Fine-scale rainfall nowcasting – Short Term Ensemble Prediction System

31/03/14

Clive Pierce, Alan Seed, Neill Bowler, Andrew Bennett

STEPS – background

- **WWRP FDP – Sydney 2000**

Bowler, Pierce & Seed, 2006. STEPS: A probabilistic precipitation forecasting scheme which merges an extrapolation nowcast with downscaled NWP. *Q. J. R. Meteorol. Soc*., 132, 2127–2155.

Seed, Pierce & Norman, 2013. Formulation and evaluation of a scale decomposition-based stochastic precipitation nowcast scheme, Water Resources Research, 49, 6624–6641, doi:10.1002/wrcr.20536

STEPS – capabilities & applications

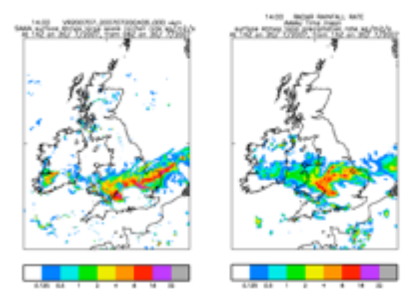
- Precipitation nowcasting
- Ensemble generation
- Generation of seamless composite precipitation forecasts
- Statistical downscaling
- Design storm modelling

QPN – the challenges

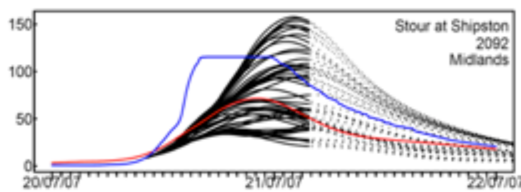
- **Space-time characteristics**
  - ➢ **Fractal & dynamic scaling properties**
  - ➢ **Intermittency in space and time**
  - ➢ **Non-Gaussian distribution**
- **Nowcasting**
  - ➢ **Radar-based surface rain rate estimation**
  - ➢ **Reducing and characterising observation & extrapolation errors**
  - ➢ **Exploiting the capabilities of hires NWP**
- **Hydrological impact**
  - ➢ **Propagation of errors through hydrological forecast and impact models**

Big whorls have little whorls
That feed on their velocity,
And little whorls have lesser whorls
And so on to viscosity

L. F. Richardson



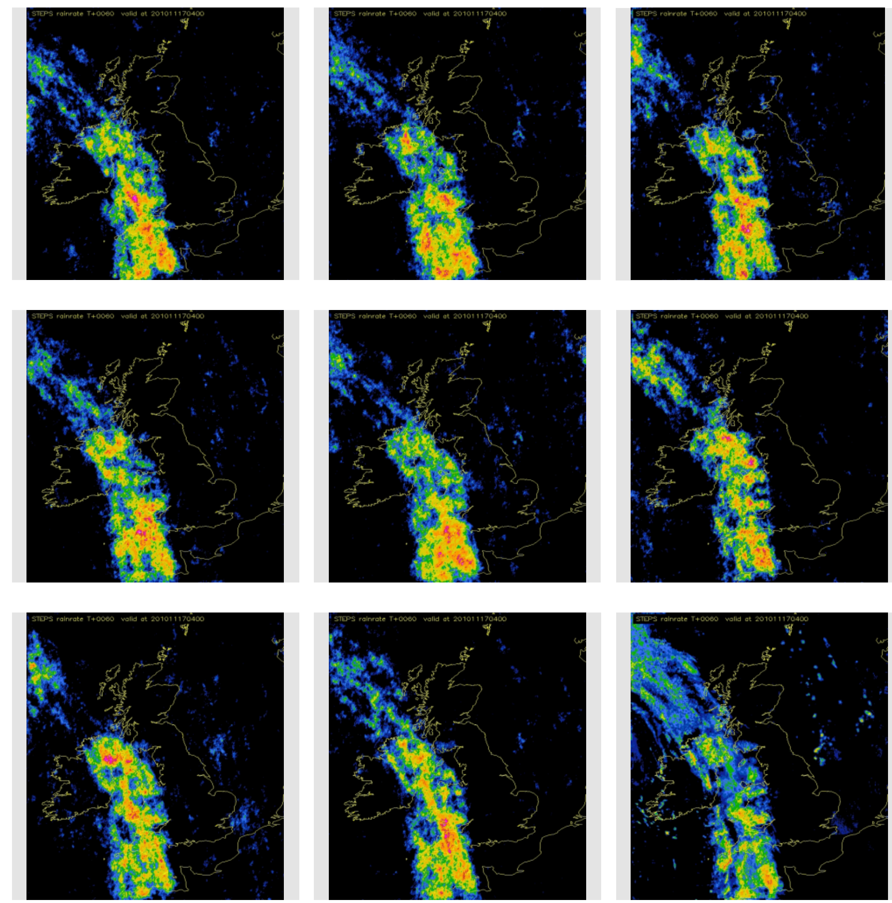
Hires NWP ***Radar***



G2G flow ensembles – Cole et al. (2010)

Short Term Ensemble Prediction System

- **Multiplicative cascade framework**
  - Adaptive, seamless blending
- **Parametric and non-parametric noise generators**
  - Seamless blending, ensemble generation and statistical downscaling
- **Errors modelled**
  - Radar
  - Extrapolation nowcast
  - NWP



Control

STEPS nowcast ensemble – 0300 UTC 17 November 2010

STEPS scale decomposition

$$R_{i,j}(t) = \prod_{k=0}^{N-1} X_{k,i,j}(t)$$

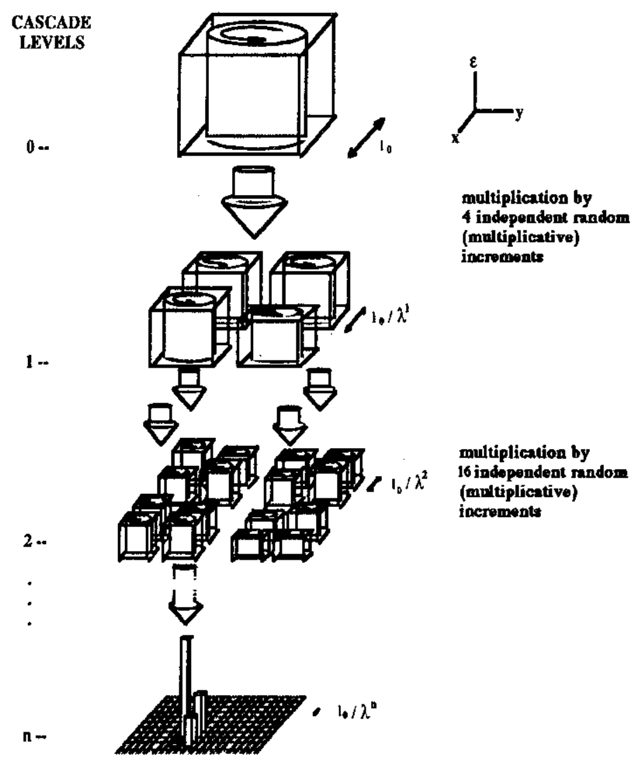
for $i=1,\ldots,L$, $j=1,\ldots,L$, $L=2^{N-1}$

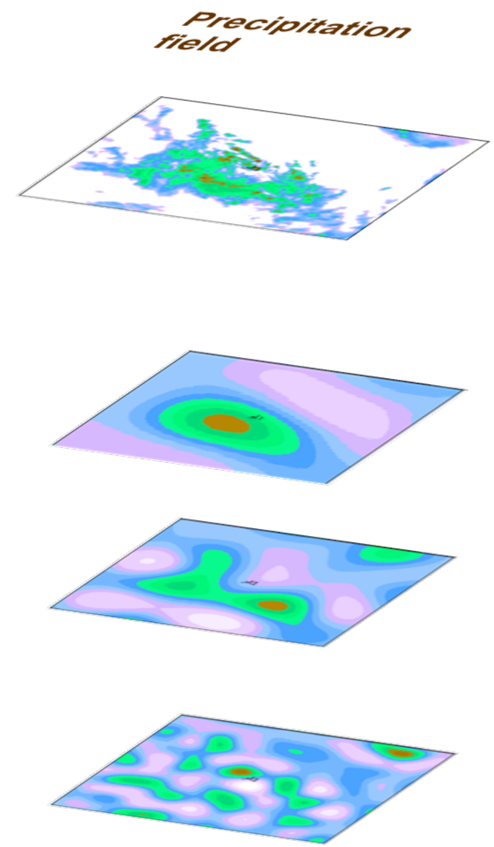
N **= number of cascade levels**

$X_k(t)$ **=** ***kth*** **field in the cascade represents the variability in the original field with frequencies,** ω_k **in the range**

