Deltares

Enabling Delta Life

D-Flow Flexible Mesh

Hydrodynamic modelling using structured and unstructured meshes

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Hydrodynamics & Morphology interest group

Present modelling situation

Aims

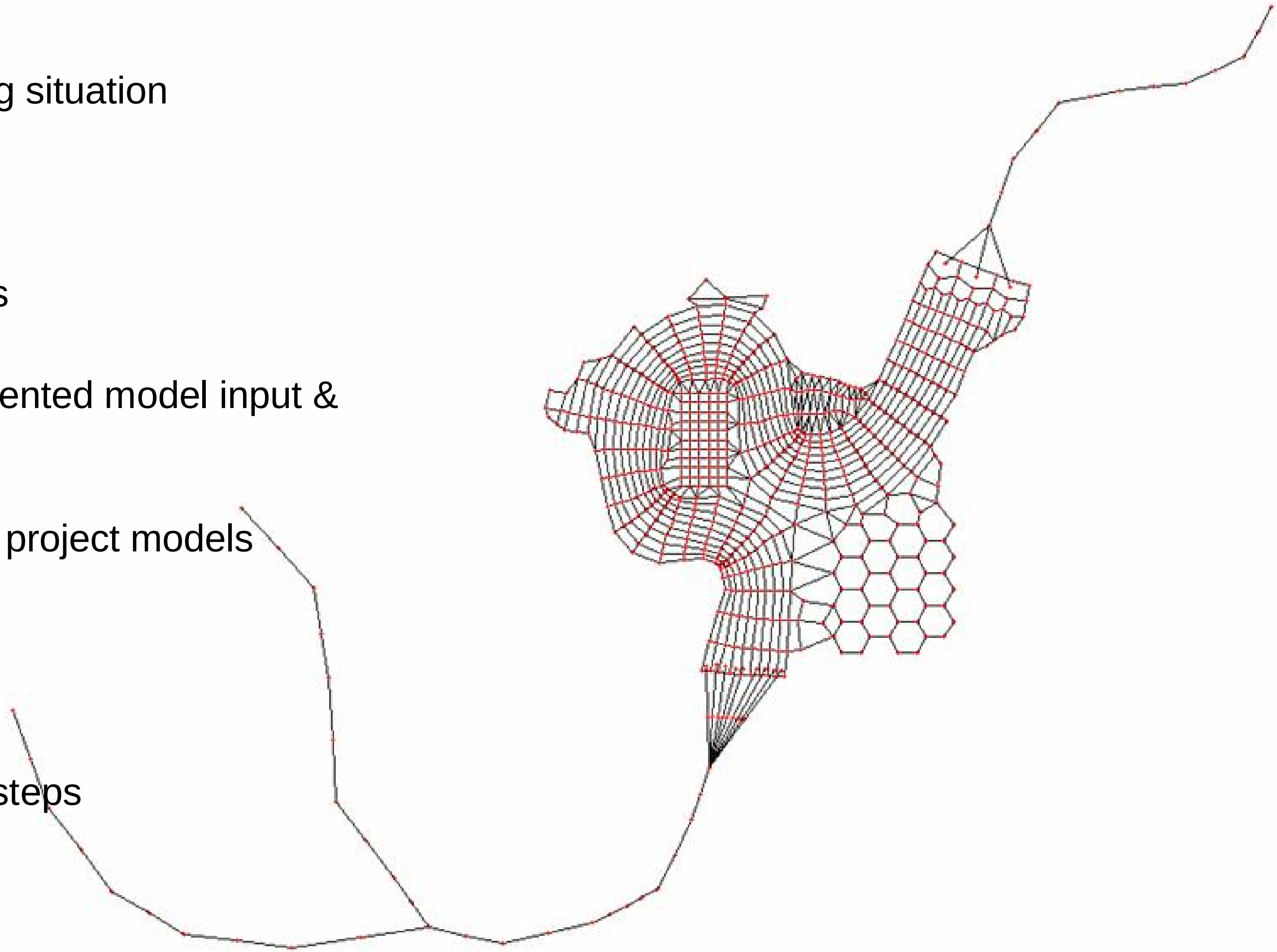
Basic test models

Currently implemented model input & output

Current and past project models

3D prototype

Options for next steps



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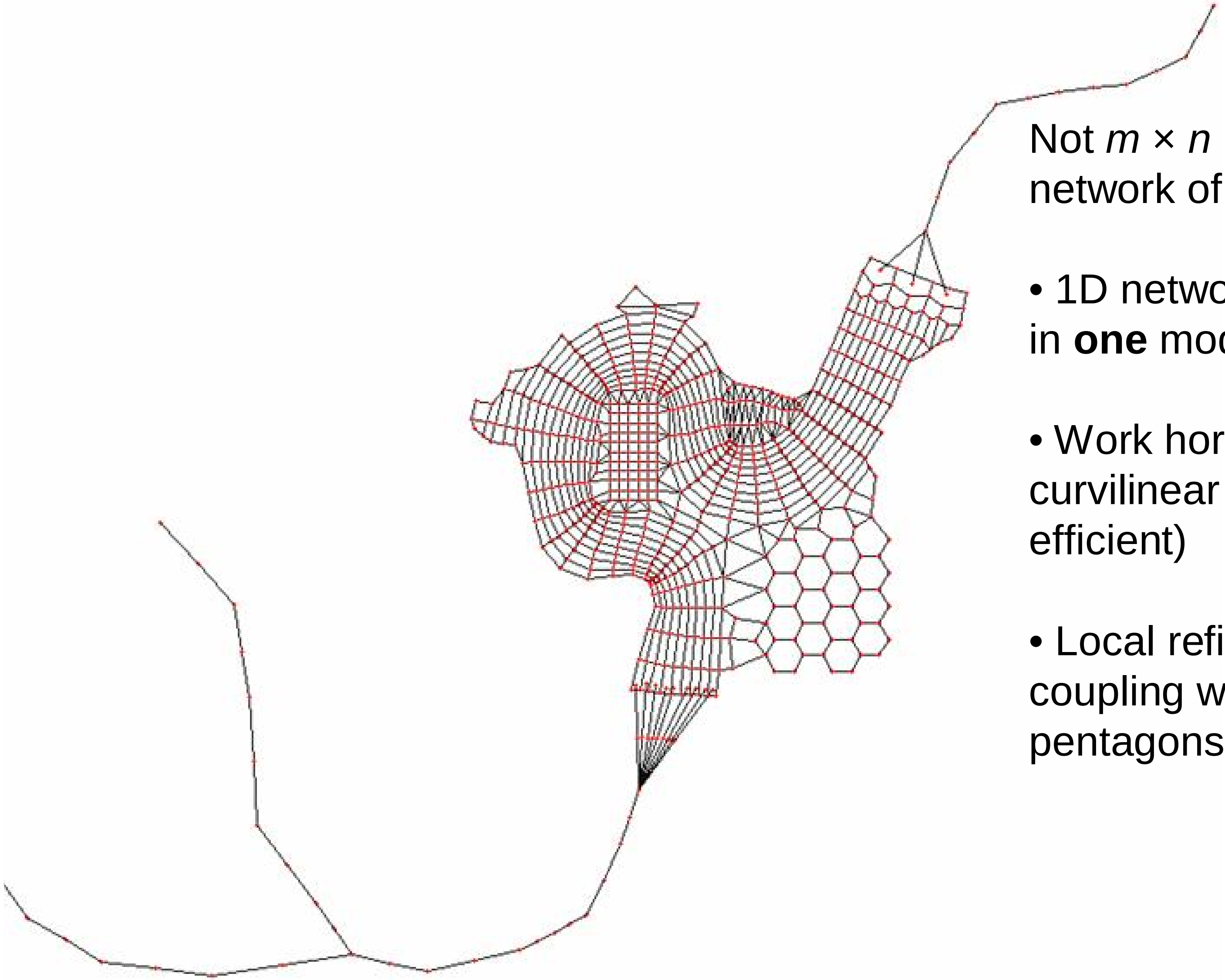
Sobek-1D2D


Delft3D/TRIWAQ
curvilinear;
spherical;
rectangular grids

D-Flow *Flexible Mesh*: unstructured grids



Not $m \times n$ quads, but instead a network of 'nodes and links':

• 1D network and 2D/3D grid in **one** model (flexible coupling)

• Work horse remains based on curvilinear grids (accurate, efficient)

• Local refinement through coupling with triangles, pentagons.

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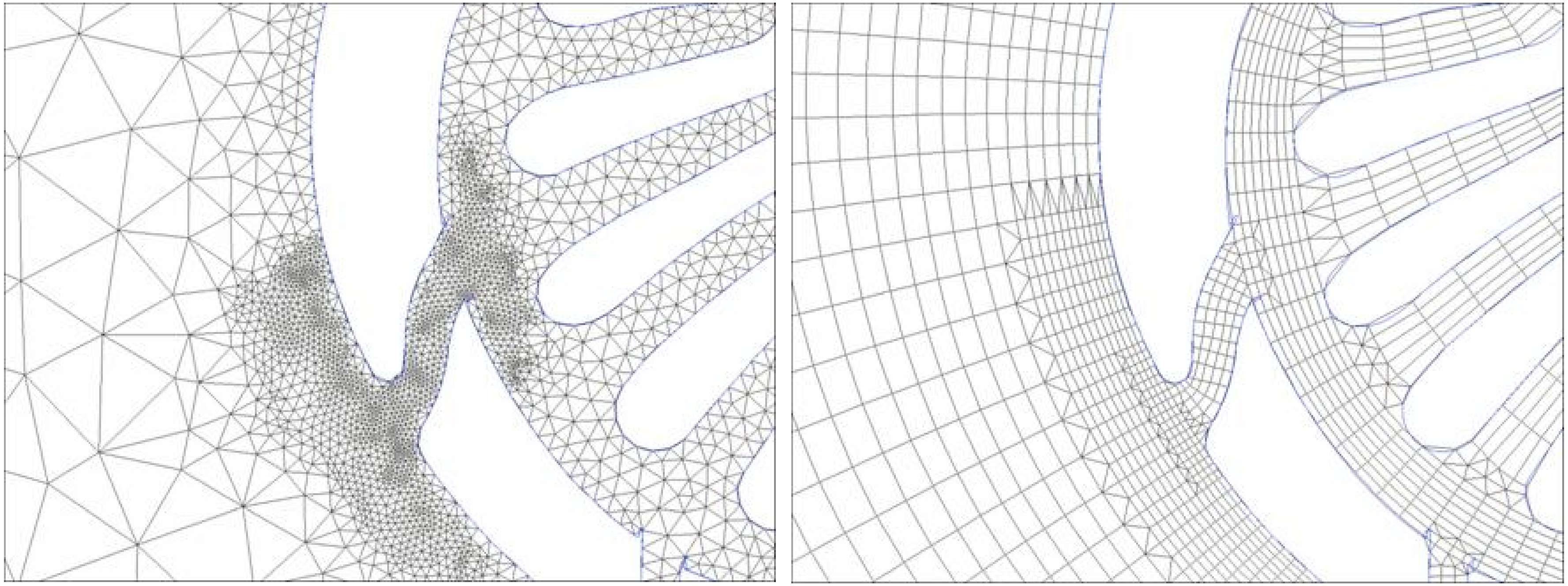
Unstructured: Curvilinear + …



We still advise orthogonal curvilinear grids in majority of domain:

- **Very accurate** (align with channels, gullies, coast lines)
- Experienced and **skilled user base**
- Couple and refine by triangles, pentagons: **best of both worlds**.

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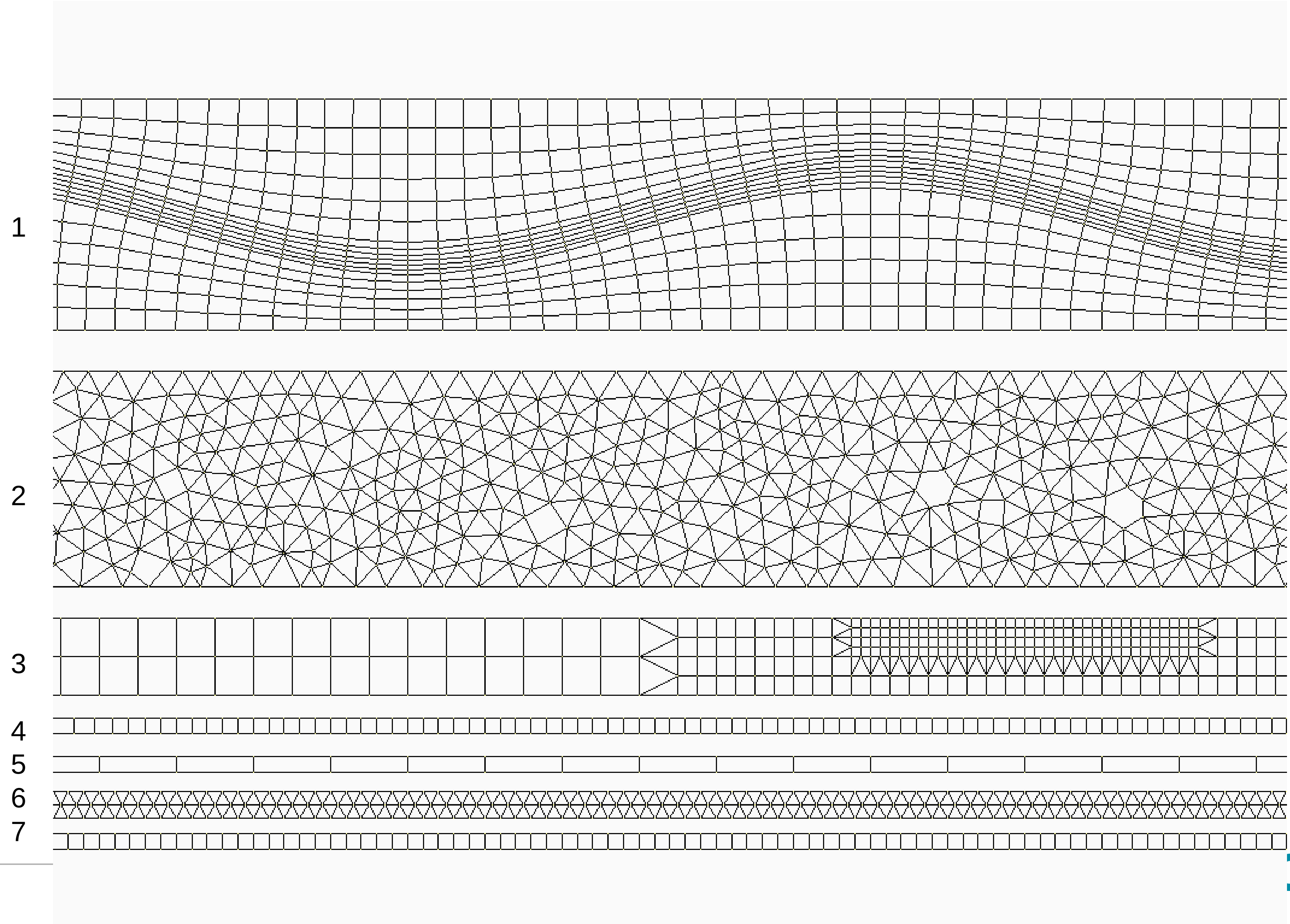
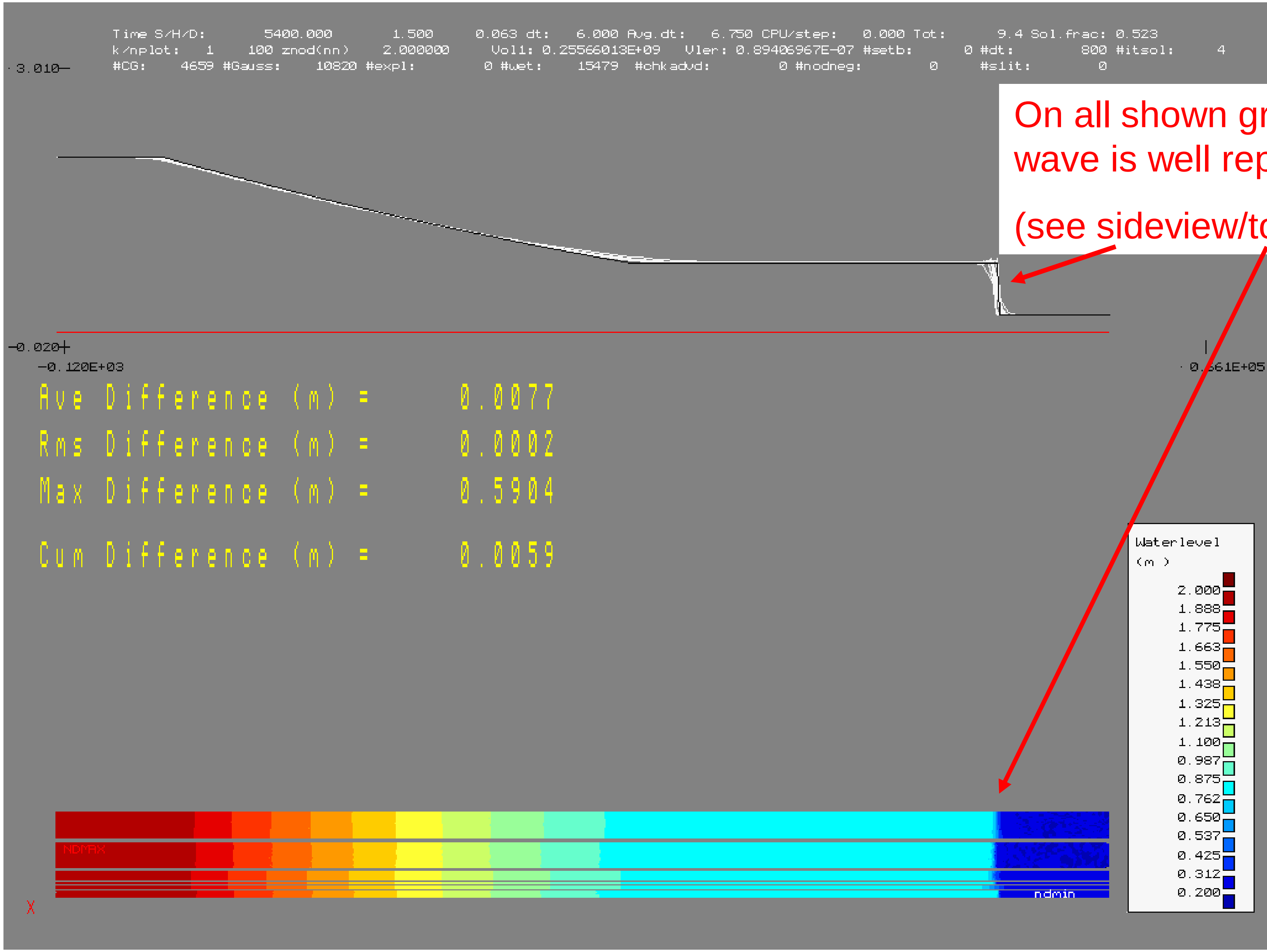
Quasi-1D Dam break Tests on various networks



