Retrieval of Rain-Rate Using the Advanced Microwave Sounding Unit(AMSU)

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Abstract

Rain-rate retrieval using the NOAA/AMSU (Advanced Microwave Sounding Unit) (Zaho et al., 2001) has been implemented at METRI/KMA since 2001. Here, we present the results of the AMSU derived rain-rate and validation result, especially for the rainfall associated with the tropical cyclone for 2001. For the validation, we use rain-rate derived from the ground based radar and/or rainfall observation from the rain gauge in Korea. We estimate the bias score, threat score, bias, RMSE and correlation coefficient for total of 16 tropical cyclone cases. Bias score shows around 1.3 and it increases with the increasing threshold value of rain-rate, while the threat score extends from 0.4 to 0.6 with the increasing threshold value of precipitation. The averaged rain-rate for all 16 cases is 3.96mm/hr and 1.41mm/hr for the retrieved from AMSU and the ground observation, respectively. On the other hand, AMSU rain-rate shows a much better agreement with the ground based observation over inner part of tropical cyclone than over the outer part (Correlation coefficient for convective region is about 0.7, while it is only about 0.3 over the stratiform region). The larger discrepancy of the correlation coefficient with the different part of the tropical cyclone is partly due to the time difference in between ice water path and surface rainfall. This results indicates that it might be better to develop the algorithm for different rain classes such as convective and stratiform.

1. Introduction

Retrieval of rainfall from satellite data is playing an important role in the estimation of both climate-scale and instantaneous precipitation. Visible and infrared satellite imagery has been used for this purpose in the past time, but these methods which use brightness temperature or reflectivity observed from satellite are indirect and sometimes semisubjective. Therefore they cause large systematic and random errors, particularly for stratiform or warm precipitation in extratropical latitudes (Conner and Petty, 1998). On the other hand, rain-rate retrieved from passive microwave sensor is more accurate rather than visible and infrared data since it is able to penetrate the dense cloud and detects the hydrometeors within clouds. Many microwave sensor such Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR), Microwave Sounding Unit (MSU), Special Sensor Microwave/Imager (SSM/I), TRMM(Tropical Rainfall Measuring Mission) Microwave Imager(TMI) etc. is used to estimate the rainfall for global scale.

Retrieval technique from passive micowave data can be grouped into two categories. The first is emission-based, where liquid precipitation increases over a radiometrically cold (usually ocean) background. The second is scattering-based, where precipitation, especially that above freezing level, causes brightness temperature decreases over a radiometrically warm (usually land) background because of scattering effect of hydrometeor within cloud (Spencer et al., 1983). Brightness temperature where there is the rainy cloud over the sea is higher than the surrounding clear region because of low emissivity of sea. Emission-based method usually is used for retrieval of rain-rate over sea region. However, emission –based algorithm cannot

be applied in the land region since its high emissivity and scattering-based algorithm is used for retrieval of rain-rate over the land. The emission method is best know, based on work by Wilheit et al. (1977), and can be used only over the ocean. The scattering method was elucidated with aircraft observations of the effect at 92GHz(Wilheit et al. 1982), and with Numbus 7 Scanning Multichannel Microwave Radiometer (SMMR) 37GHz data (Spencer et al. 1989).

Use of microwave data has suffered from the relatively low resolution and narrow swath of microwave observations. The spatial resolution of microwave data is more larger than that of mesoscale convective system which occurs the heavy rainfall (Spatial resolution of MSU : 100km). SSM/I which is one of the most developed microwave sensor has about 25-50km resolution. The characteristics of SSM/I has been improved but its data is hard to get with real time.

The Advanced Microwave Sounding Unit (AMSU) was launched aboard the NOAA-15 satellite on May 1998 and NOAA-16 satellite on September 2000. The AMSU has significantly improved spatial resolution, radiometric accuracy, and the number of channels over the previous Microwave Sounding Unit (Kidder et al., 2000). The AMSU consists of AMSU-A and AMSU-B. The frequency range of AMSU-A which has 1-15 channels is 23-89GHz and the highest spatial resolution is about 50km. The AMSU-B consists of 5 five channels of 16-20 and the frequency range is 89-183GHz with the highest spatial resolution of 15km. The AMSU has a capability of rain-rate retrieval by dint of highest frequency channels (e.g. 89 and 150 GHz). The highest frequency scattering can detect even the small ice particles, so the estimation of rain-rate using AMSU is possible using these channels.

We describe a result of retrieved rain-rate using NOAA-16/AMSU and validation result over the tropical cyclone. Section 2 presents a data used in this study and verification method. The summary of retrieved rain-rate and validation is shown in section 3. A conclusion and future works are give in section 4.

