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A Catchment-Scale Real-Time Flood Forecasting System Based on Full Hydrodynamic Modelling

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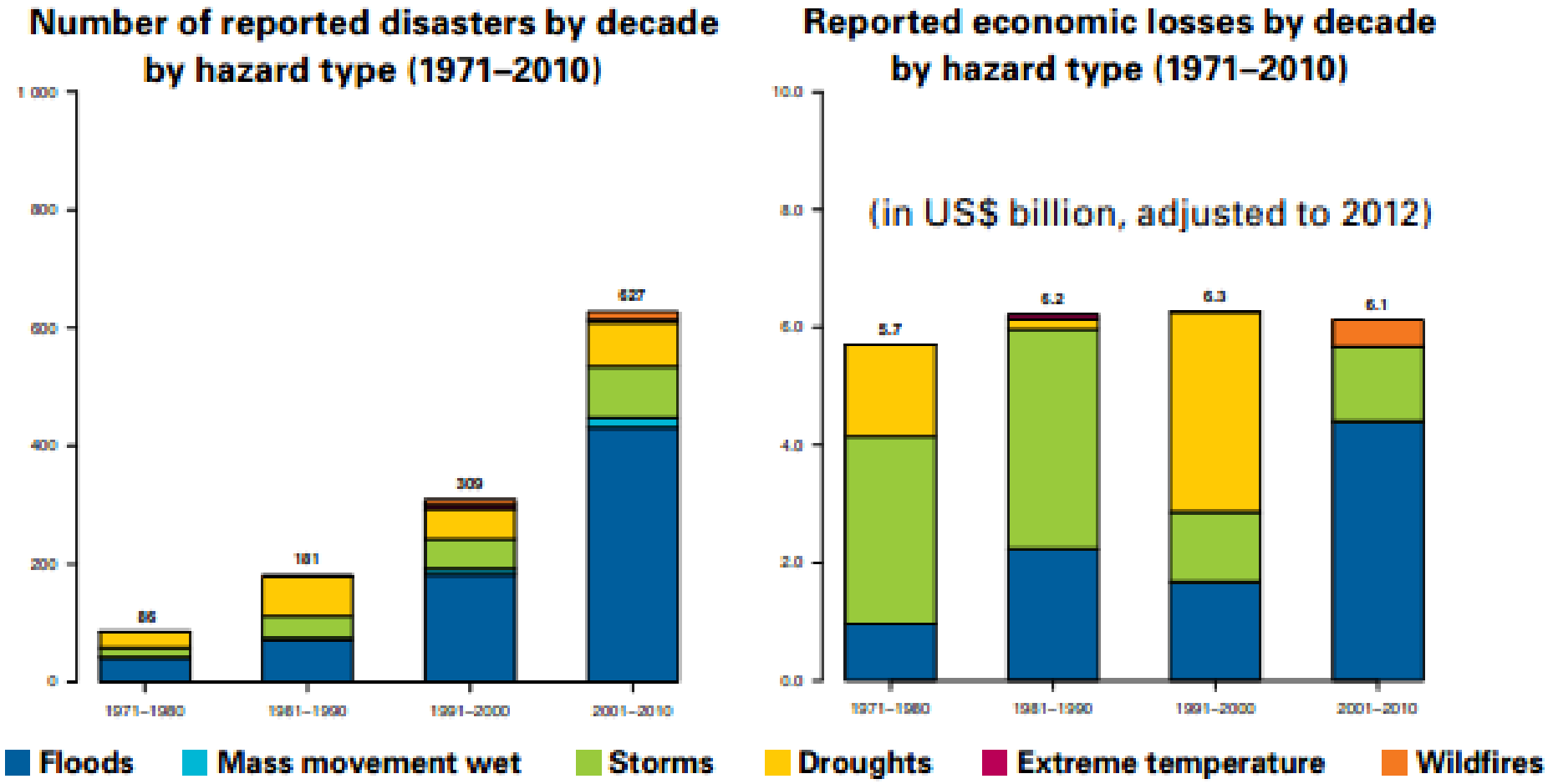
Outline

- Background
- **Hi**gh-**P**erformance **I**ntegrated hydrodynamic **M**odelling **S**ystem (HiPIMS)
- Framework of the flood forecasting system
- Application in Eden River catchment, UK
  - Data preparation
  - Forecasting results
  - Sensitivity to grid resolution
- Conclusions

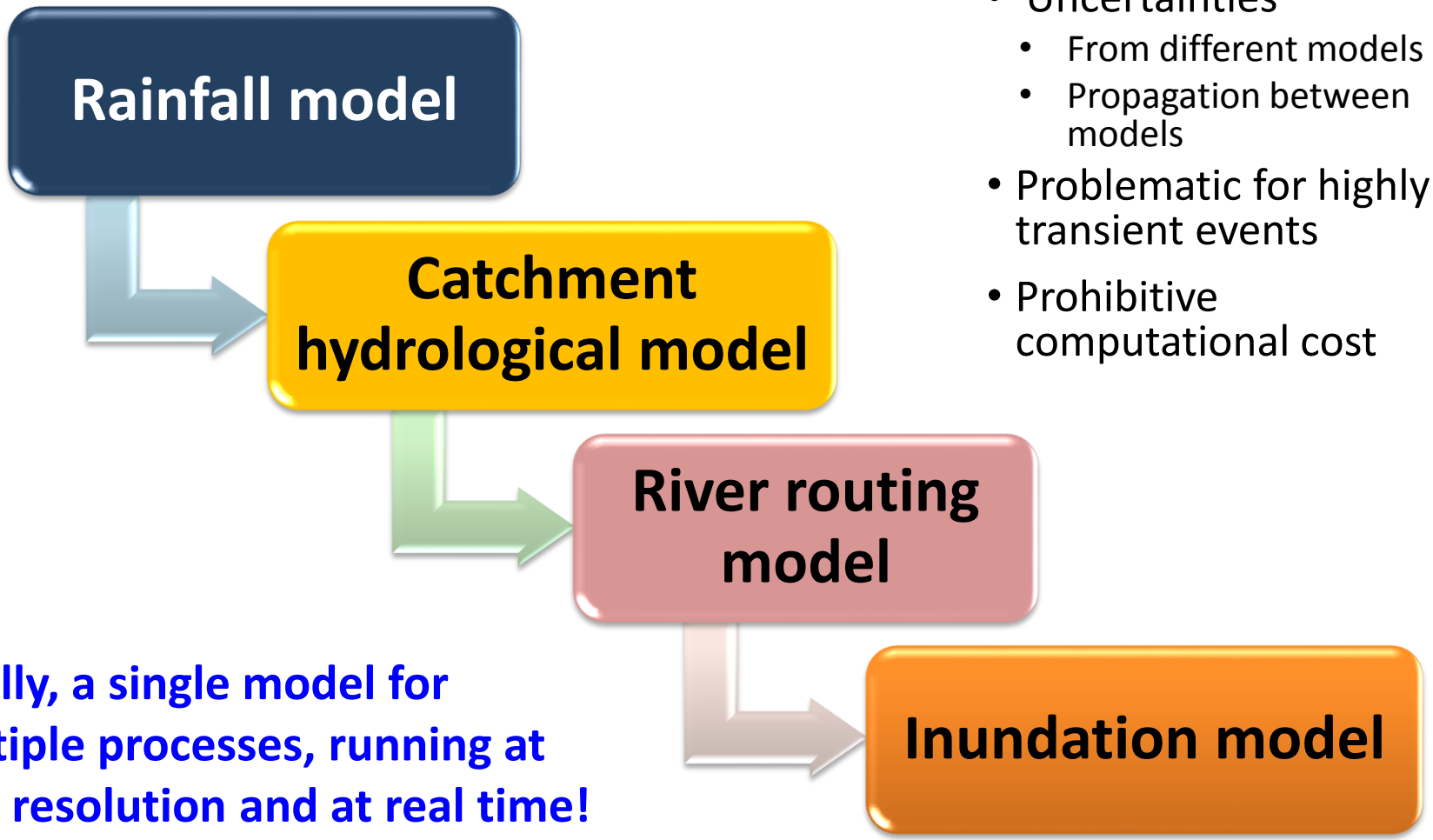
More and More Disastrous Events



From World Meteorological Organization report, WMO-No. 1123, 2014

Fluvial flood modelling/forecasting

- **Conventional flood modelling**



- **Key challenges**
  - Uncertainties
    - From different models
    - Propagation between models
  - Problematic for highly transient events
  - Prohibitive computational cost

Ideally, a single model for multiple processes, running at high resolution and at real time!

