571 VALIDATION OF CRIMSS EDR PRODUCTS WITH MATCHED ECMWF ANALYSIS, RAOB MEASUREMENTS, AND IASI RETRIEVALS

Murty Divakarla[1], C.D. Barnet[2], M. Goldberg[2], D. Gu[3], X. Liu[4], W. Blackwell[5], E. Maddy[6], S. Kizer[7], G. Guo[6], X.L. Ma[3], A. Gambocorta[6], T. King[6], N. Nalli[6], and K.Zhang[6]

1. I.M. Systems Group, Inc., 3206 Tower Oaks Blvd., Rockville, MD, 20852.
2. Center for Satellite Research and Applications (STAR), NOAA, 5200 Auth Road, Camp Springs, MD 20746.
3. Northrop Grumman Aerospace Systems, One Space Park, Redondo Beach, CA 90278
4. NASA, Langley Research Center, Hampton, VA 23681.
5. MIT Lincoln Laboratory, 244 Wood Street, Lexington, MA 02420.
6. Dell, 8270 Willow Oaks Corp Dr, Fairfax, VA 22031.
7. Science Systems Applications, Inc., One Enterprise Pkwy, Hampton, VA 23666.

Abstract

Atmospheric Vertical Temperature Profiles (AVTP), Atmospheric Vertical Moisture profiles (AVMP), and other Environmental Data Records (EDRs) retrieved by the Cross-track Infrared Sounder (CrIS) and Advanced Technology Microwave Sounder (ATMS, together termed CrIMSS) EDR algorithm were evaluated using matched European Center for Medium-Range Weather Forecasts (ECMWF) analysis fields, radiosonde (RAOB) measurements, and the retrieval products from Infrared Atmospheric Sounder Interferometer (IASI) observations. The proxy CrIS and ATMS Sensor Data Records (SDRs) needed to generate CrIMSS EDR products were derived for the "Focus Day," October 19, 2007, using IASI, Advanced Microwave Sounding Unit (AMSU) and Microwave Humidity Sounder (MHS) observations, respectively. Empirical bias tuning procedures were employed in the CrIMSS EDR algorithm to make the proxy SDRs consistent with the forward model used in the CrIMSS algorithm. The CrIMSS AVTP and AVMP products were evaluated for 46 granules of the Focus Day data set. Using the ECMWF and/or RAOB measurements as the truth, bias and Root Mean Squared (RMS) differences were computed for the CrIMSS and IASI EDR products. The results of the evaluation reveal that the bias tuning component to account for forward model errors and sensor errors is critical to the CrIMSS EDR algorithm performance. Evaluation of the 'infrared plus microwave' AVMP and AVTP retrievals reveals reasonable agreement with the ECMWF and IASI retrieval products. Further assessment of the CrIMSS EDR products with RAOBs and other correlative data sets is in progress to demonstrate launch-readiness.

1. Introduction

The Cross-track Infrared Sounder (CrIS) and the Advanced Technology Microwave Sounder (ATMS) planned to be flown aboard the National Polar-orbiting Operational Environment Satellite System (NPOESS) form the next generation operational sounding system to derive many geophysical parameters. The CrIS instrument is a Fourier Transform Spectrometer (FTS) instrument with a total of 1305 Infrared (IR) sounding channels in 3 bands covering longwave (655-1095 cm^{-1}), midwave (1210-1750 cm^{-1}), and shortwave (2155-2550 cm^{-1}) bands (Glumb and Predina, 2009). The instrument has 9 Fields of Views (FOVs, 3 x 3) for each Field of Regard (FOR) and the radiances are apodized using a Blackman apodization function. It is similar to the recently launched, hyper-spectral sounding instruments, such as the European meteorological polar-orbiting satellite (EUMETSAT) Meteorological Operational satellite programme (MetOp) IASI (launched in 2006) and Aqua satellite Atmospheric Infrared Sounder (AIRS, launched in 2002). The IASI instrument is also an FTS instrument with 8461 channels covering the IR spectrum from 645-2760 cm^{-1} (Diebel et al., 1996). The instrument has four (2 x 2) FOVs for each FOR and the radiances are Gaussian apodized. The AIRS instrument is a cooled grating spectrometer that provides 2378 channels covering the IR spectrum from 3.74-4.61µm, 6.20-8.22 µm, and 8.8-15.4 µm (Aumann et al., 2003). The AIRS instrument has 9 FOVs (3 x3) for each FOR like the CrIS. The MetOp satellite is in the 9:30 AM/PM orbit and the Aqua satellite is in the1:30 AM/PM orbit.

All these hyper-spectral IR sounders are accompanied by microwave (MW) sounding instruments to enable the generation of high quality geophysical products in scenes with up to 80% cloud-cover. The IASI instrument is accompanied by the 15-channel Advanced Microwave Sounding Unit (AMSU-A), and the 5-channel Microwave Humidity Sounder (MHS). The Aqua-AIRS is accompanied by the AMSU-A instrument. The AMSU-A aboard the MetOp and the Aqua satellites is a 15-channel temperature sounder utilizing the 55 GHz Oxygen absorption band. The MHS instrument is mainly a humidity sounder centered on the water vapor line at 183.31 GHz. The ATMS instrument has a combination of channels similar to that of the AMSU-A and MHS. Table 1 shows the characteristics of these instrument channels, similarities and differences.

The CrIS/ATMS instrument suite is a part of the many NPOESS Preparatory Project (NPP) instruments (http://science.nasa.gov/missions/npoess-preparatory-project-npp/) expected to be launched in October 2011. Algorithms to process CrIS/ATMS observations into

Corresponding Author Address: Murty Divakarla, 5211 Auth Road, Camp Springs, MD 20746; e-mail: Murty.Divakarla@noaa.gov.

Sensor Data Records (SDRs), and process SDRs into geophysical parameter retrievals (here after called Environmental Data Records, EDRs) have been developed. The Northrop Grumman Aerospace System (NGAS) has adapted the Atmospheric Environmental and Research (AER) CrIS and ATMS (CrIMSS) EDR algorithm to retrieve Atmospheric AVTP, AVMP, atmospheric pressure profiles and many other ancillary EDR products.

A pre-launch evaluation of the CrIMSS EDR products helps to insure that the EDR algorithm produces products meeting the specifications (Barnet et al., 2011). The evaluation can also suggest possible improvements to the EDR algorithm to mitigate unforeseen circumstances for at-launch readiness. This paper presents an evaluation of the CrIMSS AVTP and AVMP EDR products. The IASI SDR and EDR products and collocated validation datasets generated at National Oceanic and Atmospheric Administration (NOAA) for the Focus Day October 19, 2007 were used to generate proxy CrIS/ATMS SDRs and NGAS-CrIMSS EDR products. Proxy data generator algorithms developed by Liu and Kizer (2009) and Jairam et al. (2009) were applied to IASI and AMSU-A/MHS observed SDRs to generate CrIS and ATMS proxy SDRs, respectively. The CrIMSS EDR operational code (CrIMSS_V1.5) ported to work on Linux/Unix platforms (Kizer et al., 2010) was implemented at NOAA center for Satellite Applications and Research (STAR) to derive CrIMSS-EDR products. The CrIMSS EDR products were evaluated with collocated ECMWF analysis fields. The IASI EDRs were used as a baseline to measure CrIMSS EDR performance, since they are based on the source radiances used to derive proxy SDRs.

2. NOAA IASI and NGAS-CrIMSS EDR Products

NOAA/STAR operates two near-real time processing systems, one for Aqua-AIRS/AMSU-A processing, and the other for IASI/AMSU-A/MHS processing. Data products derived from these systems have been in dissemination to many weather centers for many years (Goldberg et al., 2004, Barnet, 2009). The NOAA IASI EDR retrieval algorithm is an adaptation from the AIRS/AMSU-A retrieval suite (Susskind et al., 2003; Aumann et al., 203) with enhancements to process IASI/AMSU-A/MHS SDRs (Barnet et al., 2009). The system produces Level-1C radiance products (SDRs for IASI/AMSU-A/MHS), cloud cleared radiance files (CCRs), and EDRs of AVTP, AVMP, ozone, surface and cloud parameters, and many other trace gas products. The system is getting augmented as NOAA Unique CrIS/ATMS Product System (NUCAPS) for future CrIS/ATMS product production. The IASI system uses the MW retrieved atmospheric state to compute first cloud-cleared radiances, for subsequent improvements in cloud-clearing and in the final infrared (IR) physical retrieval. The system produces Level-1C radiance products (SDRs), cloud cleared radiance files, and Level-2 EDR profiles of Atmospheric Vertical Temperature (AVTP), Atmospheric Vertical Moisture (AVMP), ozone, surface and cloud parameters, and many other trace gas products. The AVTP, AVMP and other products are available from three stages of the retrievals algorithm, viz. (1) MW-only stage, (2) regression stage, and from the (3) the final physical IR retrieval stage.

