Assimilating Megha-Tropiques SAPHIR Data in the NOAA GDAS

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1. Introduction

The National Oceanic and Atmospheric Administration (NOAA) Center for Satellite Applications and Research (STAR), in support of the Joint Center for Satellite Data Assimilation (JCSDA) has extended the Gridpoint Statistical Interpolation (GSI) data assimilation system used in the National Centers for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS) to assimilate SAPHIR L1A2 brightness temperature (TB) data into the Global Forecast System (GFS) in a clear-sky, ocean-only capacity.

Extending the GDAS to assimilate SAPHIR TBs has been a multi-step process: the SAPHIR data were obtained in BUFR format from a EUMETSAT data stream and assessed for errors and biases, quality control (QC) procedures tailored to SAPHIR had to be developed and implemented, and the impacts of assimilating SAPHIR TBs on GDAS analyses and GFS forecasts have been, and continue to be, assessed. The use of the Community Observation Assessment Tool (COAT) has been integral to assessment and QC procedures, and the use of the COAT and the Multi-Instrument Inversion and Data Assimilation Preprocessing System (MIIDAPS) will ultimately allow for the optimization of the assimilation of SAPHIR observations. These tools have the potential to assist in efforts to assimilate radiance observations over non-ocean surface types, and in all-sky conditions.

2. SAPHIR Data Assessment and Quality Control

Prior to assimilation, the SAPHIR L1A2 data were assessed in the COAT for quality. The COAT is a utility independent of any data assimilation system, and has the ability to co-locate observations (in this case, SAPHIR L1A2 TBs) with fields from European Center for Medium-range Weather Forecasting (ECMWF) analyses or GDAS/GFS analyses. It uses the Community Radiative Transfer Model (CRTM) to simulate TBs from co-located numerical weather prediction (NWP) analysis fields, and provides a channel-by-channel assessment of satellite-observed TBs with respect to the co-located simulated TBs in all sky conditions and over all surface types. As a result of these capabilities, the COAT may be used as a testbed to independently evaluate QC and filtering procedures for SAPHIR L1A2 TB data before these procedures are implemented within an assimilation system.

Figure 1. Testing the GWP retrieval developed for SAPHIR: a) GWP retrieval results (mm) using SAPHIR TBs from 05 June 2015, b) co-located GWP (mm) field from a 05 June 2015 ECMWF analysis, and c) a density scatter plot showing ECMWF analysis GWP versus GWP retrieved from one day of observed SAPHIR TBs, with the best fit line. Note similar precipitation features in a) and b), and the slope of the best fit line in c) being near 1.