HiPIMS

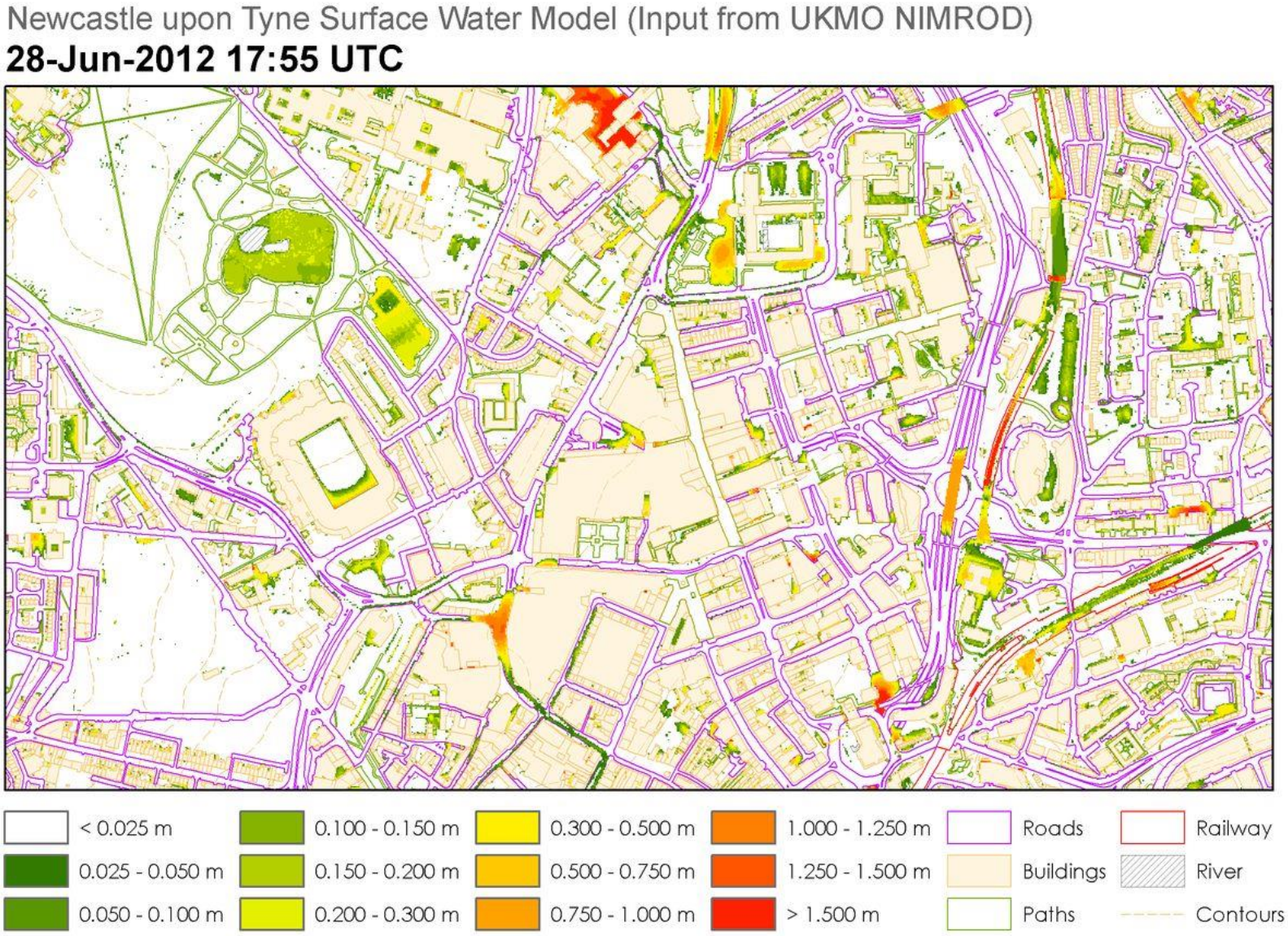
High-**P**erformance **I**ntegrated hydrodynamic **M**odelling **S**ystem

- Fully 2D depth-integrated governing equations for shallow flow hydrodynamics/other processes
- Numerical schemes
  - 1st-order Godunov-type scheme
  - 2nd-order Godunov-type scheme
- CUDA/OpenCL
  - Cross-platform
  - Cross-architecture
  - Flexible modelling framework
  - Any modern CPUs or GPUs

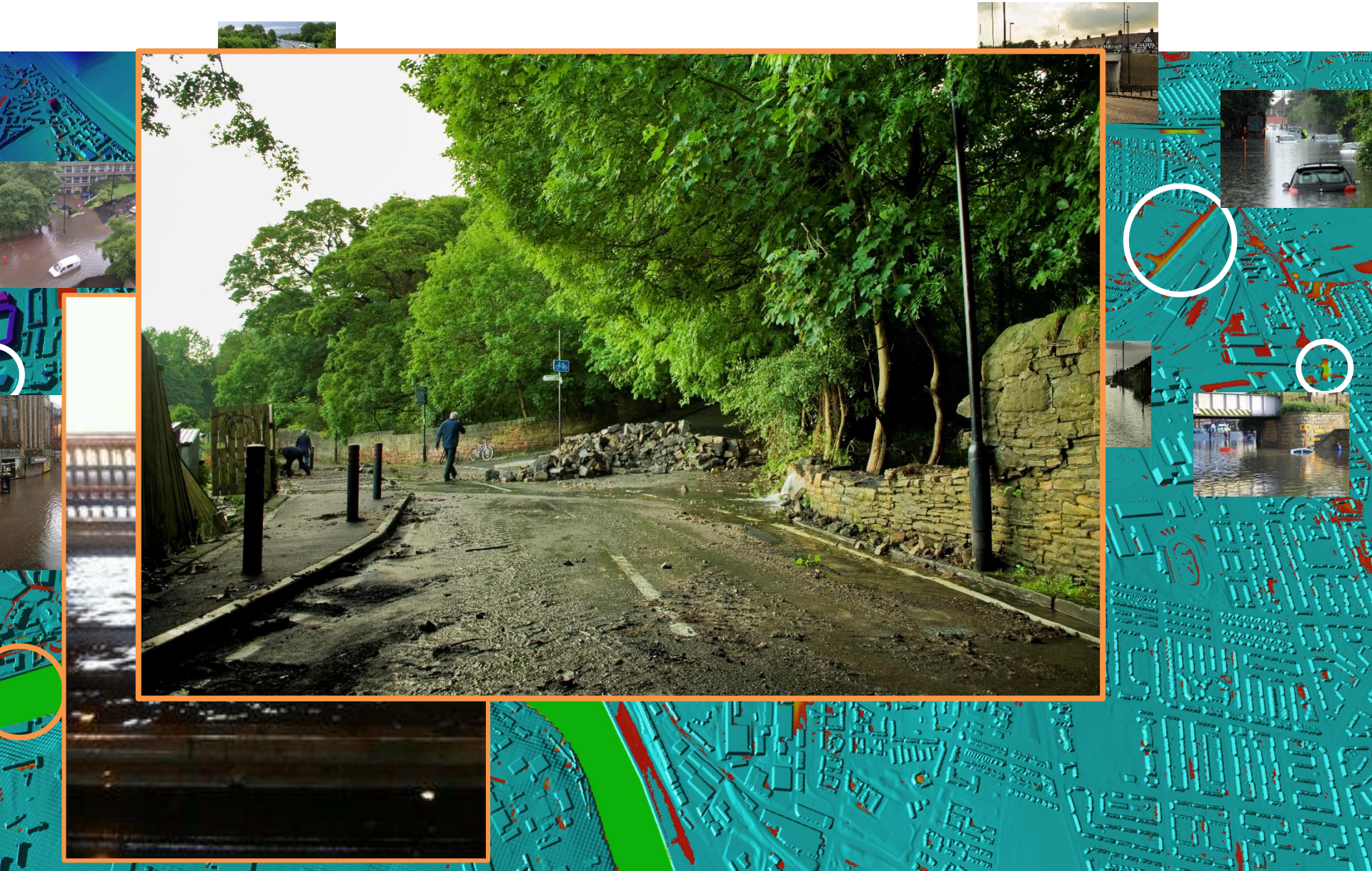
Smith LS, Liang Q (2013) *Computers & Fluids* 88: 334-343.
Liang Q, Smith LS (2015) *J. Hydroinformatics*, 17(4): 518-533.
Amouzgar R, Liang Q, et al. (2016) *IJOPE* 26(2): 154-160.
X Xia, Q Liang, X Ming, J Hou (2017) *Water Resources Research*, 5

