The Telemac system

From small scale processes…

…. to large scale applications

www.opentelemac.org

User club (October 2011): 130 participants
2000 users in more than 100 Countries

	2 dimensions St Venant	3 dimensions Navier-Stokes
Free surface flow	TELEMAC-2D	TELEMAC-3D
Sediment transport	SISYPHE	SEDI-3D
Water quality	DELWAQ (Deltares)	
Waves	TOMAWAC & ARTEMIS	

Libraries, pre- and post-processors

- BIEF
- Finite elements
- Blue Kenue
- FUDAA
- ParaView

BAW

HR Wallingford
Working with water

Daresbury
COMMERCIAL VENTURES LTD
Analytical Research and Technology Service

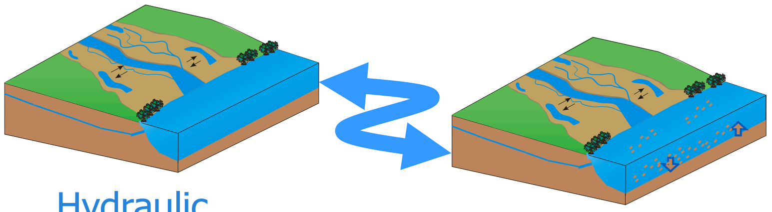
SOGREAH
CONSULTANTS

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE
Ministère
de l'Écologie,
de l'Énergie,
du Développement
durable
et de la Mer

eDF
CHANGER L'ÉNERGIE ENSEMBLE

Multi-scale, multi-physics

- **Coupling of models**
  - Chaining
  - Internal coupling
    - Telemac-2D or Telemac-3D/Sisyphe
    - Telemac-2D/To
  - Platform (Open MI)



