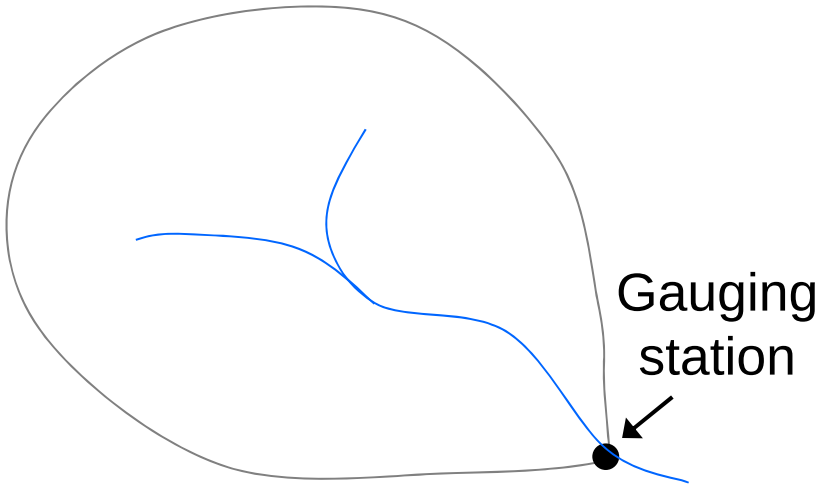
# Probabilistic Flood Forecasting for Small Catchments using the G2G Model

Steve Cole, Alice Robson, Phil Howard,
Vicky Bell and Bob Moore
**Centre for Ecology & Hydrology, Wallingford**

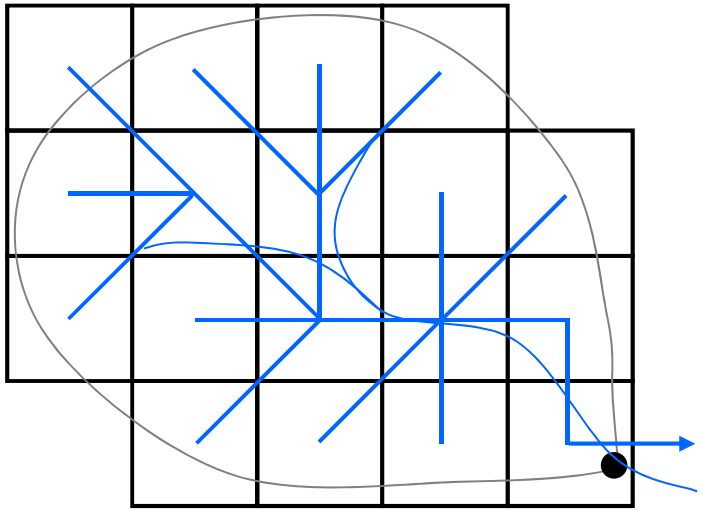
# Lumped and Distributed hydrological modelling

## Lumped Model




- One model for each gauging station
- Many parameters calibrated to observed flow location
- Flow estimates for one location only
- Uses catchment average rainfall

## Distributed Model (G2G)



- One model for large regions (UK)
- Small set of regional parameters, strong support from digital datasets
- Flow estimates in each grid (1km$^2$)
- Uses gridded rainfall estimates

# Need for distributed models of flood response

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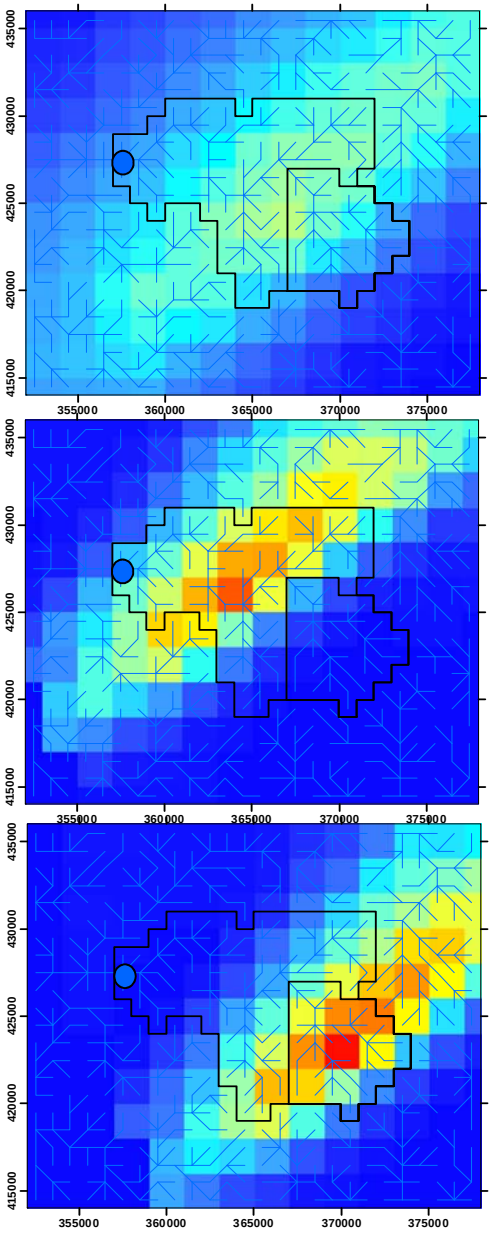
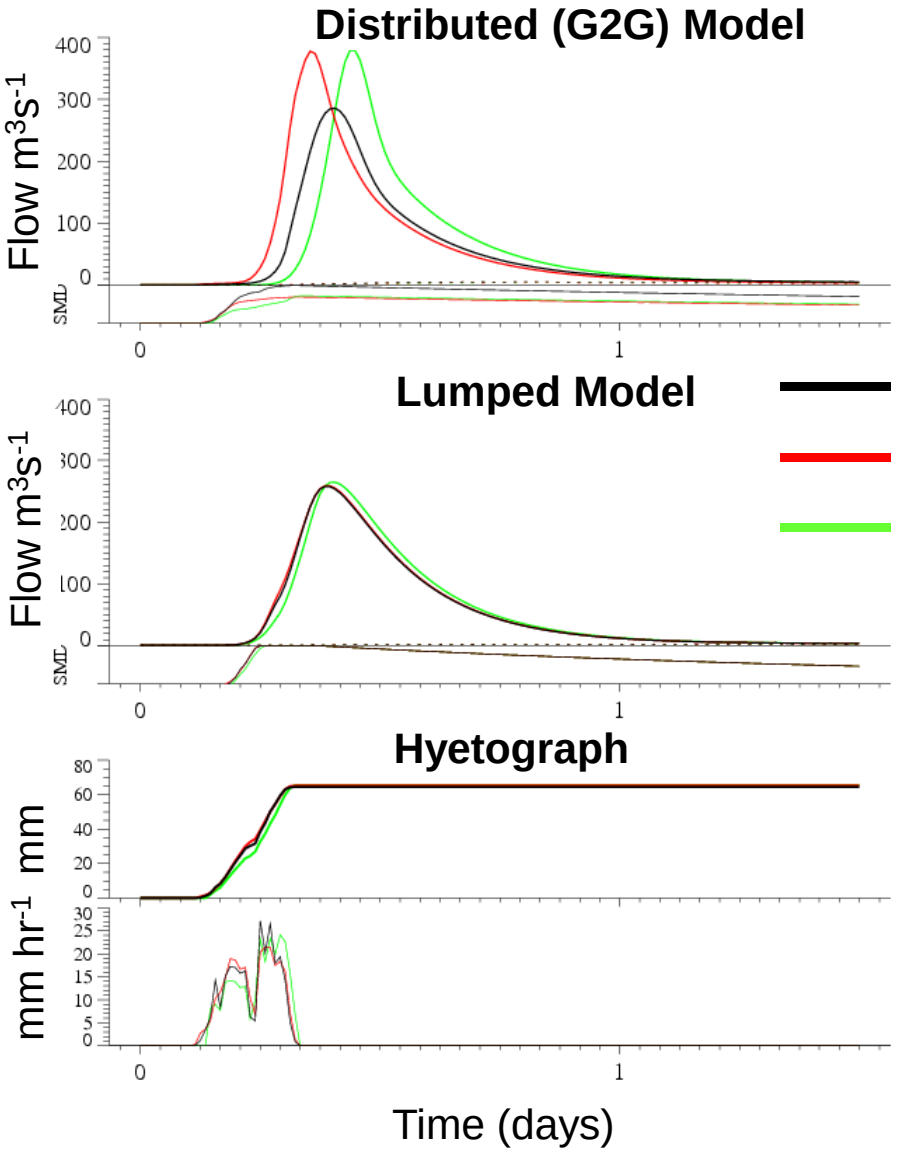
Storm total




## Impact of spatial extent and location of storm on flood response?




Catchment-wide storm

Lower catchment storm

Upper catchment storm

Darwen at Blue Br. (135km$^2$)

Moore et al. (2006), IAHS Pub. 305

# Motivation

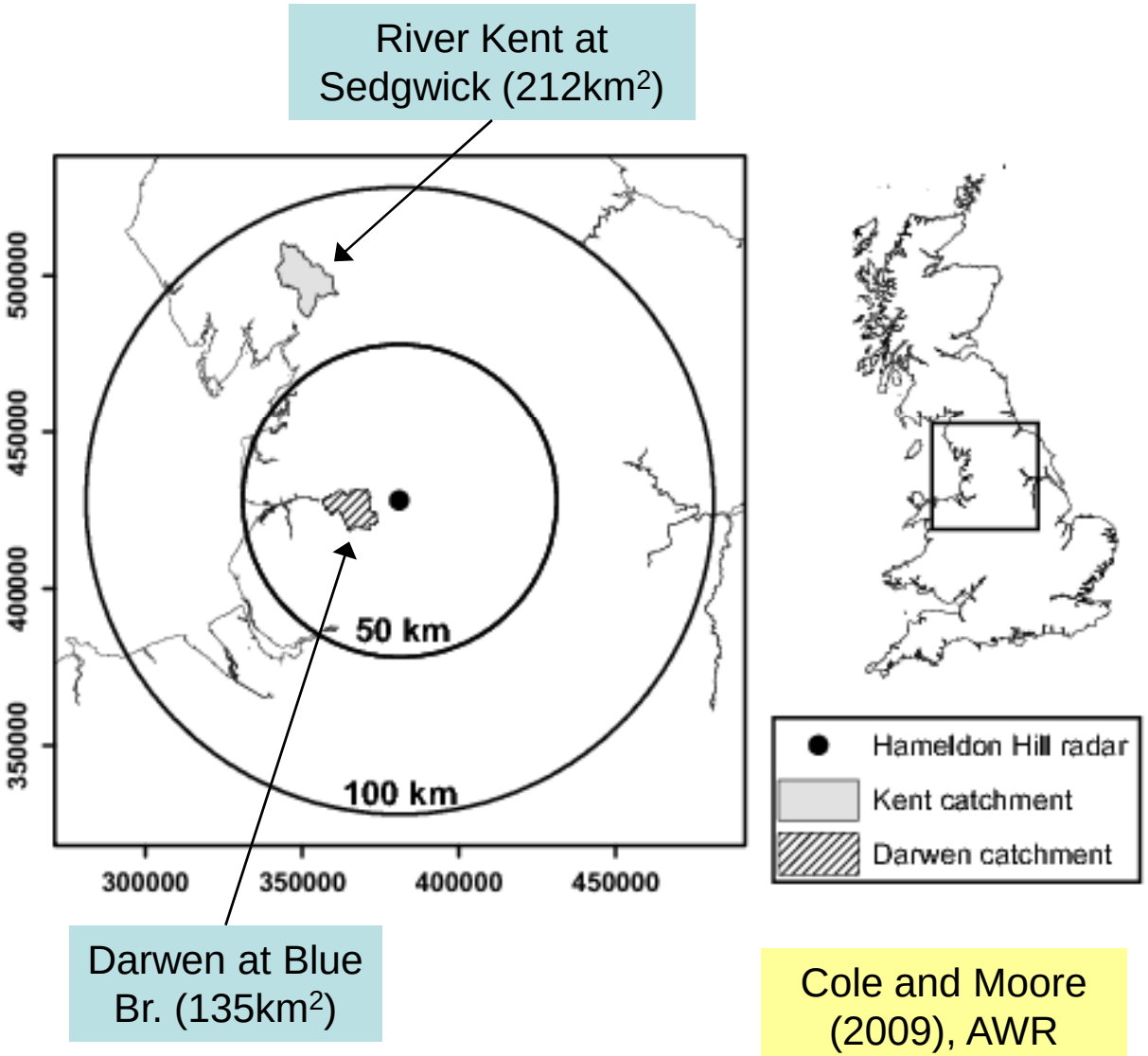
- Distributed hydrological models offer a natural approach to area-wide flood forecasting that includes small catchments