Previous application in Newcastle

Newcastle City Centre: 34km^2, 2m resolution, ~8M cells



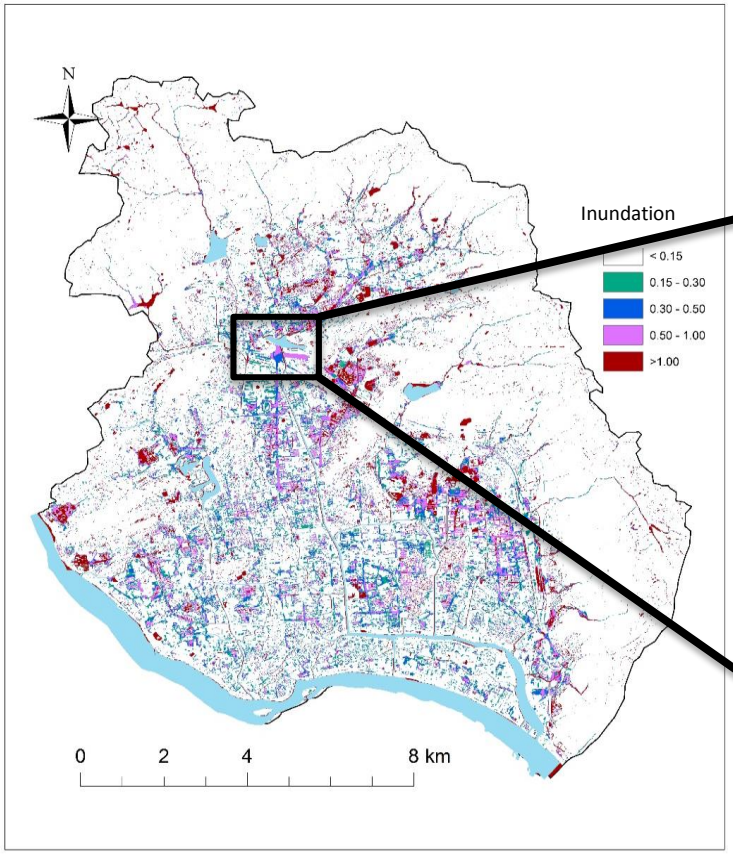
Modelling versus Reality

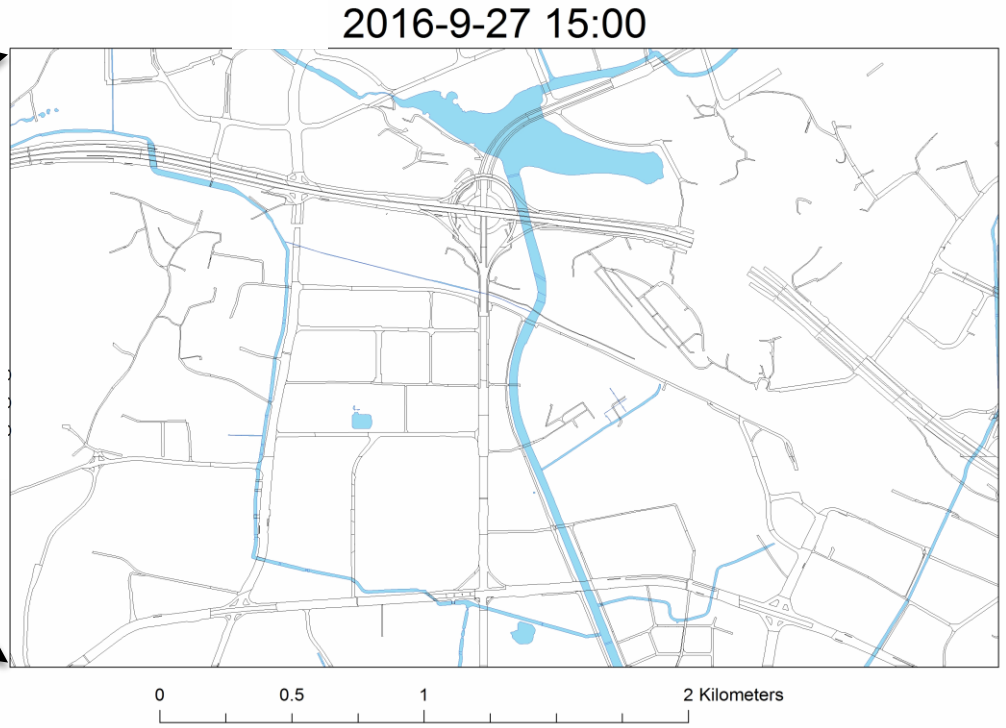


Previous application in Fuzhou

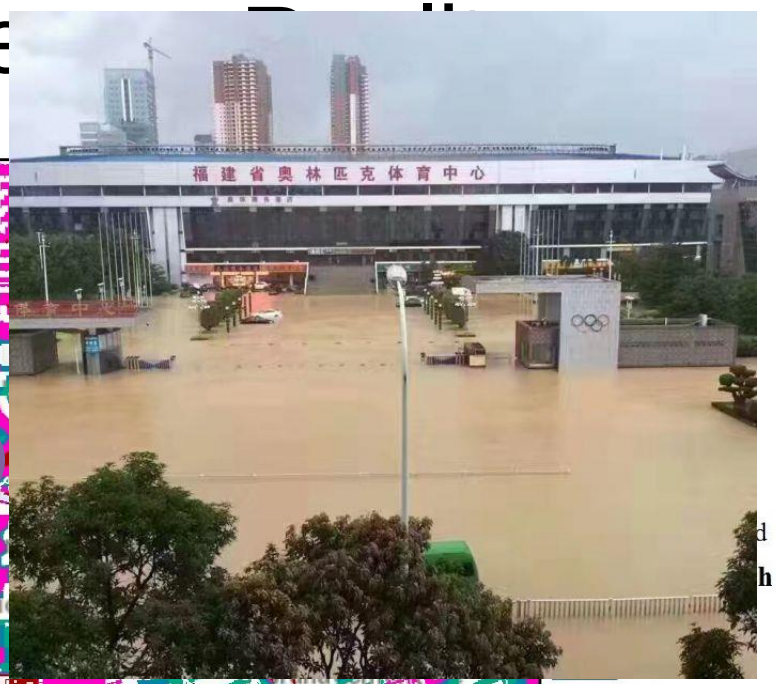
Typhoon Megi formed on 22 Sep 2016, caused rainstorm and flooding in Fuzhou

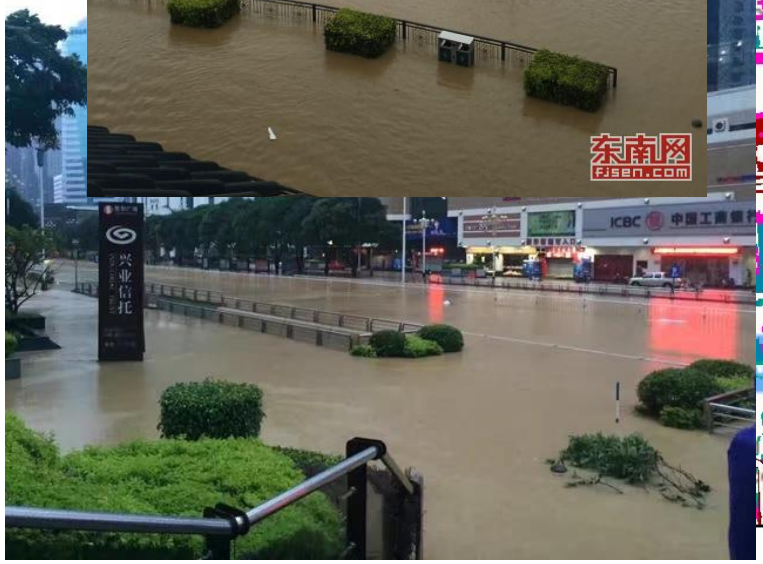
- Domain size: 260 km^2
  - Fuzhou and the wider catchment
- Resolution: 2 m
- Cells: 83 millions
- Simulation on 8 x NVIDIA K80 GPUs; **two times faster than real time**





Modelling ve

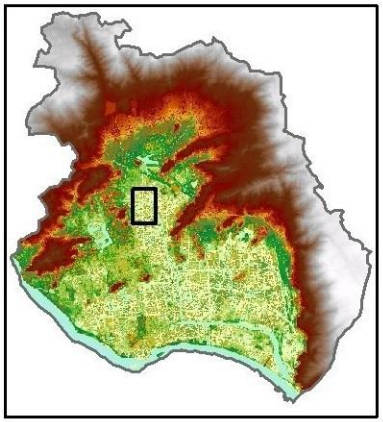




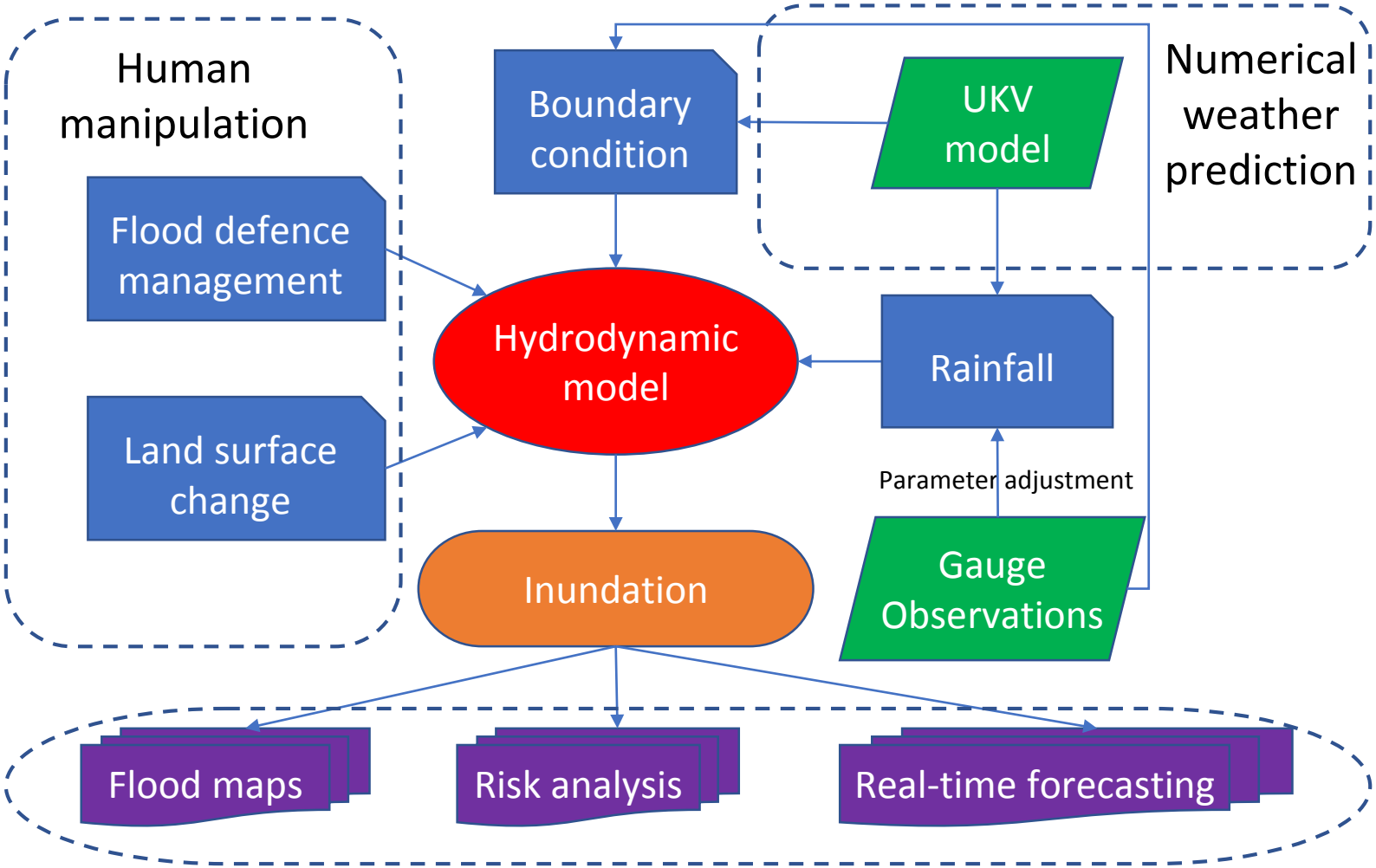
h (m)

