Earth-space Propagation through rain and associated tropospheric processes at a tropical location

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Abstract

The propagation of satellite signals at frequencies above 10 GHz has been studied to investigate the characteristic features of tropical rain. The propagation effects, namely, attenuation, scintillation and depolarization caused by varying structures of rain have been investigated to indicate their interrelationship. The varying relationship between attenuation and scintillations indicates the evolution of turbulence during different types of rain events. Also, the rain-induced depolarization of the signal is related to rain attenuation in different manner during stratiform events, when the melting layer is present, than during convective events when large rain drops are mainly responsible for depolarization in the absence of melting layer.

1. Introduction

Rain climatology at the tropical location of Kolkata is characterized by several special features, such as, strong Indian South-west Monsoon (ISM), pre-monsoon rain mainly connected with convective phenomenon, seasonal variation of rain heights, melting layer formation during the evolution of rain features in rain events, large variation of rain drop size distribution. Rain induced propagation effects are of much concern in the tropical location as they impair the performance of satellite communication links above 10 GHz. The propagation of radio signals above 10 GHz is affected mainly through three phenomena, namely, attenuation, scintillation and depolarization. The propagation effects, both in the extent and type, differ significantly at tropical location compared to that of temperate regions. Although, microwave propagation studies over earth-space paths have been carried out at several tropical locations [1-6] yet many distinctive phenomena having effects on the propagation of microwave signals are to be adequately investigated.

2. Experimental Observations and Discussions

At the University of Calcutta, Kolkata (22°34' N, 88°29' E), India, Ku-band satellite signal from NSS-6 has been continuously monitored since June 2004. The Ku-band receiving system comprises of two identical receiving channels with antennas having orthogonal polarizations to receive co-polar and cross-polar component of the satellite signal. The co-polar channel is utilized to monitor signal level of the satellite signal experiencing attenuation and scintillations, and the cross-polar channel is used to monitor cross-polar enhancement of the signal indicating the depolarization effect. The detailed description of the receiving system has been described in our earlier papers [3, 4, 7]. An impact type of Disdrometer, collocated with the receiving system, is used for the ground based drop size distribution (DSD) and rain rate measurements.

For the study of the vertical rain structure, a Micro Rain Radar (MRR), a vertically pointing FM-CW radar at 24.1 GHz, has been operated at the same site. The vertical profile of rain rate and radar reflectivity can indicate the presence of melting layer with bright band signatures.

3. Result and Discussion

Rain attenuation is the most dominant phenomenon which is responsible for signal impairments above 10 GHz and the effect is particularly crucial in tropical regions. The other two rain-induced effects, namely, scintillations and depolarization of signal are related to rain attenuation. The inter-relationship among rain attenuation, scintillation and depolarization can indicate the characteristics feature of the propagation conditions at frequencies above 10 GHz.

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3.1 Rain Attenuation and Scintillation

The bulk refractive index structure of raining medium is responsible for rain attenuation. Small scale irregularity structures generated due to turbulence associated with rain events are responsible for scintillations, fast fluctuations of signals. The fast fluctuations are superimposed on the large scale variation of signal level due to attenuation (Fig. 1). The usual relationship shows an increase of scintillation intensity with attenuation indicating the growth of turbulence with rain intensity in the medium. There is a difference in the rain attenuation versus scintillation relationship for convective and stratiform rain. Severity of turbulence along with drop size distributions determine the mean flow of the kinetic energy into the medium which consequently determines the intensity of scintillations. The pre-monsoon and monsoon rain due to diverse atmospheric conditions show different relationships between rain attenuation and scintillations.

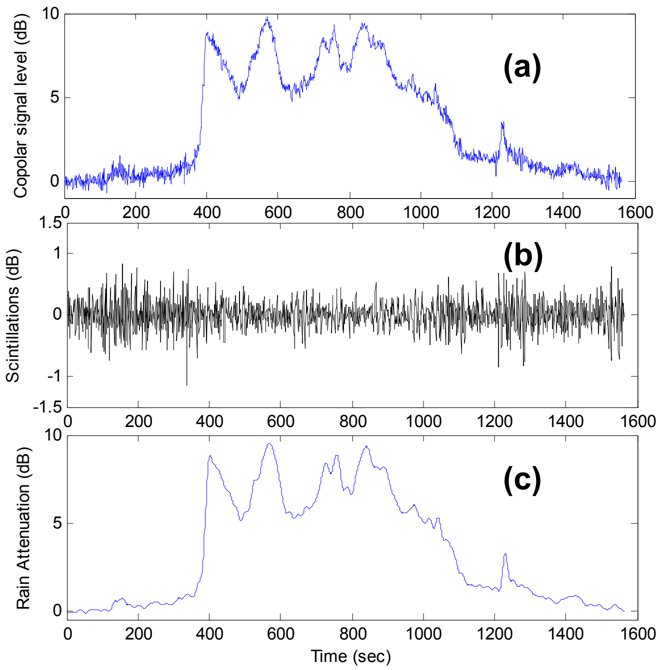

Fig. 1: (a) Co-polar signal level variation during the rain event on July 20, 2007, (b) fast fluctuations obtained after high pass filtering of signal variation, and (c) rain attenuation of satellite signal obtained after low pass filtering for the same event