**BUT:**

- What rainfall estimates and forecasts should be used?
- How to formulate area-wide distributed models for operational use in flood forecasting?
- How do these area-wide models perform at small gauged and ungauged locations?

# Gridded rainfall estimators: examples

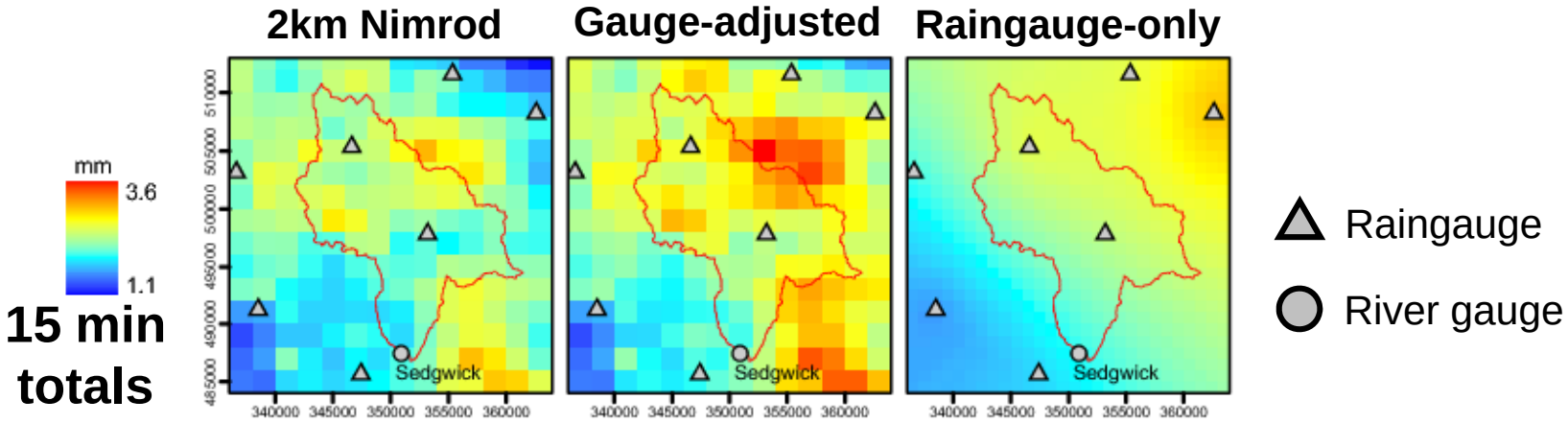
- Using Hameldon Hill radar in North-West England
- Two relatively steep upland catchments
- Strong topographic control on flow response



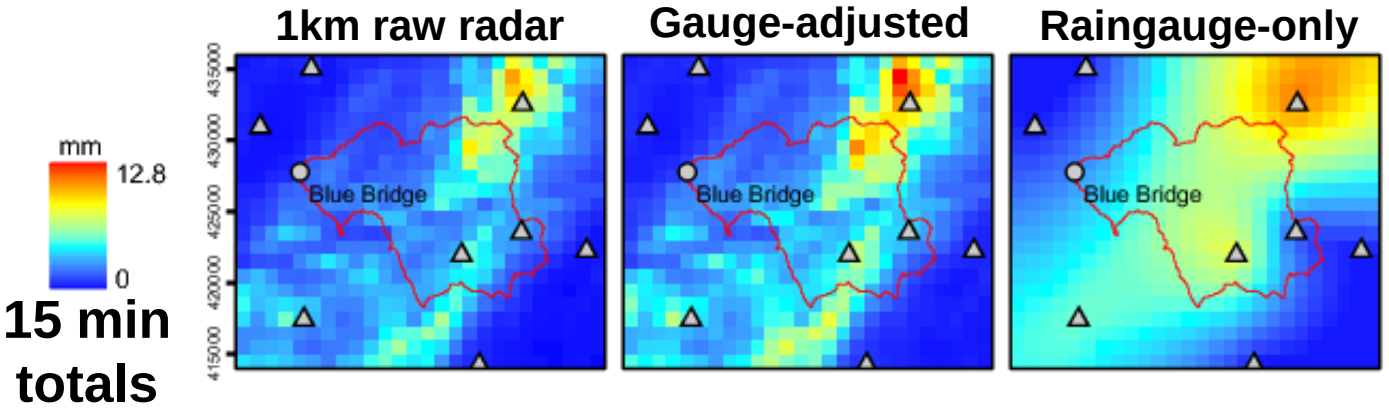

Cole and Moore (2009), AWR

# Gridded rainfall estimators: examples

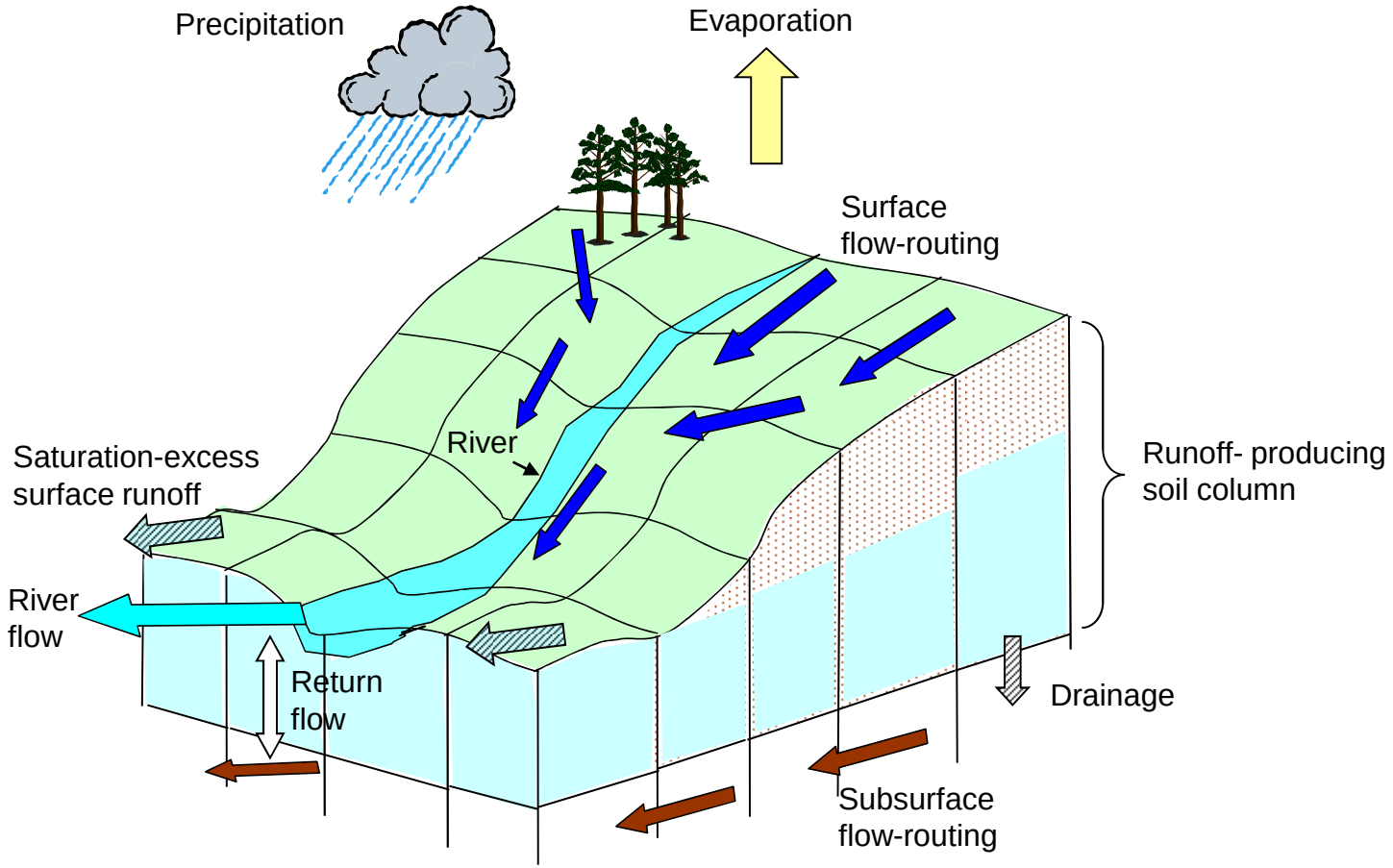
- River Kent catchment, orographic event, 3 Feb 2004




- River Darwen catchment, convective event, 14 June 2002



# Grid-to-Grid distributed model (G2G)




- Uses digital spatial datasets (e.g. terrain)
- Responds to spatial variation of rainfall input
- Grid-to-Grid routing using Kinematic Wave scheme