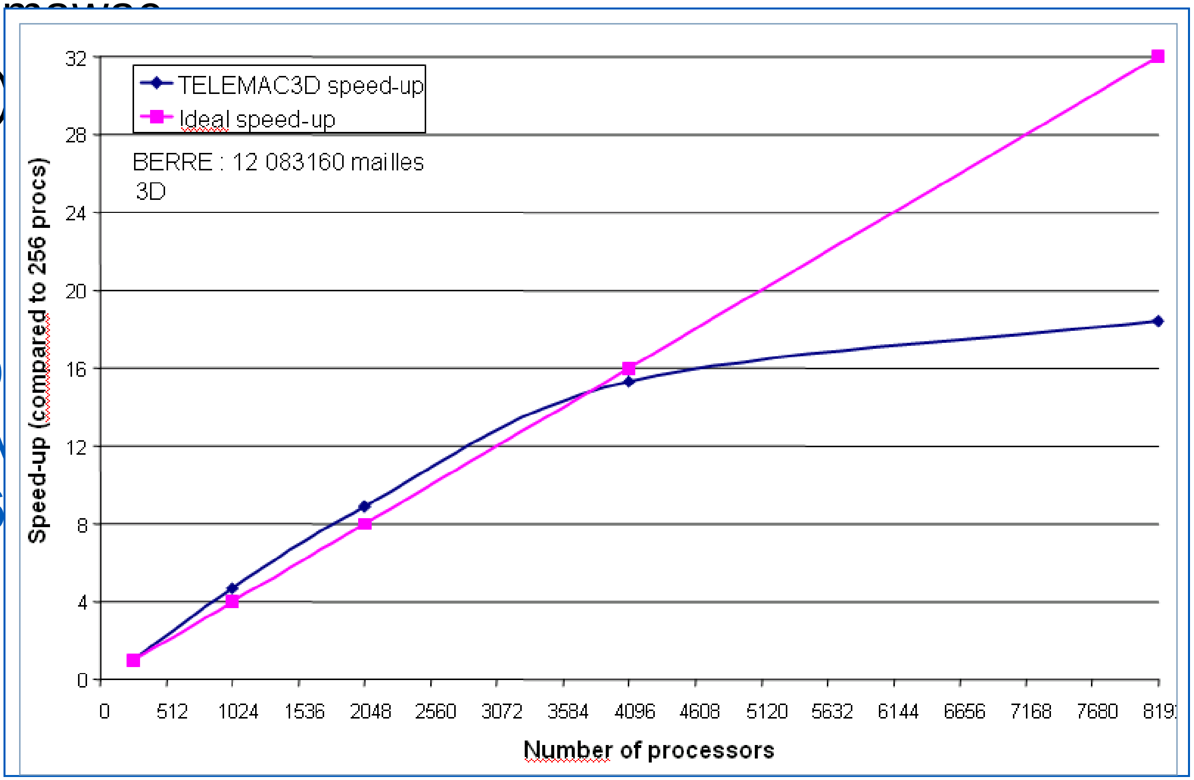
Parallelism with domain

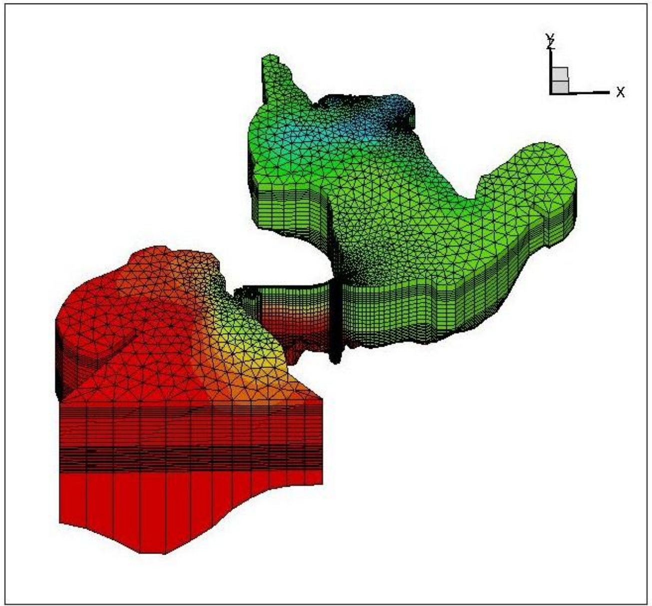
All options parallel

With one million p

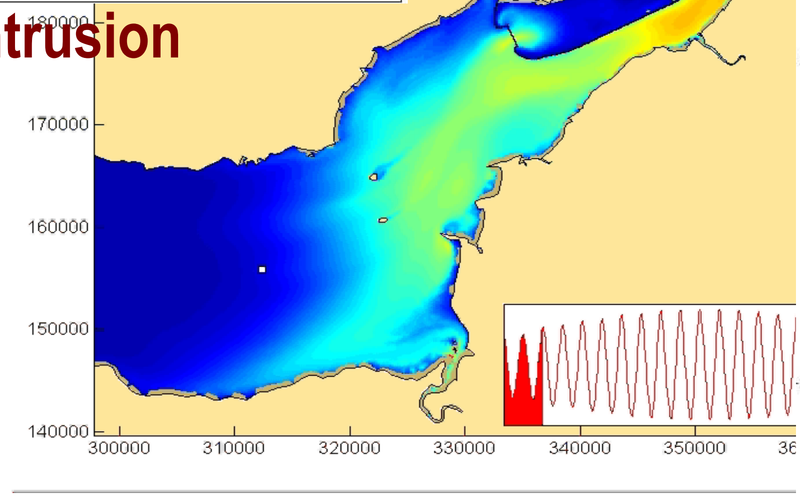
processors, on IBM

Tested up to 8096

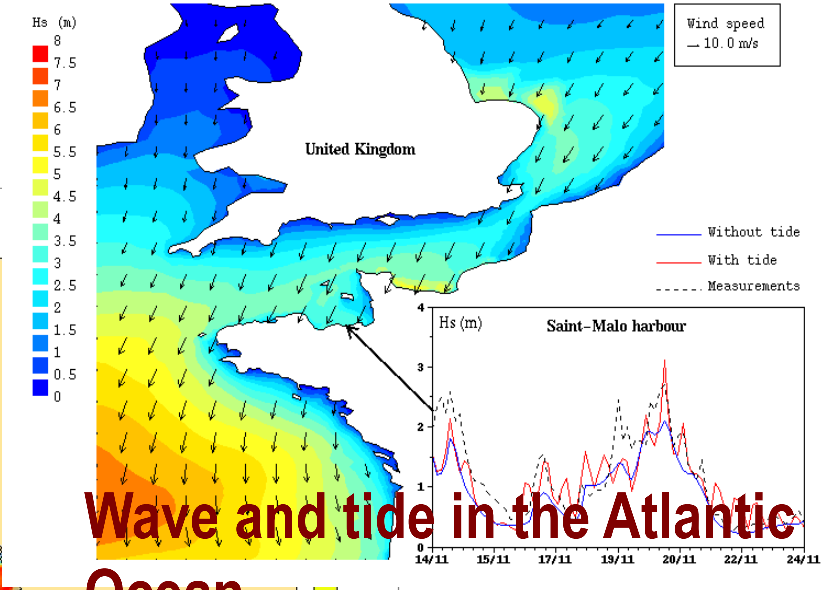




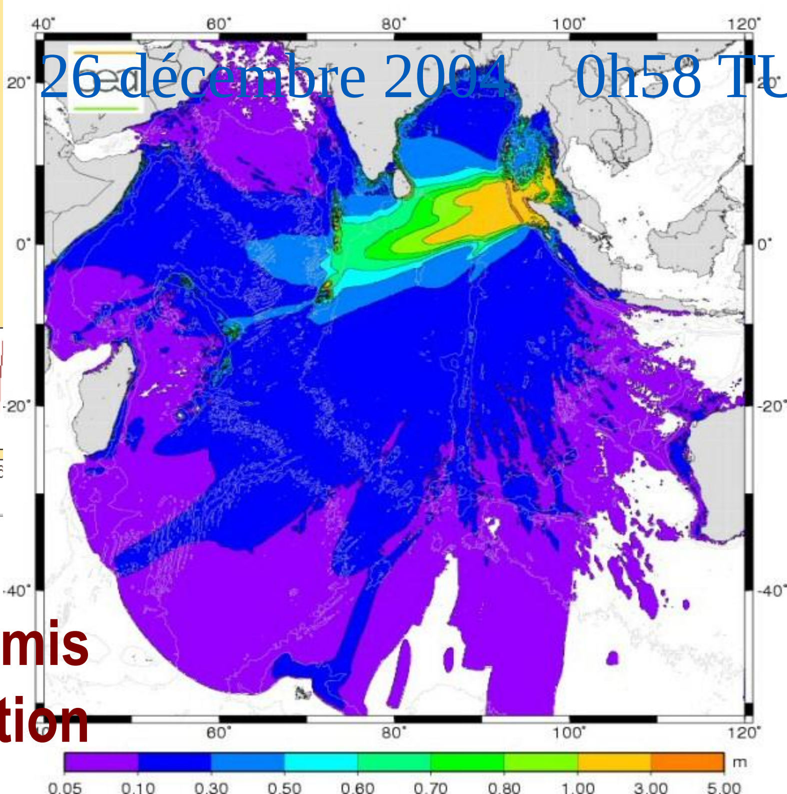
Salinity intrusion



Sediment in estuaries

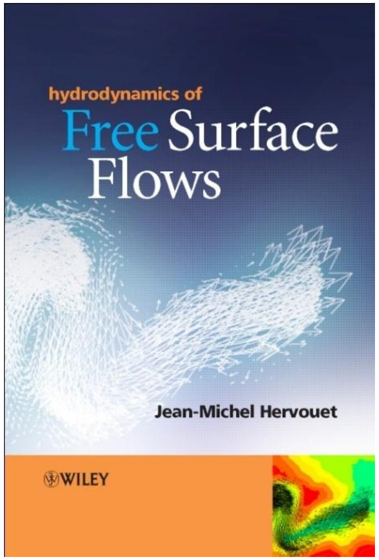


Wave and tide in the Atlantic Ocean

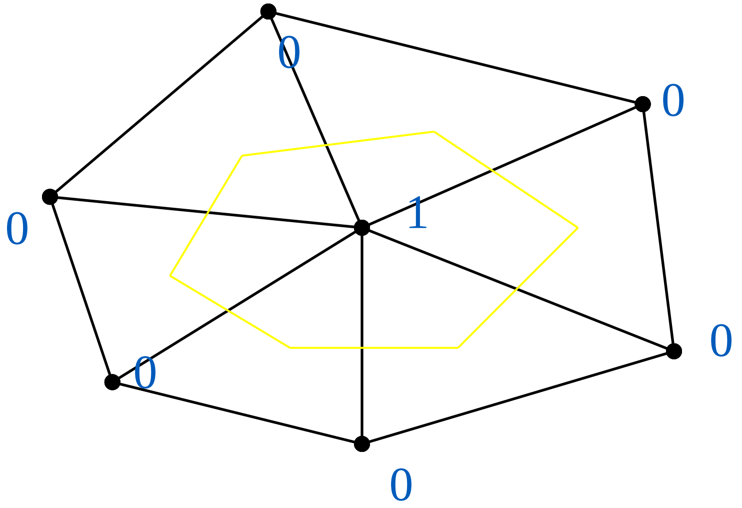


Tsunamis propagation

Bief Library



- Unstructured grids
- FORTRAN 90, PERL, MPI
- Finite elements / Finite volumes
- Implicit schemes
- Fundamental operation on matrix, vectors, scalars



- Definition of basis function:

$$\sum_{j=1}^{n} \Psi_j = 1$$

- Decomposition of each variable:

$$f = \sum_{j=1}^{n} f_j \Psi_j$$

- Variational principles:

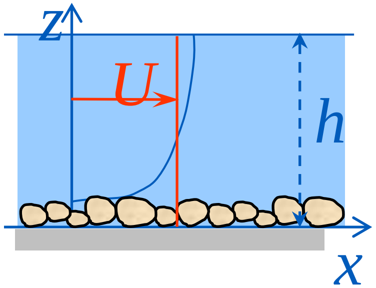
$$f = 0 \Leftrightarrow MF = 0$$

- Mass matrix: $M_{ij} = \iint_{\Omega} \Psi_i \Psi_j \, d\Omega$

Telemac-2D / Telemac-3D

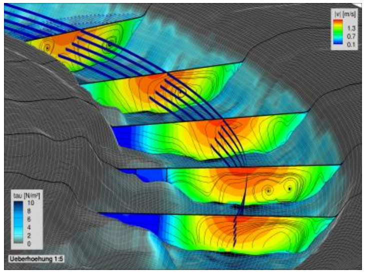
Riad Ata

$$(U,V)=\frac{1}{h}\int (u,v)dz$$



- h<<L
- Hydrostatic pressure
- Non recirculating, well mixed

Chi-Tuàn Pham



$$\mathbf{U}=(u,v,w)$$

- **Turbulent flow**
- **Hydrostatic**
- **non-hydrostatic pressure**

Equations

- **Shallow water (St venant)**

$$\frac{\partial h}{\partial t}+\nabla h\overline{\mathbf{U}}=0$$

$$\frac{\partial \overline{\mathbf{U}}}{\partial t}+\overline{\mathbf{U}}\cdot\nabla\overline{\mathbf{U}}=-g\nabla Z_s+\frac{1}{h}\nabla(h\mathbf{D})-\frac{\boldsymbol{\tau}_b}{\rho h}+\frac{\boldsymbol{\tau}_s}{\rho h}$$

- **RANS**

$$\nabla\mathbf{U}=0$$

$$\frac{\partial \mathbf{U}}{\partial t}+\mathbf{U}\cdot\nabla\mathbf{U}=\vec{g}+\nabla p+\nabla\left((\nu+\nu_t)\nabla\mathbf{U}\right)$$

Bottom friction

- Quadratic frition law $\tau_b=\frac{1}{2}\rho C_D\overline{U}^2$
- Logarithmic velocity profile

$$\frac{\overline{U}}{u_*}=\frac{1}{\kappa}Log\left(\frac{11h}{k_s}\right)$$

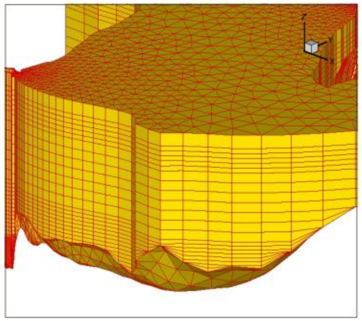
- Logarithmic velocity profile (first plan)

$$\tau=\rho u^{*2}=\rho\left[\frac{\kappa}{\log 30(\Delta/k_s)}\right](u^2+v^2)$$

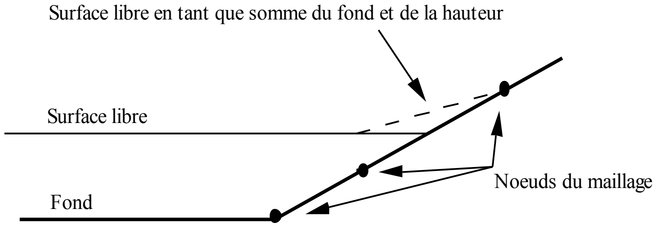
Telemac-2D / Telemac-3D

- Other Important features
  - Cartesian or spherical coordinates
  - Courant numbers up to 10
- Robust and efficient

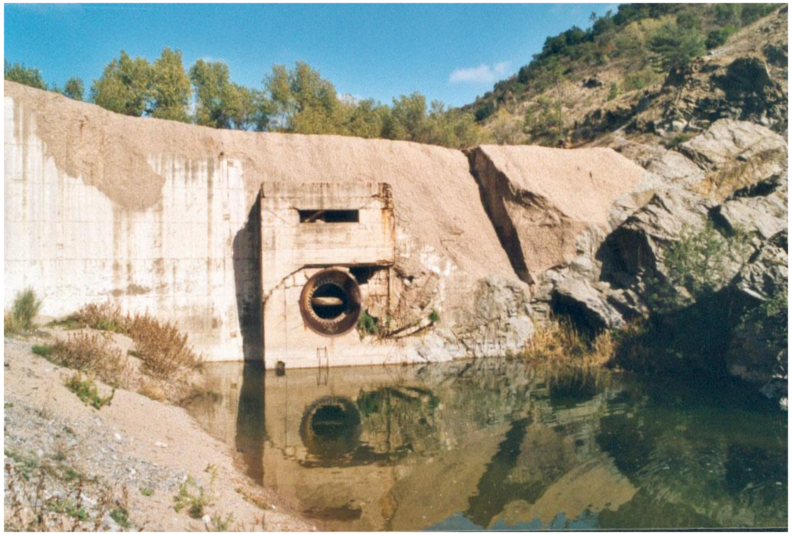
- Sensitivity of model results
  - Turbulence model (k-ε,mixing length)
  - Vertical grid resolution



- Treatment of dry zones
  - No element removal, all points treated even if dry
  - Continuity, positivity of depth, conservation and monotonicity of tracers ensured by an edge-based treatment of fluxes (*Hervouet et al., AIRH congres, 2011*)



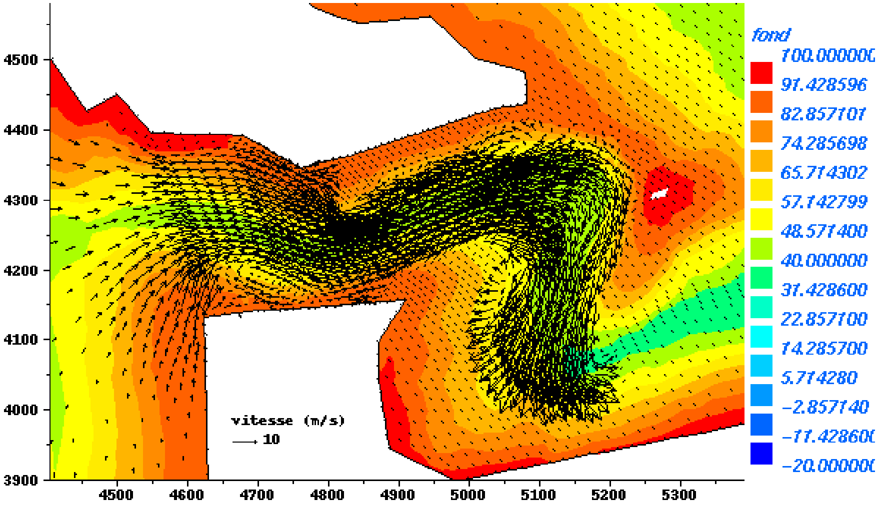
Malpasset dam break



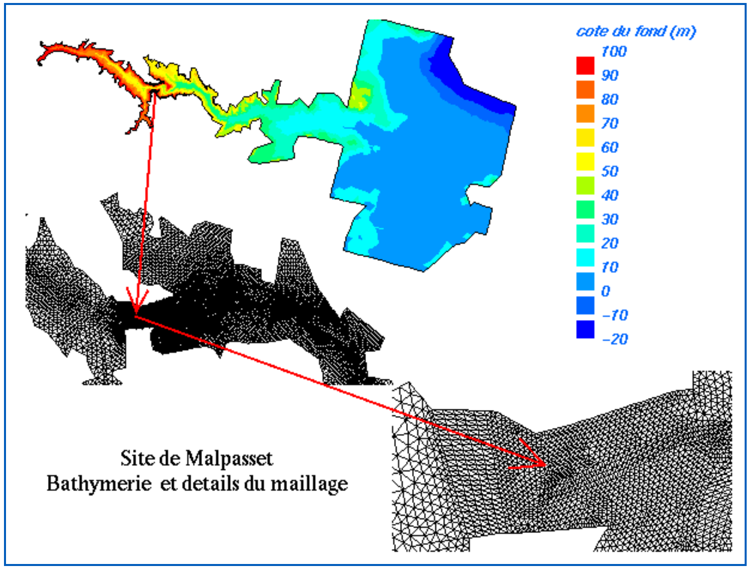
Malpasset dam, 48 million m^3, broke on 2 December 1959, there were 433 casualties.