Wetbed Dambreak for different grid types



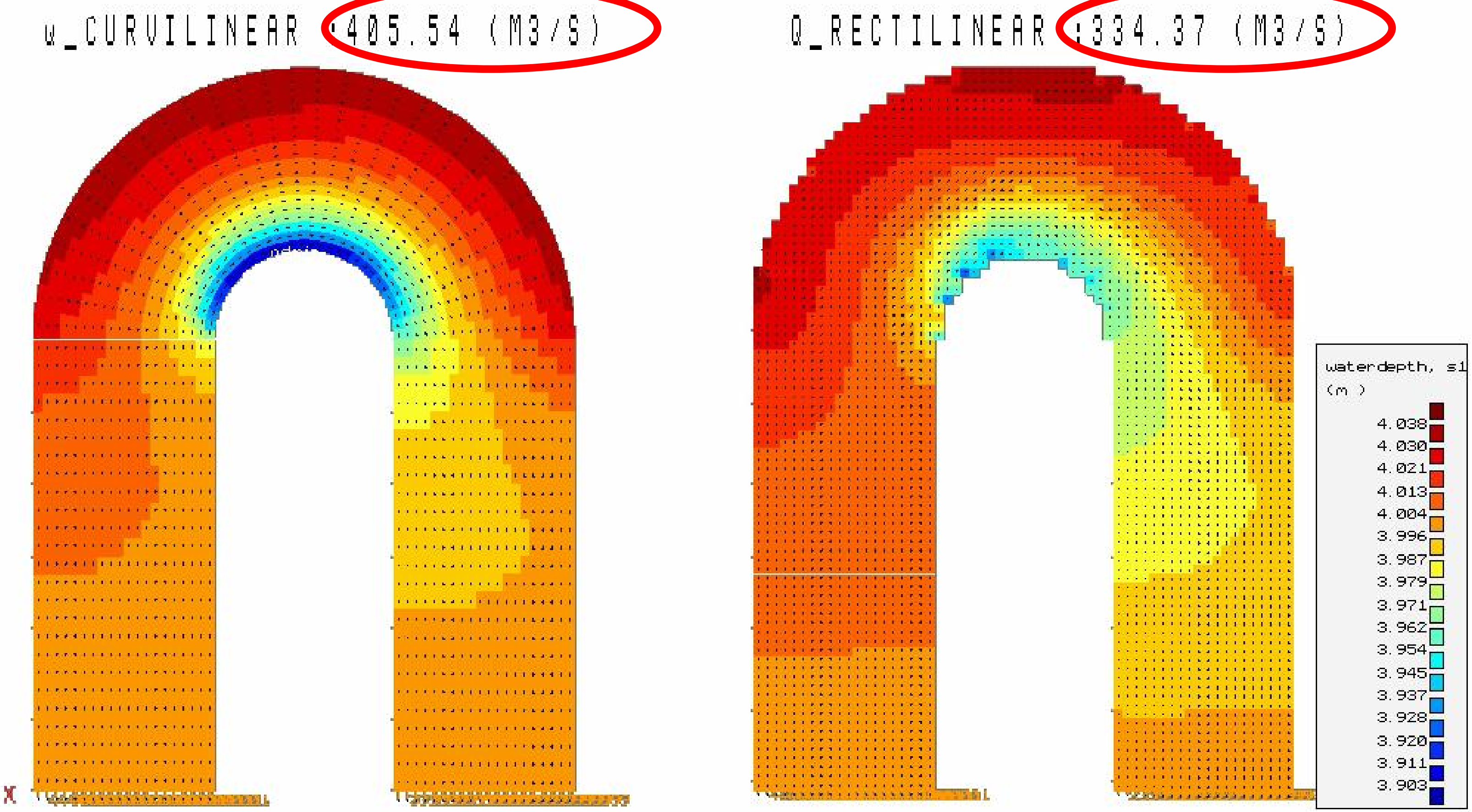
On all shown grids, shock wave is well represented.

(see sideview/topview)

Test of bends: Staircase problem?

```
Time S/H/D:      21210.014      5.892    0.245 dt:   2.000 Avg.dt:   1.996 CPU/step:   0.000 Tot:     76.0 Sol.frac: 0.775
k/nplot:    1    100 s1(nn):    4.075749 znod(nn):   4.002989   hsav:    4.002759458 #setb:      0 #dt:      10626 #itsol:     7
CG:    2394 #Gauss:      2612 #expl:        0 #wet:     5006  #chkadvd:       0 #nodneg:        0     #s1it:        0
```

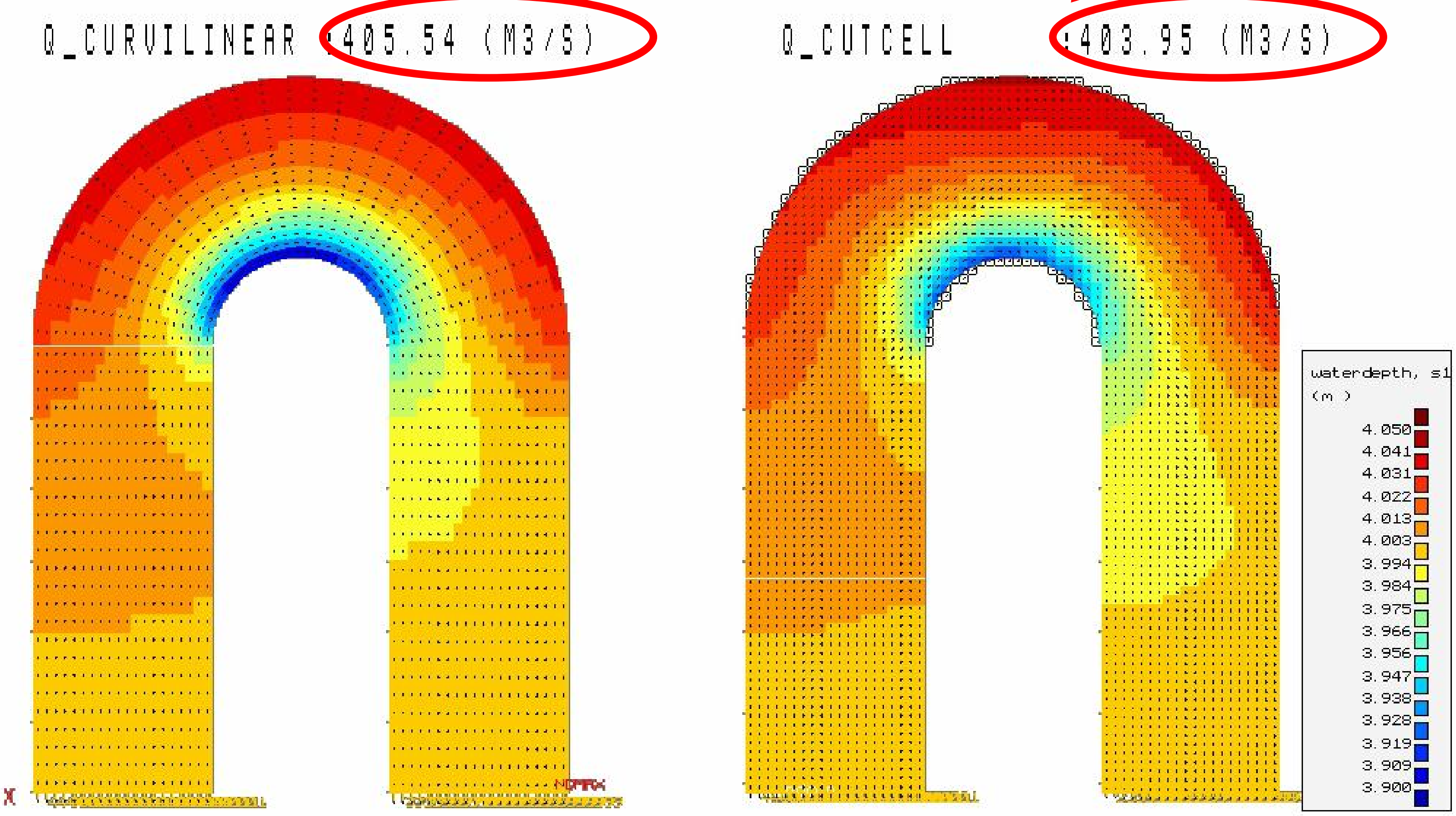
Large difference in steady state discharge due to staircase wall friction!



Cutcell !

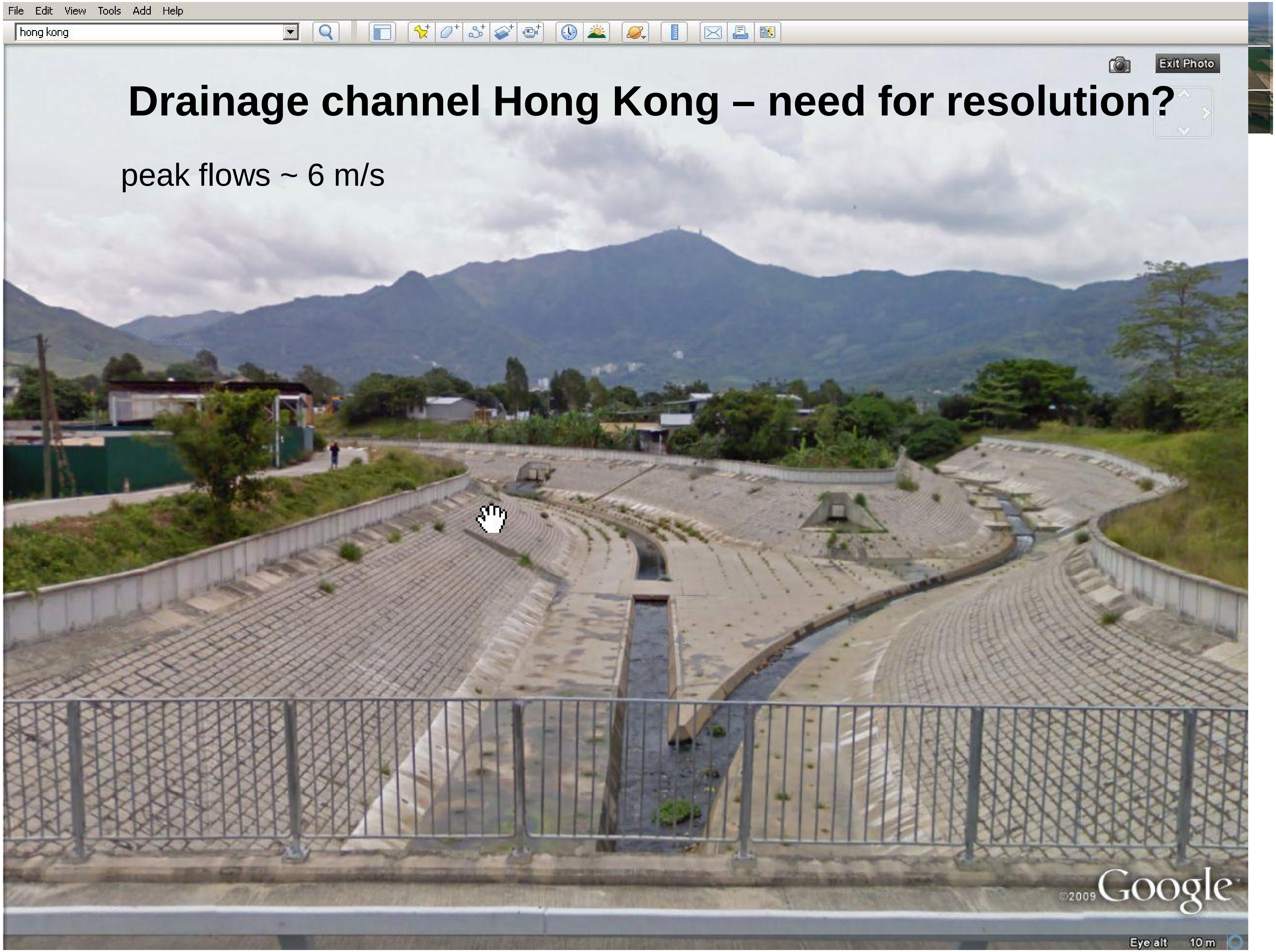
```
Time S/H/D:      20970.419      5.825      0.243 dt:    1.585 Avg.dt:    1.606 CPU/step:    0.000 Tot:     80.7 Sol.frac: 0.728
k/nplot:    1     100 s1(nn):     4.075749 znod(nn):    4.002989    hsav:    4.003257046 #setb:       0 #dt:       13056 #itsol:     5
#CG:     2394 #Gauss:      2612 #expl:          0 #wet:      5006   #chkadvd:        0 #nodneg:          0     #slit:          0
```

Cutcell approach on structured grids does produce accurate discharge values.

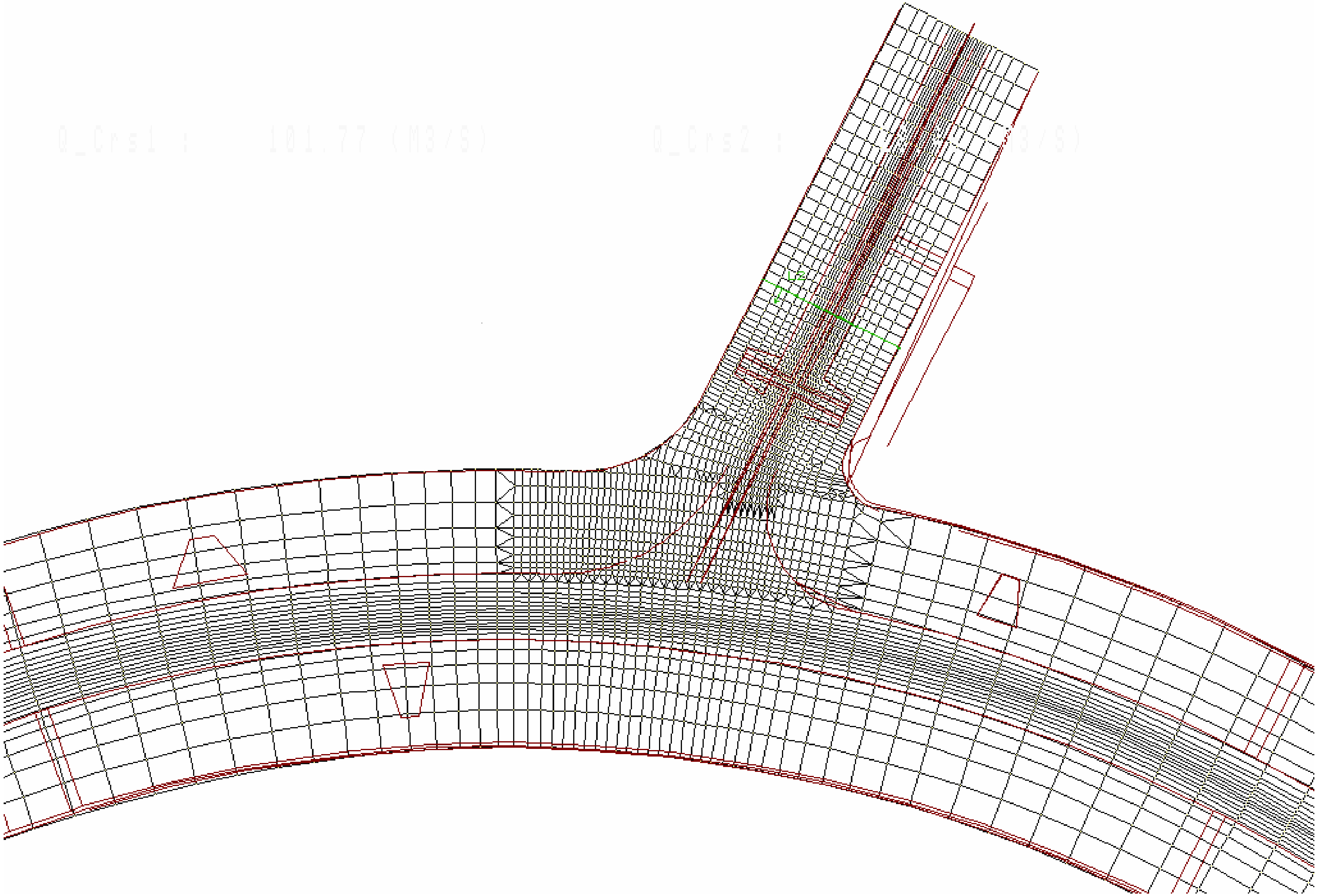


Drainage channel Hong Kong – need for resolution?

