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Improving the impact of EO data on moisture and cloud forecasts

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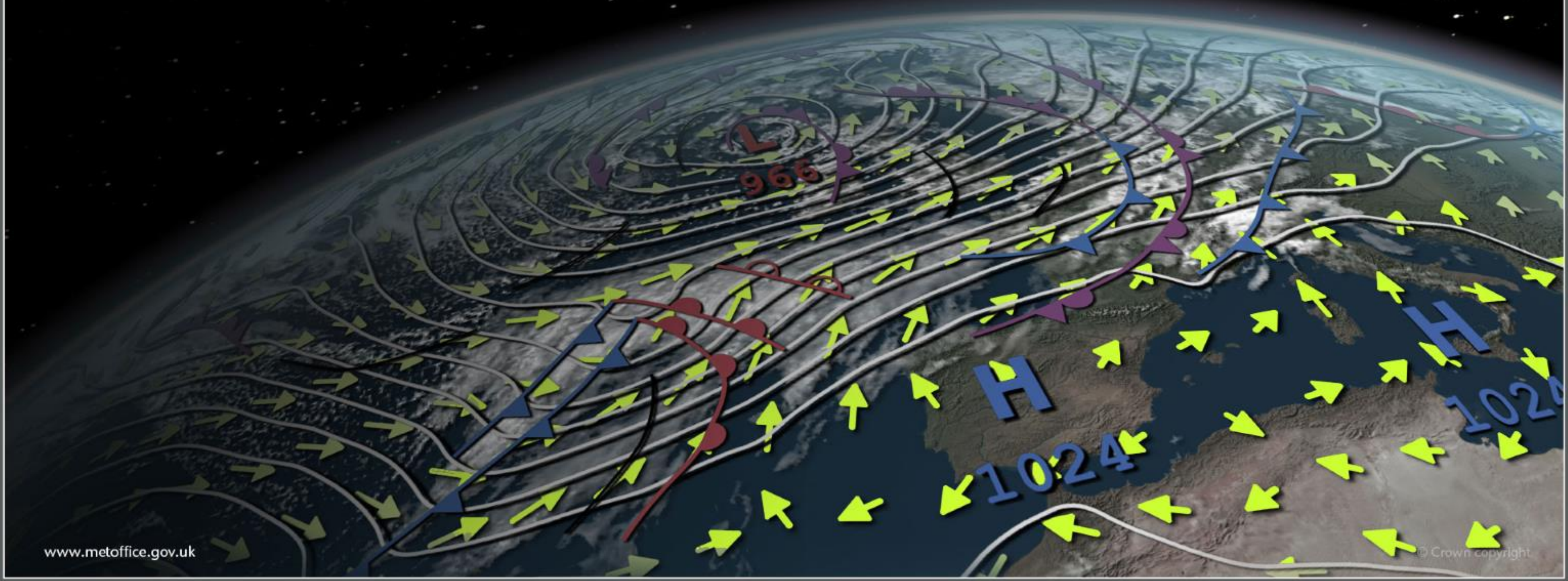

Outline

- Progress on assimilation of cloud-affected MW obs
- Motivation for need of new moisture incrementing op
- Brief review of current treatment of moisture in VAR
- Design of the new op
- Statistical training strategy of the new op
- Summary

Motivation (1/2)

- In each six-hour global DA window approx 8m obs are used to constrain a state vector with about 6 x 10^8 components.
- At the Met Office, satellite observations significantly affected by cloud are currently discarded using a number of QC flags
- This is to avoid corrupting the analysis with obs and errors that are not modelled well
- Better cloud and precip parametrization schemes, better models of cloud radiative effects and better error characterizations have led to the operational assimilation of all-sky radiances at ECMWF and now at NCEP

Motivation (2/2)

- The all-sky observation operator needs profiles of different water phases: a reliable scheme to partition moisture increments from VAR among the different phases is needed
- A consistent scheme to assimilate moisture-sensitive obs also key to progress convective-scale 4DVar
- Also useful for assimilation of precip data in Var
- Current operational (global only) increment scheme is nonlinear to keep total moisture increments meaningful when close to dry or saturated conditions
- The subsequent introduction of our current moist nonlinear CV relaxes requirement of more complex incrementing op