Mesh

- 26 000 elements
- DT=4s
- 100 DT

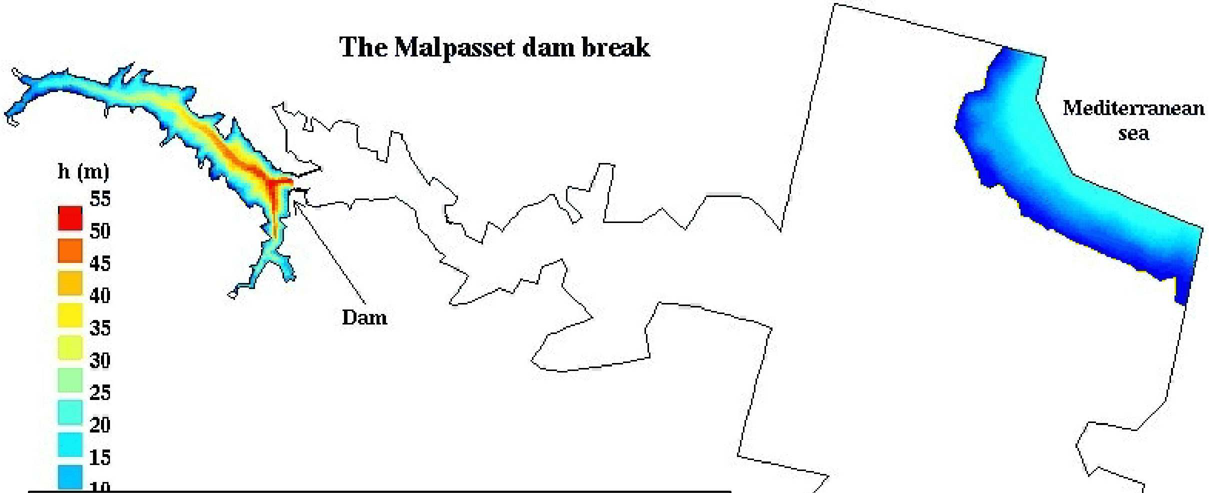


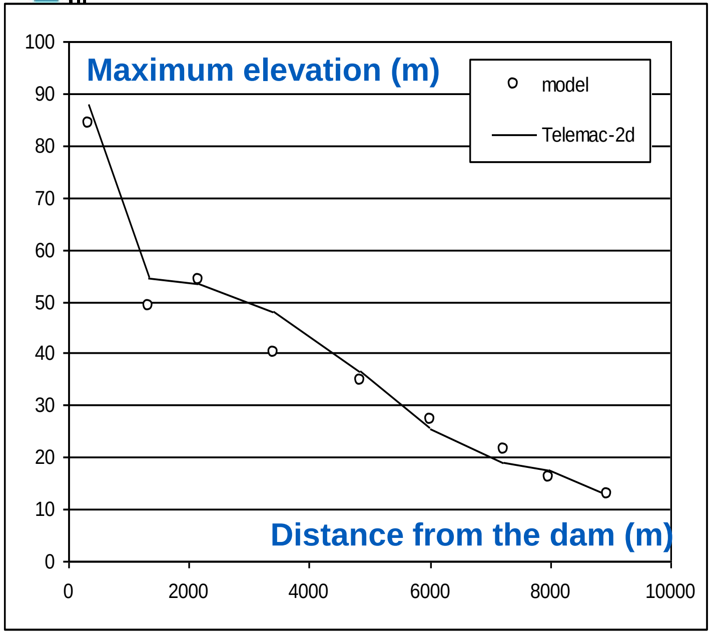
champ de vitesses apres 60 s



Site de Malpasset
Bathymerie et details du maillage

Malpasset dam break



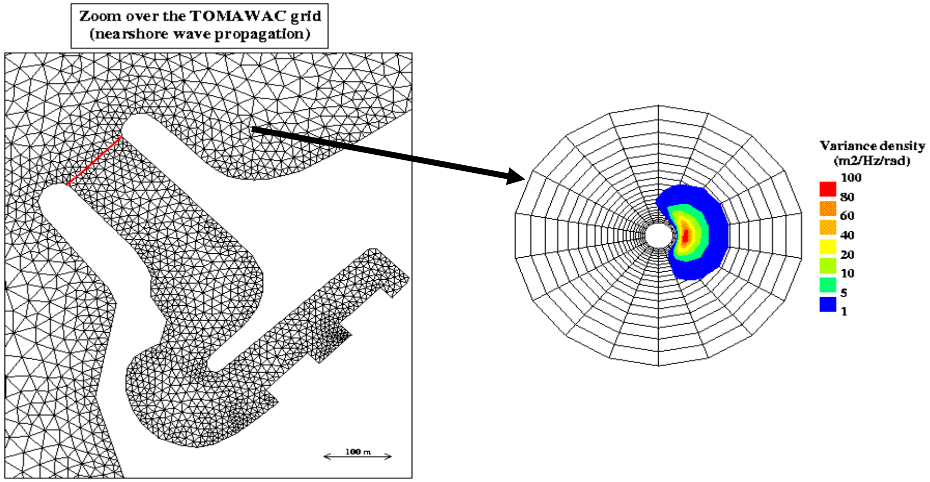


Linux **HP Z600**	**Telemac-2D**	**Telemac-3D** **(2 planes)**
1 proc.	52 s	188 s
8 proc.	11 s	36 s

Tomawac

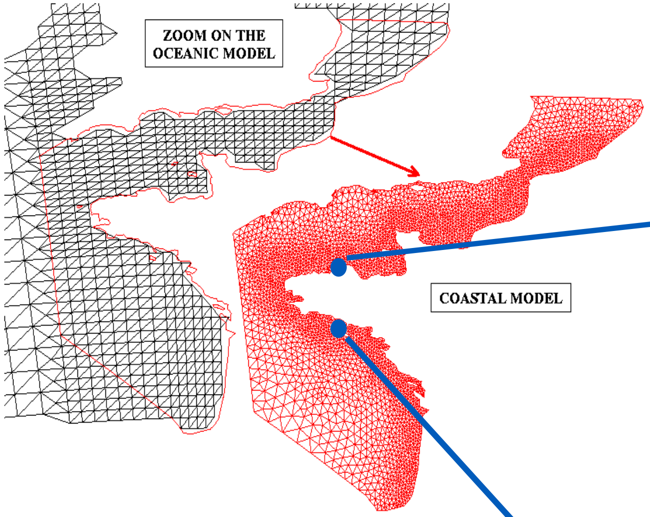
Giovanni Mattarolo

- Third generation spectral wave model
  - F: variance density directional spectrum
- Conservation of the wave action:
  - Shoaling
  - Refraction
  - Non-linear interactions
  - Wind generation
  - Wave dissipation (breaking, white capping)



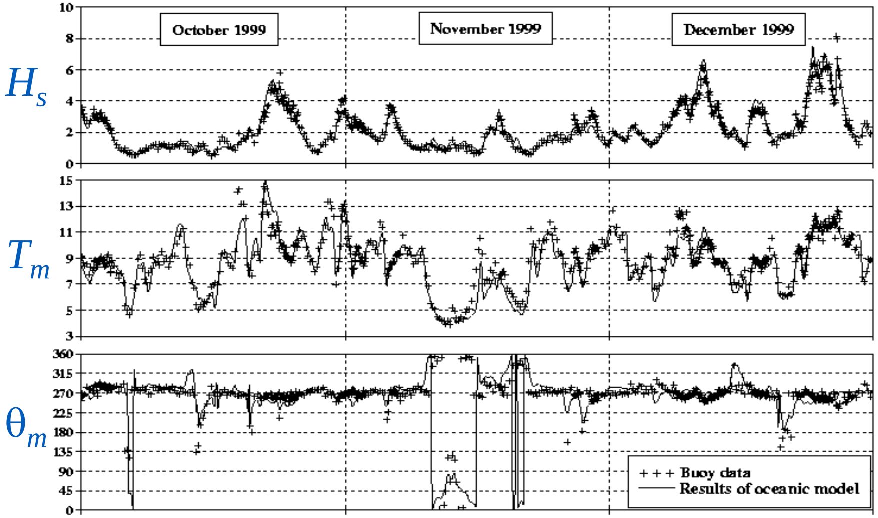
- Wave-current interaction (Telemac-2d/Tomawac)
- Applications: oceanic to coastal zones

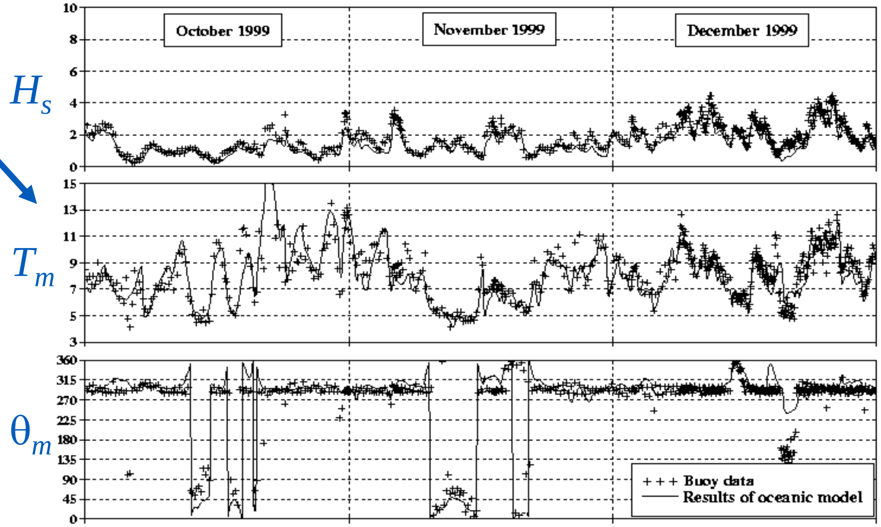
Waves in the Atlantic Ocean



Dec 1999

+ + **Observé**
---- **Simulé**





Oceanic wave model

- **25 500 elements**
- **DT=600s**
- **1 year computation**

Processors	**CPU time (s)**
1	90 000
8	18 000
16	6 500
20	5 500
24	6 000

Pablo Tassi

Sisyphe / Sedi 3d

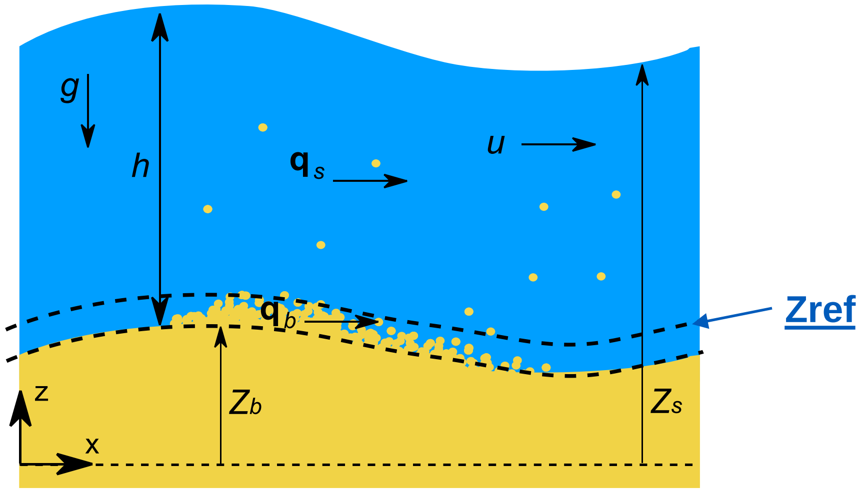
Catherine Villaret

- Bed load

→Total load /bed load formula

→ Exner equation

$$(1-n)\frac{\partial Z_b}{\partial t} + div\,\vec{Q}_s = 0$$



- 2D suspended load

$$\frac{\partial \overline{C}}{\partial t} + .\nabla(\overline{CU}) - \frac{1}{h}\nabla\left(K_t \vec{\nabla}\overline{C}\right) = \frac{E-D}{h}$$

