Developments in convective scale assimilation at the UK Met Office

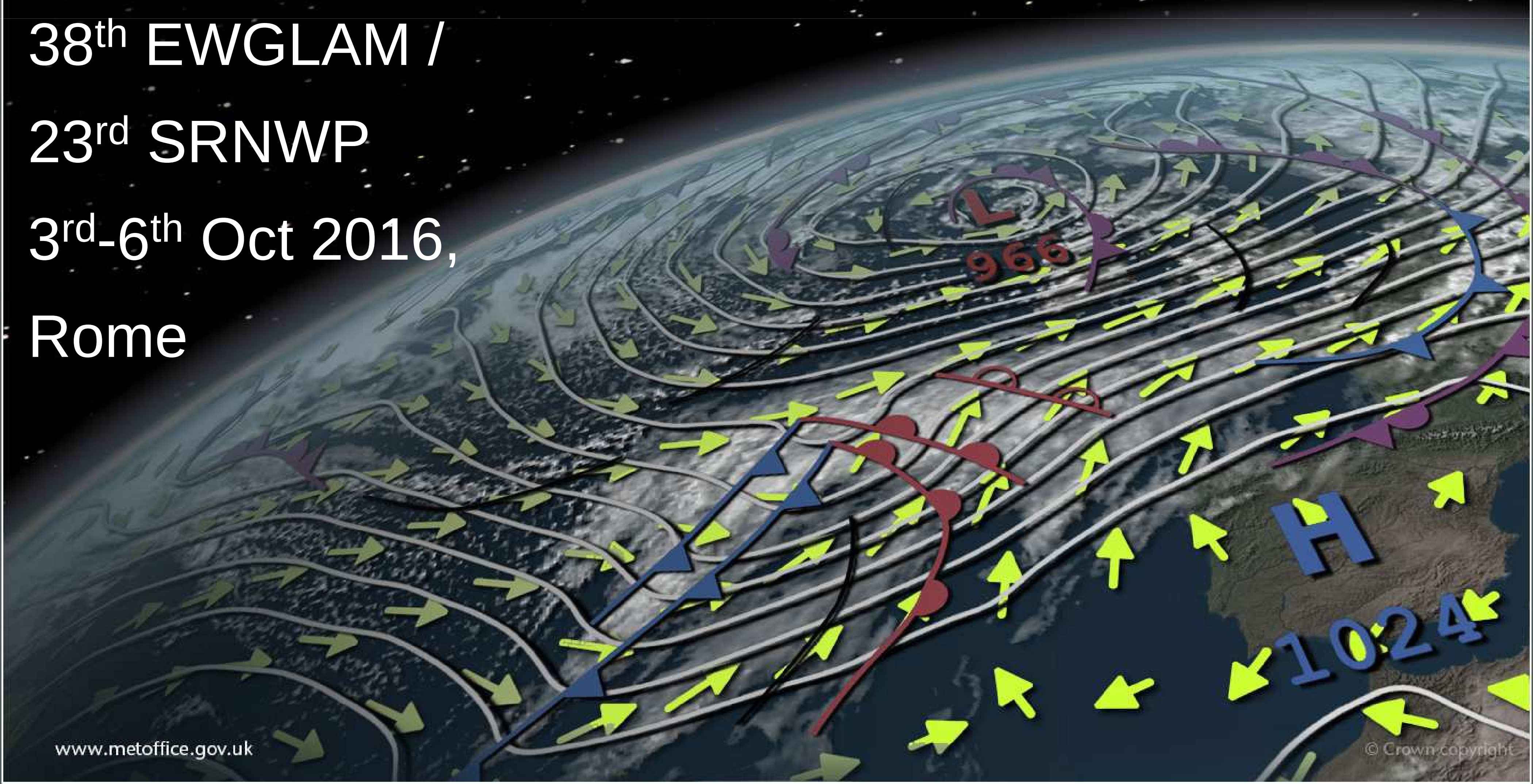
Bruce Macpherson

38th EWGLAM /

23rd SRNWP

3rd-6th Oct 2016,

Rome

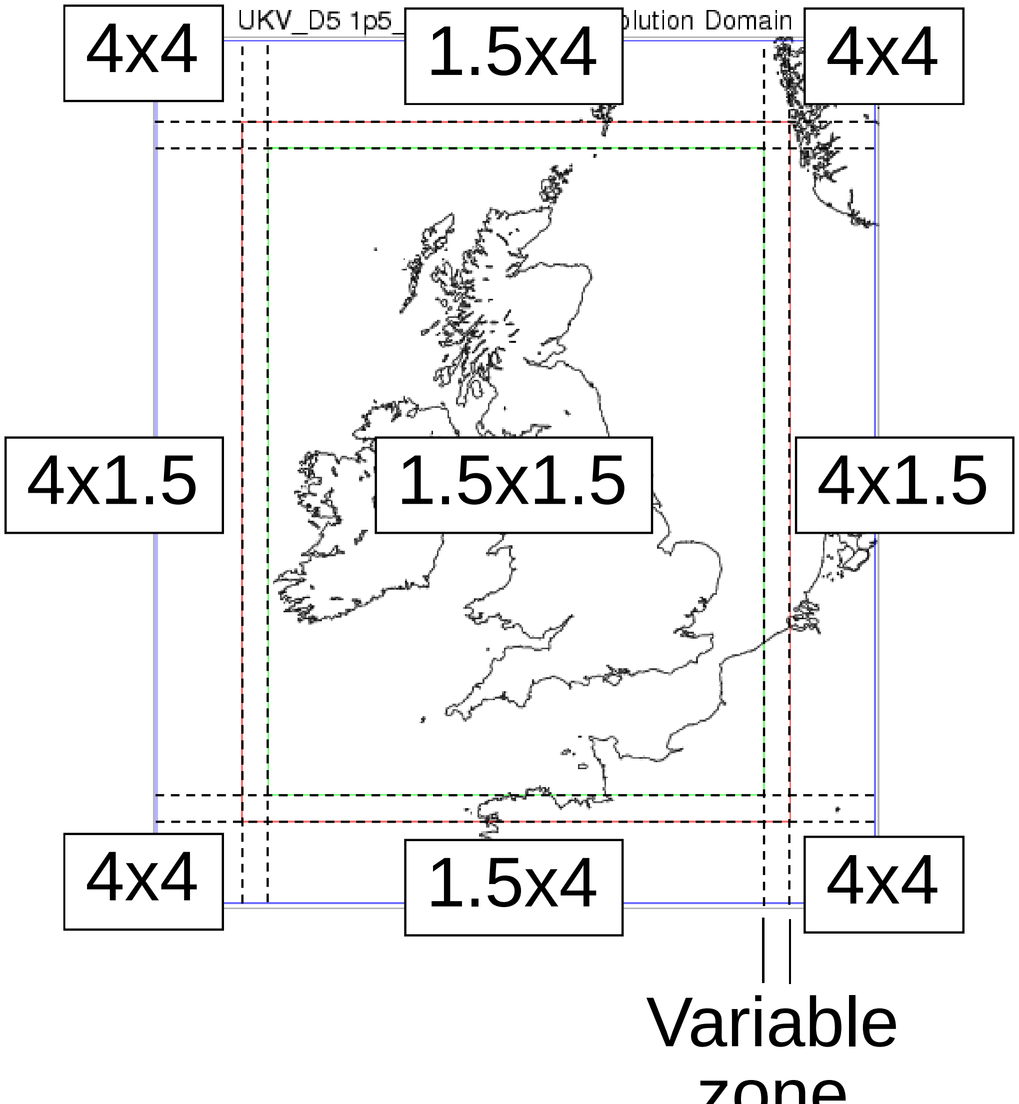


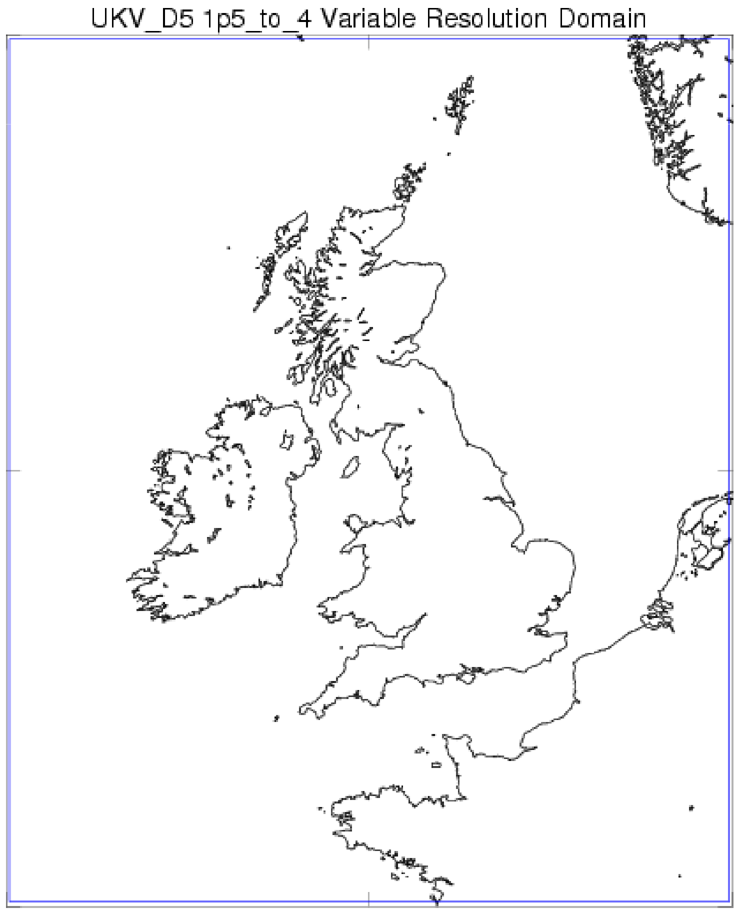
Contents

This presentation covers the following areas

- Description of UKV DA system
- Recent upgrades
- Current projects (hourly 4DVAR)

UKV Domain





744(622) x 928(810) points

UKV Data Assimilation

- 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 17km Global model at DT 03, 09, 15, 21 UTC
  - Lateral boundaries from hh-6hr run of 17km Global model at DT 00, 06, 12, 18 UTC
- 3DVAR (with FGAT) + IAU for all observations, *except* Latent Heat Nudging for radar-derived surface rain rate

UKV – extra observations *not* assimilated in global model

- radar-derived surface rain rate (hourly, 5km resolution)
- visibility from SYNOPs (hourly)
- T_{2m} & RH_{2m} from roadside sensors (hourly)
- Doppler radial winds (3-hourly)
- SEVIRI Channel 5 radiances above low cloud
- high-resolution AMVs from MSG
- 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

Recent Upgrades

March ‘16 Upgrade (PS37)

Covariances

- ‘Swapped Transform Order’ with improved representation of spectrum in training data (allows for shorter wind length scales)

Cloud

- Creation of ‘GeoCloud’ cloud fraction data within OPS (instead of within offline AUTOSAT)
- Enable insertion of thicker cloud obs from SYNOP (instead of single layer)
- Revise model cloud thickness climatology from recent data

