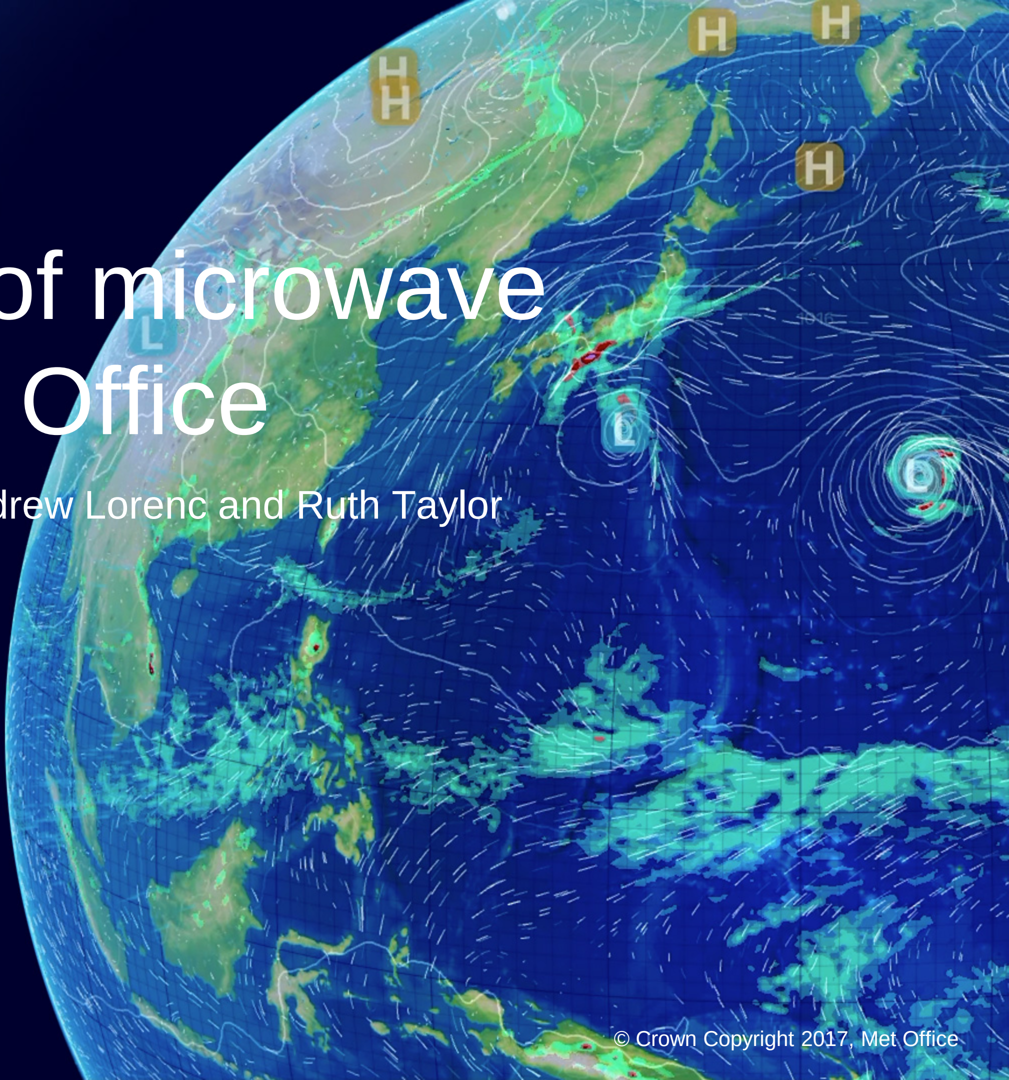
All-sky assimilation of microwave sounders at the Met Office

Stefano Migliorini, Brett Candy, William Bell, Andrew Lorenc and Ruth Taylor

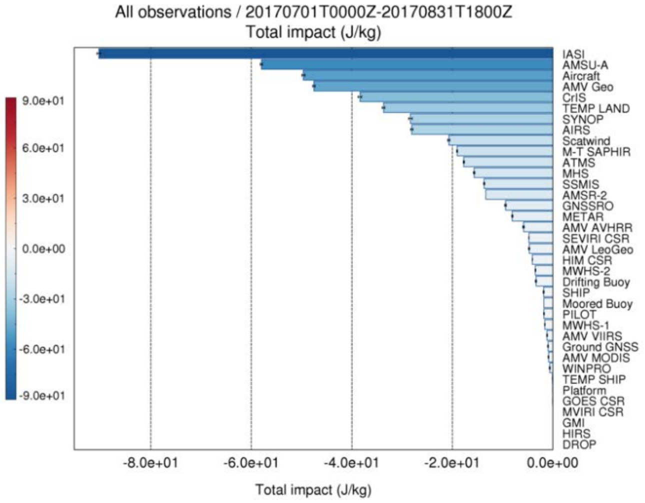
Met Office

stefano.migliorini@metoffice.gov.uk



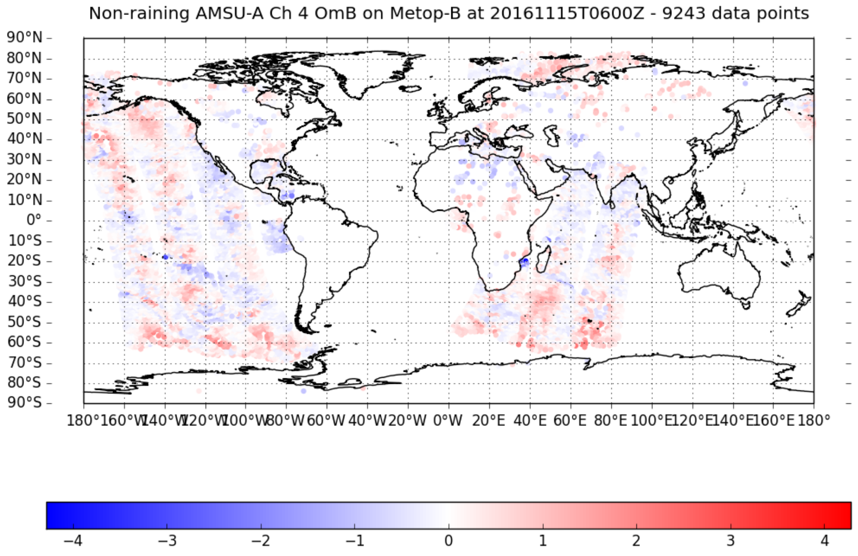
Motivation

- Microwave sounding radiances are an important source of information to constrain short range forecasts
- AMSU-A radiances provide the second highest impact as measured by the FSOI over a two month period over last summer
- Obs from low peaking channels (Ch 4 and Ch 5) are discarded when significantly affected by cloud
- Strong motivation to move to all-sky assimilation of microwave sounders



Cloud-affected radiances

- Cloud flags are currently rejecting most of AMSU-A channel 4 data and a significant portion of channel 5 data



