Generalisation of Topographic resolution for 2D Urban Flood Modelling

Solomon D. Seyoum
Ronald Price
Zoran Voijnovic

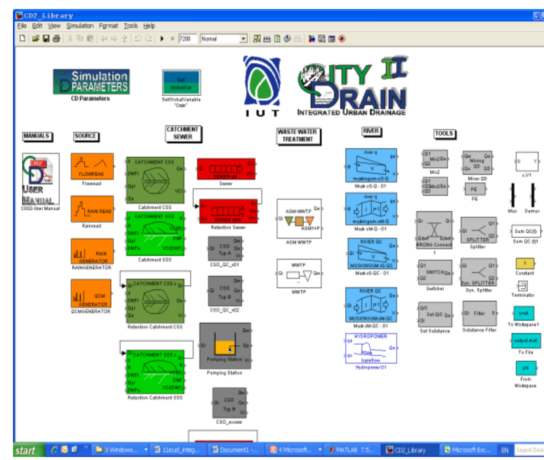
Outline

- Introduction
- Urban Flood Modelling and Topographic data
- DTM Generalisation
- Remedial solutions
- 2D overland flow model
- Case study and Results
- Conclusions

Introduction

- The need for IUWS modelling lead to development of different models depending on temporal and spatial scales
  - Aquacycle, ICS (Integrated Catchment Simulator), KOSIM-WEST, City Drain and many more

- CityDrain Model
  - an existing tool for integrated model assessment of interactions between elements of the urban drainage system;
    - catchment runoff,
    - sewers,
    - treatment plants and
    - receiving waters
  - open source software
  - use simplified conceptual hydrologic flow (Muskingum flow routing)
  - can not address flooding and surcharge conditions

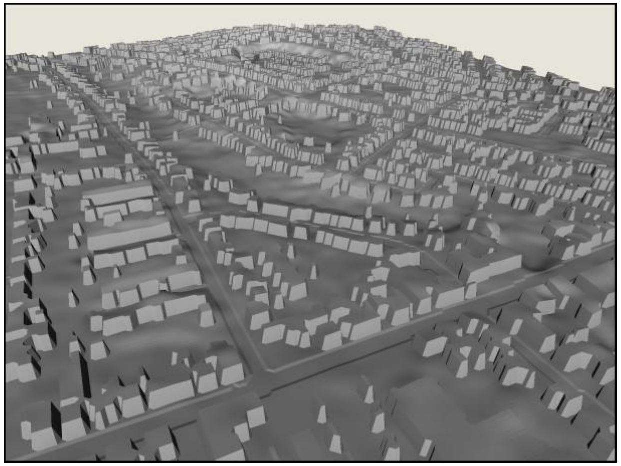


Introduction

- Enhancing City Drain by improving the capability of the conceptual sewer component to simulate surcharge flows
- But still City Drain can not be used to predict flood extent, flood depth and velocity which are important for flood risk and flood hazards assessment
  - Prompted us to develop 2D urban flood model and a coupled 1D-2D model to simulate interaction between sewer network and overland flow.
  - My presentation today is on the development and application of coarse resolution 2D urban flood model which uses information extracted from fine grid resolution topography data.

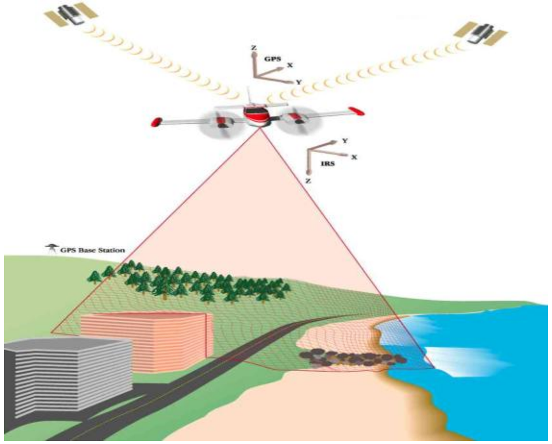
Urban Flood Modelling and Topographic Data

- Urban Flood Modelling usually requires prediction of flood flows over complex topography
- 2D inundation models – often preferred choices and shown to provide good prediction of flood inundation extent
- Traditionally, 2D models have been constrained by scarcity of detailed topographic data



Urban Flood Modelling and Topographic Data

- This constraint has been dramatically relaxed by the emergence of new data capture techniques
  - airborne remote sensing
  - aerial digital photogrammetry
  - Light Detection And Ranging (LiDAR)
- High resolution data obtained from these new topographic data sources are increasing opportunities for representation of structural elements in complex floodplains
  - walls, buildings , railroads, curbs



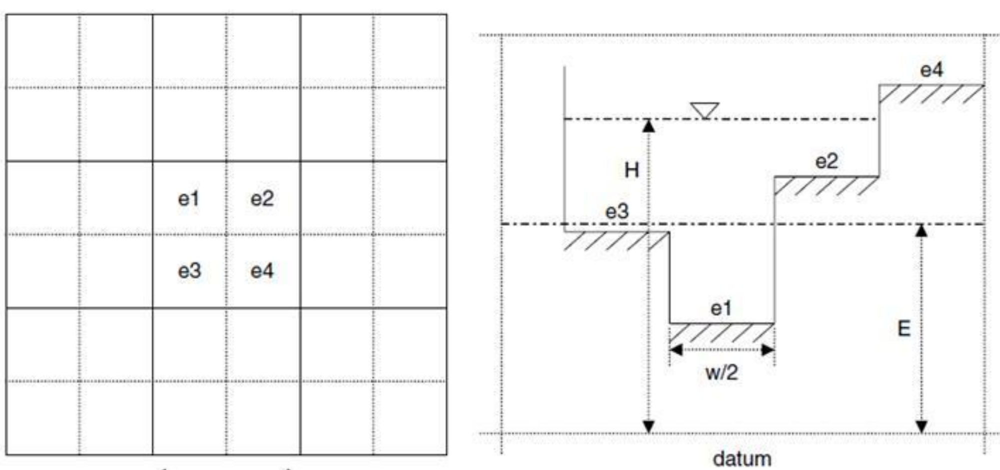
Urban Flood Modelling and Topographic Data

- However models with high resolution topographic data are not extensively applied to urban areas due to their computational constraints and thus unable to make optimal use of available data.
- When there is a need to simulate many flood realizations (eg. optimization of urban drainage) or for real time application coarse resolution models are often used.
- Accuracy of such coarse grid models deteriorate as the grid size increases.

- To reduce simulation time different approach are used
  - Use of simplified models (eg. coupled 1D and kinematic wave 2D models)
  - DTM generalization (coarsening)
  - Roughness parameterisation
  - Use of parallel computing

DTM Generalisation

- DTM Generalisation Problem
  - “spreading” of dominant feature
  - Surface topology changes
  - Alleyways are lost
  - Surface flow-paths diverted

