Improvement to humidity assimilation at the Met Office and possible impacts near the tropopause

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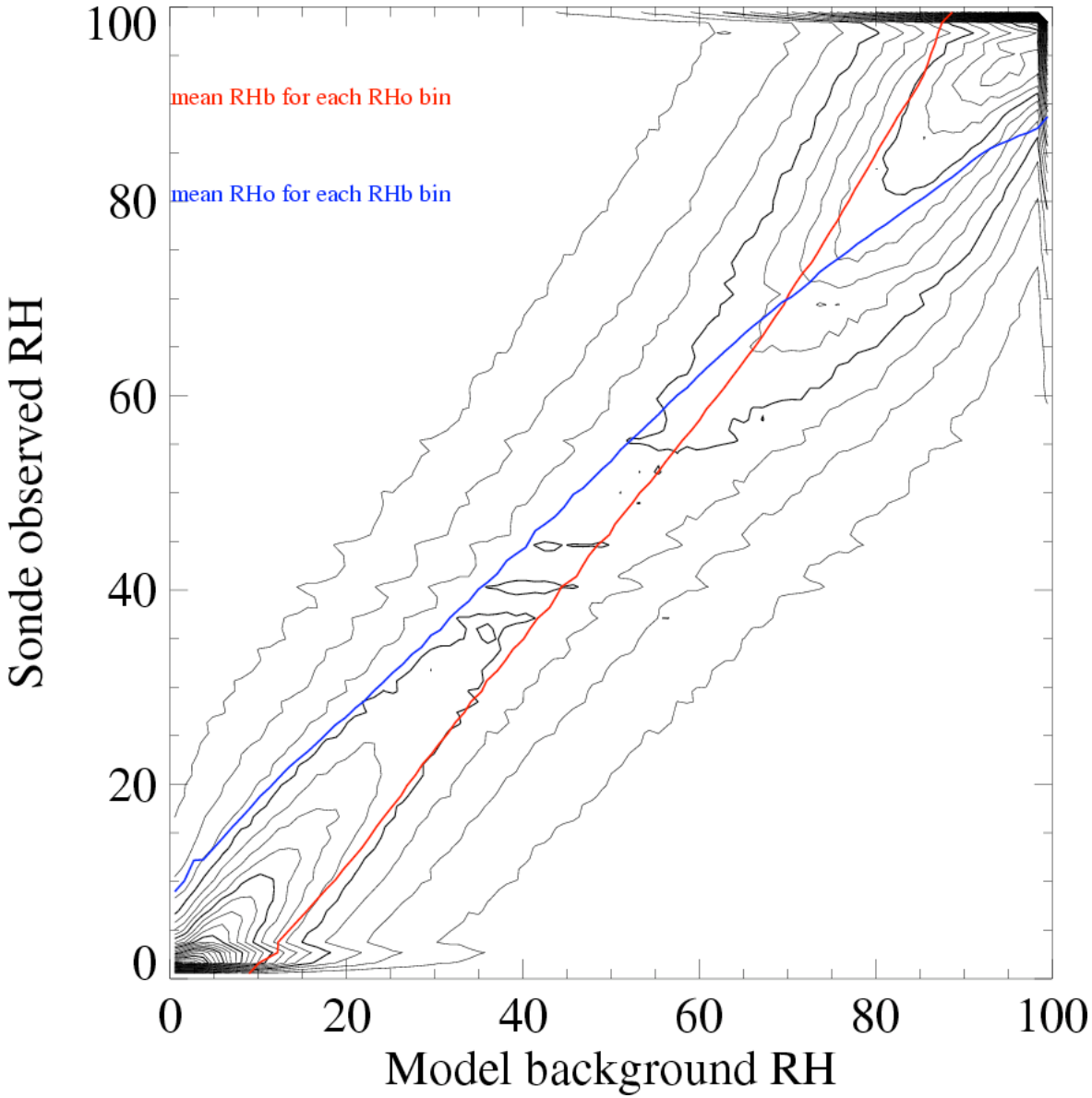
Water in the atmosphere

- Broad, non-Gaussian pdfs (Sherwood et al, 06)
- Problems for data assimilation:
  - Small scale features
  - Complex relationships with other variables
  - Limits at 0 and ~qsat (truncated pdfs)
- Humidity analysis is important for NWP:
  - Andersson et al (2005, 2007): with current obs/ modelling/assimilation humidity obs can have significant impact
  - Plus humidity affects our weather! Continuing efforts to use precipitation and cloud data better

