Precipitation Assimilation: a review and latest developments at the Met Office

Lee Hawkness-Smith

MetOffice@Reading

EWGLAM / SRNWP 1 October 2018

Overview

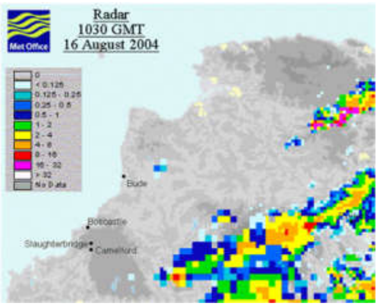
- Motivation
- Precipitation observations
- Quality control
- Assimilation methods
- Progress at the Met Office

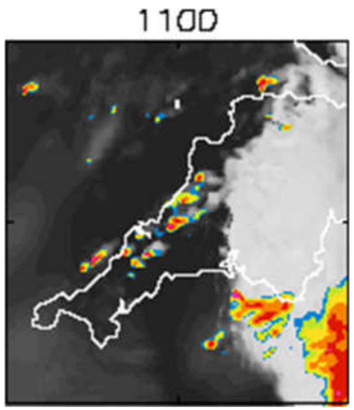
Why assimilate precipitation?

Nowcasting: forecast hazardous weather and precipitation *quantitatively* and *promptly*

~ to T+6 within 15 minutes of data time

Nowcasting techniques





Extrapolation

- ✓ Quick and simple technique
- × What about orographic enhancement, mesoscale dynamics, etc. ?

NWP

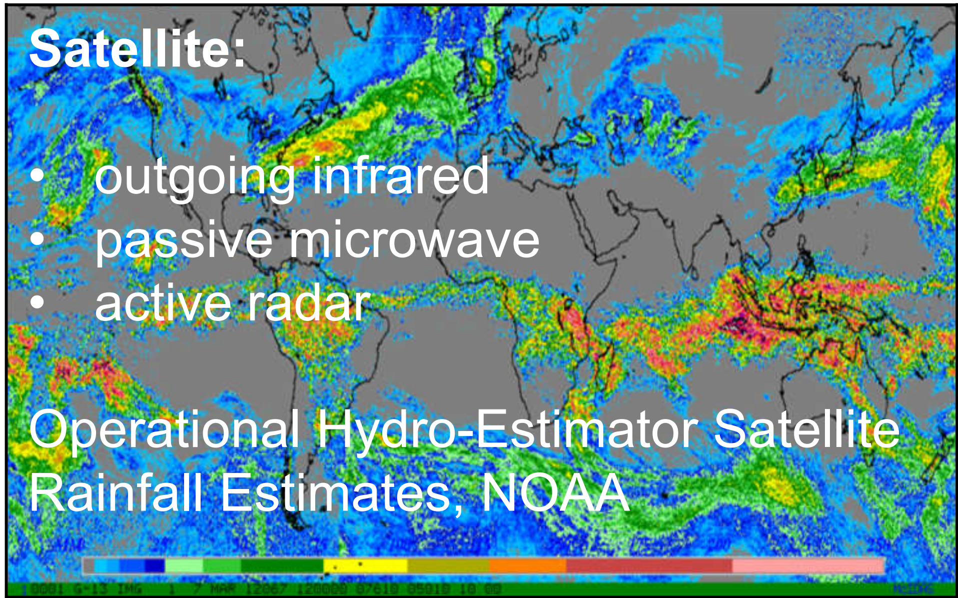
- ✓ More physically realistic modelling of the evolution of weather events
- × Requires high spatial and temporal resolution modelling and data assimilation, and therefore rapid collection, processing and dissemination of large data volumes – takes time to compute and to spin-up

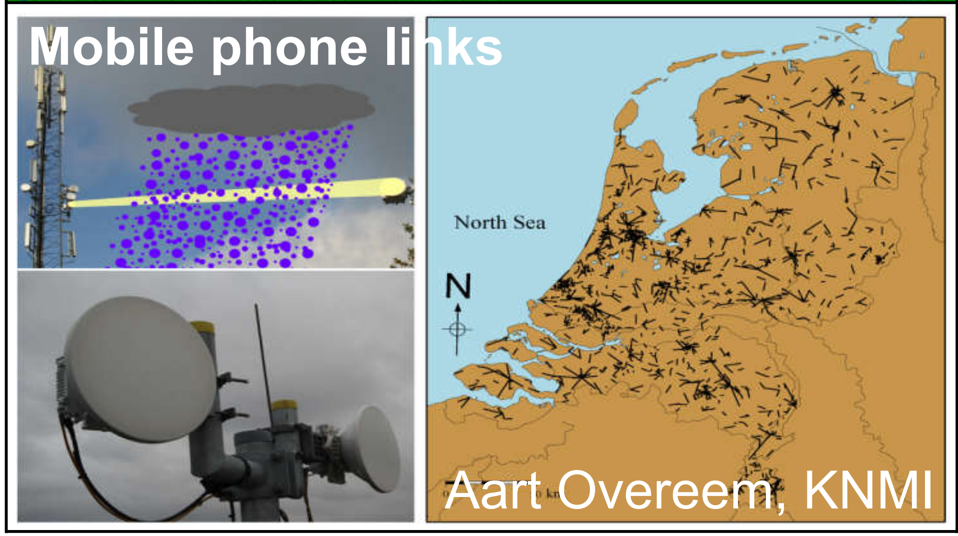
Merged

- Use best available data at given forecast time

Met Office

Precipitation observations





Quality control issues for radar

Met Office

wet radome

attenuation

anomolous propagation

-NOISE-

P rti l beamf ll ng

Data assimilation techniques used for precipitation

- **Physical initialization**
  Modify moisture and temperature fields to be consistent with observed precipitation rates
- **Latent heat nudging**
  Rescale model latent heat profiles by the ratio of observation / model precipitation ratios
- **1D-Var+3D/4D-Var**
  Use a 1D variational method to generate temperature and humidity increments for assimilation in 3D or 4D-Var
- **Incremental 4D-Var**
  Minimise the differences between the model and observations by iterating a simplified, linear model
- **Full-fields 4D-Var**
  Iterate a full non-linear forecast model in the minimisation – very expensive!
- **Ensemble methods**
  Use ensemble members to represent background error covariances

Latent heat nudging

- Proven to be effective at improving precipitation in first few hours of forecast
- Latent heat increments may not be dynamically consistent with analysis
- Relationship between surface precipitation and latent heat release in model column may break down at high resolution
- Does not use full 3D information from volume scans, only derived surface rainrates
- Deriving surface rainrates leads to further errors
- Must maintain another system

Latent heat nudging of surface precipitation, Met Office

C D Jones and B Macpherson

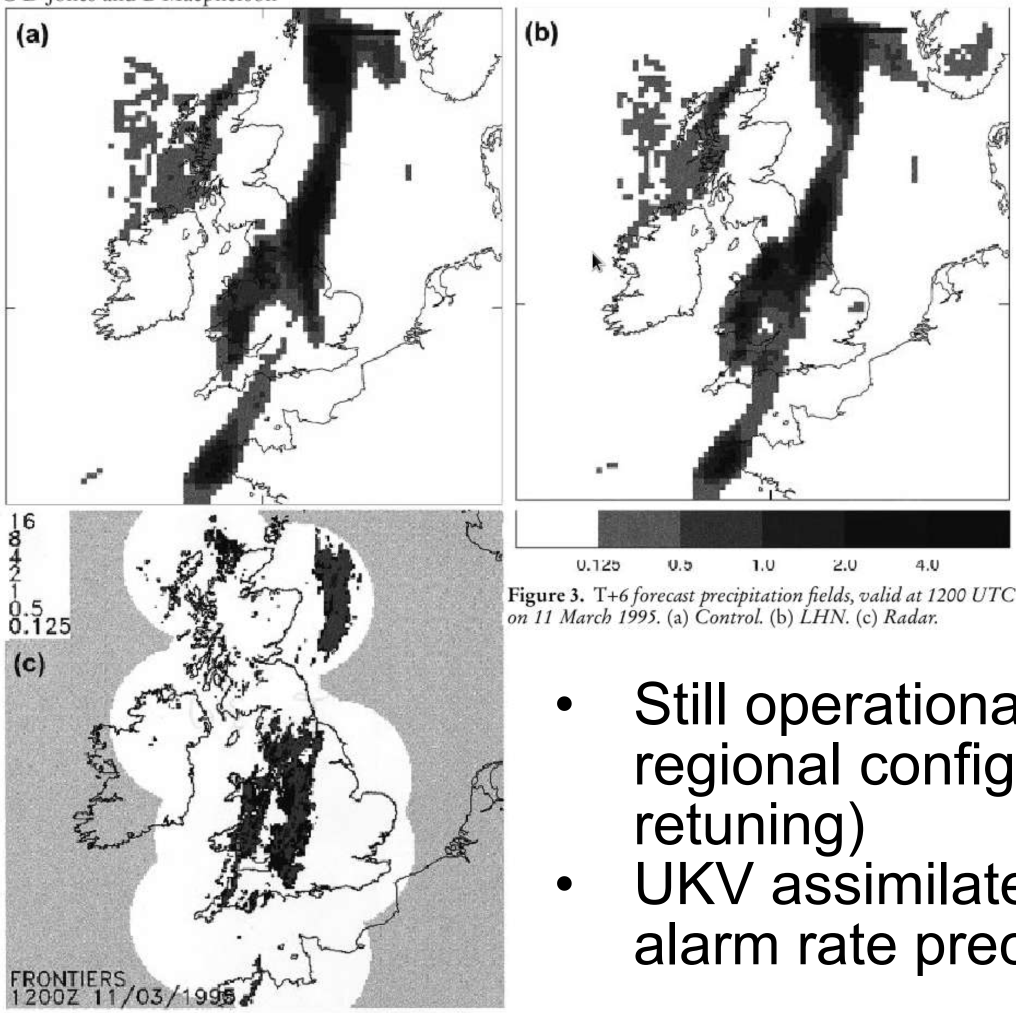


Figure 3. T+6 *forecast precipitation fields, valid at 1200 UTC on 11 March 1995.* (a) *Control.* (b) *LHN.* (c) *Radar.*

