GROUND VALIDATION OF TRMM/PR MEASUREMENTS

K. Nakagawa [a, *], H. Hanado [b], S. Kawamura [b], N. Takahashi [a], T. Iguchi [a]

[a] Applied Electromagnetic Research Center, National institute of Information and Communications Technology, Koganei, Tokyo, - (nakagawa, ntaka, iguchi)@nict.go.jp
[b] Okinawa Subtropical Environment Remote Sensing Center, National institute of Information and Communications Technology, Onna, Okinawa, - (hanado, s-kawamura)@nict.go.jp

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ABSTRACT:

In order to secure the quality of precipitation estimates, ground validation (GV) of satellite data and retrieval algorithms is essential. Since end-to-end comparisons between instantaneous precipitation data observed by satellite and ground-based instruments is not enough to improve the algorithms. The error of various physical parameters in the precipitation retrieval algorithms (e.g. attenuation factor, drop size distribution, terminal velocity, density of the snow particles, etc.) will be estimated by the comparison with the ground-based observation data. The detail of the ground validation observation network in Okinawa for TRMM/PR and GPM/DPR are described. The intensive field observations are conducted using this observation network. Comparisons between the radar reflectivity from the TRMM/PR (2A25) and COBRA and the *k-Z* relationship estimation by use of the 400MHz WPR are conducted.

1. INTRODUCTION

The Tropical Rainfall Measuring Mission (TRMM) was launched in November 1997 and is operating now. The Precipitation Radar (PR) onboard TRMM is the first space-bone radar in the world. The observation frequency of PR is 13.8GHz (Ku-band). Major objectives of PR are Major objectives of PR are (1) to provide 3-dimensional rainfall structure, (2) to achieve quantitative rainfall measurement over land as well as over ocean, and (3) to improve the accuracy of TRMM Microwave Imager (TMI) measurement by providing the rain structure information. The Global Precipitation Measurement (GPM) mission is an expanded follow-on mission to TRMM (Tropical Rainfall Measuring Mission) and a GPM core satellite will carry dual frequency precipitation radar (DPR) and a GPM Microwave Imager on board. The DPR, which is being developed by National Institute of Information and Communications Technology (NICT) and Japan Aerospace Exploration Agency (JAXA), consists of two radars; Ku-band precipitation radar (KuPR) and Ka-band radar (KaPR). The DPR is expected to advance precipitation science by expanding the coverage of observations to higher latitudes than those of the TRMM/PR, measuring snow and light rain by the KaPR, and providing drop size distribution information based on the differential attenuation of echoes at two frequencies (T. Iguchi et. al. 2002). To improve the accuracy of rainfall intensity and rain retrieval algorithm from space-bone radars, radiometers and ground-based radar, the vertical profile of the raindrop size distribution is very important (T. Iguchi et. al. 2003, C. Kummerow et. al. 2001, K. Aonashi and G. Liu 2000).

In this paper, the detail of the ground validation observation network in Okinawa for TRMM/PR and GPM/DPR are described. The intensive field observations are conducted using this observation network. Comparisons between the radar reflectivity from the TRMM/PR (2A25) and COBRA and the *k-Z* relationship estimation by use of the 400MHz Wind Profiler are conducted.

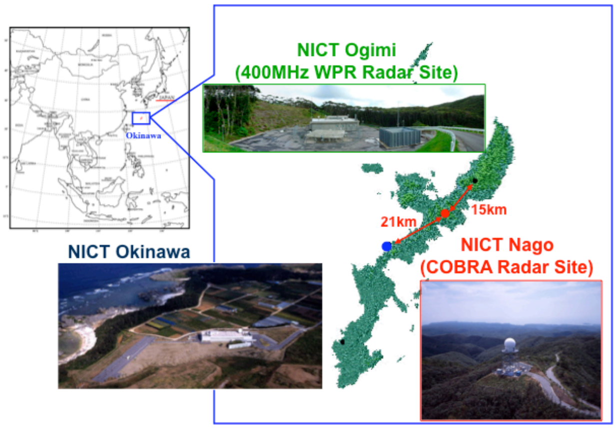


Figure 1. Site locations of the ground validation site in Okinawa

2. GROUND VALIDATION SITE IN OKINAWA

National Institute of Information and Communication Technology (NICT) has three facilities in the main island of Okinawa. Figure 1 shows the site locations of the ground validation site. The main office is the Okinawa Sub-tropical Environment Remote Sensing Center (NICT Okinawa), and two radar sites are the Ogimi Wind profiler Facility (NICT Ogimi) and the Nago Precipitation Radar Facility (NICT Nago).