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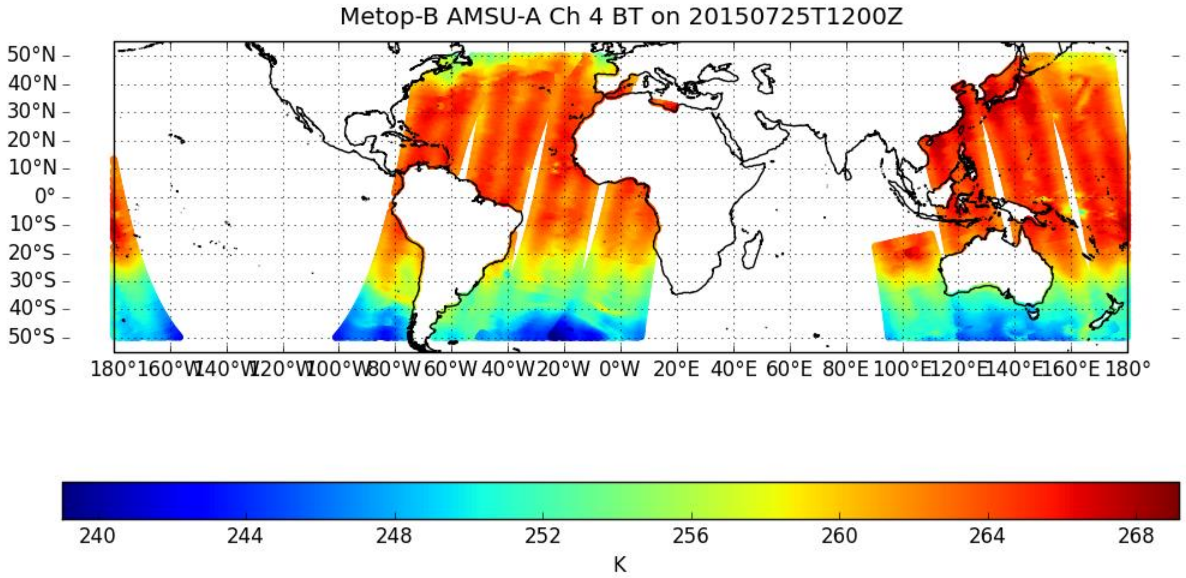
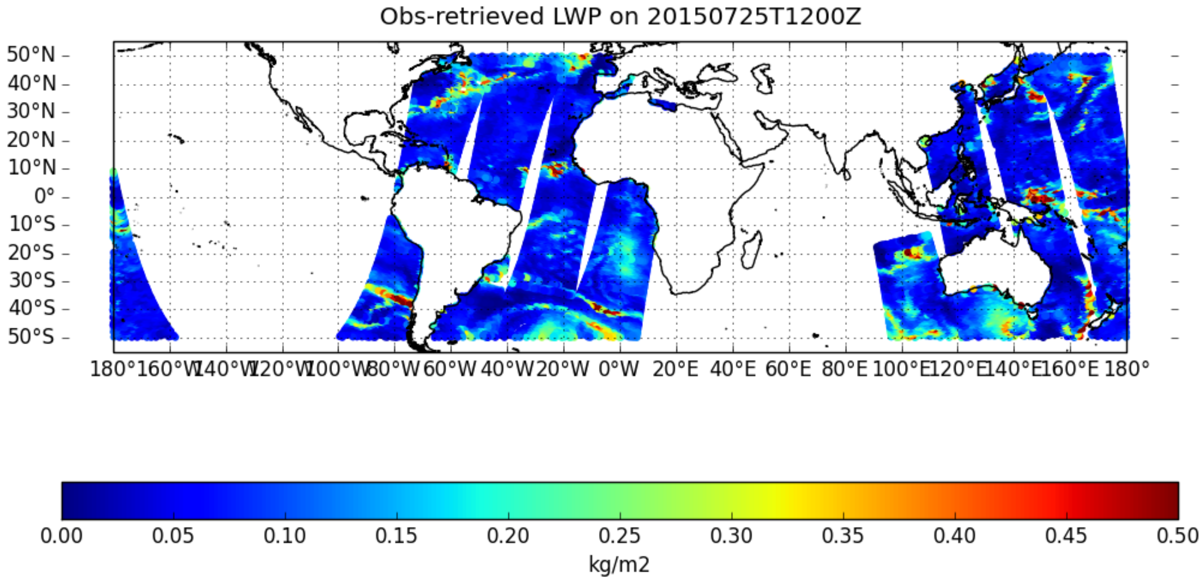
Cloud-affected radiances

- AMSU-A Channel 4 (52.8 GHz) on Metop-B, all available obs over ocean, -50 deg < lat < 50 deg, 20150725 1200 UTC



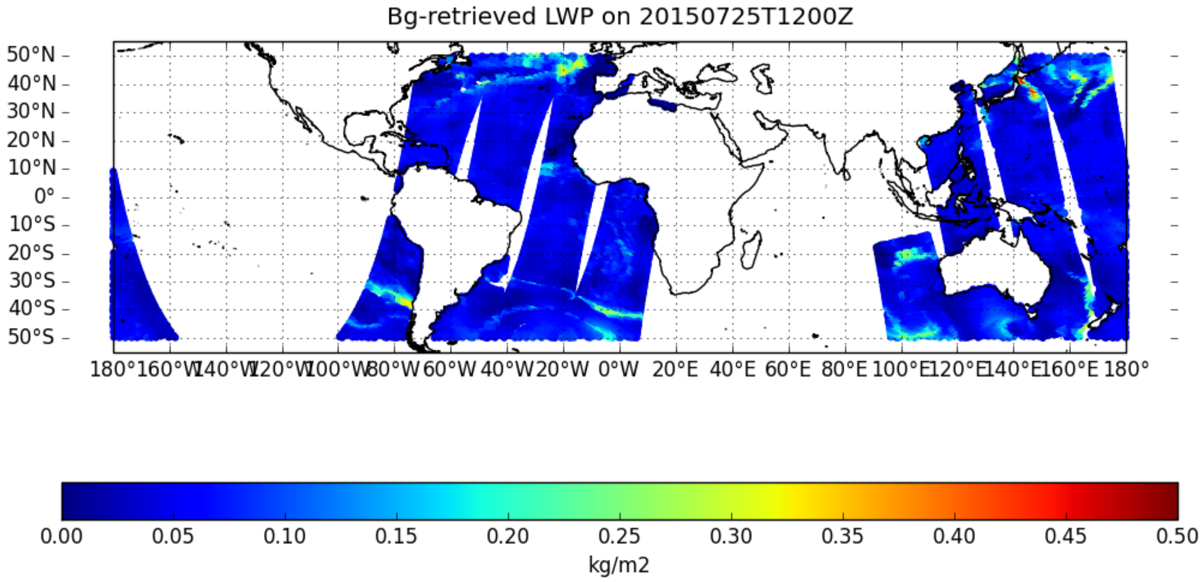
Cloud retrievals

- Retrieved LWP from all available obs over ocean, -50 deg < lat < 50 deg, 20150725 1200 UTC



