Assimilation of Transformed Retrievals from IASI radiances at the Met Office

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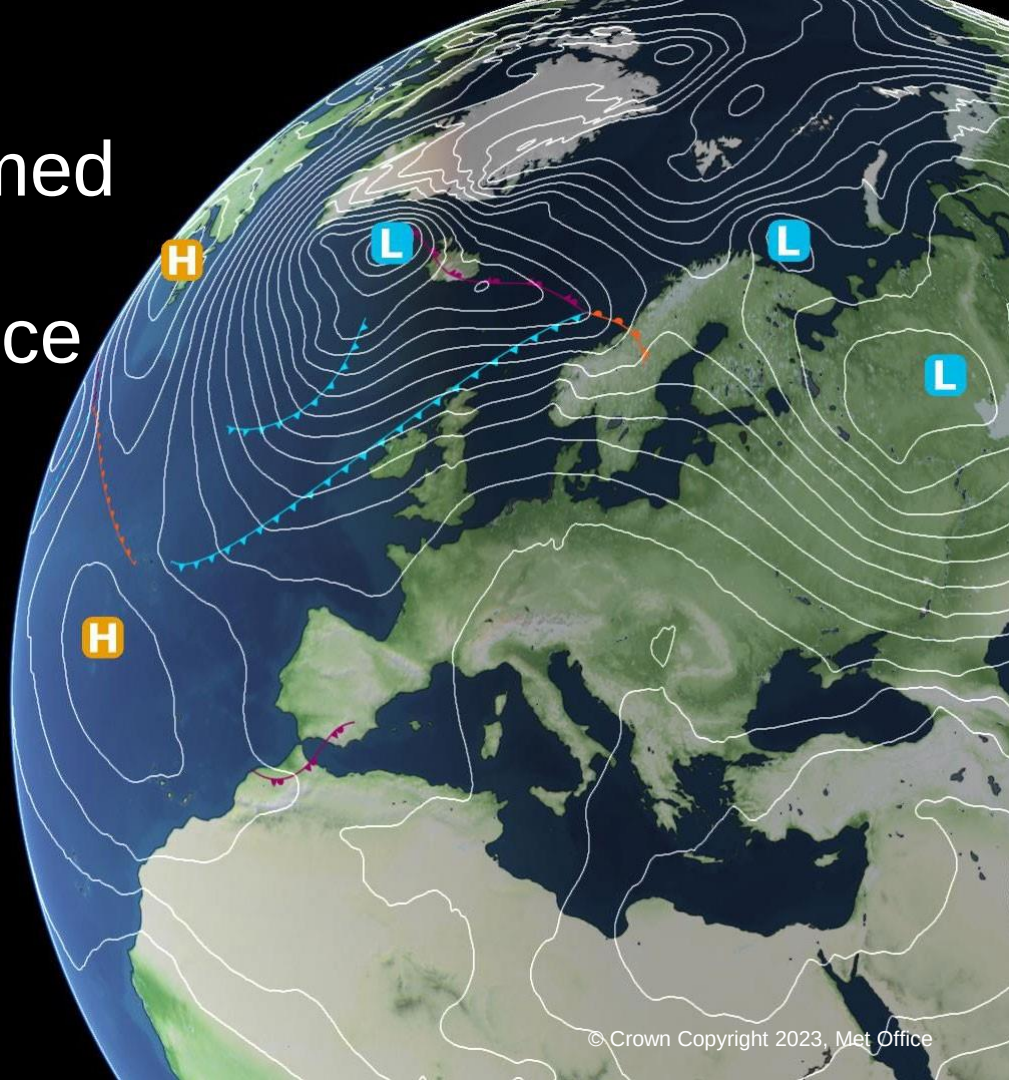
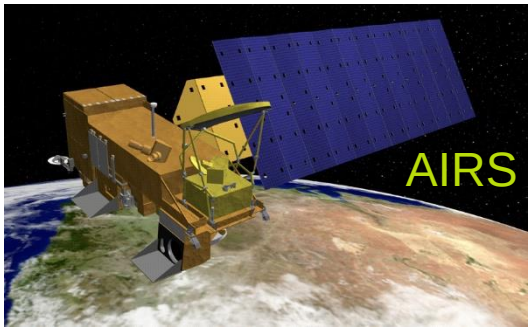
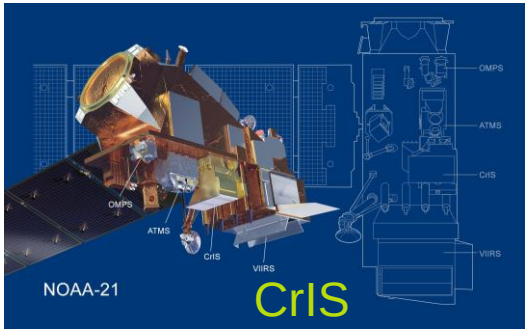


