Fifty years of shallow flow modelling in The Netherlands and the transition from structured to unstructured grid modelling

Erik de Goede and several Deltares' colleagues

JONSMOD2018, Firenze

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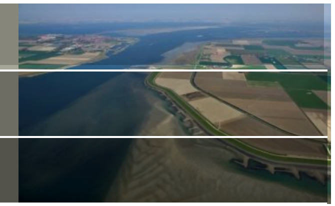
Outline



Part 1 (Numerics):

- Hydrodynamic modelling in The Netherlands 1967-2017; milestones and key features
- 6.000+ Delft3D papers (see oss.delft3d.nl), but no overview paper of key features

Part 2 (Unstructured grid modelling for transport of salinity)

- Transition from structured to unstructured modelling: 2011 – ..
- Triangles versus quadrangles for modelling transport of salinity

Hydrodynamic modelling in 1967-2017

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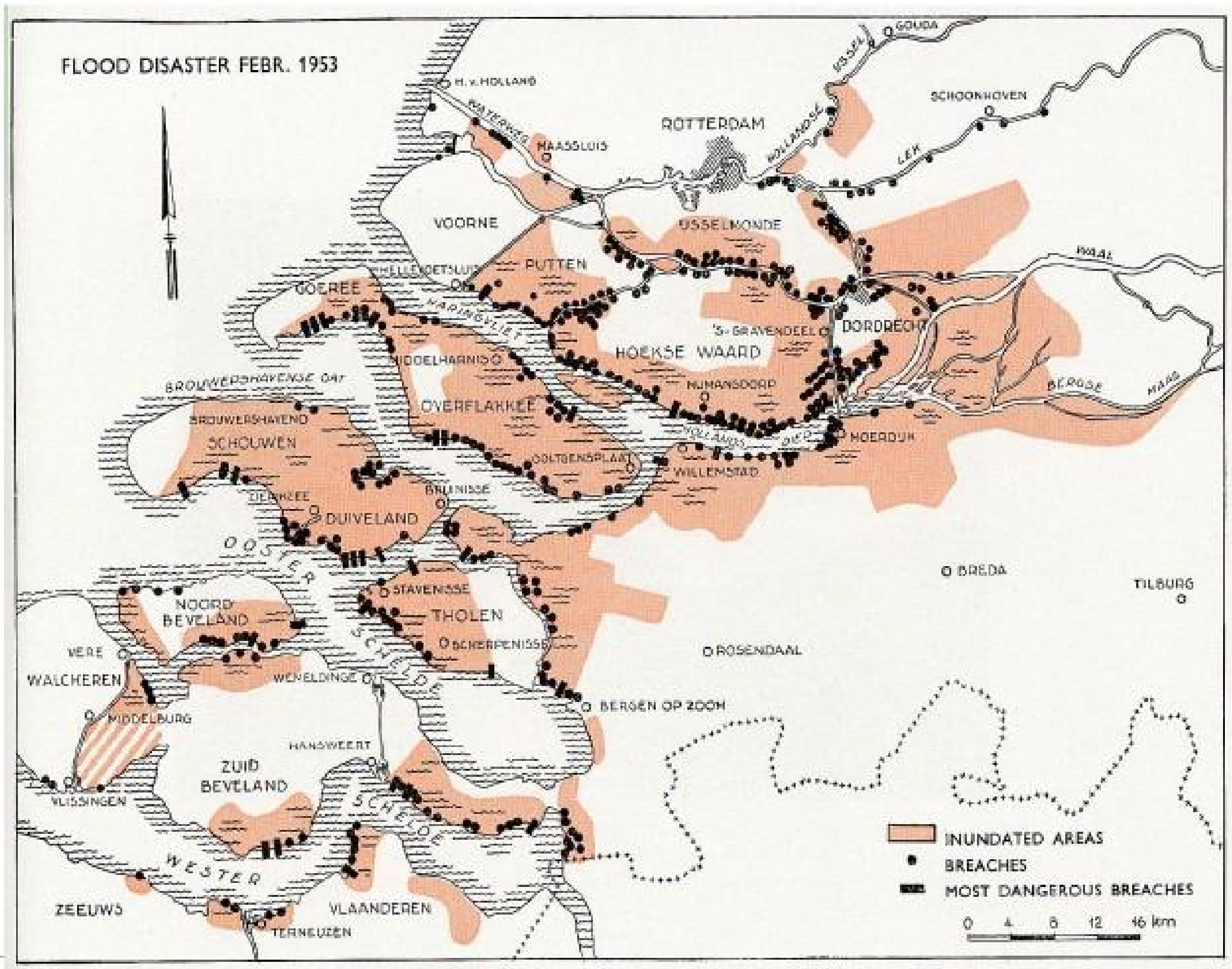
Extent of flooding in Delta area, February 1953



1836 human deaths

750,000 affected

100,000 evacuated

136,250 ha inundated

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Ouderkerk aan de IJssel, Sunday morning

Low water - extra low due to the Papendrecht breach

Eastern Scheldt Storm Surge barrier; 4 October 1986

Delta works; hydraulic and numerical modelling

Construction works were supported by hydraulic scale models, numerical models and field campaigns

For Eastern Scheldt storm surge barrier simultaneous operation of different models:

- hydraulic research started in 1969
- numerical models started in 1970s, with approximately 8000 grid points in 2D models
- comparable accuracy for scale models and numerical models
- In 1983 decided to use numerical models only

Hydraulic scale modelling at Delft Hydraulics

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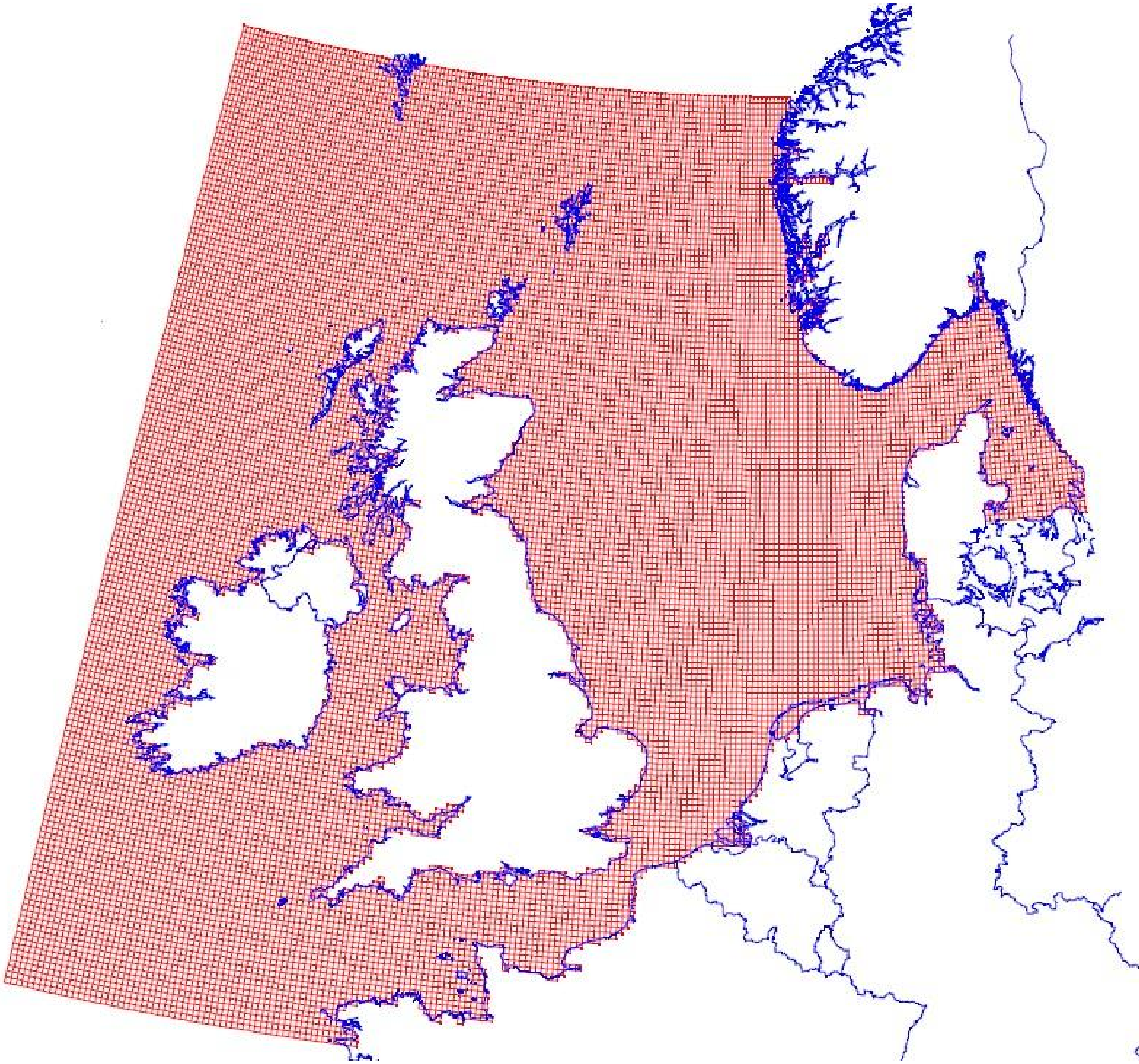
Operational North Sea models (1980s, 1990s)



