# Convective Scale Data Assimilation and Nowcasting

ECMWF Seminars 2011

**Susan P Ballard,** David Simonin, Zhihong Li, Jean-Francois Caron, Lee Hawkness-Smith, Cristina Charlton-Perez, Helen Buttery, Nicolas Gaussiat, Graeme Kelly and Robert Tubbs and Bruce Macpherson, Gareth Dow and Richard

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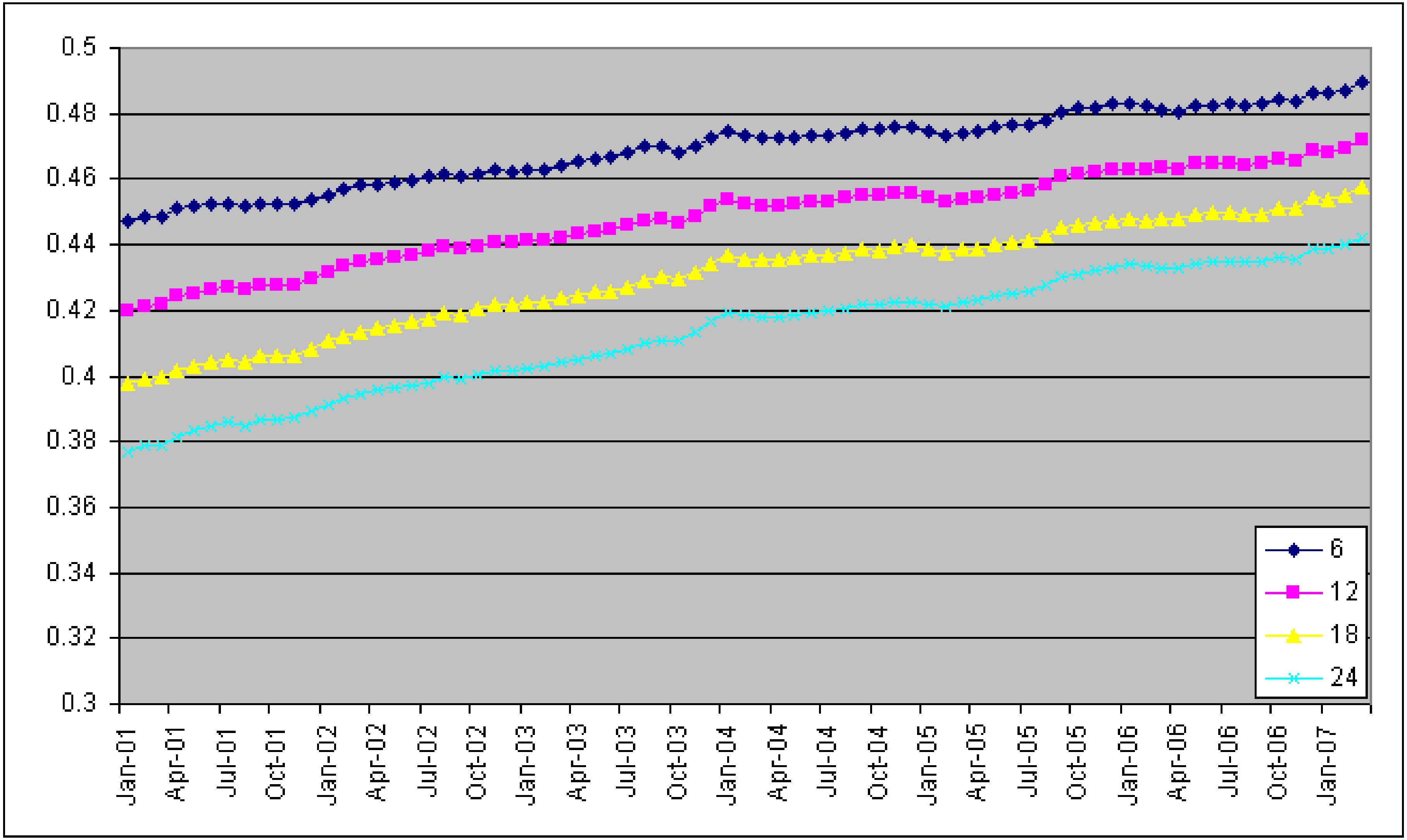
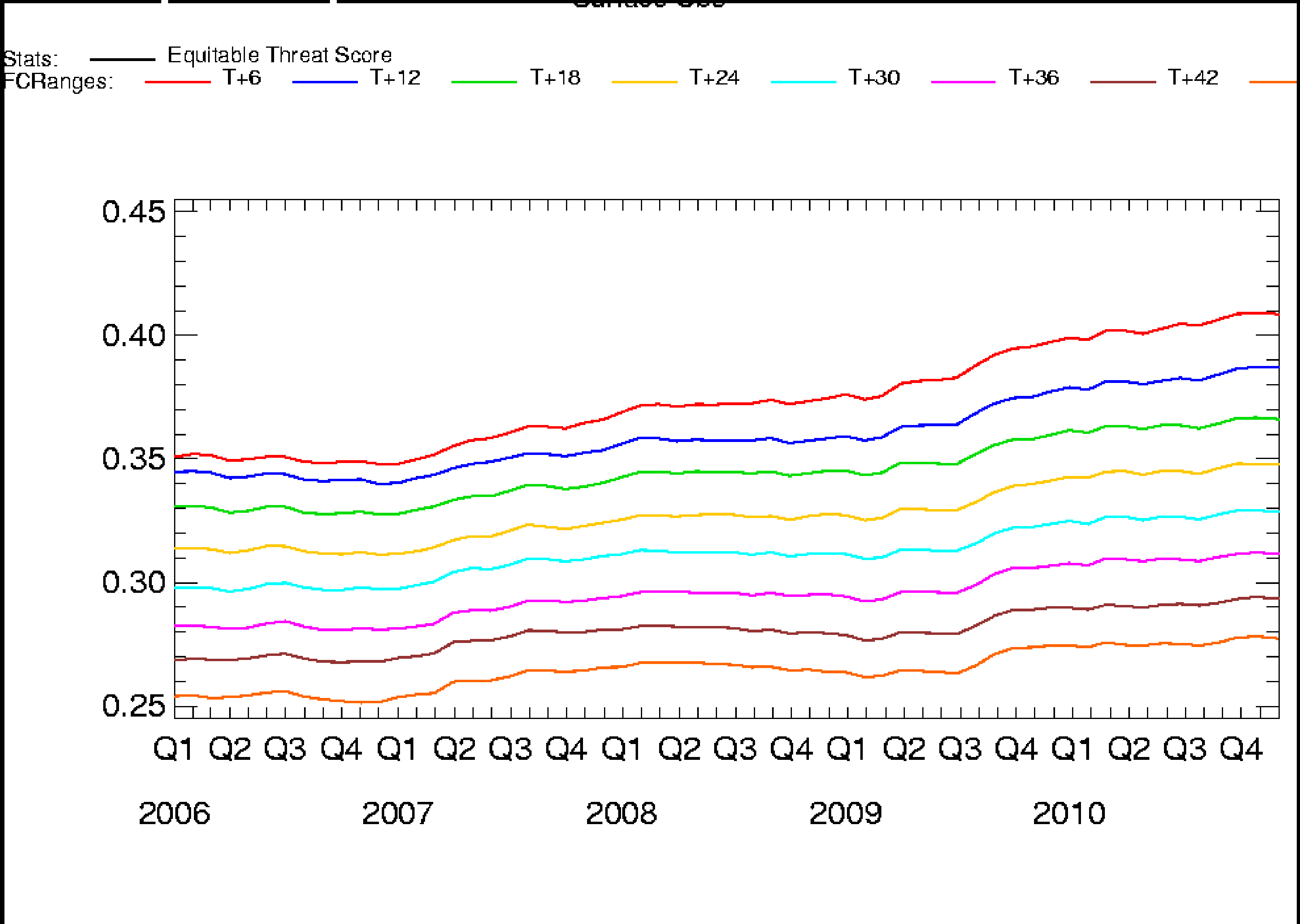
- Introduction
- Scientific Challenges
- Availability of Observations
- NWP-Based Nowcasting
- Future Observations and needs

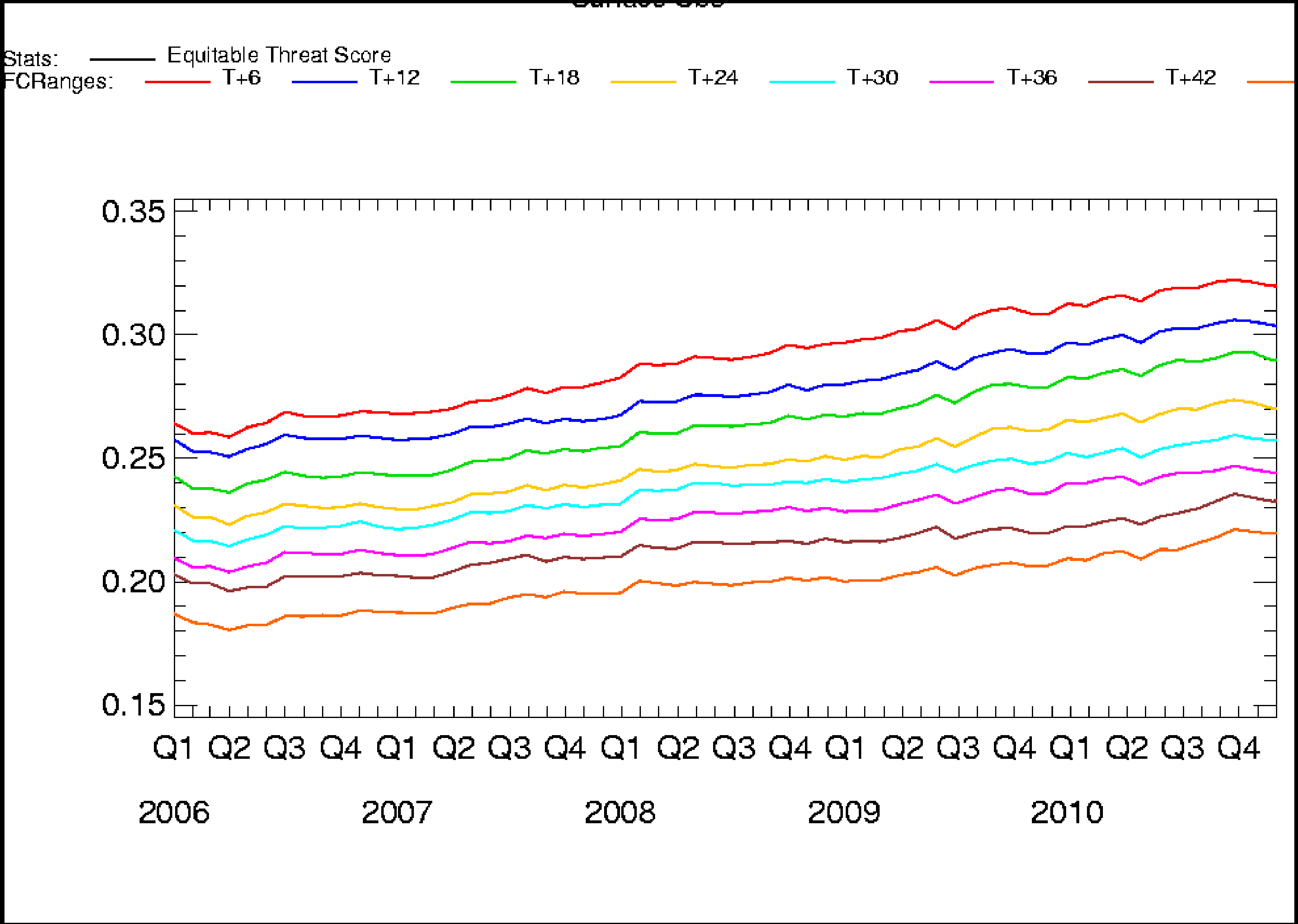
# Improvements in Limited Area Forecasting in UK index



# Improvements in Precipitation Forecasting - 6hr accumulated precip >= 0.5mm



# Improvements in cloud forecasting >.325 cloud fraction



# Issues

- DA Method
- Boundary Conditions
- Continuous Cycling or Restart from Larger scale?
- Control Variables
- Balance Constraints
- Synoptic Scale
- Background Errors
- FGAT
- Observations
- Verification

# Operational Convective Scale Data Assimilation Systems

Met Office

- Met Office, UK area, 1.5km, 3D-Var, 3hourly DA, 6hourly fc
- Meteo France, France, 2.5km, 3D-Var, 3hourly cycling
- DWD, Germany, 2.8km, nudging, Meteo Swiss, 2km – developing LETKF
- HIRLAM 3.3km, 3D-Var
- USA, 13km, GSI, hourly
- JMA, Japan, 5km, 4D-VAR with forecasts every 3 hours to 15 or 33hours.
- KMA, 10km, WRF 3D-Var, testing Met Office systems

ALL LIMITED AREA DOMAINS

# Met Office NWP/Data Assimilation Systems

25km global 2010

– 4D-Var – conventional observations – 6hourly

12km NAE limited area - 6hourly

– 4D-Var – conventional + cloud plus latent heat nudging

4km UK 2005 - 3hourly DA, 6 hourly forecasts

– 3D-Var – conventional + cloud plus latent heat nudging

1.5km UKV 2009 - model variable resolution – 3km VAR grid – DA/FC as UK4

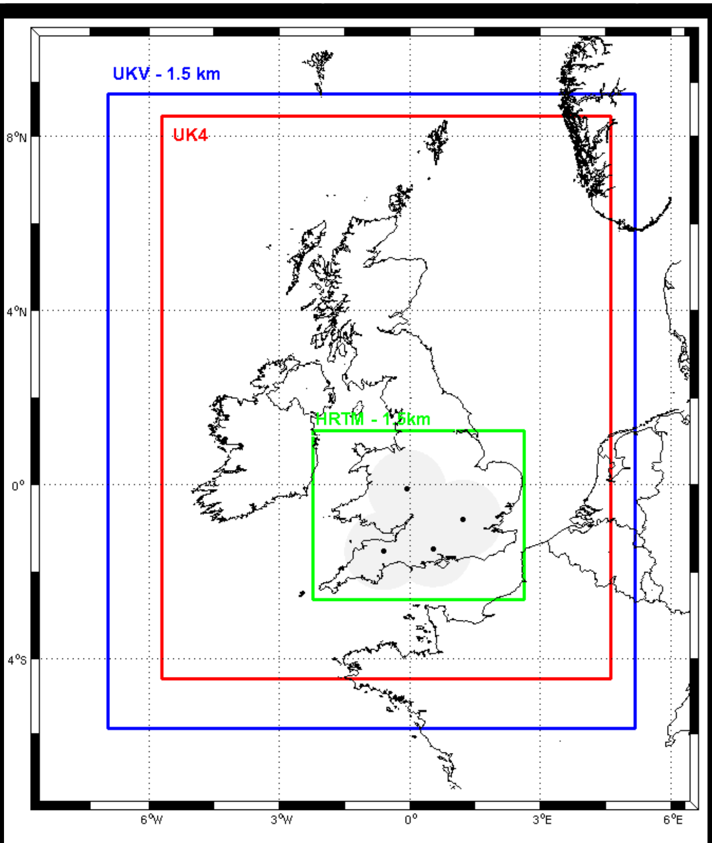
– 3D-Var – conventional +cloud plus latent heat nudging

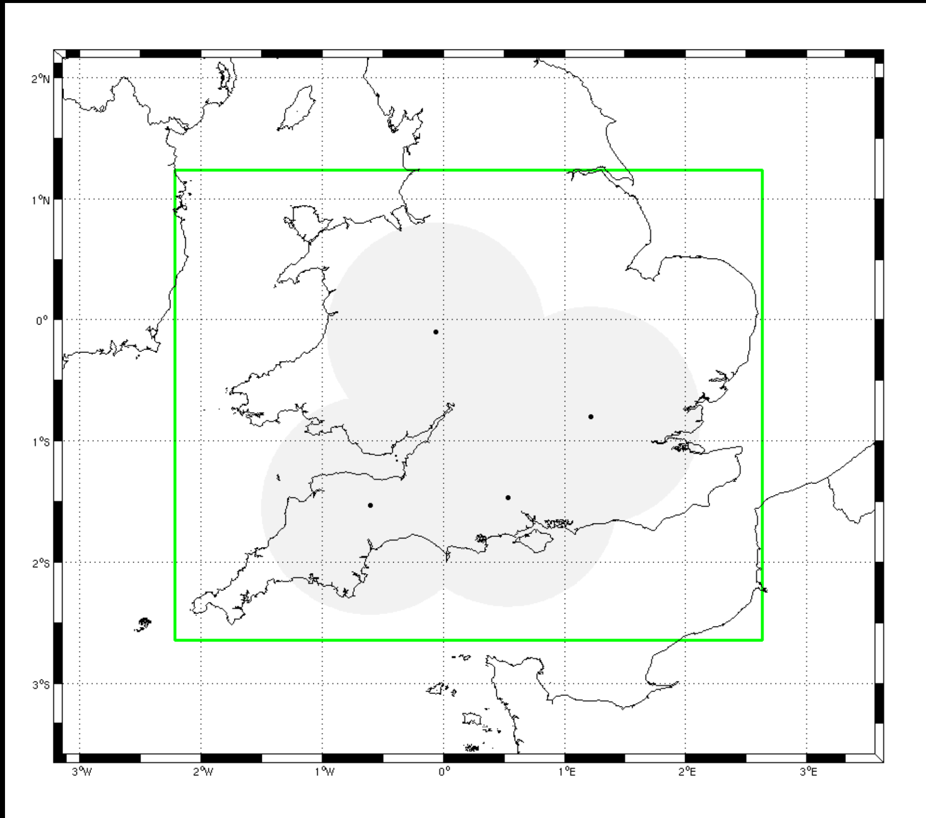
1.5km test nowcasting system – southern UK – hourly DA and forecasts

