1.3 Review of setup for rainfall observation at ground level

In order to identify the distribution of rainfall amounts, it is desirable to integrate and share the rainfall data managed and possessed by different organizations and thereby reduce areas with no data on observed rainfall. In order to use rainfall data as input into flood simulation systems, a system is required to equip rainfall gauging stations with telemeters and summarize rainfall data on a real-time basis.

In this section, the area that would be covered if the data collected at telemeter gauging stations of RID, TMD and DWR were integrated was identified, and the number of additional rainfall gauging stations required in the area with no rainfall data was examined.

(1) Setting the area to be covered by one rainfall gauging station

The area to be covered by a single rainfall gauging station was considered as described below.

1) Setting the area to be covered using the sampling plan method

2) Setting the area to be covered using the results of RRI model analysis

1) Setting the area to be covered using the sampling plan method

The concentration of rainfall gauging stations was evaluated using the sampling plan method. The evaluation procedure is shown below.

Step 1: Select the study rainfall (when flow increases rapidly at Nakhon Sawan)

Step 2: Select the study basin (catchment area = A km2)

Step 3: Verify the number of rainfall gauging stations (n)

Step 4: Set the number of samples (r) (r = n-1 to 1)
*Sample = Rainfall at gauging station

Calculate Es for r = n-1 to 1

Step 5: Calculate the sample mean
(sample mean = nCr = n!/(r- n)!/ r!)
*Sample mean = Mean rainfall in the basin

Step 6: Calculate the standard deviation es of sample mean from nCr sample means
Standard relative error Es = es/
*   = Mean of sample means

-The probability of the variance between the mean rainfall in the basin calculated from r samples of rainfall at gauging stations and the real mean rainfall in the basin being smaller than es (mm) is 68.3%.
(68.3% = Percentage in the standard deviation)
-For the accuracy of the mean rainfall in the basin calculated from r samples of rainfall at gauging stations, Es serves as an index.

Step 7: Develop a relationship between r and Es

Fig. 1-1 Procedure for evaluating the concentration of gauging stations using the sampling plan method

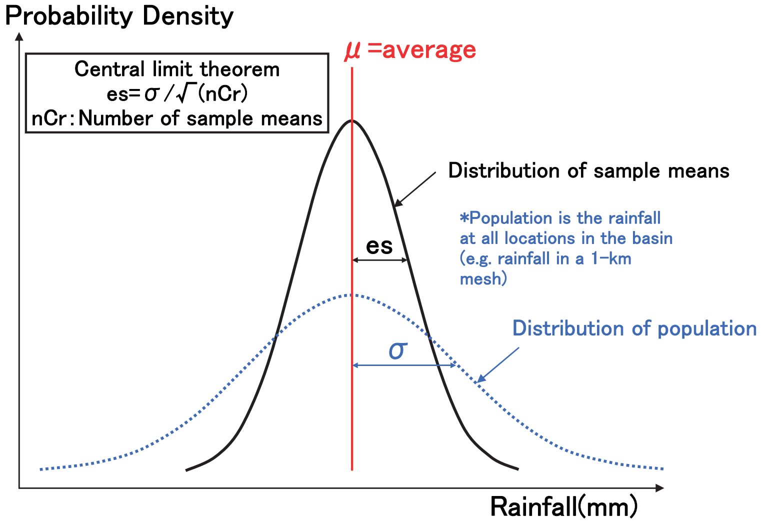


Fig. 1-2 Distribution of a population and distribution of sample means related to the planar distribution of rainfall

Step 1 Select the rainfall

The rainfall on the following days were selected when the maximum daily rainfall occurred during the several days preceding the day when rainfall occurred causing a flow increase at Nakhon Sawan (C2).

June 25, 2011, July 14, 2011, July 31, 2011, Sept. 12, 2011 and Sept. 28, 2011

Step 2 Select the basin

Three basins were selected where relatively large quantities of observed rainfall data were available (Fig. 1-3).