Limits on q/RH skew distribution

- Holm (2002)
  - Introduced symmetrising transform to make humidity errors more Gaussian
- Our transform based on his – differences in detail. Plot (Lorenc, 2007) shows O vs B; B vs A similar (Holm)
- Near zero or 100% (A-B) is very skewed
- Transform to a function of (A +B)/2 (Holm) – distribution is much more symmetric
- This makes the analysis nonlinear
- Lorenc also showed that neglect of RH – T corrns in cloudy layers not justified



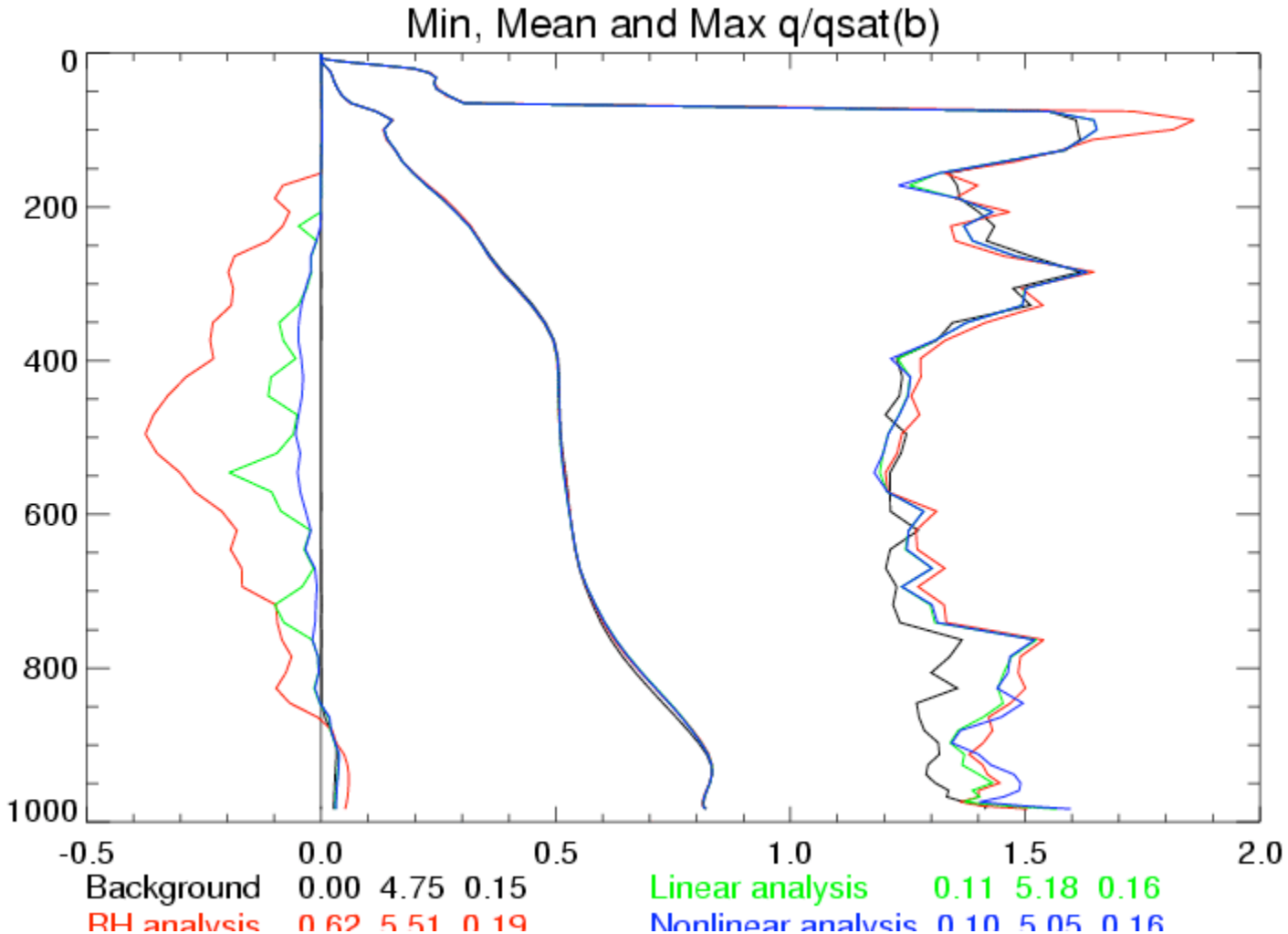
The transformed humidity control variable (1)

- $\mu = (q_T' - h q_T \partial(\ln e_s) / \partial T\ T') \ a/qsat(\mathbf{b})$
- q_T' increment of total q – including cloud
- h=h(RH**b**) is q/T correlation - gives "balanced" q_T increment from T'
- a=a(RH**a**,RH**b**) is normalising factor so that $\sigma(\mu) \approx 1$ this reduces under/overshoots
- If a=a(RH**b**) then we have **linear transform**
- if a=h=1 then $\mu \approx RH_T'$ (p' term ignored)