The CrIMSS EDR algorithm (Snell et al., 2003; NGAS, 2007; Lynch et al., 2009) developed by the AER Inc., is the official EDR algorithm to process near-future CrIS/ATMS SDRs available from the NPP satellite. NGAS adapted the AER-CrIMSS EDR algorithm to produce a science code version to retrieve AVTP, AVMP, atmospheric pressure profiles and many ancillary EDRs (NGAS, 2007). A near-real time operational code based on the science code was developed by Raytheon to produce EDRs operationally. The CrIMSS EDR Version 1.5 operational code (OPS) was ported by Kizer et al. (2009) to function on Linux/Unix platforms and is available through Joint Polar Satellite System (JPSS) program office. The functionality and the validity of the EDR products generated by the ported version were verified by Liu and Kizer (2010) for their consistency with the CrIMSS EDR OPS code. The algorithm produces AVTP and AVMP products for the ‘MW-only’, and for the ‘IR+MW’ retrieval. These are analogous to IASI AVTP and AVMP products from MW, and IR physical retrieval stages, respectively.

3. The CrIS/ATMS ‘Focus-Day’ Proxy Data Package for CrIMSS EDR Evaluation

To generate proxy SDRs and evaluate EDR products from a new instrument suite like the CrIS/ATMS, it is necessary to have SDRs and EDRs from a similar sounding instrument, and collocated truth (e.g., ECMWF/RAOB) measurements. Since both IASI and CrIS are FTS instruments, and the IASI instrument observes radiances for the whole IR spectrum (645-2760 cm^{-1}) at a much higher spectral resolution (0.25 cm^{-1}) than the CrIS, it is possible to derive CrIS proxy radiance spectra by a direct transformation of the IASI radiances. One such algorithm was developed by Liu and Kizer (2009) to derive CrIS SDRs by matching the spectral resolution between the two FTS instruments. The AMSU-A and MHS instruments accompanying the IASI instrument provide the necessary data for the ATMS proxy generator algorithm developed by Jairam et al., (2009). The algorithm uses a regression method to derive ATMS SDRs taking into account both the spectral and spatial differences between the ATMS and AMSU/MHS instruments. The NOAA IASI operational system-produced SDRs and EDRs and other ancillary data (surface pressure, land fraction etc) provide the much needed data to generate CrIS/ATMS proxy SDRs, and in turn, the CrIMSS EDR products. The ECMWF, National Center for Environmental Prediction – Global Forecast System (NCEP-GFS) analysis fields, and RAOB measurements collocated with the AIRS/IASI EDR products form the basis for many validation data sets (Divakarla et al., 2006; Divakarla et al., 2008;

Divakarla et al., 2009a, Divakarla et al., 2009b) and provide the truth measurements for CrIMSS EDR evaluation.

One of the validation data sets is the “Focus Day” data set for October 19, 2007 which consists of MetOp (9:30 AM/PM) IASI/AMSU-A/MHS global SDRs, IASI retrieval products (EDRs), matched NCEP/GFS, and the ECMWF analysis fields, and global RAOB measurements. Using this data set, necessary infrastructure was created at NOAA/STAR to generate CrIS/ATMS proxy SDRs and CrIMSS EDR products. A package consisting of all the ‘Focus-Day’ (October 19, 2007) data sets was released to the Integrated Program Office (IPO, currently restructured as JPSS) to facilitate pre-launch CrIS/ATMS calibration/validation activities. The release, “The CrIS/ATMS Proxy Data Package, Release 1.0”, consists of 236 three-minute granules CrIS/ATMS proxy SDRs, matched IASI/AMSU-A/MHS SDRs, IASI EDR products, and the NCEP-GFS and ECMWF forecast analysis fields (Barnet et al., 2010). Figure 1 depicts approximate geographic locations of these granules. The matched NCEP-GFS forecast/ analysis fields provide surface pressure required as a boundary condition to perform CrIMSS EDR retrievals. The ECMWF forecast/analysis fields help emulate the available data sets for early validation of the CrIMSS EDRs. The Focus Day package and a document (Barnet et al., 2010) with a complete description and evaluation of the data sets, and reader/writer routines are available for a down-load from NOAA website (ftp://ftp2.orbit.nesdis.noaa.gov/smcd/tking/IPO_REL_V 1.0). The second data set contains global RAOB-matched collocations of IASI/AMSU-A/MHS (and AIRS/AMSU-A) SDRs, NCEP-GFS and the ECMWF analysis fields. A time-match criterion of (±3 hours) and a distance-match criterion of 100 km in radius were used in generating the collocations. These data sets are produced on a daily basis and are referred to as MetOp Global Data (MGD) sets. A subset of the MGD data set (May 1-15, 2008), and corresponding proxy CrIS/ATMS SDRs at global RAOB locations is in the final stage for a release to the JPSS program office. A third data set planned for future release is the NOAA Aerosols and Ocean Science Expeditions (AEROSE), details of which are discussed by Morris et al. (2006) and Nalli et al.(2011). The Algorithm and Theoretical Basis Documents (ATBDs) for the NOAA IASI SDR/EDR products (Barnet, 2009), the NGAS CrIMSS EDR algorithm (NGAS, 2007), and details of the CrIS/ATMS Proxy generator algorithms (Liu and Kizer, 2009; Jairam, 2009) are available at JPSS Program Office, and also as Sounding Atmosphere Team (SOAT) meeting presentations (SOAT, 2009; SOAT, 2010), and hence are not discussed.

The CrIS/ATMS Focus Day package is in use at STAR, at the Langley Research Center (LaRC), NGAS, and by many other user groups to evaluate the CrIMSS EDR performance and to improve the CrIMSS algorithm by employing empirical bias tuning (Gu et al., 2011). This paper presents an evaluation of the CrIS/ATMS SDRs and EDR products derived using the Focus Day data set, and utilizing the empirical bias-tuning procedure developed by Gu et al. (2011). Utilization of MGD data set to evaluate CrIMSS EDRs is in progress.

4. Evaluation Criteria and Statistical Metrics

The CrIS and ATMS proxy SDRs were first evaluated with corresponding channel observations from the IASI/AMSU-A/MHS SDRs to ensure that the proxy SDRs are of good quality for use with the CrIMSS EDR algorithm. The CrIMSS-EDR products were evaluated with matched ECMWF analysis fields, RAOB measurements, and the MetOp-IASI EDRs produced at NOAA. The ECMWF/RAOB measurements were taken as the truth and bias and RMS differences between the truth and CrIMSS AVTP and AVMP products were computed for (a) ‘MW-only’ retrievals, and for (b) ‘IR+MW’ reported retrievals. IASI EDR product statistics were also computed for the same ensemble for the ‘MW-stage’ retrievals and for the final IR physical retrieval that correspond to (a) and (b), respectively. Temperature statistics were derived for 1 km layers for 1000 hPa to 0.01 hPa. For water vapor, statistics were computed for column densities converted to integrated column water in 2-km layers from the surface to 100 hPa. The water vapor bias is computed as a percentage of the reference (ECMWF or RAOB) water vapor amount in the layer (100 x (RET – REF)/REF). RET stands for the AVMP product from the IASI or the CrIMSS algorithm. The percent error for each 2-km layer was computed by weighting the standard deviation with the reference water vapor amount in the layer (Divakarla et al., 2006). A set of 46 granules were used to generate statistics. In addition to the statistical metrics, an in-depth qualitative analysis of CrIMSS EDR products was performed using the ECMWF and IASI EDRs for a selected set of granules.

5. Results and Discussion

Following sections discuss the evaluation of CrIS/ATMS SDRs and CrIMSS AVTP and AVMP products.

5.1 The CrIS and ATMS Proxy SDR Evaluation

Proxy CrIS SDRs were evaluated by comparing the brightness temperatures of the CrIS spectrum with that of the IASI spectrum both spectrally and spatially. Similarly, plots of AMSU-A and ATMS brightness temperature maps were compared for all the ATMS channels that have identical characteristics as that of AMSU-A (Table 1). Figure 2 shows the brightness temperature spectra observed by the IASI instrument, and the corresponding proxy brightness temperatures for the CrIS instrument for a typical FOR. The IASI instrument has 4 fields of view (FOVs) for each Field of Regard (FOR). To generate 9 FOVs for the proxy CrIS data set, these 4 IASI observations are interpolated onto 9 measurement locations. The higher spectral resolution of the IASI instrument is evident from the figure. The

CrIS proxy brightness temperature spectrum is of lower spectral resolution than IASI and has a total of 1305 IR channels in 3 bands covering longwave (655-1095 cm^{-1}), midwave (1210-1750 cm^{-1}), and shortwave (2155-2550 cm^{-1}) channels.

