The EUMETSAT Network of Satellite Application Facilities

NWP SAF

Numerical Weather Prediction

Report of Visiting Scientist mission NWP_VS16_03

Document NWPSAF-MO-VS-055

Version 1.0

19-09-16

An investigation of the impact of the assimilation of M-T SAPHIR data in the Met Office data assimilation system

Indira Rani[1], William Bell[2], Amy Doherty[2], and Stuart Newman[2]

1 National Centre for Medium Range Weather Forecasting, India

2 Met Office, Exeter, UK

Met Office

ECMWF

Royal Netherlands Meteorological Institute
Ministry of Transport, Public Works and Water Management

METEO FRANCE
Toujours un temps d'avance

An investigation of the impact of the assimilation of M-T SAPHIR data in the Met Office data assimilation system

Indira Rani (NCMRWF),
William Bell, Amy Doherty, and Stuart Newman (Met Office)

This documentation was developed within the context of the EUMETSAT Satellite Application Facility on Numerical Weather Prediction (NWP SAF), under the Cooperation Agreement dated 29 June 2011, between EUMETSAT and the Met Office, UK, by one or more partners within the NWP SAF. The partners in the NWP SAF are the Met Office, ECMWF, KNMI and Météo France.

Copyright 2016, EUMETSAT, All Rights Reserved.

Change record			
Version	Date	Author / changed by	Remarks
0.1	10/9/16	Indira Rani	Draft version
0.2	15/9/16	W. Bell/A. Doherty/S. Newman	Some revisions
1.0	19/9/16	Indira Rani	Final version

An investigation of the impact of the assimilation of M-T SAPHIR data in the Met Office data assimilation system.

Background and Objectives

During a previous visit to the Met Office, during winter 2014/15, Dr Indira Rani completed a successful assessment of M-T SAPHIR data within the Met Office global assimilation and forecasting system. In addition to improving the short range fits to independent humidity sensitive observations the assimilation of M-T SAPHIR data significantly improved short range fits to the tropospheric temperature sounding and window channels of the advanced IR sounders (IASI, AIRS and CrIS) and improved the influence of the microwave imager radiances in this regard. M-T SAPHIR data was introduced into the Met Office's operational forecasting system in March 2016.

The purpose of this 4 week VS mission was to further investigate the benefit of the M-T SAPHIR data through a series of assimilation experiments and single observation experiments aimed to elucidate the complementarity of microwave imager data and SAPHIR data. The VS mission aimed to study the benefit brought by the SAPHIR channel at 183.31 ± 11 GHz.

Relevance to NWP SAF Deliverables

The M-T SAPHIR instrument offers several unique features for NWP data assimilation: the low inclination of the orbit means that the revisit time in the tropics is much shorter than polar orbiting satellites; and the instrument includes a channel at 183.31 ± 11 GHz, associated with a weighting function which peaks lower than the lowest peaking sounding channels of MHS (190.311 GHz) or AMSU-B (183.311 ± 7 GHz) (Vijayasree *et al*., 2014). NWP SAF partners have recently carried out evaluations of data from the M-T SAPHIR instrument (e.g. Brogniez *et al*., 2015; Clain *et al*., 2015). Results to date have been positive and the data is already exploited operationally at Metèo-France and ECMWF. Assimilating the data has been found beneficial in improving short range forecast fits to other humidity sensitive observations. The channel at 183.31 ± 11 GHz is similar in information content to the 165.5 GHz channel of MetOp-SG MWS, first planned for launch in 2021.

Plan

The main tasks for the visit were:

1. To conduct a series of assimilation experiments to asses the impact of SAPHIR data on the current Met Office NWP model.

2. Compare weighting functions of MHS, ATMS and M-T SAPHIR for conditions sampled by M-T SAPHIR in the latitude band 30ºS - 30ºN;

3. Conduct a series of single observation experiments, within the Met Office data assimilation system, to include:

    a. The effect of assimilating M-T SAPHIR radiances, for a (small) set of situations;
    b. The effect of assimilating (co-located with *(a)*) ATMS radiances.
    c. The effect of assimilating (co-located) AMSR-2 imager radiances;
    d. The effect of assimilating a-c together.

4. Carry out 1D-Var studies to compare the effects of MHS and SAPHIR data on analysis accuracy.

5. To quantify surface contributions to lowest peaking SAPHIR channels, and develop refined quality control checks to screen these observations.