2.1 C-band polarimetric radar (COBRA)

The C-band polarimetric radar (COBRA) is installed at NICT Nago. The COBRA system is a ground-based, monostatic pulse Doppler radar using a single wave (5340 MHz) in the C-band. Its main specifications are listed in Table 1. The maximum observation range is a radius of approximately 300 km, although this depends on the repetition frequency and the transmitted pulse. The spatial resolution is 37.5–600 m, depending on the pulse width and the over-sampling rate.

* Corresponding author.

Figure 3. Outline of the intensive field observation network in Okinawa, Japan

To enable polarimetric observations, an antenna with a good side-lobe level and cross-polarization ratio and a radome with little attenuation were selected. Two transmitter (klystron) units are used to observe polarization. The transmission polarization for each pulse is selected from six possible polarizations: horizontal polarization, vertical polarization, ±45-degree-tilt linear polarizations, and right- and left-handed circular polarizations. The return signal is measured by two receivers simultaneously, one for the horizontal polarization and the other for the vertical polarization. The pulse width can be adjusted to 0.5, 1.0, or 2.0 µs. The system is controlled by a GPS signal with a 10-MHz clock (K. Nakagawa et. al. 2003).

The polarimetric observation parameters of COBRA are as follows. The precipitation intensity, R, is calculated from its Z-R relationship with the radar reflectivity factor, Z. In addition, polarization parameters are calculated, including the differential reflectivity between the horizontal and vertical polarizations, ZDR ($=ZHH/ZVV$), the linear depolarization ratio, LDR ($=ZHV/ZHH$), the cross-correlation coefficient, $\rho HV(0)$, and the differential propagation phase between the horizontal and vertical polarizations, ΦDP (and its derivative in the range direction, KDP) .

Table 1. Specification of the COBRA system

Frequency	5340 MHz (C-band)
Peak power	250 kW × 2 (Dual Klystron)
Pulse width	0.5, 1.0, 2.0 µs
PRF	250-3000 Hz, 1-Hz step
Antenna	4.5–m Φ parabola (8–m Φ radome)
Antenna gain	45.6 dBi (H) / 45.7 dBi (V) (include radome)
Beam width	0.91 deg (H) / 0.91 deg (V)
Side-lobe level	< -31.8 dB (AZ), < -28.3 dB (EL)
Cross-pol ratio	39.2 dB (H) / 40.3dB (V) (integ in a beam)
Doppler estimation	Pulse-pair / FFT
Range bin num	> 2000 bin
Antenna scan	PPI : 0.5-10 rpm, 0.1-rpm step RHI : 0.1-3.6 rpm, 0.1-rpm step

2.2 400-MHz Wind Profiler

The 400-MHz Wind Profiler (400-MHz WPR) is installed at NICT Ogimi. The 400-MHz WPR is able to observe simultaneously the atmospheric turbulence echo and the echo from precipitation (as shown in Figure 2) (T. Adachi et. al. 2001). Therefore, by analyzing the echo power spectrum of the received signal, the rain drop size distribution can be estimated for which the effects of wind speed, the intensity of atmospheric turbulence, and background winds have been removed. Several methods have been proposed to estimate DSD from the UHF/VHF Wind Profiler data (e.g. K. Wakasugi et al., 1986, Sato et al., 1990). The DSD below the melting layer observed by the 400-MHz WPR is basically retrieved by a non-parametric method (T. Kobayashi and A. Adachi, 2005). As the primary observation target of 400-MHz WPR is atmospheric turbulence, the receivers are sometimes saturated for rainfall observation. Therefore, a calibration factor for the 400-MHz WPR is used that is obtained by a comparison with the radar reflectivity of COBRA (Y. Kitamura et al., 2005).