peak flows ~ 6 m/s



Drainage channel Hong Kong – 1: locally fine resolution



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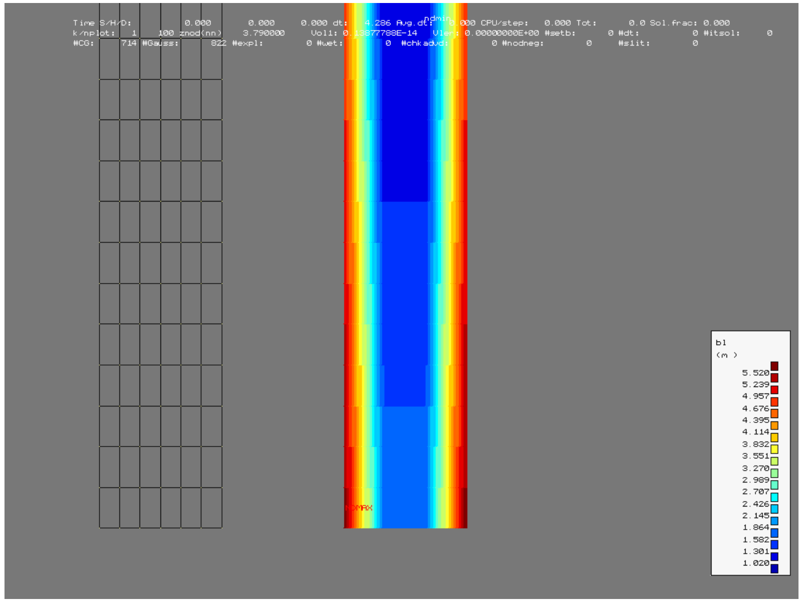
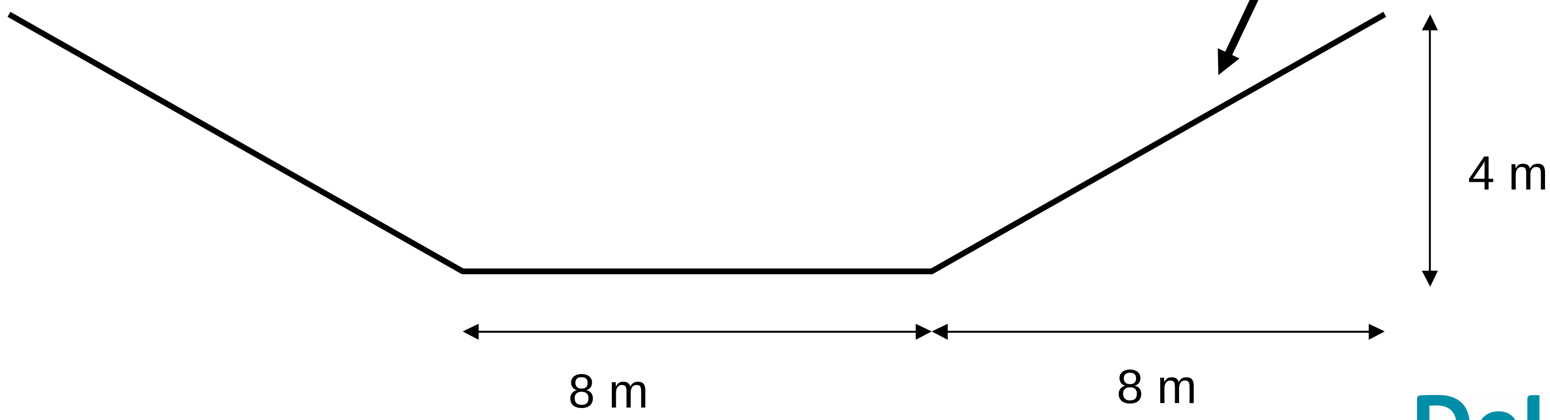
Drainage channel 2: cross section resolution



How much resolution is needed to capture channel's shape?
(# cells in cross sections)

Channel inclination = .0075



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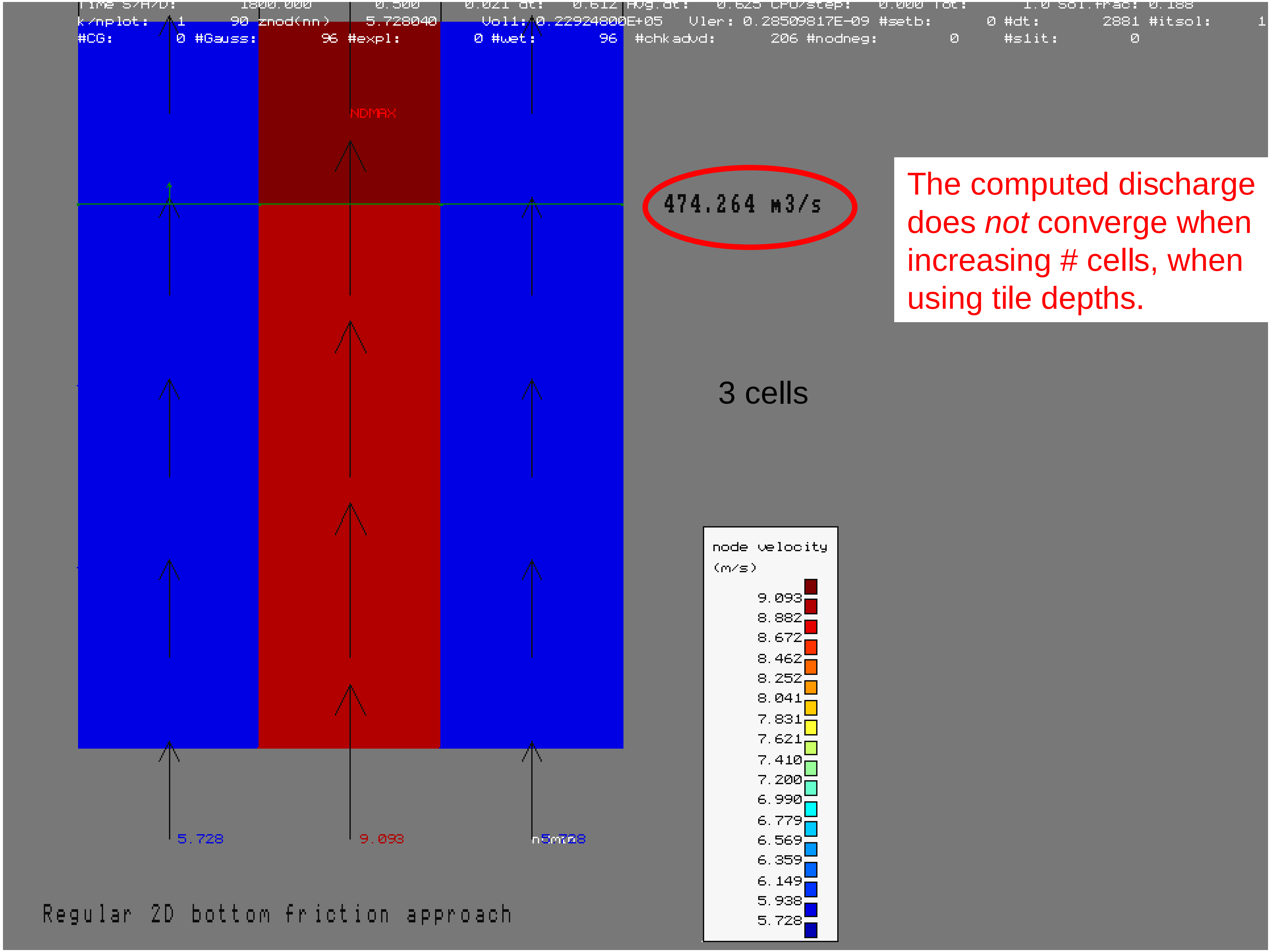
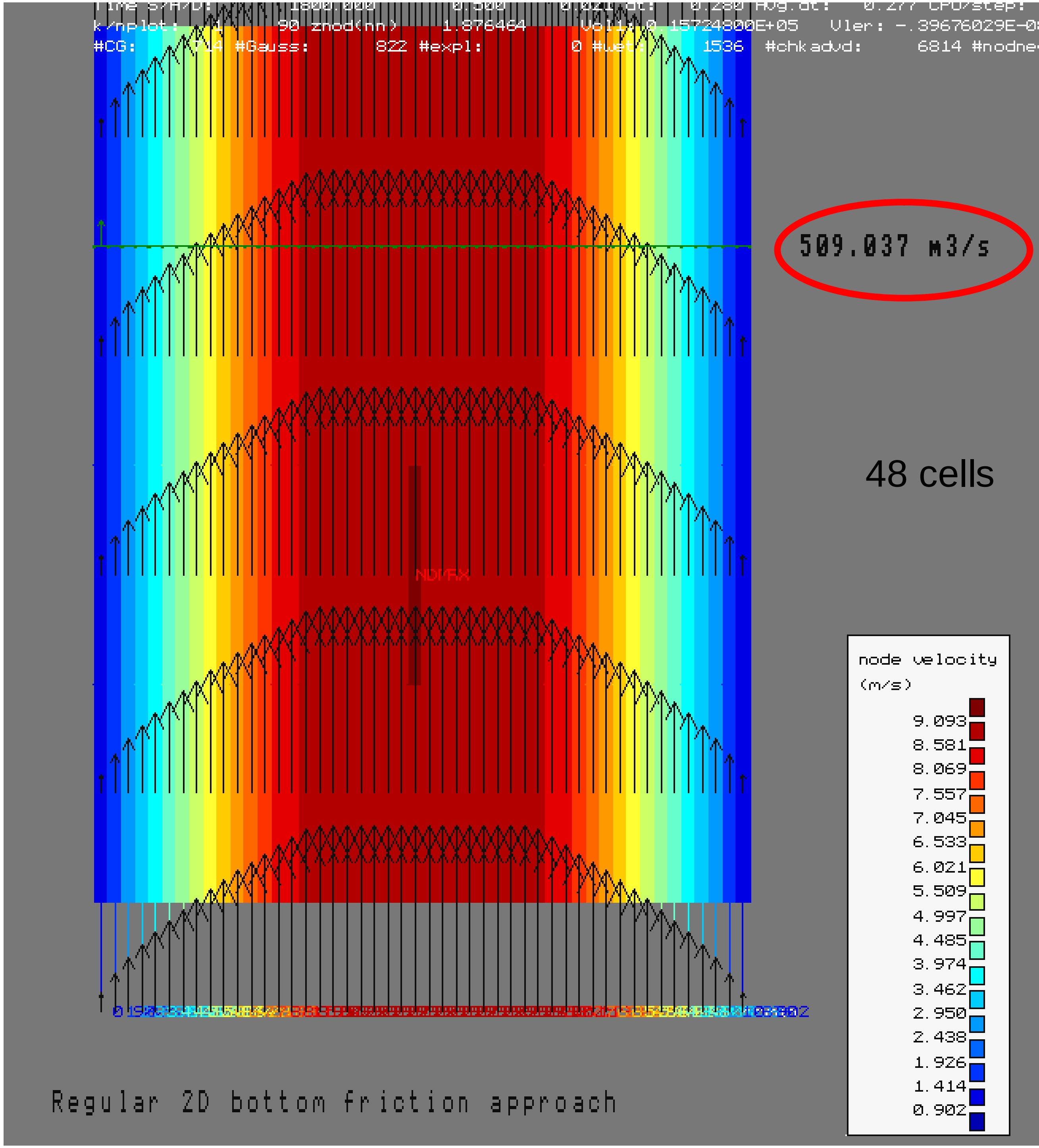


The computed discharge does *not* converge when increasing # cells, when using tile depths.

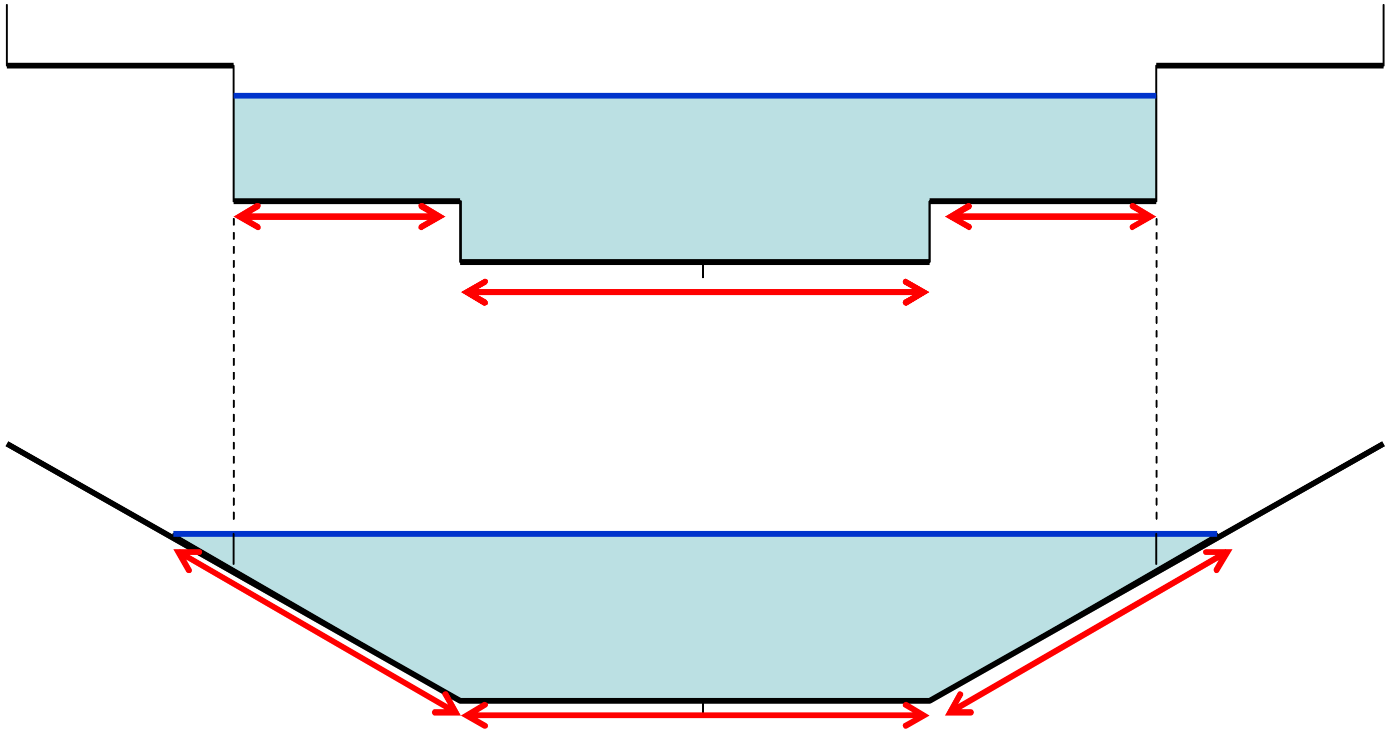
3 cells



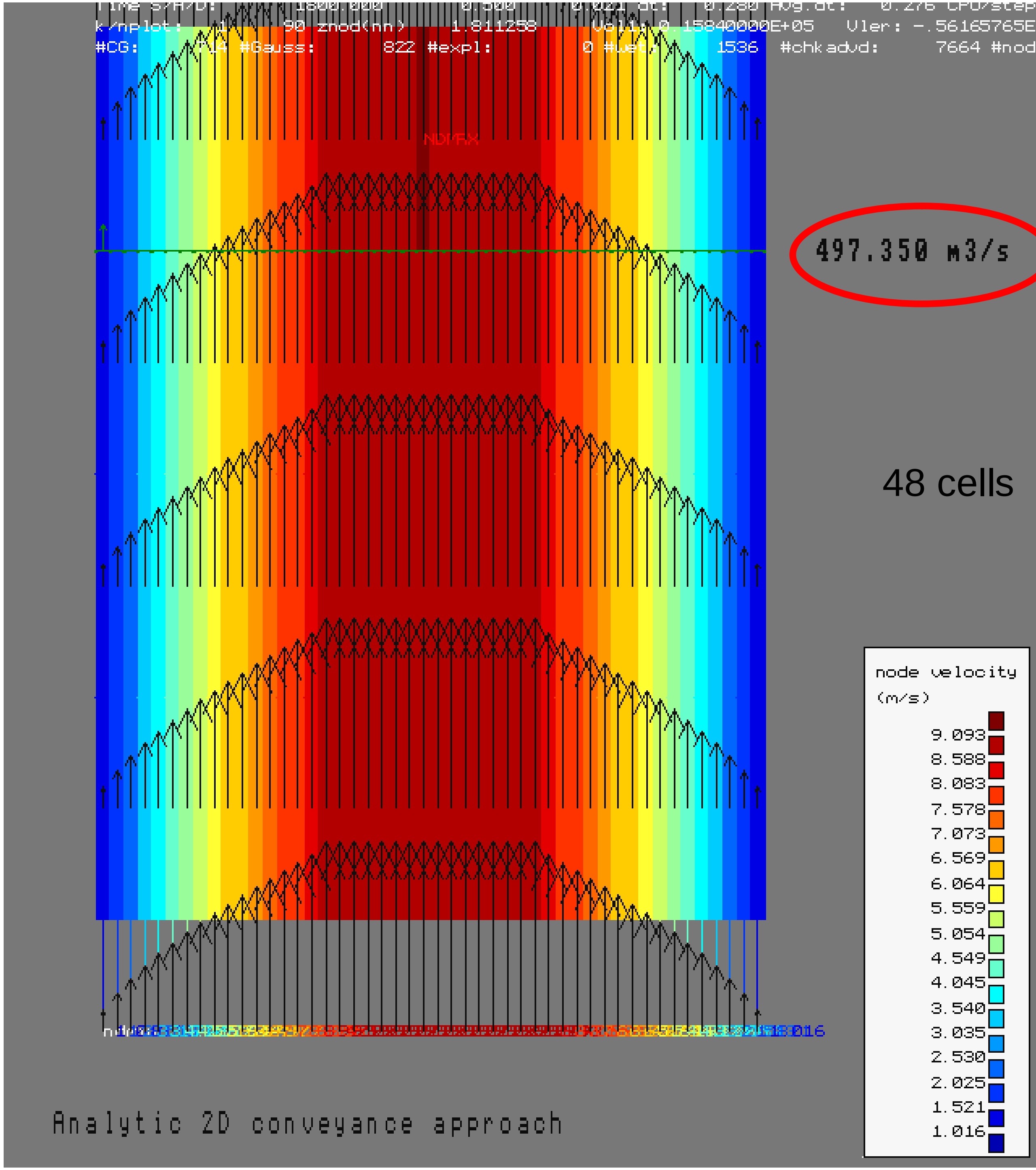
The computed discharge does *not* converge when increasing # cells, when using tile depths.