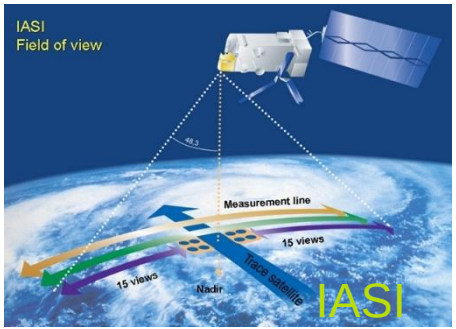
Passive atmospheric temperature/humidity sounding: current instruments



https://airs.jpl.nasa.gov/mission/overview/



https://www.nesdis.noaa.gov/our-satellites/currently-flying/joint-polar-satellite-system



https://www.eumetsat.int/iasi

- A wealth of data from IR sounders available in NRT for NWP applications
- IASI: 3 satellites, 8461 channels, 30 cross-track samples with 2x2 FOVs
- AIRS: 2378 channels, 90 cross-track samples
- CrIS: 3 satellites, 1305 (NSR) / 2211 (FSR) channels, 32 cross-track samples

Passive atmospheric temperature/humidity sounding: forthcoming instruments

- IASI-NG: 3 satellites (first launch in 2025), 16921 channels, 14 earth-viewing cross-track samples with 4x4 FOVs
- MTG-IRS: 2D detector acquires 160 x 160 spectra (1960 spectral channels) over a dwell, for 4 local area coverage (LAC) zones. Full disk acquired every 60 mins, LAC4 (Europe) every 30 mins

https://www.eumetsat.int/mtg-infrared-sounder

https://www.eumetsat.int/eps-sg-iasi-ng

Assimilation of satellite data for NWP

- Satellite data make up for most observations that are routinely assimilated at the Met Office
- Huge amount of data are discarded due to operational/computational constraints, imperfect knowledge of spatial correlations, shortcomings in NWP models and observation operators.
- Recent work at the Met Office shows that it is possible to assimilate a reduced set of obs components – Transformed Retrievals (TRs) – and achieve comparable results as when assimilating radiances directly.

Met Office

Transformed Retrievals

- Linearized and normalized measurements

$$\hat{\mathbf{y}} = \mathbf{y}^o - H(\mathbf{x}^a) + \hat{\mathbf{H}}\mathbf{x}^a \cong \hat{\mathbf{H}}\mathbf{x}^t + \boldsymbol{\varepsilon}^o \qquad \hat{\mathbf{y}}' \cong \mathbf{R}^{-1/2}\hat{\mathbf{H}}\mathbf{x}^t + \mathbf{R}^{-1/2}\boldsymbol{\varepsilon} \equiv \hat{\mathbf{H}}'\mathbf{x}^t + \boldsymbol{\varepsilon}'$$

$$\mathrm{cov}(\boldsymbol{\varepsilon}^o) = \mathbf{R} \qquad \mathrm{cov}(\boldsymbol{\varepsilon}') = \mathbf{I}$$

- Projection onto signal-to-noise basis (in obs space)

$$\mathbf{S} = \mathbf{R}^{-1/2}\hat{\mathbf{H}}\mathbf{B}^{1/2} = \hat{\mathbf{H}}'\mathbf{B}^{1/2} = \mathbf{U}_r\boldsymbol{\Lambda}_r\mathbf{V}_r^T$$

$$\mathbf{y}'_{\mathrm{ret}} = \mathbf{U}_r^T\hat{\mathbf{y}}' \qquad \mathbf{H}'_{\mathrm{ret}} = \mathbf{U}_r^T\hat{\mathbf{H}}' = \boldsymbol{\Lambda}_r\mathbf{V}_r^T\mathbf{B}^{-1/2}$$

- signal-to-noise matrix **S**, with r = rank(**S**) ≤ min(m,n)
- $\mathbf{y}'_{\mathrm{ret}}$ is assimilated with $\mathbf{H}'_{\mathrm{ret}}$

Met Office

Information content of observations

- From **S** we can calculate degrees of freedom for signal (DFS)

$$d_s = \sum_{i=1}^{r} \frac{\lambda_i^2}{1+\lambda_i^2} = \sum_{i=1}^{r} d_{si}$$

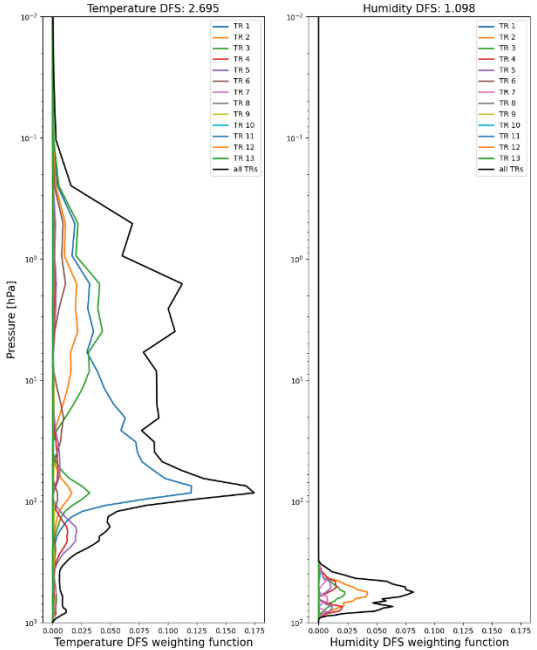
$$\mathbf{B} = \boldsymbol{\Sigma}^{1/2}\mathbf{C}\boldsymbol{\Sigma}^{1/2} \qquad \tilde{\mathbf{S}} = \mathbf{R}^{-1/2}\hat{\mathbf{H}}\boldsymbol{\Sigma}^{1/2} = \hat{\mathbf{H}}'\boldsymbol{\Sigma}^{1/2} = \tilde{\mathbf{U}}_r\tilde{\boldsymbol{\Lambda}}_r\tilde{\mathbf{V}}_r \qquad \tilde{d}_s = \sum_{i=1}^{r} \frac{\tilde{\lambda}_i^2}{1+\tilde{\lambda}_i^2} = \sum_{i=1}^{r} \tilde{d}_{si}$$