0.3 - 0.5
0.5 - 1.0
> 1.0

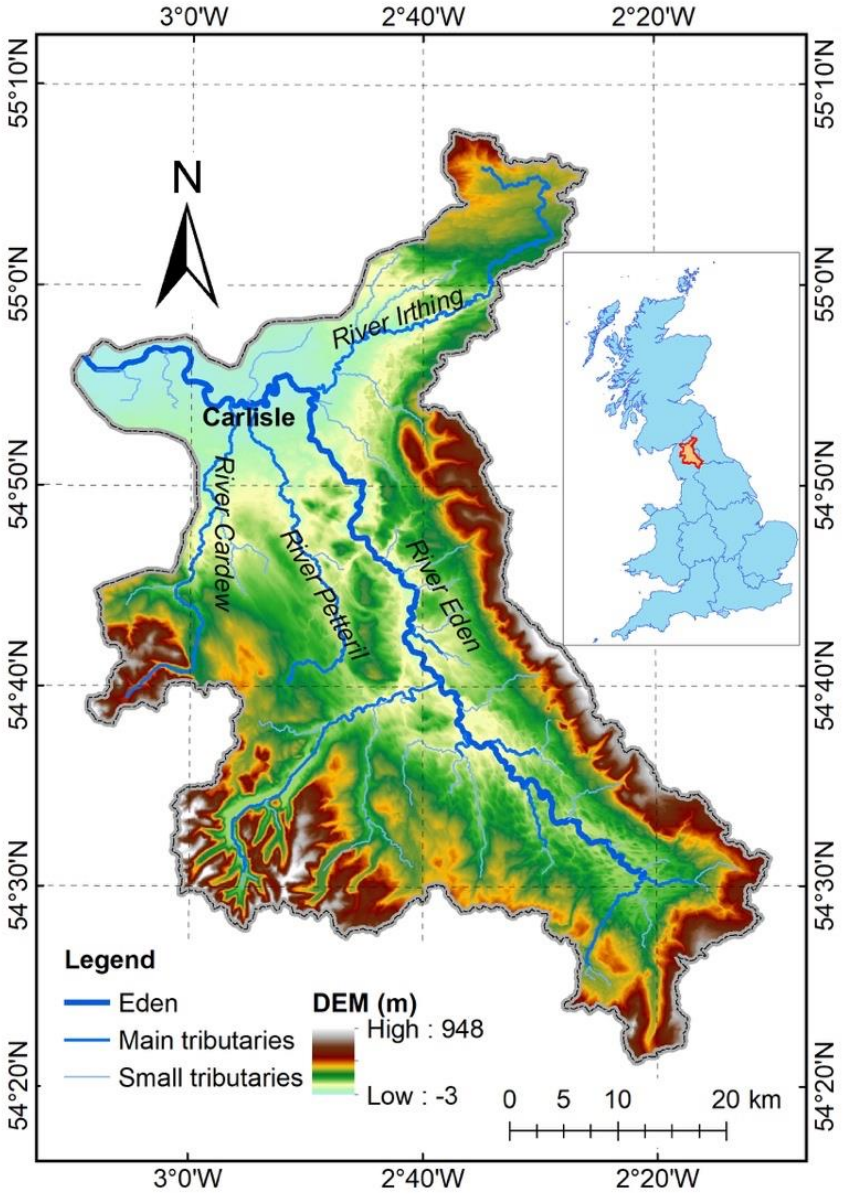
N



A new flood forecasting system



Storm Desmond in Eden Catchment



- Catchment area: 2500 km^2
- Length of main stream: 145km
- Discharge (at Sheepmount, Carlisle)
  -- Average: 51.82 m^3/s
  -- Max: 1700 m^3/s
- Largest settlement: Carlisle (Population: 75,306)
- Storm Desmond
  -- Low pressure system (939mb at its lowest) formed on 4th December 2015 and dissipated on the 8th December
  -- Across the Atlantic Ocean with its centre passing right to the North of the UK

Flood forecasting: Data

- Topography
  - DEM (5m)
  - River cross sections
  - Landuse (5m)
    - *Source: Digimap & EA*
- Rainfall
  - Numeric rainfall prediction from UKV model (1.5km)
  - Rainfall radar data (1km)
    - *Source: Met Office*

- *Observations*
  - *River water stage*
  - *Surveyed flood extent*
    - Source*: EA*

