Deltares

Enabling Delta Life

One- two- and three-dimensional hydrodynamic modelling with D-Flow Flexible Mesh

Herman Kernkamp, Sander v/d Pijl, Arthur v Dam,
Wim v Balen, Willem Ottevanger, Guus Stelling

D-Flow FM

Why DFM?

Specific features of DFM

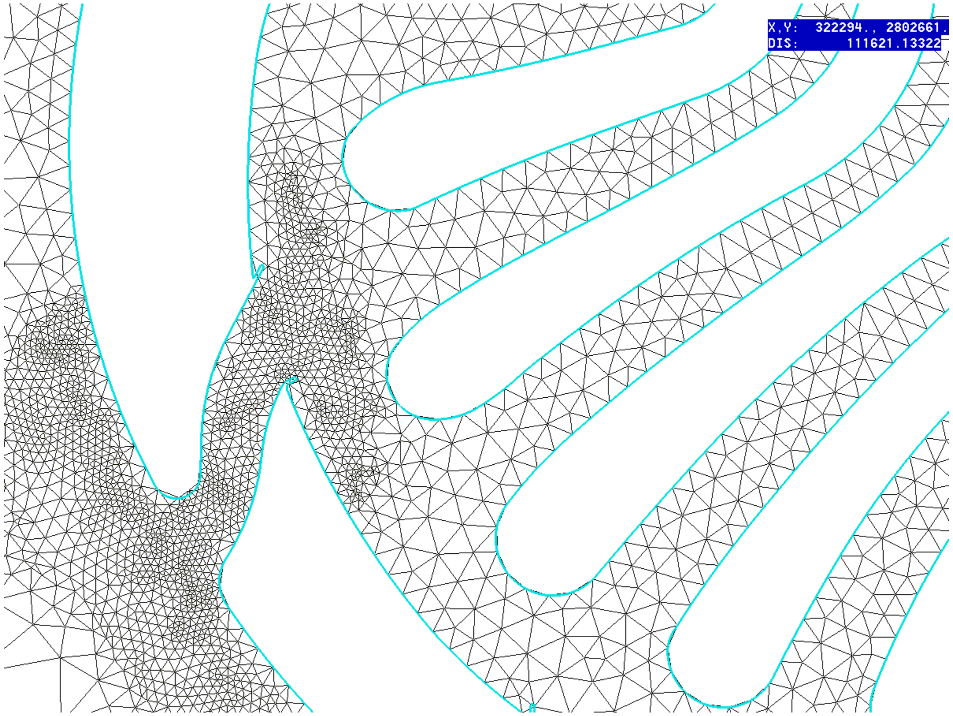
Some applications

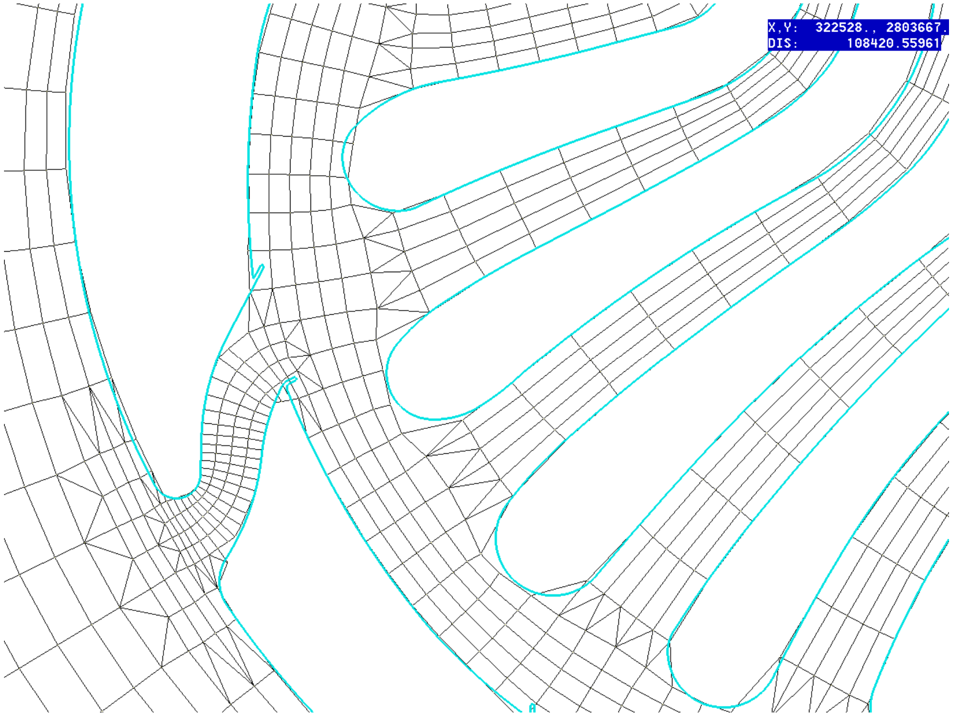
Why DFM


Sobek-1D2D

Delft3D/TRIWAQ

Preferred : Curvilinear + occasional triangle





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US Dept of State Geographer
Image Landsat
© 2013 Mapabc.com
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Imagery Date: 4/10/2013 1°08'23.28" S 119°55'37.54" E elev -593 ft eye alt 4186.37 mi
Google earth


Celebes Sea
Pulau Tarakan
East Kalimantan
Borneo
West Kalimantan
Indonesia
Central Kalimantan
Makassar Strait
Gorontalo
North Sulawesi
Gulf of Tomini
Molucca Sea
Sulawesi (Celebes)
South Sulawesi
Gulf of Boni
Java Sea
Banda Sea
Semarang
© 2013 MapIt
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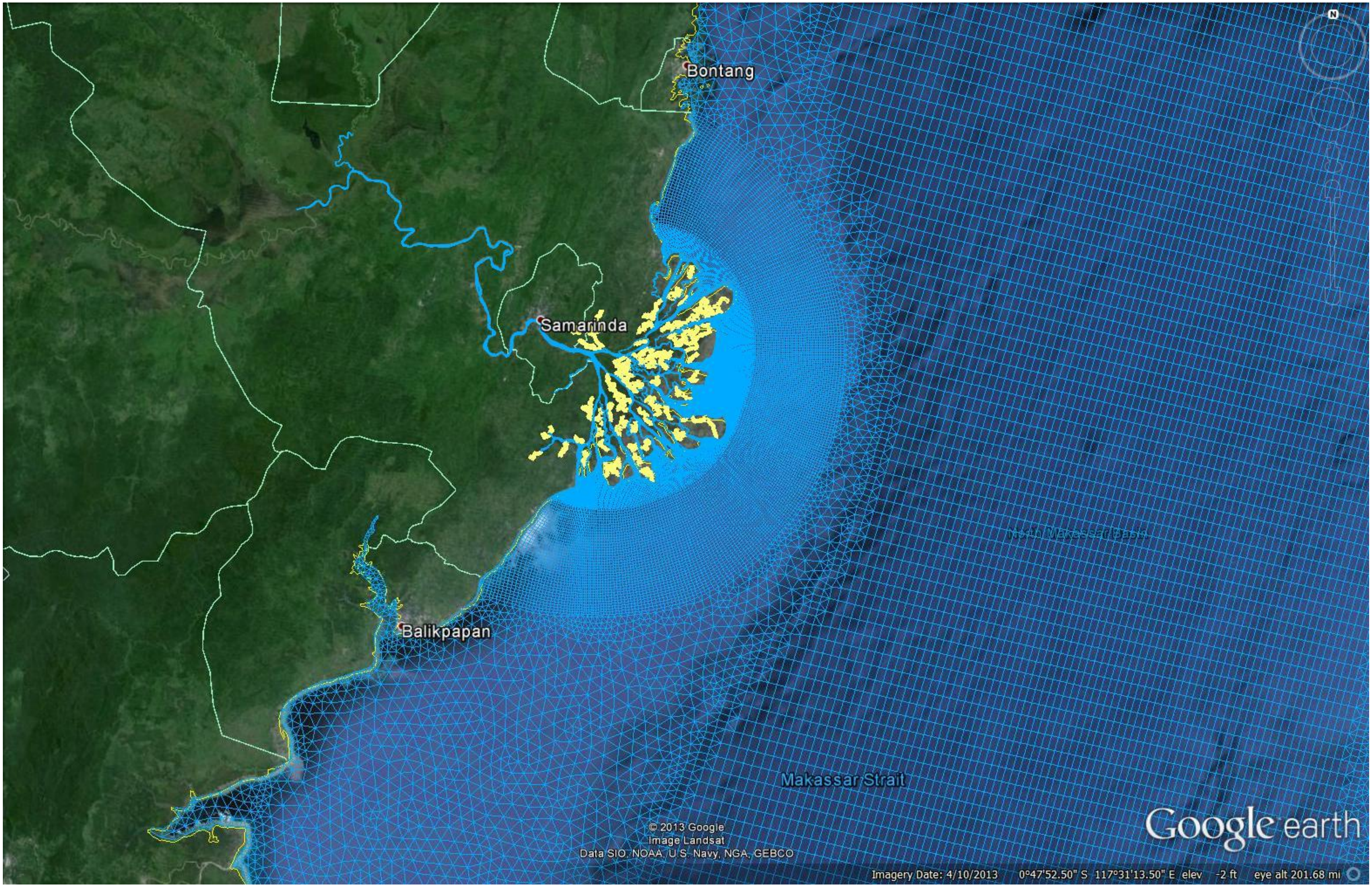
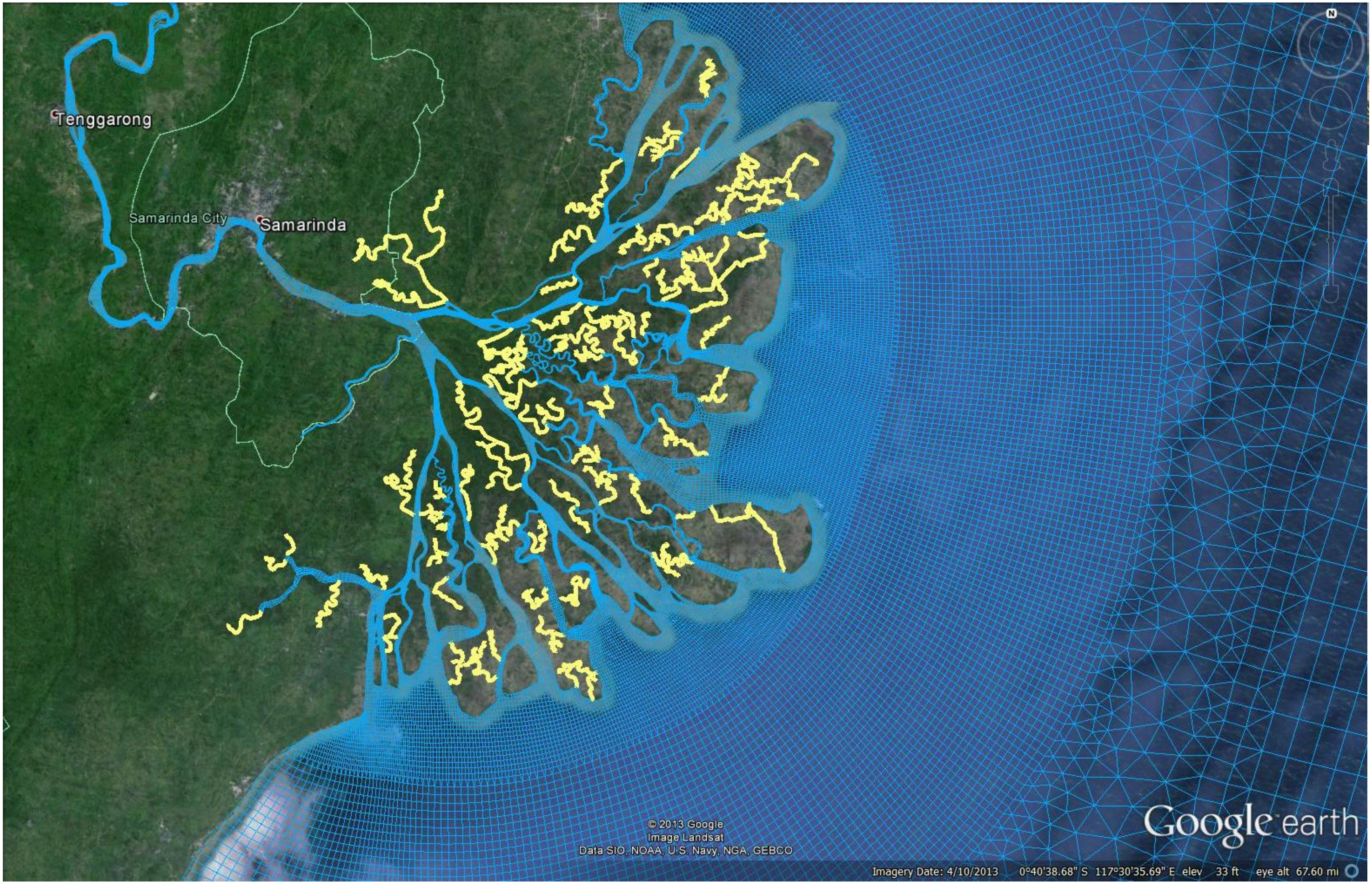
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth
Imagery Date: 4/10/2013 1°30'23.23" S 118°50'32.19" E elev -6151 ft eye alt 1009.76 mi


Bontang
Samarinda
Balikpapan
Makassar Strait
© 2013 Google
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth
Imagery Date: 4/10/2013 0°47'52.50" S 117°31'13.50" E elev -2 ft eye alt 201.68 mi


Tenggarong
Samarinda City
Samarinda
© 2013 Google
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth
Imagery Date: 4/10/2013 0°40'38.68" S 117°30'35.69" E elev 33 ft eye alt 67.60 mi

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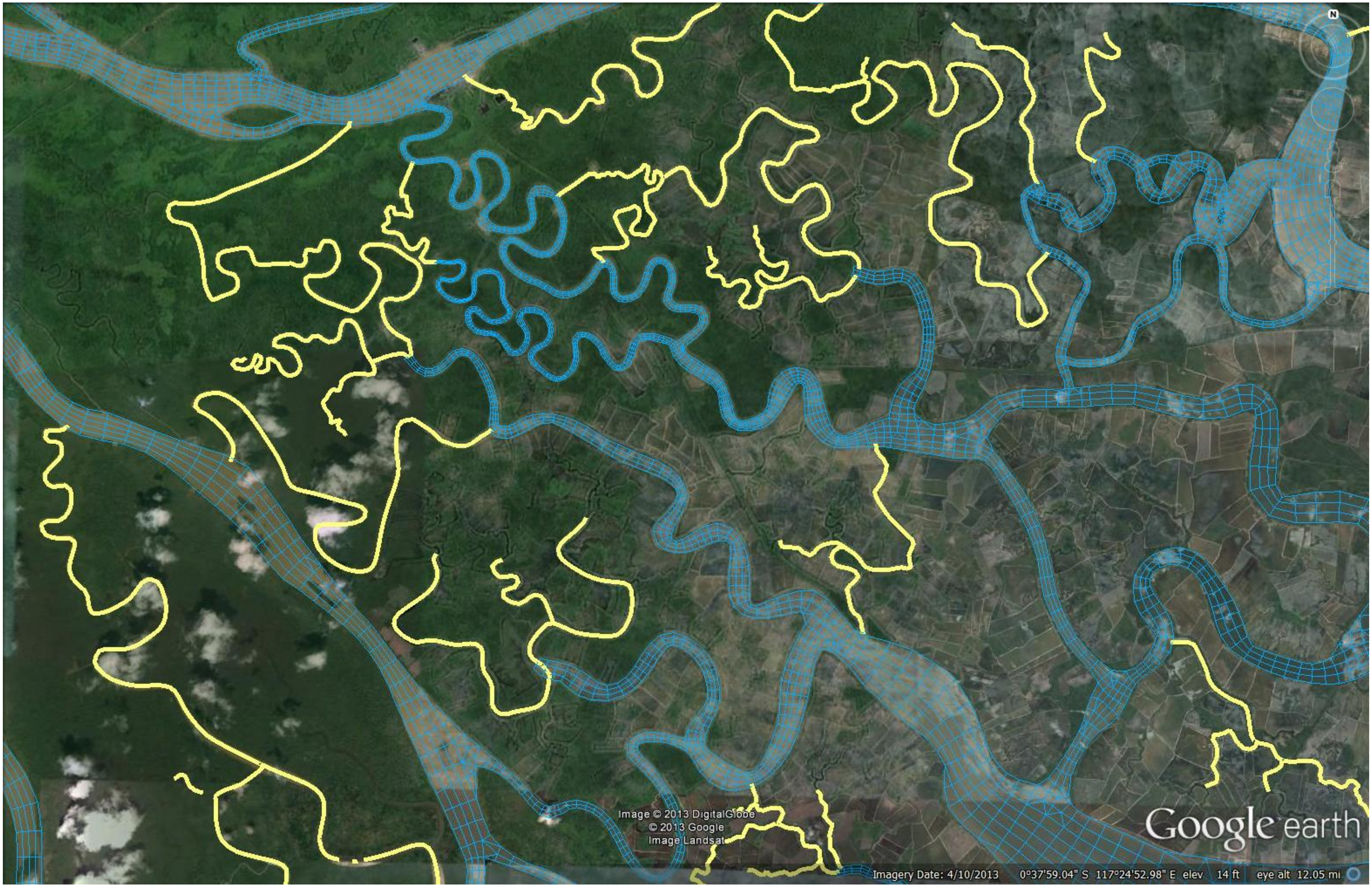
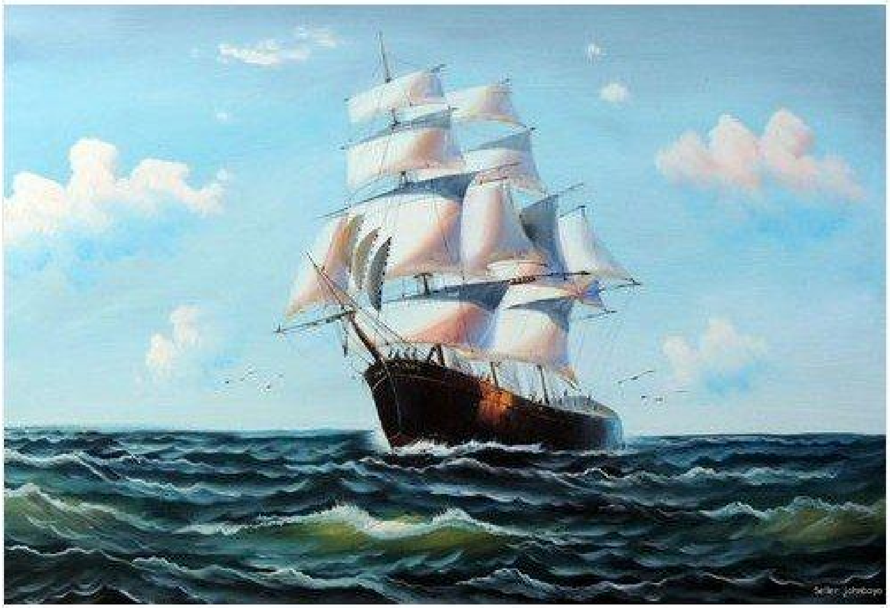


