35th EWGLAM / 20th SRNWP

Antalya, 30th Sept-3rd Oct 2013

Developments in convective scale assimilation at the UK Met Office

Bruce Macpherson, Gareth Dow, Bob Tubbs,

Peter Francis, Gordon Inverarity, Richard Marriott

Contents

This presentation covers the following areas

- Description of UK 1.5km DA system
- Recent upgrades
- Assimilation & Observation impacts
- Future plans

UK 1.5km DA cycling

- 8 three-hour assimilation cycles per day
- Forecasts to t+36 every 3 hours
  - Observation cut-off hh+ 75min
  - Lateral boundaries from hh-3hr run of 25km Global model at DT 03, 09, 15, 21 UTC
  - Lateral boundaries from hh-6hr run of 25km Global model at DT 00, 06, 12, 18 UTC

UK 1.5km DA

- 3DVAR (with FGAT) + IAU for all observations

  except Latent Heat Nudging for radar-derived surface rain rate

- VAR grid is uniform 3km resolution over whole domain (including area of variable UM resolution)

  - Variable→ fixed grid interpolation for VAR linearisation states and ‘model observation’ columns

  - Fixed → variable grid interpolation for VAR increments

- Adaptive vertical grid

UK 1.5km – extra observations *not* assimilated in global model

- radar-derived surface rain rate (hourly, 5km resolution)
- visibility from SYNOPs (hourly)
- T_{2m} & RH_{2m} from Highways Agency roadside sensors (hourly)
- Doppler radial winds (3-hourly)
- SEVIRI Channel 5 radiances above low cloud
- GeoCLOUD cloud fraction profiles (3-hourly, 5km resolution)
  - zero cloud down to cloud top, missing data below
- cloud fraction profiles from SYNOPs (3-hourly)
  - zero cloud up to cloud base, missing data above

Met Office

UK 1.5km – forecast error covariances

- **Lagged NMC method + CVT software**
  - 152 UK1.5 forecast pairs
  - t+6 - t+3
  - Jan – Jun 2012

- **Horizontal scales**

  (leading vertical mode)

  - psi 150km
  - chi 190km
  - Ap 70km
  - mu 30km
  - log m 60km

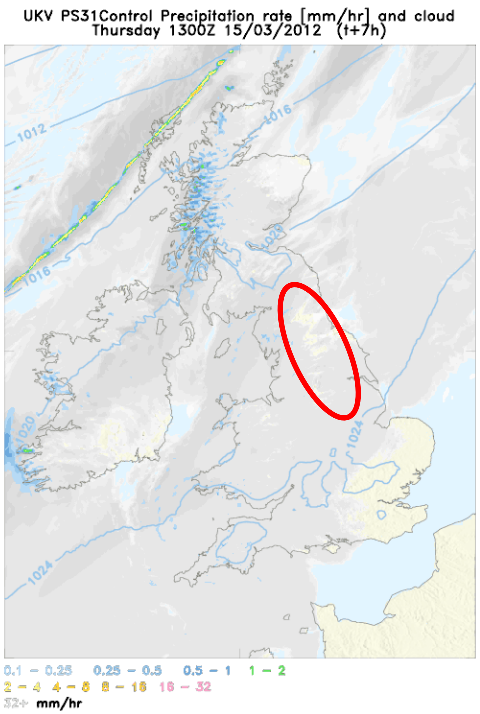
  } *smaller* (applies to Ap, mu and log m)

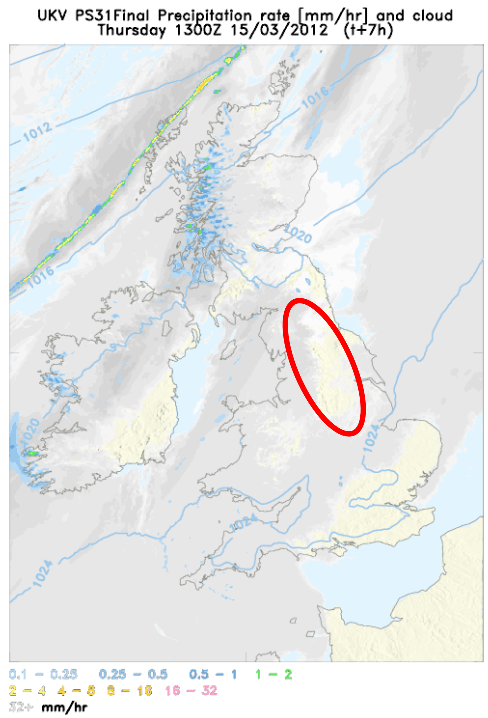
- Now derived from training data & consistent with variances (previously, fixed values specified for all modes)

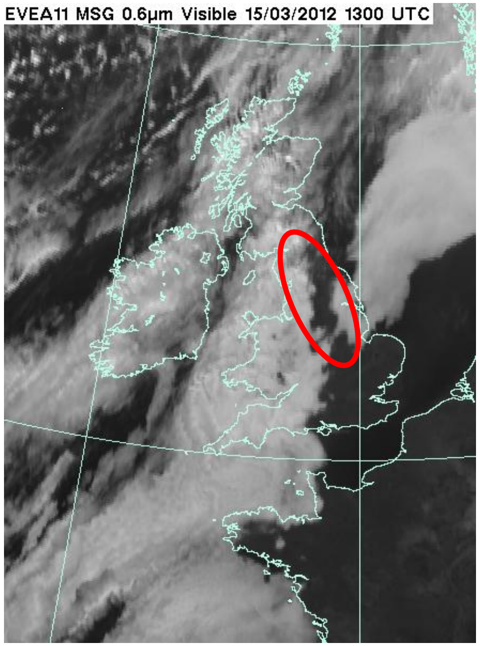
Recent Upgrades (since July 2011)

- new humidity control variable
- new ‘CVT’ covariances (shorter horizontal scales)
- additional satellite data
  - SEVIRI Ch 5 above low cloud
  - high-resolution AMSU-B
- replacement of MOPS cloud data with direct assimilation of GeoCLOUD (satellite) and SYNOP cloud fraction obs
- increasing Doppler radial wind coverage across UK

Impact of CVT covariances on Sc (15th March 2012, T+7)







Old Covariances

New CVT Covariances

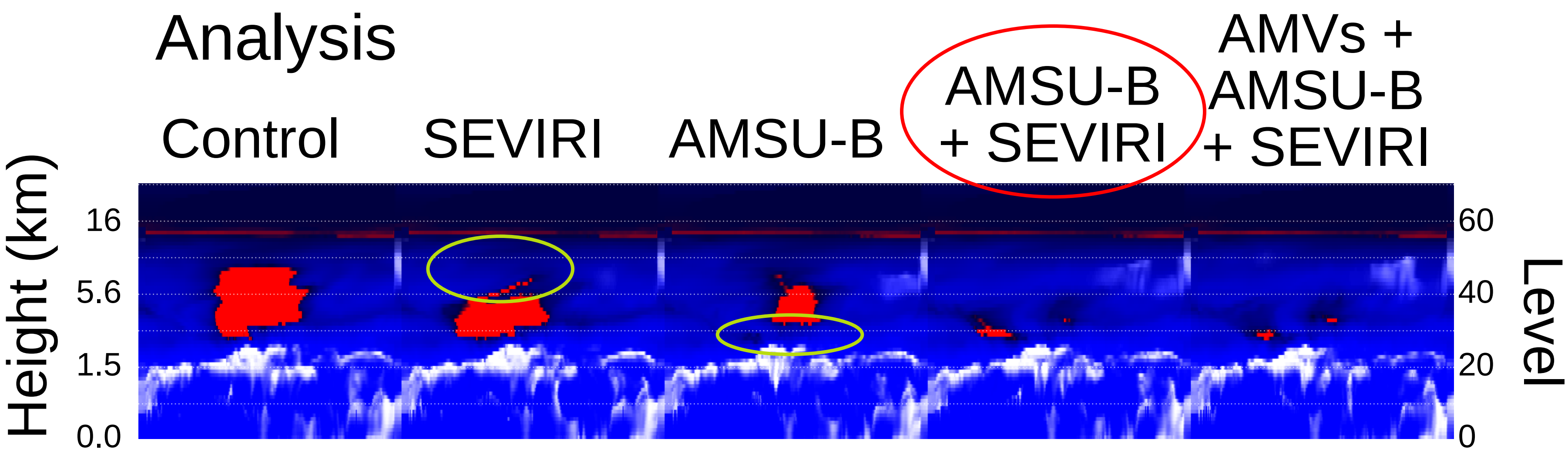
Gareth Dow

Impact of SEVIRI Ch 5 + AMSU-B on upper-tropospheric humidity

(13 Feb 2012 case 03Z)

- SEVIRI data improves humidity in the upper troposphere
- AMSU-B data improves humidity above the cloud top
- Complement each other

Colour scale logarithmic from 10^{-8} to 1 (red, black, blue, white)

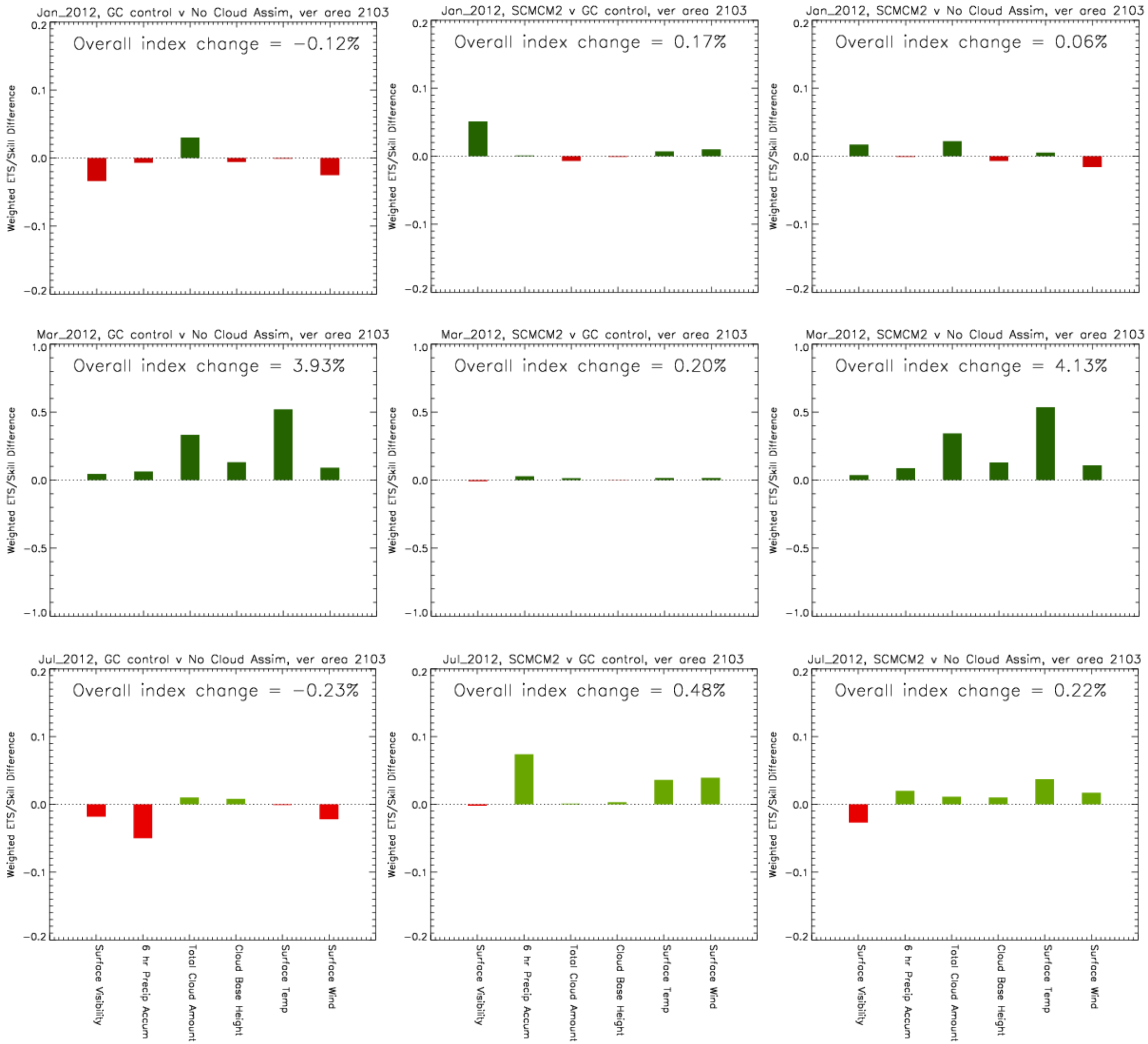


Bob Tubbs

UK Index impact

GeoCloud Surf Cloud both

Cloud Assim



Jan/Feb

March

July

GC v none GC+**SC** v GC GC+**SC** v none

Peter Francis

UK Index Impacts in UK 1.5km
(~3 weeks winter 2011, t+0→t+24)

