Empirical Prediction Models of 1-min Rain Rate Distribution for Various Integration Time

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Abstract

In a wireless channel above microwave frequency, rain attenuation is very important. In order to predict rain attenuation, 1- min. rain rate distribution is required. This paper discusses appropriate conversion methods to estimate 1-minute rain rate from that of other integration time. Based on the measurement data filed in ITU-R WP3J including ETRI data for 6 consecutive years, distributions of rain rate with 1-, 5-, 10-, 20-, 30-minute integration time were analyzed, both on the global and regional basis, and the parametric relationship between the statistical characteristics of 1-minute and other measurement data were investigated to deduce the conversion methods. It is shown that the global model works good with good accuracy for 5-, 10-, 20-min integration time, and the global model is also applicable globally with good accuracy for 5-, 10-, 20-min integration time. The global conversion model was adopted last year as an ITU-R document for new recommendation. The regional conversion model would also be very useful for locations of similar climatic zone.

Key words : Conversion Coefficient, Conversion Coefficient, Integration Time, Rain Rate, Rain Rate Distribution.

Ⅰ. Introduction

In accordance with Recommendation ITU-R P.618-8 or P.530-10, the rain rate distribution is required to predict rain attenuation for estimation of unavailable time percentage of the communications link above 10 GHz band. Furthermore, it is recommended that the distribution should be deduced from observed rainfall data with an integration time of 1 minute or less. However, only a limited number of such data sets are usually available. A large amount of rainfall data sets collected by meteorological agencies in many countries are typically available for longer integration time, such as 10-min, 20-min, 30-min, etc.

Considering above problems, ITU-R WP 3J has focused on the development of an effective conversion method for rain rate distribution from various integration times. Since the first contribution from Korea was submitted to the WP3J, many discussions were made and many data sets were collected in order to find out most appropriate conversion method for various integration data on a global basis[1]~[7].

In this paper, new global and regional conversion models are introduced, and errors of the conversion models for various integration time were analyzed, especially the regional model and its validity, additive to the previous paper[8].

Ⅱ. Conversion Principle

Several methods have been suggested for converting a rainfall distribution with different integration-time to that with 1-minute integration[8]~[12].

Two kinds of approaches can be considered for conversion. One is the method based on the equal rainfall rate and the other method is the equal-probability based approach. In the previous WP 3J meeting, most administrations agreed to the latter approaches.

A representative equal-probability based method was suggested by Burgueño[10]:

$$R_1(p) = a \times [R_\tau(p)]^b \tag{1}$$

where, $R_1(p)$ and $R_\tau(p)$ are rainfall rate with 1- and τ -minute integration time exceeded p % of annual time, respectively. The parameters a and b are conversion coefficients of the power relationship between rainfall rates for equal probability. Fig. 1 shows an example of equal-probability relation between rain rate data with different integration times, using ETRI's 6-year data.

Ⅲ. Deduction of Global and Regional Conversion Models

In order to find out best coefficient sets for each integration time data, all possible data were collected. For-