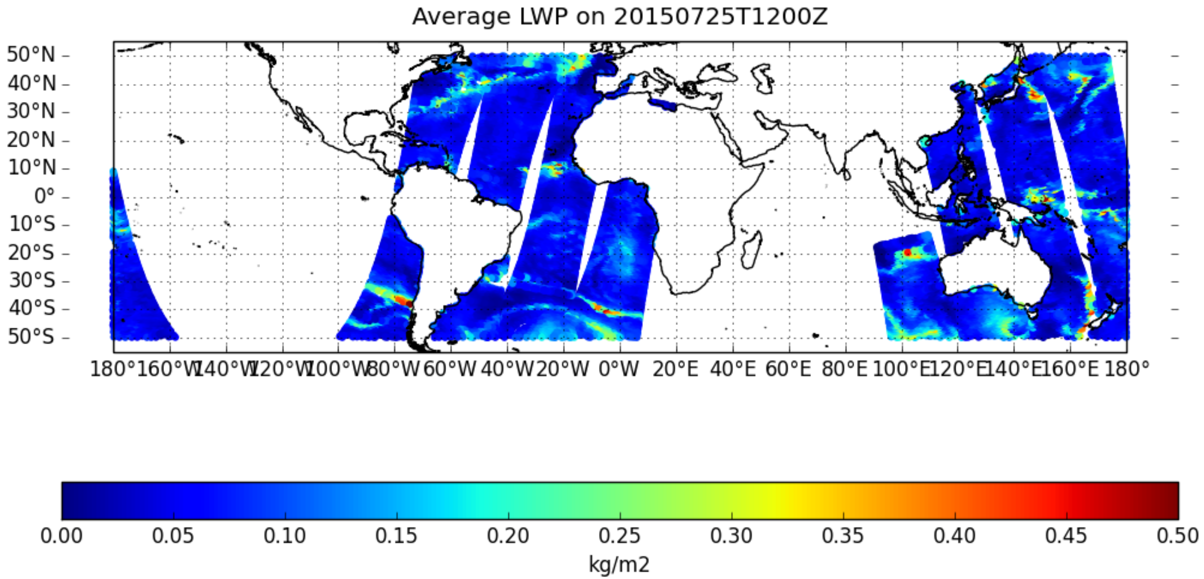
Cloud retrievals

- Retrieved LWP from all available simulated obs over ocean, -50 deg < lat < 50 deg, 20150725 1200 UTC



Cloud retrievals

- Average retrieved LWP from all available (simulated) obs over ocean, -50 deg < lat < 50 deg, 20150725 1200 UTC