– 3D-Var or 4D-Var - conventional plus latent heat and moisture nudging

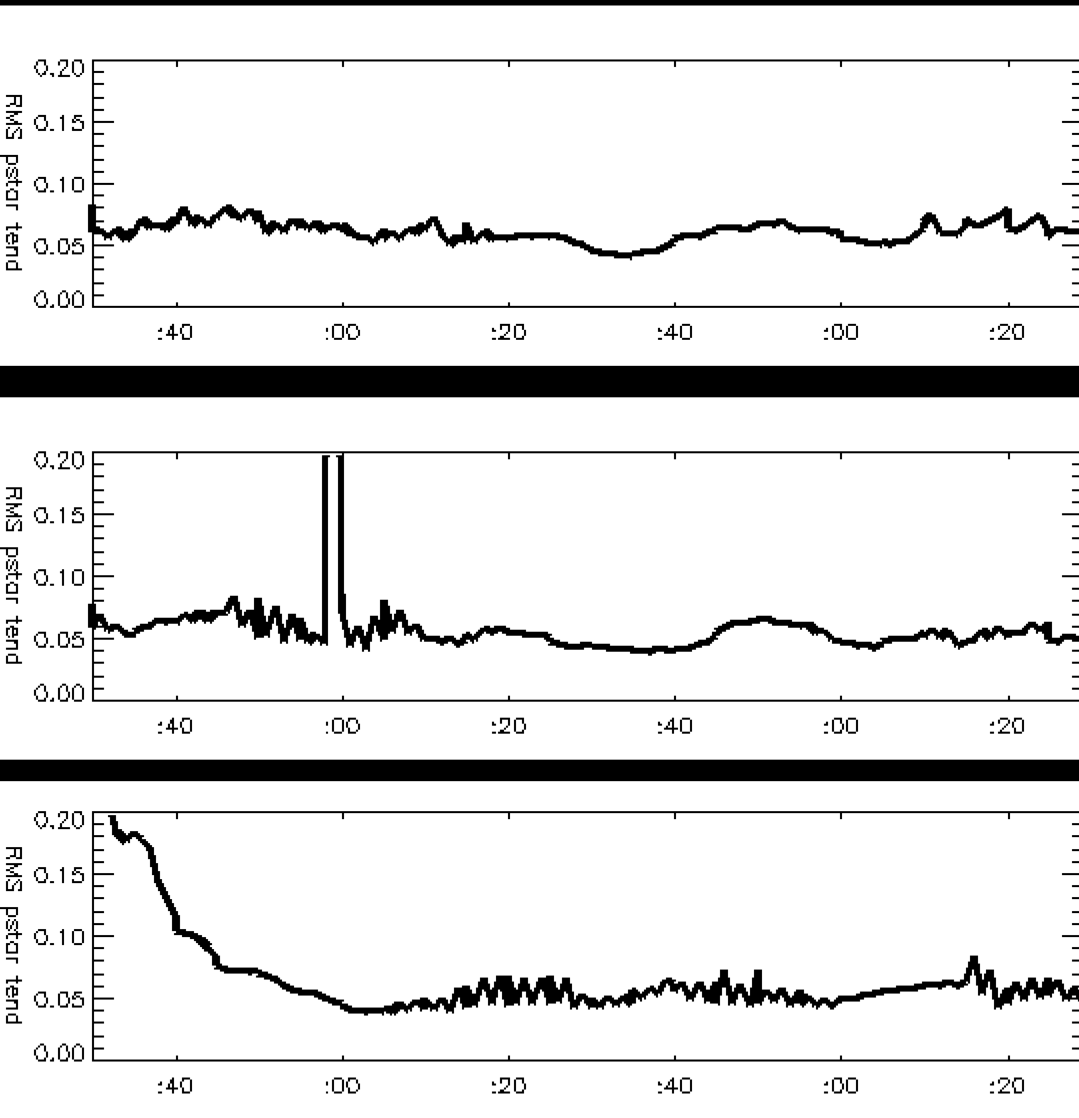
# Met Office Model Domains

| Model | Resolution | VAR | Time Window | Cycling | Forecast Length |
|---|---|---|---|---|---|
| UK4 / UKV | 4 km / 1.5km | 3D-Var | 3 | 3 | T+36 |
| NDP | 1.5 km | 3D/4D-Var | 1 | 1 | T+7/12 |



# Balance and Boundary Updates - rms pstar tendency - NDP



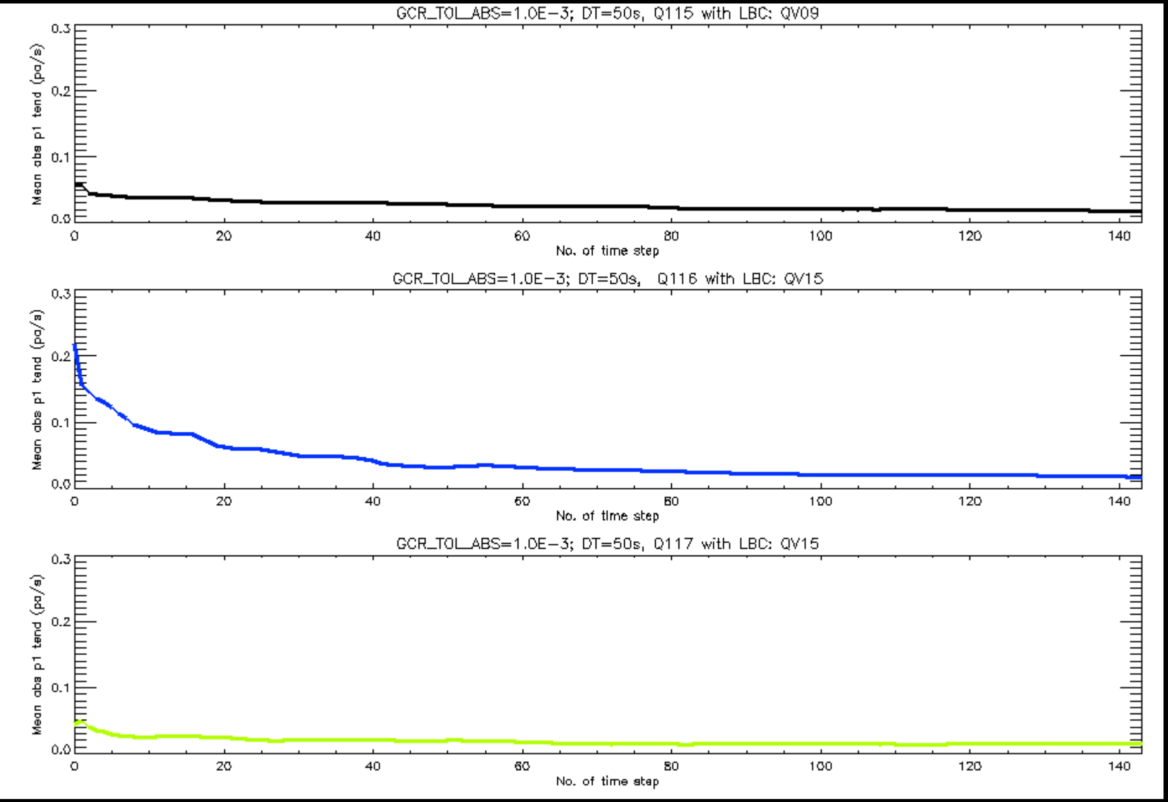

3D-Var
Analysis increments
at T+0,
start of window T-30mins

Top – with IAU

Middle – no IAU

Bottom – IAU and
boundary update to
next run – T+6 later than
for previous cycle

# Balance and Boundary Updates - rms pstar tendency - NDP



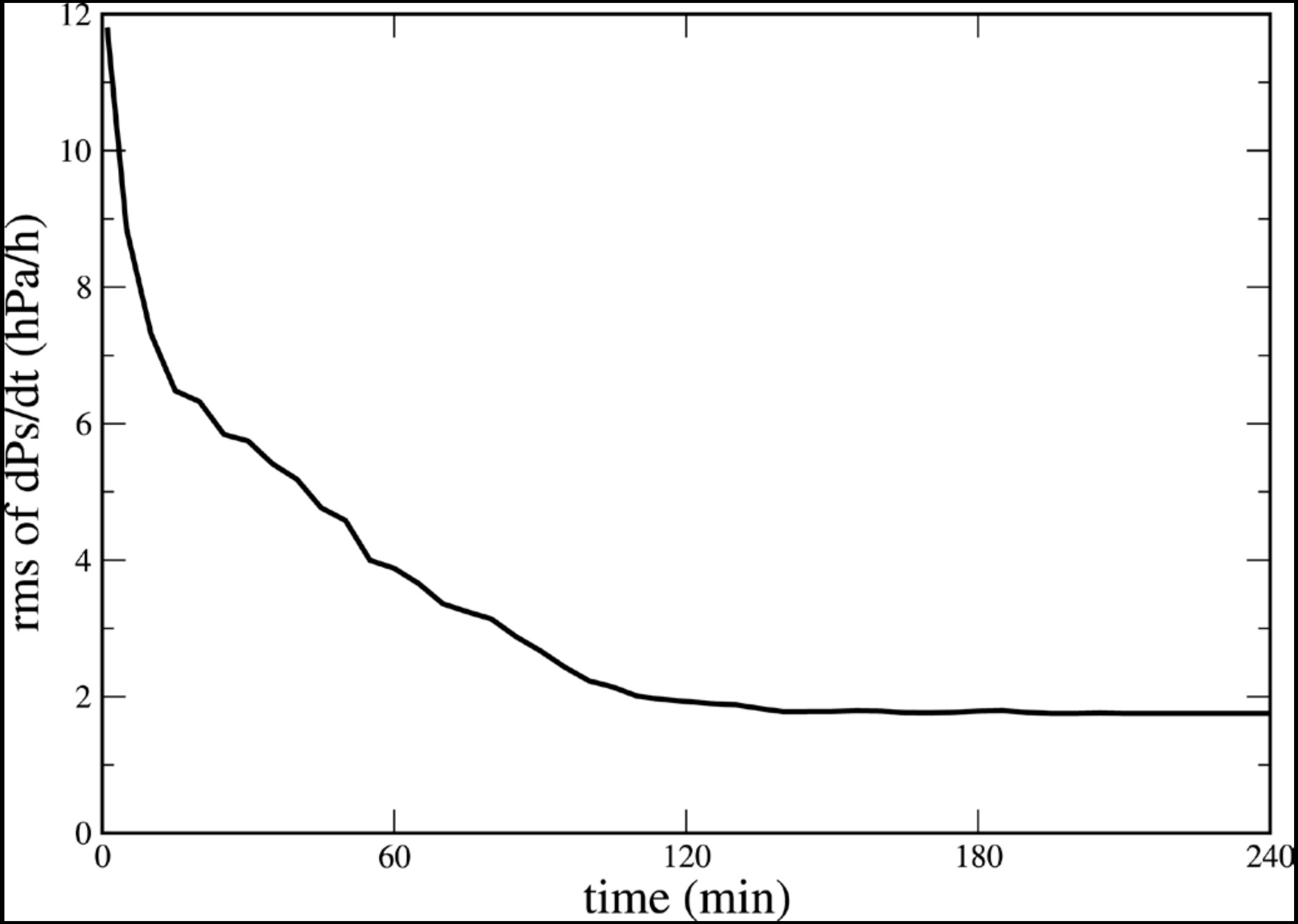

4D-Var Analysis increments
at T-30mins,
start of window T-30mins

Top – 15Z, 9Z lbc

Middle – 16Z, 15Z lbc

Bottom – 17Z, 15Z lbc

# Meteo France, Seity et al 2011 rmse surface pressure tendency



# Analysis boundary conditions

- Met Office – zero increments – unrealistic gradients near boundaries
- HIRLAM extension zone and non-zero increments – problems with increments wrapping around to opposite side of domain
- COSMO nudging – no problems?
- Boundary conditions as control variables – what happens as extend into forecast mode?

# Control Variables - I

- Global, large domain, coarse resolution – assume geostrophic and hydrostatic balance
- eg increments of velocity potential, stream function, unbalanced pressure and relative humidity or some form of humidity transform in the Met Office system and WRF,
- vorticity, divergence, temperature, surface pressure and specific humidity in ALADIN.
- Expect the constraints to break down at convective scale

# Control Variables - II

- Kawabata et al 2007 - JMA
  - 2km 4D-Var, horizontal wind (u,v), vertical wind(w), nonhydrostatic pressure, potential temperature, surface pressure and pseudo relative humidity (Dee and Da Silva 2002) 50km lengthscale
- Microphysics – reflectivity assimilation – hydrometeors ?
  - Metoffice based around qt with cloud incrementing operator
- Bannister et al 2011 - Geostrophic and hydrostatic balances found to decay as the horizontal scale decreases.
- geostrophic balance becomes less important < 75 km
- hydrostatic balance becomes less important < 35 km

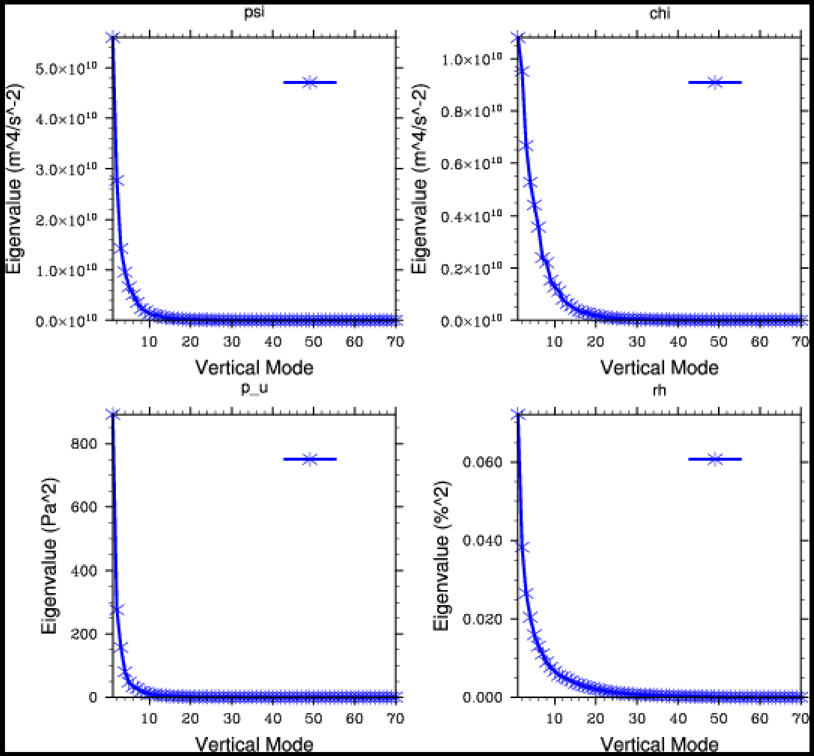
# Background Errors

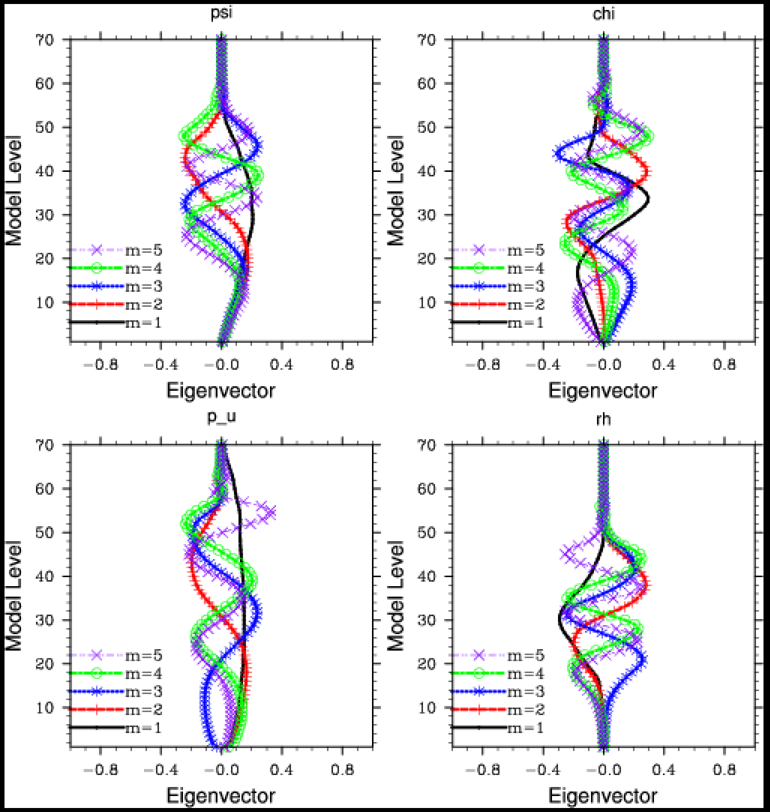
- NMC method – Met Office - SOAR horizontal correlation function
  - UKV T+24/T+12, 30 cases
    - 180km for streamfunction, 130km for velocity potential and unbalanced pressure and 90km for humidity and logm
  - UKV  T+6/T+3
    - 130 to 30km for velocity potential and stream function
    - 60 to 5km for unbalanced pressure and 40 to 5km for humidity
  - NDP T+6/T+3 every 6 hours, 75
    - 60 -10km vel pot, stream fn , 30-2km unbalanced pressure and 30-2km for humidity
- Ensembles – Meteo France
  - Brousseau et al 2011
  - 6 members, 26 days, 3hour range