Met Office

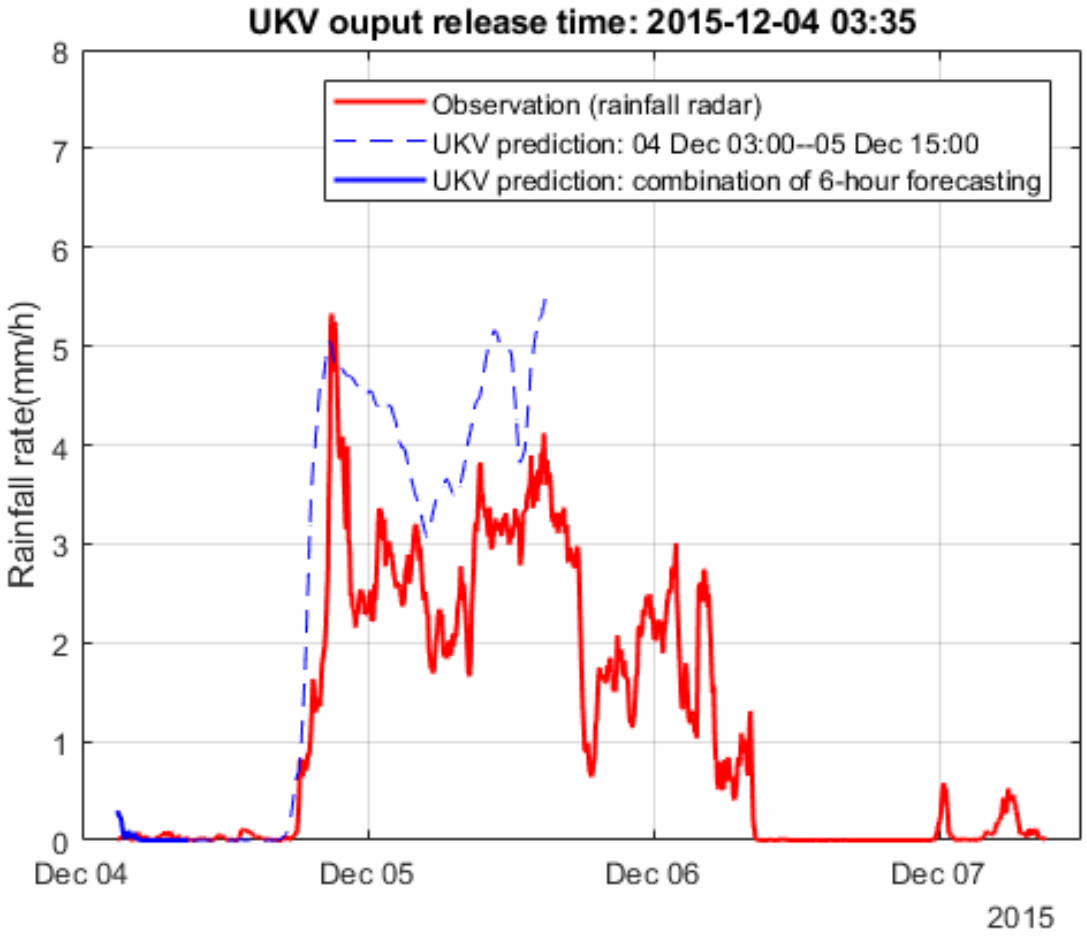
Environment Agency

Digimap®

Flood forecasting: Rainfall inputs

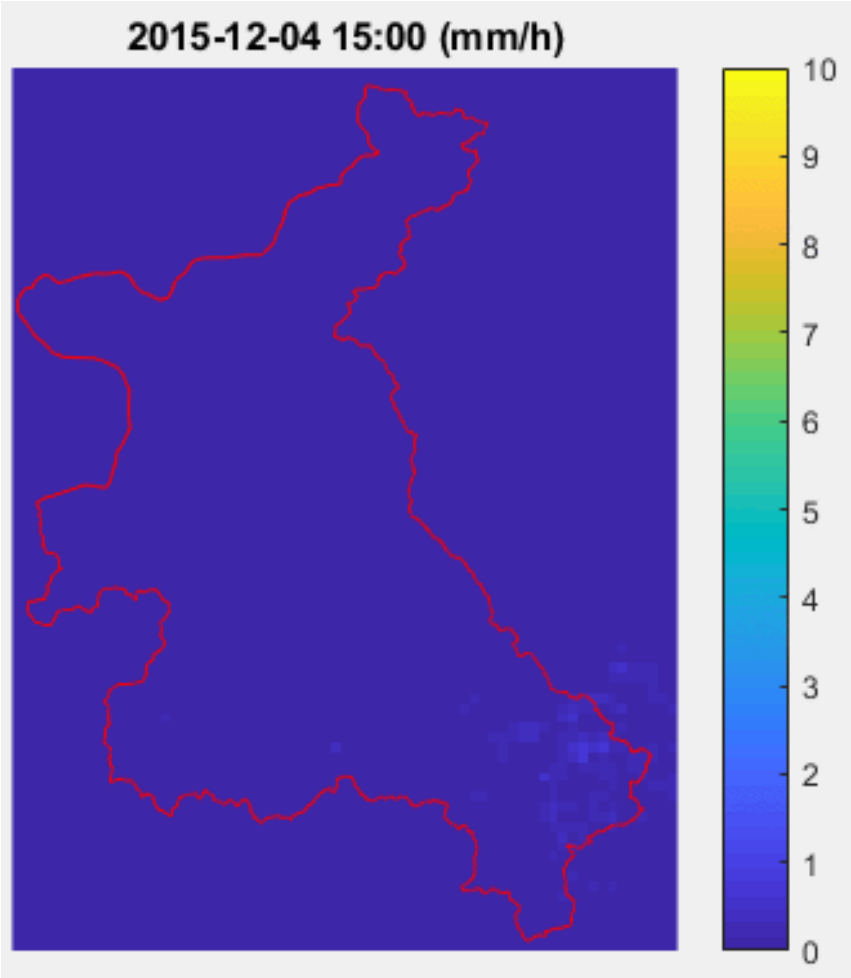
- UKV model
  - Release frequency
    - every 6 hours
  - Lead time
    - 36 hours
  - Spatial resolution
    - 1.5km
  - Time resolution
    - 5min

- Storm Desmond: average rainfall rate at Eden Catchment

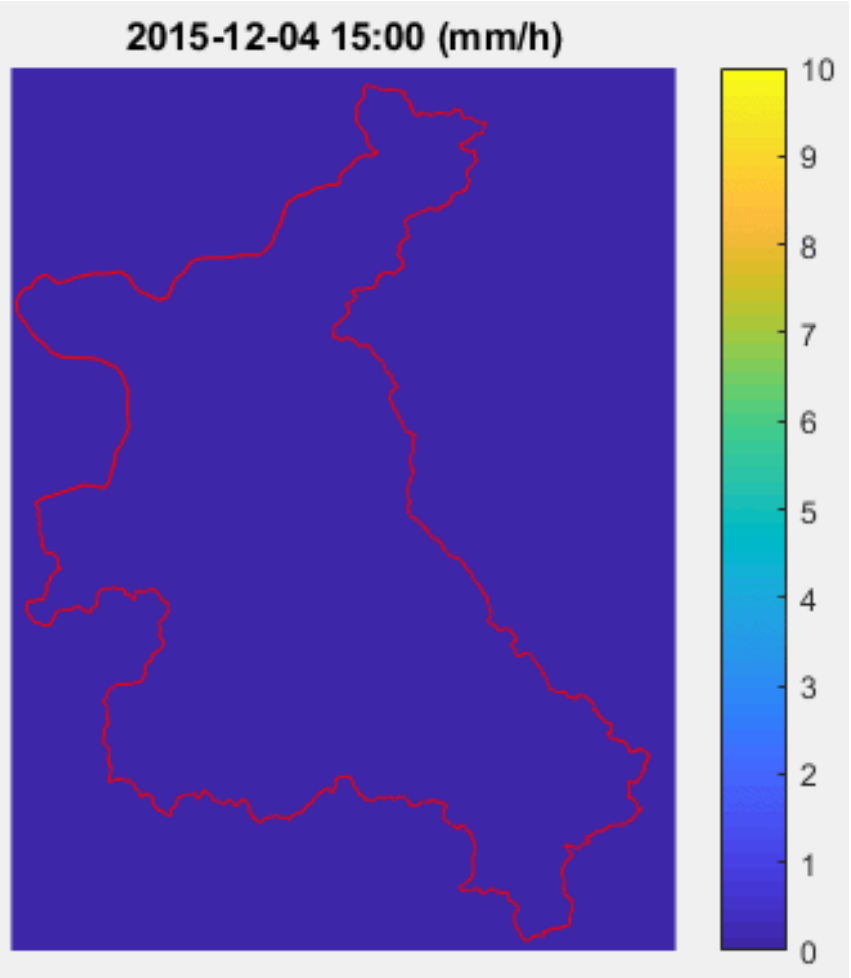


Flood forecasting: Rainfall input (Desmond)

Rainfall radar (1km)

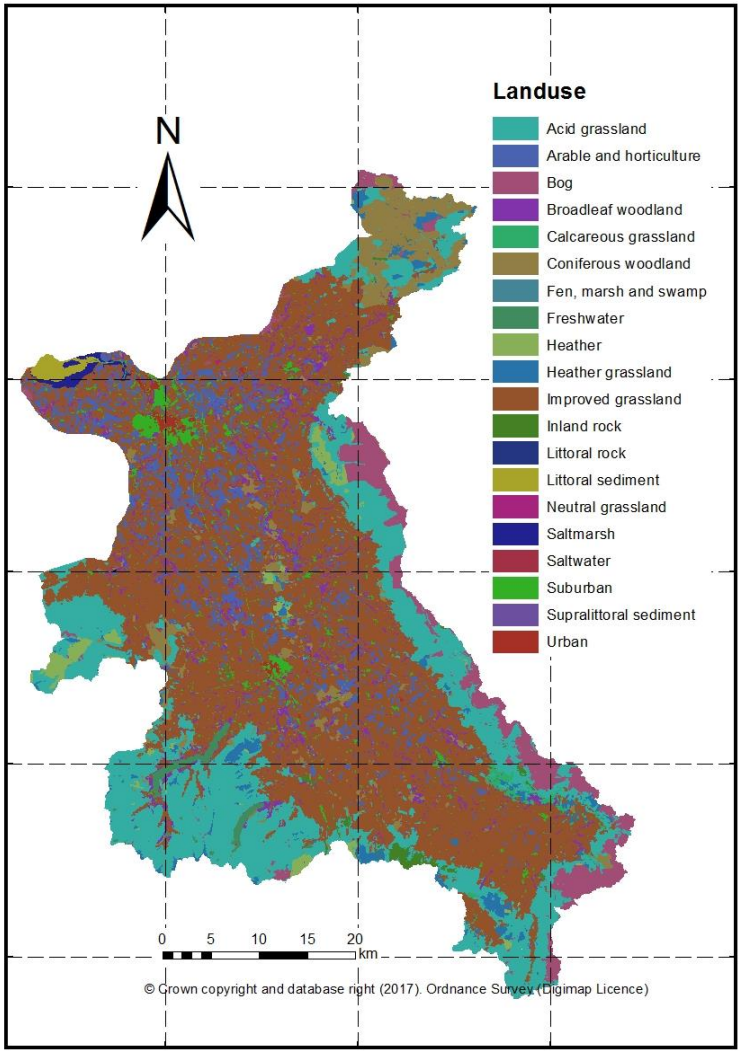


Weather Prediction (1.5km)