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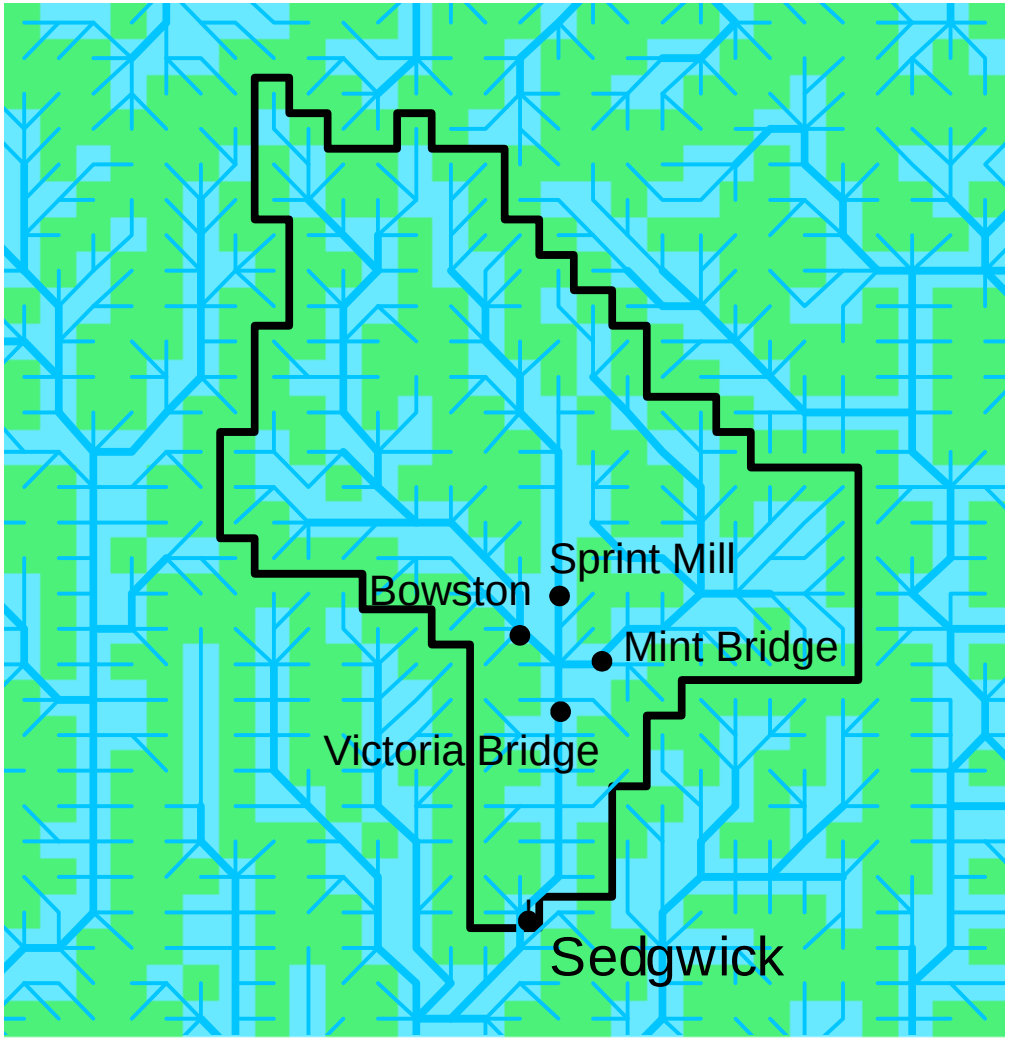
# G2G routing: use of terrain data

1. **Flow directions**: apply automated method to 50m DTM to infer 1km flow-paths

2. **Catchment boundary delineation**: inferred from flow-path directions

3. **Land/river designation:** drainage area + river length threshold

4. **Select forecast locations:** gauged or ungauged



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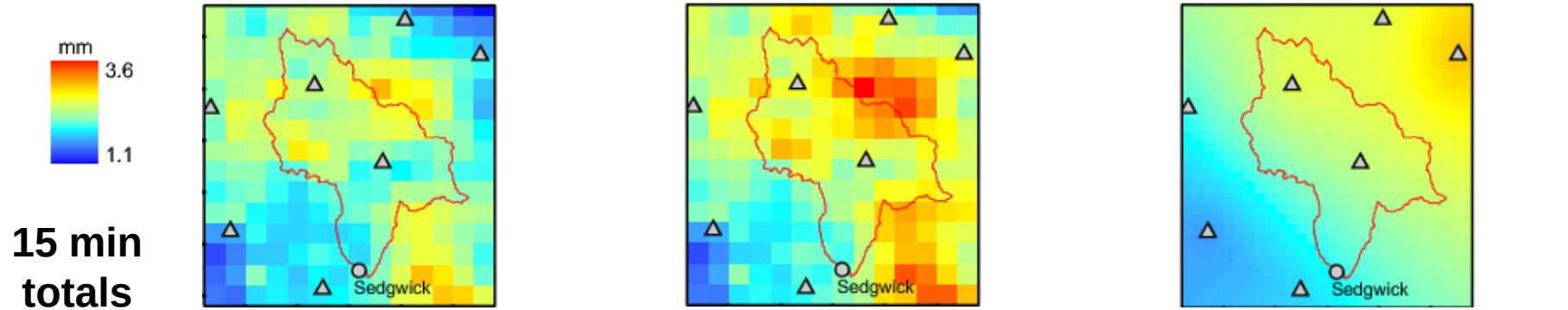
# G2G model assessment of rainfall estimators

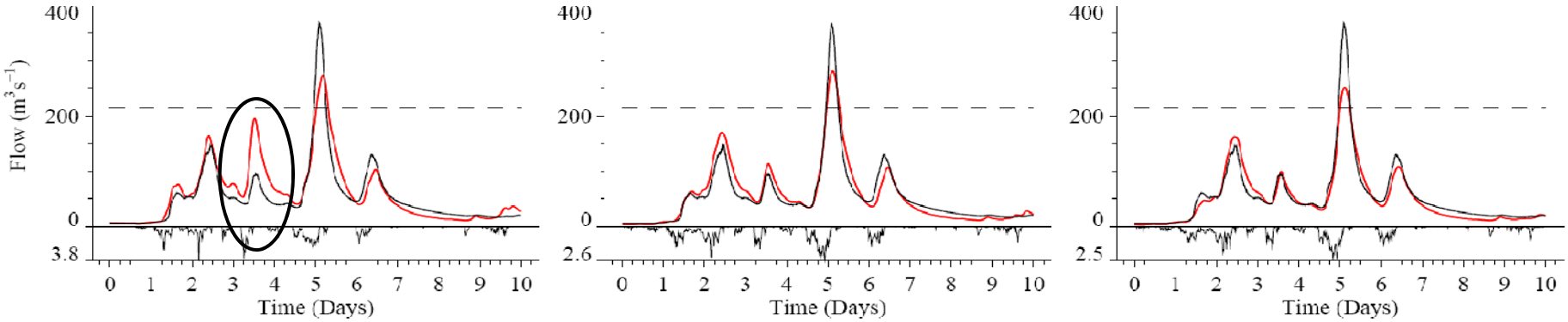
Novel multiquadric surface fitting method (Cole & Moore, 2008)

→ Improved rainfall estimates

→ Validated by hydrological modelling

**2km radar data** | **Gauge-adjusted radar** | **Raingauge-only**




Distributed model (G2G) —— Observed — — — Rating curve maximum

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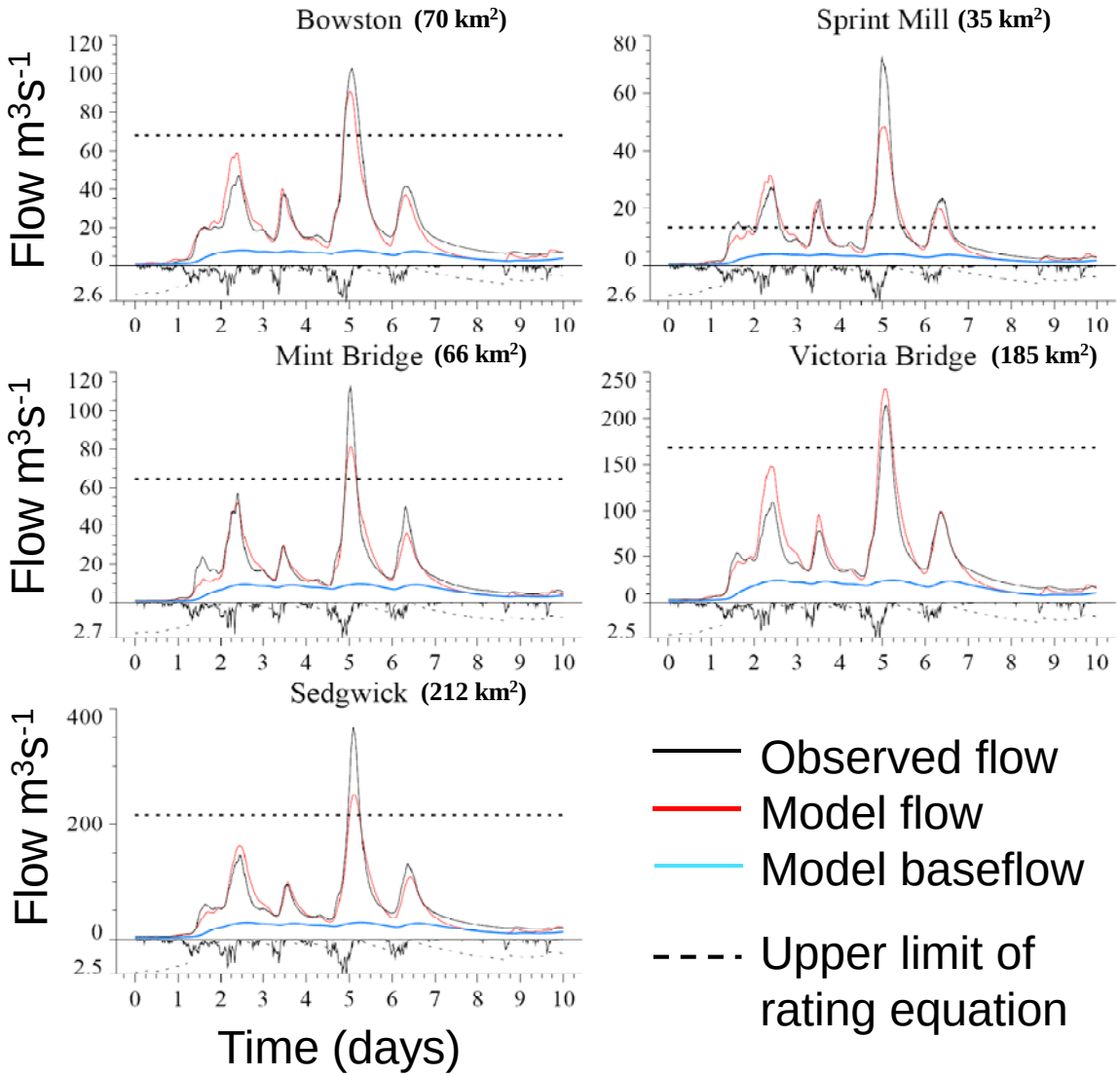
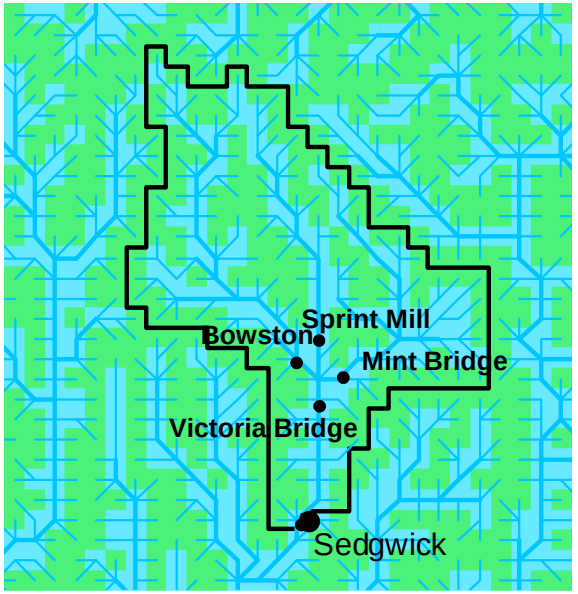
# G2G model assessment at 'ungauged' sites