Image © 2013 DigitalGlobe
© 2013 Google
Image Landsat
Google earth
Imagery Date: 4/10/2013 0°37'59.04" S 117°24'52.98" E elev 14 ft eye alt 12.05 mi

Specific features of DFM

Flow speed vs Wave speed



1-2 m/s => Advection explicit

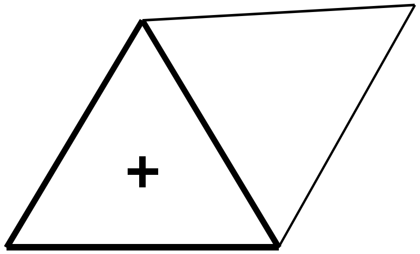
221 m/s => Pressures implicit

Finite volume approach

Conservation of:

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

Volume

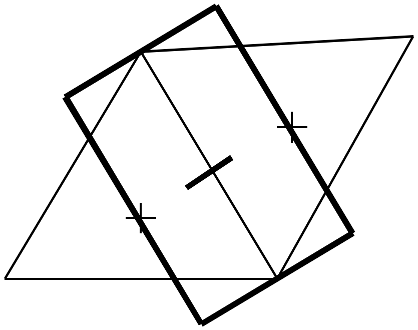


$$\frac{\partial Vc}{\partial t} = \sum_{in\zeta} Qc_{in} - \sum_{out\zeta} Qc_{out}$$

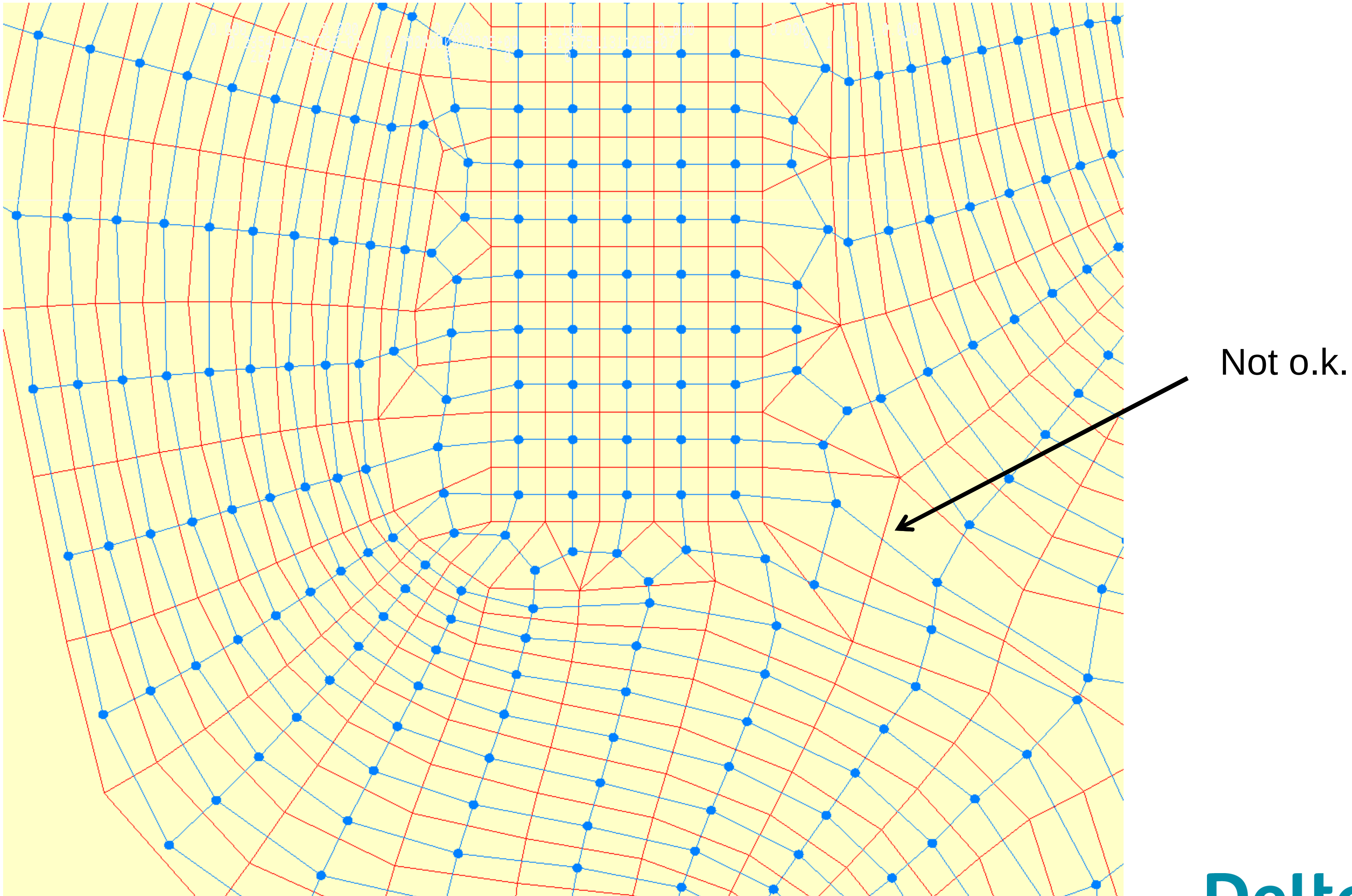
Mass

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

Momentum



Not Orthogonal



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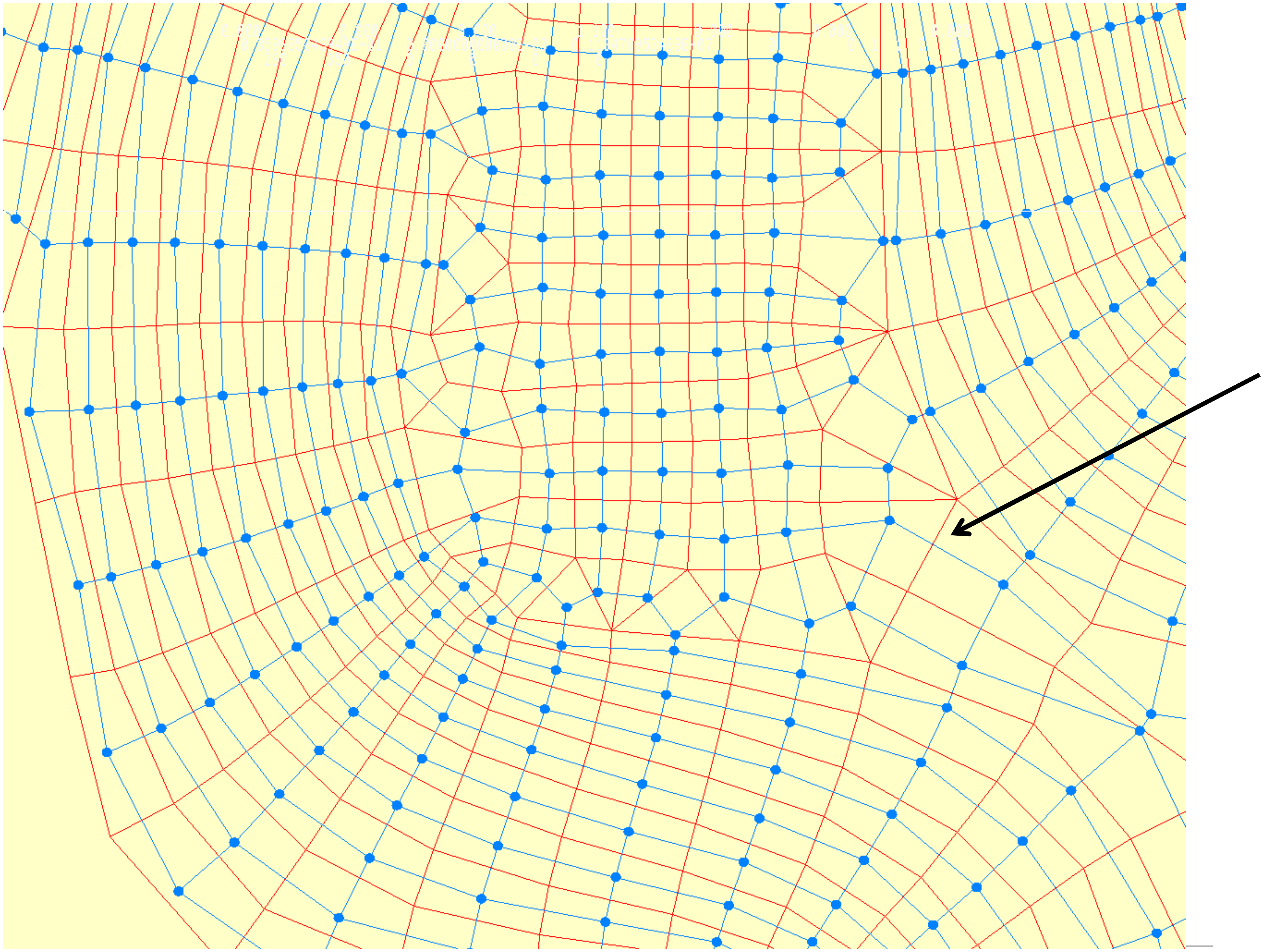
Orthogonal !



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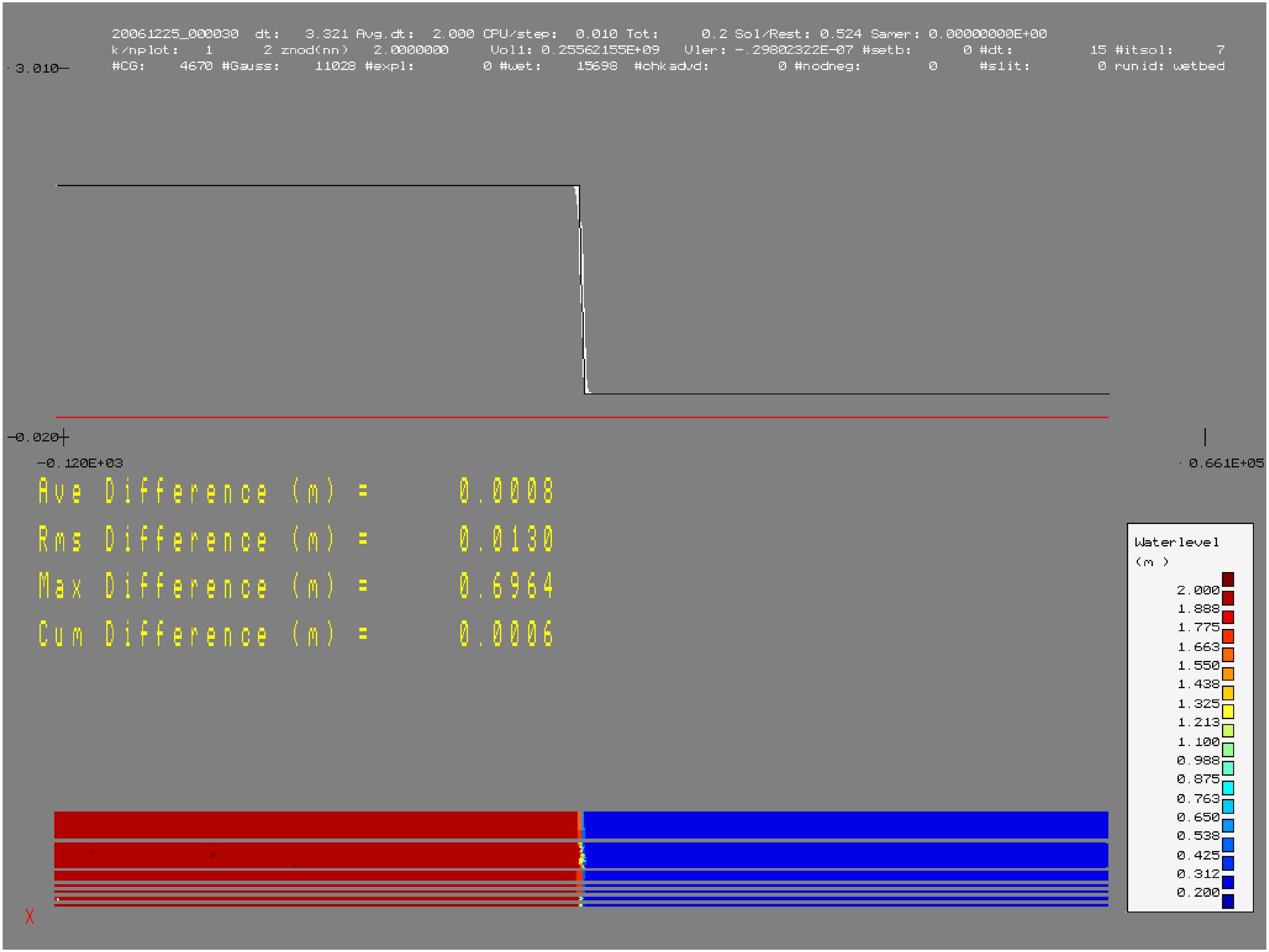
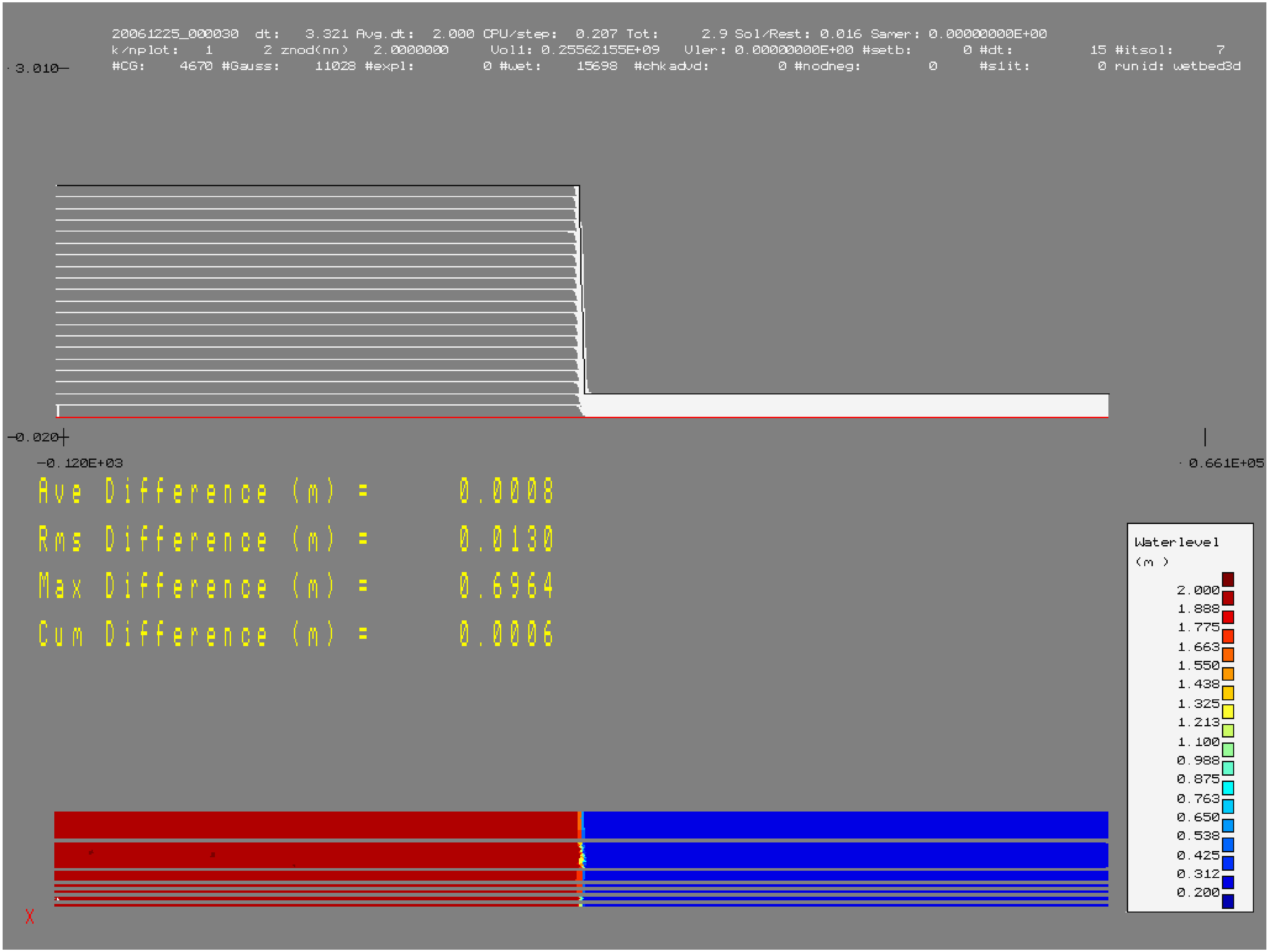
Shock capturing advection scheme