Fig. 1-3 Study basins

Step 3 Verify the number of rainfall gauging stations

Verification was made of the number of locations in the study basin where daily observed rainfall could be obtained on the day when the study rainfall occurred.

Steps 4 and 5 Calculate the sample mean and calculate the standard deviation of sample mean (es)

r samples (r = n-1 to 1) were extracted at n locations, and nCr sample means (mean rainfall in the basin) were calculated.

For example, observed rainfall could be obtained at 34 locations in the Bhumipol Dam basin. Then, mean rainfall in the basin was calculated while r varied from 33 to 1. In the case where r = 4, for example, 46,376 mean rainfall in the basin could be calculated.

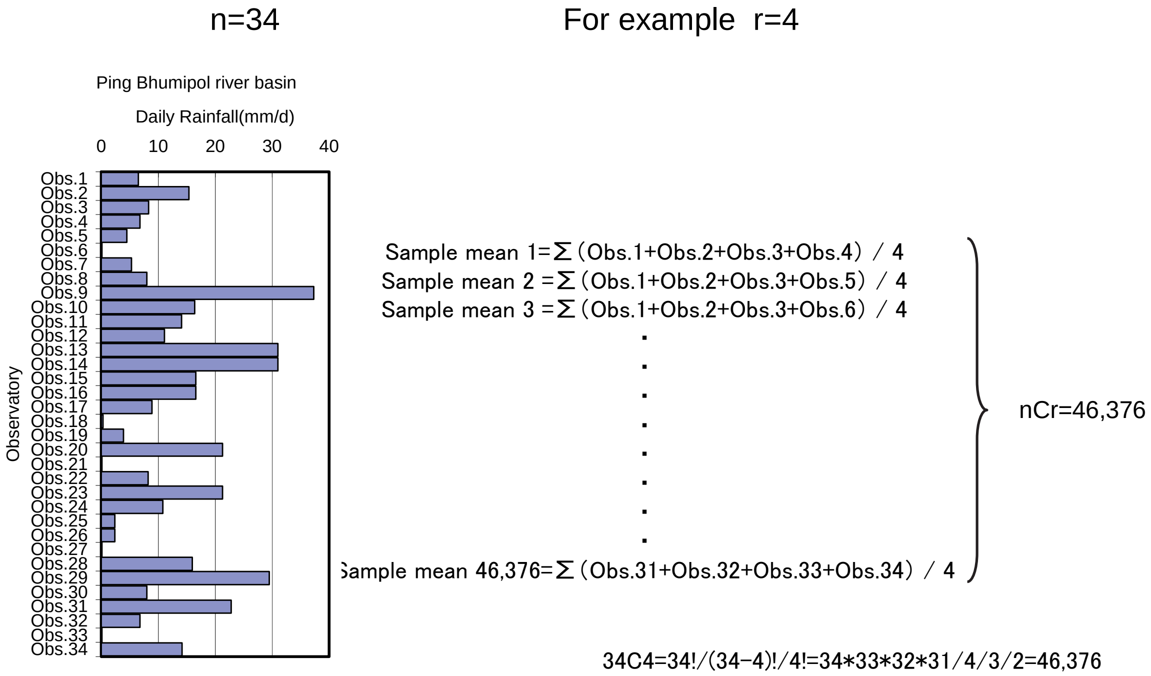


Fig. 1-4 Calculation of sample mean

Steps 5 and 6 Calculate the sample mean and calculate the standard relative error (Es)

In the case where mean rainfall in the basin (sample mean) was calculated extracting 30 observed rainfall amounts from observed rainfall amounts at 34 locations, the sample mean was 11.7mm, standard deviations es was 0.6 mm and standard relative error Es = es/ was 6% (upper left in Fig. 1-5),

Similarly, in the case where mean rainfall in the basin (sample mean) was calculated extracting 20 observed rainfall amounts from observed rainfall amounts at 34 locations, was 12.3 mm, es was 0.6 mm and Es was 7% (at the middle on the left in Fig. 1-5)