3D suspended load

$$\frac{\partial C}{\partial t} + \vec{u}.\overrightarrow{grad}(C) + \underbrace{\frac{\partial (W_s C)}{\partial z}}_{Settling} = \underbrace{div(\gamma_t\,\overrightarrow{grad}(C))}_{Turbulentdiffusion}$$

$$\boxed{(1-n)\frac{\partial Z_b}{\partial t} + (E-D) = 0}$$

Erosion rate

Deposition rate

Non cohesive

D_{50}>60µm

- Erosion-deposition rates

→Equilibrium concentration formula

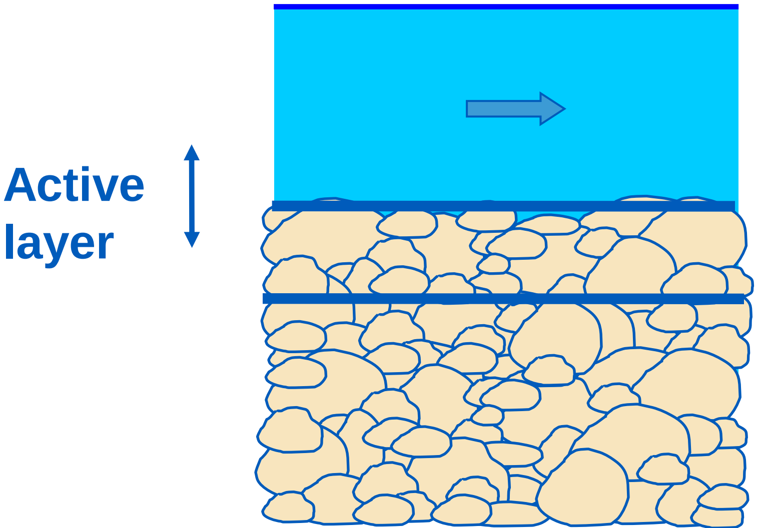
$$E = W_s C_{eq}$$

(e.g. Van Rijn, 1984)

- Deposition rate (implicit):

$$D = W_s C_{zref}$$

- Sand grading effects



Cohesive

D_{50}<60µm

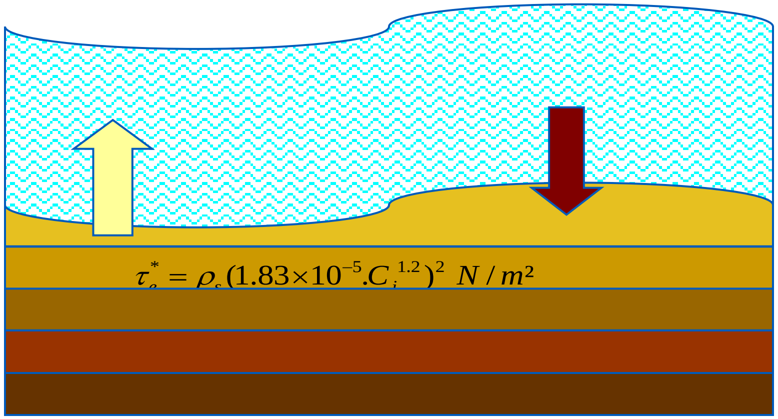
- Erosion-deposition laws

(Krone and Partheniades)

$$E = M\left[\left(\frac{\tau_0}{\tau_e}\right)^2 - 1\right]$$

$$D = WsC\left[1 - \left(\frac{\tau_0}{\tau_d}\right)^2\right]$$

- Consolidation model



$$\tau_e^* = \rho_s (1.83\times10^{-5}.C_i^{\,1.2})^2 \ N/m^2$$

Sisyphe / Sedi-3D

2D suspended load

- Correction on the convection

(Huybrechts, Villaret, and Tassi, River Flow 2010)

$$\overline{CU} = \alpha \overline{C}\,\overline{U} < \overline{C}\,\overline{U}$$

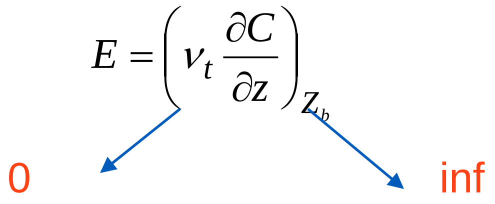
Assuming:

- Log velocity profile
- Rouse concentration profile

$$\alpha = h \frac{\int_a^h U(z)C(z)dz}{\int_a^h U(z)dz \int_a^h C(z)dz} \leq 1$$

3D suspended load

- Treatment of boundary condition

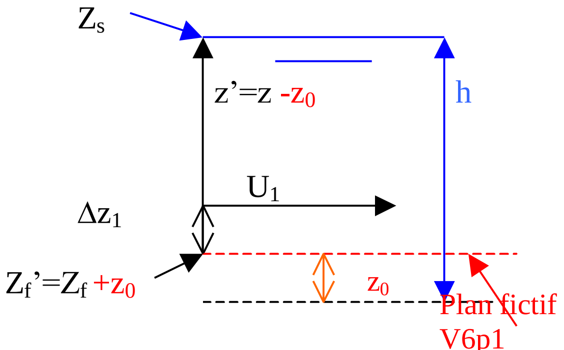


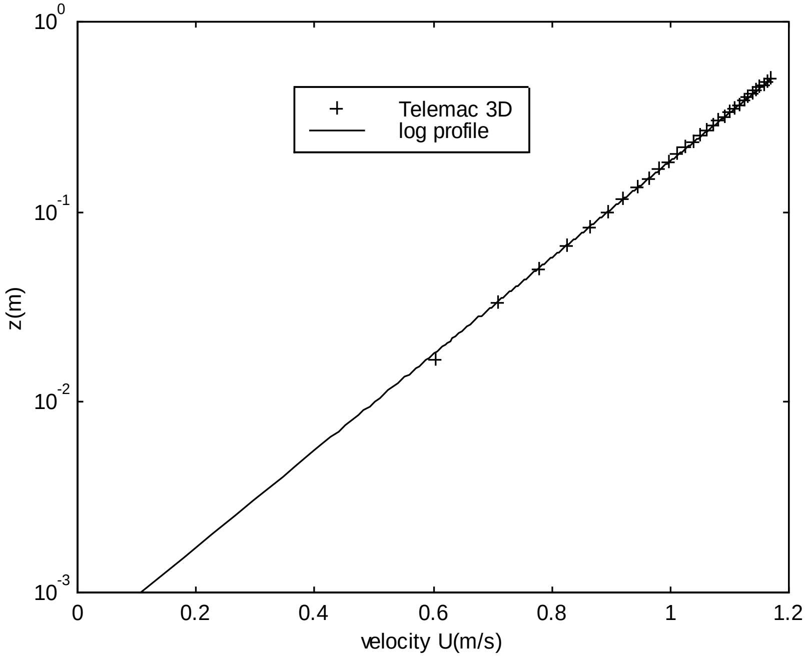
$$E = \left(\nu_t \frac{\partial C}{\partial z} \right)_{Z_b}$$

- Sensitivity of model results to

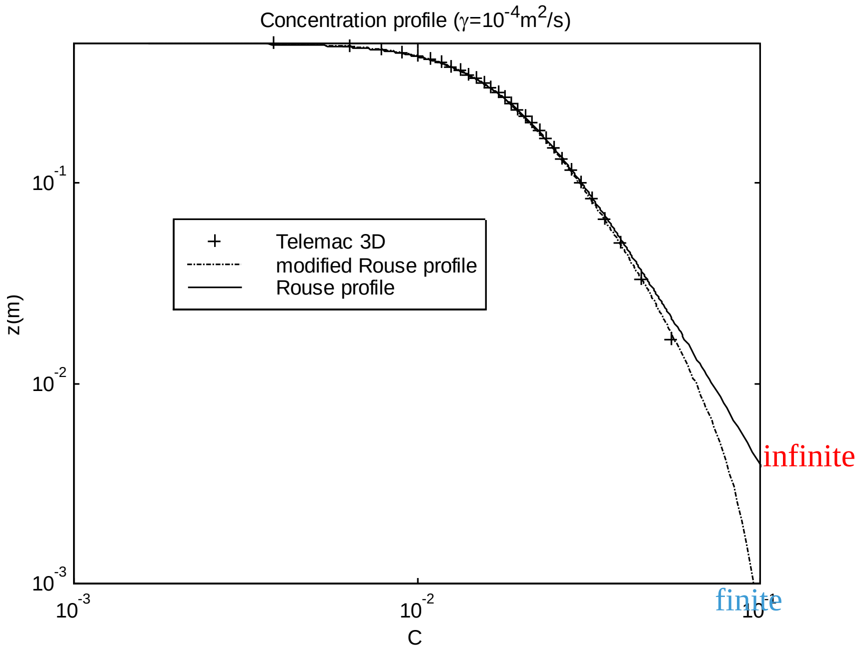
-turbulence model (k-ε, …)

-Vertical grid resolution





Concentration profile (γ=10^-4m^2/s)



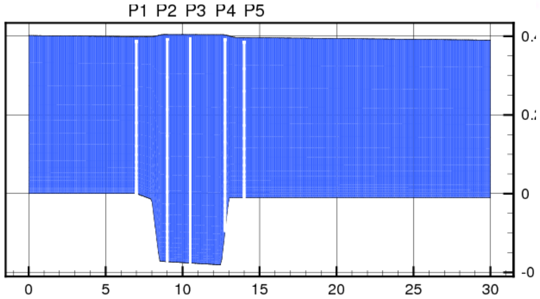
$$C = C_{h/2}\left[\frac{h-z}{z+\frac{\gamma}{\kappa u_*}}\right]^{\frac{-W_c}{\kappa u_*}}$$

