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Short-term hybrid forecasts blending NWP rainfall forecasts and radar nowcasts for probabilistic flow predictions

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Objectives

- Implementation of a stochastic hybrid system merging radar-based and NWP rainfall forecasts for short-term probabilistic predictions
- Use of deterministic and ensemble rainfall forecasts as drive to hydrological predictions
- Development of a categorical non-dimensional measure for the assessment and the comparison of probabilistic and deterministic flow predictions
- Event-focused assessment of the hydrological prediction

Quantitative Precipitation Forecasts (QPFs)

Numerical Weather Prediction (NWP) models

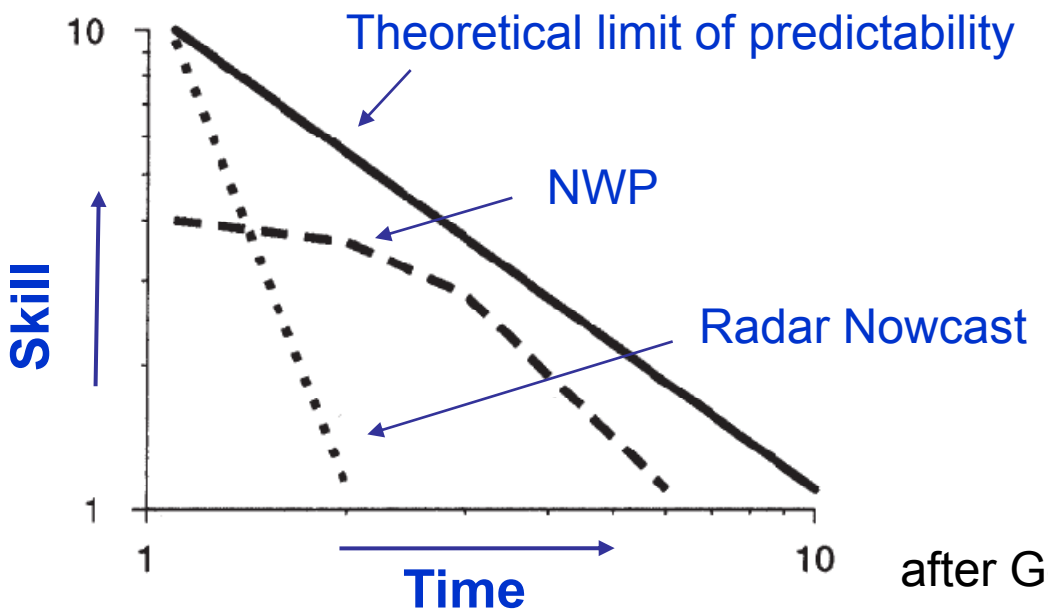
- Simulate dynamics and physics of the atmosphere
- Hydrological application of NWP rainfall forecasts limited by the resolution

Radar nowcasts

- Extrapolation from consecutive radar scans
- High spatial (≤5km) and temporal (≤1h) resolutions

Skill Vs Lead time

More skilful rainfall forecasts from the blending of radar nowcasts and NWP rainfall forecasts?

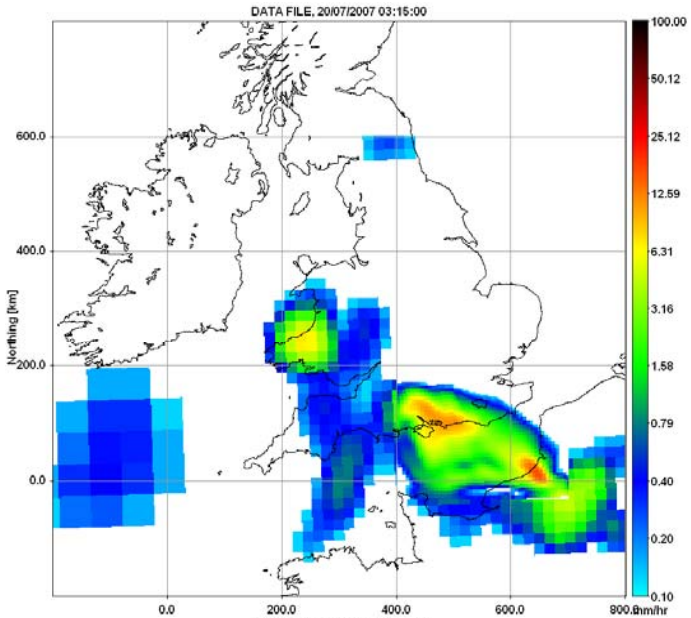


after Golding, 1998

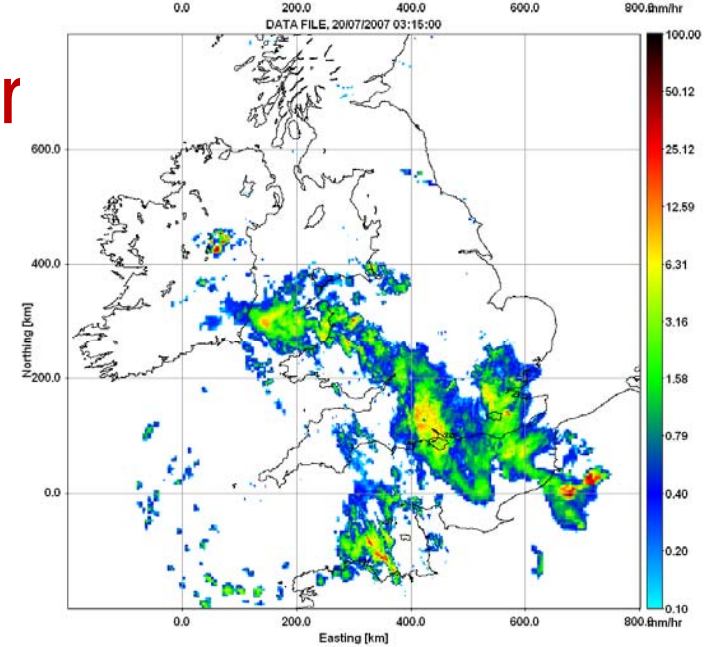
Loss of information as a function of Lead Time

