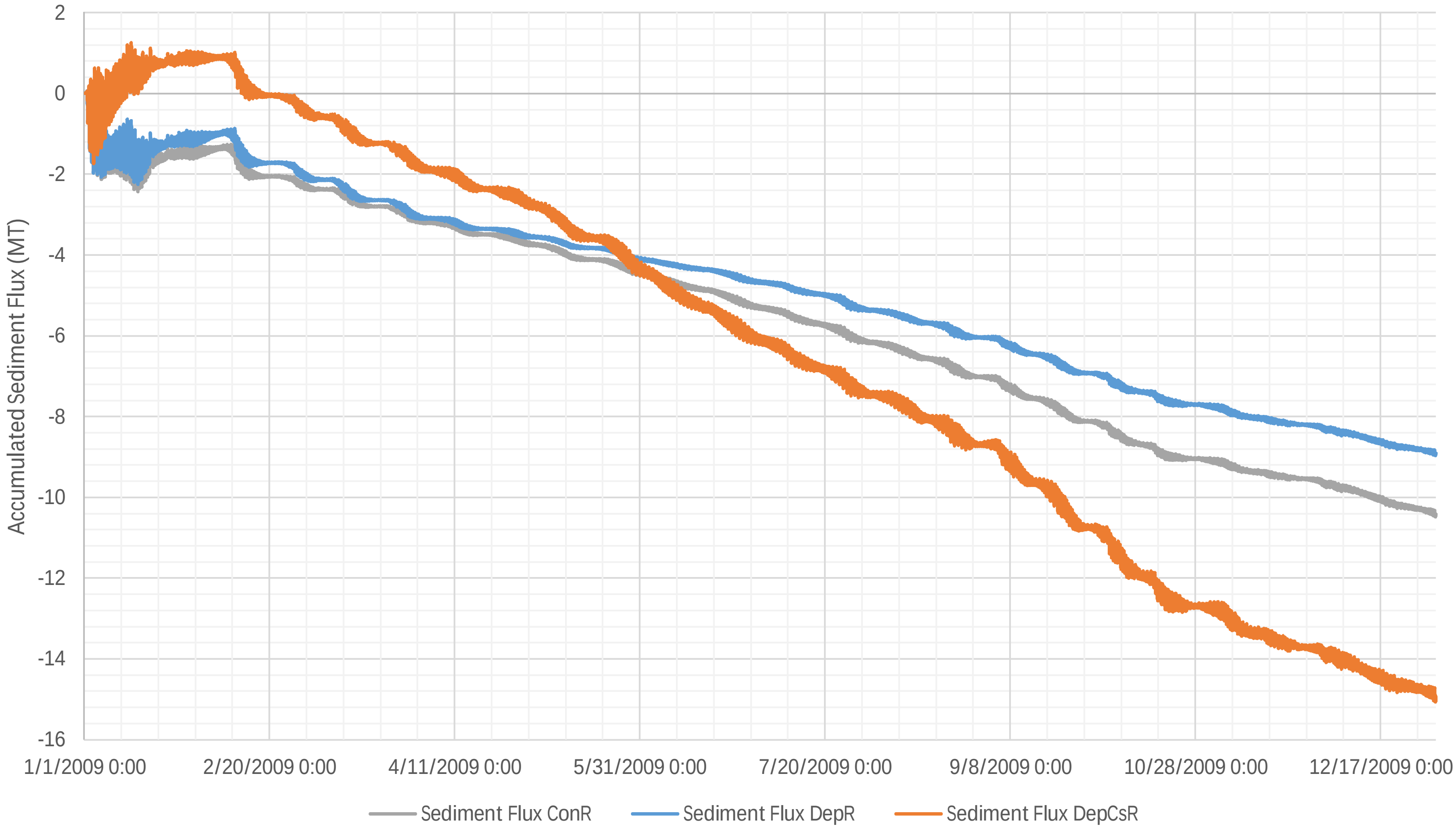
Suspension concentration at step 7000

Model Performence



Suspension concentration at step 7000

Model Performence



sediment exporting to the North Sea