The focus of this work was the assimilation of clear-sky SAPHIR L1A2 TBs. Though it is not expected that SAPHIR will be sensitive to the surface, an overly conservative approach was taken, and only data over ocean have been considered. As SAPHIR is also not expected to be sensitive to cloud, it was only necessary to filter out precipitation-contaminated brightness temperatures from the assessment. A graupel water path (GWP) retrieval was developed in order to screen for observations that may have been affected by precipitation. The retrieval, which is a multi-linear regression trained on simulated brightness temperatures from ECMWF analysis fields, was implemented in the COAT, and any points where retrieved GWP exceeded 0.05 kg/m² were assumed to be in precipitating conditions, and removed from further consideration in the data quality assessment.
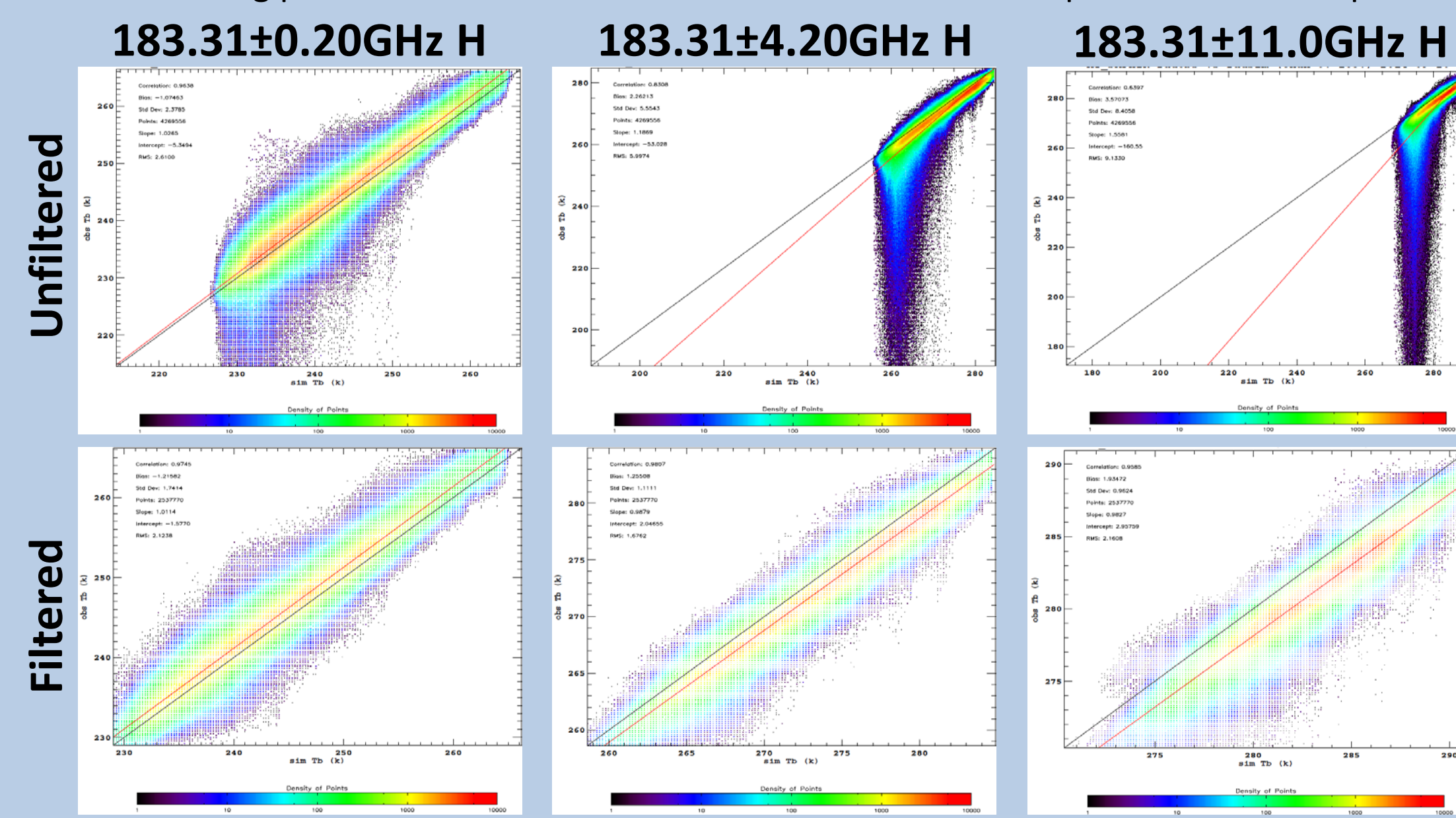

Figure 2. Unfiltered (top) and filtered (bottom) observed versus simulated TBs for, left to right, SAPHIR channels 1 (183.81±0.20GHz H), 4 (183.31±4.20GHz H), and 6 (183.31±11.00GHz H).

Freq (GHz)	Unfiltered Observations			Filtered Observations		
	Count	Bias	Stdv	Count	Bias	Stdv
183.31 ± 0.20H	4269556	1.07	2.38	2537770	1.22	1.74
183.31 ± 1.10H	4269522	-0.41	2.82	2537737	-0.11	1.40
183.31 ± 2.80H	4269556	-1.45	4.49	2537770	-0.73	1.22
183.31 ± 4.20H	4269556	-2.26	5.55	2537770	-1.26	1.11
183.31 ± 6.80H	4269556	-2.59	7.02	2537770	-1.29	1.04
183.31 ± 11.0H	4269556	-3.57	8.41	2537770	-1.93	0.96

Table 1. Bias, standard deviation (Stdv, rounded to two decimal places), and observation count from the COAT for TBs over ocean from all SAPHIR channels on 20 September 2014 for unfiltered and filtered cases, with TBs simulated from ECMWF analysis fields as a reference.
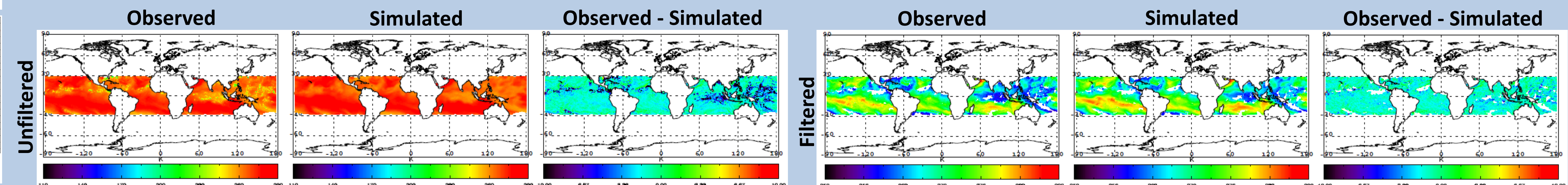

Figure 3. Observed and simulated TBs for SAPHIR Channel 4 (183.31±4.20GHz H) for 20 September 2014, with observed – simulated TB difference for both unfiltered (left) and filtered (right) observations. Note the difference in scales and colorbars for filtered and unfiltered observed and simulated plots (both observed – simulated plots are on the same scale).

3. Analysis and Forecast Impacts

A reader to ingest SAPHIR L1A2 BUFR data into the GSI was developed. This reader filters out points with non-ocean surface classifications, and any data flagged within the BUFR file as being bad, before thinning the data to a user-prescribed thinning grid. A GWP retrieval, tested in COAT, was implemented in the GSI, and a QC subroutine was developed to filter out any points where retrieved GWP is over 0.5 kg/m² (as was done in the COAT). The system uses user-prescribed errors/weights for each channel, as well as user-prescribed values for a gross check.

In the results shown here, SAPHIR L1A2 TBs were thinned at 45km, and a gross check of 3K was applied to observations passing the GWP QC. The errors/weights used for the experiment were set equal to the COAT results for standard deviations of filtered SAPHIR TBs. The experiment was started from the 01 June 2015 00Z GDAS cycle, and run for several weeks assimilating the current operational observation system, plus the SAPHIR TBs. The first 7 days of the experimental run were used as spin up, and removed from any assessment of analyses or forecasts. The experimental time period used extended to 18 July 2015 00Z.
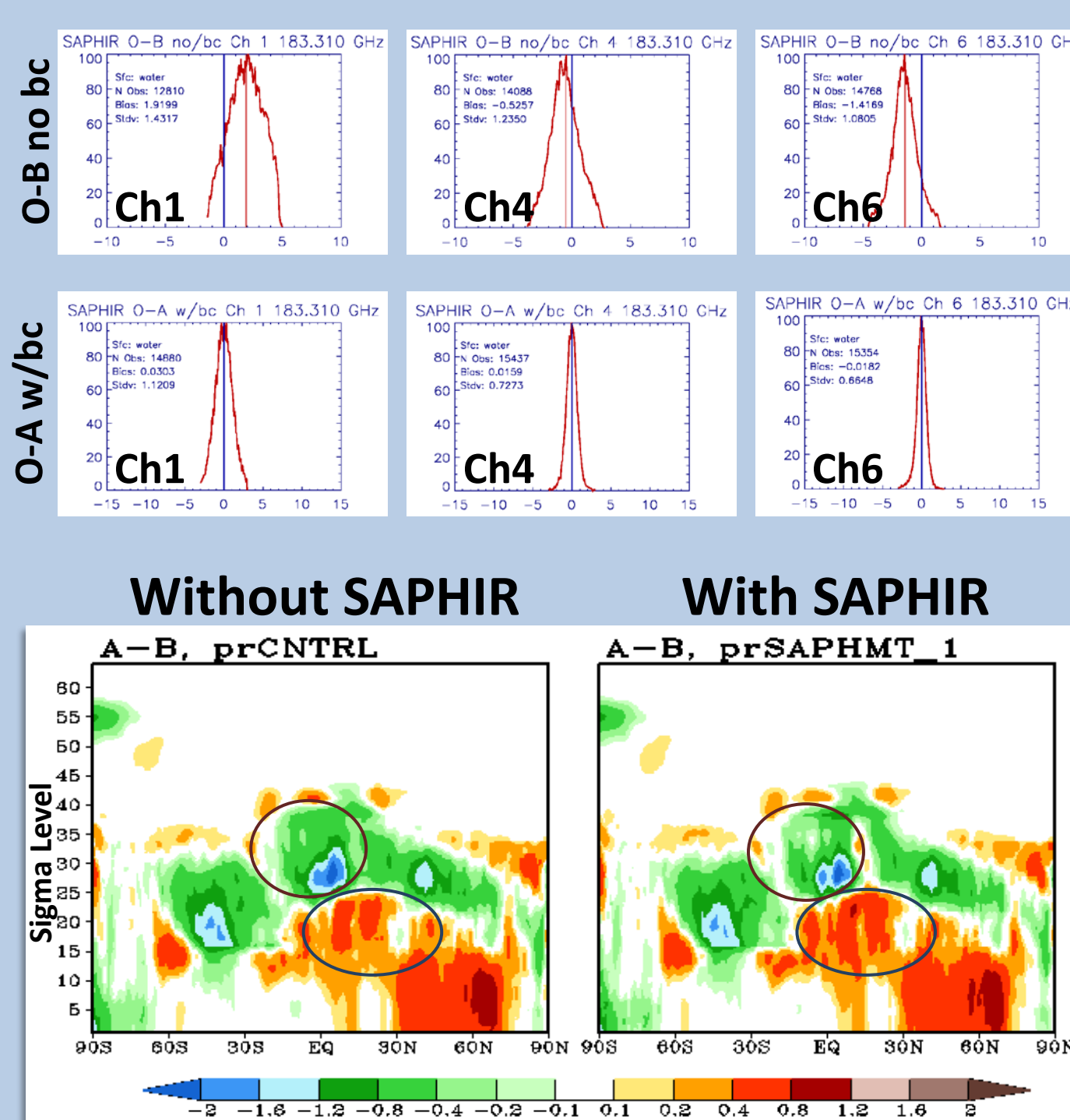

Figure 4. O-B (top) and O-A with bias correction (bottom) for SAPHIR channels 1, 4, and 6, from a GDAS cycle assimilating SAPHIR TBs.

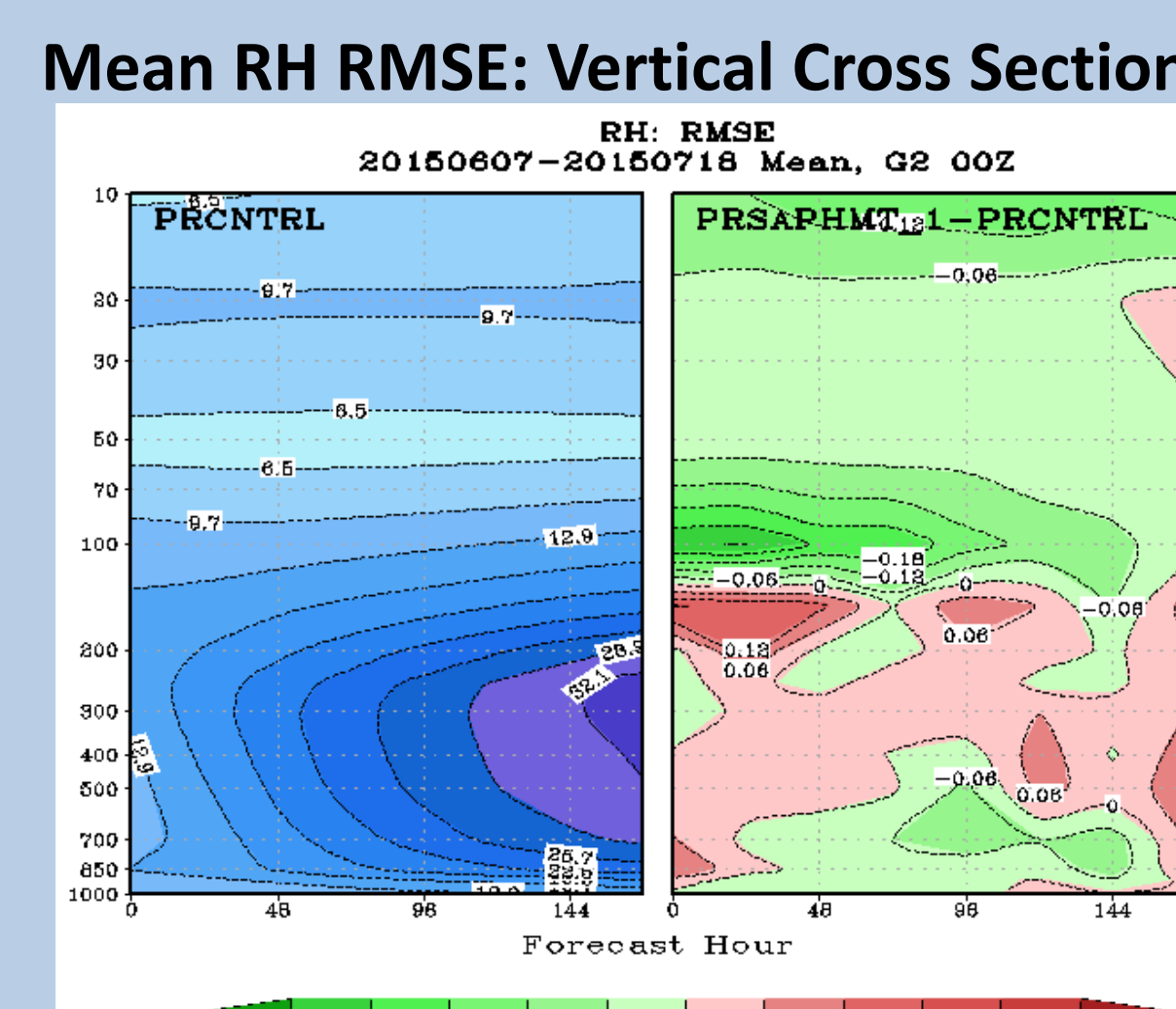### Mean RH RMSE: Vertical Cross Section

Figure 6. A vertical cross section of mean RH from 07 June 2015 to 17 July 2015. RH RMSE for the control (left, no SAPHIR), and the difference in RMSE (right) between the experiment (with SAPHIR) and control, where greens indicate improvement.
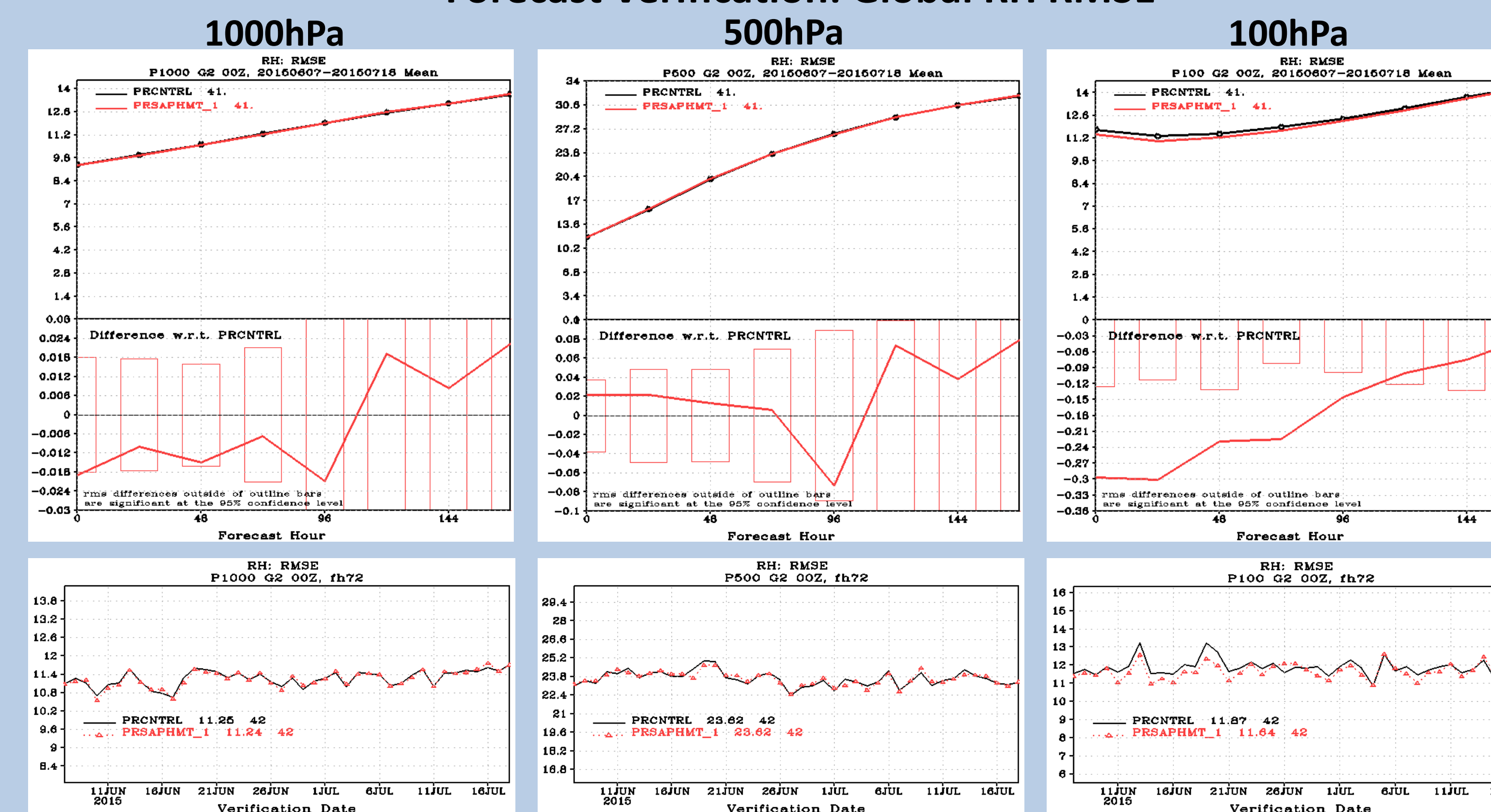
Forecast Verification: Global RH RMSE

Figure 7. Forecast verification results for the time period of 07 June 2015 to 18 July 2015. Red lines represent the experiment (SAPHIR assimilated), and black lines represent the control. Forecasts are verified against ECMWF analyses: Mean RMSE (global) dieoff curves (top) for RH at 1000hPa, 500hPa, and 100hPa. Boxes in bottom half of the dieoff curve plots indicate the 95% confidence level; lines within these boxes are considered significant. Day3 forecast timeseries of global RMSE (bottom) for RH at 1000hPa, 500hPa, and 100hPa for the 07 June 2015 to 18 July 2015 time period.

Figure 5. A vertical cross section of RH analysis increments for the control (left, without SAPHIR) and the experiment (right, with SAPHIR assimilated), averaged over 07 June 2015 to 21 June 2015, indicating where SAPHIR is adding (reds/oranges) and removing (greens/blues) moisture from the analysis.