DCSMv5 model (1/8 by 1/12 degrees ~ 8 km)

19.000 grid points

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Illustration of 2-D/3-D hydrodynamic models in NL

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Milestones for 2D and 3D SWE modelling in NL

1967 - 1986	2-D hydrodynamic modelling, closure of Eastern Scheldt storm surge barrier in 1986
1986 - 1994	3-D hydrodynamic modelling (σ layers); coupling to water quality and waves, vector computing
1995 - 2004	High performance computing; morphology
2004 - now	Consolidation (only a few major numerical developments; Z-modelling in 3-D
2011 - now	Delft3D open source
2011 - now	Unstructured grid modelling with Delft3D Flexible Mesh Suite

Milestones SWE model suites and modules in NL

	structured		unstructured
Model Suite / modules	**Delft3D (1986)**	**Simona (1990)**	**Delft3D Flexible Mesh (2015)**
Hydrodynamics	TRISULA / Delft3D-FLOW (1986)	WAQUA (1967) TRIWAQ (1992)	D-Flow Flexible Mesh (2015) For 2-D; test version for 3-D
Water quality	Delft3D-WAQ (1990)	Delft3D-WAQ (2000)	D-Water Quality (2016) test version for 2-D and 3-D
Waves	Delft3D-WAVE (1995)	Coupling to SWAN (2000)	D-WAVE (2017) test version for 2-D
Morphology	Delft3D-FLOW (1995)	-	D-Morphology (2017) test version for 2-D
Particle tracking	Delft3D-PART (1995)	SIMPAR (1995)	-

Key numerical features of Delft3D-FLOW and WAQUA/TRIWAQ

1. Alternating Direction Implicit (ADI) time integration method, enabling large time steps Leendertse (1967)
2. High order advection scheme with little (fourth-order) numerical dissipation to increase robustness Stelling (1983)
3. Advection near open and closed boundaries Stelling (1983)
4. Unified grid approach for curvilinear and spherical grids
5. Efficient wetting and drying algorithm
6. Extension to 3-D of the 2-D ADI method
7. Robust and accurate k-epsilon turbulence model
8. Efficient high performance computing, with emphasis on a limited number of processors (e.g., 1 to 64)

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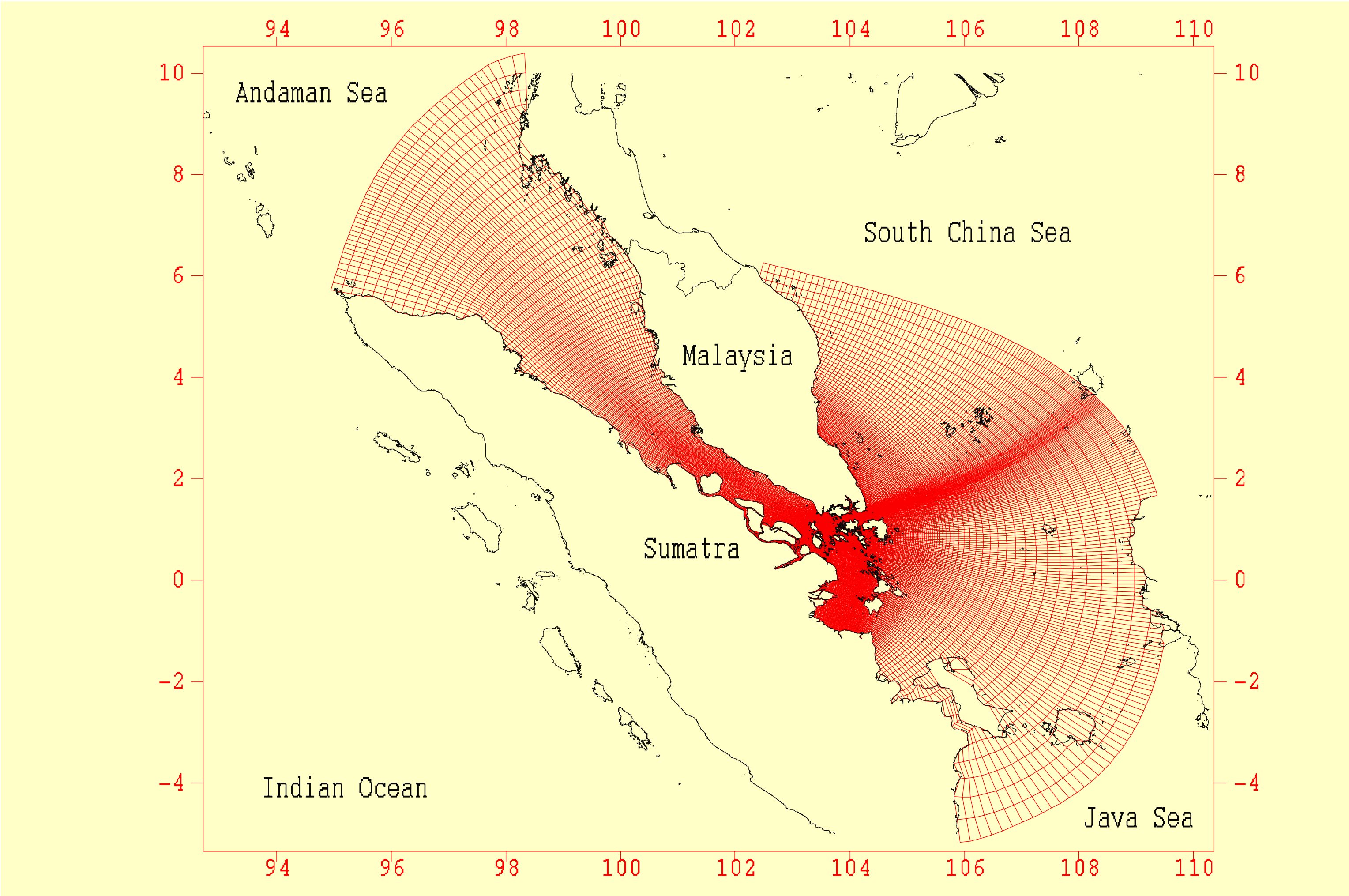
Grid generation; Malacca Straits model (1)