Figure 3a shows a comparison of brightness temperature maps for a typical window channel (962.5 cm^{-1}). An examination of these figures reveals very good agreement between the CrIS and IASI radiances both spectrally and spatially. Comparison of the CrIS proxy with the IASI brightness temperatures for the channels that are very close in wavenumbers (some window channels) agree very well, typically within a degree. For channels that have high resolution line structure, the differences are slightly larger. These differences are due to higher spectral resolution of the IASI instrument compared to that of the CrIS and should not be interpreted as errors in the CrIS proxy data sets.
Figure 3b shows the comparison of proxy ATMS 23GHz channel brightness temperatures with the AMSU-A observations. As shown in Table 1, some of the ATMS channel characteristics are exactly identical to the AMSU-A channels, and a comparison of the channels identical in all respects should provide very good agreement. An examination of the figures reveals that the AMSU-A channel 1 and ATMS channel 1 match well for most of the globe except the differences are larger over sea/ice boundaries for the high latitude regions (>70^{o} latitudes). Evaluation of other ATMS channels that have identical characteristics as the AMSU show promising agreement. Again, differences for dissimilar ATMS and AMSU channels are real and demonstrate real differences and are not to be interpreted as errors in the proxy data. Some of the differences at high latitudes sea/ice boundaries and at the land/sea interface were resolved in the updated version and we are currently reprocessing the ATMS proxy data with the latest algorithm. Nevertheless, the data generated and presented with the current version is quite good for use with the NGAS EDR algorithm.

5.2. CrIMSS EDR Evaluations

The NOAA/STAR IASI System employs the AIRS Science Team approach (Susskind et al., 2003) with enhancements to generate IASI EDRs (Barnet et al., 2010) and produces AVTP and AVMP products from the (1) microwave stage, (2) regression stage and for (3) the final physical retrieval stage. The CrIMSS EDR (CrIMSS_V1.5) algorithm employs a simultaneous retrieval algorithm (NGAS, 2007) and also produces AVTP and AVMP products for the 'MW-only' retrieval and for the 'IR+MW' retrieval analogous to IASI AVTP and AVMP products from stages (1), and (3) respectively. While the IASI system uses real SDR observations from the IASI/AMSU-A/MHS observations, the CrIMSS EDR algorithm uses the CrIS/ATMS proxy SDRs. Hence, some of the limitations imposed by the proxy data generator algorithms, and the sensor artifacts might influence the CrIMSS EDR performance/yield. Thus, the whole intent of this validation exercise is not to compare different retrieval systems and their performance but to address any unforeseen issues with the CrIMSS EDR algorithm and to suggest possible improvements for launch readiness.

A set of 46 granules (Figure 4) were used in this evaluation process. The granules were chosen to assess the degree of difficulty encountered by the EDR algorithm for different situations. The set includes day and night granules from tropics, mid-latitudes, and polar regions and over the ocean and land. In an earlier evaluation of the CrIMSS EDR products with the ECMWF and IASI EDRs, Divakarla et al. (2010a, 2010b) have revealed the need for an empirical bias tuning component in the CrIMSS EDR algorithm. Accordingly Gu et al. (2011) have developed a bias-tuning procedure and was implemented in the CrIMSS EDR algorithm. The CrIMSS EDRs generated after implementing the bias-tuning procedure were used in this evaluation. Figure 5 shows the percentage of accepted samples by the NOAA-IASI system and the NGAS CrIMSS EDR algorithm for tropics, midlatitudes and the polar regions, and over the ocean and land. The total sample size is about 30,000, and the overall global yield is about 73% and 35% for the NOAA IASI EDRs, and the NGAS CrIMSS EDRs, respectively.

The CrIMSS EDR algorithm shows relatively lower yields over the land and the polar granules. This may be due to some of the limitations of the ATMS proxy SDRs that have known difficulties over the sea/ice boundaries and beyond ±70 degree latitudes. Thus, to be on safe side, samples that fall within ±60 degree were chosen (IASI yield 78%, CrIMSS yield 43%), and bias and RMS differences were computed for different regions (tropics, mid-latitudes) and for different categories (land, ocean, and ALL cases that correspond to land+ocean+coast samples).

Figure 6 shows the AVTP and AVMP biases with reference to the ECMWF analysis fields before and after employing the bias-tuning procedure in the CrIMSS EDR algorithm. The figure illustrates that biases with the ECWMF were quite large when the EDR algorithm was run without the bias-tuning component. The larger bias might be due to forward model differences used by the ATMS proxy data algorithm and the forward model used in the CrIMSS EDR algorithm, side lobes, and other artifacts in the proxy ATMS SDRs. Without bias-tuning, the 'MW-only' stage retrievals were found not to converge or converge to a wrong solution. Another possible consequence of 'MW-only' retrieval bias is its influence on the computed cloud-cleared radiances used in the next 'IR+MW' retrieval stage, and consequent biases shown in the Figure 6 for the 'IR+MW' retrieval stage. However, after employing the bias-tuning procedures in the CrIMSS EDR algorithm, the biases observed with respect to ECMWF were quite small and are similar to the biases observed with the IASI retrievals shown in subsequent figures. Figures 7a-b show the RMS difference and biases for the CrIMSS 'MW-only' and 'MW+IR' AVTP and AVMP products with respect to the ECMWF for the sea-only cases. Also shown in the figures are the corresponding RMS differences and biases for the IASI retrievals for the same ensemble. The IASI retrievals used here are from a former version of the current NOAA operational version and we are currently updating these EDR products with the current operational version. Nevertheless, these IASI EDRs are close to the current operational version for comparison as a baseline. An examination of these figures reveals that the temperature retrievals from the CrIMSS EDR algorithm are quite comparable to the IASI retrievals, but with a relatively smaller yield (Tropical Oceans, IASI: 88%, CrIMSS: 53%; Midlatitude Oceans: IASI: 74%, CrIMSS: 48%, Figure 5). The CrIMSS water vapor retrievals show a little larger wet bias, and correspondingly larger RMS difference with the ECMWF analysis.

Figure 8 shows the comparison of Total Precipitable Water (TPW) derived from IASI final physical IR retrieval, CrIMSS 'IR+MW' retrieval and ECMWF analysis fields for granules 139-142 over the ocean (Granule locations are shown in Figure 1). A qualitative evaluation of the figure reveals that the patterns match pretty well, and the CrIMSS EDRs show a slight overestimation of water vapor (more reddish in color) compared to the ECMWF, and rightly portrayed as a wet bias in Figure 7b. When statistics (Figures 9a-b) were computed for ALL samples (ocean+land+coast, LAT60, Figure 5), the AVTP and the AVMP retrievals show a little larger RMS differences (Figure 9a) at the surface (1.2º K and 1.4ºK in Figure 7a vs. 1.4º and 1.6ºK in Figure 9a for the IASI and CrIMSS, respectively for AVTP, and minor degradation in the water vapor RMSD) to that of ocean-only cases. The statistics for ALL cases are also dominated by the ocean samples because there are more ocean granules than the land granules in the 46 granule data set, and the CrIMSS EDR yield is also lower over the land than over the ocean (Figure 5). In general, uncertainties in the spectral emissivity, daytime convective build-up, and the error in the interpolated surface pressure due to topography do contribute for lower yields over the land. In addition, some of the limitations of the proxy data over land might be contributing to the lower yield. This requires further investigation. We are also investigating the larger biases observed in the CrIMSS AVMP statistics. This may require another look into the bias-tuning procedures, and selection of more confident clear-cases for use in the CrIS and ATMS bias-tuning procedures. A number of groups (NGAS, LaRC, and STAR) are currently looking into improving the bias-tuning. Nevertheless, results presented here with the first cut bias-tuning efforts by Gu et al. (2011) show very encouraging results to move forward, and identify problem areas for a possible mitigation. We are currently processing all the 236 granules of the Focus Day and the MGD data set with the latest versions (updated ATMS proxy, updated IASI EDRs from the operational version, improved bias-tuning with very confident clear cases, etc.) for a more comprehensive analysis.

The availability of IASI AVTP and AVMP products, associated QC flags and other ancillary products (MW and IR emissivities at the hinge points, cloud-cleared radiances, cloud amounts, noise-amplification factors in cloud-cleared radiances) offer a wide variety of diagnostic measures to further assess and improve CrIS/ATMS proxy SDRs and CrIMSS EDR products. Plots of statistics for different regions and stratifications (tropics, midlatitudes, polar; ocean, land; day and night; clear and cloud-cleared) are available and can be obtained from the corresponding author. One encouraging results is that, although the NOAA IASI EDR algorithm and the CrIMSS EDR algorithm use different approaches in minimizing the observed and calculated radiances in the retrieval algorithm, the biases observed with reference to ECMWF analysis fields are very similar for the AVTP EDRs.