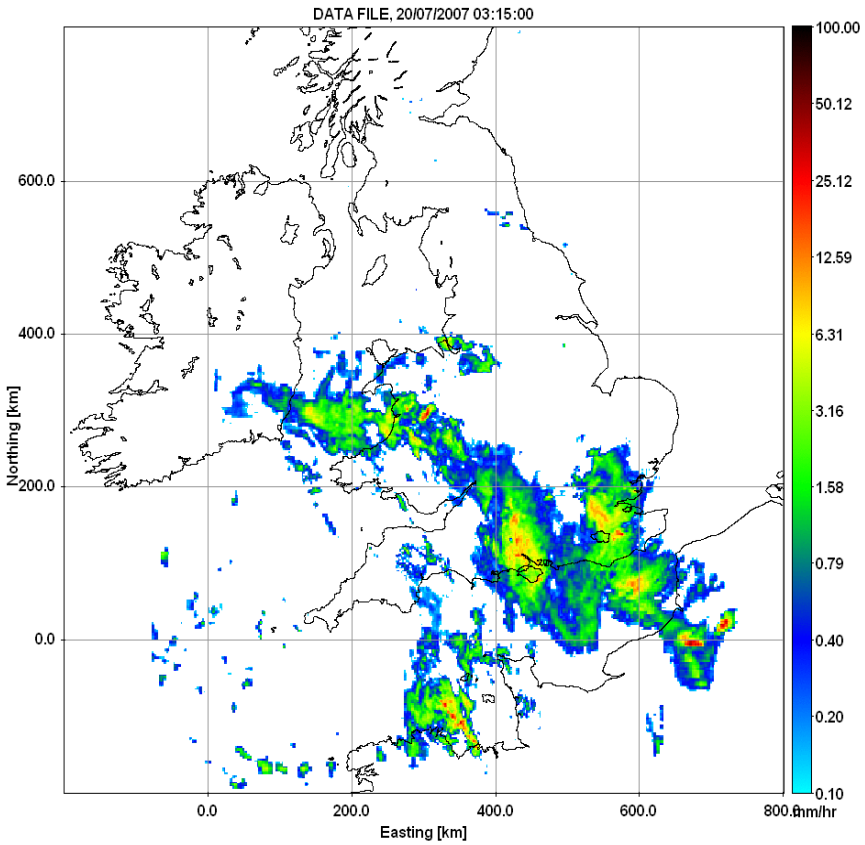
Hybrid rainfall forecasts

NWP



Radar

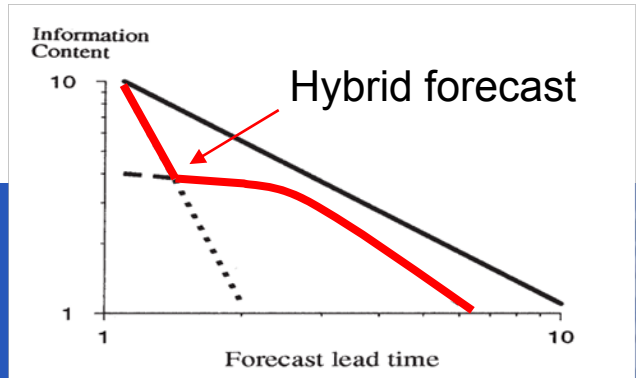




Blending radar-based and NWP rainfall forecast

STEPS (Short-term ensemble prediction system) Bowler et al., 2004

- UK Met Office and Australian Bureau of Meteorology
- Extrapolation radar nowcast merged with a high-resolution NWP rainfall forecast
- Stochastic ensemble rainfall forecasting scheme



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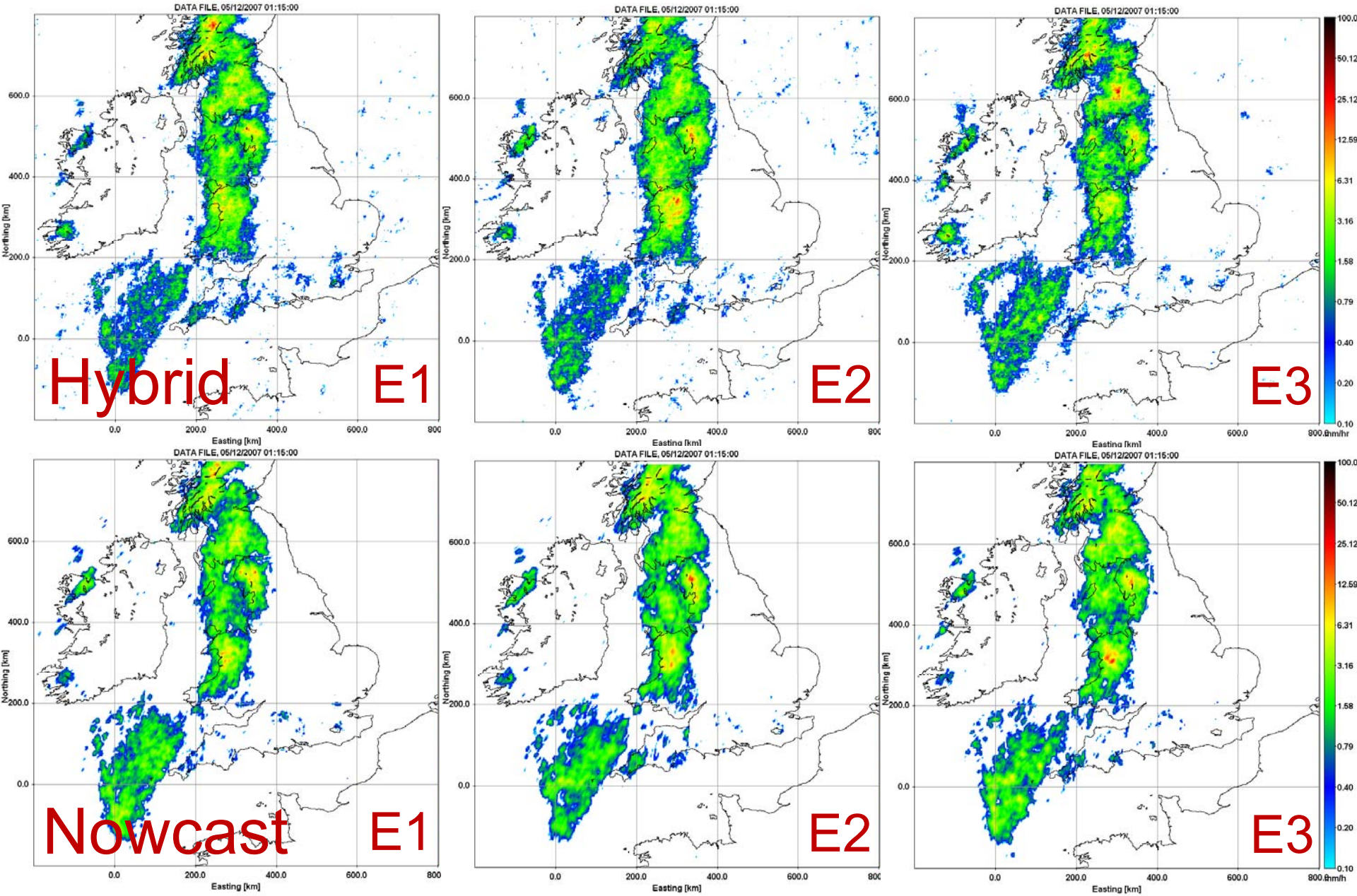
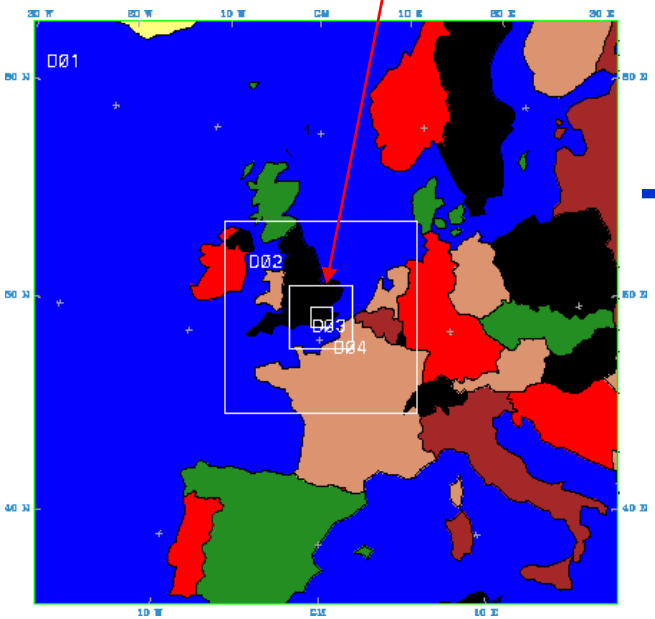
Ensemble rainfall forecasts