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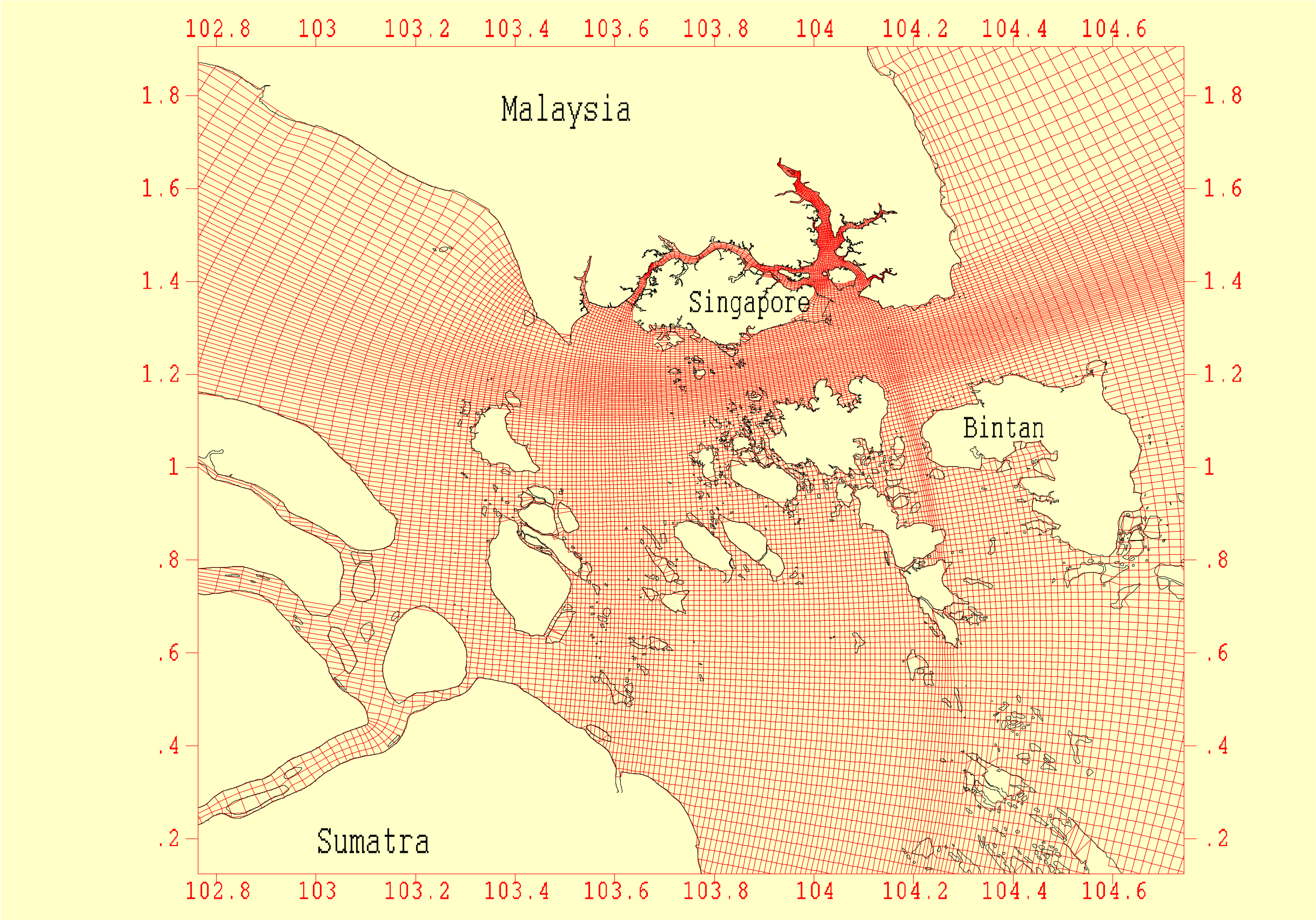
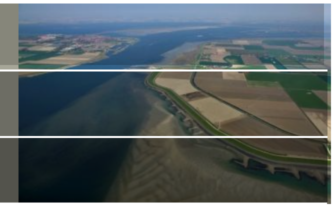
Grid generation; Malacca Straits model (2)



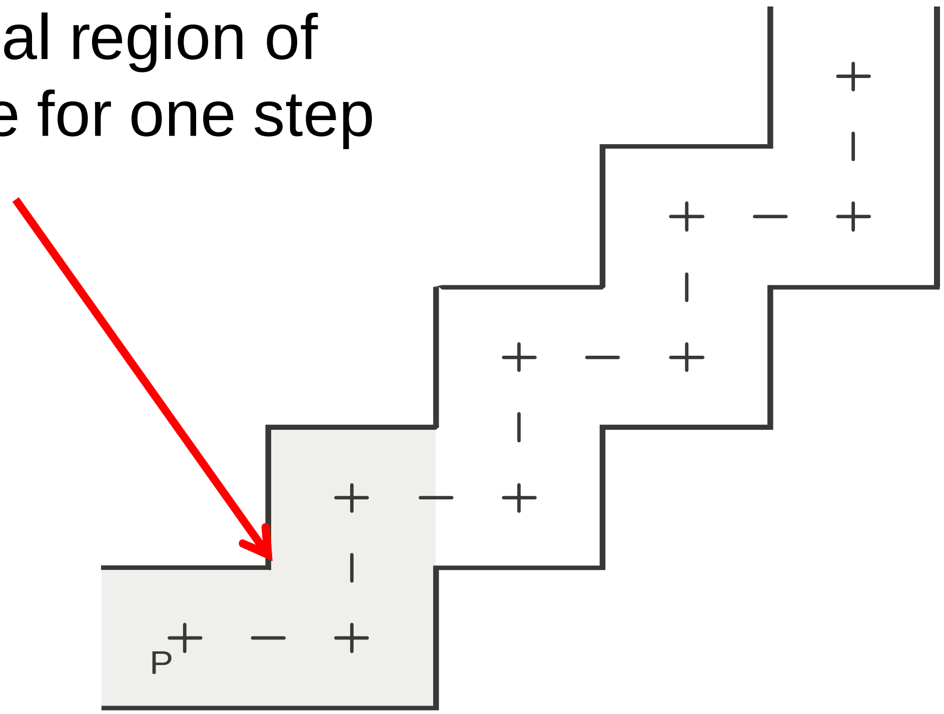
ADI time integration scheme



- Robust ("unconditionally stable")
- Accurate (at least second-order accurate)
- Computationally efficient on sequential and parallel computers
- Suitable for time-dependent and steady state problems
- Contains dissipativity to increase the robustness, but this is small (fourth-order) and does not deteriorate the accuracy
- Special discretizations near open boundaries and structures
- Special boundary conditions aren't required due to the splitting in directions.

Disadvantage of ADI method?

Numerical region of
influence for one step



The reduced accuracy near staircase boundaries can be largely avoided in the area of interest by using curvilinear grids

Towards unstructured modelling; 2011- ...