6. Summary and Conclusions

It should be noted that the NOAA/STAR IASI System has been working for at least 3 years and has matured over time. In addition, the system uses real SDR observations in contrast to proxy SDRs used by the CrIMSS algorithm. Thus, the whole intent of this validation exercise is to address any issues with the CrIMSS algorithm/EDRs and suggest possible improvements to mitigate unforeseen circumstances for launch readiness. The evaluation performed on the CrIMSS proxy SDRs/EDRs reveals that:

1. Proxy Data are of Good Quality: The CrIS proxy SDRs are a direct transformation of IASI Level-1C data. It is mathematically accurate, and no ad hoc conversion is needed. The ATMS proxy SDRs are of good quality for most of the globe except for high latitude regions (>70^{o} latitudes) and over the sea/ice boundaries. We are in the process of implementing the latest ATMS proxy generator algorithm that might help to alleviate some of the issues observed over the land and over the polar regions.

2. Bias-tuning is critical for CrIMSS EDR Performance: Bias tuning procedures implemented in the CrIMSS algorithm improve CrIMSS EDR performance substantially. We are currently testing and improving the bias-tuning efforts by applying stringent clear-case detection and selecting highly confident clear-cases.

3. EDR Performance: The CrIMSS algorithm shows reasonable ability for a launch-ready performance. Lower yields of CrIMSS EDR algorithm over polar granules and land cases is probably due to the limitations imposed by the proxy SDRs and needs to be verified. We anticipate that the new ATMS proxy SDRs and other enhancements (improved bias tuning, optimization of noise) will improve further, the agreement between CrIMSS EDRs and the truth measurements.

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Table 1. Spectral comparison of ATMS, AMSU-A channels (Jairam et al., 2009).

	AMSU/MHS			ATMS		
	Ch	GHz	Pol	Ch	GHz	Pol
AMSU-A	1	23.8	QV	1	23.8	QV
	2	31.399	QV	2	31.4	QV
	3	50.299	QV	3	50.3	QH
				4	51.76	QH
	4	52.8	QV	5	52.8	QH
	5	53.595 ± 0.115	QH	6	53.596 ± 0.115	QH
	6	54.4	QH	7	54.4	QH
	7	54.94	QV	8	54.94	QH
	8	55.5	QH	9	55.5	QH
	9	fo = 57.29	QH	10	fo = 57.29	QH
	10	fo ± 0.217	QH	11	fo±0.3222±0.217	QH
	11	fo±0.3222±0.048	QH	12	fo± 0.3222±0.048	QH
	12	fo ±0.3222±0.022	QH	13	fo±0.3222±0.022	QH
	13	fo± 0.3222±0.010	QH	14	fo±0.3222 ±0.010	QH
	14	fo±0.3222±0.0045	QH	15	fo± 0.3222±0.0045	QH
	15	89.0	QV			
MHS	16	89.0	QV	16	88.2	QV
	17	157.0	QV	17	165.5	QH
	18	183.31 ± 1	QH	18	183.31 ± 7	QH
	19	183.31 ± 3	QH	19	183.31 ± 4.5	QH
	20	191.31	QV	20	183.31 ± 3	QH
				21	183.31 ± 1.8	QH
				22	183.31 ± 1	QH

- Exact match to AMSU/MHS
- Only Polarization different
- Unique Passband
- Unique Passband, and Pol. different from closest AMSU/MHS channels

QV = Quasi-vertical; polarization vector is parallel to the scan plane at nadir

QH = Quasi-horizontal; polarization vector is perpendicular to the scan plane at nadir

Based on: Thomas Kleespies, "Rel. Info. Content of the ATMS and AMSU/MHS," IEEE Trans. Geosci. And Remote Sensing, Vol. 45, No. 7 July 2007

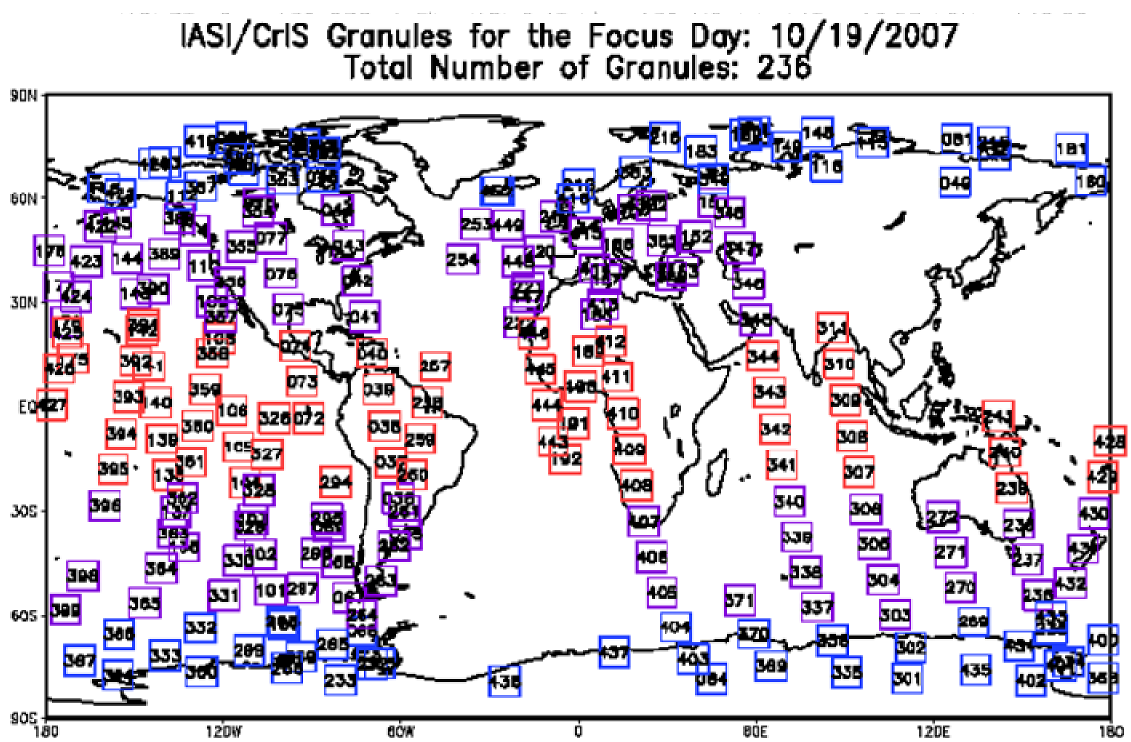


Figure 1. Locations of CrIS/ATMS proxy data SDR granules for the focus day October 19, 2007. The data were derived from the MetOp IASI/AMSU-A/MHS matched ascending and descending (9:30AM/PM) IASI/AMSU-A/MHS granule data sets. About 236 granules, each with approximately 3 minutes of data were plotted in the figure. The granule locations and the size of the granules are approximate depictions and are not to scale in the figure. Different colors are used to depict granules for the tropics, mid-latitudes and polar regions. The proxy data package can be down-loaded from NOAA FTP web-site (ftp://ftp2.orbit.nesdis.noaa.gov/smcd/tking/IPO_REL_V1.0).