Variable	Without SAPHIR		With SAPHIR		Change with SAPHIR	
	RMSE	Stdv	RMSE	Stdv	RMSE	Stdv
RH 1000hPa	7.34	5.28	7.29	5.25	0.69%	0.57%
RH 850hPa	5.99	5.95	6.02	5.97	0.50%	0.34%
RH 700hPa	4.22	4.16	4.22	4.17	0.00%	0.24%
RH 500hPa	3.07	2.95	3.08	2.95	0.33%	0.00%
RH 300hPa	5.55	3.69	5.47	3.65	1.46%	1.10%
RH 250hPa	5.61	3.82	5.55	3.75	1.08%	1.87%
RH 200hPa	4.47	4.24	4.51	4.23	0.89%	0.24%
RH 100hPa	4.89	4.54	4.63	4.26	5.62%	6.57%

Table 2. Root mean square error (RMSE) and standard deviation (Stdv, rounded to two decimal places) averaged over the 42-day time period of 7 June 2015 to 18 July 2015 of analysis RH at multiple levels for an experiment assimilating SAPHIR data and a control (without SAPHIR). Comparisons are made against ECMWF analyses from the same time period. The percentage difference between experiment and control statistics is given in the right columns; results in green indicate a positive change, results in red indicate analysis degradation.

To assess the impact that the assimilation of SAPHIR TBs on the GDAS analysis and GFS forecast, experiment results (for 00Z cycles only) were compared against results from a control run where no SAPHIR data were used, and ECMWF analyses from the experimental time period. As SAPHIR is a water vapor sounder, fields of relative humidity (RH) have been the focus of impact assessment. Impacts on other variables (e.g. temperature, height, wind) appear generally neutral/insignificant. The impact that assimilating SAPHIR data has on the GFS forecast RH also appears mostly neutral when verified against ECMWF analyses, though there are indications of a significant positive impact on RH at high levels (e.g. 100hPa) when SAPHIR TBs are assimilated.

4. Conclusions

SAPHIR L1A2 TBs have been assessed in the COAT, QC procedures for clear-sky filtering of SAPHIR TBs have been developed, and the GDAS has been extended to assimilate these TBs in clear-sky conditions over ocean. Initial assessments of the impact, relative to ECMWF, that the assimilation of SAPHIR TB data has on analyses and forecasts from the GDAS/GFS system have been made.

- SAPHIR TBs can be used to retrieve GWP fields with features similar to those seen in ECMWF analyses.
- The implementation of a filter for SAPHIR TBs based upon thresholding retrieved GWP from SAPHIR L1A2 data has shown efficacy in improving the quality statistics (e.g. bias, standard deviation) of SAPHIR data in the COAT.
- When ingested and filtered in the GSI, SAPHIR TBs behave as expected, and resulting O-As for SAPHIR observations (with bias correction) have standard deviations below the prescribed observation errors.
- The ocean-only clear sky assimilation of SAPHIR TBs appears to have a mostly neutral impact on GDAS analyses and GFS forecasts when verified against ECMWF analyses. There are indications of a positive impact in analysis and forecast RH at upper levels when SAPHIR data are assimilated.

5. Future Work

- Continue assessing the impacts that assimilating SAPHIR data has on GDAS/GFS analyses and forecasts:
  - Perform additional tests for forecasts skill.
  - Analyze hurricane track errors.
- Optimize thinning of SAPHIR data in the GSI.
- Optimize SAPHIR representation in the GSI and use of SAPHIR TBs by continuing to fine-tune error estimates and by further tailoring QC routines to SAPHIR, if needed, based on results from forecast assessments, and from the COAT and MIIDAPS.
- Fully extend MIIDAPS pre-processor to SAPHIR, and pre-process SAPHIR TBs through MIIDAPS prior to assimilation.
- Ultimately assimilate SAPHIR TBs in all-sky conditions, over all surface types.