The transformed humidity control variable (2)

- Transform has to be monotonic/invertible
  - Use iterative (secant) method to get from μ to q_T'
- Start with $a=1/\sigma_{|(RH\mathbf{a}+RH\mathbf{b})/2}$ but modify it for large increments to make sure $\partial\mu/\partial q_T' > 0$
- Holm splits into sub/super-saturated regimes to avoid monotonicity problems, we don't have to. Holm uses fitted functions we use look up table.
- Multiple inner loops – re-linearised (and recalculate a, h) every 10 iterations – different to ECMWF

Min/Max values



- Linear (green): reduces negative values
- Nonlinear (blue): reduces them even more

Results for the troposphere

Two sets of trials

- Jun/Jul 2009 period
- Fc diff COV stats
- N108 VAR, N320 fc
- Prelim trial: cloud water advection (slightly –ve)
- Soil moisture error

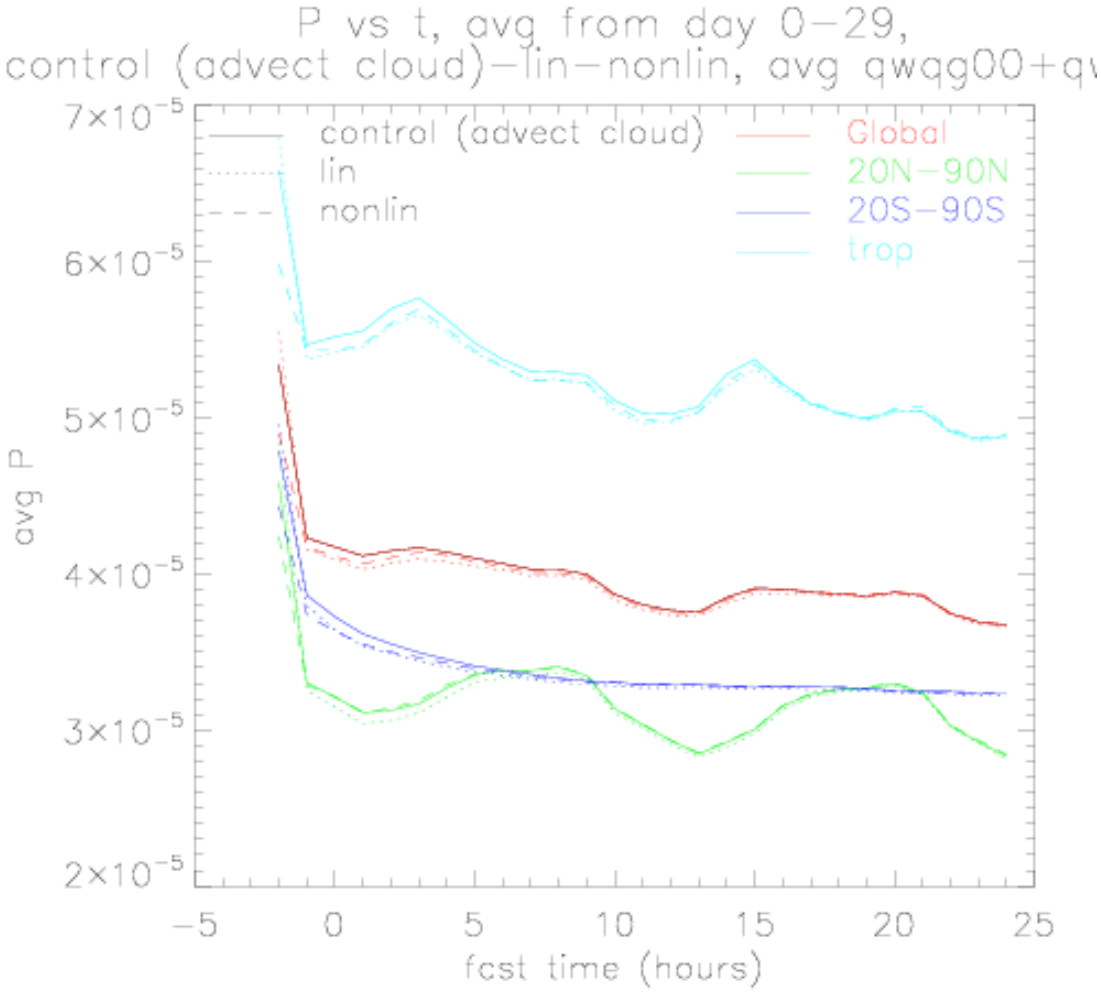
- Dec09/Jan10 period
- Ensemble COV stats
- New cloud scheme
- N108/N216 VAR, N320 fc
- *Corrected low level COV*

