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# RAIN DEPOLARIZATION CHARACTERISTICS RELATED TO RAINFALL TYPES

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## 1. Introduction

Slant-path rain depolarization in higher frequency bands such as the Ka-band (30/20 GHz) is induced by differential attenuation (DA) as well as differential phase shift (DPS) between major (nearly horizontal) and minor (nearly vertical) axes of rain drops[(1),(2)]. The severe rain depolarization events are usaually accompanied by rain attenuation more than 10 dB, which exceeds the rain margins of current satellite communcation systems. In the near future, however, the satellite trainsmission power is expected to be increased by using large spacecraft. Also, techniques for controlling the earth-station transmission power according to the rain attenuation are being developed. Therefore, the rain depolarization characteristics are still worthy of investigation for dual polarization communication systems, although considerable rain attenuation arises at the same time.

In general, the effect of DA is the more prominent, the more intense is rainfall rate or rain attenuation. Also, recent theoretical calculations suggest that the proportion of DA to DPS is significantly affected by the rainfall types according to drop-size distribution (DSD)[(3)]. Note that the DA component is a critical factor of cross-talk problems between orthogonal polarization channels, since it causes residual depolarization after the DPS cancellation using phase shifters[(4)].

In this study, we investigate the rain depolarization events observed by the CS-2 and CS-3 beacon signals (19.45 GHz, circular polarization, elevation angle=49.5°) during 1986-1988[(5)]. The rain depolarization characteristics are described in relation to rainfall rates and rain attenuation statistics. Also, an impact of DSD is presented, including direct measurements of raindrops. The DA component obtained from the cross-polarized phase is then discussed in the light of possibility of depolarization cancellation.

## 2. Dependence on Rainfall Rate

Average values of the cross-polarized phase relative to the co-polar phase are calculated for the rainfall events that primarily indicated the effects of rain depolarization rather than ice depolarization during 1986-1987. The dominance of rain depolarization is evaluated by their positive sign of $\Delta XPD = XPD_I - XPD_0$[(5)] (dB), where $XPD_I$ is the observed XPD, and $XPD_0$ is theoretical rain XPD calculated from the observed attenuation[(2)]. The standard deviation ($\sigma$) of raindrop canting angles is here assumed to be 0°, which gives rise to the lowest XPD due to the horizontal alignment of raindrops. The positive value of $\Delta$XPD (usually 0-3 dB) results from increase of $\sigma$ in severe rain. Furthermore, we select the rainfall events with their duration time more than 30 min or so, to keep good correspondence with the mean rainfall rate.

Figure 1 shows a scattergram between the mean cross-polar phase and the mean rainfall rate for these rainfall events. The symbols of the data points are classified by the season when they were obtained. The cross-polar phase is, as a whole, seen to gradually increase as the rainfall rate increases, although the data points are largely scattered.

The cross-polar phase ($\psi$) is theoretically related to the rainfall rate R (mm/h) by[3]

$$\psi = tan^{-1}(\alpha R^{\beta}) - 180^{\circ} \quad (\mathrm{deg}) \tag{1}$$

where the coefficients $\alpha$ and $\beta$ are specified by DSD. Note that the cross-polar phase is inherently independent upon the propagation path length $L$ (km), and theoretically determined by the rainfall rate and these coefficients only. In this calculation, the effects of the mean raindrop canting angle is also considered to be negligible[6].

The three thin lines in Fig.1 indicate the theoretical values for typical DSD's of Joss-thunderstorm (Jt), Marshall-palmer (MP), and Joss-drizzle (Jd), respectively, as attached by the respective abbreviations. The observed mean cross-polar phases are also found to distribute around the theoretical values. This correspondence suggests that such a wide distribution of the cross-polar phase from -100° to -150° is not only ascribed to the amount of rain volume but also to substantial difference of the propagation medium caused by DSD.

From a seasonal point of view, the summer (triangles) and the early autumn (squares), in which thunderstorms or showers are easy to occur, "literally" tend to yield the Joss-thunderstorm type events. To contrast, the Joss-drizzle type events are frequently seen in the spring (circles) and the early summer (part of triangles) including the "Baiu" period. Especially in May and July of 1987, almost all rain depolarization events seem to conform to the Joss-drizzle type, as denoted by black circles and triangles, respectively.