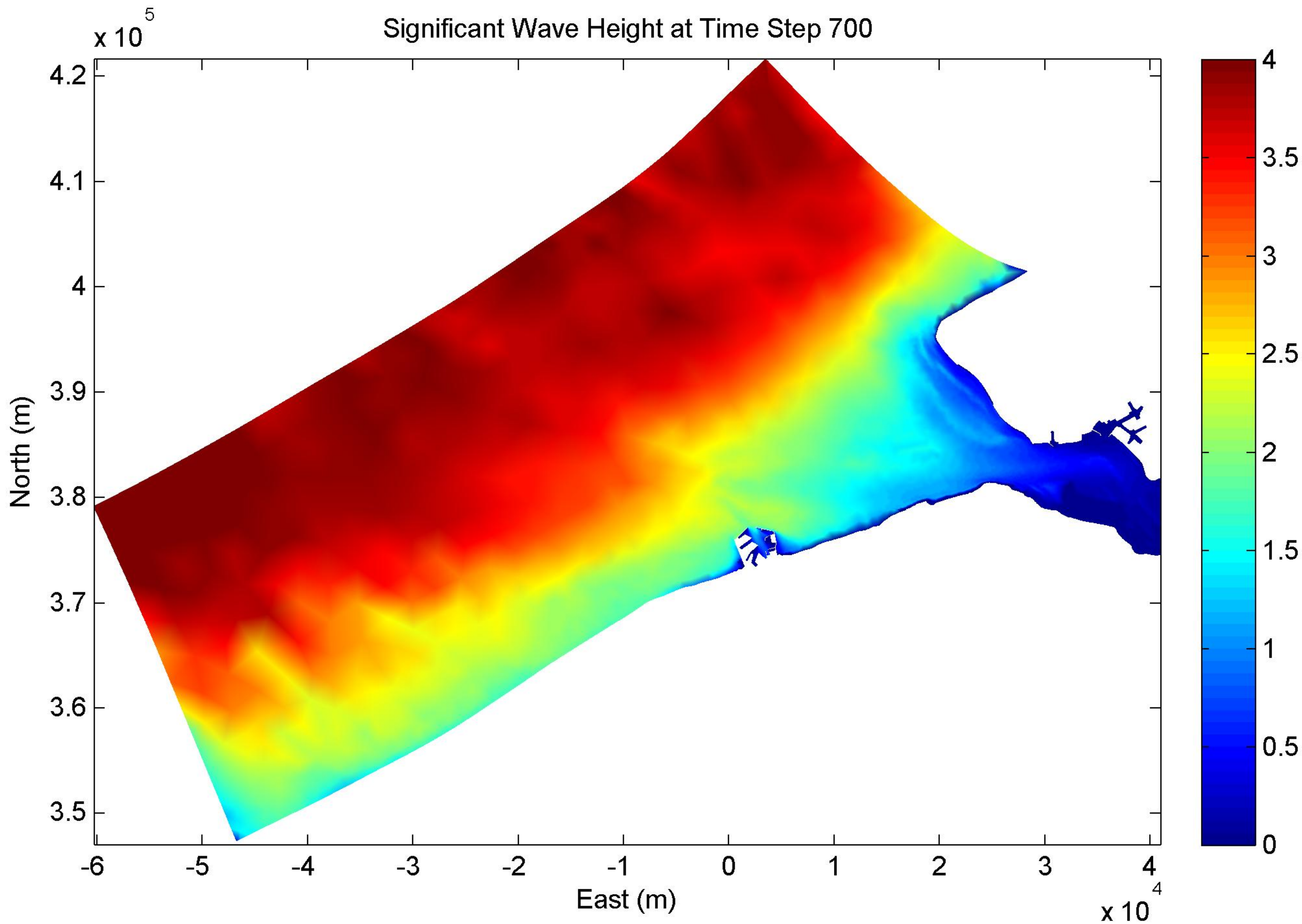
KU LEUVEN

Costal Waves

- Stationary wind towards the coast
- Boundary significant wave height = 1.5m
- Boundary peak frequency = 0.125