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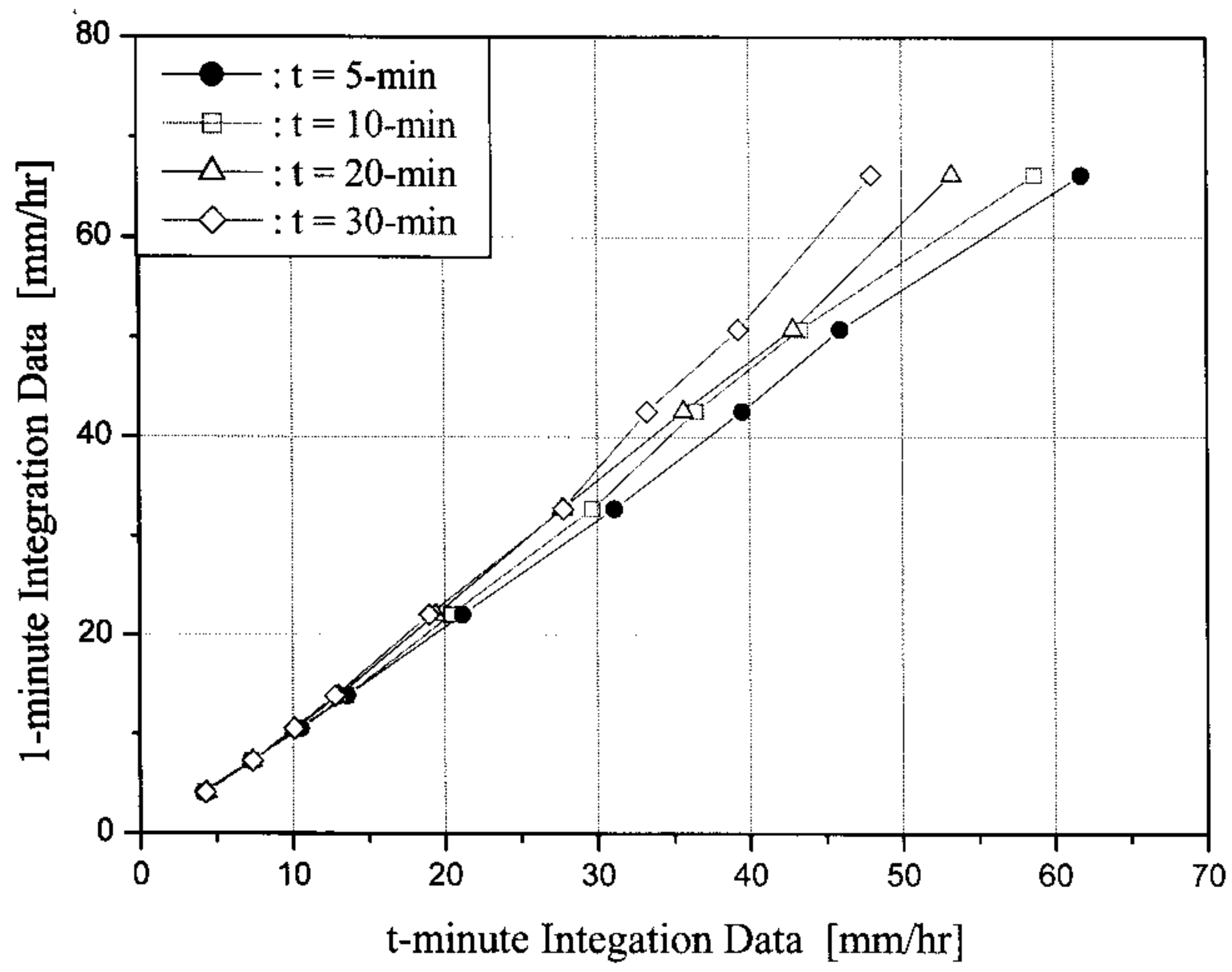


Fig. 1. Example of equal-probability relation between rain rate data with different integration times.

tunately, several countries submitted rain rate data to the previous WP 3J meetings. ETRI and CNU collected 6-year measurment data with various integration time at Daejeon in Korea.

The data used to derive the above mentioned coefficients were obtained from WP 3J contributions from Brazil, China, Czech Republic, listed in Table 1, and ETRI's 6-year measurements shown in Table 2.

Table 1. 1 Measurement sites.

Site	Period	Integration time	Climate	Reference
KOR-Daejeon	6 years	1, 5, 10, 20, 30-min	Temperate	New
CZE-Prague	NA	1, 5, 10, 20, 30-min	Temperate	New
CHN-Haikou	NA	1, 5, 10-min	Tropical	Doc.3J/5 (2003)
CHN-Guangzhou	NA	1, 5, 10-min	Subtropical	Doc.3J/5 (2003)
CHN-Nanjing	NA	1, 5, 10-min	Subtropical	Doc.3J/5 (2003)
CHN-Chongqing	NA	1, 5, 10-min	Subtropical	Doc.3J/5 (2003)
CHN-Xinxiang	NA	1, 5, 10-min	Temperate	Doc.3J/5 (2003)
CHN-Changchun	NA	1, 5, 10-min	Temperate	Doc.3J/5 (2003)
BRA-Equatorial	12 year stations	1, 5, 10, 20, 30-min	Equatorial`	Doc.3J/64 (2004)
BRA-Rio de Janeiro	10 years	1, 5, 10, 20, 30-min	Temperate	Doc.3J/64 (2004)
BRA-Tropical	7 year stations	1, 5, 10, 20, 30-min	Tropical	Doc.3J/64 (2004)

Table 2. ETRI Measurement data(Annual Average).