# NDP CovStats using Gen_BE

From a set of 75 6h-3h forecast using same LBCs, every 6h (valid at 00, 06, 12 and 18 UTC)

- Variances
- First 5 vertical modes



# NDP CovStats using Gen_BE

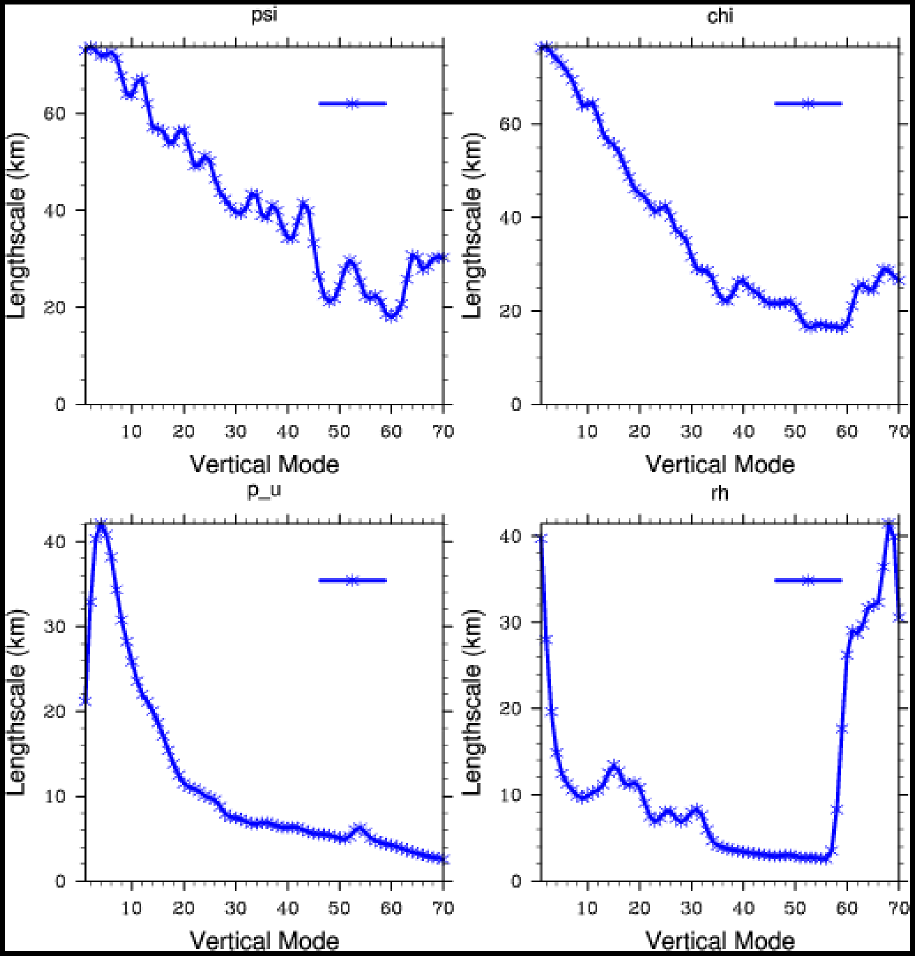
From a set of 75 6h-3h forecast using same LBCs, every 6h (valid at 00, 06, 12 and 18 UTC)

- SOAR horizontal length scales in vertical mode space

UKV = 130 km*

* For every mode

UKV = 180 km*




UKV = 130 km*

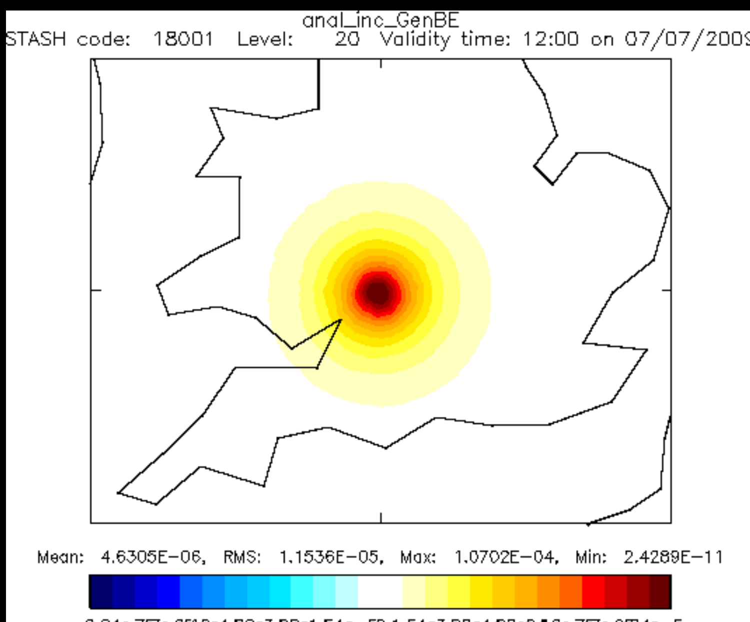
UKV = 90 km*

# Single pseudo-obs experiments

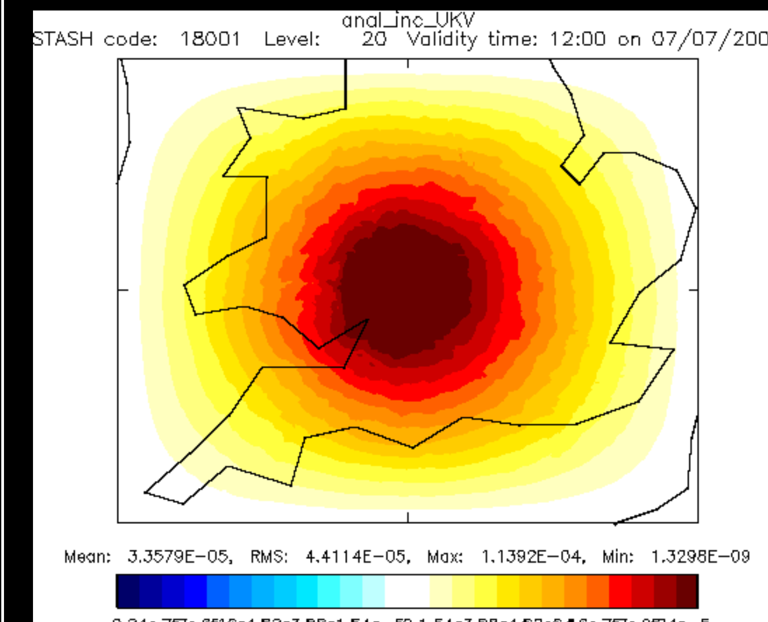
http://www-nwp/~frfc/work/hrtm/1obs/gen_be1.html

Response to the assimilation of a pseudo humidity (q) at level 20 (~850 hPa)

innovation = 2 g/Kg and observation error = 0.1 g/Kg




humidity (q) at level 20 (~850 hPa)

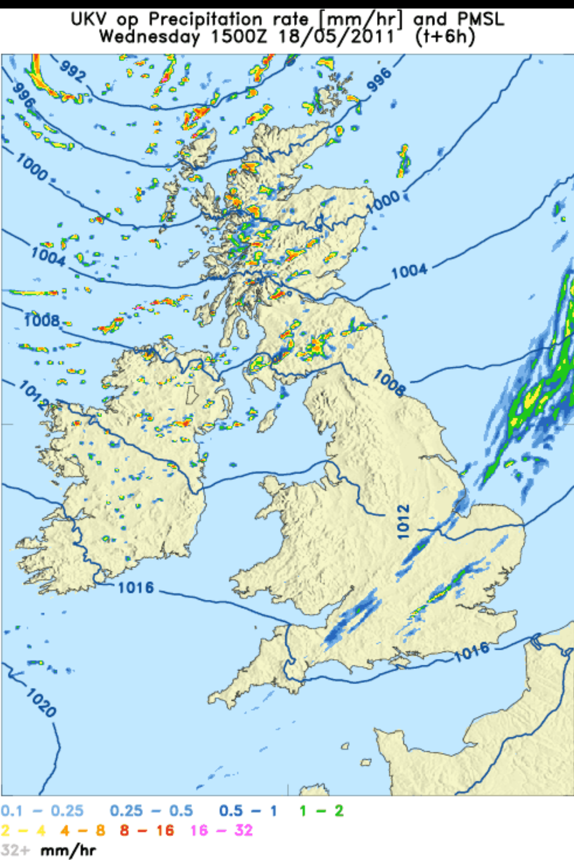



humidity (q) at level 20 (~850 hPa)