2. Methodology

2.1 Data

Rain-rate from AMSU has been retrieved operationally since 2001 tropical cyclone cases. The retrieval method refers to the study of Zaho et al. (2001) who uses the relationship between ice water path and rain-rate. This method derived from the cloud model simulation using MM5.

Ice water path is derived from Weng and Grody (2000), Zaho and Weng (2002) that uses the AMSU 89 and 150GHz channels.

The verification case of tropical cyclone in this study is Cimaron (7. May – 15. May), Pabuk (13. Aug. – 21. Aug.), Danas (9. Sep. – 12. Sep.) and Haiyan (11. Oct. – 18. Oct.).

To validate the AMSU rain-rate, the Japan Meteorological Administration radar estimates is used for ground truth over land. Fig. 1 denotes the locations and coverage of the radar. In order to verify the AMSU and radar rain-rate at the same observation location, precipitation data is analyzed using a Barnes objective analysis method with the same grid resolution (0.2 x 0.2 degree).

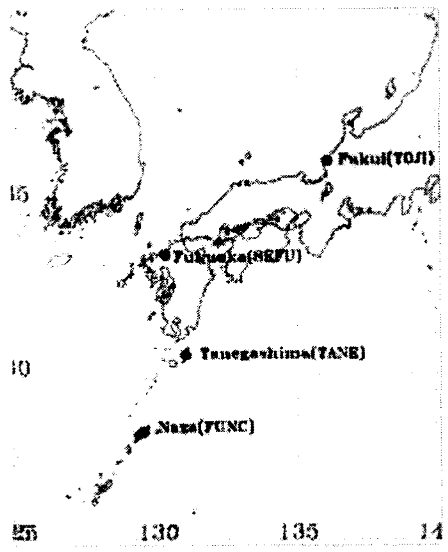


Fig. 1. Locations of Japan Meteorological Administration radar and its coverage.

2.2 Verification method

Verification methods used in this study follow the study of Byon et al. (2000) and correlation coefficient, Bias score, Threat score, Bias and Root-mean-square error(RMSE) is chosen as a statistical skill score. Fig.2 contingency table is applied for bias score and threat score. If the radar and the AMSU reach or exceed a precipitation threshold amount, the number of occurrence increases at the each element of the matrix. Bias score is defined as

$$Bias\ score = \frac{S}{R} = \frac{A+B}{A+C} \qquad (1)$$

Where S is the number of AMSU rain-rate with precipitation equal to or exceeding a given threshold amount and R is the number of occurrence in which the radar rain-rate meet or exceed the threshold. The bias score indicates how well the satellite estimates the frequency of occurrence of a given threshold, although it provides no information on the accuracy of the retrieval. The bias score reveals overestimation (Bias score > 1) and underestimation (Bias score < 1) by the AMSU.

Threat score measures the skill in estimating a given threshold at a location and is defined by

$$Threat\ score = \frac{A}{A+B+C} \qquad (2)$$

Theoretical range of threat score is 0 –1, if the threat score 1 means perfect estimation.

The bias score and threat score based on the contingency table only measure AMSU accuracy based on the frequency of occurrence at or above a precipitation threshold, and thus do not determine the magnitude of the precipitation errors in the AMSU. Therefore, it is also important to calculate bias and RMSE using the quantitative precipitation from AMSU. Bias for a given threshold is defined as

$$Bias = \frac{\sum_{n=1}^{NRDR} \frac{S_n}{R_n}}{NRDR} \qquad (3)$$

Where Sn is the AMSU rain-rate, Rn is the radar rain-rate at an observation point, and NRDR is the total number of observation at that location reaching a certain threshold.

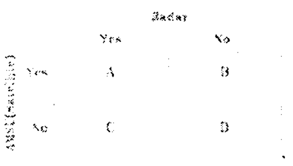


Fig. 2. Layout of the contingency table, where each element of the matrix (A, B, C and D) holds the number of occurrences in which the radar and the AMSU reach or exceed a precipitation threshold amount.

RMSE can be defined by

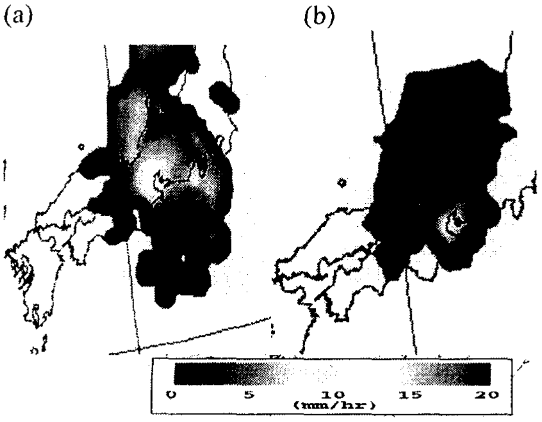
$$RMSE = \sqrt{\frac{\sum_{n=1}^{NRDR}(S_n - R_n)^2}{NRDR}} \qquad (4)$$

The RMSE measures the magnitude of the difference between the AMSU and the radar rain-rate values.