%	1-min	5-min	10-min	20-min	30-min
1	4.06	4.12	4.21	4.33	4.28
0.5	7.26	7.24	7.28	7.32	7.34
0.3	10.54	10.51	10.40	10.13	10.08
0.2	13.85	13.56	13.50	12.96	12.77
0.1	22.10	21.16	20.40	19.39	18.97
0.05	32.73	31.11	29.68	27.71	27.75
0.03	42.55	39.54	36.49	35.64	33.26
0.02	50.78	45.97	43.36	42.86	39.29
0.01	66.27	61.80	58.73	53.27	48.00

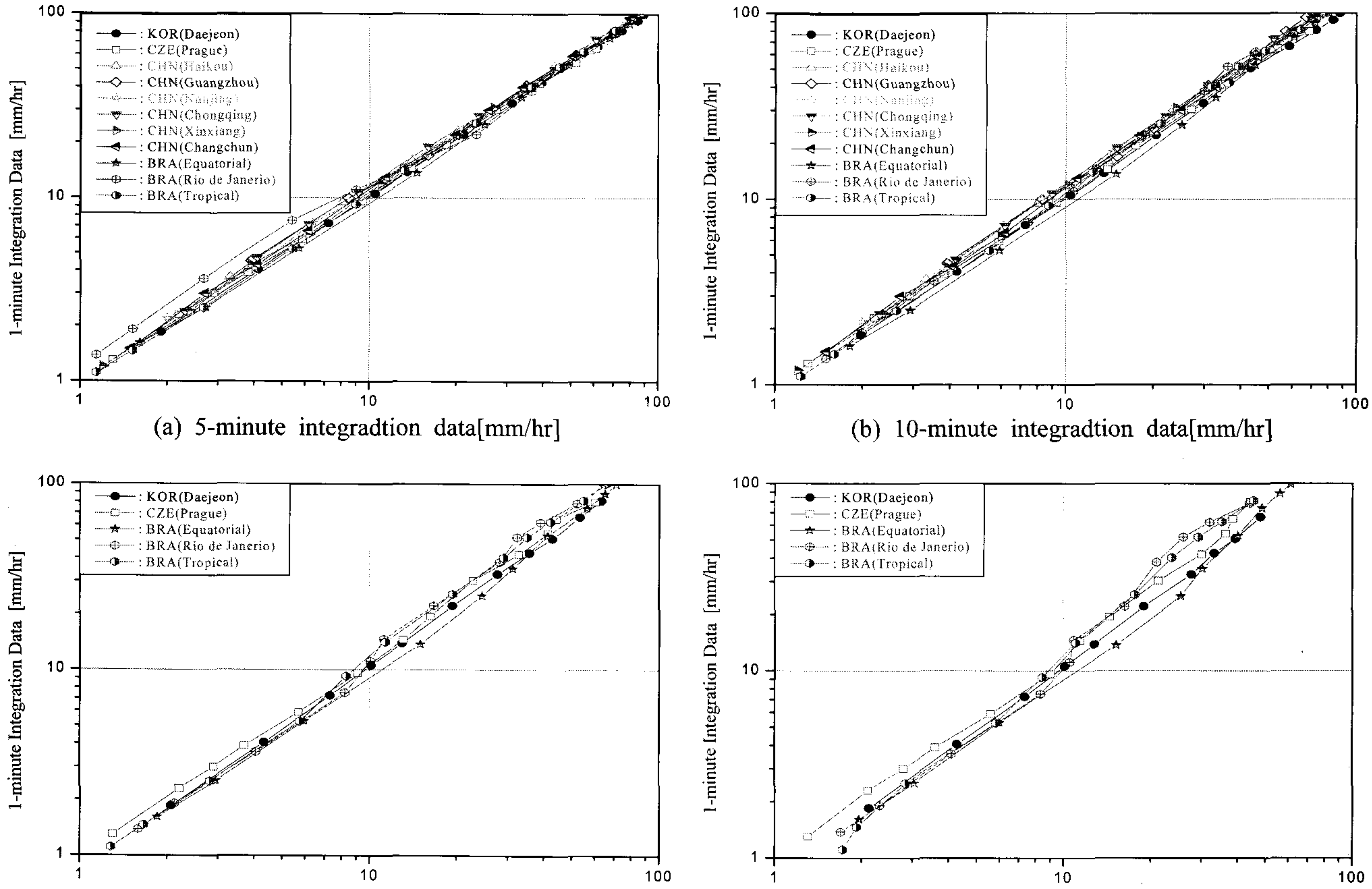
3-1 Regional and Global Coefficients

The appropriate coefficients can be obtained by the relationship between 1-minute rain rate data and each τ -minute data for a given time probability. The parametric relations were analyzed from the plots shown in Fig. 2.