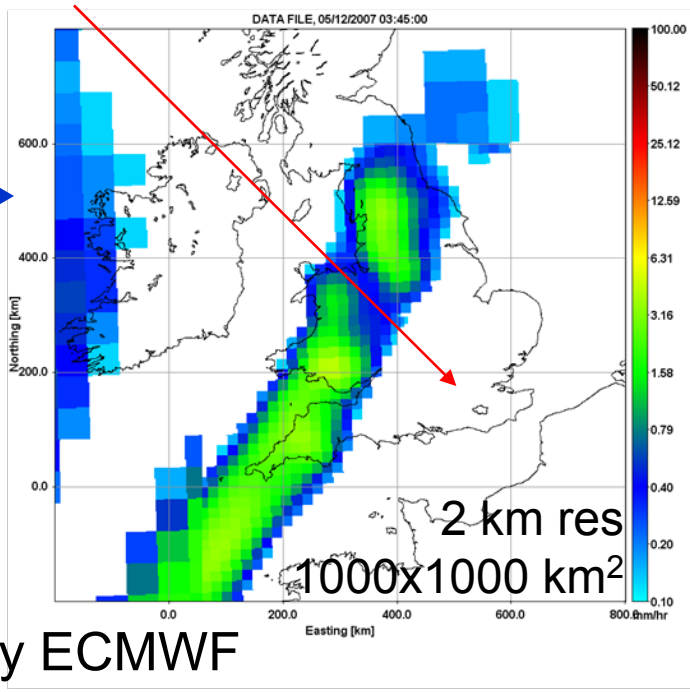


NWP model - MM5 NCAR/Penn State Mesoscale Model

Upper Medway ~250 km^2

Dom 1 @54 km
Dom 2 @18 km
Dom 3 @6 km
Dom 4 @2 km





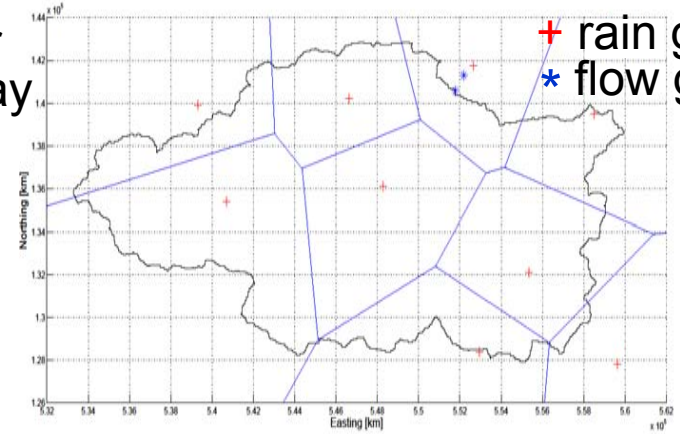
Initial and boundary conditions to MM5 provided by ECMWF

Deterministic forecast :

- u, v, T, RH and GH at different pressure levels between 1 and 1000 hPa
- ST and MSLP

Set up of the simulations

Upper Medway



+ rain gauges
* flow gauges

Rain Gauges

ECMWF —IC/LC→ **NWP (MM5)**

@~55 km and 3 h

Deterministic forecast

1 deterministic forecast

Starting time = t_0

Forecasting time = 24 hr

@ 54, 18, 6 and 2 km and 15 min

UKMO Radar → **STEPS**

Scans at:

t_0, t_0-Δt, t_0-2Δt

Δt = 15 min

@ 2km

1 deterministic and

20 ensemble hybrid forecasts

Starting time:

t_0+1 hr; t_0+ 2hr; t_0+ 3hr; … t_0+18hr

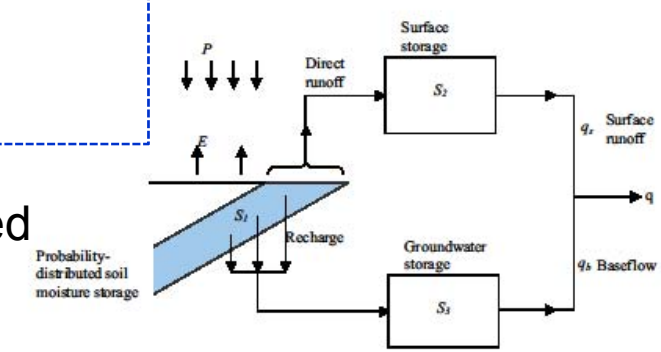
Forecasting time = 6 hr

@ 2 km and 15 min

PDM

Upper Medway

Flow

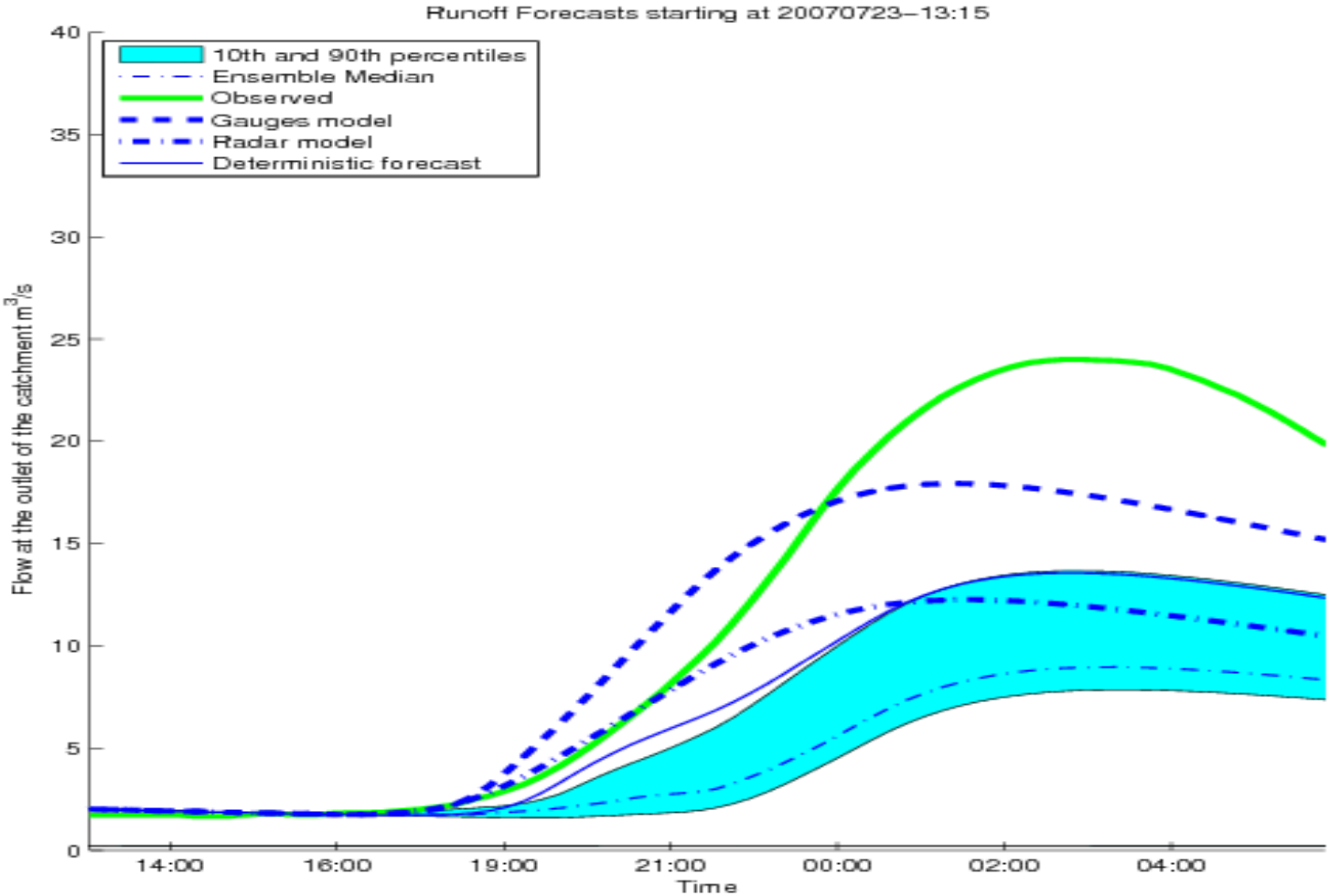


PDM-Probability Distributed Model (Moore, 2007)

Events

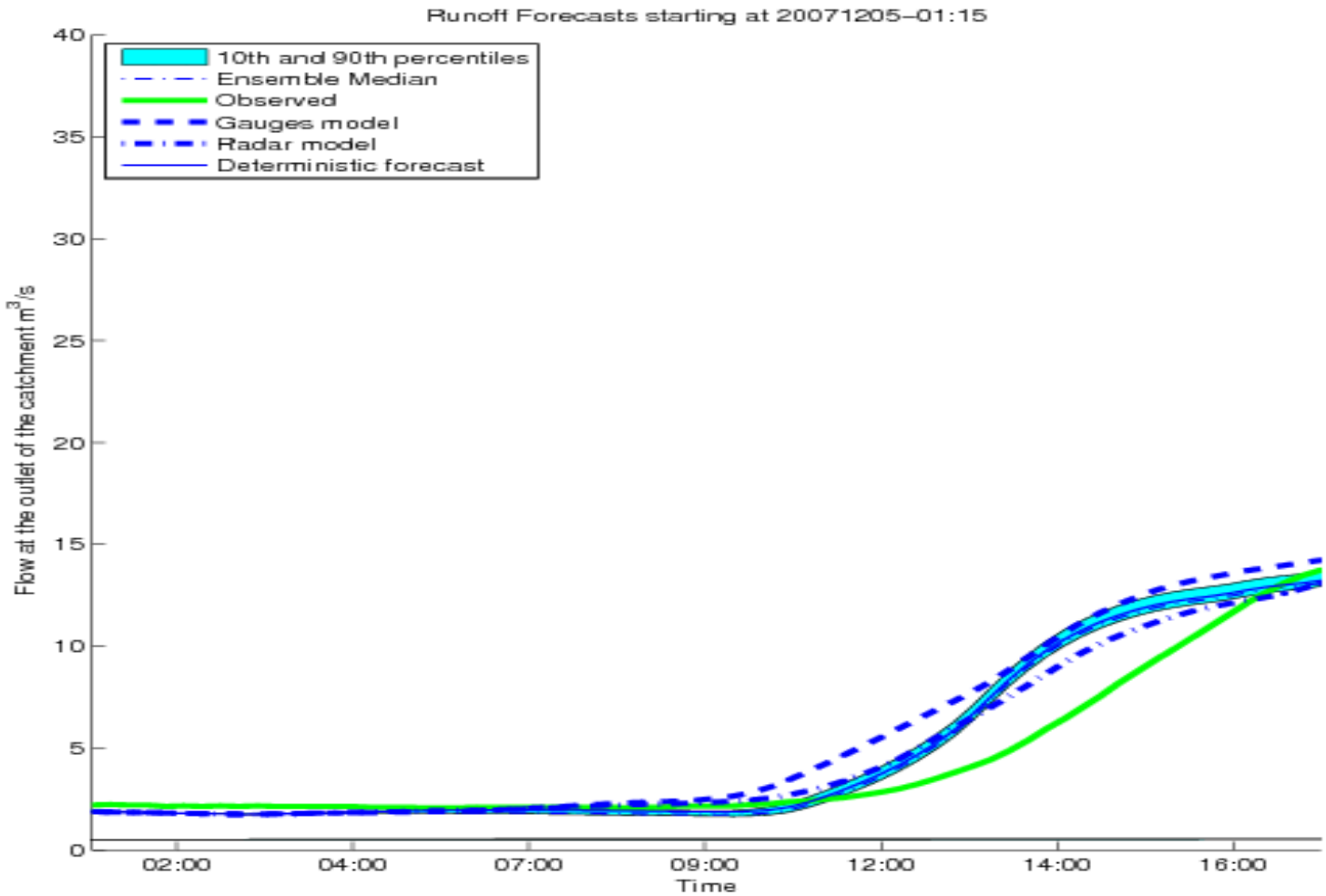
	Starting time NWP	Number Forecasts	24-h rain gauges (mm)	24-hr rain radar (mm)	Characteristics
17 Jan 2007	12 UTC	17	12.7	10.6	Frontal rainfall from Atlantic and North France
22 Jan 2007	00 UTC	18	8.2	8.2	Mainly convective rainfall over the South-East of England
29 Jun 2007	00 UTC	18	20.5	10.7	Large frontal event connected to the development of convective rainfall over the South-East. In the period May-June Britain experienced more than twice the average rainfall 1961-1990
20 July 2007	00 UTC	18	43.5	23.5	Frontal event with embedded convective elements. Exceptional rainfall on 19 and 20 July caused flooding in Tewkesbury (Gloucestershire)
23 July 2007	12 UTC	17	20	14.4	Frontal with embedded convective cells
18 Nov 2007	12 UTC	17	25.9	26.6	Mainly frontal event associated to the passage of weather fronts developing off North-West Scotland and moving towards South
5 Dec 2007	00 UTC	18	12.1	12.1	Frontal rainfall with the occurrence of some intense showers over the Medway area

