LARGE-SCALE VALIDATION OF DAILY RAINFALL ESTIMATES OF UNCORRECTED AND CORRECTED AMSU-B DERIVED RAIN RATE RETRIEVALS

Daniel Vila¹, Ralph Ferraro¹², Huan Meng¹² and John Janowiak³

¹ CICS/ESSIC/UMD, 2207 Computer & Space Science Building, College Park, MD, USA
² NOAA/NESDIS/STAR, 5200 Auth Road, Camp Spring, MD, USA
³ NOAA/CPC, 5200 Auth Road, Camp Spring, MD, USA

Abstract

A long-standing problem of great interest among the meteorological and hydrological communities has been how to represent the spatial distribution of precipitation. In this case, satellite-derived quantitative precipitation estimates (QPE) are an extremely powerful tool for obtaining rainfall patterns that can be used in many applications. To optimally use these data for forecasting and research applications, it is important to evaluate the errors in satellite-based rainfall estimates.

One of these algorithms is based on the scattering signal associated with high frequency channels (89 and 150-GHz) of the Advanced Microwave Sounding Unit – B (AMSU-B). Despite the fact that AMSU (a “sounder”) wasn’t designed for rainfall retrieval, many studies (i.e., Zhao and Weng, 2002; Ferraro et al., 2005) show that it’s possible to use this information for precipitation retrieval. Nevertheless, the weakness of this technique is related with the inability to retrieve rain that has little or no ice; and with the cross-scan characteristics of the instrument (different footprints for different local zenithal angles). This situation tends to generate, in the first case, much less rain coverage over ocean than other algorithms based on emission techniques (i.e., Kummerow, 2001) and a shift in the frequency distribution for low zenithal angles in the second case. An improvement to the current scattering based algorithm that uses cloud liquid water content over the ocean and a local zenithal angle normalization process will be evaluated.

This study is focused on the preliminary results of large-scale validation of daily rainfall estimates of uncorrected and corrected AMSU-B derived rain rate retrievals over several regions of the American continent. The retrieval of both estimations will be compared against daily accumulations using a gauge analysis over land.

INTRODUCTION

Since the first launch of the Advanced Microwave Sounding Unit (AMSU) on board the NOAA 15 satellite in July 1998, many environmental passive microwave (PMW) products have been operationally generated by NOAA. New products such as Ice Water Path (IWP) and Ice Particle Size are also derived, owing to the unique AMSU-B millimeter wavelength channels (Weng et al, 2003). These products, combined with those derived from the DMSP Special Sensor Microwave Imager (SSM/I), the Aqua Advanced Microwave Scanning Microwave Radiometer (AMSR-E) and the passive microwave (TMI) sensor on board the Tropical Rainfall Measuring Mission (TRMM) offers the scientific community an excellent source of global hydrological products. Nevertheless, because each sensor presents a unique set of particular characteristics (viewing geometry, spatial and temporal resolution and differences in wavelength channels), it’s important to understand those differences in order to combine the rainfall retrievals from different sources. Several researchers found that rainfall derived from the AMSU-B algorithm differs in many respects from SSM/I and other PMW estimation techniques. While SSM/I is equipped with channels that detect both emission and scattering signatures, the AMSU-B sensor only has high-frequency channels; thus, only precipitation that is detectable from a scattering signature can be estimated (Joyce et al, 2004).
The high temporal frequency of rainfall retrievals from AMSU-B (wider swath and four satellites at the time of this writing) are very helpful to better understand the diurnal cycle for different rainfall regimes around the world. It is also important to note that the high frequency channels on board AMSU-B offers the ability to detect lighter rain rates over land (Qiu et al, 2005) and even snowfall (Kongoli, 2004). Additionally, there are several current and near term sensors with similar capability to AMSU-B, including the Microwave Humidity Sounder (MHS), carried on NOAA 18 and MetOp-A. Nevertheless, the cross-scan characteristic of the instrument (different footprints for different local zenithal angles) generates differences in rainfall retrieval histograms for different local zenithal angles. These differences, over land, were corrected using an AMSU-B rain-rate correction scheme based on geometrical characteristic of the viewing target (see detail in Vila et al, 2007).

It is the purpose of this paper to evaluate the performance of the AMSU-B rain-rate correction scheme over land and to demonstrate its utility comparing the obtained results with other PMW rainfall retrievals and raingauge analysis based on daily accumulation. Section 2 will describe the database used in this study and a brief explanation of the correction scheme over land; section 3 presents several application examples over selected regions of South and North America while section 4 contains a summary of the paper.

**DATA AND CORRECTION METHODOLOGY**

The Advanced Microwave Sounding Unit-B (AMSU-B) is a 5 channel microwave radiometer. AMSU-B covers channels 16 through 20. The highest channels: 18, 19 and 20, span the strongly opaque water vapor absorption line at 183 GHz and provide data on the atmosphere's humidity level. Channels 16 and 17, at 89 GHz and 150 GHz, respectively, enable deeper penetration through the atmosphere to the Earth's surface. This is a cross-track, line scanned instrument designed to measure scene radiances in the 5 mentioned channels. At each channel frequency, the antenna beamwidth is a constant 1.1 degrees (at the half power point). Ninety contiguous scene resolution cells are sampled in a continuous fashion (beam positions from 1 to 90, where position 45 is in the nadir of a given line), each scan covering 50 degrees on each side of the subsatellite path. These scan patterns and geometric resolution translate to a 16.3 km diameter cell at nadir at a nominal altitude of 850 km, while this diameter is around 36 km in the limb of the image.

The data used in this paper is the NOAA AMSU-B swath derived products dataset. In this case, two months of swath data (January and July 2005) from NOAA 15-16-17 and 18 (MHS data for NOAA 18, just only for July 2005) were used to evaluate the performance of the AMSU-B rain-rate correction scheme over land. For this particular study, corrected (CORR, Vila et al., 2007) and uncorrected (UNCORR; Weng et al. 2003; Ferraro et al., 2005; Qiu et al. 2005) rainfall retrievals were included in the same swath file in order to evaluate the improvement of the proposed correction technique. Other ancillary parameters like local zenithal angle, latitude and longitude, date and time and type of orbit are also included in the file. This database contains around 7000 files.

Several datasets are used to compare AMSU-B retrievals (CORR and UNCORR) with other rainfall retrieval sources. The main purpose of this paper is to validate AMSU-B retrievals against rain gauge daily observations. Nevertheless, other satellite based estimations were also included for comparison purposes like SSM/I GPROF V6.0 (Goddard Profiling Algorithm, Kummerow et al, 2001) and TMI 2A12 rainfall retrieval algorithm (Kummerow, 1996).

Two different regions in the American continent were selected to make this validation. The first one is located in southeastern South America (55W – 45W, 20S - 30S) and covers approximately the upper catchment of Del Plata basin (Figure 1, left panel) and the second one is located in eastern United States (85W – 75W, 30S - 40S), centered in the Carolinas (Figure 1, right panel). In both cases, the rain gauge coverage for the studied period is relatively dense compared with other regions in the continent and covers different seasonal regimes (one summer and one winter month in both hemispheres).
Although the main advantage of this scattering signature approach is the higher temporal resolution of NOAA POES satellites with a spatial resolution of 16 km at nadir and a wider swath than the SSM/I and TMI sensors, the weakness of this technique is related with the inability to retrieve rain that has little or no ice and with the cross-scan characteristics of the instrument (different footprints for different local zenithal angles).

This weakness is expressed as an unrealistic shift in the peak of the relative frequency histogram for low rain rates for AMSU-B retrievals. Beam positions around 43 - 48 (near nadir), have a larger shift; while beam positions 1-4 or 86-90 (pixels near the limb) has a smaller shift and, on the other hand, the absence of high rain rates (<15 mmh-1) for near-limb positions is remarkable when compared with SSM/I retrievals.

The normalization process of AMSU-B derived rain rates to correct that systematic bias is performed using a Gaussian PDF with \( \mu \) (peak histogram position) and \( \sigma \) (standard deviation of observed distribution) depending on LZA, latitude and surface type. For high rain rates, a linear correction scheme with a slope value depending on the square root of the ratio between SSM/I footprint, which it is constant, and AMSU-B footprint, which depends on LZA is proposed to correct AMSU-B derived rain rates.

The derived correction scheme is presented in Figure 2 for three different local zenithal angles (LZA=0, near nadir; LZA=28, between nadir and limb; and LZA=56, near limb) and two different latitudes (Lat = 10°, upper panel and Lat = 55°, lower panel) representing a tropical and a mid-latitude environment over land. While for low rain rates, this scheme generates a reduction of the uncorrected rain rates (depending on the LZA and latitude); for high rainfall rates, a general increase in the corrected values is observed after applying the proposed correction scheme due to a higher-than-one slope value.

There is a second step in the correction scheme based on the fact that the current technique presents an inability to retrieve rain that has little or no ice, but it is important to point out that this issue is not so important over land as over ocean because the AMSU-B retrieval algorithm is based on a scattering approach (typically used over land for all PMW estimations). More details can be found at Vila et al. (2007).
VALIDATION PROCEDURE AND RESULTS

The first step in the validation procedure is to perform the daily gauge analysis. In the first case, the rain gauge data were obtained from the Centro de Previsao de Tempo e Estudos Climaticos (CPTEC/INPE) from Brazil, from the Global Telecommunication System (GTS/WMO) and the National Weather Service of Argentina (SMN). The analysis was carried out using the ordinary Kriging scheme with linear variogram and a spatial resolution of 0.25 degrees. In the North American case, the analysis was performed by NOAA/CPC using a Modified Cressman (1959) scheme (Glahn et al. 1985; Charba et al. 1992) with the same spatial resolution.

To make a proper comparison among different retrievals and to reduce the effect of a lower temporal sampling of SSM/I and TMI data, a 5-days running mean (pentads, expressed as mm/day) was performed beginning in the first day of the period (i.e., day 1-5, day 2-6, etc.). The same procedure (simple mean) was made with satellite retrievals. In this case, all valid retrievals at each pixel location for each sensor (AMSU-B, SSM/I and TMI) for the five day periods were considered in the average.

During January 2005 over the South American region, the mean number of samples over a given location was approximately 16 valid rainfall retrievals for every 5-days period (around 3 samples per day) with a maximum of 24 samples for a given location. In the case of SSM/I, the mean was 10 samples for each location while for TMI was just only a mean of 6 samples for each 5-days period was obtained.

The basic statistics follows the guidelines of International Precipitation Working Group (IPWG) to validate and intercompare satellite rainfall estimates (Ebert et al., 2007). The statistics used in this study are the bias, the Root Mean Square Error (RMSE) and the mean areal rainfall. Some other categorical statistics such as bias score (BIAS) is also computed. This parameter can be computed from a rain / no-rain contingency table and measure the performance of a given algorithm. In all cases, raingauge analysis is assumed as ground truth.