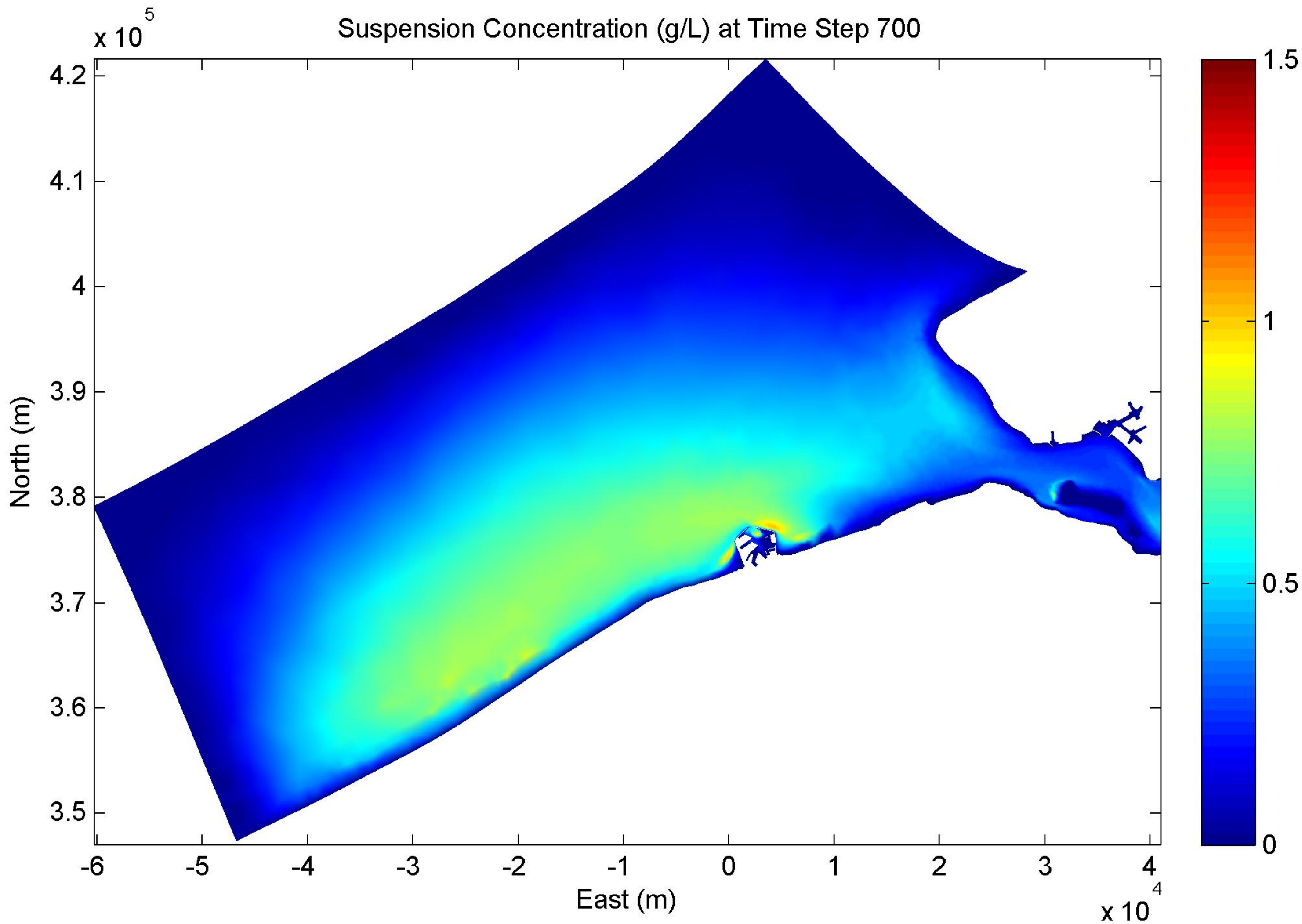
- Three-way coupling
- Wave-current interactions