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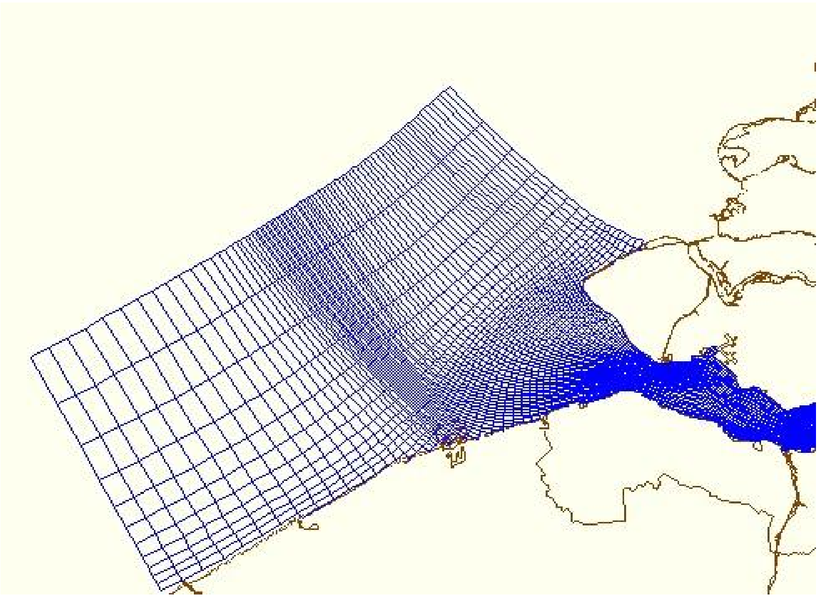
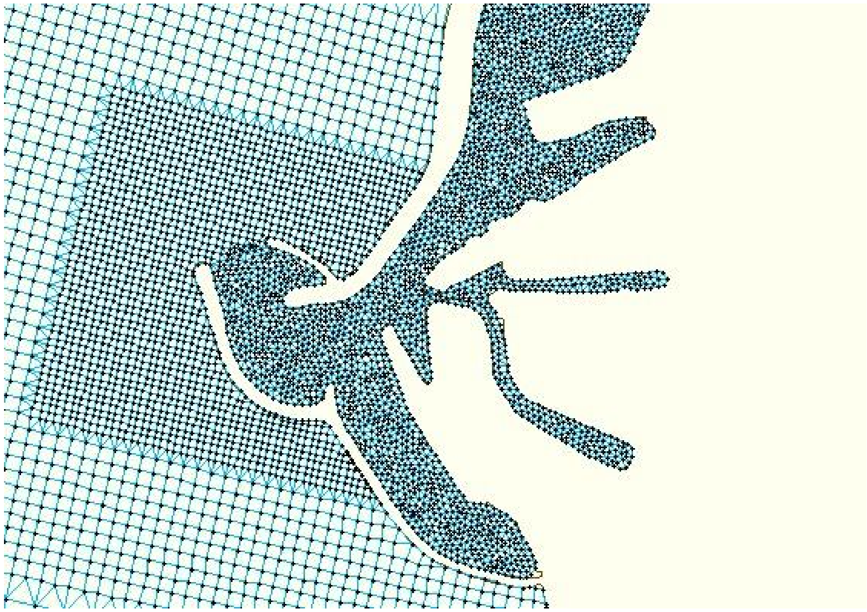
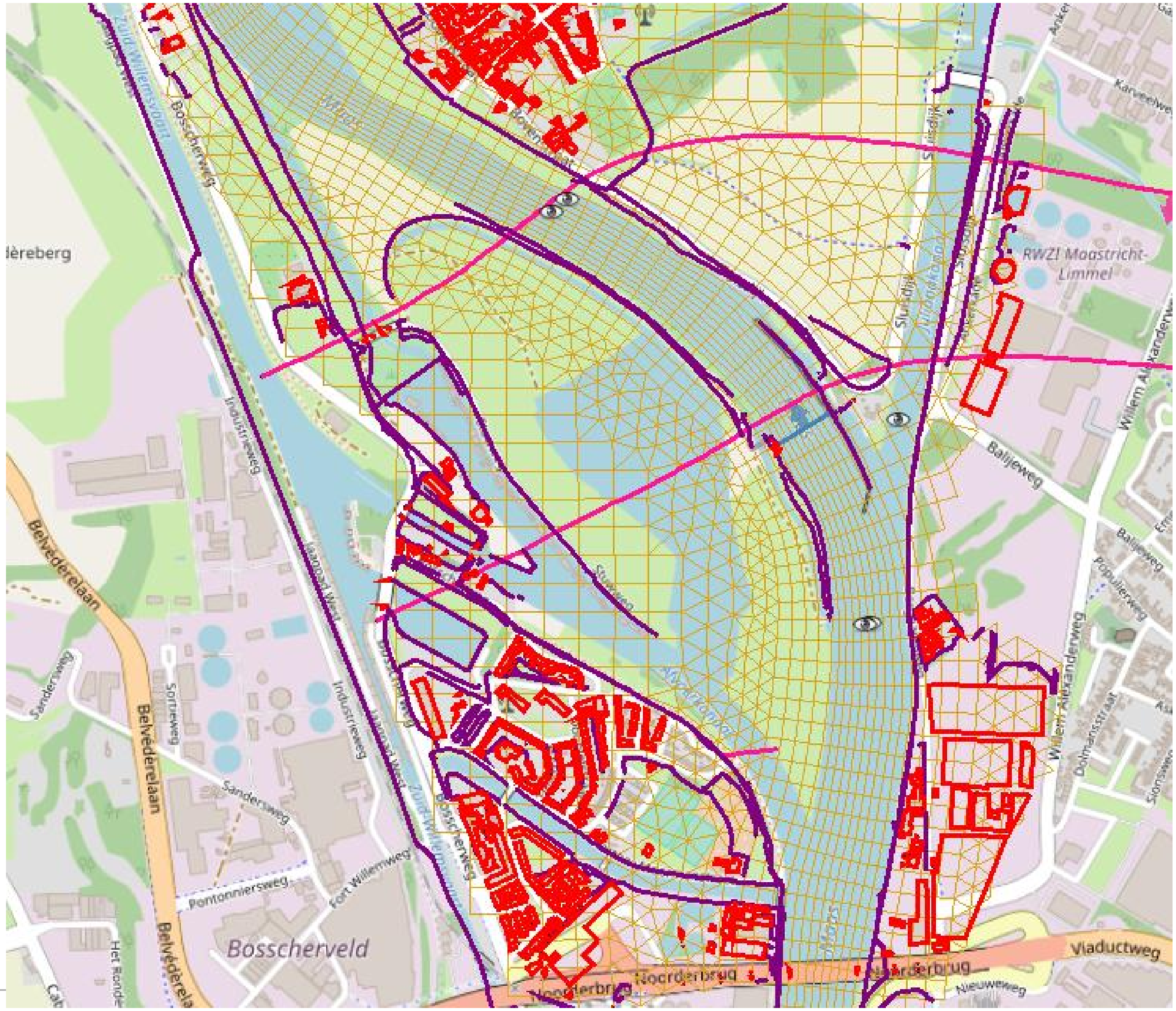
Delft3D 4 and Delft3D Flexible Mesh

- Delft3D 4 modelling suite (structured grid modelling)
- Delft3D Flexible Mesh modelling suite: unstructured grids with triangles, quadrangles, ..





Meuse grid at Maastricht/Borgharen (1)



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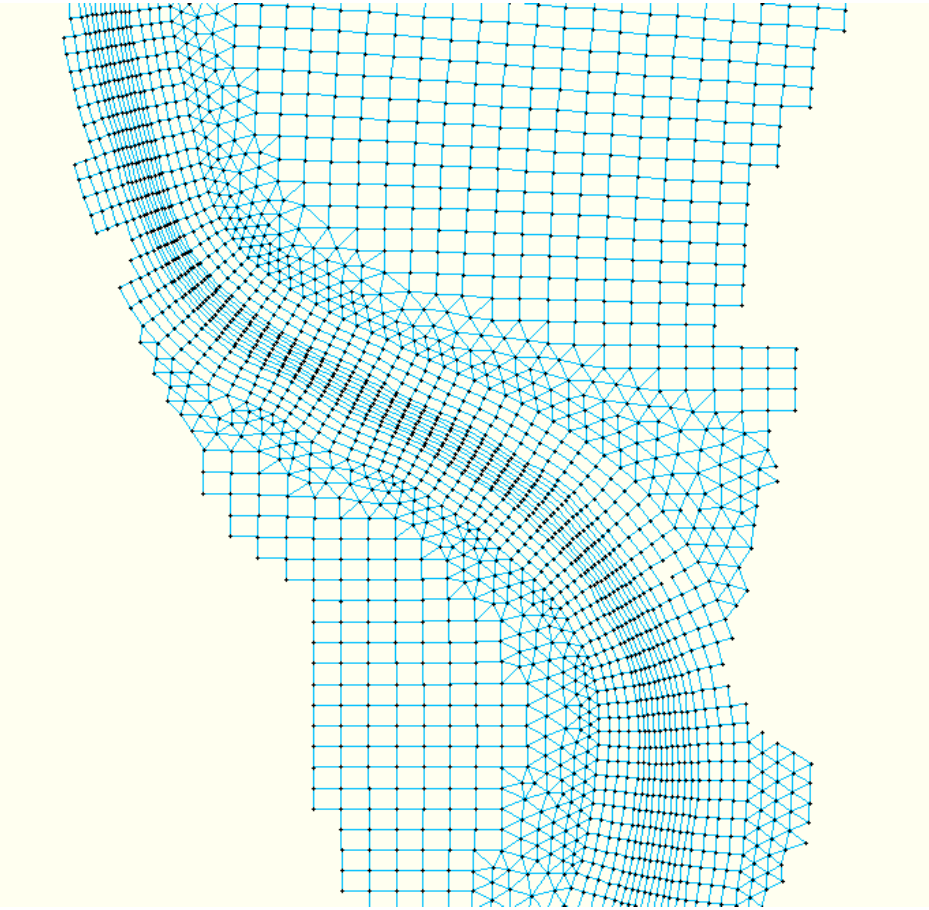
Meuse grid at Maastricht/Borgharen (2)

Rectangular/curvilinear quadrangles preferred over triangles?