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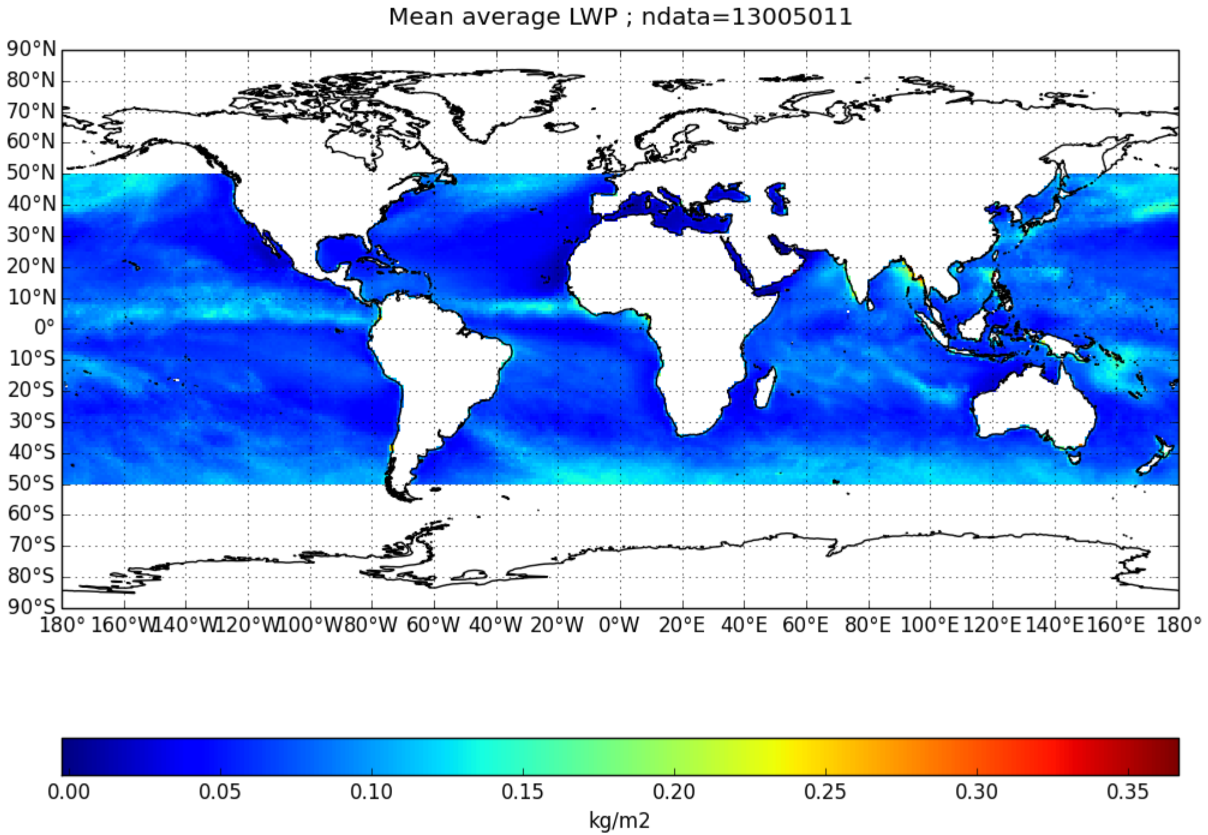
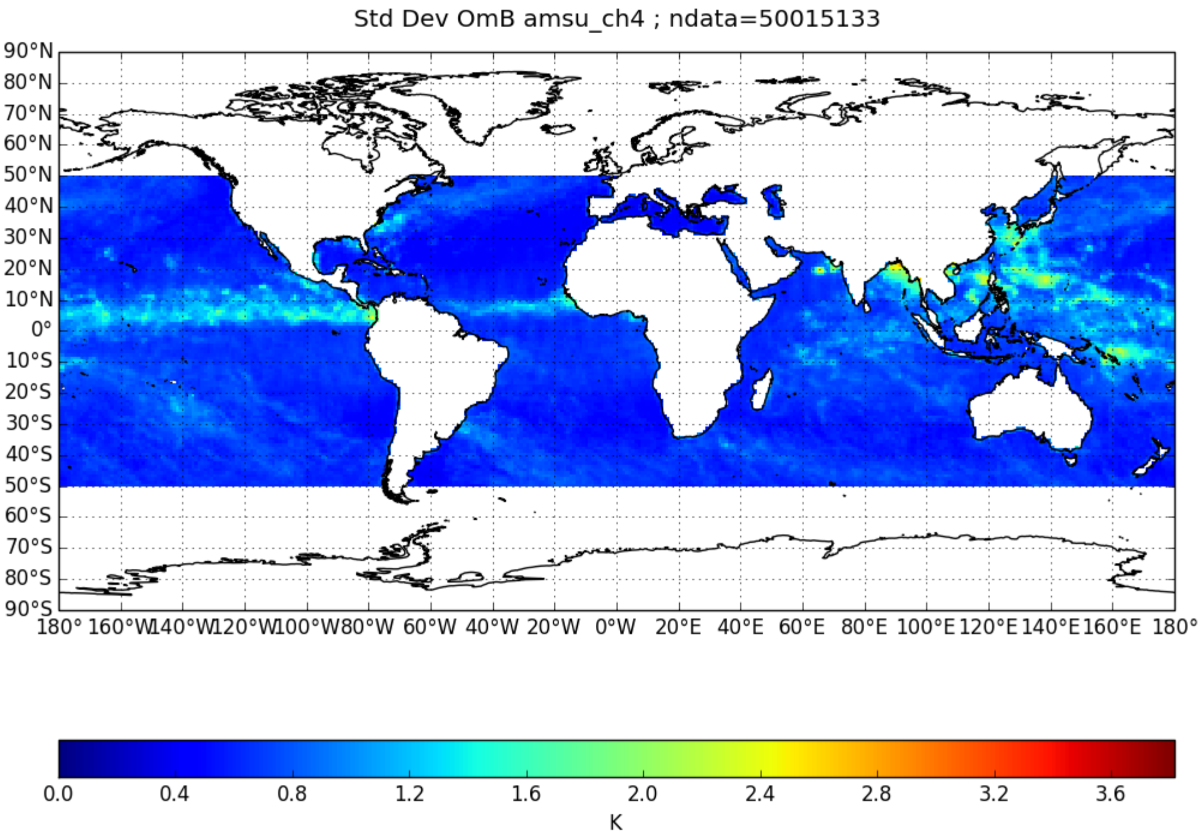
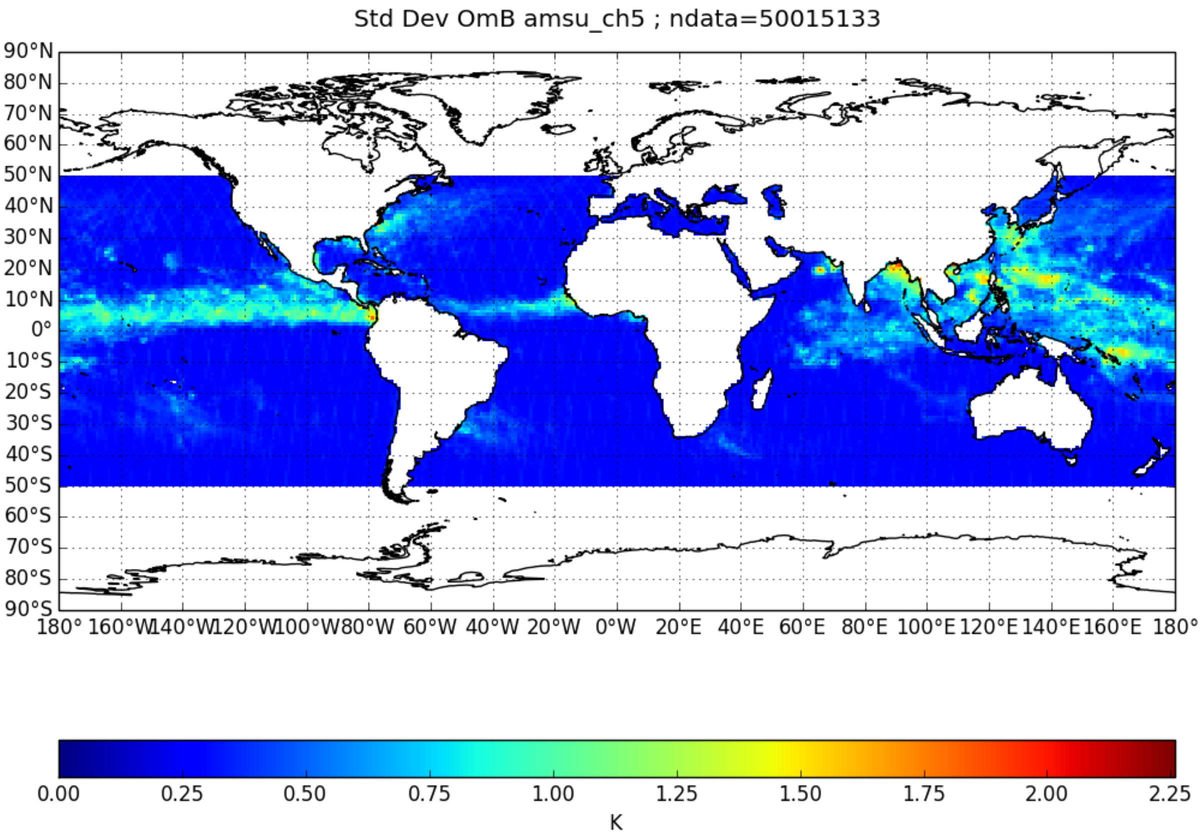
- AMSU-A average LWP all available obs over ocean, -50 deg < lat < 50 deg, 20150621 0600Z – 20150727 1200Z