Figure 3 shows the validation results for the mean rainfall of 5-days period starting at 16 January 2005 over Southern American region (southern hemisphere summer). In this case, UNCORR overestimate the amount of rain compared with raingauge analysis while CORR is closer to the ground truth. In both cases, the area covered with rainfall is almost the same because the correction scheme produces just only a ‘rescaling’ process in the AMSU-B rain rate estimations. The worst results are observed when raingauge analysis is compared with SSM/I GPROF and TMI retrievals. In this case, not only the mean areal rainfall amount is underestimated but also the area covered with rainfall is
about 40% smaller than the observed rainfall. Two factors are critical for this behavior. First of all, sampling errors due to the number of samples at each location could affect the previous results. SSM/I and TMI samples are significantly smaller when compared with AMSU-B, so the diurnal cycle is poorly represented by SSM/I and TMI data. The second issue is related with the fact that those sensors (SSM/I and TMI) have not high frequency channels. These channels are very useful to detect lighter rain rates over land (Qiu et al, 2005). This gap will be partially solved by the new high frequency channels of the Special Sensor Microwave Imager Sounder (SSM/IS) flying on DMSP F-16 and F-17. This is a conical scanner with 24 channels from 19 to 183 GHz and a swath width of 1700 km.

Figure 3: Rainfall estimation for different satellite based algorithms. Upper left: AMSU-B Corrected. Upper right AMSU-B Uncorrected, middle left: SSM/I GPROF estimation, middle right: TMI 2A12 retrieval and gauge analysis (bottom panel)
This behavior is also present in the summer of northern hemisphere in the Carolinas region (July 2005). Figure 4 (upper panel) shows the evolution of the mean area rainfall for the 5-days running mean starting at the beginning of a given day for all estimates, while in the bottom panel, the bias score is presented. This parameter represents the ratio between the estimated area covered by rain and the area of observed rain.

![Mean Areal Rainfall](image1)

**Figure 4:** Upper panel: Mean areal rainfall for different algorithms (dashed lines) and observed precipitation (solid line) for the average of 5-days period in July 2005. Bottom panel: Bias score for the same period.

The mean areal rainfall observed over the eastern US is better represented by CORR algorithm, while UNCORR exhibits larger values during the whole period when compared with the rainfall analysis. In this case, TMI has larger values of all estimations in the middle of the period but the area is smaller than the observed area. This fact can be explained because the locations with larger precipitation rates are largely overestimated while light rain is dismissed.

During the winter time in both hemispheres, where the lighter rain rates are present because stratiform regime is more frequent during this period of the year, all algorithms tend to underestimate the observed rainfall. The dependence of the PMW algorithms upon ice scattering-based brightness
temperature (TB) depressions implies that they will miss light rain over land that contains little or no ice. This situation are more noticeable in SSM/S and TMI algorithms because the largest frequency for these sensors is 85 GHz, while AMSU-B rain-rate derived algorithm is based on 150 an 85 GHz scattering indexes, so some light rain is detected in these frequencies. Figure 5 shows the observed vs. estimated mean areal rainfall for eastern US during January 2005 for each algorithm.

Figure 5: Scatter plot of observed vs. estimated rainfall for different algorithms. Upper left: AMSU-B uncorrected, upper right: AMSU-B corrected, bottom left: SSM/I GPROF and bottom right: TMI 2A12. All amount are expressed in mm/day

SUMMARY AND CONCLUSIONS

This paper has presented an evaluation of a correction scheme for AMSU rain-rate algorithm compared with rain gauge analysis for 5-days running mean in different regions of the American continent. Comparisons with other PMW retrievals like SSM/I GPROF V6 and TMI 2A12 are also presented.

Taking into account the main advantage of having four NOAA satellite plus the recently launched MetOp European polar orbiter satellite, a new correction scheme over land has been developed based on the AMSU-B footprint geometry (different footprint size for different beam positions).

After applying the proposed scheme, a useful improvement of rain rate spatial pattern is observed in both regions, especially during summer time. In this case, GPROF and TMI estimations exhibit the largest bias when compared with rain gauge analysis. This behavior is due to the lower temporal resolution of DMSP and TRMM satellites but it is also highly influenced by the fact that SSMI and TMI sensors have not high frequency channels. These channels are very useful for light rain rate detection. During the winter, all algorithms tend to underestimate the accumulated rainfall because
light rain is present in most of the cases. This is a key challenge for all satellite-based precipitation algorithms (Turk, 2007)

REFERENCES