Converged answer = wrong answer

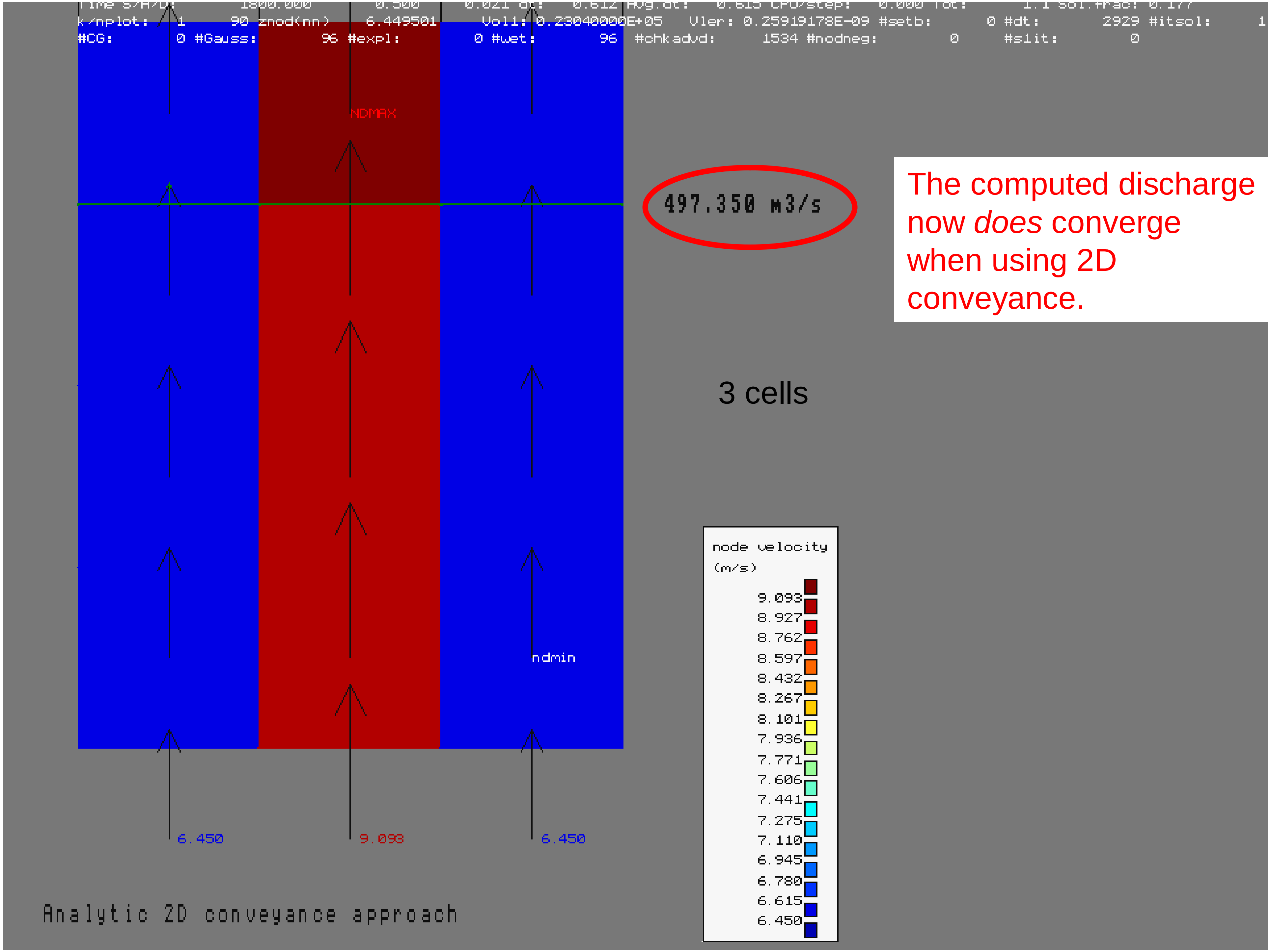
No matter how many tiles in cross direction: wall friction is never accounted for and bottom friction underestimated.



Solution: 2D analytical conveyance: compute friction integral along entire cell's edge, based on bathymetry at cell's corner points.



The computed discharge now *does* converge when using 2D conveyance.

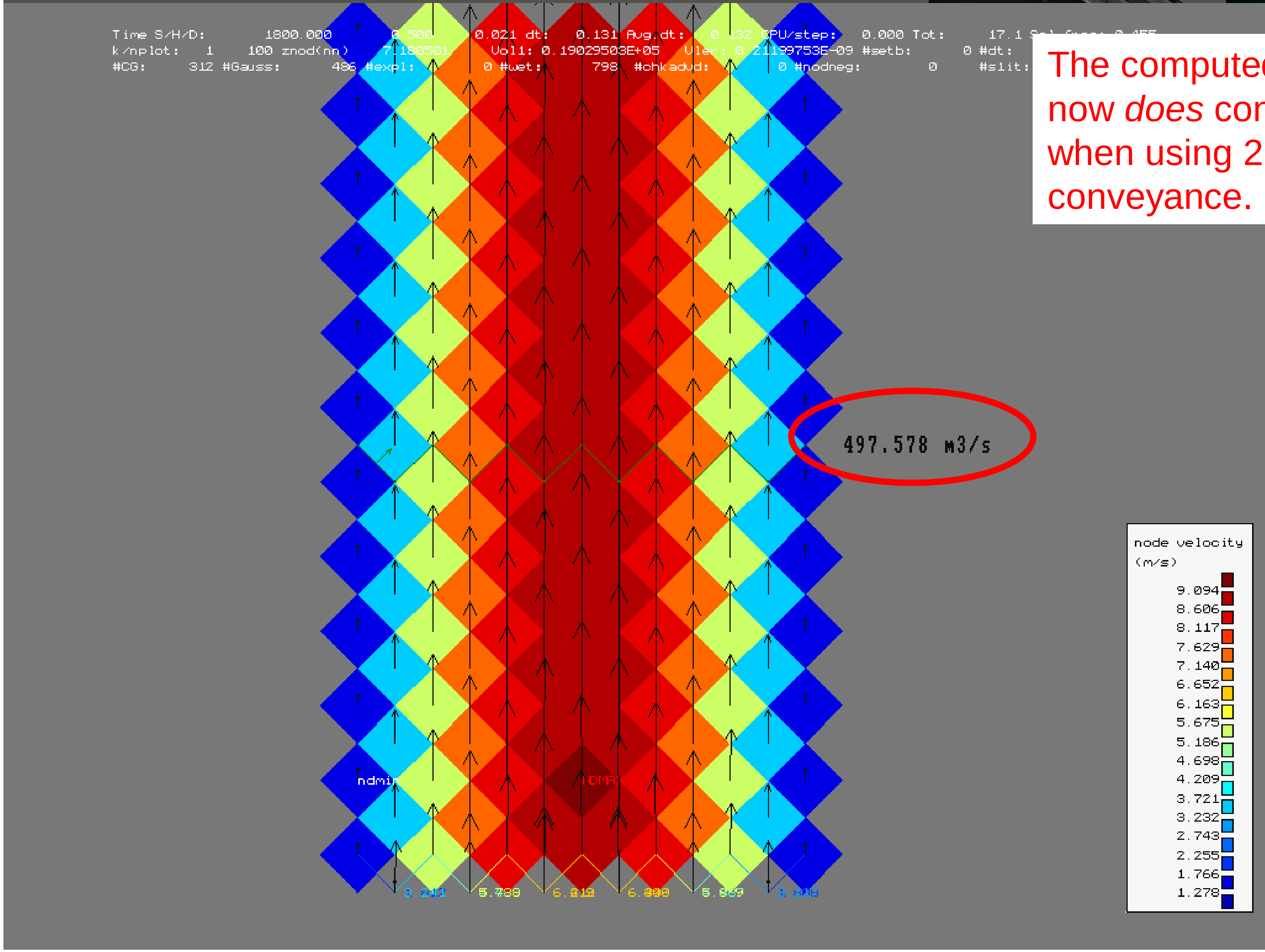


The computed discharge now *does* converge when using 2D conveyance.

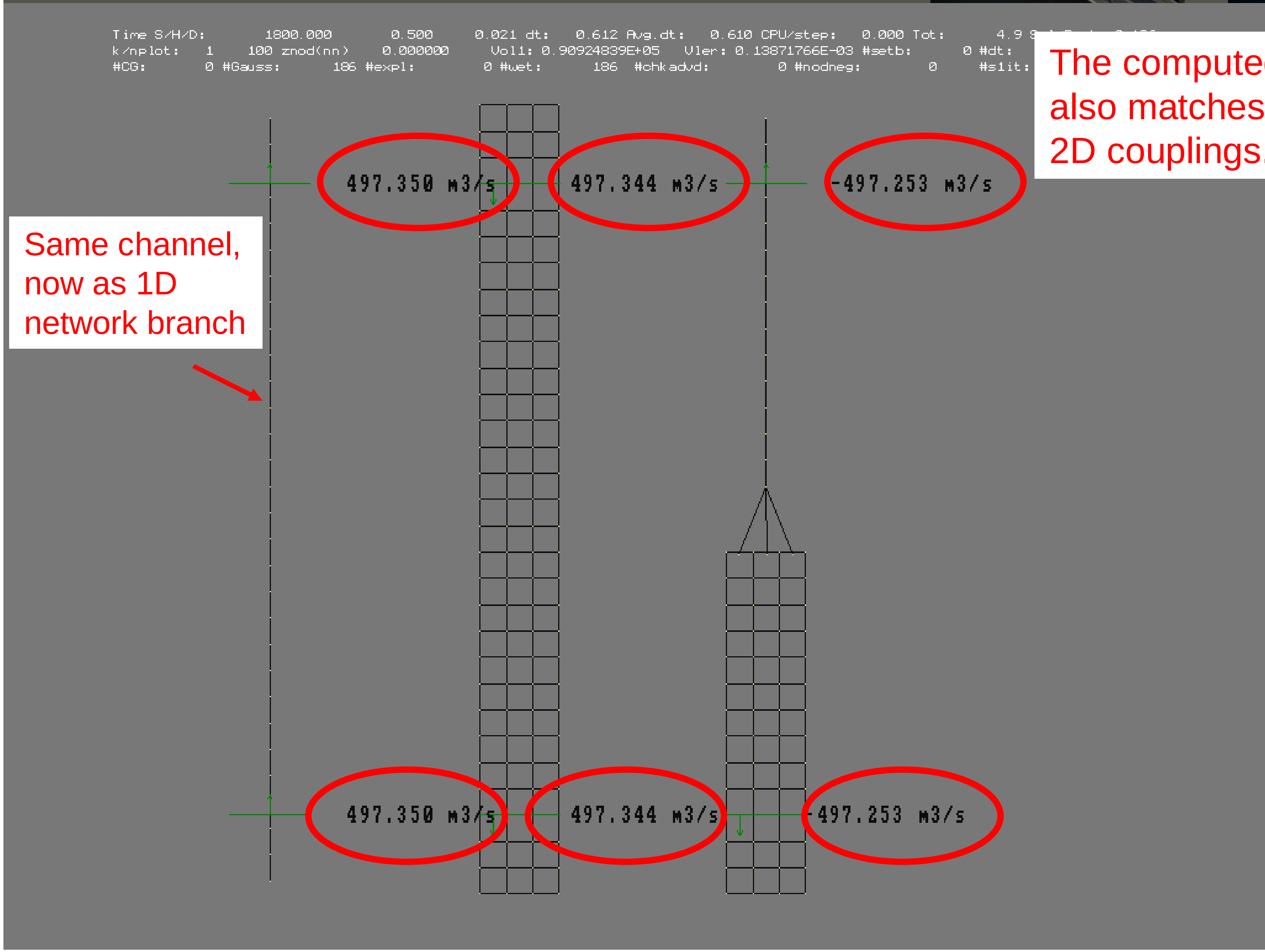
3 cells

Same channel, 45 deg. rotated grid

The computed discharge now *does* converge when using 2D conveyance.



D-Flow Flexible Mesh: Grid integration of 1D, 2D, 1D2D



The computed discharge also matches across 1D-2D couplings.

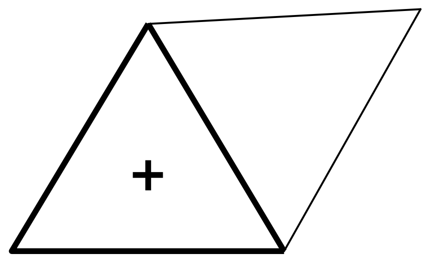
Same channel, now as 1D network branch

D-Flow FM: Finite volume approach

Conservation of:

$$\frac{\partial V}{\partial t} = \sum_{in\zeta} Q - \sum_{out\zeta} Q$$

Volume

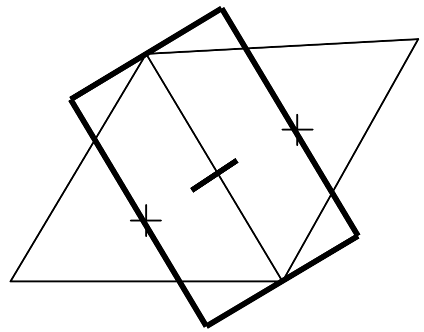


$$\frac{\partial Vc}{\partial t} = \sum_{in\zeta} Qc_{in} - \sum_{out\zeta} Qc_{out}$$

Mass

$$\frac{\partial V_u \rho u}{\partial t} = \sum_{inu} Q\rho_{in} u_{in} - \sum_{outu} Q\rho_{out} u_{out} + \sum F_u$$

Momentum




Momentum conserving advection

$$\frac{\partial V_u u}{\partial t} = \sum_{in} Q u_{in} - \sum_{out} Q u_{out} + .. \qquad (u_{in} = \overline{u}_{in} . \overline{n}_u)$$

$$V_u \frac{\partial u}{\partial t} + u \frac{\partial V_u}{\partial t} = \sum_{in} Q u_{in} - \sum_{out} Q u_{out} + ..$$

$$\frac{\partial u}{\partial t} = \frac{1}{V_u} \left\{ \sum_{in} Q u_{in} - \sum_{out} Q u_{out} - u \left(\sum_{in} Q - \sum_{out} Q \right) \right\} + ..,$$

$$\frac{\partial u}{\partial t} = \frac{1}{V_u} \left\{ \sum_{in} Q (u_{in} - u) - \sum_{out} Q (u_{out} - u) \right\} + ..,$$

$$\frac{\partial u}{\partial t} = \frac{1}{V_u} \left\{ \sum_{in} Q (u_{in} - u) \right\} + .., \ (u_{out} = u) \qquad (\textit{first order upwind})$$

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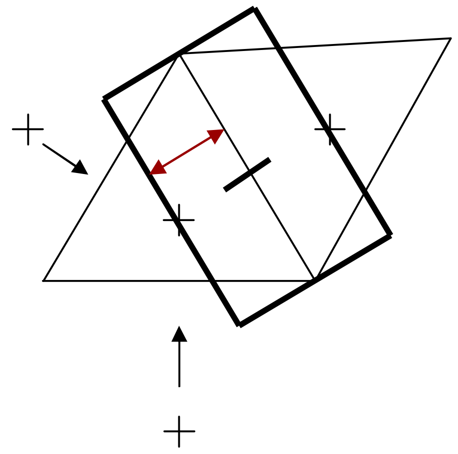
Advection (Kramer, Stelling)

Advection term gets contributions from left and right nodes

$$\frac{\partial u}{\partial t} = \frac{1}{V_u}\left\{\sum_{in} Q(u_{in} - u) - \sum_{out} Q(u_{out} - u)\right\} + ..$$

$$\frac{\partial u}{\partial t} = \frac{1}{V_u}\left\{\begin{array}{l} \alpha_L \left(\sum_{inL} Q(u_{in} - u) - \sum_{outL} Q(u_{out} - u)\right) + \\ \alpha_R \left(\sum_{inR} Q(u_{in} - u) - \sum_{outR} Q(u_{out} - u)\right) \end{array}\right\} + ..$$

control volume Perot



$$\alpha_L = \frac{\Delta x_L}{\Delta x_L + \Delta x_R} ; \alpha_R = 1 - \alpha_L$$

$$V_u = \alpha_L V_L + \alpha_R V_R$$

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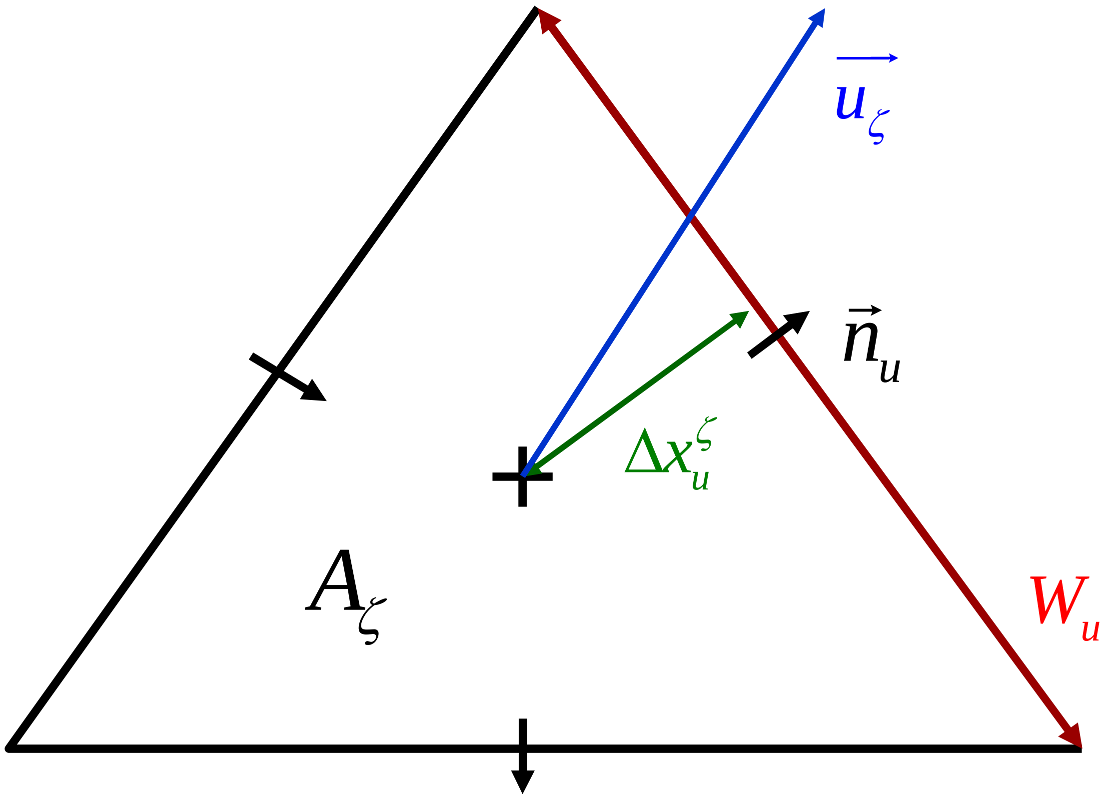
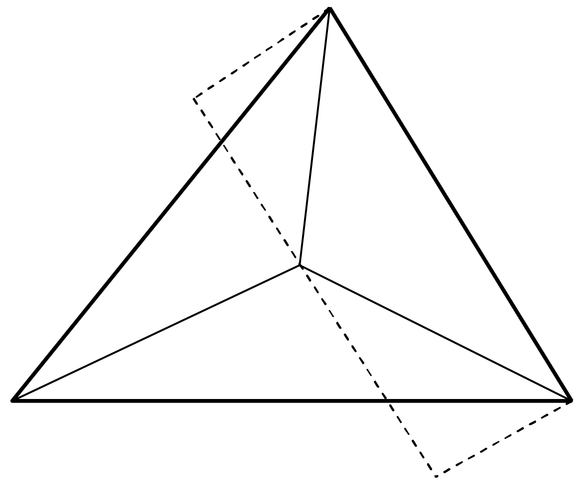
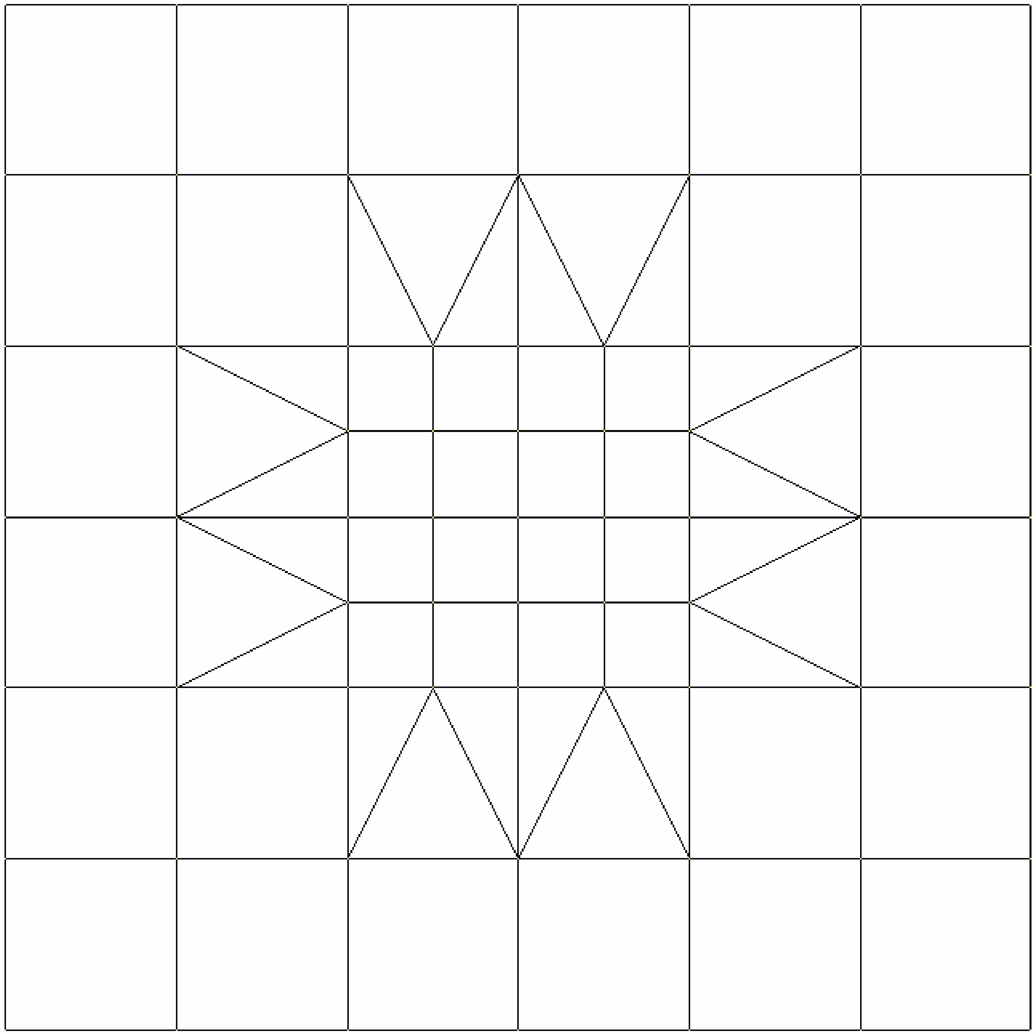
Cell centre velocities (Perot)

