SAPHIR Data Assimilation in the NOAA GDAS

Erin Jones[1], Kevin Garrett[1], Eric Maddy[1], and Sid Boukabara[2]

1. Riverside Technology, Inc., JCSDA 2. NOAA/NESDIS/STAR, JCSDA

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 were developed and implemented, and the impacts of assimilating SAPHIR TBs on GDAS analyses and GFS forecasts were 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 allow for the optimization of the assimilation of SAPHIR observations in clear-sky and non-clear-sky contexts. 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.

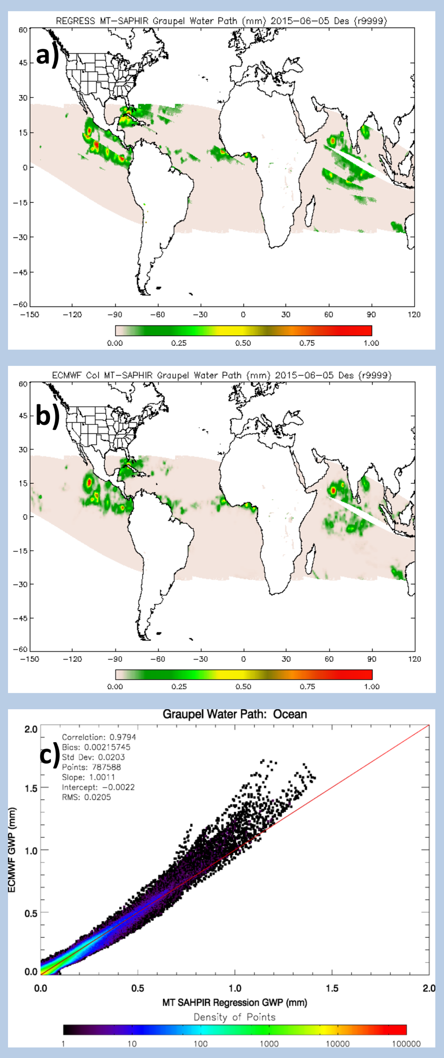


Figure 1. Testing the GWP retrieval developed for SAPHIR: **a)** GWP retrieval results (mm) using SAPHIR TBs from 05 June 2015, **b)** co-located GWP (mm) field from a 05 June 2015 ECMWF analysis, and **c)** a density scatter plot showing ECMWF analysis GWP versus GWP retrieved from one day of observed 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.

