Spatial Correlation Property of Rainfall Rate Inferred From TRMM and Rain Gauge Data

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1. Introduction

Rain attenuation is a serious problem for satellite communication links using frequencies above 10 GHz. Information on the spatial structure of rainfall is needed for the design of reliable satellite communication systems. Spatial correlation coefficient of rainfall rate is an important parameter in the rain attenuation prediction method. It has been studied about the spatial correlation coefficient about horizontal direction, but there are few examples of the studies about the vertical structure of rainfall rate, and it is important to consider the vertical structure of it from the viewpoint of the elevational dependence of satellite-to-earth links. It rains more than two-thirds of the precipitation in the tropical region which makes up much forest and sea areas. TRMM satellite can provide quantitative measurements of rainfall over all land and ocean areas of the tropics, and Precipitation Radar (PR) on the satellite is able to observe 3-dimensional structures of the rainfall rate in this region. Since the convective activity in the Southeastern Asia area is the most active in the world, it is important to understand the spatial structure of the rainfall rate in this area. Moreover, anisotropy properties of the spatial correlation inferred from rain gauge data in Japan are analyzed to compare these areas. In this study, 3-dimensional spatial correlation coefficients of rainfall rate which considered horizontal and vertical directions in Southeastern Asia area inferred from measurement of PR, and anisotropy properties of the spatial correlation are analyzed in Southeastern Asia and Japan areas.

2. TRMM PR Data Analysis

2.1 Analytical Method

Fig.1 shows the 3-dimensional structure of the TRMM PR scans to analyze the 3-dimensional correlation coefficient of the rainfall rate. One rectangular parallelepiped in Fig.1 is the volume of resolution for the TRMM PR, and this volume is a depth of 0.25km and a diameter of about 5.0km. X-, y- and z- axes are Scan, angle and range directions respectively. Fig.2 shows process of analysis. We take an analysis domain which the rain exists and take the small domain of A ⊆ B ⊆ C [km^3] in the analysis domain, fix one small domain. We calculate the spatial correlation coefficient by moving the other small domain in the object domain. If R_1(x_1,y_1,z_1) is the rainfall rate of the analysis domain (1) and R_2(x_2,y_2,z_2) is the rainfall rate of the analysis domain (2), spatial correlation coefficient ρ(x, y, z) is estimated from the Equation 1. Cov (R_1, R_2) is covariance between R_1 and R_2, Var(R_1) is variance of R_1, and Var(R_2) is variance of R_2.

2.2 Data Used

The TRMM PR data used in this paper was measured in the Southeastern Asia area at longitude from 90 to 160 degrees, and latitude from -10 to 20 degrees in June and July 2006. We used 15 events and averaged these estimated results. Fig.3 shows a data sample which is the averaged rain rate data for each ray between the two predefined heights of 2 and 4 km. The small domain of A ⊆ B ⊆ C assumed each axes half length of the analysis domain. The red rectangular frame is the analysis domain.
2.3 Analyzed Results

Fig.4 and 5 show 2-dimensional distribution of the spatial correlation coefficients at near ground and at the center of y-axis, respectively. It is noticed that anisotropy properties are shown, and the spatial correlation coefficients are large in south-north direction compared with in west-east direction as shown in Fig.4. Fig.6 shows the graph of the spatial correlation coefficients at the center of y-axis within 20km of x-axis. The correlation coefficients in vertical direction (z-axis) are smaller than that in horizontal direction (x-axis) as shown in Fig.8. This suggests that the spatial structure of the rainfall rate in the Southeastern Asia area is approximated by layer structure.

The relation between the coefficients and the horizontal distance is approximated by the Equation 2 where ρ represents a correlation coefficient and D represents a distance in km. The parameters and in the Southeastern Asia area inferred from the least-squares method are 0.165 and 0.427, respectively. We discuss these results in the following section.

3. AMeDAS Data and Analysis

3.1 AMeDAS Data

The AMeDAS is an automatic weather observational system operated by the Japan Meteorological Agency. This system measures the precipitation, the wind direction, the wind velocity, temperature and the daylight hours to observe weather conditions finely, temporally and regionally. The observatory which measures the precipitation has it of about 1,300 places (about 17km in each every direction) in Japan. In this study, we used the data with 10-minutes integration time for 10 years from January, 1997 to 2006 in Kanto including major cities and Owase has much rainfall.

3.2 Analyzed Results

The correlation coefficients are estimated by the Eq.1 except the z-axis. Fig.7 shows the correlation coefficients as a function of the separation distance. Fig.7-(a) and Fig.7-(b) show the coefficients in Owase and Kanto areas including Tokyo, respectively. It is noticed that there is a clear distance dependence of the coefficients. The parameters and using the least-squares method are given in Table.1. It is noticed that the parameter in Japan is larger than in the Southeastern Asia area. This result suggests that the spatial correlation of the rain in Japan is smaller than in the Southeastern Asia area. The approximated relations using Eq.2 are shown in Fig.7 by solid lines. The approximated relation agrees well with the measured results. From Fig.7, it can be noticed easily that the coefficients in Owase are smaller than Kanto, and those in Owase are farther from the approximated line than Kanto. This result suggests that the coefficients in Owase may depend on not only the separation distance, but some other factor.

Fig. 8-(a) and 8-(b) show the distributions of the correlation coefficients derived from the rainfall data of Owase and Kanto respectively. It is noticed that anisotropy properties are shown by the correlation coefficients inferred from AMeDAS data of many pairs of locations. The correlation is lower in the case of Owase than Kanto generally. In addition, anisotropy properties exist compared with both areas. Particularly, the correlation strongly depends on an orientation North East/South West in Owase but its orientation is not in Kanto. The shape of the color data in Kanto looks like a circle compared to in Owase.

As the cause of these results, we can expect that the weather depends on winds in the area including Japan which cause rain blow from an orientation South/West to North/East. The orientation of winds changes to North/South by the mountains of the Midland in Kanto. Therefore, it is expected that such a difference of the shape of the correlation coefficient between these regions exists.

4. Conclusion

We analyzed the spatial correlation in Southeastern Asia and Japan areas. In Southeastern Asia area, we analyzed 3-dimentional spatial correlation using TRMM PR data. As a result, spatial structure of the rainfall rate in Southeastern Asia area is layer structure. We have shown that anisotropy properties of the spatial correlation exist in both areas. It is quite useful for the design of a site diversity technique or an adaptive common-resource-sharing technique for the satellite communication systems using Ka band or above of Ka band.
In future work, not only the analysis of the Southeastern Asia area, but that of worldwide should be studied and also the dependence on precipitation type such as convective or stratiform rain should be studied.

References

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<tr>
<th></th>
<th>Owase</th>
<th>Kanto</th>
<th>Southeastern Asia</th>
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<tr>
<td>$\alpha$</td>
<td>0.262</td>
<td>0.239</td>
<td>0.165</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.416</td>
<td>0.379</td>
<td>0.427</td>
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Table 1: Fitting parameters between correlation coefficients and separation distance

Eq. 2: Empirical function for correlation coefficient

\[ R(D) = \exp(-D^\beta) \]

Fig. 6: Spatial correlation coefficient at the center of y axis

(a)

(b)

Fig. 7: Separation distance dependence of the correlation coefficients, in the case of Owase (a) and Kanto (b).

(a)

(b)

Fig. 8: Anisotropy properties of the correlation coefficient, in the case of Owase (a) and Kanto (b).