23 July 2007



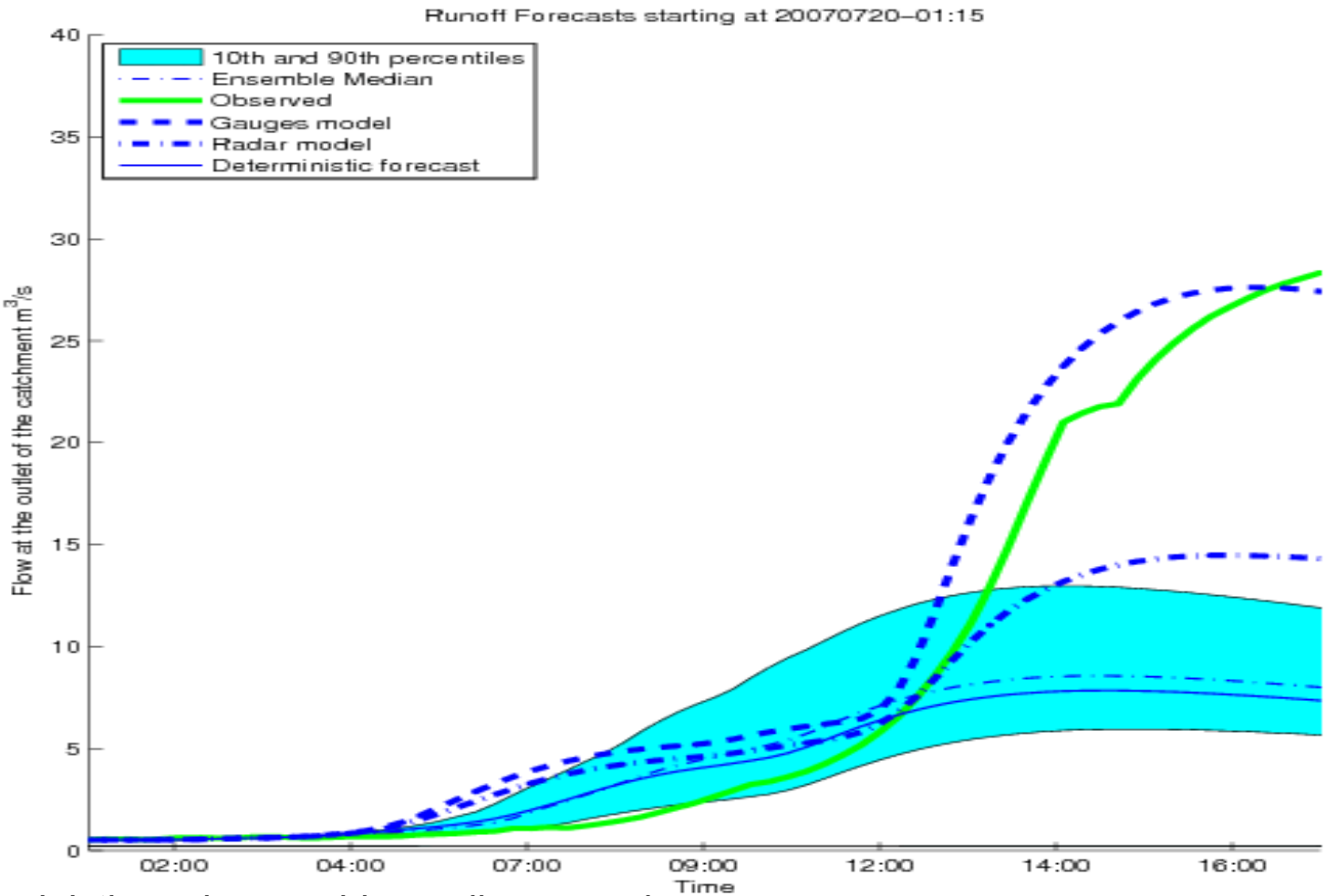
- Deterministic agrees with gauges modelled flow until 16:15 and tends to overestimation afterwards
- Ensemble median produces larger underestimation/overestimation
- Ensemble spread quite large for some of the forecast starting times
- Intensity of the event well captured

