Ku-Band Signal Depolarization over Earth-Space Path in Relation to Scattering of Raindrops at a Tropical Location

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Abstract

The depolarization of a satellite signal due to scattering by rain drops has been studied at a tropical location. The depolarization phenomenon is observed in terms of an enhancement of cross-polar component of a horizontally polarized Ku-band signal. The differential phase shifts, dominantly responsible for causing depolarization at Ku-band due to scattering by spheroidal raindrops, are computed by employing the point matching technique and using experimentally obtained rain drop size distribution (DSD) data. The differential phase shift is significant for large drops (> 3mm). Consequently, DSD plays an important role in determining the depolarization of the satellite signal.

1. Introduction

Rain-induced depolarization of satellite signals at frequencies greater than 10 GHz depends on the oblateness of raindrops that causes anisotropy in the propagation medium. The depolarization effect is described in terms of cross-polar discrimination (XPD) in the context of satellite communications and has been widely studied in the temperate climatic regions [1-3]. However, observations on the depolarization of the satellite signal are still sparse in the tropical region [4-5]. The depolarization is caused by the differential attenuation and differential phase shift due to forward scattering by different rain drop sizes. At Ku-band, the differential phase has the dominant contribution towards the depolarization effect. The differential phase depends on the size of the scatterer, and hence rain drop size distribution plays an important role in determining the extent of depolarization of the signal. The depolarization effect at Ku-band has been studied at a tropical location [5]. In the present paper, the differential phase is obtained by applying the point matching technique and using the measurements of DSD by a disdrometer. The obtained differential phase has been related to the extent of depolarization effect manifested in terms of an enhancement of the cross-polar component of a plane polarized satellite signal at a tropical location.

2. Experimental Arrangements

Ku-band signal propagation data from NSS-6 has been obtained at the receiving station at Kolkata (22°34′N, 88°29′E), India, a tropical location, since 2004. The co-polar and cross-polar components of the horizontally polarized satellite signal at frequency 11.172 GHz are being continuously monitored at the site. Both of the receiving channels are identical and the elevation of the path is 62.5°. The separation between the two orthogonally polarized channels is about 18 dB. The co-polar antenna is utilized to measure the attenuation and the cross-polar one is used to monitor the depolarization of satellite signal with a sampling interval of 1 sec. For the rain drop size distribution measurements, an impact type of disdrometer, co-located with the satellite receiving system, has been used. The disdrometer provides the rain drop size distribution data with a sampling interval of 30 sec.

3. Scattering of Rain Drops

The parameters that cause depolarization of radio signal propagating through the raining medium are differential phase and differential attenuation. Both of these parameters can be estimated from the forward scattering amplitudes of non-spherical rain drops as [6]:

$$\Delta A = 8.686 \times \mathrm{Im}(k_h - k_v)L \tag{1}$$

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$$\Delta\phi = \left(\frac{180}{\pi}\right) \times \mathrm{Re}(k_h - k_v)L \tag{2}$$

where, the horizontal and vertical components of actual propagation constants in the rain-filled medium are respectively denoted as k_h and k_v and L is the propagation path length through the medium which is taken to be 5.4 km. k_h and k_v can be expressed as:

$$k_{h,v} = \left(\frac{2\pi}{k}\right)\int f_{h,v}\, n(a)\, da \tag{3}$$

f_h and f_v being the forward scattering amplitudes in the horizontal and vertical direction due to raindrops having drop size distribution n(a), a being the equivolumetric radius of a raindrop. The forward scattering amplitudes for spheroidal drops are obtained using the point matching technique [7]. The model of axial ratio of rain drops is taken from Beard and Chuang [8]. To indicate the dependence of the scattering parameters of rain drops on its size, the real parts of the forward scattering amplitudes for the horizontal and vertical polarization and their differential values against the drop radius at 11.172 GHz are plotted in Fig. 1. It is seen that at Ku-band, the differential value becomes significant for large raindrops and increases up to a radius of about 3.2 mm beyond which it starts decreasing.