$$\frac{2^{k-1}}{L} < \omega_k < \frac{2^k}{L}\ pixel^{-1}$$

at time, ***t*****.**

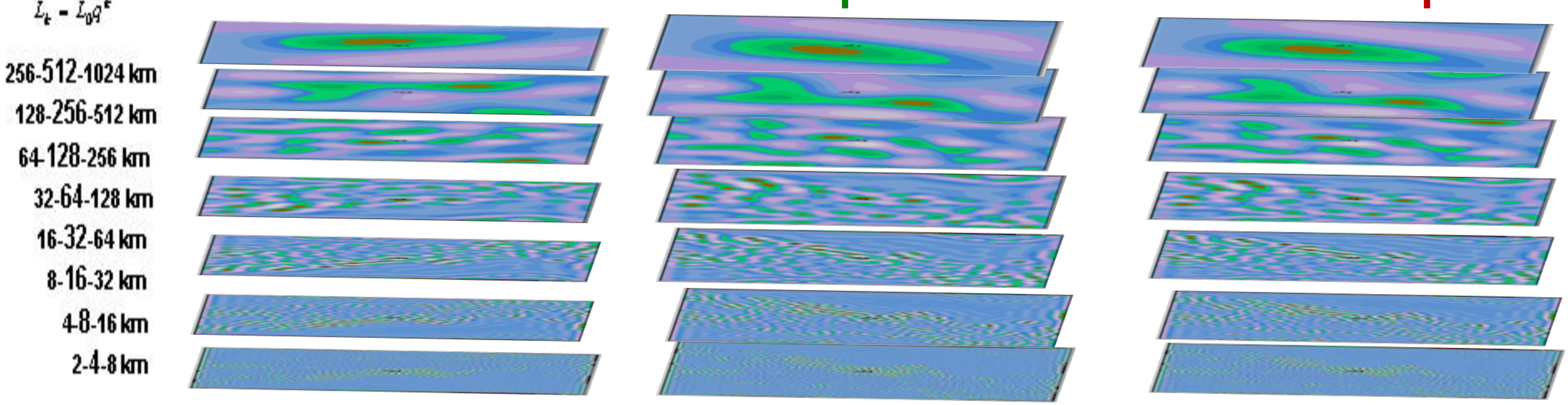




$$dBR_{i,j}(t) = \sum_{k=0}^{N-1} X_{k,i,j}(t)$$

STEPS nowcast

Extrapolation + NWP forecasting member p Noise member p



Weights ~ fraction of explained variance

$$Y_k^{now,p} = w_k^e Y_k^e + w_k^{nwp} Y_k^{nwp,p} + w_k^n Y_k^{n,p}$$

Nowcast **Extrapolation cascade** **NWP cascade** **Noise cascade**

Nowcast advection scheme

Met Office

- Optical Flow (Bowler *et al*., 2004)
- Partition rain analysis into blocks
- Find optimum velocity for each block

$$D_t R = u\frac{\partial R}{\partial x} + v\frac{\partial R}{\partial y} + \frac{\partial R}{\partial t} = 0$$

- Apply smoothness constraint

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = 0$$ and $$\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} = 0$$

- Smooth velocity field

Temporal updating of extrapolation and noise cascades

- Extrapolation cascade
  - AR-2 model updates each level of the cascade
  - re-normalised every time step

$$Y^{e}_{k,i,j}(t) = \phi_{k,1}(t)Y^{e}_{k,i,j}(t-\Delta t) + \phi_{k,2}(t)Y^{e}_{k,i,j}(t-2\Delta t)$$

- Noise cascade
  - Spatial PSD evolves from radar to NWP
  - AR-2 model updates each level of the cascade

$$Y^{n}_{k,i,j}(t) = \phi_{k,1}(t)Y^{n}_{k,i,j}(t-\Delta t) + \phi_{k,2}(t)Y^{n}_{k,i,j}(t-2\Delta t) + \phi_{k,0}(t)\varepsilon_{k,i,j}(t)$$

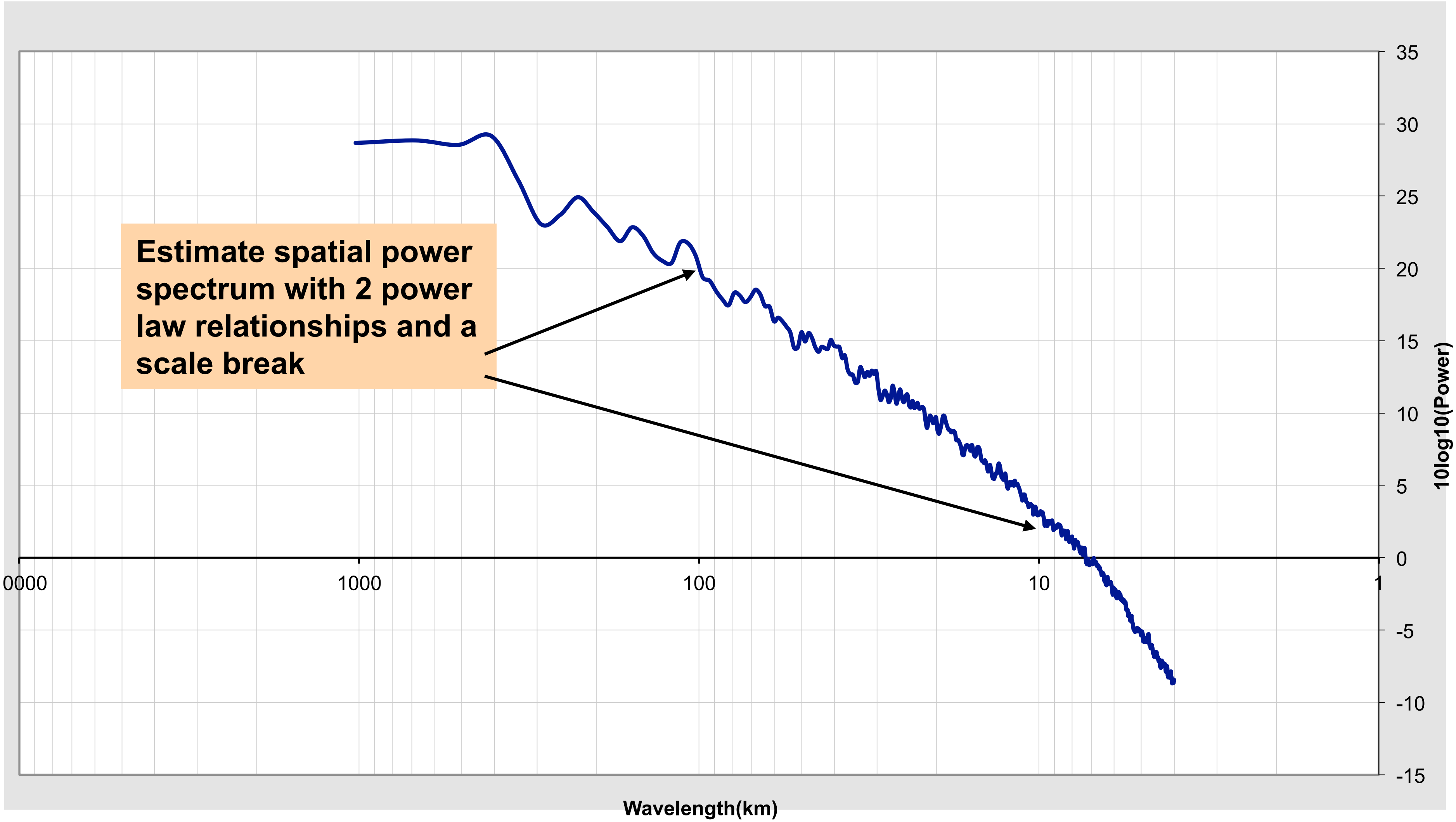
$\varepsilon_{k,i,j}$ = time independent noise

Met Office

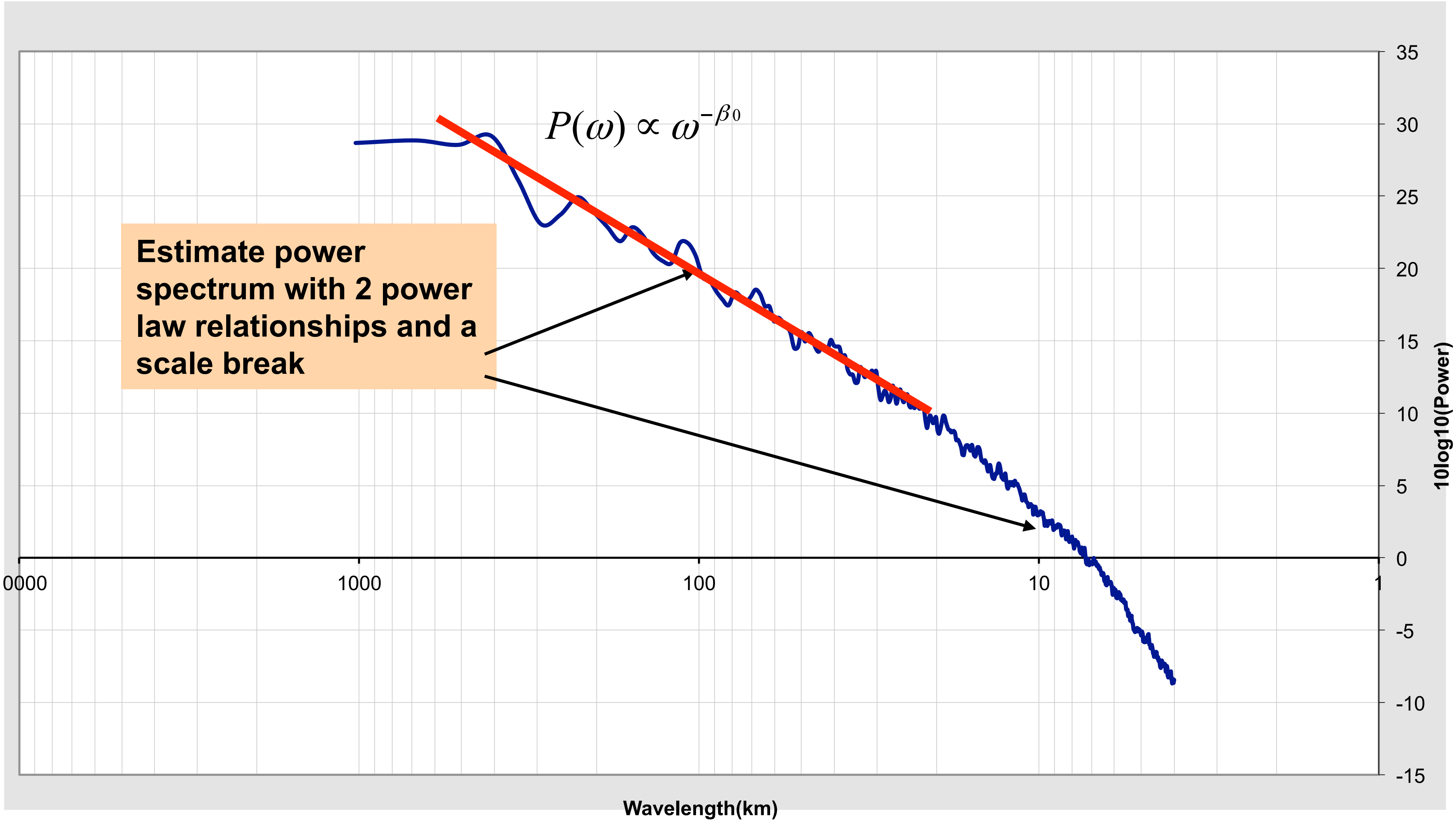
Noise generation

- **Non-parametric model**
  - ➢ **FFT-based filter applied to field of white field using radar or NWP forecast field**
  - ➢ **Predominant anisotropy preserved**
  - ➢ **No parameter fitting required**
- **Parametric model**
  - ➢ **Apply 2 power law filters to field of white noise with slopes estimated from radar or NWP**
  - ➢ **Assumes change in slope of the power spectrum at 40 km scale**
  - ➢ **Generates isotropic noise**