Costal Waves



KU LEUVEN

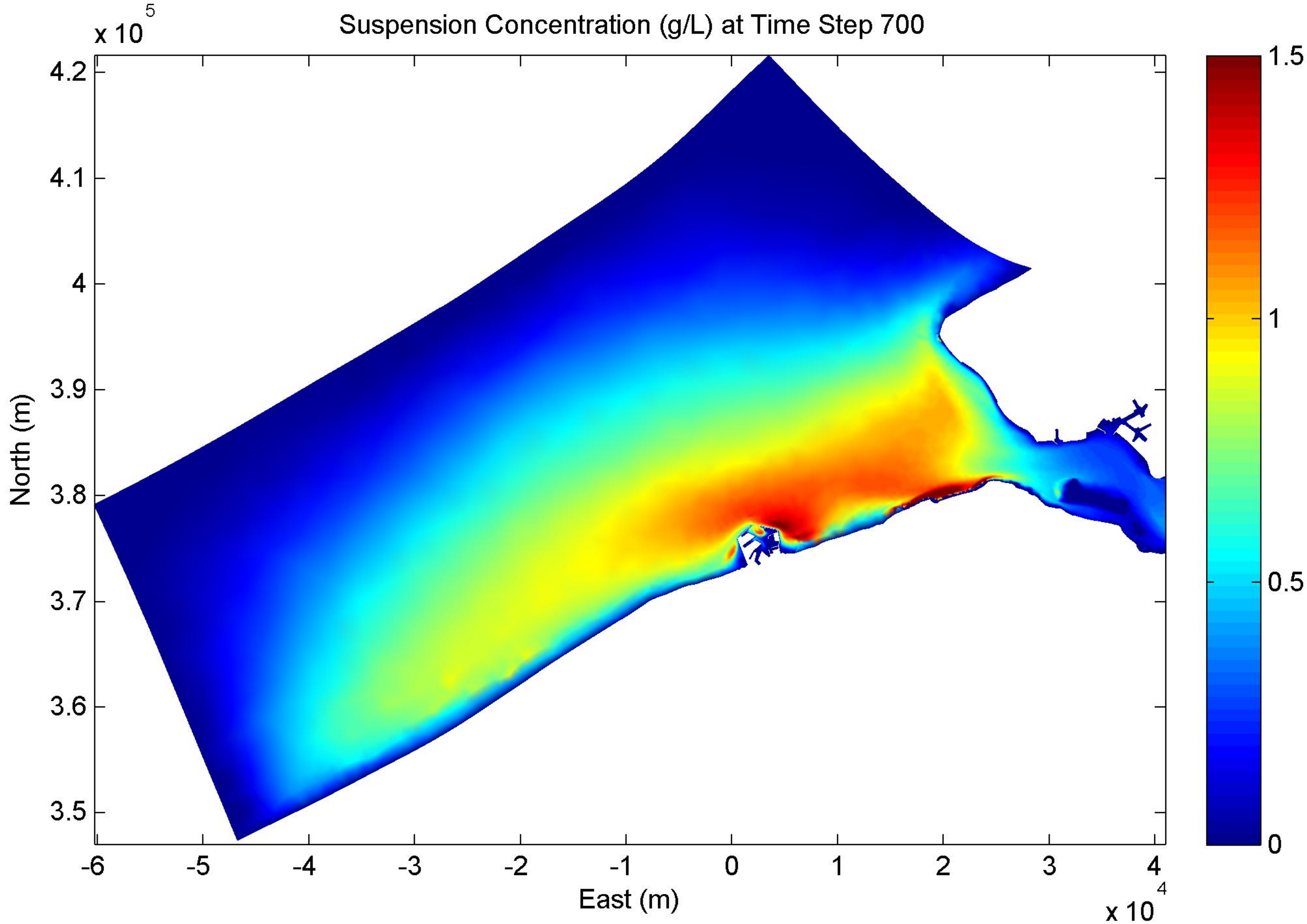
Costal Waves



(without costal waves)

KU LEUVEN

Costal Waves



(with costal waves)

KU LEUVEN

Thanks for your attention!