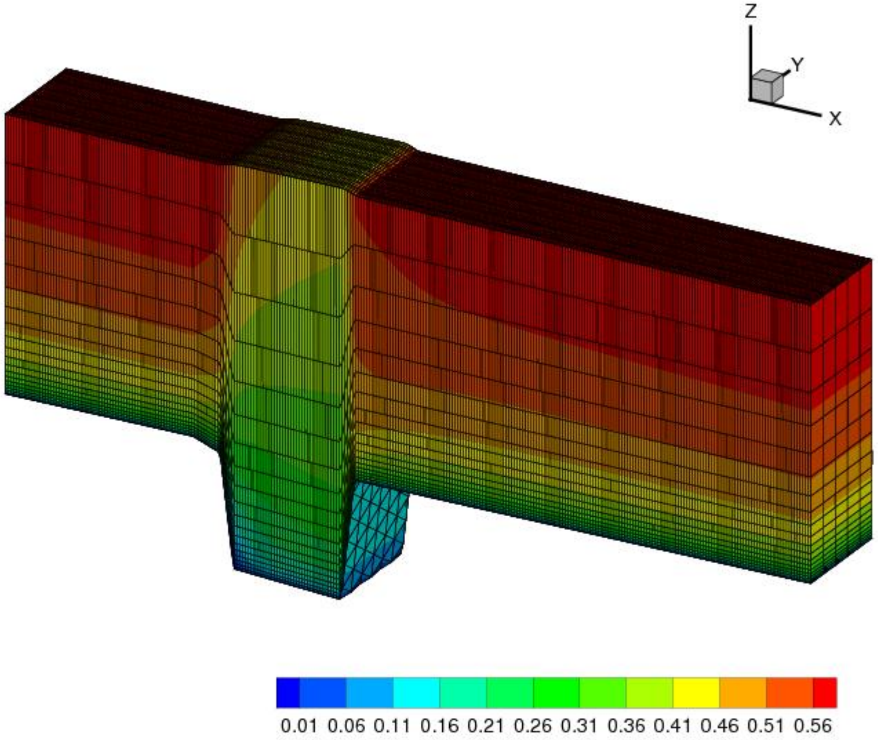
Finite values →

γ : laminar diffusivity

Trench evolution in 2D/3D

van Rijn (1987)
h= 0.39 m
U= 0.51 m
d_{50}=0.16 mm



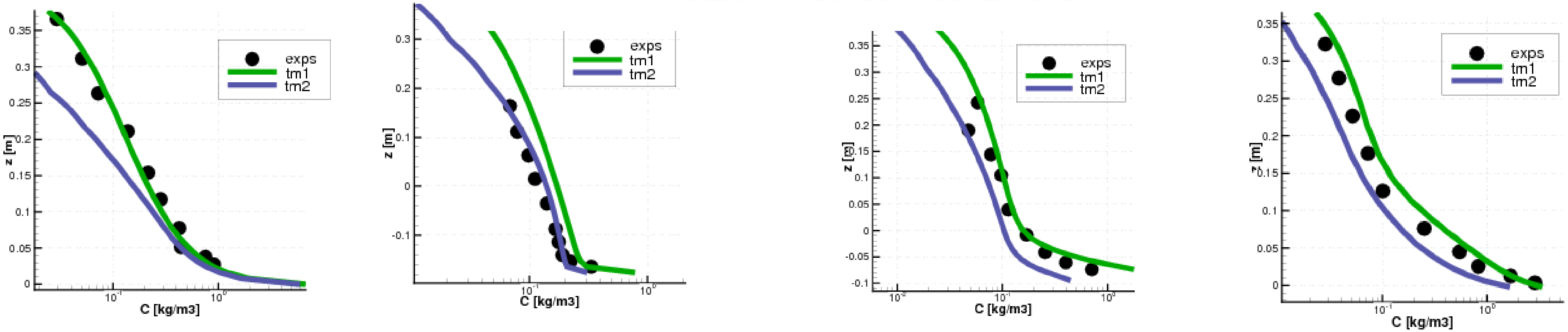


3D model

16 planes

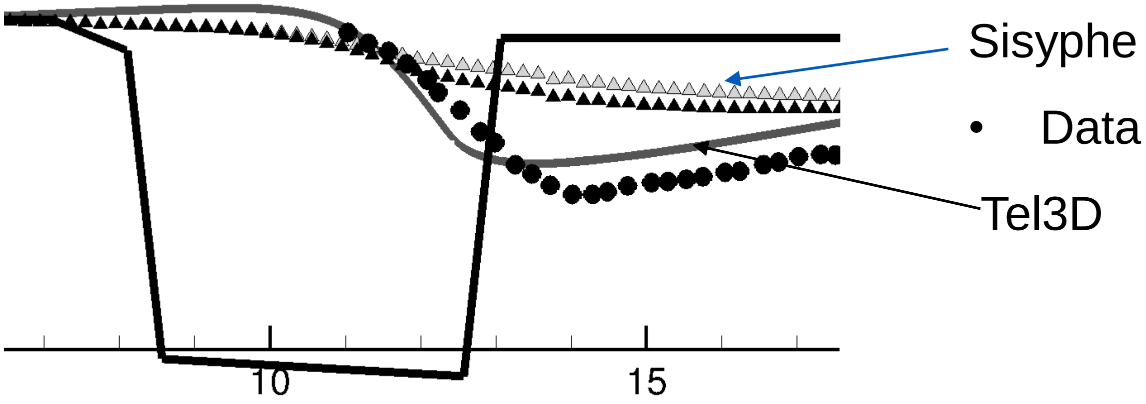
non-hydrostatic

pressure



concentration profiles (tm1=k-ε; tm2=mixing length)

Trench evolution in 2D/3D



Bed evolution after t=15 hs

- 2D model overestimates transport rates
- Convection velocity correction

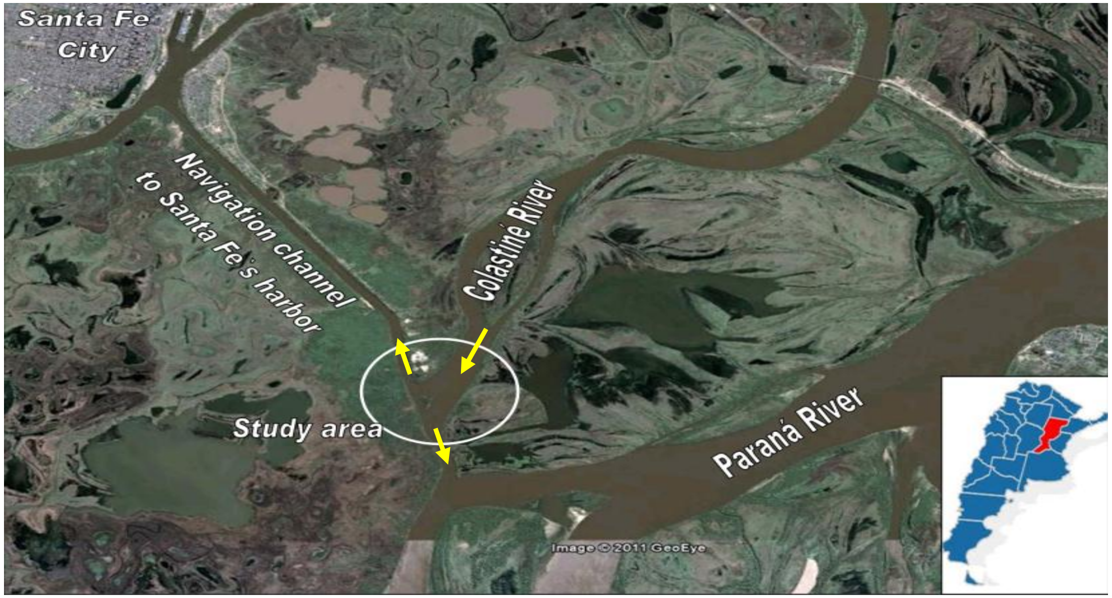
→ Improves the results

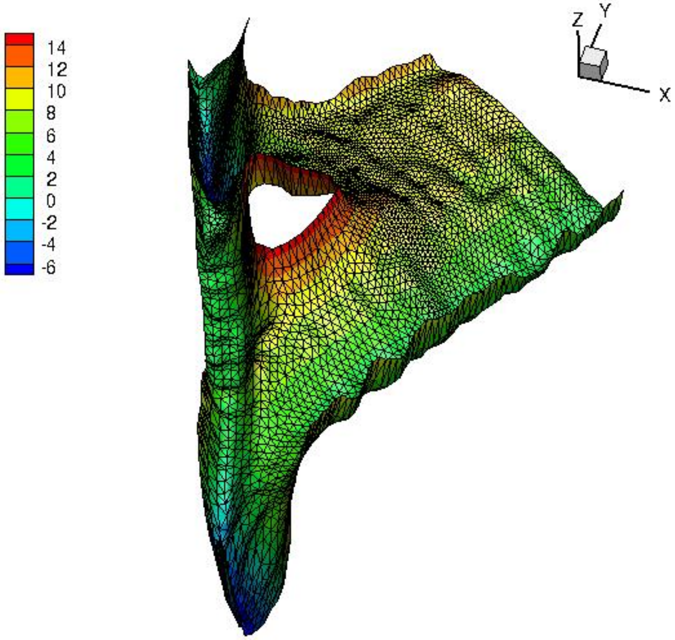
→2D model : good compromise between model accuracy and computational time for non-recirculating flow

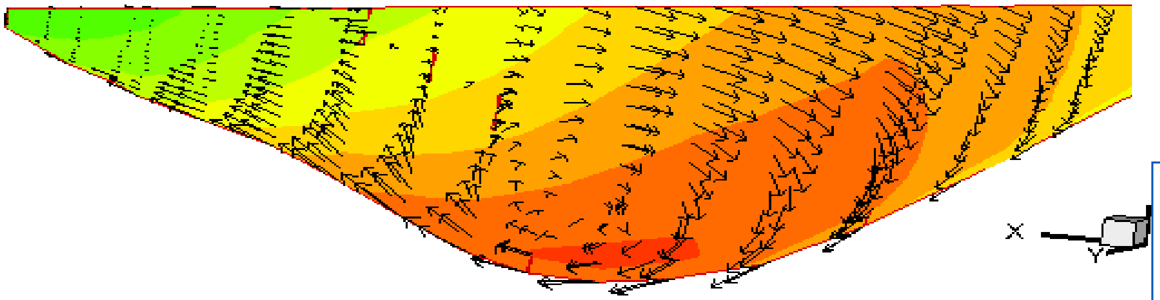
Secondary flow pattern in river

Telemac-3d : flow patterns at a river difluence

(Tassi, Vionnet and Morell, 2011)







- **6,623 elements x 15 layers**
- **time step = 0.1 s**
- **steady state 100,000 time steps**