- DFS weighting function (DFSwf): $\mathbf{s}_i = \frac{d_s}{\tilde{d}_s}\tilde{d}_{si}\tilde{\mathbf{v}}_i \circ \tilde{\mathbf{v}}_i \in \mathbb{R}^{r\times n}$

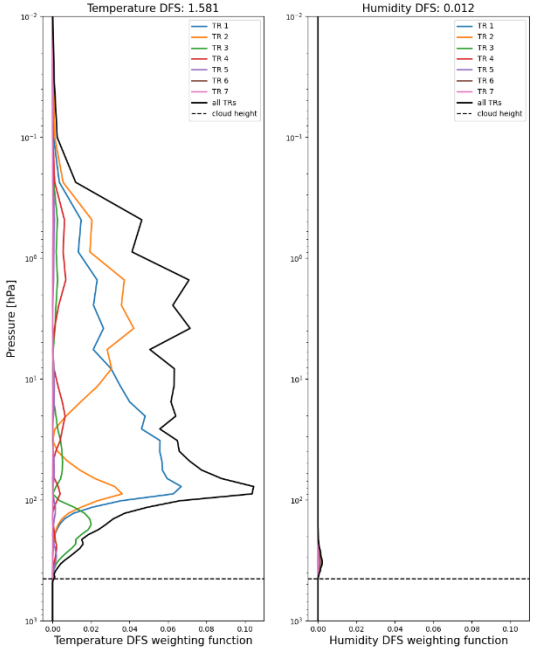
- Cumulative DFS weighting function: $\mathbf{s} = \frac{d_s}{\tilde{d}_s}\sum_{i=1}^{r}\tilde{d}_{si}\,\tilde{\mathbf{v}}_i \circ \tilde{\mathbf{v}}_i$