From each plot, the regional conversion coefficients, shown in Table 3, were obtained by best fitting. In or-

Table 3. Conversion coefficients(Regional and Global).

Site	5- to 1-min		10- to 1-min		20- to 1-min		30- to 1-min	
	a	b	a	b	a	b	a	b
KOR_Dae	0.934	1.032	0.864	1.069	0.774	1.124	0.723	1.162
CZE_Pra	0.970	1.032	0.864	1.069	0.774	1.124	0.723	1.162
CHN_Hai	1.097	1.017	0.955	1.071	NA	NA	NA	NA
CHN_Gua	1.122	1.005	1.000	1.076	NA	NA	NA	NA
CHN_Nan	1.067	1.014	1.039	1.060	NA	NA	NA	NA
CHN_Cho	1.110	1.010	1.005	1.075	NA	NA	NA	NA
CHN_Xin	0.999	1.032	0.964	1.080	NA	NA	NA	NA
CHN_Cha	1.023	1.031	0.982	1.067	NA	NA	NA	NA
BRA_Equ	0.929	1.036	0.770	1.102	0.712	1.146	0.540	1.245
BRA_Rio	0.956	1.041	0.908	1.093	0.725	1.196	0.544	1.348
BRA_Tro	0.947	1.041	0.873	1.094	0.764	1.172	0.554	1.331
Global	1.014	1.027	1.0939	1.078	0.780	1.149	0.648	1.250



(a) 5-minute integradtion data[mm/hr]

(b) 10-minute integradtion data[mm/hr]

(c) 20-minute integradtion data[mm/hr]

(d) 30-minute integradtion data[mm/hr]

Fig. 2. Relations between rain rate for 1-min and other integration time, corresponding to equal probability.

der to find out a representative coefficient set, which can cover all regional characteristics for each integration time data, mean coefficients of the regional coefficients, corresponding to rain rate distributions of 0.01~1.0 % time percentage, were selected as 'Global Coefficients'. The global conversion coefficients are given at the bottom of Table 3.

3-2 Verification of the Suggested Conversion Models

In order to verify the validity of the global and regional coefficients, errors of the converted rain rate distributions were analyzed.

Using the equation (1) and the conversion coefficients given in Table 3, the rain rate distributions for longer integration time were converted to 1-min data, and the results were compared to 1-min measurement data.

Absolute error(ε_R, mm/hr) and relative error(ε_P, %) for regional and global coefficients, defined in equation (2) and (3), are compared in Table 4~7.

$$\varepsilon_R = |R_{measured} - R_{converted}| \qquad [mm/hr] \tag{2}$$

$$\varepsilon_p = \begin{cases} \dfrac{\varepsilon_R}{R_{measured}} \times 100 & \text{for } 1.0 \le \varepsilon_R \quad [\%] \\ 0 & else \end{cases} \tag{3}$$

From the results given above, we can see that the global conversion errors for 5-min, 10-min, and 20-min data are small, except for one region, the maximum average error being less than 7 %. For 30-min data, however, errors are quite big. For regional coefficients, regional conversion errors for 5-min, 10-min, and 20-min data are small, the maximum average error being less than 5 %. For 30-min data, however, errors are quite big. It should be noted that rain rate for 0.01 % time percentage is quite high, which corresponds to the rain attenuation for 99.99 % channel availability. Thus, the reasonably small error for 5-min, 10-min, and 20-min data, up to 0.01 % time percentage, means that the suggested global conversion model works good.

As we can see in Table 4~7, the regional conversion models have smaller errors than the global ones as one can expect. For locations of similar climatic zone, the regional model given in this paper would be very useful. In other locations, the global model could be used.

Ⅳ. Conclusion

In this paper, new conversion models for rain rate distribution are introduced. The validity of the global and regional model were verified by comparing to the com-

Table 4. Error of conversion from 5-min data.