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Moisture in VAR

- Model variables: u, v, w, θ, Π, ρ, q, q_{cl}, q_{cf}, C_l, C_f, C_t
- Perturb. forecast (PF) model vars: (u', v', w', θ', Π', ρ', q', q_c') = **w**'
- **w**' components not independent: we need uncorrelated $\mathbf{v}_p$ and transform $\mathbf{U}_p$ such that **w**' = $\mathbf{U}_p$ $\mathbf{v}_p$
- Met Office CVs: $\mathbf{v}_p$ = (ψ', χ', $p^{A'}$, μ') = stream function, velocity potential, unbalanced pressure, humidity variable
- μ' proportional to rh'_T (q'_T) close to (away from) saturation: temperature-sensitive obs preserve cloud when μ'=0
- Parameter transform $\mathbf{U}_p$ determines q'_T from μ'

Partitioning the moisture increments (1/2)

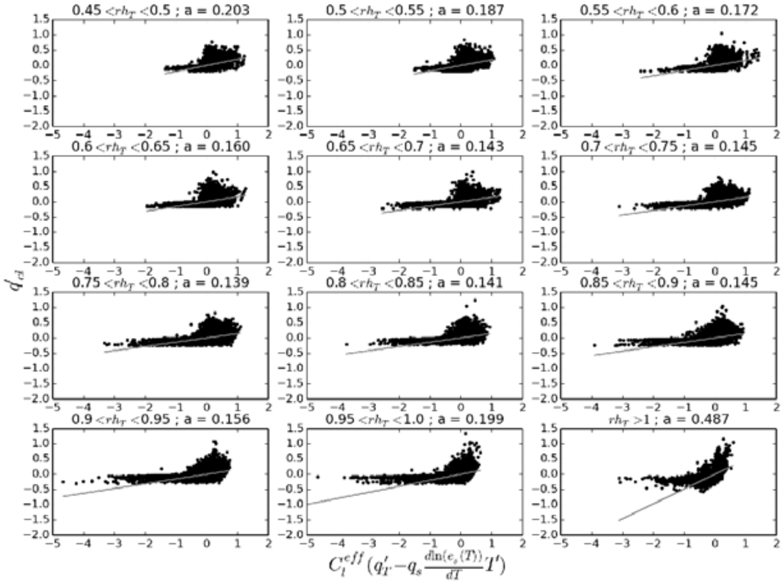
- Single moist CV requires an operator to distribute total water increments so as to pass them to obs operator and prognostic models: liquid increments

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

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

$$C_l^{eff} \equiv \frac{C_l(1-C_f)}{1-C_l C_f}$$

$$(q'_{cl})_{diag} \cong a(z_l, \delta_{rh}) q'_{cl}$$



- Migliorini, Lorenc and Bell (2017), QJRMS

Partitioning the moisture increments (2/2)

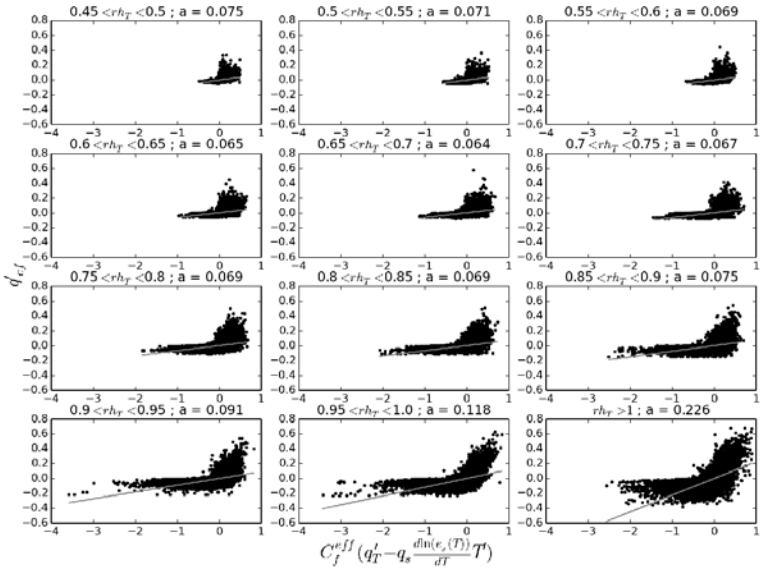
- Single moist CV requires an operator to distribute total water increments so as to pass them to obs operator and prognostic models: ice increments

$$q'_{cf} = C_f (q'_T - q'_{cf} - q'_s) \cong C_f (q'_T - q'_{cf} - q_s \frac{\partial \ln e_s}{\partial T} T')$$

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

$$C_f^{eff} \equiv \frac{C_f (1 - C_l)}{1 - C_l C_f}$$

$$\left(q'_{cf}\right)_{diag} \cong b(z_l, \delta_{rh}) q'_{cf} \qquad q' = q'_T - \left(q'_{cl}\right)_{diag} - \left(q'_{cf}\right)_{diag}$$



- Migliorini, Lorenc and Bell (2017), QJRMS

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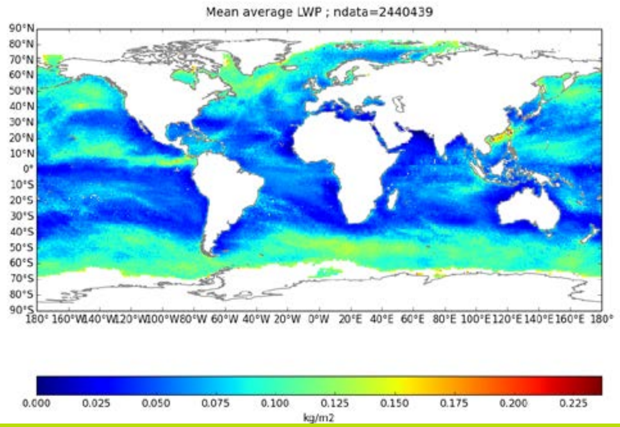
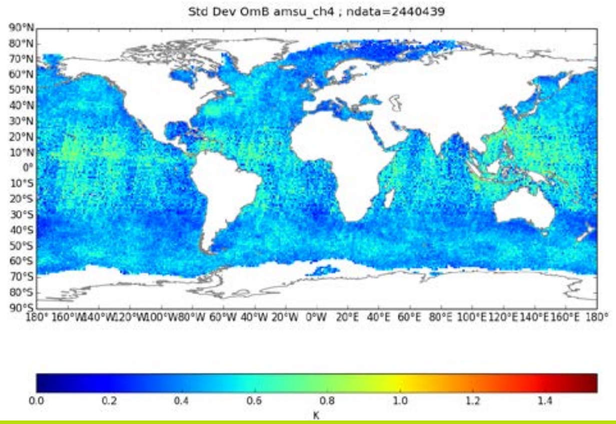
Uncertainties in the presence of cloud

- A monitoring experiment was set up to evaluate errors for AMSU-A Ch 4 and Ch 5 observations affected by cloud. To this end, the data assimilation system was modified to perform radiance calculations on model rather than on standard levels.
- LWP retrieved from both real and simulated AMSU-A Ch1 and Ch2 observations (Weng et al., 2003)