Some difference in setup between runs

But generally similar results for humidity

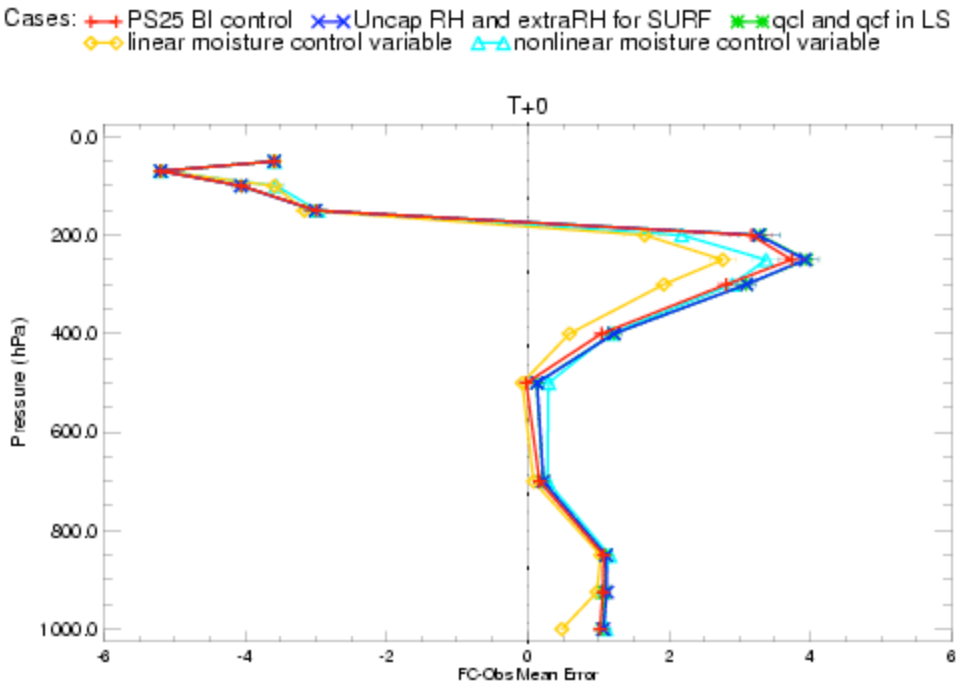
Precipitation spin-down

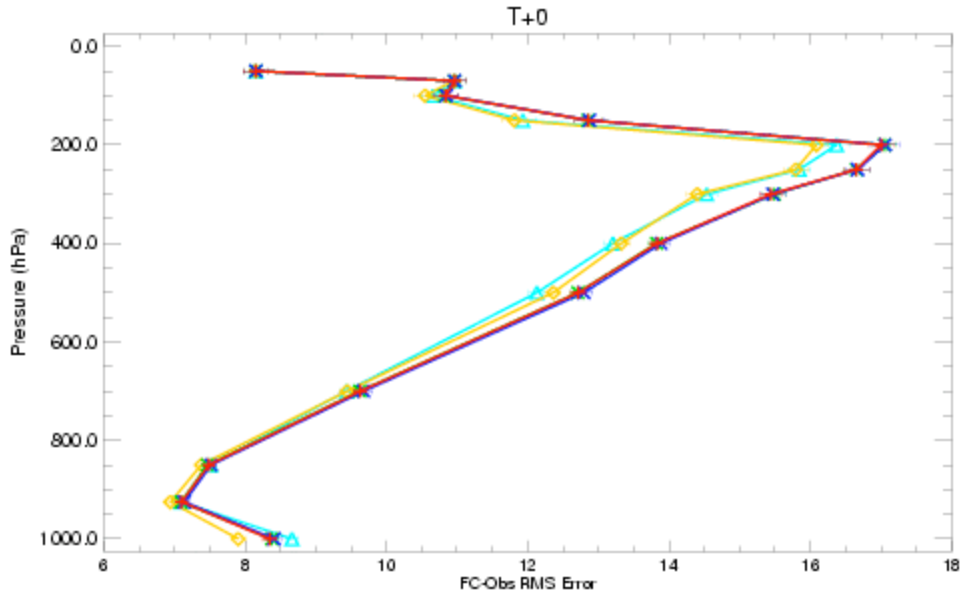
- Excessive pptn over first hour (esp. over oceans) then slower decline
- Nonlinear trial (dashed) reduces jump by ~40%
- linear / non linear versions similar



Vs Sondes 20-90°N

- T+0 mean fit: bias ~ 0 in mid-trop, model dry in strat (also vs IASI); model moist or sondes dry in upper-trop (IASI, bias ~ 0) 1% moist near surface?
- T+0 rms fit: largest diffs in upper-trop – better fit for trials there
- Discovered “normalisation bug” – near surface q SDs too small. Running with this fixed (Dec/ Jan) improves verification vs obs Jun/Jul trial.