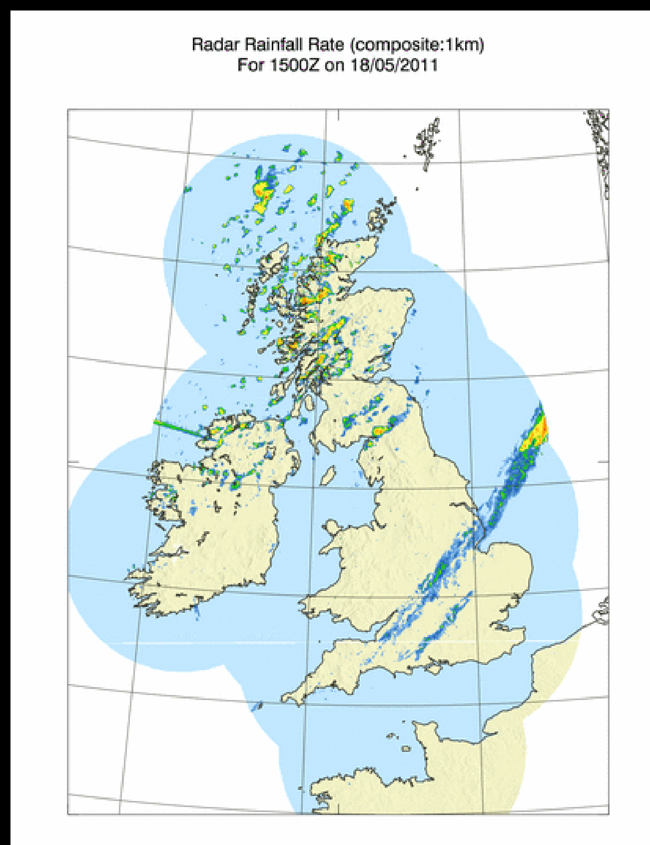
Met Office

# 15Z 18th May 2011

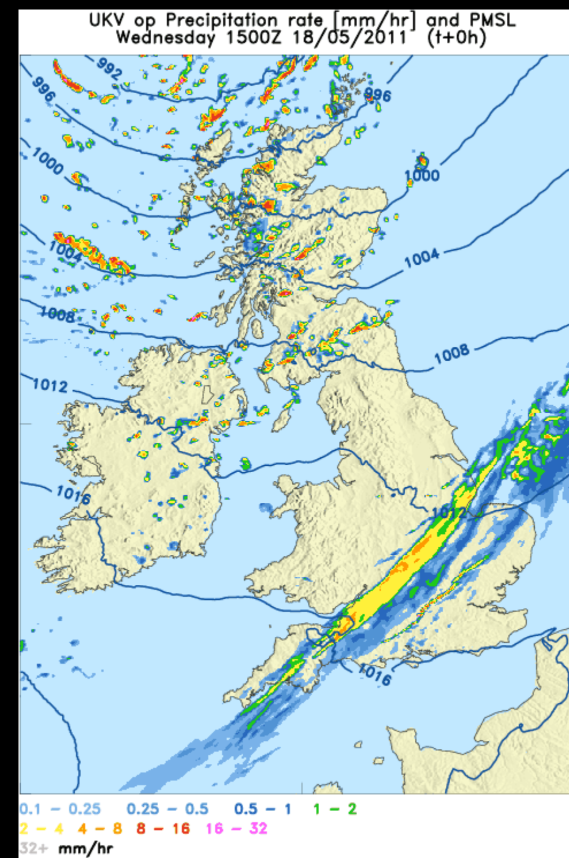
T+6




radar

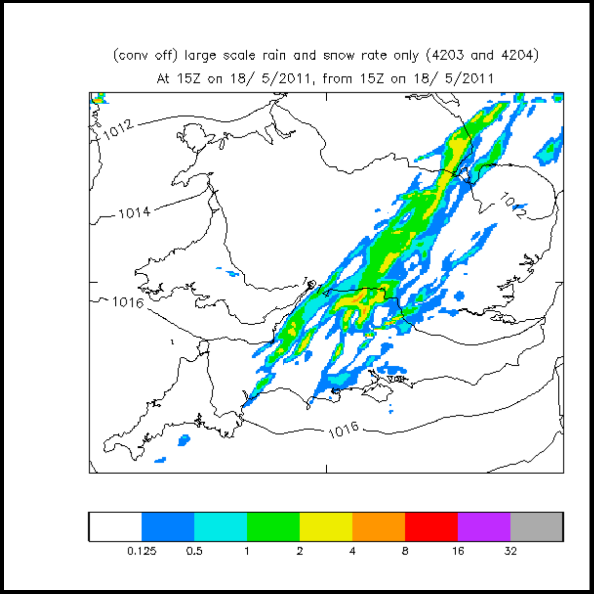



T+0

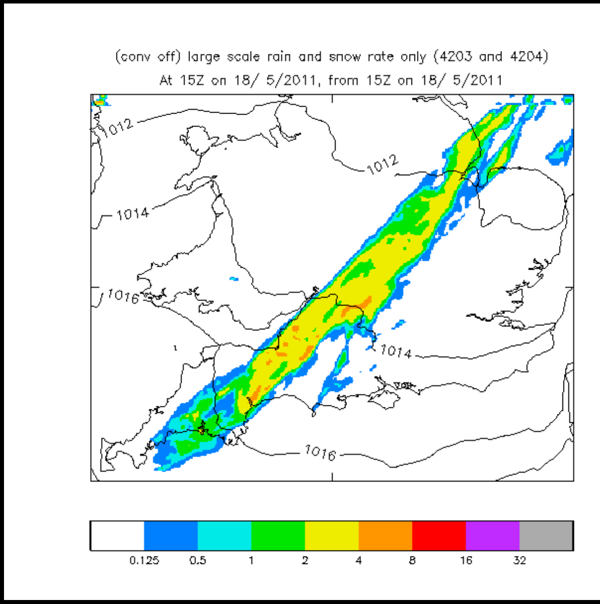


# Impact of Observations T+0

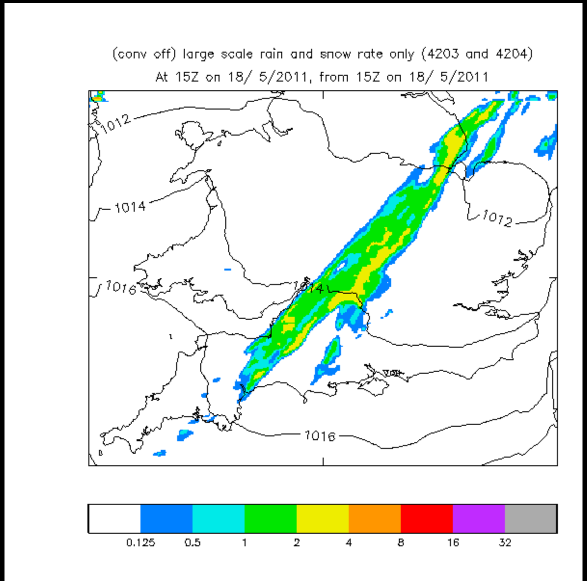
No obs



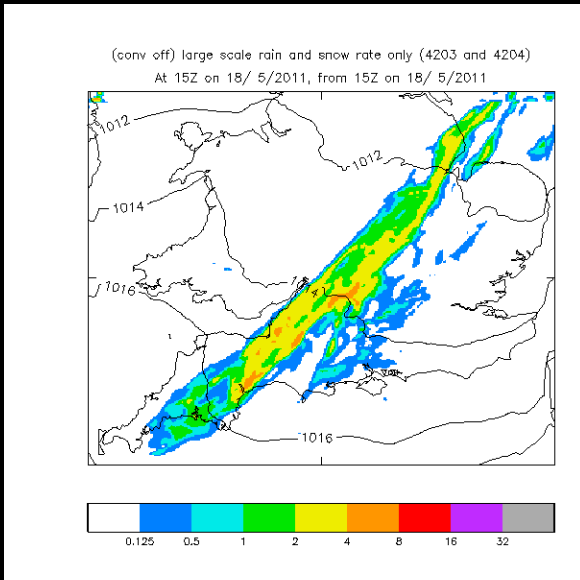

All obs




No GPS



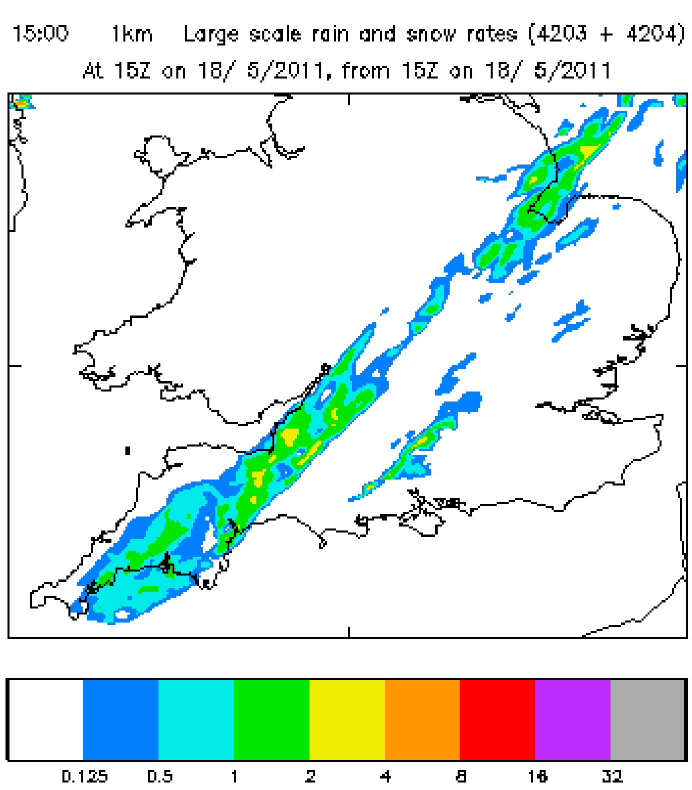

No doppler wind

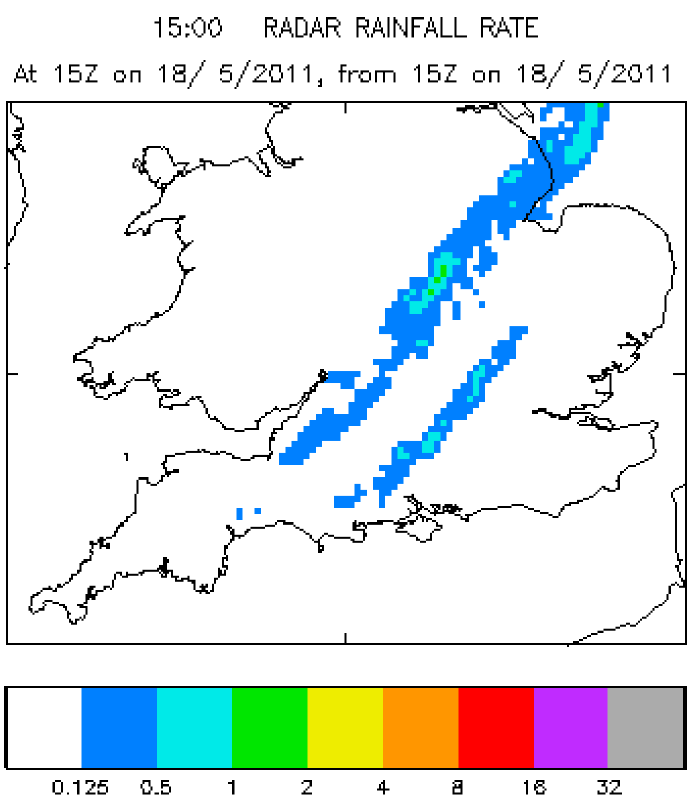


# Impact of new  Cov Stats in NDP

All obs

radar



# Choice of the Monitor Function

Lorenc (2007) showed that a significant part of the observed background-error correlation structure could be explained by regarding it as a function of static stability.

Most choices of monitor function need regularisation to perform effectively and ensure that a good mesh resolution is maintained everywhere, an example is given by:

$$M = \sqrt{1 + c^2 (\partial\theta / \partial z)^2}$$

$M$ is always positive and can be modulated by a scaling factor $c$.

If the scaling factor $c$ is set to zero, the computational grid and the physical grid are the same.

Since mesh points will be clustered where the monitor function is large, this choice of $M$ will cluster mesh points in regions of large static stability.

# Horizontal Smoothing

Met Office

The adaptive mesh transform is a 1D transformation in the vertical only. The transformation depends on horizontal position.

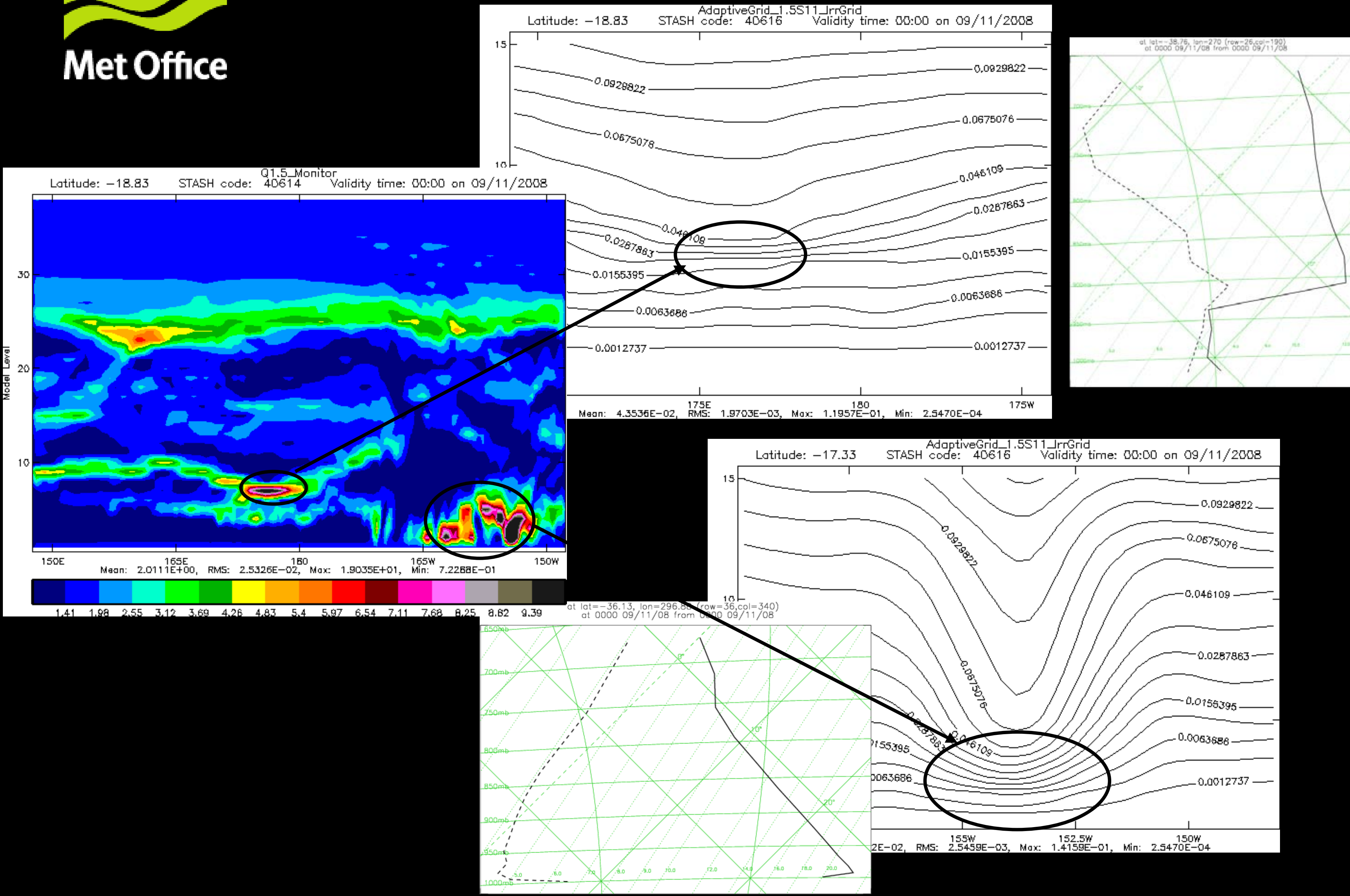
The monitor function is calculated for every horizontal grid point. In order to avoid a loss of horizontal coherence in the mesh a horizontally smoother mesh can be generated by smoothing the regularised monitor function prior to the mesh calculation.

The smoothing at point $i, j$ (longitude/latitude) can be expressed as:

$$\hat{M}_{i,j} = \frac{\sum_{k=-1}^{1} \sum_{l=-1}^{1} M_{i+k,j+l} \gamma^{|k|+|l|}}{\sum_{k=-1}^{1} \sum_{l=-1}^{1} \gamma^{|k|+|l|}} \qquad \text{with} \quad \gamma \in [0, 1]$$

The degree of smoothing applied can be increased by iterating this smoothing procedure *N* times.

# Monitor Function and Adaptive Grid



# Current Use of Observations

- Hourly in 3 or 6 hour windows
- FGAT 3D-VAR, time of ob in 4D-VAR
- Does FGAT have benefit for fast-moving systems at convective scale?
- UKV
  - 3hourly cloud cover, hourly rain rate
  - Hourly synop – screen T, RH, wind , pressure and visibility
  - Radiosonde when available
  - Hourly amdar, wind profiler (6 high mode), GPS time delay, scatterometer winds, AMVs
  - Hourly SEVIRI IR – 2 upper Trop water vapour over land plus 3 low level window/humidity channels over sea

# Convective Scale Data Assimilation Strategy For Nowcasting

Met Office

**Techniques:**

**3DVAR, 4DVAR, latent heat and moisture nudging**

**Needs:**

**Hourly analyses and forecasts to customer within 15mins of data time**

**Therefore data must be in Met Office in real time**

**With 4D-Var can exploit high spatial and temporal resolution**

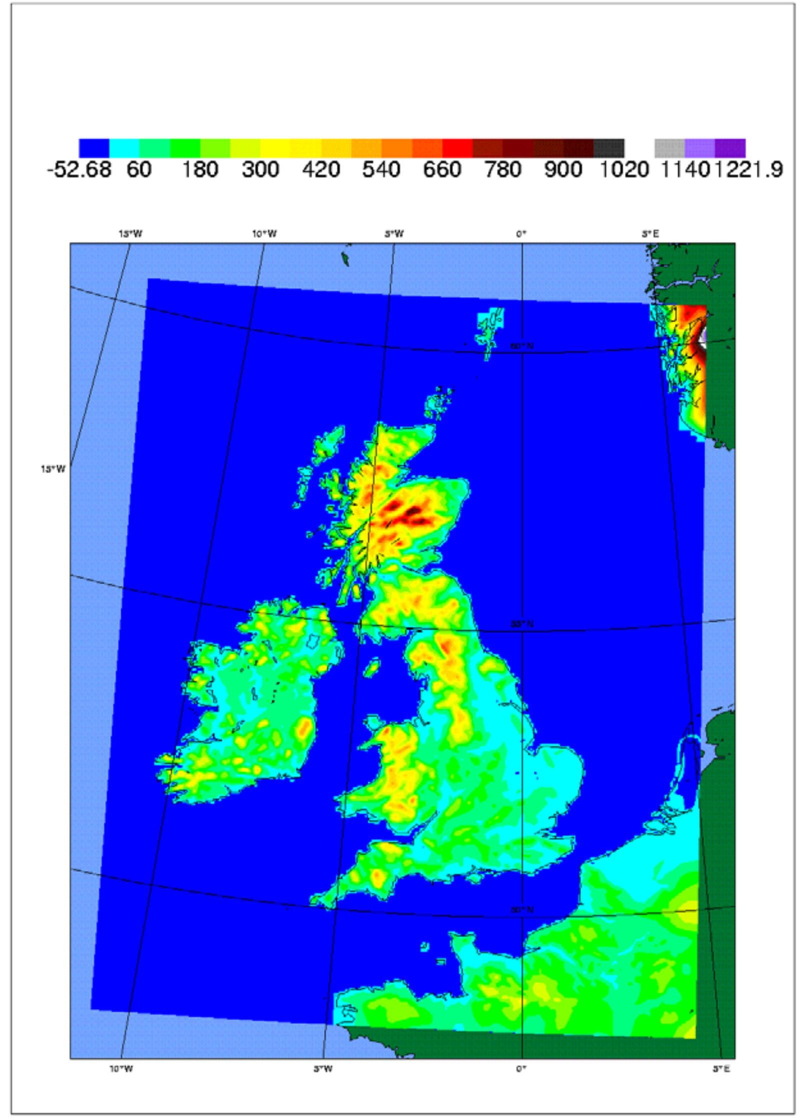
**High temporal resolution eg every 5 -15mins may help to offset poor or limited horizontal resolution**

**Exploit more observations – type and time frequency eg**
**GPS, AMDAR, Meteosat imagery (clear and cloudy)**
**use of radar Doppler winds, reflectivity and refractivity data**

Met Office

# Current Nowcasts - UKPP

- UKPP analysis of surface rain rate every 5 mins at 2km
- Radar composite plus 2DVAR of UK4 and MSG outside radar area
- Nowcasts every 15mins to 7 hours using T-30, T-15 and T+0 rain analyses to derive field of motion
- Blend UK4 and nowcast using STEPS
- 8 member ensemble
- Hourly temperature, precip type, cloud, wind, visibility etc
- Start 1min after DT but waits 7mins for radar rates and satellite imagery



