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Study of 1-min rain rate integration statistic in South Korea

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ABSTRACT

The design of millimeter wave communication links and the study of propagation impairments at higher frequencies due to a hydrometeor, particularly rain, require the knowledge of 1-min. rainfall rate data. Signal attenuation in space communication results are due to absorption and scattering of radio wave energy. Radio wave attenuation due to rain depends on the relevance of a 1-min. integration time for the rain rate. However, in practice, securing these data over a wide range of areas is difficult. Long term precipitation data are readily available. However, there is a need for a 1-min. rainfall rate in the rain attenuation prediction models for a better estimation of the attenuation. In this paper, we classify and survey the prominent 1-min. rain rate models. Regression analysis was performed for the study of cumulative rainfall data measured experimentally for a decade in nine different regions in South Korea, with 93 different locations, using the experimental 1-min. rainfall accumulation. To visualize the 1-min. rainfall rate applicable for the whole region for 0.01% of the time, we have considered the variation in the rain rate for 40 stations across South Korea. The Kriging interpolation method was used for spatial interpolation of the rain rate values for 0.01% of the time into a regular grid to obtain a highly consistent and predictable rainfall variation. The rain rate exceeded the 1-min. interval that was measured through the rain gauge compared to the rainfall data estimated using the International Telecommunication Union Radio Communication Sector model (ITU-R P.837–6) along with the empirical methods as Segal, Burgueno et al., Chebil and Rahman, logarithmic, exponential and global coefficients, second and third order polynomial fits, and Model 1 for Icheon regions under the regional and average coefficient set. The ITU-R P. 837-6 exhibits a lower relative error percentage of 3.32% and 12.59% in the 5- and 10-min. to 1-min. conversion, whereas the higher error percentages of 24.64%, 46.44% and 58.46% for the 20-, 30- and 60-min. to 1-min., conversion were obtained in the Icheon region. The available experimental rainfall data were sampled on equiprobable rain-rate values where the application of these models to experimentally obtained data exhibits a variable error rate. This paper aims to provide a better survey of various conversion methods to model a 1-min. rain rate applicable to the South Korea regions with a suitable contour plot at 0.01% of the time.

1. Introduction

Satellite services are being developed at higher frequencies due to the availability of this portion of the spectrum. However, the broadband services operating in these frequencies ranges show a severe impact due to hydrometeors, especially rain resulting in the degradation of the quality of the received signal. The attenuation due to rainfall increases more at frequencies above 10 GHz (Ramadorai, 1987; Crane, 1996). The earliest attempts to develop a comprehensive rain attenuation prediction technique came through the actions of the International Telecommunication Union Radio Communication Study Group 3 (ITU-R, formerly the CCIR). The procedure estimates the cumulative distribution of rain based on the concept of a global map, dividing the surface of the earth into climate regions and provides an average annual rain rate distribution for each region as considered by the earlier ITU-R P. 837-5 method (Ippolito, 1986). The ITU rain attenuation prediction method is based on 0.01% of a rain rate rain rate parameters for a year (Owolawi, 2011b). ITU-R P. 618-12 (ITU-R P 618-12, 2015) focuses on the use of a 1-min. integration time for the rainfall rate as the prominent integration time for the prediction of rain attenuation. Furthermore, ITU-R P. 530-16 (ITU-R P 530-16, 2015) uses rain rate at 0.01% of the time for prediction of rain attenuation on a terrestrial line-of-sight communication system. Unfortunately, meteorological agencies around the world provide a rainfall rate distribution with a longer integration time, usually higher than a 1-min. integration time. To convert higher integration time rainfall data to the equivalent 1-min. distribution, various procedures have been tested considering physical, analytical and empirical models. The 1-min.

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integrated time data covering long observation periods are typically recorded using rain gauges at a specific site. The measurement was performed over the period of a decade (2004–2013). These databases enable the evaluation of the performance of the 1-min. rainfall rate as estimated by the ITU-R model (ITU-R P837−-6, 2012), also known as the EXCELL Rainfall Statistics Conversion (ERSC) method with experimental 1-min. data. The results are analyzed using several error calculations, and this method is not been able to adequately represent the rainfall rate statistics of South Korea, particularly for higher time conversions from 20-, 30-, and 60-min. to 1-min. This paper studied the suitability of different conversion techniques through regression analysis and error calculation against the calculated 1-min. rain rate from the experimental 1-min. rainfall amount. Furthermore, the numerical analyses have been performed at a new site, namely, Icheon, for a greater time percentage exceeding 1% to 0.001% of the time. In addition, the contour plot for 0.01% of the time was generated for the 1-min. time interval using the Kriging interpolation method. The remainder of this paper is organized as follows: In Section 2, we give a brief overview of experimental setup and rain rate distribution of the South Korea regions. In Section 3, we present the conversion methods for rainfall rate distribution. Section 4 details the performance evaluation of several techniques while Section 5 presents the paper's conclusions.