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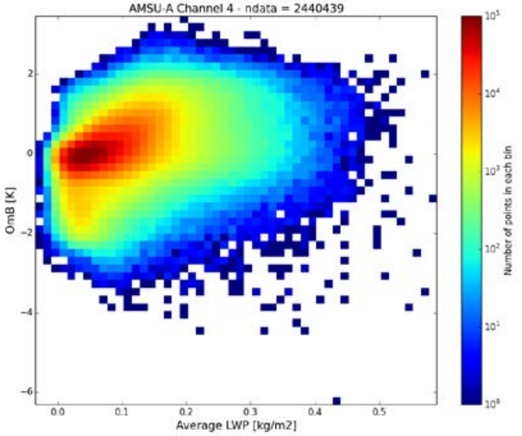
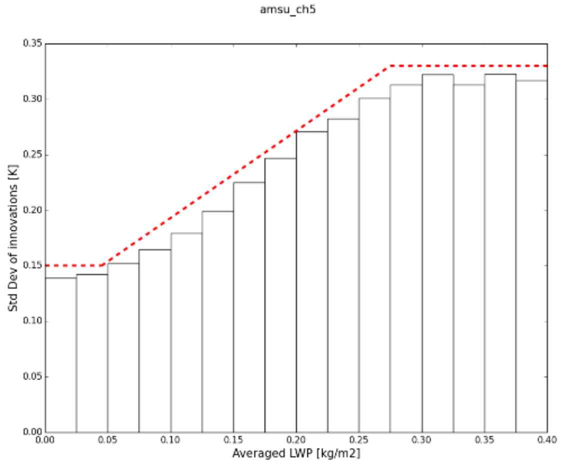
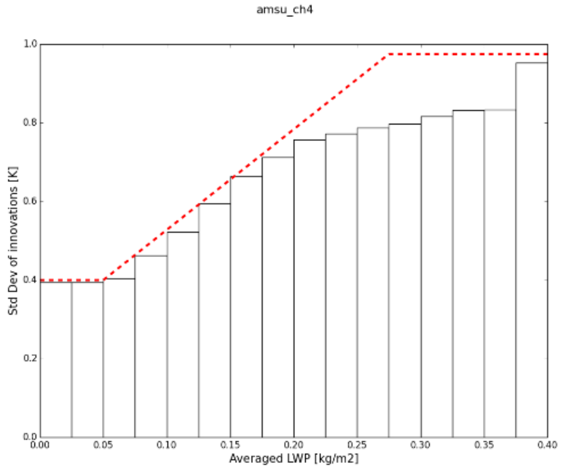
Cloud-dependent errors

- Evidence of non-linear dependence of the innovation distributions on average LWP
- Also significant biases esp. at low LWP values (but no VarBC corrections on data)
- Stddev of innovations are still well approximated by piece-wise linear relationship in avg LWP

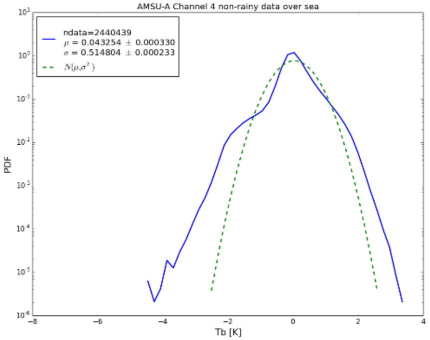


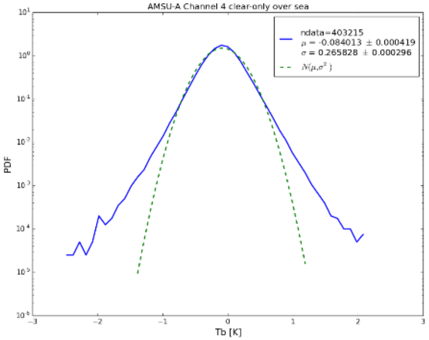


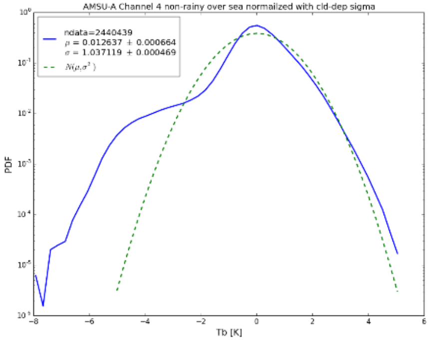


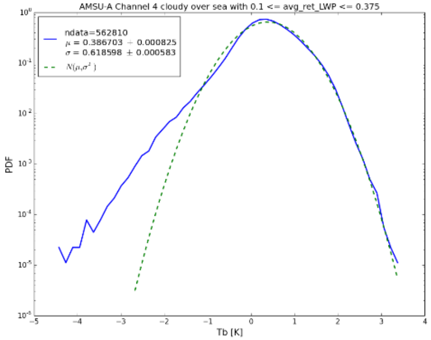
Innovation distribution

- Innov distrib for non-raining scenes noticeably non-Gaussian (K-L distance from Gaussian: d_{KL}= 0.1681) compared to clear-sky only (d_{KL}= 0.0336).
- Normalization by cloud-dependent errors still does not ease non-Gaussianities (d_{KL}= 0.1629)
- Significant improvements for clear plus cloudy scenes with 0.1 kg/m2 ≤ LWP ≤ 0.375 kg/m2 (d_{KL}= 0.0288)









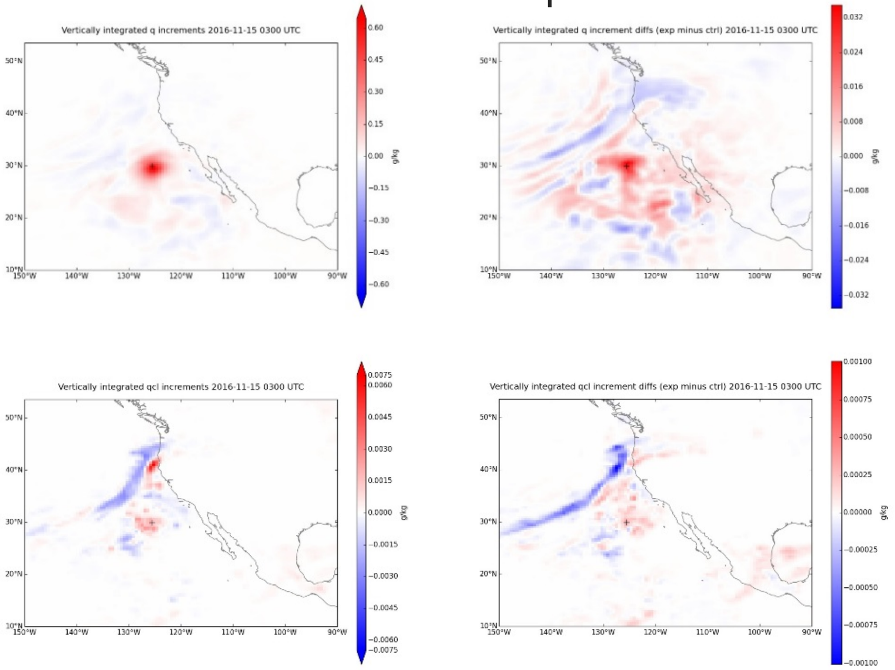
Single-ob experiment

- Analysis increments from assimilation of a single cloudy scene
- Radiances from MHS Ch3 and Ch4, AMSU-A Ch6 and Ch8 to Ch14 on Metop-B (CTRL) compared to those obtained when AMSU-A Ch4 and Ch5 radiances (normally discarded in the presence of cloud) were also assimilated (Exp)

CTRL | Exp minus CTRL

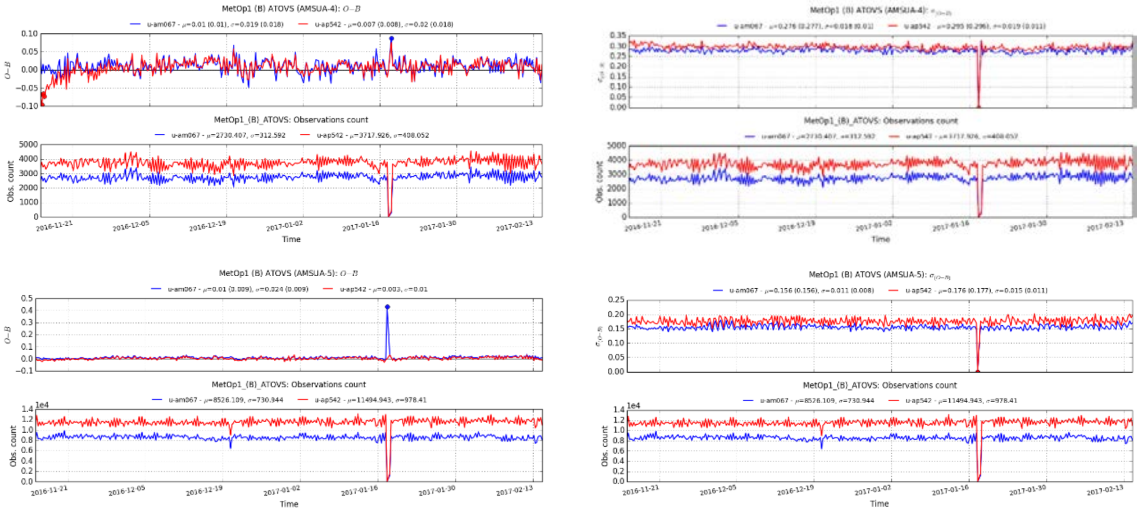
$\sum_i q'(z_i)$

$\sum_i q_{cl}'(z_i)$



Trial experiment

- Trial experiment from 15 November 2016 0600 UTC to 20 February 2017 1200 UTC
- RTTOV on model levels; new moisture incrementing operator; non-zero jacobian wrt clw for ATOVS; all-sky (nonprecipitating) AMSU-A Ch5; Ch4 with 0.1 kg/m2 < LWP < 0.375 kg/m2



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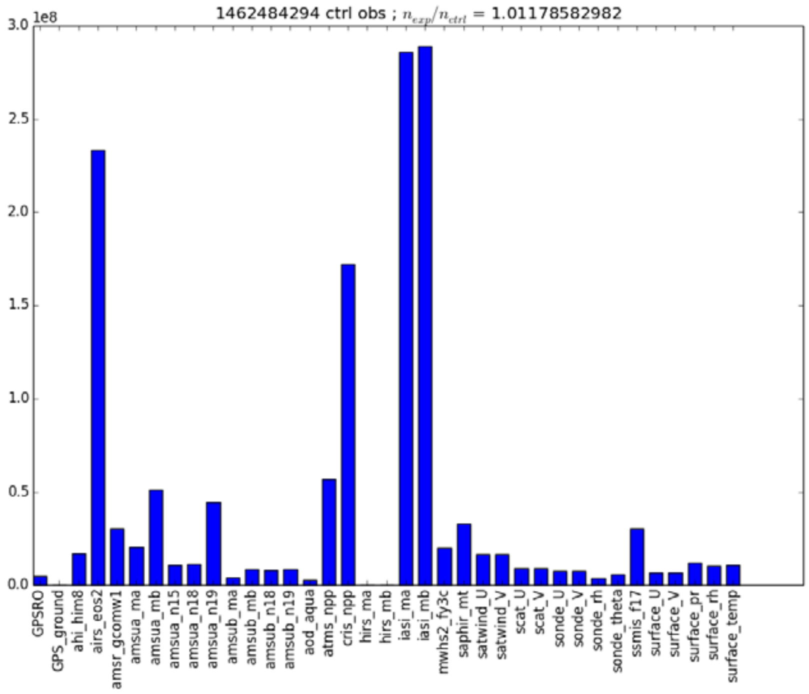
Trial experiment

- Total number of obs



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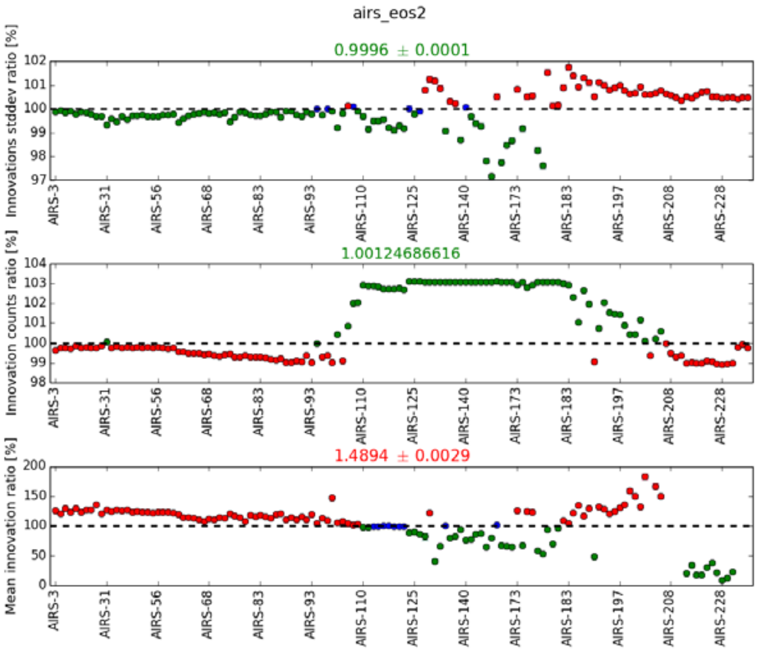
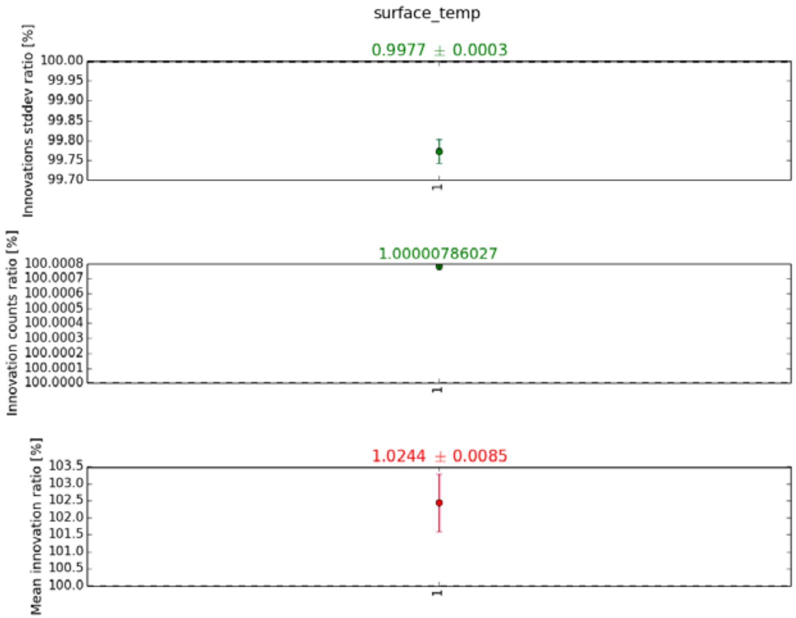
Trial experiment