Assimilation Experiments

During the mission a series of extended assimilation experiments were run to assess the current impact of the SAPHIR observations in the Met Office system. The experiments used a low resolution (N320) version of the Met Office forecast model. The experiments covered the period 5th November 2015 - 29th May 2016. A spin-up period of seven days allowed VarBC coefficients to stabilise, allowing the experiments to be verified for 138 00Z and 139 12Z forecasts, giving a total of 277 forecasts. Experiments were verified relative to a baseline configuration which comprised the full Met Office observing system minus the microwave imagers (AMSR-2 and SSMIS) and SAPHIR. SAPHIR and the imagers were added separately and together, giving a total of four extended assimilation experiments (one control and three tests), note that the experiment for control + SAPHIR had not completed at the time of writing and these results are based on only 207 forecasts. The results are summarised in Figure 1 below.

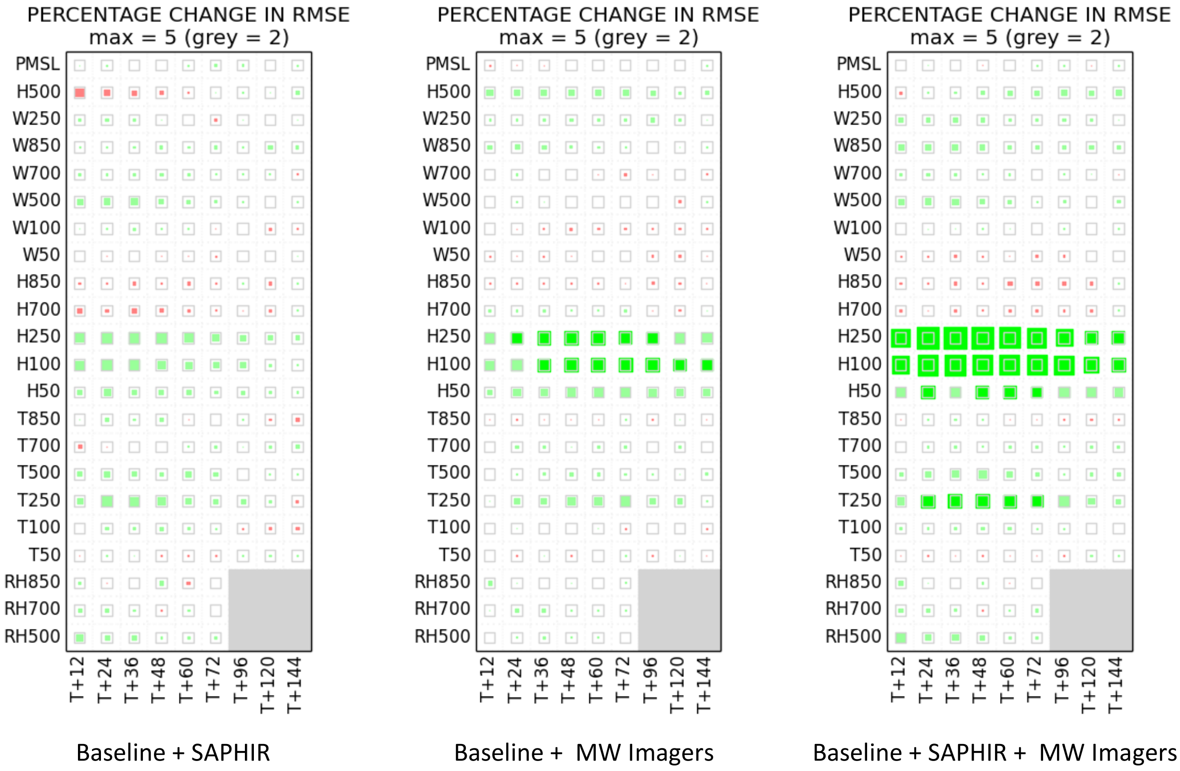

Figure 1. A summary of the impacts of the addition of SAPHIR sounding data, and microwave imager data to an otherwise full baseline configuration. Verification, covering the tropics only, is relative to the baseline, and uses observations. The baseline + MW imagers and Baseline + SAPHIR + imagers experiments were verified for 277 00Z and 12Z forecasts over the period 12th November 2015 to 29th May 2016, while the baseline + SAPHIR experiment was verified for 207 forecasts up to 24th April 2016.

Weighting Functions

Weighting functions for SAPHIR, MHS and ATMS were inspected for a set of twelve tropical atmospheric profiles. As an example, Figure 2 shows weighting function for a profile located at 22ºN, 63ºW.

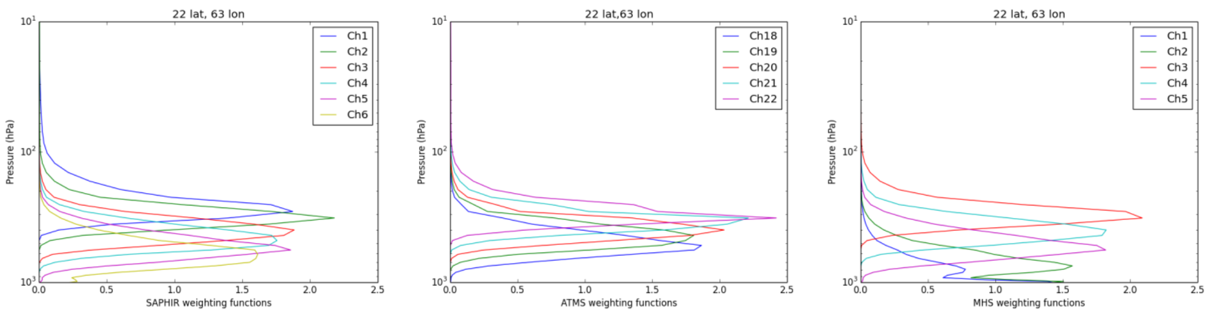

Figure 2. Typical weighting functions for SAPHIR (left), ATMS (centre) and MHS (right) for a profile sampled at 22˚N, 63˚W.

In common with the other profiles inspected, Figure 2 shows that the SAPHIR channel at 183.31 ± 11 GHz provides a relatively 'clean' sounding channel with little sensitivity to the surface, in contrast to MHS channel 1 (89 GHz) and channel 2 (157 GHz). The 183.31 ± 11 GHz channel also extends the vertical range spanned by the weighting functions of SAPHIR relative to those provided by ATMS.

Single Observation Experiments

A series of single observation experiments using data from microwave sounders (SAPHIR and ATMS) and a microwave imager (AMSR-2) were conducted to elucidate the complementarity of microwave imager data and the SAPHIR data. This study also aimed to investigate the benefit of the additional surface peaking channel (183.31 ± 11 GHz**)** in SAPHIR compared to the microwave channels in ATMS.

Methodology

Single observation experiments were designed in such a way that at each selected location, analysis increments were produced for each instrument alone and together. Care was taken to assimilate only the humidity channels from both sounders and imager to inspect the analysis increments in specific humidity. The temperature sounding channels of ATMS were not assimilated in the single observation experiments. The experiments were designed to see how the SAPHIR channels drive the humidity increment when it is assimilated in addition to imager data, and also to analyse how the SAPHIR increments differ from those driven by ATMS humidity channels. Table 1 illustrates the channel frequencies and associated errors from each instrument assimilated in the single observation experiments and in the global assimilation experiments discussed previously and in the section following.

Table 1: Assimilated channels from each instrument.

Instrument	Channel number	Channel frequency (GHz)	Observation error (K)	Stdev (C-B) (K)
SAPHIR	**1**	183.31 ± 0.20	**4.0**	**2.0**
	2	183.31 ± 1.10	**4.0**	**1.8**
	3	183.31 ± 2.80	**4.0**	**1.6**
	4	183.31 ± 4.20	**4.0**	**1.6**
	5	183.31 ± 6.80	**4.0**	**1.7**
	6	183.31 ± 11.0	**4.0**	**2.0**
AMSR-2	**7**	18.7 (H)	**9.6**	**2.4**
	8	18.7 (V)	**5.6**	**1.5**
	9	23.8 (H)	**14.4**	**3.5**
	10	23.8 (V)	**7.6**	**1.9**
	11	36.5 (H)	**12.0**	**3.3**
	12	36.5 (V)	**5.6**	**1.6**
ATMS	**6**	53.596 ± 0.115	**0.375**	**0.15**
	7	54.40	**0.375**	**0.13**
	8	54.94	**0.35**	**0.13**
Used in global	**9**	55.50	**0.6563**	**0.14**
assimilation	**10**	57.29	**0.55**	**0.19**
experiments	**11**	57.29 ± 0.217	**0.6545**	**0.24**
only	**12**	57.29 ± 0.3222 ± 0.048	**0.75**	**0.29**
	13	57.29 ± 0.3222 ± 0.022	**1.2294**	**0.45**
	14	57.29 ± 0.3222 ± 0.010	**1.812**	**0.74**
	15	57.29 ± 0.3222 ± 0.0045	**5.1282**	**1.25**
	18	183.31 ± 7.00	**4.0**	**0.82**
Used in both	**19**	183.31 ± 4.50	**4.0**	**0.90**
single ob expts	**20**	183.31 ± 3.00	**4.0**	**0.95**
and global	**21**	183.31 ± 1.80	**4.0**	**1.3**
	22	183.31 ± 1.00	**4.5**	**1.50**