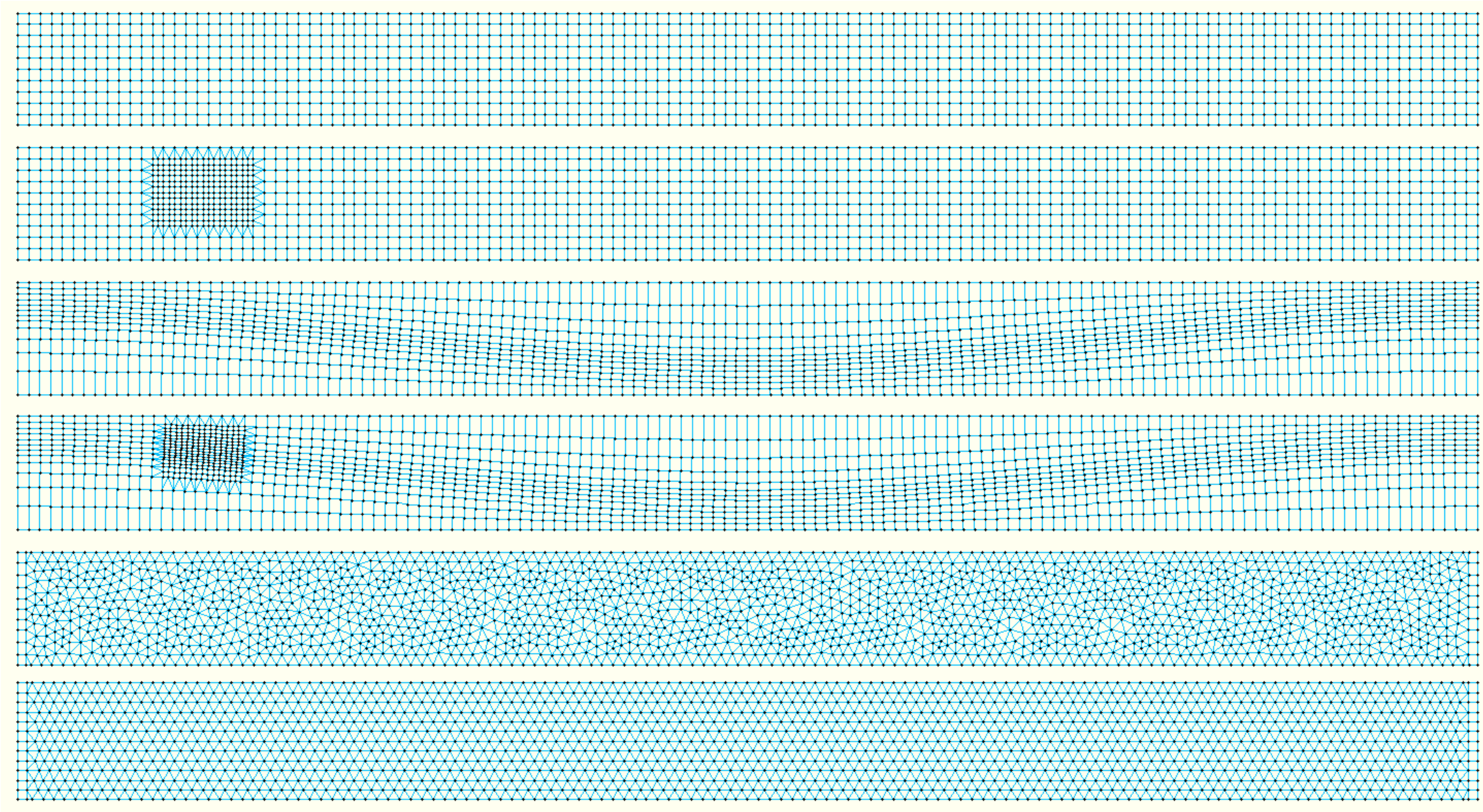
Because of:

- Less numerical diffusion
- Larger volumes of rectangular compared to triangles (and thus larger time steps and less computation time)



Salinity intrusion for schematic case

Grids for schematic case with meandering channel



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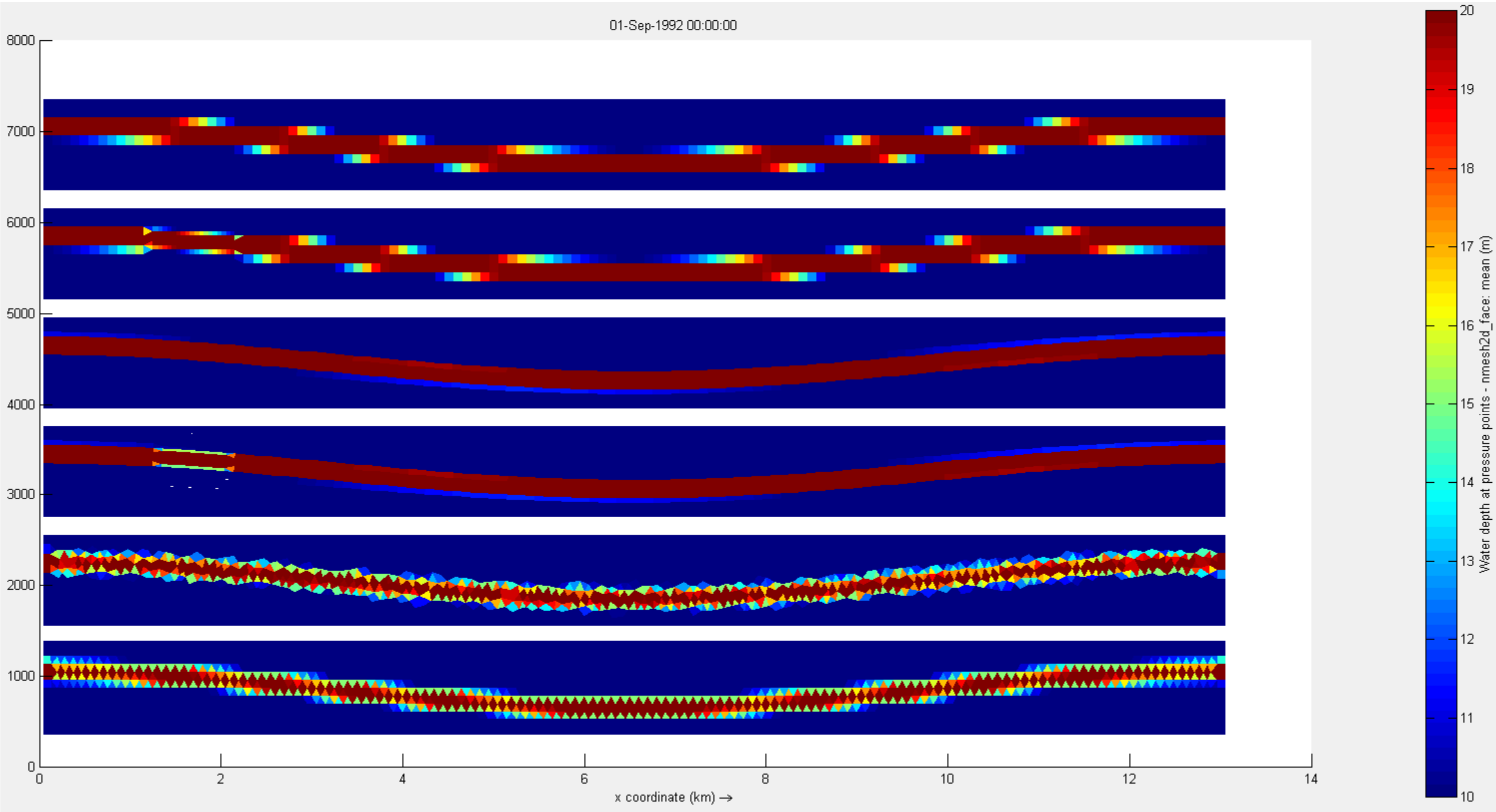
Bed level for schematic case