- AMSU-A Channel 4 (52.8 GHz) all available obs over ocean, -50 deg < lat < 50 deg, 20150621 0600Z – 20150727 1200Z

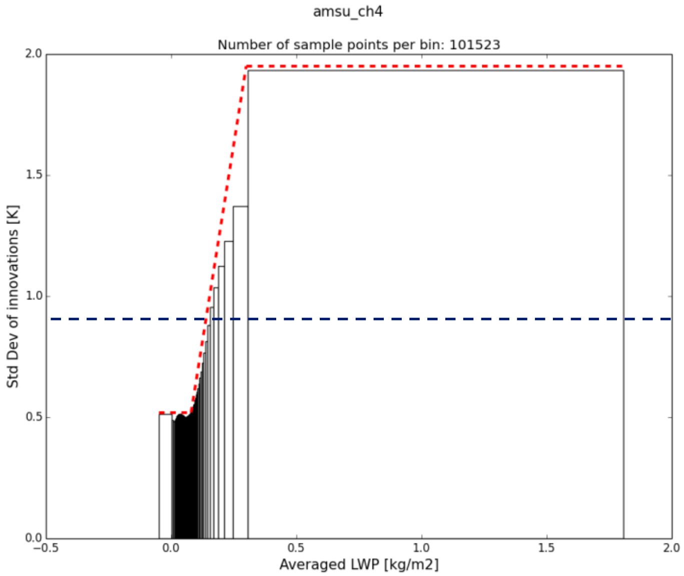


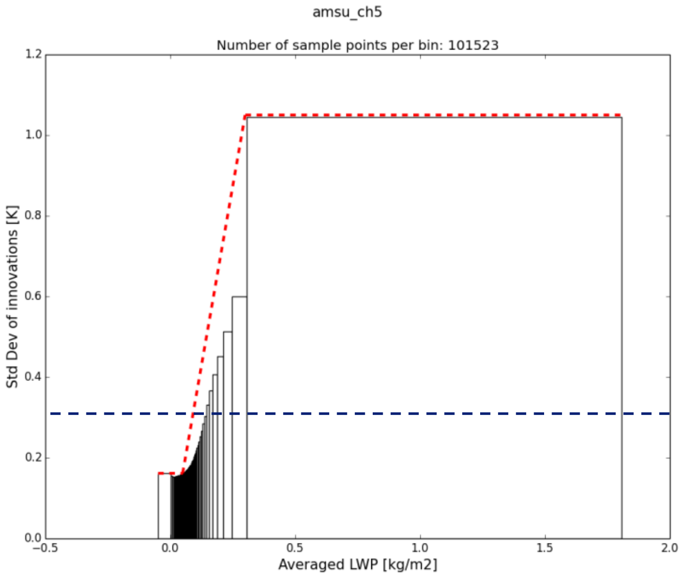
- AMSU-A Channel 5 (53.6 GHz) all available obs over ocean, -50 deg < lat < 50 deg, 20150621 0600Z – 20150727 1200Z



Cloud-dependent errors

- AMSU-A Channel 4 and 5 (52.8 GHz and 53.6 GHz) all available obs over ocean, -50 deg < lat < 50 deg, 20150621 0600Z – 20150727 1200Z





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Moisture analysis in VAR

UM and VAR variables and transforms

- Model variables: $\mathbf{x} = (u, v, w, \theta, \Pi, \rho, q, q_{cl}, q_{cf}, C_l, C_f, C_t)$
- Perturb. forecast (PF) model vars: $(u', v', w', \theta', \Pi', \rho', q'_T) = \mathbf{w}'$
- $\mathbf{w}'$ components not independent: we need uncorrelated $\mathbf{v}_p$ and transform $\mathbf{U}_p$ such that $\mathbf{w}' = \mathbf{U}_p \mathbf{v}_p$
- Met Office CVs: $\mathbf{v}_p = (\psi', \chi', p^{A'}, \mu', \log m')$ = stream function, velocity potential, unbalanced pressure, moist variable, log of aerosol concentration
- Incrementing op: $\mathbf{x}' = S_{q_T}^{-I} S_{grid}^{-I} \mathbf{w}'$

Moisture in VAR

- VAR only uses a single moist control variable derived from (iterative) linearization of total relative humidity increments so that it is approximately Gaussian, unbiased and uncorrelated with the other control variables

$$rh_T = \frac{q_T}{q_s(T)} = q_T\left(\frac{p}{\varepsilon e_s(T)}\right) \qquad rh'_T \cong \frac{q'_T}{q_s} - \frac{q_T}{q_s}\frac{\partial \ln e_s}{\partial T}\Pi\theta' \qquad \mu' = a\left(\frac{q'_T}{q_s} - h\frac{q_T}{q_s}\frac{\partial \ln e_s}{\partial T}\Pi\theta'\right)$$

- *h* regression coefficient between $\frac{q'_T}{q_s}$ and $\frac{q_T}{q_s}\frac{\partial \ln e_s}{\partial T}\Pi\theta'$: uncorrelated; *a* ~ $1/\sigma(rh_T^b|rh_T^b + rh_T')$: nonlinear, more Gaussian

- The implied parameter transform $\mathbf{U}_p$ then determines increments of total specific humidity q'_T

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Current moisture incrementing op

- Let q_s, q_{cl}, $q_T = q + q_{cl}$ be the grid-box mean saturation specific humidity, specific liquid cloud water and total specific humidity. Asterisks denotes local quantities.

$$q_{cl} = \int_0^{\infty} q_{cl}^{*}\psi(q_{cl}^{*})dq_{cl}^{*} = \int_{-(q_T - q_s)}^{\infty} (q_T - q_s + s)G(s)ds \qquad C_l = \int_{-(q_T - q_s)}^{\infty} G(s)ds$$

- For a given G(s) (see Smith 1990) this leads to a $q_{cl} = f(q_T, T, p)$ nonlinear function of q_T ,T and p which can be iteratively linearized

$$q'_{cl} = \left(\frac{\partial f}{\partial q_T}\right)q'_T + \left(\frac{\partial f}{\partial T}\right)T' + \left(\frac{\partial f}{\partial p}\right)p'$$