Computed velocities along XS-3

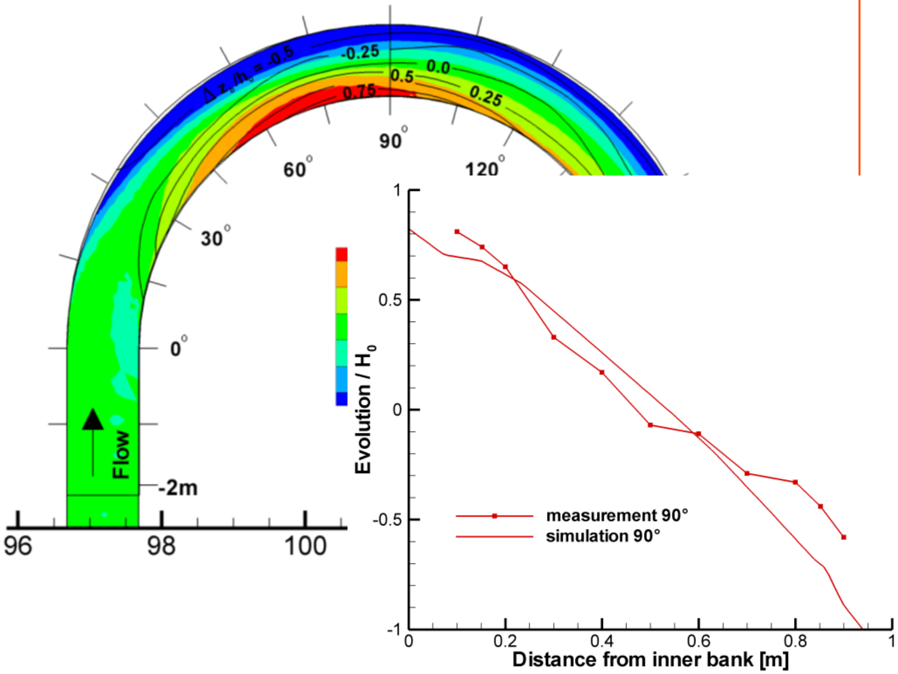
Meandering channels

Telemac 2D/Sisyphe

→Secundary current parameterization in 2D

Yen's experiments (1995)

- bedload only

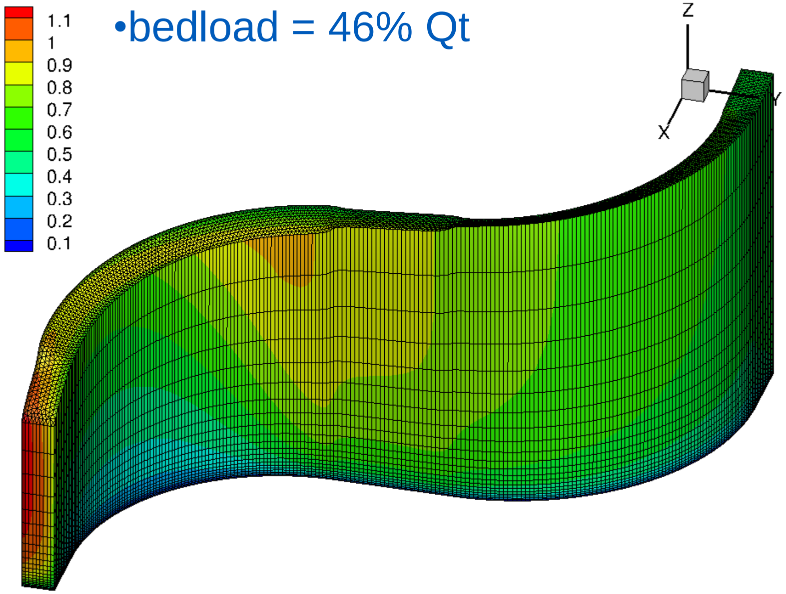


Telemac 3D/Sisyphe

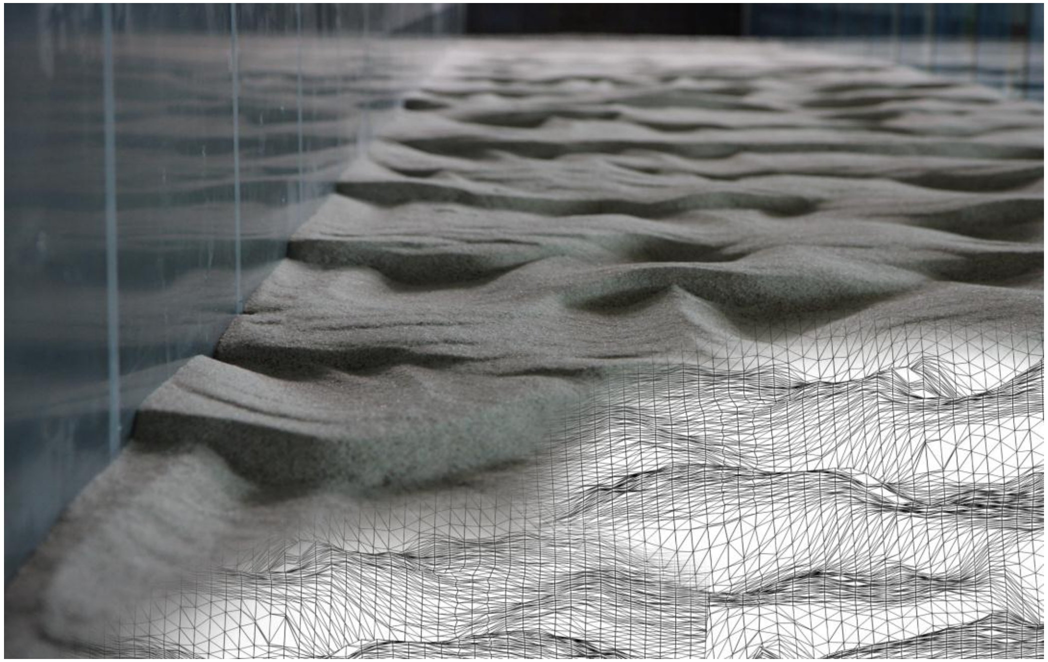
→ Turbulence model

Onishi's experiments (1972, 1976)

- suspension = 54% Qt
- bedload = 46% Qt

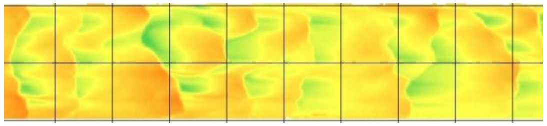


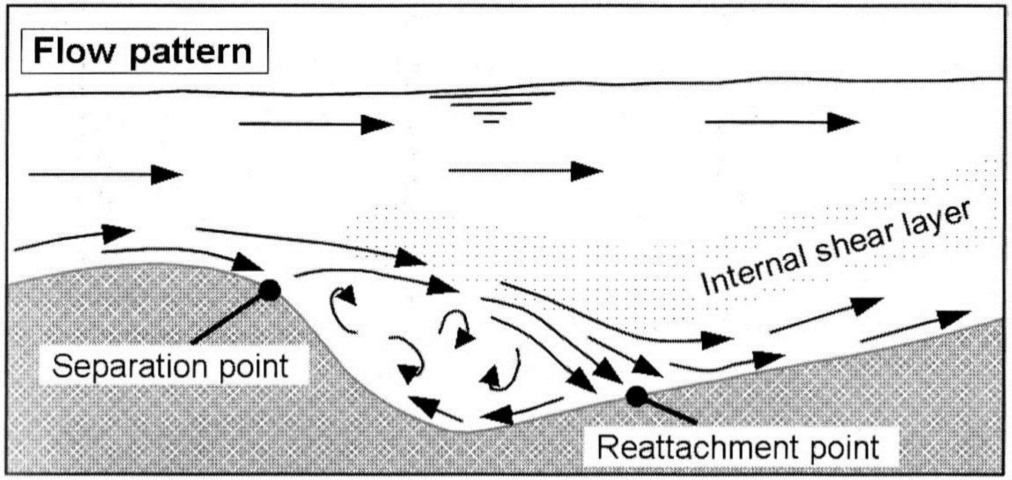
Numerical simulation of bedforms



Flume experiments

- Length: 30m
- Width: 5m (2x2m)
- Discharges: 77-240 l/s
- Bed-load: sand (D50≈1mm)