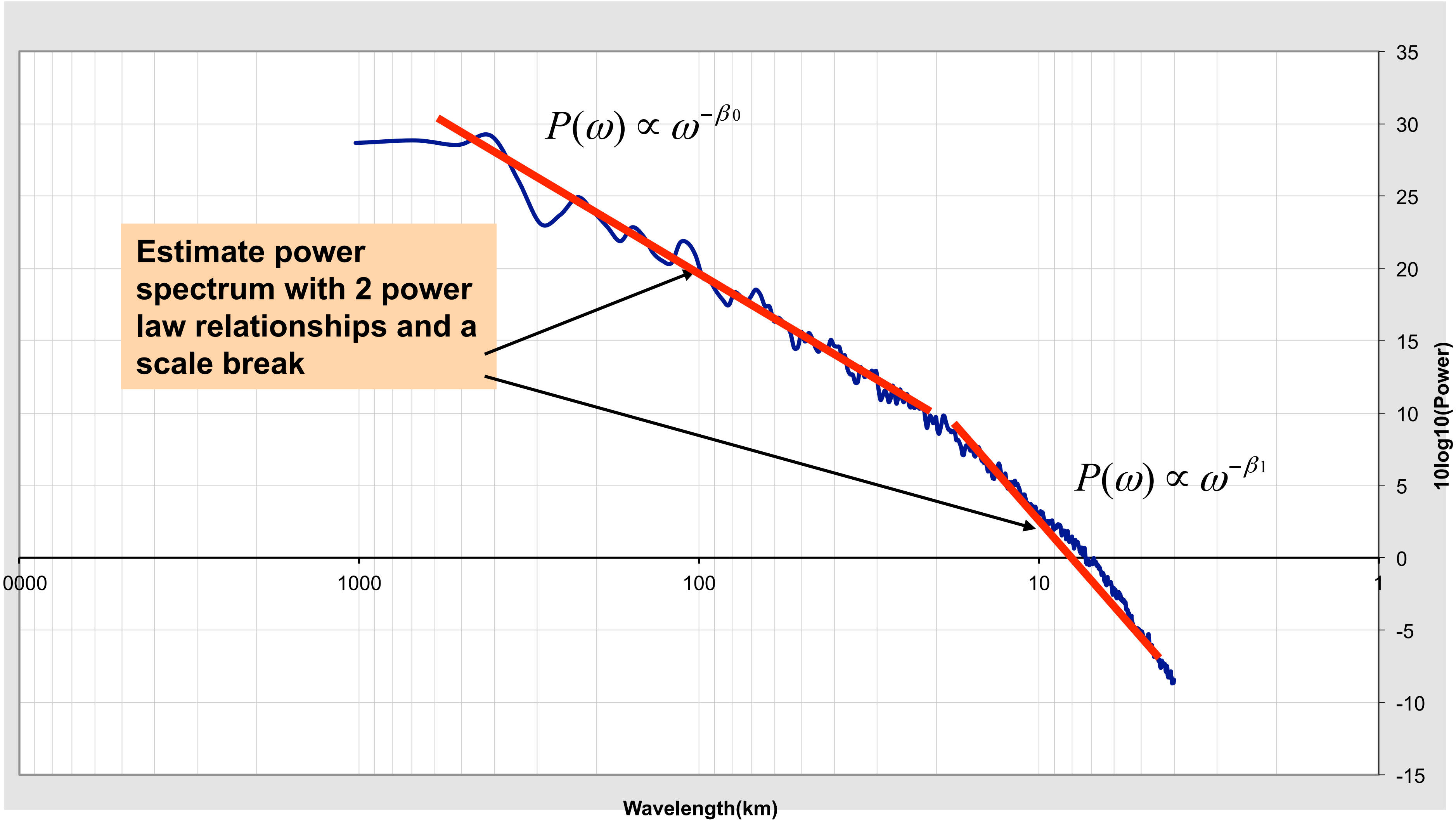
Parametric noise generation



Parametric noise generation

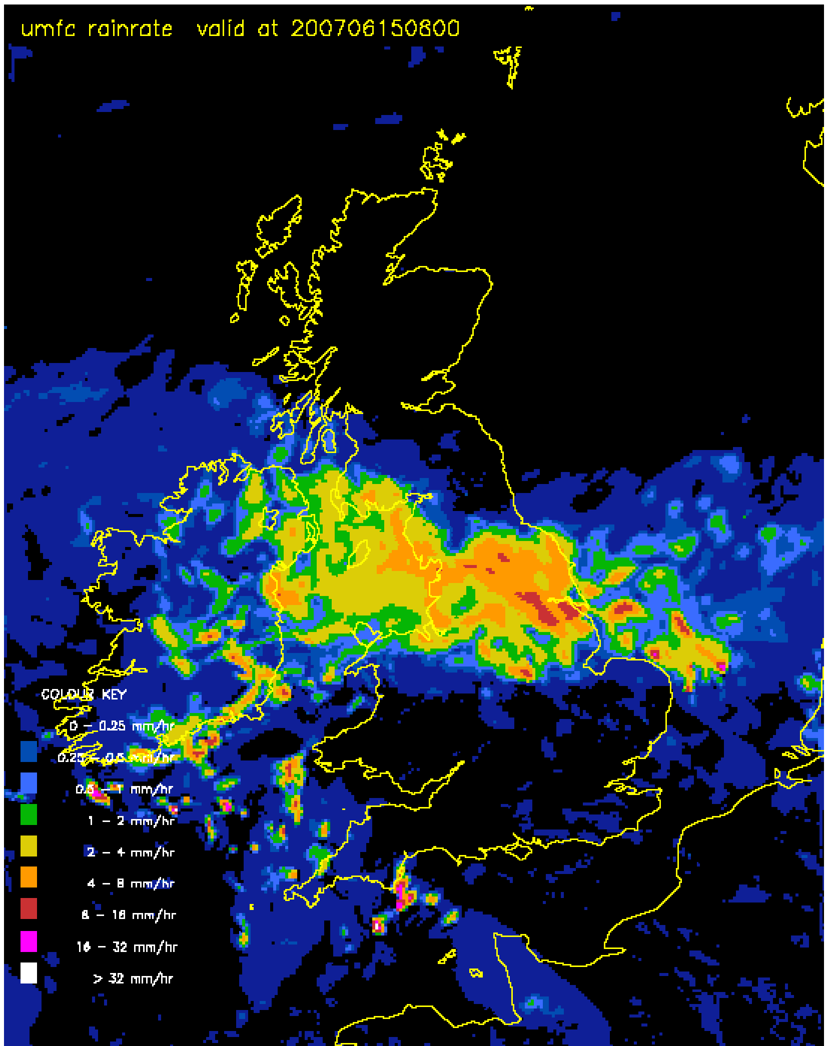


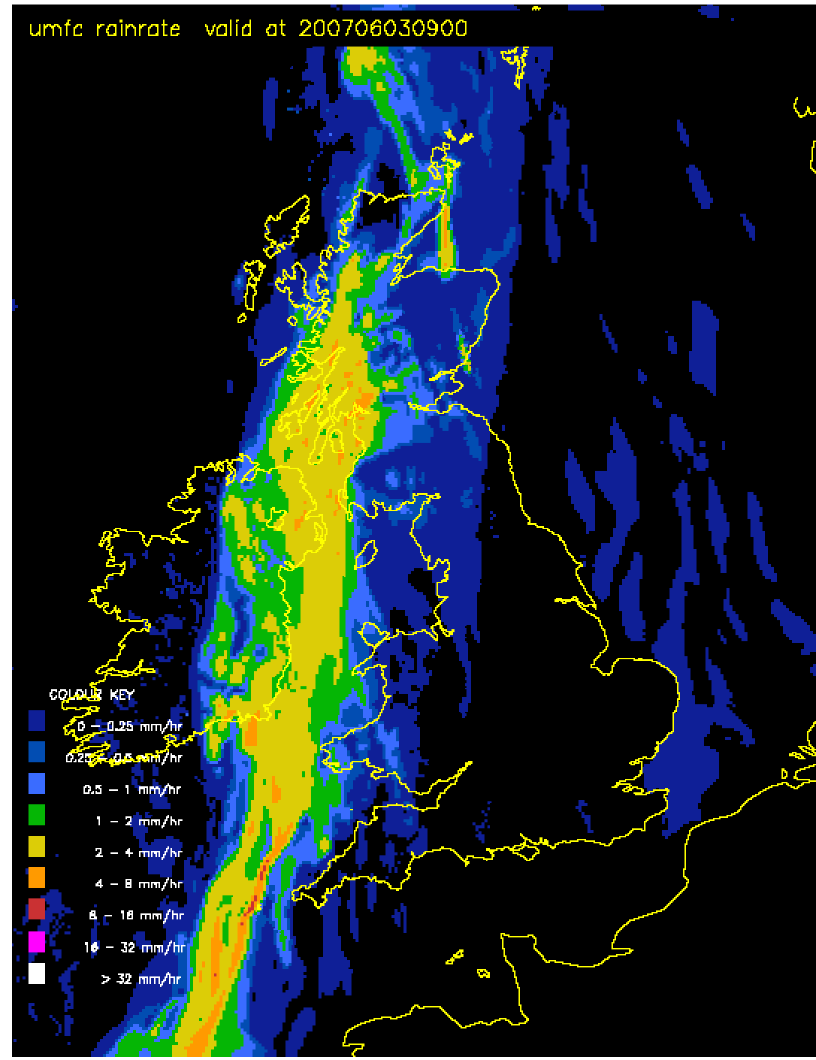
Parametric noise generation



Non-parametric noise generation

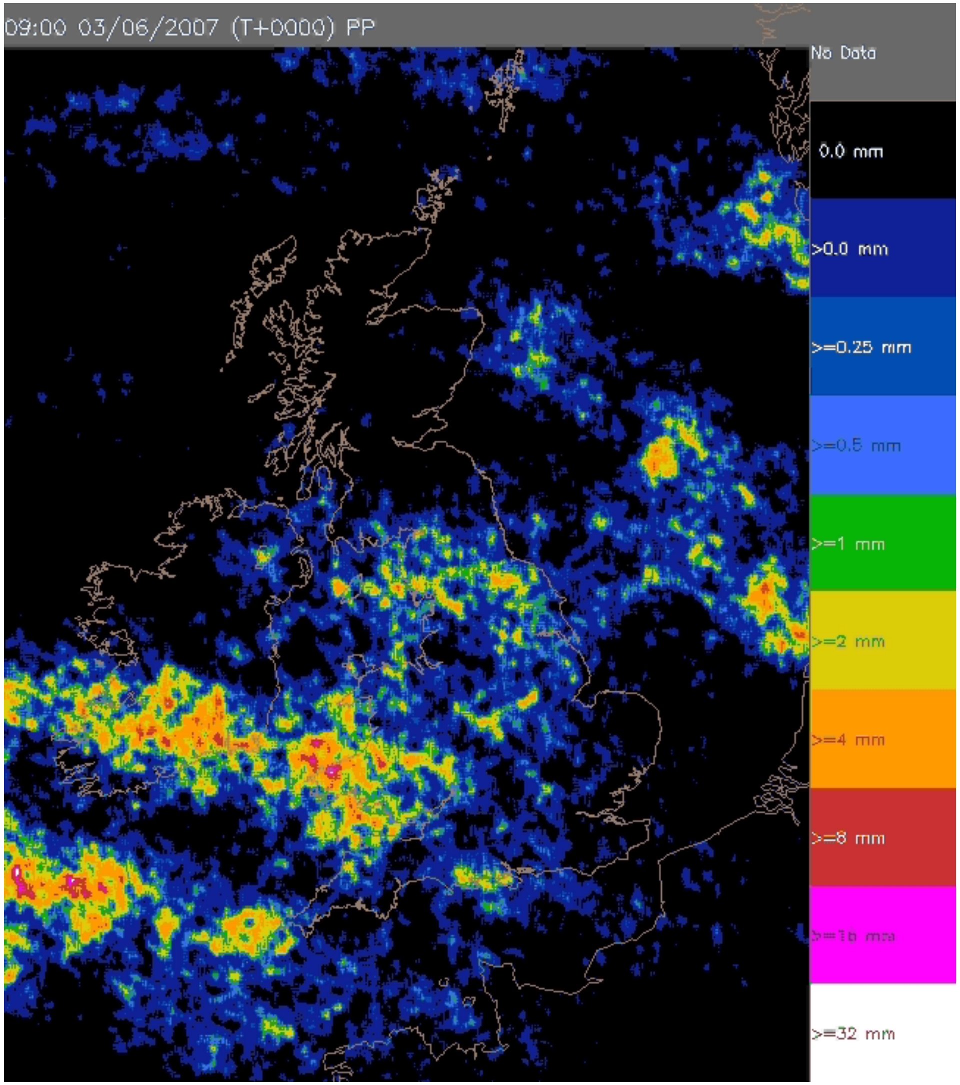
Fields with completely different precipitation structure





Non-parametric noise generation

Time series of temporally correlated noise with properties tending from one field to the other



Radar errors

Error sources (Austin,1987)

- **Physical biases**
  - ground clutter
  - beam blockage
  - anaprop
- **Measurement biases**
  - poor calibration
  - inappropriate Z-R, VPR
- **Random sampling errors**
  - temporal & spatial sampling
  - random variability in VPR and Z-R