A. No UK analysis - latest Global lateral boundary forcing only	**0 %**
B. as A + continuous UK assimilation with 'standard obs'	**+6.5%**
C. As B + extra obs not in global system	**+7.3%**

(cf ~2% annual increase in UK Index &

~10% added value over global NWP system)

UK Index Impacts in UK 1.5km
(~4 weeks winter 2011, t+0→t+24)

A. Downscaler –from interpolated Global analysis with fixed aerosol	0 %
B. as A + full continuous UK assimilation with prognostic aerosol	+5.1%

Gareth Dow

UK Index Impacts in UK4 Observation denial experiments

(~5 weeks winter, t+0→t+24)

Surface	+2.9%
Satellite	+1.7%
Upper Air (excluding aircraft)	+2.1%
Aircraft	+2.0%
Radar	+2.0%
"Extra" (all obs networks not in global model)	+0.5%

Gareth Dow

Extra Benefit of UK DA system
compared to downscaled global analysis

- Most consistent benefit from assimilating 'conventional' observations at higher (4km, 1.5km) resolutions

- Mixed performance from the extra observation types which, on occasion, can reduce the benefit of the full UK DA system (mainly an issue with MOPS cloud in Sc situations - have recently moved from MOPS cloud analysis to GeoCloud + Surface Cloud in UK1.5)

Gareth Dow

UK 1.5km DA – future developments in *observations*

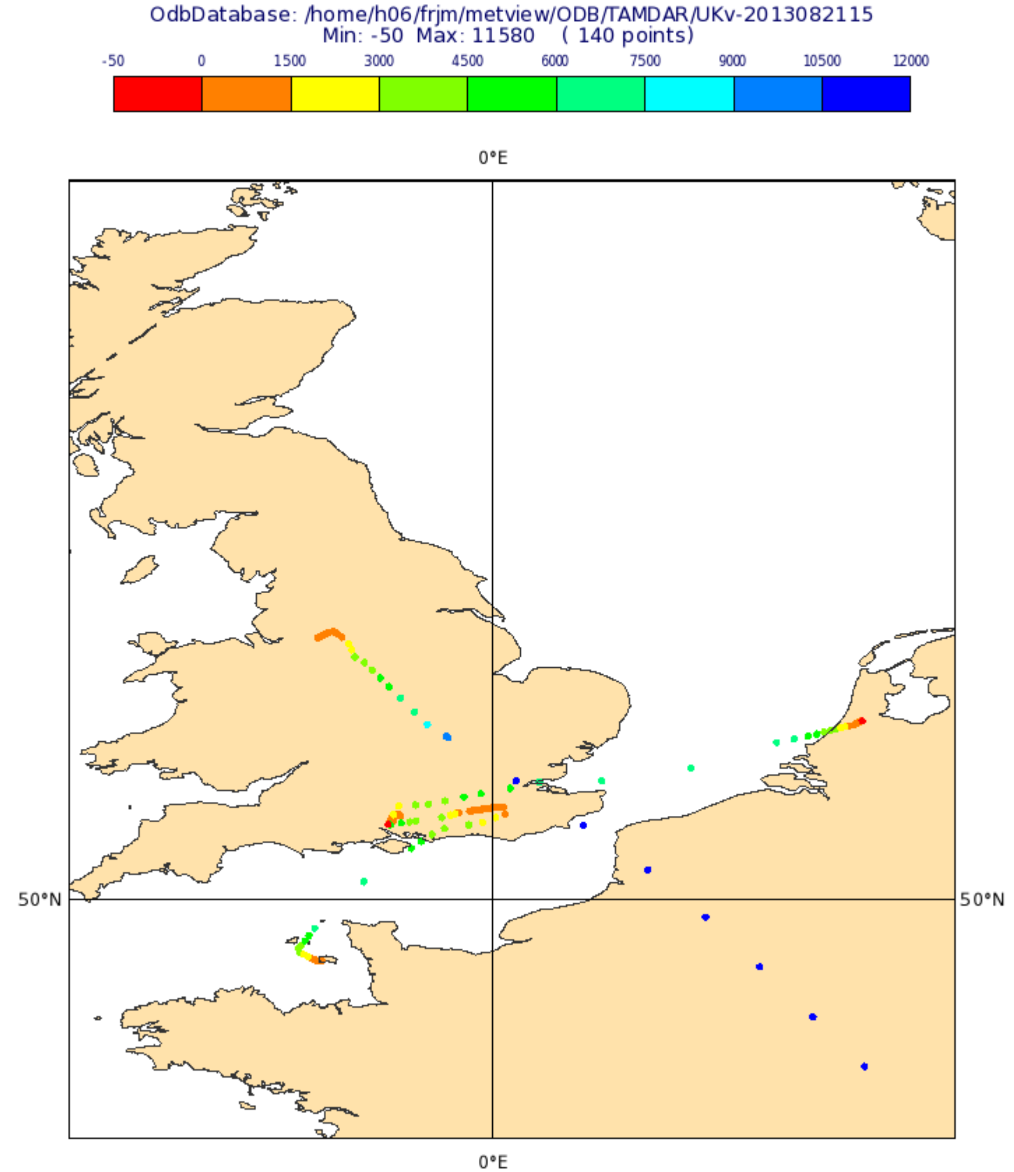
- BUFR sonde data (with balloon drift)
- high resolution AMV data
- more roadside sensor data (England → whole UK)
- improve cloud assimilation
  - increase weight for satellite & surface reports
  - avoid assimilating cloud tops close to existing cloud in model background
  - derive cloud top height observations within each assimilation cycle, using latest model background vertical profiles (instead of within external AUTOSAT system)

Monitoring of Flybe TAMDAR data

- since 20th Aug 2013
- 3 aircraft so far

  (~200 obs per day each)
- wind quality ~ AMDAR
- T slightly worse
- RH similar quality to US TAMDAR

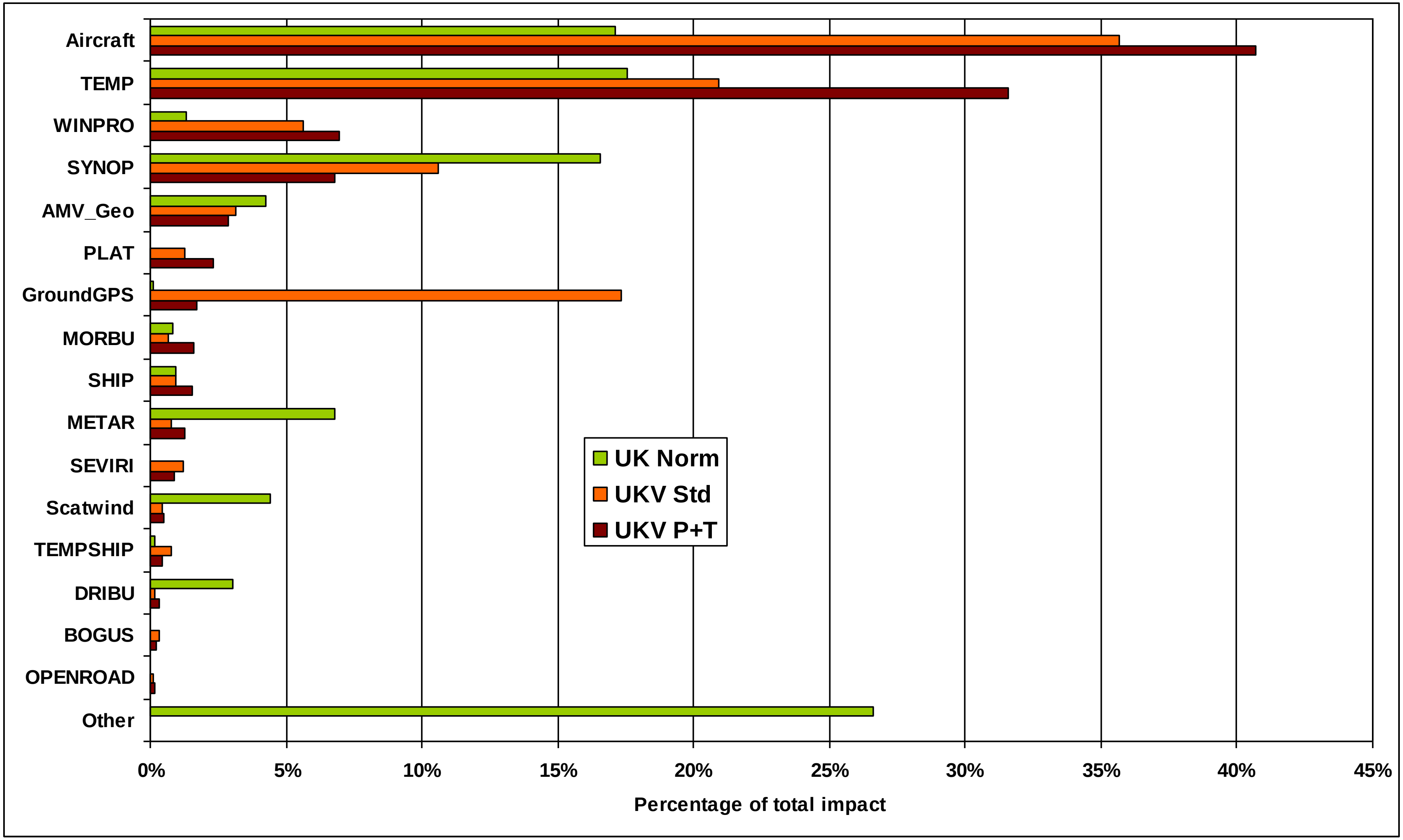
  [~15-20% sd for (o-b) below 500hPa]



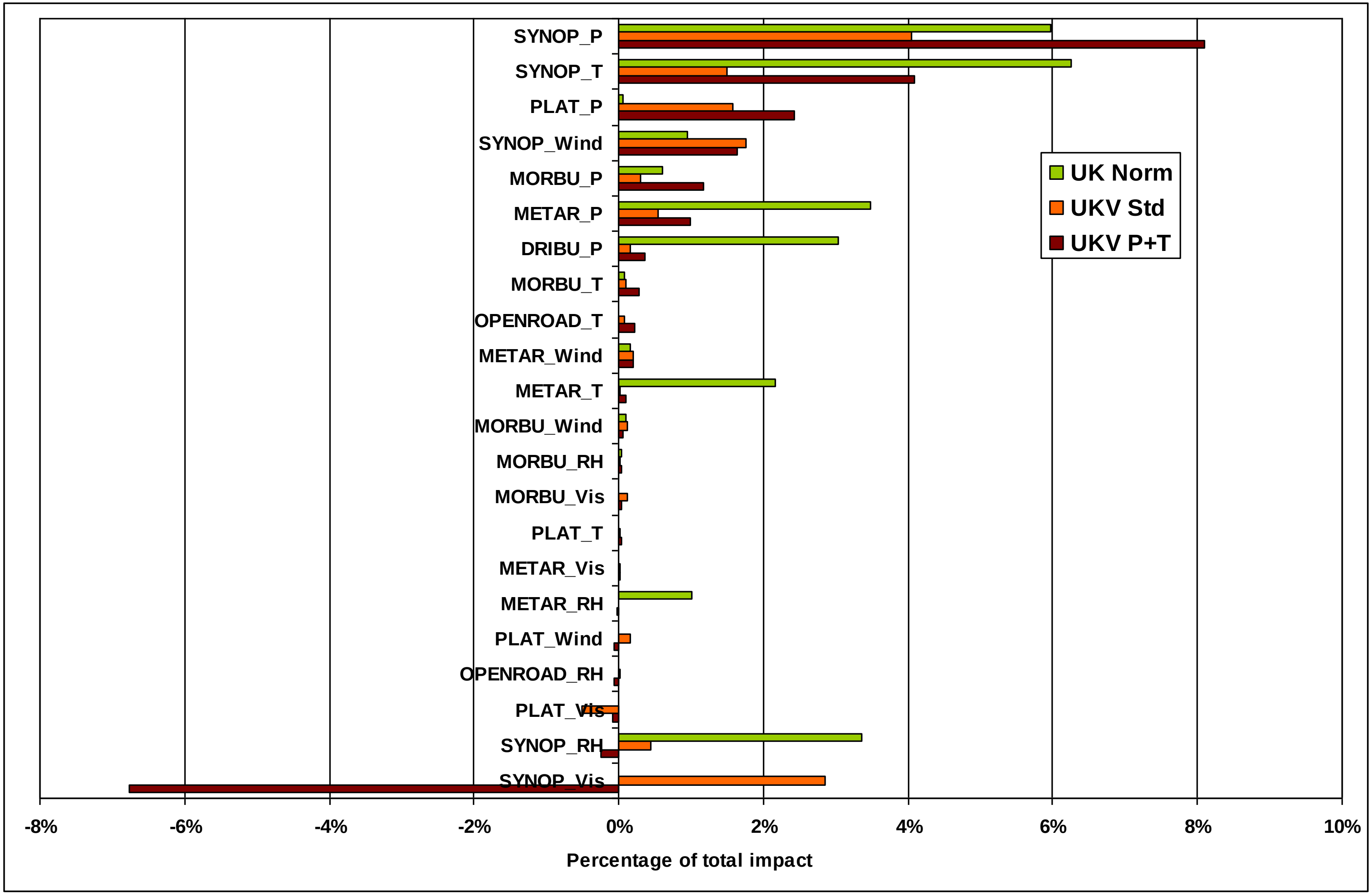
FSO tool at convective-scale

- challenge of model non-linearities
- linear Perturbation Forecast model and adjoint valid only for short forecast periods (3-6 hours)
- verifying analyses used within forecast error norm are assumed to be independent of the forecasts – not good assumption at t+3
- preliminary work with P/T norm at t+3, maybe including v and q up to t+6?
- initial comparison with global FSO results for UK area with 'standard' moist energy norm