- Frozen cloud can be diagnosed as $q_{cf} = \frac{F}{1-F}q_{cl}$ where $F = \frac{q_{cf}}{q_{cl} + q_{cf}}$
- Problems in the UKV UM configuration (precipitation spin-down): switched off, all increments to vapour, with cloud liquid and frozen water fields unchanged

New moisture incrementing op

Design of the new scheme

- Based on linear relation between q'_{cl} and (q'_T, T', p')

$$q_{cl} = \int_0^{\infty} q_{cl}^* \psi(q_{cl}^*) dq_{cl}^* = \int_{-(q_T - q_s)}^{\infty} (q_T - q_s + s) G(s) ds \cong C_l (q_T - q_s)$$

$$q'_{cl} = C_l (q'_T - q'_s) \cong C_l \left(q'_T - q_s \frac{\partial \ln e_s}{\partial T} T'\right) \qquad q' = q'_T - q'_{cl}$$

- Physically consistent: in cloud q'_{cl} pos correl with q'_T and neg correl with T'. In clear air zero correl with q'_T. Consistent with moist CV design. [need for additional CV to create cloud in clear air??]

- Frozen cloud option

$$q'_{cl} = C_l (q'_T - q'_{cf} - q'_s)$$

$$q'_{cf} = C_f (q'_T - q'_{cl} - q'_s)$$

$$q'_{cl} \cong \frac{C_l (1 - C_f)}{1 - C_l C_f} \left(q'_T - q_s \frac{d \ln(e_s(T))}{dT} T' \right) \qquad q'_{cf} \cong \frac{C_f (1 - C_l)}{1 - C_l C_f} \left(q'_T - q_s \frac{d \ln(e_s(T))}{dT} T' \right)$$

$$q' = q'_T - q'_{cl} - q'_{cf}$$

New moisture incrementing op (1/2)

- Model for moisture increments can also be trained against ensembles of model forecasts. In this case:

$$(q'_{cl})_i = a(\overline{rh_T}, z)\overline{C}_l\left((q'_T)_i - \overline{q}_s\overline{\frac{\partial \ln e_s}{\partial T}}(T')_i\right)$$

- And for the frozen cloud option:

$$(q'_{cl})_i = a(\overline{rh_T}, z)\frac{\overline{C}_l(1-\overline{C}_f)}{1-\overline{C}_l\overline{C}_f}\left((q'_T)_i - \overline{q}_s\overline{\frac{\partial \ln e_s}{\partial T}}(T')_i\right) \qquad (q'_{cf})_i = b(\overline{rh_T}, z)\frac{\overline{C}_f(1-\overline{C}_l)}{1-\overline{C}_l\overline{C}_f}\left((q'_T)_i - \overline{q}_s\overline{\frac{\partial \ln e_s}{\partial T}}(T')_i\right)$$

- Training coefficients at given rh_T bin interval (5% res) and "wet" model level (separate training for global and UK)

- Final increments: $(q'_{cl})_{diag} = a(rh_T,z)\, q'_{cl}$; $(q'_{cf})_{diag} = b(rh_T,z)\, q'_{cf}$; $(q')_{diag} = q'_T - (q'_{cl})_{diag} - (q'_{cl})_{diag}$

New moisture incrementing op (2/2)

- Simpler design now acceptable as q'_T derived from nonlinear moist control variable
- Now $C_{l,f}$ from UM reconfiguration: consistent with cloud scheme and dynamics
- Statistical link with MOGREPS for given rh_T and model level. Coefs could even be computed at appropriate time
- Frozen cloud increments through C_f : no ad-hoc assumptions
- Cloud increments only when $C_{l,f} > 0$
- Straightforward calculation of partitioned analysis increments: no need for inclusion in the UM IAU; diagnostic output
- Cheaper and self contained

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Statistical training

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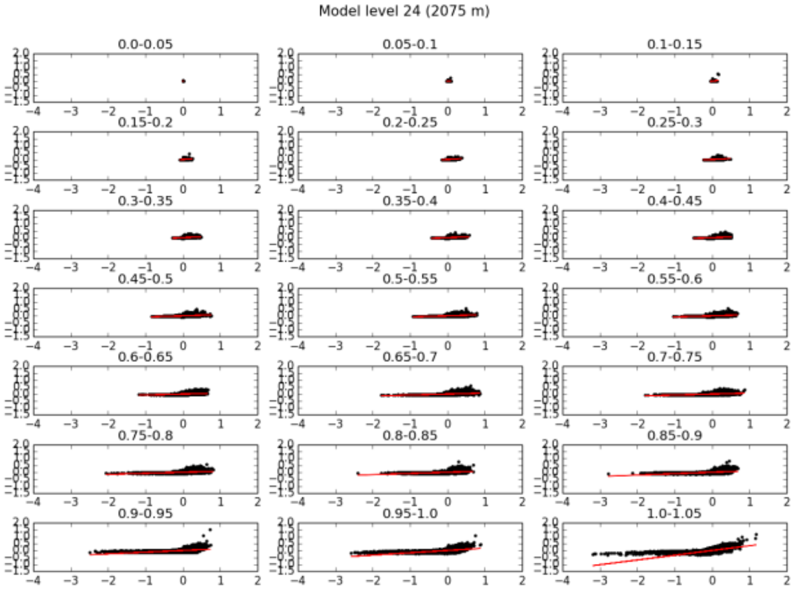
Linear diagnostics of moisture