Solutions

Clutter indicators, radar horizon maps etc.

Radar-gauge adjustment

Derive error distributions and use to generate perturbation fields for ensemble generation

Radar errors

$$\varepsilon(x,y,t) = 10Log_{10}\left(\frac{R_{true}(x,y,t)}{R_{radar}(x,y,t)}\right)$$

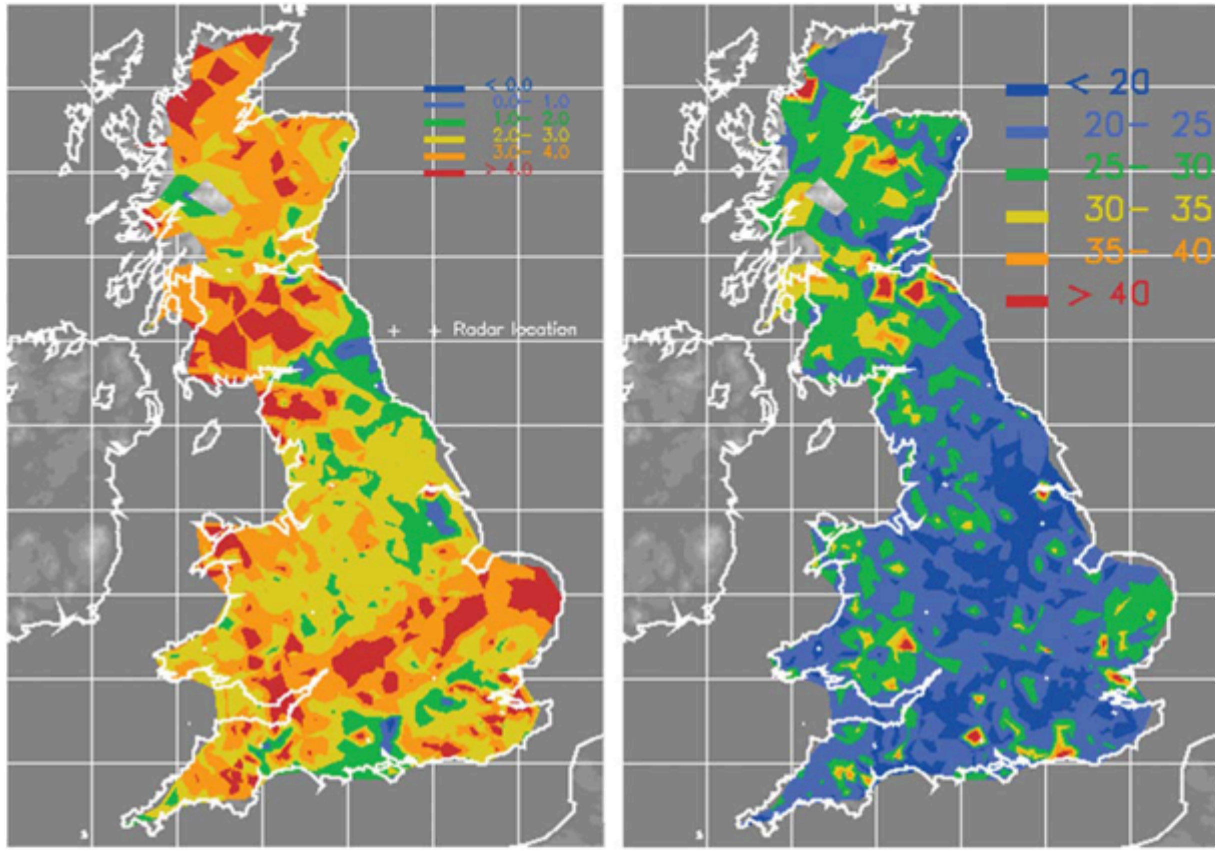
Spatial error structure

Radar-gauge error covariance matrix

Temporal error structure

AR-2 models

Multiplicative perturbations decomposed & applied to radar cascade



Spatially interpolated mean radar-gauge error vector mm/h

Spatially interpolated variance of the radar-gauge errors / $(mm/h)^2$

Spatially interpolated mean and variance of radar-gauge errors derived for Met Office radar network following Germann *et al*., 2009

