Proceedings of ISAP'04, Sendai, JAPAN

An Investigation on Lavergnat-Gole Conversion Method for Different Integration Time Rain Rate Distributions by Using Regional Climatic Parameters

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1. Introduction

The most serious transmission impairment is caused by the rain attenuation in radio systems using frequencies above about 10 GHz. It is required in the system design to predict the rain attenuation distributions on radio links, and accordingly it is necessary to know one-minute rain rate distributions. On the worldwide basis, however, the observations for rain rate are made mainly with long integration times such as 60 minutes in Japan (e.g. 60-min. of AMeDAS : Automated Meteorological Data Acquisition System of Japan Meteorological Agency), and measurements of one-minute rain rate distribution are rare in the world. Therefore, it is necessary to derive the conversion method for these data into one-minute rain rate data. Although there are a few conversion methods up to now, almost all these methods are derived experimentally[1][2][3]. Therefore, it must be cautious to apply these methods to other location and integration times that were not used to derive these methods.

A different integration time rain rates conversion method was proposed by Lavergnat and Gole[4], which could be used for arbitrary integration times. This method was tested, however, only for Gometz-la-Ville, France (ITU-R rain climatic zone E), and further investigation was required.

In this paper, we analyzed effects of the regional climatic parameters on this method, and extended this method for the worldwide application by using KIT (Kitami Institute of Technology) databank that contains different integration time rain rate data sets from 54 locations in 23 countries. It was found that a good accuracy in worldwide rain rate conversion could be obtained by using regional climatic parameters such as thunderstorm ratio and so on, and it was proved that this model could be expanded to arbitrary integration times and regions. Moreover, we analyzed this method in Japan by the data at eight principal cities[5], and it was found that a good conversion accuracy could be obtained by using a parameter appropriate to Japan.

2. Worldwide databank of different integration time rain rates (KIT data bank)

For analysis in this study, a databank of different integration time rain rates was newly constructed from many literatures. It contains data sets from 54 locations in 23 countries. Those are: 1.Stockholm(SE), 2.Helsinki(FI), 3.Keimola(FI), 4.Chilbolton(GB), 5.Cranfield(GB), 6.Kelvedon Hatch(GB), 7.Slough(GB), 8.Wotton(GB), 9.Copenhagen(DK), 10.Paris(FR), 11.Gometz la Ville(FR), 12.Barcelona(ES), 13.Darmstadt(DE), 14.Mseno(CZ), 15.Praha(CZ), 16.Warsaw(PL), 17.Bari(IT), 18.Bologna(IT), 19.Fucino(IT), 20.Ghilardona(IT), 21.Gera Lario(IT), 22.Milano(IT), 23.Rome'84-'88(IT), 24.Rome'75-'76(IT), 25.Rome'75-'77(IT), 26.Torino(IT), 27.Udine(IT), 28.Kefallinia(GR), 29.New Delhi-WM(IN), 30.New Delhi-MON(IN), 31.Taejon(KR), 32.Yokosuka(JP), 33.Nagoya(JP), 34.Bangkok(TH), 35.Ile-Ife(NG), 36.Kingston(CA), 37.Holmdel(US), 38.Miami'73(US), 39.Miami'57-'58(US), 40.New York(US), 41.Palmetto(US), 42.Urbana(US), 43.Kourou(GF), 44.Belem(BR), 45.Brasilia(BR), 46.Manaus(BR), 47.Rio de Janeiro(BR), 48.Santa Rita(BR), 49.Iquitos(PE), 50.Ipoh(MY),

ISBN: 4-88552-207-2 C3055©IEICE

51.Ipoh'92-'95(MY), 52.Kuala Lumpur(MY), 53.Singapore'92-'95(SG), 54.Singapore'99(SG).
This databank also includes the average annual total rainfall M_{year} (mm), the average number of thunderstorm days D_{th} (day), and the thunderstorm ratio β[6], etc.

3. Lavergnat-Gole method[4][7]

This method was developed as an application of stochastic process for the time intervals between raindrops, and has reliable theoretical background. The advantage of this method is that it allows a conversion between any integration times.

This method was given by eqns.(1) and (2). P_1 is the cumulative probability obtained with a rain gauge of integration time t_1 (min.), and R_1 (mm/h) is rain rate for P_1. P_2 is the cumulative probability obtained with a rain gauge of integration time t_2 (min.), and R_2 (mm/h) is rain rate for P_2. It was recommended that the parameter a was equal to 0.115 for ITU-R climatic zone E (Gometz-la-Ville, France), and it was suggested that the parameter a had the regional dependence[4][7]. Therefore, if the parameter a for each location can be estimated, it can be expected to expand this method into worldwide one.

$$P_2(R_2) = k^a P_1(R_1), \qquad k \equiv t_2 / t_1 \tag{1}$$

$$R_2 = R_1 / k^a \tag{2}$$

4. Worldwide analysis for regional dependence of parameter a

In the first place, n-minute integration time rain rate distributions (P_1, r_1) in the KIT databank were converted into one-minute distributions (P_2, r_2). The most suitable value of a was determined to minimize the conversion error. The KIT databank includes eight data sets without one-minute rain rate data (data no. 6, 8, 9, 14, 29, 30, 40, 43). For those data sets, the most suitable values of a were calculated based on the minimum integration time data instead of one-minute data. Based on these inversely calculated a values, their regional dependence were analyzed.