- G2G model calibrated at **Sedgwick only**
- 15-min raingauge data used
- Comparable results at ungauged sites

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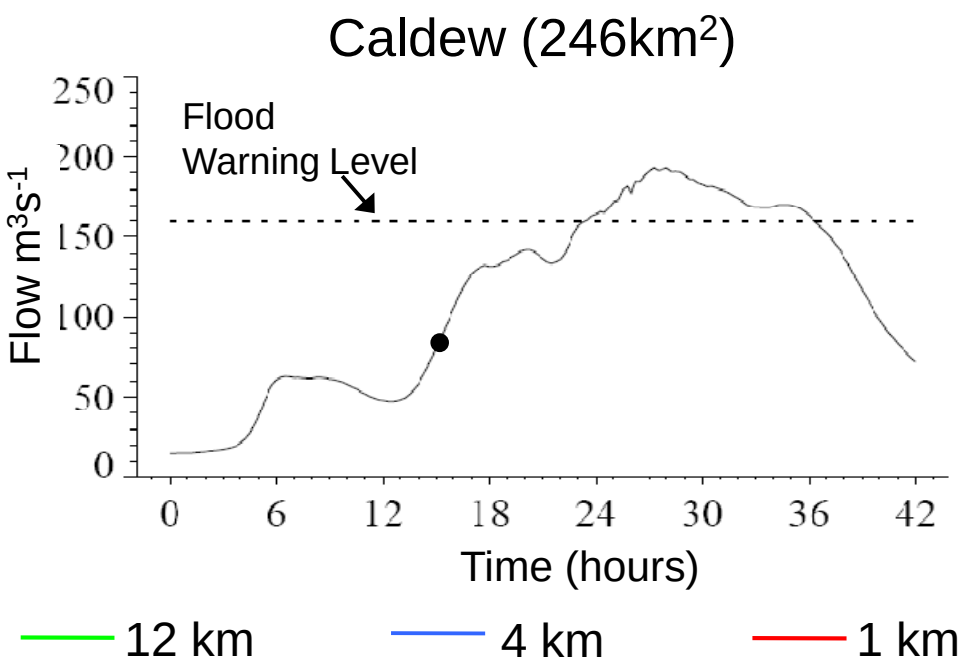
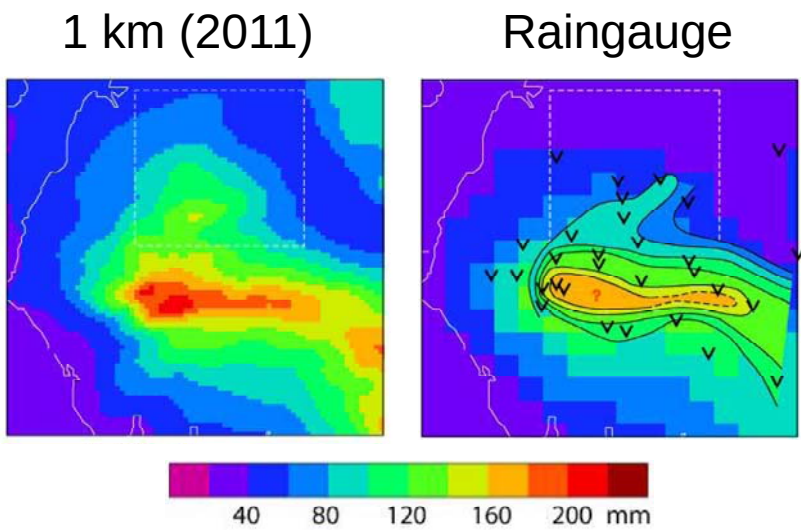
# Hydrological flood forecasts using NWP

Collaboration with the Joint Centre for Mesoscale Meteorology, EA and CEH using the Carlisle 2005 Floods (uses the PDM model).

Q: Can new 1 or 4 km NWP rainfalls provide reliable flood forecasts?

A: Yes, for the Carlisle floods (orographically enhanced frontal rain)




Roberts, Cole *et al.*, 2009, Met. Apps

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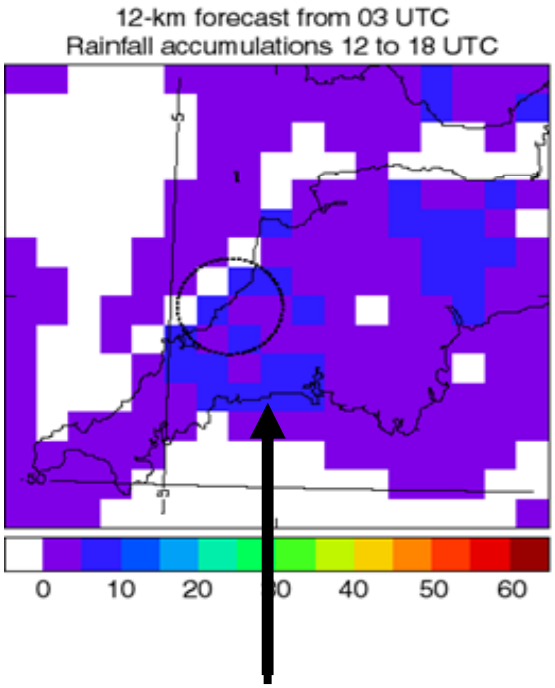
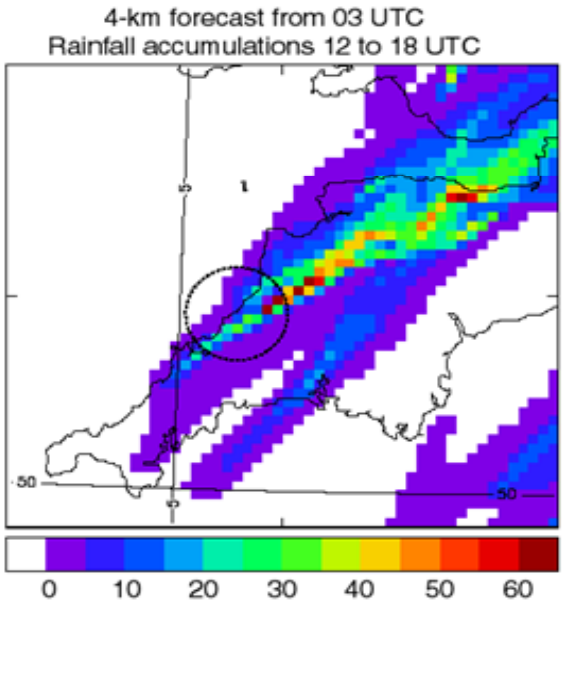
# Boscastle 2004 case study

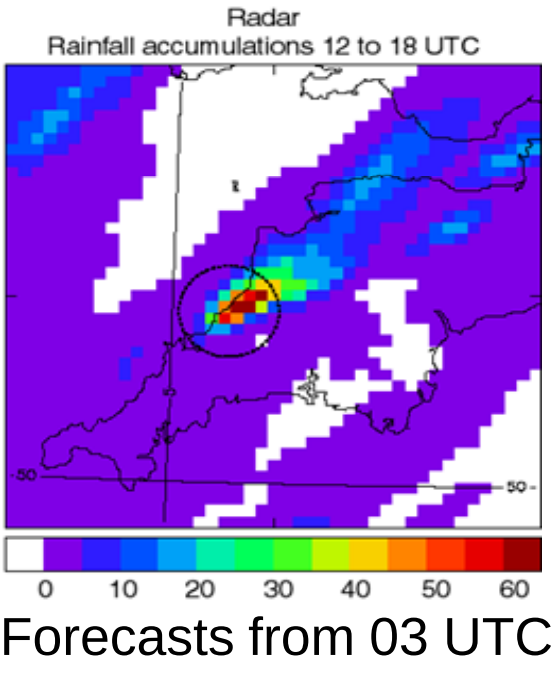
12 km




4 km




NIMROD radar




Forecasts from 03 UTC

20 km radius
from Boscastle

**Courtesy Nigel Roberts,
JCMM (Met Office)**

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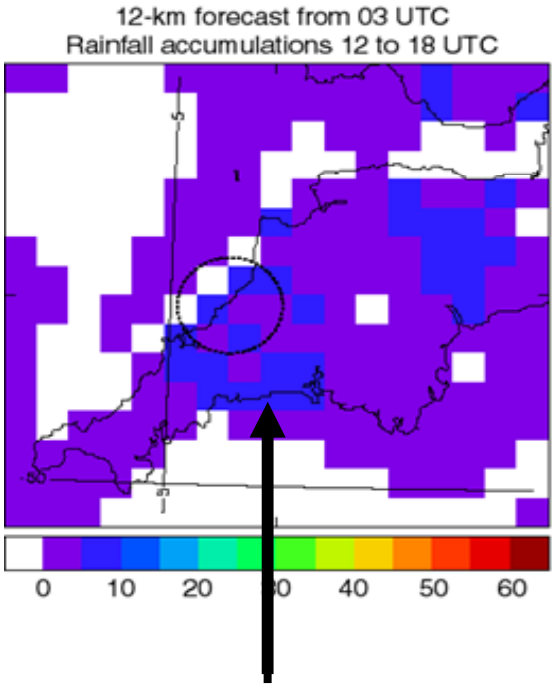
# Boscastle 2004 case study