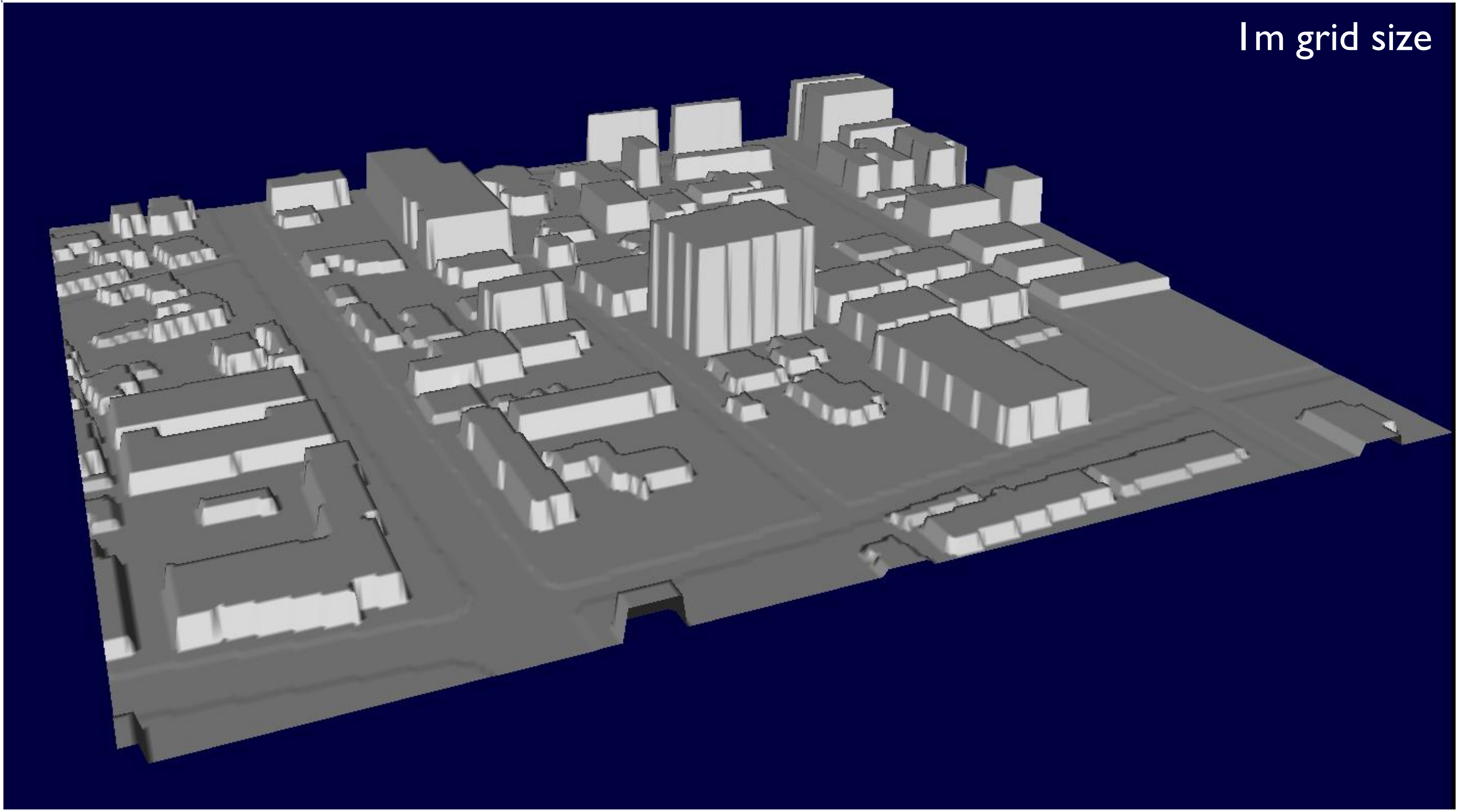


$$E = \sum_{k=1}^{4} e_k$$

From: Yu and Lane, 2006

DTM Generalisation

- 7 ha area



DTM Generalisation

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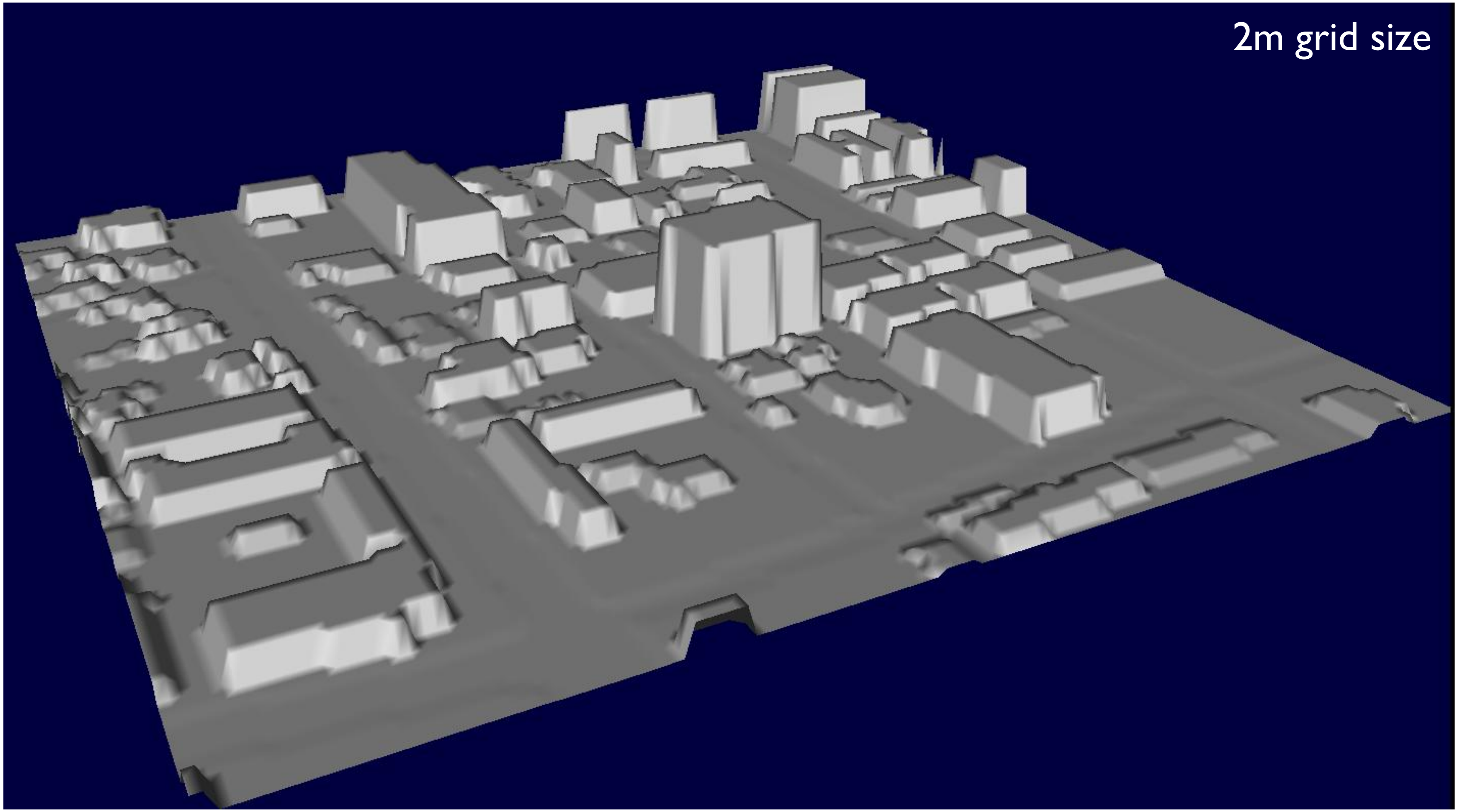

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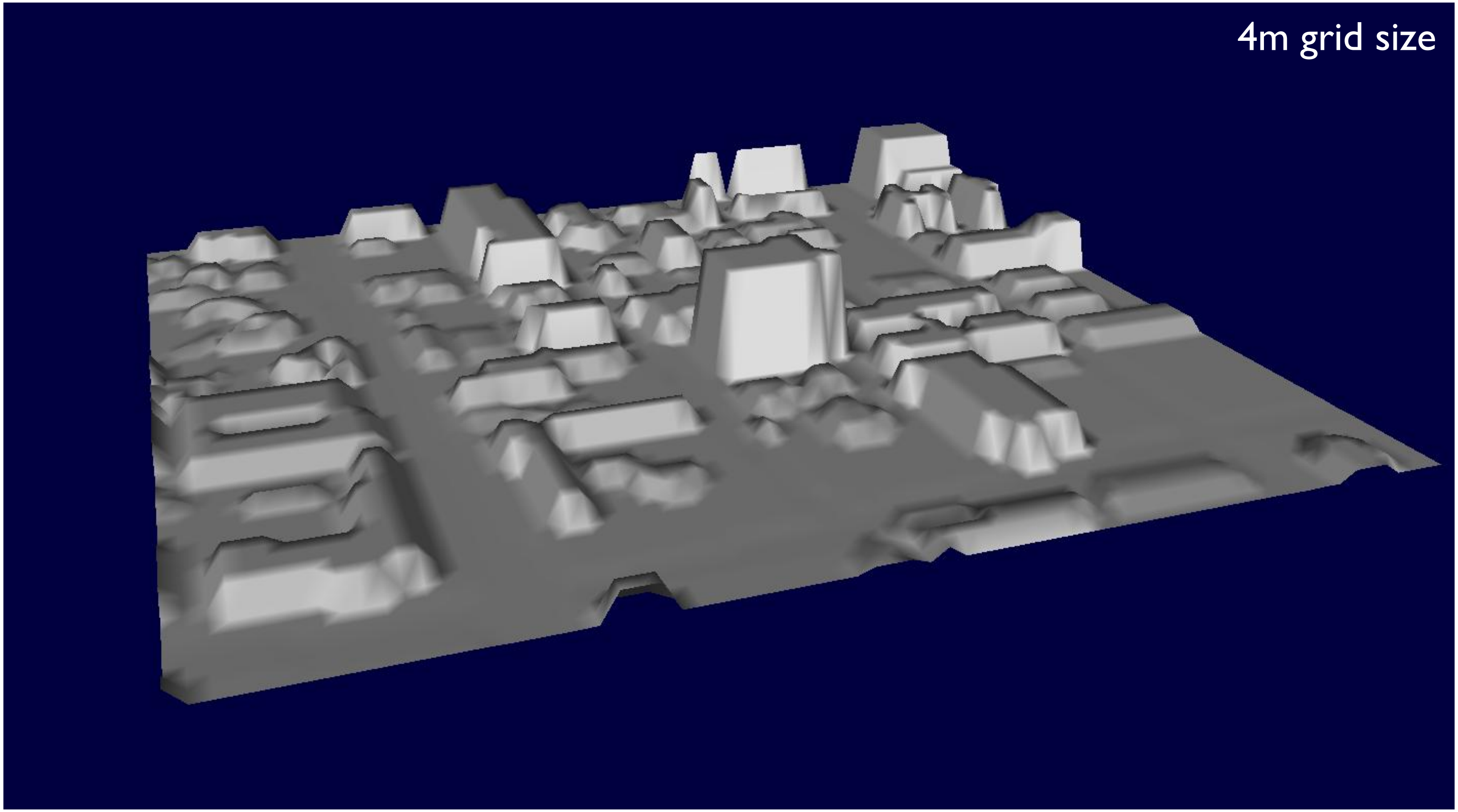