Satellite radiances

- add CrIS and AIRS (to supplement IASI)
- add ATMS humidity channels

Met Office

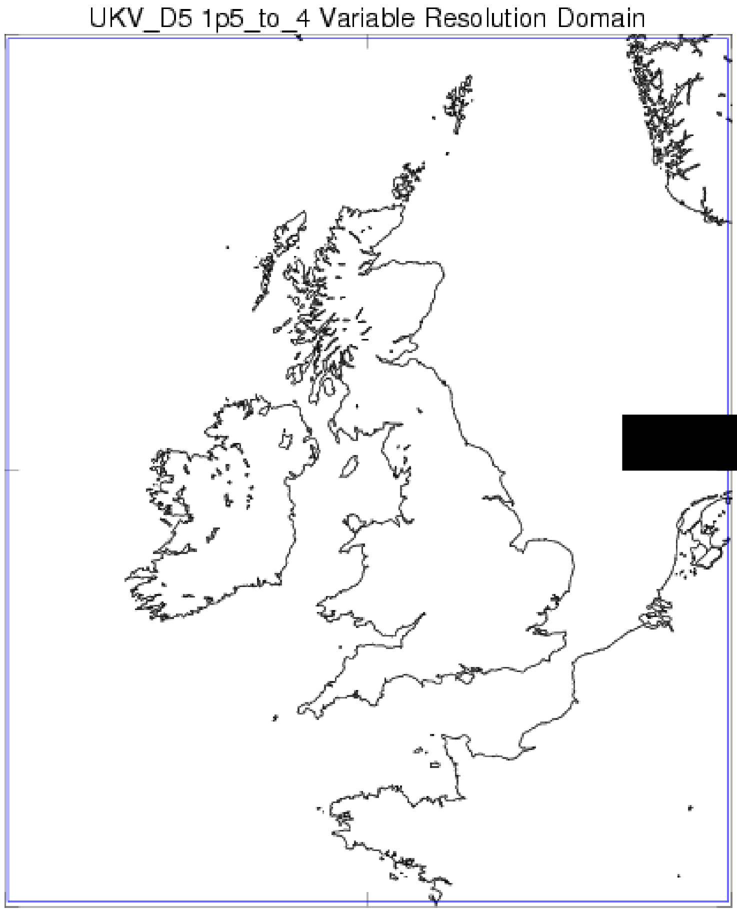
+ Roadside sensor network

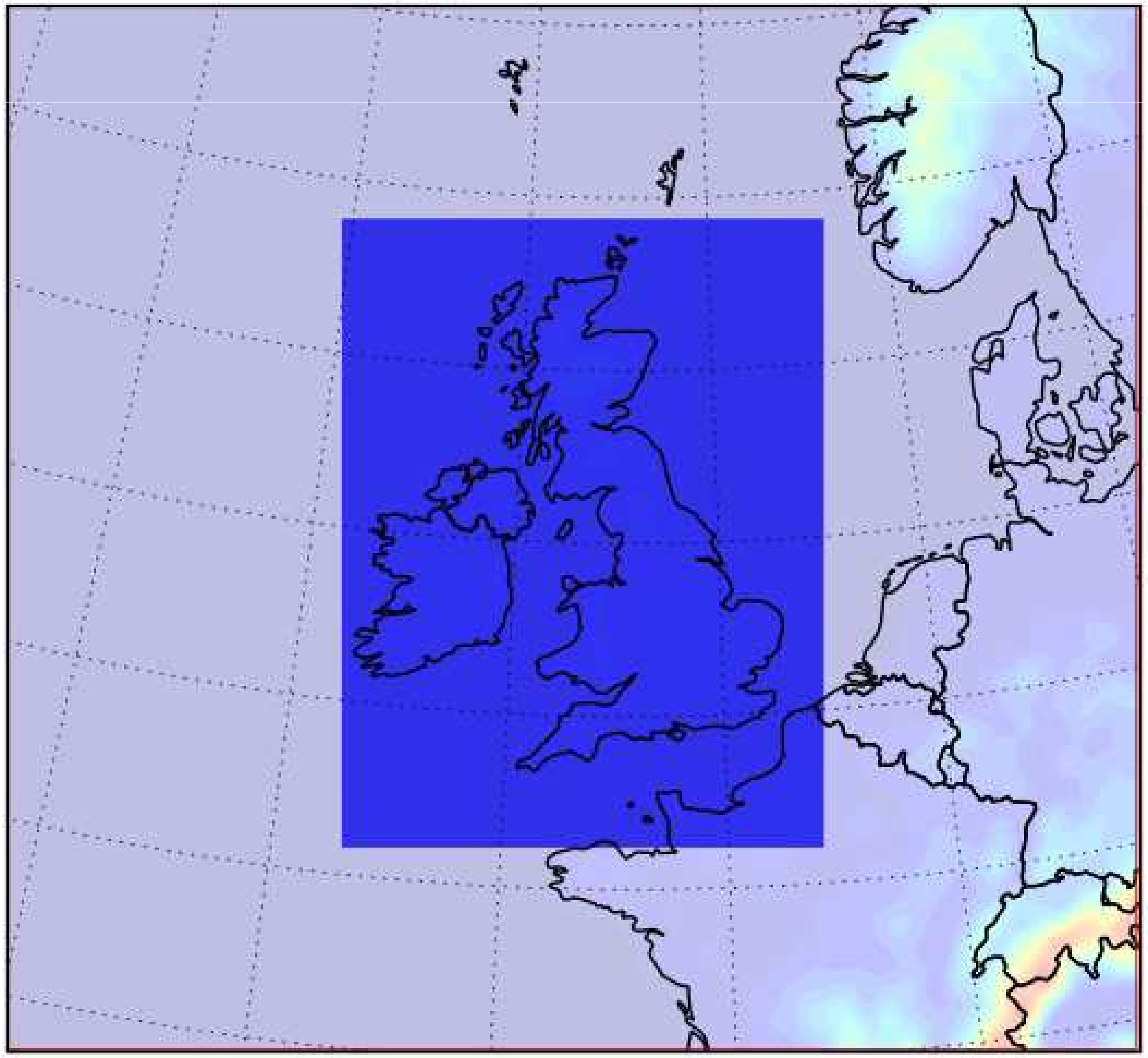
T2m / rh2m
(assimilate 12% more)

Visibility
(monitor & introduce)

Current Projects

Extended UKV area
(operational Nov 2016)