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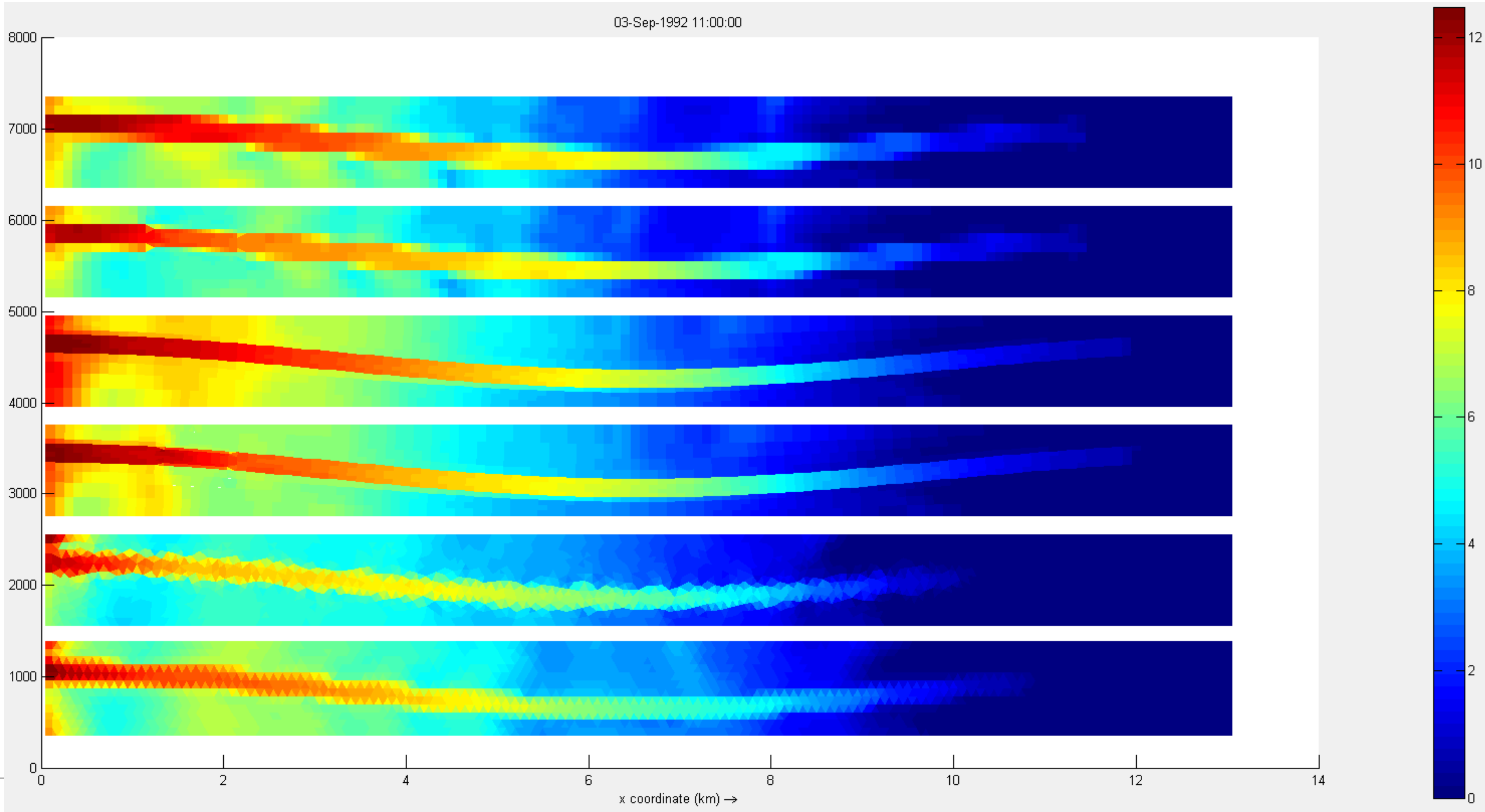
Salinity intrusion for schematic case



Haringvliet real-life salinity intrusion

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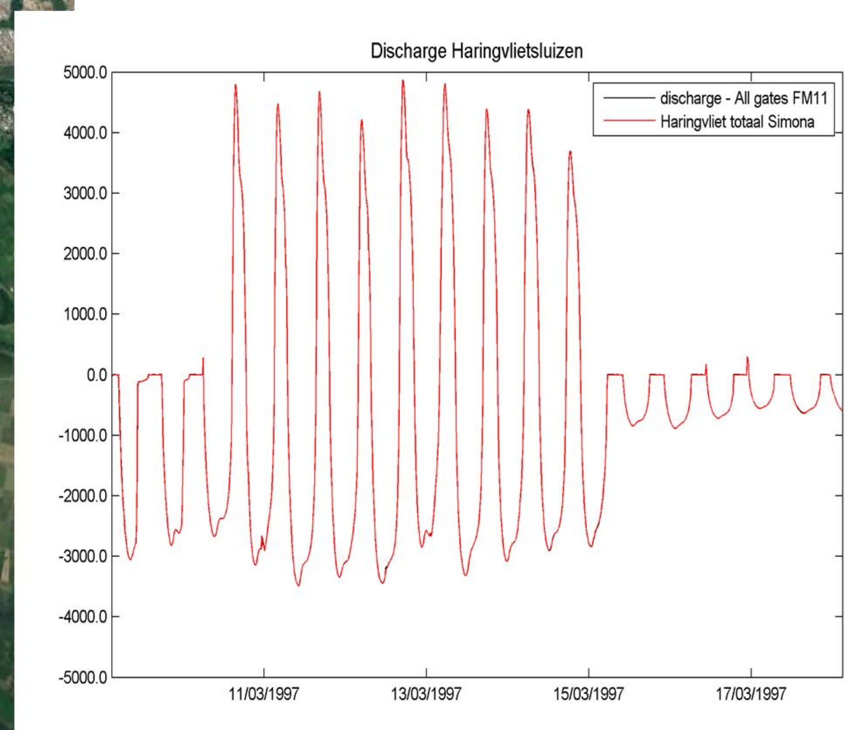
Haringvliet trial of saline water inlet

Testcase 1997

- Inlet of saline water during five days



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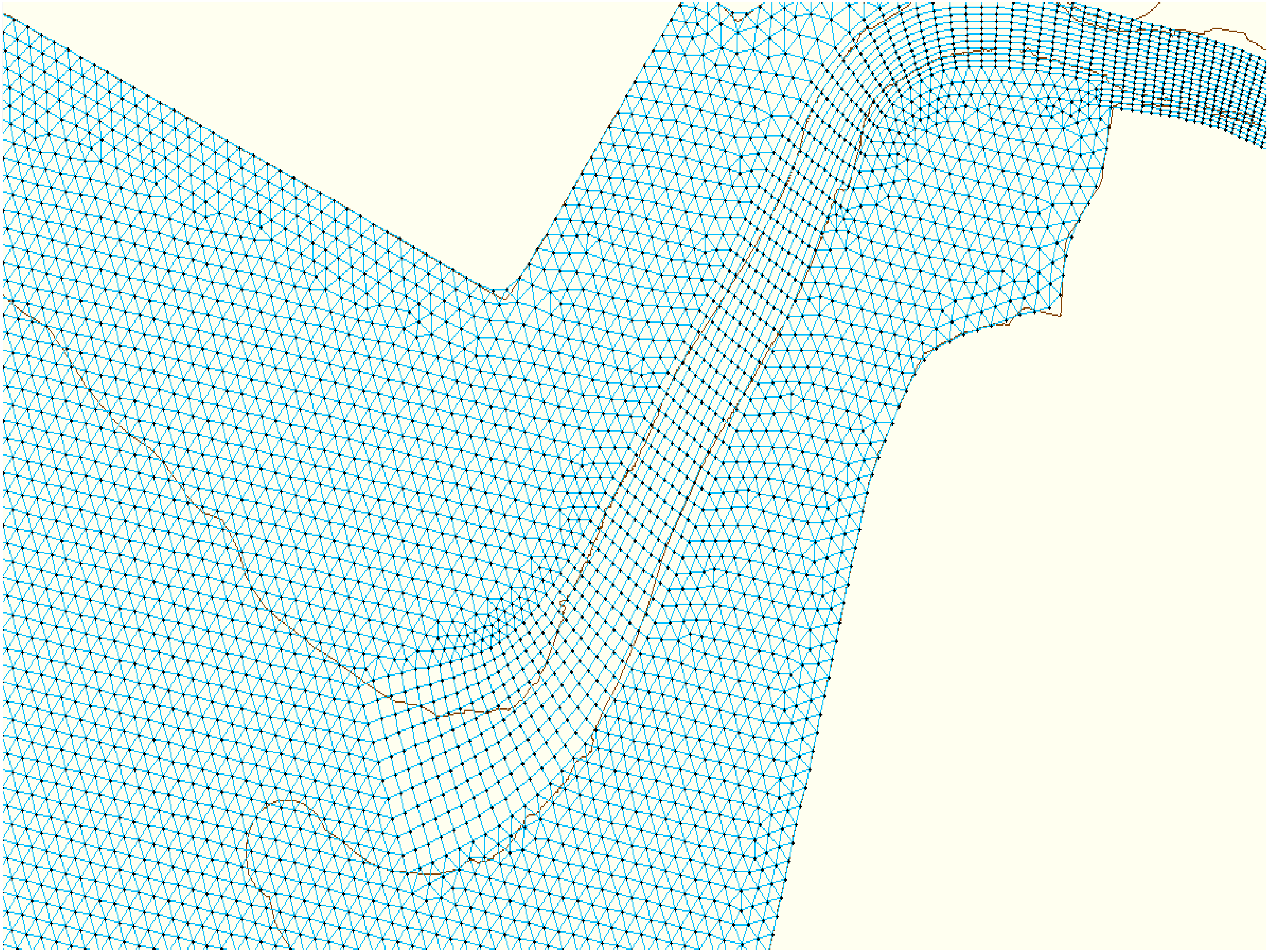
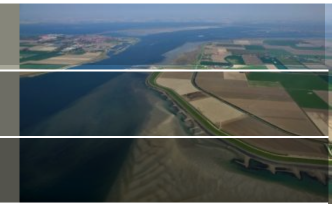