Extrapolation nowcast errors

- **Advection velocity error**
  - **Optical flow diagnosed velocity used to advect radar analysis**
  - **Velocities smoothed & bias corrected**
  - **Perturbation applied – homogeneous in space, uncorrelated with nowcast velocity ,variance a function of forecast lead time,**

$$v_{noisy}(t+t_l) = v_{smooth}(t)\left[1-\frac{t_l}{60}f\left(\left|vsmooth\right|\right)\right] + v_{perturbation}(t+t_l)$$

$$v_{perturbation}(t+t_l) = f(t_l)v_{perturbation}(t)$$

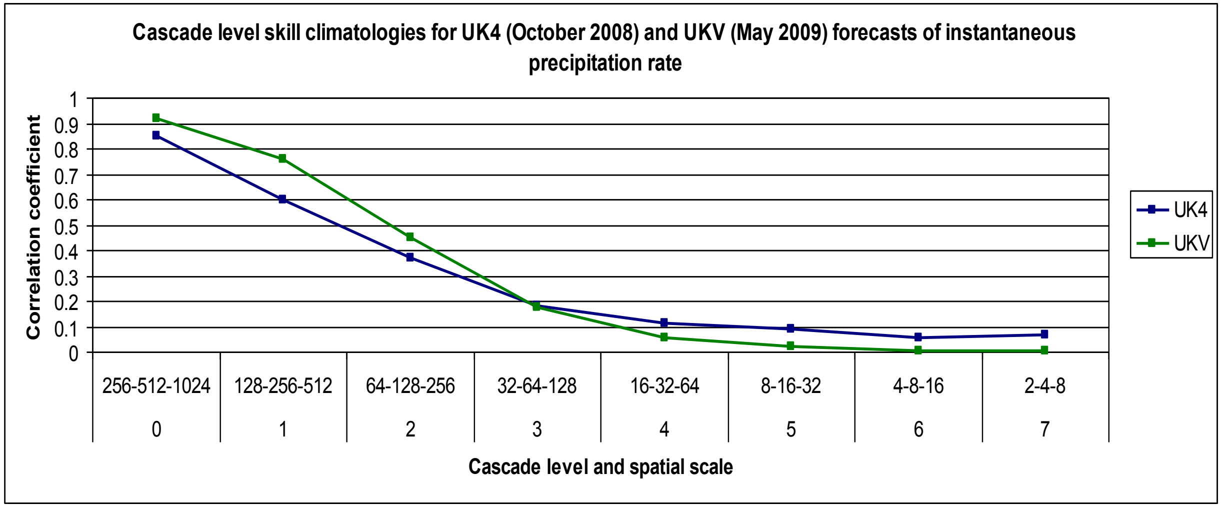
- **Lagrangian evolution error**

$$Y_k^{nowcast,p} = w_k^{extrap}Y_k^{extrap} + w_k^{nwp}Y_k^{nwp,p} + w_k^{noise}Y_k^{noise,p}$$

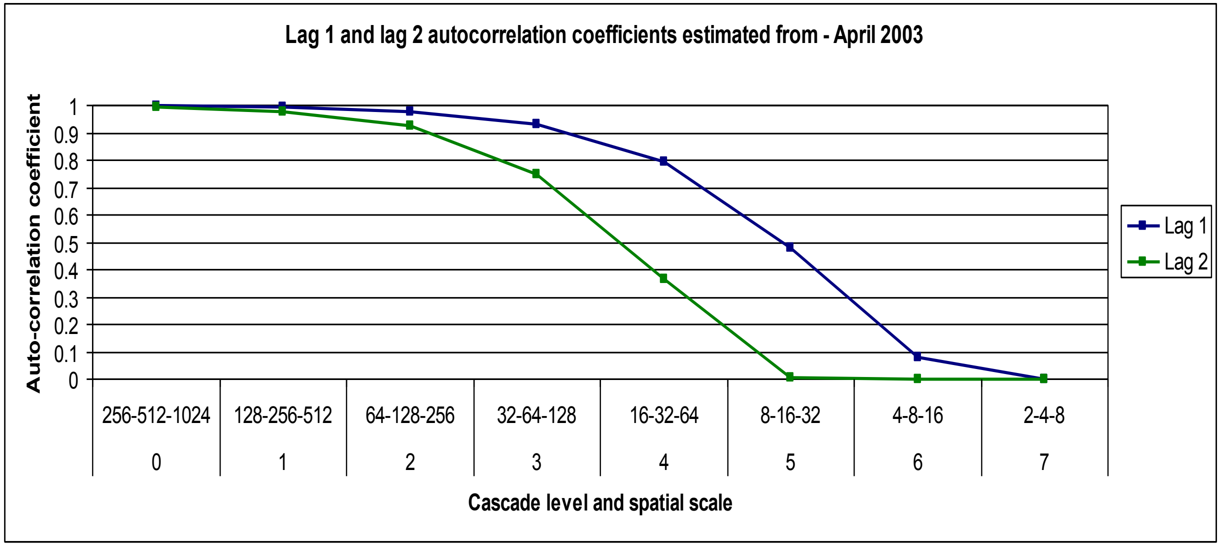
Performance of extrapolation nowcast and hires NWP – implications for STEPS behaviour

Met Office

On average convective scale content in NWP forecasts unskilful



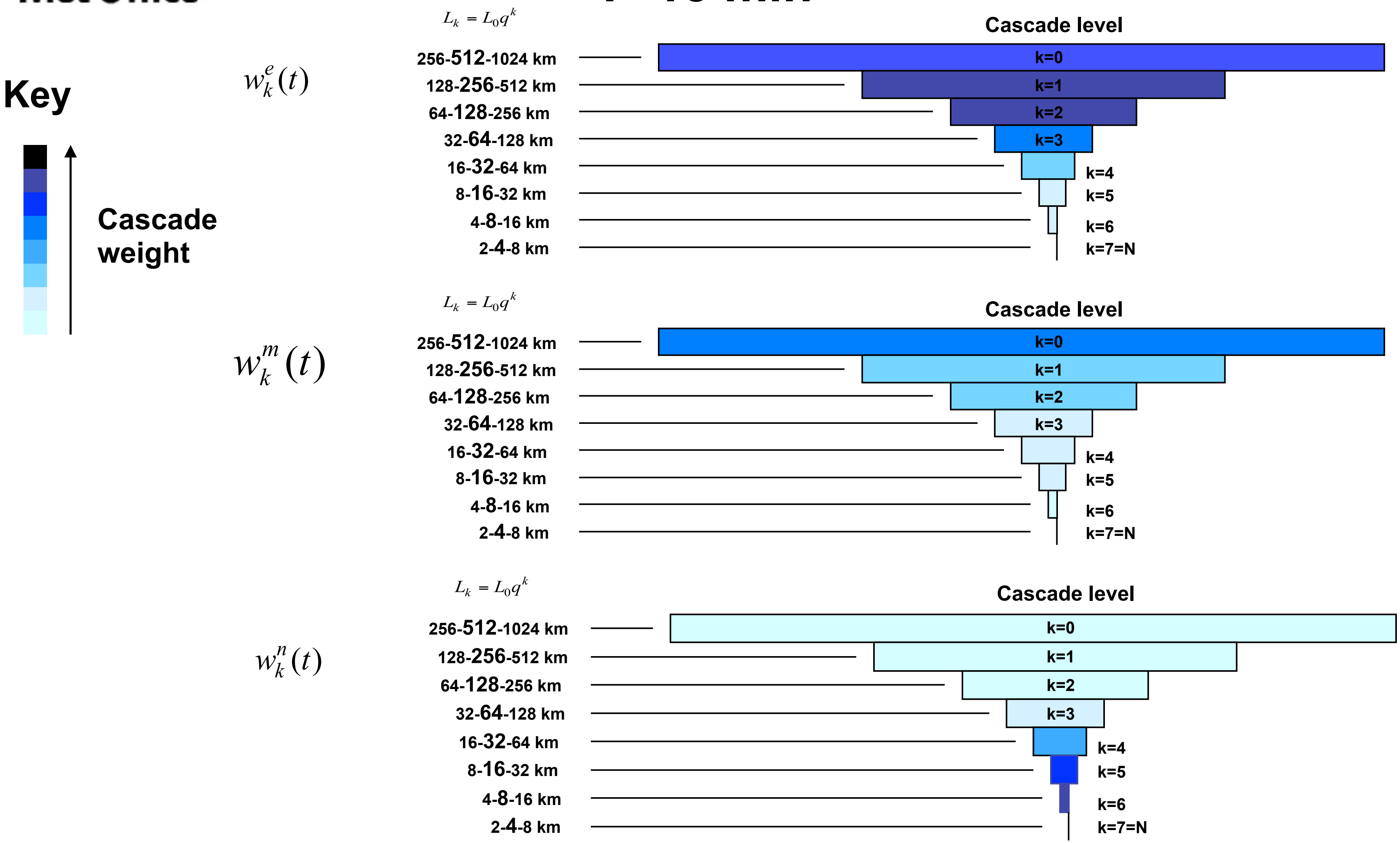
Extrapolation nowcast skill declines rapidly at the convective scales