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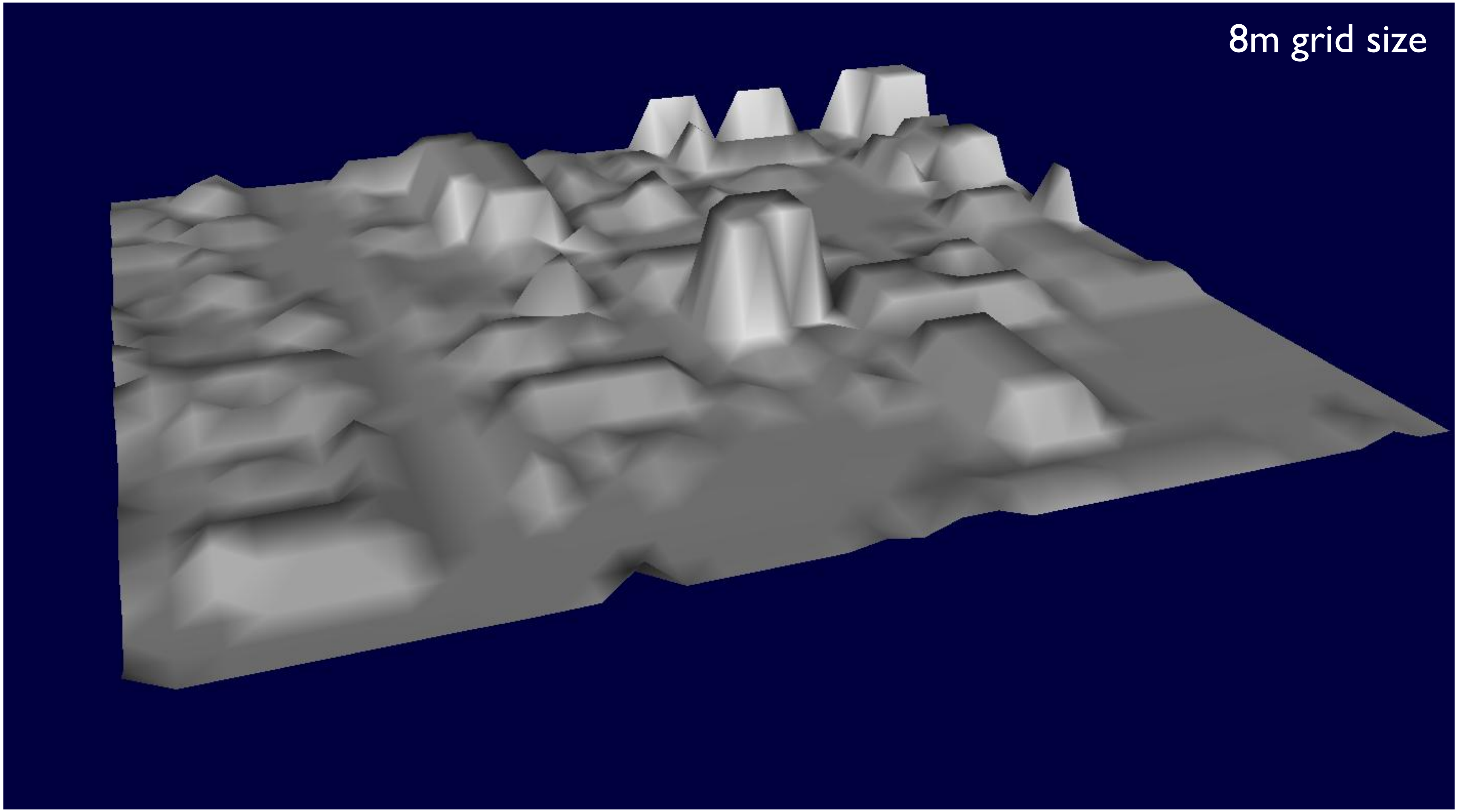

DTM Generalisation

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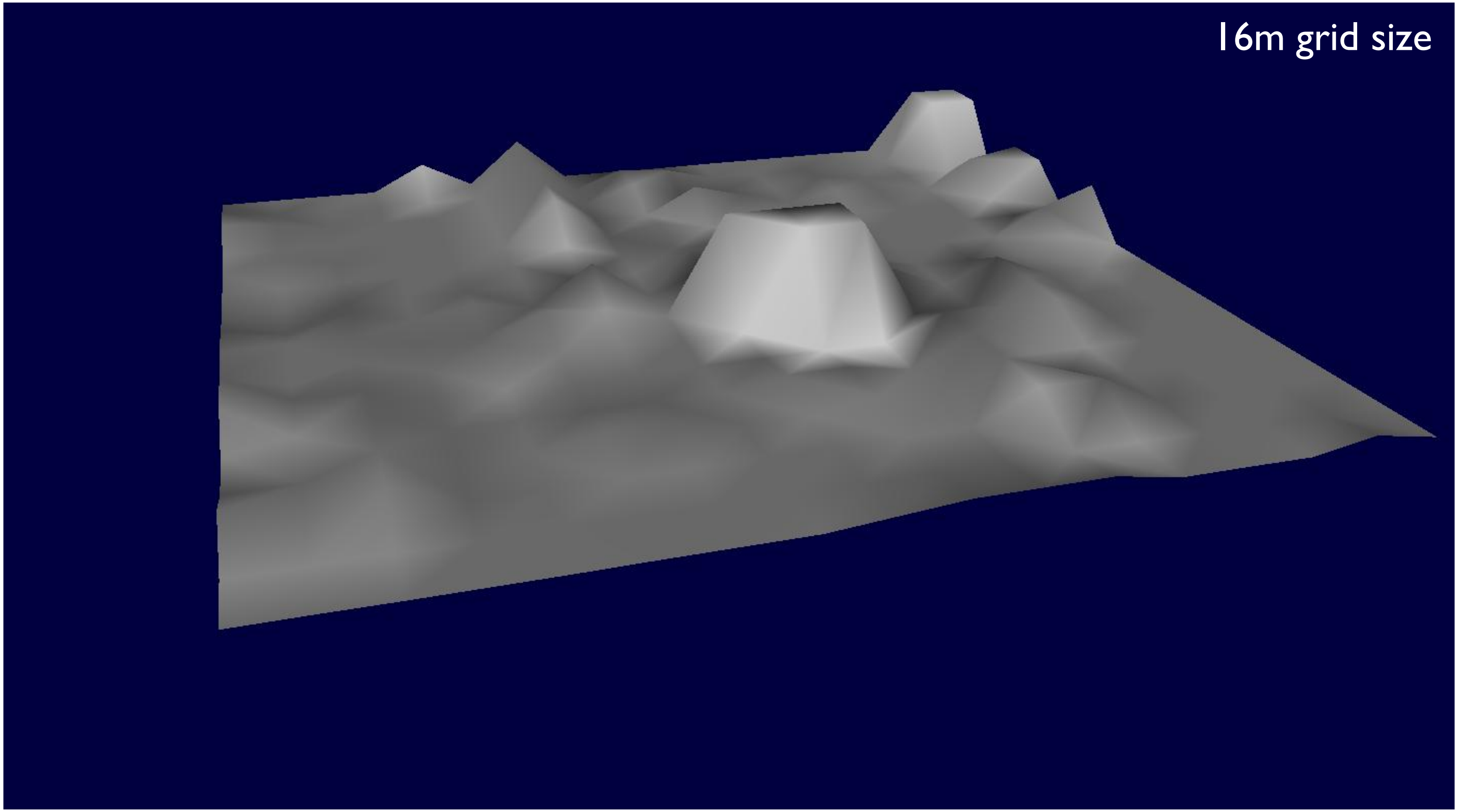