20061225_000030 dt: 3.321 Avg.dt: 2.000 CPU/step: 0.010 Tot: 0.2 Sol/Rest: 0.524 Samer: 0.00000000E+00
k/nplot: 1 2 znod(nn) 2.0000000 Vol1: 0.25562155E+09 Vler: -.29802322E-07 #setb: 0 #dt: 15 #itsol: 7
#CG: 4670 #Gauss: 11028 #expl: 0 #wet: 15698 #chkadvd: 0 #nodneg: 0 #slit: 0 runid: wetbed
3.010
-0.020
-0.120E+03
0.661E+05
Ave Difference (m) = 0.0008
Rms Difference (m) = 0.0130
Max Difference (m) = 0.6964
Cum Difference (m) = 0.0006
Waterlevel
(m)
2.000
1.888
1.775
1.663
1.550
1.438
1.325
1.213
1.100
0.988
0.875
0.763
0.650
0.538
0.425
0.312
0.200
X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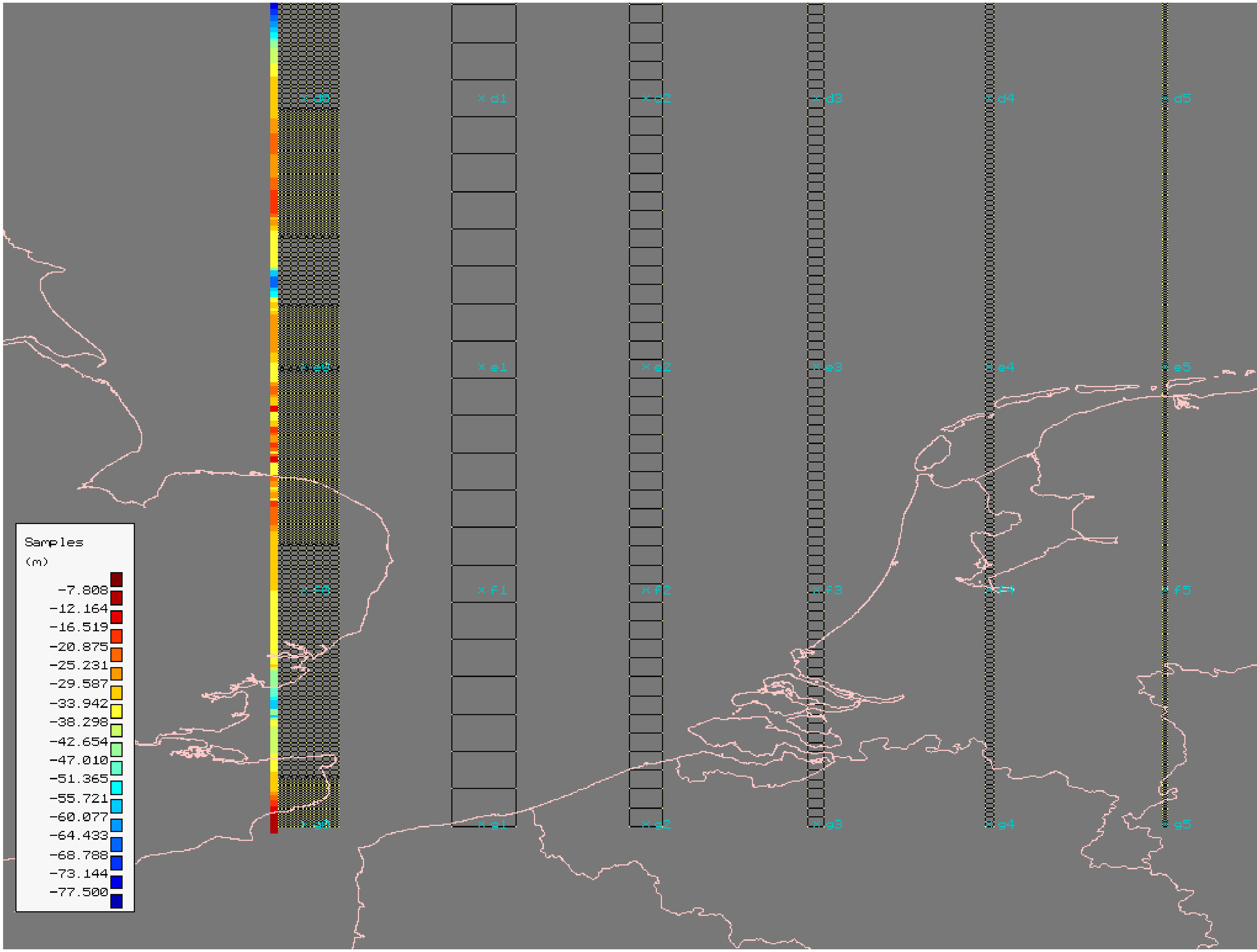
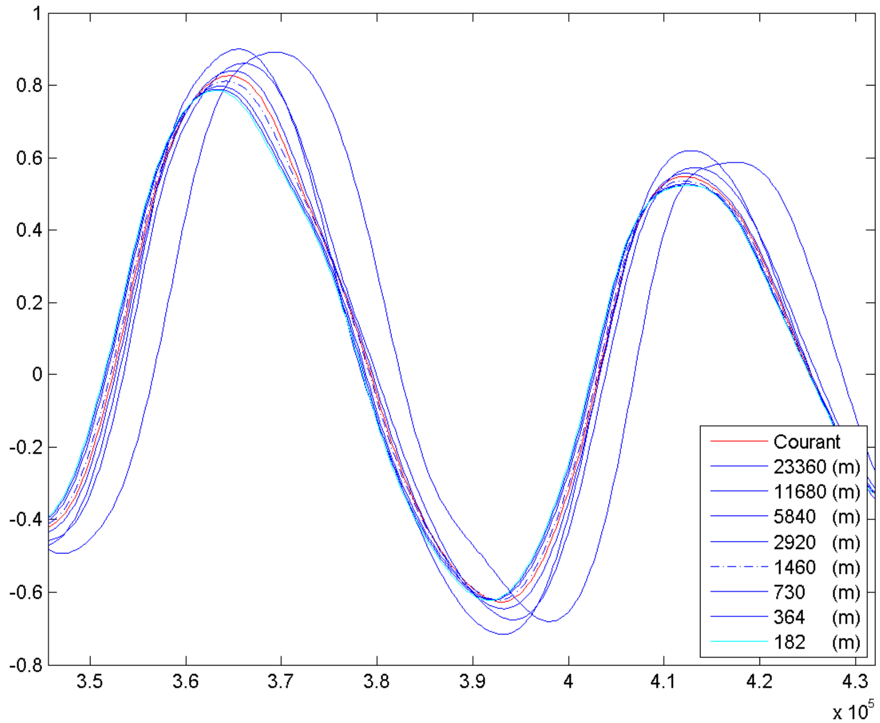
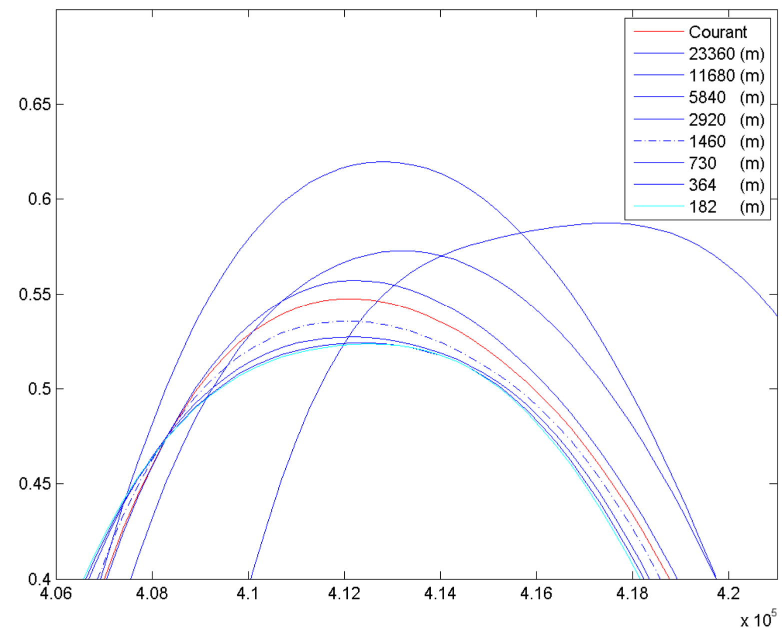
k/nplot: 1 2 znod(nn) 2.0000000 Vol1: 0.25562155E+09 Vler: 0.00000000E+00 #setb: 0 #dt: 15 #itsol: 7
#CG: 4670 #Gauss: 11028 #expl: 0 #wet: 15698 #chkadvd: 0 #nodneg: 0 #slit: 0 runid: wetbed3d
3.010
-0.020
-0.120E+03
0.661E+05
Ave Difference (m) = 0.0008
Rms Difference (m) = 0.0130
Max Difference (m) = 0.6964
Cum Difference (m) = 0.0006
Waterlevel
(m)
2.000
1.888
1.775
1.663
1.550
1.438
1.325
1.213
1.100
0.988
0.875
0.763
0.650
0.538
0.425
0.312
0.200
X

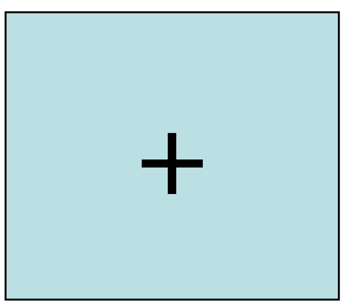
Spatial convergence



Grid convergence parallel: cell centre bathy.







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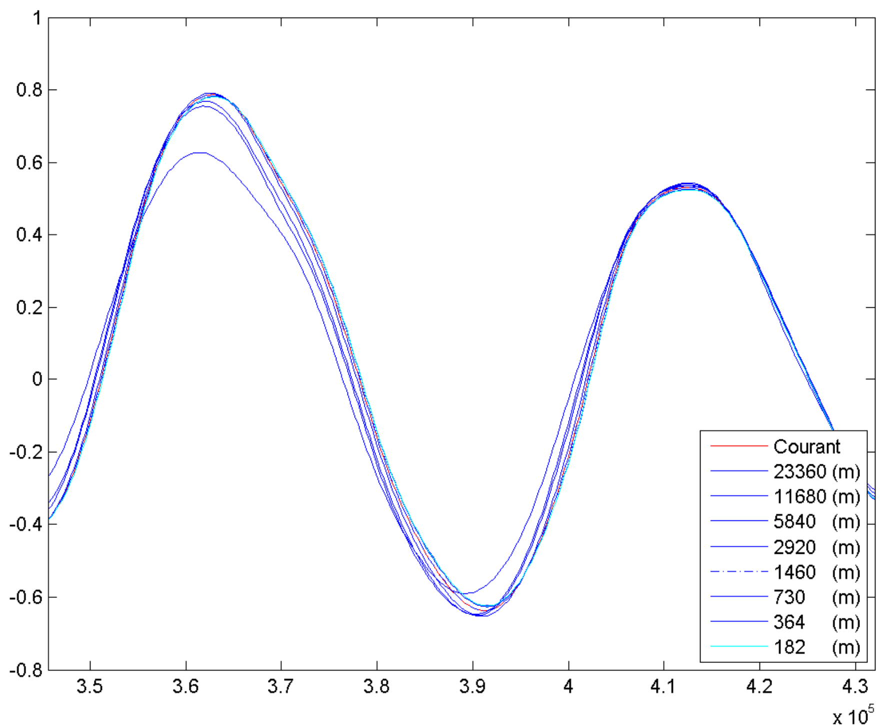
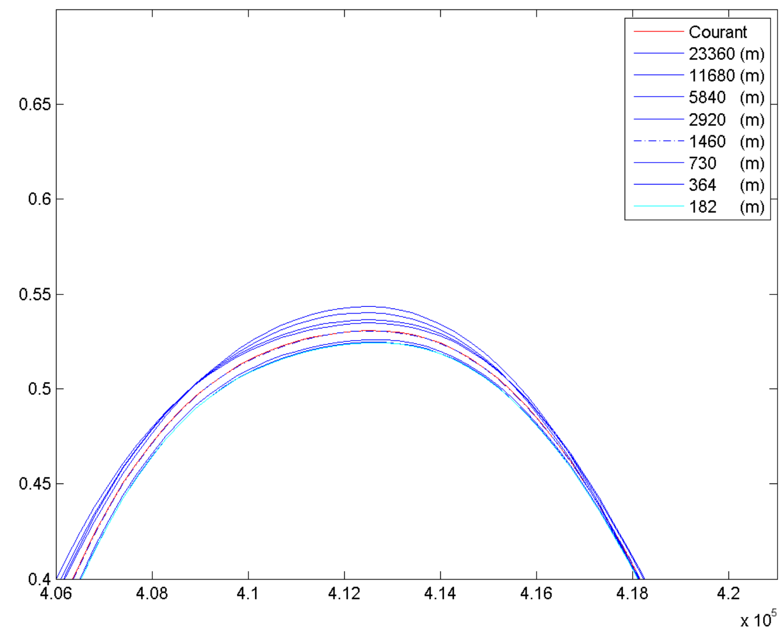
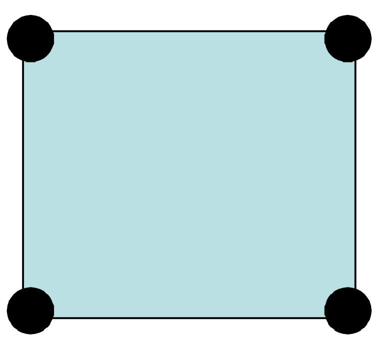
Grid convergence parallel: netnode bathy.







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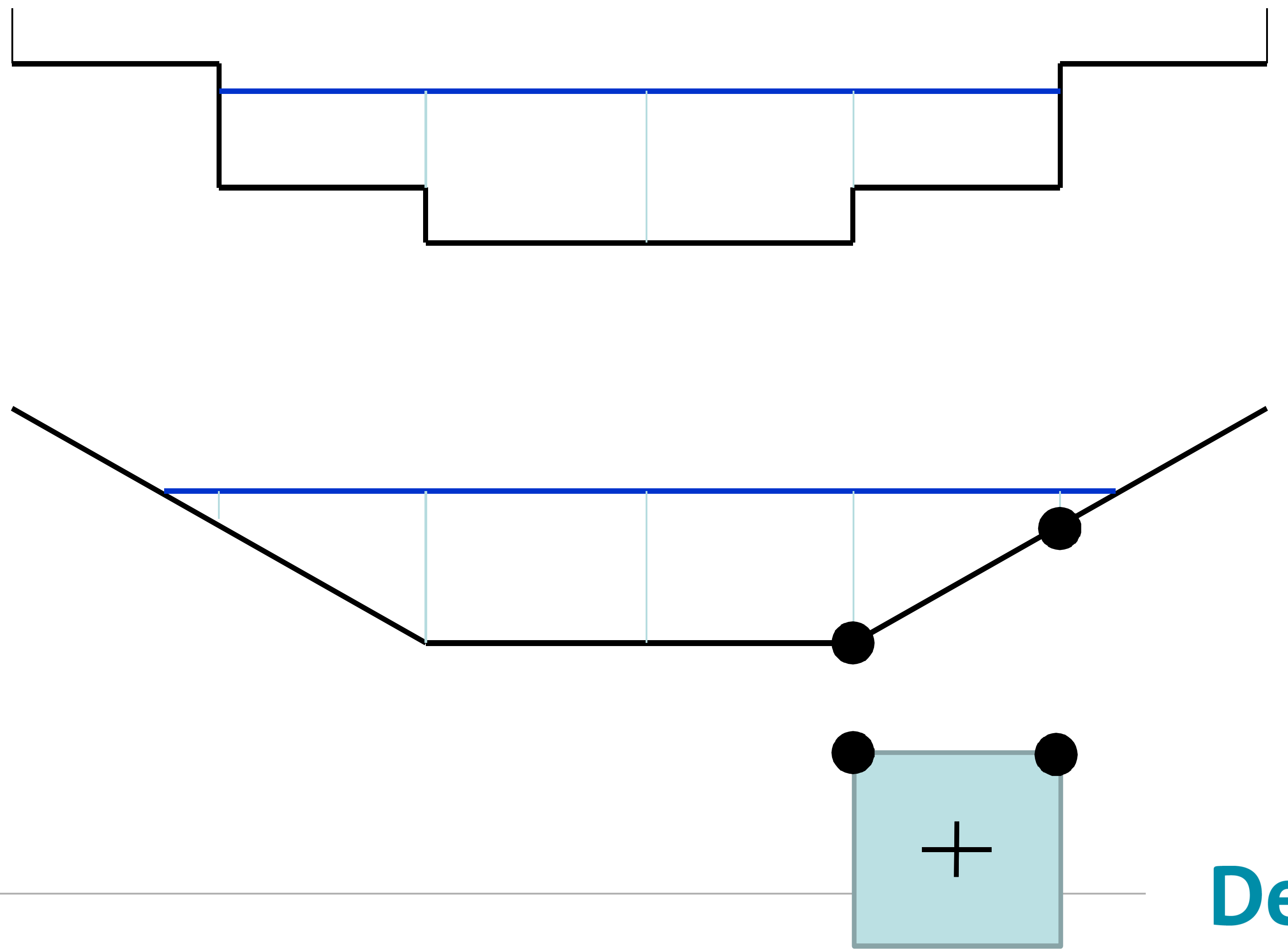
Continuous wet area => more gradual drying&flooding