Hourly UK-wide 4DVAR

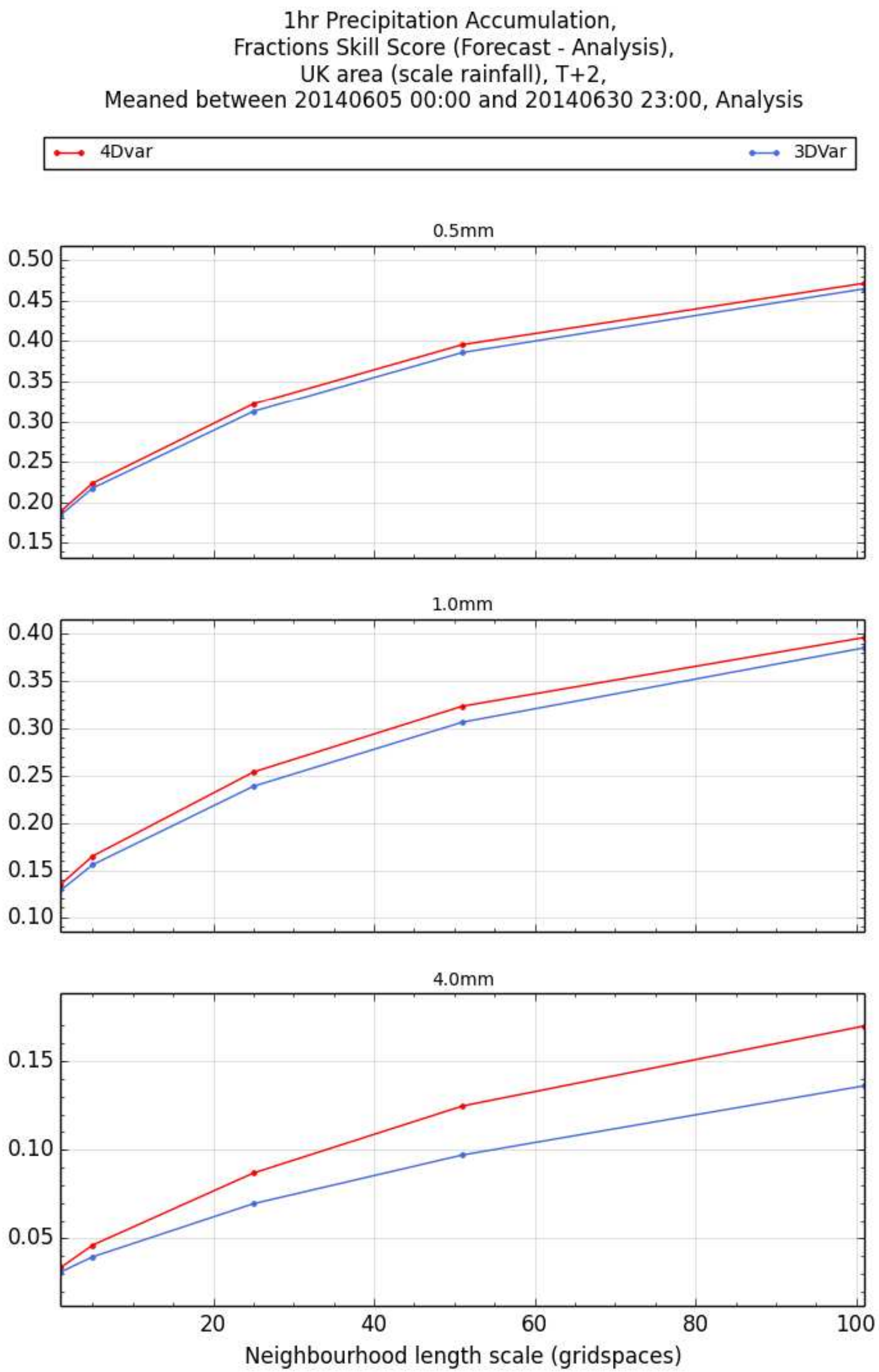
- **Build on Nowcasting Demonstration Project run for 2012 Olympics (Ballard *et al*., 2016)**
- **Improve post-processing products in 0-6hr period**
- **Hourly updates to t+12 – potential benefit in severe weather**

UKV 4DVAR system - status

- Observation cut-off 45 mins
- Include vertically adaptive grid
- Perturbation Forecast model resolution 3km (*or maybe 4.5km*)
- Initialisation by digital filter ‘Jc term’
- Doppler radial winds every 10mins
- AMVs, wind profiler, SEVIRI radiances every 15mins
- Surface rain rate from radar every 15mins (for LHN)
- Other data mostly hourly
- Radiosondes (only upper part of ascent assimilated)