- Still operational in UKV and other regional configurations (with retuning)
- UKV assimilates Euro Low False alarm rate precip every 15 minutes

Jones & Macpherson (1997)

1D-Var+3D/4D-Var

- Assimilate observations in a consistent framework with other observation types
- Avoid handling the non-linearities of radar reflectivity observations in the full 3D/4D-VAR
- Double use of background information may reduce impact of observations and reinforce incorrect features in the model
- Information loss as observations treated in a column

1D-Var+3D-Var assimilation of radar reflectivities, Météo-France

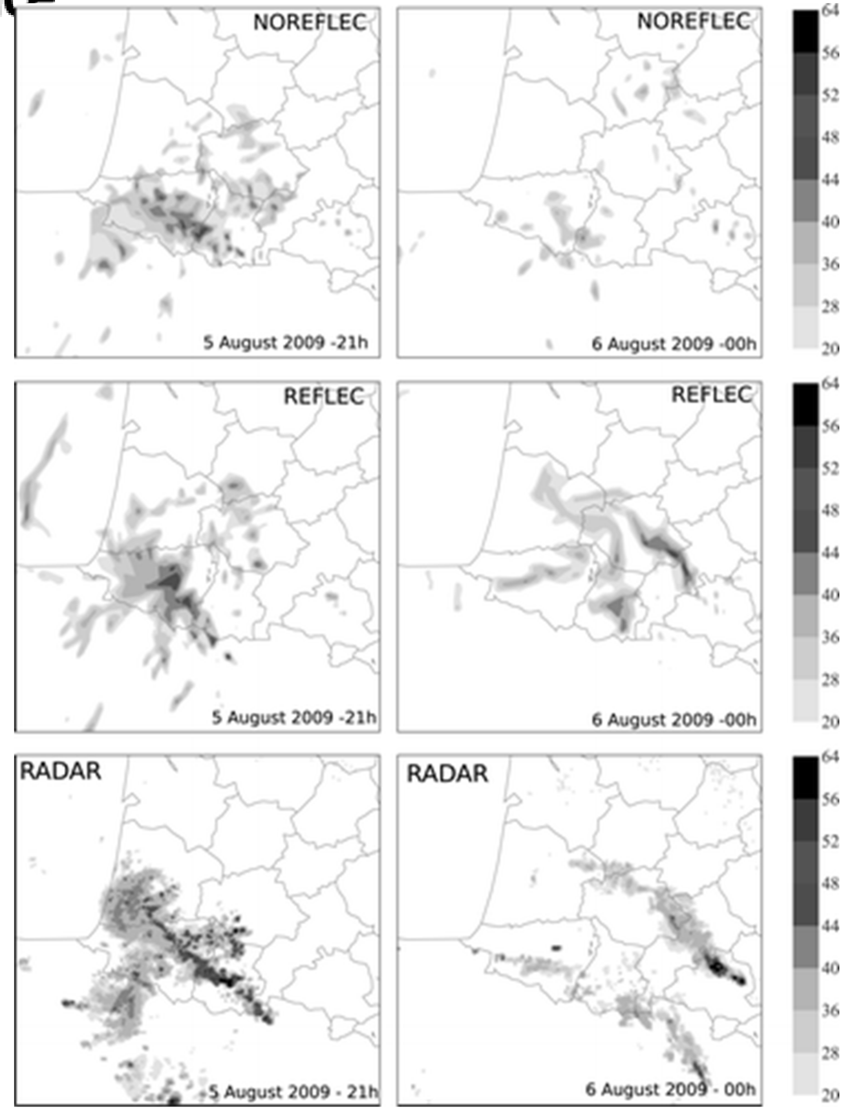


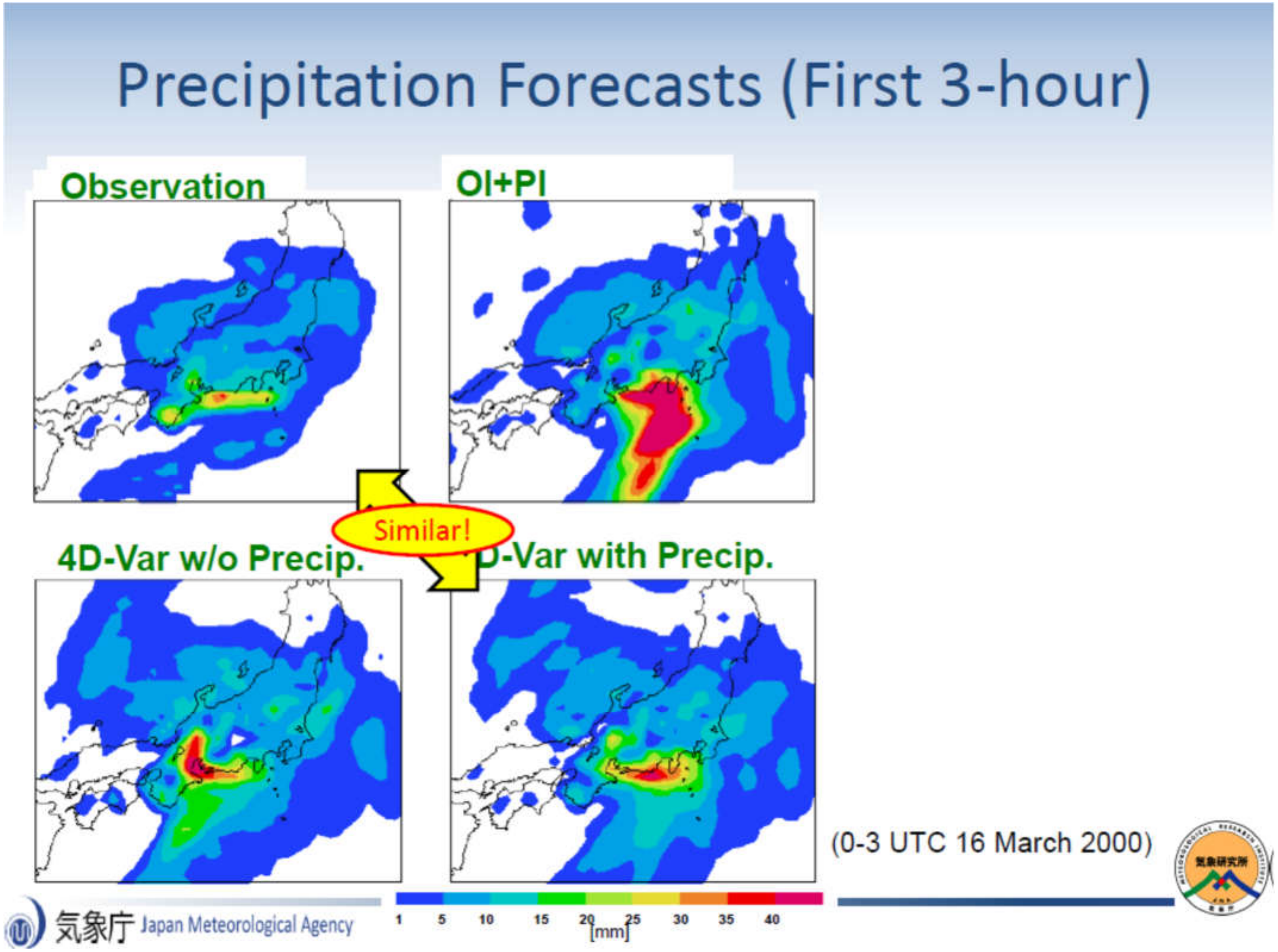
Fig. 14. Comparison between (middle) REFLEC and (top) NOREFLEC of the model reflectivity field at 2000 m MSL, and from the 3-h forecast on the (top and middle left) 2100 UTC 5 Aug 2009 and (top and middle right) 0000 UTC 6 Aug to the (bottom) radar composite.

Wattrelot, et al. (2014)

4D-Var

- No a priori diagnostic adjustment of moisture or heating rate
- Directly assimilate all observations together in a consistent framework
- (Aim for) consistency in microphysics
- It has worked well for satellite radiances
- Requires a simple (for convergence) yet physically reasonable adjoint model – challenging for precipitation processes
- How do we assimilate observations when the background has zero rain?