All ob-types – Total impacts



Surface types – Total impacts



Met Office

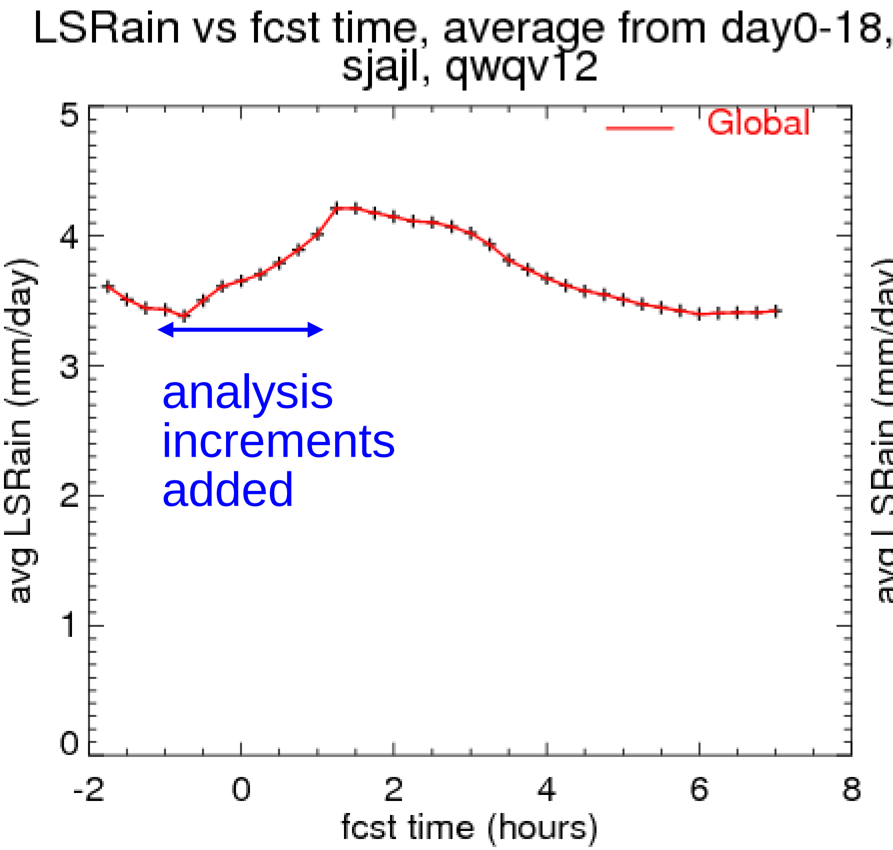
FSO – Summary

- Linearisation tests.
  - case 1 – T, P pass at T+3;   Only P passes at T+6.
  - case 2 – U, V, W, T, P, q pass at T+3;   T, P, q pass at T+6.
- Boundary conditions seem to account for about half of the T+3 forecast impact.
- TEMP, Aircraft and WINPRO show large impacts in the UKV results.
- GNSS gives a large impact on the standard UKV error norm – presumably on the humidity component.
- Fractions of beneficial obs seem to be larger in the UKV results. (This could reveal a bias in the verification.)
- Next step is to implement an obs-based forecast error metric.

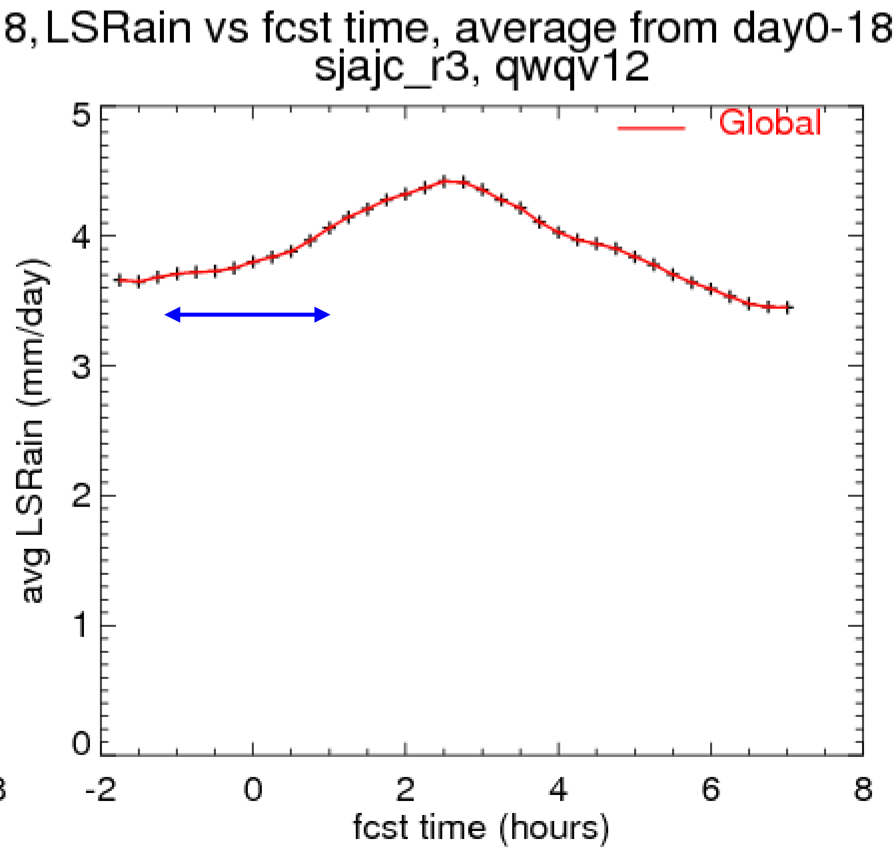
UK 1.5km DA – future developments in *observations* - II

- high resolution IASI data
- CrIS advanced IR sounder
- radar reflectivity
- radar refractivity

Bypass moisture incrementing operator (ie add q_t' to q) – impact on spin-up



Control



Control+bypass

Keith Ngan

UK 1.5km DA – future developments in *algorithms*

- test ‘affordable’ 4DVAR on UK-wide configuration
  - build on Nowcasting Demonstration Project (NDP) experience
  - apply on 3rd (final) step of adaptive vertical grid sequence
- 2016-17 - Operational implementation of next-generation NWP-nowcasting system

Met Office

Questions?

Met Office

Additional slides

New Humidity Transform

- $\mu = (q_T' - h c T') \, a / qsat(\mathbf{b})$

- q_T' increment of total q – including cloud
- T' temperature increment
- $h=h(RH\mathbf{b})$ gives "balanced" q_T increment from T'
- $a=a(RH\mathbf{a},RH\mathbf{b})$ is normalising factor so that $\sigma(\mu)\approx 1$ this reduces under/overshoots
  - *h* and *a* are derived from training data
- If $a=a(RH\mathbf{b})$ then we have linear transform

Adaptive Mesh Transform

(Piccolo & Cullen, 2011: Q. J. R. Met. Soc., 137, 631-640)
(Piccolo & Cullen, 2012: Q. J. R. Met. Soc., 138, 1560-1570)

- aims to change the vertical background-error correlations by moving the vertical levels to concentrate mesh points around temperature inversions.

- movement of the levels is guided by a scalar ***monitor function***, chosen to be a function of the *static stability* which strongly controls vertical mixing in the atmosphere and thus probably the vertical correlation structure of model variables.

- in the Met Office VAR system, the adaptive method is implemented as an extra transformation in the sequence of variable transformations used to simplify the background term of the cost function:

$$\delta\mathbf{x} = \mathbf{U}\boldsymbol{\chi} = \mathbf{U}_p \mathbf{U}_a \mathbf{U}_v \mathbf{U}_h \boldsymbol{\chi} \quad \text{and} \quad \mathbf{B} = \mathbf{U}\mathbf{U}^T$$

where $\mathbf{U}_a$ is the "adaptive mesh transform“, placed between the parameter transform $\mathbf{U}_p$ and the vertical transform $\mathbf{U}_v$

Adaptive Grid Formulation

The first step of the $\mathbf{U}_a$ transform is to calculate a *monitor function* M (>0) in physical space z $\in$ [0,1]:

$$\int_0^1 M(z')dz' = 1$$

The second step is to generate the adaptive mesh in physical space by defining a computational coordinate $\zeta \in [0,1]$:

$$\varsigma(z) = \int_0^z M(z')dz'$$

The map from computational domain to physical domain is thus defined by a unique one-dimensional map which connects intervals of a prescribed length.

Finally, the control variables χ which will be generated at points ζ by the vertical transform are then interpolated to the true levels z.

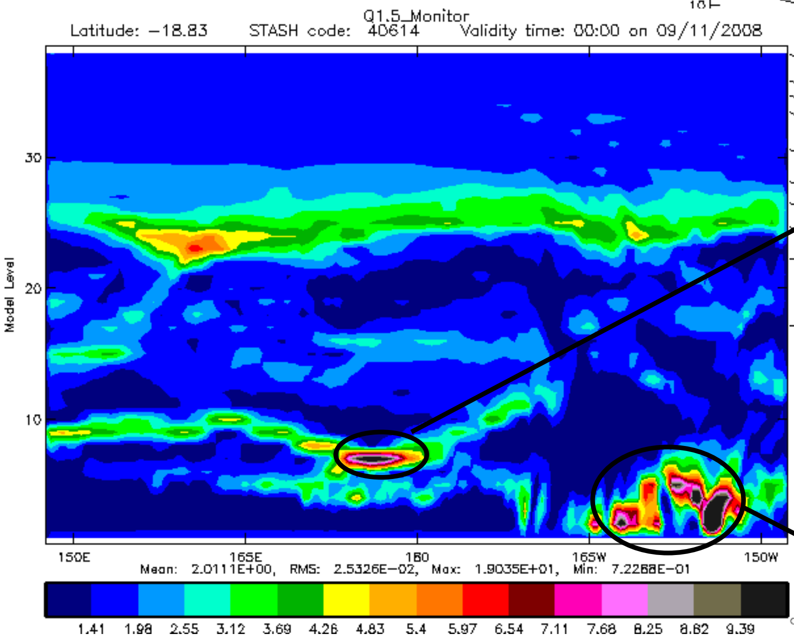
Choice of the Monitor Function

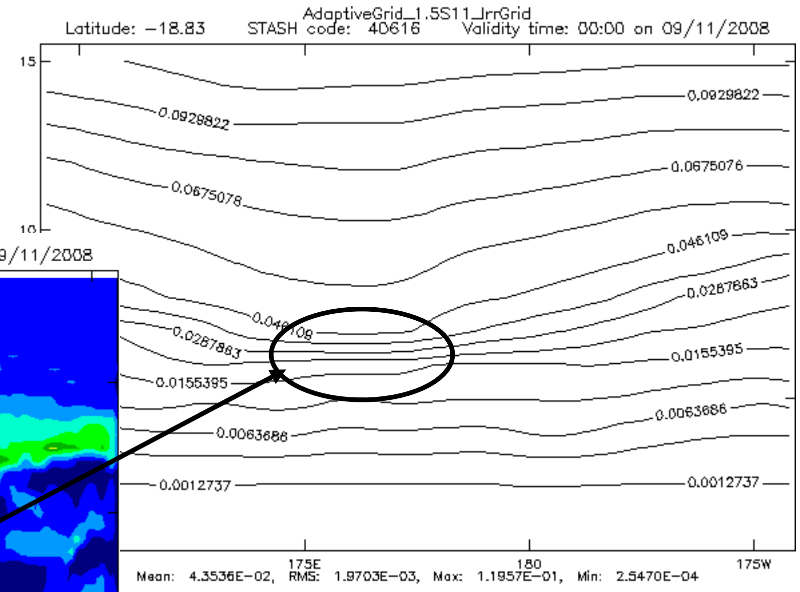
$$M = \sqrt{1 + c^2 (\partial\theta/\partial z)^2}$$

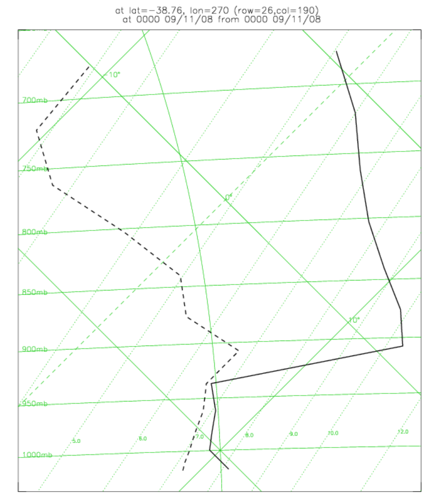
$M > 0$ and can be modulated by a scaling factor c.
If c = 0, the computational grid and the physical grid are the same.