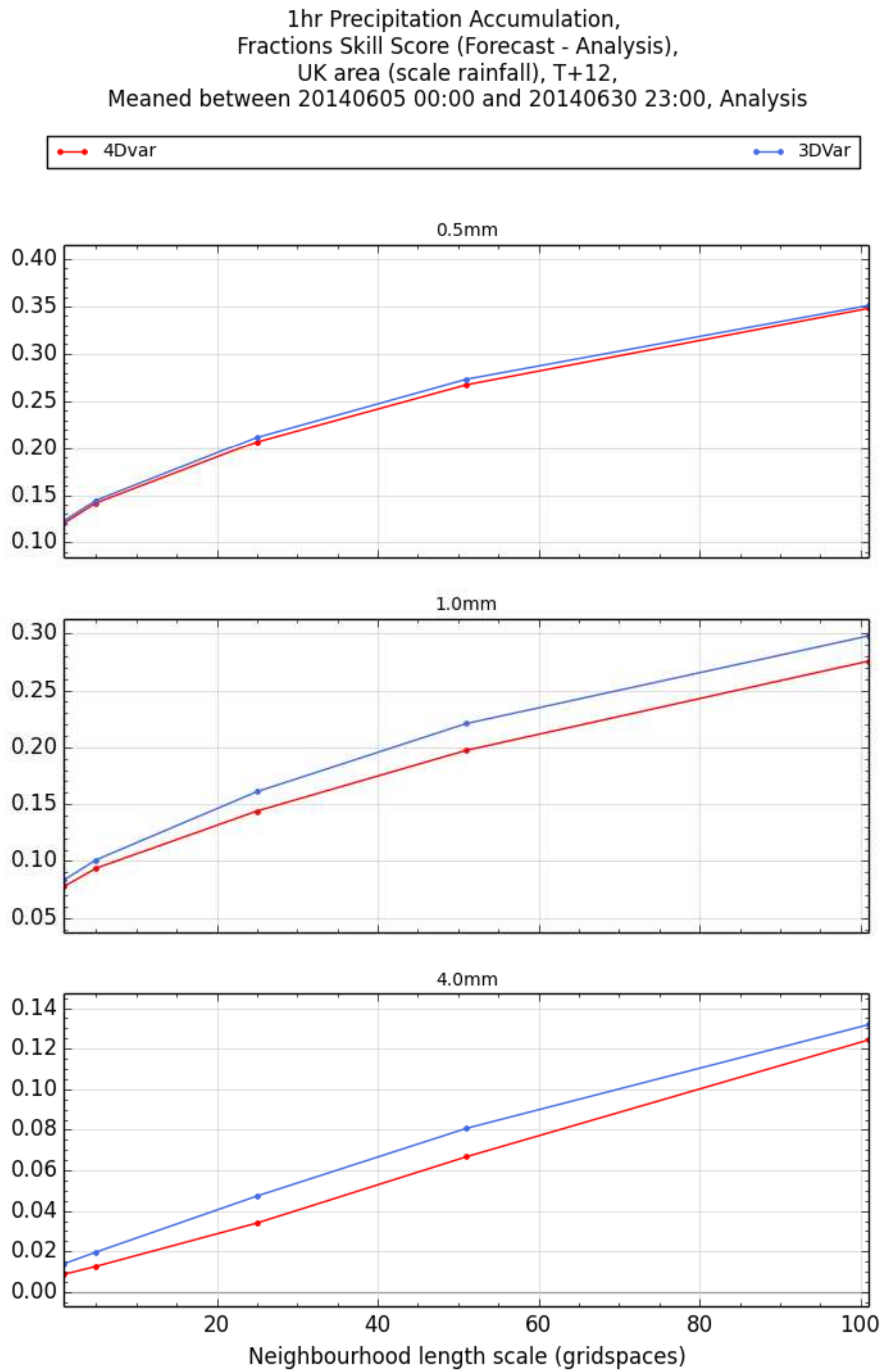
UKV 4DVAR - results

- *Improved* very short-period rainfall (better spin-up)
- FSS v radar at t+2
- 4DVAR 3DVAR



UKV 4DVAR - results

- *Degraded* rainfall by t+12 (short cut-off?)
- FSS v radar at t+12
- 4DVAR 3DVAR

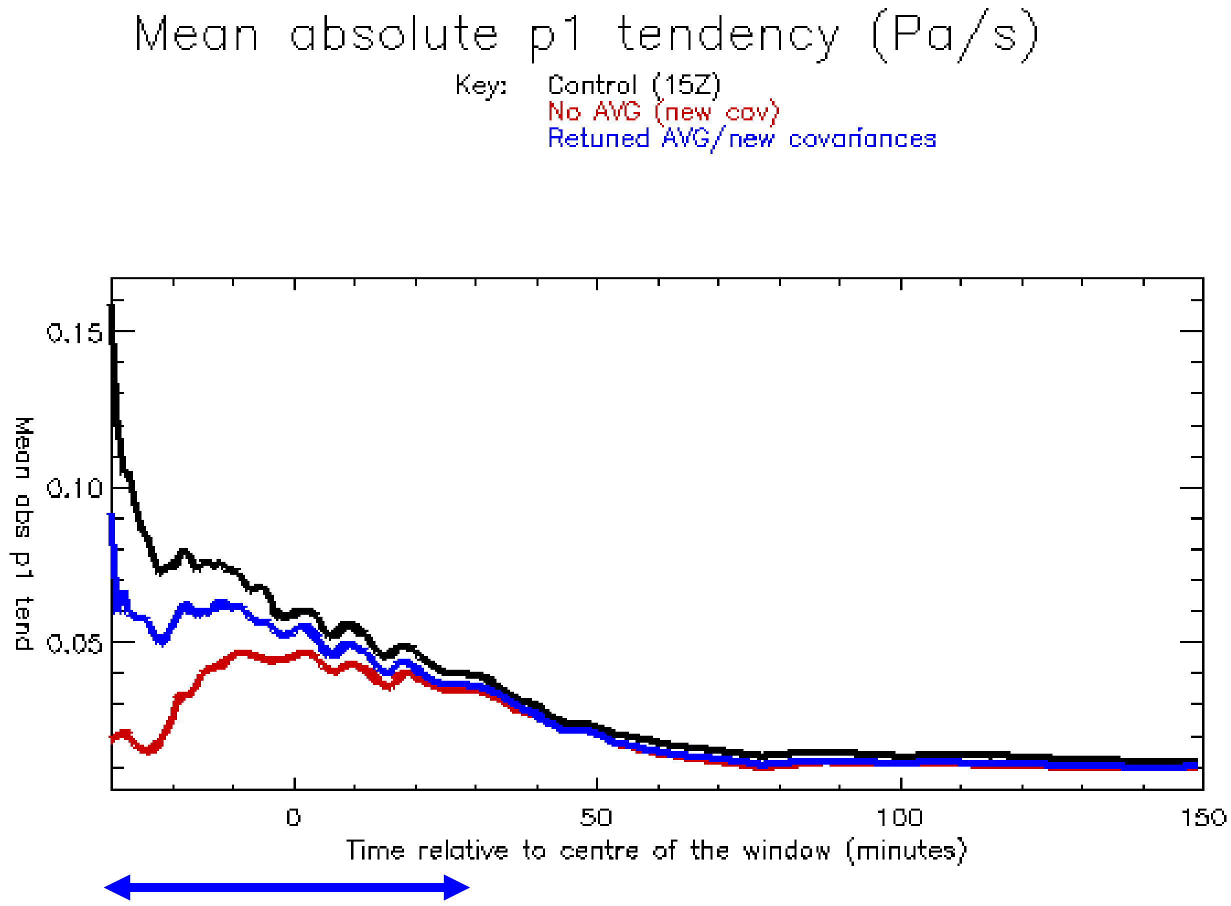


Gravity wave activity in 4DVAR – impact of covariances, adaptive grid and new lateral boundary data

