Weather Radar in Operational Hydrology

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UK floods
Urban drainage

- UDS complex and in parts old and in need of refurbishment.
- 90 significant flooding incidents 1976-88.
- Sewage discharges to natural water courses
- Accurate high resolution (1km x 1km) rainfall forecasts needed.
- Changes in rainfall patterns and amounts may cause problems in UDS management.
Why do (some) hydrologists still distrust radar estimates of rainfall?

Rainfall rate (mm h\(^{-1}\)) on 21 June 2004, around 9:48 UTC, given by the Hameldon Hill C-band radar located some 24 km north of the centre of Manchester, North West England.

The red and white dot indicates Manchester city centre. This image is an example of the radar product used in this work (10 m in image, with 2 x 2 km\(^2\) spatial resolution).
Flood protection and forecasting
Basis of flood forecasting

• May not be able to rely on local measurements of rainfall or river flow as hydrometric networks can be destroyed.

• Increasing dependence upon,
  - **weather radar**
  - high resolution NWP
  - knowledge of antecedent conditions
  - hydrologic modelling which needs to deal with uncertainty.

**BUT ALL THE ABOVE HAVE UNCERTAINTY ASSOCIATED WITH THEM**
Problems impacting radar measurements of precipitation

Schematic representation of the problem areas associated with the measurement of precipitation by radar. 1. Radar beam overshooting the shallow precipitation at long ranges; 2. Low-level evaporation beneath the radar beam; 3. Orographic precipitation above hills which goes undetected beneath; 4. Bright-band; 5. Underestimation of the intensity of drizzle because of the absence of large droplets; 6. Radar beam bent in the presence of a strong hydrolapse, causing it to intercept land or sea.
Input-Output-Storage models

- Initially developed in the 1960s (Lambert, 1969).
- Later developed for multiple storages where each storage capacity is assumed to represent a certain proportion of the catchment (PDM models).
- As the stores fill, the proportion of the area producing fast runoff can be calculated.
Model structures: Transfer Function models

(a) Linear
\[ Q_t = a_1 Q_{t-1} + a_2 Q_{t-2} + \ldots + a_m Q_{t-m} + b_0 R_{t-T} + b_1 R_{t-1-T} + \ldots + b_n R_{t-n-T} \]
This is a \((m, n, T)\) order model.

(b) Non-linear
allows for:
- antecedent conditions
- slow (base flow influences; groundwater flow)
- rapid (overland)
Model structures: Distributed models e.g. SHE
HYRAD — Rainfall Estimation from Weather Radar

HYRAD developed by the Centre for Ecology and Hydrology (CEH) is the standard radar display system in use by the Environment Agency in support of flood warning throughout England and Wales.

Display of cumulative rainfall fields over minutes, hours, days and months

System monitoring of real-time data reception

Static and rapid display of images in multiple windows and with zoom and pan
Storm Amplification Experiments
(courtesy R. Moore and S. Cole)

- Transposed a historic convective storm to River Kent
- Change alignment of storm track and channel orientation

Northerly storm track

Southerly storm track

Modified storm totals
Lumped vs Distributed modelling
(courtesy Moore and Cole, 2006)

Comparing lumped and distributed hydrological model response (at one location) to different storm tracks

Northerly storm track

Southerly storm track

Grid-to-Grid Distributed

PDM Lumped
Flash Flood Guidance

- The volume of rainfall of a given duration distributed uniformly over a small catchment that is just enough to cause minor flooding at the catchment outlet.

Flow

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Romance

Rural

Urban

Using analytical expression with rainfall measurement

High resolution (1 km) radar imagery 7 May 2000
Comparison of discharge bias and MAE for a stochastic model of the urban River Croal, UK using radar data input and the semi-rural Baron Fork River, USA using a distributed model.
Weather and flood models need to be integrated

- For small areas, local rainfall leads to flash flooding. Changes in extreme rainfall will translate into increased flood risk.