- Satellite data innovations



Trial experiment

- In situ data innovations



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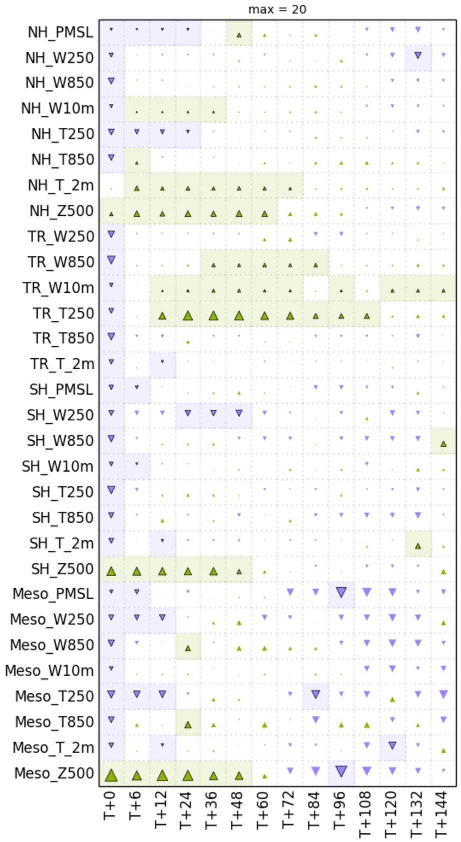
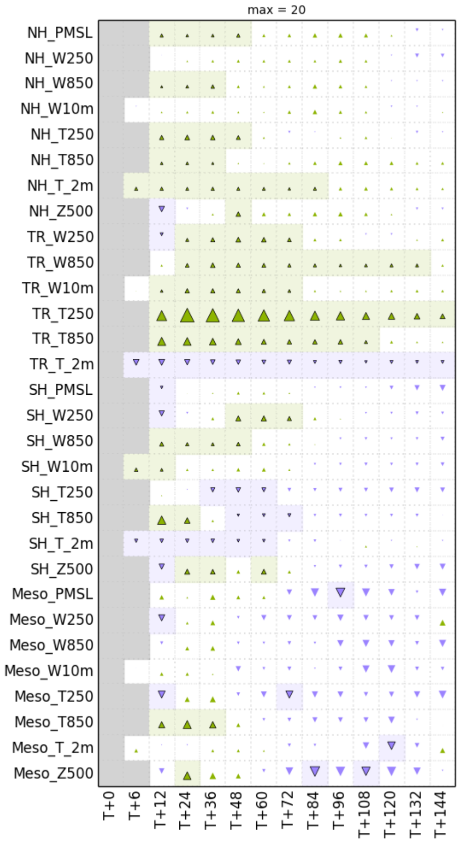
Score cards

- Change in RMSE (green: smaller than control) against EC analyses (left) and against obs (right)
- Max RMSE diff = max triangle area: 20%
- Shading when diff significant at 0.05 level
- Meso: over the UKV domain

% Difference (all-sky modlevs vs. OS39)
Change in RMSE against observations for 20161125-20170220



% Difference (all-sky modlevs vs. OS39)
Change in RMSE against ECMWF analyses for 20161125-20170220



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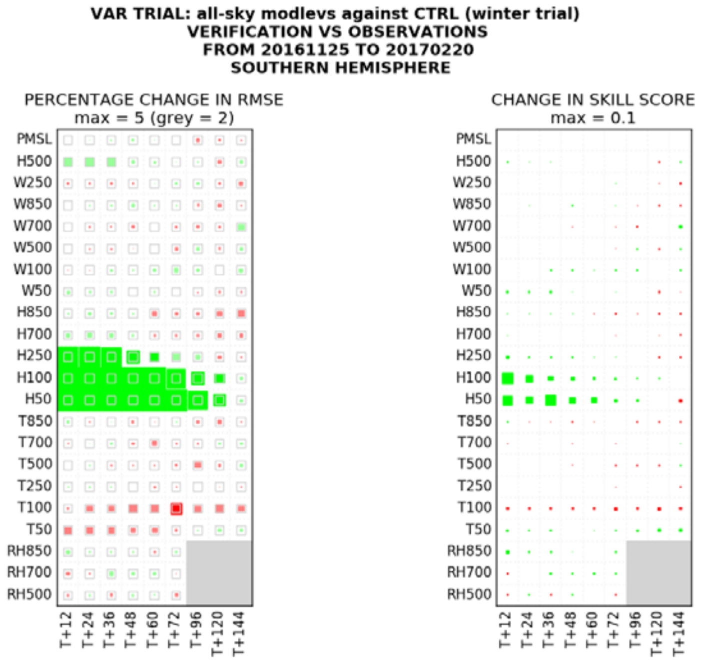
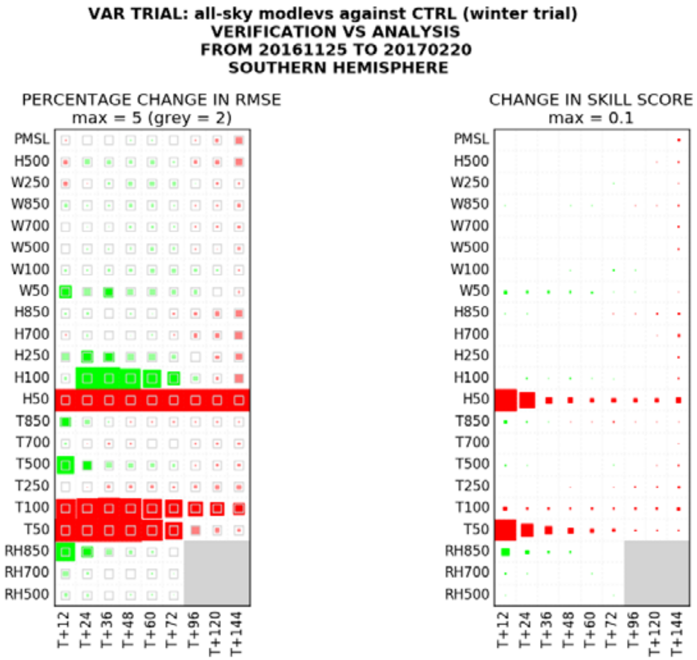
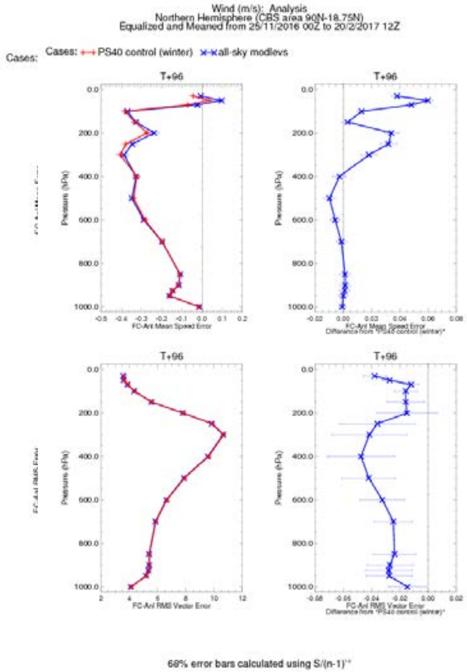
Verification

