EFFECT OF SPATIAL NON-UNIFORMITY OF RAIN ON OBSERVATION BY A SPACEBORNE RADAR

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INTRODUCTION

Spaceborne rain radar is one of the most promising means to quantitatively measure rain rate distributions on a global scale, the knowledge of which is required to better understand the Earth climate. From this background, spaceborne radar programs such as TRMM [1], [2], TRAMAR [3], and BEST [4] have recently been planned in USA/Japan, USA, and France. To realize accurate rain observations by spaceborne radars, the evaluation of rain rate retrieval errors arising from the non-uniform distribution of rain in the spaceborne radar beam footprint (hereafter referred to as the beam filling bias error) is a very important subject because it is technologically difficult to use a large radar antenna with beamwidth narrow enough to allow the beam footprint to be filled with uniform rain.

This problem has recently been examined for various rain rate retrieval techniques such as the conventional method based on a relationship between radar reflectivity Z and rain rate R, dual-frequency method, surface reference method, etc.[5]. Those examinations are, however, based on simplified rain models. This paper is, therefore, aimed to investigate the beam filling bias error problem more quantitatively on the basis of real rain data obtained by a ground-based C-band rain radar at Kashima Space Research Center. Although the magnitude of beam filling bias error highly depends on the types of rain retrieval techniques [5], this paper is concentrated in the evaluations for the conventional Z-R method, as a baseline examination.

FORMULATION OF BEAM FILLING BIAS ERROR

The rain observation volume for spaceborne rain radar has a horizontally elongated disk-like shape, e.g., with about 4km in diameter and 0.25 km in thickness at nadir observation for the case of the TRMM rain radar. The radar reflectivity measured by a spaceborne radar is, hence, essentially an area-averaged one with respect to the beam footprint. The area-averaged radar reflectivity $\overline{Z}$ is, then, converted to an apparent area-averaged rain rate Ra based on a empirical Z-R relationship which is originally established for a spatially uniform rain. Since Z-R relationship is nonlinear, Ra is not identical to a true area-averaged rain rate (Rt). Assuming a most commonly used Z-R relationship, $Z=200\ R^{1.6}$, the difference between Ra and Rt is expressed by

$$DR = Ra - Rt = \left(\frac{\overline{Z}}{200}\right)^{\frac{1}{1.6}} - Rt \qquad (1).$$

DR gives a measure of the beam filling bias error for the conventional Z-R method. In the following, the values of DR for the beam footprint size of currently planned TRMM rain radar (4 km in diameter) are evaluated on the basis of the CAPPI (Constant Altitude Plan Position Indication) data obtained by the ground-based C-band radar.

EVALUATION BASED ON RAIN RADAR CAPPI DATA

The CAPPI data used consists of 4-bit digitized rain rate data obtained at every 1 km grid point on a circular observation plane with radius 20 km and with altitude 1 km for one year from April 1979 to March 1980. The CAPPI data was obtained every 12 minutes in raining times. Examples of the CAPPI rain rate data are shown in Figs. 1.

In the evaluation of the value of DR, a circular beam footprint of spaceborne radar is approximated by a 4kmx4km square area (pixel) on the CAPPI mode observation plane. One pixel includes rain rate data at 4x4(=16) grid points. The pixel-averaged rain rate is used as the value of Rt. At each grid point, radar reflectivity is related to rain rate through $Z=200\ R^{1.6}$. The pixel-averaged radar reflectivity is used as the value of $\overline{Z}$. The value of DR is, then, derived from the pixel averaged values Rt and $\overline{Z}$ through Eq. (1). The process mentioned above is applied to all the CAPPI mode data for one year.