DTM Generalisation

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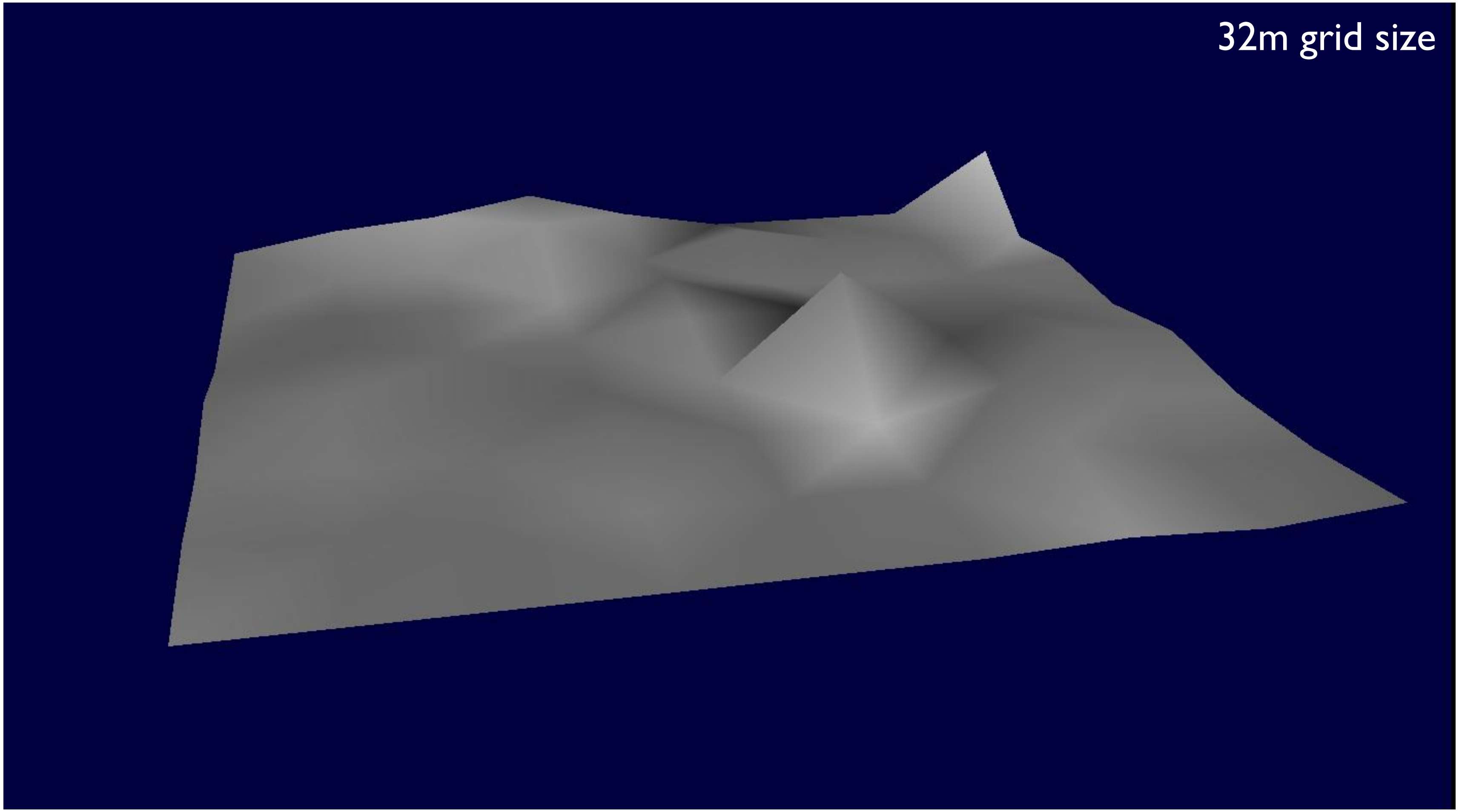

DTM Generalisation

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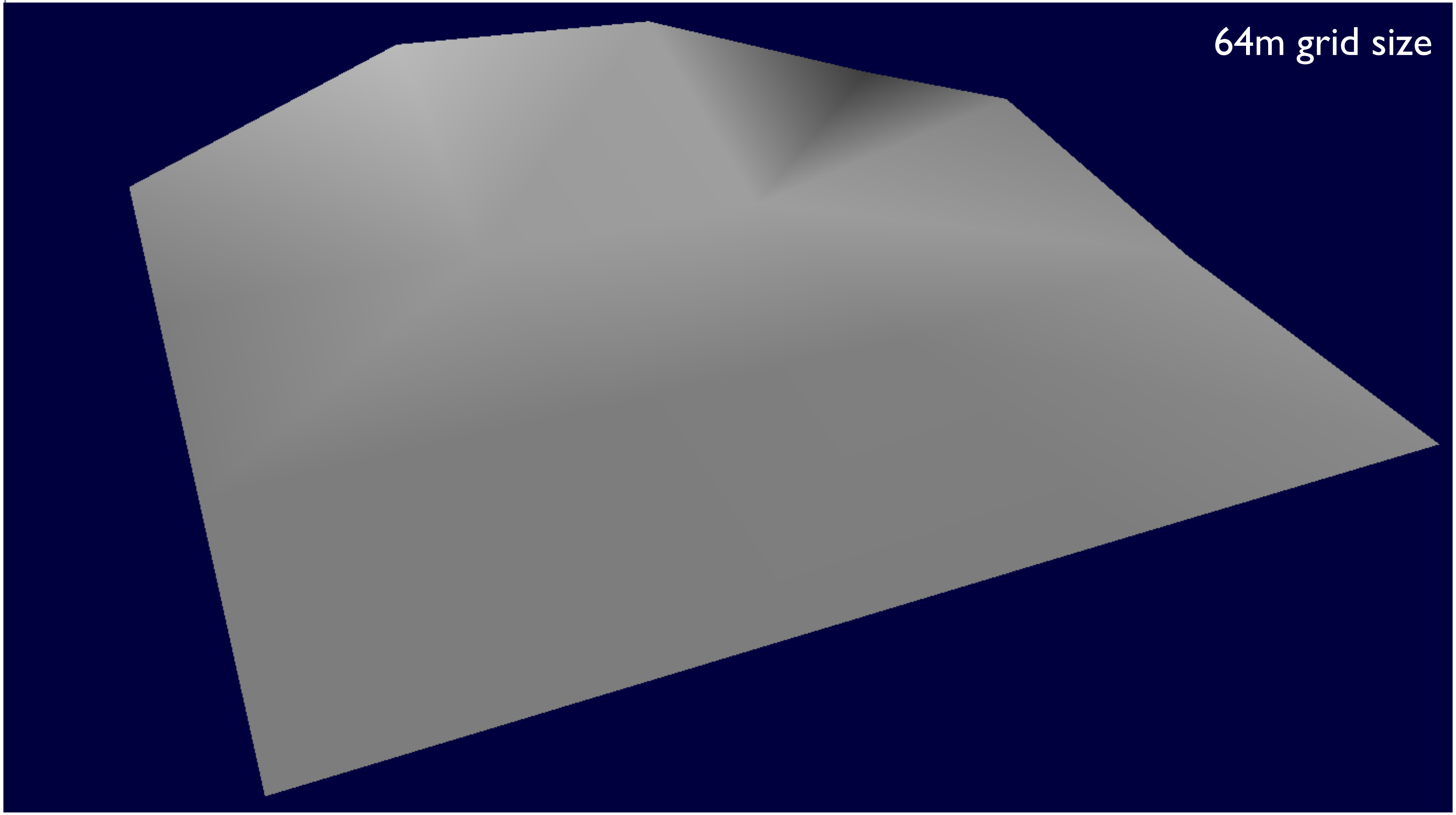
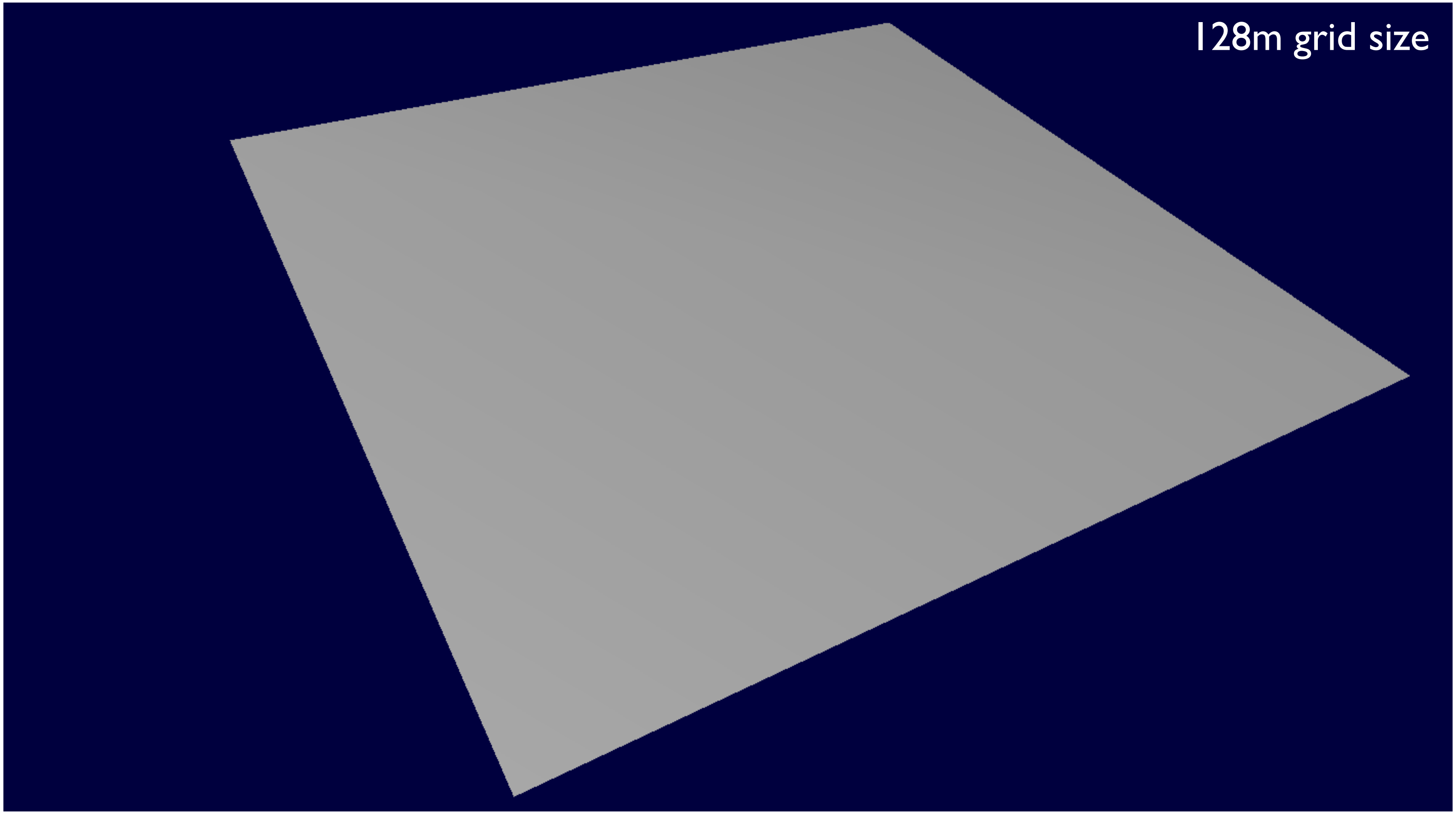