$$\vec{u}_\zeta = \frac{1}{A_\zeta}\sum^{faces} \Delta x_u^\zeta W_u \vec{n}_u u$$

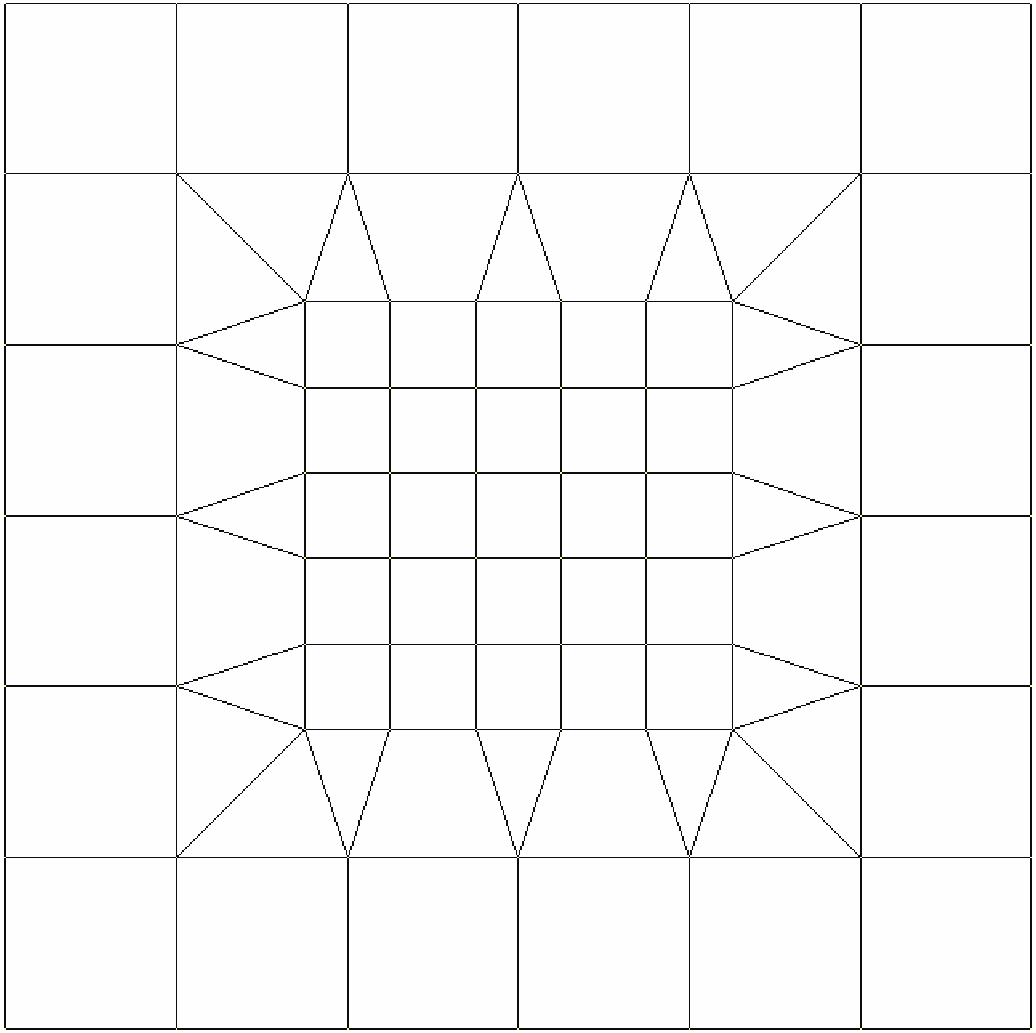




Orthogonal mesh refinement I

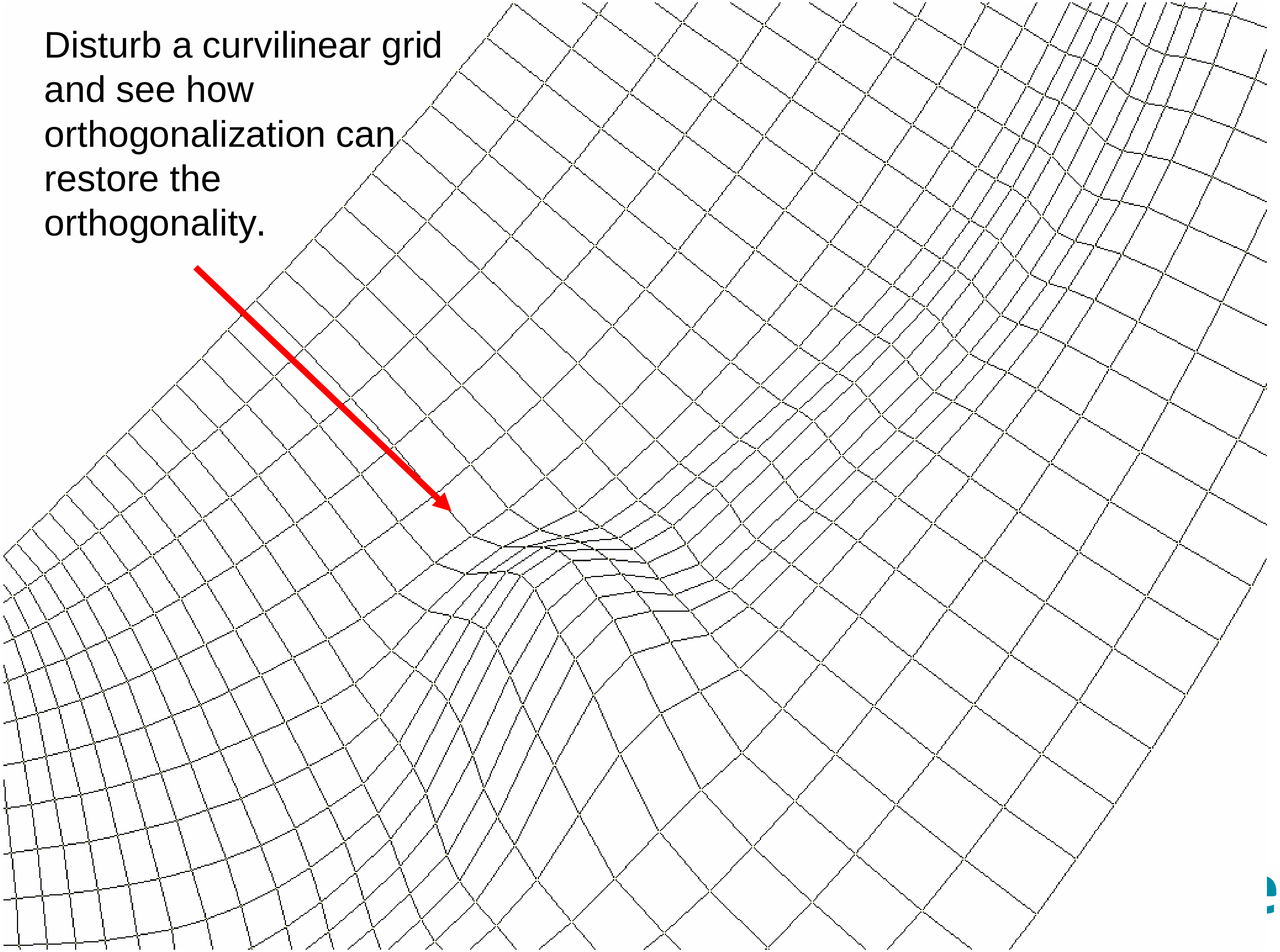


Orthogonal mesh refinement II



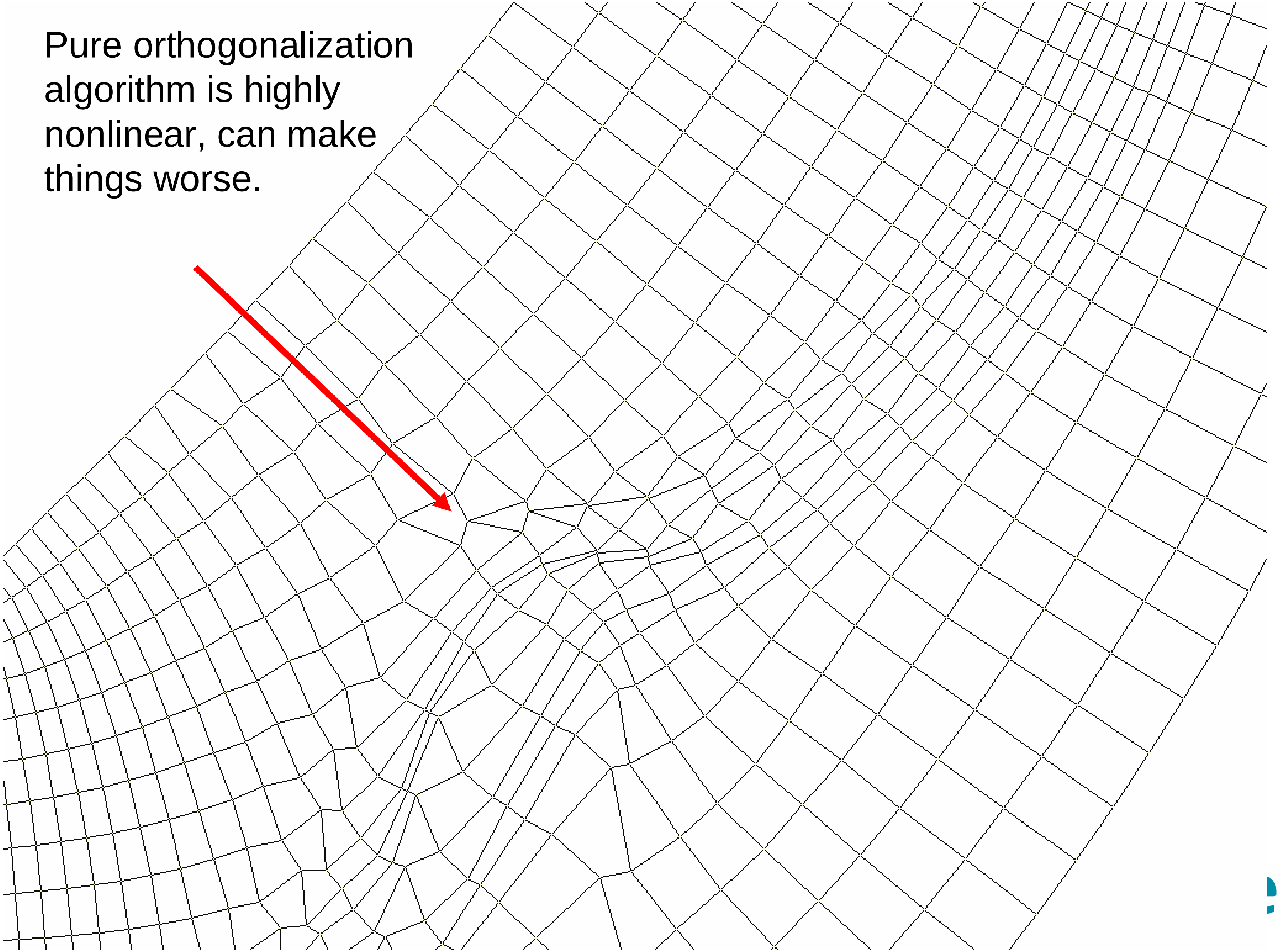
Orthogonalisation

Disturb a curvilinear grid and see how orthogonalization can restore the orthogonality.



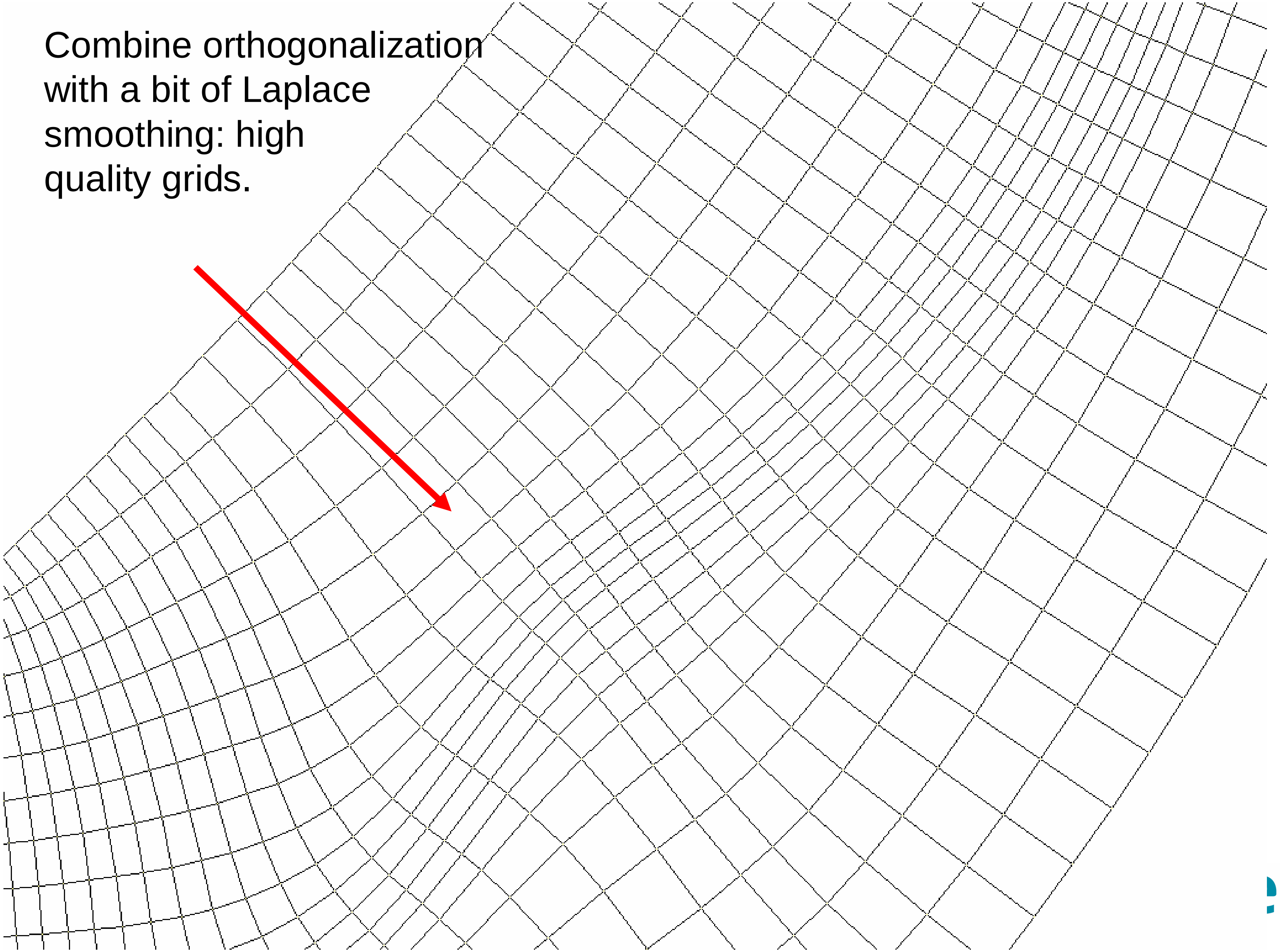
Orthogonalisation Pure: Bow Tie

Pure orthogonalization algorithm is highly nonlinear, can make things worse.