Overview of simulations



	Network	Water lev. pts.	Netlinks	Netnodes	Δt	Comp. T.[s]
R1	Curvilinear	40994	82500	41600	15.9	7200
R2	Triangles (62 m)	28839	44000	15100	13.3	4900
R3	Quadrangles (41 m)	32250	59300	27000	12.5	6500
R4	Quadrangles (36 m)	40087	74200	34100	12.5	8300
R5	Triangles (40 m)	61565	93000	31500	11.5	12200

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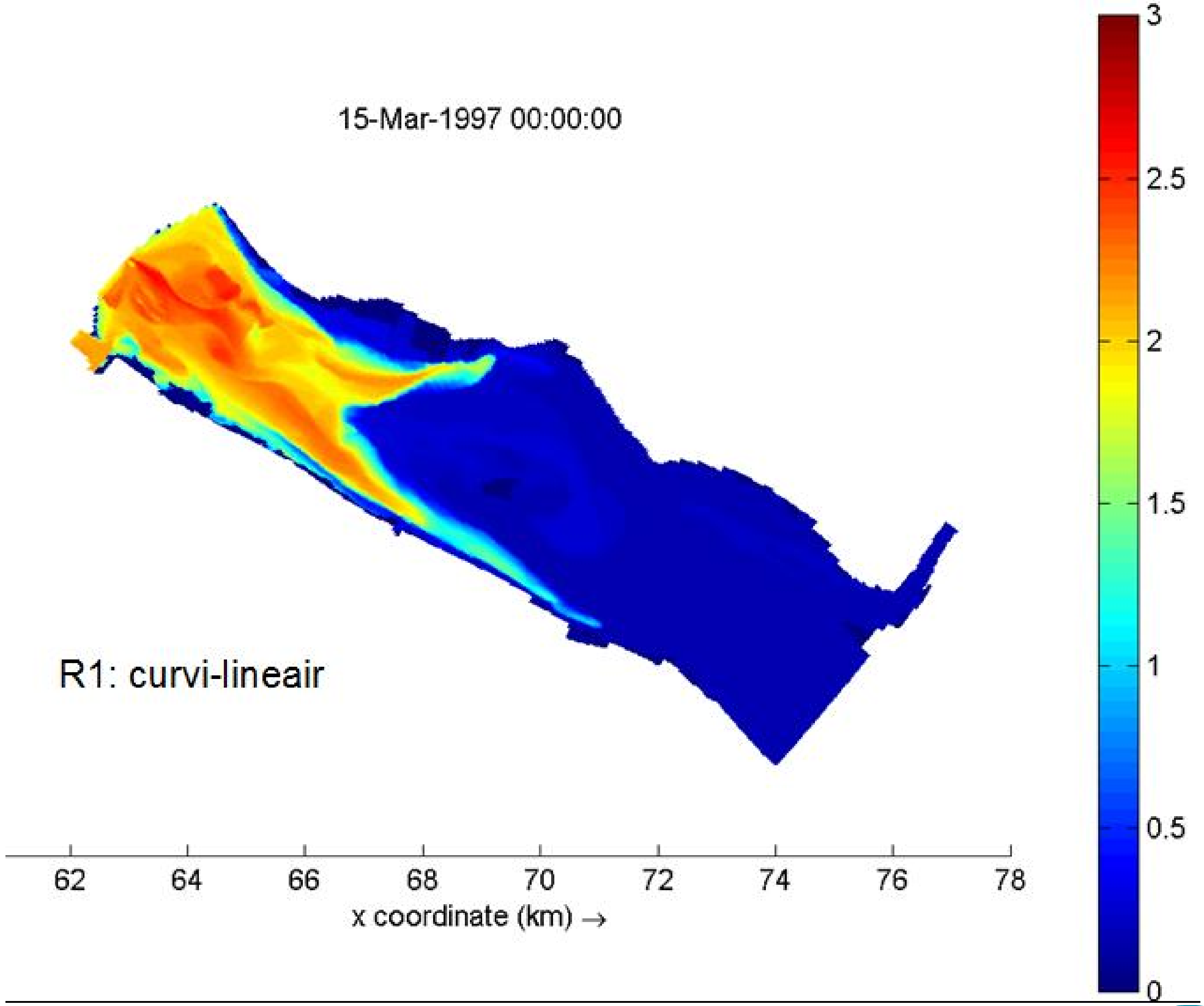
Salinity intrusion for curvilinear grid