File Edit View Tools Add Help
hong kong
Exit Photo
peak flows ~ 6 m/s
©2009 Google
Eye alt 10 m

Subgrid: Analytic 2D Conveyance approach

$$\frac{uU}{C^2R} = i, U = \frac{u}{\beta^2}$$

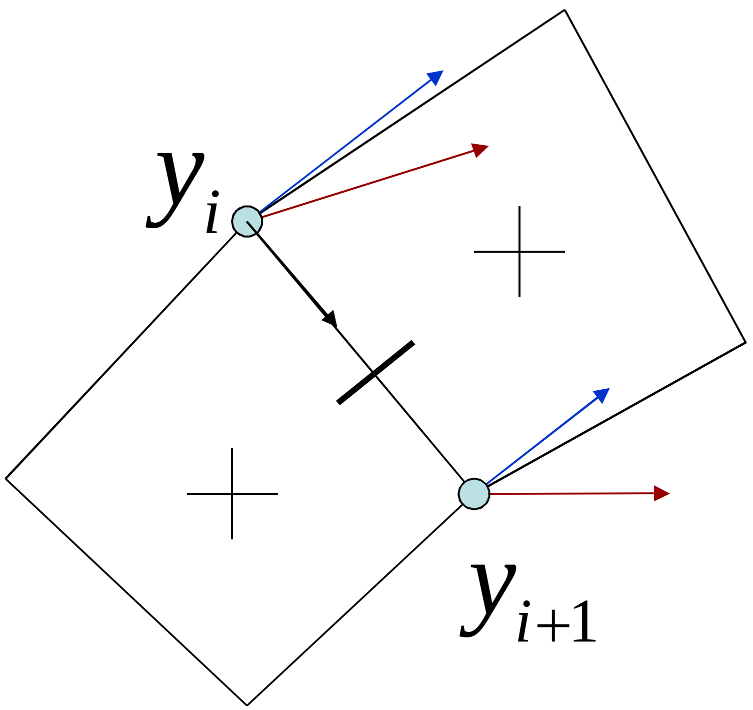
$$u_j = \beta C\sqrt{R_j}\sqrt{i}, K_\beta = \frac{\beta A_j R_j^{\frac{2}{3}}}{n}$$

$$\beta = \beta_i - \delta\left(y - y_i\right), \delta = \frac{\beta_i - \beta_{i+1}}{y_{i+1} - y_i}$$

$$K_\beta = \int_{y_i}^{y_{i+1}} \frac{\beta_i - \delta\left(y - y_i\right)}{n\left(1+\alpha_i^2\right)^{\frac{1}{4}}}\left(h_i - \alpha_i\left(y - y_i\right)\right)^{\frac{5}{3}} dy$$

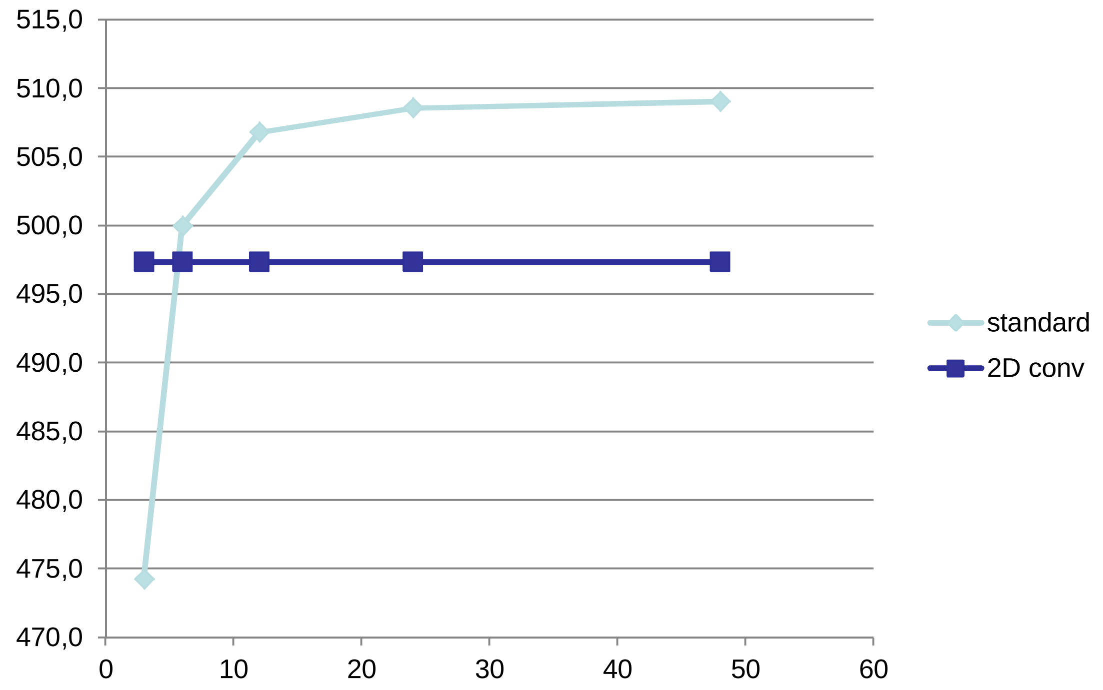
$$K_\beta = \frac{T}{n\left(1+\alpha_i^2\right)^{\frac{1}{4}}}$$

$$T = \int_{y_i}^{y_{i+1}} \left(\beta_i - \delta\left(y - y_i\right)\right)\left(h_i - \alpha_i\left(y - y_i\right)\right)^{\frac{5}{3}} dy$$



Subgrid, grid convergence flow perpendicular

Discharge m3/s

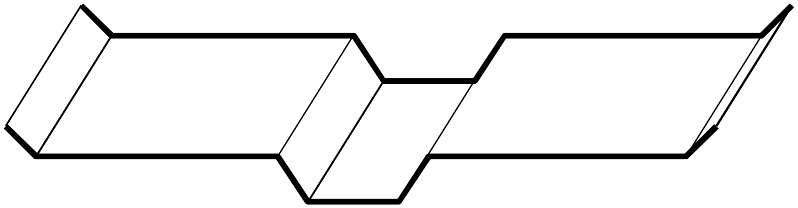


Nr of cells in cross-sectional direction.

Subgrid: non-linear volumes

$$\frac{dV}{dt} + \sum_{out} Q - \sum_{in} Q = 0$$

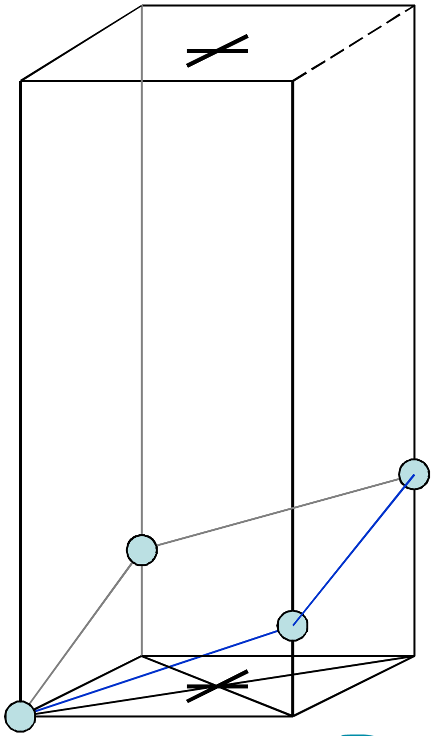
$$\frac{V^{n+1} - V^{n}}{\Delta t} + \sum_{out} A_u u - \sum_{in} A_u u = 0$$



Large change of volume

with waterlevel:

Newton iteration

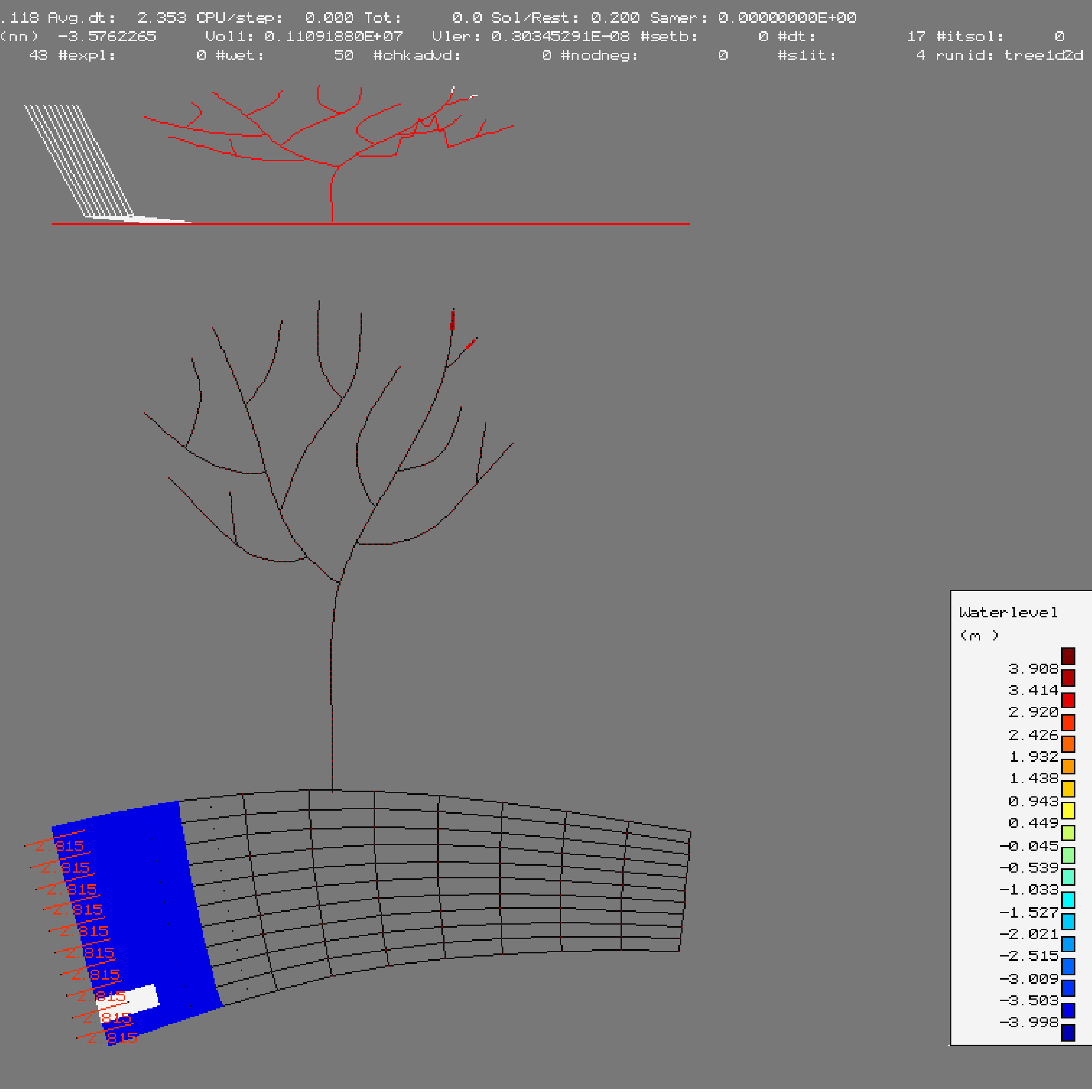


$$V^{p+1} = V^{p} + \left(\zeta^{p+1} - \zeta^{p}\right)\frac{\partial V^{p}}{\partial \zeta}$$

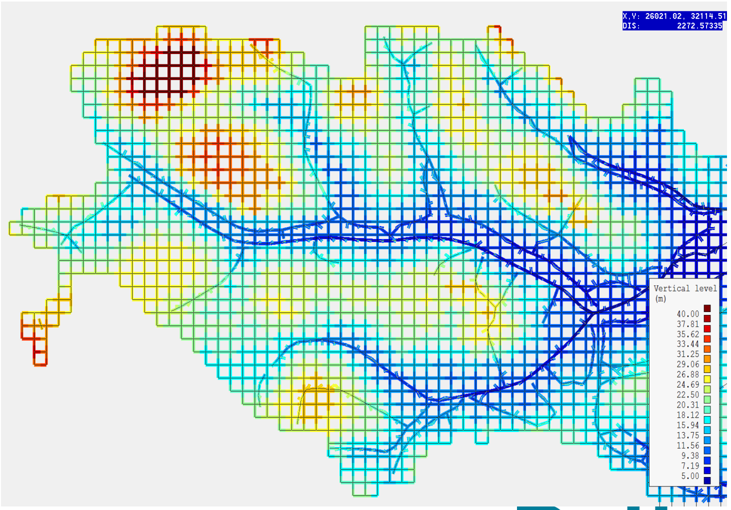
$$V^{p+1} = V^{p} + \left(\zeta^{p+1} - \zeta^{p}\right) A_{\zeta}^{p}$$

$$\frac{V^{p} - V^{n} + \left(\zeta^{p+1} - \zeta^{p}\right) A_{\zeta}^{p}}{\Delta t} + \sum_{out} A_u u - \sum_{in} A_u u = 0$$

Nonlinear continuity 1D2D



Singapore rainfall runoff: Non-linear volumes



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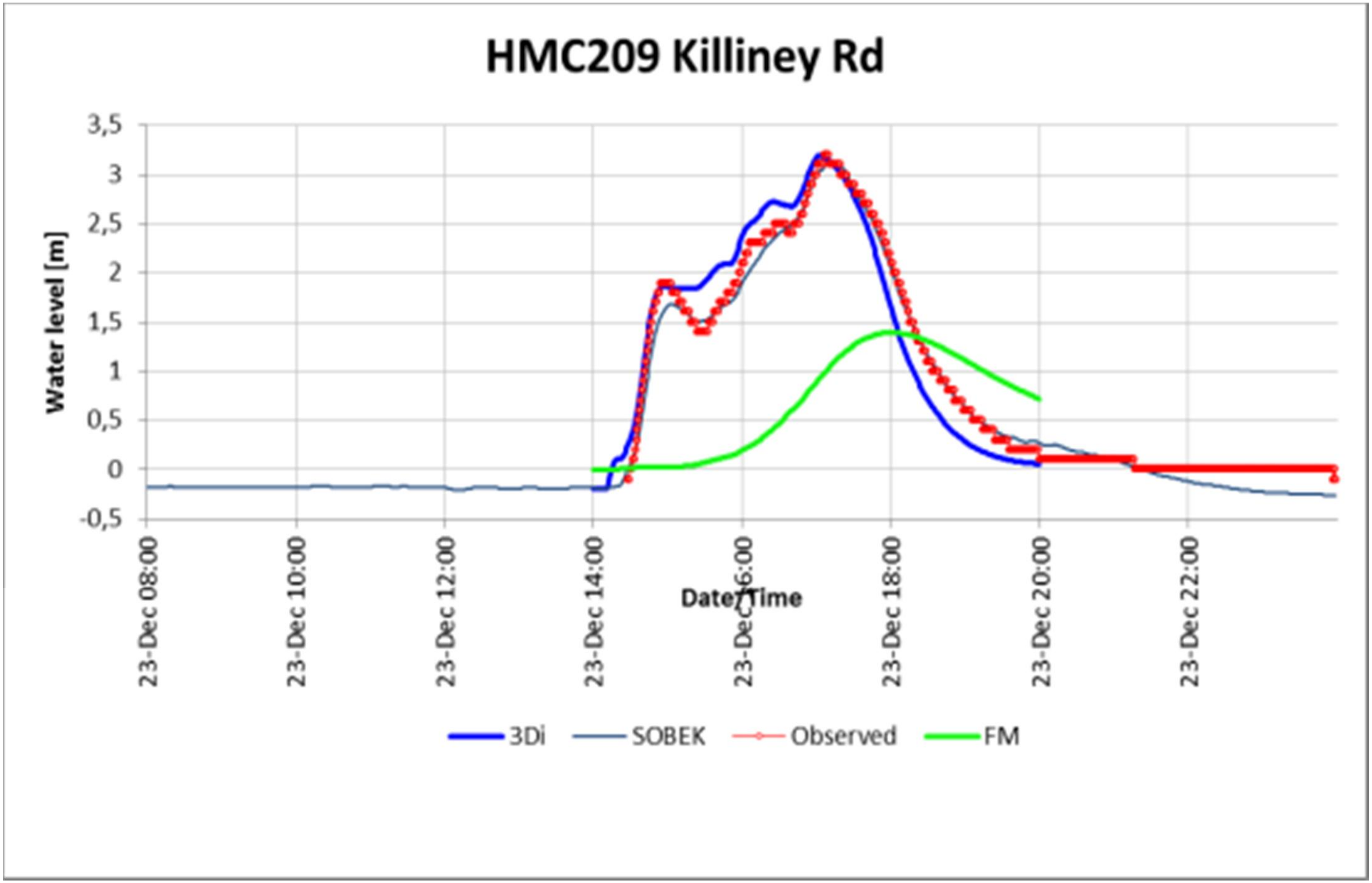
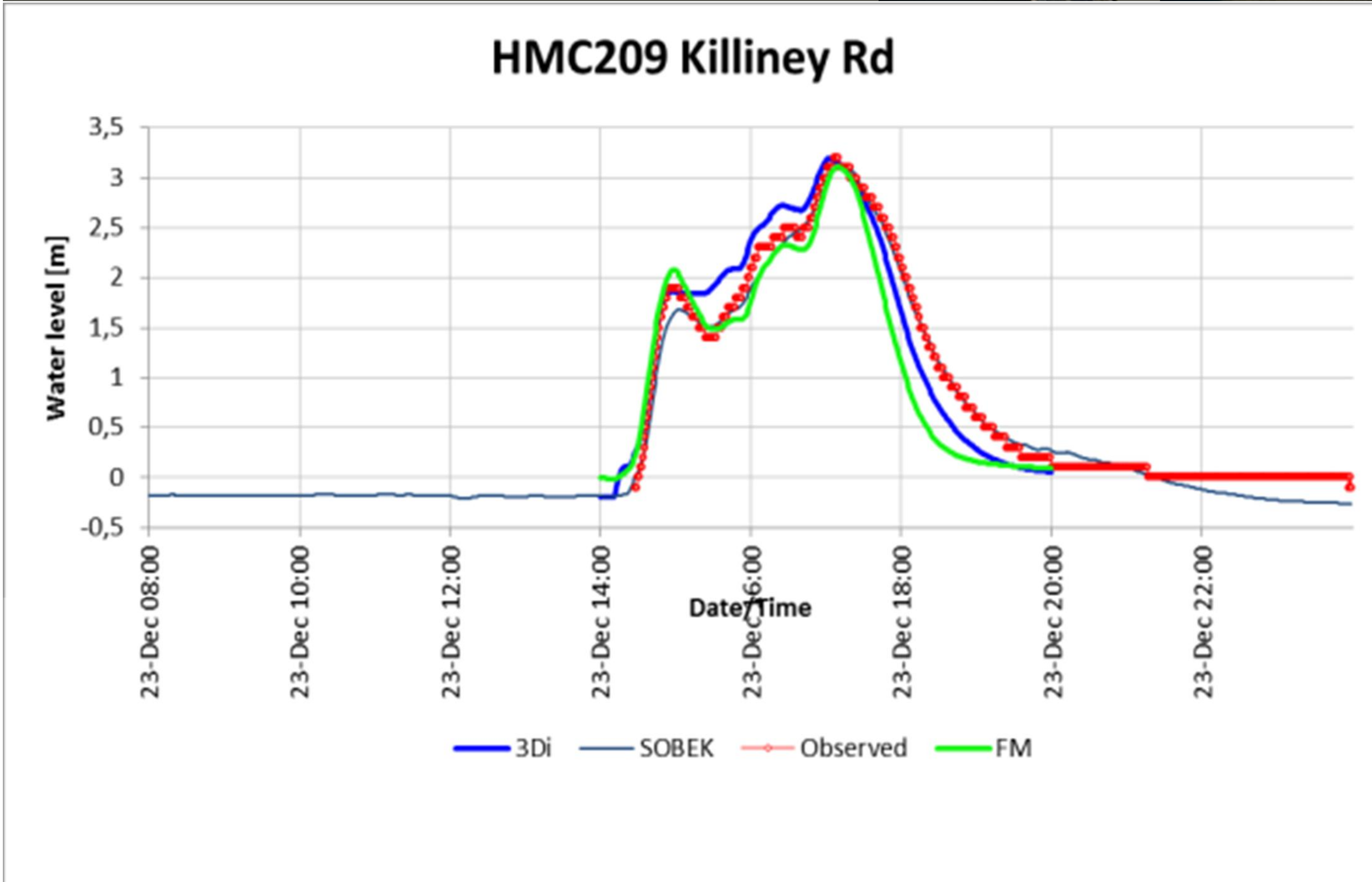
Singapore rainfall runoff: Linear volumes

