Simulations of potential impact of RFI on assimilation of AMSU-A data at the Met Office

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RFI Conference
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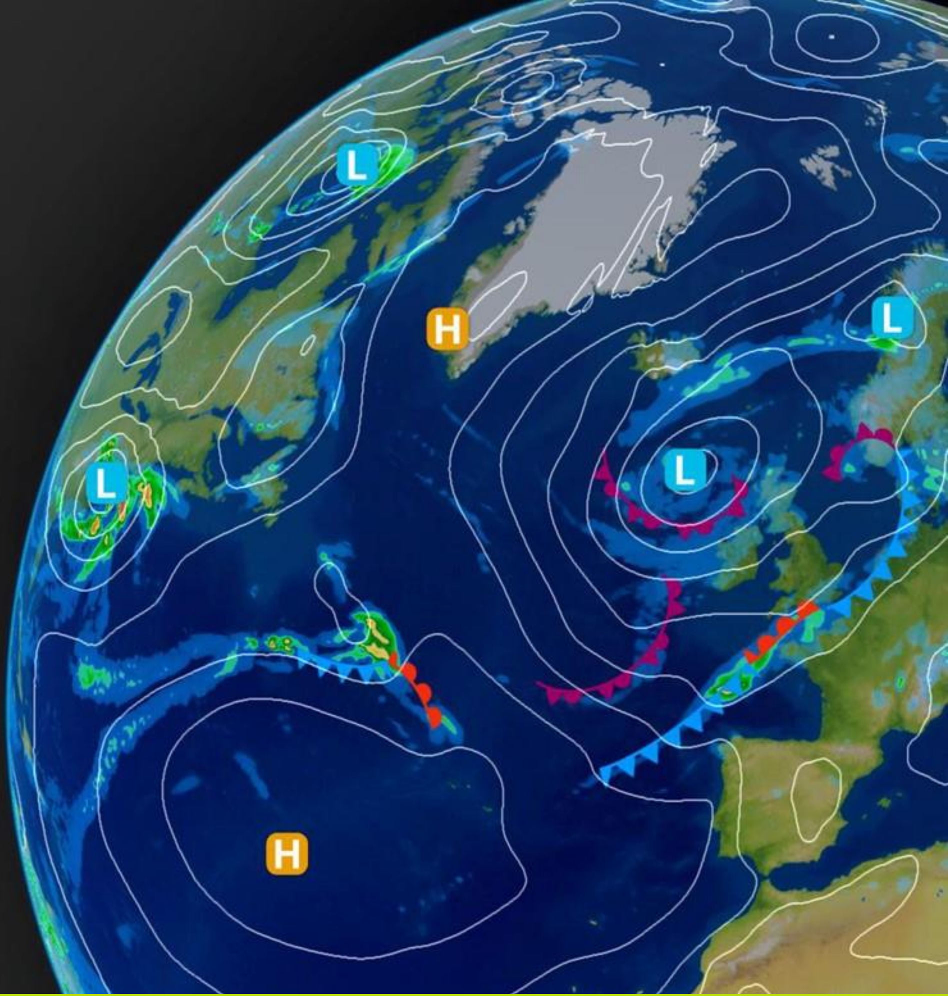