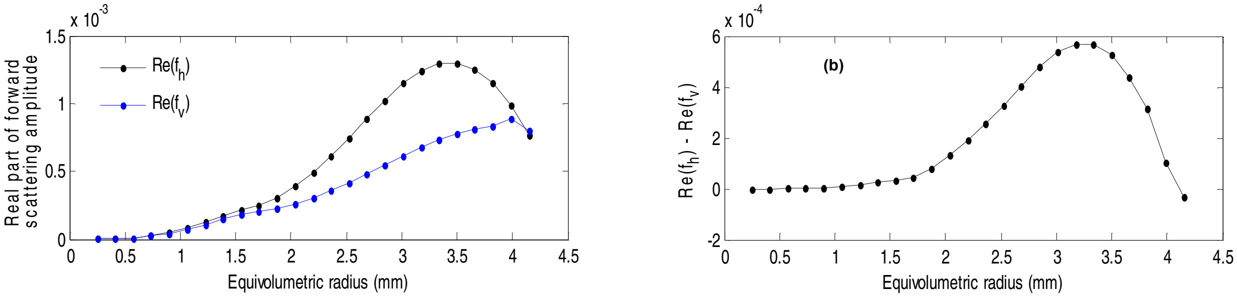

Fig. 1. (a) Variation of real values of the forward scattering amplitudes with drop radius for horizontal and vertical polarization and (b) their differential values at 11.172 GHz

The differential attenuation and the differential phase at Ku-band, which are plotted against rain rates in Fig. 2, are calculated using the formulation given in (1) and (2) and considering Marshall-Palmer DSD [9]. It can be noted that the differential attenuation is very small compared to the differential phase at Ku-band and it is mostly the latter which contributes towards the depolarization of the Ku-band signal.

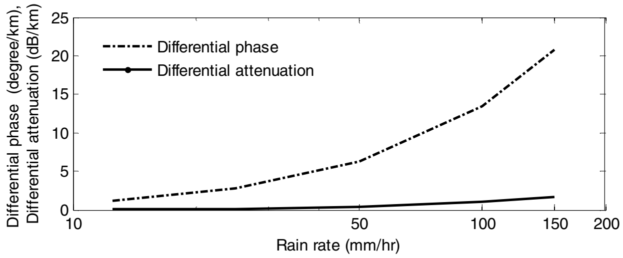

Fig. 2. Variation of differential phase and differential attenuation against rain rate at 11.172 GHz

4. Experimental Results and Discussions

Measurements of co- and cross-polar signal level of Ku-band satellite transmission and DSD observations with a disdrometer have been utilized in the present investigation. Two case studies have been made in this paper. Fig. 3 presents two different events occurring on 30 May 2006 and 25 August 2009. In the figures the time variation of the following parameters are shown: (i) co-polar attenuation, (ii) cross-polar enhancement, (iii) drop size distribution, and (iv) differential phase shift. Two broad peaks are observed in the variation of co-polar attenuation and cross-polar enhancement of the satellite signal during the two events. For the event of 30 may 2009, during the first peak, the maximum value of co-polar attenuation is around 11 dB and the maximum cross-polar enhancement is around 9 dB, and, during the second peak, the co-polar attenuation drops down to around 3 dB but the cross-polar enhancement still retains a high value around 6 dB . Again, for the event of 25 August, the first peak gives a value of about 5 dB of co-polar attenuation and 2.5 dB of cross-polar enhancement whereas for the second peak, the co-polar attenuation reaches a value around 9 dB but the cross-polar enhancement has still a comparatively low value of 3.5 dB. For this event, after the second peak, the attenuation and cross-polar enhancement gradually reduces.

To indicate the role of rain DSD in causing the depolarization of satellite signal and, thereby, resulting in an enhancement of cross-polar component of the satellite signal, ground-based disdrometer measurements during the rain events are presented. It is clearly seen that for the event of 30 May, large drops in the size range 3-4 mm are present in large numbers during the second peak of cross-polar enhancement which is found to be large. On the other hand, for the event of 25 August, disdrometer observations show the presence of comparatively smaller drops during the first peak than in the second peak, the cross-polar enhancement being perceptibly low for the first peak.