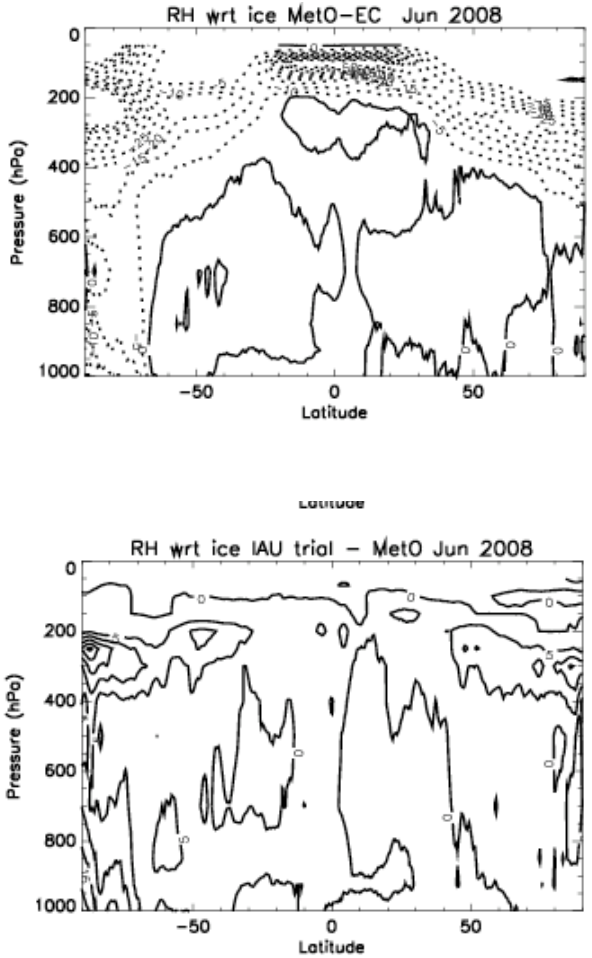
Summary of other impacts

- Most forecast fields improved, esp. Southern Hem.
- Improves mass fields, not just humidity
- Better fit to satellite data – eg in June/July, AIRS/AMSU humidity channels show improved fit, eg NOAA18, AMSU ch 18: O-B 4.1%, O-A 2.5% better rms

Near the tropopause – validation against Aura MLS

Stratospheric humidity assimilation at the Met Office

- Has proved difficult – until 2009 stratospheric increments not used and humidity restricted to 1.55-4.66 ppmv limit above 2 PVU level
- Contributed to upper troposphere dry bias – in 2009 this was changed to zero analysis increment above 5 PVU level
- Preliminary assimilation work with MIPAS stratospheric humidities not very successful (Thornton et al, 2009)