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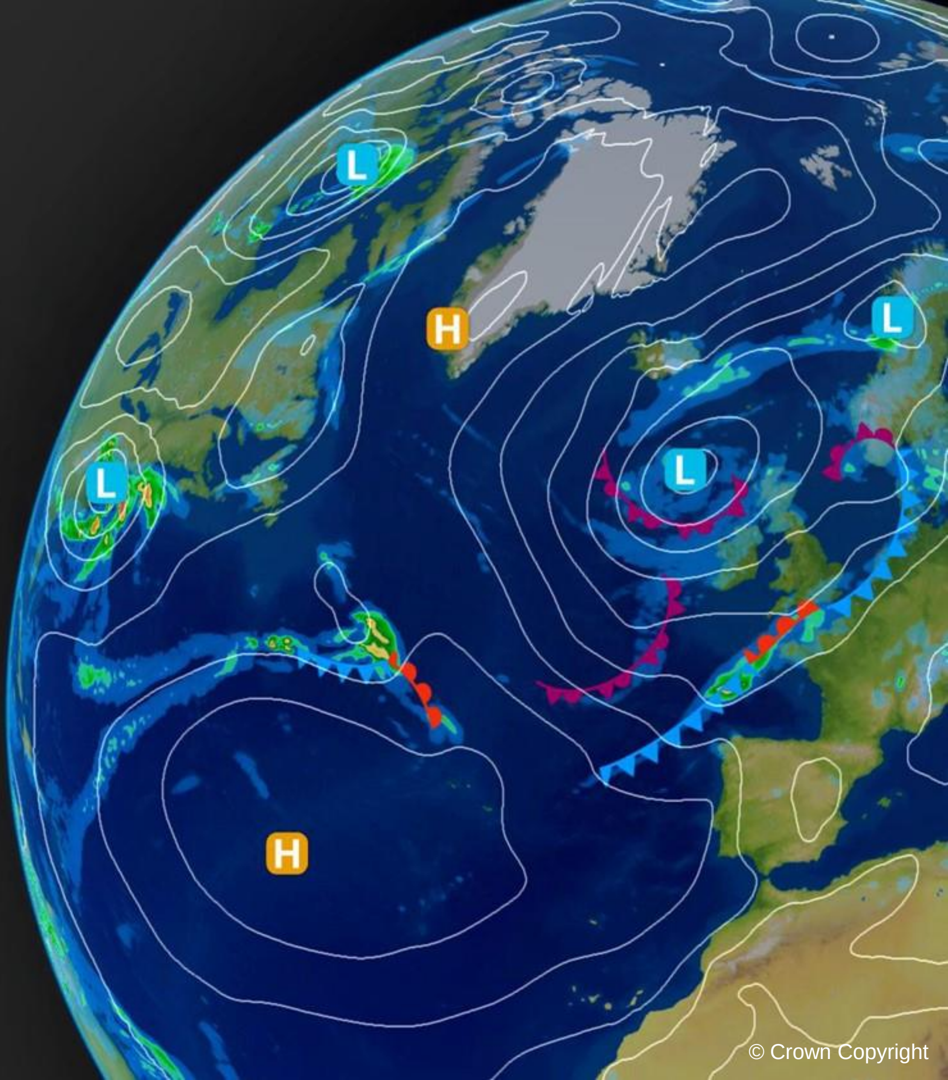
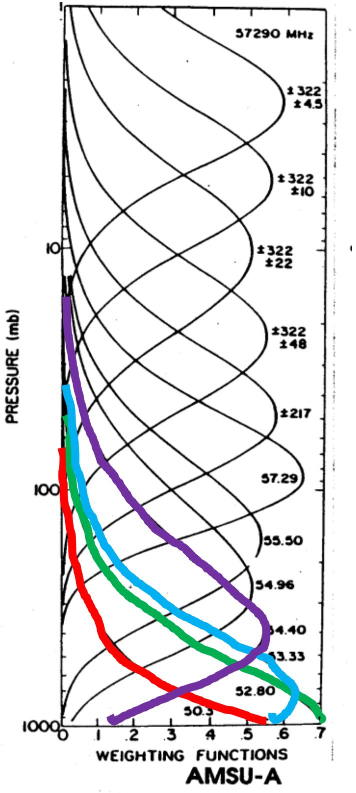
Outline

- Introduce microwave sounders and their impact on NWP
- Evaluate impact of introduction of surface-generated “RFI” in Met Office NWP system
  - Impact on stats of obs assimilated
  - Impact on NWP skill scores
- Investigate influence of VarBC in the process

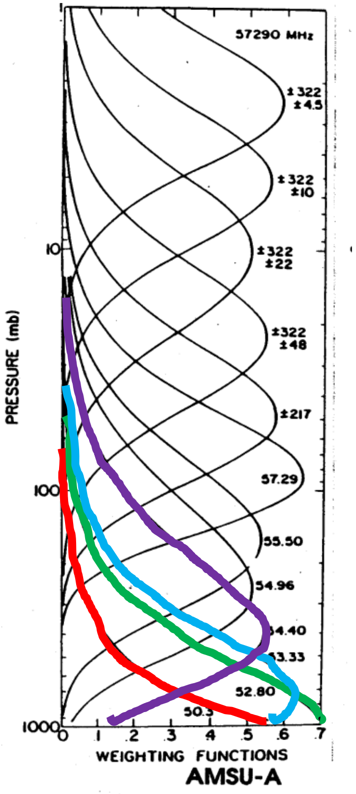


AMSU-A



- AMSU-A is a microwave temperature sounder with 15 channels: channel 1 at 23.8 GHz, channel 2 at 31.4 GHz, and channels 3-14 between 50 and 60 GHz.
- Centered on the rising wing of an oxygen line, these channels together give an estimate of the temperature profile for each multi-channel observation.
- Providing 1,000,000 such observations per day over the entire globe the 5 AMSU-A's in the Met Office DA system provide a strong constraint on the 3-D thermal structure of the atmosphere.