05 Dec 2007



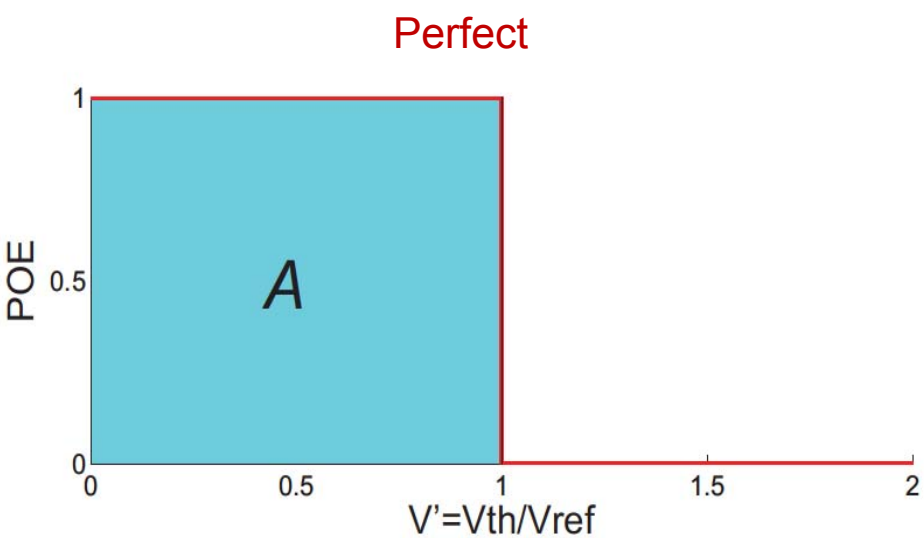
- Deterministic and ensemble median very close to gauges and radar modelled flow
- Deterministic tends to overestimation in comparison with the ensemble median
- Intensity of the event well captured

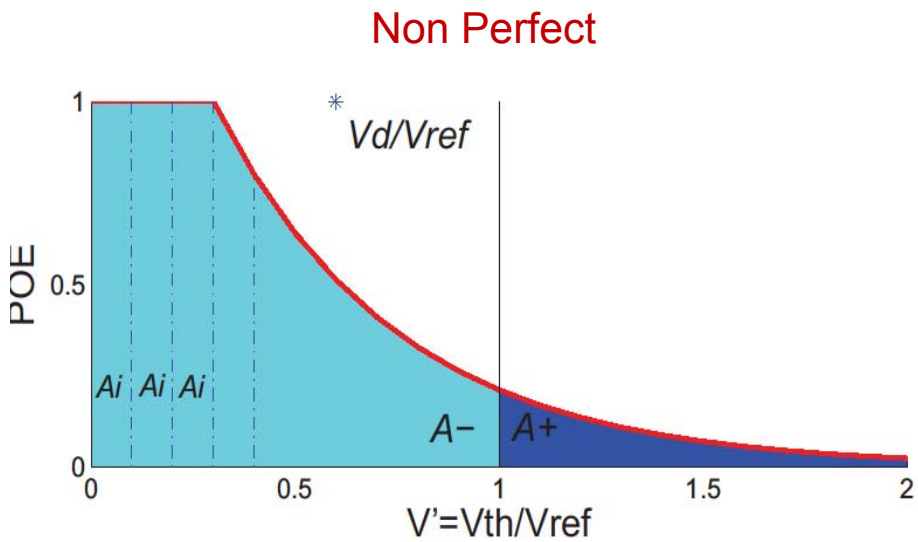
20 July 2007



- Deterministic and ensemble median very close
- Gauges modelled flow and observed flow are largely underestimated
- Radar modelled flow also produces a lower peak than the gauges modelled flow, due to radar rainfall underestimation for this event

Flow forecasts assessment



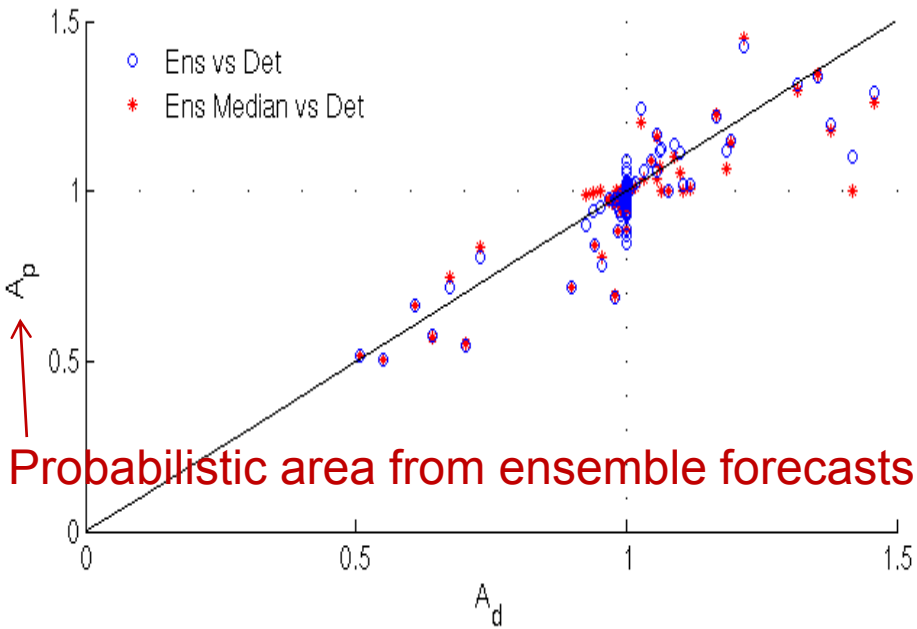


- V_o, V_g, V_r: Reference volumes equal to observed flow, gauges and radar modelled flow integrated over a temporal evaluation window
- V_{th}: thresholds, e.g. V_{th} ranges from 50% to 150% of the reference V_o, V_g, V_r
- V': normalized thresholds
- Perfect and non-perfect probabilistic system for V_{th} between 0 and 200% of the reference
- For a perfect system A tends to be close to 1
- A- (left of V'=1) and A+ (right of V'=1) measure underestimation/overestimation
- The performance improves as A- →1 and A+ → 0
- V_{th} ranges from 5% to 90% of the reference (V_o, V_g, Vr) and A+ referenced to the value of 1 (e.g. 50% overestimation equals to A+=1.5)
- V_d/V_{ref}: integrated flow from deterministic forecast normalized by the reference
- For the comparison, the probability assigned to V_d/V_{ref} is 1