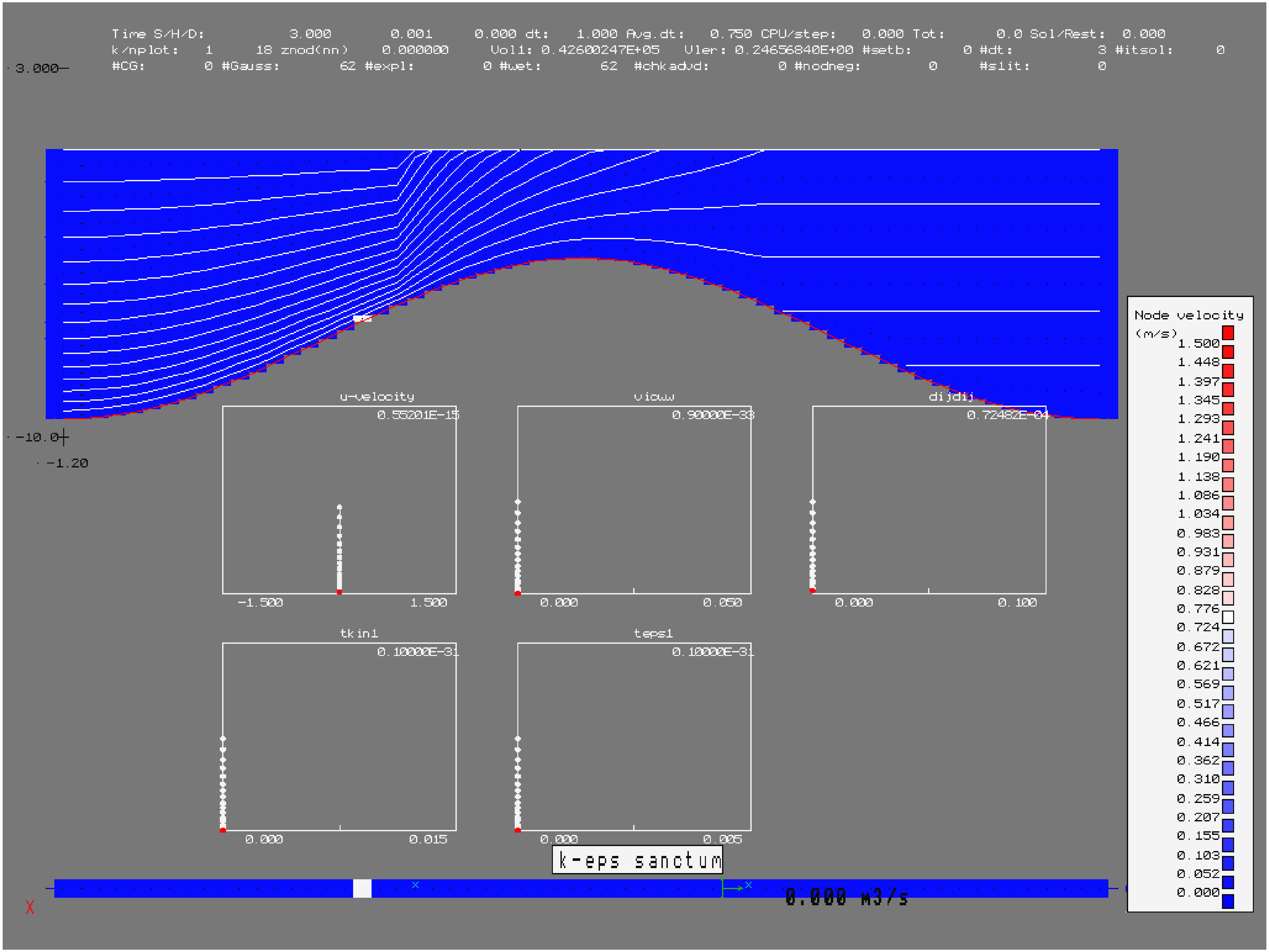


Singapore rainfall runoff: Non-linear volumes



Flexible in vertical

Deltares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k/nplot: 1 18 znod(nn) 0.000000 Vol1: 0.42600247E+05 Vler: 0.24656840E+00 #setb: 0 #dt: 3 #itsol: 0
#CG: 0 #Gauss: 62 #expl: 0 #wet: 62 #chkadvd: 0 #nodneg: 0 #slit: 0
3.000
-10.0
-1.20
u-velocity
0.55201E-15
-1.500
1.500
viow
0.90000E-33
0.000
0.050
dijdij
0.72482E-04
0.000
0.100
tkin1
0.10000E-31
0.000
0.015
teps1
0.10000E-31
0.000
0.005
k-eps sanctum
0.000 m3/s
X
Node velocity
(m/s)
1.500
1.448
1.397
1.345
1.293
1.241
1.190
1.138
1.086
1.034
0.983
0.931
0.879
0.828
0.776
0.724
0.672
0.621
0.569
0.517
0.466
0.414
0.362
0.310
0.259
0.207
0.155
0.103
0.052
0.000

Epsilon b.c. : Flux mid layer ~ Delft3D
Ustar : Layer integrated unlike Delft3D

D3D

$$\varepsilon = \text{cewall}*\left(\frac{u_*^2}{\sqrt{c_\mu}}\right)^{1.5} / z_0$$

$$\upsilon_{t(\Delta z/2)} = \kappa u_* z_0$$

DPM, DFM

$$\frac{\partial \varepsilon}{\partial z} = \frac{(\varepsilon_{b+1} - \varepsilon_b)}{\Delta z_b} = \frac{u_*^3}{\kappa\left(\frac{\Delta z_b}{2} + 9\right)^2}$$

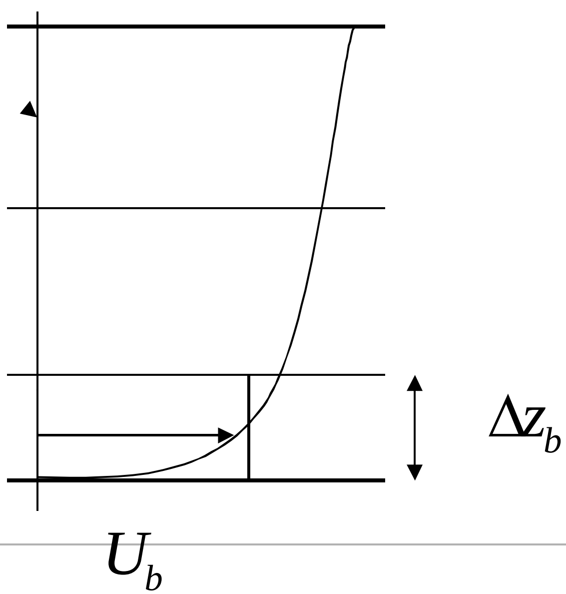
Mid layer

Delft3D, DPM

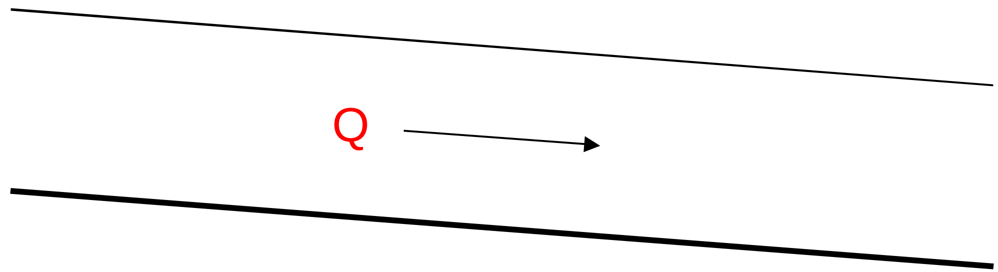
Layer integrated

DFM, TRIWAQ

$$u_* = \frac{\kappa U_b}{\ln\left(\frac{\Delta z_b}{2 z_0} + 1\right)}, \quad or \quad u_* = \frac{\kappa U_b}{\ln\left(\frac{\Delta z_b}{e z_0} + 1\right)}$$



Log profile: Friction vs Pressure slope.mdu



L=610 m

i=5e-5

H=5 m

C=60 $m^{0.5}/s$

Dx=Dy=10 m

$U=C(Hi)^{0.5}=0.94868$ m/s

$Q=47.434\ m^3/s$

$u_* = Ug^{0.5}/C=0.0495$ m/s

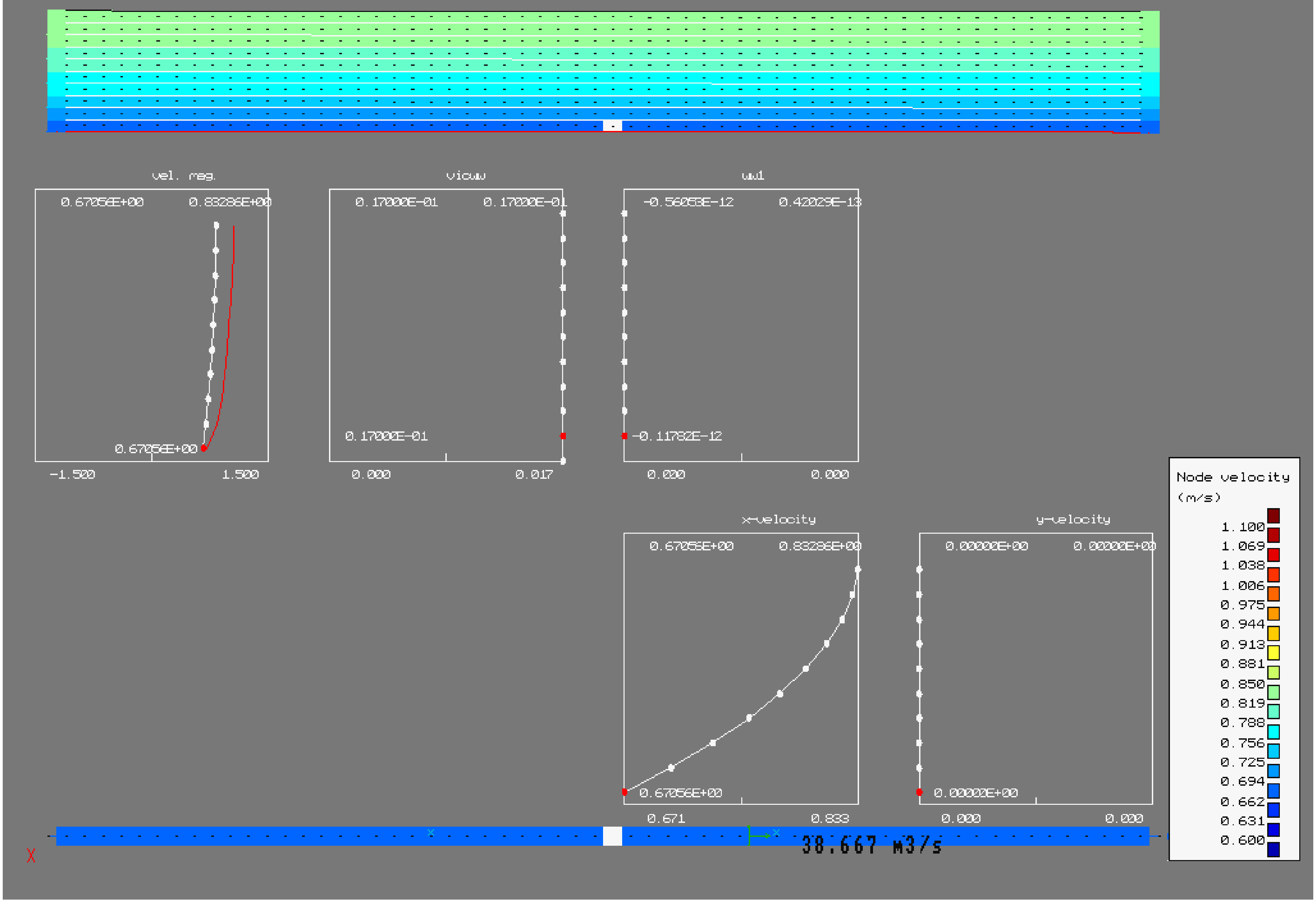
$K= u_*^2/cmu^{0.5}=0.00816\ m^2/s^2$

Constant $\upsilon_\tau = \kappa u_* H/6 = 0.0169 \quad (m^2/s)$

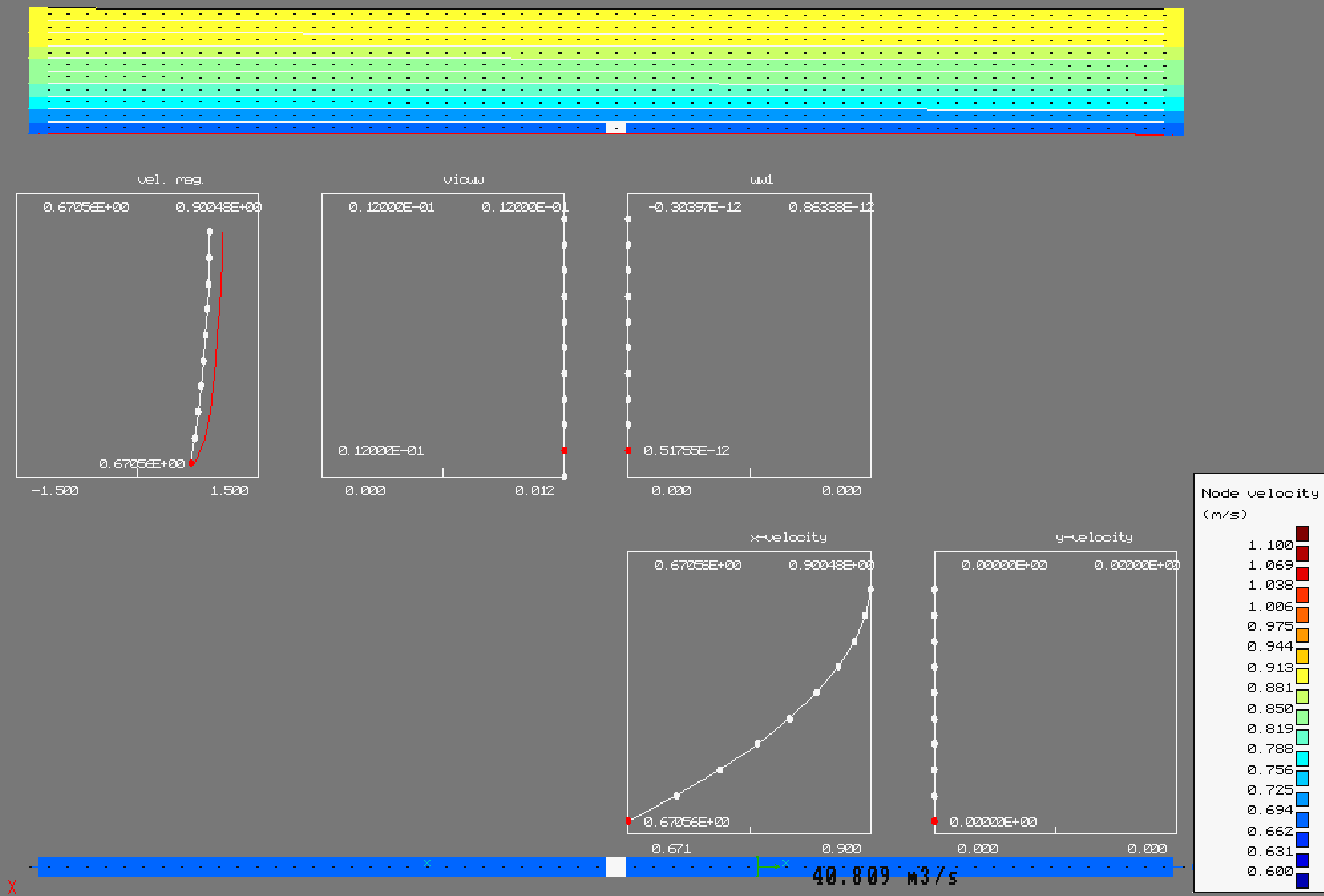
Parabolic $\upsilon_\tau(z) = \kappa u_* z\left(1-\frac{z}{H}\right) \quad ; \quad \upsilon_\tau(H/2) = 0.0253 \quad (m^2/s)$

