Further Experiences using Sub Grid Technology

U-Channel – Elbe Estuary

Project A 395 5 03 70150 : UnTRIM Subgrid-Topografie
prepared for UnTRIM User Meeting 2010, Trento, Italy, May 9 – 11, 2011
Overview

• **U-Channel Test Case**
  - UnTRIM$^2$ edition 2009 – a short repetition
  - UnTRIM$^2$ edition 2010

• **Elbe Estuary Test Case (UnTRIM$^2$ vs. UnTRIM2007 with “classic unstructured grid”)**
  - structured grid
    - tidal dynamics
  - unstructured flow aligned grid
    - tidal dynamics
    - changes of water level due to channel deepening

• **Summary**
U-Channel

A : constant flow; E : constant water level

- schematization of bathymetry – computational grid (CG) versus sub grid (SG)
sensitivity of results on:
  - program edition
  - bottom friction
  - dimensionality (2D, 3D)
  - boundary water level (standard, standard + 2 m)
U-Channel Schematization
U-Channel: 2D, Chezy, with advection

- 2D vertically averaged
- with advection
- no horizontal viscosity
- constant Chezy bottom friction

- Constant flow
- Effect of numerical diffusivity due to advection

FINE CG (12, 6, 3)
COARSE CG (2, 1)

1 classic grid CG = 10 m (12 cells in cross section)
2 sub grid, CG = 20 m (6 cells in cross section)
3 sub grid, CG = 40 m (3 cells in cross section)
4 sub grid, CG = 60 m (2 cells in cross section)
5 sub grid, CG = 120 m (1 cell in cross section)

UnTRIM2 – Edition 2009
U-Channel: 2D, Chezy, no advection

- 2D vertically averaged
- no advection
- no horizontal viscosity
- constant Chezy bottom friction

KanalAnfang
KurveEingang
KurveErstesViertel
KurveMitte
KurveAusgang
AbstromMitte
KanalEnde

0 1000.0 2000.0 3000.0 4000.0 5000.0 6000.0 7000.0 8000.0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
mNN

distance along channel axis [m]
water level along channel axis [m]

constant flow

COARSE CG (2, 1)
FINE CG (12, 6, 3)

1 classic grid CG = 10m (12 cells in cross section)
2 sub grid, CG = 20m (6 cells in cross section)
3 sub grid, CG = 40m (3 cells in cross section)
4 sub grid, CG = 60m (2 cells in cross section)
5 sub grid, CG = 120m (1 cell in cross section)

UnTRIM2 – Edition 2009

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U-Channel: 2D, “Conveyance” Chezy, no advection

- 2D vertically averaged
- no advection
- no horizontal viscosity
- modified Chezy bottom friction

1 classic grid CG = 10m (12 cells in cross section)
2 sub grid, CG = 20m (6 cells in cross section)
3 sub grid, CG = 40 m (3 cells in cross section)
4 sub grid, CG = 60 m (2 cells in cross section)
5 sub grid, CG = 120 m (1 cell in cross section)

UnTRIM2 – Edition 2009
U-Channel: The UnTRIM2010 Backslide

- 2D vertically averaged
- no advection
- no horizontal viscosity
- constant Chezy bottom friction

1. Classic grid CG = 10m (12 cells in cross section)
2. Sub grid, CG = 20m (6 cells in cross section)
3. Sub grid, CG = 40m (3 cells in cross section)
4. Sub grid, CG = 60m (2 cells in cross section)
5. Sub grid, CG = 120m (1 cell in cross section)

UnTRIM2 – Edition 2010
Bottom Friction Correction Factor

\[ f_{j,k} = \frac{1}{A_{jk}} \int_{\Gamma_j} \Delta z_{j,k}(y) \left( \frac{H_{j,k}(y)}{\gamma_j(y)} \right)^p \, dy \]

\[ u_{j,k}(y) = \frac{1}{f_{j,k}} \left( \frac{H_{j,k}(y)}{\gamma_j(y)} \right)^p \]

**properties**

* flow within layer not modified;
* explicit part of bottom friction improved;
* exponent \( p \) is a **calibration parameter**;
* no effect in case of flat subgrid.
U-Channel: 2D, normal water level

- 2D vertically averaged
- no advection
- no horizontal viscosity
- constant Chezy bottom friction
- PEXP = 1.0

FINE and COARSE CG

due to improved PSI computation
due to bottom friction weighting

1 classic grid CG = 10m (12 cells in cross section)
2 sub grid, CG = 20m (6 cells in cross section)
3 sub grid, CG = 40 m (3 cells in cross section)
4 sub grid, CG = 60 m (2 cells in cross section)
5 sub grid, CG = 120 m (1 cell in cross section)

UnTRIM2 – Edition 2010
U-Channel: 3D, normal water level

- Constant flow
- 3D vertically structured
- No advection
- No horizontal viscosity
- Nikuradse bottom friction
- k-epsilon vertical viscosity
- PEXP = 1.0

Bottom friction weighting → perfect results? or sheer luck?