Met Office

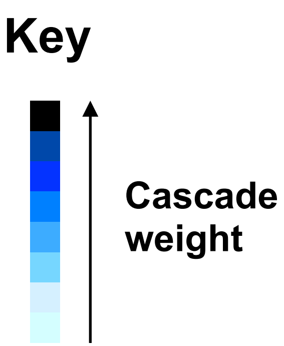
STEPS behaviour

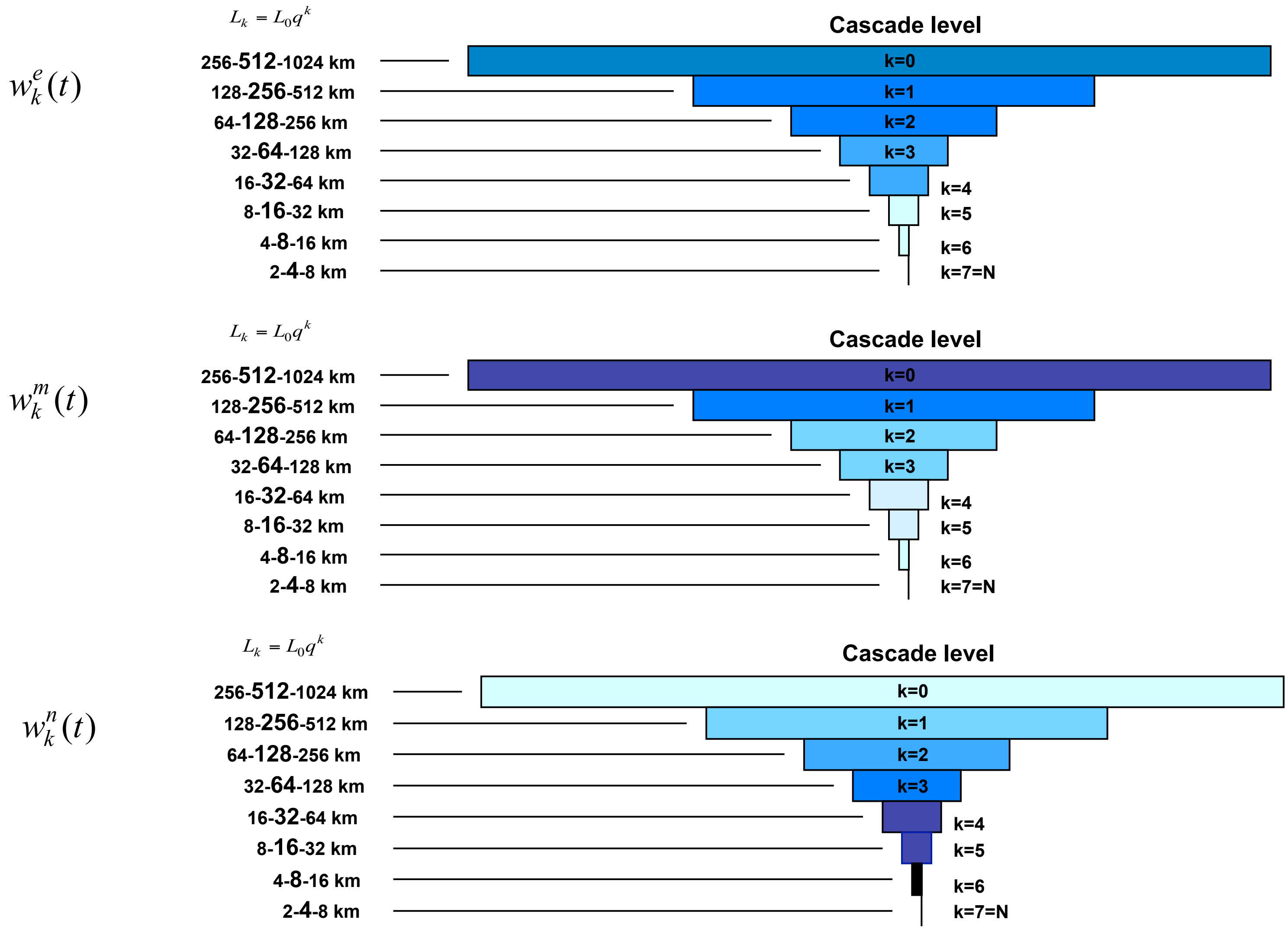
T+15 min



STEPS behaviour

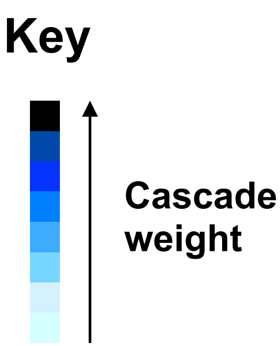
T+60 min

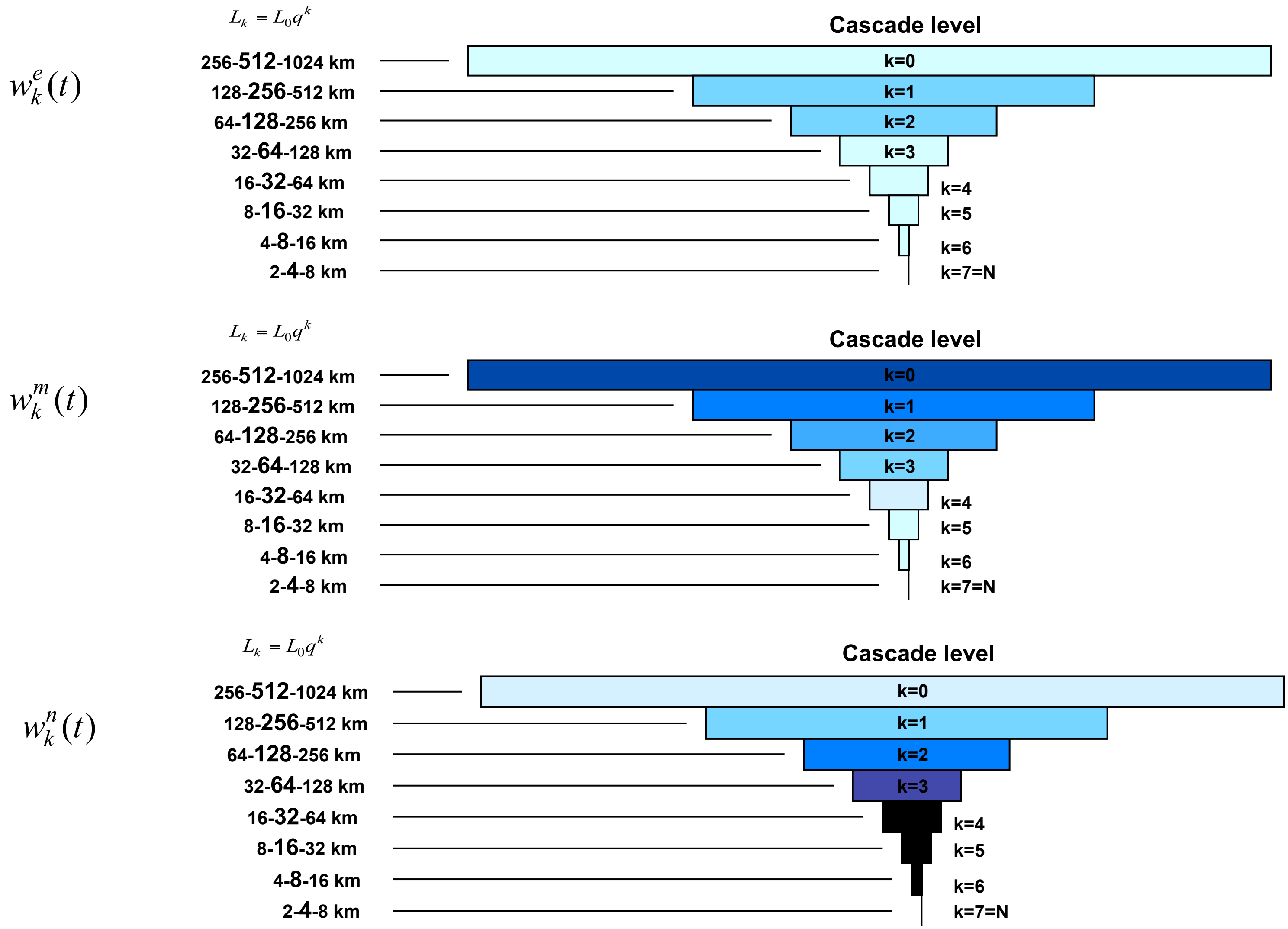




STEPS behaviour

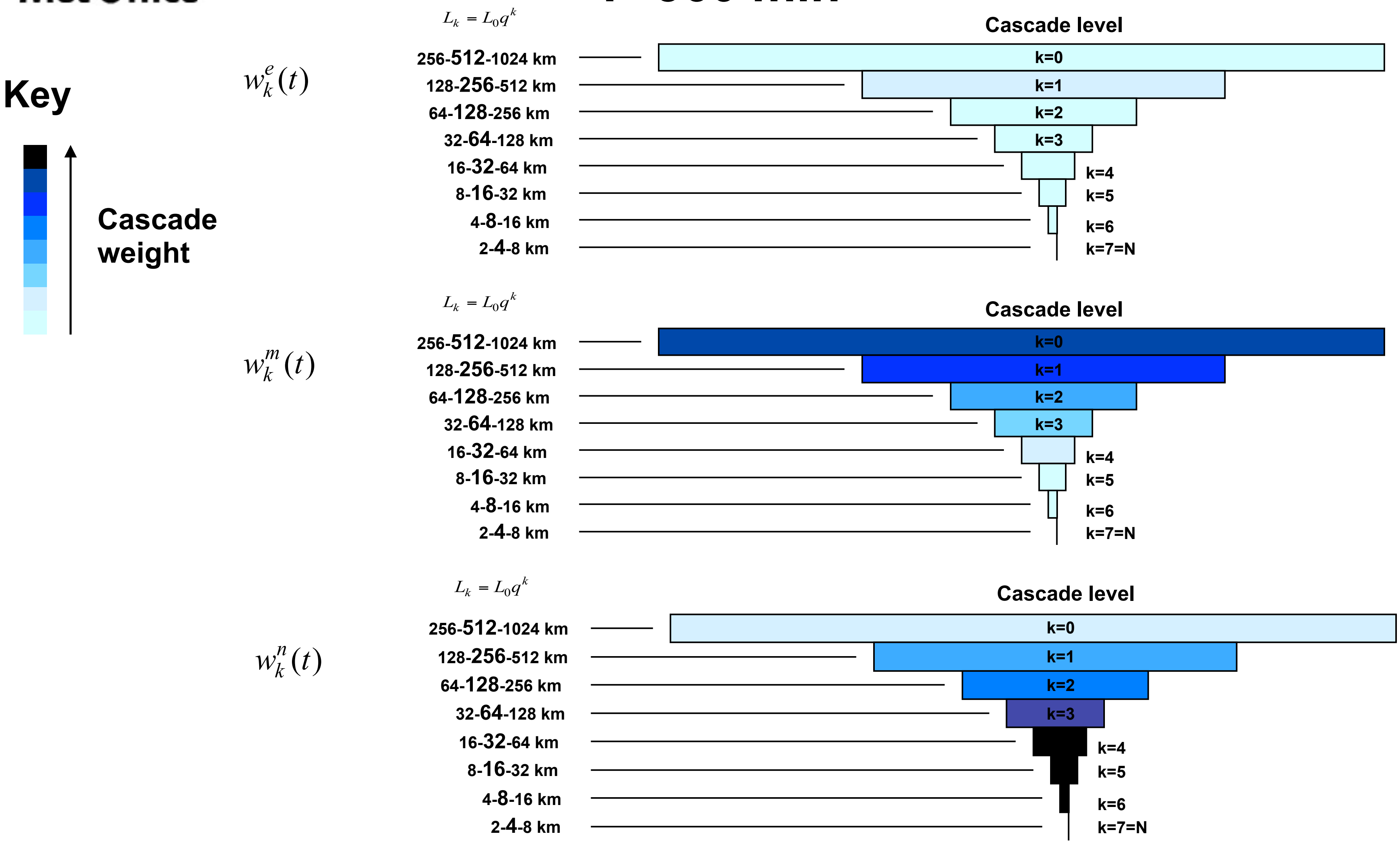
T+180 min



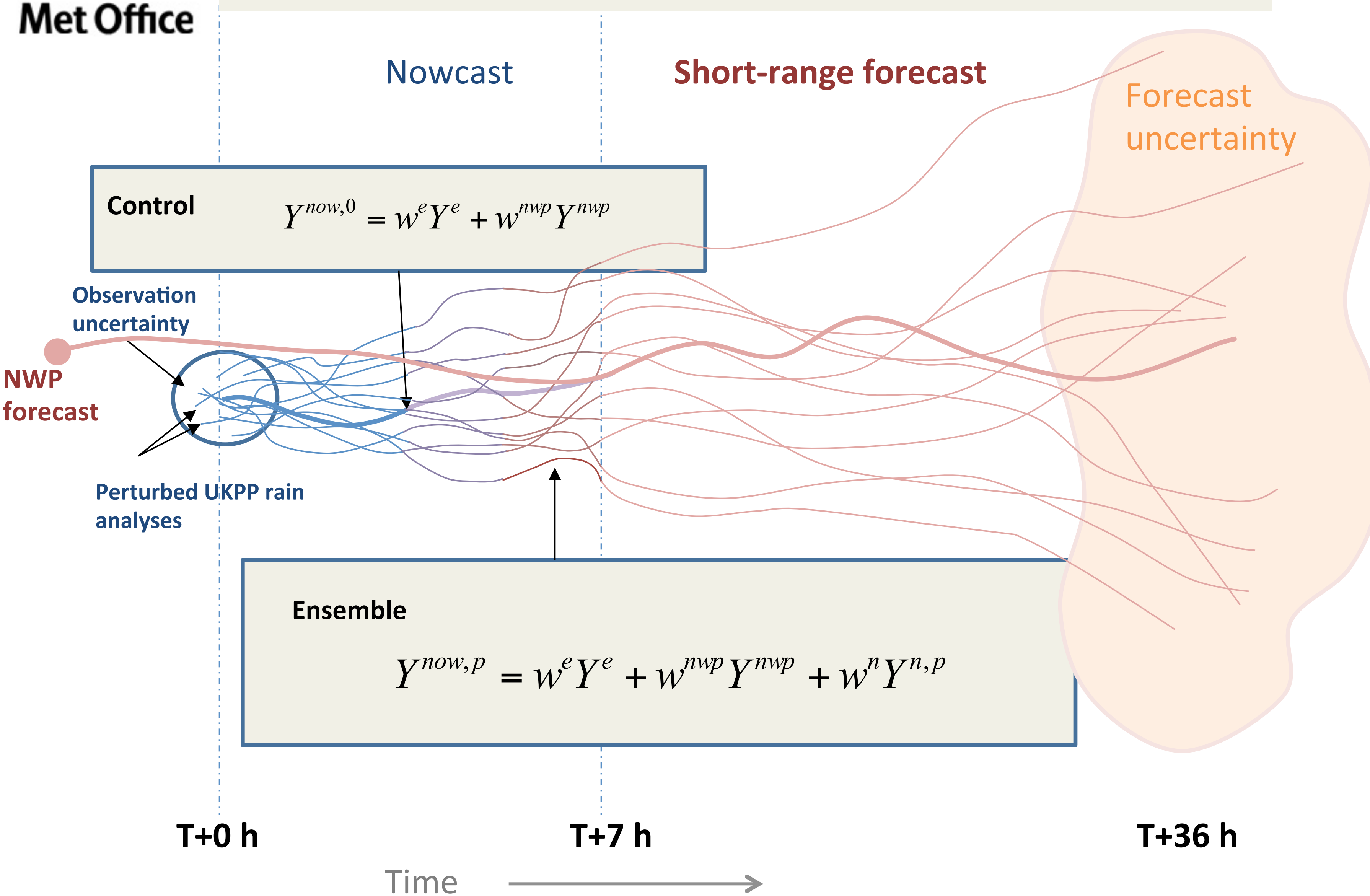


STEPS behaviour

T+360 min

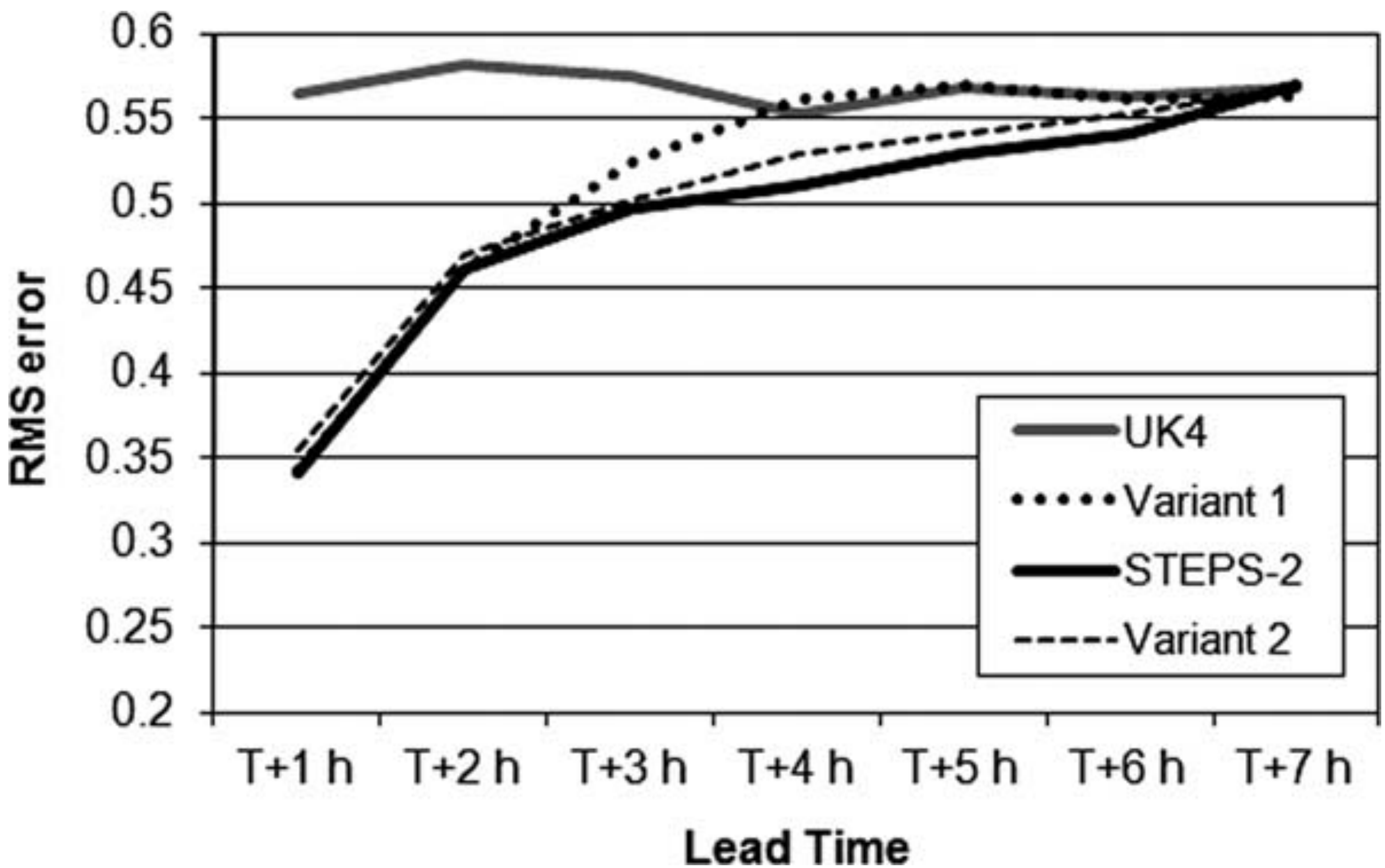


STEPS nowcast and short-range forecast from single NWP forecast solution



STEPS performance – control nowcast

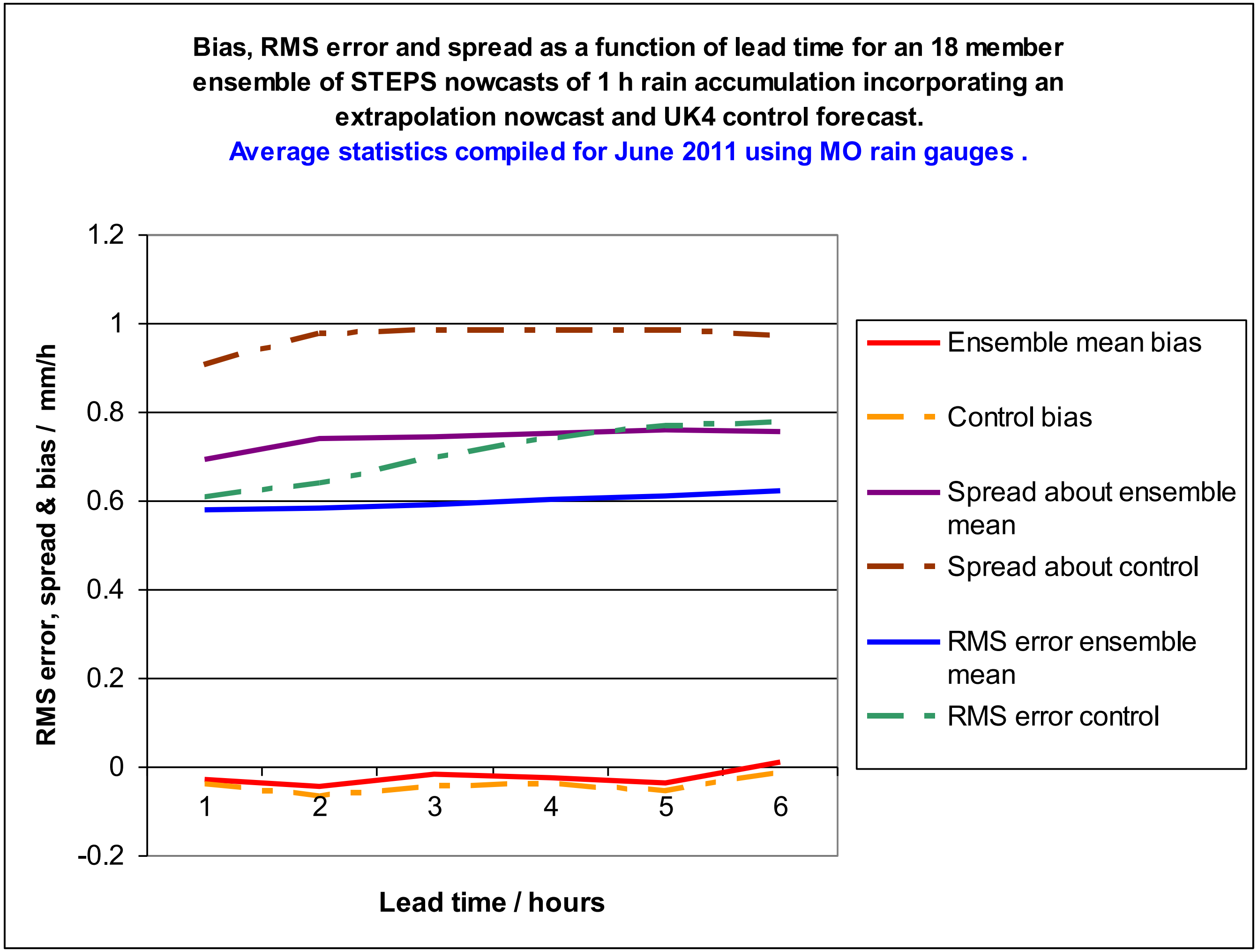
Verification against rain gauges



STEPS performance – nowcast ensemble

Verification against rain gauges

- STEPS spread-skill relationship measured against rain gauge – June 2011