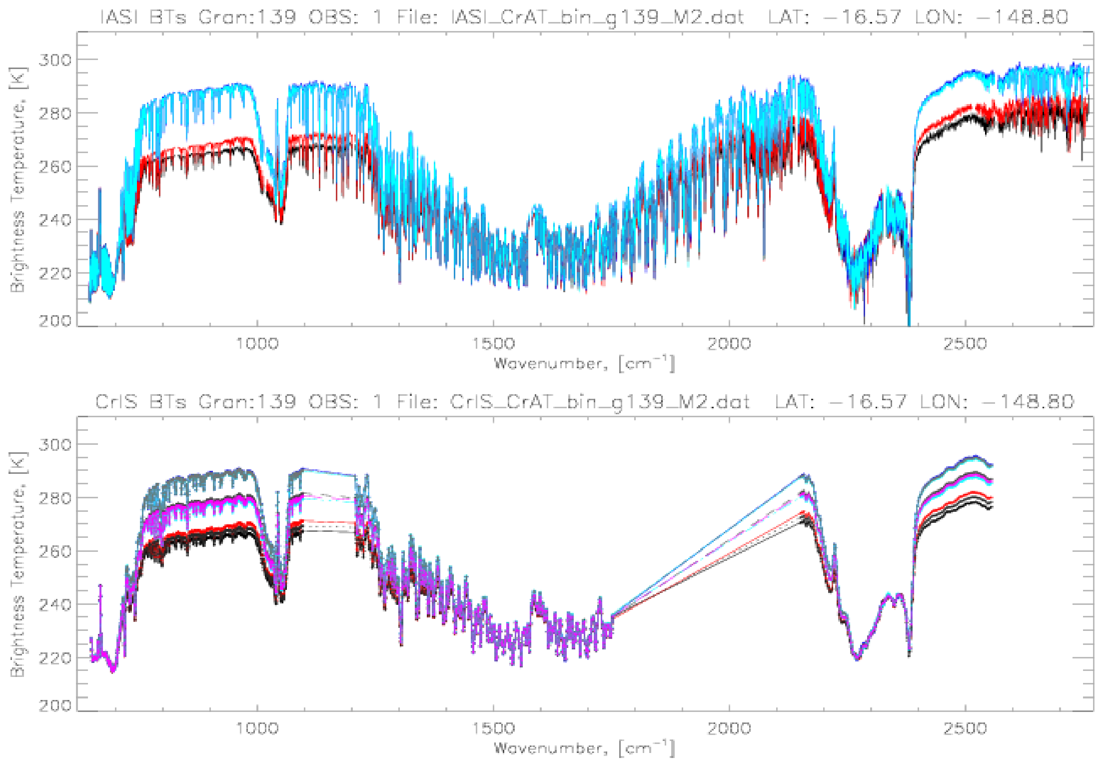
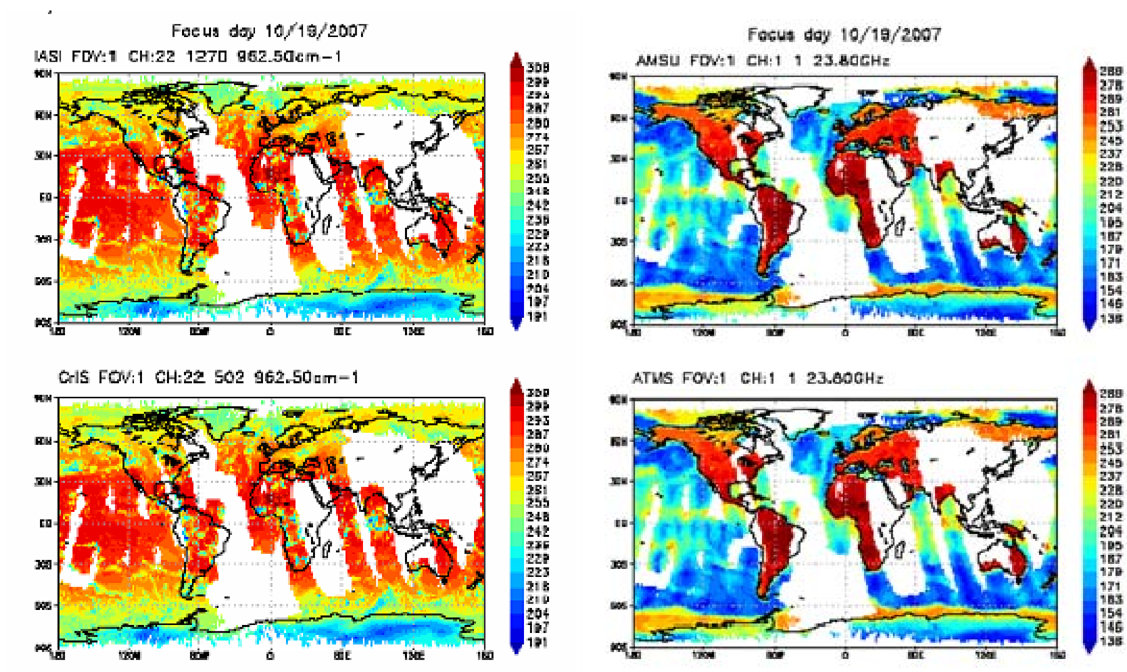


Figure 2. IASI observed brightness temperature spectra (top) and the corresponding CrIS proxy brightness temperature spectra (bottom). The IASI instrument has 8461 IR channels spanning the IR spectrum 645-2760 cm^{-1}. The instrument has 4 fields of view (FOVs) for each Field of Regard (FOR) and the radiances are Gaussian apodized. The CrIS instrument has a total of 1305 IR channels in 3 bands covering longwave (655-1095 cm^{-1}), midwave (1210-1750 cm^{-1}), and shortwave (2155-2550 cm^{-1}) channels with spectral gaps between the bands. The instrument has 9 FOVs for each FOR and the radiances are Blackman apodized.



(a) (b)

Figure 3(a). Focus Day (October 19, 2007) Brightness temperature map of IASI (left top) and proxy CrIS (left bottom) for 962.5 cm^{-1} window channel . (b) Brightness temperature map of AMSU-A (right top) and proxy ATMS (right bottom) for 23GHz channel.

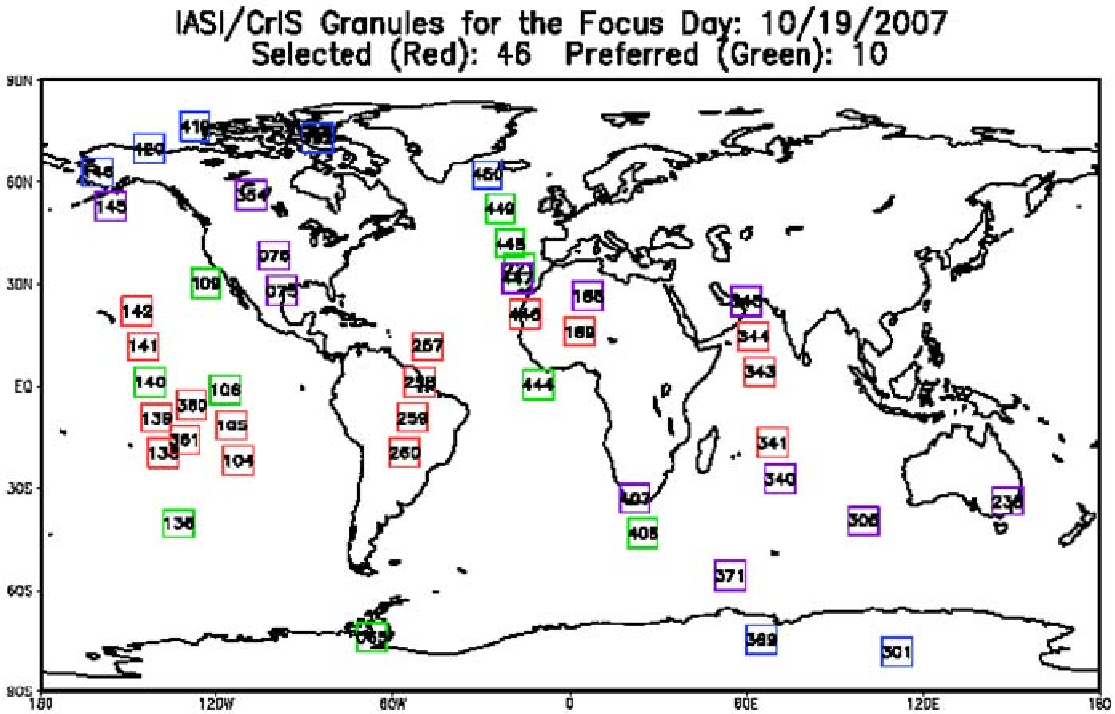


Figure 4. Locations of selected proxy data granules used in the validation of NGAS-CrIMSS EDR products. The selection is based on the accepted number of samples, and the number of clear soundings as evidenced by the IASI retrieval system. (The granule locations and the size of the granules are approximate depictions and are not to scale in the figure).

