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Studies on the inter-relation of Ku-band scintillations and rain attenuation over an Earth–space path on the basis of their static and dynamic spectral analysis

Arpita Adhikari, Animesh Maitra *

S.K. Mitra Centre for Research in Space Environment, Institute of Radio Physics and Electronics, University of Calcutta, Kolkata 700 009, India

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A B S T R A C T

An attempt has been made to inter-relate simultaneously occurring rain attenuation and scintillations of Ku-band signals over an Earth–space path at a tropical location. The power spectral analysis has been carried out to determine required cut-off frequency of filtering to separate out rain attenuation and scintillation effects. The power spectra of low- and high-pass filtered time series of satellite signal level data exhibit respective slopes in frequency domain that support theoretical values. Furthermore, wavelet analysis reveals the variability of different modes of signal variations in time–frequency space and the two phenomena are related by means of their global wavelet spectra.

1. Introduction

The rain attenuation and scintillations are two major propagation phenomena that cause degradation of satellite signal at frequencies above 10 GHz. Absorption and scattering of the signal due to the rain droplets are responsible for rain attenuation. The rain attenuation is manifested as large scale variations of satellite signal determined by the rain rate variation. On the other hand, scintillations are fast fluctuations of the signal caused by small scale structures occurring mainly due to the turbulence-induced refractive index variations of the propagation medium. The turbulence-induced scintillations can take place in clear air conditions (Moulsley and Vilar, 1982; Vilar and Haddon, 1984; Karasawa et al., 1988a, 1988b; Otung and Evans, 1995; Vasseur and Douchin, 1997; Marzano and d'Auria, 1998; Vasseur, 1999; Kassianides and Otung, 2003), and also in the raining condition with concurrently occurring rain attenuation (Haddon and Vilar, 1986; Basili et al., 1990; Filip and Vilar, 1990; Karasawa and Matsudo, 1991; Matricciani et al., 1995, 1996; Matricciani and Riva, 2008; Otung and Evans, 1995; Salonen et al., 1996; Touw and Herben, 1996; Jones et al., 1997; Van de Kamp et al., 1997; Mertens and Vanhoenacker-Janvier, 2001; Suryana et al., 2005). Although the signal degradation caused by scintillations is not so significant in comparison to rain attenuation, yet it is important to assess the relative role of the phenomenon in presence of rain attenuation in order to reveal the type of rain and cloud and their combined effect on the Earth–space satellite link quality and availability. Also, scintillations can become significant in the case of low-power margin communication systems and for Earth–space satellite links with elevation angles less than 10° (Banjo and Vilar, 1986). To ensure the efficient utilization of the channel capacity it is important to evaluate the amount of signal deterioration due to simultaneous occurrence of the rain attenuation and scintillations (Filip and Vilar, 1990). Inter-relationship between the two physical phenomena can reveal the behavior of turbulences embedded in the rain structure under different raining conditions. The irregularities in the refractive index structure of the propagation medium can also give rise to phase scintillations (Ishii, 1995). Even though the measurement of phase scintillation is beyond the scope of the present study, it may be noted that the phase scintillations, which can accompany amplitude scintillations, can affect the phase sensitive communication and navigational systems significantly. Although, the inter-relation of these two co-occurring phenomena has been addressed by various authors (Haddon and Vilar, 1986; Basili et al., 1990; Filip and Vilar, 1990; Karasawa and Matsudo, 1991; Matricciani et al., 1995, 1996, 2008; Touw and Herben, 1996; Mertens and Vanhoenacker-Janvier, 2001; Garcia et al., 2002; Matricciani and Riva, 2008), reports from the tropical region are still inadequate (Suryana et al., 2005).

In this paper, scintillations occurring simultaneously with rain attenuation at Kolkata (22°34′ N, 88°29′ E), India, a tropical location, have been studied on the basis of the static and dynamic spectral analysis of the Ku-band satellite signal level data. The spectral analysis of the signal variation has been used to study the effects due to rain attenuation and scintillation. These power spectra reveal the power at different frequencies considering that

* Corresponding author. Tel.: +91 33 2350 9116; fax: +91 33 2351 5828.
E-mail address: animesh.maitra@gmail.com (A. Maitra).

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the spectral distribution remains same over the entire time span over which the signal has been sampled. Furthermore, the wavelet analysis technique has been adopted to indicate dynamic behavior of the inter-relationship between the two effects during rain events.

2. Mathematical basis

One of the most significant mathematical tools in the study of time series data is power spectral analysis. It is well suited to the time series data representing fluctuations of the satellite signal propagating over Earth–space path. The periodogram method (Schuster, 1898) has been adopted here for the power spectral estimation of the time series data. This classical nonparametric mechanism of spectral estimation employs a number of squared magnitude Fast Fourier Transformed rectangular windows to calculate the power distribution of the input sequence (Zaknich, 2005). Power spectral densities (PSDs) of the time series of two different-scaled signal variations, namely scintillations and rain attenuations, are usually found to have different slopes (Matricciani, 1994; Vanhoenacker-Janvier and Vasseur, 1995; Matricciani et al., 1995, 1996; Vasseur and Douchin, 1997; Kassianides and Otung, 2003; Savvaris et al., 2004; Matricciani and Riva, 2008), and thus are significant in establishing the degree of influence of the two phenomena while occurring simultaneously. Although PSDs provide the information about the power distribution of a time series at different frequencies, yet it is a static analysis. The wavelet analysis technique has been adopted for the present study to decompose the non-stationary time series of signal variations into time and frequency domains simultaneously. This technique has recently been reported to study tropospheric scintillations of Ku-band satellite signal (Maitra et al., 2006) and the ionospheric scintillation phenomenon in the amplitude of GPS signals (Materassi and Mitchell, 2007).

The wavelet analysis is basically a continuous and redundant way of decomposing a time varying signal into both space and scale by utilizing the projection of the signal on to functions called wavelets. This allows detailed information about the amplitude variation of numerous wave packets, having different periodicities, with respect to the time variation of the event.

The wavelet analysis starts with the generation of a prototype function called “mother wavelet”. The signal is then decomposed into a series of functions of finite periodicities consisting of mother wavelet functions of different magnitudes along the entire time span of the event. To have a good trade-off between time and frequency resolution of the decomposed components, the Morlet wavelet is a good choice. As the frequency of the constituent modes increases, the temporal and frequency resolution of the Morlet wavelet, respectively, gets better and worse. The fact is quite

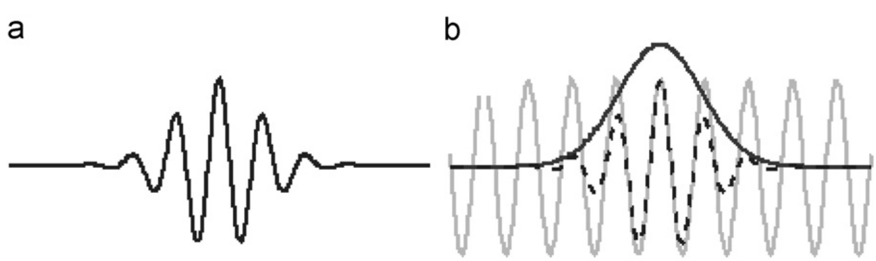

Fig. 1. (a) Time variation of an arbitrary Morlet wavelet. (b) Representation of the Morlet wavelet (black dashed) as a sine curve (gray) with a Gaussian envelope (black) (http://paos.colorado.edu/research/wavelets/wavelet2.html).

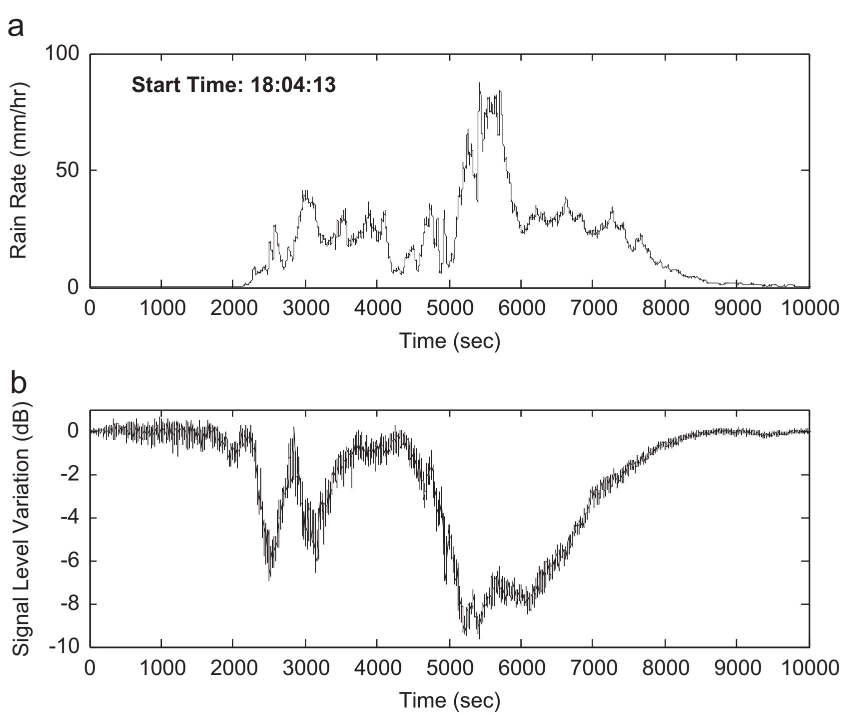

Fig. 2. (a) Variation in rain rate during a rain event on 02 June 2008 and (b) the record of Ku-band satellite signal level showing simultaneous occurrence of rain attenuation and scintillations during the rain event.