(a) Global coefficients

Site	0.01～0.1 % of time		0.01 % of time	
	Mean ε_R	Mean ε_P	ε_R	ε_P
KOR_Dae	1.92	2.87	3.78	5.70
CZE_Pra	0.82	1.07	0.20	0.00
CHN_Hai	3.06	2.71	6.95	6.32
CHN_Gua	2.02	1.71	1.42	1.32
CHN_Nan	1.12	1.11	1.77	2.46
CHN_Cho	1.31	2.10	3.89	5.32
CHN_Xin	0.50	0.59	0.34	0.00
CHN_Cha	0.79	1.29	1.49	2.53
BRA_Equ	2.65	5.09	1.93	1.68
BRA_Rio	1.41	1.54	1.92	2.44
BRA_Tro	0.42	0.10	0.27	0.00
Average	1.46	1.83	2.18	2.52

(b) Regional coefficients

Site	0.01～0.1 % of time		0.01 % of time	
	Mean ε_R	Mean ε_P	ε_R	ε_P
KOR_Dae	0.58	0.75	0.48	0.00
CZE_Pra	0.67	0.74	0.14	0.00
CHN_Hai	1.80	1.80	3.56	3.23
CHN_Gua	1.78	1.96	1.12	1.04
CHN_Nan	0.85	0.86	1.43	1.99
CHN_Cho	1.04	1.02	2.35	3.21
CHN_Xin	0.51	0.57	0.01	0.00
CHN_Cha	0.55	0.60	0.08	0.00
BRA_Equ	1.31	2.10	3.21	2.79
BRA_Rio	1.47	1.62	1.82	2.32
BRA_Tro	0.51	0.32	1.07	1.31
Average	1.01	1.12	1.39	1.45

Table 5. Error of conversion from 10-min data.

(a) Global coefficients

Site	0.01～0.1 % of time		0.01 % of time	
	Mean ε_R	Mean ε_P	ε_R	ε_P
KOR_Dae	5.24	9.88	9.42	14.2
CZE_Pra	0.89	2.82	2.46	8.11
CHN_Hai	2.72	2.01	2.97	2.70
CHN_Gua	4.07	3.94	0.97	0.00
CHN_Nan	1.10	2.26	0.10	0.00
CHN_Cho	2.14	3.57	6.61	9.06
CHN_Xin	0.96	1.74	3.55	6.02
CHN_Cha	0.45	0.13	0.83	0.00
BRA_Equ	6.44	12.4	11.30	9.80
BRA_Rio	1.93	2.90	2.13	2.72
BRA_Tro	0.99	1.26	1.89	2.32
Average	2.45	3.90	3.84	5.00

(b) Regional coefficients

Site	0.01～0.1 % of time		0.01 % of time	
	Mean ε_R	Mean ε_P	ε_R	ε_P
KOR_Dae	1.32	1.73	0.83	0.00
CZE_Pra	0.53	1.20	1.56	5.15
CHN_Hai	2.20	2.38	1.13	1.02
CHN_Gua	1.76	2.48	5.23	4.84
CHN_Nan	0.63	0.75	2.04	2.83
CHN_Cho	1.13	1.36	2.75	3.77
CHN_Xin	0.83	1.11	1.69	2.86
CHN_Cha	0.42	0.24	0.49	0.00
BRA_Equ	1.85	3.12	0.51	0.00
BRA_Rio	2.11	2.53	0.07	0.00
BRA_Tro	1.13	1.55	1.53	1.88
Average	1.27	1.68	1.62	2.03

Table 6. Error of conversion from 20-min data.

(a) Global coefficients

Site	0.01～0.1 % of time		0.01 % of time	
	Mean ε_R	Mean ε_P	ε_R	ε_P
KOR_Dae	3.08	6.09	8.88	13.4
CZE_Pra	0.50	0.72	1.96	6.45
BRA_Equ	4.56	10.8	4.65	4.03
BRA_Rio	3.59	9.66	5.37	6.84
BRA_Tro	2.35	5.26	3.59	4.41
Average	2.82	6.50	4.89	7.03

(b) Regional coefficients

Site	0.01～0.1 % of time		0.01 % of time	
	Mean ε_R	Mean ε_P	ε_R	ε_P
KOR_Dae	0.52	0.66	1.24	1.87
CZE_Pra	0.53	2.31	0.89	0.00
BRA_Equ	2.85	5.84	6.98	6.06
BRA_Rio	2.10	6.65	3.43	4.38
BRA_Tro	1.00	1.05	2.15	2.64
Average	1.40	3.30	2.94	2.99

Table 7. Error of conversion from 30-min data.