FINE and COARSE CG

1. Classic grid CG = 10m (12 cells in cross section)
2. Sub grid, CG = 20m (6 cells in cross section)
3. Sub grid, CG = 40m (3 cells in cross section)
4. Sub grid, CG = 60m (2 cells in cross section)
5. Sub grid, CG = 120m (1 cell in cross section)

UnTRIM2 – Edition 2010
U-Channel: 3D, normal water level plus 2 m

- 3D vertically structured
- no advection
- no horizontal viscosity
- Nikuradse bottom friction
- k-epsilon vertical viscosity
- PEXP = 1.0

KanalAnfang - Constant flow - Coarse CG (2, 1)
ZustromMitte
KurveEingang
KurveMitte
KurveAusgang
AbstromMitte - KanalEnde

1. Classic grid CG = 10m (12 cells in cross section)
2. Sub grid, CG = 20m (6 cells in cross section)
3. Sub grid, CG = 40m (3 cells in cross section)
4. Sub grid, CG = 60m (2 cells in cross section)
5. Sub grid, CG = 120m (1 cell in cross section)

Bottom friction weighting → not “perfect”!
PEXP becomes calibration parameter!
Elbe Estuary

- **grid series**
  - structured \( CG = 400 \text{ m}, 200 \text{ m}, 100 \text{ m}, 50 \text{ m} \) and \( 25 \text{ m} \) / \( SD = 25 \text{ m} \) and \( 10 \text{ m} \)
  - unstructured \( UG \approx 400 \text{ m}, 200 \text{ m}, 100 \text{ m}, 50 \text{ m} \) / \( SD = 24, 12, 6, 3 \)
  - each grid version prepared for *current* and *deepened* bathymetry (Elbe km 624 – 748).
  - unstructured grids also prepared with “flat” sub grid UF.
  - one “classical” grid used to produce “reference” results.

- **sensitivity studies**
  - tidal wave (without advection)
  - bottom friction (without advection)
  - advection of momentum
  - predicted change of water level due to channel deepening
  - scalar transport (salinity)

Identical boundary conditions, boundary data and parameters used in all model runs.
Elbe Estuary – Fairway – CG400SD025m

Sub grid resolution fairway = 25 m

Classic grid

Topography mMSL


Sub grid (CG = 400 m, SD = 25 m)
Elbe Estuary – Fairway – CG050SD025m

- Classic grid
- Sub grid (CG = 050 m, SD = 25 m)

Sub grid resolution
Fairway = 25 m
Elbe Estuary – Sensitivity Geesthacht - SD025m

CG050 → CG050: comparable results for all computational grids used

ABOVE reference

BELOW reference

UnTRIM2 – Edition 2009

CG050 | CG100 | CG200 | CG400 | – – classic | (SD025m-series)

- 2D vertically averaged
- no advection
- no viscosity
- Chezy bottom friction
ΔTR to CLASSIC (with sub grid) – 3D, Nik, k-ε, advection

- 3D vertically structured
- with advection
- k-ε: vertical viscosity
- Nikuradse: bottom friction

SD025m structured grid series

time step: classic = 30 s, CG400 = 240 s, CG200 = 120 s, CG100 = 60 s, CG050 = 30 s

UnTRIM2 – Edition 2010

pronounced reduction of TR in upstream stretch
comparable results in seaward stretch

few points with no successful analysis

reference is CLASSIC

CG400 → CG050: sensitivity on CG resolution

ABOVE reference

BELOW reference

ADV

UG
ΔTR to CLASSIC (with sub grid) – 3D, Nik, k-ε, advection

- 3D vertically structured
- with advection
- k-epsilon vertical viscosity
- Nikuradse bottom friction