4D-Var assimilation of hourly surface precipitation, JMA



Koizumi (2018)

Ensemble methods

- For pure ensemble methods, no linearisation or adjoint required
- Direct use of flow dependent covariances
- More suited for massively parallel computing
- Limited ensemble size due to computational constraints means localization required
- No members may have precipitation

EnKF assimilation of 3D radar reflectivities, DWD

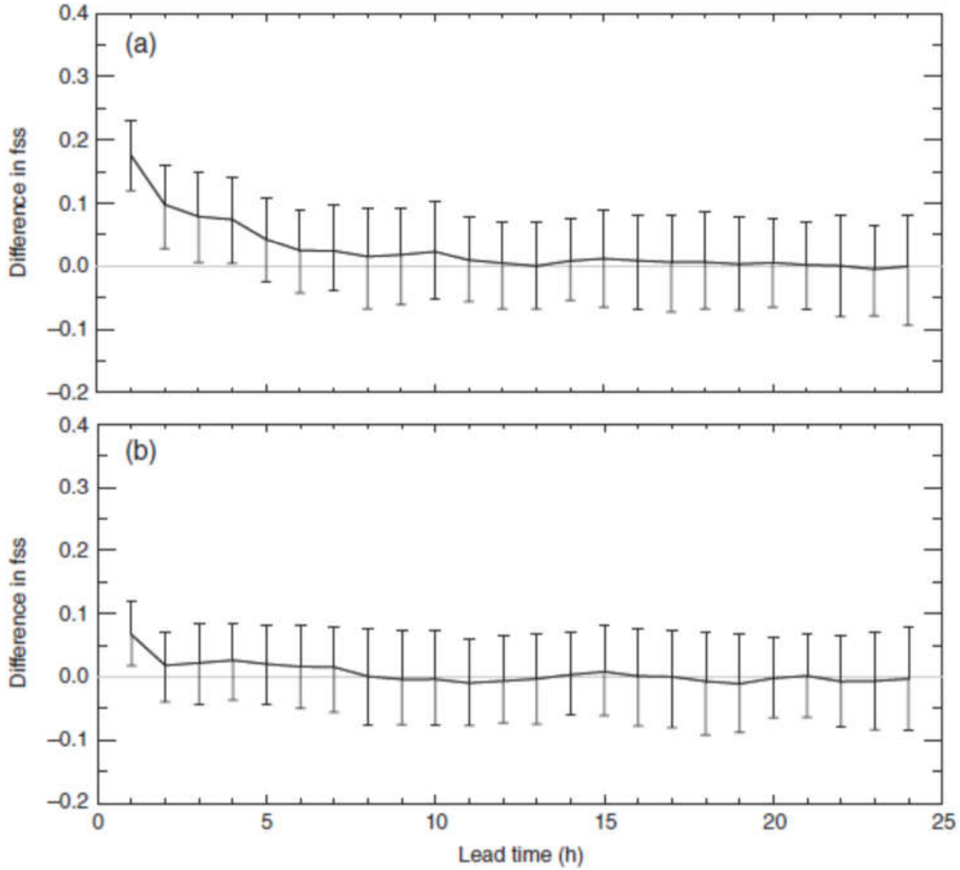
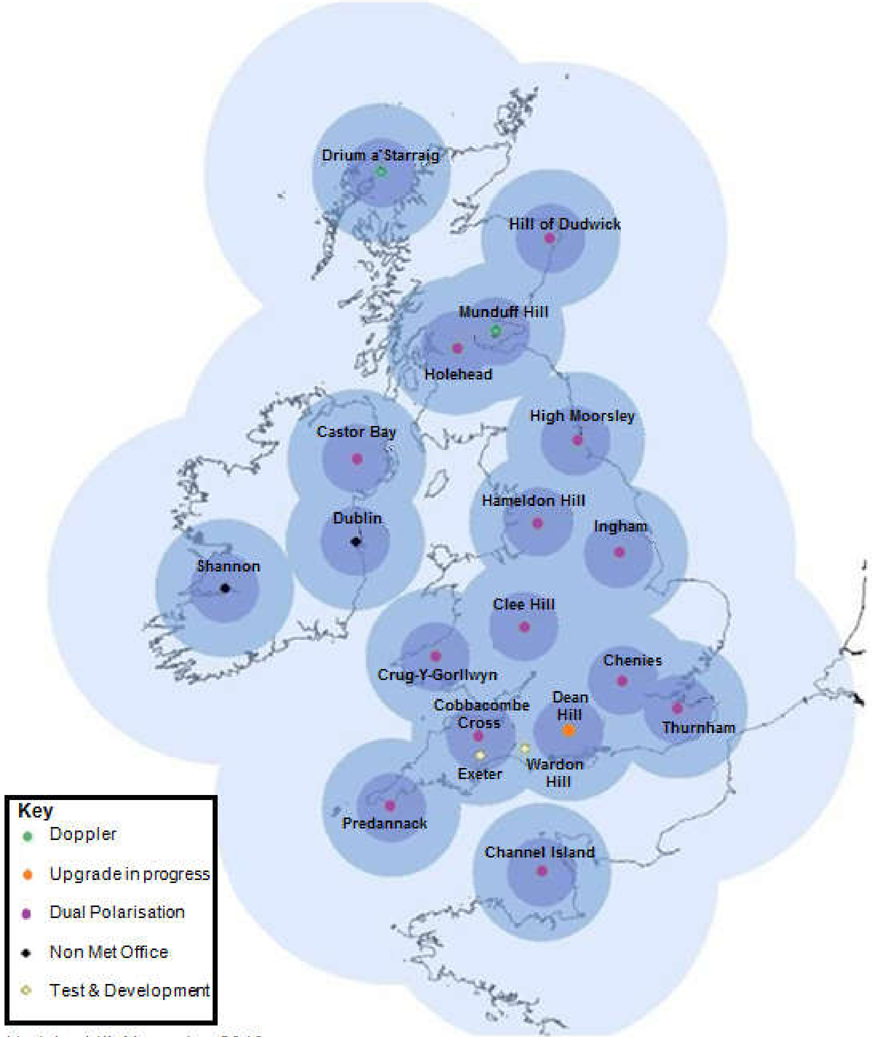


Figure 9. The difference in Fraction Skill Score (FSS) against forecast lead time over the 29 deterministic forecasts: (a) CONV+RAD minus CONV and (b) CONV+RAD minus CONV+LHN. The FSS is calculated for a neighbourhood of five grid points (in each horizontal direction) and a threshold of 0.5 mm h^{-1}. The error bars are obtained via bootstrapping (2.5 and 97.5%iles).

Bick et al. (2016)

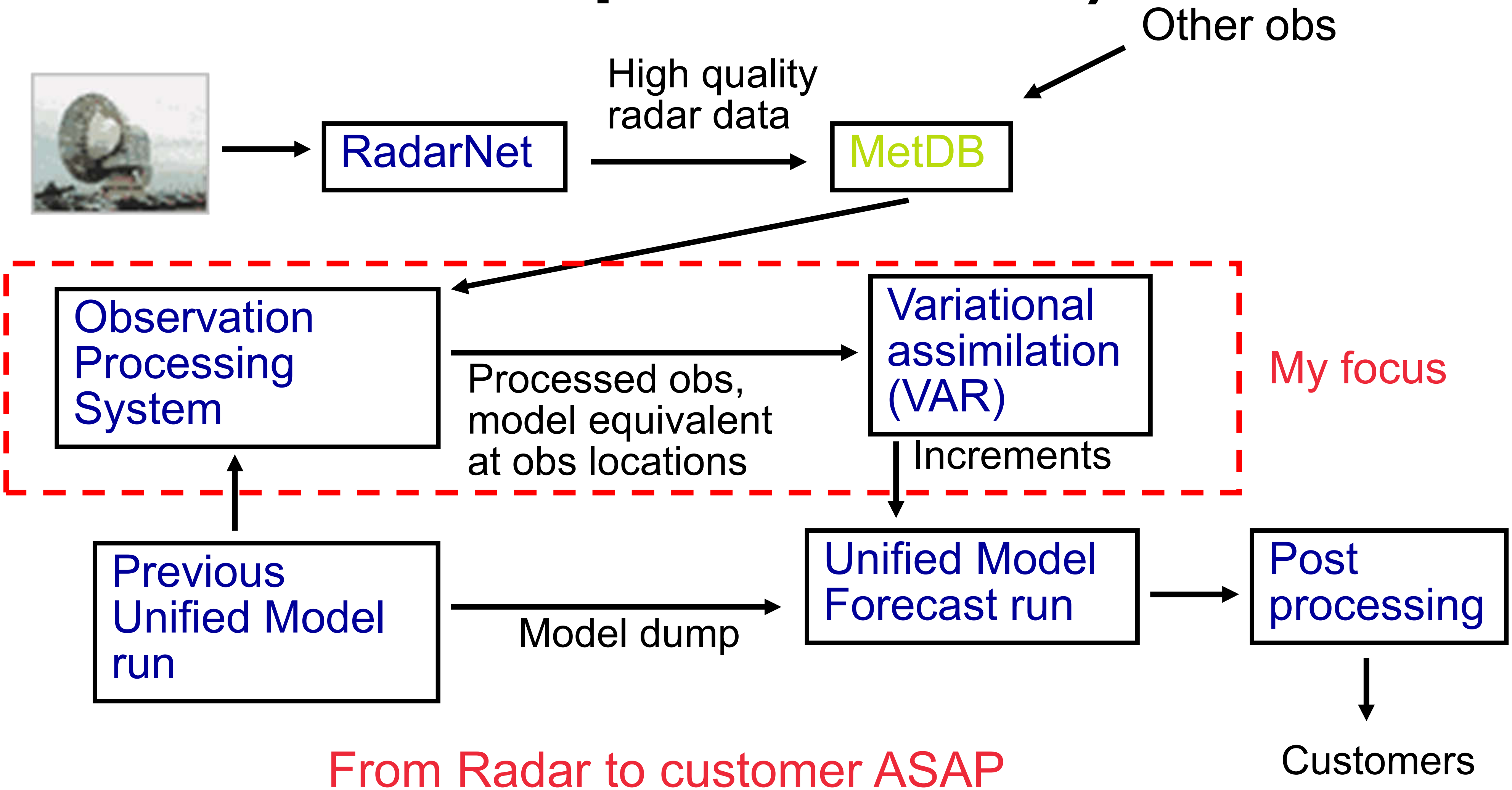
The UK Radar network

- 18 operational C-band weather radars in the British Isles
- All UK radars now Doppler capable
- Up to 5 long-pulse reflectivity scans every 5 minutes out to 250 km
- Doppler scans every 10 minutes
- Dual-polarization upgrade complete
- 3D data from all radars in UK network available for assimilation



Update: 14th November 2016

NWP production process (from a radar data assimilation scientist point of view)



From Radar to customer ASAP

OPS processing of radar reflectivity: extraction and processing

- Flags generated in RadarNet used to reject non-hydrometeorological echoes: clutter, speckle, beam blockage
- Dry observations and noise accepted
- Circle superobbing and Poisson thinning applied as with Doppler, but with broader superobs and sparser thinning. Dry obs can be thinned sparser than precip.
- Model QC: reject obs where background T > 3C, to avoid bright band melting layer. No other model QC.
- Observation error currently specified as 2 single numbers, one for dry, one for precip. Use ½ (O-B) from first trials for precip.