# Comparison of NWP forecasts and STEPS (advection) Nowcasts of Precipitation – RMSF error of 1hour accumulation > 1mm

RMSF=

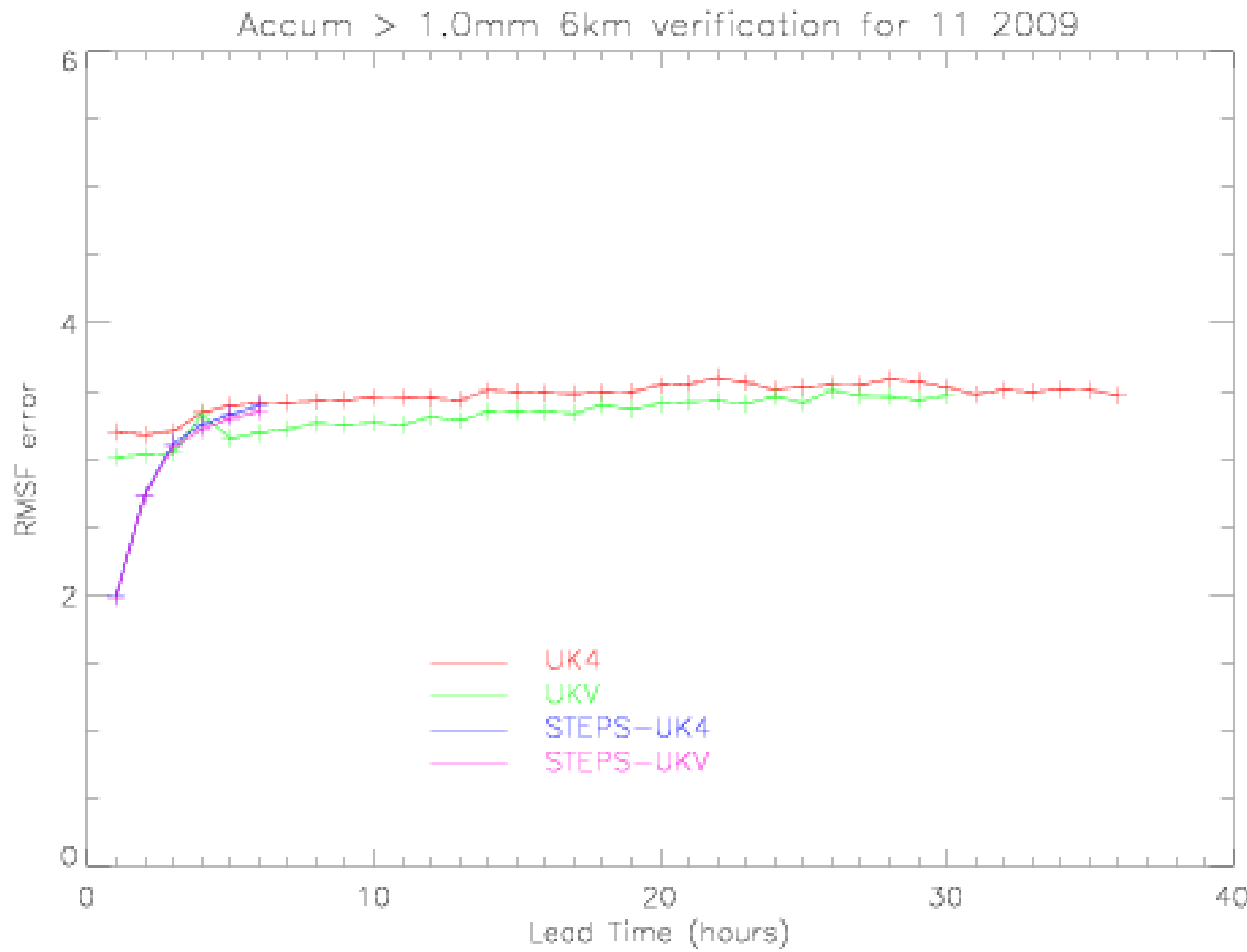
$\mathrm{Exp}(\mathrm{Sum}/N)^{0.5}$

Sum= sum(i-1,N)

$\mathrm{Log}(F_i/O_i)^2$

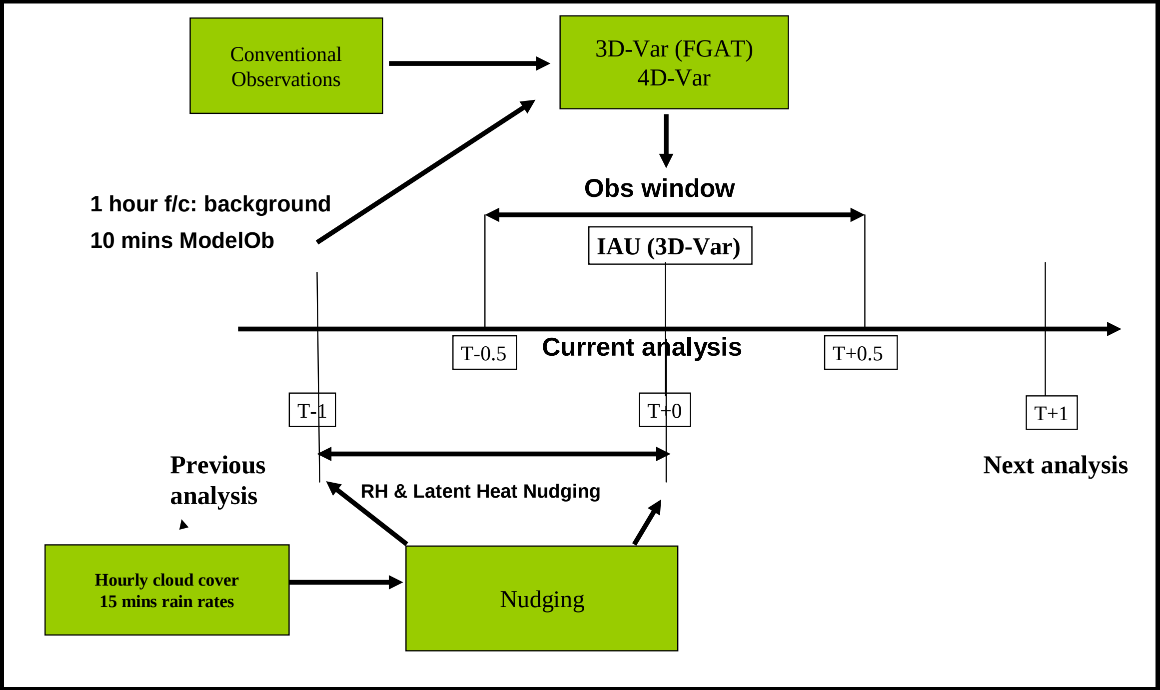
where
O=radar estimate

Both smoothed to 6km



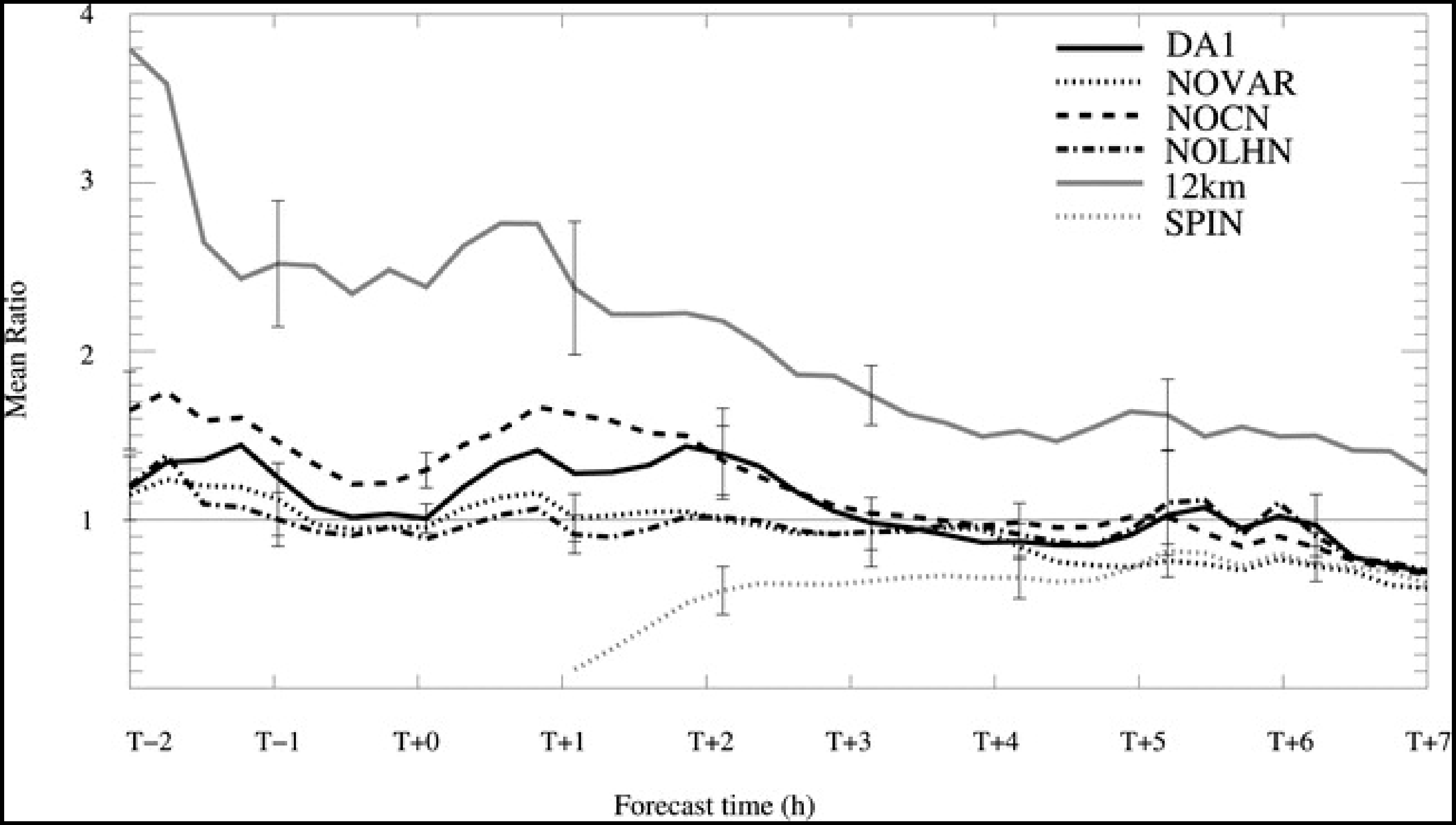
# Hourly 3D/4D-Var DA cycle

- Assimilation/ Obs window T-0.5 to T+0.5
- LH and cloud (RH) nudging from T-1 to T+0

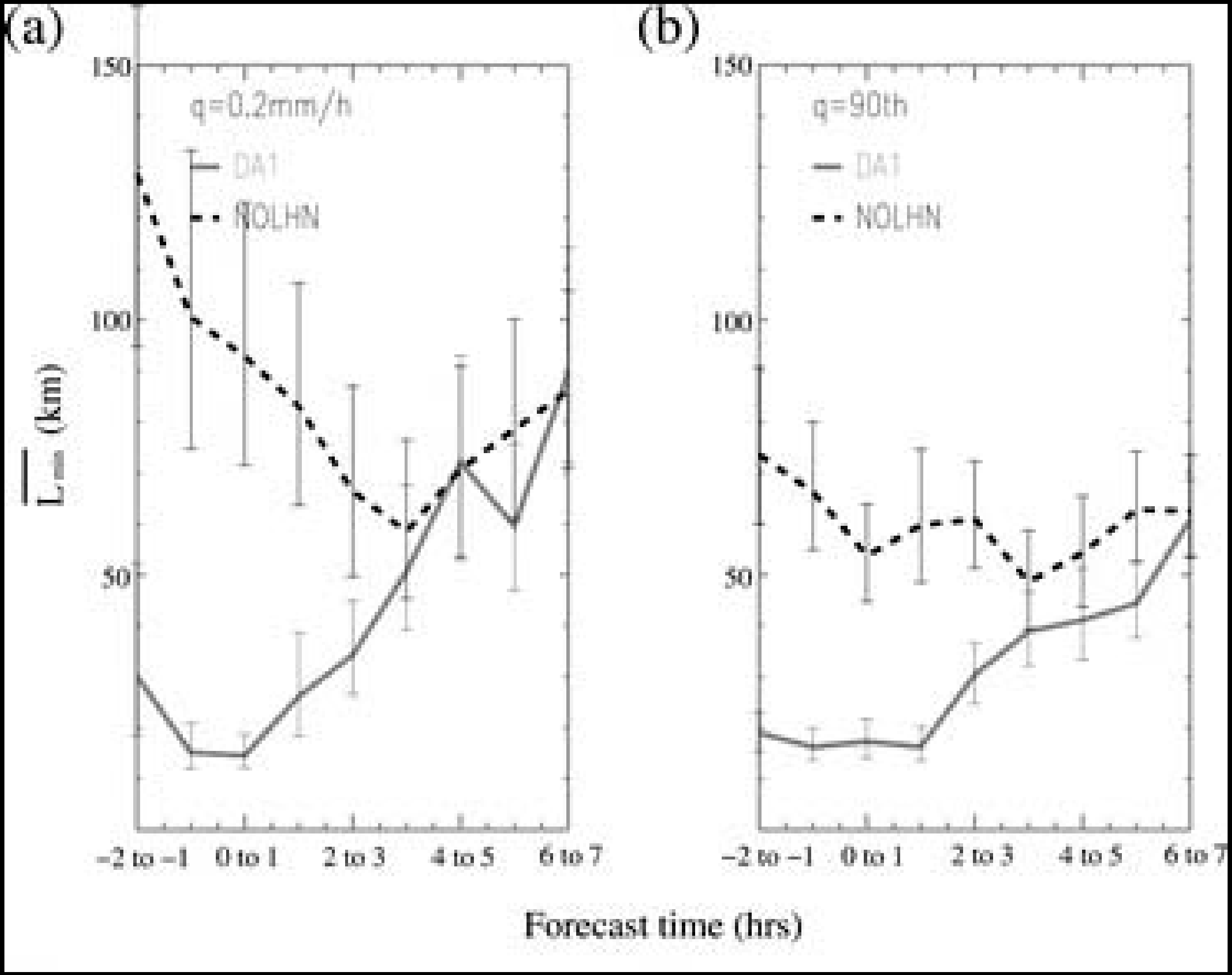



Schematic diagram of 3D/4D-Var DA cycle with MOPS cloud and LH nudging in SUKF 1.5km hourly nowcasting system

# Impact of model resolution and data assimilation on areal coverage of precipitation compared to radar derived rain rates – all runs 4km compared to 12km resolution – 3DVAR



# Impact of Latent Heat Nudging on skill of 4km forecasts measured in terms of minimum scale of acceptable skill (Roberts and Lean)



# Use of observations in hourly 1.5km NDP assimilation

- 3D/4D-Var
  - Conventional data types: Surface, Satwind, SEVIRI, Aircraft, Sonde (Wind profiler 15 mins), GroundGPS (10 mins)
  - Newer novel data types: Radar radial Doppler winds (5 mins), Radar reflectivity
- Latent Heat and Cloud (moisture) nudging
  - MOPS surface precipitation rates – 15 minutes
  - MOPS cloud cover – 60 minutes

# Data availability in MetDB

Met Office

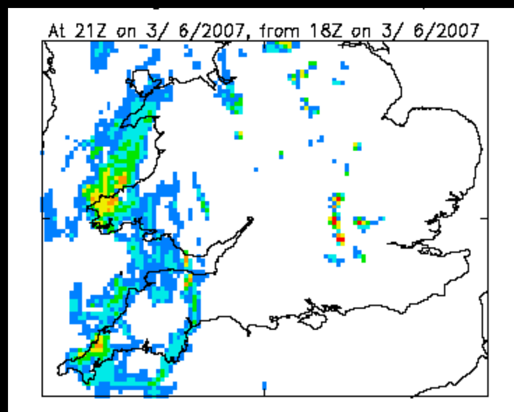
No. of obs available for 40 mins cutoff time on Q122 hourly cycle (22Z) 15 September 2009

| Observation Types | Raw | Surplus | Actual Use |
|---|---|---|---|
| Surface – LNDSYN<br>Surface – SHPSYN | 109<br>9 | 0<br>0 | 109<br>9 |
| Satwind – MSGWINDS | 30 | 0 | 3 |
| Aircraft – AMDARS | 21 | 4 | 17 |
| Sonde – WINPRO | 19 | 5 | 8 – one per hour |
| GroundGPS – GPSIWV | 465 | 36 | 24 – one per hour |
| Sonde – WINPRO | 19 | 0 | 13 – 15 mins |
| GroundGPS – GPSIWV | 465 | 0 | 60 – 10 mins |

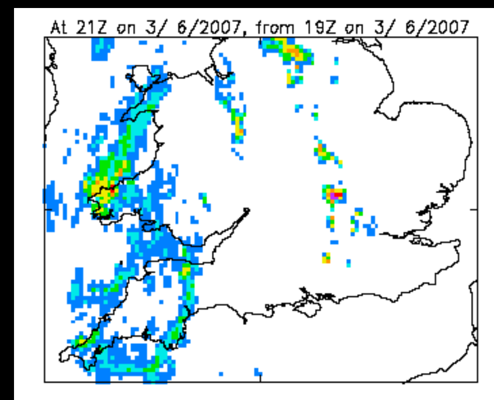
GoundGPS has a much later arrival time than other data types

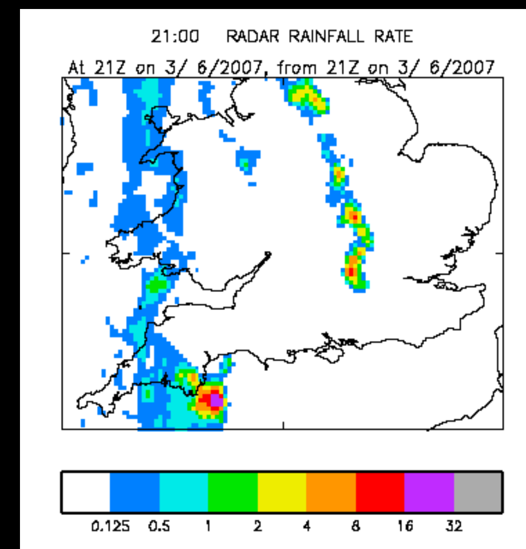
# Impact of hourly 4D-Var data assimilation Including latent heat nudging of 15min Radar derived rain rates – forecasts of surface rain rate valid at 21Z 3/6/2007