### 3. Relation to Attenuation Statistics

In statistical analysis, the aforementioned periods of May and July in 1987 are focused. That is, the equi-probability values between cumulative distributions of the rainfall rate and rain attenuation are calculated in each of these months[7]. The results are shown in Fig.2. The thin line similarly indicates theoretical values based on

$$A = aR^{b}L \quad (\mathrm{dB}) \tag{2}$$

where the coefficients $a$ and $b$ depend on DSD[8]. This calculation requires the equivalent path length $L$ (km) for the rain region, so that the rain height $H$ (km) is inferred from the average ground temperature[7]. The slant-path length is then given by $L=H/sin49.5^{\circ}$.

Calculation for the Jd-type DSD is here compared with that for the MP type one, whereas the Jt type is omitted since its characteristic overlaps with that of the MP type in the rainfall rates considered. It is found from Fig.2 that the monthly statistics of the observed attenuation is closer to the Jd type than the MP type. Such a feature is seen for (a) May 1987 at least in the higher rainfall rates, and generally found for (b) July 1987 in the entire range. This result well agrees with the distribution of the cross-polar phase detected for these months in Fig.1, so that the effects of the Jd-type DSD are shown to consistently appear in the rain attenuation and depolarization characteristics.

### 4. Comparison with DSD Measurements

Some examples of DSD have been actually obtained on the ground, although the observation method is primitive. Figure 3(a) depicts the spatial number density of raindrop diameters estimated from the direct measurements by the "absorbent paper method" on August 5, 1988. The thick line indicates the root-mean-square fit for the data points (circles), and the dashed lines indicate the calculations based on the respective DSD models. The DSD measurements were performed for the rainfall event with duration time of about 1 h, exposing sheets of filter paper, dusted with dye, to the falling raindrops during one minute per every 10 min. In this event, the DSD is, on an average, found to lie between the MP and the Jt models. Figure 3(b), on the other hand, shows the distribution of the cross-polar phases observed in the same period. Most of the phases are also found between the theoretical values based on the MP-type and the Jt-type DSD's, being consistent with the direct measurements of DSD.

## 5. Improvement by DPS cancellation

Finally, possible improvements performed by the phase shifters in the receiving earth station are considered for the observed rain depolarization events[4]. Let us suppose that the depolarization canceller composed of phase sifters[9] may eliminate the DPS component of the observed depolarization. The improvements of *XPD* (dB) for circular polarizations are given by[5],[10]

$$IX = 20log_{10}|CXPD/CX_{DA}| = 20log_{10}|cos\psi|^{-1} \text{ (dB)} \tag{3}$$

where *CXPD* is the complex depolarization factor of the observed XPD and $CX_{DA}$ is the residual DA component of *CXPD* after the DPS cancellation. Note that the observed mean cross-polar phase ranges from -100° to -150° as shown in Fig.1, and its maximum and minimum yield the improvements of 15.2 dB and 1.25 dB, respectively, based on Eq.(3). Thus, the effects of the depolarization canceller are quite different between the rainfall events due to the large discrepances of their cross-polar phases caused by the type of DSD.

## 6. Conclusion

The rain depolarzation observations of the CS-2 and CS-3 beacon signals have shown that the mean cross-polar phase of each event is distributed in a wide range from -100° to -150°. Theoretical consideration suggests that this large variation of the cross-polar phase is primarily caused by the difference of DSD rather than the rain intensity. The effects of DSD are also confirmed, compared with the direct measurements of raindrop diameters on the ground. Since the cross-polar phase determines the residual DA component after the DPS cancellation of the rain depolarizations, the type of DSD is important for the improvement of XPD to be sufficiently performed by phase shifters. In future, more detailed knowledge of local or seasonal dependence of DSD in each rain depolarization event will be needed for practical design of dual-polarization satellite communication systems.

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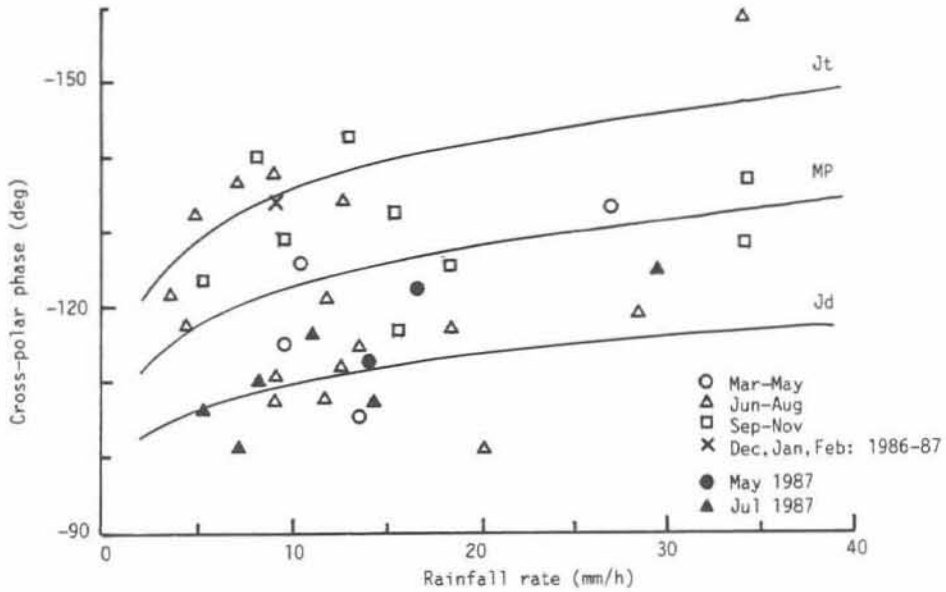


Fig.1 Dependence of cross-polar phase on rainfall rate obtained from each rain depolarization events during 1986-1987.

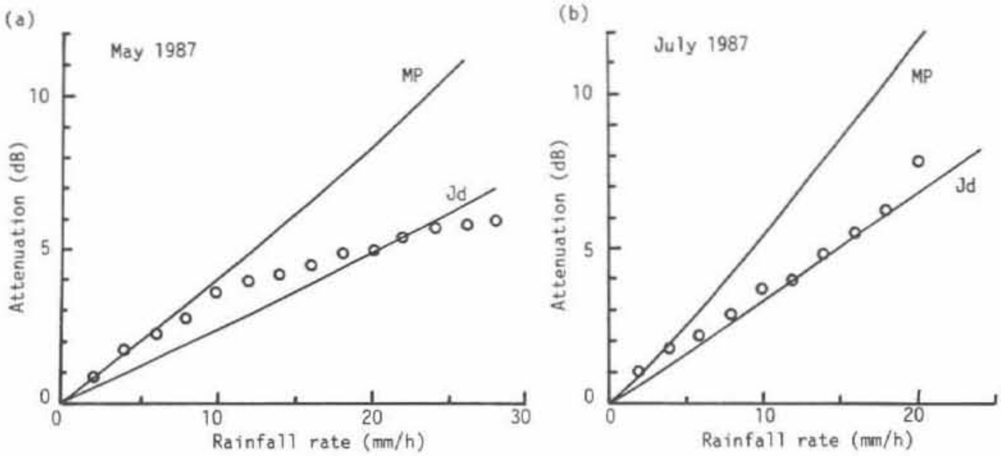


Fig.2 Equi-probability values between cumulative distributions of rainfall rate and rain attenuation observed in (a) may and (b) July 1987.

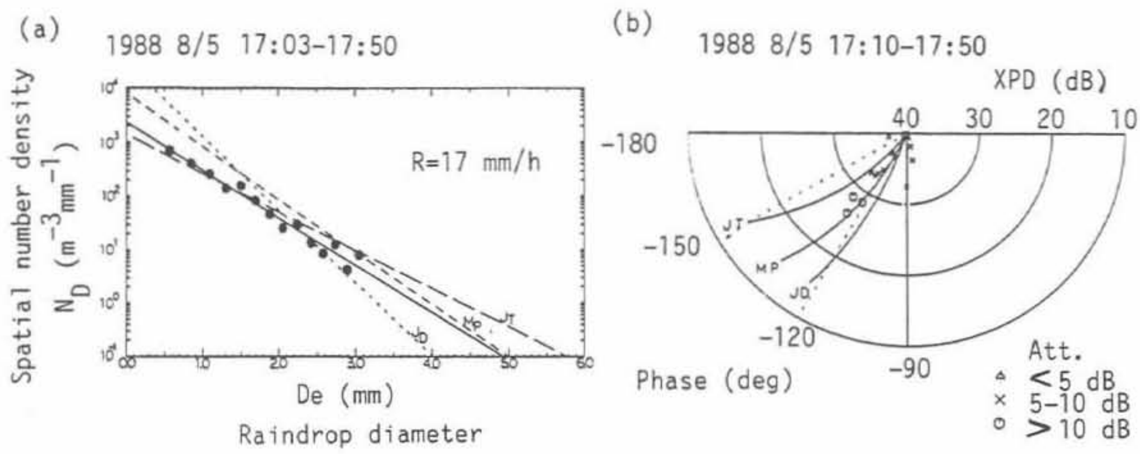


Fig.3 Spatial number density of raindrop diameter (a) and the cross-polar phase (b) measured on August 5, 1988.