3. Result

Fig. 3 shows the AMSU rain-rate validated against with the radar rain-rate in 21 Aug. 2001. The AMSU rain-rate delineates the typhoon center and raining area corresponded with radar. But the AMSU derived rain-rate is higher than that of the radar estimates. A statistical verification result for this case shows the AMSU and radar rain-rate corresponds very well but the AMSU precipitation is overestimated about twice as much as of radar rain-rate. An explanation is that the radar rain-rate may be underestimated due to inaccuracies in the Z-R relationships; to attenuation effects; or to the difficulties in precipitation at large distances. Radar also has difficulty detecting precipitation when rain drops are very small or when the precipitation is in the form of snow. Under these conditions radar precipitation may be underestimated (Zaho et al., 2001).

(a) (b)



(c)

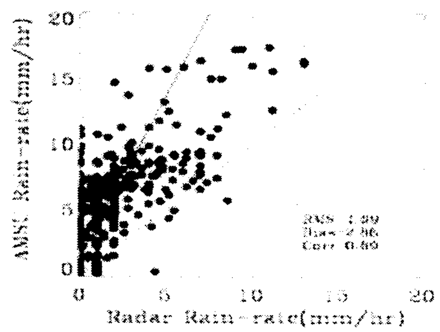


Fig. 3. (a) The AMSU rain-rate estimates for Pabuk (21. Aug., 2001). (b) Radar rain-rate. (c) Validated result.

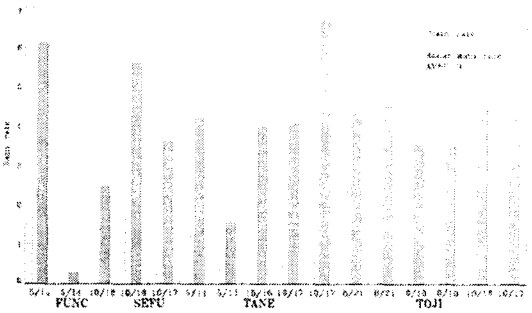


Fig. 4. Time series of rain-rate for AMSU and radar observation.

Spatial mean rain-rate of the AMSU and radar is compared over the 16 cases of tropical cyclone for 2001 (Fig. 4).

The difference of the AMSU and radar rain-rate varies with the case but it is also shown the AMSU is overestimated against with the radar in all cases. The average rain-rate of the AMSU is 3.96 mm/hr, and that of the radar is 1.41mm/hr.

The correlation analysis has done between the AMSU and the radar rain-rate for the Fig. 4 cases (Fig. 5). The averaged correlation coefficient is about 0.46. The AMSU algorithm uses the ice water content within cloud to retrieve the rain-rate, thus if the rainfall is related to the ice content, it provides a good rainfall estimate. However, it is considered to be cause a severe error if it rains from warm rain process by stratiform cloud. Therefore we classified rain-rate of tropical cyclone case as a convective and stratiform rain. The rainfall occurred by convective cloud is the 6 cases of the total 16 cases and the correlation coefficient is 0.7, while the correlation coefficient shows 0.3 for the stratiform cases.

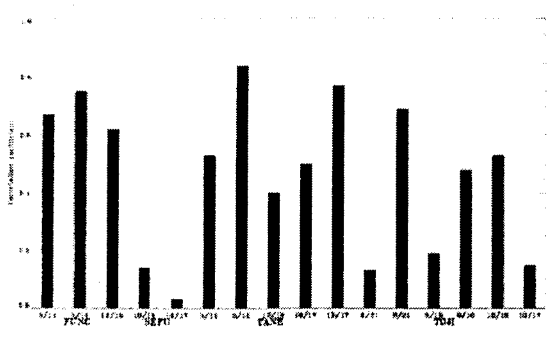


Fig. 5. Correlation coefficients between AMSU and radar rain-rate for tropical cyclone occurred in 2001.

The bias score increases as increasing of rain-rate threshold, in other to say, it showed that AMSU rainfall is overestimated. At the 0.0 – 1.0 mm/hr thresholds,