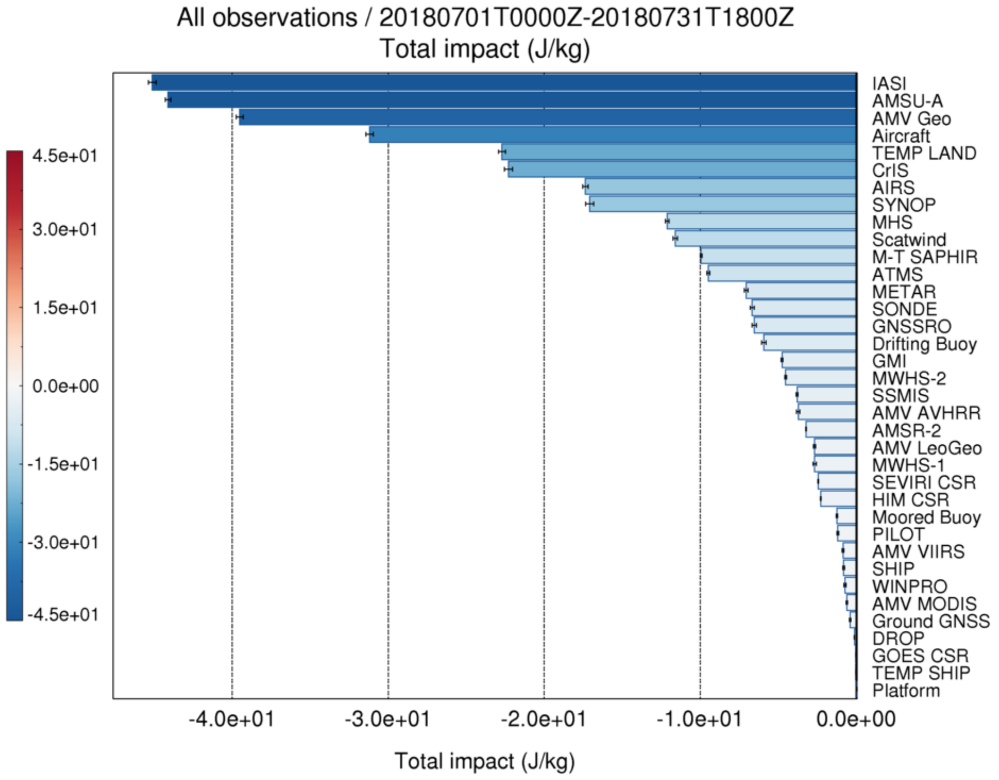
AMSU-A



- Microwave temperature sounders such as AMSU-A, ATMS and MWTS provide the greatest total impact in most global NWP systems along with the hyperspectral IR sounders.
- Figure shows weighting functions for AMSU-A channels 3-14. Red, channel 3; green, channel 4; cyan, channel 5; and purple, channel 6.
- Channel 3 has greatest sensitivity to surface emissions with decreasing sensitivity with increasing channel number.
- In the Met Office NWP system, channels 1-3 are not assimilated. They are used only for quality control such as background checks, gross bounds checks and a 1D-Var retrieval which constrains the surface temperature and emissivities used in the assimilation of other channels.
- Observations from channels 4-14 are assimilated in 4D-Var after QC and 1D-Var.
- The failure of the 1D-Var to converge causes the whole multi-channel observation to be rejected while other quality control (QC) checks typically cause rejections of individual channels.
- RFI impact is only considered here for Channels 1-6 which have greatest surface sensitivity.

Importance of AMSU-A

- Figure shows forecast sensitivity (FSOI) results for all observation type we assimiliate.
- AMSU-A has most impact of all MW sounders.
- Second only to the IASI’s
- AMSU-A is the microwave instrument type that we use most aggressively over land.
- Most likely to be impacted by surface-sourced RFI.



RFI Trials: general

- Run coarse-resolution NWP models over the period 1 Dec 2017 to 28 Feb 2018
- Four suites run:
  - Control mimicking the Met Office Operational Suite
  - Three RFI injection scenarios:
  - 1. 24 GHz only (AMSU-A Ch. 1) – interference from 26 GHz 5G deployment
  - 2. 50-55 GHz only (AMSU-A Ch. 3-6)

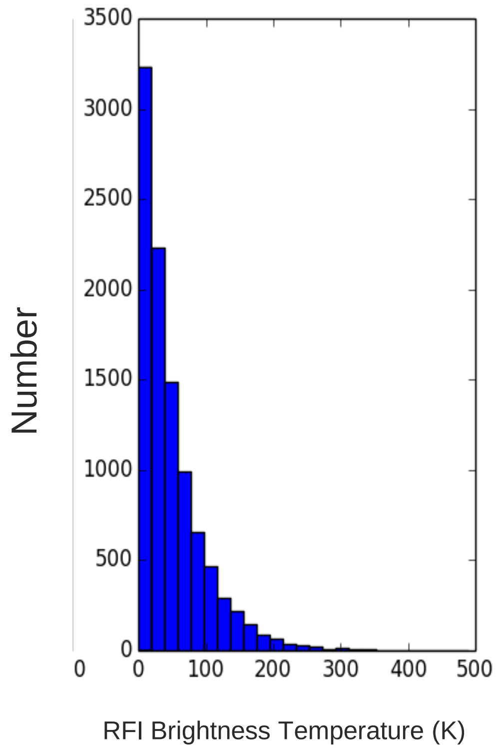
    3. selected bands in 20-55 GHz (AMSU-A Ch. 1-6)
- Study the differences between these experiments and the control to investigate impacts.
- If the control is an example of perfect use of this data these trials will give us a general estimate of the loss of NWP skill due to the RFI.

RFI Trials: RFI sources

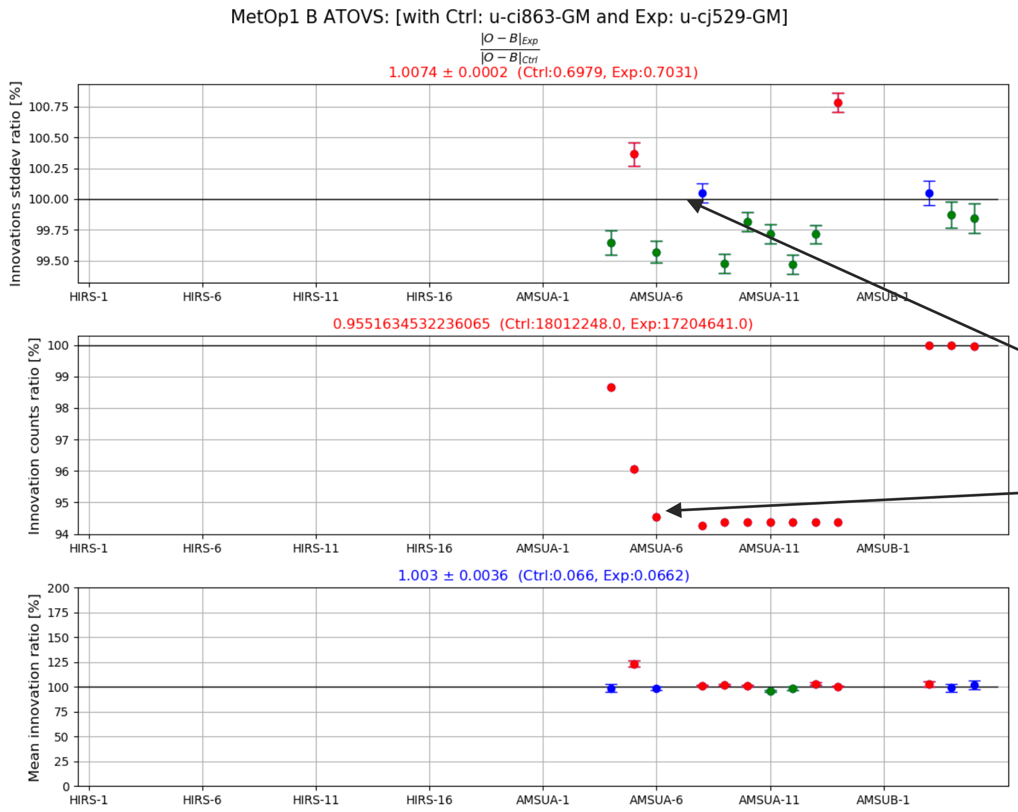
Assume a source of RFI over all land under 1000 m elevation (except ice caps)

- Assumption is that noise source is at the land surface
- Zero sea, satellite or extra-terrestrial contributions.
- Ignore scattering and sidelobe contributions.

- Attempt to simulate the case were people have mobile phones, car radar or 5G infrastructure that emits in the bands of interest.
- As RFI is generally positive definite, exponential distribution added to observed T_B
- Weighted by the surface to space transmission
- Two cases: Mean $T_{B, RFI}$ set to 5 K and 50 K
  - Right order of magnitude based on my calculations using emission level limits suggested by the UK regulatory agency OfCom for out-of-band emissions into AMSU-A Ch. 1 by 5G infrastructure.
- Figure depicts distribution for mean 50 K RFI prior to multiplication by transmissivity. The distribution is sampled independently for each channel in each observation.
- As transmissivity is a function of frequency the $T_{B, RFI} * \Gamma$ seen by the satellite will decrease with channel number



24G_50K case: Observation statistics in 4D-Var



Compare statistics after 4D-Var convergence for channels assimilated, 4-14 only.

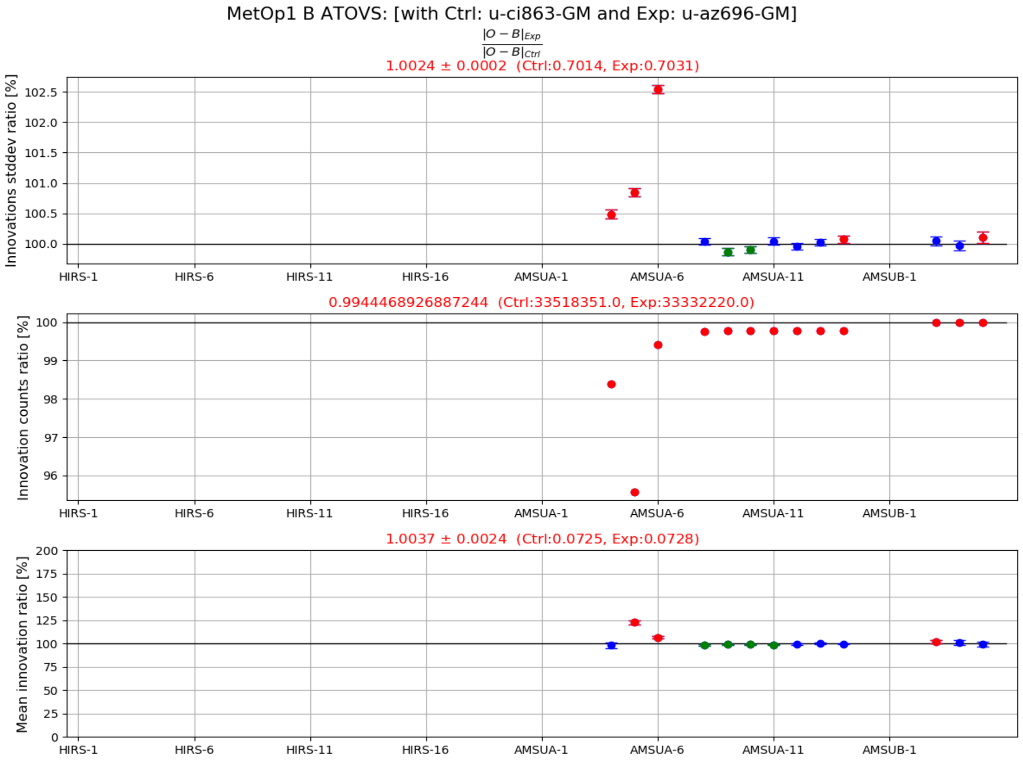
Presented as ratio of experiment to control

Minimal impact on model fit to Obs

Decrease in total number of obs assimilated in 4D-Var by ~6%.