4D-Var reflectivity assimilation scheme: Include 3D reflectivity in hourly UKV

PF model:

Autoconversion-like term from diagnostic cloud water, rain falls out in single timestep (no evaporation)

Cloud increments related to background cloud fraction

Linearity assumption is poor for precipitation: keep assimilation time window short

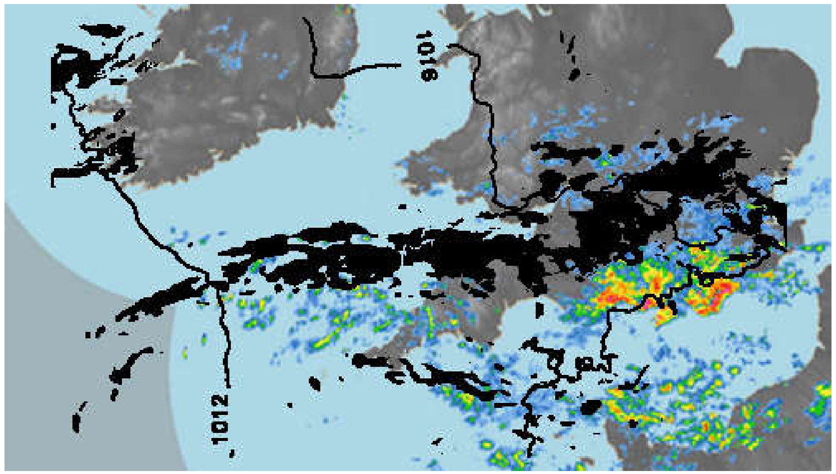
Radar Reflectivity operator:

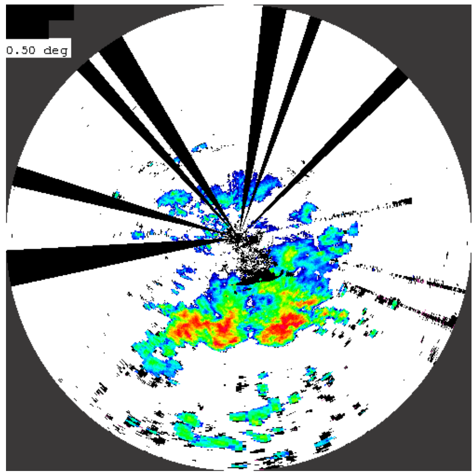
Current operator uses interpolation to a point and simple Z-R or Z-q_r relation for rain (no assimilation of ice yet)

Unified Model has reflectivity diagnostics,
still need a simple relation for the PF & adjoint model

Innovations can be very large: reweight with Huber norm

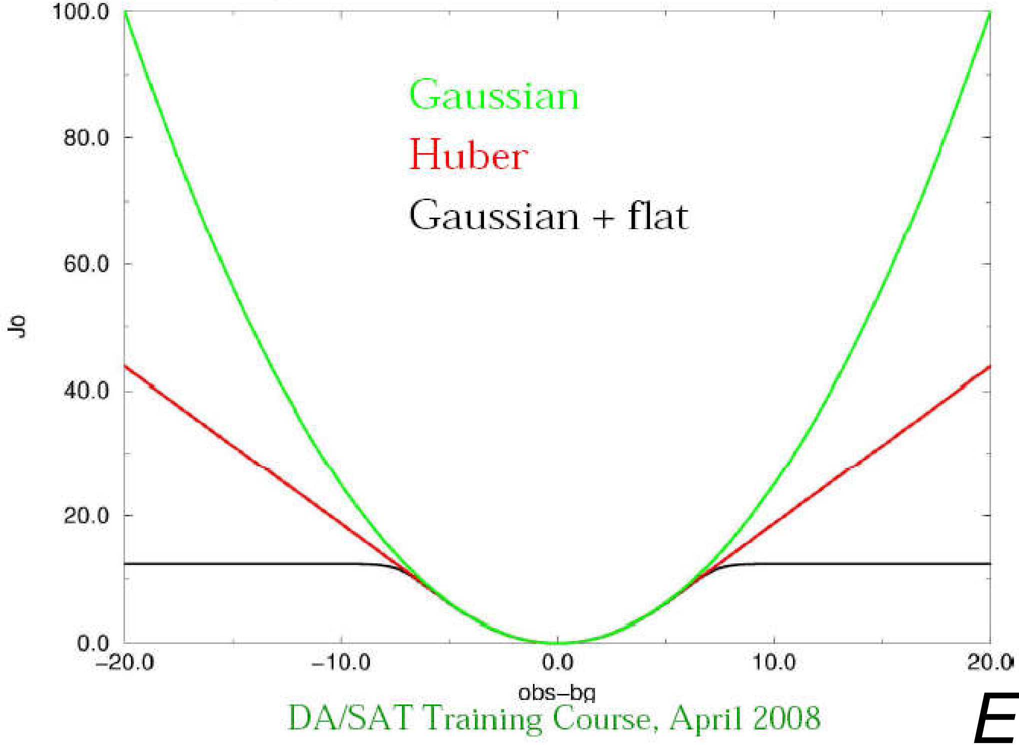
Assimilate dry and rainy observations,
reject non-hydrometeorological echoes





The Huber-norm – a compromise between the l_2 and l_1 norms

$$p^H = \begin{cases} x^2/2 & \text{if } |x| <= k, \\ k|x| - k^2/2 & \text{if } |x| > k, \end{cases}$$



Erik Andersson

- Weights of large innovations reduced but not rejected
- Alternative approach is to make a error a function of observation value (e.g. JMA)

© Crown copyright Met Office

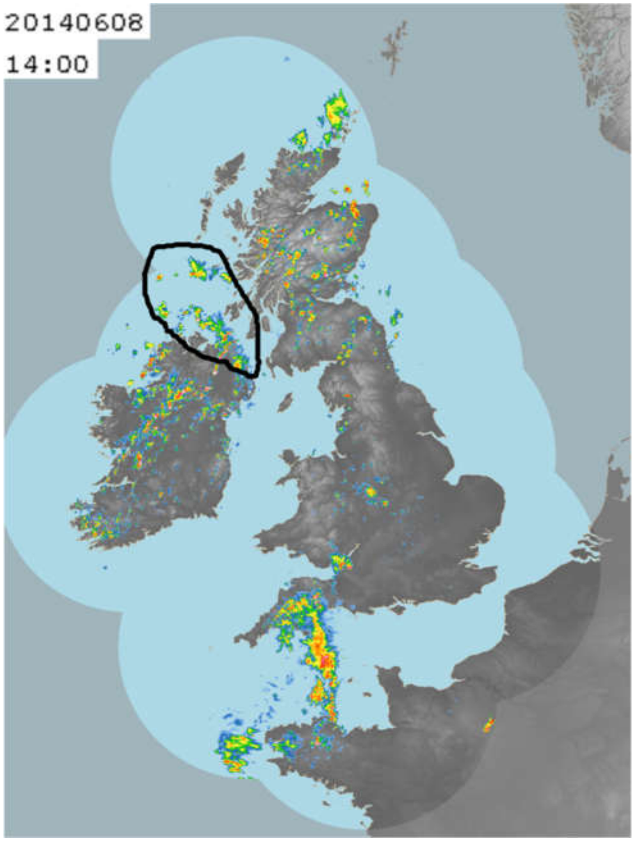
First UKV trials

- Trial period: 5 – 30 June 2014
- Assimilate √(Z+1) – scales with mass of water
- Include obs where no rain in background
- Configurations:
    - Control
    - Control – LHN
    - Control + Reflectivity
    - Control – LHN + Reflectivity

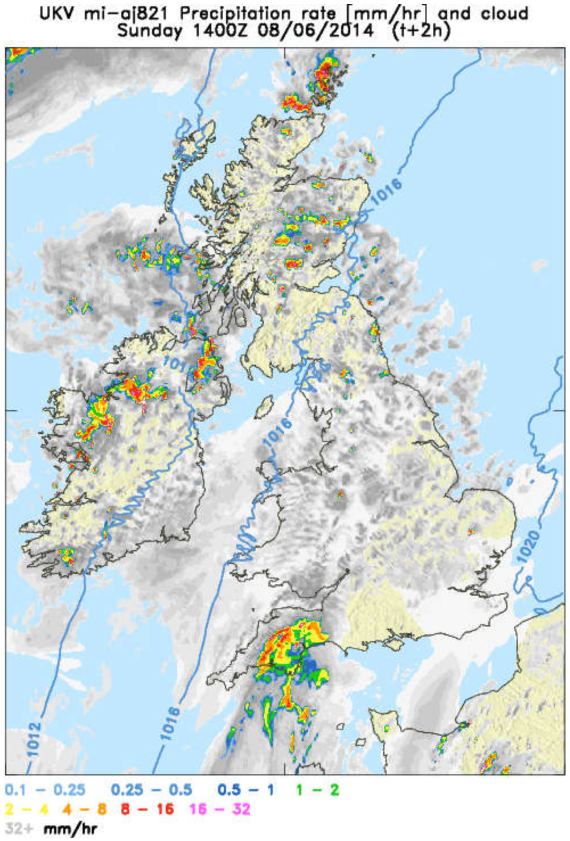
First UKV trials

- All trials ran to completion
- Case study demonstrated ability to generate convergence line with precip
- Ob coverage technically constrained in OPS
- Significant dry bias