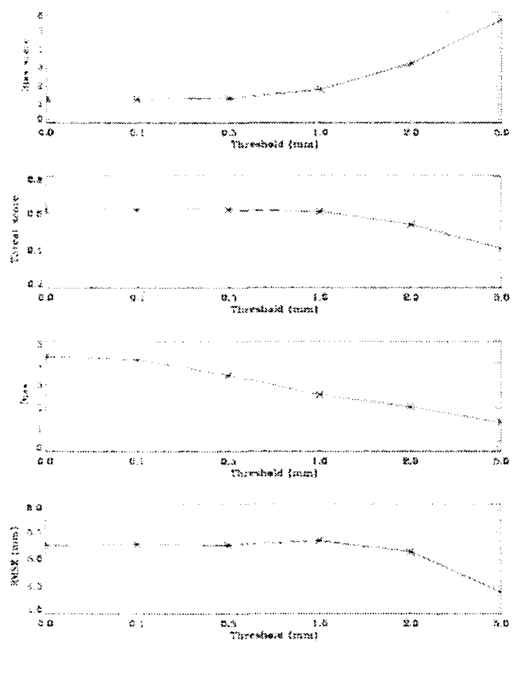


Fig. 6. Verification results of rain-rate retrieved from AMSU

distribution of the bias score is consistent with 1.3, while the bias score rises for the 2.0 and 5.0 mm/hr thresholds. The threat score is around 0.6 for the 0.0 – 1.0 mm/hr thresholds, but decreases slightly for thresholds greater than 1.0 mm/hr. The bias and RMSE describe the quantitative rain-rate error show that AMSU is higher than that of radar. The tendency of overestimation increases at the low precipitation thresholds. The RMSE shows around 5.3 mm/hr at 0.0 – 2.0 mm/hr thresholds, while it drops to around 4.4 mm/hr for the 5.0 mm/hr threshold (Fig. 6).

4.Conclusion and future works

Rain-rate is retrieved using NOAA/AMSU and it is validated with radar over the tropical cyclone for 2001. Analysis cases are the 4 cases of tropical cyclone occurred in 2001 and total 16 cases of radar observation is validated.

The algorithm used in this study uses the ice water path of cloud to retrieve rain-rate and ice water path is estimated from the scattering parameter of 89, 150GHz measurements.

The AMSU rain-rate is overestimated against with the radar and the correlation coefficient was higher in the convective region than stratiform region. There is also the time difference between the AMSU rainfall and that of the radar for the lower correlation coefficient case. This indicates that the algorithm causes an error for the rainfall occurred from warm rain process since rain-rate retrieved from ice water path. In addition to, though the effective ice particle size is very small it rains in the real atmosphere, but the AMSU rain-rate is 0 mm/hr in this case. This problem effected from the scattering parameter calculation result from the radiation model simulation using the hypothesized ice particle size.

Improvement of the rain-rate for the stratiform region and adoption of appropriate regression coefficient for tropical cyclone and regional atmosphere conditions are required in the future study.

References

Byon, J. Y., S. Y. Lee and S. H. Sohn, 2000: Verification of ARPS precipitation forecasts over the Korean Peninsula. *Journal of Korea Meteorological Society*, **36**, 337-352.

Conner, M.D. and G. W. Petty, 1998: Validation and intercomparison of SSM/I rain rate retrieval methods over the continental United States. *J. Appl. Meteor.*, **37**. 679-700.

Kidder, S. Q., M. D. Goldberg, R. M. Zehr, M.DeMaria, J.F.W. Purdom, C. S. Velden, N. C. Grody and S. J. Kusselson, 2000: Satellite analysis of tropical cyclones using the advanced microwave sounding unit (AMSU)., *Bull. Amer. Meteor. Soc.*, **81**, 1241-1259.

Spencer, R. W., W. S. Olson, W. Rongzhang, D., W. Martin, J. A. Weinman and D. A. Santek, 1983: Heavy thunderstorms observed over land by the Nimbus 7 Scanning Multichannel Microwave Radiometer. *J. Climate Appl. Meteor.*, **22**, 1041-1046.

Spencer, R. W., H. M. Goodman, and R. E. Hood, 1983: Precipitation retrieval over land and ocean with SSM/I: Identification and characteristics of the scattering signal. *J. of Atmos. and Ocean Tech.*, **6**, 254-273.

Weng, F. and N. C. Grody, 2000: Retrieval of ice cloud parameters using a microwave imaging radiometer. *J. Atmos. Sci.*, **57**,

1069-1081.
Wilheit, T. T., A. T. C. Chang, M. S. V. Rao, E. B. Rodgers and J. S. Theon,, 1977: A satellite technique for quantitatively mapping rainfall rates over the oceans. *J. Appl. Meteor.*, **16**, 551-560.
Wilheit, T. T. et al., 1982: Microwave radiometric observations near 19.35, 92 and 183 GHz of precipitation in Tropical Storm Cora. *J. Appl. Meteor.*, **21**, 1137-1145.
Zaho, L. and F. Weng, 2002: Retrieval of ice cloud parameters using the advanced microwave sounding unit(AMSU). *J. App. Meteor.*, **41**, 384-395.
Zaho, L., F. Weng and R. Ferraro, 2001: A physically-base algorithm to derive surface rainfall rate using advanced microwave sounding unit-B (AMSU-B) measurements. 11th Conf. on satellite meteorology and oceanography.