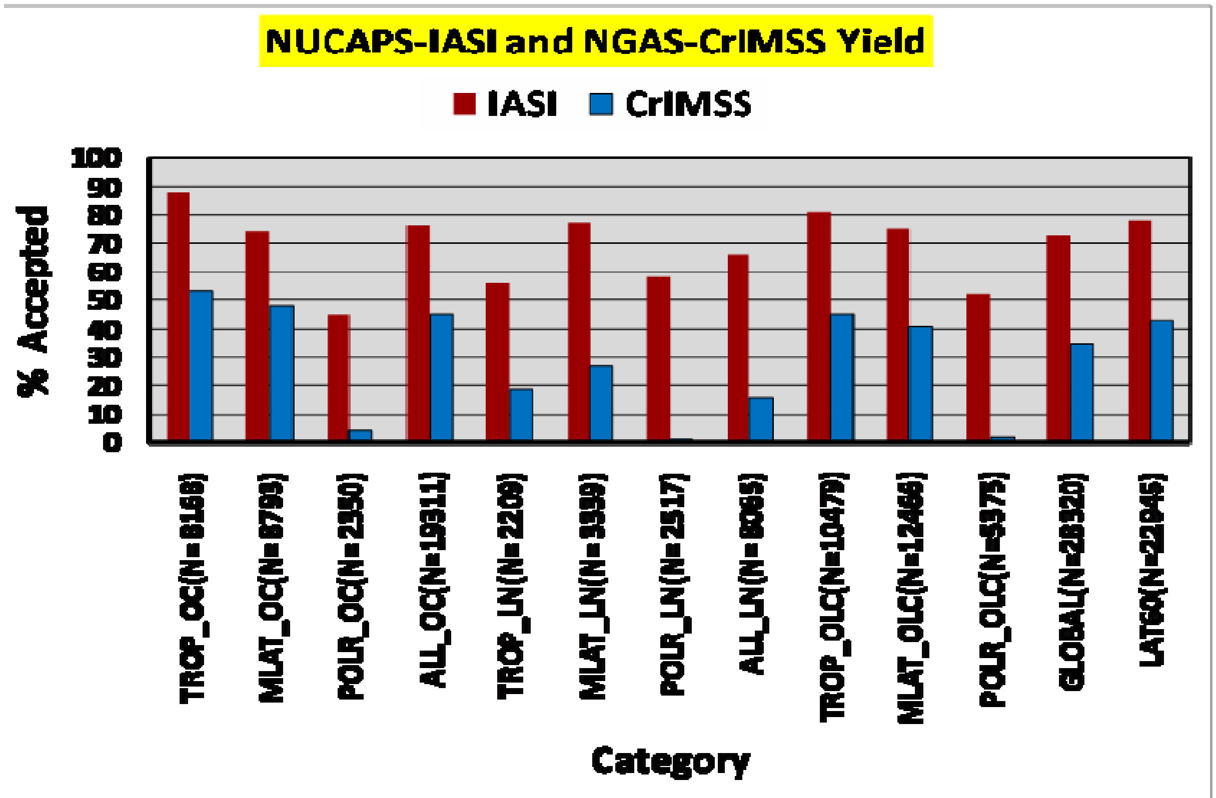


Figure 5. Percentage of accepted samples for the NOAA IASI and the NGAS-CrIMSS EDR algorithm for tropics, midlatitudes, polar regions and over the ocean and land. The total GLOBAL sample size is about 30,000, and the overall yield is about 73% and 35% for the NOAA IASI EDRs, and the NGAS CrIMSS EDRs, respectively. The IASI system uses actual IASI/AMSU-A/MHS SDRs. The CrIMSS EDR algorithm uses proxy CrIS/ATMS SDRs. The CrIMSS EDR algorithm shows relatively lower yields over the land and polar regions. This may be due to some of the limitations of the ATMS proxy SDRs that have known difficulties over sea/ice boundaries and beyond ±70º latitudes.

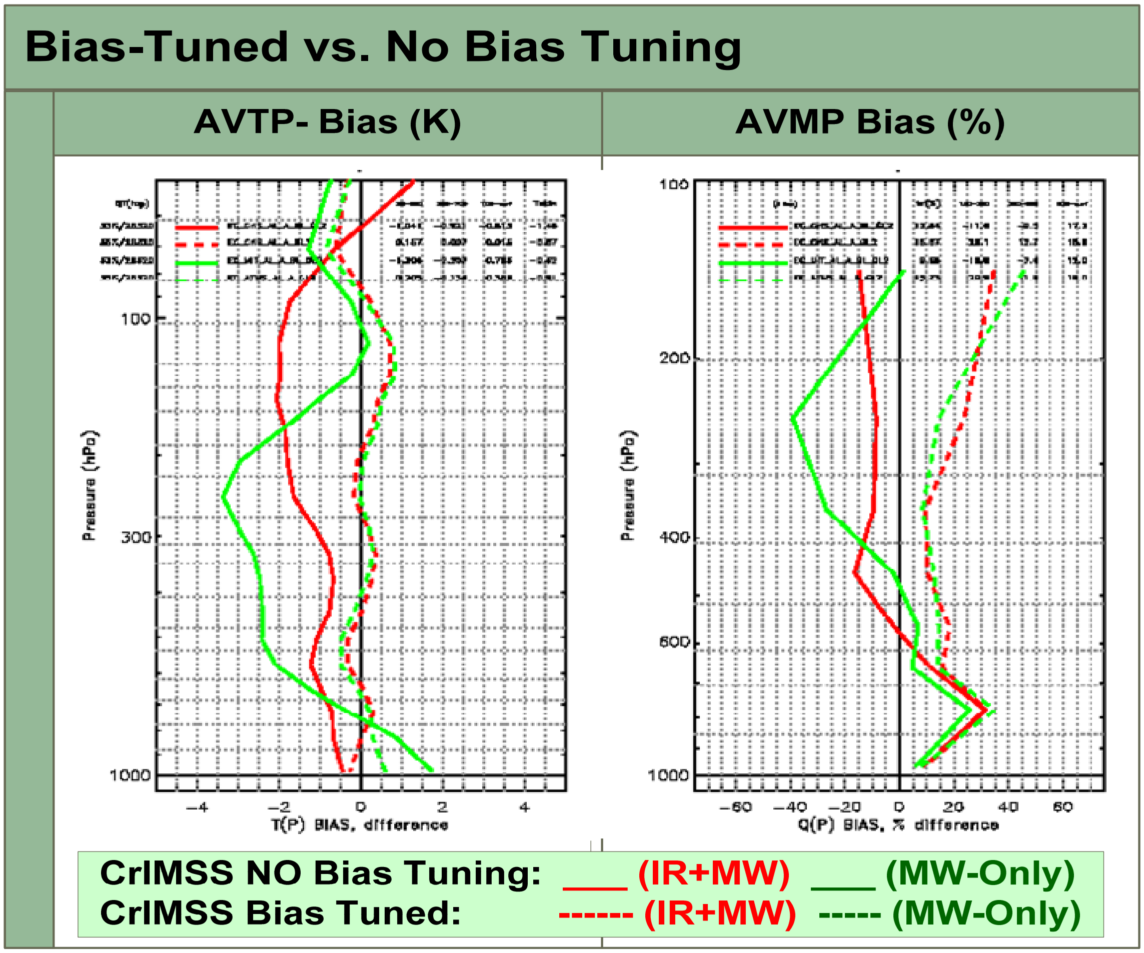


Figure 6. The CrIMSS AVTP and AVMP biases before and after the bias-tuning procedure. These figures reveal that the bias-tuning component implemented in the CrIMSS EDR code is critical for the EDR algorithm performance.