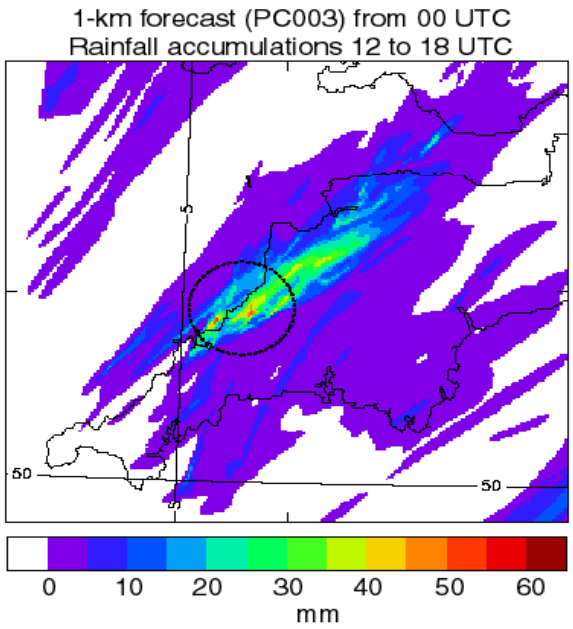
- 1 or 4km NWP major improvement over 12km product
- Still uncertainty in NWP rainfall intensities and location

12 km



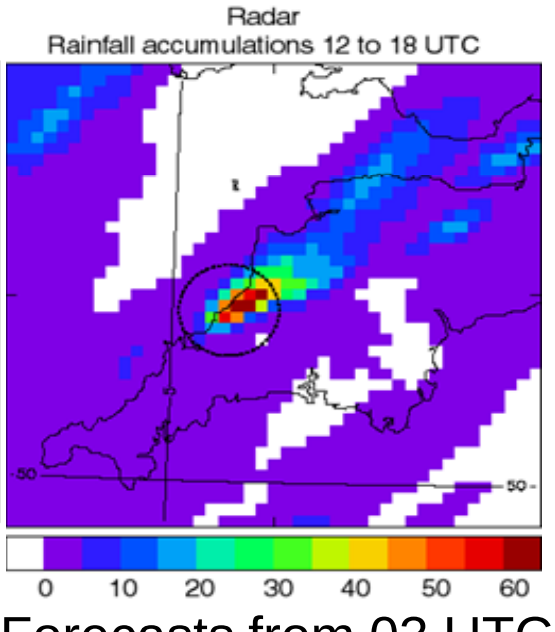

20 km radius
from Boscastle

1 km




Peak accumulations
up to 50mm

NIMROD radar



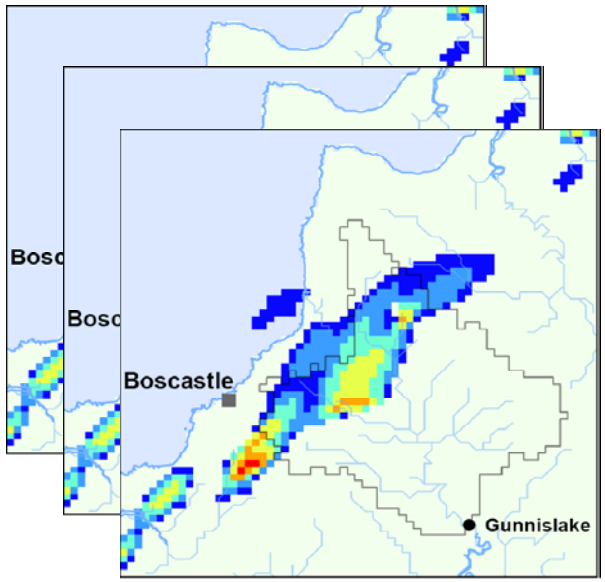

Forecasts from 03 UTC

**Courtesy Nigel Roberts, JCMM (Met Office)**

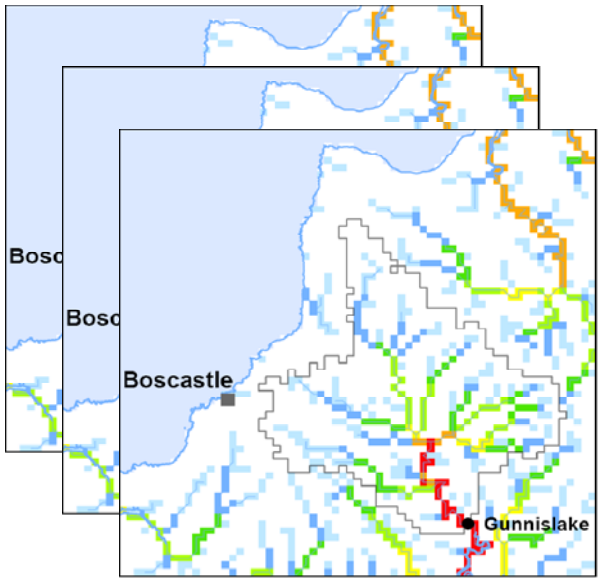
# Ensemble Flood Forecasting using G2G

- Simple psuedo-ensemble method developed to capture NWP uncertainties. Genuine ensembles will be available in 2012(?)

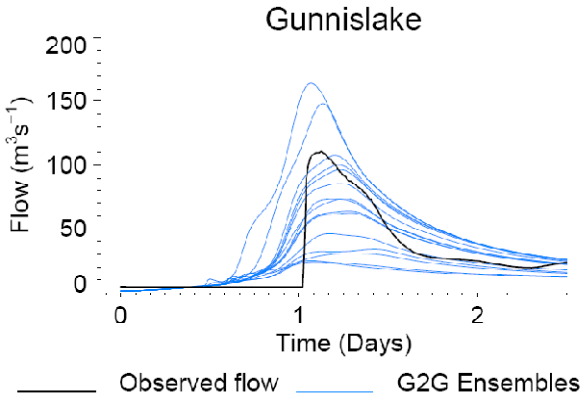
**1km NWP pseudo-ensemble**




**G2G Model 1km river flow ensemble**




**Comparison with river flow observations**




*Acknowledgements:*
Collaboration with JCMM (Met Office)

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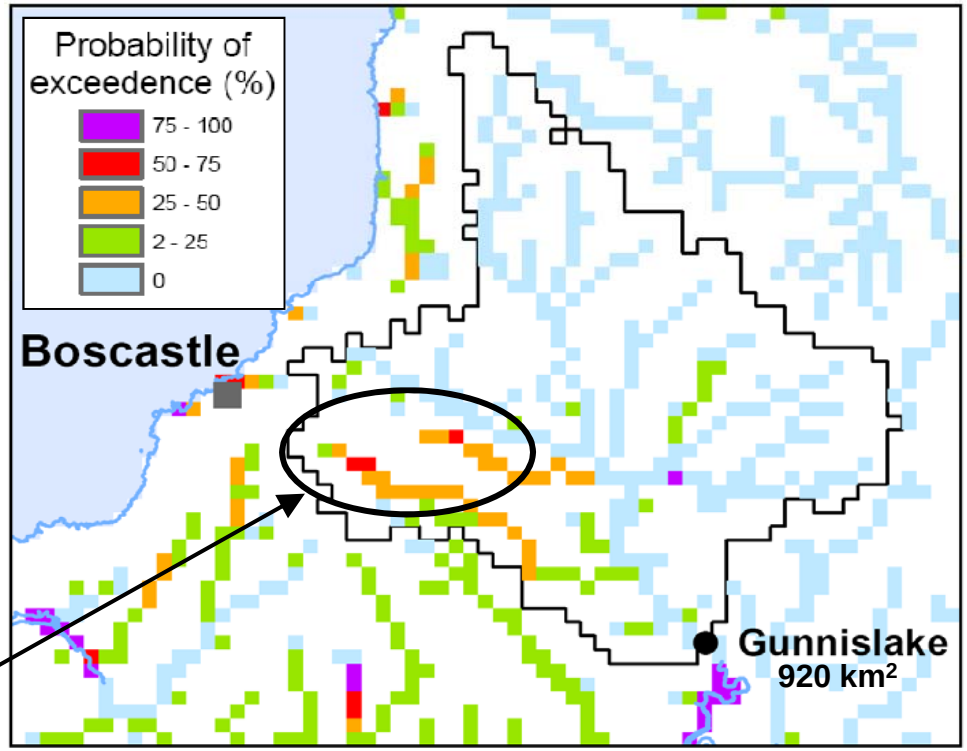
# Risk Map of flood exceedance using G2G ensembles and Q(T) flow return period grids

Probability of ***exceeding*** a given ***flow threshold***, for a given ***forecast horizon***

This example employs:

- NWP 1km rainfall pseudo-ensemble
- 10 year return period flow thresholds
- 24 hour forecast horizon

Potential to identify flood risk ***hotspots***

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# Midlands Case Study – 20 July 2007

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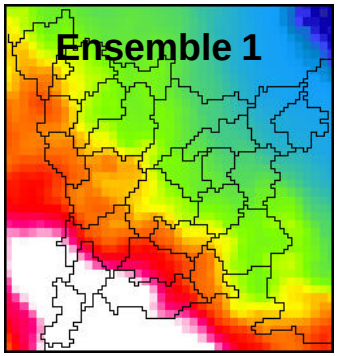
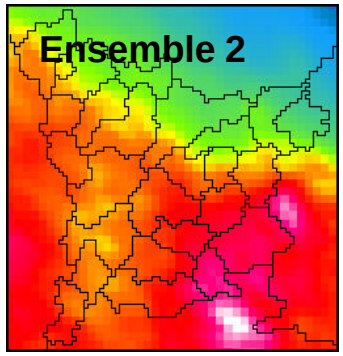
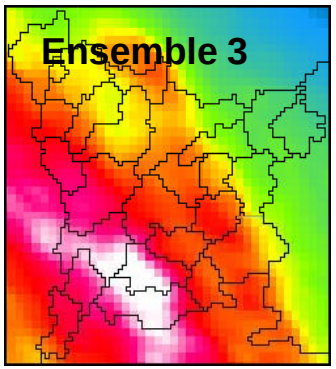
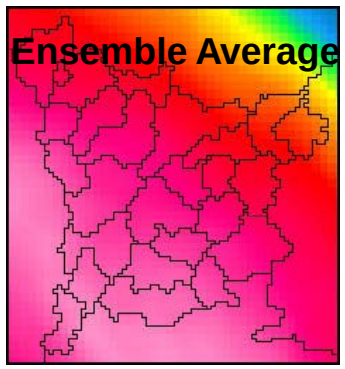
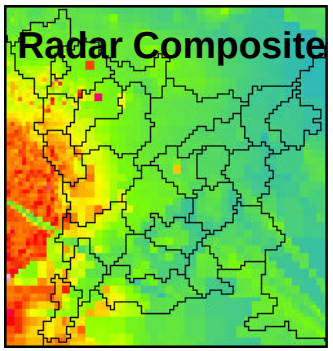
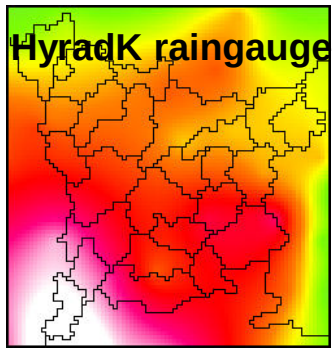