DFS weighting functions

Cloud-free location



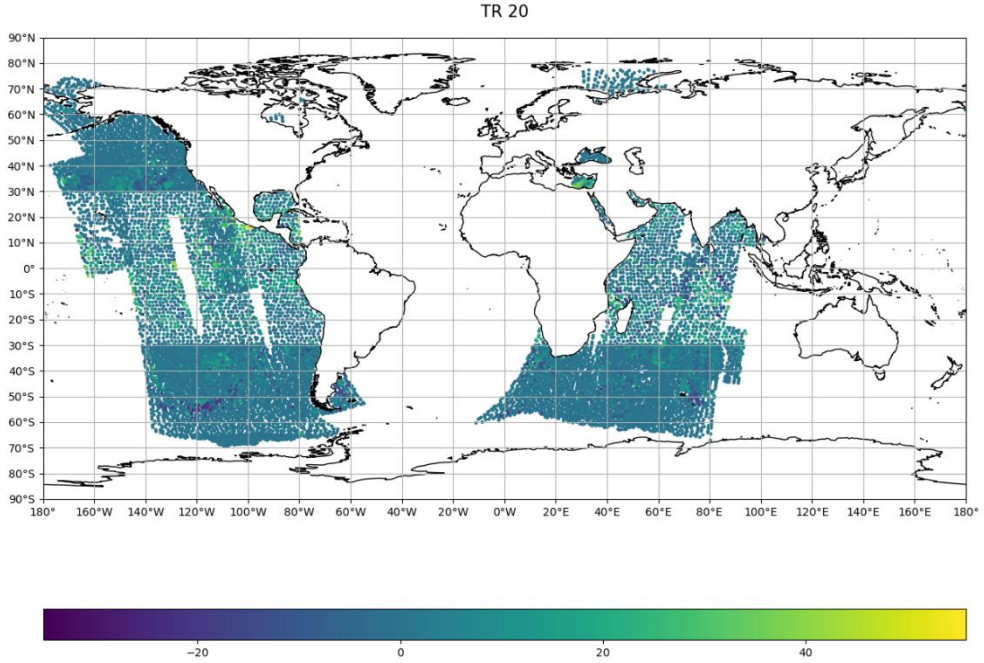
Overcast location



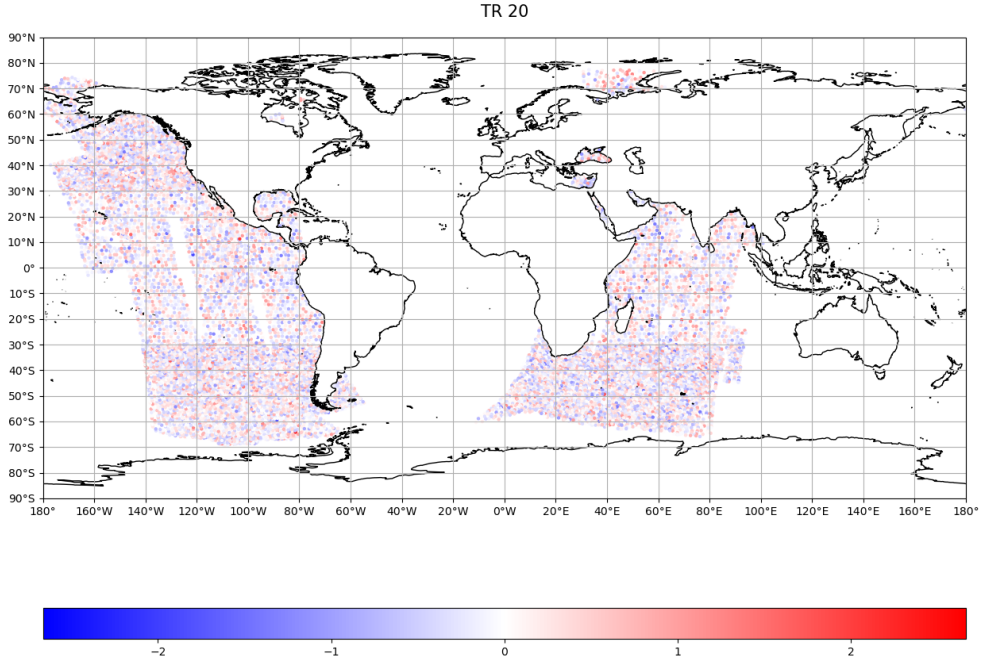
Assimilation trials

- Three-month trial with hybrid 4D-Var (no VarBC) from 1st December 2019 to 28th February 2020 using same observations (except for SSMIS and MWRI to avoid orbital bias) as those used in the Met Office operational DA scheme for the same period (in-situ or ground based, satellite products and satellite radiances including IASI – up to 175 radiances – on Metop-1(B) and Metop-3(C)): CTRL trial
- Same as CTRL except for replacing IASI rads with TRs: TR trial
- Same as TR trial but only assimilating $\mathbf{y'}_{\mathrm{ret}_i}$ with $\lambda_i > 0.1$: TR_L0p1 trial