2. Procedure of experimental setup and rain rate distribution

South Korea has a temperate climate with four distinct seasons. Winters are usually long, cold and dry. Summers are very short, hot and humid. Spring and autumn are pleasant but also short in duration. The country has sufficient rainfall; rarely, it obtains less than 75 cm of rainfall in any given year or can reach over 100 cm. Maximum rainfall is observed from May until September of each year. Under these scenarios, the Korea Meteorological Administration (KMA) has developed and operated a digital system for collecting and storing rainfall data at 1-min. time intervals since 2004. KMA started routine recording and archiving of tipping bucket rain gauge observations with a 1-min. time resolution at 93 different locations out of which nine sites were considered for derivation of the regional coefficient sets. These sets were tested at the Icheon and Mokdong sites that are close to Seoul at an aerial distance of 45 km and 15 km, respectively, from the Seoul location. At the Icheon site, microwave links for 18, 38 and 75 GHz are installed for further analyzing the effect of rain attenuation on these links (Shrestha, 2016). Similarly, at the Mokdong site, the satellite communication links for 12.25, 19.8, and 20.73 GHz were established to study the effect of rain on the slant path of the communication link (Shrestha and Choi, 2016; Shrestha and Choi, 2017; Sujan et al., Choi). Thus, we have selected these sites for comparison of several empirical methods. The detailed description the nine sites mentioned indicating a prime location of South Korea along with the system setup of a tipping bucket rain gauge is described in (Sujan et al., 2016b), which signifies the derivation of prominent rain rate methods. Furthermore, OTT Parsivel, which stands for laser optical Particle Size and Velocity, is the laser-optical disdrometer, that is setup for simultaneous measurement of particle size and velocity for all liquid and solid precipitation at the Icheon and Mokdong sites where microwave and satellite links are established. Fig. 1 depicts the overview of the OTT Parsivel instrument.

As depicted in Fig. 1, Parsivel uses a laser based optical sensor to measure precipitation. The transmitter unit of the sensor generates a flat horizontal beam of light, which the receiver unit converts into an electrical signal. There are the changes in the signal whenever a hydrometeor passes through the beam within the area of measurement. The degree of dimming is a measure of the size of the hydrometeor, and together with the duration of the signal, the fall velocity is derived. Precipitation measurements are carried out with a special sensing head developed for this purpose. The sensing head detects precipitation optically one meter above ground level. The primary data are the size and velocity of each single hydrometeor, from which the size spectrum, and rainfall amount are derived. Table 1 shows the specifications of OTT Parsivel, which is used for recording the rain rate.

Fig. 1. OTT Parsivel (http://www.ott.com; OTT).

Table 1
Specifications of OTT Parsivel (OTT).

Instrument	Technical detail	Technical data
OTT Parsivel Disdrometer	Type of sensor	Optical laser diode
	Beam size	180×30 mm
	Measuring area	54 cm^2
	Range of measurement particle size	0.2–25 mm
	Range of measurement velocity	0.2–20 m/s
	Particle classification	32 size classes and 32 velocity classes
	Precipitation Intensity	0.001–1200 mm/h
	Interface	Rs422/ Rs485
	Temperature range	−40 to +70 °C

Three years of rainfall intensities with 99.95% validity over all of the time were collected by OTT Parsivel for every 10 s interval, which in turn is averaged over 1-min. as given in (Choi et al., 2012). The emitter and receiver are incorporated into the single protective housing. The output voltage changes as the hydrometeor falls through the laser beam, thereby determining the particle size and the duration of the signal that is used for the determination of the particle speed. Hence, the Parsivel disdrometer bin measured particles into particle counts per velocity and diameter class. The velocity and diameter are divided into 32 classes with varying widths for each category. The classification of the precipitation particles determines the rain rate. The corresponding software ASDO monitors the outdoor precipitation event for comfortable indoor evaluation with Window Performance. The built in sensor transmits all data to the PC through the RS 485 interface, and the data are stored in the database, and retrieved by the browser with the related time and date. To prevent ice buildup on the sensor heads, an automatic heating system is maintained and is adjusted by the temperature sensor for each second. These data are arranged for 1% to 0.001% of the time. For instance, at 0.01% of the time, the 1-min. rain rate and attenuation values are taken for approximately 158 ((3×365×24×60×0.01)/100=157.68≈158) instances for 3-years of measurement. The full list of the procedures supported by the Parsivel disdrometer is discussed in detail in (http://www.ott.com; OTT). Table 2 shows the characteristics of the sites under study. The 1-min. rainfall amount database provided by KMA for nine prime locations as well as the Icheon region was studied. Additionally, the experimental system carried out by the National Radio Research Agency (RRA) for 1-min. rain rate values were also analyzed for the two locations of three years of measurement periods, as mentioned above.

A sample data structure that is stored for the equivalent 1-min. duration at the Gwangju Site (Station ID=156) from the KMA database is shown below: