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TOWARDS IMPROVED HEIGHT ASSIGNMENT AND QUALITY CONTROL OF AMVS IN MET OFFICE NWP

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Abstract

The process of assigning a representative height to the tracked motion vector remains the dominant source of error in Atmospheric Motion Vectors (AMV) derivation schemes. This paper summarises efforts at the Met Office to improve the handling of AMV height errors in global data assimilation. Improvements in root mean square (RMS) vector difference errors are found by applying a height-dependent RH threshold to remove AMVs located in dry layers of the model. For low level AMVs, introducing an inversion correction also leads to reduced biases in some regions. Impact experiments with these changes show an improved background (short-range forecast) fit to the AMVs and humidity sensitive sounding channels. A strong positive impact on forecast RMS errors is found in winter, whilst some detrimental impacts are seen in summer against analysis. The results of this study show that model background relative humidity is a useful quality indicator for geostationary AMVs in cloudy regions, whilst some challenges remain for polar and clear-sky winds.

INTRODUCTION

Atmospheric Motion Vectors (AMVs) are operationally assimilated into Met Office global NWP analyses and are an important source of tropospheric wind information, especially over the ocean. At the beginning of 2016 winds were assimilated from 5 geostationary imagers (Meteosat-7/10, MTSAT-2, GOES-13/15), MODIS on Terra/Aqua, AVHRR on NOAA-15/18/19, AVHRR on Metop-A/B (CIMSS and EUMETSAT products) and LeoGeo from composite imagery. Note that since February 2016 Himawari-8 has replaced MTSAT-2.

AMVs are treated as wind observations at a single pressure level and errors in height assignment are currently handled via three approaches:

1) *a-priori* blacklisting of known problem areas with large systematic errors (Cotton and Forsythe, 2012),
2) down-weighting observations through specification of situation-dependent observation errors (Forsythe and Saunders, 2008),
3) bias correcting mean height errors in regional models (Lean et al., 2015).

This paper summarises efforts to further improve the handling of height errors in the assimilation. Firstly we consider applying a height correction to low level AMVs in the presence of a temperature inversion. Secondly, we investigate a situation-dependent quality control of AMVs assigned in dry layers of the model using model forecast profiles of temperature and humidity.

INVERSION CORRECTION

Low level clouds travel with the wind at cloud-base which is usually within the atmospheric boundary layer (ABL). For AMVs tracking low clouds it is therefore important that they are assigned heights within the ABL, since variations in the wind vector can increase rapidly above a capping inversion (Schmetz et al., 1996). An example of an AMV assigned above the inversion base can be seen in Figure 1. In this case the AMV speed is 18 m/s but the speed bias is almost -9 m/s. The AMV has been assigned at 762 hPa where the model is very dry (note the sharp fall in humidity above the capping inversion), whereas model best-fit pressure is found at 813 hPa near the base of the inversion. A neighbouring AMV assigned to the base of the inversion (not shown) has zero speed bias. This demonstrates that a small error in the assigned height can lead to a large observation minus background (O-B) innovation.

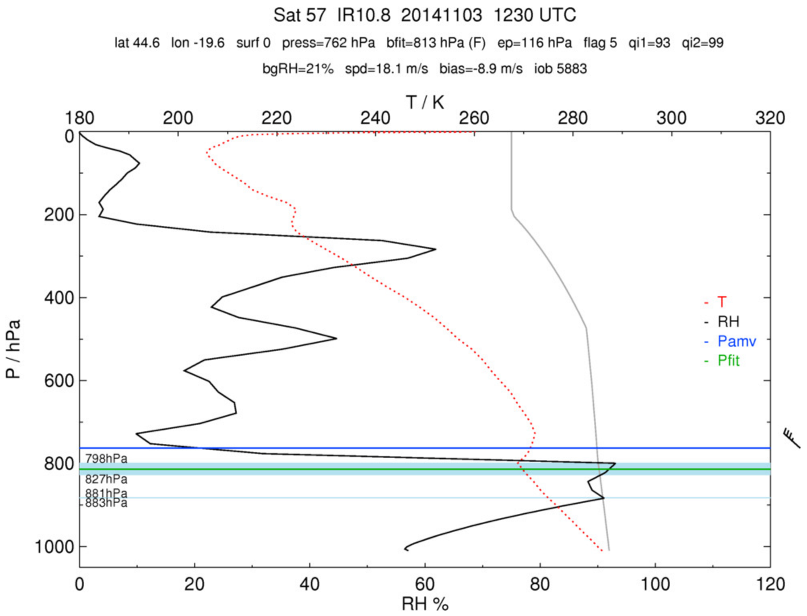

***Figure 1*: Meteosat-10 IR10.8 AMV valid at 12:30 UTC on 3 November 2014 in the N.W. Atlantic. The dark blue line is the assigned AMV height, the green line is the model best-fit pressure (height at which the AMV vector best agrees with model wind profile). Model profiles from collocated 6-hour global forecast: black is relative humidity (RH), red is temperature. Blue shaded represents a moist model layer as defined in a later section of this paper.**

Although EUMETSAT and NESDIS account for these situations via an inversion correction, there remain residual errors. These can arise from the use of a limited number of vertical model levels which fail to resolve the inversion correctly and low temporal frequency of forecast data. EUMETSAT correct AMV heights to 1/3 way up from the base of the inversion. However the Meteosat Second Generation (MSG) ground segment uses only 6-hourly forecast data, updated twice a day, and a radiative transfer model on 30 atmospheric levels (EUMETSAT, 2011). Performing an inversion correction within data assimilation allows the use of full vertical model resolution within the boundary layer and 3-hourly forecast data updated every 6 hours.

In this study we have tested applying an inversion height correction for AMVs meeting the following criteria:

- Infrared (IR) and visible channel
- Temperature inversion detected (only consider inversion layer closest to surface)
- Inversion strength ≥ 2 K to be significant
- Assigned AMV pressure > 700 hPa (low level winds only)
- AMV assigned above height of inversion base
- Check that inversion top is located in ‘dry layer’ (capping inversion, dry layer defined later)
- Only apply to geostationary AMVs, MSG apply only over sea

Polar winds are not considered for correction due to: a) the presence of shallow inversions near cold surfaces e.g. sea ice, b) quite different characteristics of model humidity, staying moist well above the inversion top (i.e. not capping).

The impact of applying an inversion correction to the geostationary winds can be seen in Table 1. On average 11% of low level winds are corrected, with MSG having the lowest fraction. Comparing root mean square vector differences (RMSVD) for the same observations at the original height and the corrected height show an overall reduction of 16%. Visible channel AMVs tend to show the largest improvement, particularly for GOES-13 (32% reduction) and MTSAT-2 (38%). For GOES-13 visible channel AMVs we see a reduced negative bias over N. America and the N.W. Atlantic, and a reduced positive bias in the stratocumulus region west of S. America. These locations are known problem regions as noted in the NWP SAF analysis reports e.g. Cotton, 2014. For MTSAT-2 large reductions in bias and vector differences are observed off the west coast of Australia and the Chinese coastal region (Figure 2). Note that GOES visible channels are not currently assimilated in operations.

Satellite	Channel	N low level corrected	% low level corrected	RMSVD at original height (m/s)	RMSVD at corr. height (m/s)	% Diff
Met-7	IR	29226	18.3	4.5	4.3	-4.4
	VIS	45481	13.4	4.0	3.3	-17.5
Met-10	IR10.8	197064	7.9	6.0	6.0	0.0
	VIS0.8	101842	6.9	4.4	4.2	-4.5
	HRVIS	195329	4.5	5.8	5.9	1.7
MTSAT	IR	288812	11.5	3.8	3.5	-7.9
	VIS	125356	17.0	3.2	2.0	-37.5
GOES-13	IR	284189	12.6	2.3	1.9	-17.4
	IR3.8	1143015	14.0	2.6	2.1	-19.2
	VIS	604504	16.9	2.8	1.9	-32.1
GOES-15	IR	181680	9.1	2.2	2.0	-9.1
	VIS	354990	11.4	2.8	2.0	-28.6
		3551488	11.4			-16.2

***Table 1*: Comparing root mean square vector differences (RMSVD) for geostationary AMVs at the original assigned height and the inversion corrected height. AMVs are from January 2015 after filtering for QI2 > 80. The number and percentage of low level winds corrected are also shown.**

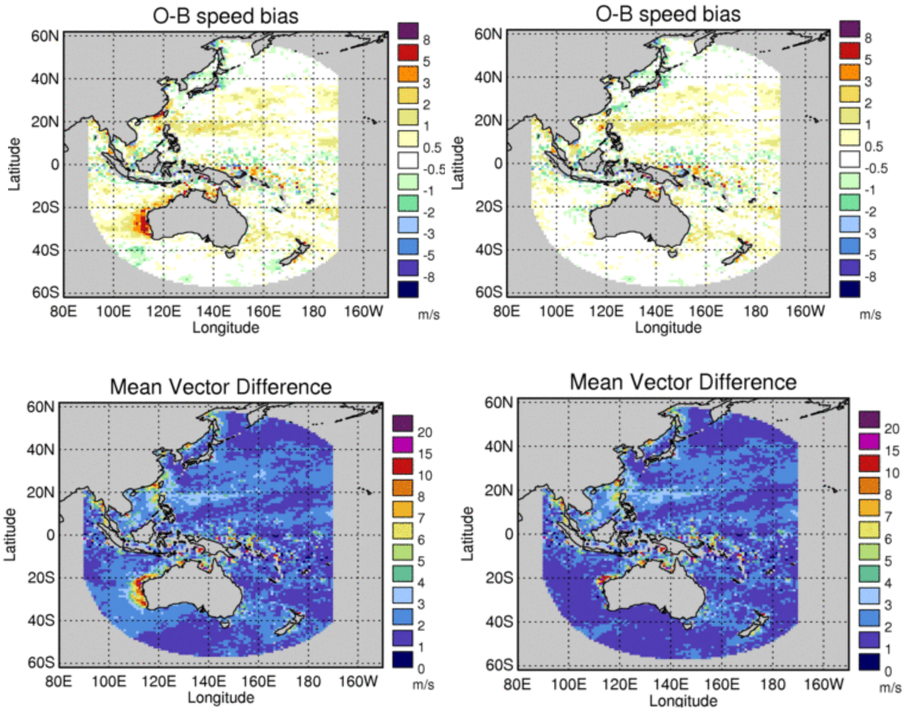

***Figure 2*: Maps of O-B speed bias and mean vector difference for MTSAT-2 visible AMVs in January 2015 below 700 hPa. Data has been filtered for QI2 > 80. Plots without inversion correction (left) and with inversion correction (right).**

DRY LAYER QUALITY CONTROL (QC)

AMVs are derived from tracking cloud and water vapour (WV) features and so ideally they should not be assimilated in regions of the model that are very dry. Even if the model is in error, and not the observation, in some cases it still may be best to reject the AMV to avoid possible spurious effects in the analysis. Here we consider a 'dry layer QC' using model background RH as a quality indicator.

The example in Figure 3 shows that for Meteosat-10 WV winds, background RH is a good indicator of data quality. We observe large O-B scatter for low RH values and decreasing speed bias and RMSVD as RH increases. Across the other MSG channels we see similar trends for the IR winds; for visible channels winds we can still observe some increase in RMSVD at low RH but trends are less clear. For the polar winds, the IR AMVs show some increase in RMSVD at low RH, but clear and cloudy WV channel winds have quite a different distribution with a higher proportion of data having RH values less than 80.

To test the use of background RH for quality control we need to define a threshold such that we can reject 'dry' AMVs with background RH values less than this limit. We start by diagnosing 'moist' model layers using height-dependant *minRH* thresholds from Zhang at al (2010), here reproduced in Table 2. Where model RH is greater than the *minRH* threshold we diagnose a moist model layer, using interpolation between model levels. If we were to simply define 'dry' model layers as where RH is less than this threshold this would classify too many AMVs as being dry. Instead we relax the threshold and define dry model layers to be where model RH is less than *minRH* x r. A relaxation value of r = 0.6 was chosen using sensitivity tests of the number and quality of AMVs that would be classified as dry. In summary, an AMV is classified as dry if background RH < minRH * 0.6, and moist if background RH > minRH. In-between these thresholds we do not classify the AMV.

The impact of applying the dry layer QC can be seen in Table 3. For Meteosat-10 WV7.3 we see a reduction in RMSVD of over 25% by removing the AMVs classified as dry. The geostationary clear-sky WV winds, which are not assimilated in operations, are heavily rejected (perhaps indicative of the difficulties with height assignment of these winds). The polar winds show smaller impacts. Overall 16% of AMVs are classified as dry and rejecting these data leads to a reduction in RMSVD of 16%. However the final number of AMVs rejected in the assimilation will be smaller, as some data would otherwise be rejected by other QC and these statistics include channels that are not used in operations. Figure 4 shows the geographical impact of the dry layer QC on low level Meteosat-10 IR AMVs. Here we see a large area of positive speed bias across N. Africa and the Arabian Peninsula has been removed, with some residual bias persisting over the tropical E. Atlantic. For high level MTSAT-2 IR winds (not shown) the dry layer QC is able to significantly reduce the magnitude of the negative speed bias associated with the jet stream. Histograms of the data rejected (not shown) demonstrate that the highest proportion of data removed is at mid level, peaking around 600-700 hPa.

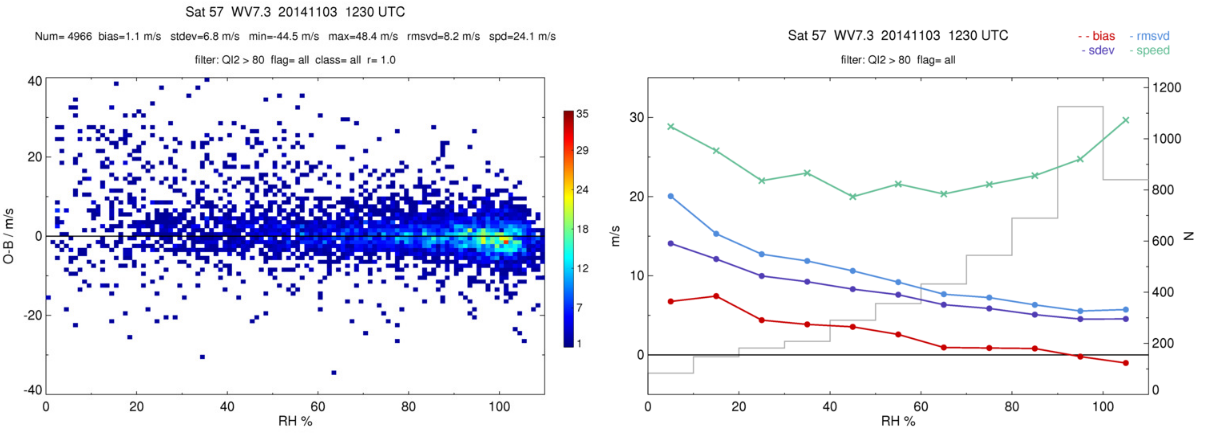

***Figure 3*: (left) 2-D histogram of O-B versus background RH for Meteosat-10 WV7.3 AMVs valid at 12:30 UTC on 3 November 2014. Data filtered for QI2 > 80. (Right) Mean statistics for the same set of AMVs binned by RH values: mean speed bias (red line), standard deviation bias (purple), RMSVD (blue) and mean AMV speed (green). Histogram shows number of AMVs in each bin.**

Altitude (km)	minRH	minRH *0.6
0	92%	55.2%
2	90%	54.0%
6	88%	52.8%
12+	75%	45.0%

***Table 2*: Height-dependant RH thresholds from Zhang et al. (2010). MinRH values decrease linearly between the defined levels.**

		Reference		Dry Layer			
Satellite	**Channel**	**N**	**RMSVD (m/s)**	**N**	**% Reject**	**RMSVD (m/s)**	**% Diff**
Met-7	IR	498918	7.6	412947	17.2	6.2	-18.4
	VIS	340190	3.7	323319	5.0	3.4	-8.1
	WV	1043885	8.7	837290	19.8	7.1	-18.4
Met-10	IR10.8	5440650	6.5	4713189	13.4	5.5	-15.4
	VIS0.8	1477934	3.3	1382028	6.5	3.0	-9.1
	HRVIS	4309987	3.7	4092704	5.0	3.4	-8.1
	WV7.3	3648984	9.4	2845035	22.0	6.9	-26.6
	WV6.2	2438393	7.8	2091766	14.2	6.9	-11.5
	CSWV7.3	996805	10.3	126602	87.3	9.7	-5.8
	CSWV6.2	544026	10.2	95621	82.4	9.3	-8.8
MTSAT	IR	4485905	5.4	4203799	6.3	4.6	-14.8
	VIS	725620	2.7	720813	0.7	2.6	-3.7
	WV	2308404	7.0	2016684	12.6	6.2	-11.4
	CSWV	1413296	11.6	530477	62.5	6.9	-40.5
GOES-13	IR	5274881	4.0	4775800	9.5	3.8	-5.0
	VIS	3770951	2.8	3580127	5.1	2.7	-3.6
	WV	2494480	5.1	2177994	12.7	4.9	-3.9
	CSWV	1109413	5.5	372954	66.4	5.0	-9.1
GOES-15	IR	4715622	4.0	4341161	7.9	3.8	-5.0
	VIS	3209339	2.6	3063279	4.6	2.5	-3.8
	WV	2659188	5.1	2354476	11.5	4.9	-3.9
	CSWV	924142	5.7	259792	71.9	4.9	-14.0
MODIS Aqua	IR	348657	4.7	290458	16.7	4.8	2.1
	WV	168448	6.2	138032	18.1	6.4	3.2
	CSWV	668023	4.3	484535	27.5	4.3	0.0
NOAA-19	IR	222740	4.3	189079	15.1	4.2	-2.3
EUM Metop-B	IR10.8	2176144	5.6	1882163	13.5	5.6	0.0
LeoGeo	IR	1830837	4.2	1666527	9.0	4.0	-4.8
		59245862		**49968651**	**15.7**		**-16.2**

***Table 3*: Comparing the number of winds and RMSVD for all AMVs (reference) and after applying the dry layer QC. AMVs from January 2015 after filtering for QI2 > 80 (geostationary) or QI2 > 60 (polar).**

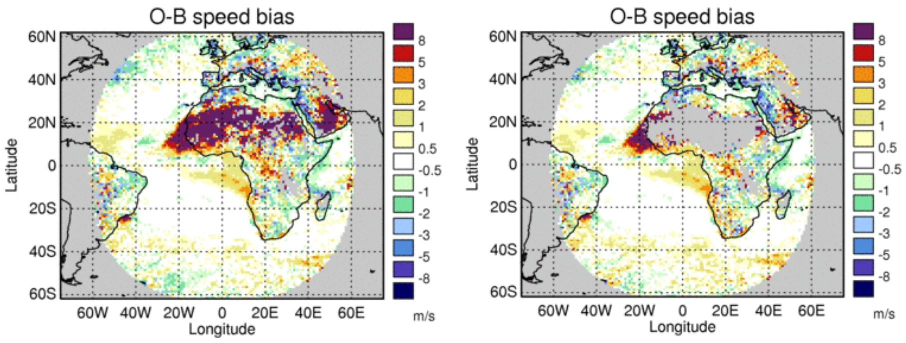

***Figure 4:* Maps of O-B speed bias for Meteosat-10 IR10.8 AMVs in January 2015 below 700 hPa. Data has been filtered for QI2 > 80. Reference data (left) and with dry layer QC (right).**

IMPACT EXPERIMENTS

Assimilation experiments are performed to evaluate the impact of the inversion correction and the dry layer QC. Although also trialled as separate components, here we present the results for the two changes combined since they should perform best when used in conjunction. The inversion correction is applied first so that there is a chance to correct the heights of winds above the ABL before they are potentially removed by the dry layer QC. Impact experiments are performed across two seasons, summer: 20150622 – 20150815 (55 days), and winter: 20151112 – 20160115 (65 days). All experiments use a PS37 N320 baseline configuration, 4D-Var, 70 vertical levels, uncoupled hybrid VAR at N108/N216. In each season a control (reference) experiment is run with AMV assimilation matching the latest use in operations, plus a trial experiment with the inversion correction and dry layer QC switched on.

In the trial experiments the number of AMVs assimilated decreases by 10% per cycle and the initial VAR penalty decreases by 17%. O-B RMS for the zonal (U) and meridional (V) AMV wind components is reduced by 6% and 5% respectively. Small benefits are also seen for O-B fits of humidity sensitive sounding channels on AIRS, IASI, CrIS and ATMS (Figure 7).

The change in forecast RMS errors for the parameters that make up the Met Office NWP Index is shown in Figure 5 and Figure 6 for both seasons. Forecasts are verified against observations, own analysis and independent ECMWF analysis, in the northern hemisphere (NH), tropics, and southern hemisphere (SH). Considering the summer experiment, validation against observations appears largely neutral whilst results against analyses are rather mixed. Against own analyses we see a slightly positive impact in the NH (long range) and W250 in the tropics and SH (short range), however there are negative impacts for SH PMSL and H500. Results against ECMWF analyses are similar, with detrimental impacts in the SH, particularly for H500. Note that due to technical issues the ECMWF verification in this season only covers the last 27 days. Further investigation of day-3 RMS errors against (own) analyses reveals an increase in RMS for mid-upper level winds below 40S latitude.

Considering the winter experiment we see much more consistent beneficial or neutral impacts across the board. Against observations and ECMWF analyses there are some positive impacts in the NH. Against own analysis there are positive impacts in the NH and also for W250 in the tropics and SH.

Table 4 shows the change in NWP Index scores which are largely positive or neutral for both seasons. Overall the performance of the AMV changes is much stronger in the NH winter season, with some detrimental impacts against analyses in the SH for the summer season.

Experiment	Observations	Analysis - Own	Analysis - ECMWF
Summer	+0.09	+0.31	-0.06
Winter	+0.42	+0.63	+0.36

***Table 4*: A summary of NWP Index scores for both trial seasons.**

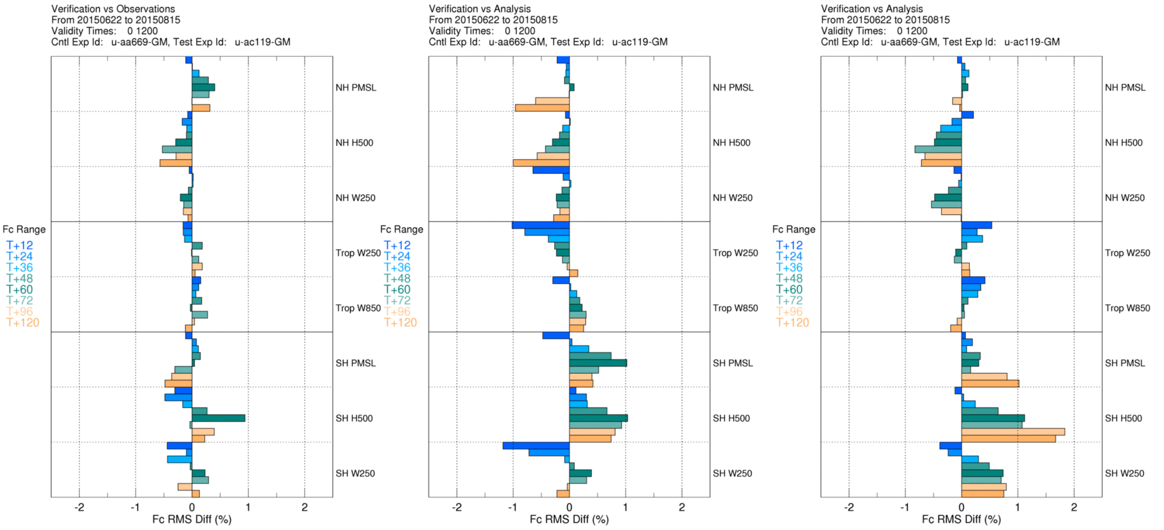

Figure 5: **Percentage change in forecast RMS error for the (summer) June – Aug 2015 experiments. The vertical axis shows the parameters that make up the NWP Index across the three latitude bands. The colours represent the different forecast lead times that are verified, with blue indicating short range and orange long range. Verification is against observations (left), own analysis (middle) and independent ECMWF analysis (right).**