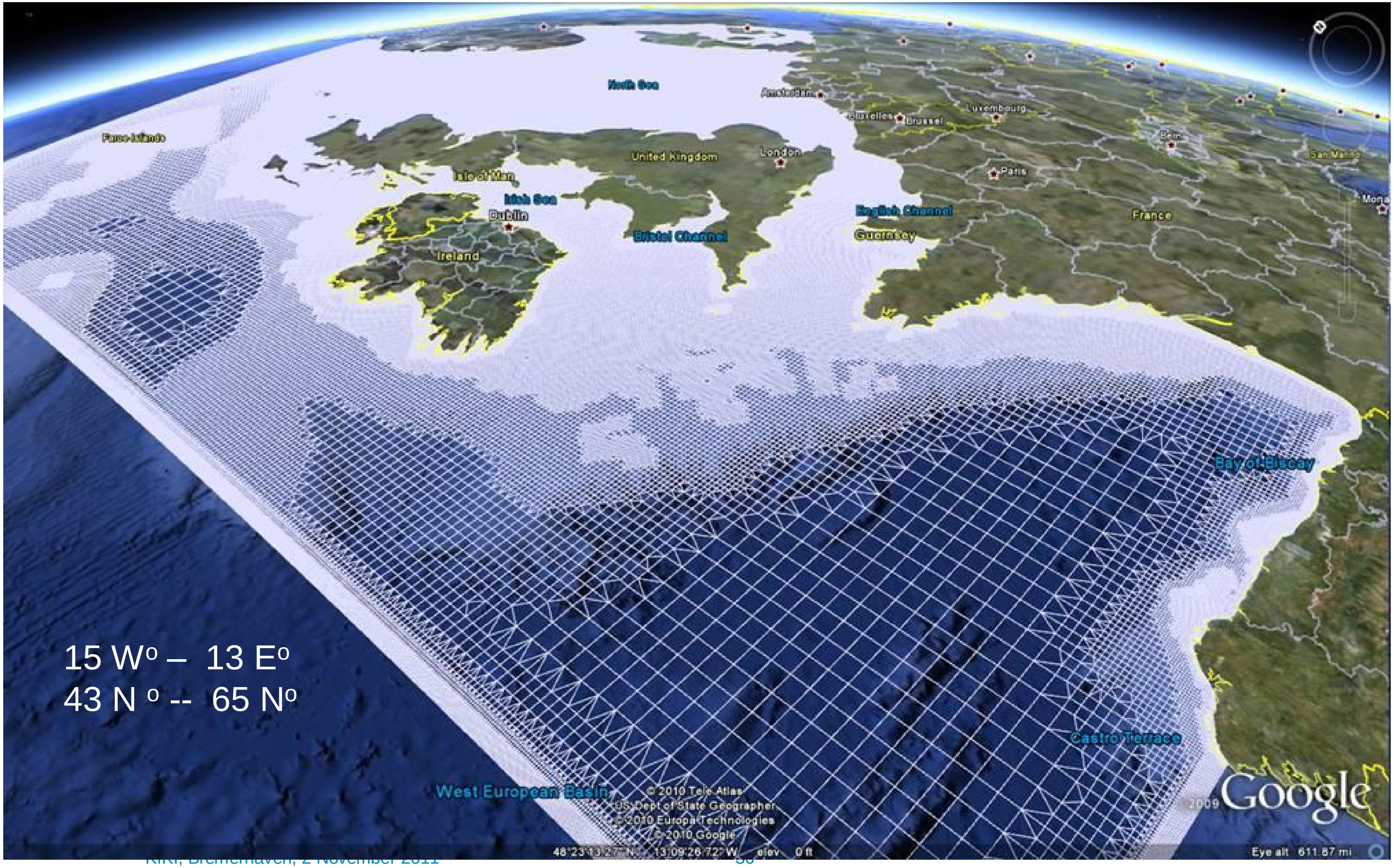


Orthogonalisation Curvi: Smooth

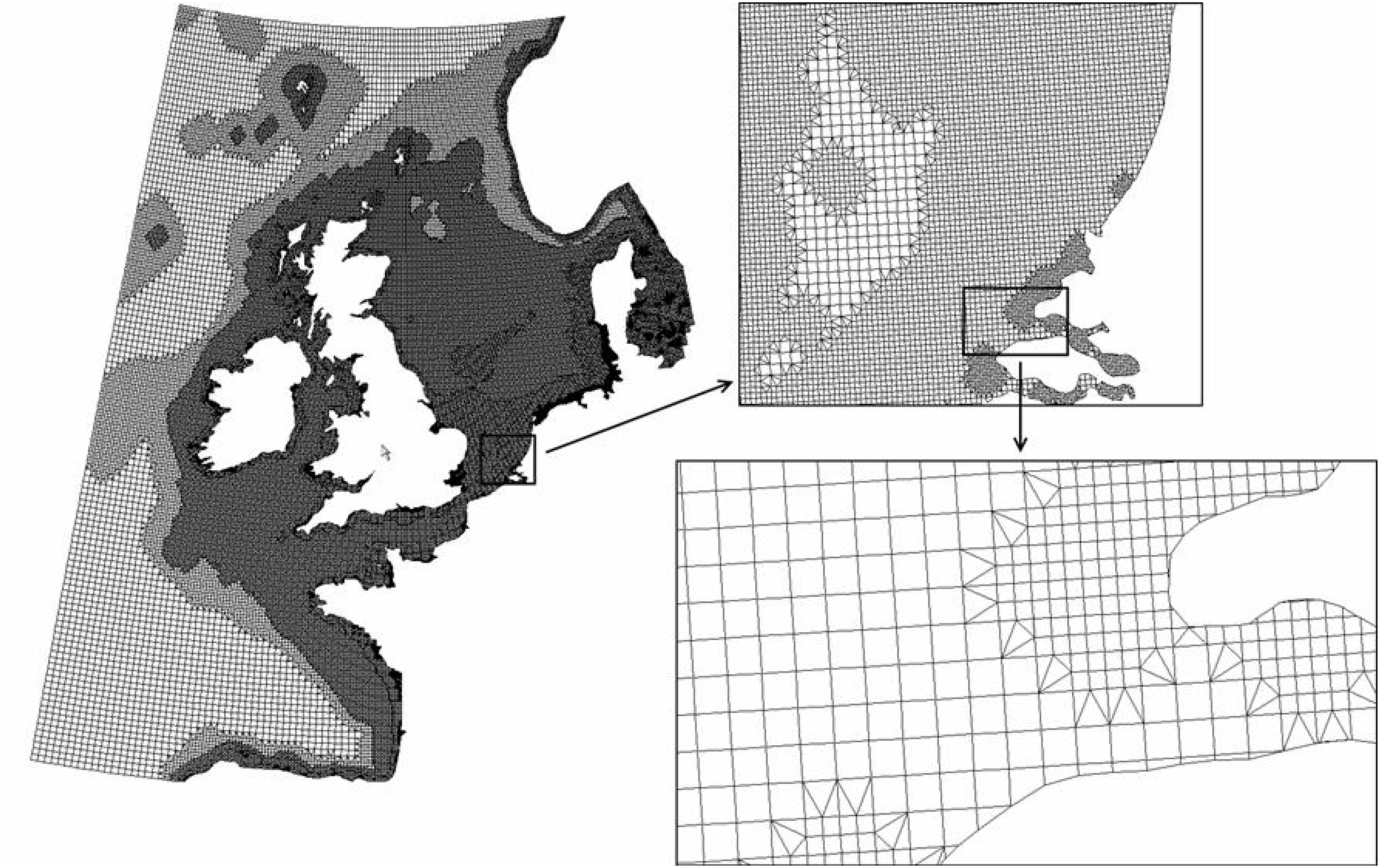
Combine orthogonalization with a bit of Laplace smoothing: high quality grids.



D-Flow FM test: tidal motion Continental shelf



CSM model Courant grid (coarse in deeper parts)



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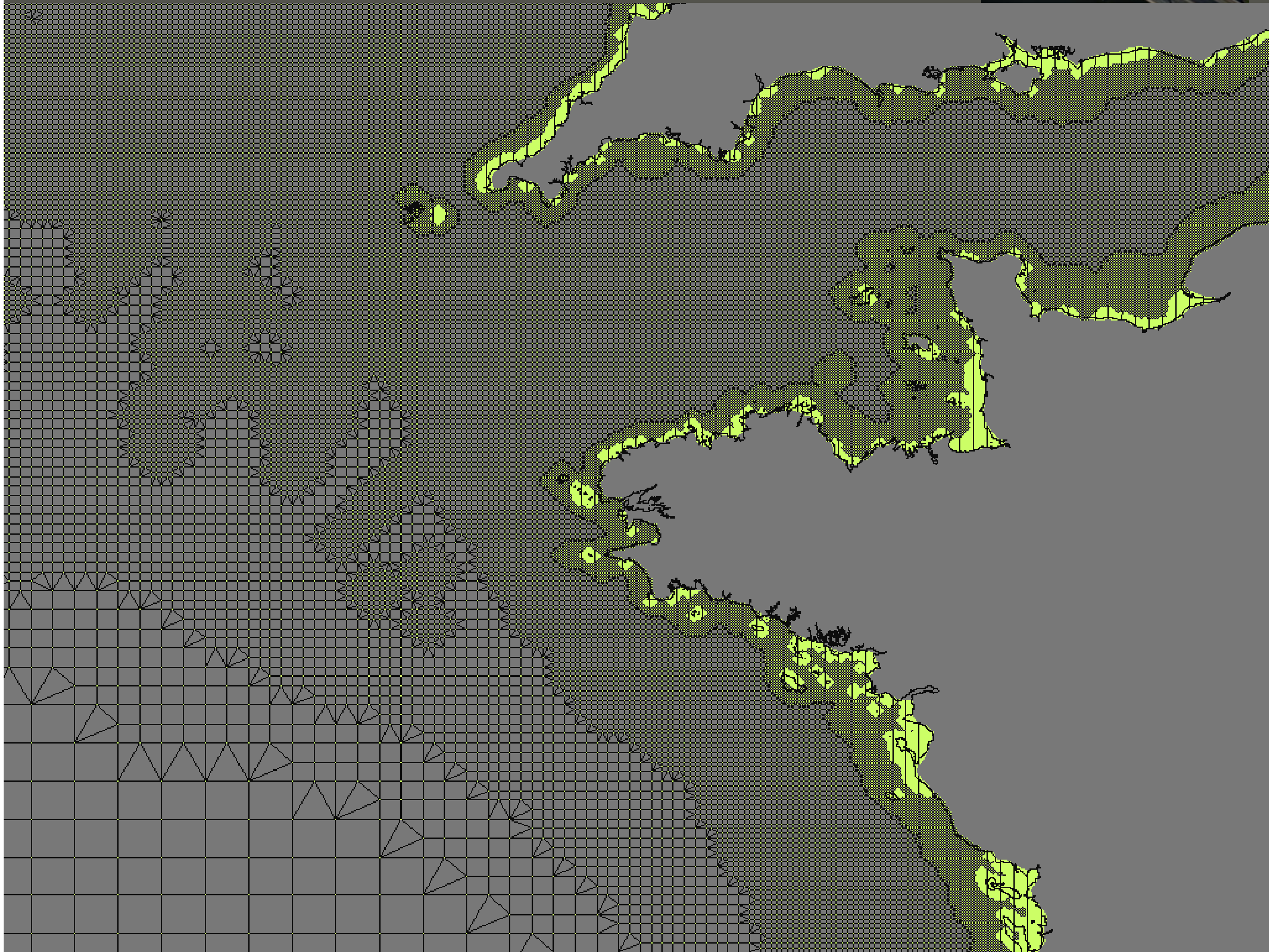
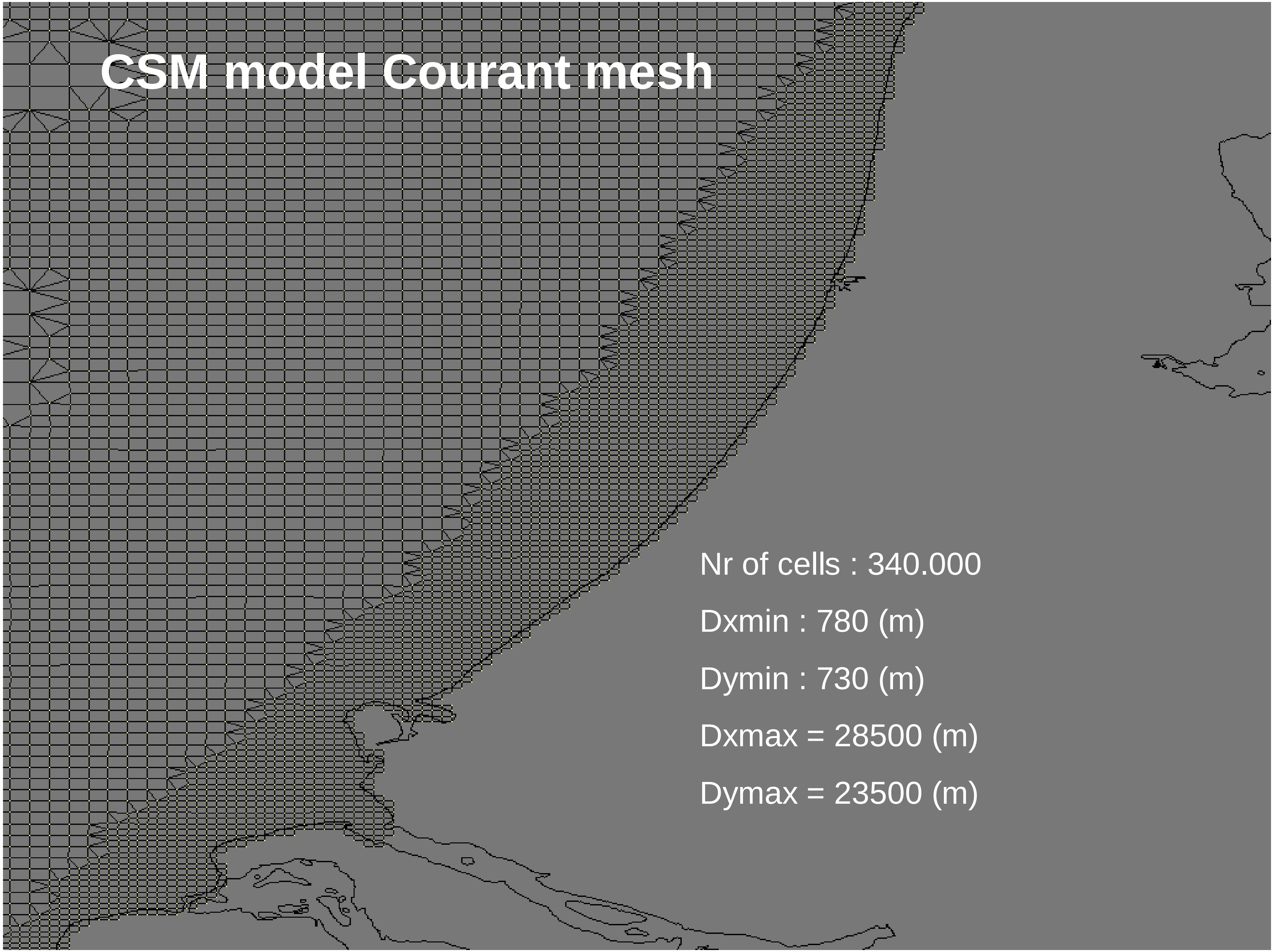
CSM model Courant mesh



CSM model Courant mesh



Nr of cells : 340.000

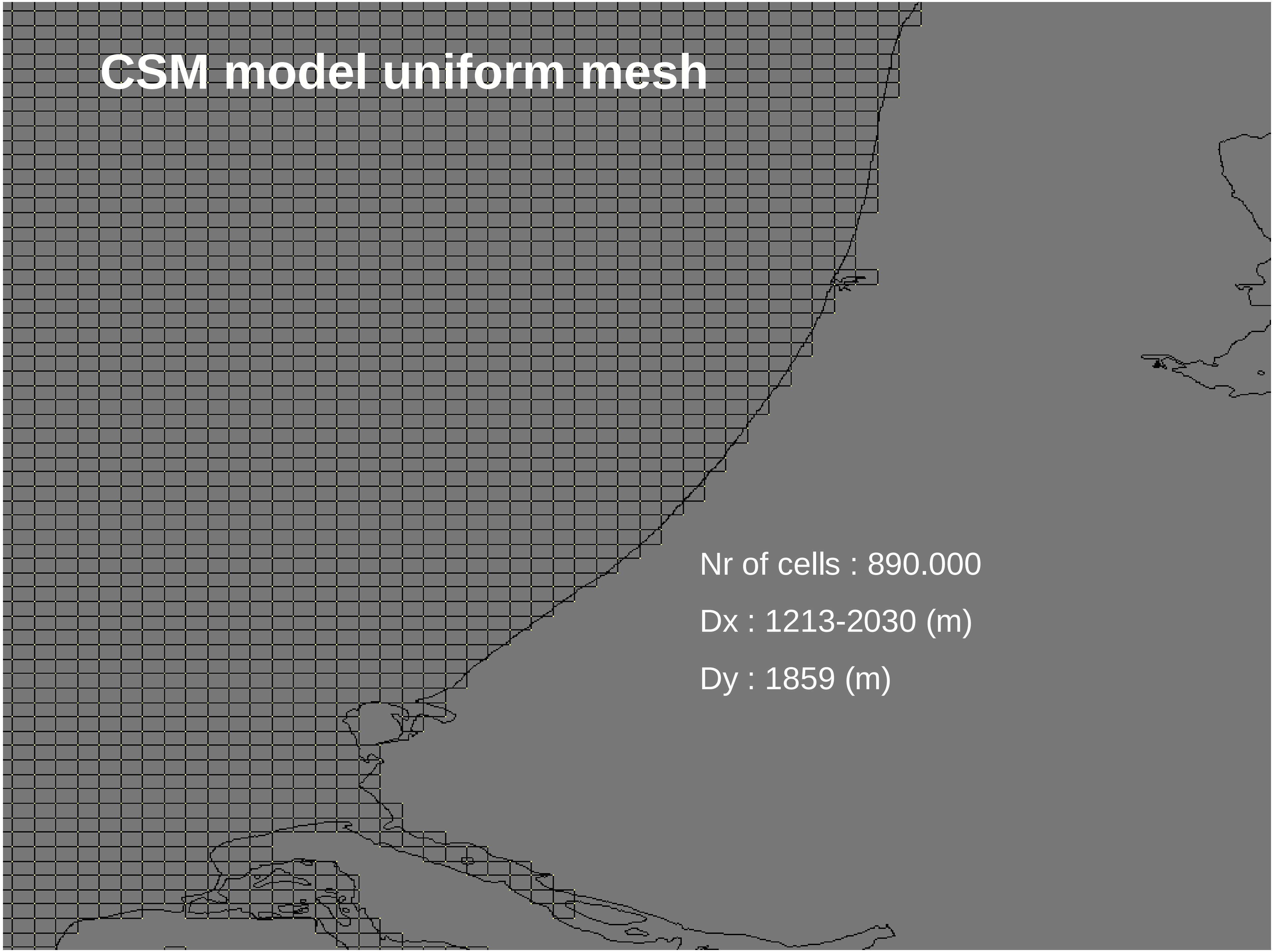
Dxmin : 780 (m)