T+3

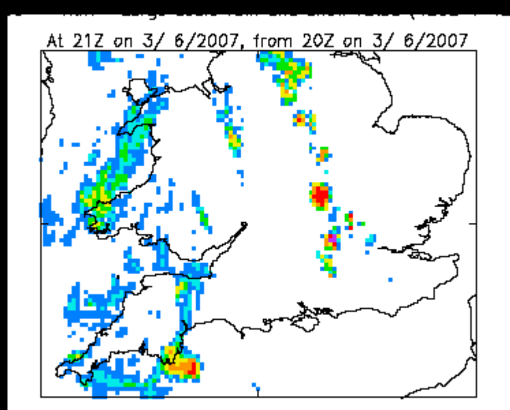



T+2

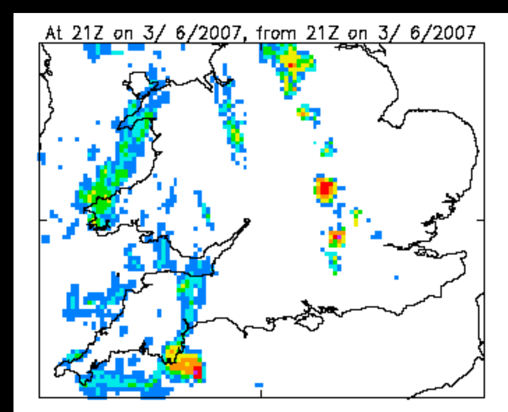



radar



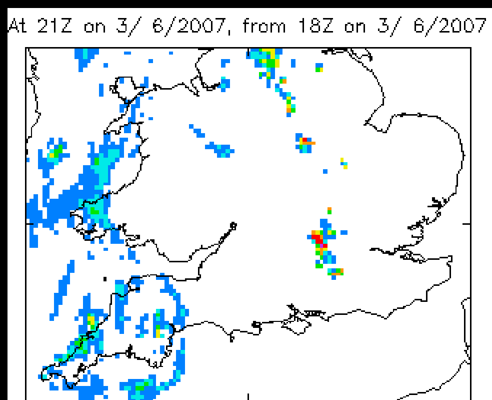

T+1



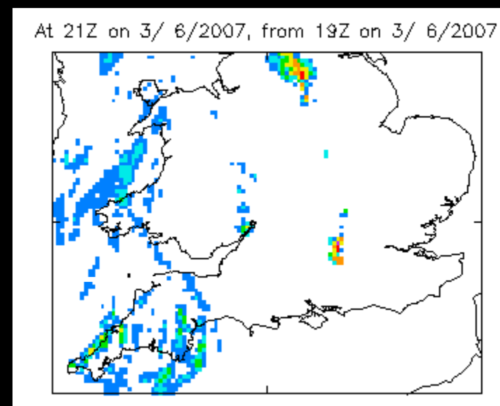

T+0

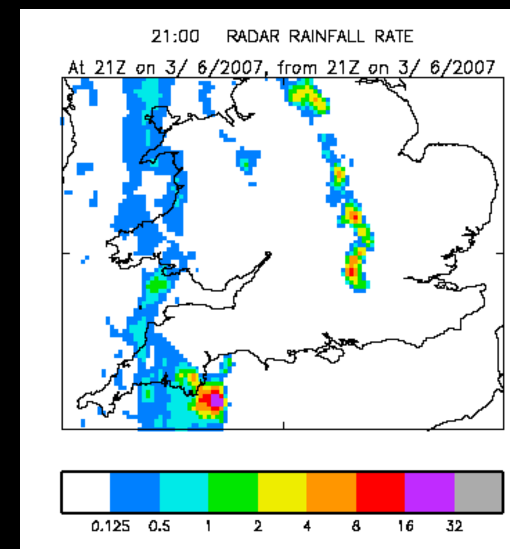
# Impact of hourly 4D-Var data assimilation +LHN Including WinPro and Ground GPS data – forecasts of surface rain rate valid at 21Z 3/6/2007

T+3

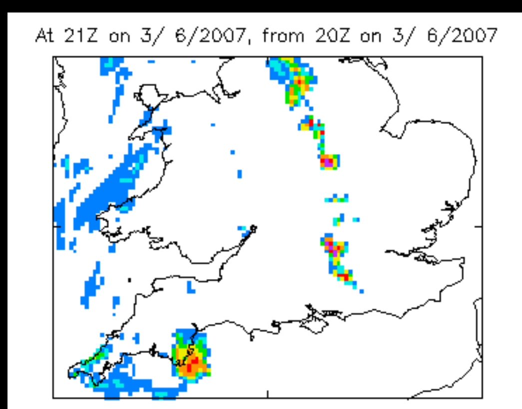



T+2

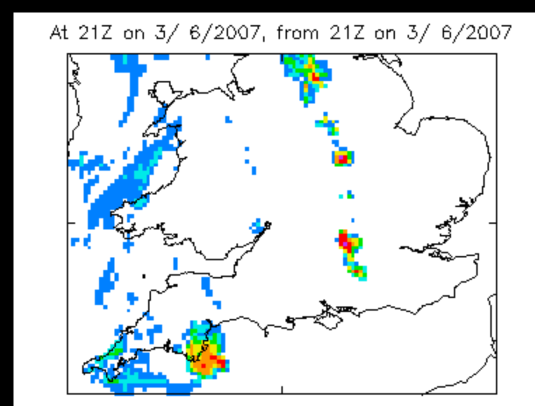



radar




T+1

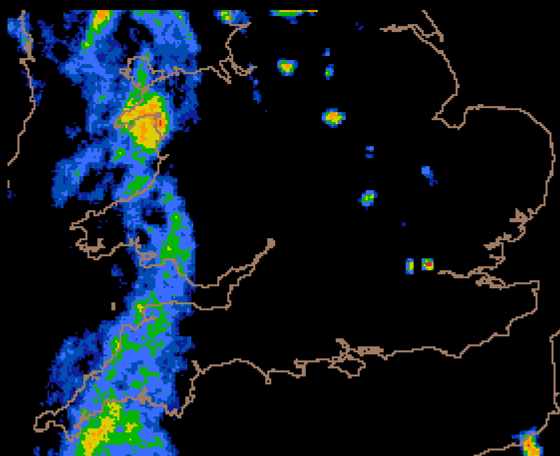



T+0

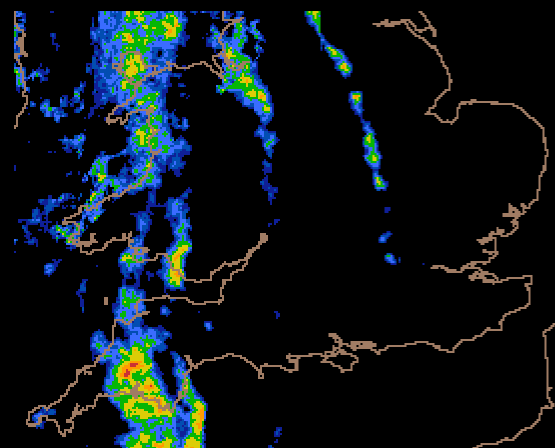
# UKPP – Met Office Nowcast – forecasts of surface rain rate valid at 21Z 3/6/2007

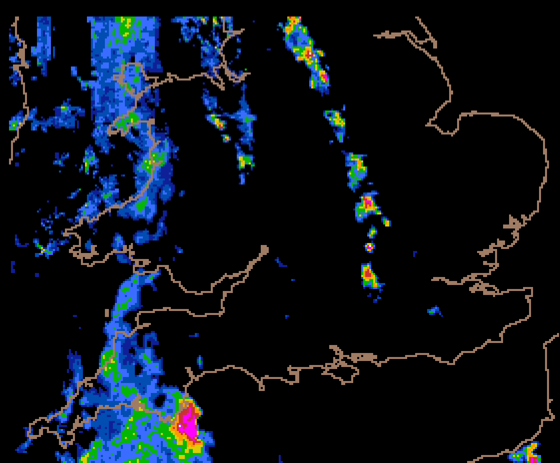
Met Office

T+3

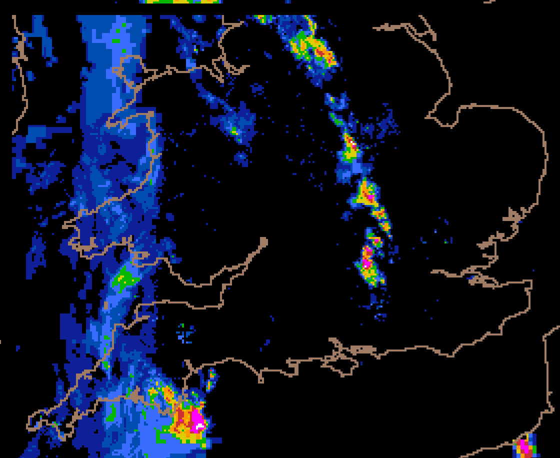


T+2

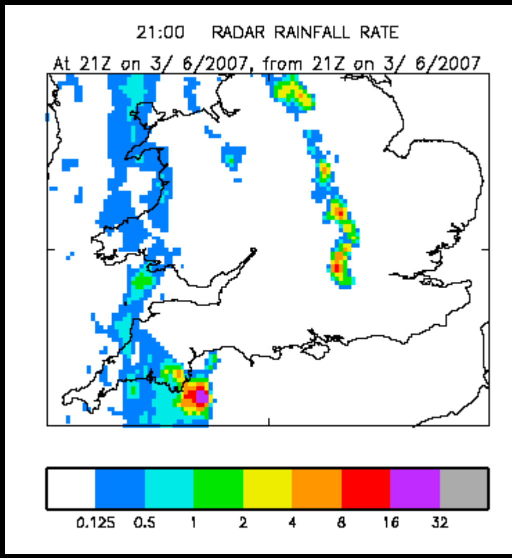




T+1



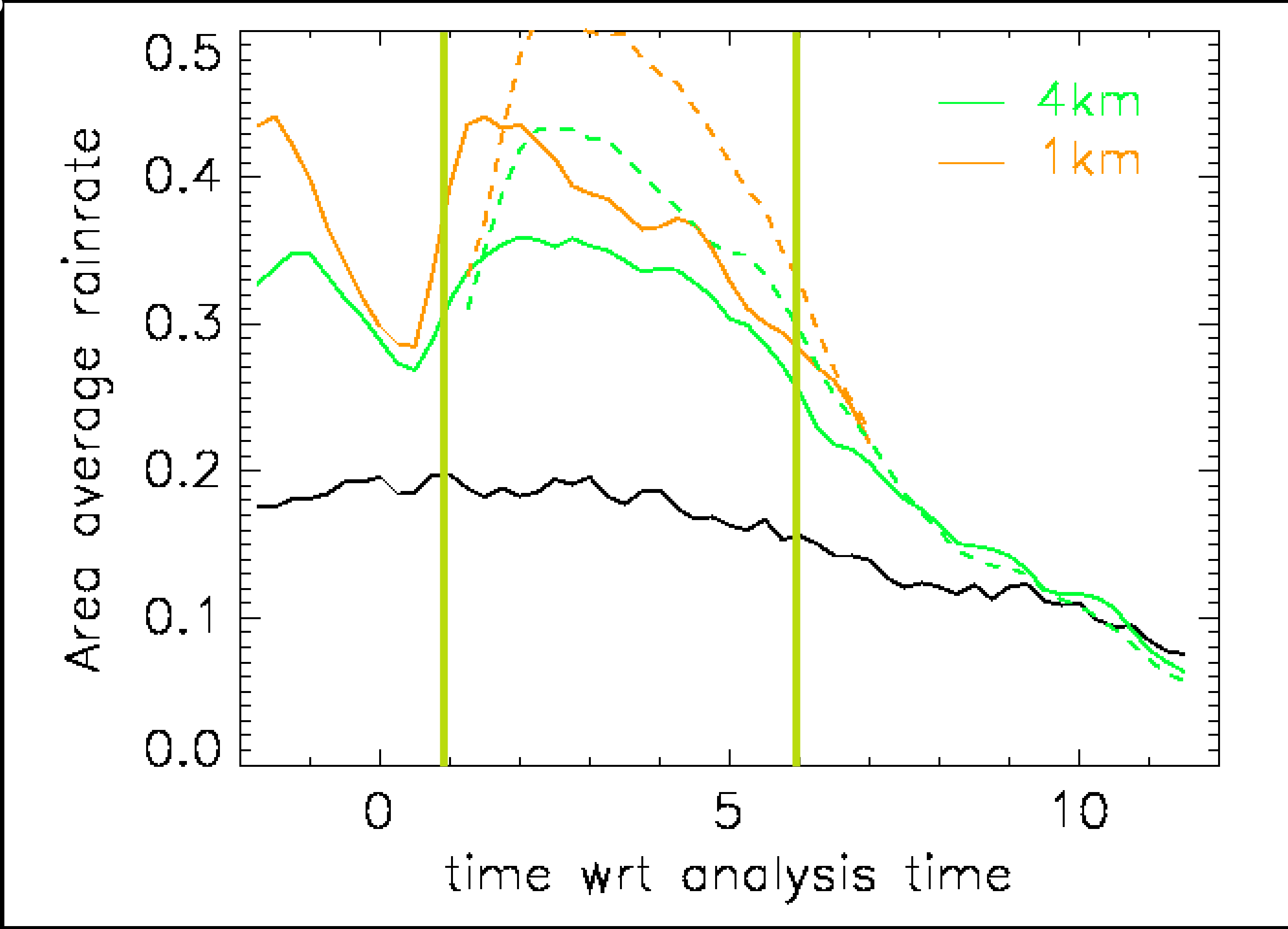
T+0




radar

# Time-dependent model domain averaged rainfall rates in 2005 Cases

- Over-prediction in both DA and spin-up runs



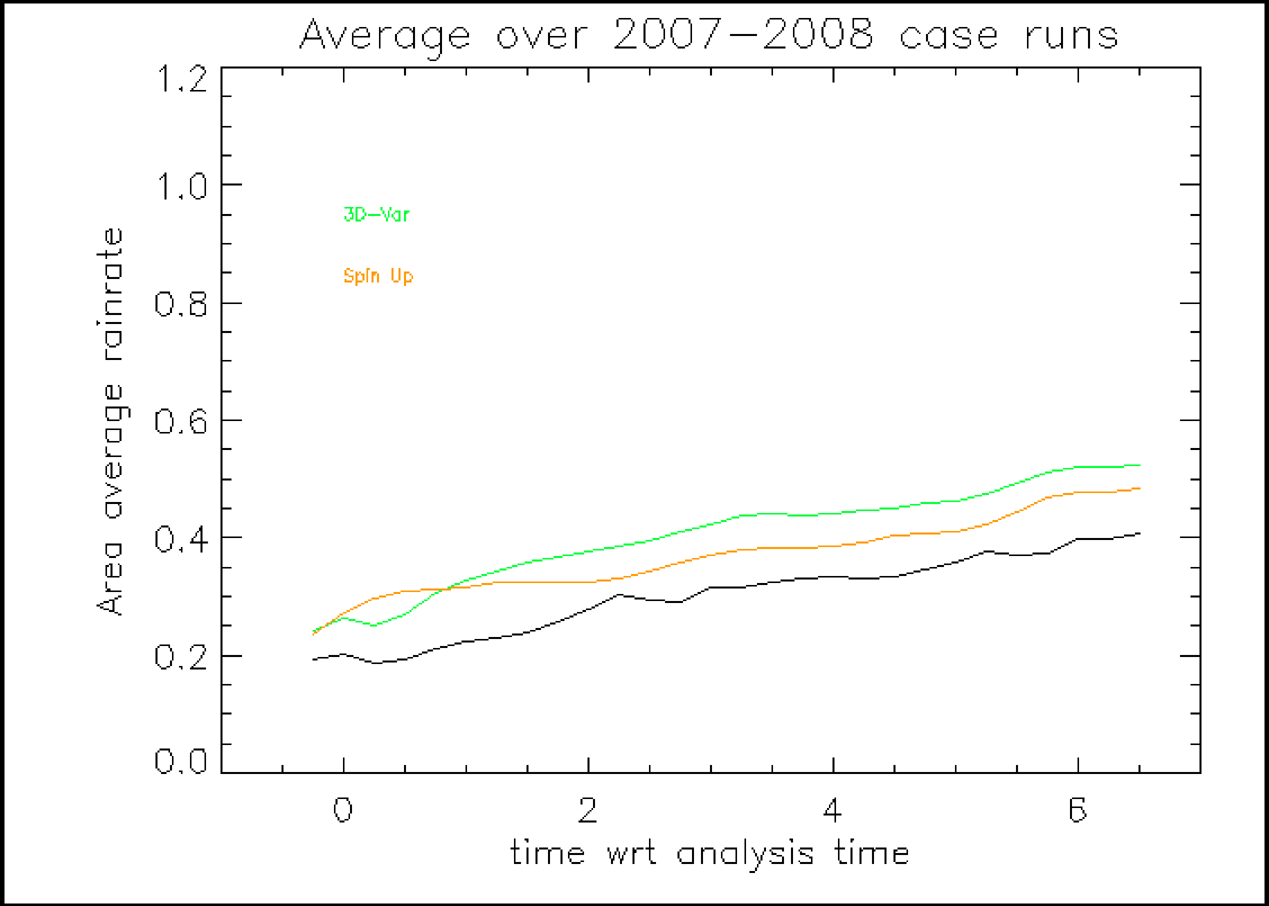

Spin-up 4km model

Spin-up 1.5km model

Radar

# Time-dependent model domain averaged rainfall rates in 2007-2008 Cases

- Over-prediction in both DA and spin-up runs, but look better than 2005 case runs




1.5km 3D-Var

1.5km Spin-up

Radar

# radar derived rain rates

- Latent Heat Nudging
  - Met Office - 1996 onwards
    - Now – Unified Model
    - Operational - 12km with 4DVAR and 4km and 1.5km with 3DVAR
    - Research - 1.5km with 3DVAR and 4DVAR nowcasting
      - CAWCR (Aus)
  - COSMO - Meteo Swiss and DWD and Arpa Italy – nudging DA
- Direct Assimilation in 4DVAR
  - Met Office research - European Reanalysis – accumulations?