Model 1

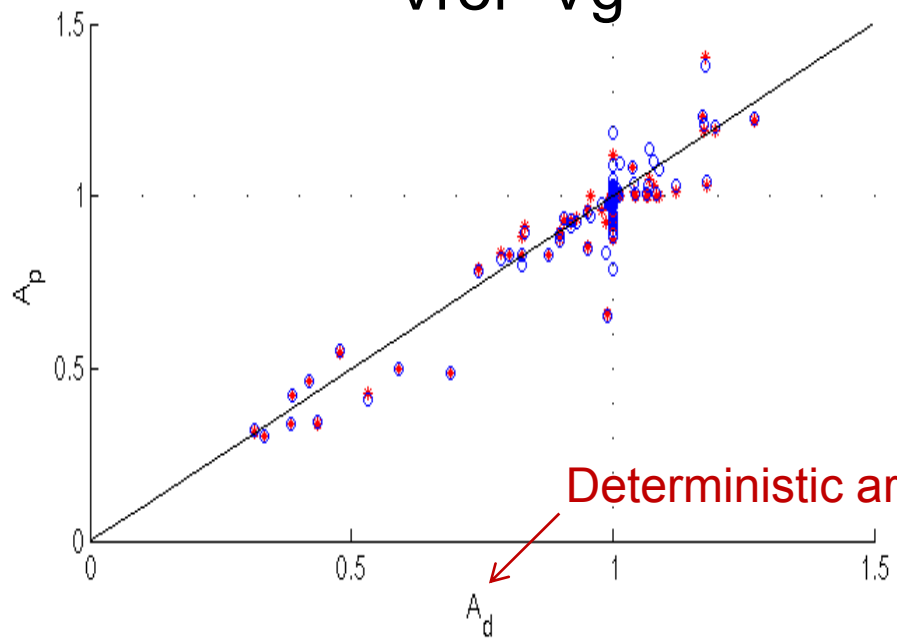
Events:17 Jan 2007; 20-23 July 2007; 05 Dec 2007

Vref=Vr



Probabilistic area from ensemble forecasts

Vref=Vg



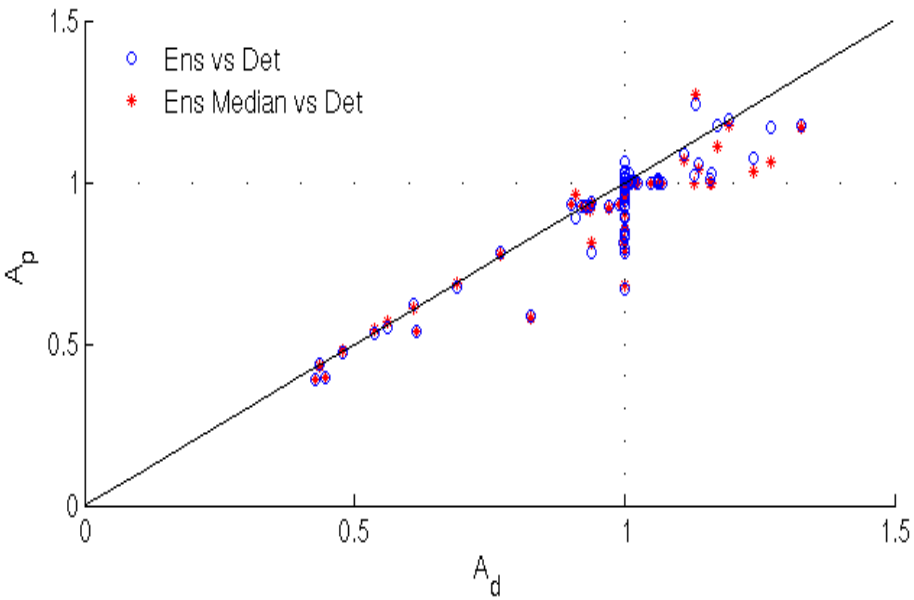
Deterministic area

- PDM Model 1- Calibrated to optimize flows >10 m3/s using 2006 data series. Better performance on high flows
- Ensemble forecasts produce a larger underestimation of the reference V_g and V_r, computed over a 17 h temporal evaluation window, i.e. the sum of catchment concentration time (11 h) and forecasting lead time (6 h)
- Deterministic forecasts produce larger overestimation of the reference V_r, and this is larger for $V_{ref}=V_g$ in comparison to $V_{ref}=V_r$

