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Effects of melting layer on Ku-band signal depolarization

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ABSTRACT

Propagation effects on Ku-band over an earth-space path is carried out at Kolkata, India, a tropical location, by receiving a Ku-band signal with horizontal plane polarization transmitted from the geostationary satellite NSS-6 (at 95°E). The amplitude of co-polar attenuation has been monitored along with the measurements of rain rate, rain drop size distribution and height profile of rain rate. The cross-polar enhancement of the signal is also monitored by receiving the same signal in orthogonal direction with another identical receiver. The experimental observations are used to study the effect of melting layer on both co-polar attenuation and cross-polar enhancement for the rain events observed during 2012–2013. Melting layer is indicated by the bright band signature in vertical profile of rain rate. The ground based drop size measurements indicate that the stratiform rain has more number of small drops whereas convective rain composed of large rain drops. The results indicate that the depolarization due to melting layer is more dominant compared to that due to the drop deformation mechanism at low rain rates.

1. Introduction

The recent developments in new satellite services have caused an increasing demand of bandwidth. This requires higher frequencies, such as Ku, Ka and V band for satellite communication. Rain attenuation effect on microwave propagation is severe above 10 GHz frequency which has been extensively dealt with experimental observations from temperate regions (Rastburg and Brussaard, 1993; Dintenmann et al., 1993; Bauer, 1997; Karasawa and Maekawa, 1997) as well as over tropical regions (Pan et al., 2001; Pan and Allnutt, 2004; Maitra et al., 2007, 2012; Adhikari et al., 2011; Das et al., 2010a, 2013). However, the information on the depolarization effect on these frequency bands is limited in the tropical region. The depolarization will be an important aspect of frequency re-use scheme where two orthogonal polarizations are used for communication. Again the studies on depolarization effect during rain are mostly concerned with scattering of rain drops (Ippolito, 1999) and the effect of melting layer has not been much reported.

The ice crystals in the atmosphere usually do not contribute much towards signal attenuation in the microwave range, but have a dominant effect in signal depolarization (Green, 2004). The effect of rain on signal propagation depends on rain rate as well as the rain fall type (Ippolito, 1999). The drop size distribution has an important role in causing the various propagation effects. The presence of melting layer in stratiform rain can also cause additional depolarization and attenuation of the signal. In the melting layer, ice coexists with liquid water for which the dielectric constant changes at that level. The signal polarization is affected by the presence of non-spherical particles at that level. Again, as the ice coated with liquid water also attenuates the signal, melting layer can have both depolarization as well as attenuation effect on the signal propagation (Crane, 2003; Green, 2004). Since the depth of melting layer compared to the total height of rain profile is small, the effect of melting layer in causing attenuation is much smaller compared to total rain attenuation. However, the depolarization effect of melting layer can be significant due to the non-spherical shape of ice crystals. The information of melting layer effect on satellite signal is therefore important for proper modeling of propagation effects. In this paper, the relation between rain attenuation and depolarization of Ku-band satellite signal in the presence of melting layer has been investigated with the experimental data at Kolkata (22°34′N, 88°29′E), India.

2. Experimental details

For our present study we have used the data from an impact type Disdrometer, a Micro Rain Radar (MRR) and a Ku-band signal receiving system operating at University of Calcutta, Kolkata.

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The Disdrometer (Distromet-RD-80) is used for the ground based drop size distribution and rain rate measurements. The device has a styrofoam cone to sense the momentum of rain drops. This information is then converted using the Gunn–Kinzer (Gunn and Kinzer, 1949) relation between fall velocity and drop diameter into 20 bins of rain drop sizes (from 0.3 mm to 5.5 mm) with $\pm 5\%$ accuracy (Tokay and Short, 1996). For the present study the instrument is used with an integration time of 30 s.

MRR is a vertically pointing frequency modulated continuous wave (FM-CW) radar. It transmits 50 mW power at 24.1 GHz of which a small fraction returns after getting scattered from different hydrometeors. The profile of fall velocity of the hydrometeors is estimated using the Doppler principle. Using Gunn–Kinzer relation the DSD profile is obtained from the fall velocity profile. The vertical DSD profile, in turn, gives the rain rate and radar reflectivity factor, and hence is capable of indicating the presence of melting layer by a radar bright band signature (Fabry and Zawadzki, 1995; Das et al., 2010b). The bright band represents an abrupt enhancement in vertical radar reflectivity profile due to the change in dielectric properties of melting ice (Kain et al., 2000).