# Radial Doppler Winds

- Met Office – operational  UK4km and UKV
  - trials 1.5km nowcast
  - Insect winds - Reading Univ and CAWCR (Aus)
- FMI – HIRLAM - monitoring
- Meteo France – AROME - operational
- DWD – COSMO - monitoring

Met Office

Need East Anglian Radar

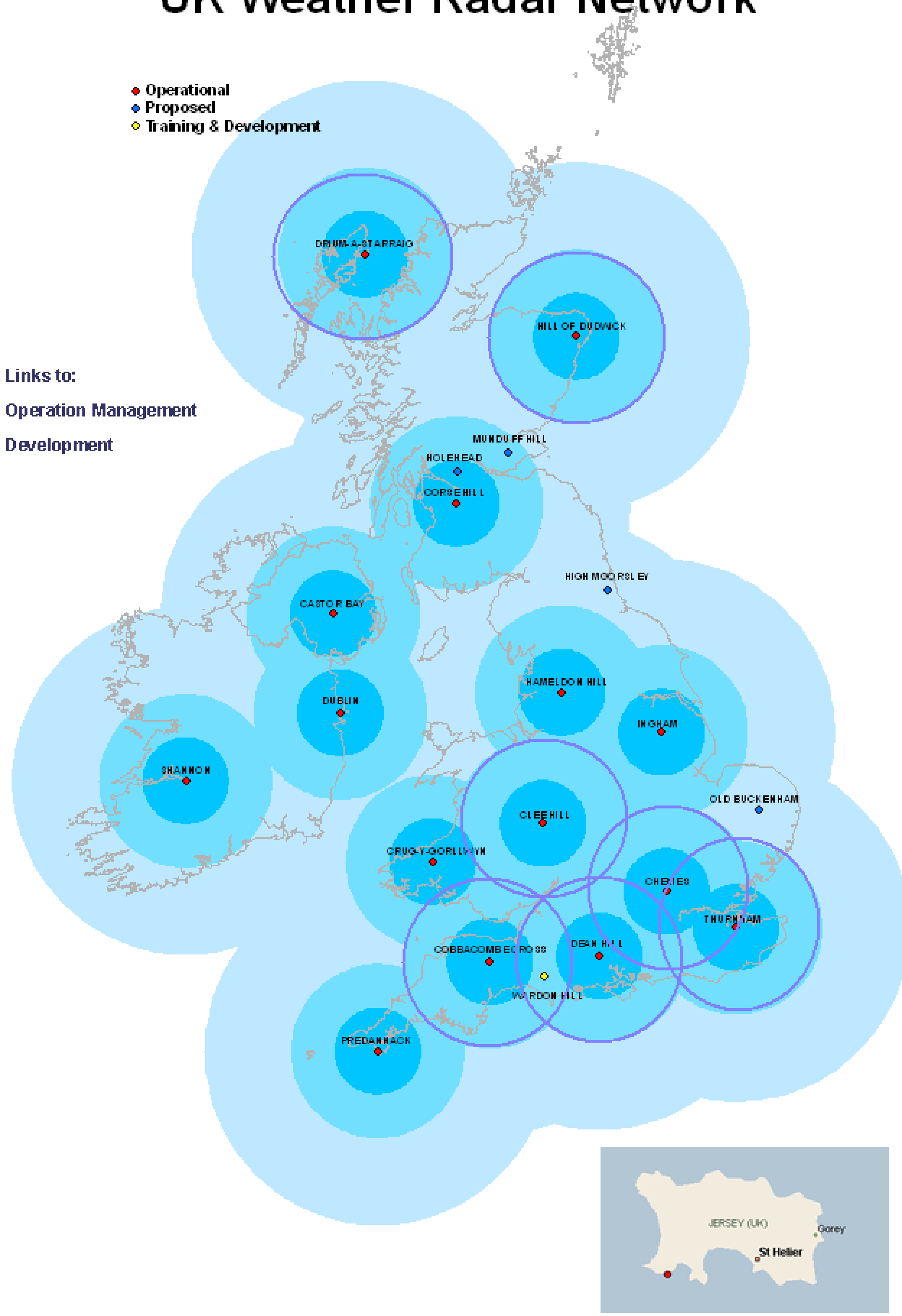
**1km resolution**

**2km**

**5km**

Purple circles are Doppler radars

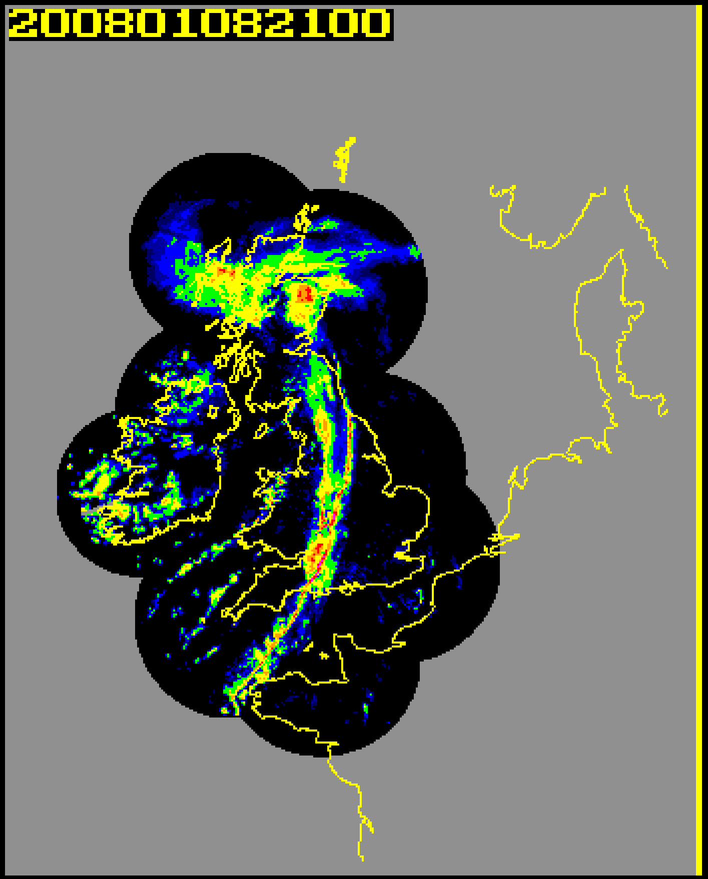
# UK Weather Radar Network



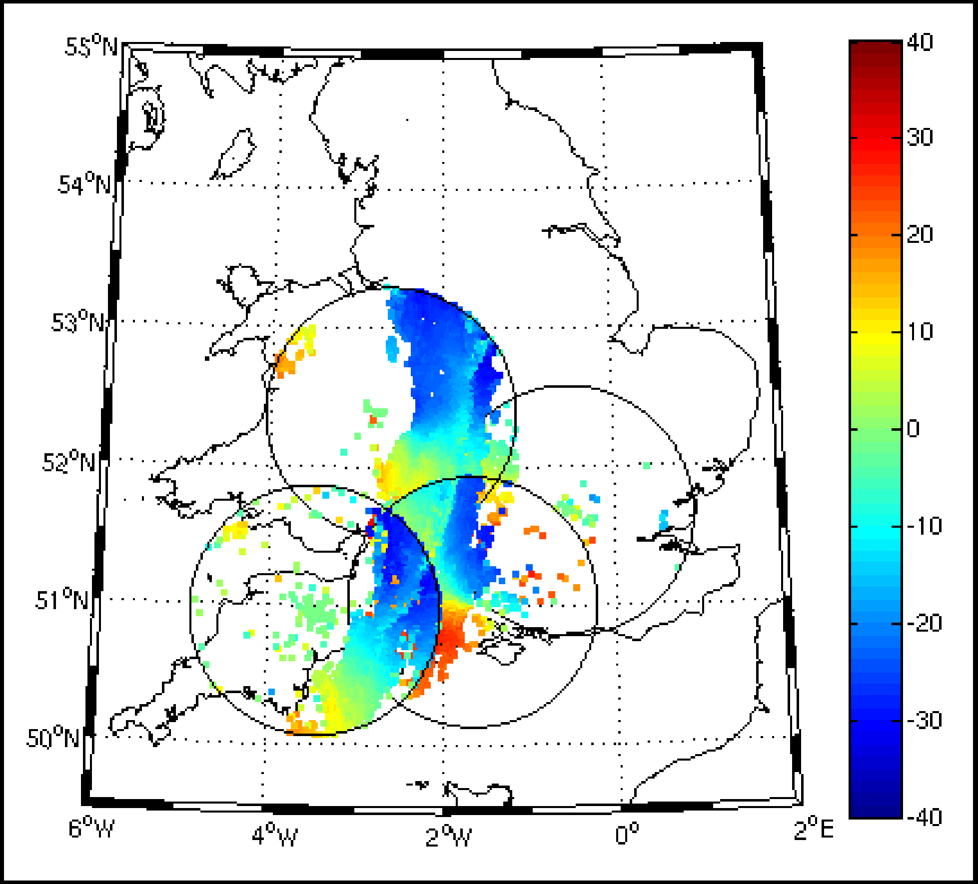
# Use of Novel observation types
# - Radar Doppler Winds – David Simonin

