CHARACTERISTIC RAPID CHANGES IN DEPOLARIZATION OF Ka-BAND SATELLITE SIGNAL IN THUNDERSTORM EVENTS

Yasuyuki Maekawa, Nion Sock Chang, Akira Miyazaki, and Toshitaka Kojima
Osaka Electro-Communication University
18-8 Hatsucho, Neyagawa, Osaka 572, Japan

1. Introduction

In the thunderstorms, the significant depolarization of microwave and millimeter waves is often caused by raindrops and ice crystals in the thunder clouds on the satellite-to-ground path. Moreover, it is well known that rapid changes in depolarization with time scale of a second or less are frequently observed in the thunderstorm events. These rapid changes are considered to be caused by the alignment of ice crystals in thunder clouds due to aerodynamic-gravitational and/or electrostatic forces[(1)-(3)]. But, very little is yet known about the mechanisms for producing this type of depolarization and the behavior of ice crystals concerning aerodynamic-gravitational and electrostatic forces in thunder clouds.

This paper discusses the depolarization characteristics in thunderstorm events using the Japan's CS-3 satellite beacon signal (19.45 GHz, right-hand circular polarization). This Ka-band satellite signal has been observed in our university for the past six years from 1990 to 1995[(4)]. The cross-polarization discrimination (XPD) and cross-polar phase relative to co-polar phase of the satellite signal radiowave have been observed every second in these periods. These data showing characteristic rapid changes in thunderstorm events are compared with time and location of lightning strokes detected by the Lightning Location and Protection System (LLPS) of a nearby electric power company.

2. Example of Thunderstorm Events

Figure 1 shows an example of the thunderstorm event observed on September 8, 1994. Fig.1(a) is the XPD changes, while Fig.1(b) is the cross-polar phase relative to the co-polar phase. In this observational period, the attenuation did not exceed 1 dB, but the severe depolarization with the XPD values of less than 20 dB is found in Fig.1(a). Moreover, the rapid changes in XPD (a) and cross-polar phase (b) can be detected almost every minute during 6:30-7:00 LT. Arrows indicate the changes that correspond to the moment of lightning strokes recorded by LLPS near the station. Note that these characteristic changes in depolarization are primarily ascribed to ice crystals near the cloud top, because the attenuation is less than 1 dB during this period.

3. Increase and Decrease of XPD

The XPD value shows both cases of increase (decrease of depolarization) and decrease (increase of depolarization) at the moment of rapid changes, although the cross-polar phase shows clockwise rotation in most cases with the mean canting angle of ice crystals decreasing in rapid changes. Figure 2 shows the ratio of the increasing XPD to the deceasing XPD against the XPD values after the rapid changes (*XPD1*), which seem to nearly indicate the background XPD values of the propagation medium without the effects of electrostatic forces after electric discharges. These data are obtained from the thunderstorm events during 1990-1994. The rapid XPD change tends to increase when the background XPD

(*XPD1*) is comparably high, whereas it tends to decrease when the background XPD is generally low. These two cases tend to occur at the beginning or end of thunderstorm events and in the middle of the events, respectively.

Next, Fig.3 depicts the distribution of the mean canting angles of ice crystals inferred from the observed cross-polar phase before (a; *CAN0*) and after (b; *CAN1*) the rapid changes in the thunderstorm events during 1990-1994. The results are here shown for the increasing XPD (thick line) and for the decreasing XPD (thin line), respectively. The positive angles indicate the clockwise rotation seen from the satellite. In general, large clockwise canting angles are found in the case of the increasing XPD, whereas a considerable number of small canting angles also exist in the case of the decreasing XPD, indicating the effects of nearly horizontal alignment of ice crystals.

4. Numerical Calculation for ΔXPD and $\Delta\phi$

The increase and decrease of XPD obtained in each rapid change are depicted against the absolute value of the change of cross-polar phase ($\Delta\phi$) in Fig.4 for the thunderstorm event on September 8, 1994. Circles (○) and triangles (△) indicate clockwise and counter clockwise rotations of canting angles, respectively, seen from the satellite, while black and white symbols indicate the rapid change with and without the CG lightning stroke, respectively. Although the relationship between ΔXPD and $\Delta\phi$ is largely scattered, some typical tendencies are found as follows. First, we can see the cases that ΔXPD is a small positive value ① or nearly 0 dB ②, and $\Delta\phi$ largely increases up to 180°. On the other hand, it is found that when ΔXPD extremely decreases down to -15 or -20 dB ③, $\Delta\phi$ approaches around 90°. Also, there are the cases that ΔXPD slightly decreases down to -10 dB ④ or -3 dB ⑤, and $\Delta\phi$ slightly increases up to 30° and then "return" to 0°. The curves ①-⑤ in the diagram indicate the numerical calculation for (ΔXPD, $\Delta\phi$), assuming that both depolarization effects near and far from the discharging point, with the XPD differences of ①+20 dB,②+2.5 dB, ③-2.5 dB, ④-9 dB and ⑤-20 dB, respectively.