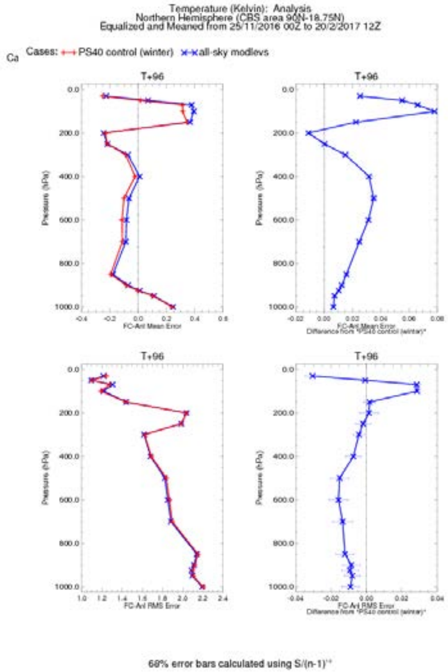
- Global NWP index: +0.126% (obs) +0.187%(EC ana)

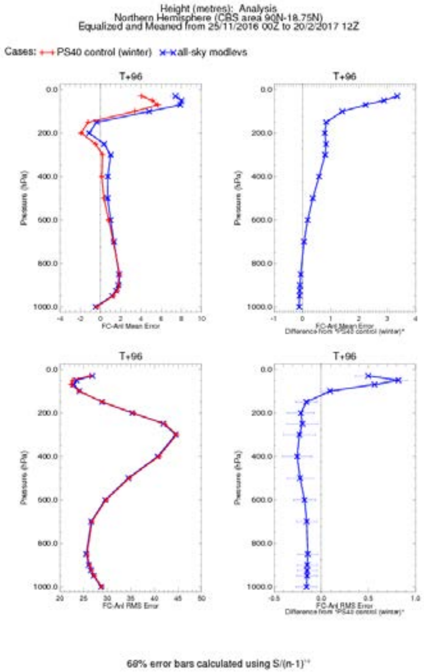




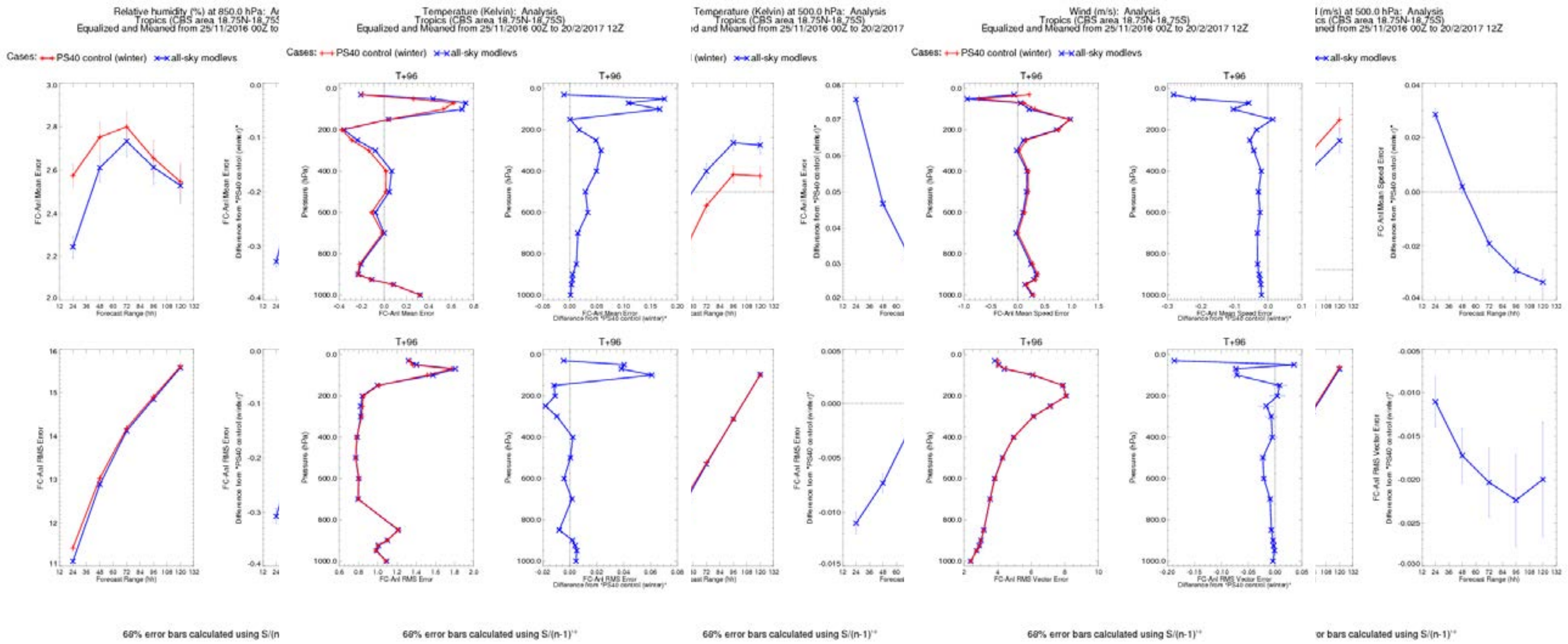
Verification: EC (NH)