Co-location Criteria

Pairs of ATMS and SAPHIR observations were chosen which were within 10 km horizontally and temporally within 30 minutes. These ATMS/SAPHIR points were then matched up with AMSR-2 which was horizontally within 10 km and temporally within 50 minutes. Figure 3 shows the co-located triplets for a particular time (00Z on 5 July 2016). Out of the thousands of co-located points we selected 18 locations for the single observation experiments, 9 in the northern hemisphere and 9 in the southern hemisphere, these are described in Table 2.

Table 2: Locations of 20 co-located triplets used in Single Observation Experiments.

No.	Latitude	Longitude
1	2.38	-170.12
2	3.68	-164.85
3	8.0	-167.6
4	8.79	-127.14
5	10.26	-167.8
6	10.95	-164.77
7	18.309	-154.17
8	20.55	-154.35
9	21.629	-130.78
10	-5.05	51.13
11	-6.17	49.009
12	-7.09	49.27
13	-8.89	54.9
14	-10.62	52.58
15	-11.57	53.82
16	-12.47	51.91
17	-18.28	38.48
18	-20.78	12.60

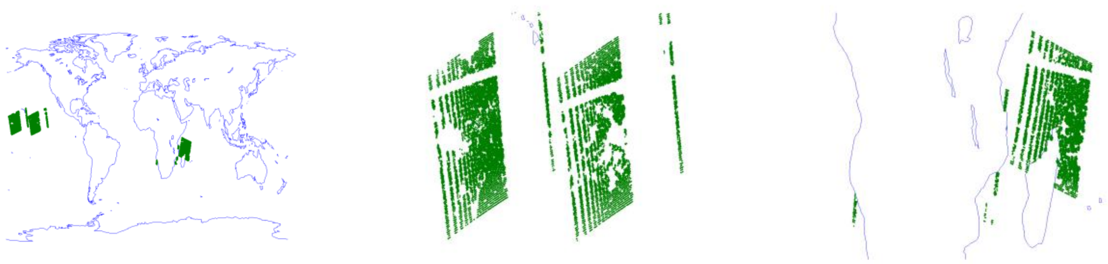

Figure 3. Co-located triplets (ATMS, SAPHIR, and AMSR-2) on 5 July 2016 00Z. Wide view (left), Pacific colocations (centre), Indian Ocean/Atlantic colocations (right).

Figures 4 and 5 show the analysis increments in specific humidity from the surface to 3 km from single observation experiments over the Northern and Southern Hemispheres respectively, the results for SAPHIR, ATMS and AMSR-2 are shown in blue, green and red lines. The analysis increment in specific humidity from the single observation experiment where all the three observations from SAPHIR, ATMS and AMSR-2 are assimilated is shown in cyan color. It is noted from both the Figures 4 and 5 that the analysis increment in humidity is generally driven by the imager (AMSR-2) and SAPHIR modifies the form of these increments. The impact of ATMS data on humidity increment is less compared to that of SAPHIR data.

Discussion of single observation experiments

At most of the locations selected over the Northern Hemisphere ATMS has zero impact (i.e. all left hand column in Figure 4; bottom two profiles in the centre column; top and bottom profiles in right hand column), the reasons for this are not clear at this time – possibilities include screening by quality control or thinning or an effect due to remapping in the preprocessing stage (Labrot *et al*., 2006) giving SAPHIR and ATMS very different resolutions (10 km for SAPHIR and 40 km for ATMS at nadir). This requires further investigation, but the results presented here do reflect the effect of each instrument on the current data assimilation system at the Met Office. It can be clearly seen from all the nine locations that the increment is controlled by the imager and SAPHIR modifies this, especially above 2 km and slightly below 1 km. We selected two profiles each over the Northern and Southern Hemispheres to illustrate the impact of SAPHIR data in the imager driven humidity increment. Over the Northern Hemisphere, the locations selected for illustration are (8.0˚N, 167.8˚W) and (21.629˚N, 130.78˚W). In Figure 4, the analysis increment in specific humidity at these locations can be found at the third column in the first and last rows.

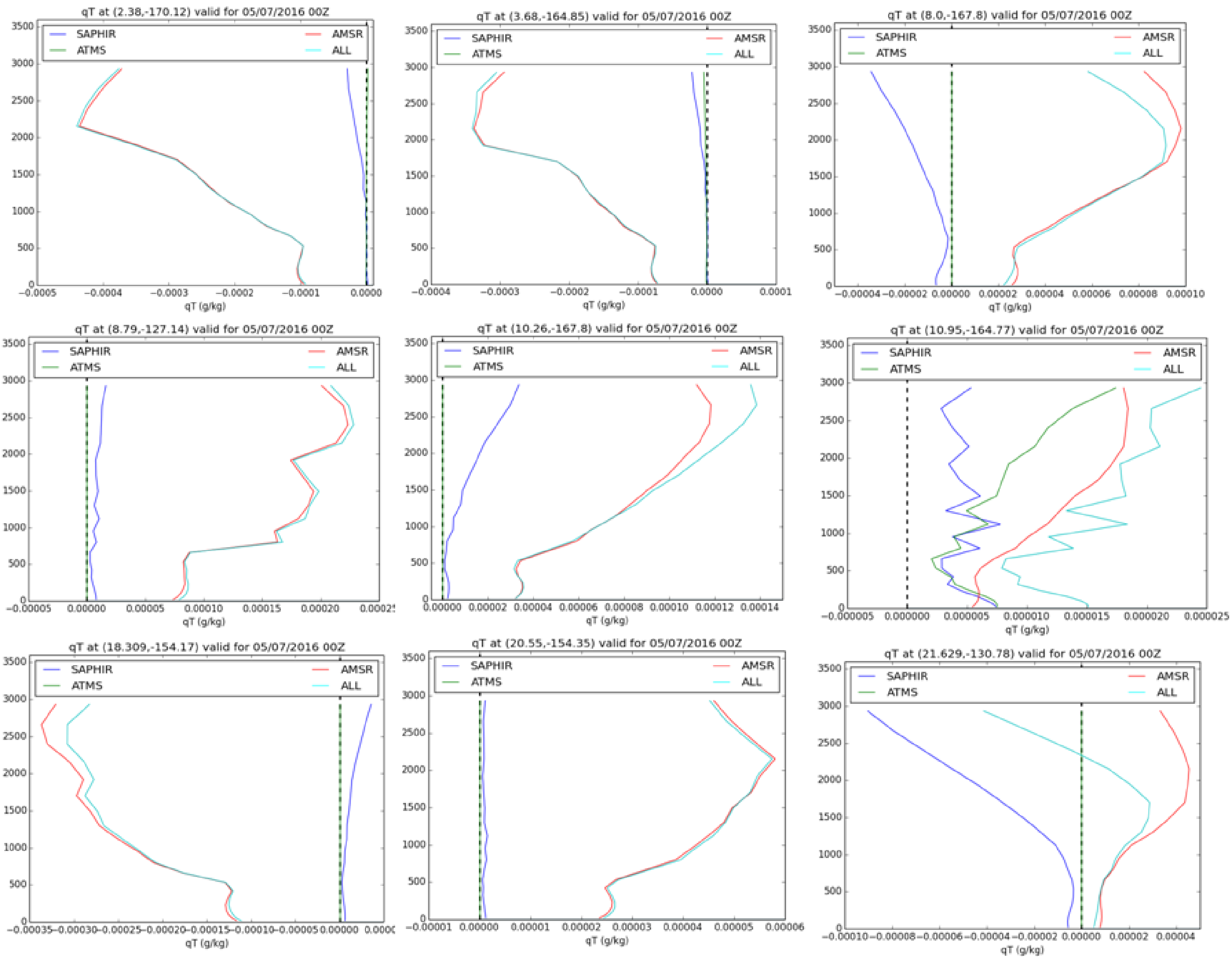

Figure 4. Single observation experiments' specific humidity analysis increment profiles over Northern Hemisphere.

In the first location (8.0˚N, 167.8˚W) SAPHIR produces a drying effect, whereas AMSR-2 produces a moistening effect. Combined the over all effect is still moistening, but below 1 km and above 1.5 km SAPHIR has acted to reduce the impact from AMSR-2 resulting in a drier increment. In the second location (21.629˚N, 130.78˚W) we can see almost the same impact of SAPHIR combined with AMSR-2. This signifies that SAPHIR modifies the imager driven humidity increment.