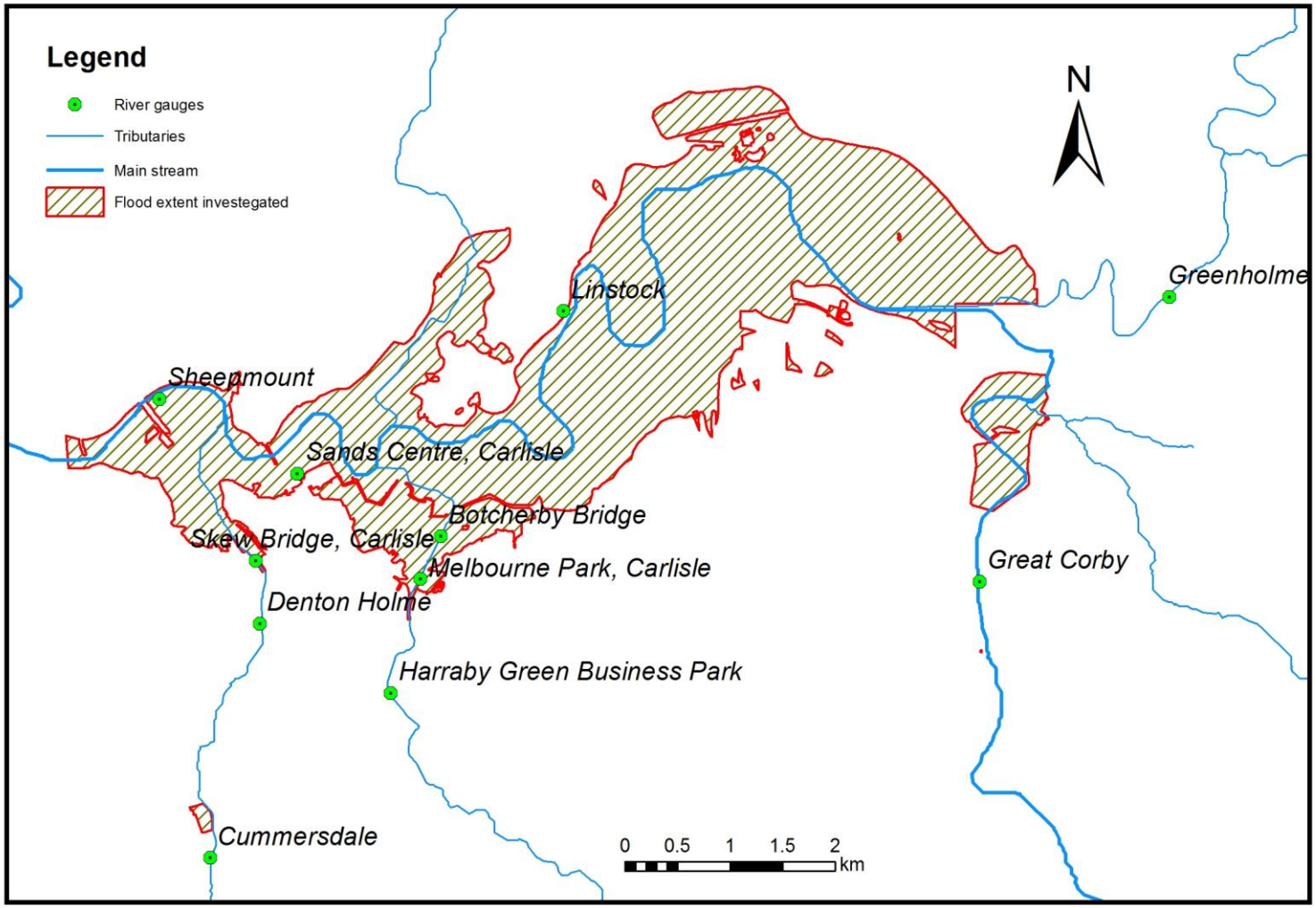
Flood forecasting: Model set up

- Resolution
  - 50m; 949,020 valid cells
  - 30m; 2,636,264 valid cells
  - 20m; 5,937,636 valid cells
  - 10m; 23,714,108 valid cells
  - 5m; 94,856,432 valid cells
- Parameters
  - Manning coefficient
  - Infiltration coefficient



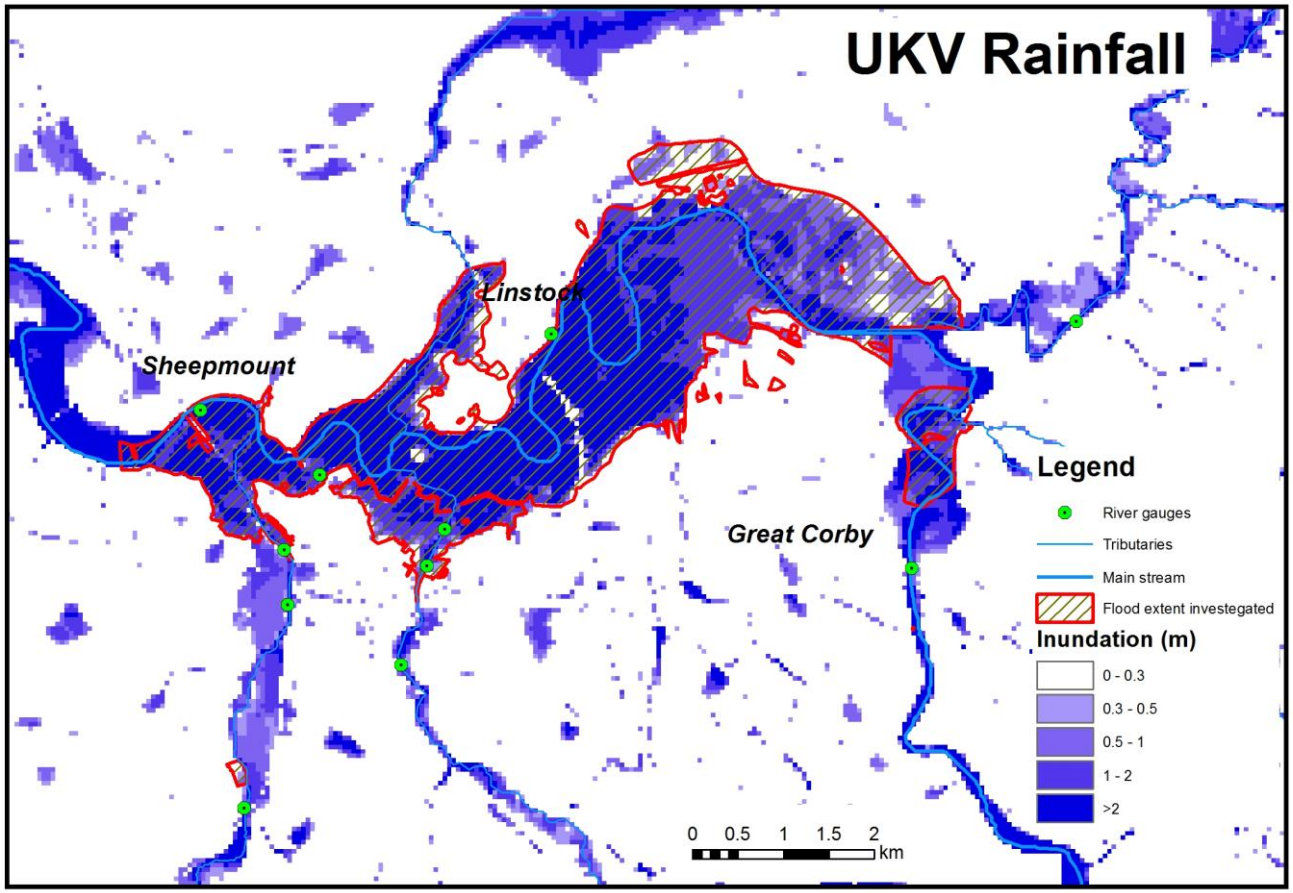
Flood Forecasting: Surveyed flood extent

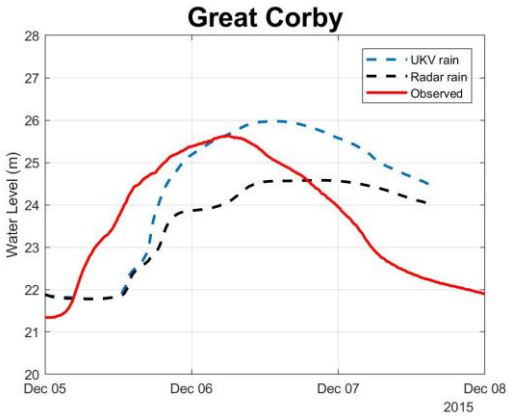
- Surveyed flood Map in Carlisle due to Storm Desmond