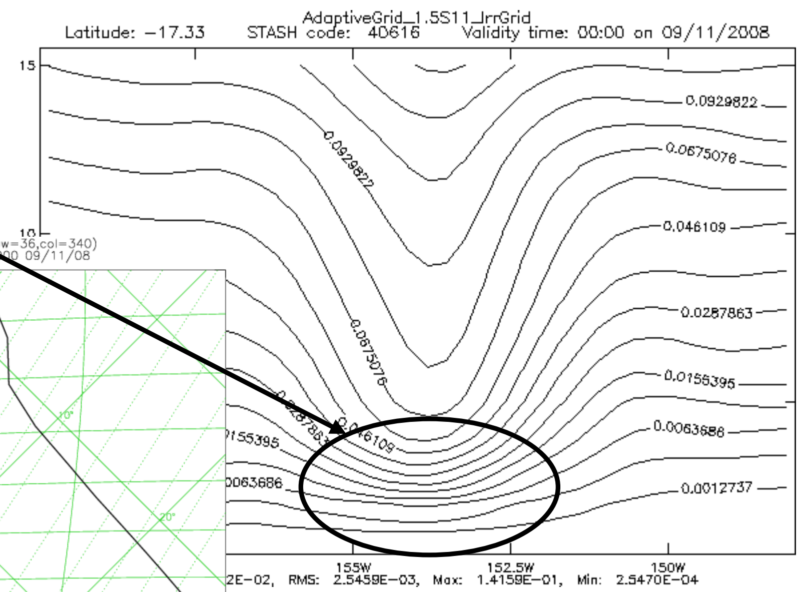
Since mesh points will be clustered where the monitor function is large, this choice of M will cluster mesh points in regions of large static stability.

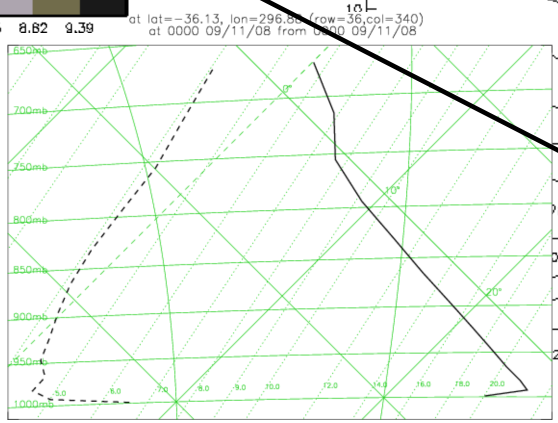
Monitor Function and Adaptive Grid





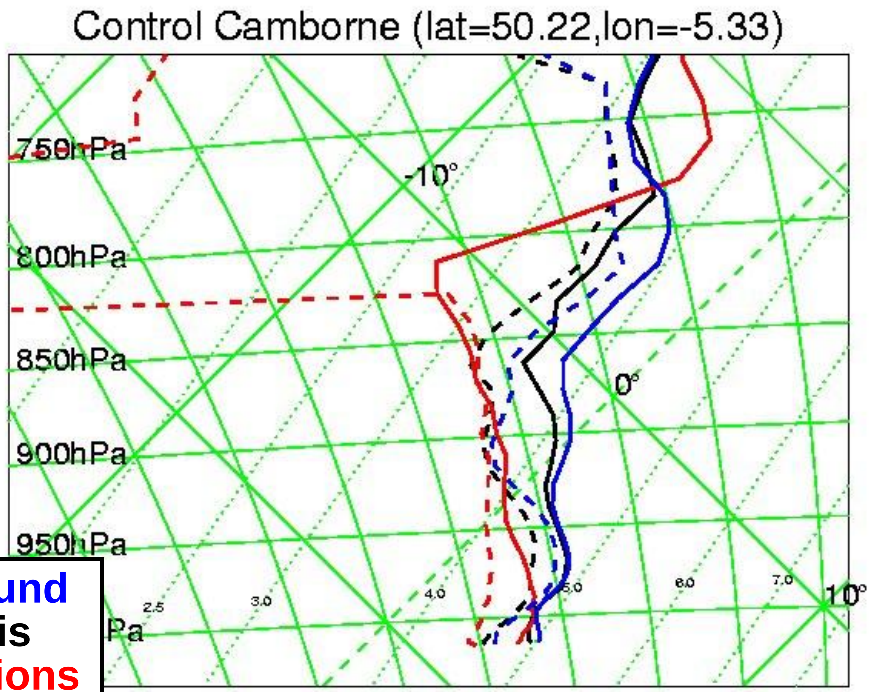




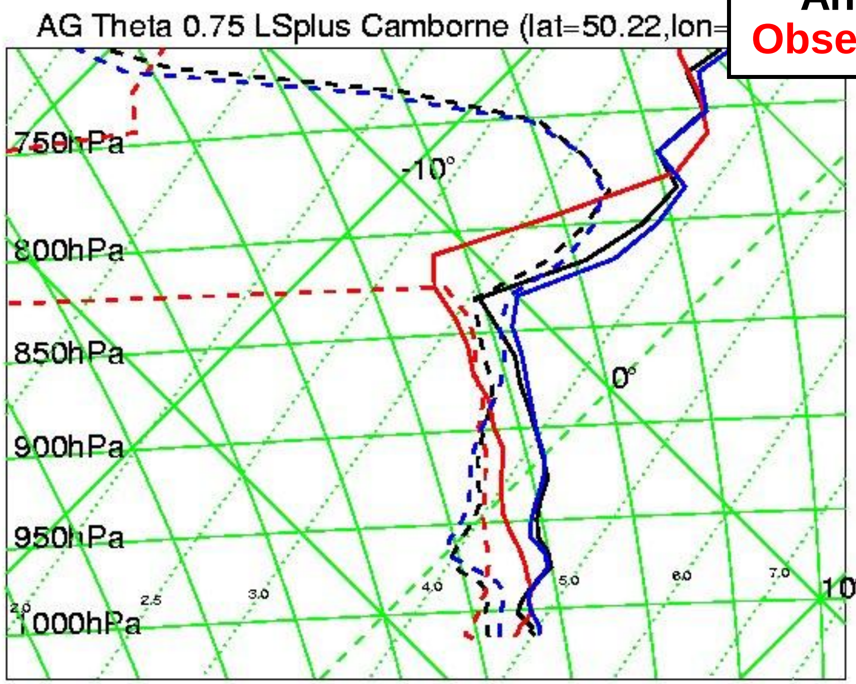


3 Jan 2011 00z: Camborne

The monitor function is based on the background state: if the inversion is not present, the vertical grid does not change.



Background
Analysis
Observations

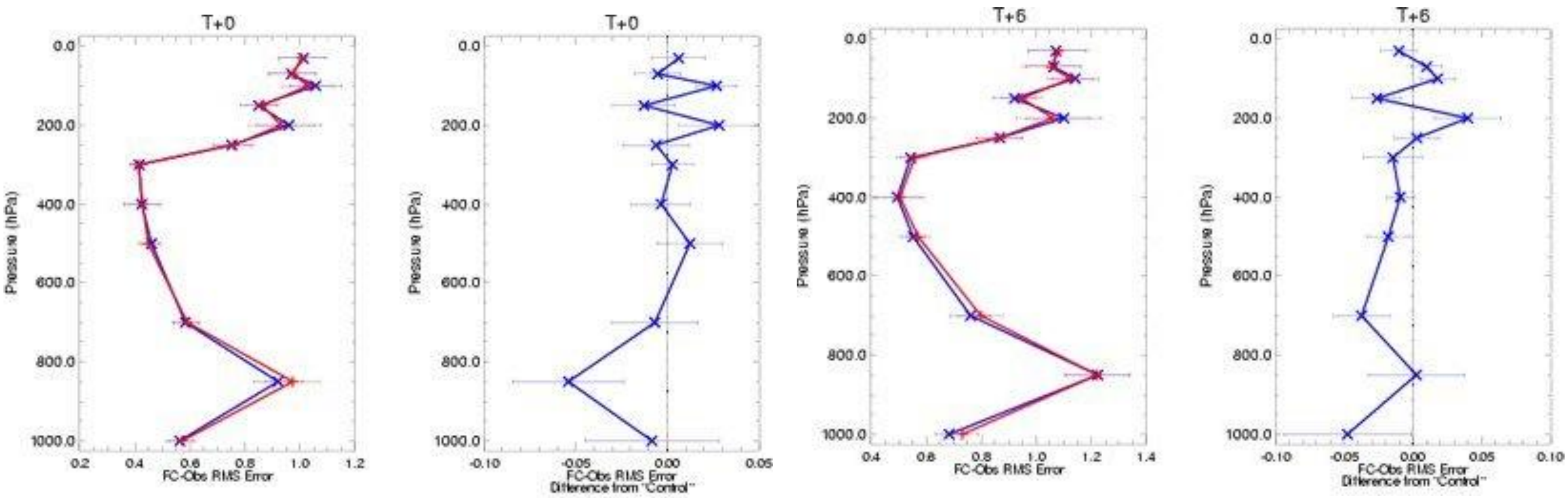


When the monitor function is based on an updated background-state using the observation's information in the minimisation process, the analysis has a clearer inversion.

Met Office

Impact of adaptive grid - analysis vs sonde observations

Temperature RMS error over the winter period



Results from the full coupled analysis/forecast system:

- ➢ small improvement of temperature RMS error versus sonde profiles in the lower atmosphere for both winter and summer cases up to T+ 6h
- ➢ (also slight improvement for cloud base height and T2m)

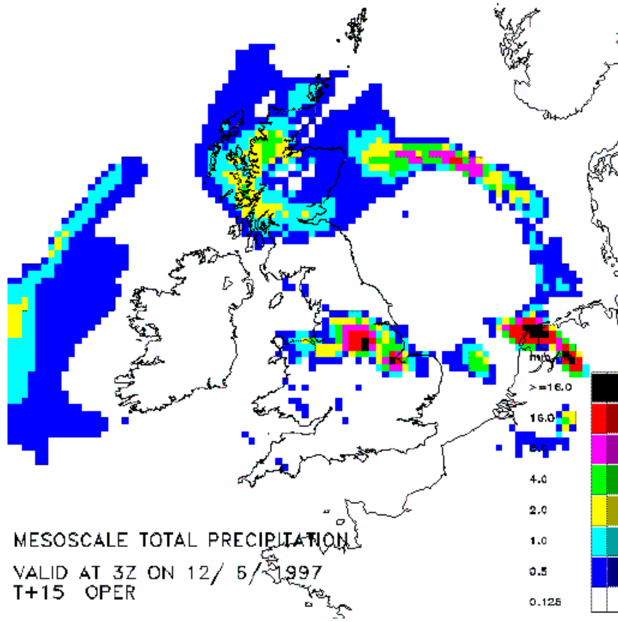
Latent Heat Nudging radar rain rate assimilation

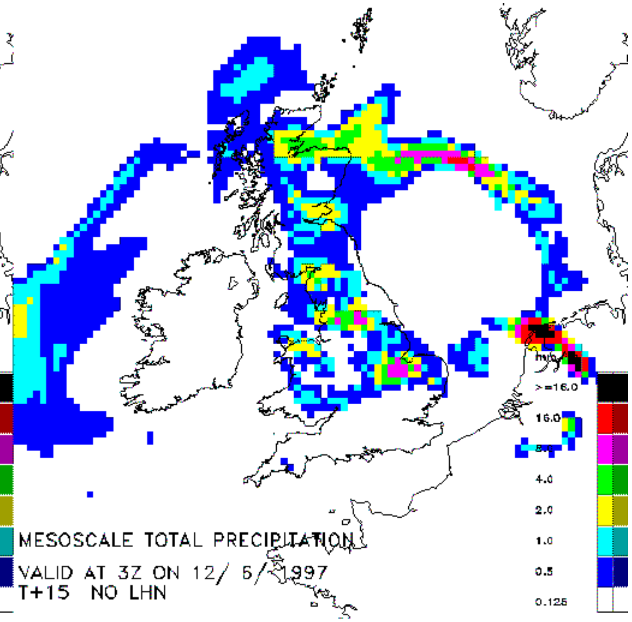
(Jones and Macpherson, 1997: Met Apps, **4**, 269-277)