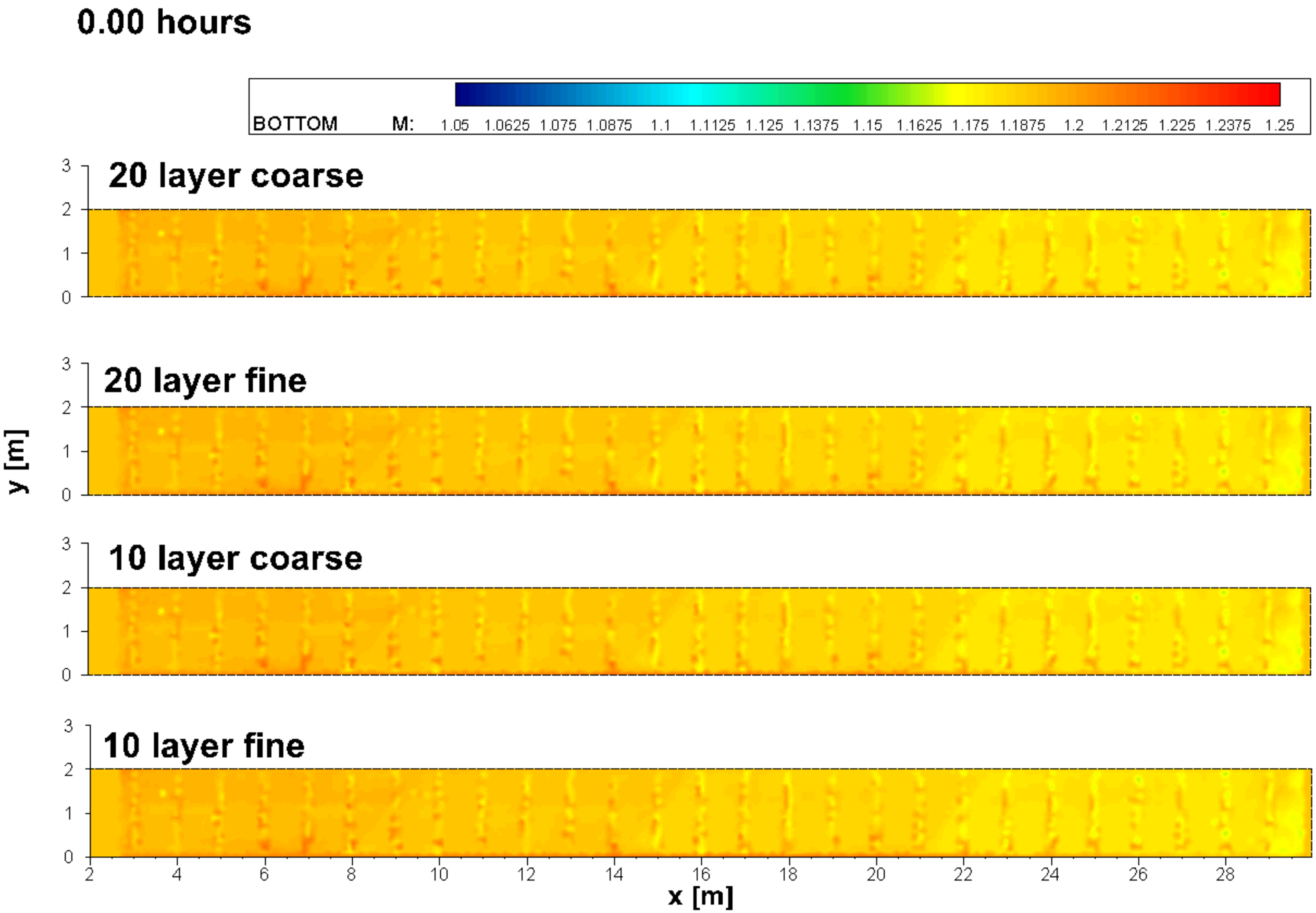




Numerical modelling with Telemac3D / Sisyphe

Analena Goll, PhD student

Numerical simulation of bedforms



Analena Goll, PhD student

Method of feedback for the bed roughness

Telemac2D

Compute flow using total roughness

Flow based on total bed roughness

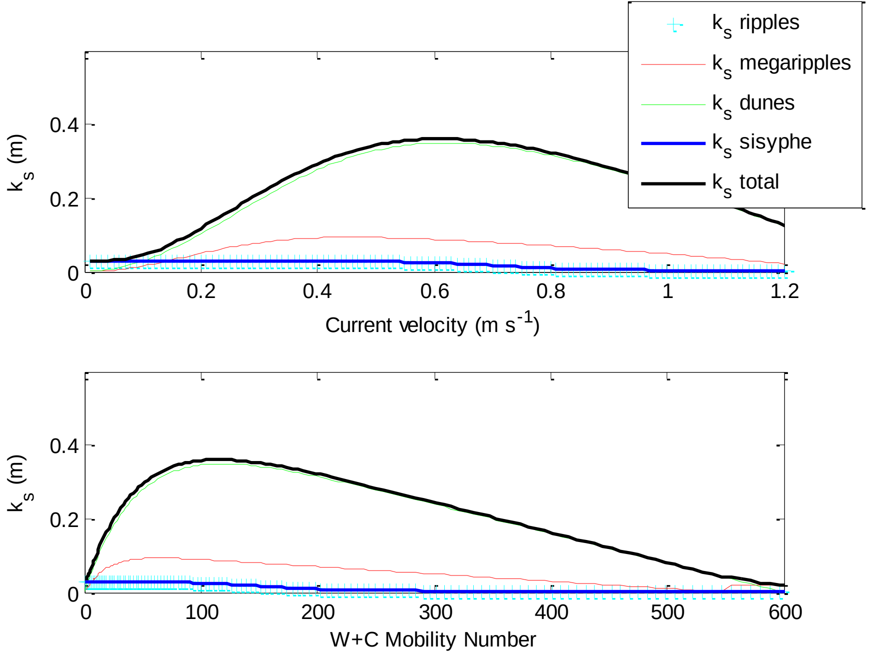
Sisyphe (in ride.f)

Compute the transport us
small-scale ripple roughn

Total bed roughness

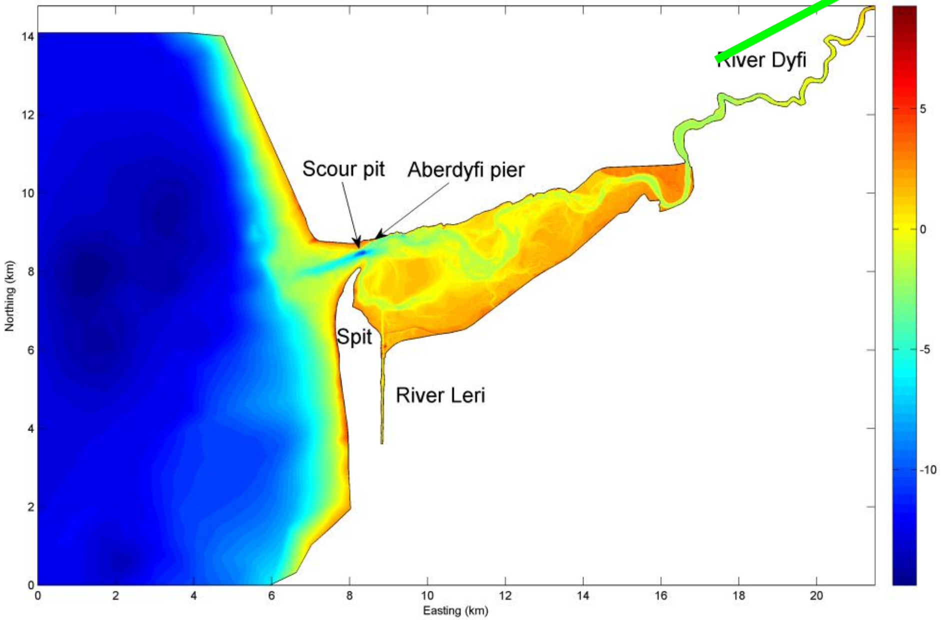
- **bed roughness predictor (dunes + megaripples + small-scale ripples), variable in time and space (Van Rijn, 2007)**

$$k_s = \sqrt{\left(k_{s,r}^{2} + k_{s,m}^{2} + k_{s,d}^{2}\right)}$$



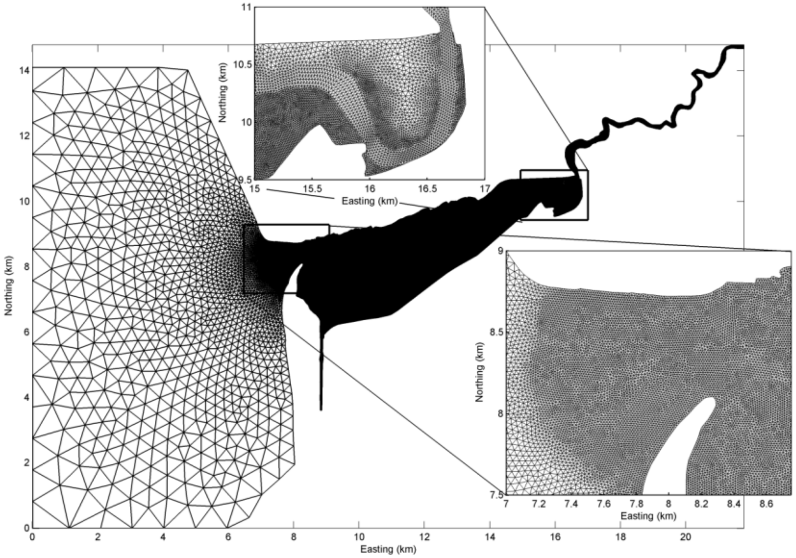
Large scale morphodynamics

- Dyfi Estuary (Wales,UK)
  - Shallow sandy macro-tidal estuary
  - Multiple banks and channels
  - Tidal range : 2 to 4.3 m offshore
  - Sediment : sand 0.2-0.25mm
  - River input : 25 m^3/s annual mean
    400 m^3/s 1 in 100 yr



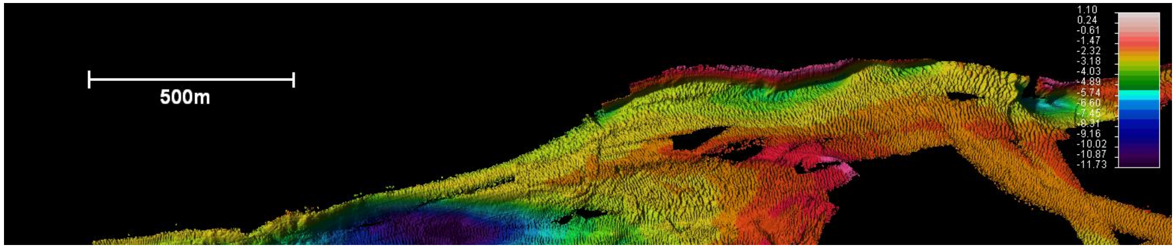
→Field validation of the modelled bed roughness (for dunes)

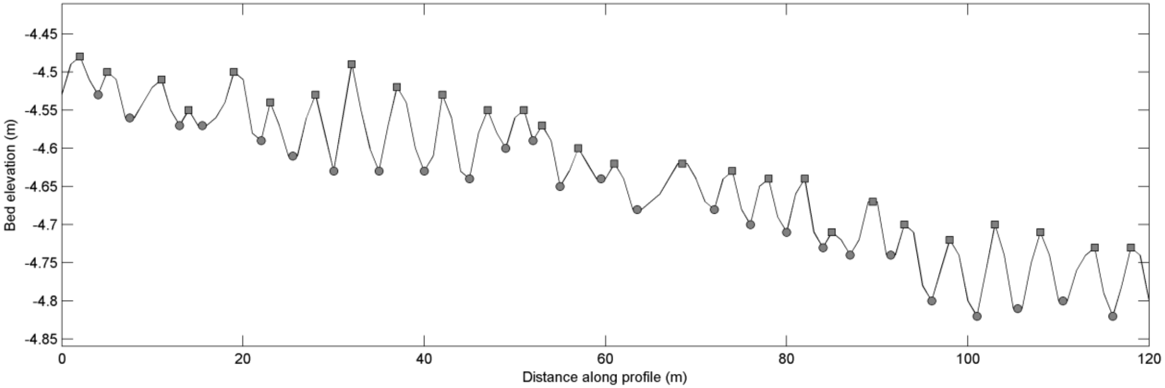
Dify estuary morphodynamics



Triangular Mesh

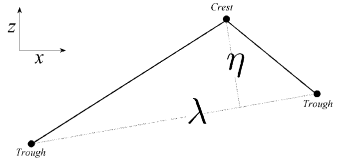
BlueKenue 91,000 nodes, resolution :1km / 15m