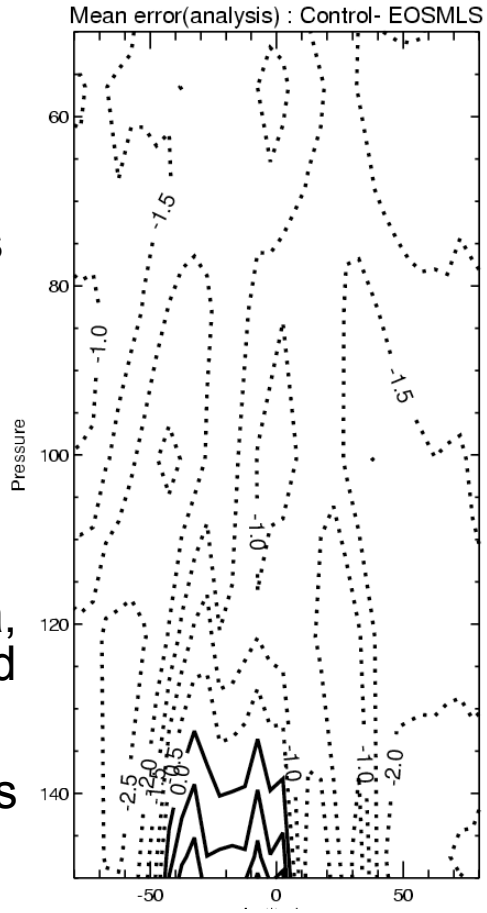


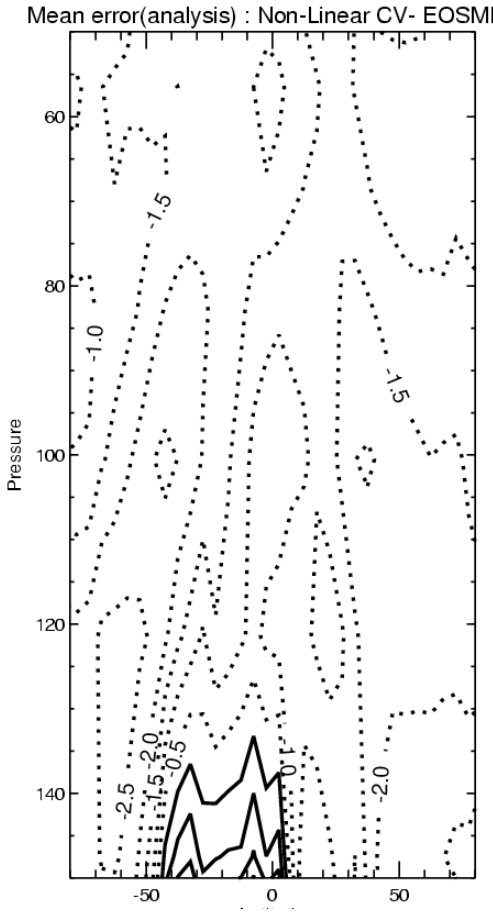
Impact of new control variable on tropopause region

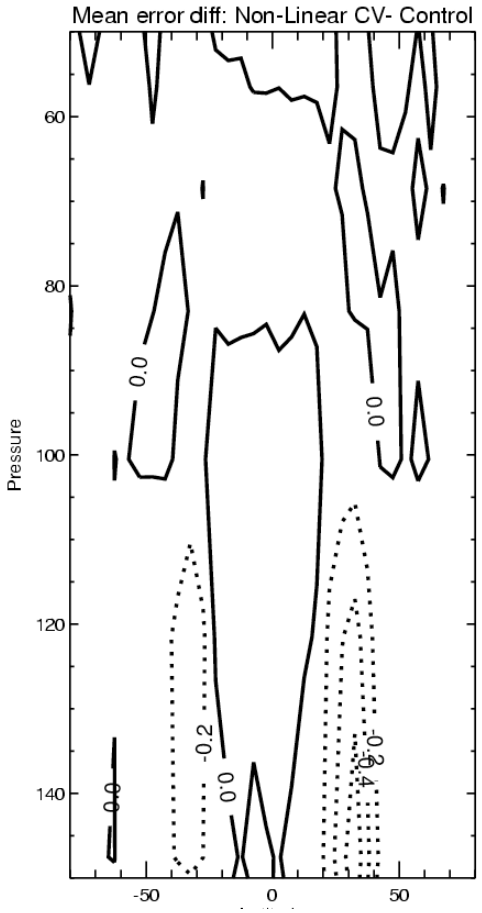
- Another potential benefit of normalisation is to reduce adverse impact of tropopause on background errors
- Results shown for 15/12/09-02/01/10 trial period
- vn2.2 Aura MLS data used in comparison – only used above 150 hPa level since issues with data quality
- Linear and non-linear CV results similar – focus on non-lnear CV v control comparison

Mean errors v Aura MLS

- Largest differences the 20-40^{o} band, both hemispheres
- Mean error reduced compared to control at 20-40^{0}S and around 150-140 hPa, but increased elsewhere.
- These errors are 20-40% of MLS