3.2 Rain Attenuation and Depolarization

Simultaneous observations of rain attenuation and depolarization effect on microwave signal propagation over earth-space paths can be useful tool for sensing of rain structures. Tropical region experiences more complex variations of rain-induced depolarization due to the distinguishable nature of stratiform and convective rain. In tropical region, rain events occur exhibiting the features of stratiform as well as convective rain even within a single event. Consequently, the relationship between attenuation and depolarization is rather complex because of the varying nature of precipitation within individual rain events and also during different seasons. The melting layer is often observed during rain events when precipitation becomes stratiform type, particularly at low rain rate. Since the contributions of melting layer towards attenuation and depolarization are different, the rain type and, consequently, rain rate can drastically change the relationship between rain attenuation and depolarization. At low values of rain attenuation, the cross-polar enhancement can be quite significant as the melting layer contributes substantially towards depolarization but does not cause significant attenuation. At high rain rates, however, the melting layer is absent and large rain drops contribute both towards attenuation and depolarization.

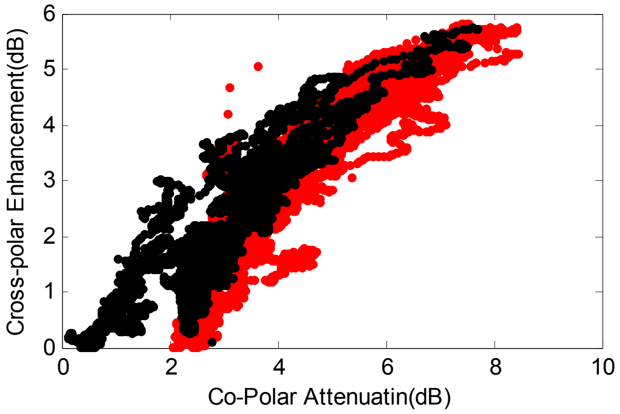

Fig. 2: Rain attenuation and depolarization with and without melting layer (Red dots indicate absence of melting layer, black dots indicate presence of melting layer)

A scatter plot between co-polar attenuation and cross-polar enhancement with and without melting layer is shown in Fig. 2 to show how the melting layer affects the signal depolarization. The black dots indicate the observations in the presence of melting layer and red dots indicate when the melting layer is not present. The signature of melting layer is obtained from observations with an MRR operated at the same location. The cross polar enhancement is observed to be substantial compared to the co-polar attenuation when melting layer is present indicating that the melting layer causes significant depolarization effect. The rain attenuation is primarily dependent on the rain drop sizes and, consequently, on rain rate even in presence of melting layer. However, the depolarization is observed to be caused by both melting layer and large rain drops. As large rain drops are not spherical in shape and ice crystals also have different shapes so the signal polarization is affected by both. The melting layer effect is particularly dominating on the signal depolarization at lower rain rates. However, at higher rain rates, when large rain drops are more abundant, the effect of rain drops are more dominant on depolarization. Thus simultaneous measurements of the attenuation and depolarization can be very effective in assessing the relative contribution of raindrops and melting layer in causing depolarization of the signal.

4. Conclusion

In this study, the relationship between attenuation and scintillations and between attenuation and depolarization of Ku-band satellite signal have been investigated to indicate some characteristic features of raining atmosphere at a tropical location. The strong turbulence associated with tropical rain causes scintillations of the signal which do not monotonically increase with rain attenuation but vary in a complex manner with attenuation depending on rain intensity and type of rain. Again, the rain-induced depolarization effect, measured in terms of cross-polar enhancement, also shows a varying relationship with rain attenuation because of the changing structure of vertical profile of rain. The intense rain, during which convective processes are active and large rain drops are more abundant, is responsible for both significant attenuation and depolarization of the signal. On the other hand, during the stratiform phase of rain, when the rain intensity is usually low, a melting layer is formed which substantially contributes toward the depolarization of the signal and not significantly towards attenuation. The above mentioned study on the interplay of attenuation, scintillations and depolarization of Ku-band satellite signal indicates varying and complex features of raining atmosphere that need to be considered in propagation modeling at microwave and millimeter-wave bands in the tropical region.

5. Acknowledgments

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