The cases ① and ② seem to indicate the depolarization effects due only to the ice crystals near the discharging point in thunder clouds. At the moment of discharge, the electrostatic force is released and the orientation of ice crystals may change from a highly aligned state to a slightly random state. This may produce the increase of XPD after the lightning discharge. Also, the large changes of cross-polar phase are considered to directly indicate the increase of mean canting angles associated with the ice crystal alignment. On the other hand, the cases ③-⑤ suggest the depolarization effects due to the ice crystals far from the discharging point as well as those near the lightning point. Since the mean canting angle of ice crystals is not increased so much in the place other than the discharging point, these two different effects between the places near and far from the lightning point may cause depolarization cancellation on the propagation path as the charge is being accumulated before the lightning. This can explain the large rapid decrease of XPD values after the lightning discharge and the phase variation of near or less than 90°.

5. Conclusion

The characteristic rapid changes in depolarization due to thunder clouds are presented using the Japan's CS-3 beacon signal (19.45 GHz) observations, and the increase and decrease in the observed XPD values and cross-polar phases are discussed in light of thunderstorm electrification mechanisms and the associated alignment degrees and canting angles of ice crystals in thunder clouds. The case of the increasing XPD for rapid changes is primarily found in the events of relatively high background XPD values. In this case, the cross-polar phase associated with the mean canting angle of ice crystals generally shows large variations. This type seems to be directly affected by ice crystals near the lightning point. The case of decreasing XPD is, to contrast, observed in low XPD values, and comparatively small phase changes suggest depolarization cancellation mechanisms between the effects of ice crystals near and far from the lightning point. These overall features are also confirmed by simple numerical calculations assuming both depolarization effects near and far from the discharging point.

References

(1) D. P. Haworth, P. A. Watson, and N. J. McEwan, *Electron. Lett.*, vol.13, pp.562-564, 1977.
(2) D. C. Cox, and H. W. Arnold, *J. Geophys. Res.*, vol.84, pp.5003-5010, 1979.
(3) C. W. Bostian, and J. E. Allnutt, *Proc. IEE*, vol.126, pp.951-960, 1979.
(4) Y. Maekawa, N. S. Chang, A. Miyazaki, and T. Segawa, *1995 IEEE AP-S Int. Symp. Digest.*, vol.1, pp.278-281, 1995.

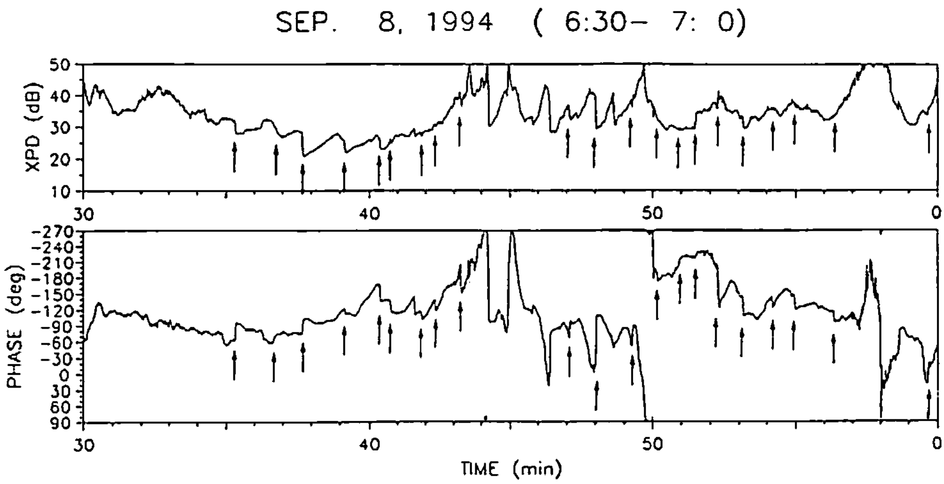

Fig.1 (a) XPD and (b) cross-polar phase observed in a thunderstorm event. Arrows indicate the time of cloud-to-ground lightning discharges.