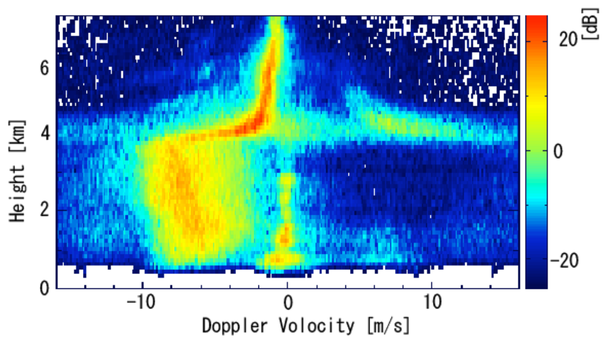


Figure 2. Doppler spectrum observed by the 400-MHz WPR

3. INTENSIVE FIELD OBSERVATION CAMPAIGN

Intensive field observations for subtropical rainfall were carried out during the month of June from 2004 to 2009. At NICT Ogimi, the 400-MHz WPR performed synchronous observation with COBRA. Ground-based measurements of the raindrop size distribution were obtained by a Joss-type disdrometer and a 2-Dimensonal video distrometer (2DVD) every minute. The rainfall intensity was also observed every minute with a tipping-bucket rain gauge and an optical rain gauge. COBRA was operated in 3-Dimensonal observation mode (volume scan) and range-height indicator (RHI) scan mode every 10 minutes. The 3-Dimensional observation took six minutes, and the RHI scan took four minutes (K. Nakagawa et. al. 2005).

4. OBSERVATION RESULTS

4.1 The radar reflectivity from 2A25 of TRMM/PR and COBRA

During field observations, there were several rain events in which the TRMM/PR passed within range of COBRA observations. COBRA was operated with 14 plan position scan indicator (PPI) and one range height indicator (RHI) scan every 6-minutes. Comparisons between the radar reflectivity from the TRMM/PR (2A25) and COBRA are conducted. The COBRA data are converted into the 3-dimensional Cartesian grid (4.0km x 4.0km horizontal, 0.25km vertical; 75 x 75 x 76 pixels). The rain attenuation of radar reflectivity observed by COBRA is corrected by use of the ZPHI method.

Figure 4 shows the comparison of horizontal radar reflectivity distribution for TRMM/PR and COBRA at a height of 2km on June 9, 2004. PR (Measured) is 1C21 data (no attenuation correction). PR (Corrected) is 2A25 data. Figure 5 (a) shows the scatter plots of radar reflectivity. Figure 5 (b) shows the probability density function (pdf) of radar reflectivity. Table 2 shows the correlation coefficient and averaged radar reflectivity. The correlation coefficients at each height are more than 0.79. The difference of the averaged reflectivity is less than 1.0dBZ. The each figure is comparison between TRMM/PR (2A25) and COBRA at each height (2km, 3km, and 4km). From these figures, the reflectivity of 2A25 corresponds with COBRA.

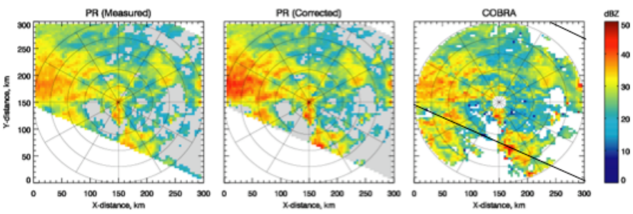
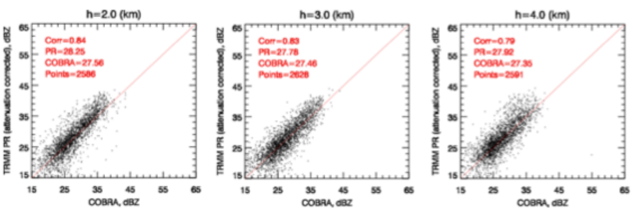
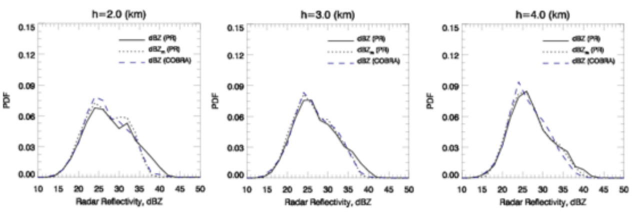