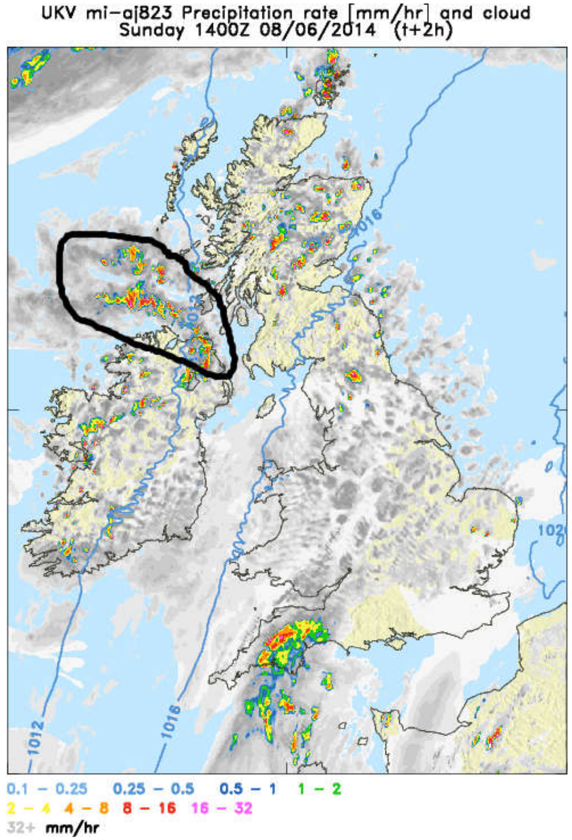
Case study:
12Z 8 June 2014 T+2



Radar obs derived



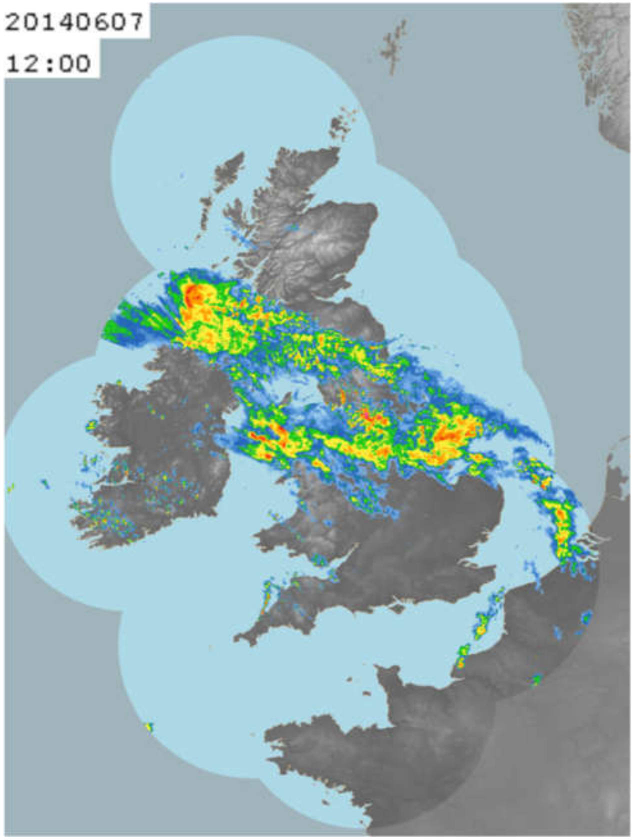
Control



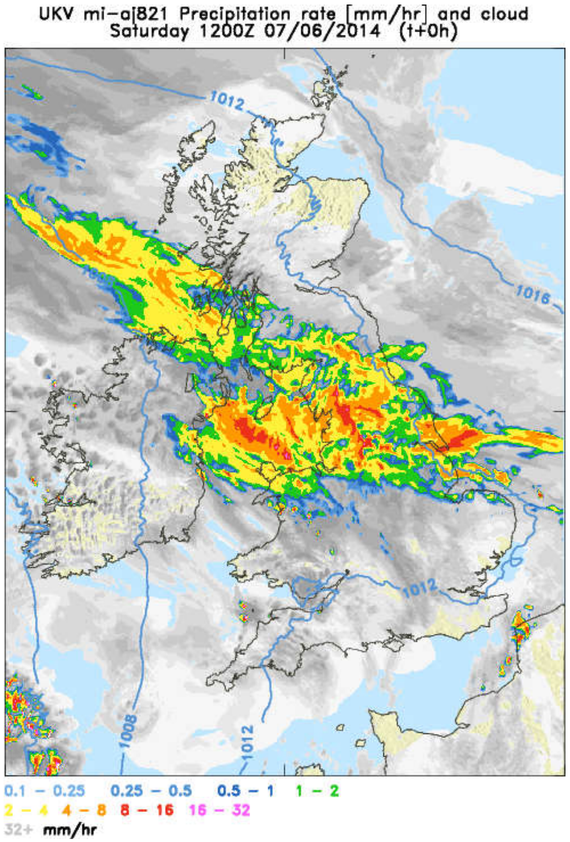
Radar|-NoLHN

Reflectivity assimilation trial correctly forecasts highlighted band of precipitation

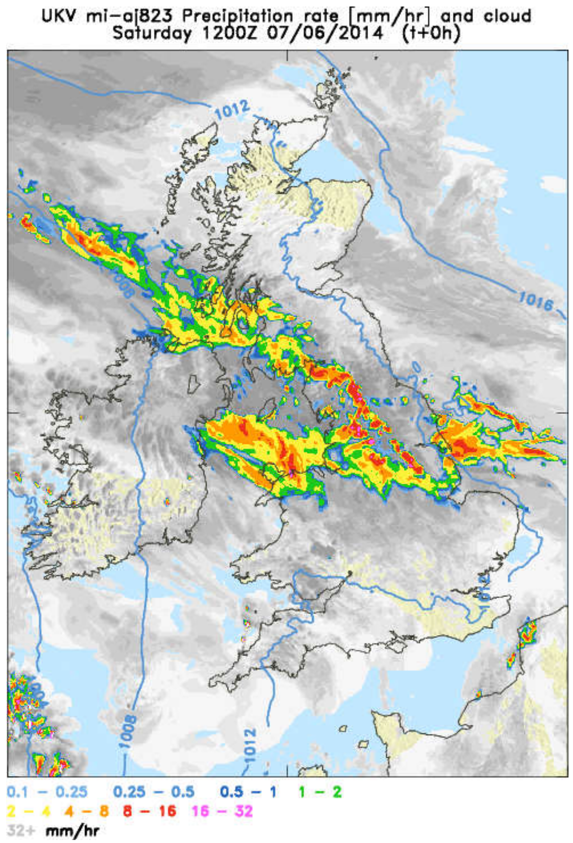
Case study:
12Z 7 June 2014 T+0



Radar obs derived



Control
Analysis



RadarZ-NoLHN
Analysis

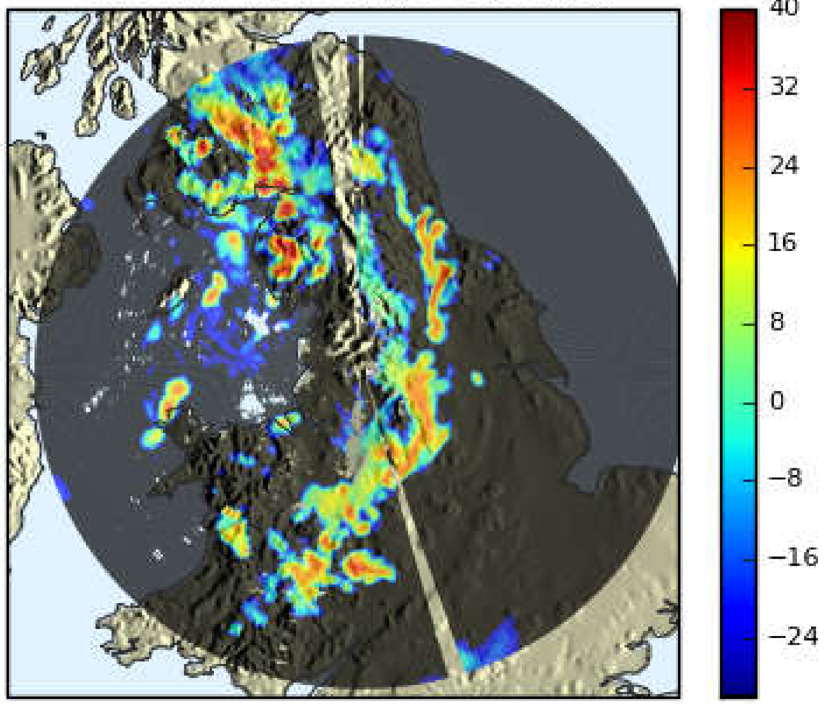
Promising initial results but scheme had dry bias