DTM Generalisation

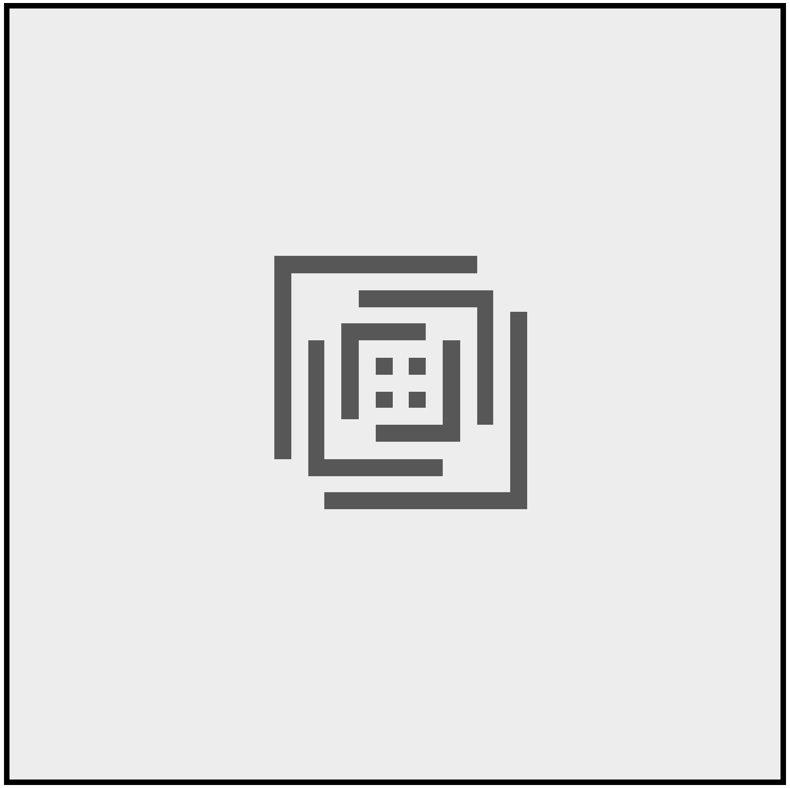
- 7 ha area

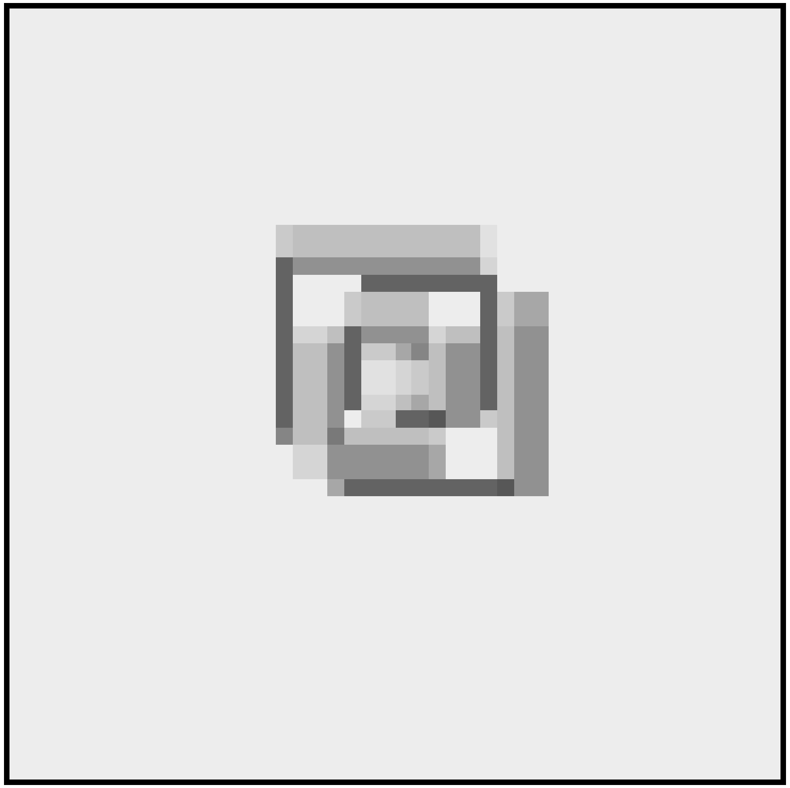


DTM Generalisation

- Researches have shown that small changes in model resolution have considerable effect on predicted inundation extent and timing
- Inundation extent is associated with
  - Smoothing effect of mesh coarsening
  - Poor representation of both cell blockage and surface routing processes
  - Effect of the above two on water level and velocities

DTM Generalisation





(a) Fine resolution (2by2m)

(b) Coarse resolution (6by6m)

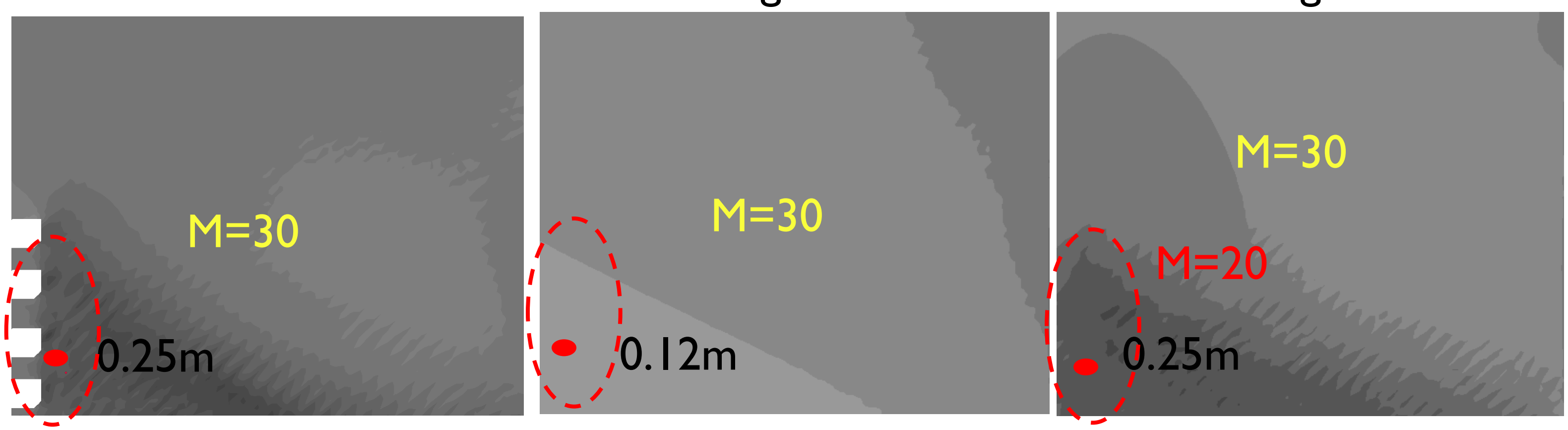
Approaches to increase coarse models accuracy

- Roughness parametrisation

Model with building blocks

Model without building blocks and unique roughness

Model without building blocks and diff local roughness



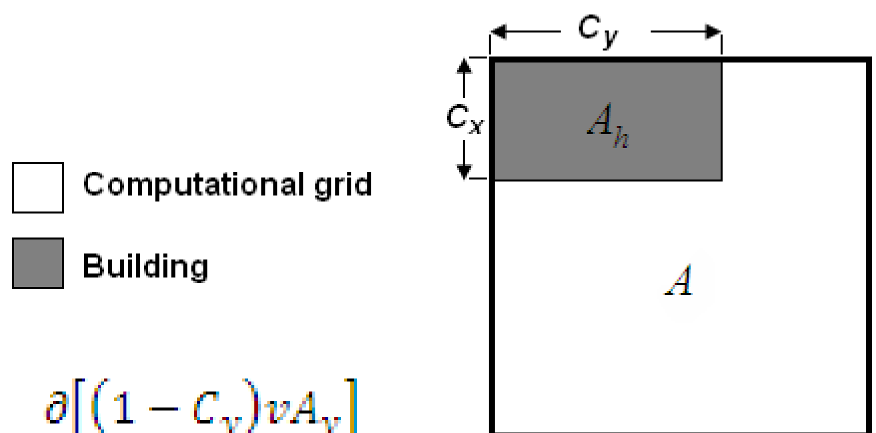
5m DTM

(Source:Vojinovic et. al., 2009)

Approaches to increase coarse models accuracy

- Incorporation of Building Coverage Ratios (BCR) and Conveyance Reduction Factors (CRF) to represent the influence of building structures within a generalised grid-cell

$$\alpha = \frac{A_h}{A}$$



$$(1-\alpha)\frac{\partial h}{\partial t} + \Delta x \frac{\partial[(1-C_x)uA_x]}{\partial x} + \Delta y \frac{\partial[(1-C_y)vA_y]}{\partial y} = q$$

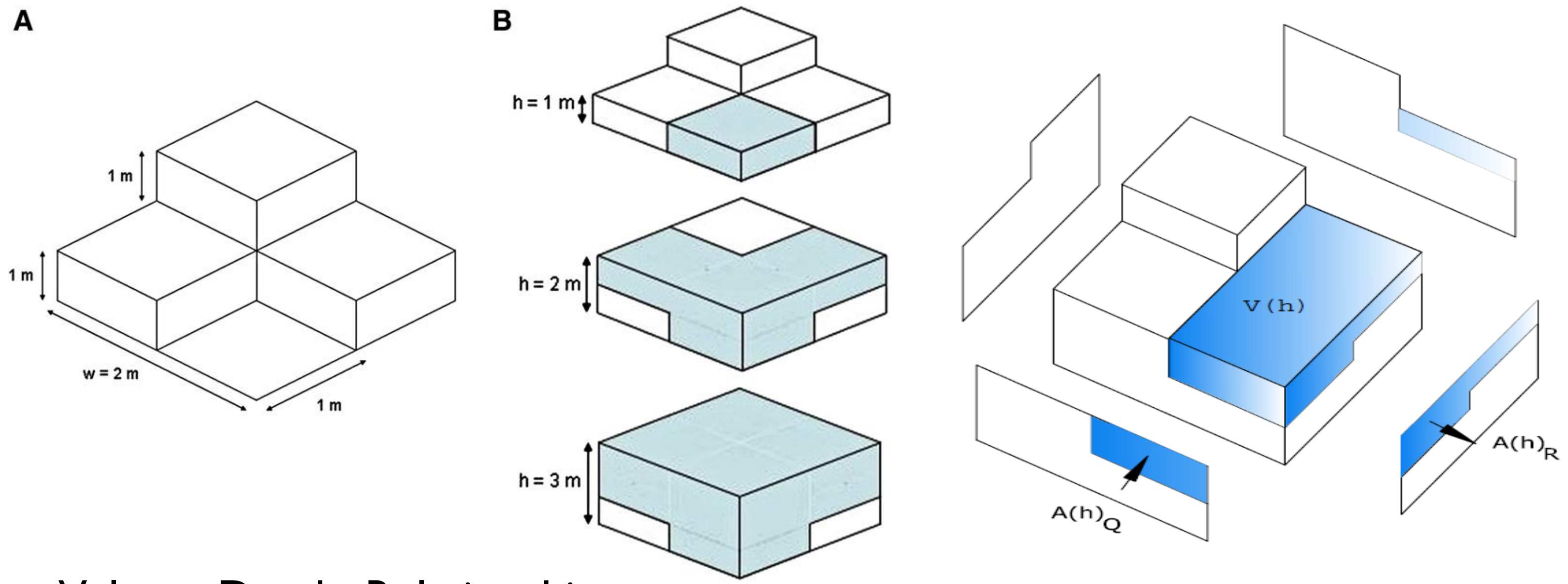
From Evans et al, 2009

Approaches to increase coarse models accuracy

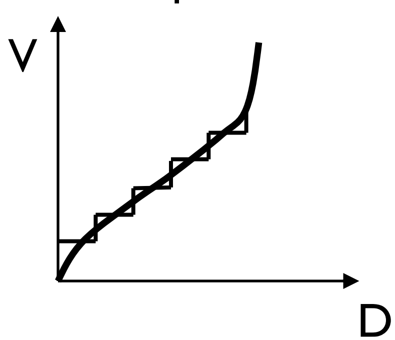
- Sub-grid scale porosity treatment
- Sub-grid parametrization which uses information beyond the scale of the model grid to effect more complex and non-linear controls on flow routing

Approaches to increase coarse models accuracy

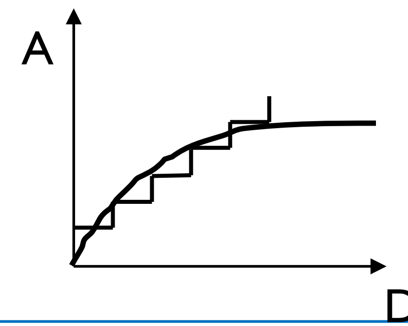
- Volume-Depth and Flow Area-Depth relationship



Volume-Depth Relationship



Flow Area-Depth Relationship



2D overland flow model

- A Non-inertia 2D overland flow model which uses the volume-depth and Flow area-depth relationship derived from fire resolution grid is developed
  - Continuity Equation

$$\frac{\partial V(h)}{\partial (t)} + \Delta x \frac{\partial Q}{\partial x} + \Delta y \frac{\partial R}{\partial y} = 0$$

  - Momentum Equations

$$x-direction \quad \frac{\partial}{\partial t}\left(\frac{Q}{A(h)_Q}\right) + g\frac{\partial h}{\partial t} + g\frac{1}{C^2 h}\frac{Q}{A(h)_Q}\left[\left(\frac{Q}{A(h)_Q}\right)^2 + \left(\frac{R}{A(h)_R}\right)^2\right]^{1/2} = 0$$

$$y-direction \quad \frac{\partial}{\partial t}\left(\frac{R}{A(h)_R}\right) + g\frac{\partial h}{\partial t} + g\frac{1}{C^2 h_R}\frac{R}{A(h)_R}\left[\left(\frac{Q}{A(h)_Q}\right)^2 + \left(\frac{R}{A(h)_R}\right)^2\right]^{1/2} = 0$$

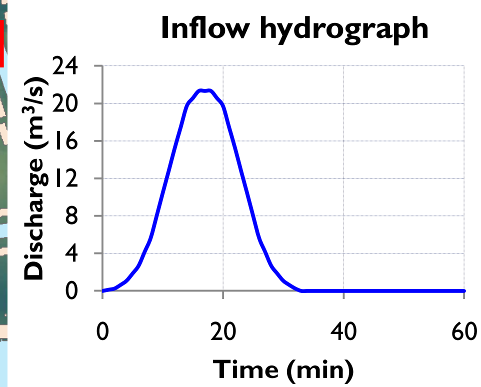
Case study

- Fine grid resolution (2m square grid) model and two coarse grid (4m square grid) models are used to simulate flooding in an urban area
    1. Average cell elevation method (grouping neighbouring cells together and taking an average value) of coarsening
    2. Coarsening with volume-depth and flow are-depth relationship

- The model results are then compared in terms of
    - peak inundation extent
    - flood depth and velocity time series at 6 points
    - Computational time

Case study

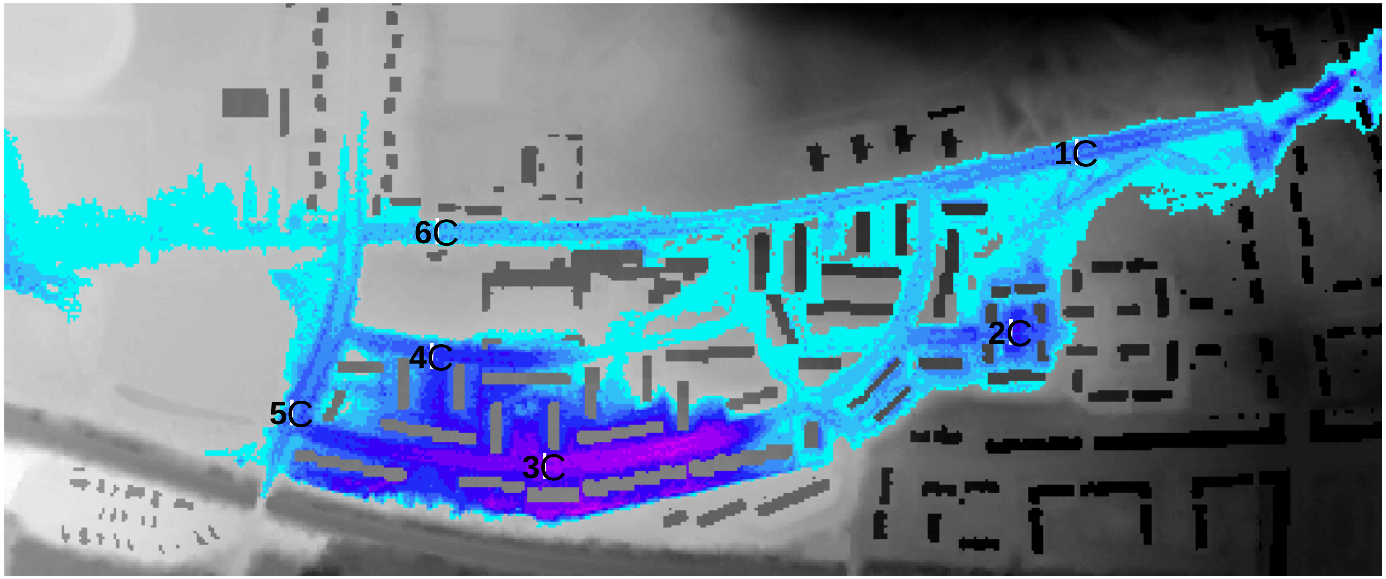
- The modelled area is approximately 0.4 km by 0.96 km ground elevations span a range of ~21m to ~37m. The DEM is obtained from the Environment Agency, UK.



- Inflow hydrograph applied as a boundary condition along 8m long line at the upstream end (red line)

Results

- Peak flood depths for 2by2m grid model



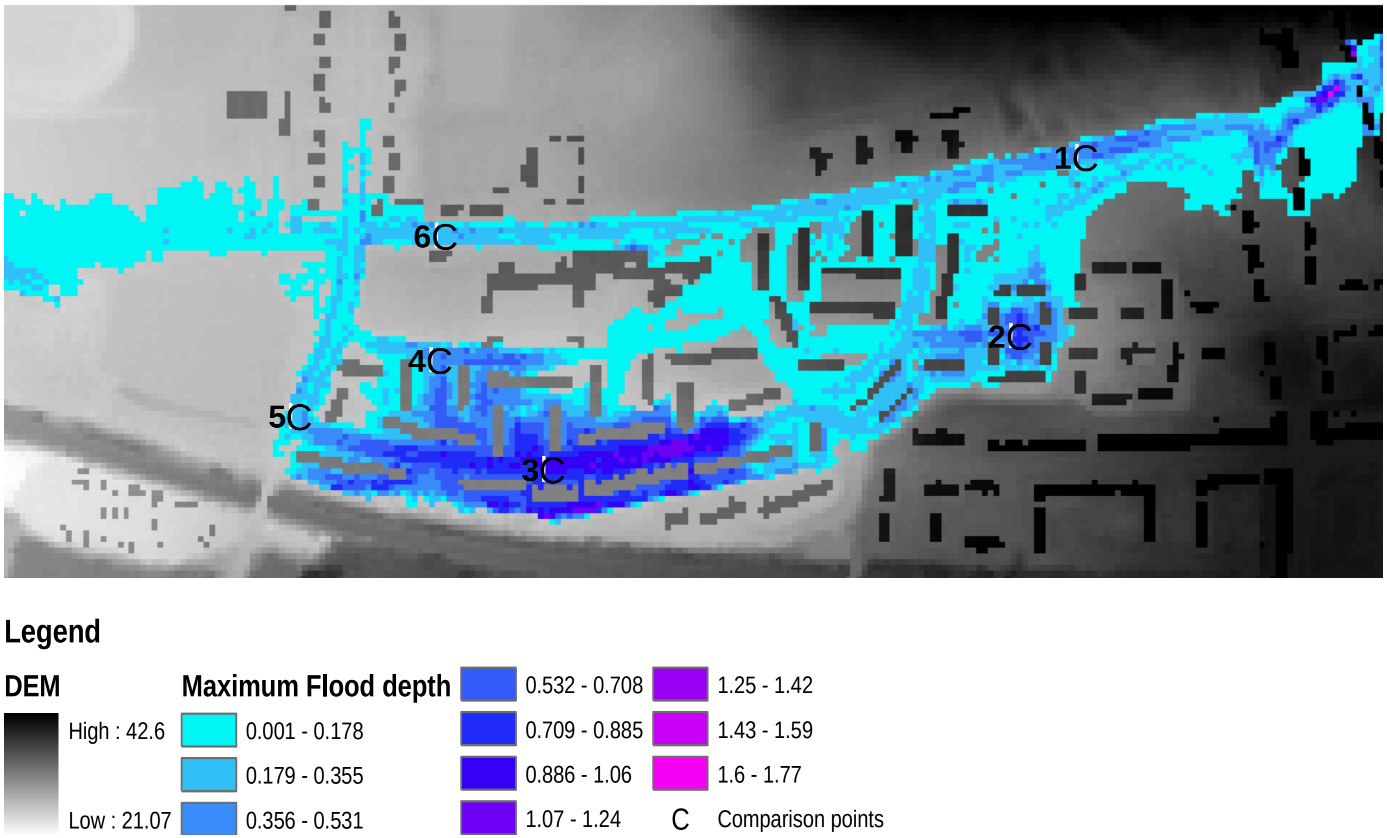
Legend

DEM
High : 42.6
Low : 21.07

Maximum Flood depth
0.001 - 0.178
0.179 - 0.355
0.356 - 0.531
0.532 - 0.708
0.709 - 0.885
0.886 - 1.06
1.07 - 1.24
1.25 - 1.42
1.43 - 1.59
1.6 - 1.77
C Comparison points