SD025m structured grid series

time step: classic = 30 s, CG??0 = 240 s (identical for all grids)
Elbe Estuary – Fairway – UG400SD024

classic grid

sub grid resolution
fairway < 16 m

sub grid (UG = 400 m, SD = 24)
Elbe Estuary – Fairway – UG050SD003

classic grid

sub grid (UG = 050 m, SD = 3)

sub grid resolution
fairway < 16 m

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Bathymetry Elbe Estuary – Medem – UG400SD024

flat sub grid (UG = 400 m, SD = 24)

sub grid (UG = 400 m, SD = 24)

identical computational grid

sub grid resolution fairway < 16 m

topography mMSL

Water Level Elbe Estuary – Medem – UG400SD024

Flat sub grid (UG = 400 m, SD = 24)

Sub grid resolution
Fairway < 16 m

Sub grid (UG = 400 m, SD = 24)

dry: h < 1 mm

Water level mMSL

-2.0 0.0 2.0

0 2.50 5.00 km
Current Velocity Elbe Estuary – Medem – UG400SD024

- Flat sub grid (UG = 400 m, SD = 24)
- Sub grid (UG = 400 m, SD = 24)

Sub grid resolution
Fairway < 16 m

Dry: h < 1 mm

Current velocity
m/s

0  0.3  0.6  1.0
ΔTR to CLASSIC (flat sub grid) – 3D, Nik, k-ε, advection

UnTRIM2 – Edition 2010

UF050 | UF100 | UF200 | UF400

few points with invalid data

UF400 → UF050: strong sensitivity on CG resolution
... current practice!

no convergence of solution yet
→ required refinement steps UF025, UF010, UF005 ...

SD024 unstructured grid series

1 d(mittlerer Thb) UF400 L100Elbe
2 d(mittlerer Thb) UF200 L100Elbe
3 d(mittlerer Thb) UF100 L100Elbe
4 d(mittlerer Thb) UF050 L100Elbe

3D vertically structured
- with advection
- k-epsilon vertical viscosity
- Nikuradse bottom friction

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ΔTR to CLASSIC (with sub grid, PEXP = 0.50) – 3D, Nik, k-ε, advection

UG400 → UG050: mild to moderate sensitivity on CG resolution
... future practice?

(stable) larger TR with sub grid included
→ more realistic flow over tidal flats?

SD024 unstructured grid series

UnTRIM2 – Edition 2010

few points with invalid data

ADV

P=0

P=1

CG

Δ

1 d(mittlerer Thb) UG400 L100Elbe
2 d(mittlerer Thb) UG200 L100Elbe
3 d(mittlerer Thb) UG100 L100Elbe
4 d(mittlerer Thb) UG050 L100Elbe

- 3D vertically structured
- with advection
- k-epsilon vertical viscosity
- Nikuradse bottom friction

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ΔTR to CLASSIC (flat | with sub grid, PEXP = 0.50) – 3D, Nik, k-ε, advection

UnTRIM2 – Edition 2010
UG050 SG | UF050 FLAT

SD024 unstructured grid series

- 3D vertically structured
- with advection
- k-ε vertical viscosity
- Nikuradse bottom friction

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A typical „classic“ Elbe model: differences „measured“ – „computed“

ΔTR | ΔHW | ΔMW | ΔLW

difference: large | moderate | large

high resolution trends

BELOW measured

ABOVE measured

differences according to project OPTEL, page 37, March 17, 2011

orientation of profile reversed to before figures
Elbe Estuary – Fairway (non-dredged) – flow aligned grid

classic grid

sub grid (UG = 400 m, SD = 24)

sub grid resolution
fairway < 16 m

N
Elbe Estuary – Fairway (dredged) – flow aligned grid

classic grid

sub grid (UG = 400 m, SD = 24)

sub grid resolution
fairway < 16 m

topography
mMSL

Elbe Estuary – $\Delta$(TR) due to dredged Fairway (2D) – Flat – PEXP = 0.0

SD024 unstructured grid series

1 d(mittlerer Thb) UF400 L100Elbe
2 d(mittlerer Thb) UF200 L100Elbe
3 d(mittlerer Thb) UF100 L100Elbe
4 d(mittlerer Thb) UF050 L100Elbe

few points with invalid data

dredged fairway section (km 624 – 748)

- 2D vertically averaged
- no advection
- no viscosity
- Chezy bottom friction

UnTRIM2 – Edition 2010
Elbe Estuary – $\Delta$(TR) due to dredged Fairway (2D) – with SG – PEXP = 0.5