ATMS has slightly more of an impact in the single observation experiments carried out for the Southern Hemisphere (Figure 5). Two of the locations show zero impact from ATMS, while the others have non-zero analysis increments, though these are still much smaller than for the other instruments. The locations selected for illustration over the Southern Hemisphere are (6.17˚S, 49.009˚E) and (10.62˚S, 52.58˚E), second columns in first and second rows of Figure 5 where the picture is similar to that seen in the Northern hemisphere. Over both of these locations, the imager driven humidity analysis increment was modified by SAPHIR and the impact of ATMS is very small or none.

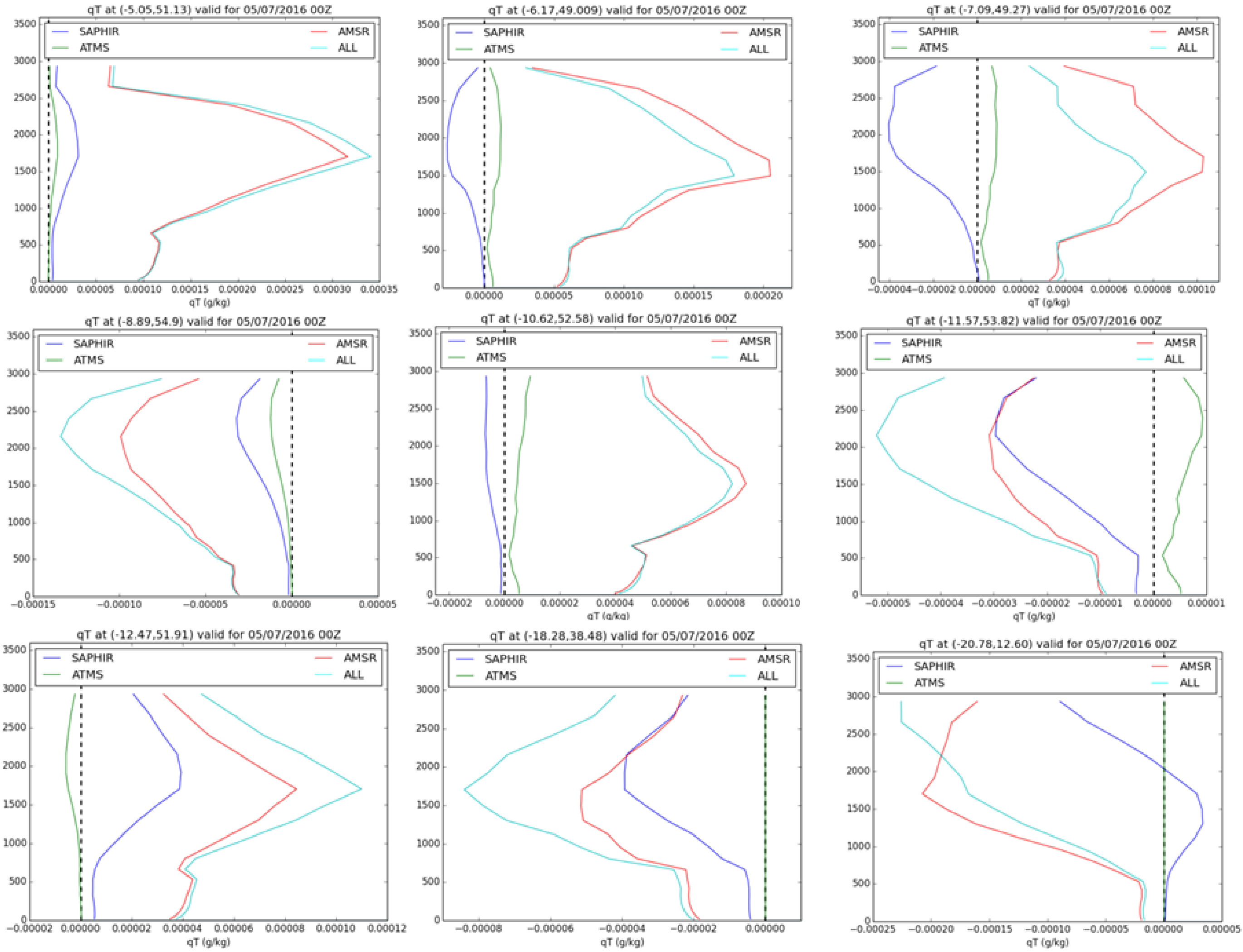

Figure 5. Single observation experiments' specific humidity analysis increment profiles over Southern Hemisphere.