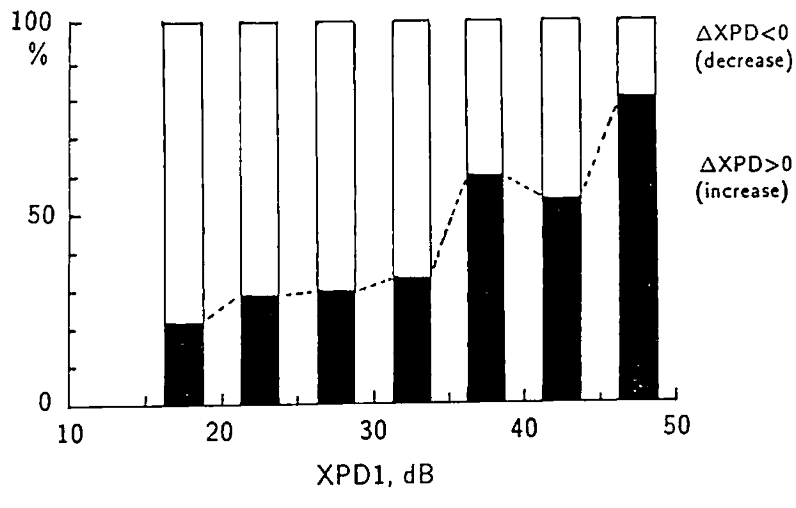

Fig.2. Ratio of increasing XPD to deceasing XPD against XPD values after the rapid changes (*XPD1*) observed in all thunderstorm events during 1990-1994.

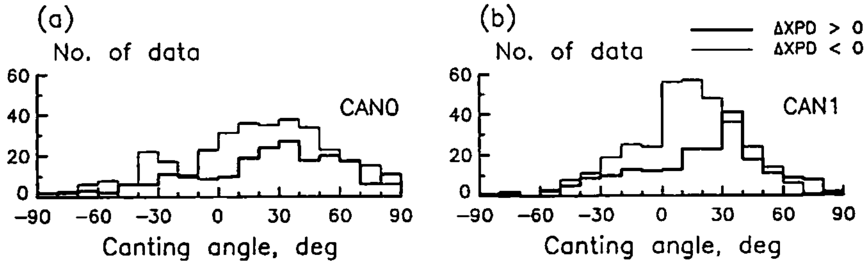

Fig.3. Distribution of mean canting angles of ice crystals before (*CAN0*) and after (*CAN1*) the rapid changes during 1990-1994.

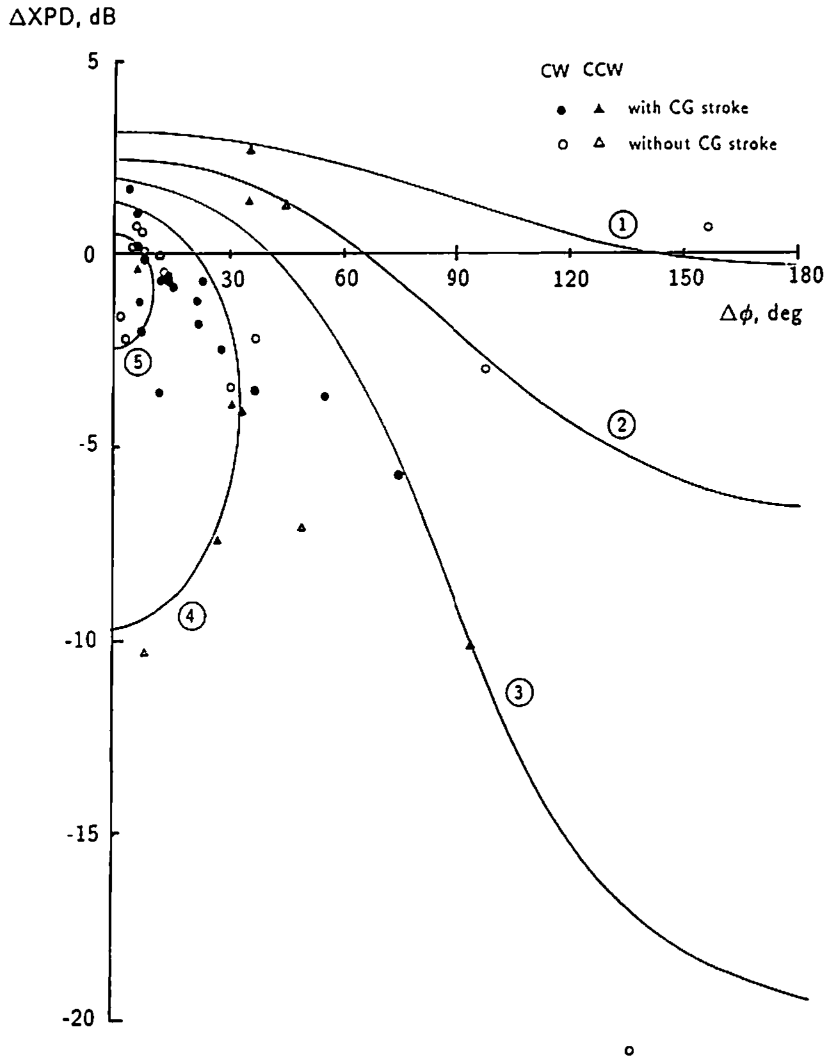

Fig.4. Increase and decrease of XPD against the rapid variation of cross-polar phase ($\Delta\phi$) observed on September 8, 1994.