This case only has RFI on Ch. 1 but failures to converge in 1D-Var causes rejection of a large fraction of obs over land for all channels 1-14.

50GHz 50K case : Observation statistics in 4D-Var



Largest impact on model fit to obs amongst the 6 experiments.

Impact limited to Ch. 4-6 in 4D-Var. No RFI in Ch. 1 and 3 means profile more likely to converge in 1D-Var.

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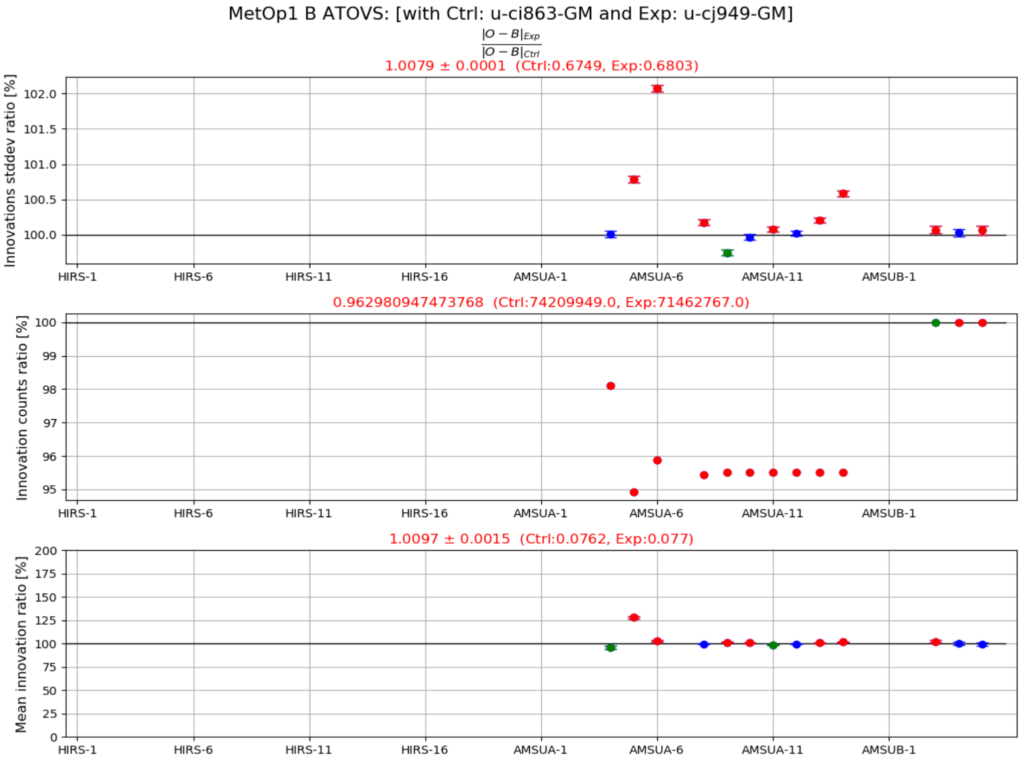
Ch. 1-6 50K case: Observation statistics in 4D-Var



Model fit to the observations is degraded by 2% on Ch. 6

Similar rejections to the 24 GHz case. Wide-spread rejections of all channels of AMSU-A.

Summary of Obs selection

- Interference at 24 GHz causes loss of observations at all AMSU-A frequencies.
  - 0.1% loss at 5 K
  - 5-6% loss at 50 K (most obs over land)
  - Due to QC + convergence failures in 1DVar
- Interference at 50-60 GHz causes loss of observations but mainly localized to Ch. 4-6. Peak loss on Ch. 5
  - 0.8% at 5 K
  - 4-5% at 50 K
  - Failures in background checks and QC as opposed to non-convergence in 1DVar
- Table shows loss of obs for 50 K RFI on Ch. 1-6

	No RFI	50 K Ch. 1-6
Ch. 4 Total Obs	64591	63739
Ch. 4 Land Obs	901	71
Ch. 5 Total Obs	56019	52578
Ch. 5 Land Obs	3827	402
Ch. 6 Total Obs	69331	66449
Ch. 6 Land Obs	13069	10201