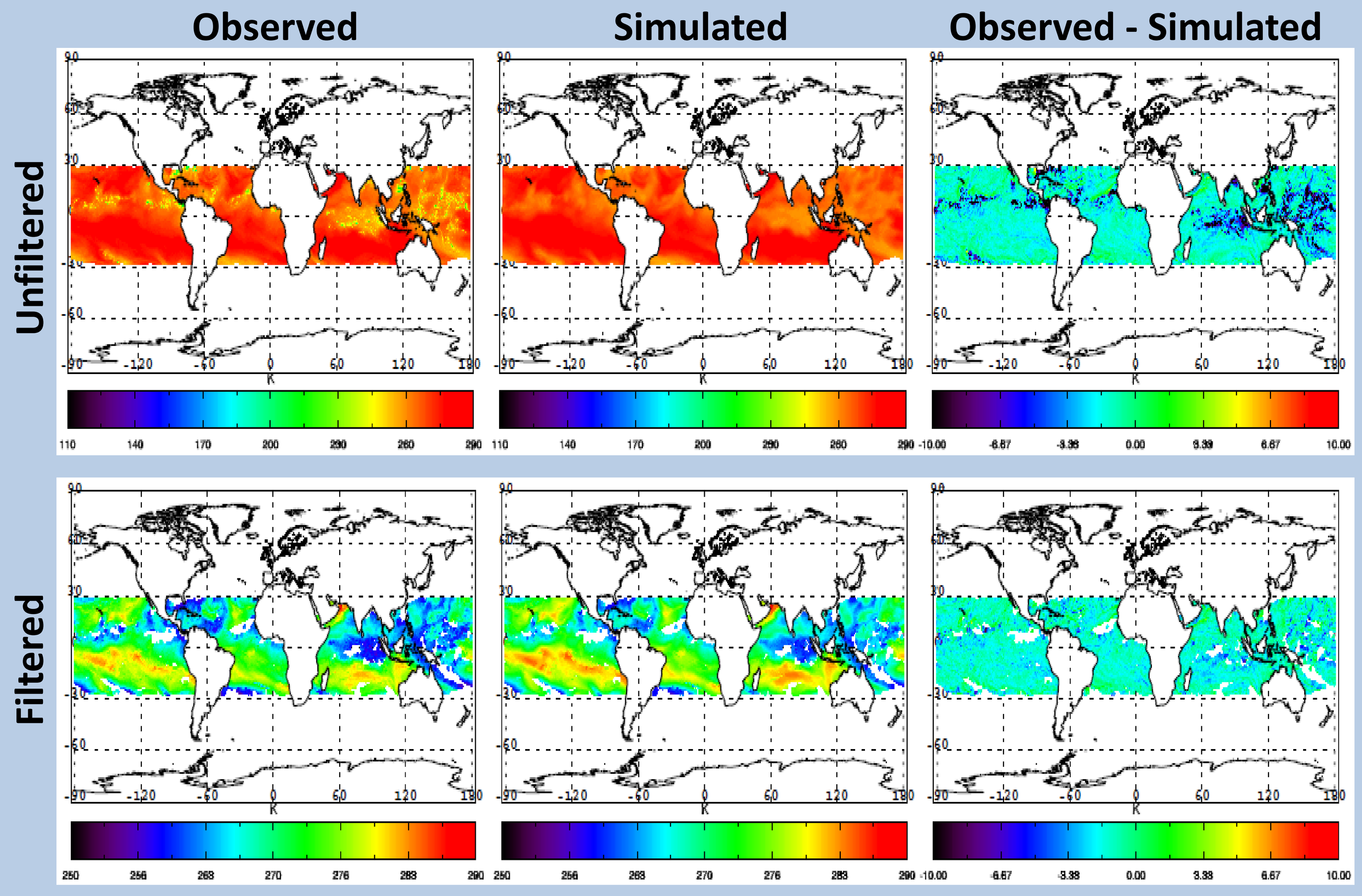


Figure 2. Observed and simulated TBs for SAPHIR Channel 4 (183.31±4.20GHz H) for 20 September 2014, with observed – simulated TB difference for both unfiltered (*left*) and filtered (*right*) observations. Note the difference in scales and colorbars for filtered and unfiltered observed and simulated plots (both observed – simulated plots are on the same scale).

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.

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 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/m^2 were assumed to be in precipitating conditions, and removed from further consideration in the data quality assessment.

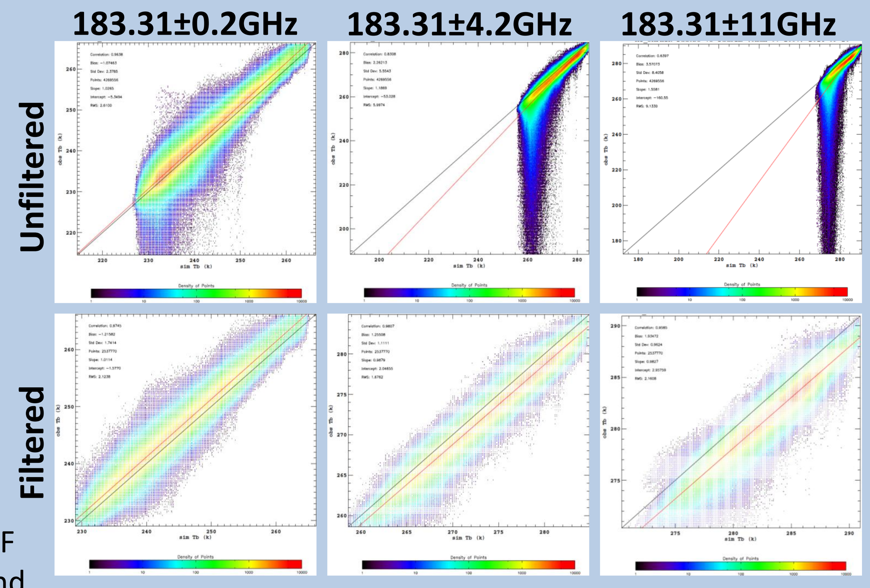


Figure 3. Unfiltered (*top*) and filtered (*bottom*) observed versus simulated TBs for, left to right, SAPHIR channels 1 (183.81±0.20GHz H), 4 (183.31±4.20GHz H), and 6 (183.31±11.00GHz H).