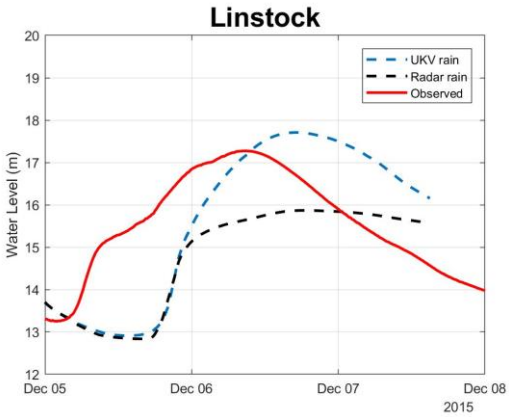


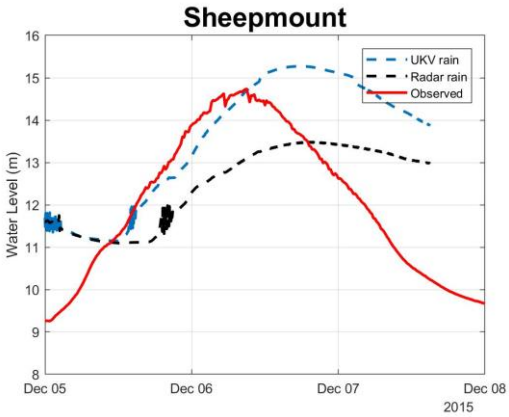
Flood Forecasting: Results

- 50m resolution



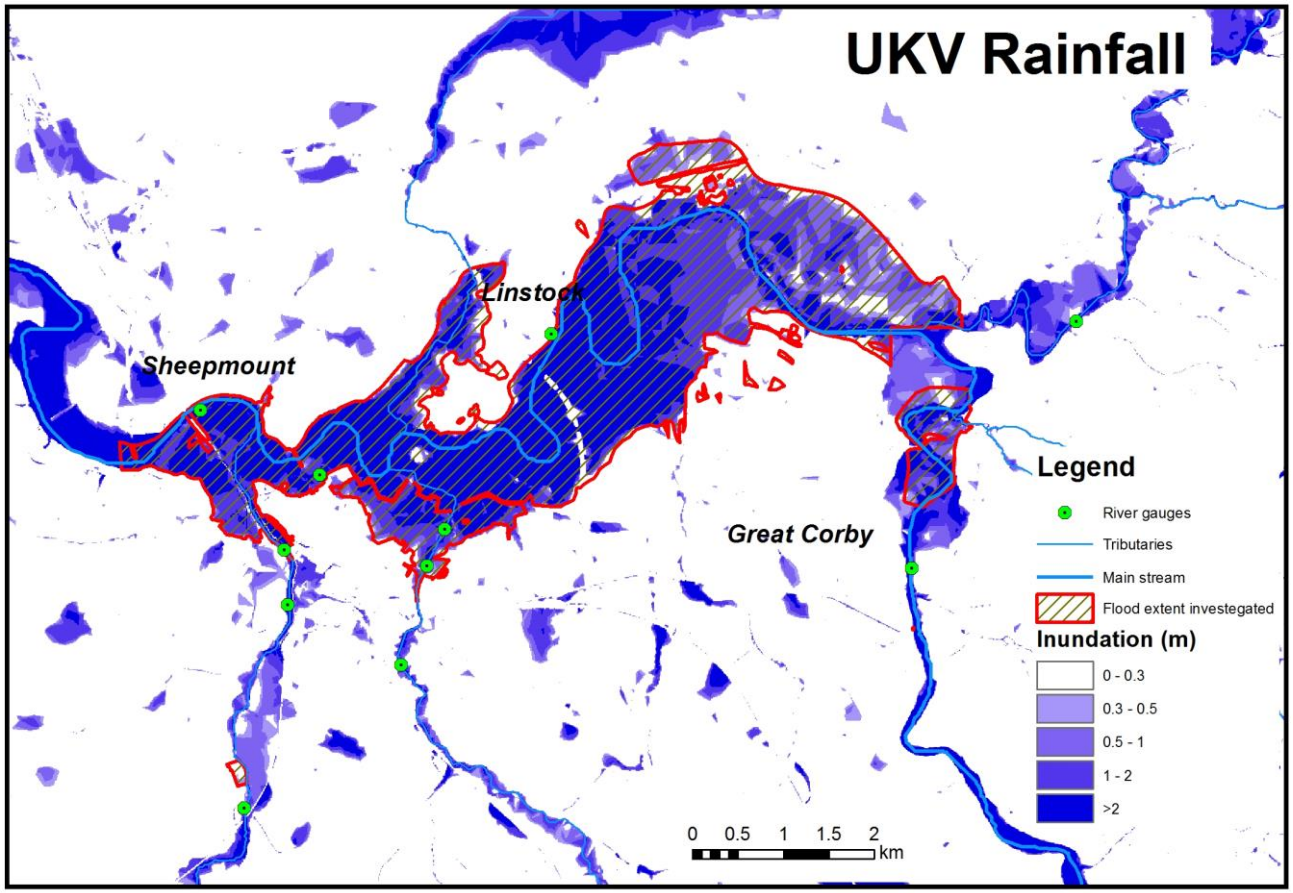


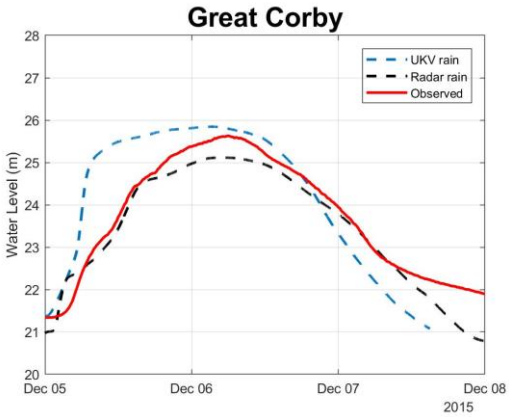


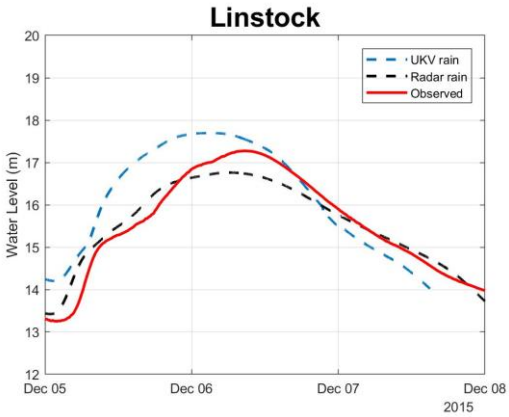


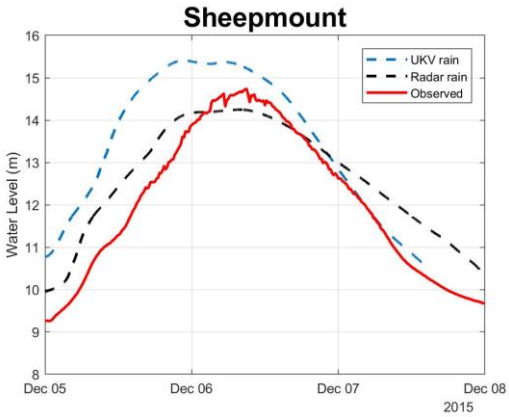
Flood Forecasting: Results

- 10m resolution



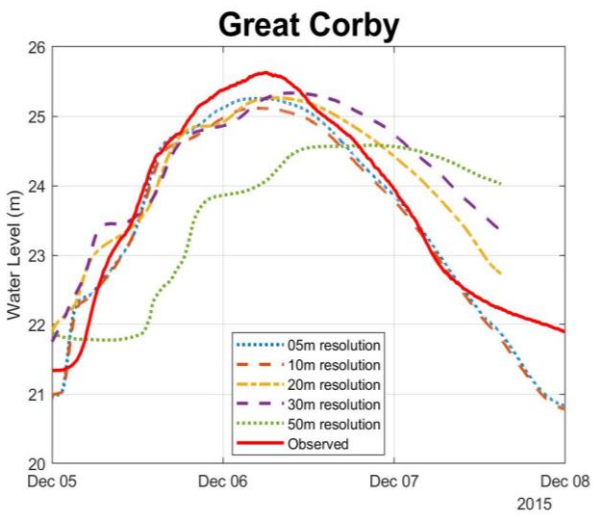


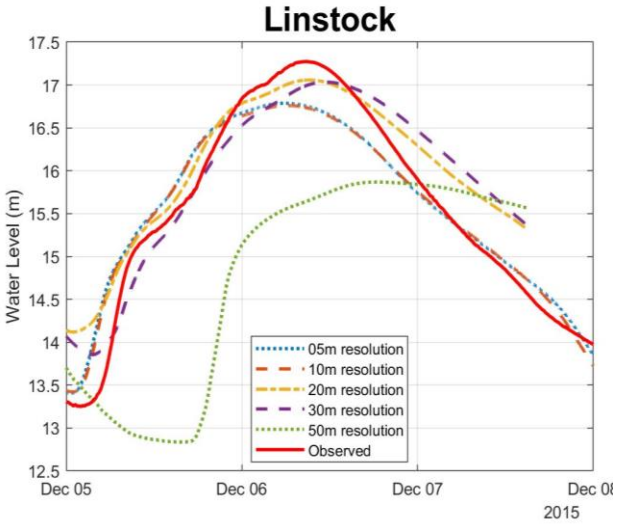


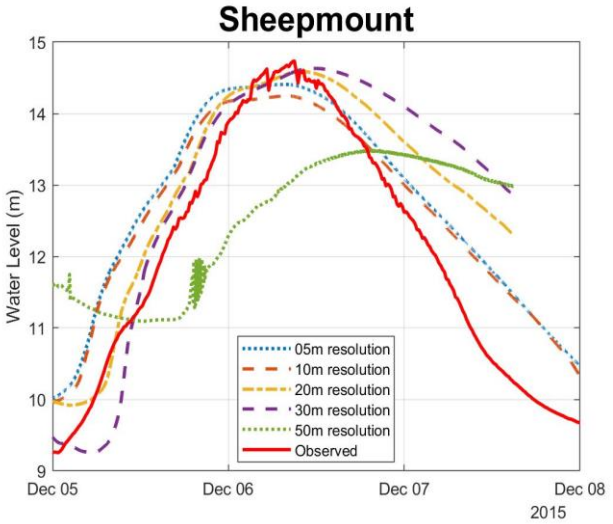


Flood Forecasting: Results

- Comparison between different resolutions





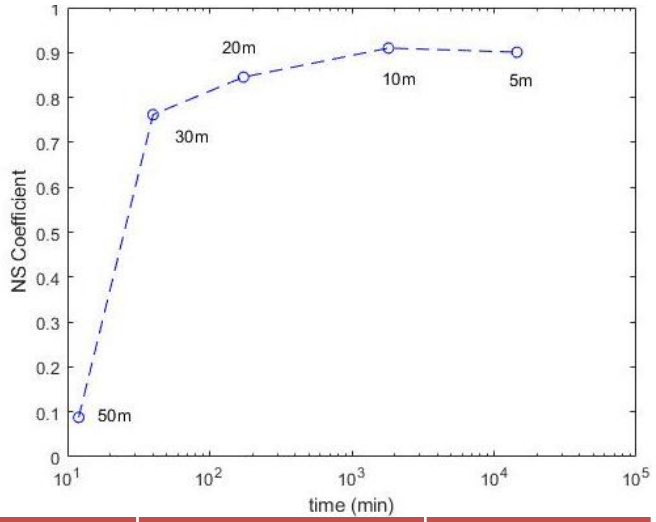


Nash–Sutcliffe efficiency coefficient

	50m	30m	20m	10m	5m
Great Corby	0.2657	0.7920	0.8837	0.9500	0.9603
Linstock	-0.3136	0.8583	0.8619	0.9327	0.9300
Sheepmount	0.3111	0.6346	0.7902	0.8472	0.8121
Average	0.0877	0.7616	0.8453	0.9100	0.9008