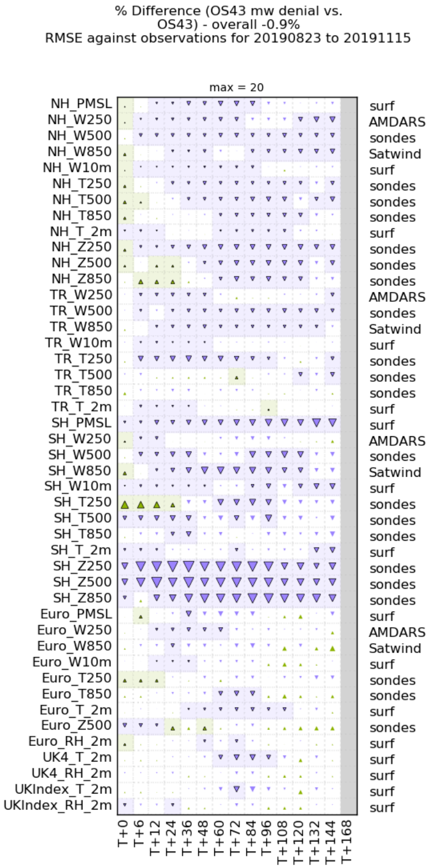
Expected NWP Impacts

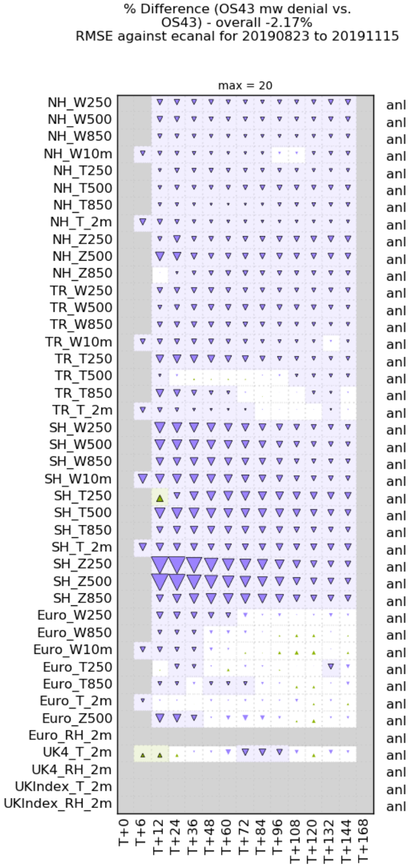
- Removing all these observations over land should have a negative impact on NWP skill scores if the data over land is used optimally.
- Worse is that some noisy data will sneak in under the detection limit. Injecting noise that isn’t identified as such should have an even worse impact on NWP skill scores. Potentially 5 K cases worst than 50 K

NWP Impacts

- Score cards summarize changes in the NWP skill in trials.
- Each row is a variable with NH, TR, SH, EURO and UK regions.
- Columns associated with forecast lead time.
- Green upward-pointing triangles show positive skill. Blue are negative.
- Overall weighted average score in upper RH corner.
- Left chart verification against observations
- Right chart verification against ECMWF analyses.

- Shown here as an example are the impacts of removing all passive microwave data from our system.





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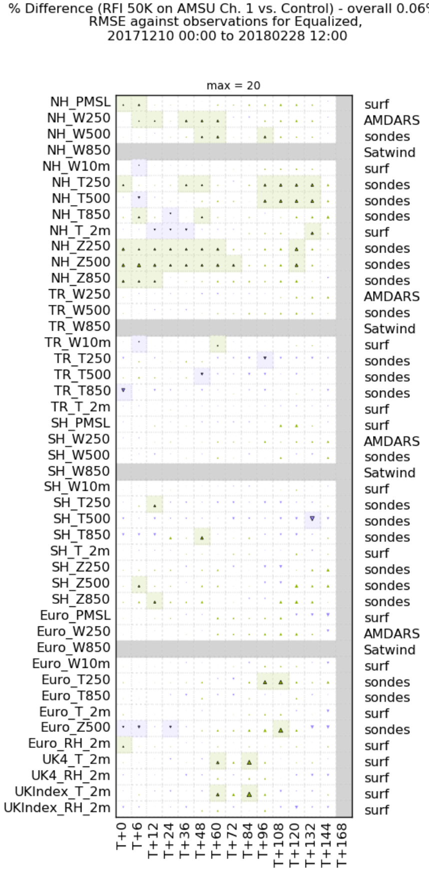
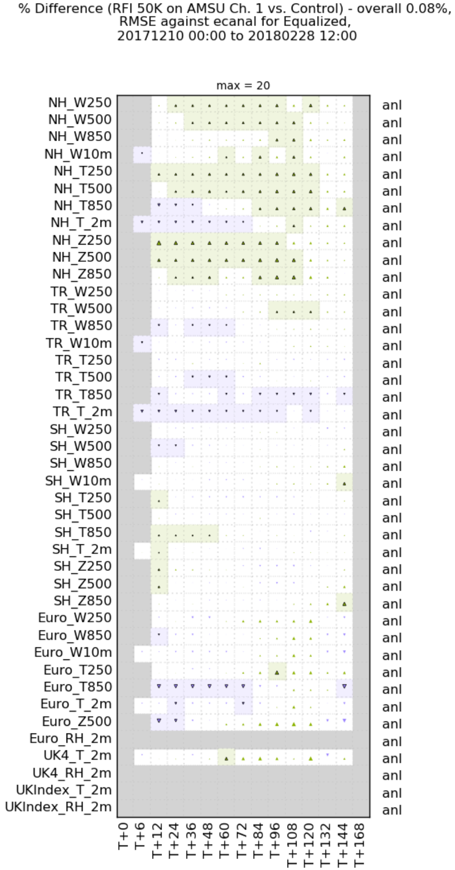
NWP Impacts: 24GHz 50K case

- 24GHz 50K case here represents removal of almost all AMSU-A obs over land at all frequencies.
- Degradation in tropical lower tropospheric and near surface temperatures.
- Improvements in winds, temperatures, thicknesses in the NH.