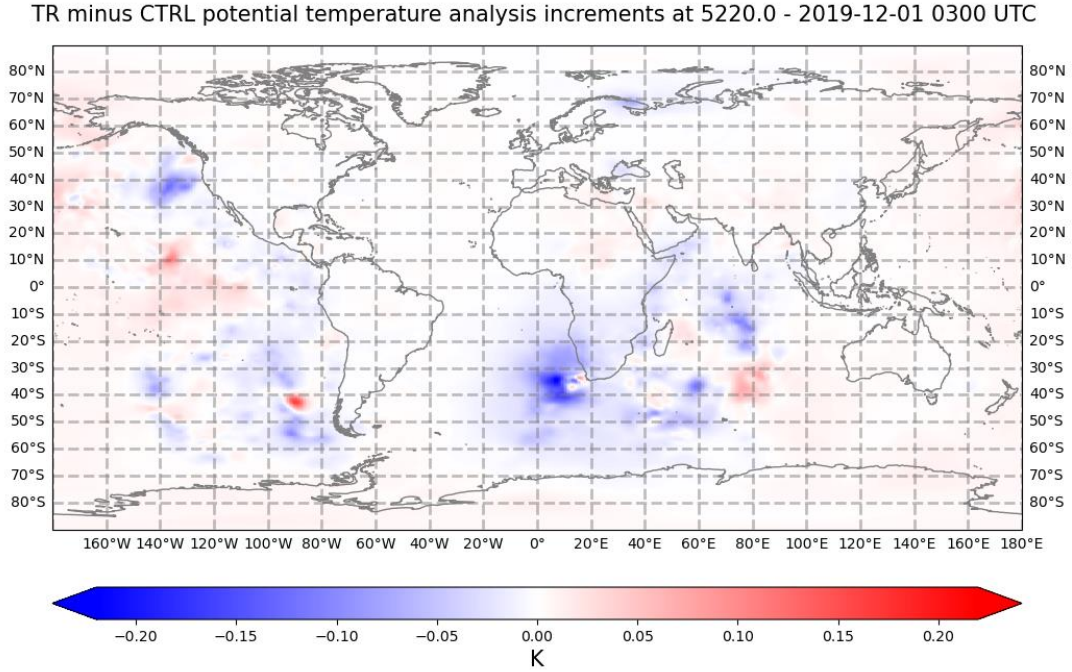
TR obs components



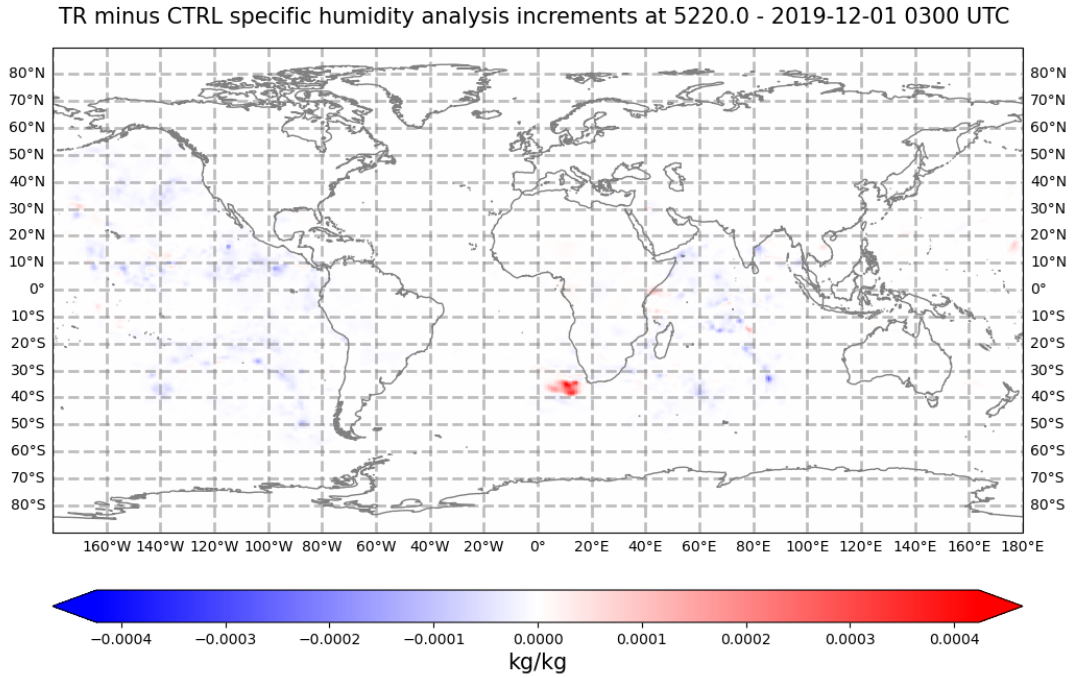
TR innovation components



Analysis increments: potential temperature

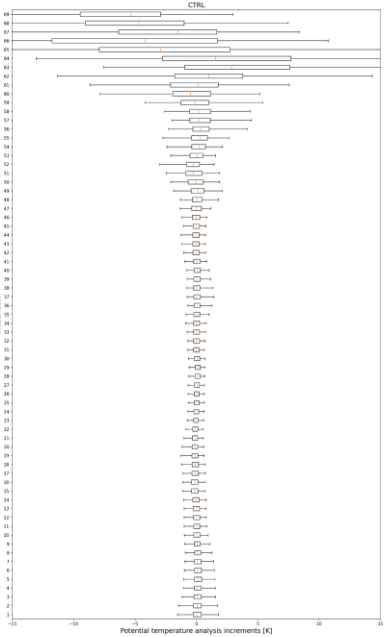


Analysis increments: specific humidity

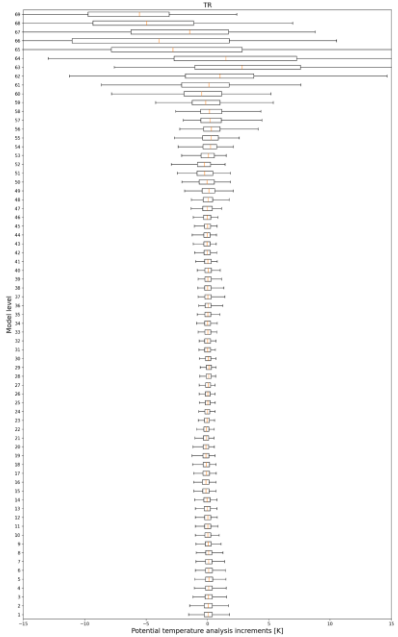


Analysis increment distrib: potential temperature

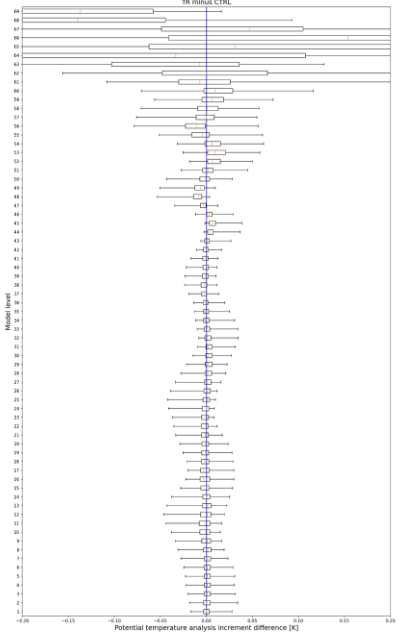
CTRL



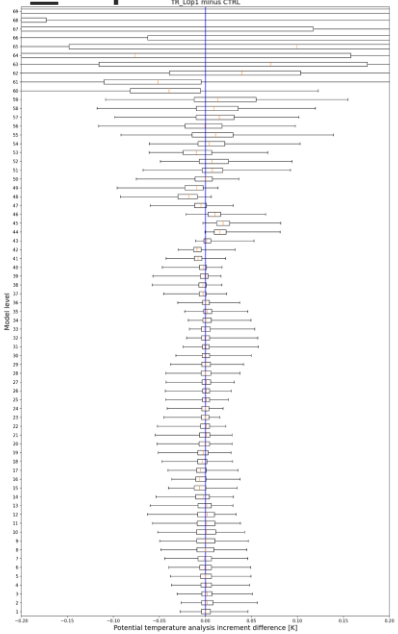
TR



TR minus CTRL



TR_L0p1 minus CTRL

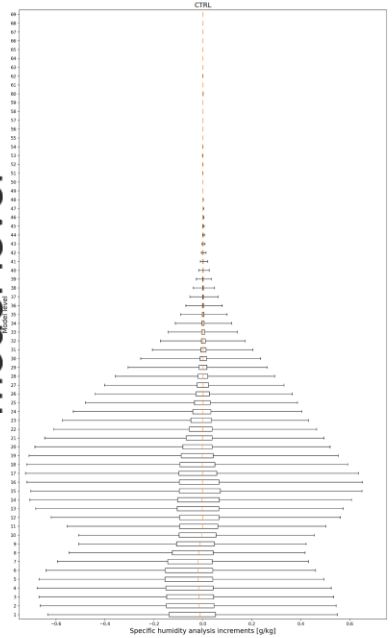


model level

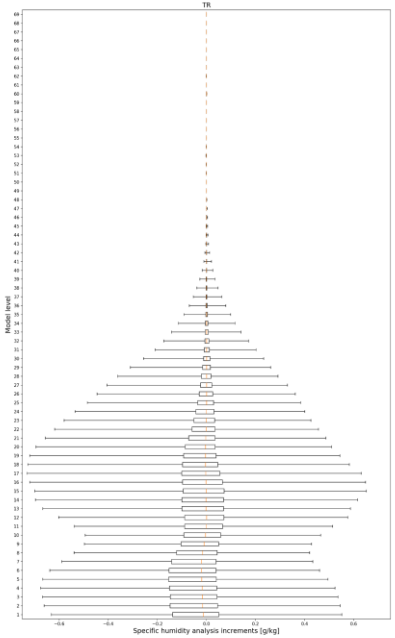
analysis increment

Analysis increment distrib: specific humidity

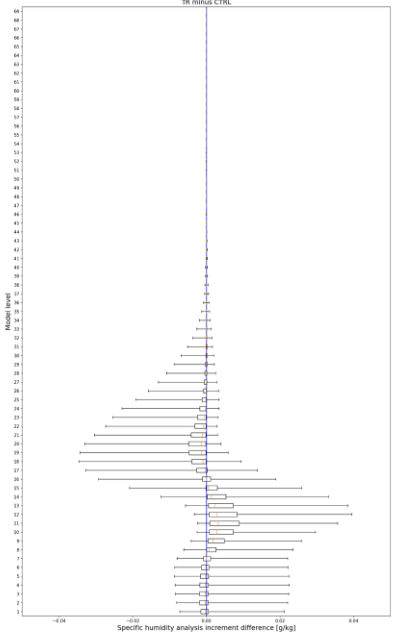
CTRL