- Global ensemble of 44 T+6 perts on 6 March 2015 1200 UTC

q'_{cl}



$$\frac{C_l(1-C_f)}{1-C_lC_f}\left(q'_T - q_s\frac{d\ln(e_s(T))}{dT}T'\right)$$

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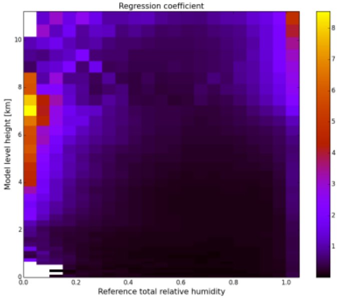
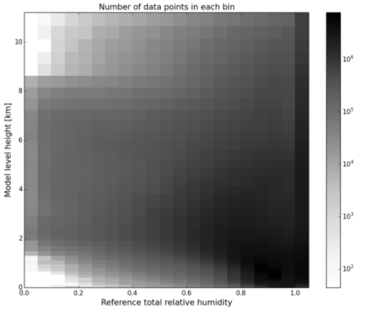
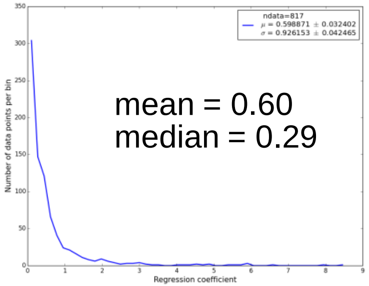
Lin diagnostics of moisture (global)

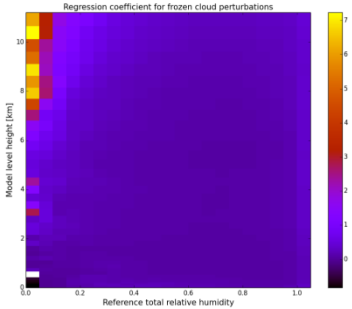
- q'_{cl} regression coefficients (20150306 06Z + 20160115 00Z)