RESULTS

The data set of DR and R obtained are grouped by contiguous intervals of Rt. On a monthly basis, the values of DR are averaged for every data group. The average relationships between DR and Rt thus obtained for August 1979 and March 1980 are shown in Figs. 2 (a) and (b), respectively. In the figures, the vertical bars mean standard deviations. It should be noted that although the vertical bars expressing standard deviations reach the region of negative values for several cases in August 1979, the values of DR in practice do not take negative values. This means that the spatial non-uniformity of rain always produce positive bias errors in the rain rate retrievals by the conventional Z-R method. The same finding is previously obtained by examinations on the basis of simplified rain model [5]. This type of bias error can not be removed even if a large amount of rain rate data are averaged. It is also noteworthy that there exist appreciable seasonal variations in the magnitudes of the beam filling bias error; the bias errors are considerably larger in August than in March. As seen in Fig. 3, the yearly average relationship between DR and Rt shows an intermediate feature between those in August and March. The values of DR for Rt=10mm/h become about 0.5 mm/h, 1.5 mm/h, and 1 mm/h for March, August, and one year, respectively. In Fig. 4, an intra-annual variation of the monthly averaged ratio of DR to Rt is shown. The ratio becomes about 12 % in August, September, and October, while it becomes less than 8 % in the other months. The annual average of this ratio is about 8.7 %.

Figures 1. Examples of CAPPI rain data.
(a) August, 1979. (b) March, 1980

CONCLUSION

The beam filling bias error has quantitatively been evaluated for the conventional Z-R method on the basis of the ground-based C-band radar CAPPI data. The beam filling bias error estimated always shows positive values, and also clearly shows seasonal variations. Greater values of the beam filling bias error, reaching about 12 %, are obtained for summer months which have higher occurrence probabilities of convective rains. The planned TRMM rain radar is aimed to measure monthly averaged rain rates over the 600kmx600km grid area in tropical and sub-tropical regions with error of less than 20 % [6]. The role of convective rain is more important in the tropical rain, so that the beam filling bias error problem as examined in this paper should not be ignored for the currently planned spaceborne rain radar programs.

REFERENCES

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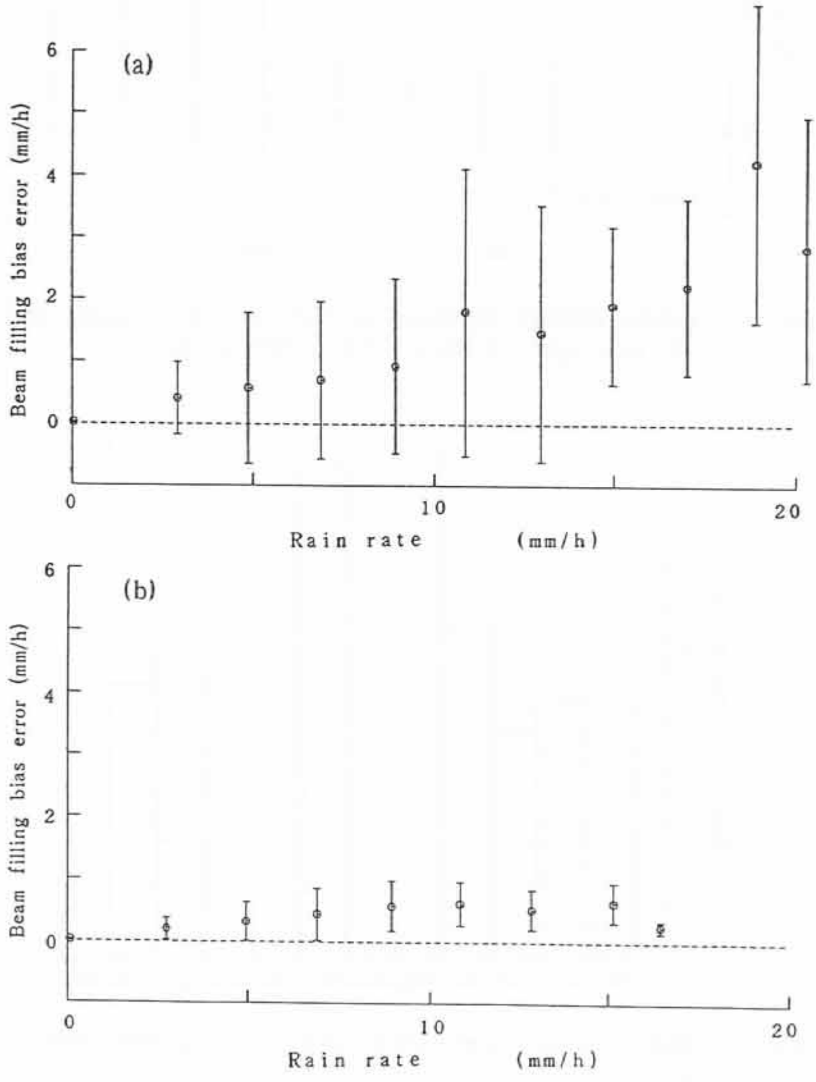