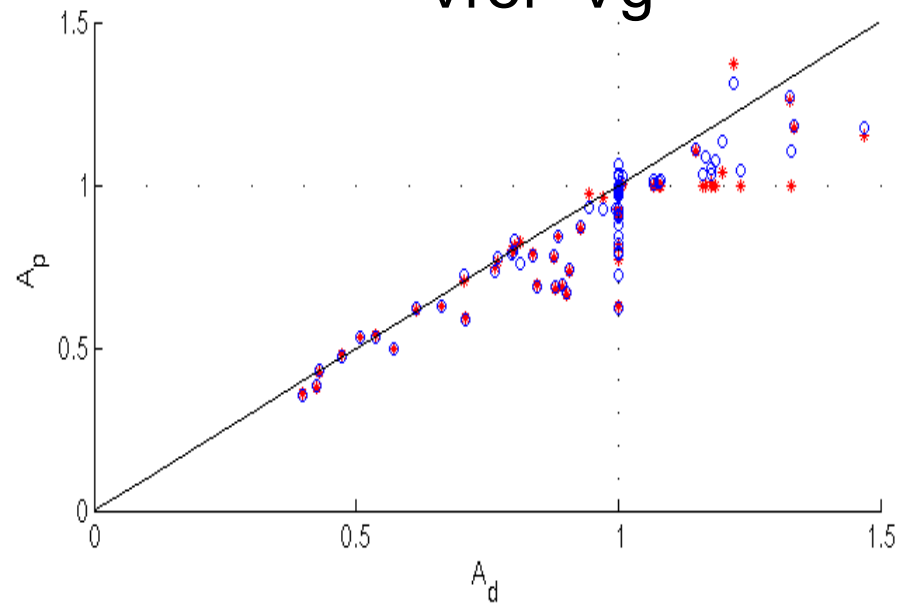
Model 2

Events:22 Jan 2007; 29 June 2007; 11 Nov 2007

Vref=Vr



Vref=Vg

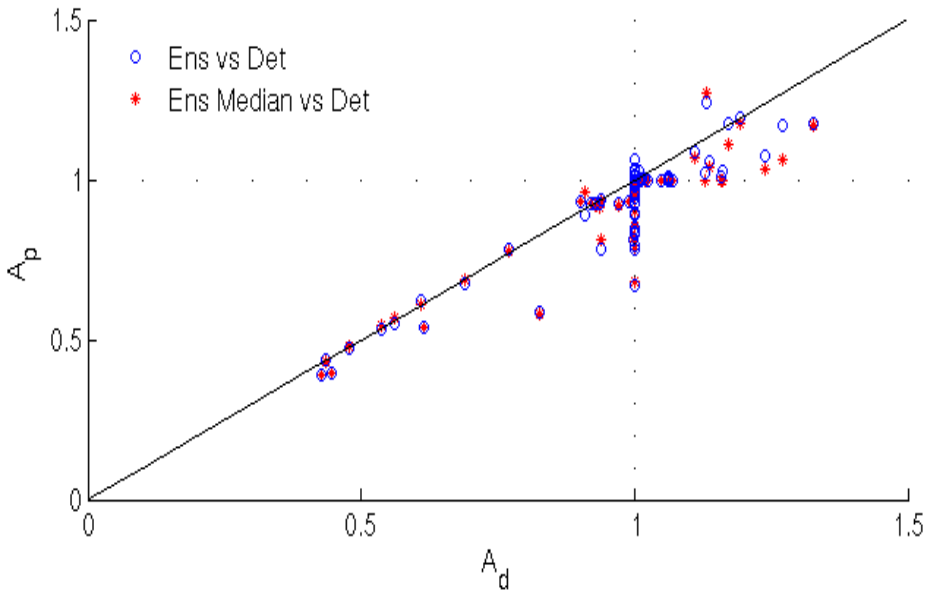


- PDM Model 2- Best performance on average. In the calibration period, RMSE=1.19 m3/s and Nash-Sutcliffe=0.69 by taking into account modelled flows > 0 m3/s
- Underestimation and overestimation of the reference V_g and V_r affect to a larger degree ensemble and deterministic forecasts respectively

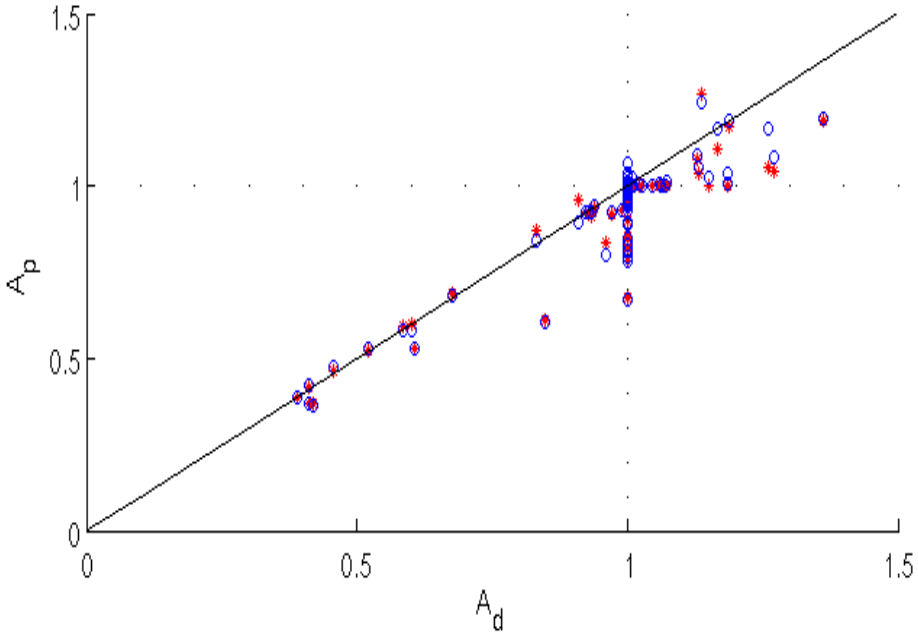
Model 2 Vs Model 1

Events:22 Jan 2007; 29 June 2007; 11 Nov 2007

Model 2



Model 1



Results obtained for the events simulated with Model 2 are very similar to those obtained Model 1 for the same events

Concluding comments

- Similar results from deterministic and ensemble forecasts
- Ensemble forecasts underestimate the reference to a larger degree compared to the deterministic forecasts, which tend to a larger overestimation
- Deterministic and ensemble forecasts provide larger overestimation against the radar-reference volume
- The results from two different model configurations are similar
- Non-dimensional measure to assess probabilistic forecasts based on the use of the probabilistic information of the forecasts through the computation of the probability of exceeding predefined normalized thresholds
- Potentially to be applied to assess the forecasts in terms of exceedance/non-exceedance of flow thresholds, peak timing thresholds, volume thresholds

References and related publications

Bowler, N., Pierce, C.E., Seed, A., 2004. Development of a precipitation nowcasting algorithm based upon optical flow techniques. Journal of Hydrology 288, 74–91

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Acknowledgements

ECMWF, BADC, the UK Environment Agency and the UK Met Office for providing some of the data sets used in this study

The UK Met Office for providing the STEPS and the nowcasting models

The authors acknowledge the support from the Engineering and Physical Sciences Research Council (EPSRC) via grant EP/I012222/1

EPSRC
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STEPS Nowcast

Modified S-PROG (Spectral Prognosis) model (Seed, 2003) to perform the extrapolation nowcast

- Spectral decomposition

  Rain rate decomposed in a multiplicative cascade on different scales

  Additive cascade in the log of the rain rate

$$Z = 10 \log_{10} (200 R^{1.6})$$

Z= radar reflectivity R= surface rain rate

- Temporal evolution of the precipitation field

  AR-2 model
- Optical flow (Bowler et al. 2004) for advection velocities

Merging

$$Y_{k,i,j}(t+t_l) = w_k^e(t+t_l)\,Y_{k,i,j}^e(t+t_l) + w_k^m(t+t_l)\,Y_{k,i,j}^m(t+t_l) + w_k^n(t+t_l)\,Y_{k,i,j}^n(t+t_l)$$

- $Y_{k,i,j}^e$ Extrapolation forecast cascade
- $Y_{k,i,j}^m$ NWP model forecast cascade
- $Y_{k,i,j}^n$ Noise cascade

k^{th} Cascade level

$i = 1, ..., L \quad j = 1, ..., L$

$L =$ *pixels*

w^e, w^m, w^n *weights*

$t_l =$ *Lead time*

$$Y_{k,i,j} = \frac{X_{k,i,j}(t) - \mu_k(t)}{\sigma_{k,i,j}(t)}$$

Normalized Fourier component into the spatial domain

$\mu_k(t)$ Mean

$\sigma_{k,i,j}(t)$ Standard deviation

Output forecast

$$Z_{i,j}(t+t_l) = \sum_{k=1}^{n} \left(\mu_k(t+t_l) + \sigma_{k,i,j}(t+t_l)\,Y_{k,i,j}(t+t_l)\right)$$

Weighted combination of extrapolation and NWP

Ensemble generation

- Noise compensate for the loss of predictability at small scales
- Noise reproduces space-time correlation of the inferred precipitation
- Ensemble members to represent uncertainty in the temporal evolution of the precipitation pattern through stochastic realizations of the noise cascade
- Perturbation added to the advection velocity to model uncertainty related to the motion of the precipitation pattern