Radar reflectivity monitoring

04 Hameldon Hill - 2016/10/17 03:00 - Scan elevation 1

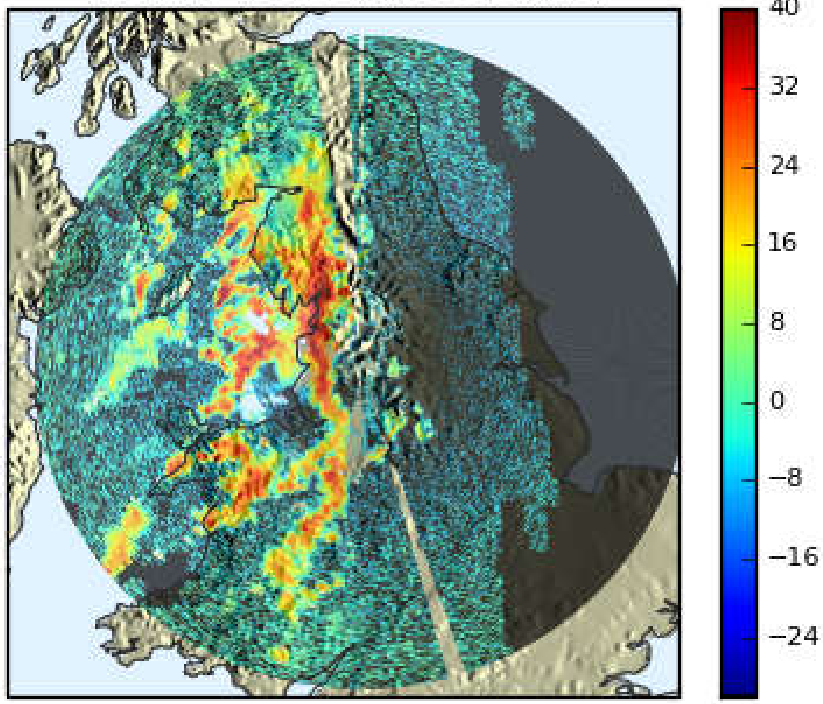
Model Reflectivity after QC

Equivalent reflectivity factor / dBZ
2016-10-17 02:59:00
Radar: 4 at 0.5 degree elevation



Reflectivity obs after QC

Equivalent reflectivity factor / dBZ
2016-10-17 02:59:00
Radar: 4 at 0.5 degree elevation



Page maintained by Lee Hawkness-Smith

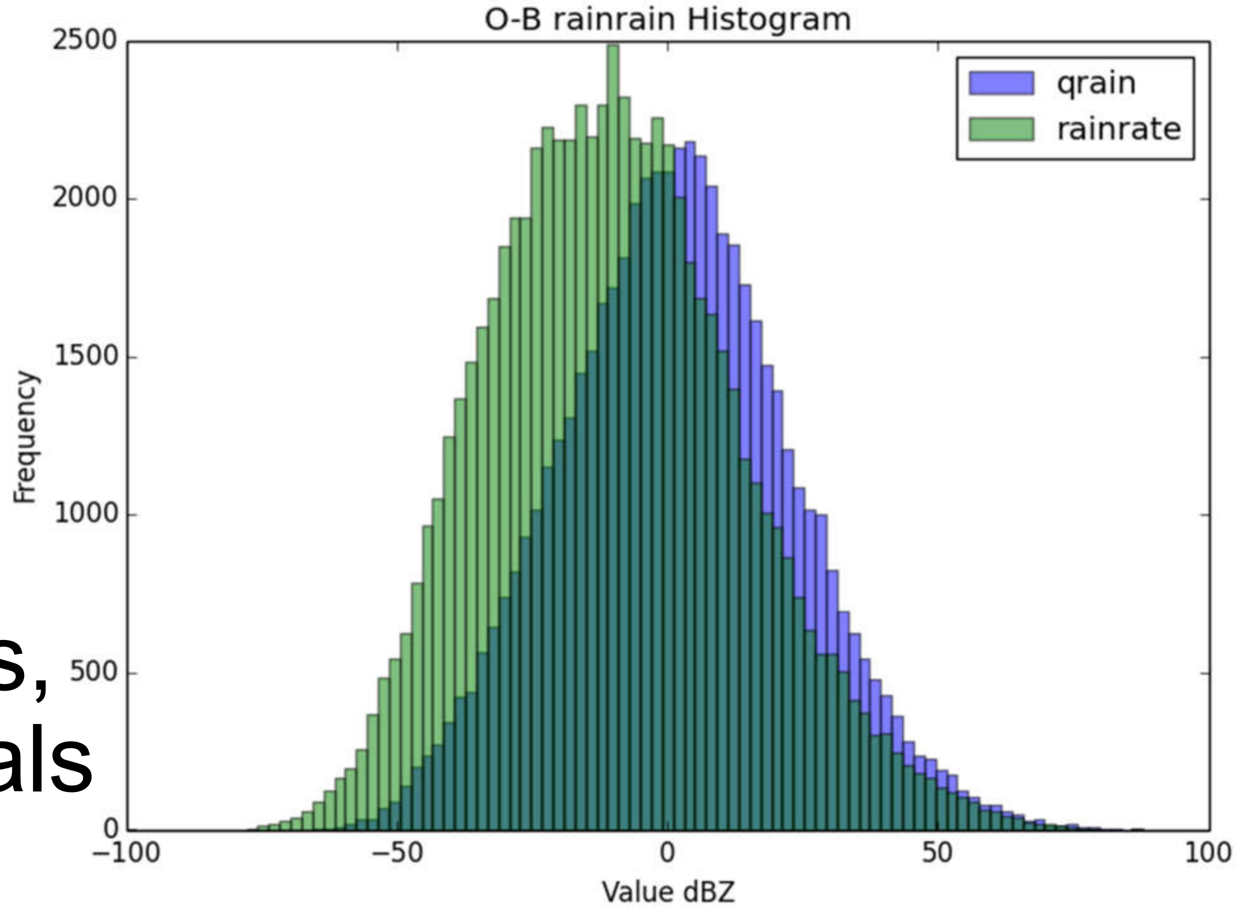
Komodo

Reflectivity operators

$Z_R = 180R^{7/4.67}$

$Z_R = 1.63x10^3 q_r^{7/4.0}$

First trials used R: after evaluating monitoring statistics, use q_r in current trials



Second UKV trials

- Summer and Winter trials run
- Use (relatively) unbiased q_{rain} operator
- Test rejecting all dry observations or sparser thinning for dry observations
- Tested using reflectivity obs every 10 minutes throughout time window, and T-30,T-15 and T+0 only
- Tested quasi-static Var configuration (gradually increasing length of assimilation window)

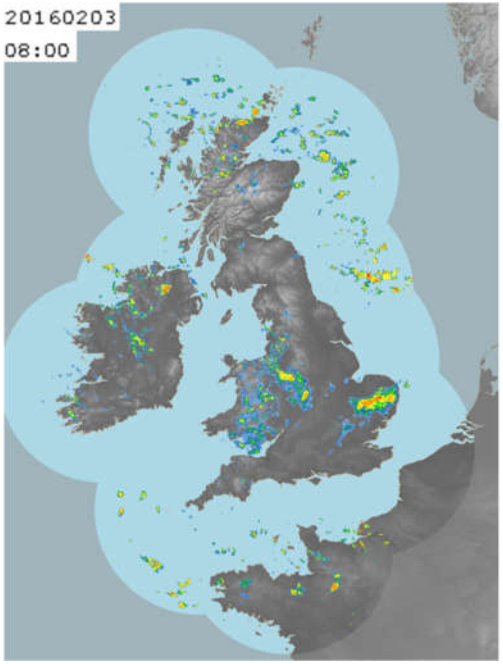
Second UKV trials

- Some very promising case studies
- Unacceptable rate of failure to converge
- Verification scores mixed