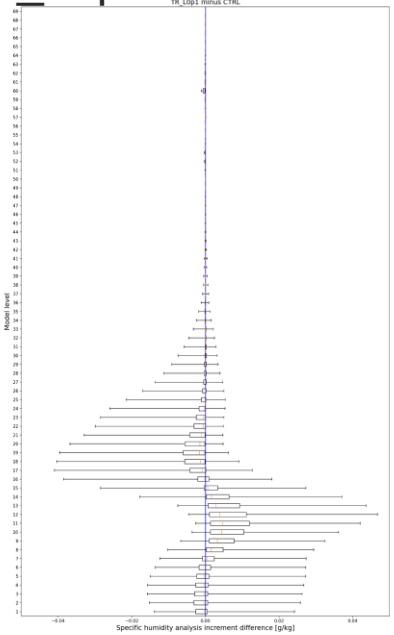
TR



TR minus CTRL



TR_L0p1 minus CTRL

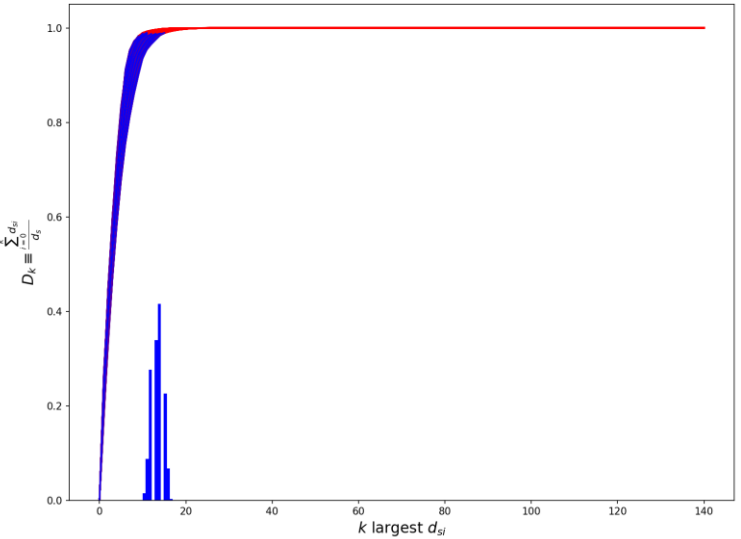


model level

analysis increment

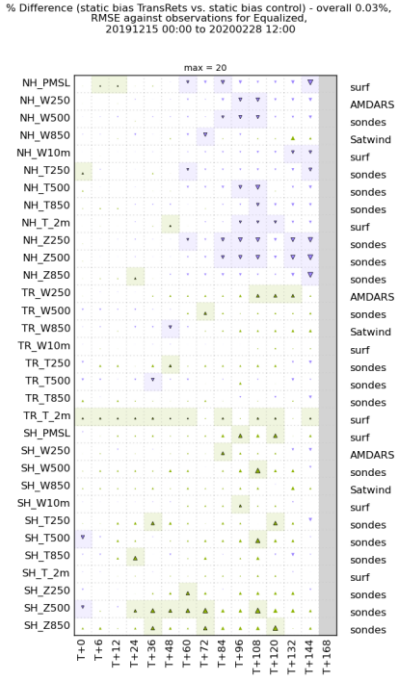
Information content of TR components

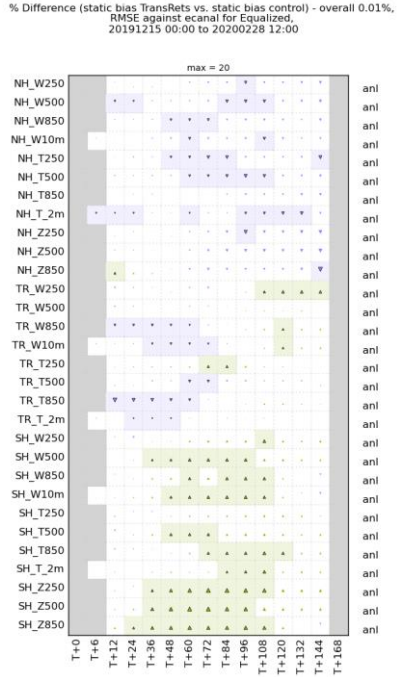
- Partial sums D_k of the k largest normalised degrees of freedom for signal for an ensemble of 3344 out of 13061 IASI observations in the first assimilation cycle with S with max rank (=140).
- Histogram of the number of TRs for the 3344 IASI obs with $\lambda_i > 0.1$
- no more than 17 TR components with largest λ_i values are required to express from 97.9% up to 99.3% of the total number of DFS from each observation.