Old covariances

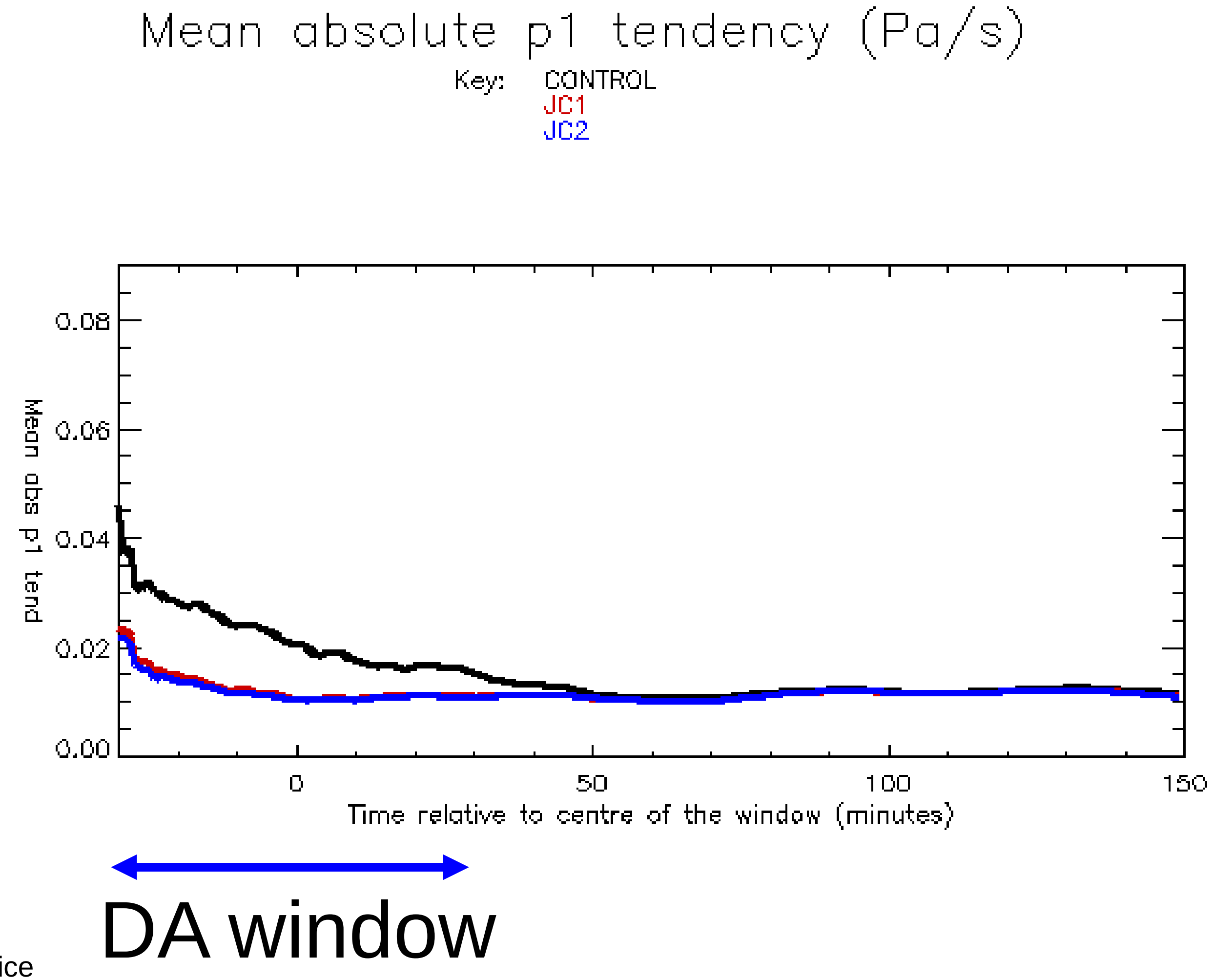
STO covariances

STO cov + noAG



DA window

Gravity wave activity in 4DVAR – impact of digital filter (Jc penalty term)



Next developments

- Optimise 4DVAR system on extended area
  - Adjust PF model numerics for greater stability
  - Reduce PF model resolution for greater stability and lower cost
- Test variational bias correction of satellite data
  - Operational in global model in March 2016
- Prepare hourly 4DVAR for PS39 (operational summer 2017)

FSOI at convective-scale

- Challenge of model non-linearities
- Linear Perturbation Forecast model and adjoint valid only for short forecast periods (~50% of 3-hr forecasts at resolution of 3km)
  - Reduced resolution PF model is more stable (6-8km)
  - Use observations-based error norm instead of analysis
- Looks more hopeful now that FSO can be useful at this scale
  - Trial system run successfully on a few cases
  - Error norm to be refined

Helen Buttery

Questions?

Additional slides

Differences when running VarBC in a LAM compared to a global assimilation?

1. The LAM only samples a limited air mass.

2. Except for SEVIRI, all other satellite instruments currently in use with VarBC are only available twice per day.

3. The boundary updating fields from the Global Model have used different VarBC coefficients.

4. The UKV model has a top at 40km and the global at 80km. RTTOV needs to extrapolate above the model top. This affects a few radiance channels.

VarBC status in UKV

- The VarBC experiment after 30 days (720 cycles) is on average fitting all radiances better than current system with fixed bias coefficients.
- The average fit to radiosondes and other data types is also improved.
- The implementation of VarBC in UKV would save a lot of current effort with the constant updating of the fixed bias correction.
- The lack of any forecast impact suggests the current fixed bias correction is OK until there are model or DA changes

Met Office

FSOI

- Use data assimilation system to assess the impact of all observations simultaneously
- Don’t require a data-denial experiment (OSE) for each separate observation type.

Forward system (DA)	*Reverse system (FSOI)*
Observation innovations	Observation sensitivities
↓	↑
(data assimilation)	(adjoint data assimilation)
↓	↑
Analysis increment	Analysis sensitivity
↓	↑
(forecast model)	(adjoint forecast model)
↓	↑
Change in forecast	Forecast error sensitivity

Met Office

FSOI

$$\left(\frac{\partial \delta e^f}{\partial \delta \mathbf{y}^O}\right)^T = \left(\frac{\partial \delta \mathbf{w}_0}{\partial \delta \mathbf{y}^O}\right)^T \left(\frac{\partial \delta \mathbf{w}_t^f}{\partial \delta \mathbf{w}_0}\right)^T \left(\frac{\partial \delta e^f}{\partial \delta \mathbf{w}_t^f}\right)^T_{\widetilde{\mathbf{w}_t^{fa}+\mathbf{w}_t^{fb}}}$$

Observation sensitivities $\left(\frac{\partial \delta e^f}{\partial \delta \mathbf{y}^O}\right)$

↑

(adjoint data assimilation) $\left(\frac{\partial \delta \mathbf{w}_0}{\partial \delta \mathbf{y}^O}\right)^T$

↑

Analysis sensitivity $\left(\frac{\partial \delta e^f}{\partial \delta \mathbf{w}_0}\right)$

↑

(adjoint forecast model) $\left(\frac{\partial \delta \mathbf{w}_t^f}{\partial \delta \mathbf{w}_0}\right)^T$

↑

Forecast error sensitivity $\left(\frac{\partial \delta e^f}{\partial \delta \mathbf{w}_t^f}\right)^T_{\widetilde{\mathbf{w}_t^{fa}+\mathbf{w}_t^{fb}}}$

Met Office

FSOI

- FSOI for the Met Office's 1.5-km UKV model
  - Linear perturbation forecast model (PF model) must be a good representation of the full non-linear model so that an adjoint can be run.
    - True for much smaller timescales for the UKV than for the global model because of small-scale highly non-linear processes such as convection.