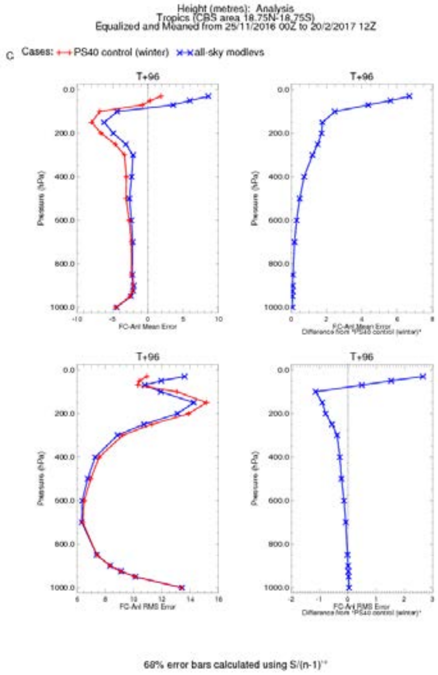


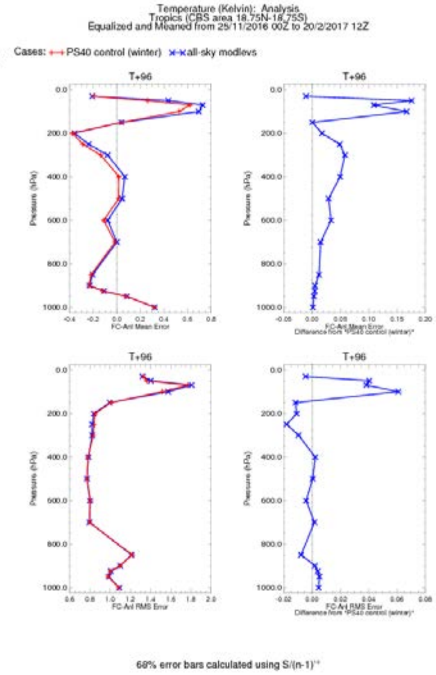


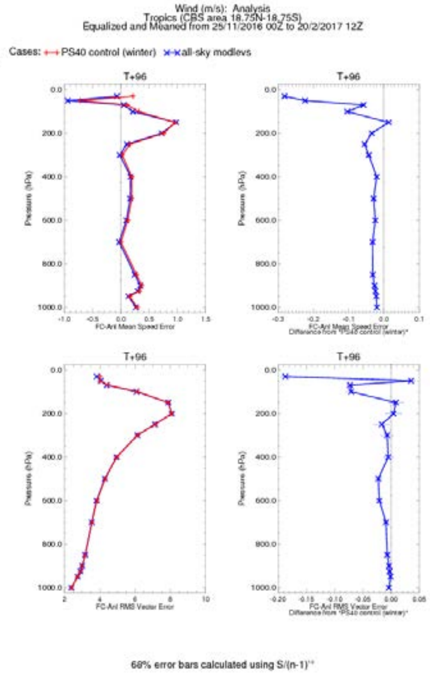
Verification: EC (TR)



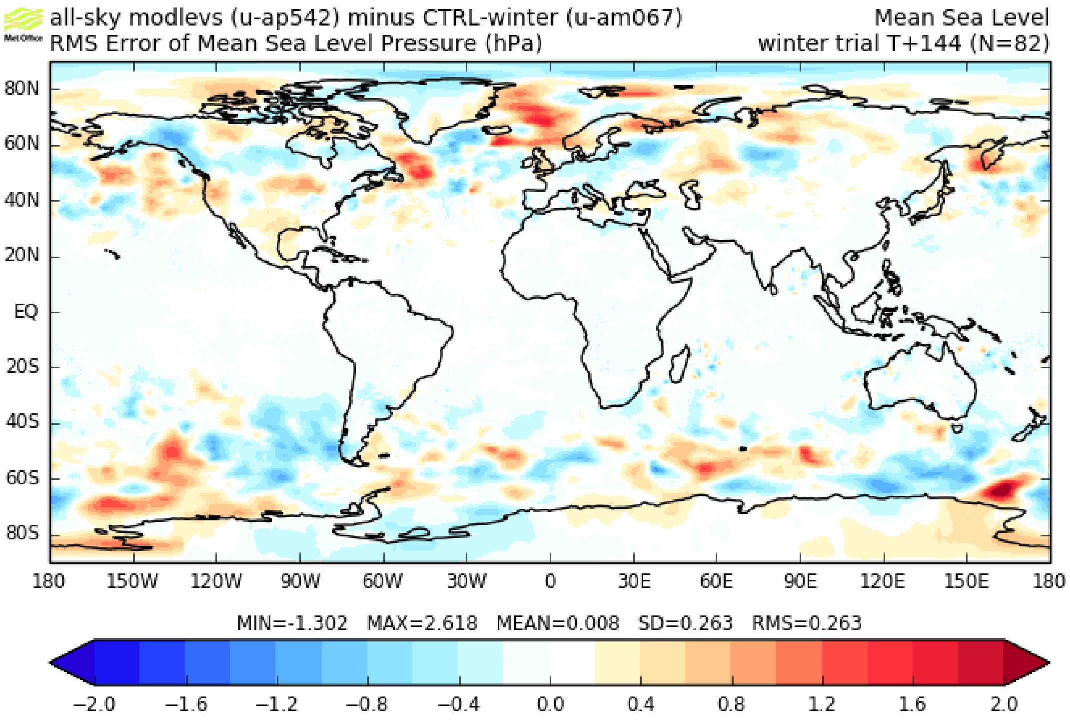
Verification: EC (SH)







Verification: MSLP (v own analyses)



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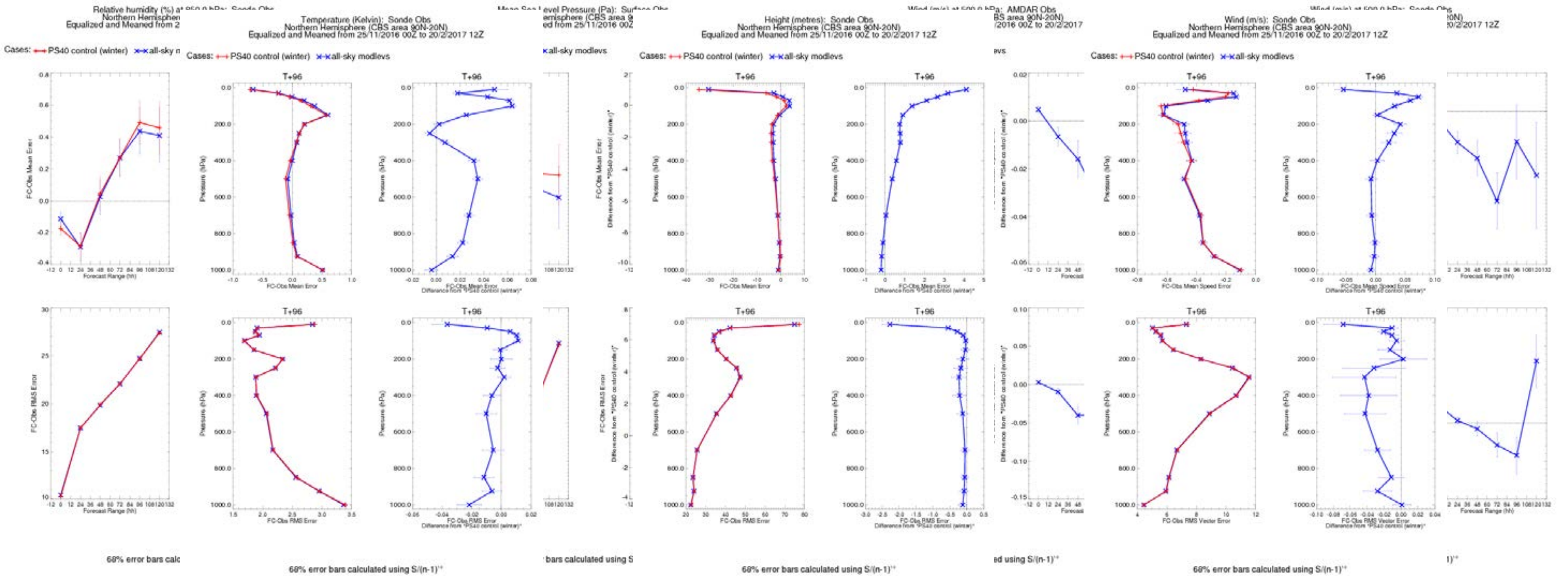
Verification: in situ (NH)