- Ensembles are skilful but slightly over spread

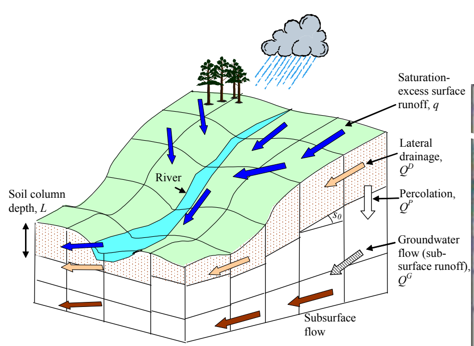


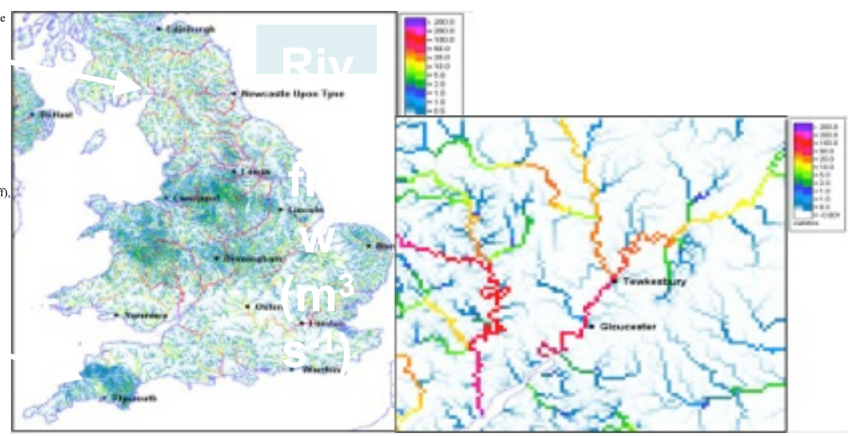
Weaknesses of STEPS formulation

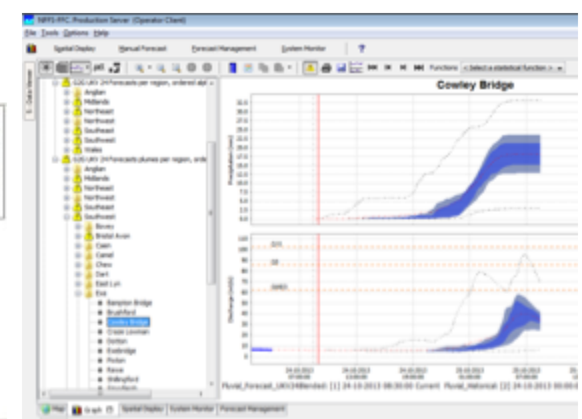
- **Form of modelled distribution**
  - ➢ **dBR - need to apply a threshold to treat dry areas**
  - ➢ **Not Gaussian**
- **Multiplicative cascade**
  - ➢ **Assumed independence between levels**
  - ➢ **Variance concentrated where rain-no-rain perimeter complex – subtle dependence on large scales**
- **Noise generation**
  - ➢ **Homogenous spatial correlations imposed on noise using FFT or power law filters**
  - ➢ **Excessive variance injected into the interiors of large areas of precipitation**