Actually using this calculated values of a for each data set, it was found that good conversion accuracy could be obtained by the above method. However, for this conversion, it was also found that the most suitable values of a was different for each integration time at the same location. In addition, there were four data that have large error in this analysis (no.8[20min→1min], no.23[60min→1min], no.28[60 min→1min], no.35[30min→1min]). These values of the calculated a were too small or had large difference of tendency for other data at the same location. Therefore, these data were excluded from this analysis.

The value of a must be constant at the same location and must not be dependent on integration time. Therefore, the means of the most suitable values of a at each location were calculated. The correlations of these mean values with the regional climatic parameters were investigated to examine the regional dependence.

Table 1 shows partial correlation coefficients between the mean of a at a location and the seven regional climatic parameters by using the multiple regression analysis. Where $|\phi|$ (°) is absolute value of the latitude, $|\lambda|$ (°) is absolute value of longitude, $R_{0.01}$ and $R_{0.001}$ (mm/h) are rain rates for 0.01 and 0.001%, respectively. It is shown that correlations between the mean of a at a location and $R_{0.001}$ (mm/h), D_{th} (day), and β are especially large. It is found that these regional climatic parameters are important in this analysis. The hypothesis that parameter a and respective regional climatic parameters are independent can be tested by using the level of significance, which is the risk of erroneous rejection of this hypothesis. The result suggests that a is dependent on $R_{0.001}$, D_{th} and β.

Two data sets (no.31 and no.49) were excluded from this multiple regression analysis because of no measurement data of $R_{0.001}$. The eight data that don't have one-minute rain rate data were also excluded. The final number of used data was 43.

From the multiple regression analysis, the parameter a can be estimated by eqn. (3).

$$
\begin{aligned}
a = & \ 0.00219126\,|\phi| - 0.000205094\,|\lambda| \\
& - 0.001165957 R_{0.01} + 0.000869955 R_{0.001} \\
& + 0.0000492772 M_{year} + 0.001336088 D_{th} \\
& - 0.173738515 \beta + 0.035580308 \qquad (3)
\end{aligned}
$$

The results by Lavergnat-Gole method using prediction eqn. (3) were compared with the result by conversion method using M distribution[8]. The detailed explanation of one-minute rain rate conversion method using M distribution is omitted in this paper, but this method was proved to have the best conversion accuracy in existing methods. The comparisons between measured and predicted one-minute rain rates by using each method were shown in Fig. 1 and Fig. 2. In Fig.1, the numerical values represent data numbers that have large conversion error.

Table 1. Partial correlation coefficients and level of significance between mean of the most suitable values of a and seven regional climatic parameters.

Climatic parameters	Partial correlation coefficients	Level of significance
$\|\phi\|$ (°)	0.1889	0.26
$\|\lambda\|$ (°)	-0.0991	0.56
$R_{0.01}$ (mm/h)	-0.2357	0.16
$R_{0.001}$ (mm/h)	0.3416	0.04
M_{year} (mm)	0.1837	0.28
D_{th} (day)	0.3164	0.06
β	-0.2941	0.08

In Fig. 2, because of this method's nature, some data that have not one-minute rain rate data and in that integration time is less than one minute were excluded. From these figures, it is found that Lavergnat-Gole method using prediction eqn. (3) has more accuracy than the conversion method using M distribution.

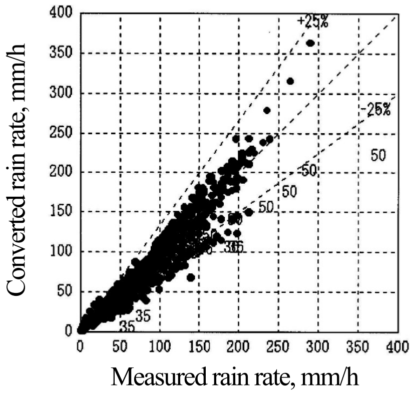

Fig.1 Comparisons between measured and predicted one-minute rain rate by Lavergnat-Gole method with eqn. (3).