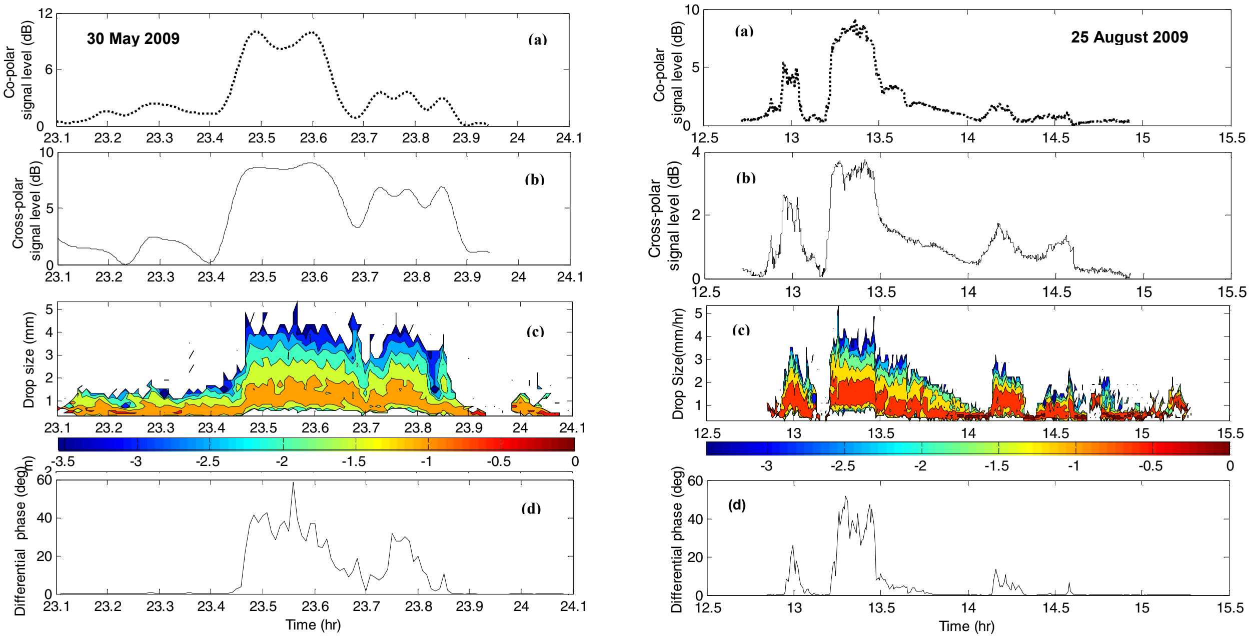

Fig. 3 Time series variation of (a) co-polar attenuation, (b) cross-polar enhancement, (c) drop size distribution, and (d) differential phase, during two rain events on 30 May 2009 and 25 August 2009.

The differential phase, obtained with measured DSD, are also given in the bottommost channels of Fig. 3. The differential phase is found to be considerable whenever the cross-polar enhancement is significant. It may be noted that during the event of 30 May, although the attenuation falls to a value of 3 dB, the differential phase is around 31° which is quite significant to cause a considerable cross-polar enhancement of 6 dB. On the other hand, during the event of 25 August, for the first peak, when the attenuation is around 5 dB, the differential phase is around 20° causing a comparatively lower cross-polar enhancement of about 2.5 dB. It is, therefore, found that rain DSD is responsible in a significant way in determining the depolarization of the signal. It may be pointed out that the ground based measurements do not completely represent the DSD picture over the entire height range. Very small drops (0.5-1mm) and very large drops (4-5 mm) show an increase in their number density with height at a tropical location [10]. Although very small drops have negligible role in causing depolarization but increasing number density of large drops at higher heights will contribute further towards the differential phase shift. The gross variation of DSD during a rain event can, however, be indicated by ground based measurements.

The dominant presence of large drops in the size range 3-4 mm is responsible for large values of differential phase. The axial asymmetry of spheroidal drops increases with the equivolumetric radius which, in fact, causes greater differential phase shift due to forward scattering of raindrops. This is also evident from Fig. 1. The depolarization and the resultant XPD of the satellite signal will be significantly determined by the rain DSD. Hence, the sole consideration of rain attenuation to characterize the depolarization will not be effective particularly in the tropical region where the type of rain varies with season and even within the rain events.

5. Conclusion

The present study reveals that the differential phase shift due to forward scattering of raindrops is mostly responsible for the depolarization of a Ku-band signal over an earth-space path. The differential phase shift at Ku-band is significant for large raindrops and therefore depends on rain DSD. The simultaneous experimental measurements of rain DSD and the enhancement of cross-polar component of the Ku-band signal, indicative of the depolarization effect, show that the presence of large drops significantly increases the depolarization effect. This demonstrates that DSD has a major role to play in determining the extent of depolarization effect.

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