Journal of Atmospheric and Solar-Terrestrial Physics 121 (2014) 83–88

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Studies on some characteristics of rain-induced depolarization of Ku-band signal over an earth-space path at a tropical location

Animesh Maitra*, Arpita Adhikari

S. K. Mitra Centre for Research in Space Environment, Institute of Radio Physics and Electronics, University of Calcutta, Kolkata 700009, India

ARTICLE INFO

Article history:
Received 17 September 2013
Received in revised form
16 October 2014
Accepted 18 October 2014
Available online 23 October 2014

Keywords:
Rain
Depolarization
Cross-polar enhancement
Drop size Distribution

ABSTRACT

The rain-induced depolarization of a Ku-band satellite signal has been studied at a tropical location, Kolkata (22°34′N, 88°29′E). The depolarization phenomenon is observed in terms of an enhancement of cross-polar component of a horizontally polarized Ku-band satellite signal at the present location. The differential phase shifts, dominantly responsible for causing depolarization caused by scattering of oblate spheroidal rain drops at Ku-band, are computed by employing the point matching technique and utilizing rain drop size distribution data, experimentally obtained at the present location. The differential phase shift is significant for large rain drops resulting in greater depolarization of signal. Consequently, rain drop size distribution plays an important role in determining the depolarization of the satellite signal. The relationship of cross-polar enhancement with rain rate shows a seasonal variation indicating higher extent of depolarization during the pre-monsoon period than during the monsoon period, the reason being the dominance of larger rain drops in the pre-monsoon period compared to the monsoon months for identical rain rates.

1. Introduction

Depolarization of satellite signal is one of the significant propagation impairments at frequencies above 10 GHz. Rain drops are not exactly spherical in shape (Oguchi, 1983a). Consequently, rain-induced depolarization of satellite signals 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 (Arbesser-Rastburg and Brussaard, 1993; Jakoby and Rucker, 1994; Karasawa and Maekawa, 1997). However, observations on the depolarization effect of the satellite signal are still sparse in the tropical region (Green, 2004; Maitra and Chakravarty, 2009). The depolarization is caused by the differential attenuation and differential phase shift due to forward scattering by different rain drop sizes. At Ku-band frequencies, the differential phase has the dominant contribution towards the depolarization effect. The differential phase depends on the size and shape of the scatterer, and, hence, rain drop size distribution (DSD) plays an important role in determining the extent of depolarization of the signal. Water being a lossy dielectric medium (Kong, 2005; Ruck et al., 1970; Harrington, 1961) both reflection and transmission properties of plane polarized wave should be taken into consideration while estimating the total depolarization during rain. Till recent times, the scattering properties of non-spherical rain drops have been analyzed through different methods (Oguchi, 1960, 1964; Morrison and Cross, 1974; Erma, 1968a, 1968b, 1969; Pruppacher and Beard, 1970; Pruppacher and Pitter, 1971; Asano and Yamamoto, 1975; Warner, 1975; Warner and Hizal, 1976; Holt et al., 1978; Li et al., 1994, 1995a, 1995b), each with its own advantages and drawbacks. In the present study, the differential phase is obtained by applying the point matching technique (Oguchi, 1973b; Morrison and Chu, 1973; Morrison and Cross, 1974) to oblate spheroidal rain drops and using the measurements of drop size distribution from 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 the current tropical location.

2. Experimental arrangements

The Ku-band signal propagation measurements (Maitra et al., 2007, 2012; Maitra and Chakravarty, 2009; Chakravarty and Maitra, 2010; Adhikari and Maitra, 2011; Adhikari et al., 2011, 2012; Bhattacharya et al., 2013) by receiving the downlink signal from a geostationary satellite NSS-6 have been carried out at the receiving station at Kolkata (22°34′N, 88°29′E), India, a tropical location,

* Corresponding author.
E-mail address: animesh.maitra@gmail.com (A. Maitra).

http://dx.doi.org/10.1016/j.jastp.2014.10.009
1364-6826/

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. The satellite dishes for receiving the two orthogonal components of the signal are identical and the elevation of the path is 62.5°. The separation between the two orthogonally polarized channels is about 20 dB. The co-polar antenna is utilized to measure the attenuation and scintillation with a sampling interval of 1 s. The cross-polar antenna tracks the orthogonal component of the same satellite signal. During rain events, a degradation of the co-polar signal level occurs and an enhancement of the orthogonal component from its clear-sky signal level takes place which is termed as cross-polar enhancement. The depolarization effect is usually measured in terms of cross-polar discrimination (XPD) or cross-polar isolation (XPI). But, the present experimental system does not facilitate direct measurement of XPD or XPI. However, the XPD degradation can be evaluated from ITU-R P.618-11 (2013) by subtracting the value of XPD at each attenuation value from a given clear air XPD. For our data set we can obtain the XPD degradation from the experimental measurements of co-polar degradation and cross-polar enhancement (Maitra and Chakravarty, 2009; Sarkar et al., 2014).

For the rain drop size distribution measurements, an impact type disdrometer, co-located with the satellite receiving system, has been used. The disdrometer provides the rain drop size distribution data, measuring drop diameter in the range of 0.3–5.3 mm and distributed in 20 different drop size bins with a sampling interval of 30 s. The data pertaining to the years 2006 and 2009 are utilized in the present study.

3. Scattering of rain drops

The parameters that cause depolarization of plane polarized 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 (Oguchi, 1983):

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

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

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. The effective path length, L, is evaluated from ITU-R P.618-11 (2013) and for the present location it is found to be 2.75 km taking the point rainfall rate for 0.01% of an average year as 90 mm/h (ITU-R P.837-6, 2012) and the rain height as given in Recommendation ITU-R P.839-3 (2001).

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 rain drops having drop size distribution $n(a)$, a being the equivolumetric radius of the rain drop. The rain drop size distribution has been evaluated by considering Marshall–Palmer distribution given by

$$n(a)da = N_O e^{-\Lambda a}\,da \tag{4}$$

where da is the drops size range, the value of which is taken as 0.325 mm for the present study and

$$N_O = 1.6\times10^4 \quad (\mathrm{m^{-3}\,mm^{-1}}) \tag{5}$$

$$\Lambda = 8.2R^{-0.21} \quad (\mathrm{mm^{-1}}) \tag{6}$$

Here R is the rain rate. The model to define the shape of rain drops is taken from Goddard et al. (1994) where the axial ratio of oblate spheroidal rain drops was represented by combining the model of Goddard and Cherry (1984) and Beard and Chuang (1987) as

$$AR = 1.075 - 0.13r - 0.0144r^2 + 0.032r^3 \quad \text{for } 2r \geq 1.1\ \text{mm} \\ \text{and } AR = 1 \quad \text{for } 2r < 1.1\ \text{mm} \tag{7}$$

where AR is the axial ratio of rain drops having equivolumetric drop radius r.

The complex refractive index of water at 20 °C temperature for 11.172 GHz is computed by utilizing double-Debye formulation (Liebe, 1989).

The forward scattering amplitudes for oblate spheroidal rain drops are obtained using the point matching technique (Oguchi, 1973). In order 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 at 11.172 GHz are plotted with the drop radii 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. This phenomenon is due to the Mie Scattering resonance occurring for scattering in the range of size parameter (r/λ) value between 0.1 and 0.2. For major axis (horizontal axis) of the raindrops this resonance at 11.172 GHz occurs at equivolumetric radius of around 3.2 mm and for minor axis (vertical axis) this occurs at much larger value of equivolumetric radius. The resultant differential phase, therefore, peaks around 3.2 mm value as shown in Fig. 1 (a) and (b).

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 (Marshall and Palmer, 1948) as indicated in relation (4). It can be noted that the differential attenuation values

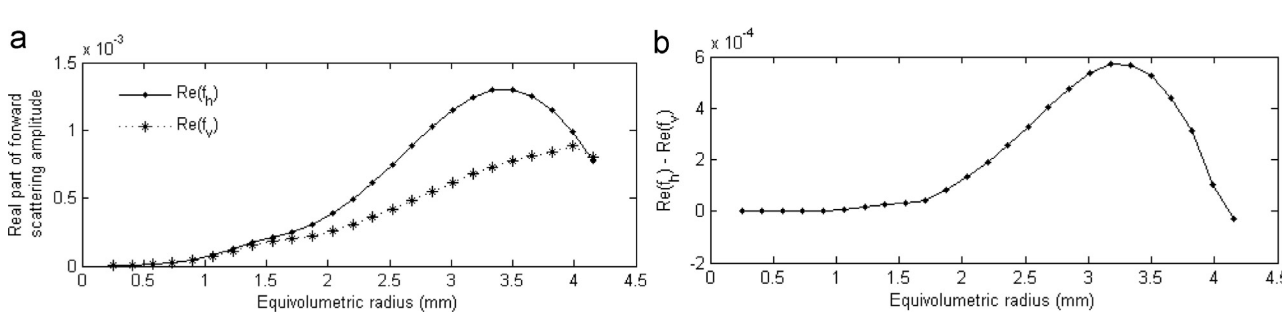

Fig. 1. (a) Variation of real values of the forward scattering amplitudes with drop radius for horizontal and vertical polarization and (b) their differential values at 11.172 GHz.