  Solution: Use lower resolution VAR grid (6-8 km)

  - The system can only be run over short time periods - the analysis would be too closely related to the previous forecast

  Solution: Observations are used to assess the forecast

- Trial system has been successfully run for a few cases

Met Office

FSOI

Sensitivity of the forecast impact to observations:

$$\left(\frac{\partial \delta e^f}{\partial \delta \mathbf{y}^O}\right)^T = \left(\frac{\partial \delta \mathbf{w}_0}{\partial \delta \mathbf{y}^O}\right)^T \left(\frac{\partial \delta \mathbf{w}_t^f}{\partial \delta \mathbf{w}_0}\right)^T \left(\frac{\partial \delta e^f}{\partial \delta \mathbf{w}_t^f}\right)^T_{\widetilde{\mathbf{w}_t^{fa}}+\widetilde{\mathbf{w}_t^{fb}}}$$

δe^f - Impact due to observations on a quadratic forecast error measure, e^f

$\delta \mathbf{y}^O$ - Vector of observation innovations

$\delta \mathbf{w}_0$ - Analysis increment at time 0

$\widetilde{\mathbf{w}_t^{fb}}$ - Error (verified against observations) in forecast from background

$\widetilde{\mathbf{w}_t^{fa}}$ - Error (verified against observations) in forecast from analysis

$\delta \mathbf{w}_t^f = \mathbf{w}_t^{fa} - \mathbf{w}_t^{fb}$ - Difference between two forecast states due to the assimilation of a batch of observations

$\left(\frac{\partial \delta e^f}{\partial \delta \mathbf{w}_t^f}\right)^T_{\widetilde{\mathbf{w}_t^{fa}}+\widetilde{\mathbf{w}_t^{fb}}}$ - Forecast error sensitivity – calculate in different way to global

Formulation and coding by Richard Marriot

Met Office

Formulation and coding by Richard Marriot

FSOI

Observations-based forecast error norm:

$$e^f = \left(\mathbf{y}^f - \mathbf{y}^O\right)^T \mathbf{R}^{-1} \left(\mathbf{y}^f - \mathbf{y}^O\right)$$

$\mathbf{y}^O$ - Vector of observations

$\mathbf{y}^f$ - Vector of predicted observations

Difference in error in a forecast from the background compared to the forecast from the analysis (i.e. updated with observations):

$$\delta e^f = \left[\left(\mathbf{y}^{fa} - \mathbf{y}^O\right)^T \mathbf{R}^{-1} \left(\mathbf{y}^{fa} - \mathbf{y}^O\right)\right] - \left[\left(\mathbf{y}^{fb} - \mathbf{y}^O\right)^T \mathbf{R}^{-1} \left(\mathbf{y}^{fb} - \mathbf{y}^O\right)\right]$$

Forecast error (verified against observations) defined as:

$$\widetilde{\mathbf{w}_t^f} = \mathbf{y}^f - \mathbf{y}^O = H\left(\mathbf{c}_x\right) + \mathbf{H}\left[\mathbf{S}^{-1}\mathbf{L}\left(\mathbf{w}_t^f - \mathbf{w}_t^b\right)\right] - \mathbf{y}^O$$

Forecast error sensitivity:

$$\left(\frac{\partial \delta e^f}{\partial \delta \mathbf{w}_t^f}\right)^T_{\widetilde{\mathbf{w}_t^{fa}} + \widetilde{\mathbf{w}_t^{fb}}} = \mathbf{L}^T \mathbf{S}^{-1} \mathbf{H}^T \mathbf{R}^{-1} \left[\widetilde{\mathbf{w}_t^{fa}} + \widetilde{\mathbf{w}_t^{fb}}\right]$$

New 'Swapped Transform Order' Covariances

- Previously applied vertical transform before horizontal transform when calibrating UKV covariances
- Horizontal transform modelled correlations by a SOAR function with a single characteristic lengthscale for each vertical mode (*150-200km for Ψ and X*)
- Reversing transform order allows horizontal correlations to vary with height and vertical correlations to vary with horizontal scale
- Full vertical correlation matrices now available for each total wavenumber
- Wind increments can now exhibit smaller-scale structure