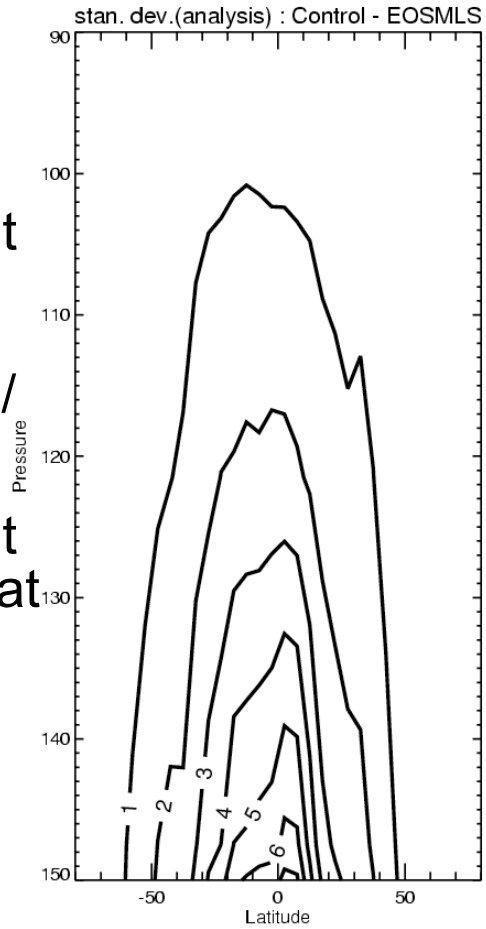


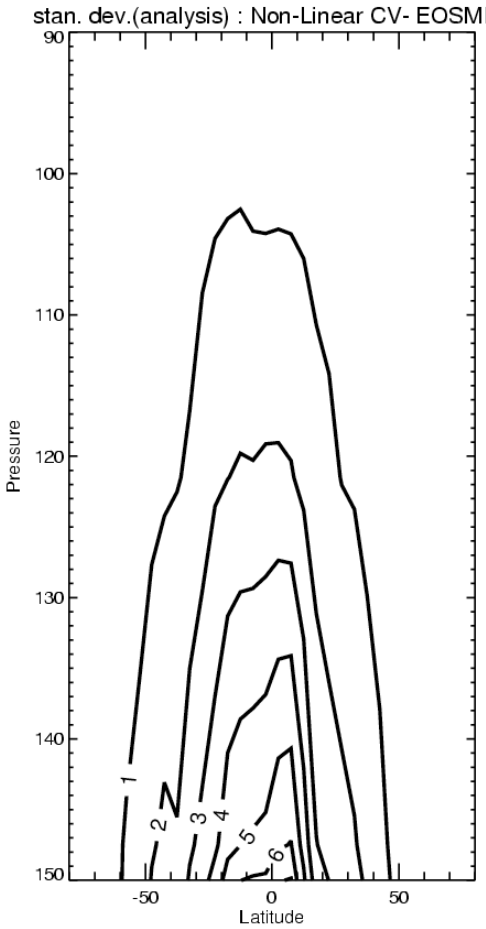


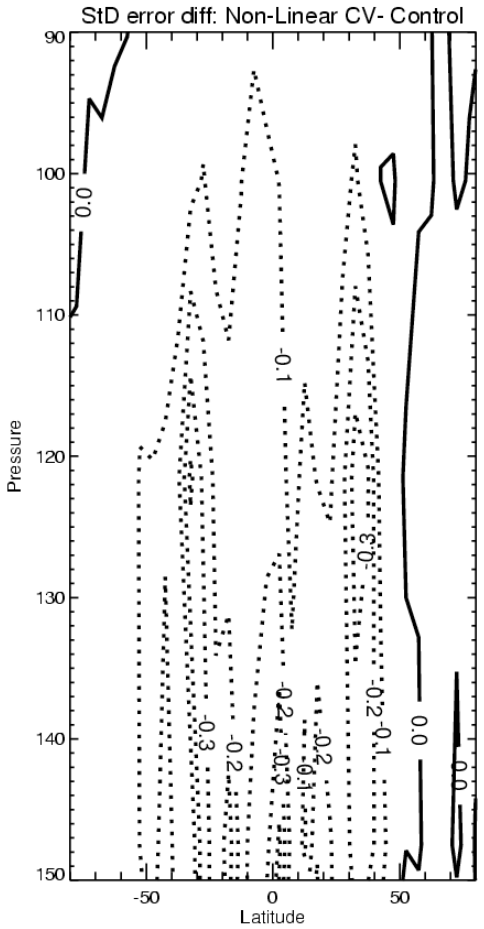
Control Non-Linear Difference

St Dev of MLS-analysis

- Better fit for new CV
- Improvement around 10-30% at higher levels / latitudes
- Improvement closer to 5% at 150 hPa, tropics