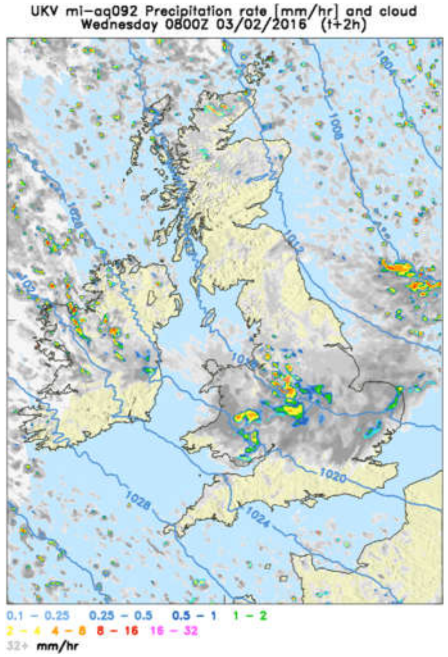
Case study: 08Z 3 Feb 2016

Met Office

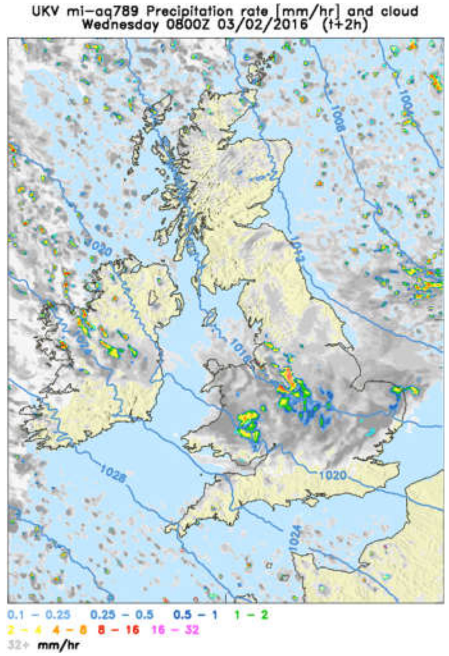
T+2



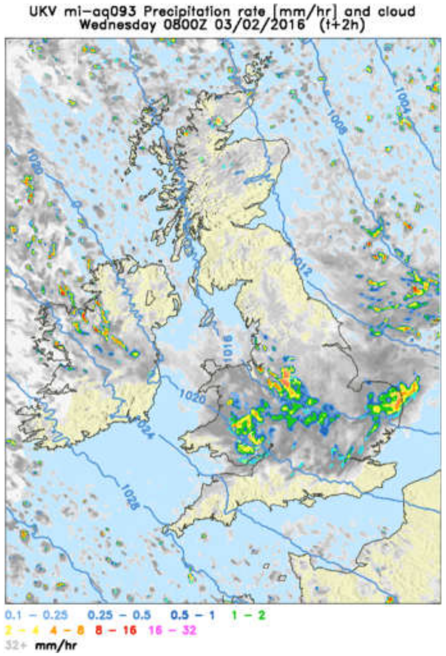
Observations



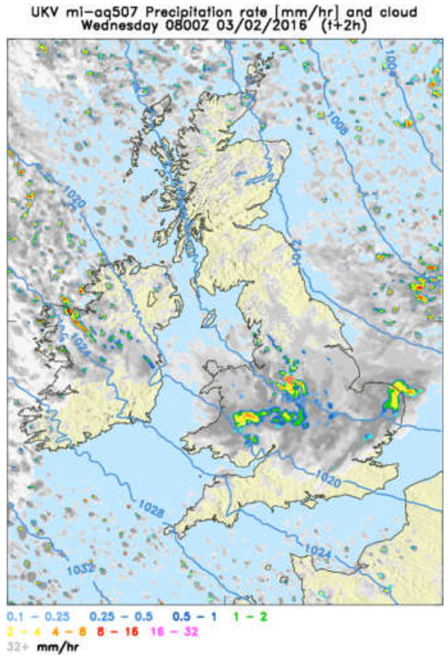
Control



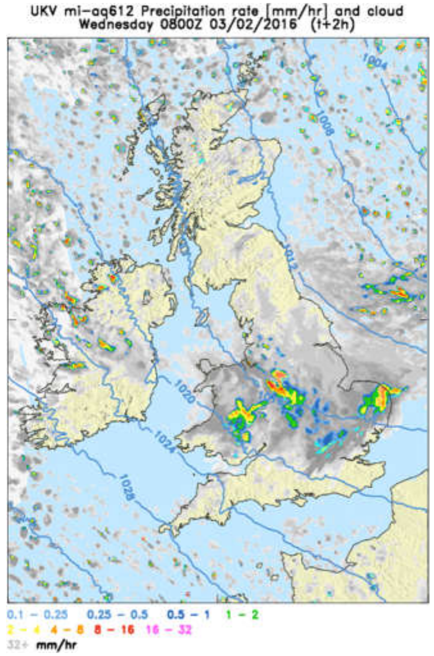
Control - LHN



RadarZ NoDry LHN



RadarZ ThinnedDry T-30,T-15,T0 NoLHN



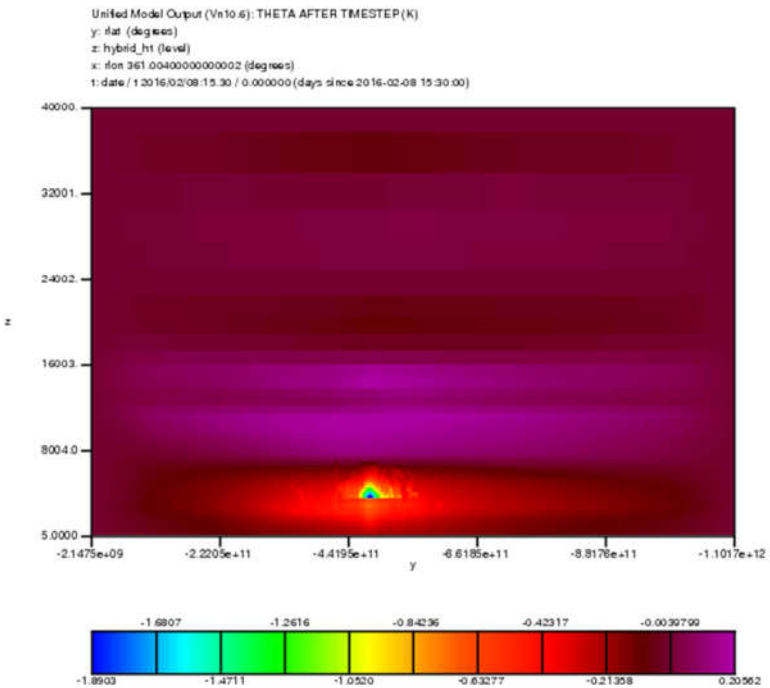
RadarZ NoDry T-30,T-15,T0 NoLHN

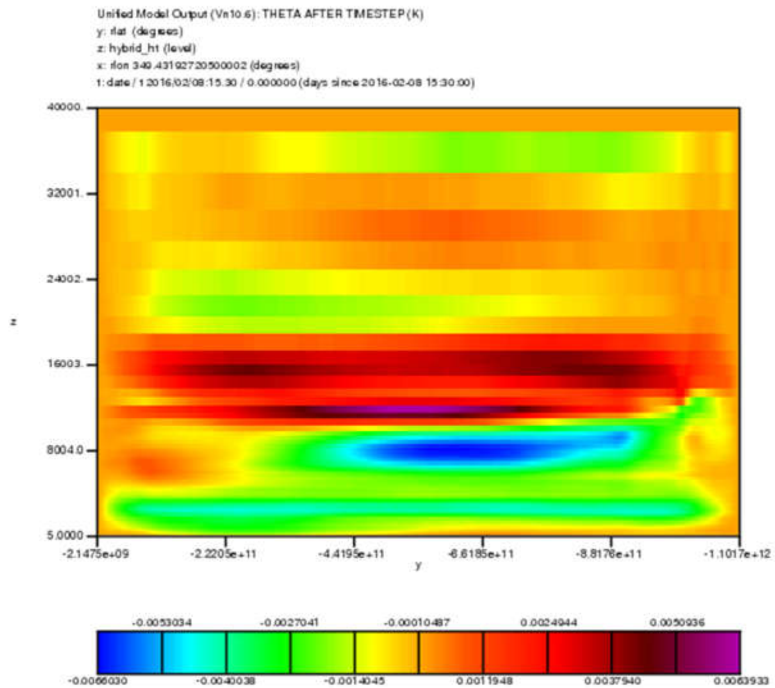
Diagnosis of Var failures

Analysing failed cycles from different trial periods in more detail showed evidence of:

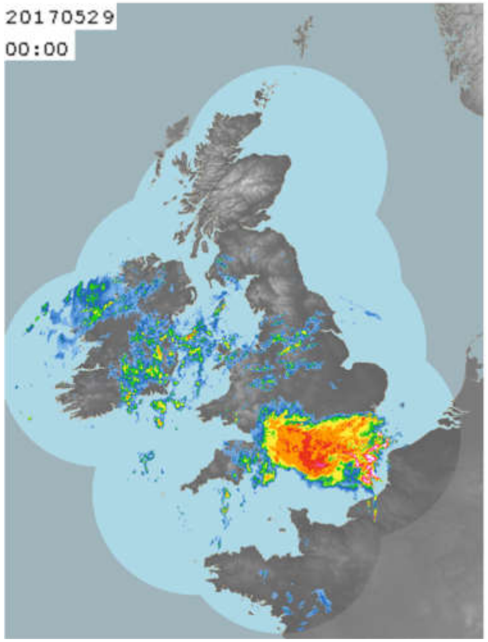
- stratospheric ringing
- large qT and theta increments at ~5km altitude