3. Analysis and Forecast Impacts

Prior to the thinning and assimilation of SAPHIR L1A2 TBs in the GSI, the SAPHIR TBs are checked for bad data quality flags in the GSI reader, and a filter is applied to remove points with non-ocean surface classifications. Data over ocean without any inherent quality flaws are then passed to a GWP retrieval, which was tested in the COAT, and a QC subroutine filters out any points where retrieved GWP is found to be over 0.5 kg/m^2 (as was also done in the COAT). The system uses user-prescribed errors/weights for each channel, as well as user-prescribed values for a gross check.

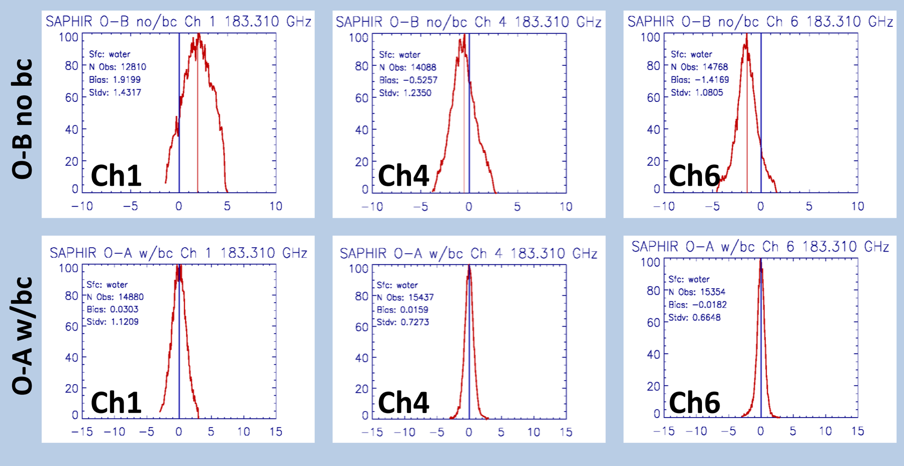
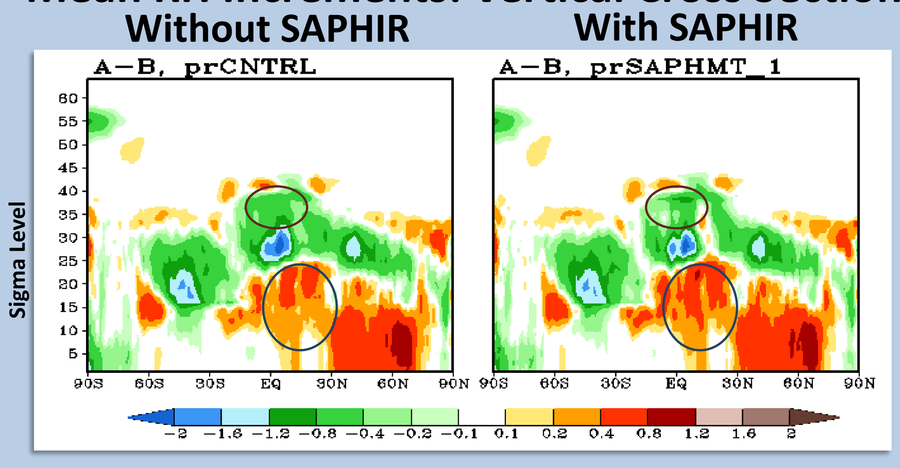


Figure 4. O-B (*top*) and O-A with bias correction (*bottom*) for SAPHIR channels 1, 4, and 6, from a GDAS cycle assimilating SAPHIR TBs.

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 operational observation system that was current at the time of the experiment, plus the SAPHIR TBs. The first 7 days of the experimental run were considered spin up, and removed from any assessment of analyses or forecasts. The experimental time period extended to 18 July 2015 00Z.

Figure 5. A vertical cross section of relative humidity (RH) analysis increments for the control (*left*, without SAPHIR assimilated) and the experiment (*right*, with SAPHIR assimilated), averaged over 07 June 2015 to 22 June 2015, indicating where SAPHIR is adding (reds/oranges) and removing (greens/blues) moisture from the analysis.