The Ku-band signal at 11.172 GHz transmitted from NSS-6 geostationary satellite (at longitude 95°E) has been received at 63° elevation from our location (Maitra et al., 2007). The polarization of the Ku-band signal is horizontal with respect to the equator. At Kolkata, the local polarization angle is $-15.6°$. Both co-polar (horizontal component) attenuation and cross-polar (vertical component) enhancement have been recorded by the two receiving systems with two antennas having identical specifications. The co-polar attenuation is measured by noting the decrease in signal level, with reference to the clear air signal level, received by the horizontally polarized antenna. Again, the cross-polar enhancement is measured by noting the increase in the signal level, with reference to the clear air level, received with the vertically polarized antenna. The signal receiving system is kept under laboratory environment to make sure that the varying temperature of the surroundings does not alter the received signal amplitude.

The satellite signal is a TV broadcast signal with low fade margin of 20 dB. The separation between the co-polar attenuation and cross-polar enhancement is about 18 dB for clear air. An enhancement in the cross-polar component of the signal indicates the depolarization of the plane polarized signal caused by the propagation medium. The data are recorded with a sampling interval of 10 s. Further details of the receiving system are provided by Maitra and Chakravarty (2009).

3. Experimental results

During the month of June to September, rain mainly occurs due to South–West monsoon (June–September) in Kolkata. Rain events due to convective activities are also encountered during pre-monsoon and post-monsoon seasons. A detailed case study of rain event occurred on June 29, 2013 has been presented to indicate the rain features during monsoon of this location and its effect on the depolarization of Ku-band signal. Another example of co-polar attenuation and cross-polar enhancement for one convective and one stratiform event occurring on 19 May 2013 is also presented to support our finding. A statistical analysis of the two years data (2012–2013), pertaining to S–W monsoon is also presented. The cumulative exceedances of rainfall rates, co-polar attenuation and cross-polar enhancement are also studied for the same period. The results are also compared with ITU-R model.

3.1. Case study of the rain event on June 29, 2013

3.1.1. Rain rate and signal strength variation

The event occurring on 29 June 2013 with duration of 10 h and 30 min pertains to South–West monsoon. The maximum rain rate in the event reaches 60 mm/h, as shown in Fig. 1(a). Fig. 1(b) shows both the co-polar attenuation and cross-polar enhancement which follow the rain rate pattern. We note that the co-polar attenuation in this event is up to 8 dB and the maximum cross-polar enhancement is 6 dB as indicated in Fig. 1(b). The anisotropy of the medium is responsible for depolarization of signal which increases with the increase in rain rate. Hence, both co-polar attenuation and cross-polar enhancement vary accordingly with the change in the rain rate.

3.1.2. Vertical profile of rain

The gradient of hydrometeor fall velocity is a good indicator to identify the melting layer as the fall velocity above melting layer is very low compared to that of melting layer region, where a sharp increase is observed. The increase in velocity is due to the phase change of ice crystals to rain drops. Melting layer is also indicated by the abrupt enhancement of radar reflectivity factor in the height profile due to melting ice crystals, called radar bright band. In case of MRR, the rain rate profile indicates the bright band much clearly than the radar reflectivity profile (Peters et al., 2005; Das et al., 2011). This is due to the fact that MRR estimates the DSD first and then the rain integral factors. The DSD measurements using MRR are valid only for melted DSD. The quantitative estimation of DSD and derived rain integral parameters in rain region are in good agreement with other ground based instruments for different regions as reported by many researchers (Peters et al., 2002,

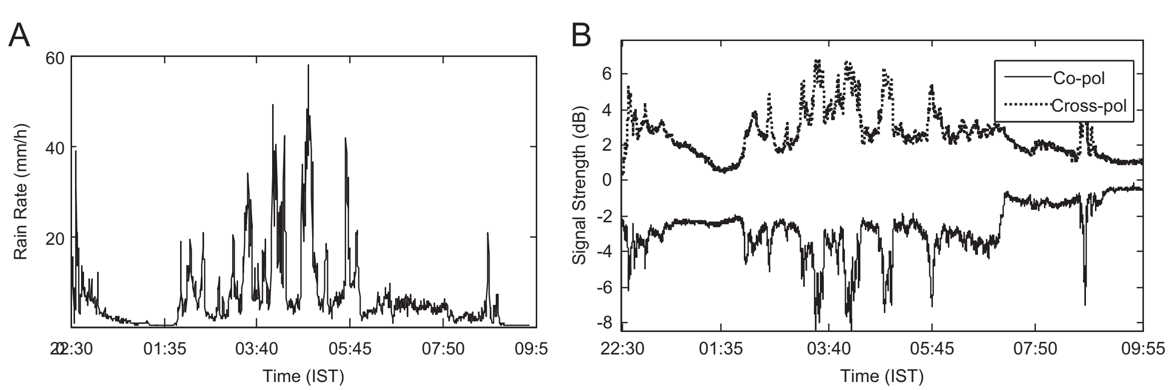

Fig. 1. Rain event recorded on 29.06.13 for (a) rain rate and (b) co-polar attenuation and cross-polar enhancement.