Figure 4. Comparison of horizontal radar reflectivity distribution for the PR and COBRA at a height of 2km (2004/06/09)



(a) Scatter plots of radar reflectivity



(b) Probability density function (pdf) of radar reflectivity

Figure 5. Radar reflectivity comparison between TRMM/PR (2A25) and COBRA at each height (2km, 3km, and 4km)

Table 2. Correlation coefficient and averaged radar reflectivity from the TRMM/PR (2A25) and COBRA

Height	Correlation coefficient	Averaged reflectivity for TRMM/PR [dBZ]	Averaged reflectivity for COBRA [dBZ]	Points
2km	0.84	28.25	27.56	2586
3km	0.83	27.78	27.46	2628
4km	0.79	27.92	27.35	2591
All	0.73	26.80	26.09	50083

4.2 *k-Z* relationship

Figure 5 shows the schematic diagram for the TRMM/PR ground validation using the intensive field observation network. The rain attenuation of radar reflectivity observed by COBRA is corrected by use of the ZPHI method. The specific attenuation, A_h [dB/km] is estimated as below,

$$10\log_{10}\left[Z_H(r)\right] = 10\log_{10}\left[Z'_H(r)\right] + 2\int_0^r A_h(s)ds \tag{1}$$

where $Z_H(r)$ is the corrected radar reflectivity, $Z'_H(r)$ is the attenuated radar reflectivity, r [km] is distance from the radar site. The *k-Z* relationship is expressed as;

$$k = \alpha Z^{\beta}\,. \tag{2}$$

where k [dB/km] is The specific attenuation and express as;

$$k = 4.343\times 10^{-3}\int_{D_{\min}}^{D_{\max}} N(D)\cdot\sigma_{ext}(D)dD\,. \tag{3}$$

The radar reflectivity Z_H [mm^6m^{-3}] is expressed as;

$$Z_H = \frac{\lambda^4}{\pi^5|K|^2}\int_{D_{\min}}^{D_{\max}} N(D)\cdot\sigma_{bks}(D)dD\,. \tag{4}$$

$N(D)$ is estimated from the 400-MHz WPR and observed by the ground-based 2DVD and the Joss-type disdrometer. σ_{ext} and σ_{bks} can be processed by the Mie scattering theory. σ_{ext} [mm^2] is the extinction cross section. σ_{bks} [mm^2] is the back scattering cross section. Using these kinds of radar information, the *k-Z* relationship is estimated for evaluation and improvement of the TRMM/PR algorithm.

Figure 6 shows the raindrop size distribution observed by the 2DVD on June 2, 2004. Figure 7 shows the *k-Z* relationship that is processed from the raindrop size distribution of Figure 6. In Figure 7, Dots are processed by use of the equations (3) and (4). Green line is the regression line of these dots. Pink and blue lines are the *k-Z* relationship in use 2A25 algorithm. The 2DVD measurements correspond with the *k-Z* relationship that is used in 2A25 algorithm.

Figure 8 shows the *k-Z* relationship for Ku-band that is estimated by the 400MHz-WPR depending on rain type. Red dots are observed on June 16, 2009. This rain event was weak rain (less than 5mm/h). Blue and light blue dots are observed on June 18, 2009. This rain event was strong rain (more than 50mm/h). It is clear that the *k-Z* relationship is different depending on rain type. The *k-Z* relationship of weak rain event is similar with that in 2A25 algorithm.