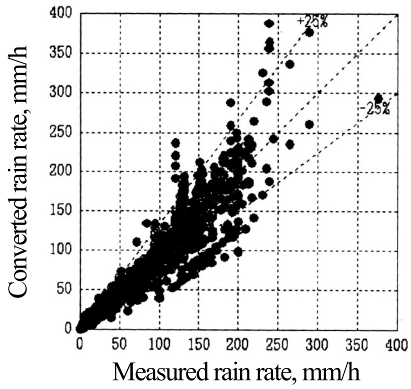

Fig.2 Comparisons between measured and predicted one-minute rain rate by using M distribution method[8].

5. Analysis of parameter *a* in Japan

Using one-minute and sixty-minute integration time rain data measured over five years at eight principal cities in Japan (Sapporo, Sendai, Tokyo, Kanazawa, Nagoya, Osaka, Hiroshima and Fukuoka)[5], we analyzed the applicability of Lavergnat-Gole method to Japan. For these data, sixty-minute rain rate distributions (P_1, r_1) were converted into one-minute distributions (P_2, r_2). The most suitable value of a was determined to minimize the conversion error. Because the both integration time rain rate distributions for above eight datasets could be approximated by M distribution very well[5], to make this analysis more simply, we assumed that the sampling rain rate values from the approximated curves for measured rain rate datasets at 14 points of percentage of time (0.0005, 0.001, 0.002, 0.003, 0.005, 0.01, 0.02, 0.03, 0.05, 0.1, 0.2, 0.3, 0.5 and 1%) are the measured values. It was found that the most suitable values of a varied between 0.2106 and 0.3064 for the eight cities. The mean of these calculated eight values, $a = 0.2381$, was determined as the appropriate a value to Japan.

Fig. 3 shows the comparison of measured and converted one-minute rain using the above a

value and the method in section 3. We can confirm that the conversion for all of data except Kanazawa data can be done within about ±10% conversion error. For Kanazawa data, the conversion error by using the M distribution method was also large[5]. So, this data needs further consideration. For other data, It was found that a good accuracy can be obtained by using the value *a* = 0.2381 in Japan as shown in Fig. 4 for Nagoya. This result means that Lavergnat-Gole method is very useful in Japan.

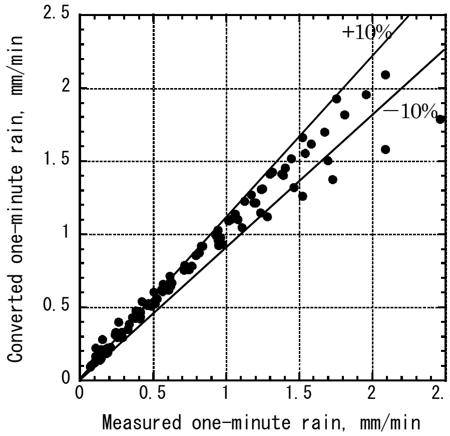

Fig.3 Comparisons between measured and converted one-minute rain by Lavergnat-Gole method using the value a=0.2381.

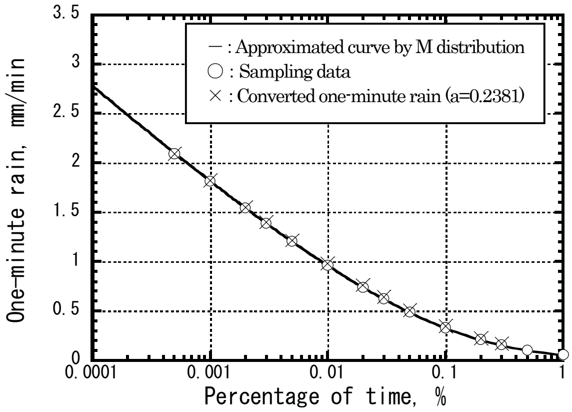

Fig.4 Measured rain data and converted values by using a=0.2381 for Nagoya.

6. Conclusion

To establish a worldwide different integration time rain rates conversion method, the Lavergnat-Gole method, by which an arbitrary integration time rain rate data can be converted into other arbitrary integration time data, was investigated by using KIT worldwide databank. From the conversion of *n*-minute integration time rain rates into one-minute rain rates, it is found that parameter *a* is dependent on regional climatic parameters, especially such as the rain rates for percentage of time 0.01 and 0.001% and the thunderstorm ratio. As the results of this analysis, it is found that this method using regional climatic parameters can have better accuracy than the conversion method using M distribution[8], and proved to have the best conversion accuracy in existing methods.

Moreover, the most suitable values of *a* in Lavergnat-Gole method were also calculated inversely at the principal eight cities in Japan. In result, it is found that Lavergnat-Gole method using the appropriate *a* value to Japan can convert sixty-minute rain rate distributions into one-minute rain rate distributions within about ±10% conversion error.

The above-mentioned results mean that Lavergnat-Gole method can be easily expanded to arbitrary integration times and locations by using regional climatic parameters, and can be useful also in Japan.

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