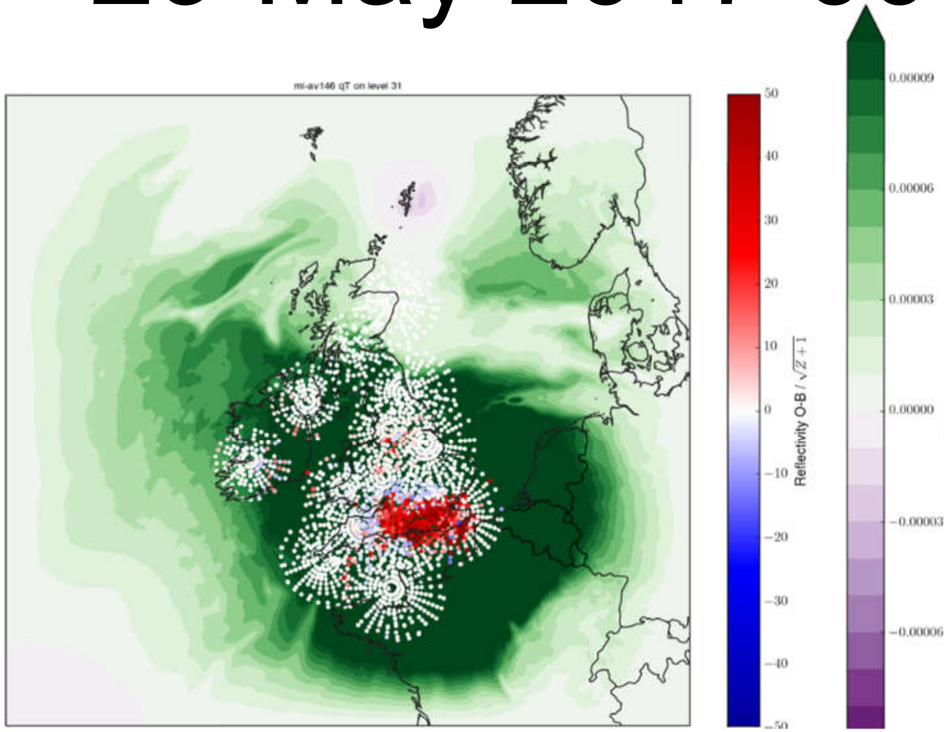
08 Feb 2016 16UTC: Theta increment

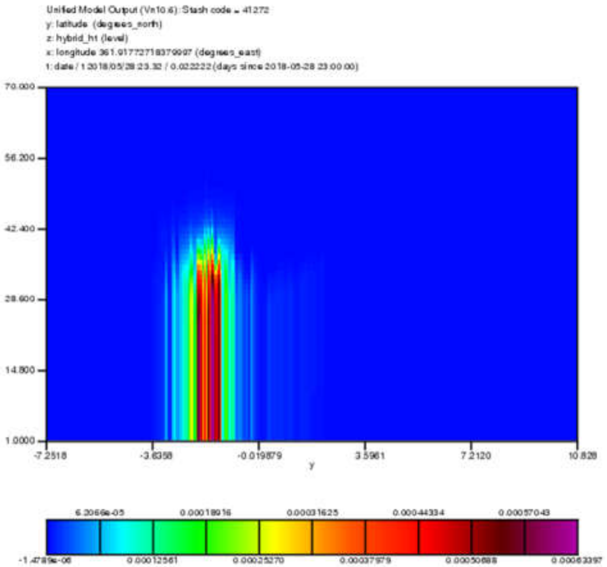


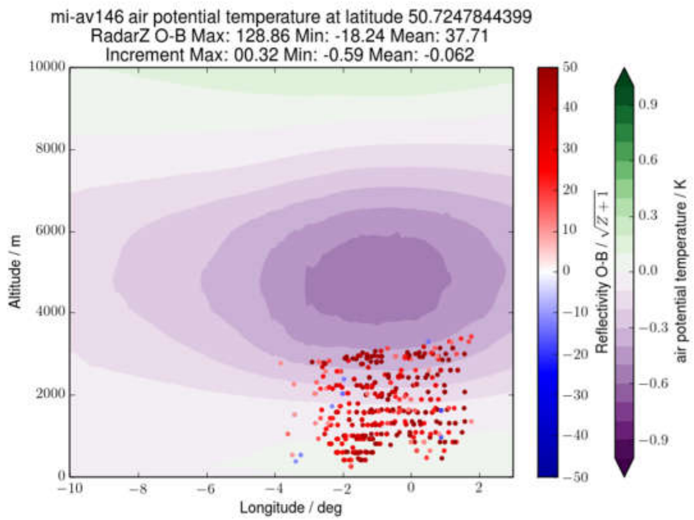


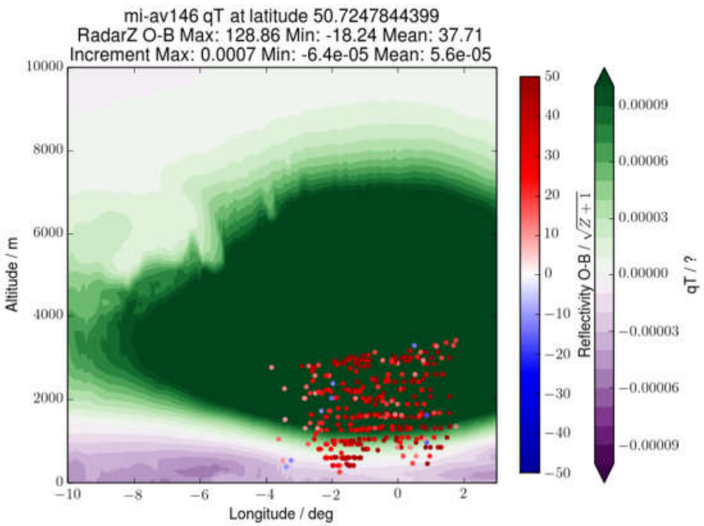
Diagnosis of Var failures
29 May 2017 00UTC











q_{rain} increment after 1 timestep

Third UKV trials

- Retune precipitation efficiency

- Abandon use of Quasi-static Var

- Assimilated reflectivity observations at T-30, T-15 and T0

Met Office

Third UKV trials

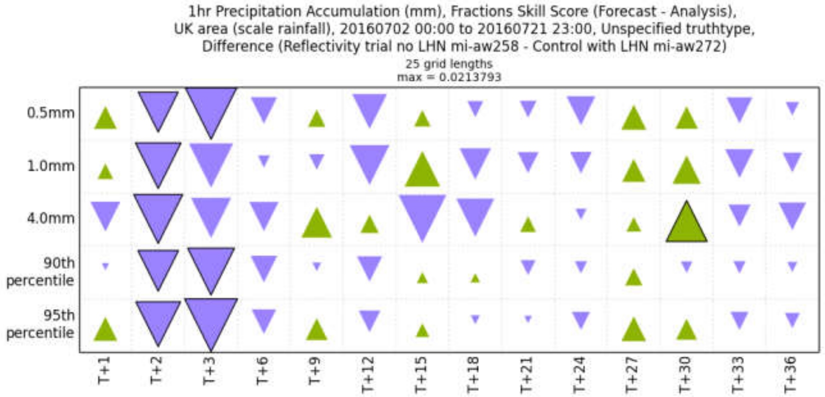
- Conservative configuration runs without failure, stretch configuration (with smaller observation error and smaller superobservations) fails at rate of ~2 cycles / month

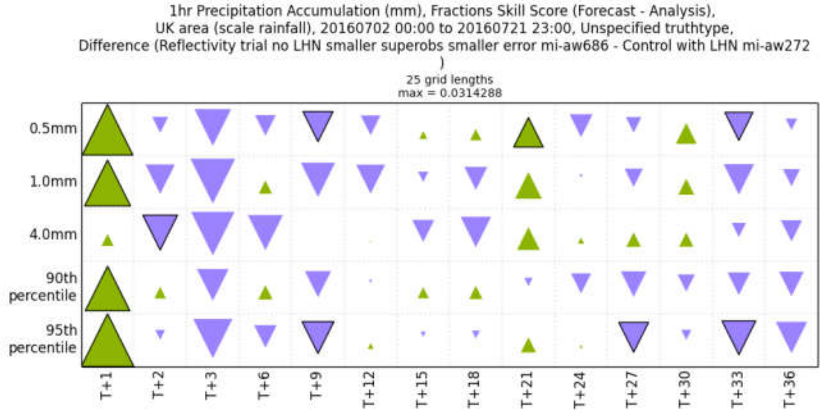
- Verification scores positive with respect to operational system!

➡ Ready for implementation! (after a little computational optimization)

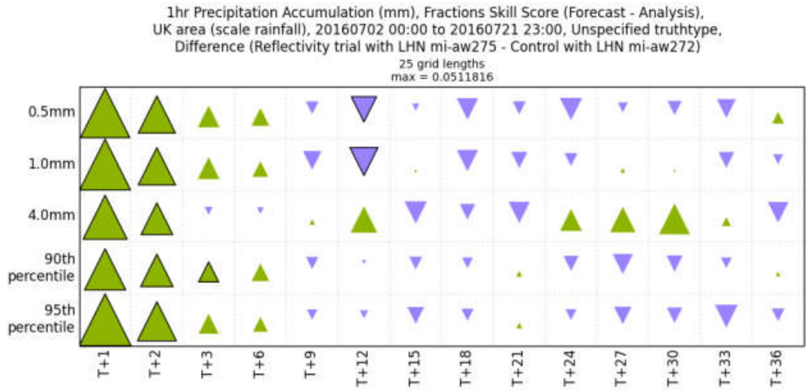
Fraction skill scores: Summer 2016

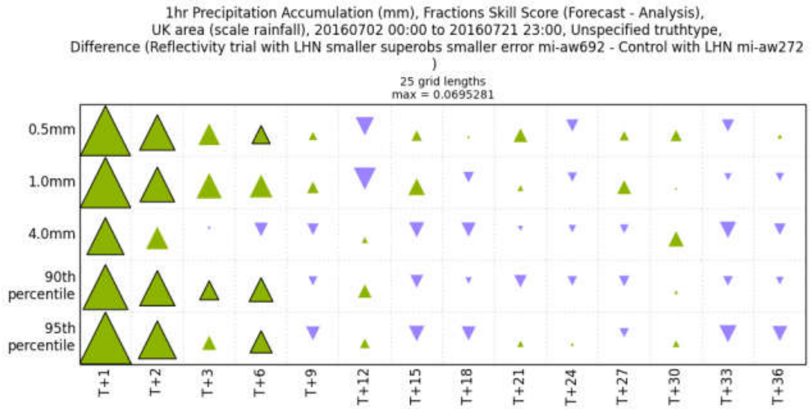
Conventional + Refl





Conventional + LHN + Refl





Conservative

Stretch

LHN retirement?
Europe may be the answer….

- Best results come from using both LHN and direct reflectivity assimilation together. Need to understand why, can we afford to maintain both systems?

- Most recent results suggest most of benefit of LHN comes from continental radar data, which is not yet available in the direct assimilation system…