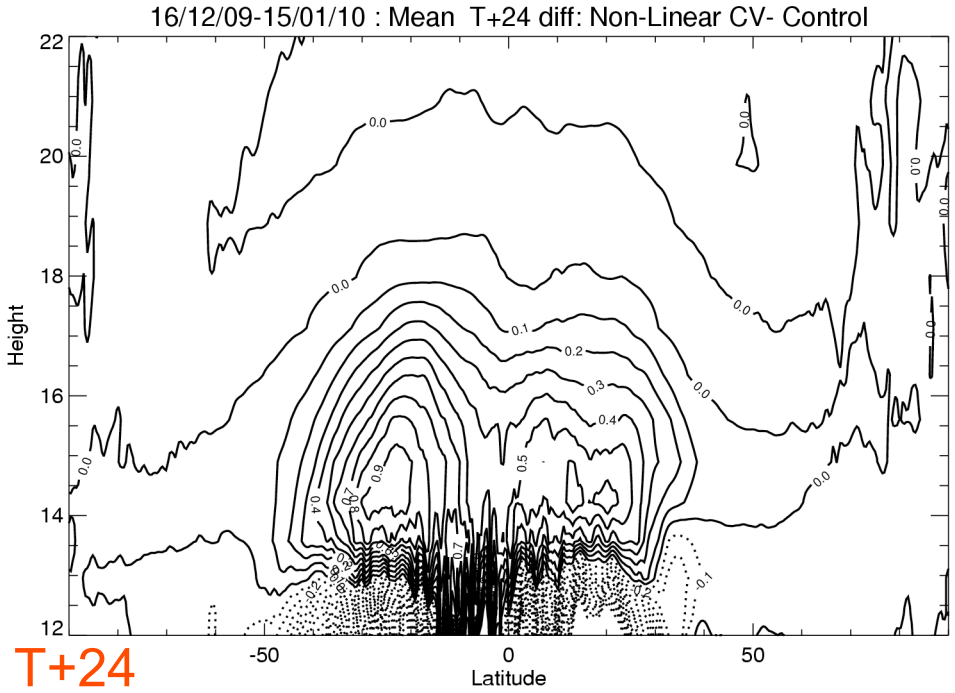




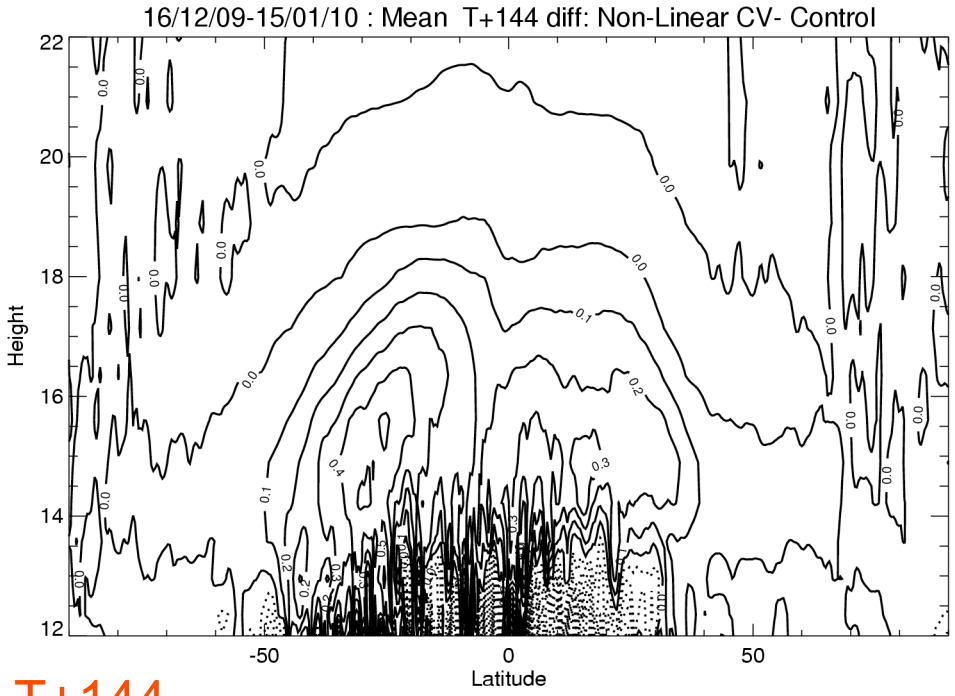
Control Non-Linear Difference

Impact of upper bound of humidity assimilation

- Trials above all switched off humidity assimilation at ~ 50 hPa
- Assess impact of this by comparing with another control run with humidity DA off at ~172 hPa
- Unfortunately (as this was old run) only forecast zonal mean humidity was available



T+24



T+144

Impact of upper bound of humidity assimilation

- More positive humidity for non-linear CV in region where negative MLS errors seen (by up to 0.9 ppmv)
- Therefore, extending humidity analysis up to ~50 hPa improves analysis (even if no observations at these heights)
- Difference between runs persists to T+144 (though is halved)

Summary

- Nonlinear humidity transform (based on Holm)
  - first nonlinear background error term in our system
- Reduces under/overshoots in analyses, Improves forecasts of humidity and Pmsl, especially in SH
- Some evidence of better use of satellite data (improved fit to humidity channels)
- Overall, small positive benefit to tropopause level humidity (v MLS)
- Higher cut-off for humidity assimilation suggests a reduction in dry bias

Future plans

- Pre-operational trials running – new CV should go operational in July
- Further work to understand tropopause level results needed
  - why is the largest tropopause-level impact of the new CV seen in the subtropics?
  - why does raising top level of humidity DA improve the results even when no obs are assimilated there?
  - impact on longer-range forecasts?
- Re-visit issue of assimilating stratosphere humidity data (eg MLS)
- Paper in preparation

Questions and answers