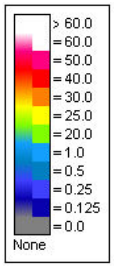



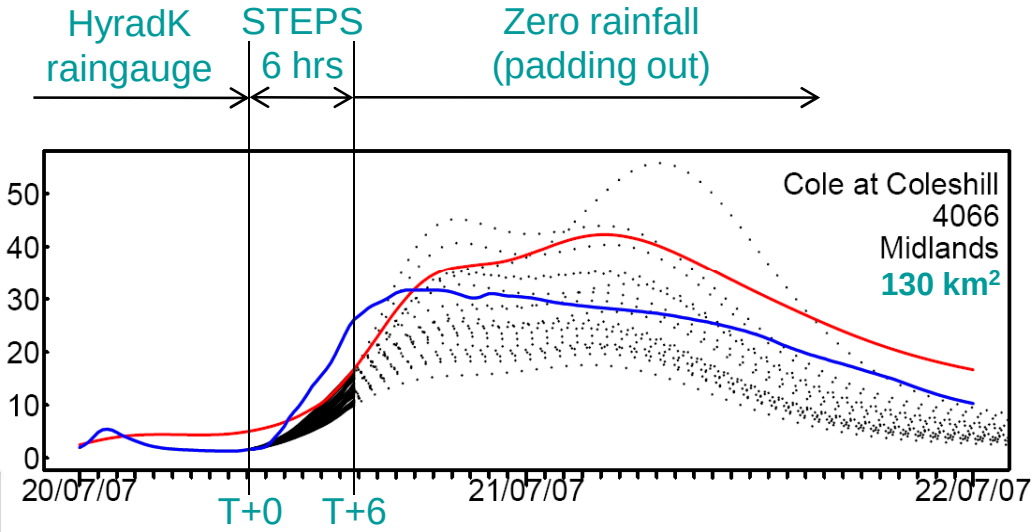




Ensemble average rainfall is less than raingauge rainfall but higher than radar

## STEPS 6-hour spatial rainfall forecast
## 0900 to 1500 20 July 2007
## 20 ensembles
## Avon & Tame (Midlands) catchments




**Ensemble hydrographs**

- observed flow
- modelled flow using raingauge rainfall
- 20 flow ensembles using STEPS
- zero rainfall used beyond 6hr STEPS

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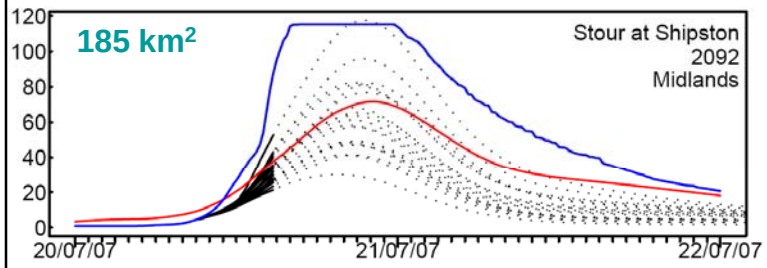
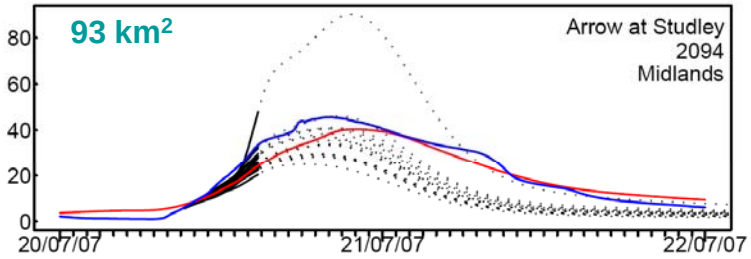
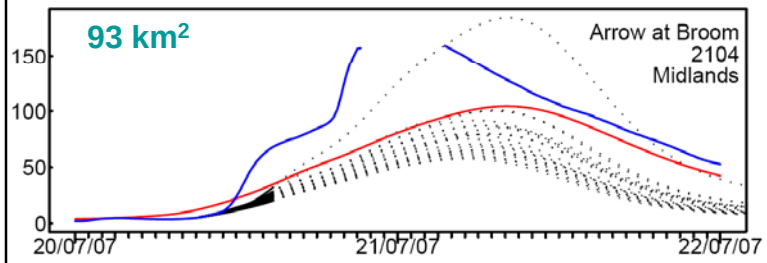
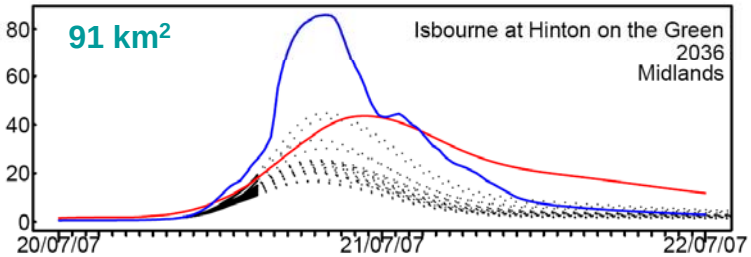
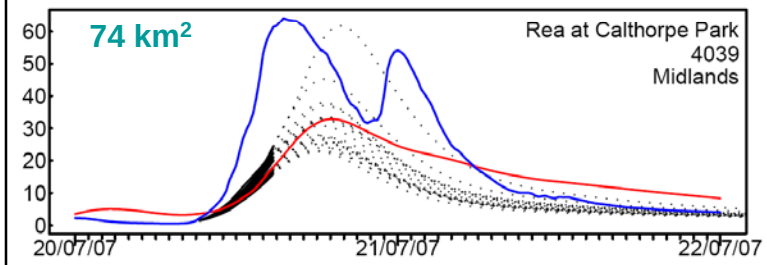
# G2G ensembles using STEPS forecasts

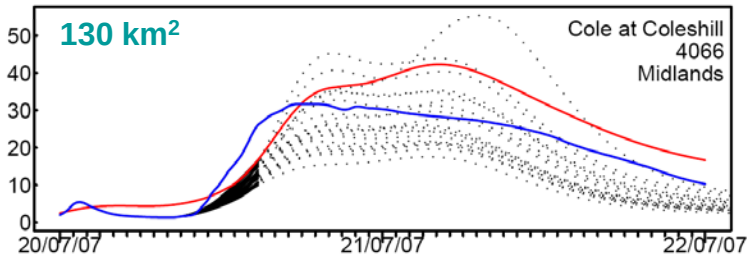



**Observed**

Modelled

20 STEPS ensemble members 20 July 2007

Traditional ensemble outputs at gauged locations

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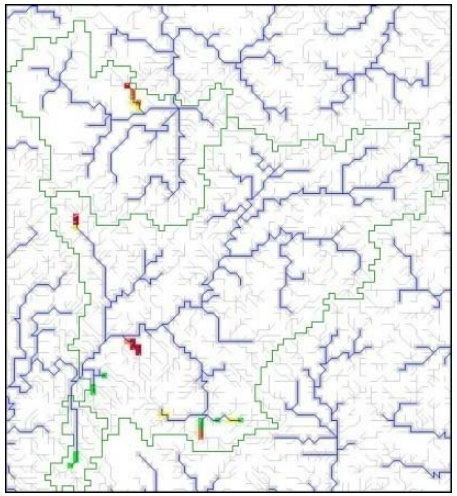
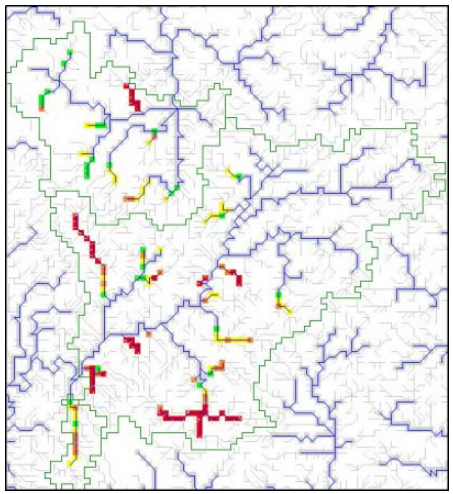
# Probability of exceedance flood maps

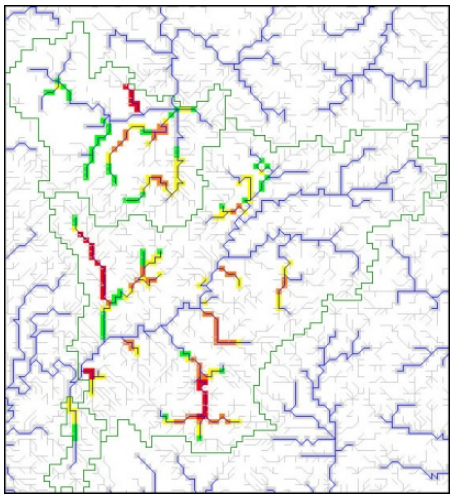
**T+3 hours**



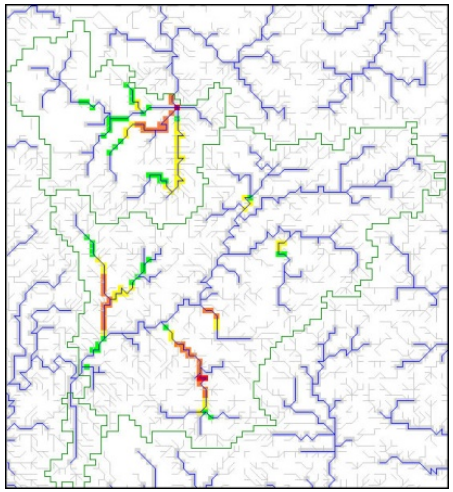
**T+6 hours**



**T+12 hours**



**T+18 hours**



10 year return period flood threshold

6-hr STEPS forecasts then zero rainfall

20 STEPS Members

09:00 20 July 2007 origin

Avon & Tame (Midlands) catchments

Key indicates probabilities of (number of members) exceeding the **10-year flood**.

| |
|---|
| 75-100% |
| 50-75% |
| 25-50% |
| 10-25% |
| 2-10% |

During early part of storm, highest exceedance probabilities are on the very small rivers.

As time progresses the main exceedance hotspots are on the larger rivers and can be tracked moving downstream and meeting at confluences.