Trial results: TR vs. CTRL score cards

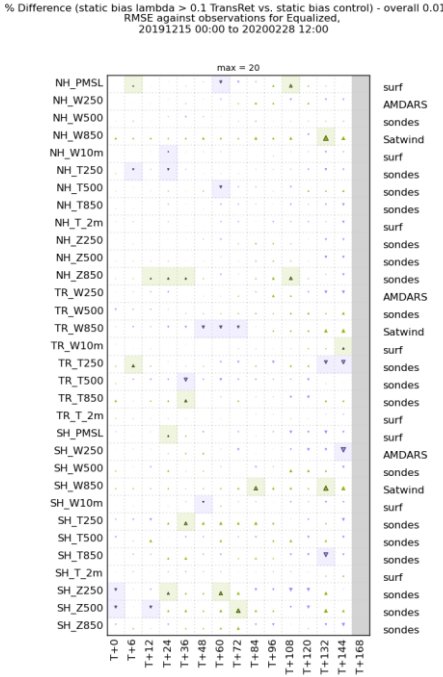
- Relative RMSE diffs for various fields and fcst lead times
- Overall results: +0.03% (obs); +0.01% (ECMWF analyses)
- TR trial seems to perform better in SH where we have more sat obs
- Overall abs diffs < 0.1% (Met Office threshold for significant change)

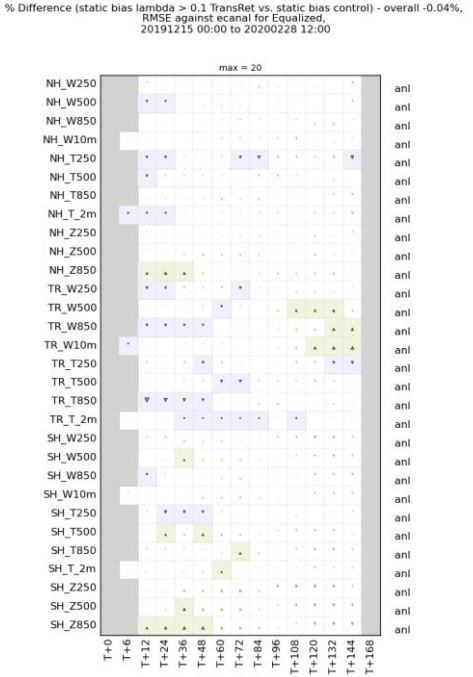




Trial results: TR_L0p1 vs. CTRL score cards

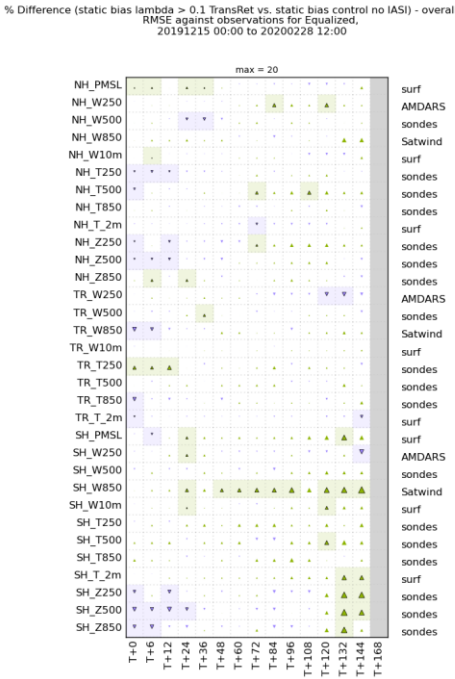
- Overall results: +0.01% (obs); -0.04% (ECMWF analyses)
- More uniform score results for different fields and lead times
- Overall abs diffs deemed not significant.
- Assimilation of fewer TR components does not change significantly comparison results