(a) Global coefficients

Site	0.01～0.1 % of time		0.01 % of time	
	Mean ε_R	Mean ε_P	ε_R	ε_P
KOR_Dae	5.95	15.17	15.6	23.60
CZE_Pra	0.67	0.70	0.64	0.00
BRA_Equ	9.16	22.58	NA	NA
BRA_Rio	5.13	13.53	4.99	6.37
BRA_Tro	3.29	7.03	4.89	6.00
Average	4.84	11.80	6.54	8.99

(b) Regional coefficients

Site	0.01～0.1 % of time		0.01 % of time	
	Mean ε_R	Mean ε_P	ε_R	ε_P
KOR_Dae	0.46	0.77	1.17	1.77
CZE_Pra	0.45	2.02	0.64	0.00
BRA_Equ	4.21	8.88	NA	NA
BRA_Rio	9.45	21.49	18.31	23.33
BRA_Tro	8.40	19.55	18.75	23.05
Average	4.59	10.54	9.72	12.04

prehensive worldwide data. The models are quite acceptable for 5-min, 10-min, and 20-min data. The suggested conversion method and the global coefficients were adopted this year as a new recommendation in the revised recommendation of ITU-R P.837-4. The regional conversion model would also be very useful for locations of similar climatic zones.

The conversion procedure discussed above can be summarized as follows:

Conversion Procedure

- Obtain the regional rain rate distribution from the long-term measured rainfall data for arbitrary integration time.
- Calculate the equi-probable rain rate for 1-min integration time from the observed τ-min rainfall data,

$$R_1(p) = a\times[R_\tau(p)]^b$$

where the coefficients a and b can be obtained from the regional rain-rate distributions, or the regional conversion coefficients can be used in similar climatic zones. In case that regional conversion coefficients are unavailable, the following global coefficients could be used.

α=1.014 b=1.027 for τ=5 minute
α=0.939 b=1.078 for τ=10 minute
α=0.780 b=1.149 for τ=20 minute

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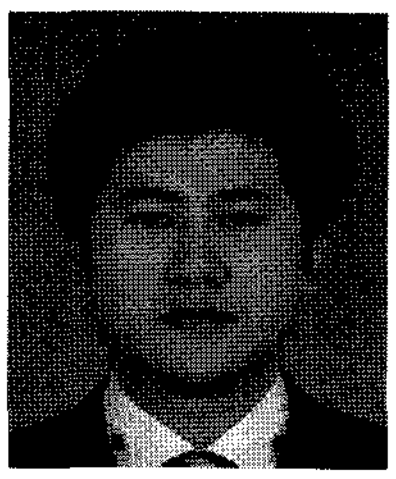

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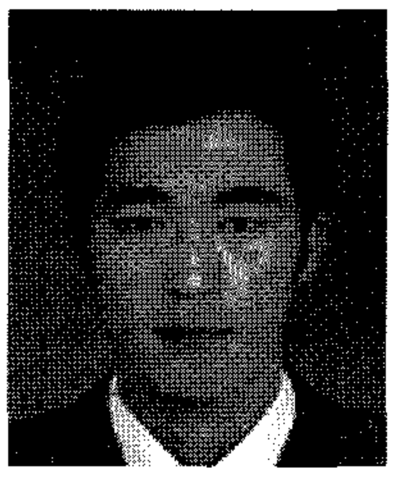

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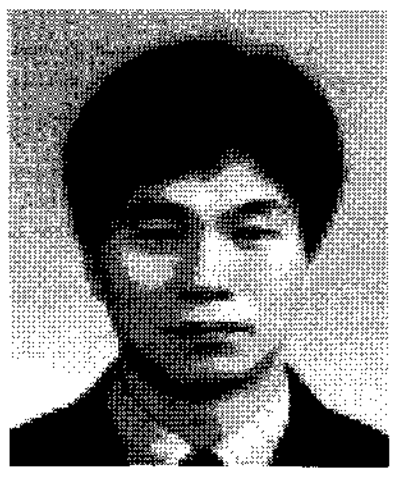

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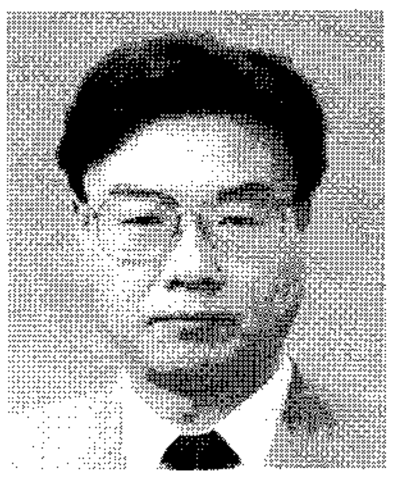

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