Operational flood forecasting with STEPS ensembles

- **Rainfall ensemble**
  - ➢ STEPS 2 km, 24 member ensembles
- **River flow/surface run-off ensemble**
  - ➢ Grid-to-Grid (G2G) conceptual-physical, distributed hydrological model (Bell *et al.*, 2009)
  - ➢ 1 km gridded run-off, kinematic routing, surface/sub-surface flow

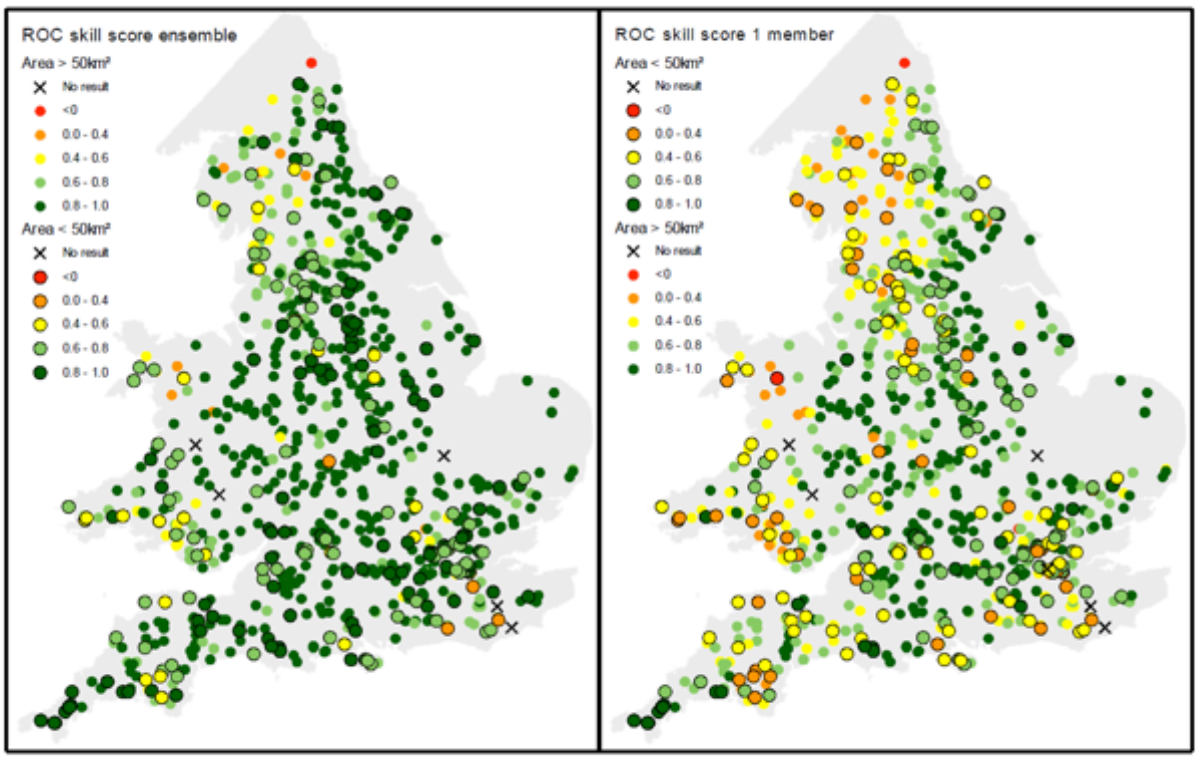


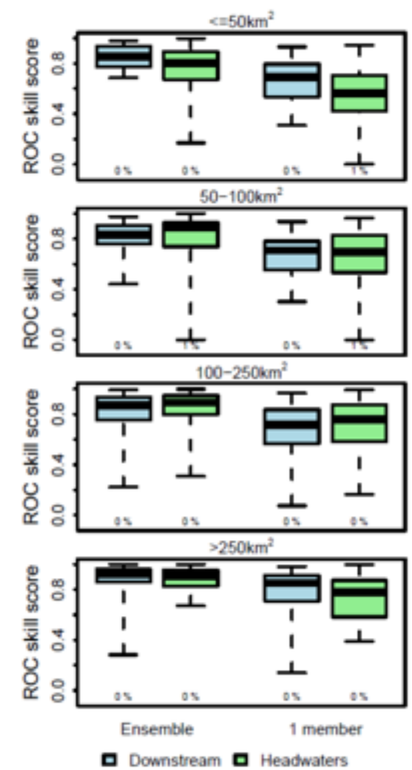




Preliminary evaluation of G2G river flow ensembles over England & Wales

- **General improvement in event/non-event discrimination using ensemble compared to single forecast scenario**





Source: CEH, Wallingford

Threshold: QMED/2 river flow threshold during the 24 hour forecast horizon

Thank you for listening