K-epsilon $\upsilon_\tau(H/2) = c_\mu \frac{k_{H/2}^2}{\varepsilon_{H/2}} = 0.0189 \quad (m^2/s)$

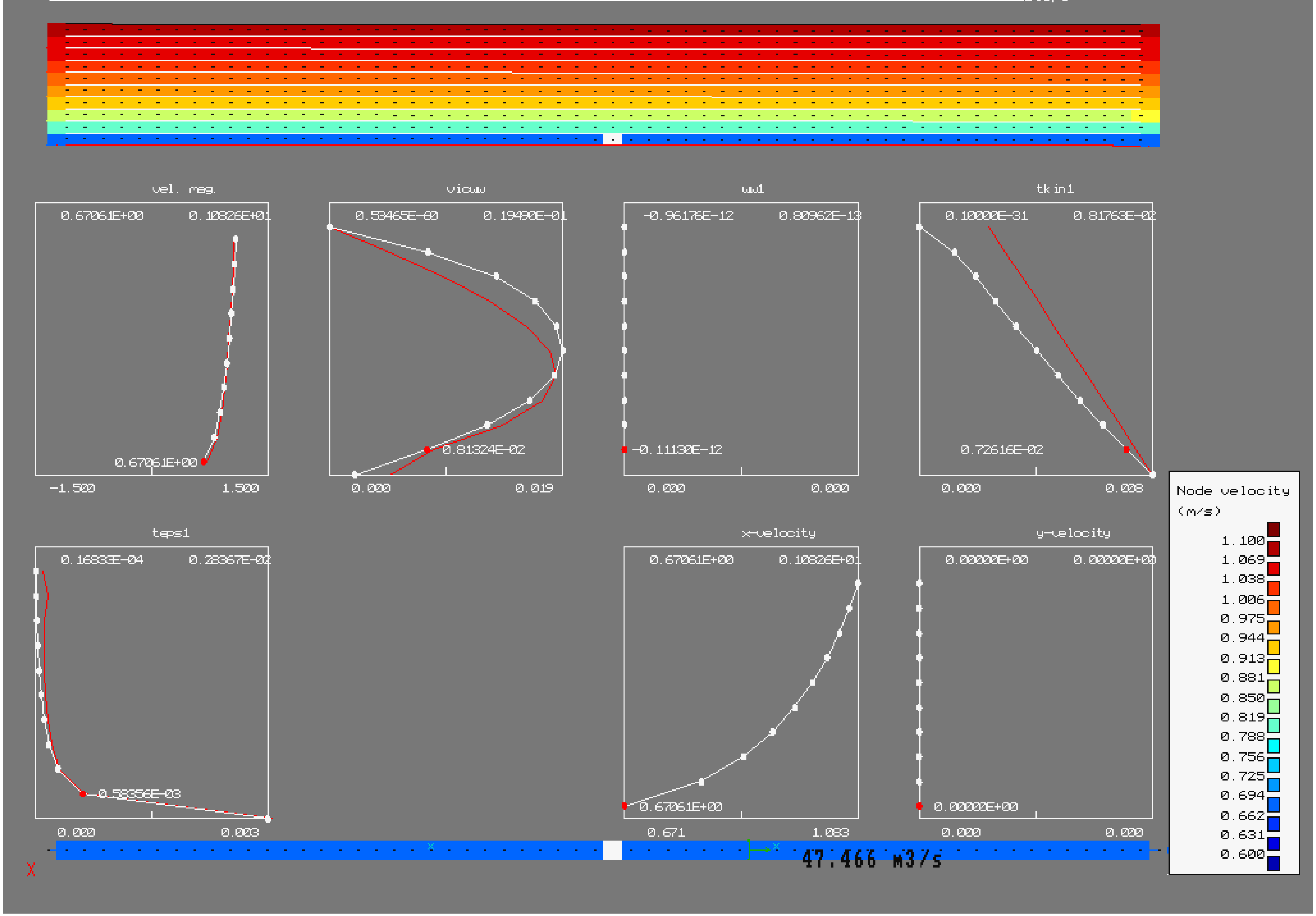
Constant eddy viscosity Elder: Q = 38.667 m3/s (47.434 m3/s)



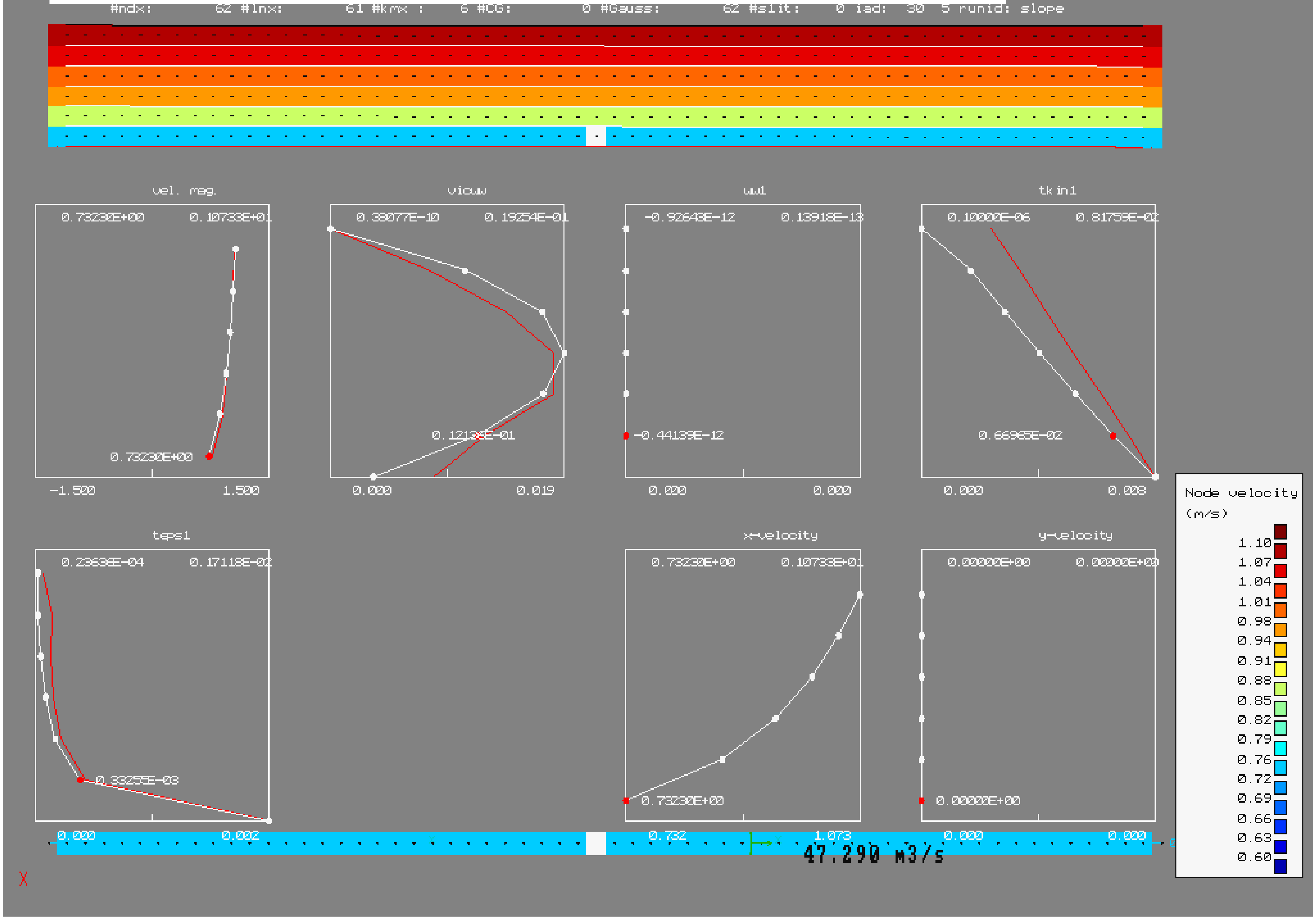
Constant eddy viscosity Elder*2/3: Q = 40.809 m3/s (47.434 m3/s)



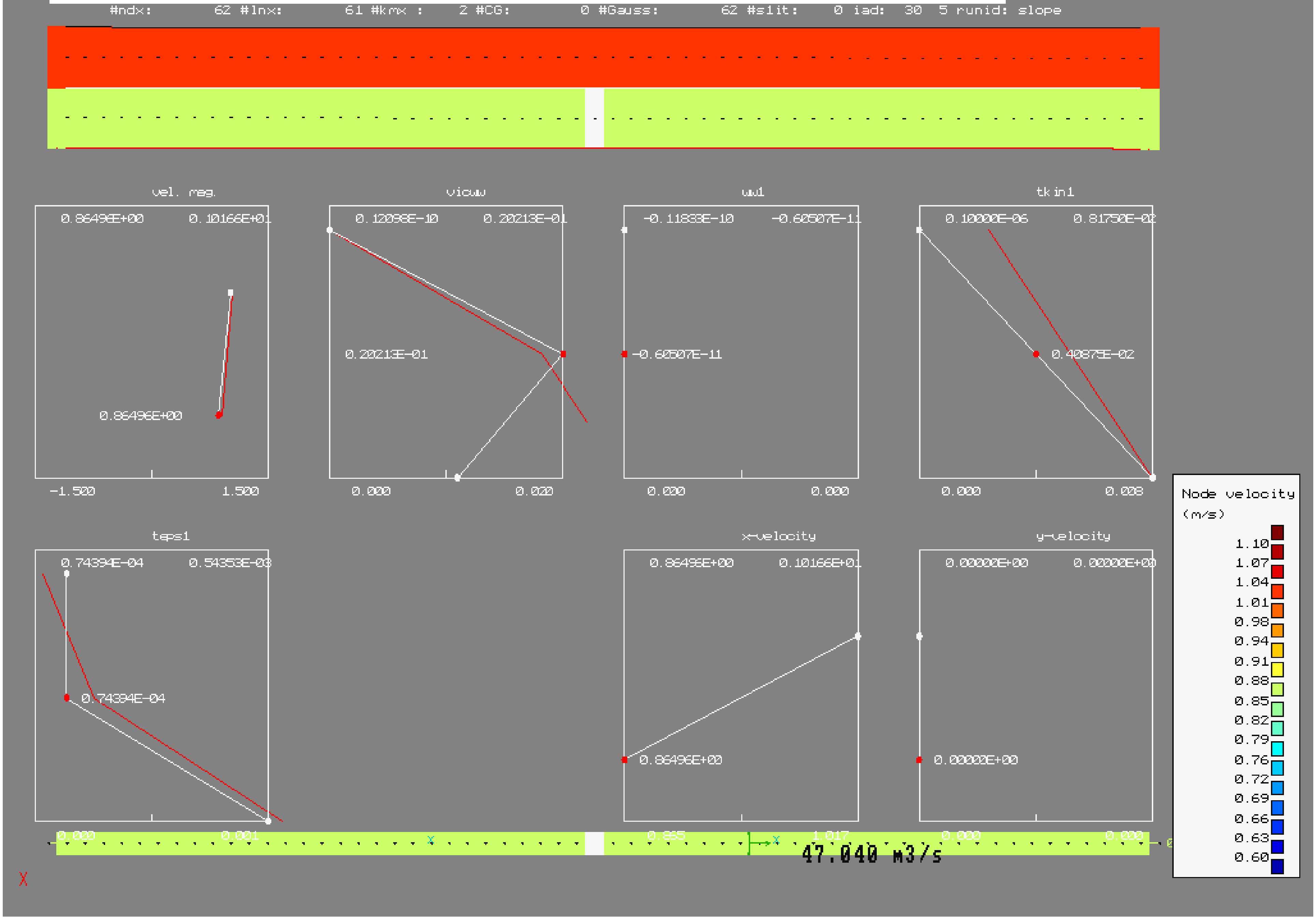
K-epsilon sigma 10 layers : 47.466 m3/s   (47.434 m3/s)



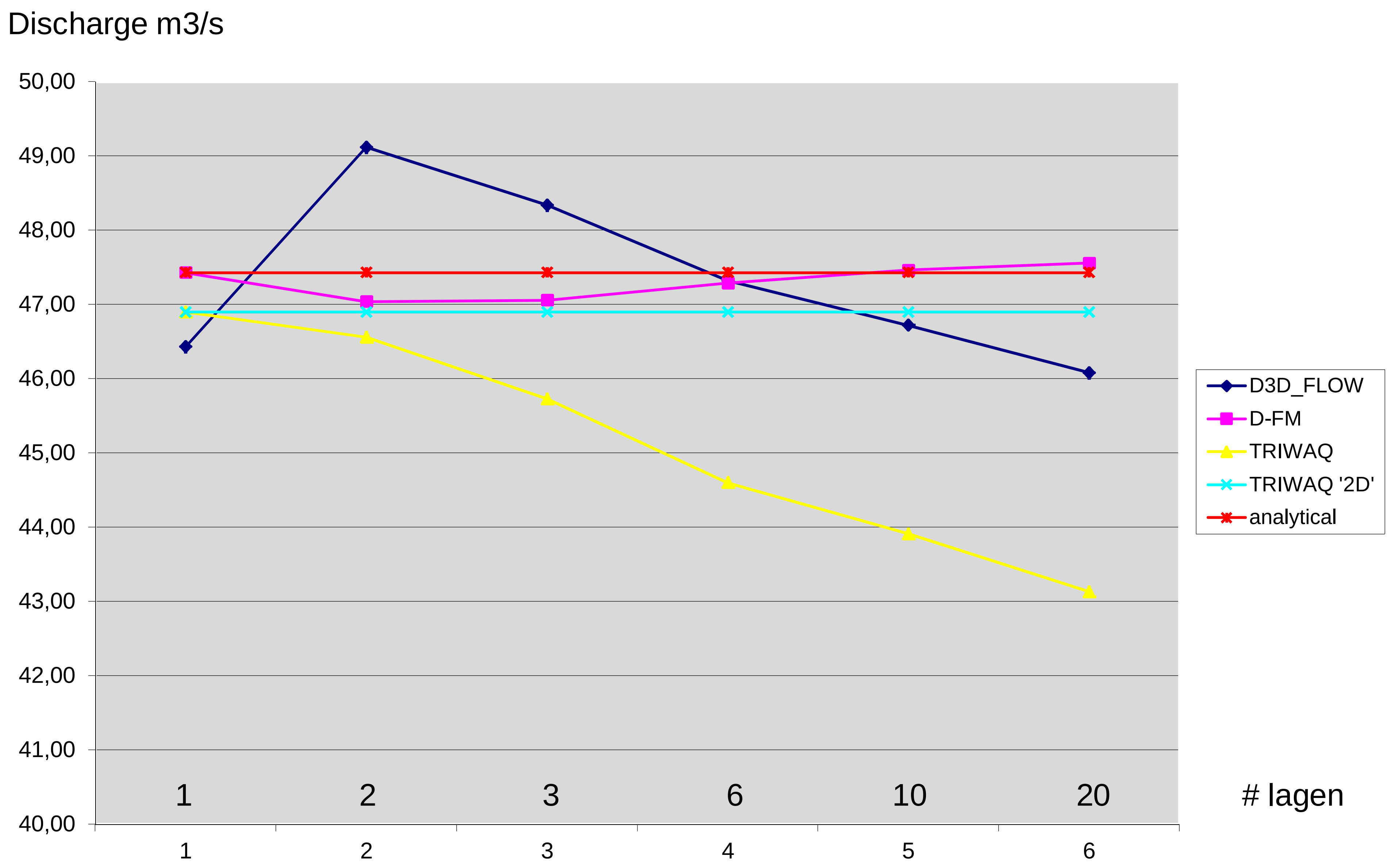
K-epsilon sigma 6 layers : 47.290 m3/s (47.434 m3/s)