# National application of G2G

- ***Several EA/Defra R&D projects recommended nationwide operational trial of G2G for flood forecasting***
  - 2004-06: Extreme Event Recognition Phase 2 (FD2208)
  - 2005-07: Rainfall-runoff and other modelling for ungauged/low-benefit locations (SC030227)
  - 2007-10: Hydrological modelling using convective scale rainfall modelling (SC060087)
- ***Pitt Review of the Summer 2007 floods***
  - Environment Agency/Met Office Flood Forecasting Centre (FFC) for England & Wales, opened April 2009
  - Scottish Flood Forecasting Service (SFFS) between SEPA/Met Office opened 2010
  - G2G now undergoing operational trials in FFC and SFFS

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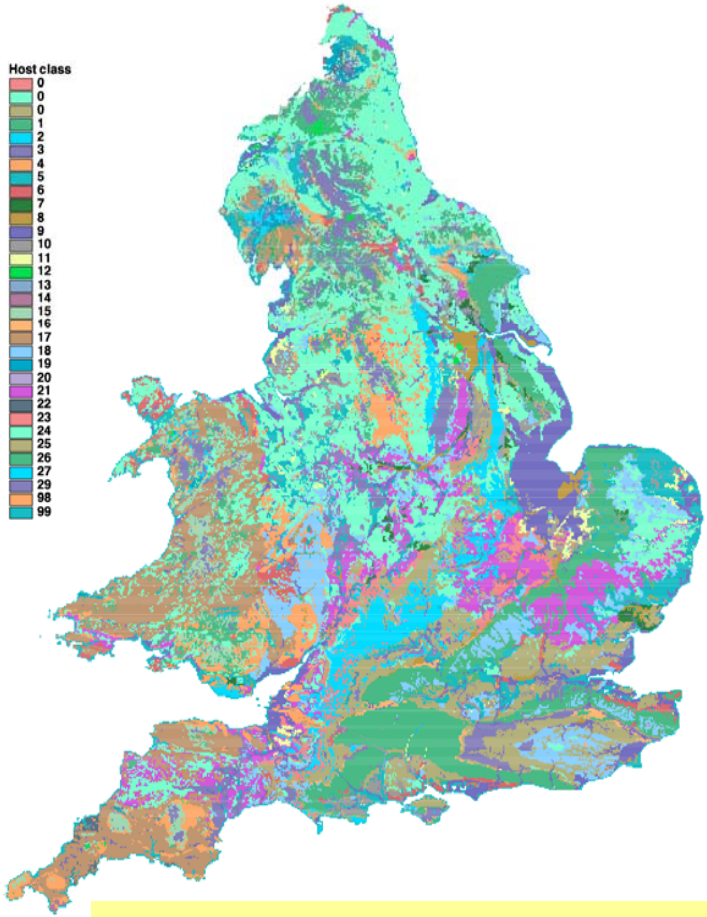
# G2G runoff production: use of soil property associations




Bell et al. (2009), JoH
Moore et al. (2006), IAHS Pub. 305

**Runoff production** key element – needs to reflect heterogeneous soil properties

Use of Soil Survey data (HOST, Seismic, other…) to obtain 1km grids of:

- water content at field capacity
- residual soil water content
- porosity
- saturation hydraulic conductivity
- horizon depth

Issues:

- Scale
- Effective values
- Lateral properties

Association table links **29** HOST soil classes to soil properties

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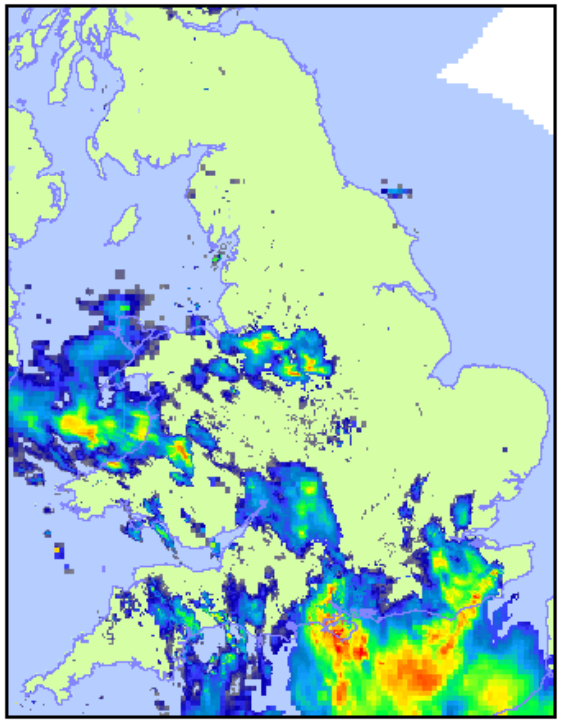
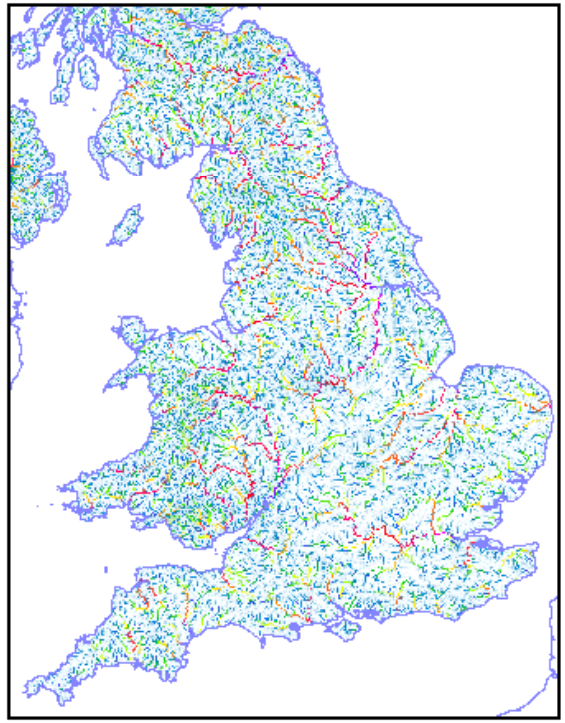
# G2G national application

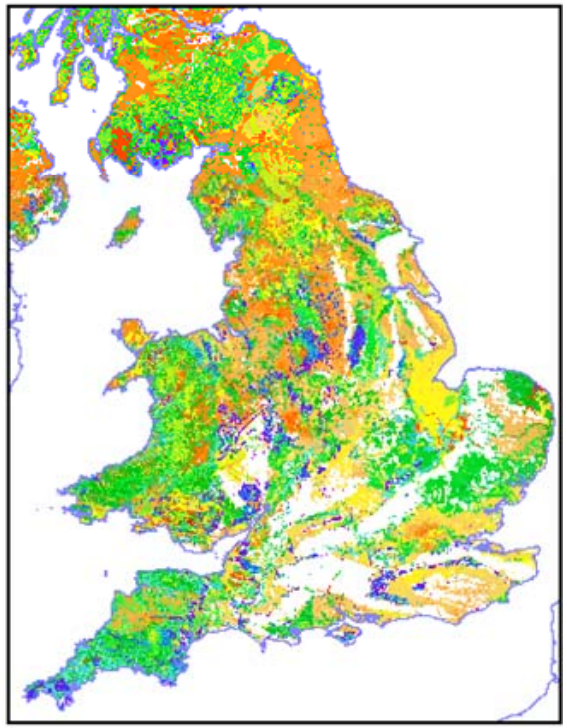
- G2G runs nationally within NFFS/FEWS using a 15 min time-step and models river flow and soil moisture on a 1km grid
- Ongoing operational trial and assessment



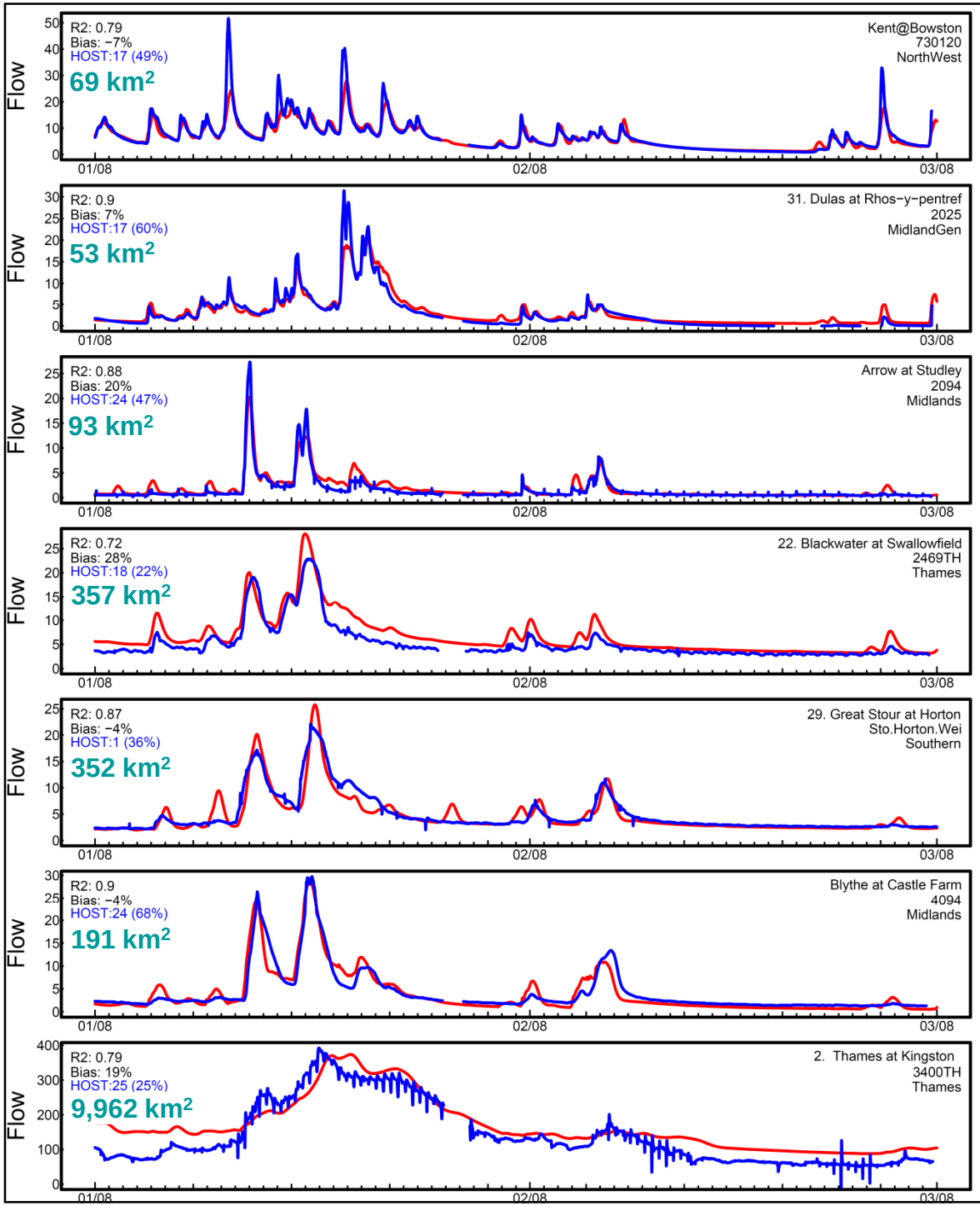
**Raingauge-adjusted radar**



**River flow**



**Soil moisture**

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Examples of catchments with generally good G2G performance