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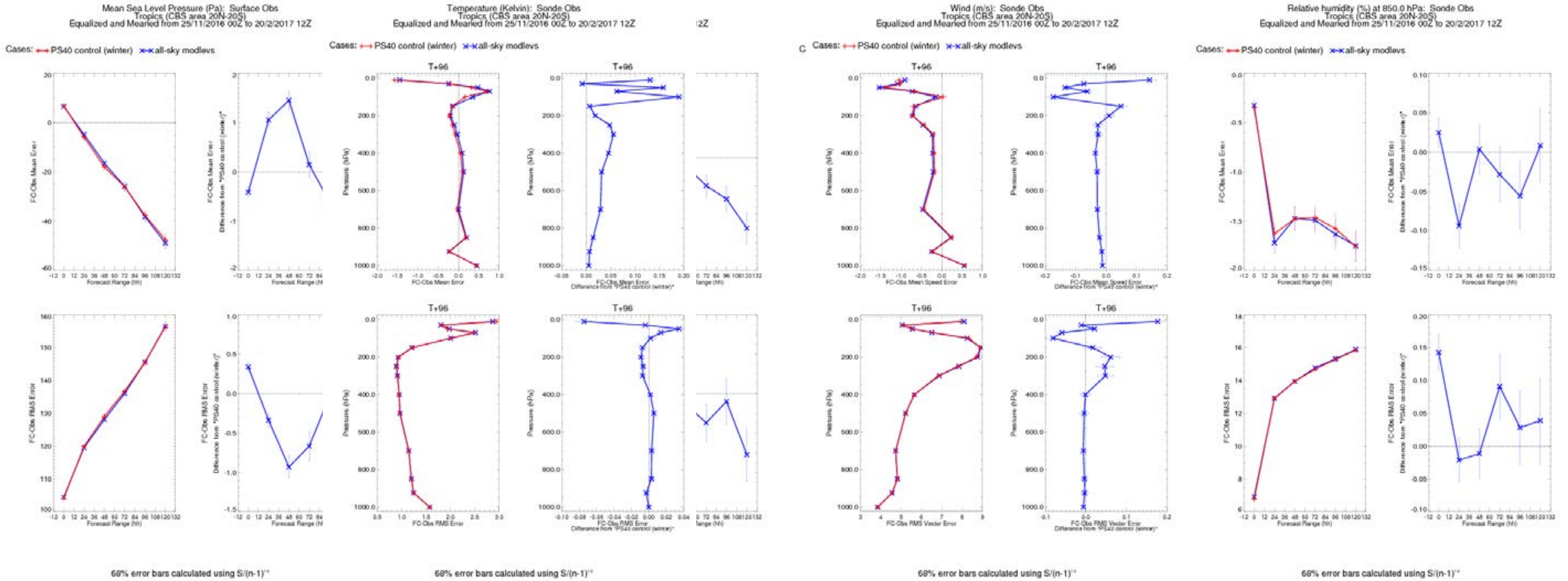
Verification: in situ (TR)



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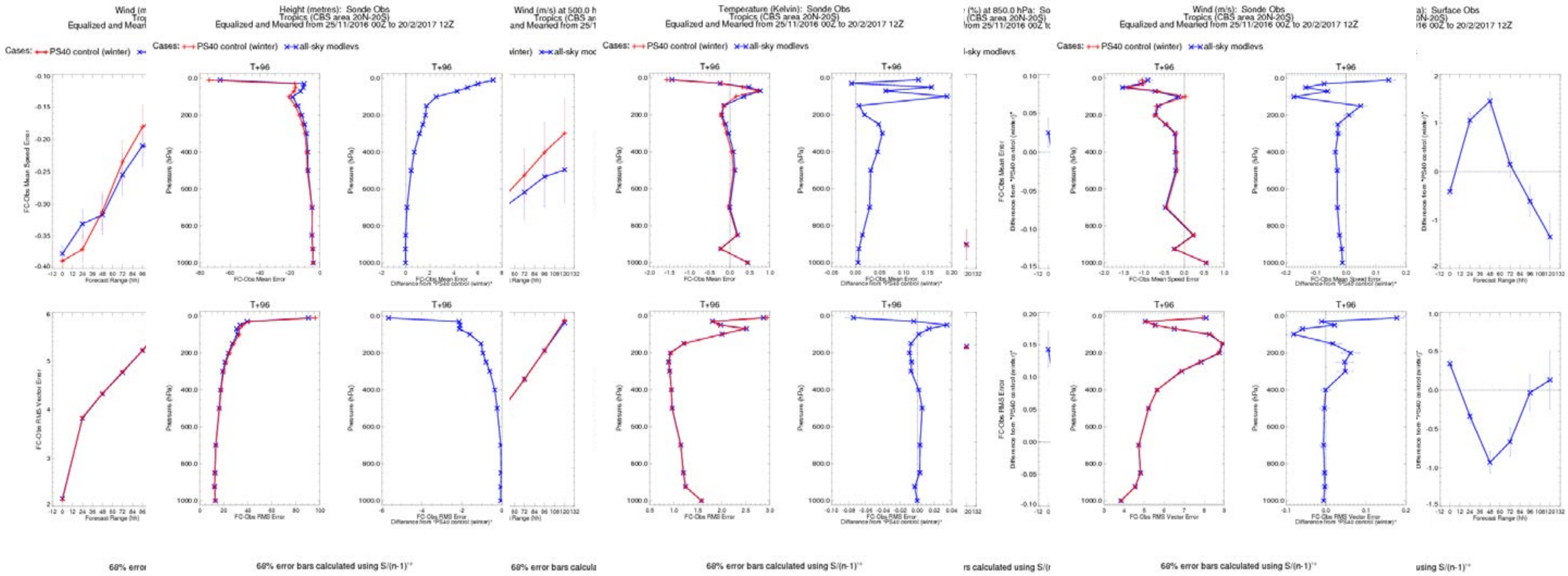
Verification: in situ (SH)



Conclusions and future work

- A pre-operational system that allows cloud affected radiances from AMSU-A to be assimilated alongside those in clear sky is being developed at the Met Office
- Results from a three-month trial show that the assimilation of non-precipitating radiances form AMSU-A Ch 4 and Ch5 has an overall neutral impact on the control run
- There are, however, consistent RMSE reductions in key indicators (TR T250, TR W850, NH PMSL, NH T2m, NH/SH H500).
- We are also planning to test the assimilation of MHS Ch 4 and Ch 5 in all-sky conditions in the UKV limited area model using hourly 4D-Var cycles, with radiances simulated using RTTOVSCATT.
- On a longer timescale we will consider minimization tests with a succession of linearization states (i.e. the so-called “outer loop”) for all-sky trials.