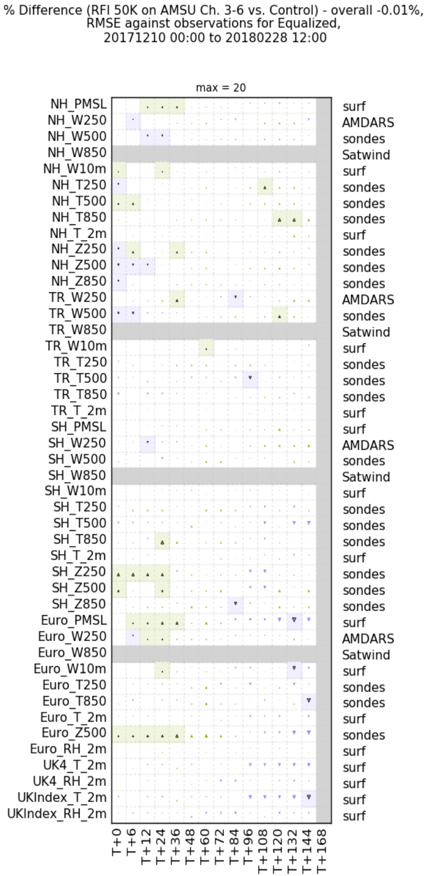
- **Overall positive**. Indicates we need to improve our use of this data.

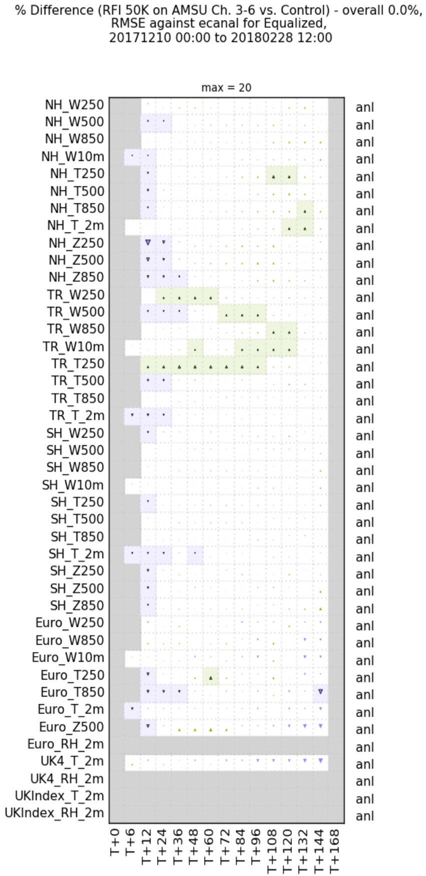




NWP Impacts: 50GHz 50K case

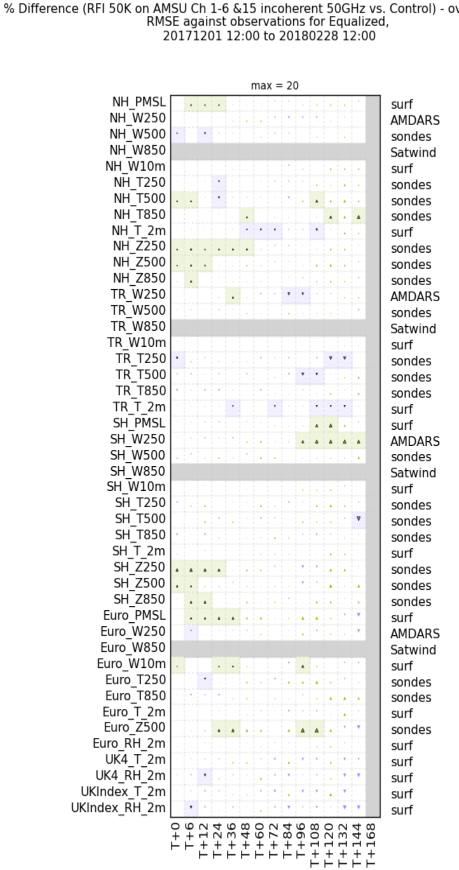
- RFI only on 50-55 GHz channels
- Degradation in short term against ECMWF which is a sign we are losing something of value here.
- Appears to be worse than loss all AMSU-A Ch 1-6 seen with 24 GHz RFI in last slide.
- Otherwise overall neutral
- Small overall score indicates we aren't getting the best value out AMSU-A data in our system