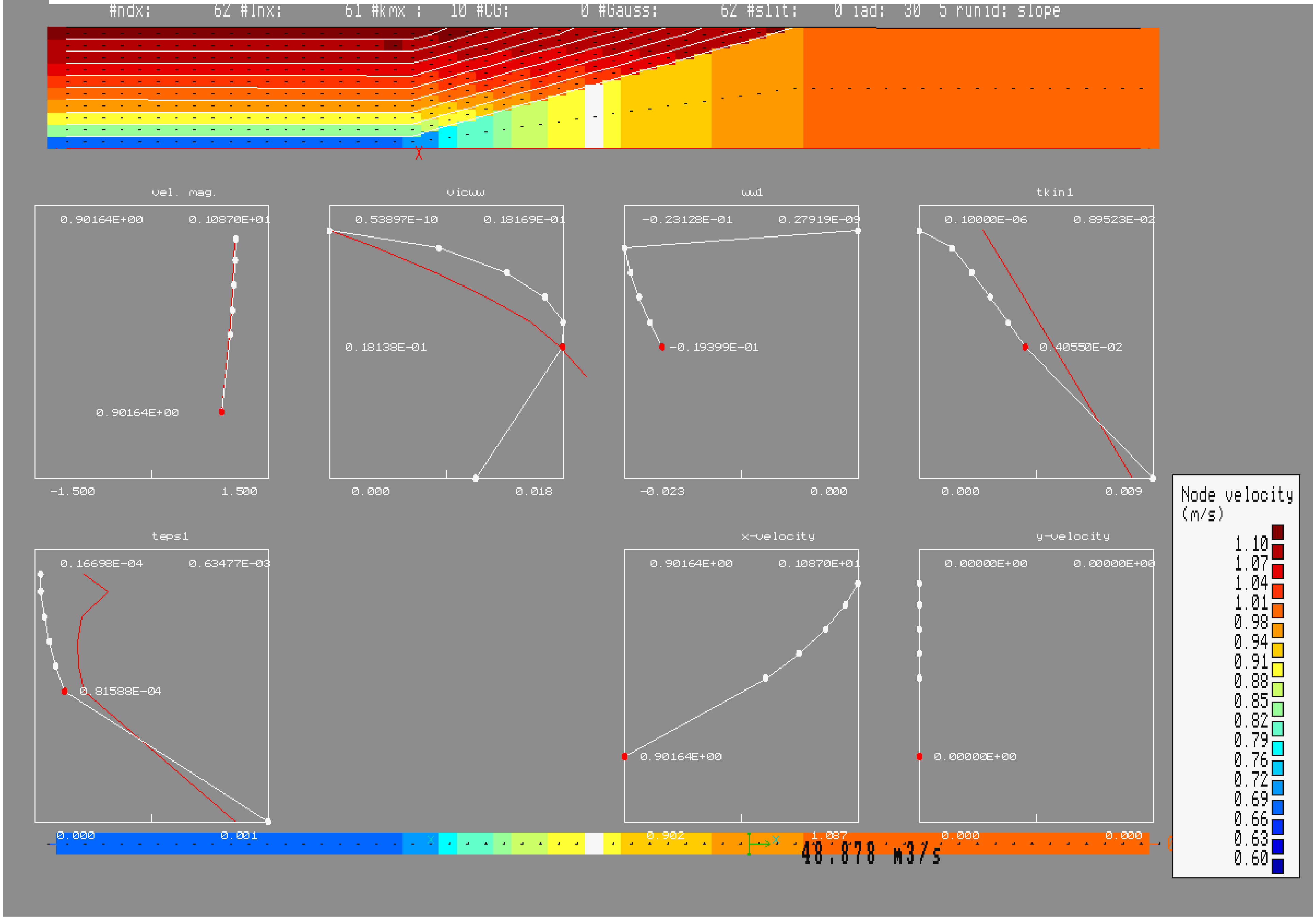
K-epsilon sigma 2 layers : 47.040 m3/s   (47.434 m3/s)



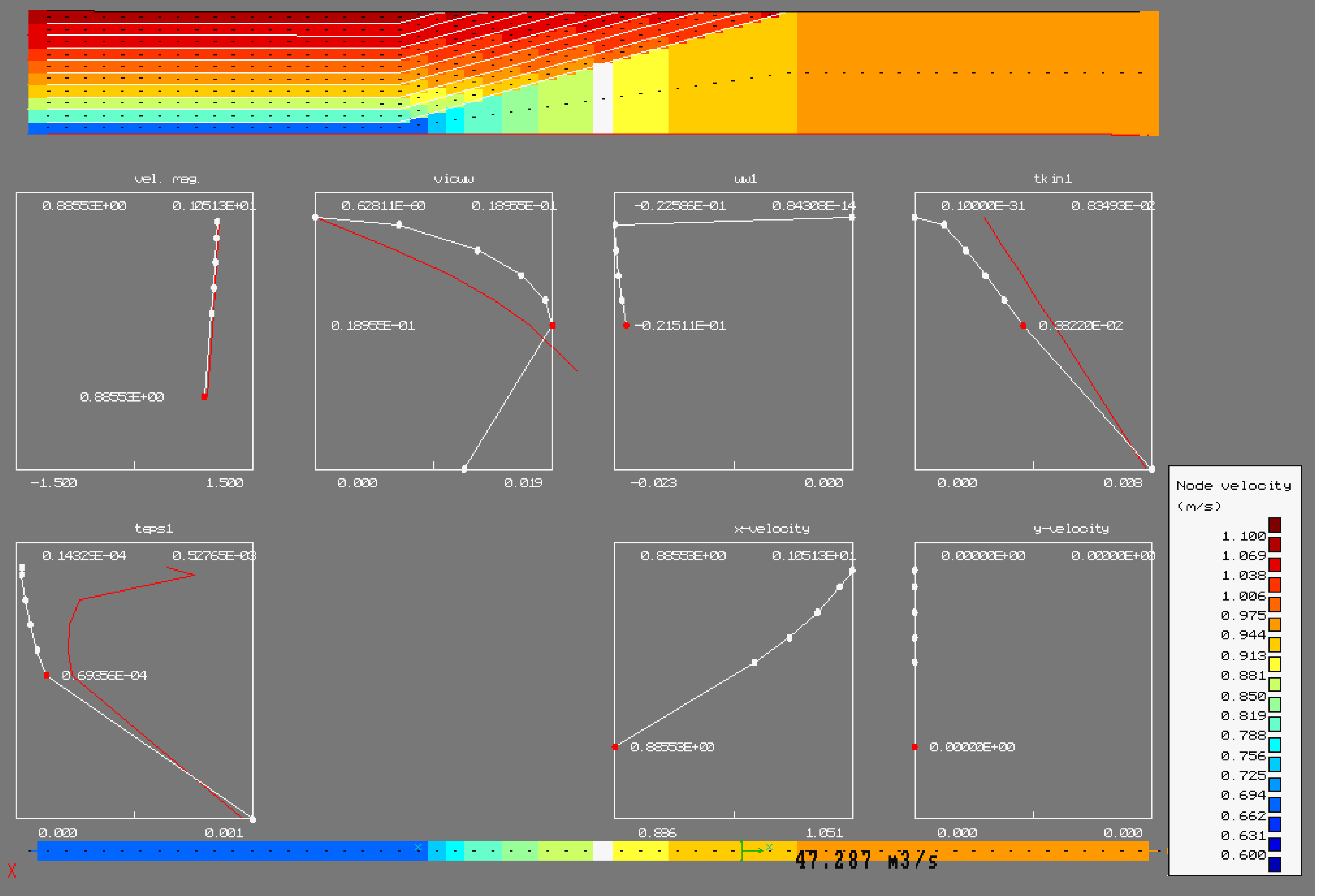
K-eps : Debiet - # lagen D3D, DFM, TRIWAQ



K-epsilon ustar layer integral mixed layers, : Q = 48.878 m3/s   (47.434 m3/s)

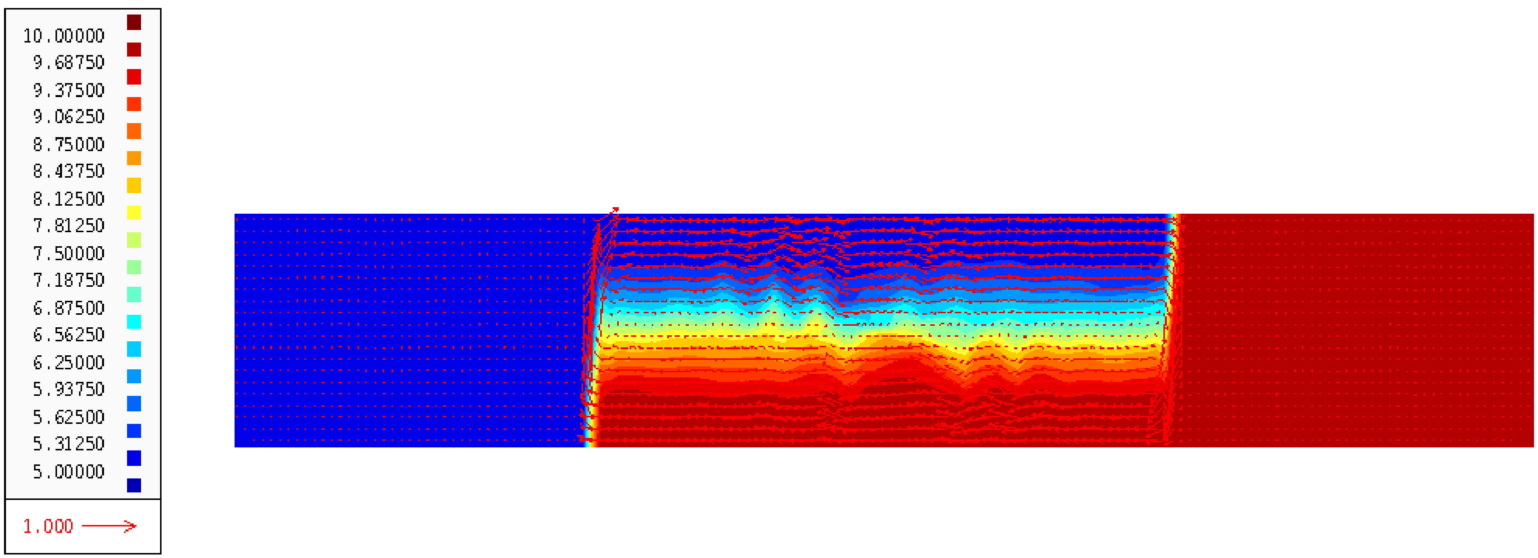


K-epsilon ustar layer integral mixed layers, noadv : Q = 47.287 m3/s   (47.434 m3/s

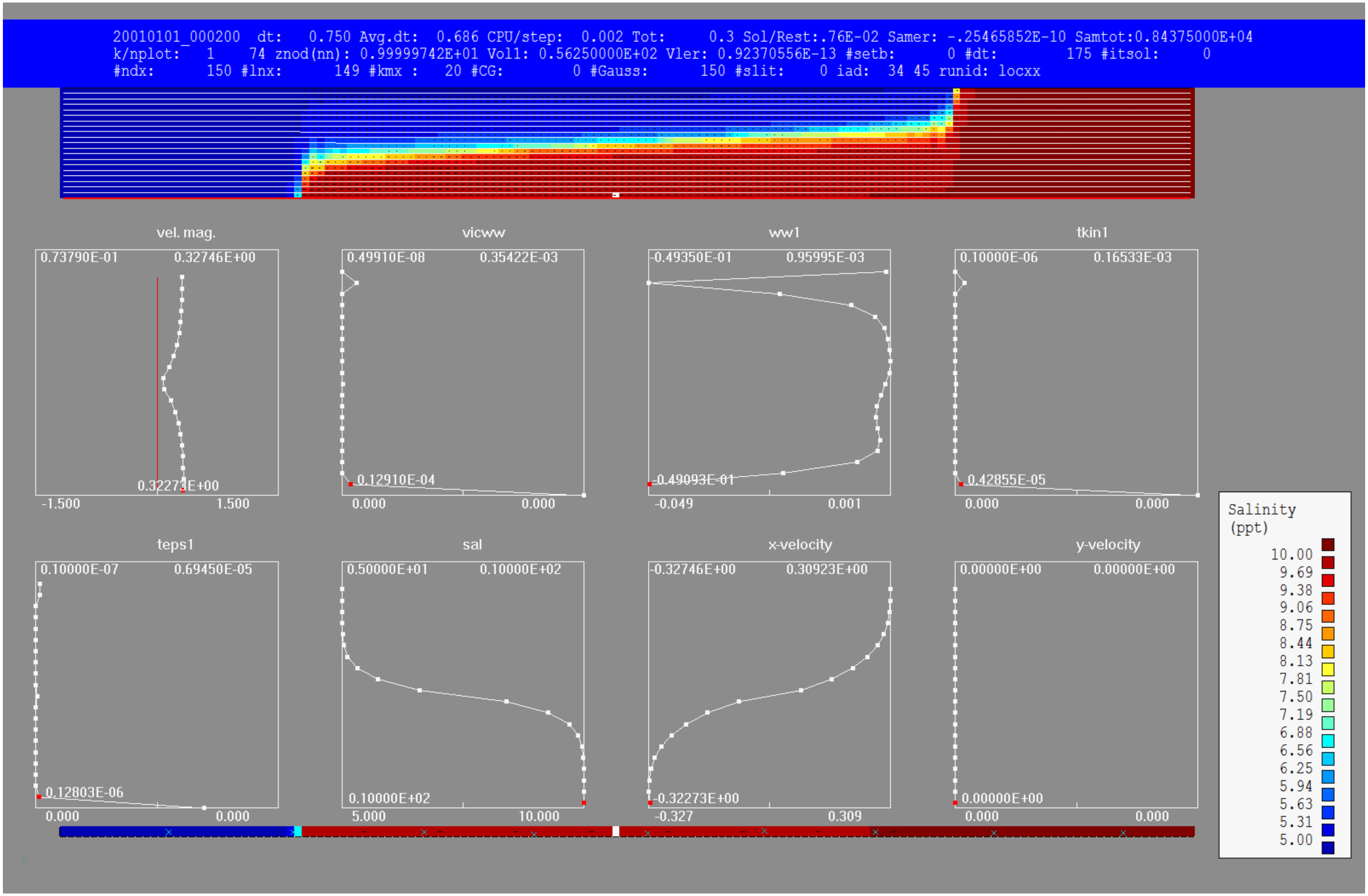


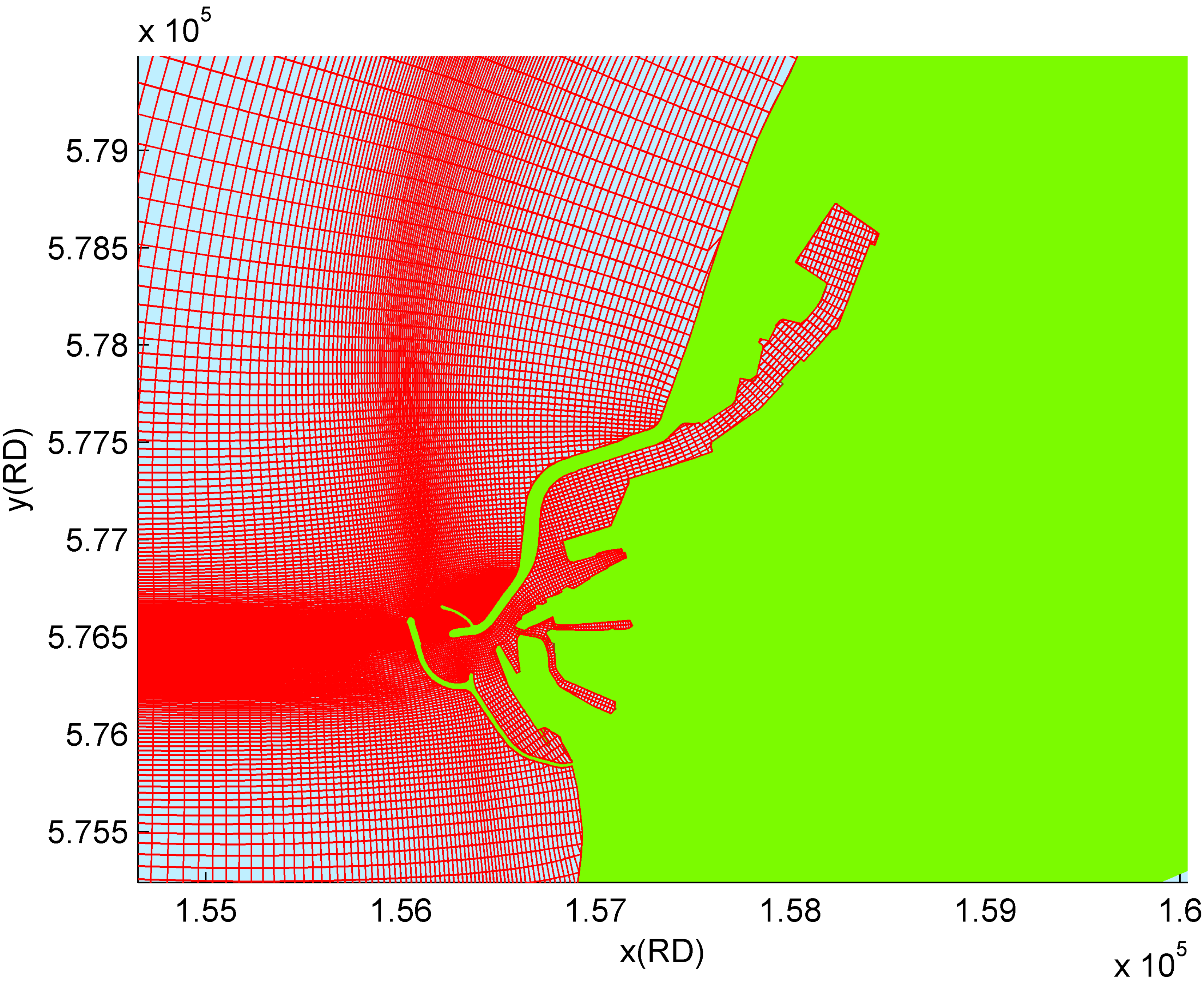
Lock exchange Delft3D v=0.01 m2/s, L=50 m