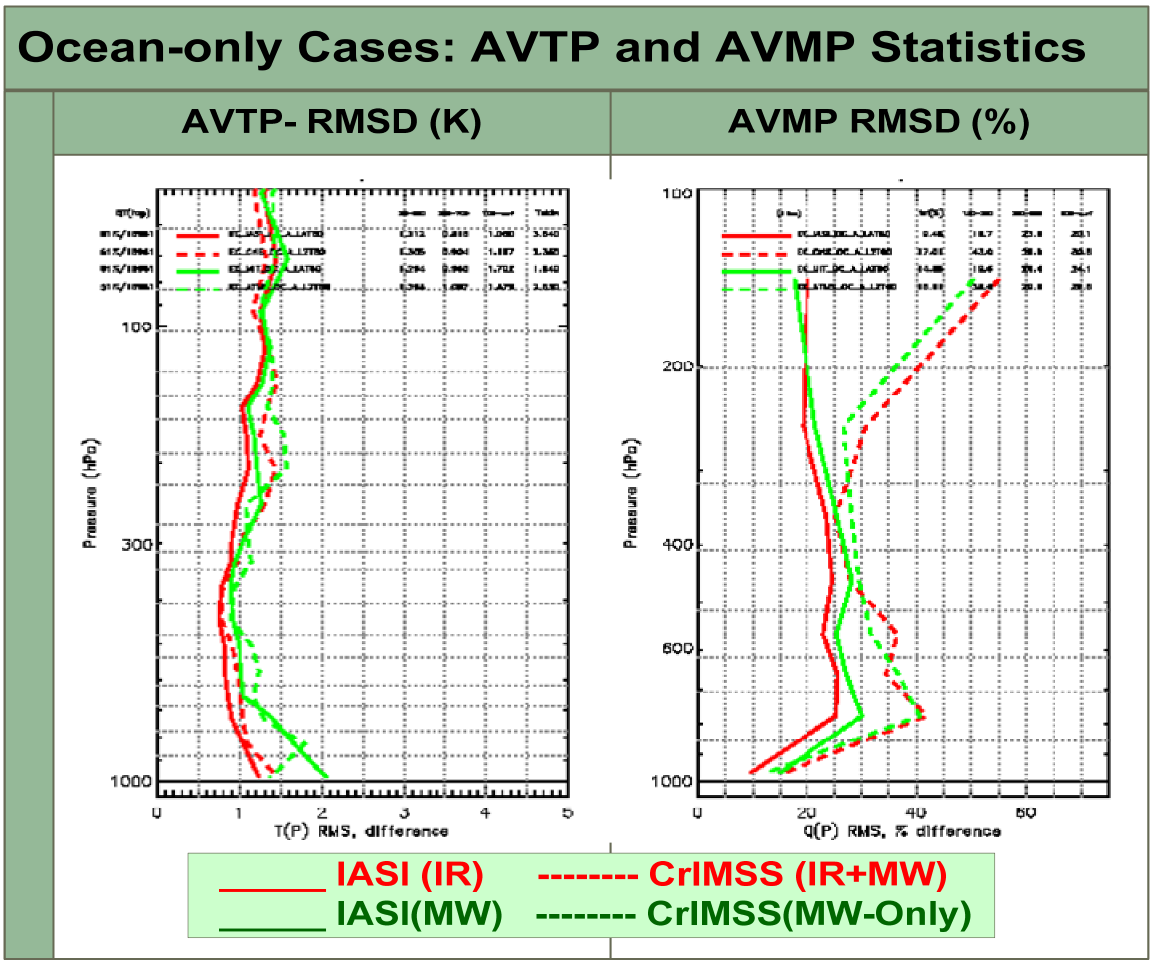


Figure 7a. AVTP and AVMP RMS differences for NGAS-CrIMSS and IASI EDRs with reference to ECWMF analysis fields for the ocean-only cases. The CrIMSS AVTP products from both the stages ('MW-only'; IR+MW') are quite comparable to the corresponding IASI EDR AVTP products. The CrIMSS AVMP RMS difference for the middle and upper troposphere shows a little larger RMS difference compared to the IASI AVMP product.

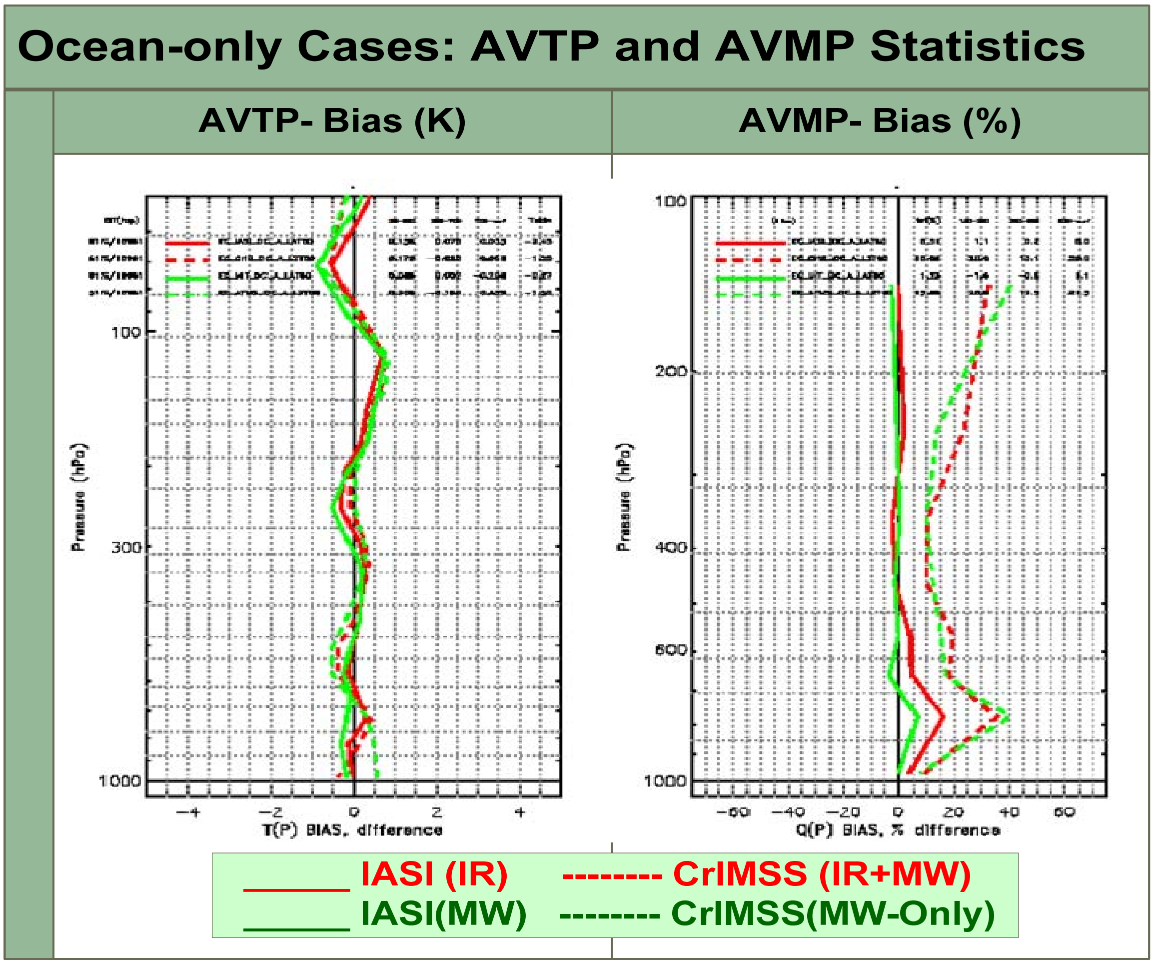


Figure 7b. AVTP and AVMP biases for NGAS-CrIMSS and IASI EDRs with reference to ECMWF analysis fields for the ocean-only cases. The CrIMSS AVTP biases show similar tendency to that of IASI EDR product. CrIMSS AVMP product shows a little larger wet bias with reference to ECMWF analysis fields. This requires further investigation.

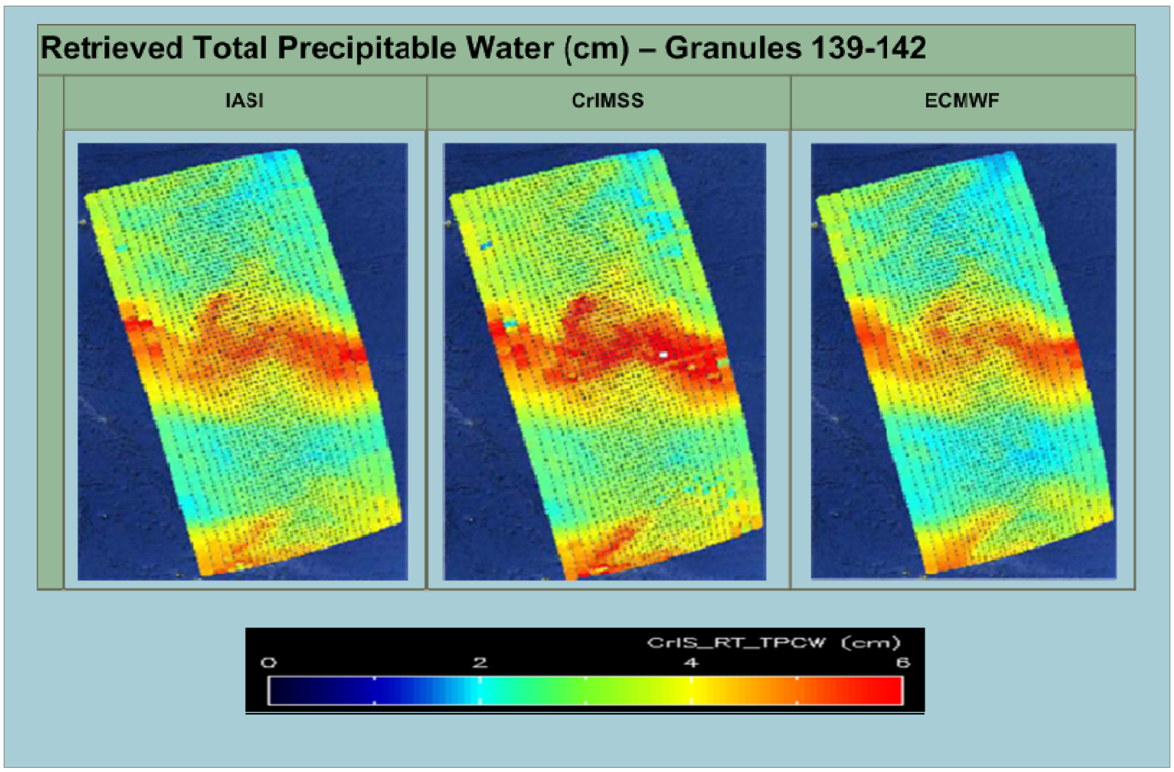


Figure 8. Comparison of Total Precipitable Water (TPW) derived from the NOAA-IASI EDRs, CrIMSS-EDRs and the ECMWF analysis fields for Granules 139-142 over the ocean (Figure 4). The figures reveal a slight overestimation of water vapor by the CrIMSS EDR algorithm in comparison to the ECWMF analysis fields, and rightly portrayed as a wet bias seen in Figure 7b for the CrIMSS AVMP.

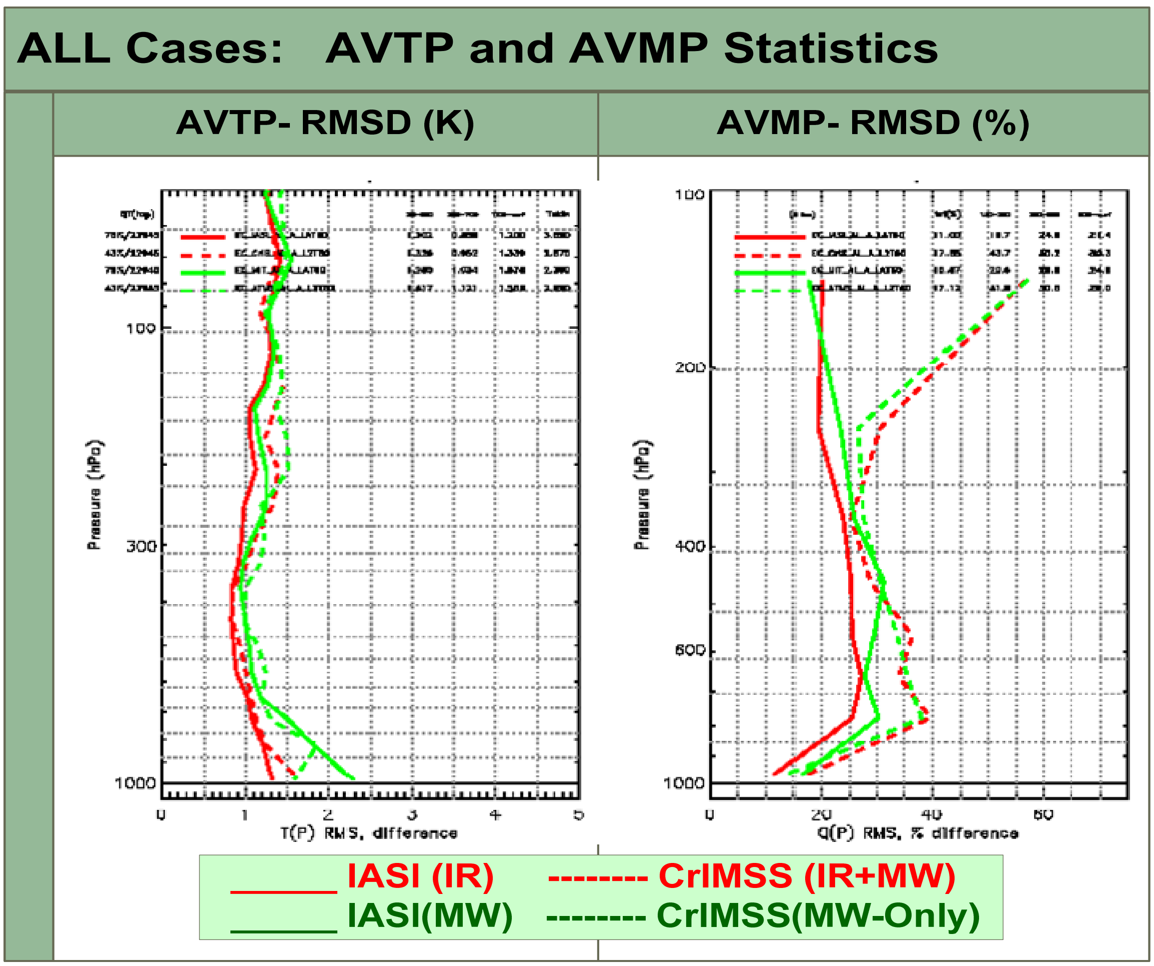


Figure 9a. AVTP and AVMP RMS differences for NGAS-CrIMSS and IASI EDRs with reference to ECWMF analysis fields for ALL (ocean, land, and coastal) cases. These statistics are similar to that of 'ocean-only' cases except at the surface where the AVTP EDRs show about two-tenths of a degree higher RMS difference. The AVMP RMS differences are a little larger at the surface compared to 'ocean-only' cases (Figure 7a). This is probably due to the uncertainties in the spectral emissivity, daytime convective build-up, and the error in the interpolated surface pressure due to topography.

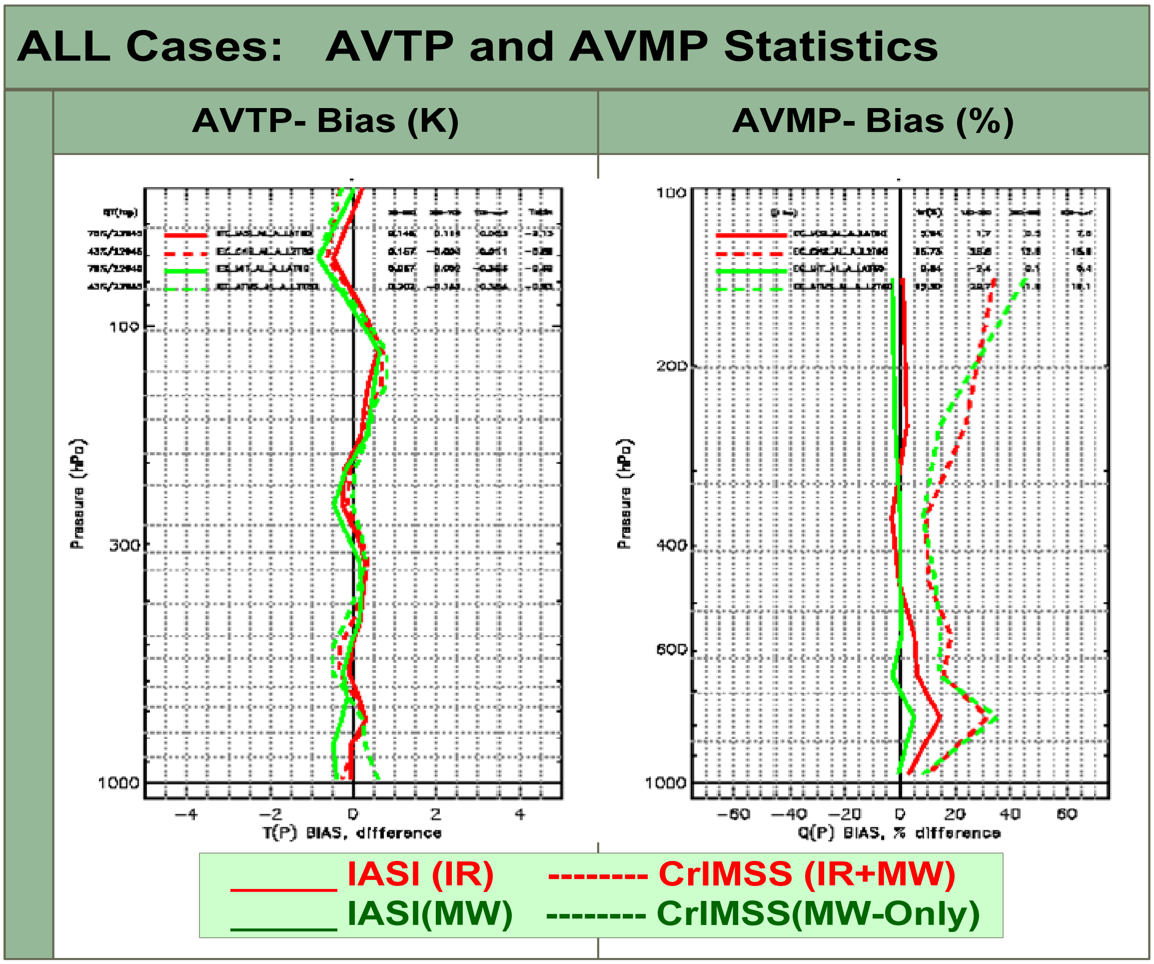


Figure 9b. NGAS-CrIMSS and IASI EDR Statistics with ECWMF analysis fields for the ocean-only cases. The CrIMSS AVTP product is quite comparable with the IASI EDR product. CrIMSS AVMP RMS difference for the middle and upper troposphere shows a little larger RMS difference compared with the IASI EDR product.