Figures 2. Monthly average relationships between beam filling bias error and rain rate
(a) August 1979. (b) March 1980.

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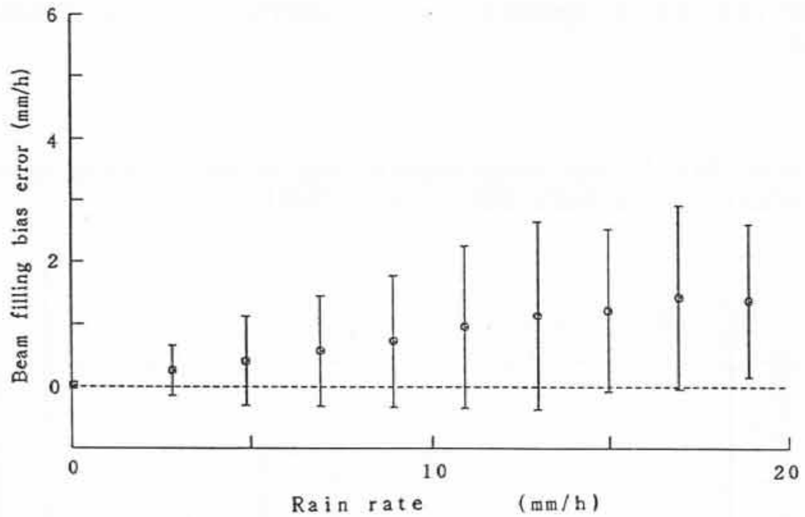

Figure 3. Yearly average relationship between beam filling bias error and rain rate (April 1979 - March 1980)

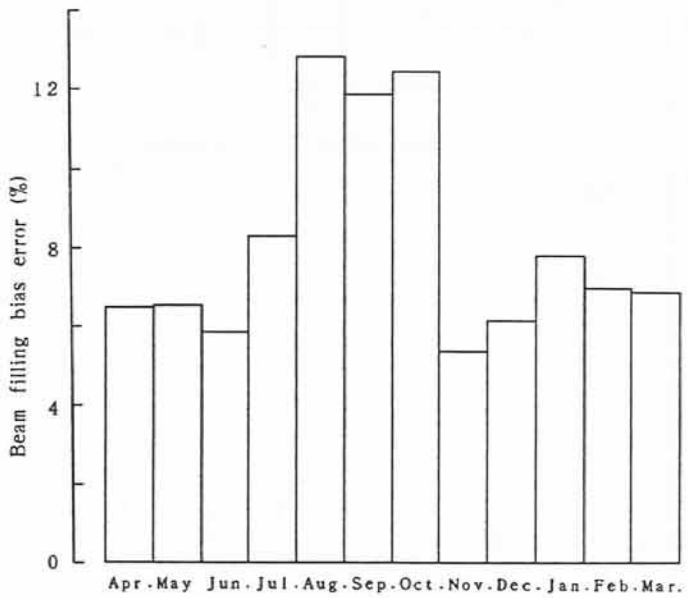

Figure 4. The ratio of beam filling bias error to rain rate