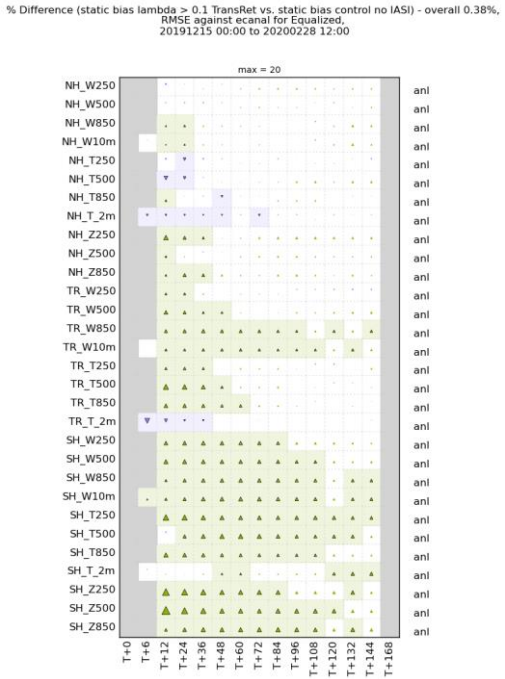




Trial results: CTRL / TR / TR_L0p1 vs. CTRL_NOIASI

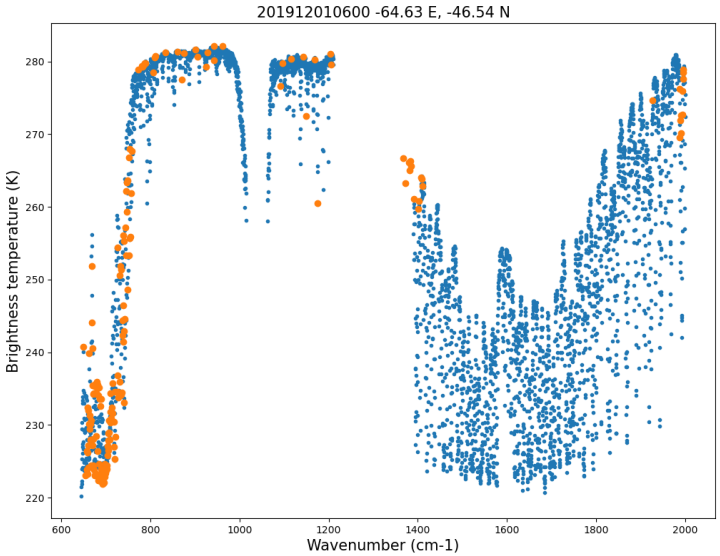
- New control trial where IASI obs are removed: CTRL_NOIASI
- Test of capability of TRs to extract information from satellite instrument that is not assimilated
- No significant difference wrt assimilation of satellite radiances

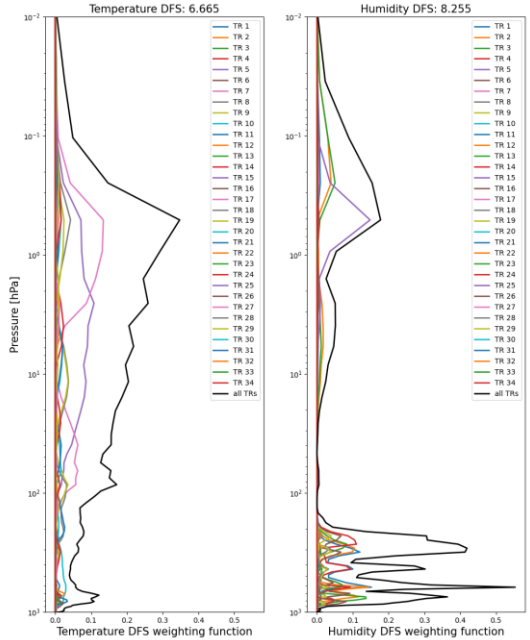




Exploiting more information from IR sensors

- DFSwfs for one cloud-free obs:
  175 vs. 4432 IASI channels





Summary

- First detailed assessment of results from assimilation of Transformed Retrievals against direct assimilation of radiances using operational NWP system
- No significant differences in statistical distribution of analysis increments
- Information content of set of rads can be condensed in much fewer TR components
- Overall forecast skill differences from set of three-month trials < 0.05%
- Comparable skill gains when assimilating radiances or TRs from a “new” instrument (IASI)
- First tests with large number of channels indicate significant information gains can be achieved (esp. for humidity in clear sky) when considering ten-fold more channels
- Paper under review in QJRMS