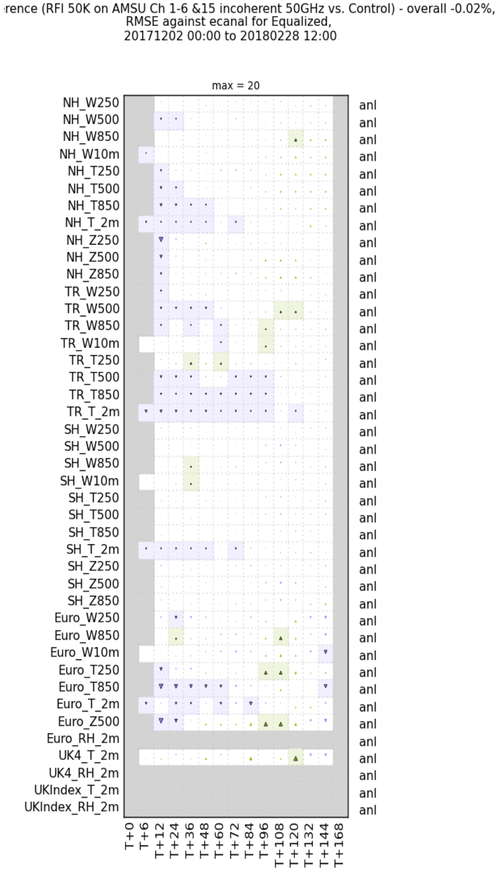




NWP Impacts: 24 & 50GHz 50K case

- RFI on all 20- 55 GHz Ch. 1-6
- Degradation in short term against ECMWF which is a sign we are losing something of significant value here.





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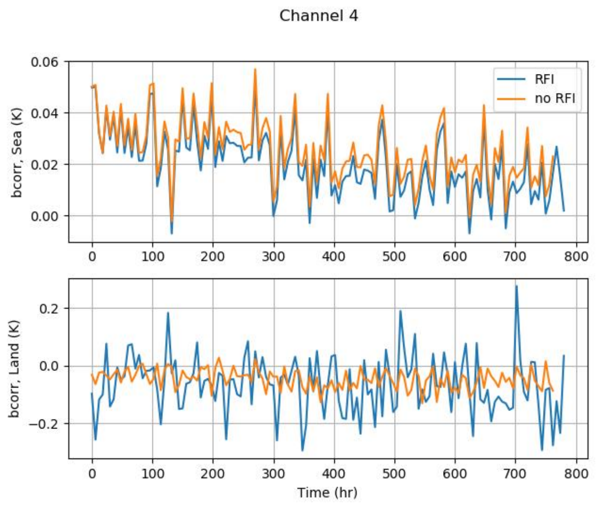
Summary of NWP impacts

Experiment	% obs count (assim/total Land + sea)	obs score	own ana	EC ana	EC ana <72 h
24GHz, 5K	99.9	0.00	0.03	0.02	-0.01
50GHz, 5K	99.9	-0.01	-0.01	0.00	-0.03
All*, 5K	99.9	-0.02	0.07	0.03	-0.03
24GHz, 50K	95.5	0.06	0.13	0.08	0.00
50GHz, 50K	99.4	-0.01	0.01	0.00	-0.01
All, 50K	96.3	0.02	0.01	-0.02	-0.08

Impact of VarBC?

- Observations with large RFI (> 4 K) are removed in QC and the 1D-Var.
- Those measurements with RFI < 4K can still cause issues in assimilation.
- Little negative impact of RFI sneaking through: Might be due to VarBC doing a good job at removing positive mean biases associated with RFI over land.
- Channels 4-14 of AMSU-A are active in our VarBC. No VarBC for Ch. 1-3.
- VarBC calculates biases from data that is assimilated. Most obs over land are not being assimilated due to QC and 1D-Var rejections so VarBC is not able to have a great deal of impact here.
- Plot on right shows bias correction for channel 4 obs over land and sea separately with and without RFI. Confirms there is little difference in the bias correction.
- Need to assimilate the data in 4d-Var to get the full impact of VarBC ideally with BC of obs over land separate from those over sea. Not

What is VarBC?
In Varational Bias Correction (VarBC), a regression model of the bias is applied to the observations such that the observations match the model in an optimal way by solving for the regression model parameters and other model control variables while minimizing the 4D-Var cost function.



Conclusions

- RFI over land found to have the expected impact on the number of AMSU-A obs assimilated.
- Found to have only a small overall impact on NWP skill in the Met Office system. There are significant degradations in the short-term forecasts which the Met Office specializes in.
- The small impact of RFI over land in our system can be explained in terms of the marginal impact of the few obs we do assimilate over land. Clearly our usage of the AMSU-A data over land is far from optimal, such that removal of these measurements over land is mostly neutral overall.
- Our observation processing system is able to remove most effected obs with QC and 1D-Var. We will need to tune it to accept observations with 24 GHz RFI while still rejecting those with RFI at 50 GHz.
- VarBC is seen to have little impact as only observations assimilated in 4D-Var can be seen and corrected by VarBC. Most RFI-effected obs are being rejected before assimilation in 4D-Var.

Potential weaknesses to investigate

- We get great impact from MW soundings over the sea. Reflection of signals from communication satellites could massively degrade our assimilation over sea.
- Sidelobe impacts of land-based RFI on measurements over sea could be where other major observation impacts are seen.
- Impacts of RFI on skin temperature and emissivity retrievals in OPS need to be investigated. Beyond QC, these retrievals are also used for assimilation in 4D-Var.
- Need a realistic geographic distribution of RFI.