- hourly radar rain rate composites at 5km resolution
- pre-processing includes clutter and anaprop removal, bright band and vertical profile of reflectivity corrections, gauge calibration
- weight during assimilation depends on radar range and beam height above freezing level

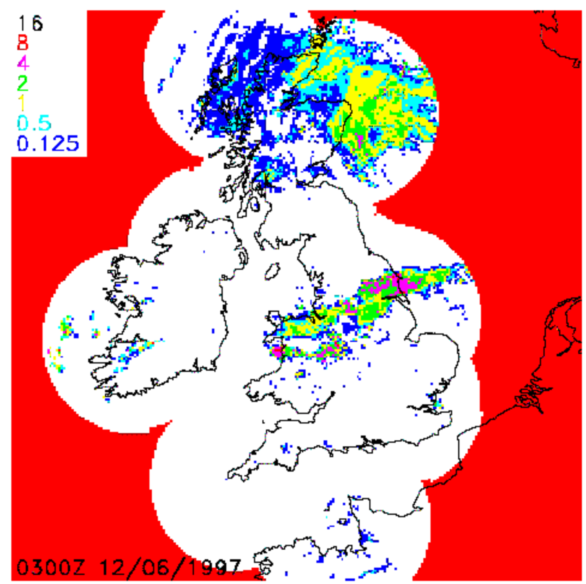
Impact of assimilation of radar data via Latent Heat Nudging

WITH radar t+15





NO radar t+15



verifying radar

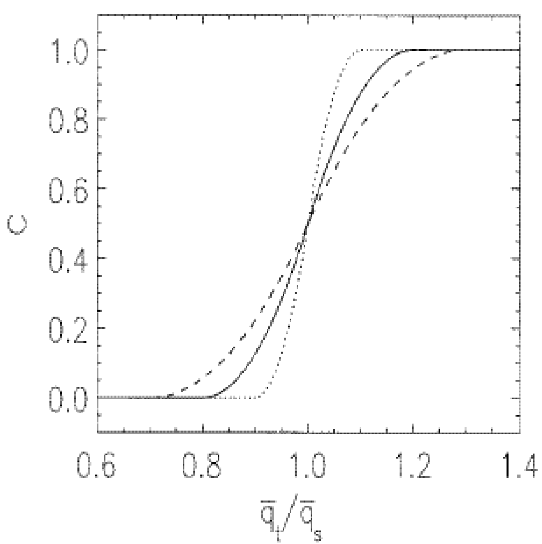
MOPS Cloud assimilation in VAR

(Renshaw & Francis, 2011: Q. J. R. Met. Soc. **137**: 1963–1974)

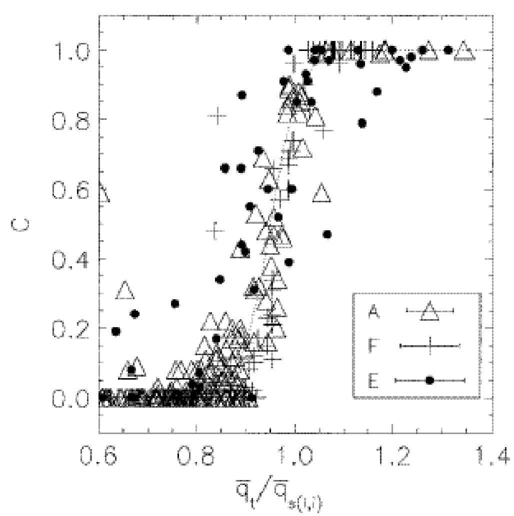
- Operational in NAE & UK models from November 2008, replacing earlier nudging scheme
- Uses 3-d gridded cloud fractions from nowcasting scheme
- Input data are satellite cloud top height and cloud mask + surface reports of total cloud cover and layer cloud amounts

Control Variable

- extra cloud control variable difficult
- have to use single moisture variable
- for now we use RH and diagnose cloud fraction = f(RH)



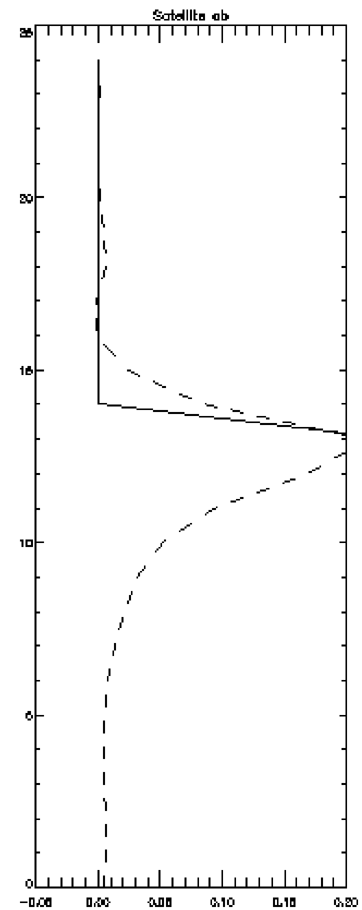
Smith scheme
QJRMS 1990



aircraft data
Wood & Field, JAS 2000

SEVIRI cloud

RH increment



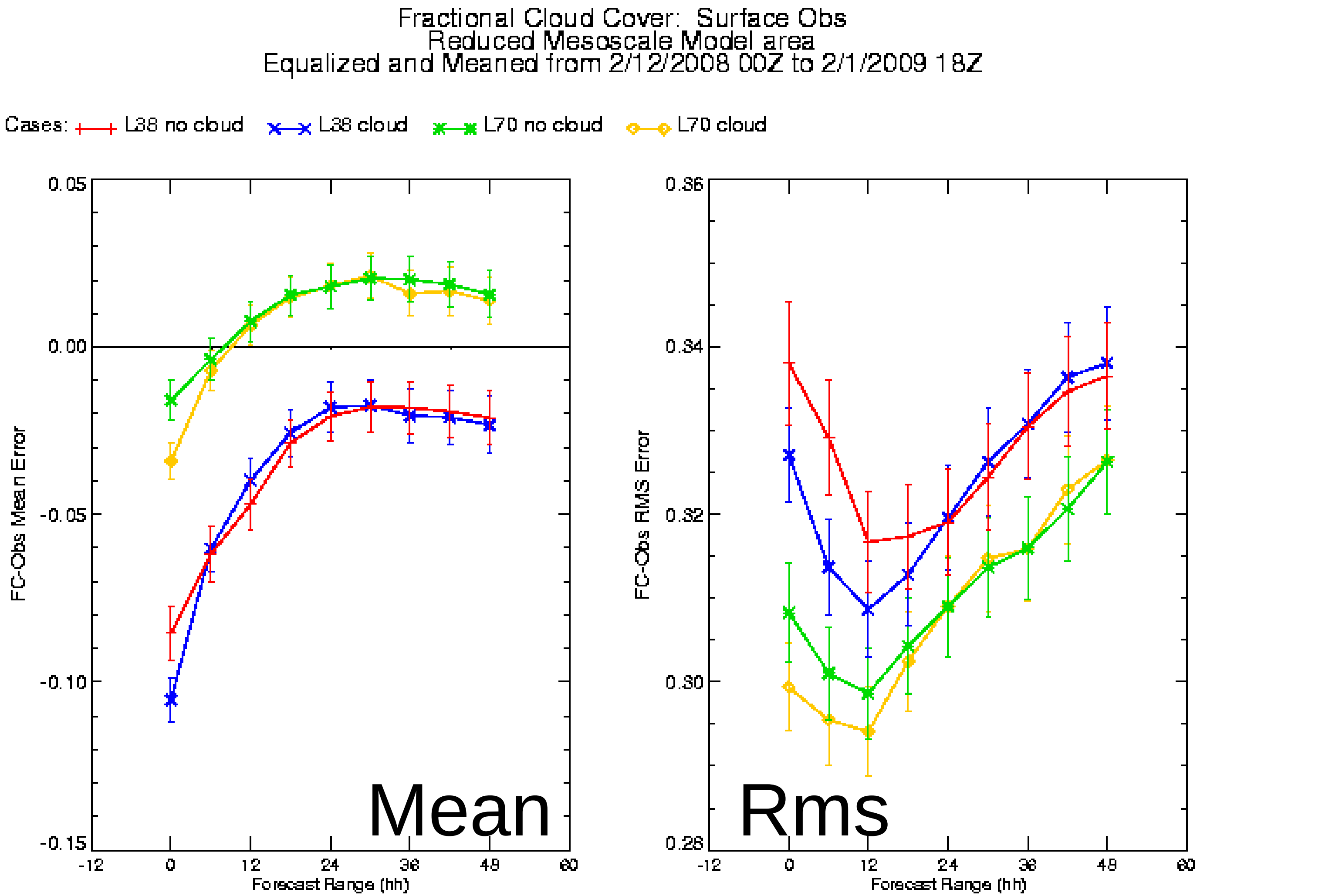
Impact of MOPS cloud assimilation in NAE for 2 different vertical resolutions

L38 NO cloud

L38 cloud

L70 NO cloud

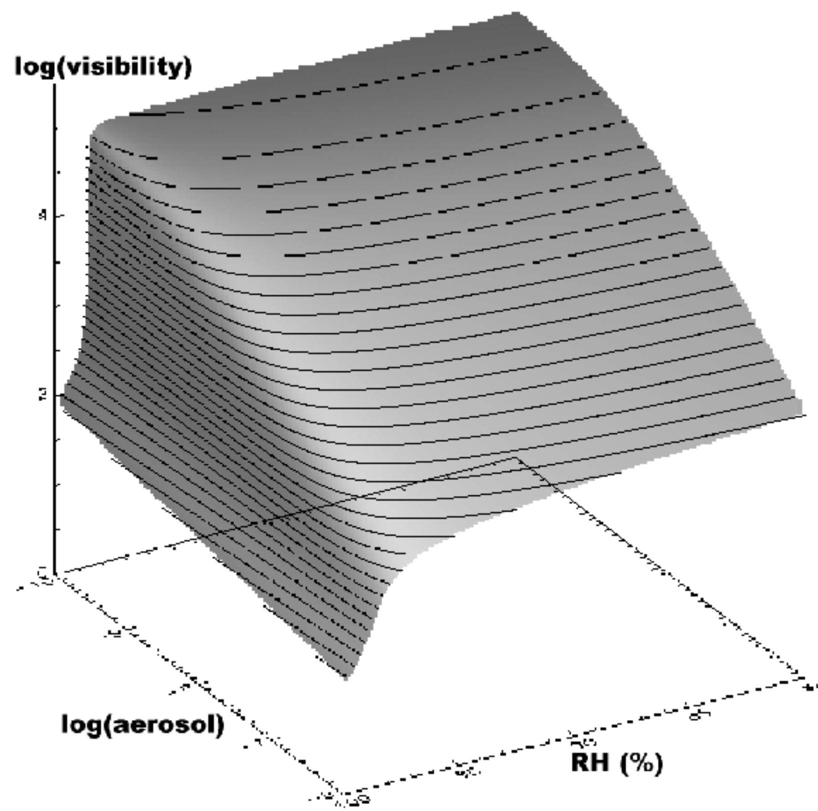
L70 cloud



Visibility forecasting and assimilation

- **UM aerosol**
  - single aerosol mass mixing ratio **m**
  - tracer advection
  - boundary layer mixing
  - emission sources
  - removal by precipitation
- **visibility diagnosis**
  - humidity
  - aerosol
  - temperature
  - precipitation rate

- **4D-Var**
  - PF advection of log(m)'

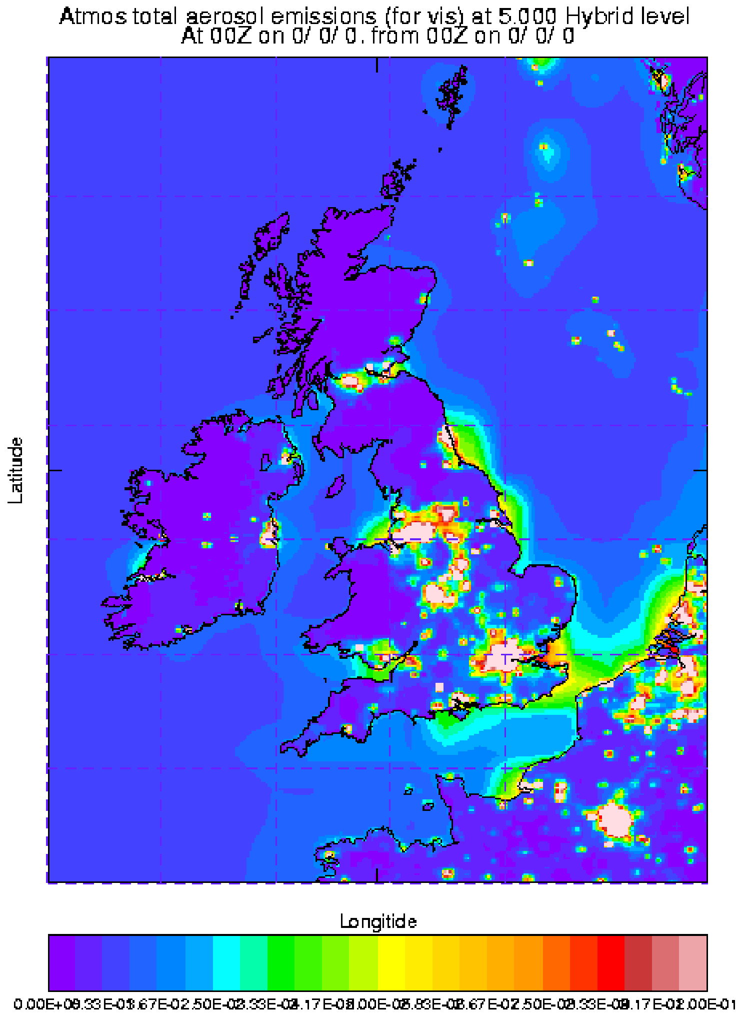


Met Office

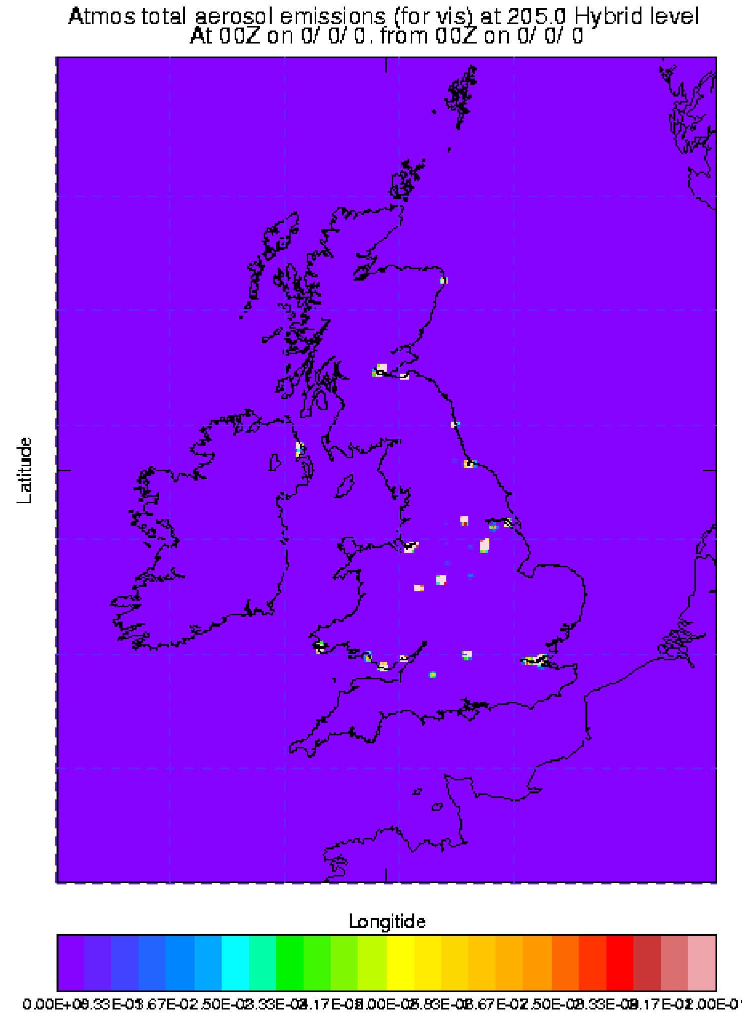
Emission sources (EMEP/GEMS-TNO)

NOx, SO_2,NMVOC

5m

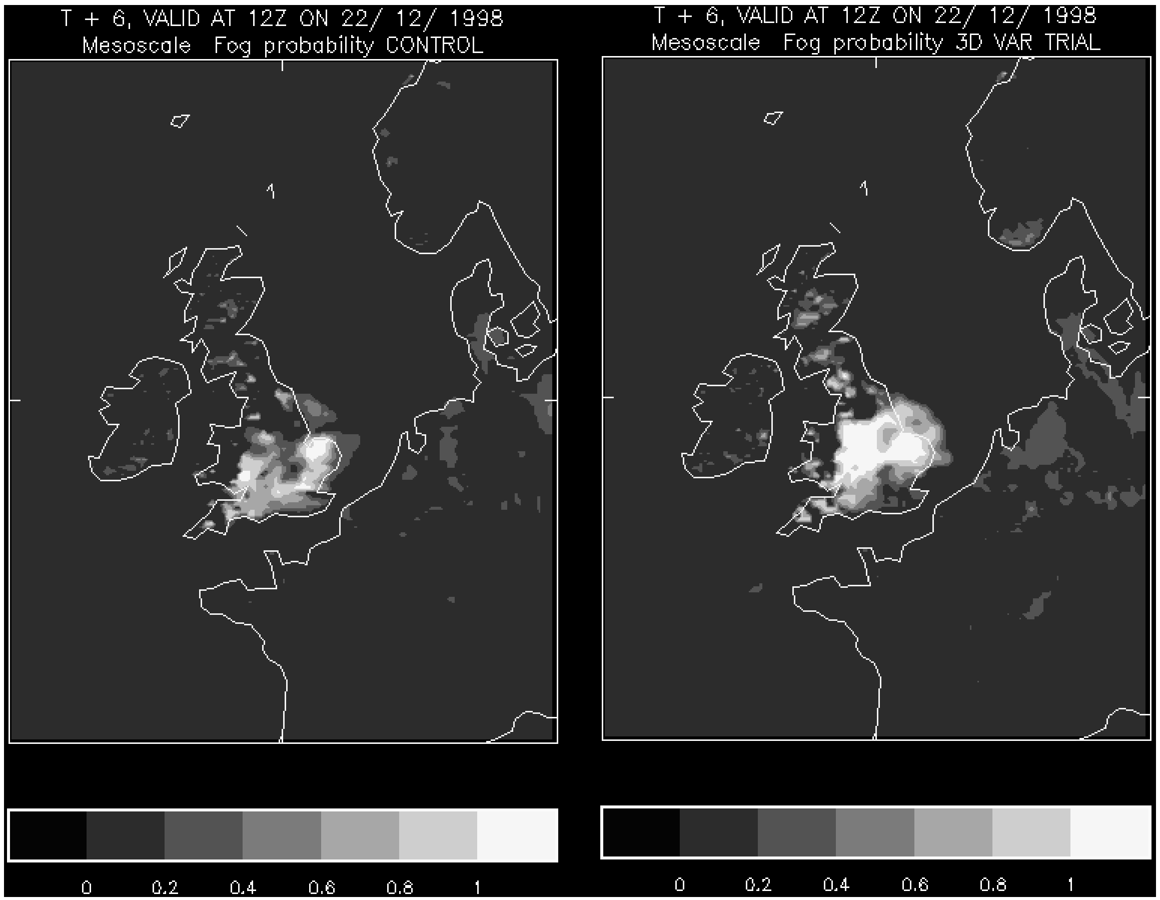


205m

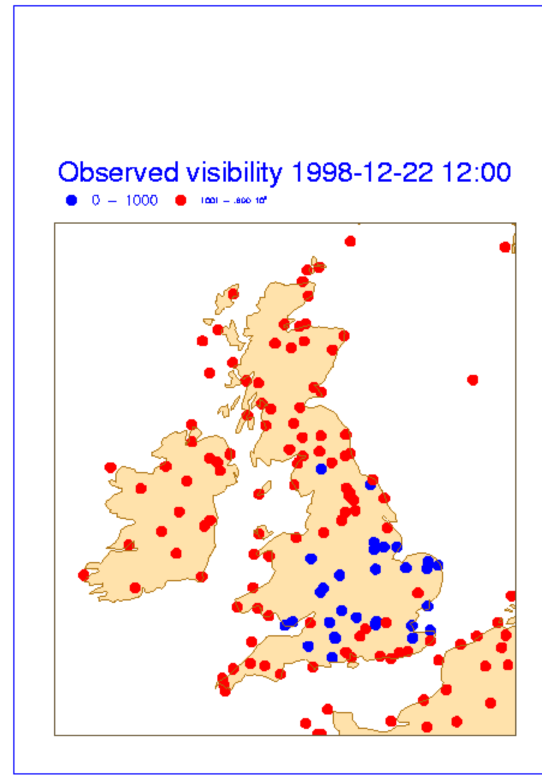


Impact of visibility assimilation

t+6 fog probability



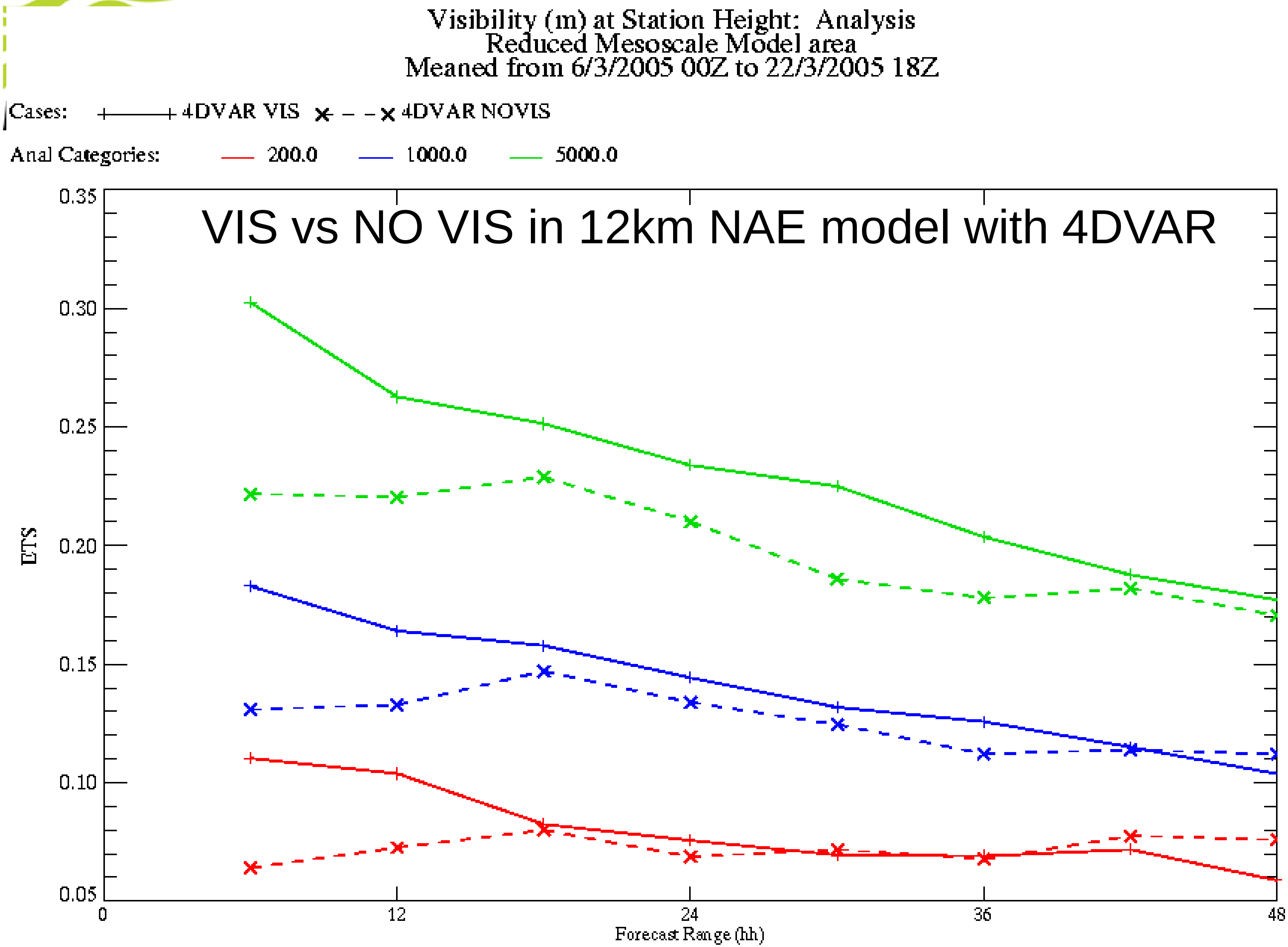
NO vis assim WITH vis assim



observed vis –

● < 1000m

Impact of visibility assimilation



Met Office

Doppler radial winds

12 radars currently providing radial winds

(plans to upgrade whole network by 2014)

9 assimilated operationally so far

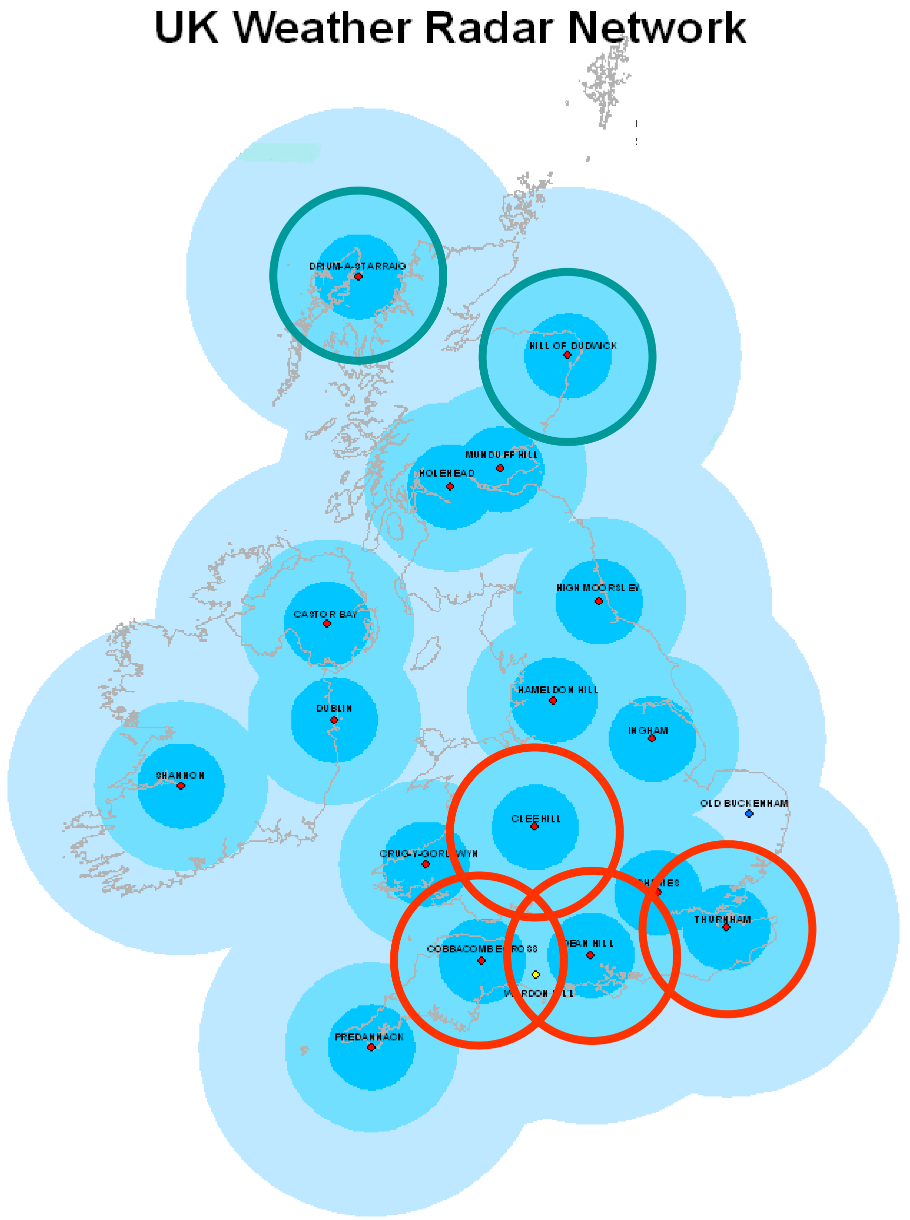
obs within 100 km radius

elevations between 1° and 9°

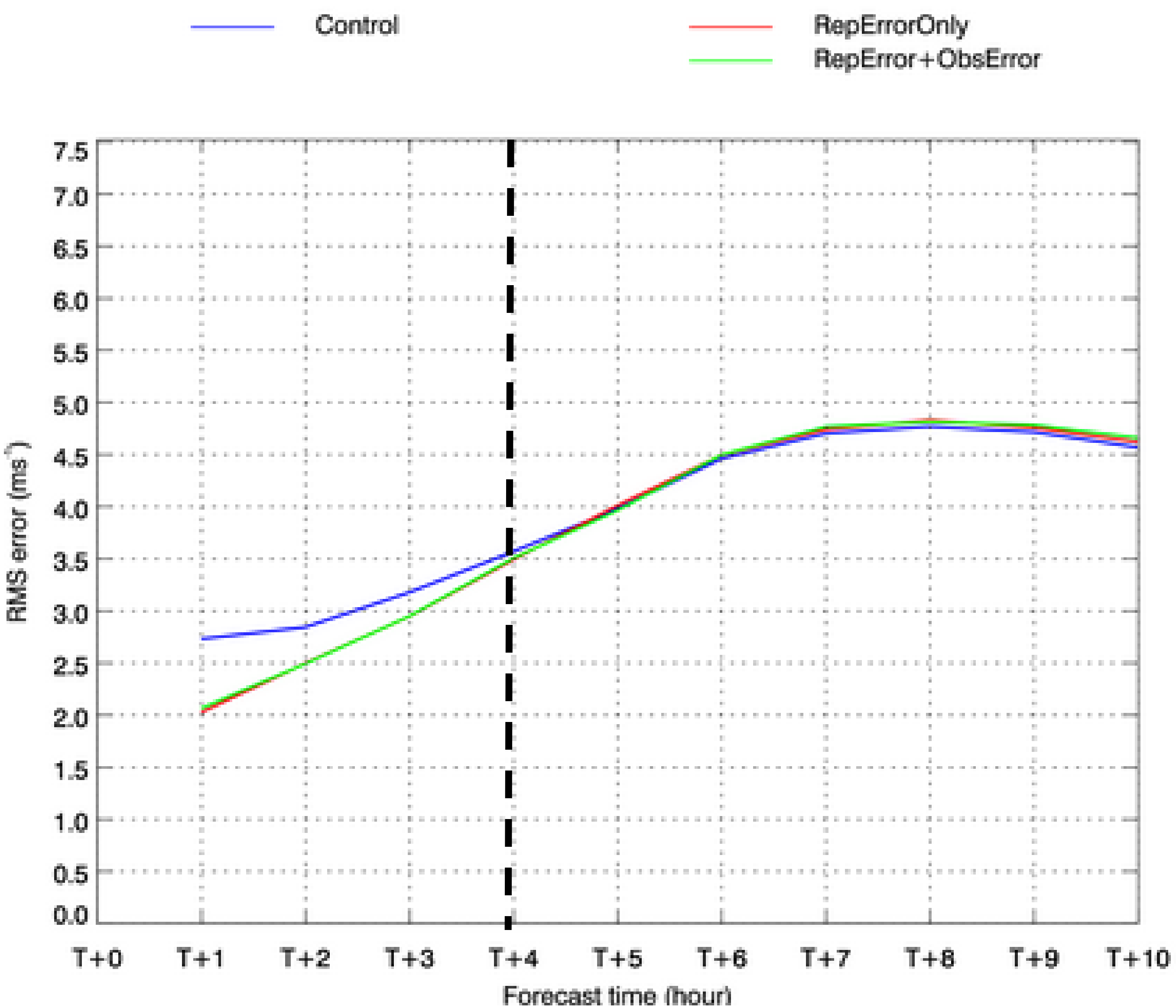
1° azimuthal, 600 m radial

available every 5 minutes

assimilated every 3 hours



RMSE against Doppler Wind



David Simonin

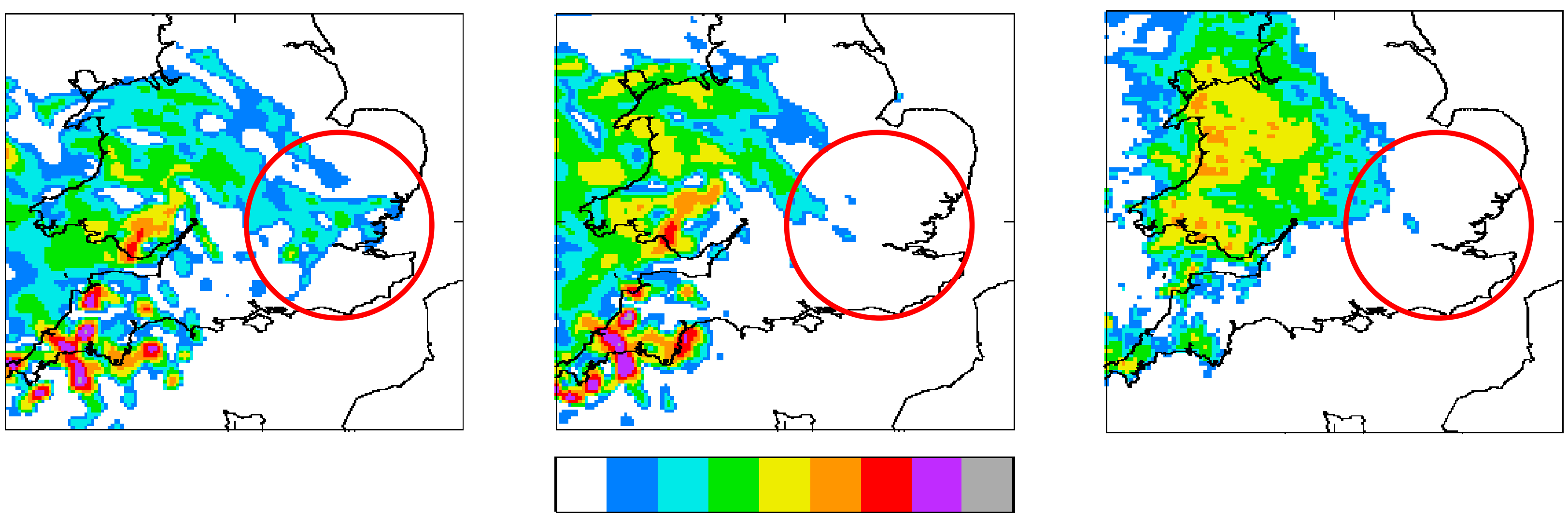
Individual case where rainfall location is seen to be improved