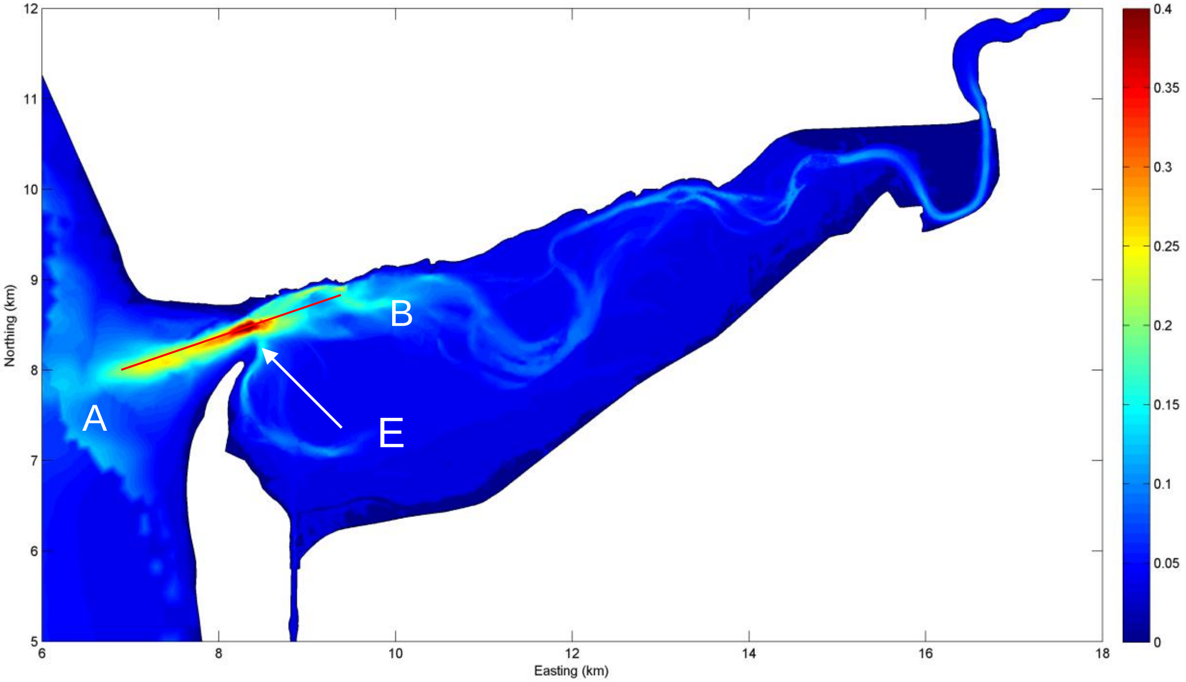
Bathymetry

LiDAR survey (2004) + Multibeam Multibeam(2007)
→Bedforms measurements



$$k_s = 0.5\eta$$

Dify estuary morphodynamics

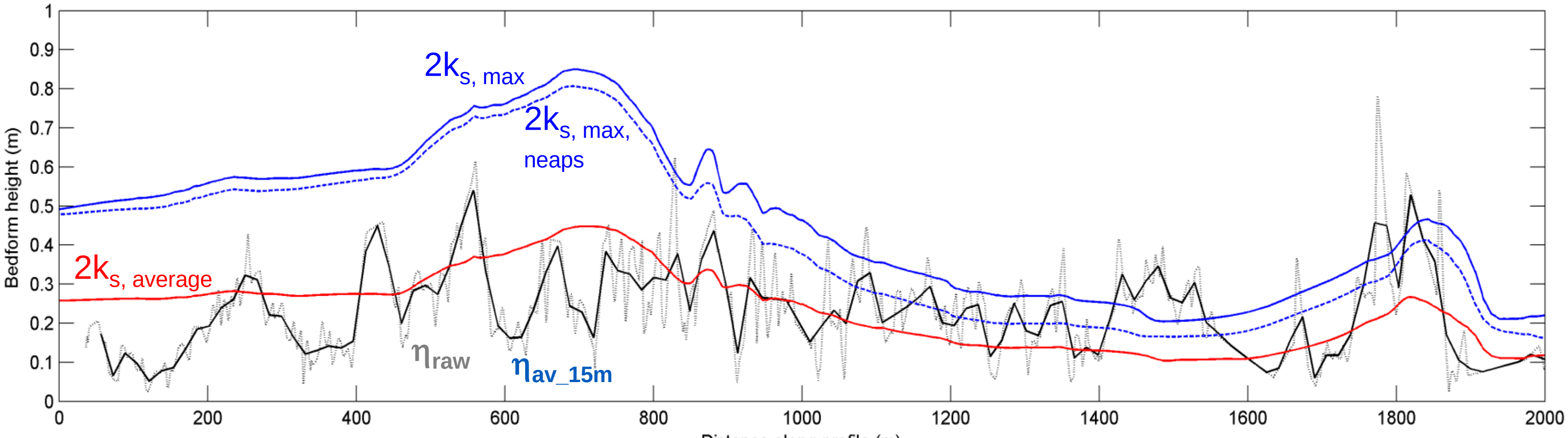


Predicted k_s (m)
(max values during spring tide)
VanRijn method (2007)

→ dune roughness in channels
→ ripple roughness over tidal flats

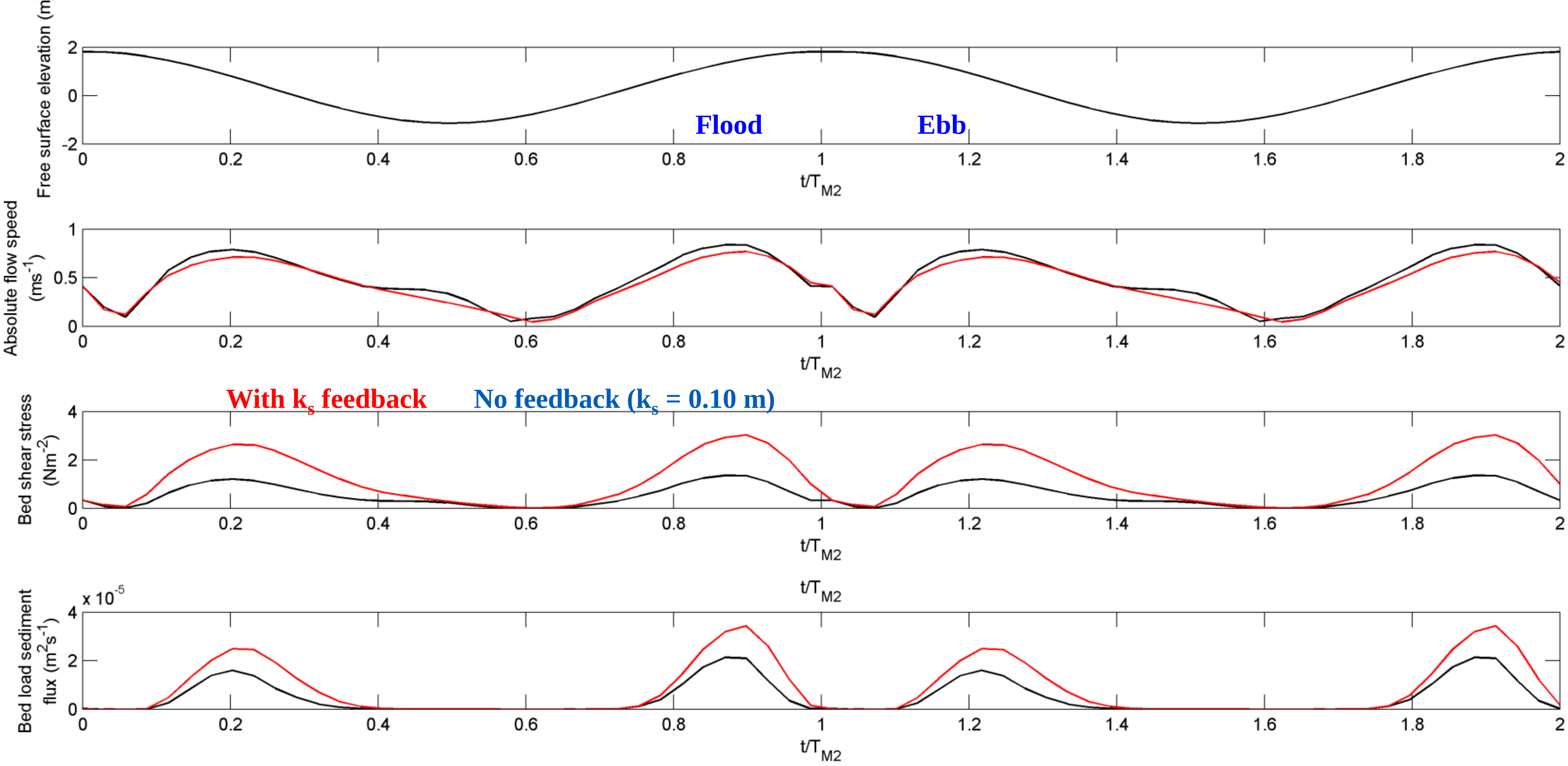
Comparison with measurements along transect AB (m)

$$k_s = 0.5\eta$$



Dify estuary morphodynamics

Comparison at Point E for two M_2 tidal cycles



Effect of feedback method for bed roughness

→ Bottom shear stress increases (by 122%)

→ Total sediment transport rate increases (by 74% on average)

Conclusion

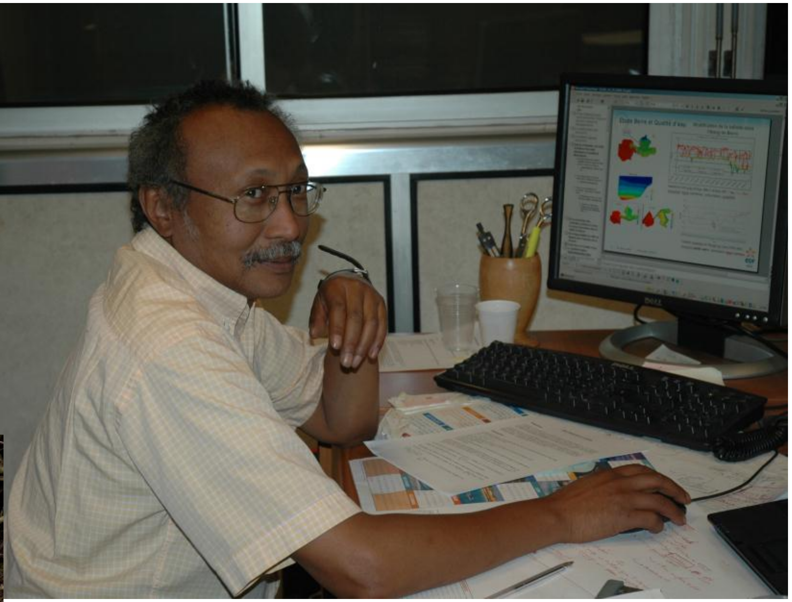
- Diversity of applications in complex environment:
  - Meandering channels, Macro-tidal estuaries, littoral applications, …
  - Dune formation to mesoscale morphodynamics (10-100 km)
- Bed roughness predictor
  - reduces some of the uncertainty in model results
  - avoids possible unconsistency between hydrodynamics and sediment transport
- More physical processes
  - Sand grading algorithm and mixed sediments
  - Mud consolidation and flocculation

Uncertainty in the sediment transport models >>> hydrodynamics models

→ New validation test cases

→ Uncertainty analysis (automatic differentiation)

Emile Razafindrakoto



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