Global Experiments

In addition to the single observation experiments, the 4D-Var global assimilation system was also run for imager and sounders separately and together. Figure 6 shows the zonal cross-section of analysis increment in specific humidity when assimilated (a) imager (AMSR-2) alone, (b) ATMS alone and (c) both AMSR-2 and ATMS. Figure 7 is similar to Figure 6 but for SAPHIR data instead of ATMS.

From Figure 6, it is clear that when ATMS is assimilated in addition to AMSR-2, the global analysis increment in specific humidity is largely driven by the imager (Figure 6(c)).

Whereas from Figure 7 (c), it is noted that when SAPHIR is added to AMSR-2, the SAPHIR data modifies the overall increment from the surface to 3 km, and particularly below 1 km (see circled region in Figure 7 (c)). This kind of modification by ATMS is not seen (Figure 6 (c)).

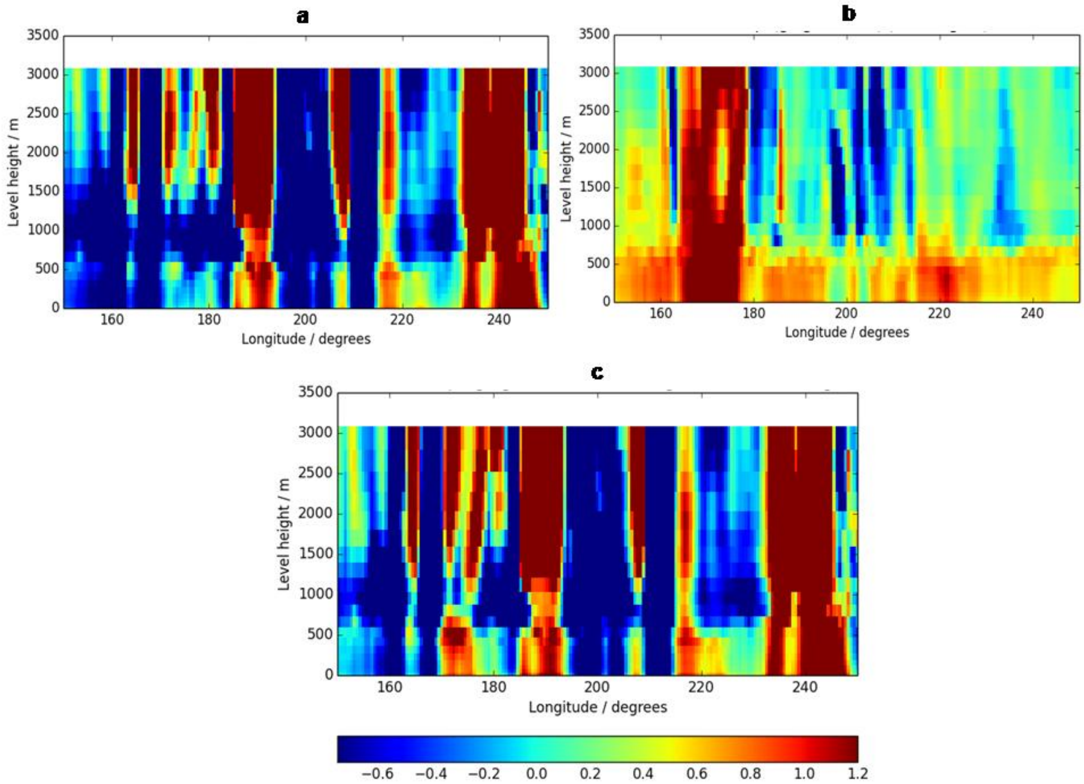

Figure6. Zonal cross-section (along 10˚N) of analysis increment in humidity increment when assimilated (a) Imager (AMSR-2) alone, (b) ATMS alone and (c) both AMSR-2 and ATMS