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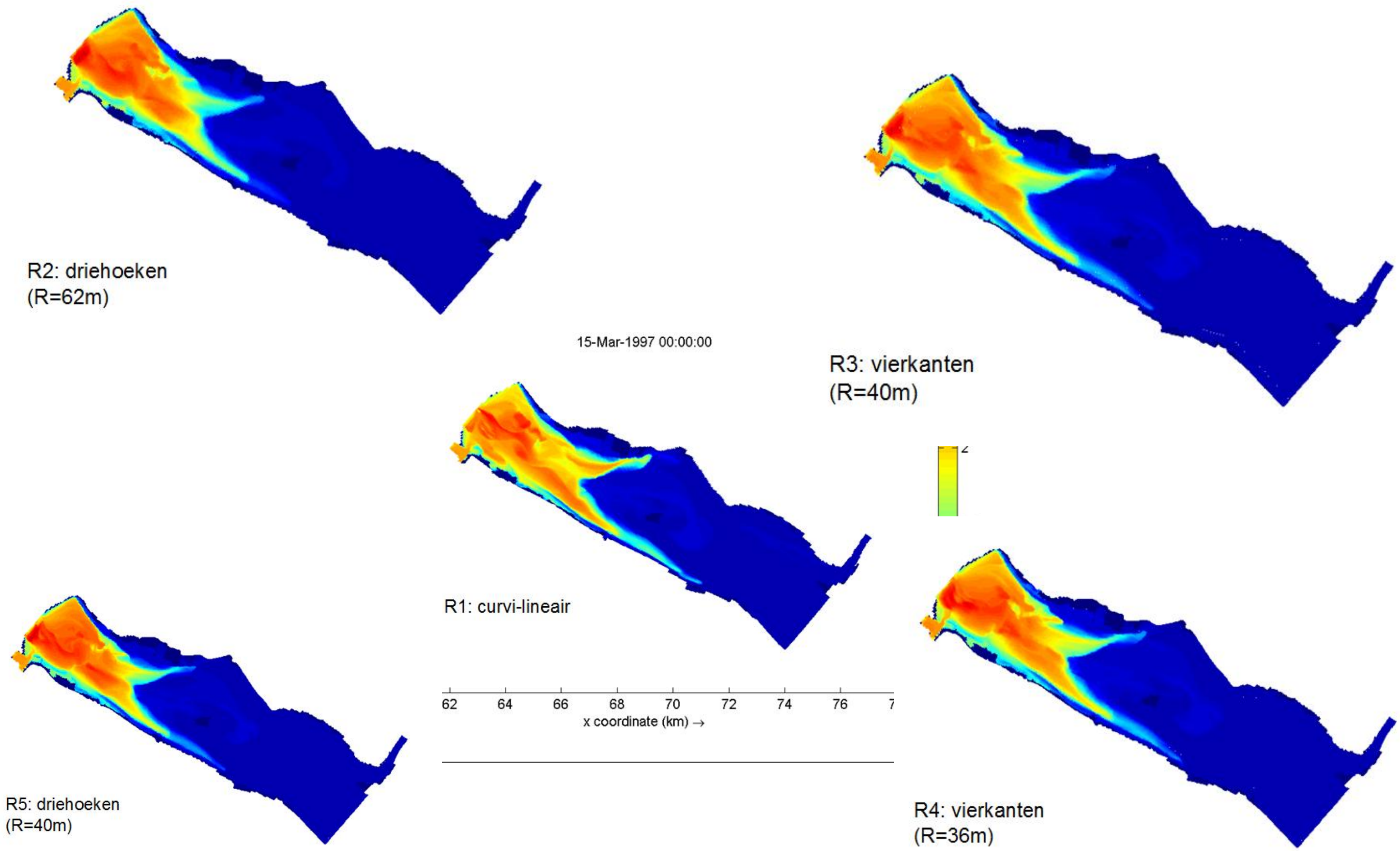
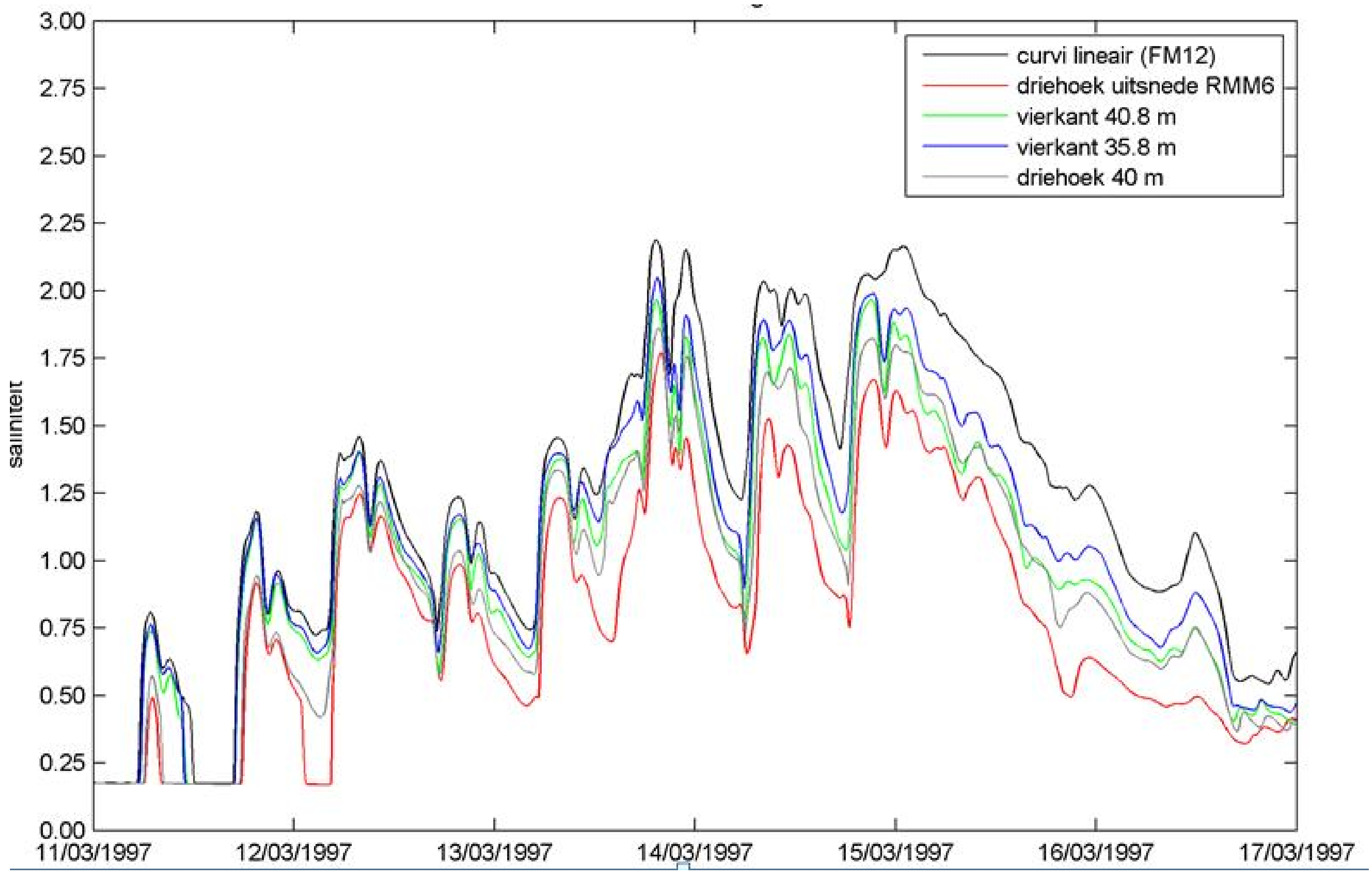
Salinity intrusion for all five grids



Salinity intrusion for all five grids



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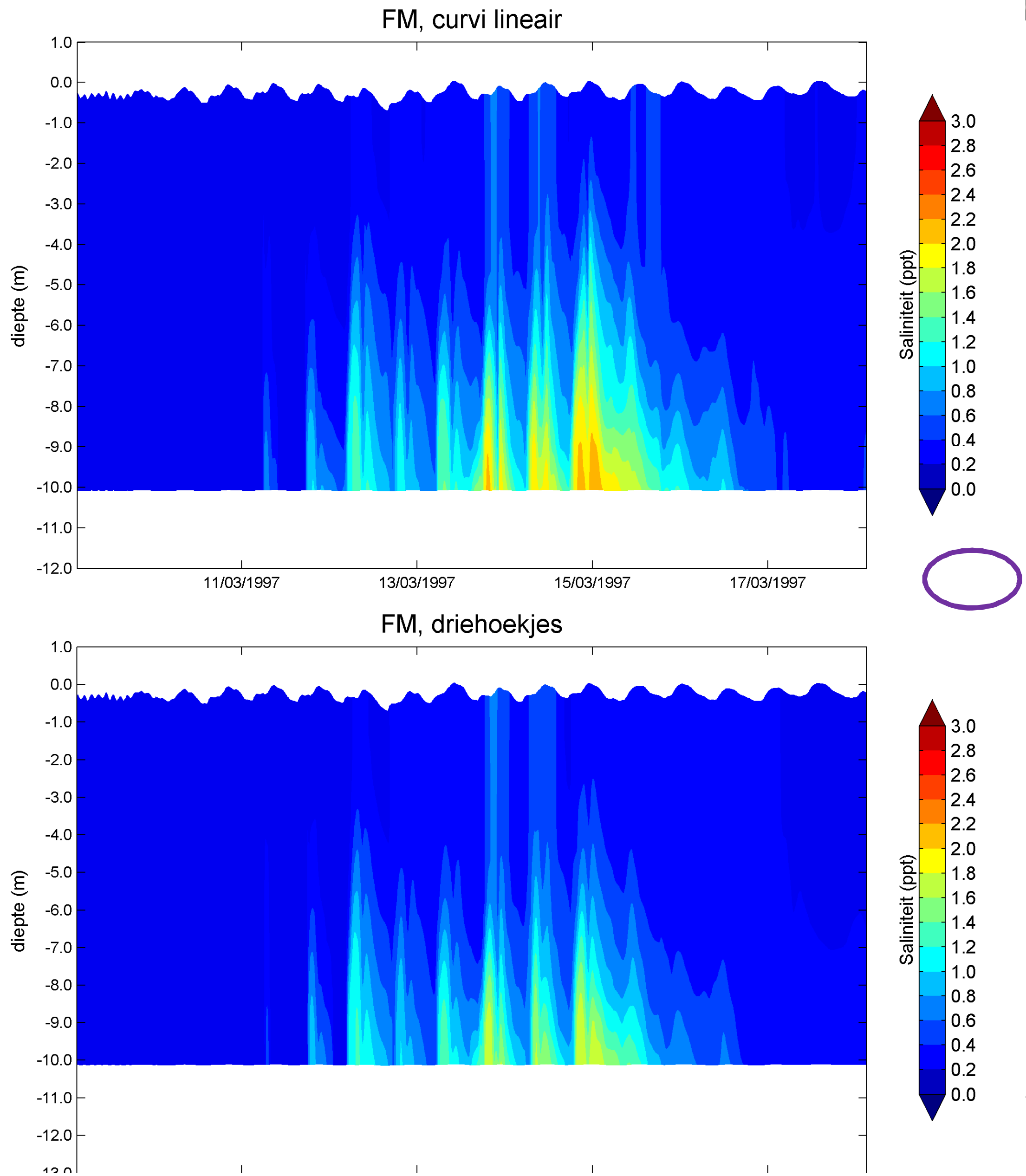

- CURVILINEAR

- TRIANGLE

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Conclusions for transport of salinity

- Triangles and quadrangles (curvilinear and squares) are both possible
- Only fully unstructured grids show somewhat less salinity intrusion
- At the cost of extra computational cells and computation time triangle grids are comparable to quadrangles w.r.t. accuracy
- Grid resolution is important for salinity intrusion

Optimal grids for unstructured grid modelling remain a learning process….

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Venice lagoon model by Technital (Verona)