Dymin : 730 (m)

Dxmax = 28500 (m)

Dymax = 23500 (m)

CSM model uniform mesh



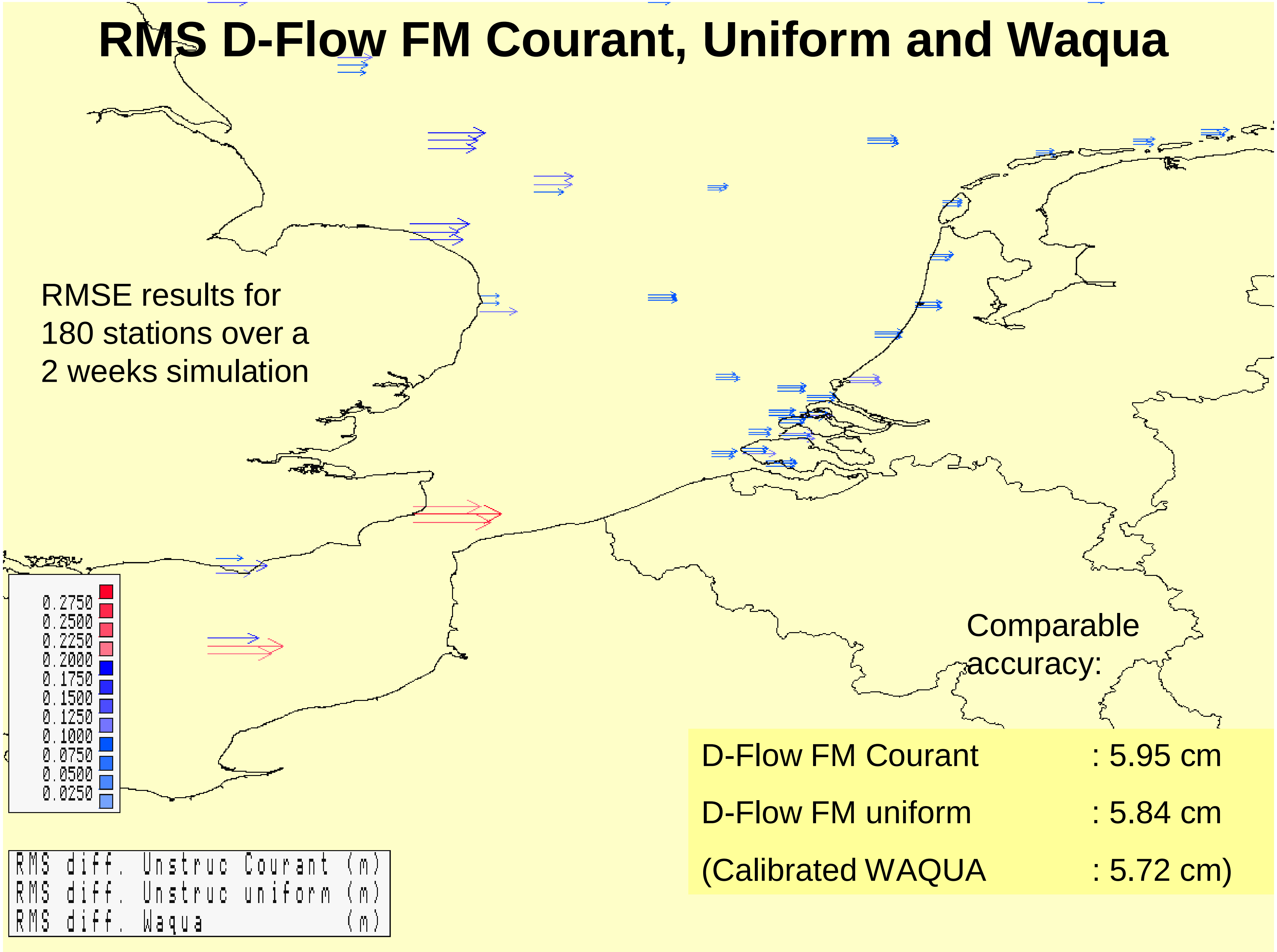
Nr of cells : 890.000

Dx : 1213-2030 (m)

Dy : 1859 (m)

RMS D-Flow FM Courant, Uniform and Waqua

RMSE results for
180 stations over a
2 weeks simulation



Comparable
accuracy:

D-Flow FM Courant	: 5.95 cm
D-Flow FM uniform	: 5.84 cm
(Calibrated WAQUA	: 5.72 cm)

Comparable accuracy, at what cost?
Comparison of computation times

Computation time one week of simulation DCMv5 (~9,3 km) in seconds

WAQUA	31s	(Dutch Rijkswaterstaat)
TRIWAQ	34s	
Delft3D-FLOW	60s	(Delft3D curvilinear)
D-Flow FM (**single** thread)	84s	
D-Flow FM (**eight** thread)	35s	
D-Flow FM (**eight** thread, Saad ilud bcgstab)	24s	(D-Flow FM, same grid)

D-Flow FM competes in computation time with established packages (in spite of possibly expected data structure overhead).

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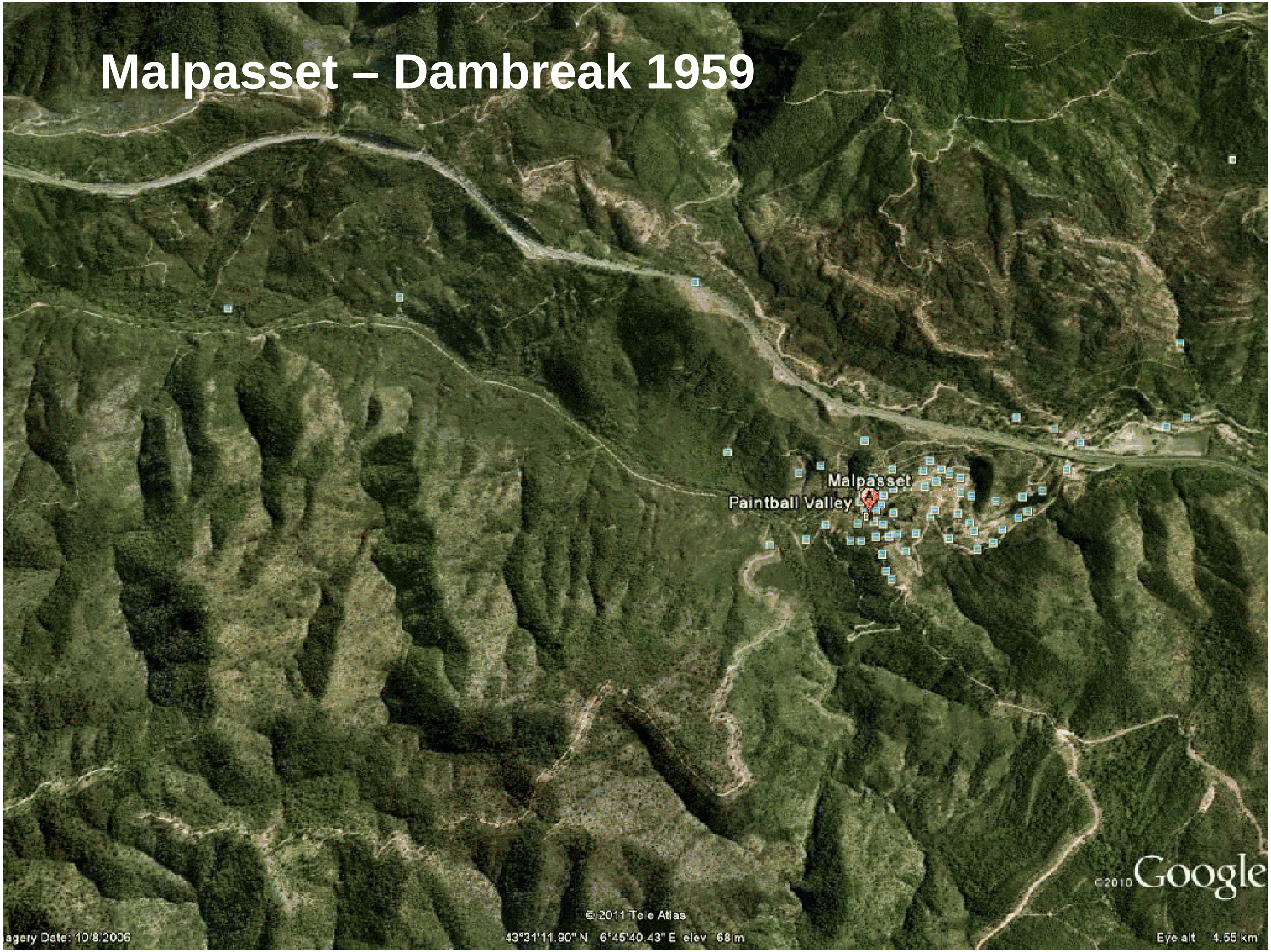
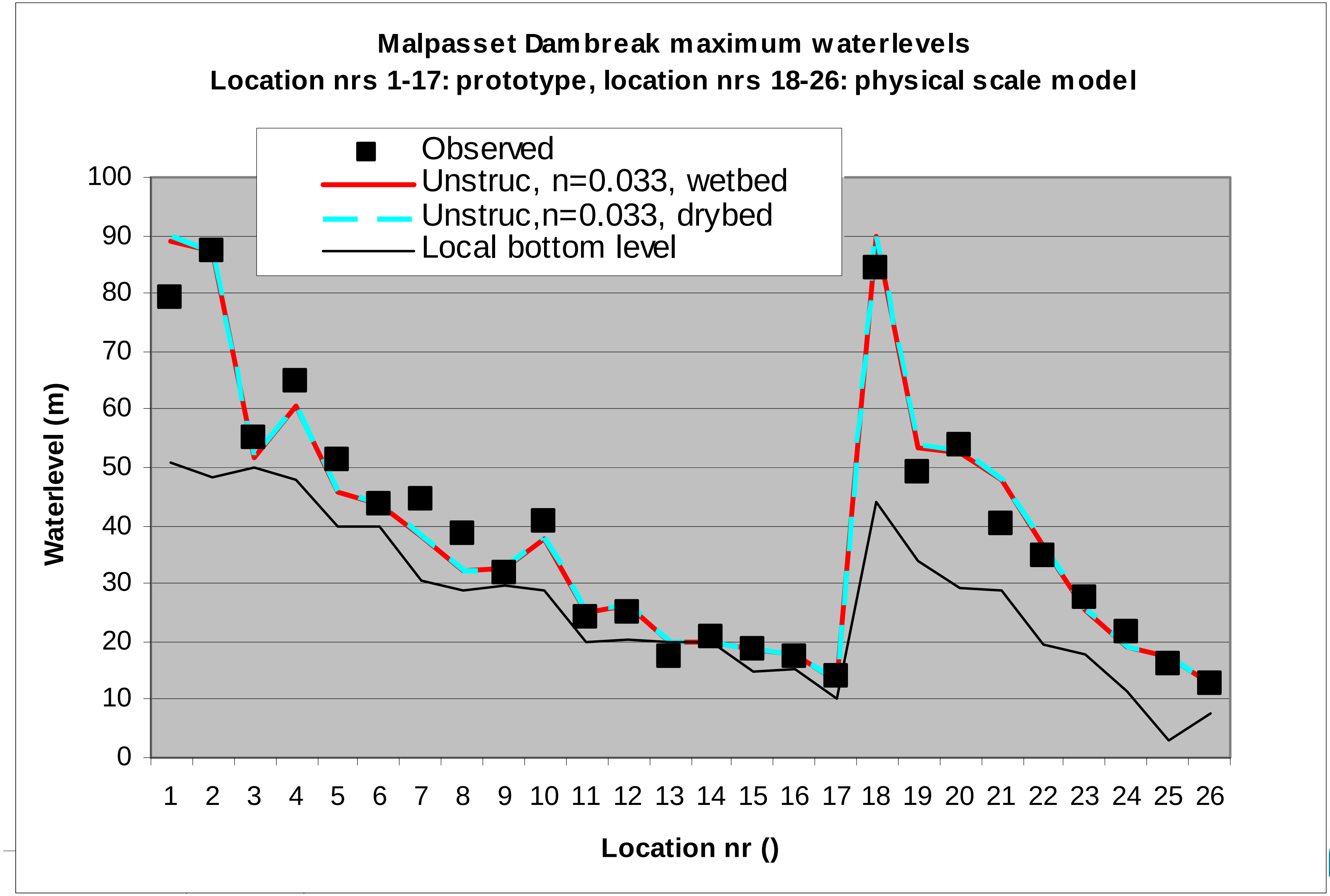
Malpasset – Dambreak 1959