Mean RH Increments: Vertical Cross Section



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, 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 with respect to ECMWF.

	Channel Frequency	Stdv of O-B no bc		Change with SAPHIR
		Without SAPHIR	With SAPHIR	
SSMI/S F17	183.31±6.6GHz H	1.09	1.06	2.83%
	183.31±3GHz H	1.18	1.16	1.72%
	183.31±1GHz H	1.36	1.34	1.49%
ATMS	183.31±7GHz H	0.88	0.87	1.15%
	183.31±4.5GHz H	0.92	0.91	1.10%
	183.31±3GHz H	0.96	0.96	0.00%
	183.31±1.8GHz H	0.99	0.99	0.00%
	183.31±1GHz H	1.05	1.04	0.96%

Table 3. Stdv (rounded to two decimal places) of O-B without bias correction applied for 183 GHz channels over ocean from SSMI/S F17 and ATMS averaged over the time period from 00Z 7 June 2015 to 18Z 5 July 2015. Results are shown for experiments assimilating and not assimilating SAPHIR data. Percentage changes shown in green indicate a reduction in O-B stdv with the assimilation of SAPHIR. It should be noted the SSMI/S F17 data were monitored, not assimilated.

Forecast Verification: Global RH RMSE

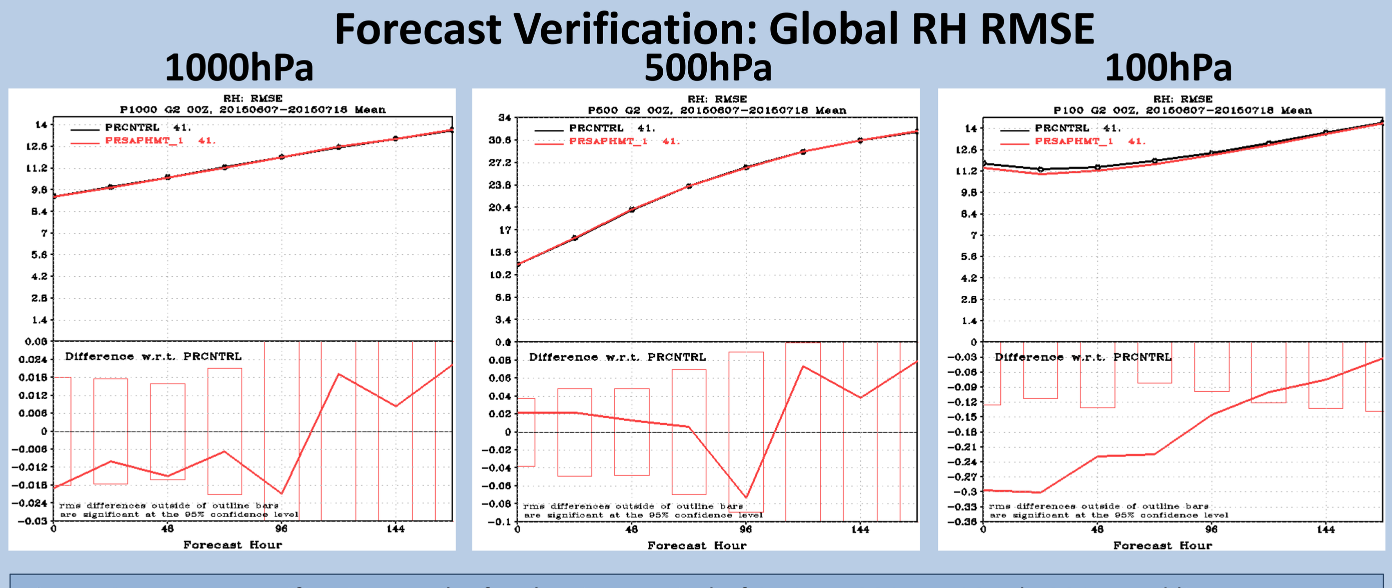


Figure 6. Forecast verification results for the time period of 07 June 2015 to 18 July 2015. Red lines represent the experiment (SAPHIR assimilated), and black lines represent the control. Forecasts are verified against ECMWF analyses: Mean RMSE (global) dieoff curves for RH at 1000hPa (*left*), 500hPa (*middle*), and 100hPa (*right*). Boxes in bottom half of the dieoff curve plots indicate the 95% confidence level; lines within these boxes are not considered significant.

To assess the impact that the assimilation of SAPHIR TBs on the GDAS analysis and GFS forecast, results (for 00Z cycles only) from experiments where SAPHIR data were and were not assimilated were verified against ECMWF analyses from the experimental time period (7 June 2015 to 18 July 2015). Impacts on non-RH variables (e.g. temperature, height, wind) appear generally neutral. The impact of assimilating SAPHIR data on GFS forecast RH appears mostly neutral when verified against ECMWF analyses, but there are indications of a significant positive impact on RH at high levels (e.g. 100hPa) when SAPHIR TBs are assimilated. Additional assessment was done by comparing the O-B of sensors with SAPHIR-like channels when SAPHIR data were and were not assimilated to see whether the assimilation of SAPHIR improved the fit of the background to these sensors.

Table 4. Anomaly correlation (AC) and RMSE (rounded to two decimal places) for various variables from 00Z forecasts where SAPHIR TBs were and were not assimilated. Forecasts were verified against ECMWF analyses over the time period of 7 June 2015 to 18 July 2015. Percentage changes in green indicate improvement with respect to ECMWF when SAPHIR is assimilated. Changes in red suggest degradation.

Variable	Without SAPHIR		With SAPHIR		Change with SAPHIR	
	AC	RMSE	AC	RMSE	AC	RMSE
500 hPa Height, day 5 NH	0.83	39.40	0.83	39.57	0.00%	0.43%
500 hPa Height, day 5 SH	0.86	58.77	0.85	59.74	1.81%	1.65%
850 hPa Temp, day 5 Global	0.72	2.57	0.72	2.57	0.00%	0.00%
850 hPa Winds, day 1 Tro	0.87	2.76	0.87	2.77	0.00%	0.36%
850 hPa Winds, day 3 Tro	0.77	3.66	0.77	3.64	0.00%	0.55%
250/200 hPa Winds, day 1 Tro	0.92	5.07	0.91	5.17	1.10%	1.97%
250/200 hPa Winds, day 3 Tro	0.83	7.32	0.83	7.37	0.00%	0.68%
1000 hPa RH, day 3 Tro	--	9.44	--	9.41	--	0.32%
1000 hPa RH, day 3 NH	--	13.80	--	13.79	--	0.07%
1000 hPa RH, day 3 SH	--	9.74	--	9.75	--	0.10%
850 hPa RH, day 3 Tro	--	15.58	--	15.49	--	0.58%
850 hPa RH, day 3 NH	--	16.79	--	16.77	--	0.12%
850 hPa RH, day 3 SH	--	22.51	--	22.43	--	0.36%
500 hPa RH, day 3 Tropics	--	19.92	--	20.02	--	0.50%
500 hPa RH, day 3 NH	--	23.88	--	23.85	--	0.13%
500 hPa RH, day 3 SH	--	26.14	--	26.13	--	0.04%
100 hPa RH, day 3 Tropics	--	17.48	--	17.24	--	1.39%
100 hPa RH, day 3 NH	--	8.26	--	7.80	--	5.90%
100 hPa RH, day 3 SH	--	6.58	--	6.49	--	1.39%

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 of assimilating SAPHIR TBs, relative to ECMWF, have 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.
- Assimilating SAPHIR TBs in clear-sky conditions over ocean appears to improve the fit of the background to observations from 183 GHz channels of other sensors.
- 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

The work presented here has been written up in a manuscript and submitted for peer-review. Additional efforts for clear-sky assimilation are likely to be minimal as the focus shifts towards all-sky radiance assimilation. Future work may include:

- Assessment of the impacts that assimilating clear-sky SAPHIR data has on GDAS/GFS forecasts of the diurnal water cycle and tropical storm tracks.
- Further optimization of SAPHIR clear-sky assimilation in the GSI by fine-tuning error estimates and/or QC procedures as needed.
- Fully extend the MIIDAPS pre-processor to SAPHIR, and pre-process SAPHIR TBs through MIIDAPS prior to assimilation.
- Extend the GSI to assimilate SAPHIR TBs in all-sky conditions, over all surface types.
- Continued coordination with NCEP in an effort to have the operational GDAS extended to use SAPHIR observations.

Contact info: erin.jones@noaa.gov