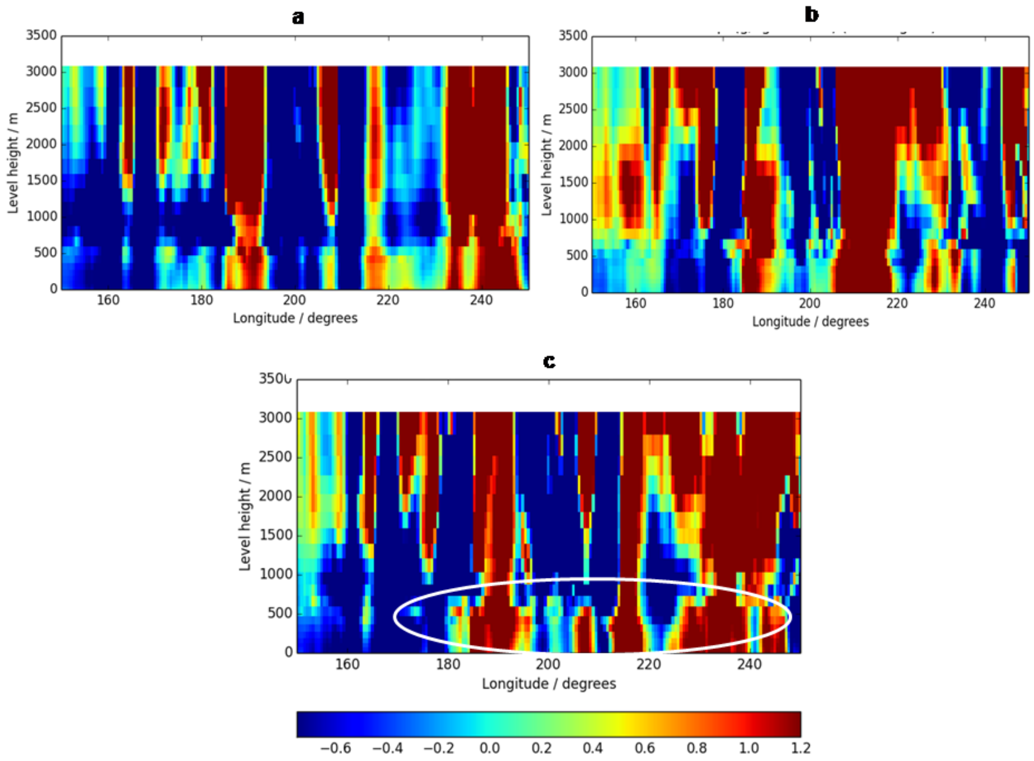

Figure 7. Similar to Figure 6, but the Zonal cross-section (along 10˚N) of analysis increment in humidity increment when assimilated (a) Imager (AMSR-2) alone, (b) SAPHIR alone and (c) both AMSR-2 and SAPHIR

Conclusions

A series of seven month assimilation experiments have reaffirmed that SAPHIR provides benefits in the analysis and forecasting of humidity, temperature and wind in the tropics in the Met Office's global assimilation system. An inspection of weighting functions showed that the 183.31 ± 11 GHz channel extends the vertical coverage of SAPHIR, relative to ATMS and MHS, by providing an additional '*clean*' 183 GHz sounding channel which has only very weak sensitivity to surface emission.

A series of single observation experiments has shown that the inclusion of SAPHIR data qualitatively changes the form of the (dominant) humidity increments driven by the imagers (including AMSR-2). The impact of ATMS on humidity increments is weaker compared to that of SAPHIR. In a global (*tropical*) context SAPHIR modifies imager driven humidity increments and the impact of ATMS is, by comparison, small.

Time did not permit the completion of the 1D-Var information content studies, or the investigation into surface effects to refine the quality control, but it is intended that these studies will be completed and that a publication is prepared on the benefits of assimilating SAPHIR data in the Met Office global model.

References

Brogniez, H., Clain, G., Roca, R., 2015, Validation of Upper-Tropospheric Humidity from SAPHIR on board Megha-Tropiques Using Tropical Soundings. JOURNAL OF APPLIED METEOROLOGY AND CLIMATOLOGY Volume: 54 Issue: 4 Pages: 896-908.

Clain, G., Brogniez, H., Payne, V. H., John, V. O., Luo, M., 2015, An Assessment of SAPHIR Calibration Using Quality Tropical Soundings. JOURNAL OF ATMOSPHERIC AND OCEANIC TECHNOLOGY Volume: 32 Issue: 1 Pages: 61-78.

T. Labrot, L. Lavanant, K. Whyte, N. Atkinson, and P. Brunel, “AAPP documentation, scientific description,” NWP SAF Document NWPSAF-MF-UD-001, Satellite Application Facility on Numerical Weather Prediction, 2006.

Vijayasree, P., Kumar, N., Karidhal, R., Harendranath, K., Raju, V.K., Shivakumar, S.K., 2014, Megha-Tropiques: mission planning, analysis, and operations. INTERNATIONAL JOURNAL OF REMOTE SENSING, Volume: 35, Issue: 14, Pages: 5370-5383., Special Issue: SI, DOI: 10.1080/01431161.2014.926412