Flood Forecasting: Results

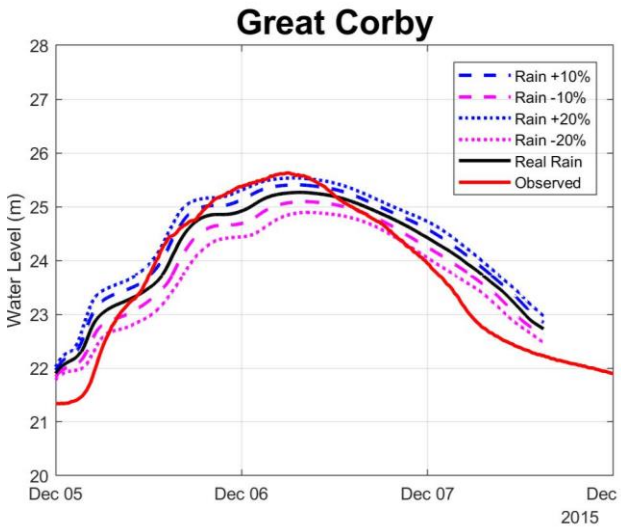
- Sensitivity to simulation resolution
- Trade-off between numerical accuracy and efficiency

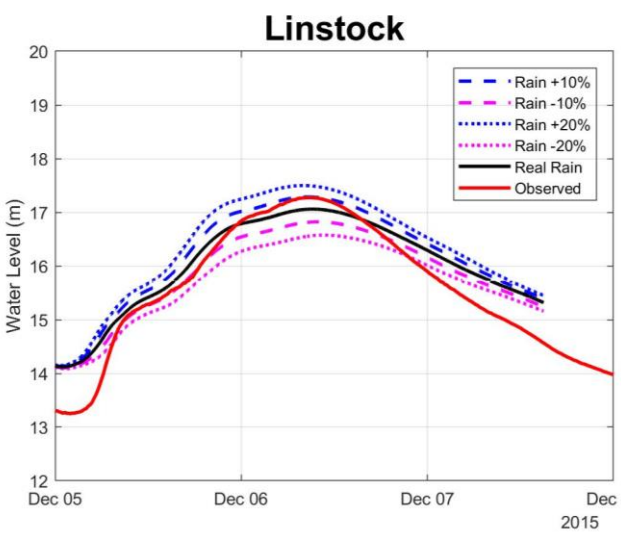


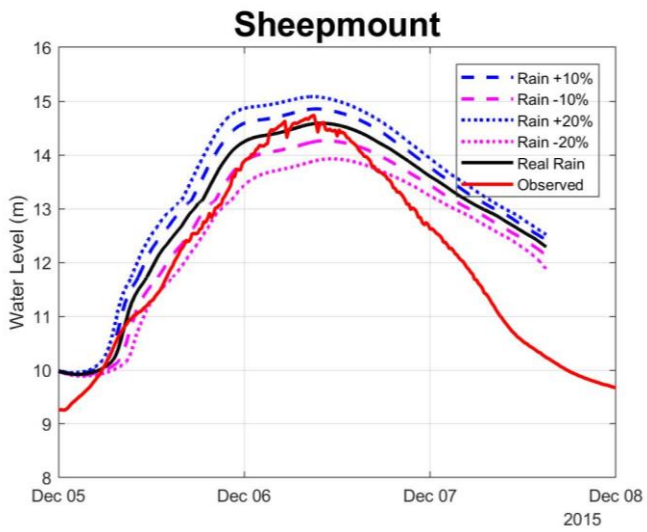
Resolution (meter)	Number of Cells (million)	Event duration (hour)	GPU Device	Computing time	Lead time
50	0.949	36	4 * NVIDIA K40 2 * NVIDIA K80	6.5min	35.89h
30	2.636	36	4 * NVIDIA K40 2 * NVIDIA K80	21min	35.65h
20	5.938	36	4 * NVIDIA K40 2 * NVIDIA K80	1h 30min	34.50h
10	23.714	36	4 * NVIDIA K40 2 * NVIDIA K80	15h 45min	20.25h
5	94.856	36	8 * NVIDIA K80	18h 50min	17.17h

Flood Forecasting: Results

- Uncertainty





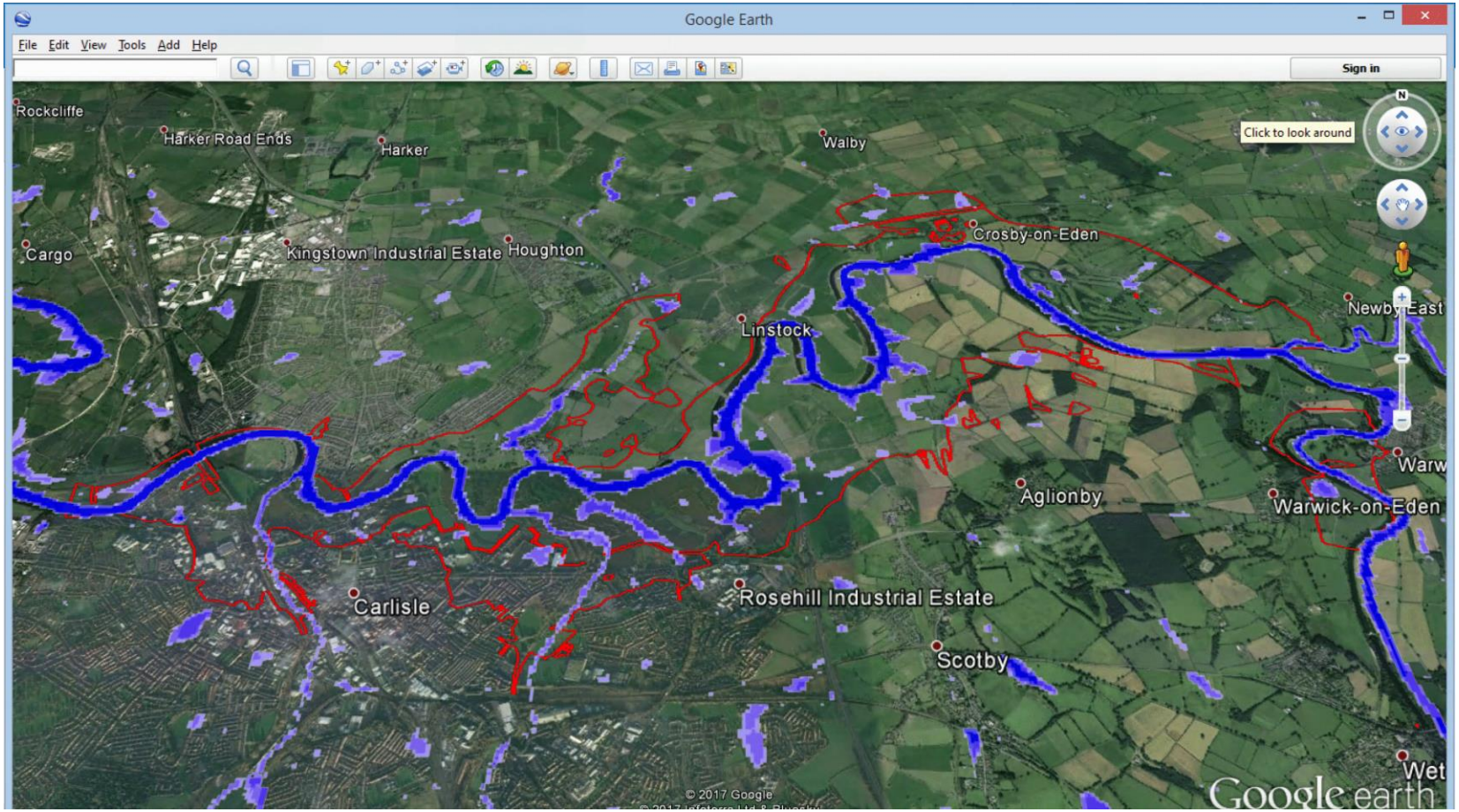


Nash–Sutcliffe coefficients for simulations with disturbed rainfall (against radar rainfall)

	+10%	-10%	+20%	-20%
Great Corby	0.9734	0.9798	0.8792	0.9276
Linstock	0.9670	0.9695	0.8594	0.8826
Sheepmount	0.9734	0.9782	0.8849	0.9213
Average	0.9713	0.9758	0.8745	0.9213

Flood Forecasting: Results

- Visualization in public digital map service
  - Google earth
  - OS Map



Conclusions

- HiPIMS is able to accurately predict flood processes on large catchments.
- NWP data can drive HiPIMS to provide satisfactory prediction of inundation.
- Uncertainty arising from rainfall input is NOT propagated or amplified to the simulated water level and flood extent.
- HiPIMS provides an effective tool for real-time high-resolution flood forecasting.
- Massively parallel hydrodynamic models may become the new norm of catchment-scale whole-system flood modelling and forecasting.

Thank you!

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Liang, Q., Smith, L.S., 2015. A high-performance integrated hydrodynamic modelling system for urban flood simulations. *J. Hydroinformatics* 17, 518.
Smith, L.S., Liang, Q., 2013. Towards a generalised GPU/CPU shallow-flow modelling tool. *Comput. Fluids* 88, 334–343.
Xia, X., Liang, Q., Ming, X., Hou, J., 2017. An efficient and stable hydrodynamicmodel with novel source term discretization schemes for overland flow and flood simulations. *Water Resour. Res.* 53, 3730–3759.