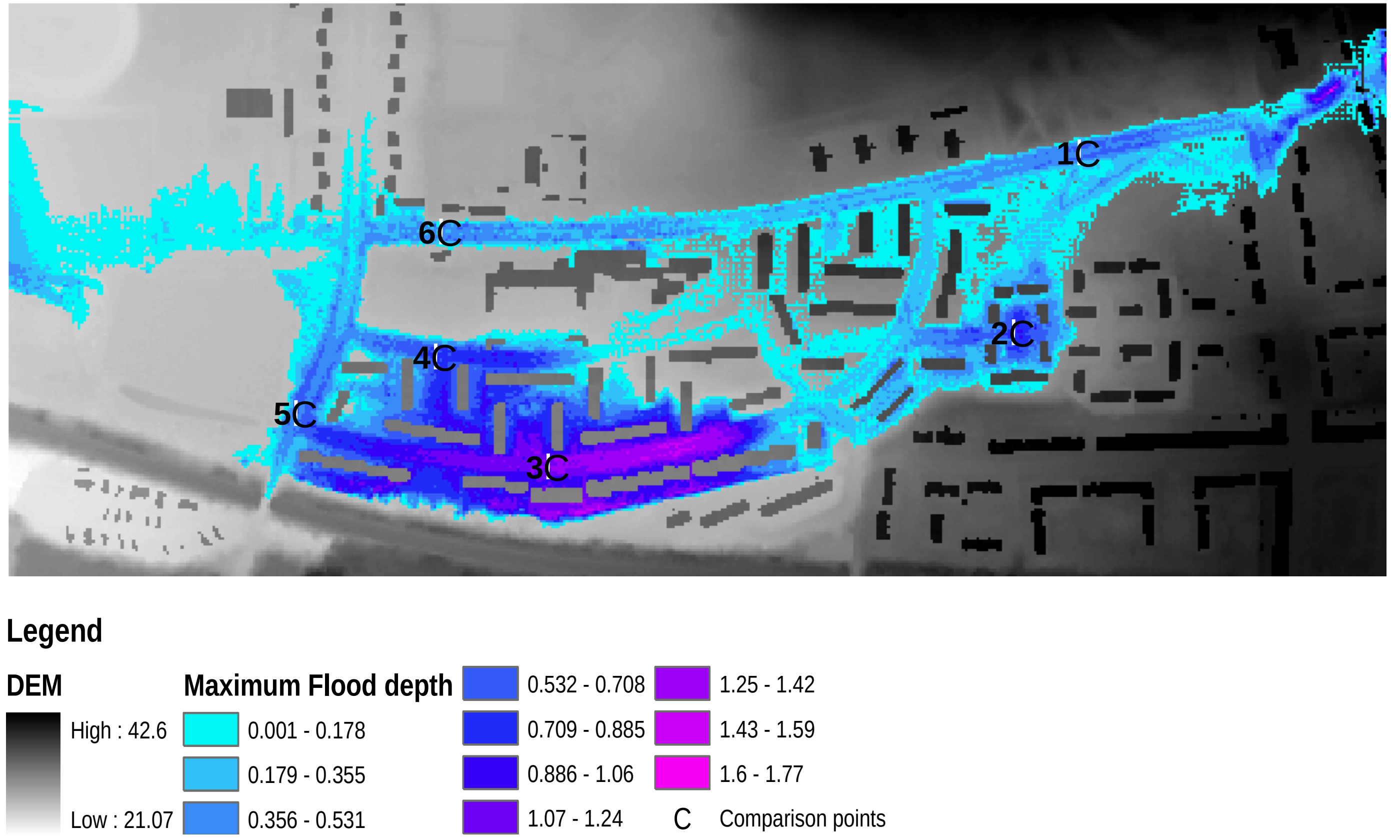
Results

- Peak flood depths for 4by4m grid model with average cell elevation



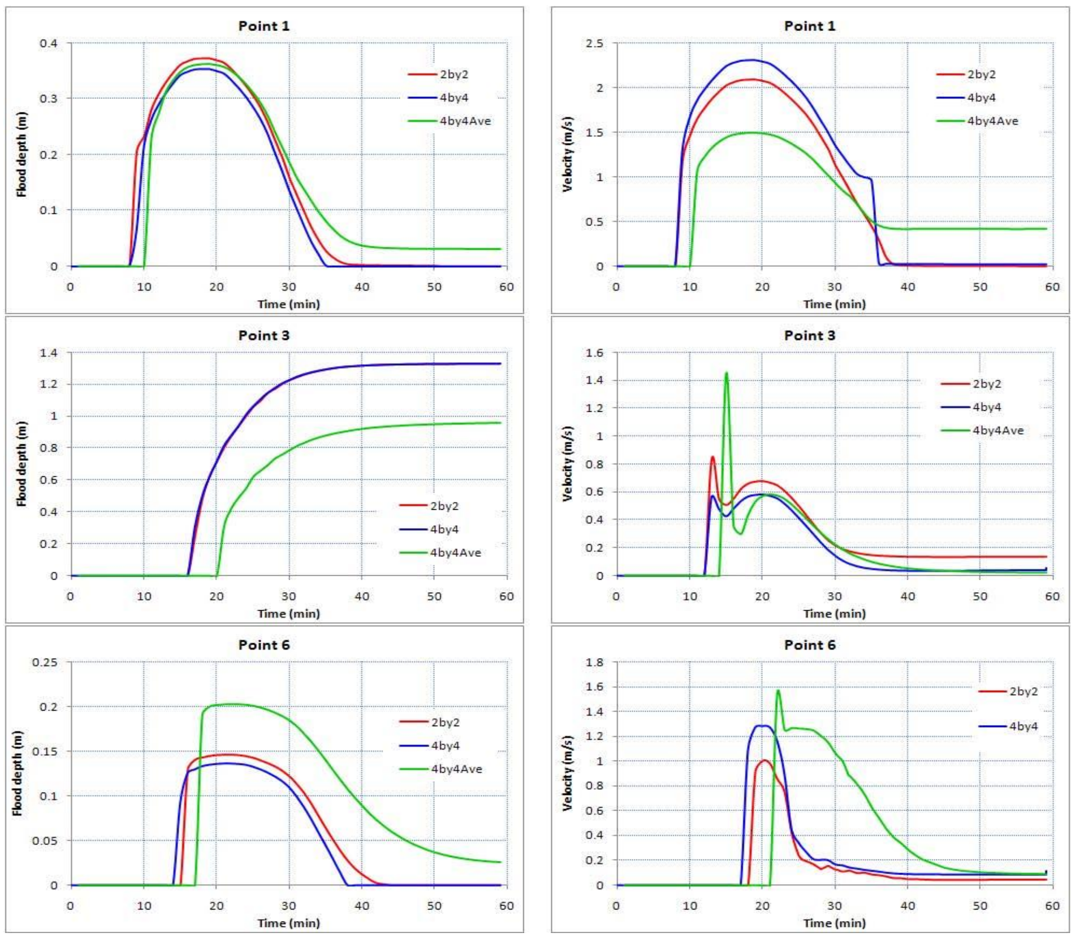
Results

- Peak flood depths for 4by4m grid model volume-depth and are-depth relationship



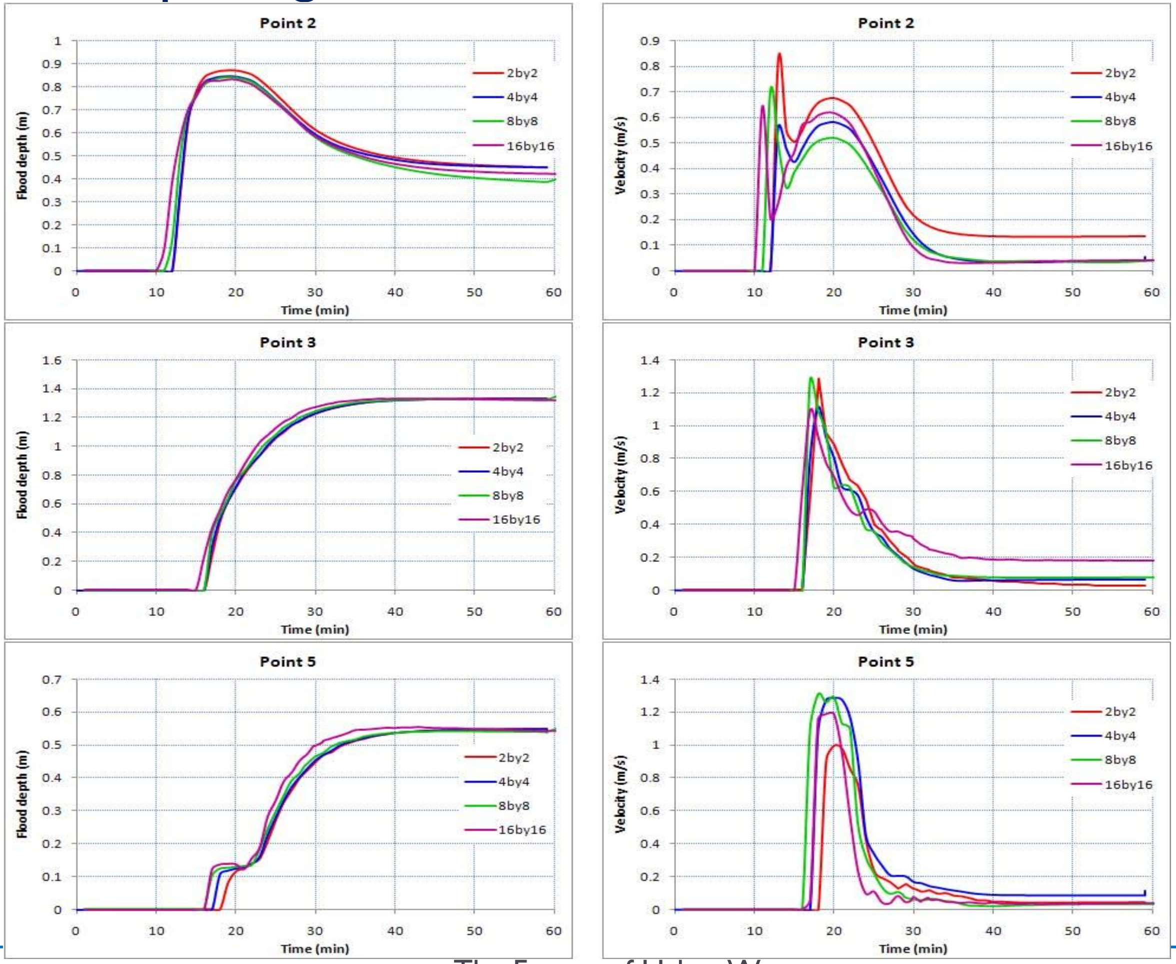
Results

- Time series of flood depth and velocity for points 1, 3, and 6



Results

- The coarse model (with volume-depth and area-depth relationships) is compared for 4m, 8m and 16m square grid resolutions



Results

Computation time

Grid resolution (m*m)	Type of coarsening	Computation time (min)
2*2		32
4*4	Average cell elevation	6.95
4*4	With volume-depth and area-depth relationship	8.9
8*8	With volume-depth and area-depth relationship	1.62
16*16	With volume-depth and area-depth relationship	0.75

Conclusion

- The prediction of flood extents by both coarse models conforms with the fine resolution model
- Flood depth and velocity time series predictions by the average cell elevation method are not consistent with the fine grid model (the predictions show delay and relatively poor result specially for points 3, 4 and 5)
- The Coarse model with volume-depth and area-depth relation ship predicted the flood depths almost in the same way as the fire grid model
- The velocity prediction by this model, though better than the predictions of the average cell elevation model, are not in good agreement with the fine model

Conclusion

- The coarse model with volume-depth and area-depth relationships show good flood depth predictions with 4by4m, 8by8m and 16 by16m grid resolutions with considerable reduction in computation time and without significant loss of accuracy.

- The results show that flood velocities are more sensitive to model grid resolution than the flood depths.

- The coarse models can be used for quick assessment of flood risk for strategic planning purposes.

- The choice of grid resolution should be weighted against accuracy specially for prediction of flood velocities

Thank you