Malpasset Dambreak



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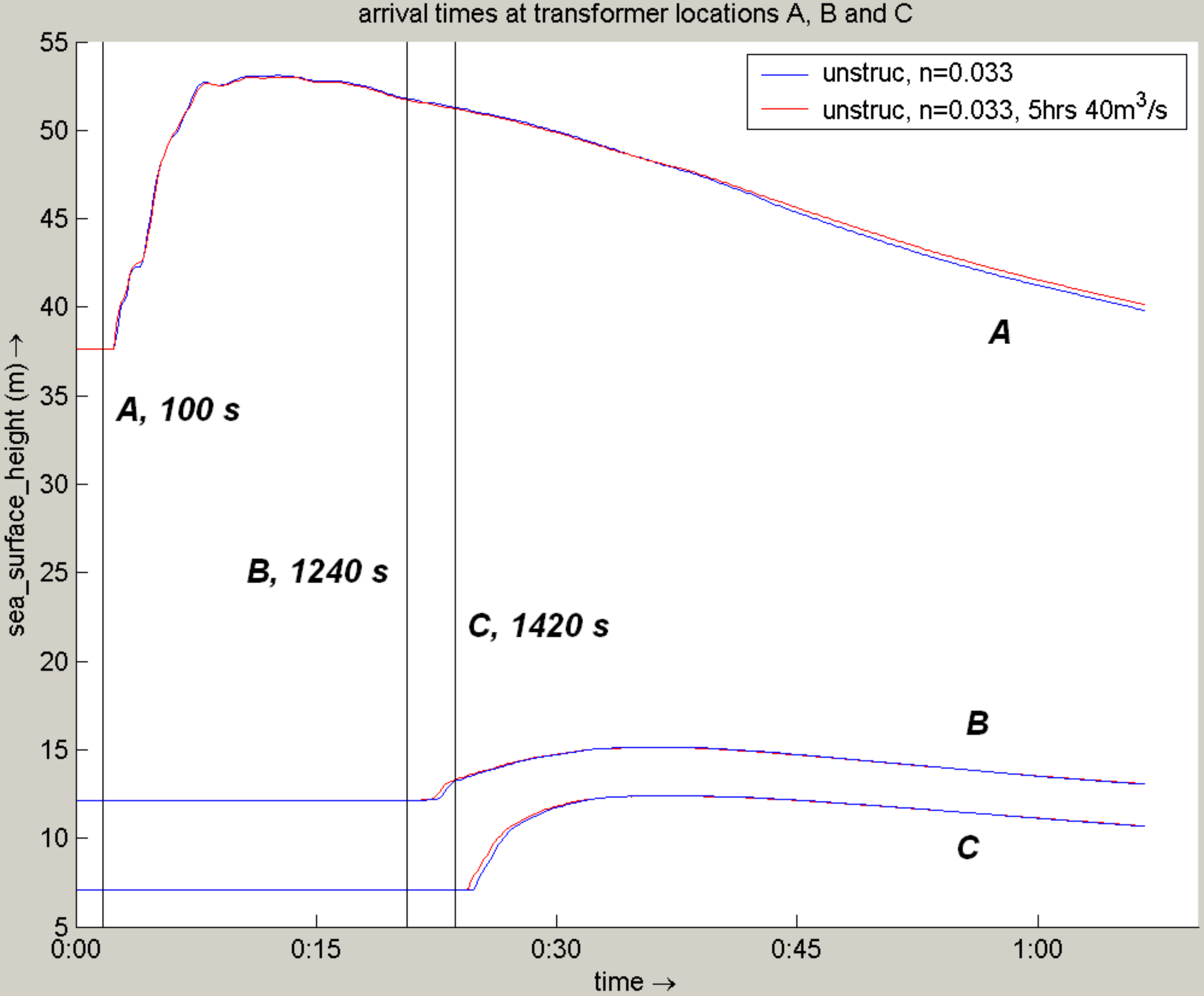
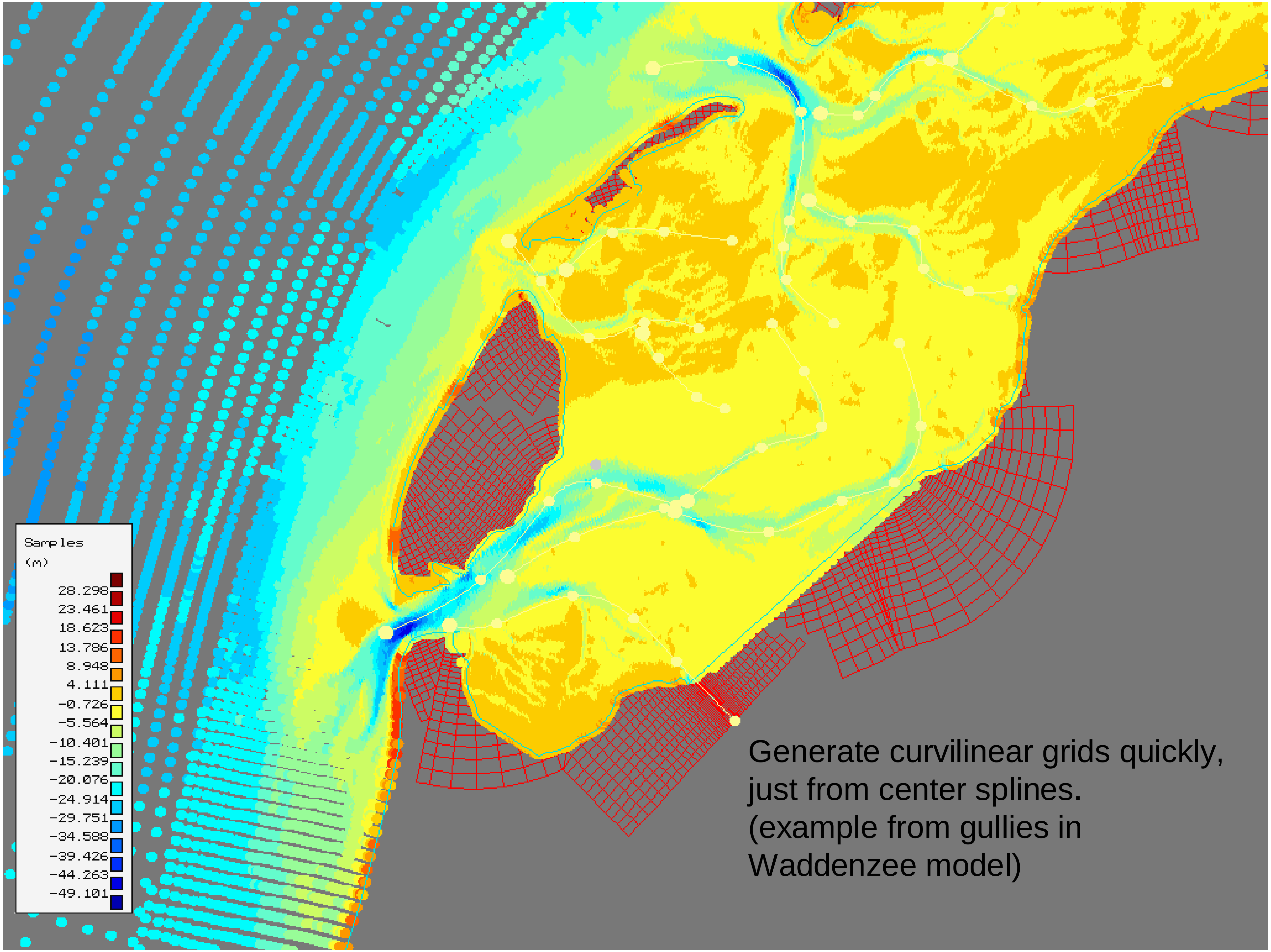
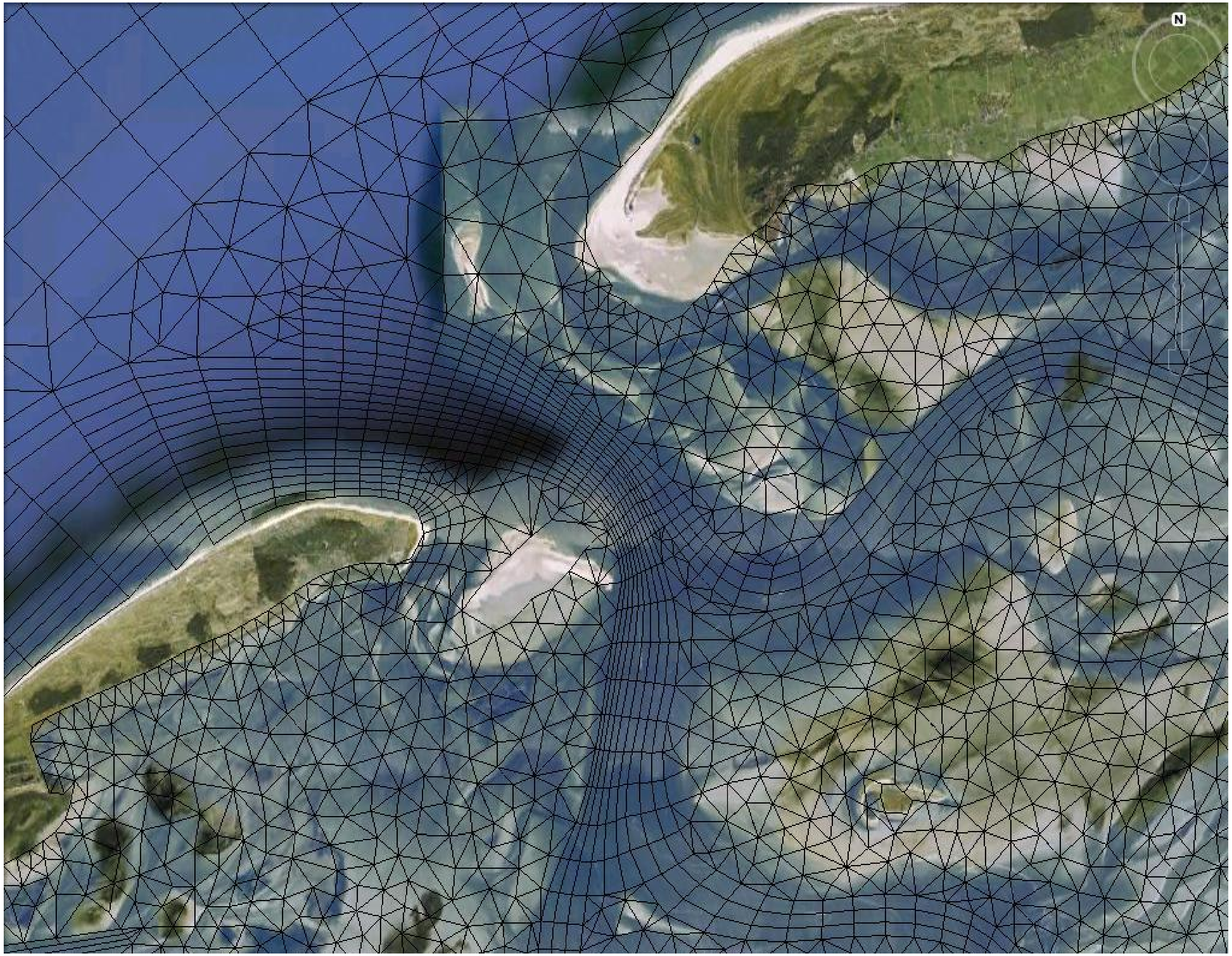
Malpasset Dambreak





Generate curvilinear grids quickly, just from center splines. (example from gullies in Waddenzee model)

Waddensea (Gerben de Boer Deltares, 2010)



2010: Preliminary conclusion:

results OK but slower

mesh generation:

(*time consuming*)

2011: center-spline based generation + new ortho-smooth combination is great improvement!

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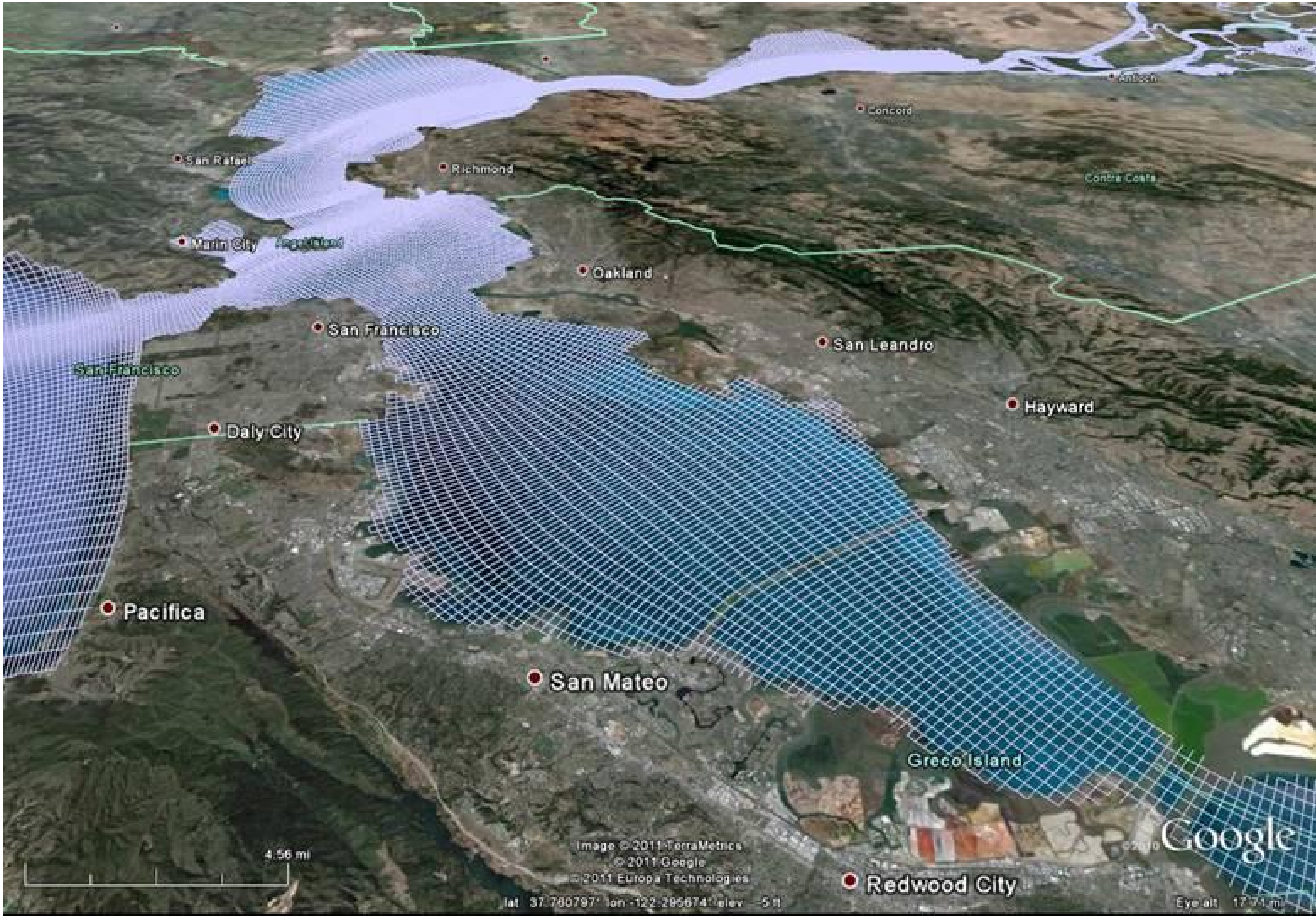
CASCaDE II: Sacramento River Delta (Mick vd Wegen IHE-USGS)



CASCaDE II: Sacramento River Delta (vd Wegen IHE-USGS)

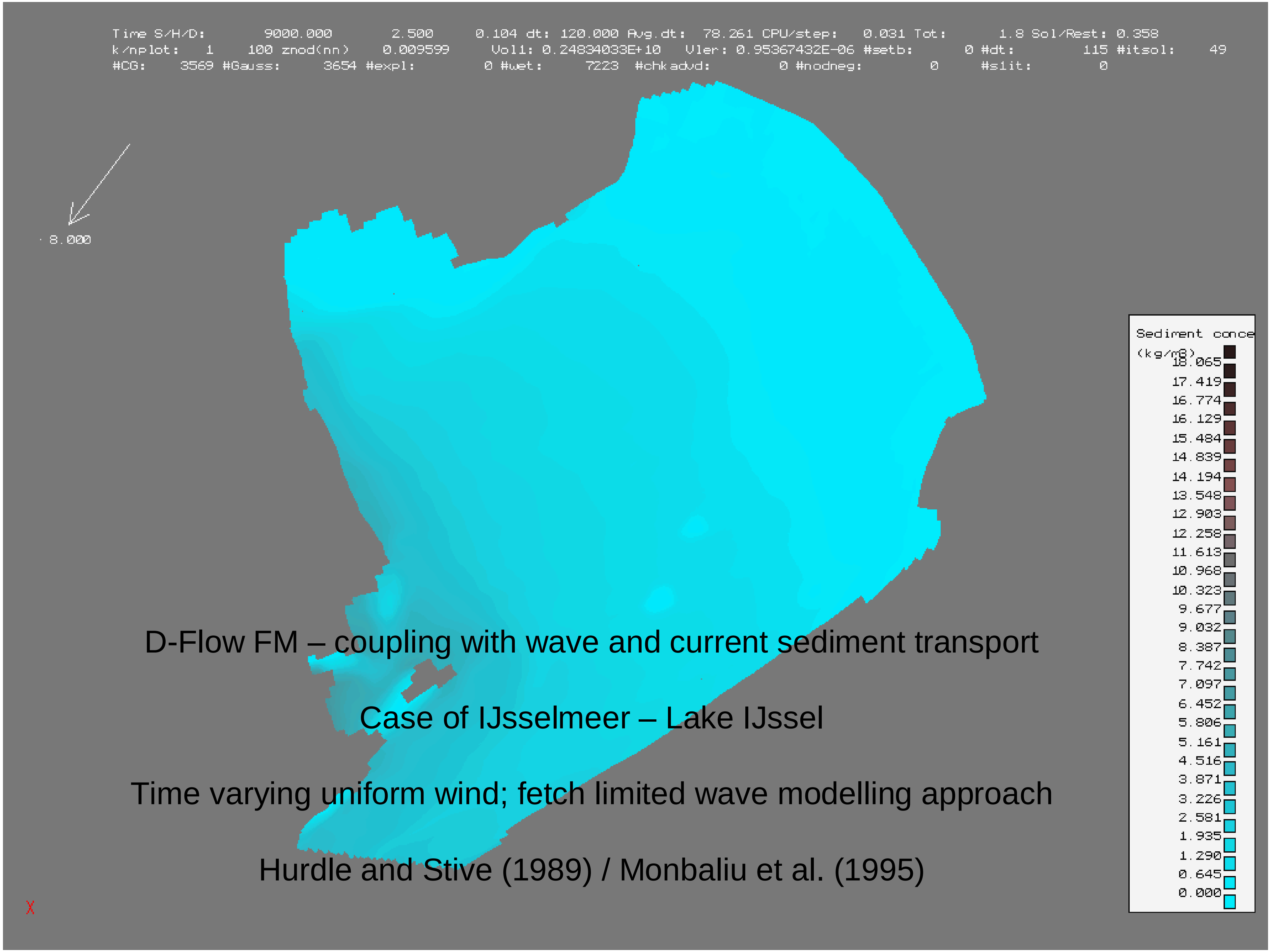
Preliminary conclusion:

2Dh OK

Controllable dam

Small cells slow down significantly

But: with CFL=2.0 factor 3 gain in overall computation time



D-Flow FM – coupling with wave and current sediment transport

Case of IJsselmeer – Lake IJssel

Time varying uniform wind; fetch limited wave modelling approach

Hurdle and Stive (1989) / Monbaliu et al. (1995)

Next steps:

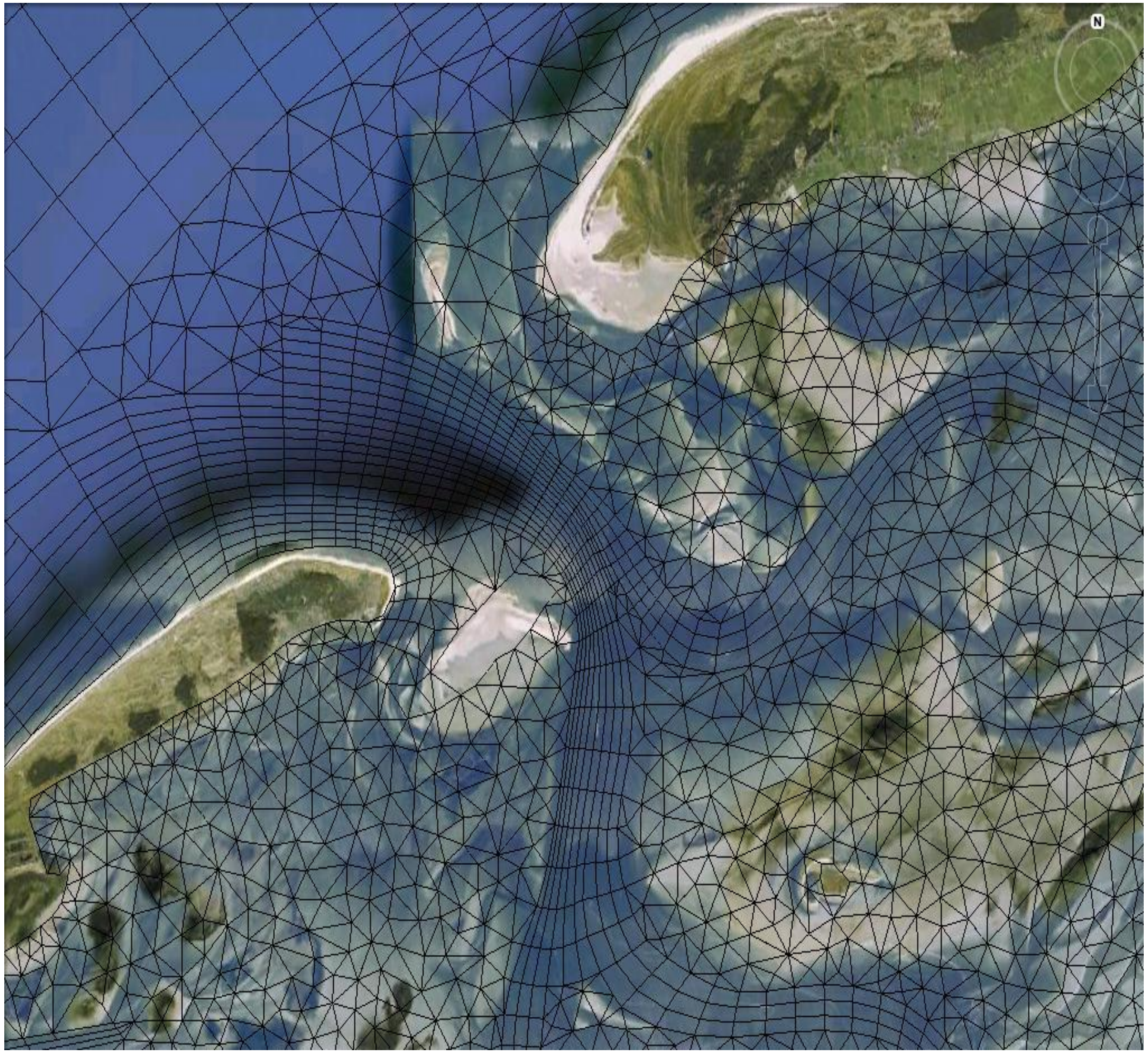
Influence of passing ships on moored ships incl. sediment stirring

1D - 2D
Last details of the 1D-2D coupling
Full size test model on 1D profiles
Non-linear continuity for closed pipes

2D
River test case

3D
Implement partially variable nr of layers
Spatially variable sigma / Z layer approach
Sediment transport, morphology, wave coupling

End of Presentation



Questions?

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