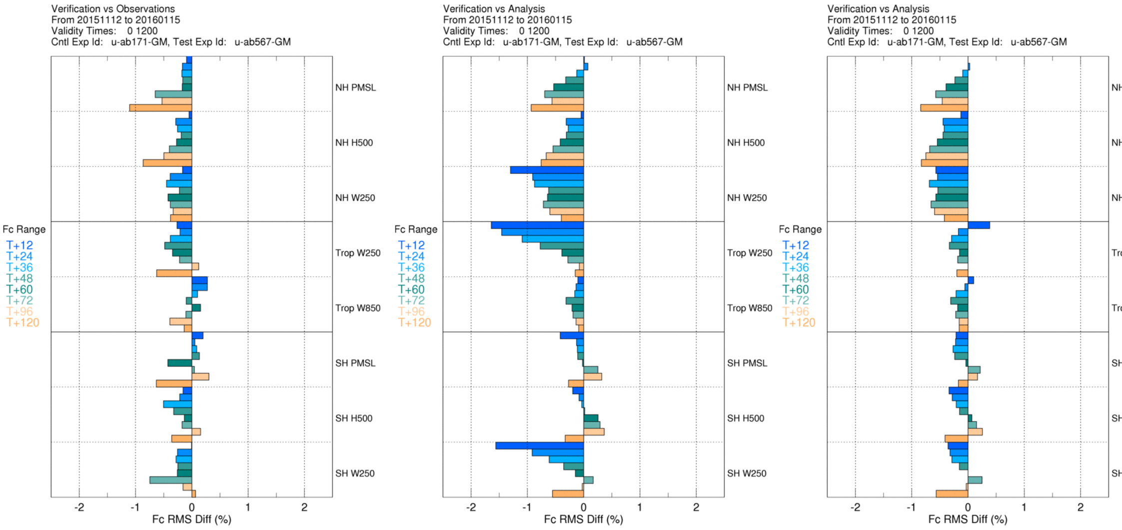

Figure 6: **As *Figure 5* but for the (winter) November 2015 – January 2016 experiments.**

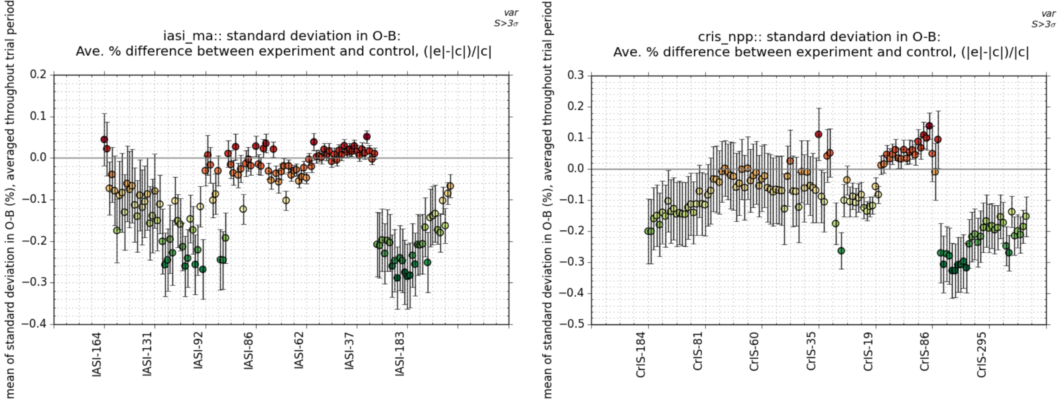

Figure 7: **Change in O-B standard deviation departures for the channels that are assimilated from IASI (left) and CrIS (right) instruments. Channels are ordered in increasing height from L-R, firstly for temperature sensitive channels and then for humidity sensitive channels.**

CONCLUSIONS

Background RH is found to be a good indicator of data quality for geostationary IR and WV winds, but is less helpful for polar winds. Applying a height-dependent RH threshold we can reject AMVs assigned to dry layers of the model leading to a large reduction in RMSVD errors for the geostationary winds, particularly from MSG and MTSAT-2. Applying an inversion height correction results in a large benefit for GOES-13 and MSTAT-2 in certain geographic regions.

Impact experiments combining the inversion correction and dry layer QC show that the number of AMVs assimilated is reduced by 10% and background RMS fits are improved ~5%. We can also observe a small improvement in background fit to microwave and advanced IR sounders humidity channels. Positive impact is seen for forecast RMS errors in NH winter season, whilst some detrimental impacts are seen in the summer season versus analysis in the SH. Although there are some detrimental impacts, due to the particularly strong performance of the experiments in the winter season these changes are due for implementation in operations as part of PS38 in November 2016.

Future work includes further understanding the issues in the summer versus analysis, and reassessing the impact now that Himawari-8 has replaced MTSAT-2. The introduction of GOES visible winds should also be considered as the inversion correction has been shown to improve biases in this channel.

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