January & February 2008

**Observed**

**Modelled**

Demonstrates modelling of different flow regimes and catchment sizes with the G2G Model

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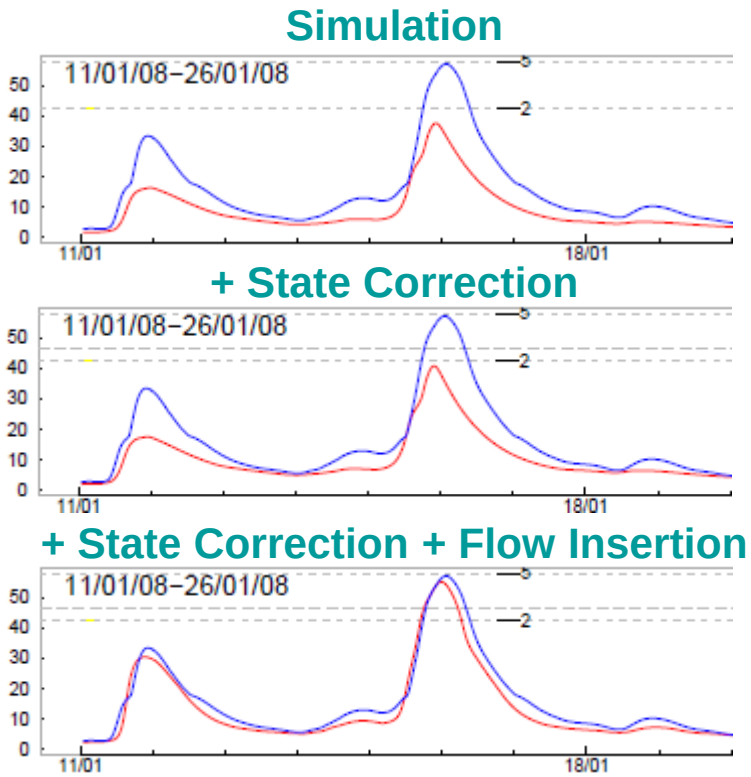
# G2G Operational Use: Data Assimilation

- **State Correction**
  - slow adjustment that improves long-term baseflow modelling
  - good quality flow data needed
  - adjusts upstream soil storages
- **Flow Insertion**
  - observed flow fed in at each gauged location with good data
  - permits ARMA forecast correction




- **Flow Insertion and Local Parameter Calibration**
  - Flow insertion allows nested catchments to be calibrated independently of upstream modelling (e.g. use lake outflows)
  - River routing speed can be calibrated for each sub-catchment

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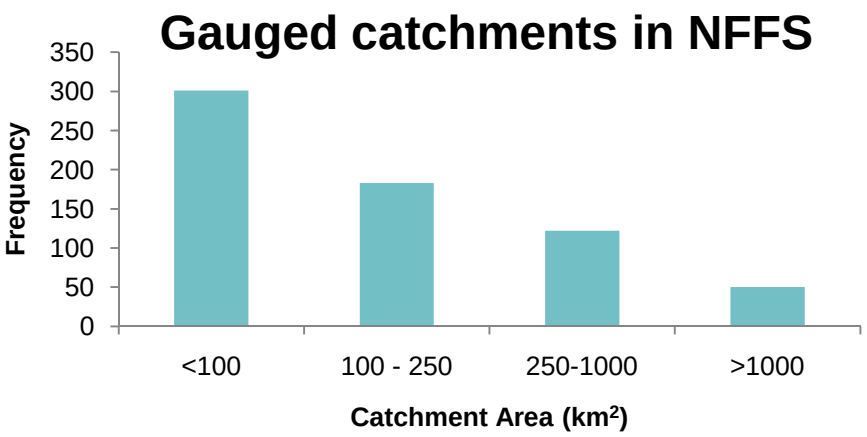
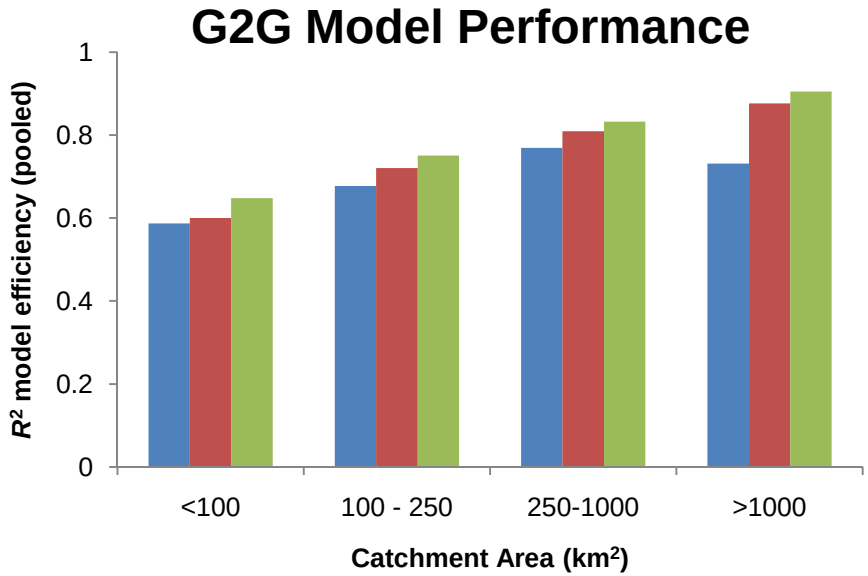
# G2G Model performance by area




- About 45% of the gauged catchments in NFFS have an area <100km$^2$
- Results for spring 2008 with state correction on
  - **No insertion + global params**
    Larger catchments tend to perform slightly better
  - **Flow insertion + global params**
    Most benefit for large catchments
  - **Flow insertion + local params**
    Most benefit for small catchments

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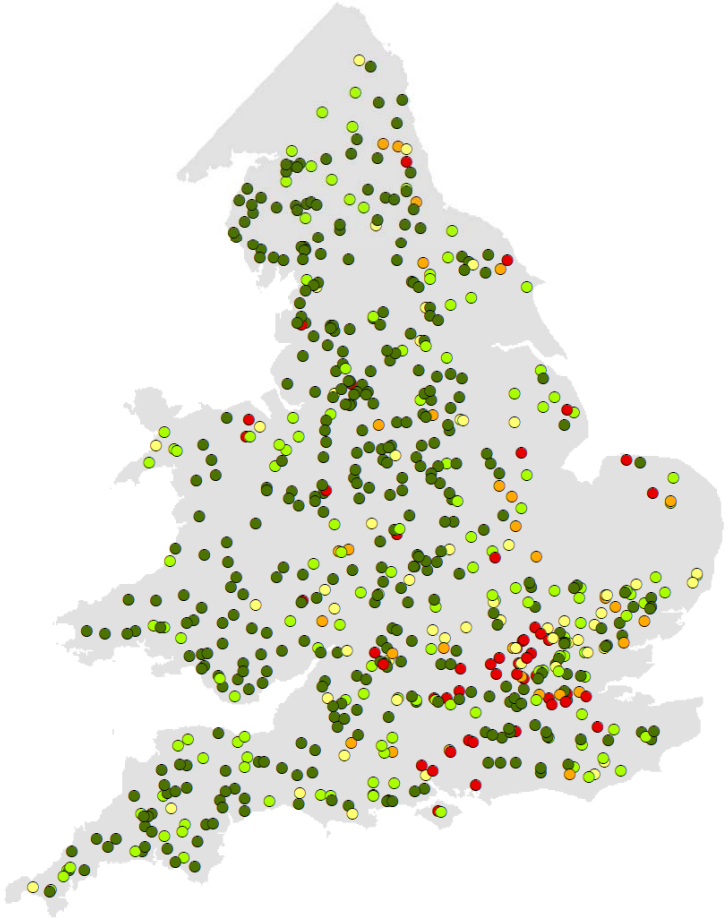
# G2G Model performance by area

- National G2G performance maps for spring 2008

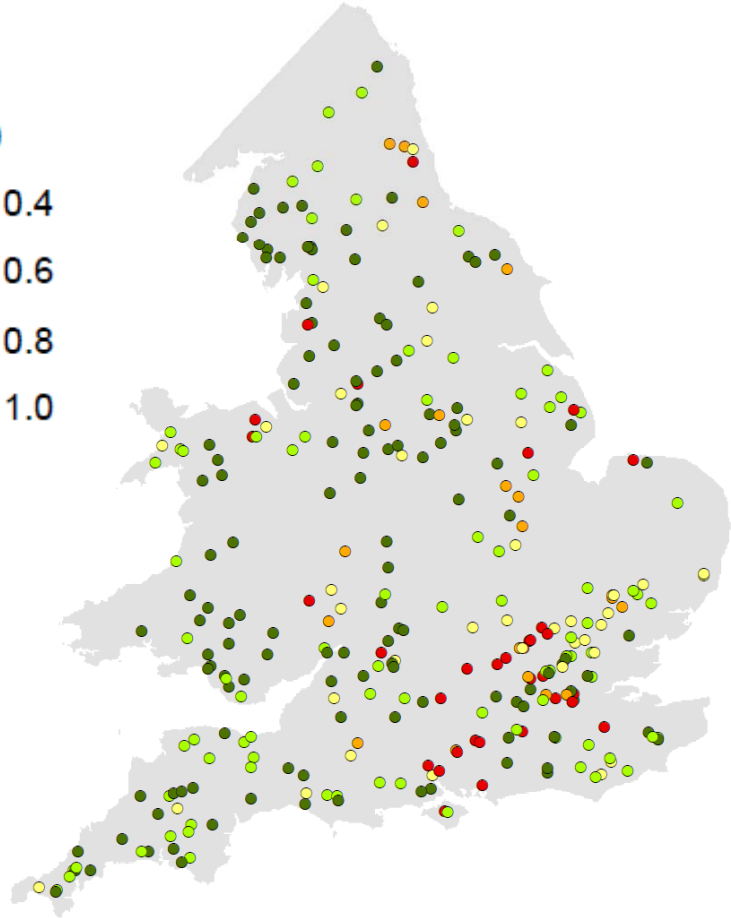
All stations



$R^2$

- < 0.0
- 0.0 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0

Area <100km$^2$



# Summary and conclusions

- **G2G Model:**
  - sensitive to spatio-temporal structure of storms
  - shapes flood hydrograph from storm and landscape properties
  - Q(T) grids allow mapping between G2G flows and flood return periods – indication of severity

- **National application of G2G for flood forecasting:**
  - results show utility for small catchments and performance improves with catchment size
  - high-resolution (4 or 1km) NWP provides better rainfall and flood forecasts and indicative flood warnings for the next few days
  - data assimilation greatly improves forecast performance
  - can produce **real-time flood risk maps**, if used with ensemble rainfall forecasts: important for small catchments