Met Office

CNTL

CNTL + radial winds

Radar

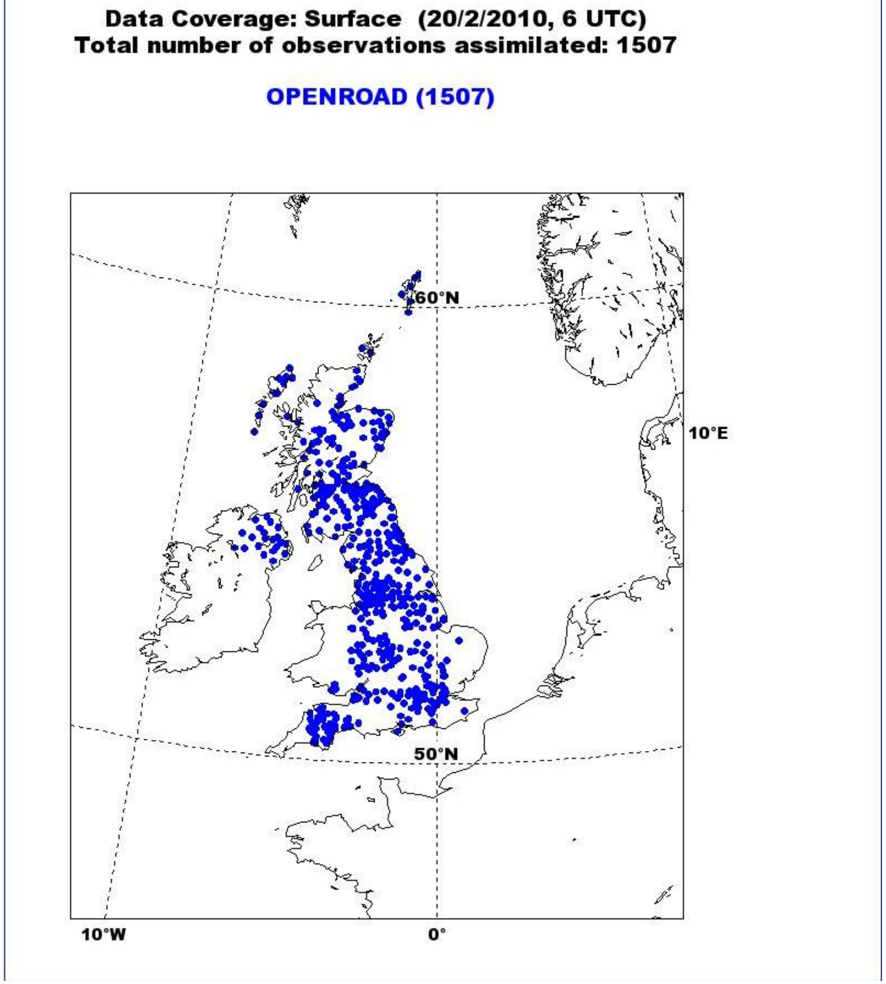


T+4

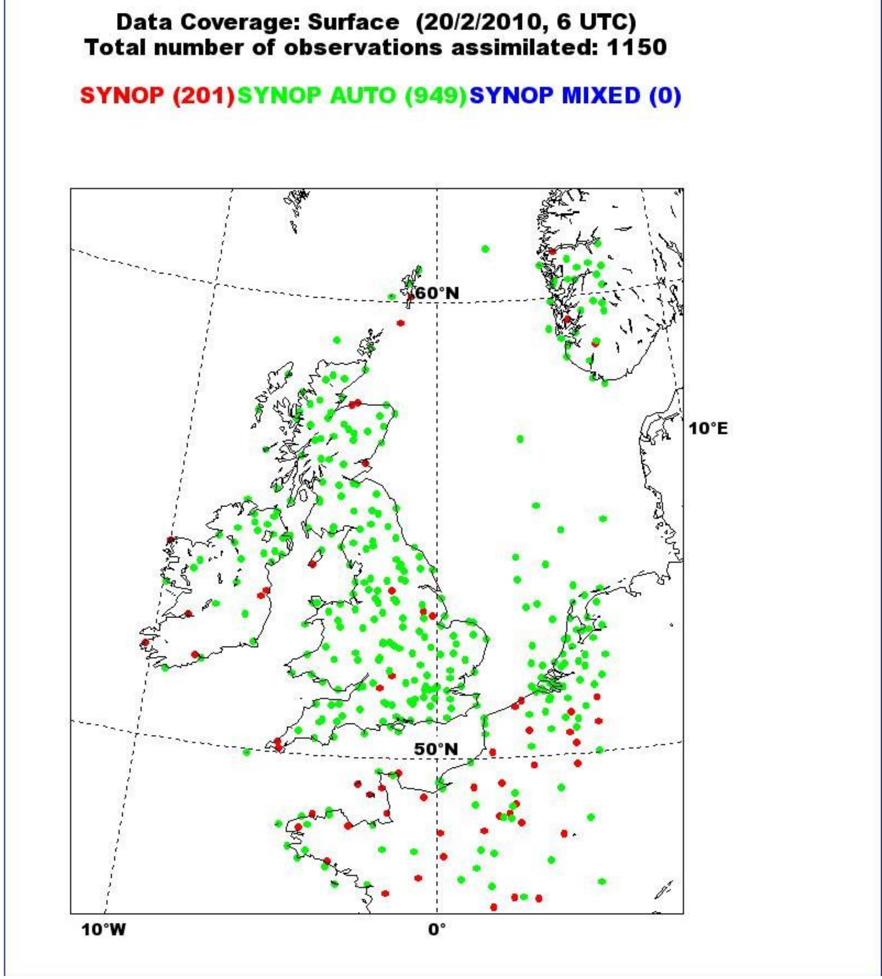
Helen Buttery

Roadside sensor network

OpenRoad – full network



SYNOP



Gareth Dow

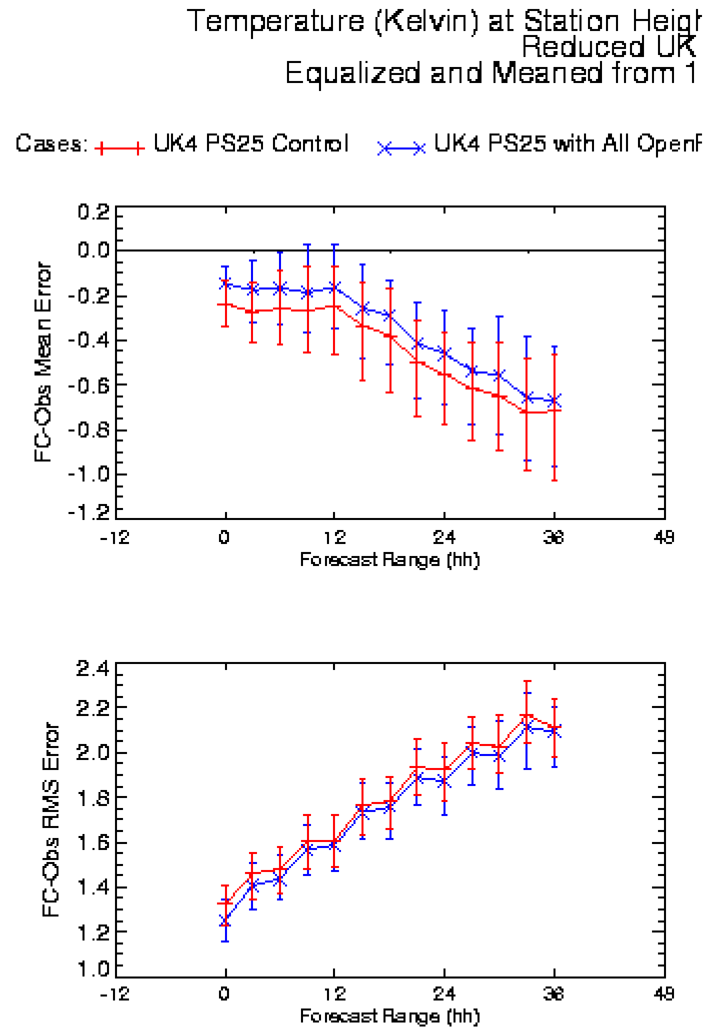
Roadside sensor network impact

Mean T2m error

control

test

Rms T2m error



(2nd half of Dec 2010)

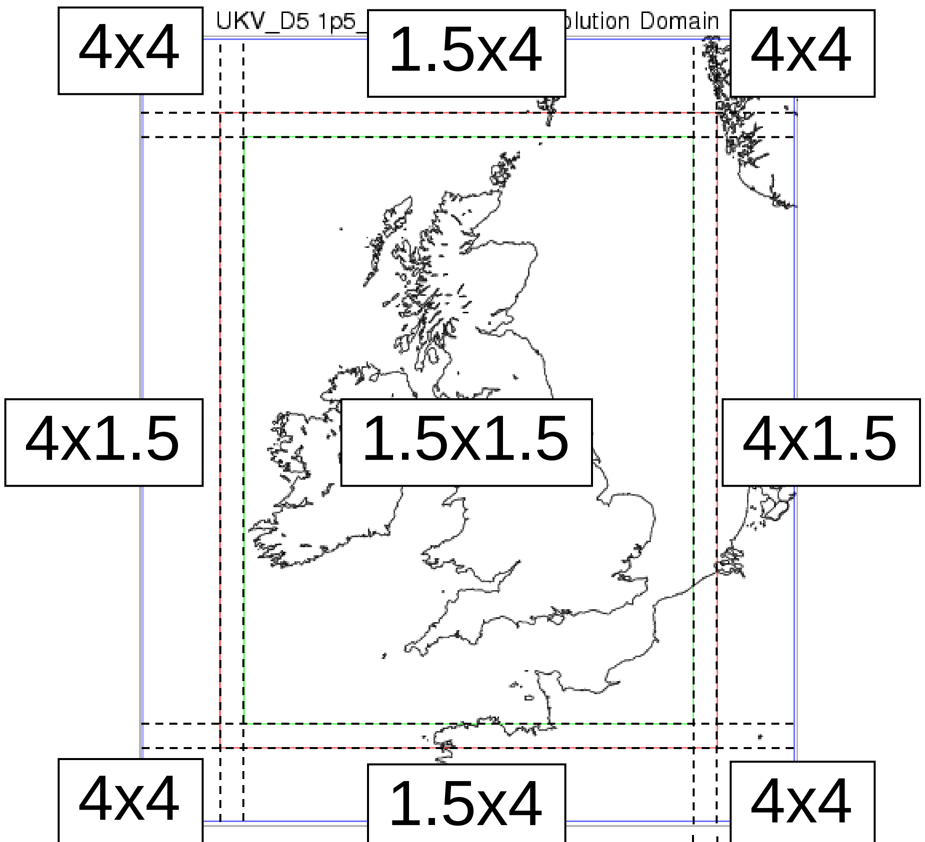
Gareth Dow

UK Index Impacts in UK4

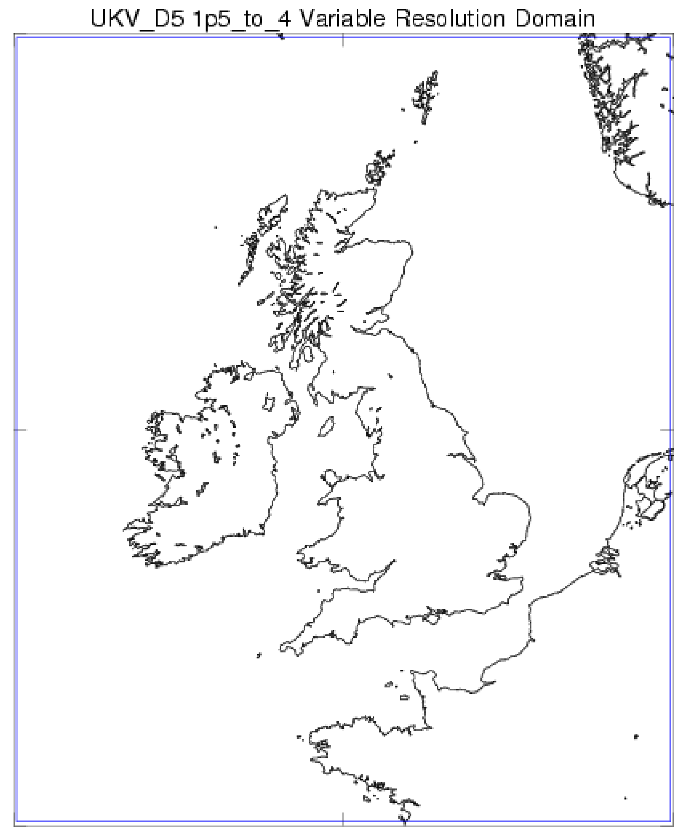
variable	*primary*	*secondary beneficial obs*
Visibility	Surface	
Precipitation	Radar	Upper Air, Aircraft, Satellite, Surface
Cloud Cover	"Extra"	
Cloud Base Height	Upper Air	
Temperature	Surface	Radar
Wind	Surface	Satellite, Upper Air, Aircraft

Gareth Dow

UK1.5km Domain



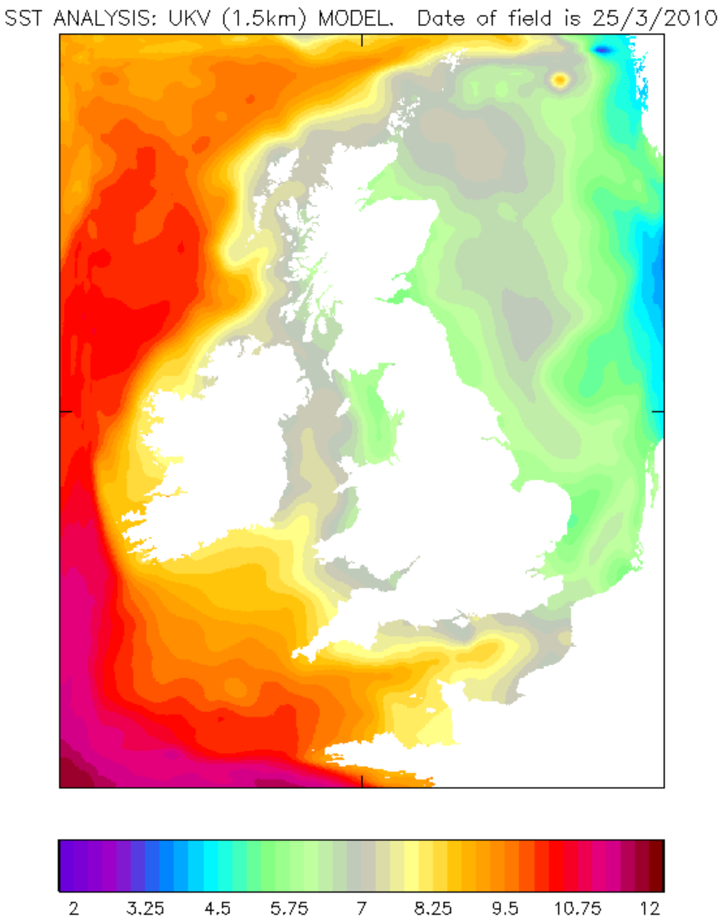
Variable zone



744(622) x 928(810) points

UK 1.5km – SST

- ❑ **updated daily from OSTIA system (~6km resolution)**



UK 1.5km – soil moisture analyses

- updated daily from interpolated global model analysis (EKF with increments from screen level temperature and humidity observations plus ASCAT soil wetness observations)
- global values used over whole model domain
- interpolation conserves beta (moisture availability)
- (long term) introduce dedicated land surface assimilation for UK model via EKF