## Some dual and triple doppler coverage

Radar rain rates 08/01/08 21UTC

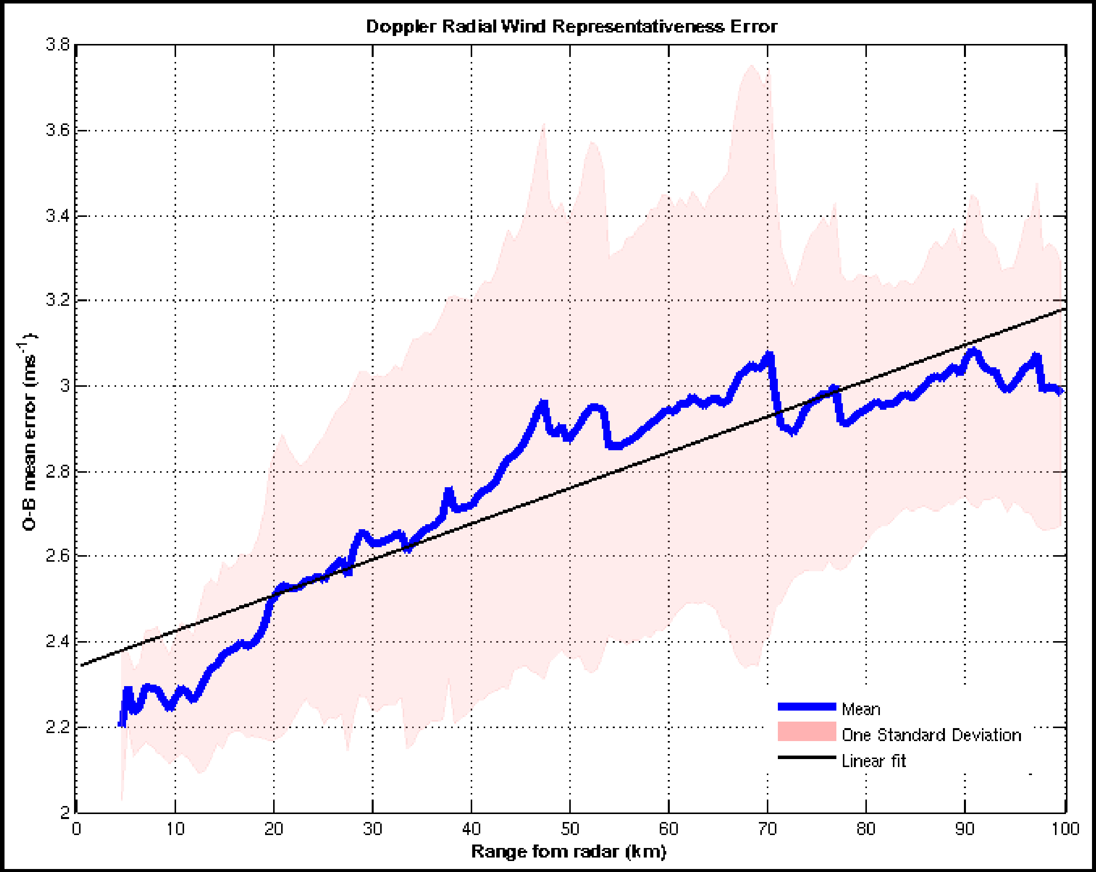



Radar doppler winds

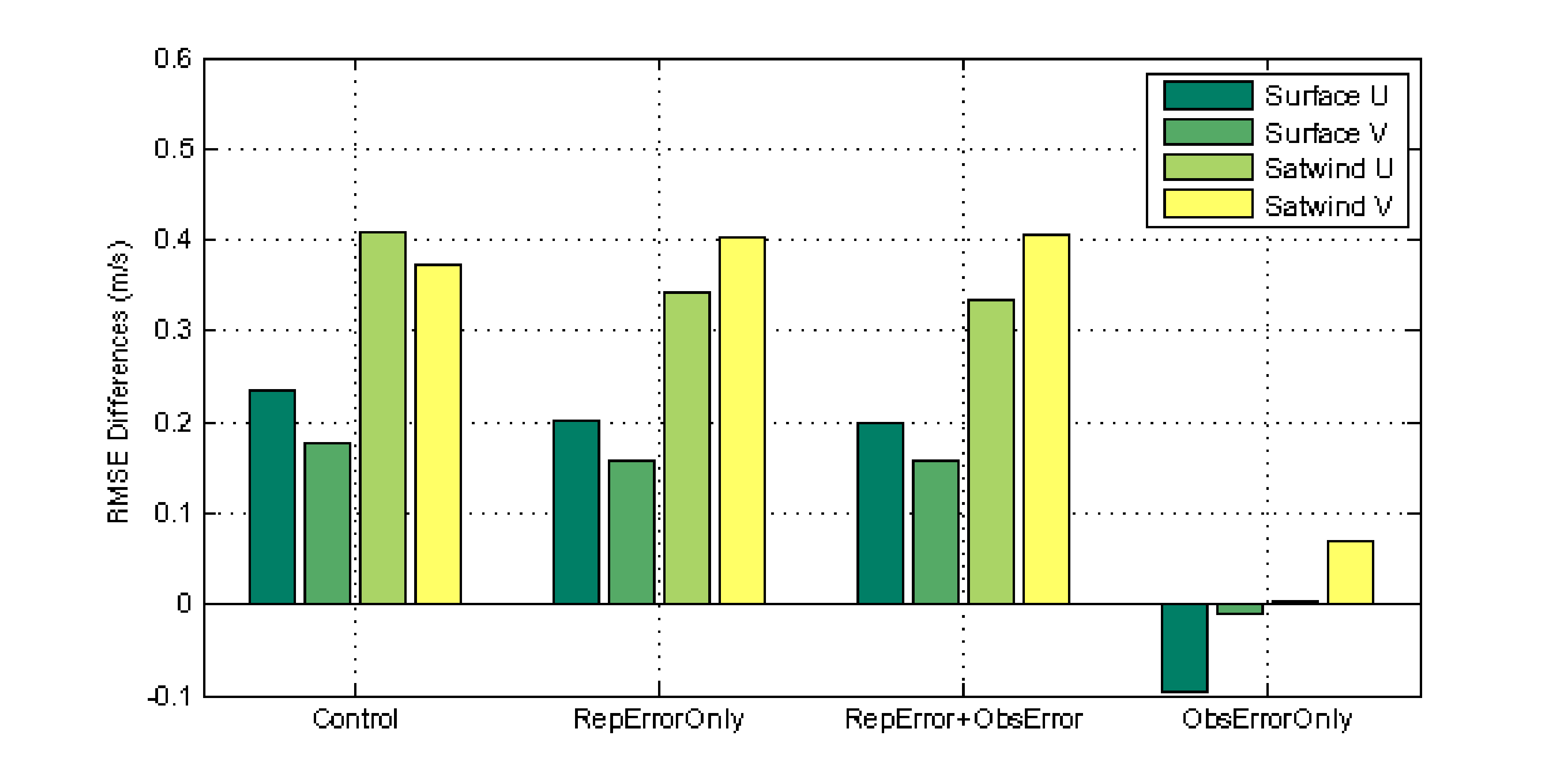


# Doppler Wind Representativeness Error

- 4 months of data
- Increase with range
- Range from 2.4 to 3.2 m/s



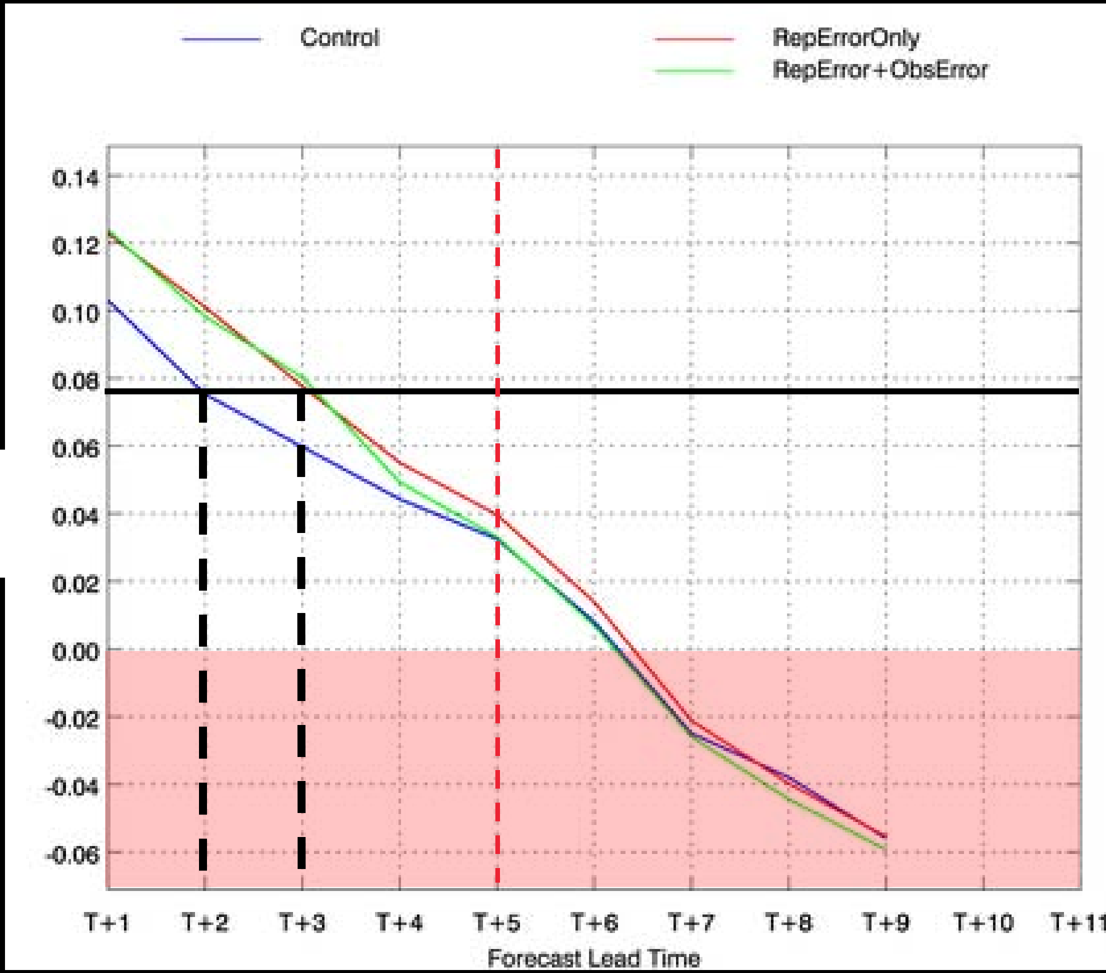
# Assimilation with Rep. Error RMSE differences



# Fractional Skill Score – Roberts and Lean

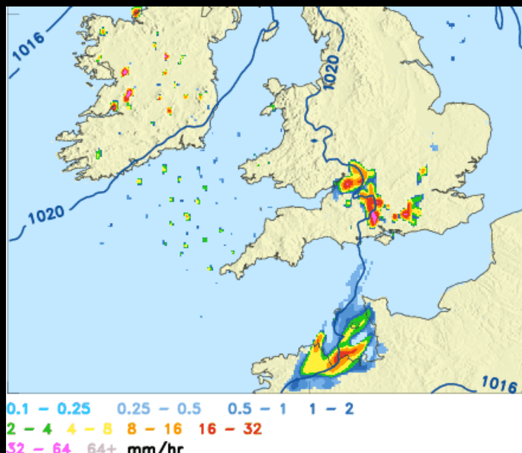
ΔFSS – 0.2 mm acc – scale 55km

Forecast skill is improved at low rain (~ 1 hour gain)

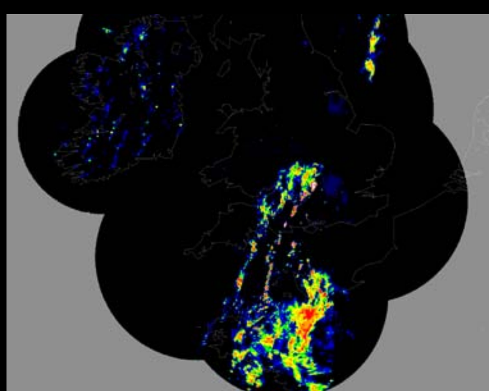


# Precipitation and Insect Winds

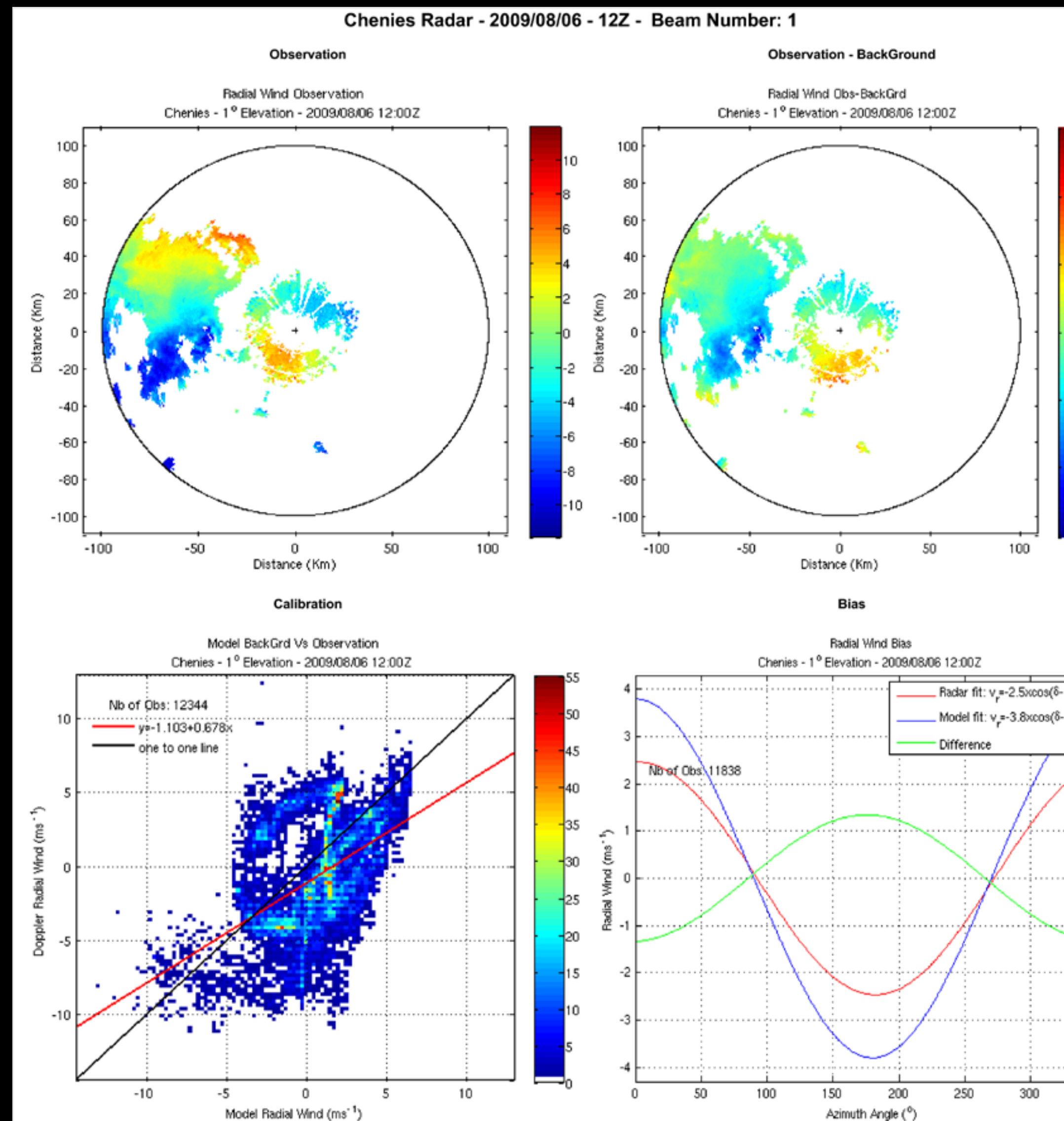
12UTC 6 Aug 2009 – precip left, insect centre




T+3 4km f/c with erroneous precip due to LHN of insect returns?



Derived rain rate includes insects



# Radar reflectivity

- Meteo France – 1+3DVAR nearest neighbour
- Met Office – indirect assimilation – 3DVAR
  - Met Office 1D-Var and collaboration with KMA/WRF
  - T, q  profiles
  - 1D-Var uses model background like old SATEMS
- Met Office – direct assimilation – 4DVAR

# Radar Refractivity

- Reading University and Met Office
  - data derivation
  - comparison with synops and GPS and model
- Future
  - Assimilation – change over 1 hour or shorter (?)
  - Direct  assimilation of phase change?

# Geostationary satellite and other observations

- Clear and cloudy radiances
  - Skin Temperature diurnal bias
- Ceilometer data
  - Derived cloud base and cover already used in 3D cloud cover analysis, future direct use in Var and also raw data
- Wind Profiler – need low mode – high vertical resolution boundary layer data
- Cloud Radar ?
- Microwave radiometer ?

# GPS, Amdar, radiosonde and surface data, AMV

- GPS arrives too late for nowcasting
- AMDAR – Easyjet flights to provincial airports
- Radiosonde – could get extra vertical resolution from 2 sec data, flight path
- 1min surface data – representativeness errors – convective v stable situations
- High resolution AMV
- Open road observations – other government agencies

# Background Errors

- Current long correlation length scales 90-180km
- Need  to derive errors for convection scale
- Ensembles – ETKF or lagged ensembles
- need  to separate synoptic and convective scale information
- Consistent boundary conditions and large scale analysis
- Vertical spread of information – how to use information on boundary layer depth

# Other Scientific Challenges

- Matching the observations during the assimilation cycle and first 2 hours of forecast
- Balance and control variables, adaptive vertical grid
- Precipitation bias in rates and area – data assimilation and modelling problems. Model too cellular – maybe need for more 3dimensional parametrizations?
- Computer resources
- Need to compare observations with UM and assess derived variables with use of direct observations
- Land surface/coupled DA

# Conclusions

- Operational  convective scale NWP beating advection type precipitation nowcast from about T+2.5hours
- Progress being made moving to direct use of radar from research to operations
- However many challenges still to extract the full benefit from the  radar data and other observations
- Only just getting access to observations to test real benefit in NWP-based nowcasting

# Questions and answers

# Fraction Skill Score (FSS)

Met Office

Fractions 'Brier' score FBS (mean square error)

$$FBS = \frac{1}{N}\sum_{j=1}^{N}(p_j - o_j)^2$$

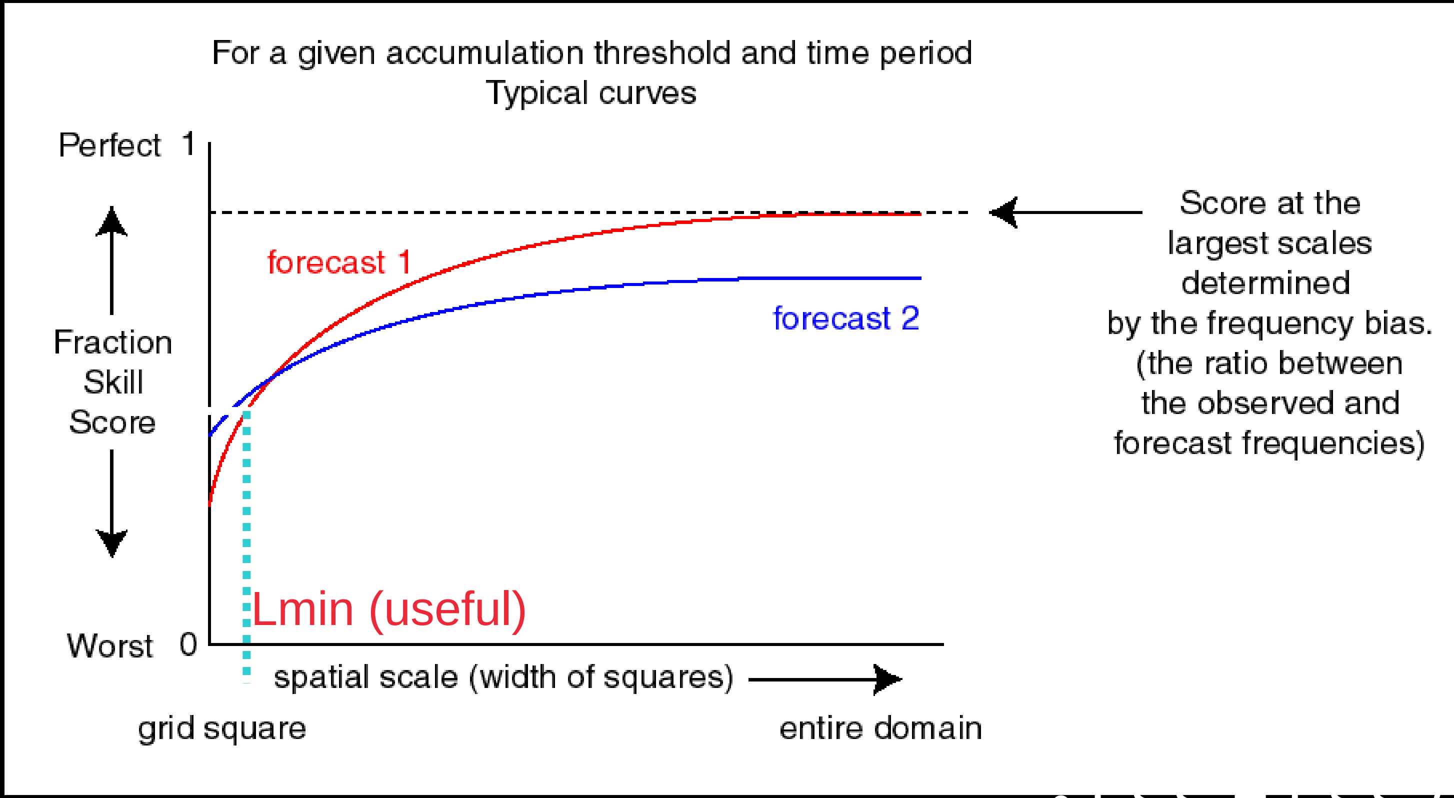
$0 \leqslant p_j \leqslant 1$ forecast fraction

$0 \leqslant o_j \leqslant 1$ radar fraction

Fractions skill score FSS

$$FSS = 1 - \frac{FBS}{FBS_{worst}}$$

# Fraction Skill Score (FSS)




1

• FSS = FSS (L) by changing sampling squares, L

$FSS_{target}$ is half way between perfect and random f/c

From Nigel Roberts