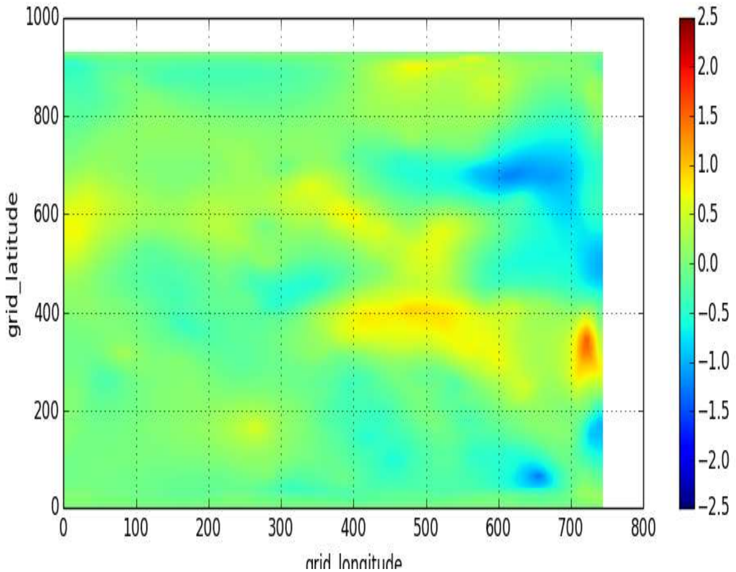
Marek Wlasak & Gordon Inverarity

v analysis increment

Met Office

Previous

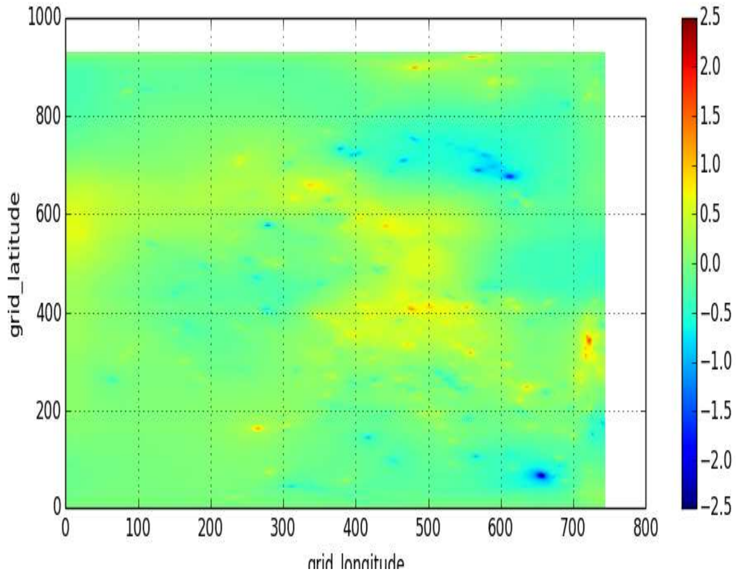
Latitude



Longitude

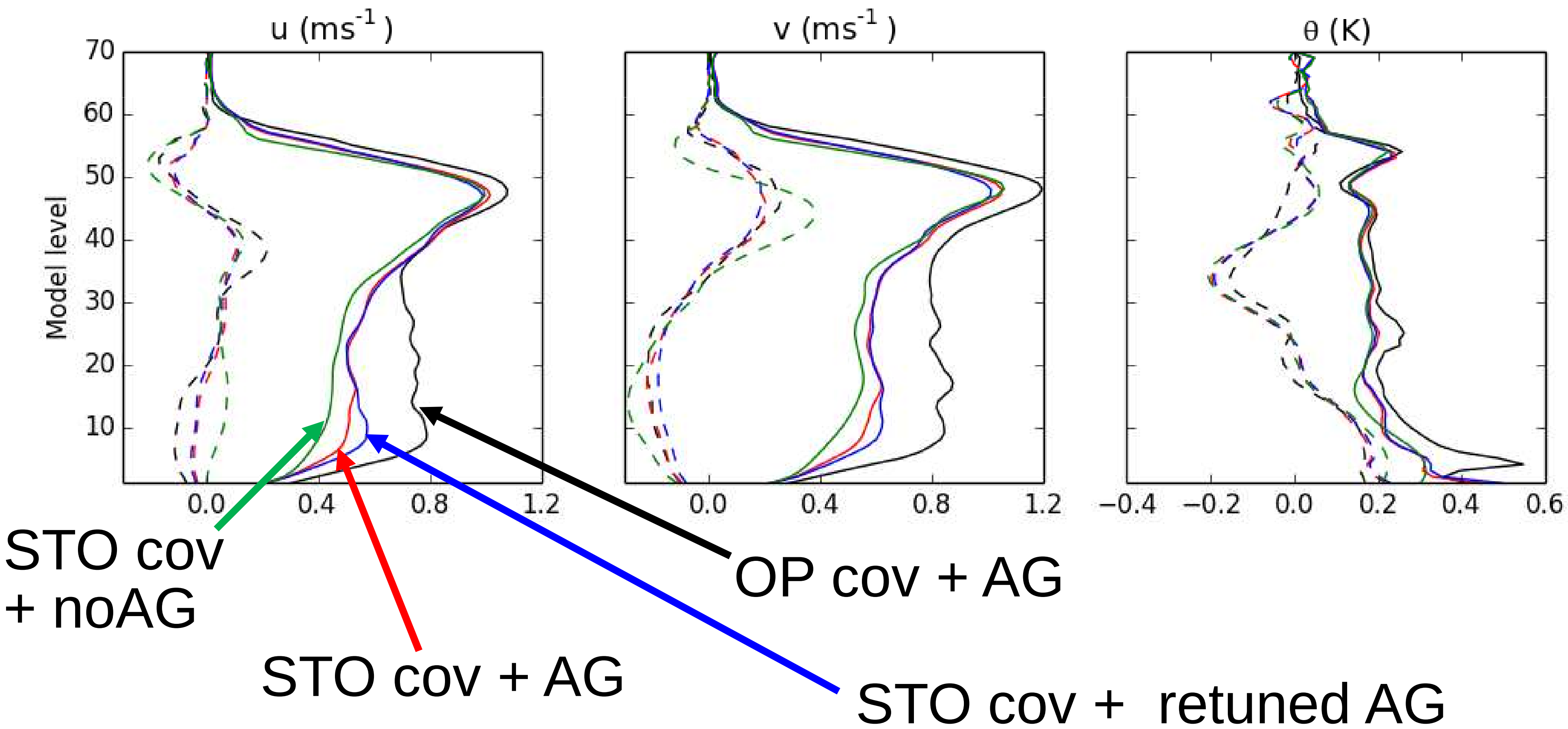
Swapped Transform Order

Latitude



Longitude

Analysis increments



GeoCloud

- Derive GeoCloud data within UK OPS step, using *latest* high resolution UK model profiles

  - replace creation in external AUTOSAT system, using (*older*) global model profiles

  - Prepare for GeoCloud assimilation anywhere

Bob Tubbs

February ‘15 Upgrade (PS35)

- Introduce IASI
- Migrate to Metop A/B coastal scatterometer products
- For insertion of GeoCloud data, use model climatology of cloud thickness to decide cloud ‘thickness’

Peter Francis

Sensitivity to age of global lateral boundary data

- Boundary data are important even for short-period UKV forecasts
- CONTROL – standard set up, where 00, 06, 12, 18 UTC UKV runs use t-6 global lbcs
- TEST – t+0 global lbcs replace t-6 lbcs
- IMPACT – UK NWP Index 1-1.5% better with ‘fresh’ lbcs (1 month trial) cf UKV model ~5% better than global model
- Conclude -
  - more frequent global runs may improve 0-12hr UK forecast