SD024 unstructured grid series

- 2D vertically averaged
- no advection
- no viscosity
- Chezy bottom friction

few points with invalid data

dredged fairway section (km 624 – 748)

reference is UGxxx

UnTRIM2 – Edition 2010

TR

1 d(mittlerer Thb) UG400 L100Elbe
2 d(mittlerer Thb) UG200 L100Elbe
3 d(mittlerer Thb) UG100 L100Elbe
4 d(mittlerer Thb) UG050 L100Elbe

m

m
Elbe Estuary – Δ(TR) due to dredged Fairway (2D) – with SG – PEXP = 0.5

SD024 unstructured grid series
+ sub grid bathymetry + advection

- 2D vertically averaged
- with advection
- no viscosity
- Chezy bottom friction
Elbe Estuary – Δ(TR) due to dredged Fairway (3D) – with SG – PEXP = 0.5

SD024 unstructured grid series

1 d(mittlerer Thb) UG400 L100Elbe
2 d(mittlerer Thb) UG200 L100Elbe
3 d(mittlerer Thb) UG100 L100Elbe
4 d(mittlerer Thb) UG050 L100Elbe

+ sub grid bathymetry + 3D

- 3D vertically structured
- no advection
- k-epsilon vertical viscosity
- Nikuradse bottom friction

UnTRIM2 – Edition 2010

few points with invalid data

reference is UGxxx

dredged fairway section (km 624 – 748)

1 d(mittlerer Thb) UG400 L100Elbe
2 d(mittlerer Thb) UG200 L100Elbe
3 d(mittlerer Thb) UG100 L100Elbe
4 d(mittlerer Thb) UG050 L100Elbe

TR

INCREASE

DECREASE

Meter
Elbe Estuary – \( \Delta \text{(TR)} \) due to dredged Fairway (3D) – **with SG – PEXP = 0.5**

**SD024 unstructured grid series**
- 1 d(mittlerer Thb) UG400 L100Elbe
- 2 d(mittlerer Thb) UG200 L100Elbe
- 3 d(mittlerer Thb) UG100 L100Elbe
- 4 d(mittlerer Thb) UG050 L100Elbe

**Max 2D, no advection**

**few points with invalid data**

**dredged fairway section (km 624 – 748)**

**UnTRIM2 – Edition 2010**

- 3D vertically structured
- with advection
- k-epsilon vertical viscosity
- Nikuradse bottom friction

**Reference is UGxxx**
Elbe Estuary – Δ(TR) due to dredged Fairway (3D) – Flat – PEXP = 0.0

SD024 unstructured grid series

1 d(mittlerer Thb) UF400 L100Elbe
2 d(mittlerer Thb) UF200 L100Elbe
3 d(mittlerer Thb) UF100 L100Elbe
4 d(mittlerer Thb) UF050 L100Elbe

few points with invalid data

few points with invalid data

3D vertically structured
with advection
k-epsilon vertical viscosity
Nikuradse bottom friction

reference is UGxxx

UnTRIM2 – Edition 2010

CUXHAVEN

HAMBURG

max 2D, no advection

TR

0 25000.0 50000.0 75000.0 1.00E5 1.250E5 1.500E5

Km590
Km600
Km620N
Km630N
Km640
Km650
Km660
Km670
Km680
Km690
Km700
Km710
Km720
Km740

-0.11
-0.09
-0.07
-0.05
-0.03
-0.01
100E-04
0.01
0.03
0.05
0.07
0.09
0.11

INCREASE
DECREASE
Conclusions

• **less restrictive grid generation**
  - easy fit of lateral boundaries
  - tributary rivers approximated as one-dimensional channels
  - homogeneous, flow aligned grid (quadrilaterals, triangles in case of “emergency”)
  - channel deepening can be realized in sub grid

• **accurate representation of flow area and volume**
  - tidal volume can be made correct to measurement accuracy independent of grid resolution
  - improved results for tidal flow (tidal flats, tidal prism, drying and wetting, …)

• **potential applications**
  - long term simulations (HD + salt) - a year in a day, 30 years in a month
  - storm surge simulations with flooding of large areas
  - channel deepening → changes of water level: ? (further investigations required)
  - studies on significance of resolution on model predictions (estimate error of prediction)
  - fast running operational models
Conclusions – Grids

TRIM2D (1995)  
50 × 50 m

UNTRIM (2006)  
unstructured

Lecture Hall at BAW  
37 × 13 m

BSH (2010)  
90 × 90 m

UNTRIM² (2011)  
unstructured sub grid
Last but not Least

- **UnTRIM2 Edition 2010 – User Interface Description**

- **BAW Hydraulic Engineering – Research and Development**

- **NetCDF (CF metadata) for Unstructured Grid (in collaboration with DELTARES)**

- **Thanks to Christoph Lippert (smile consult GmbH) and Frank Böker (BAW)**
The End