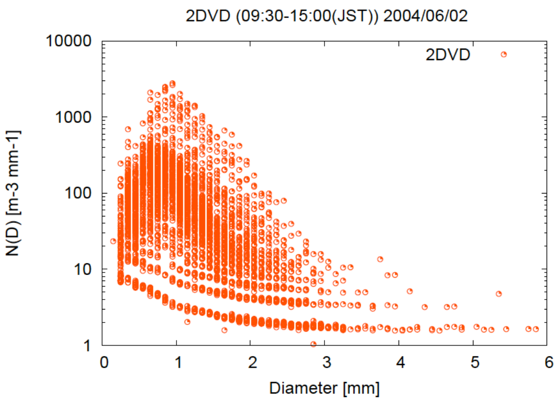


Figure 6. Raindrop size distribution observed by the 2DVD, 2004/06/02, 09:30-15:00 (JST)

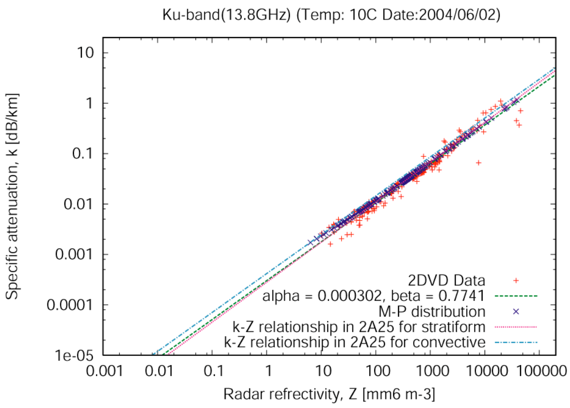


Figure 7. The *k-Z* relationship for Ku-band estimated by use of the 2DVD

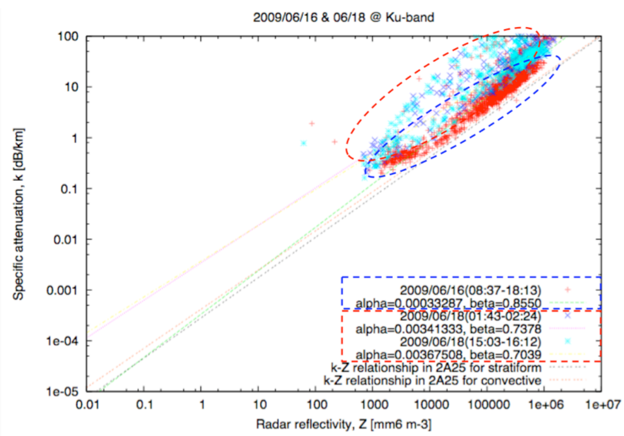


Figure 8. The *k-Z* relationship for Ku-band that is estimated by the 400MHz-WPR depending on rain type (weak and strong rain)

5. SUMMARY

In order to secure the quality of precipitation estimates, ground validation (GV) of satellite data and retrieval algorithms is essential. Since end-to-end comparisons between instantaneous precipitation data observed by satellite and ground-based instruments is not enough to improve the algorithms. The error of various physical parameters in the precipitation retrieval algorithms (e.g. attenuation factor, drop size distribution, terminal velocity, density of the snow particles, etc.) will be estimated by the comparison with the ground-based observation data.

Intensive field observations for subtropical precipitation using a 400-MHz WPR (400-MHz WPR), a 2D-Video distrometer (2DVD), a Joss-type disdrometer, a Micro-rain radar (MRR), and COBRA (C-band polarimetric radar) were carried out during the month of June from 2004 to 2009 at the Okinawa Sub-tropical Environment Remote Sensing Center, of the National Institute of Information and Communication Technology (NICT Okinawa). Using these vertical and ground-based measurements of raindrop size distributions, the extinction cross-section and the back scattering cross section can be processed by the Mie scattering theory. Then, the specific attenuation (k) and the radar reflectivity (Z) for Ku-band are estimated. The vertical variations and characteristics (depending on rain type) of rain attenuation for Ku-band can be analyzed. The GPM/DPR for Ku and Ka-band algorithm can be also evaluated using the ground validation observation network.

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