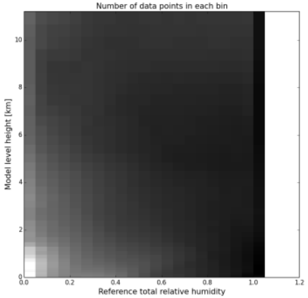


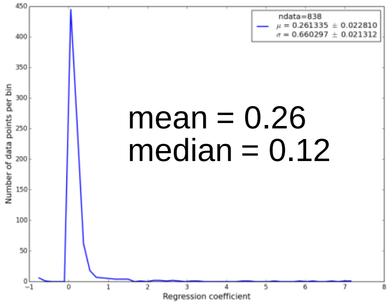




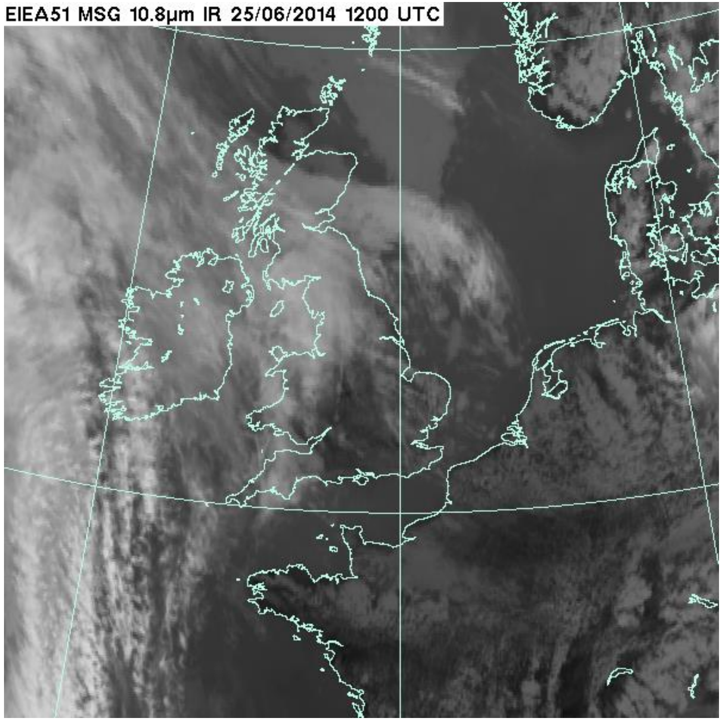
- q'_{cf} regression coefficients





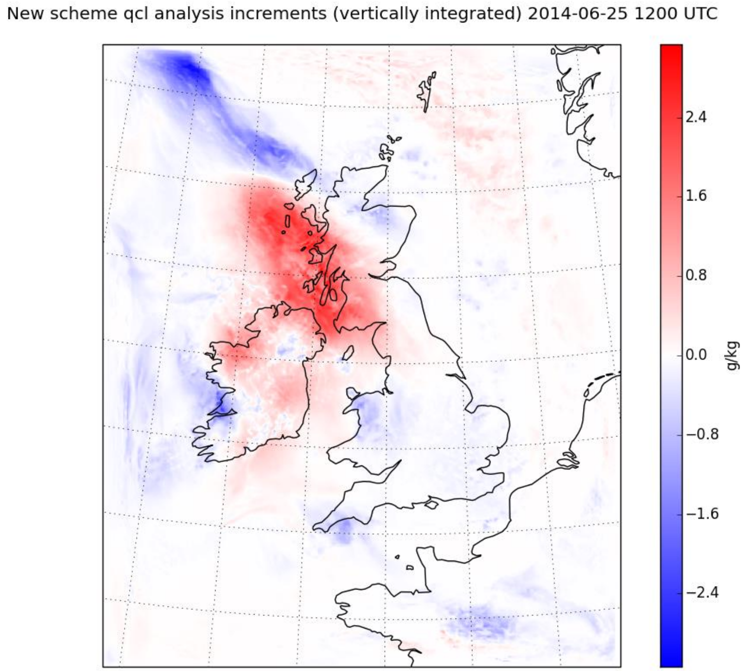


Meteosat IR image



Moisture analysis increments

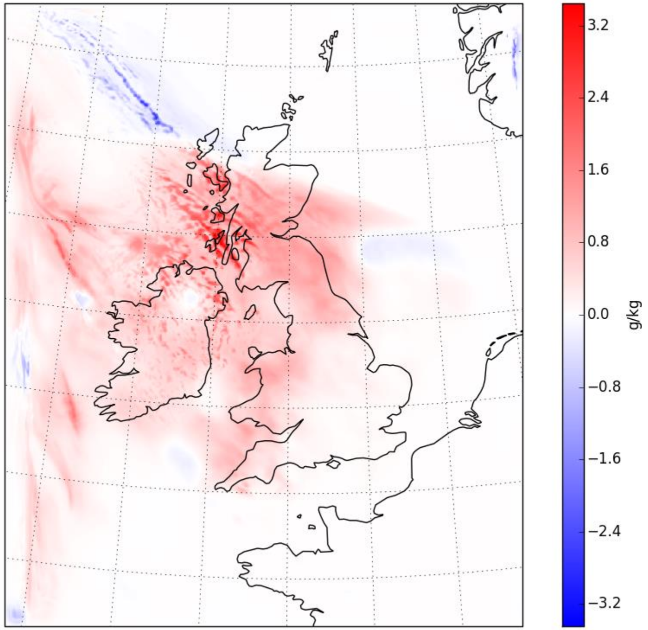
- qcl increments, new scheme



Moisture analysis increments

- qcf increments, new scheme

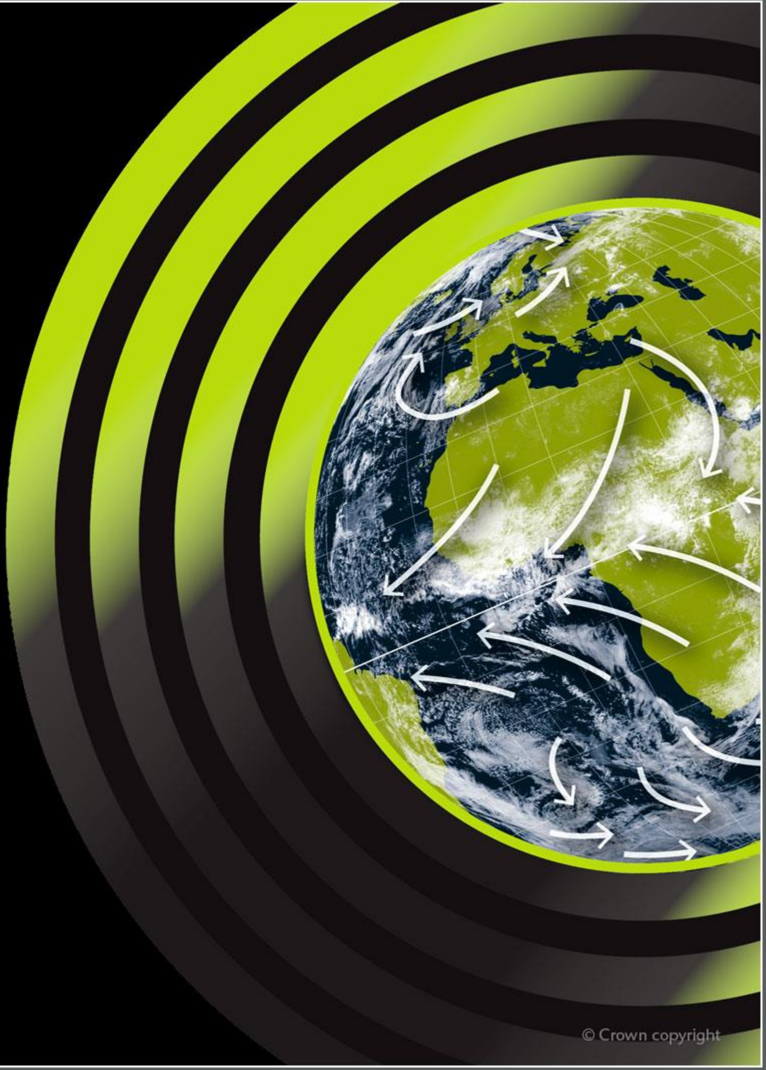
New scheme qcf analysis increments (vertically integrated) 2014-06-25 1200 UTC



Summary

- Moisture-sensitive obs are under-used. Need for cloud-dep errors
- In VAR water phases analysed via single moist control variable: need for a diagnostic relation to partition the increments into different water phases
- Present increment op complex nonlinear code that is not performing well: either limited or switched off (as in the UKV)
- New operator: linear (in qT’, theta’); directly linked to operational UM cloud scheme and (in)directly to op ensemble; only needed in VAR; partitioned increments output
- Key requirement for two major projects using VAR: all-sky assimilation of satellite data; Convective-scale 4DVar (including precip assimilation)

Thanks for your attention



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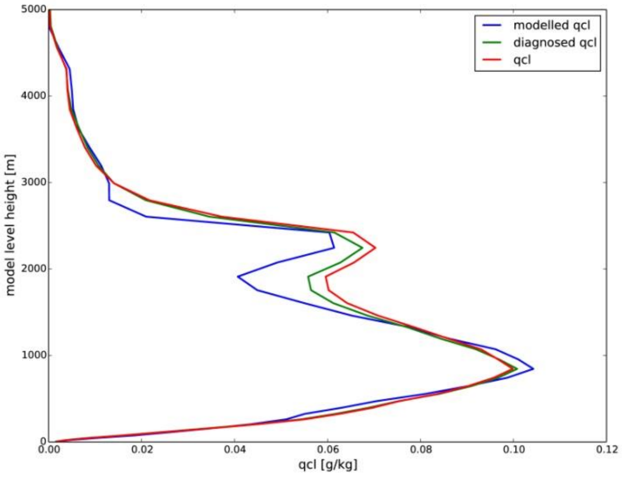
Consistency tests

- Red: qcl from 1st ens member. Blue: ens mean qcl + flin(qt1',theta1'). Green: ens mean qcl + a(rht,z) * flin(qt1',theta1'). Note: a(rht,z) from same ensemble

global mean



global set of profiles