- For larger areas, longer periods of rainfall, past conditions are important, e.g., warmer drier summers and autumns may lower winter flood risk even if winter rainfall increases.
Data assimilation and ensembles

• Generation of random parameter sets are used to produce an ensemble of flow forecasts constrained by some measure of acceptability.

• The spread of the ensemble may relate to physical processes not well represented in the model cf NWP stochastic parameterisation schemes.

• Defining uncertainty bounds using objective measures of performance.

• A complementary or alternative technique is to use a Bayesian post processor or fuzzy statistics.

• Assimilation of radar data into NWP models
Ensemble flow forecasts (cumecs) for the River Mole, UK made at 2100 UTC, 21 December 2002 for a lead time of 9 hours using perturbed radar-based forecasts

From Pierce et al, 2004
CEH Grid-to-Grid Hydrological Model: UK-wide proof-of-concept now implemented at the UK National Flood Forecasting Centre, Exeter (previously London)

Observed flow: black line

Bowston

River flow (m$^3$s$^{-1}$)

“Ungauged” G2G model assessment

Polson 09/11/06 – 27/12/06 $R^2 = 0.866$

Days

Days

1930h 25 Nov 2006

“Source-to-Sea” Demonstration
Grid-to-Grid Model: UK-wide proof-of-concept

- Area-wide forecasting for any location (1 km resolution)
- Conceptual-physical distributed model
- Process links to basic landscape properties
- Exploits spatial property datasets on elevation, soil, geology and land-cover
High resolution numerical forecasts

- 1-2 km grid lengths now beginning to be used operationally.
- Realistic forecasts now being produced, but problems remain e.g. Representing sub-grid scale processes.
- These forecasts are expected to replace radar-based nowcasts for lead times beyond two hours or so.
- However the assimilation of radar data is likely to become an essential part of operational procedures.
Illustrating Cobbacombe radar 5 hour total rainfall (mm) (left panel) and 1 km UM forecast rainfall (mm) for 12-17 UTC 16 August 2004 (from Golding et al, 2005) [performance due in part to the dynamic impact of the sea breeze with orography which introduced a level of stationarity to the convection]
Example of the exploitation of new data sources, data assimilation and ensemble techniques for storm and flood forecasting Boscastle storm Case study: Boscastle storm

(a) a ‘pseudo-ensemble’ of high-resolution 1 km NWP rainfall, (b) an ensemble of distributed hydrological model simulations of river flow using the Grid-to-Grid (G2G) model, (c) comparison of G2G ensembles with observations for the River Tamar at Gunnislake (location and 1 km catchment boundary is given in (a) and (b)).

courtesy R. Moore and S. Cole
The problem of issuing an alert under flood forecasting uncertainty

(courtesy E. Tordini)
The direct use of radar satellites for event-specific flood risk mapping-12 December 2006 on the Dee River in Wales (UK)
Concluding remarks

• Forecasting the potential and likely occurrence of floods is fraught with difficulties particularly in a changing climate.

• Radar data are likely to be the basis of forecasts for 1-2 hours ahead. However for longer lead times high resolution NWP assimilating radar data input to distributed hydrological models offer the best hope of improvement.

• It will be necessary to constrain uncertainty using both rainfall and hydrological model ensembles with statistical procedures.

• It is likely that reliable accurate quantitative predictions of floods will remain a challenging target.
Some questions relating to the use of radar for hydrological forecasting

- How do we deal with uncertainty in radar estimates of precipitation when inputting the data to hydrological models?
- What are appropriate methods of combining radar and raingauge data for operational implementation?
- What are the benefits of polarisation radar to hydrology?
- How do we use radar estimates of precipitation for hydraulic modelling in urban areas?
- What is the optimum use of radar in high-resolution numerical model forecasting?
- How should radar data be used for pluvial flood forecasting?
- How should we extract information from radar – hydrological model ensemble forecasts?
- How can hydrology benefit from new radar techniques and technologies?