Date : 1998-02-10
Time : 00:02:00
runid : loc
Cross-sect. at N: 2
Salinity

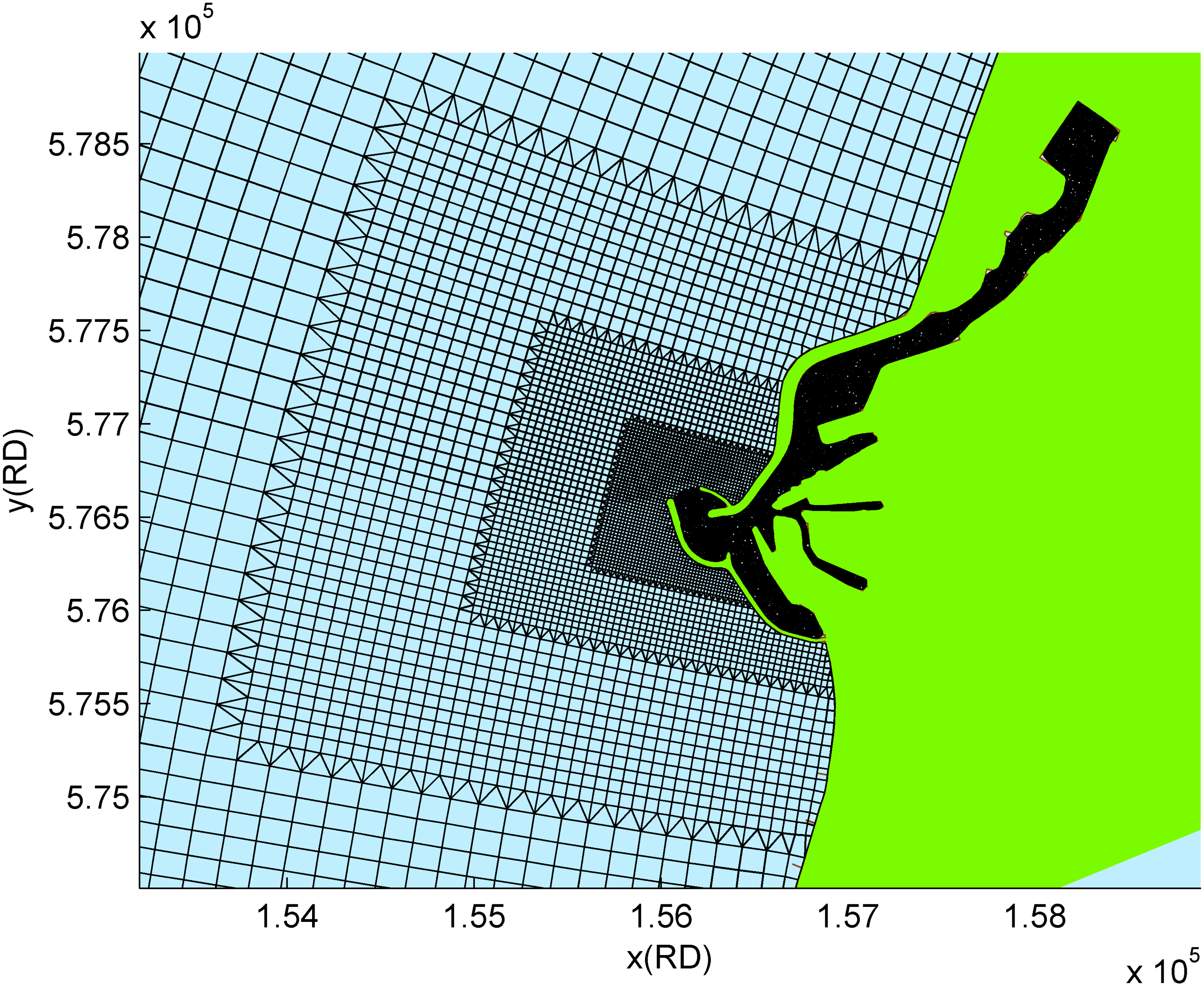


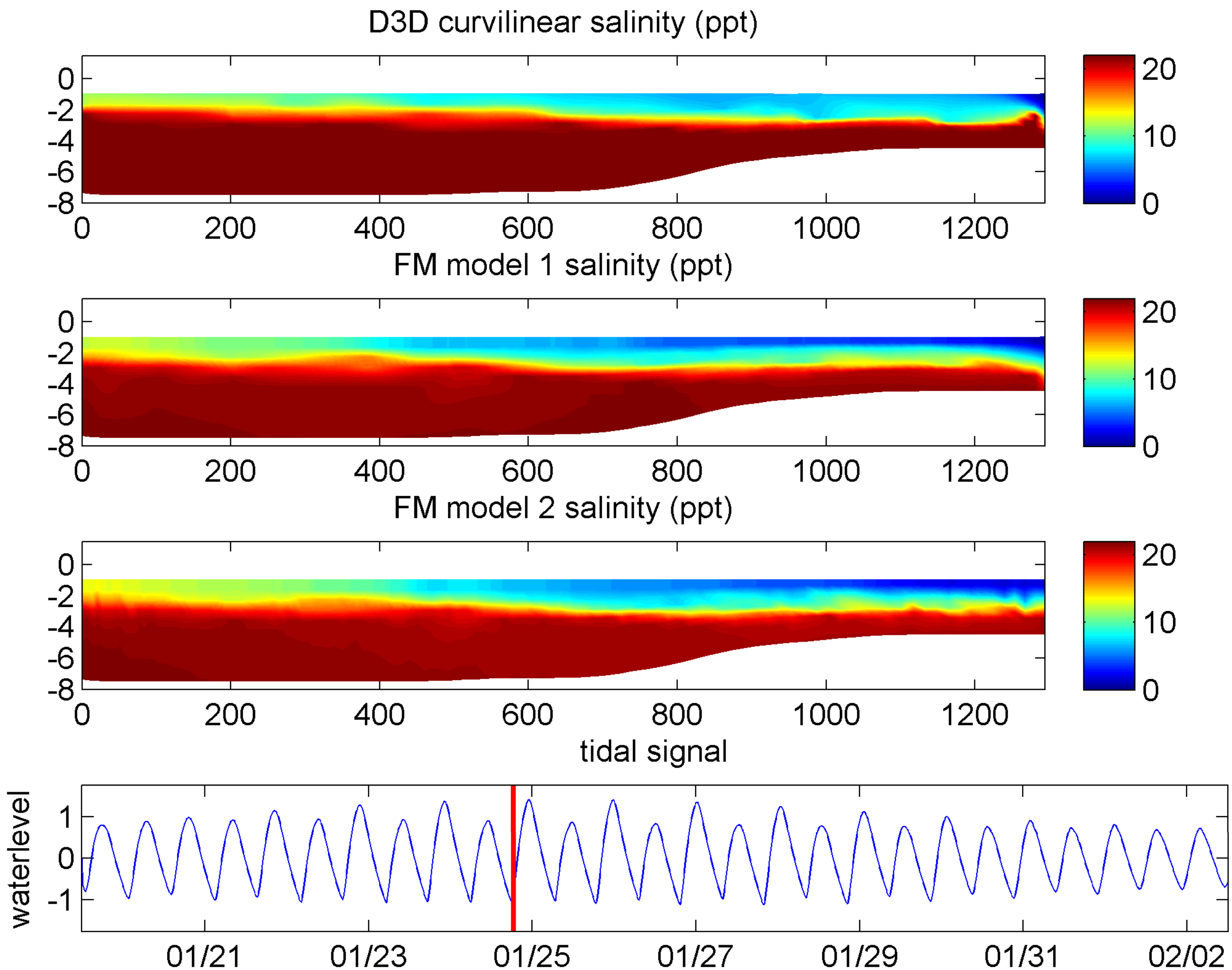
Lock exchange DFM, v=0.01 m2/s, L=64 m



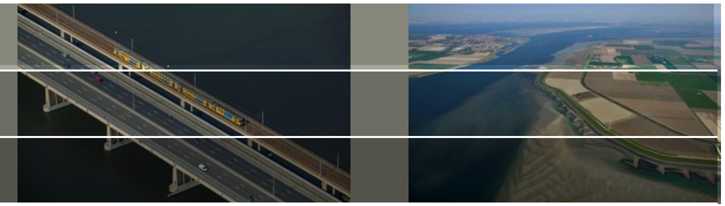


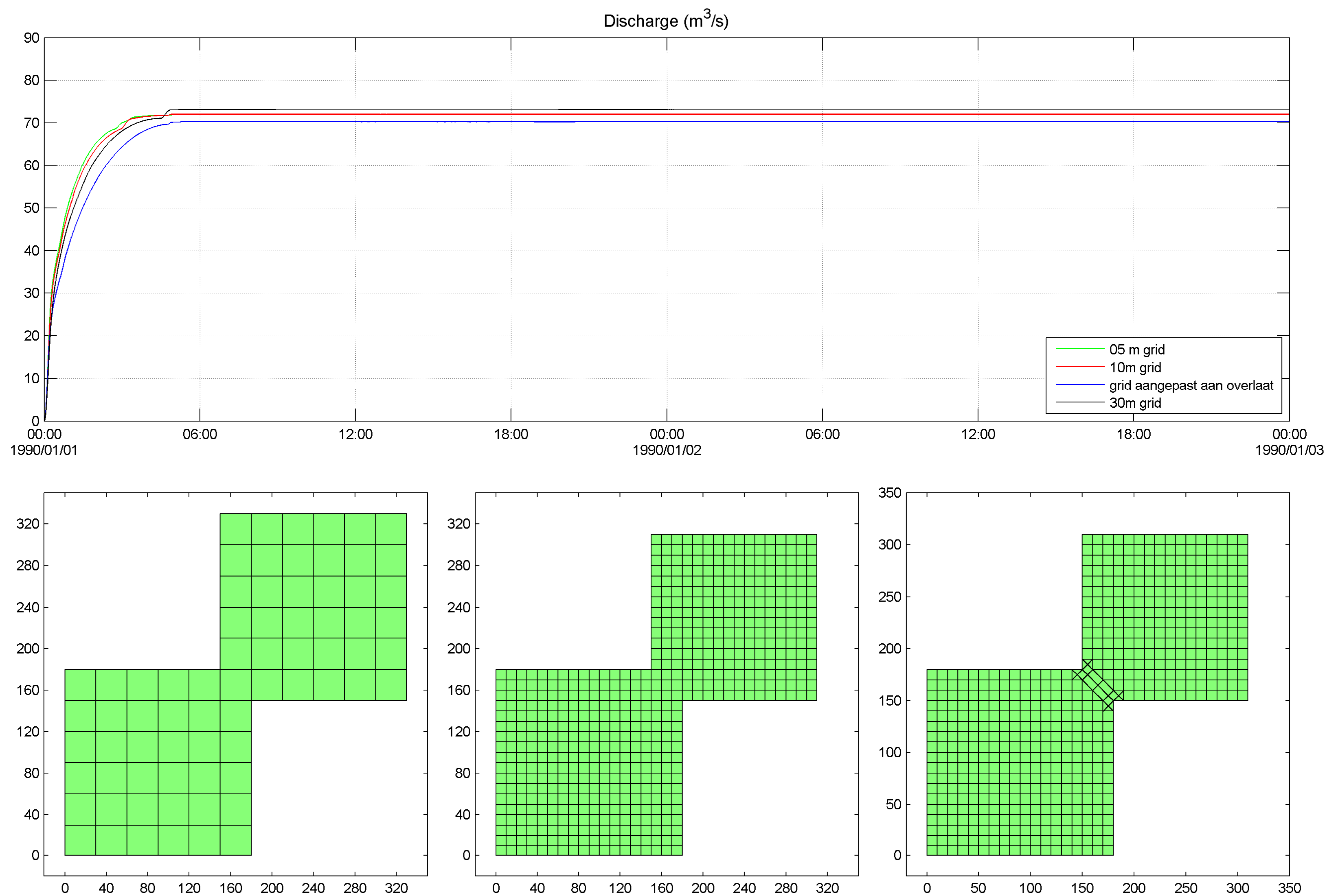
x 10^5
5.79
5.785
5.78
5.775
5.77
5.765
5.76
5.755
y(RD)
1.55
1.56
1.57
1.58
1.59
1.6
x(RD)
x 10^5

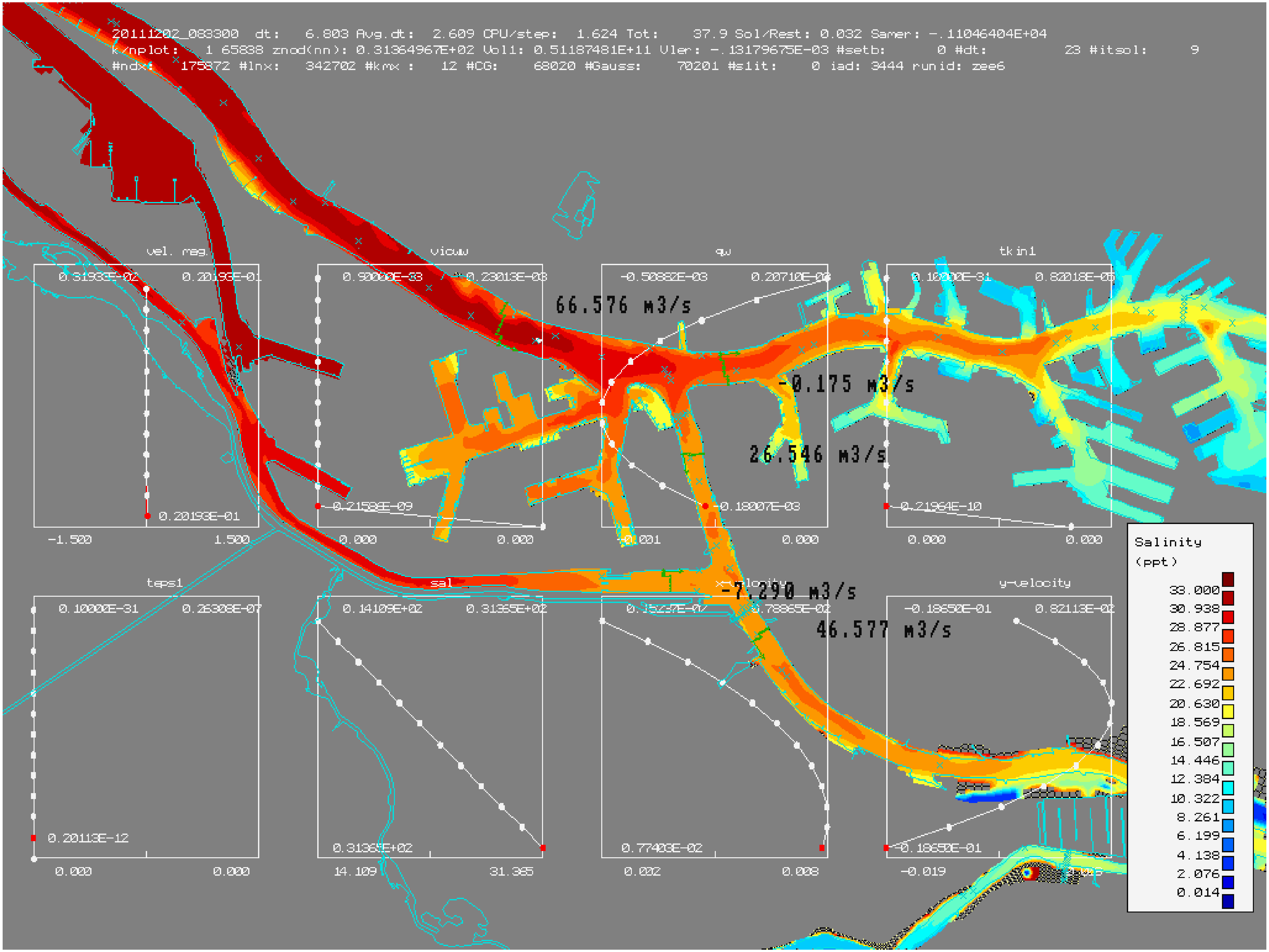

x 10^5
5.785
5.78
5.775
5.77
5.765
5.76
5.755
5.75
y(RD)
1.54
1.55
1.56
1.57
1.58
x(RD)
x 10^5


D3D curvilinear salinity (ppt)
FM model 1 salinity (ppt)
FM model 2 salinity (ppt)
tidal signal
waterlevel
0
-2
-4
-6
-8
0 200 400 600 800 1000 1200
20
10
0
1
0
-1
01/21 01/23 01/25 01/27 01/29 01/31 02/02

Subgrid weir







20111202_083300 dt: 6.803 Avg.dt: 2.609 CPU/step: 1.624 Tot: 37.9 Sol/Rest: 0.032 Samer: -.11046404E+04
k/nplot: 1 65838 znod(nn): 0.31364967E+02 Vol1: 0.51187481E+11 Vler: -.13179675E-03 #setb: 0 #dt: 23 #itsol: 9
#ndx: 175872 #lnx: 342702 #kmx : 12 #CG: 68020 #Gauss: 70201 #slit: 0 iad: 3444 runid: zee6
vel. mag.
0.31933E-02
0.20193E-01
0.20193E-01
-1.500
1.500
vicww
0.90000E-33
0.23013E-03
0.2158E-09
0.000
0.000
qw
-0.50882E-03
0.20710E-03
-0.18007E-03
-0.001
0.000
tkin1
0.10000E-31
0.82018E-05
0.21964E-10
0.000
0.000
teps1
0.10000E-31
0.26308E-07
0.20113E-12
0.000
0.000
sal
0.14109E+02
0.31365E+02
0.3136E+02
14.109
31.365
x-velocity
0.78865E-02
0.77403E-02
0.002
0.008
y-velocity
-0.18650E-01
0.82113E-02
-0.18650E-01
-0.019
66.576 m3/s
-0.175 m3/s
26.546 m3/s
-7.290 m3/s
46.577 m3/s
Salinity
(ppt)
33.000
30.938
28.877
26.815
24.754
22.692
20.630
18.569
16.507
14.446
12.384
10.322
8.261
6.199
4.138
2.076
0.014