In the case where mean rainfall in the basin (sample mean) was calculated extracting 10 observed rainfall amounts from observed rainfall amounts at 34 locations, was 12.3 mm, es was 1.9 mm and Es was 15% (lower left in Fig. 1-5)

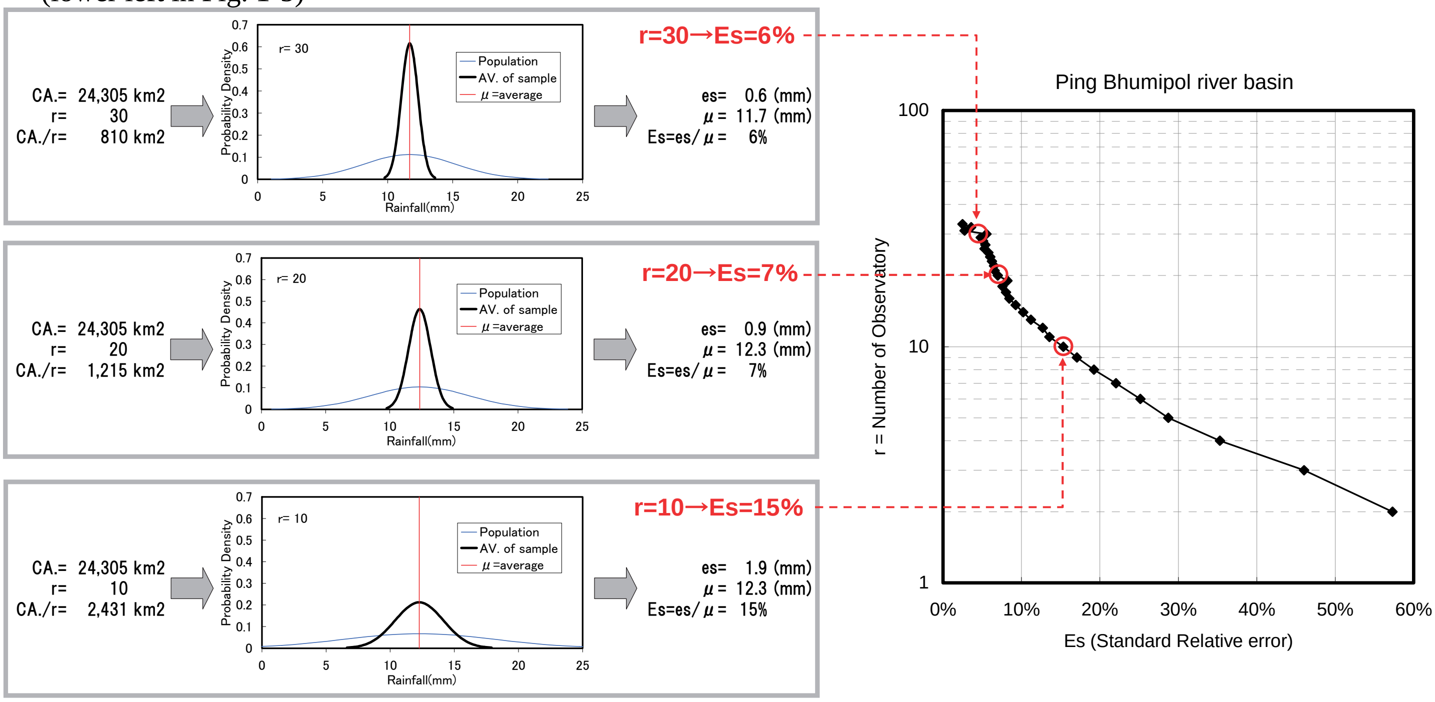


Fig. 1-5 Calculation of standard relative error Es

Step 7 Develop a relationship between the number of gauging stations and standard relative error Es

If the tolerance for standard relative error Es is assumed to be 10%, gauging stations will be required at 14.5 points in the Bhumipol Dam basin and the area that a gauging station should cover will be approximately 1700 km2.

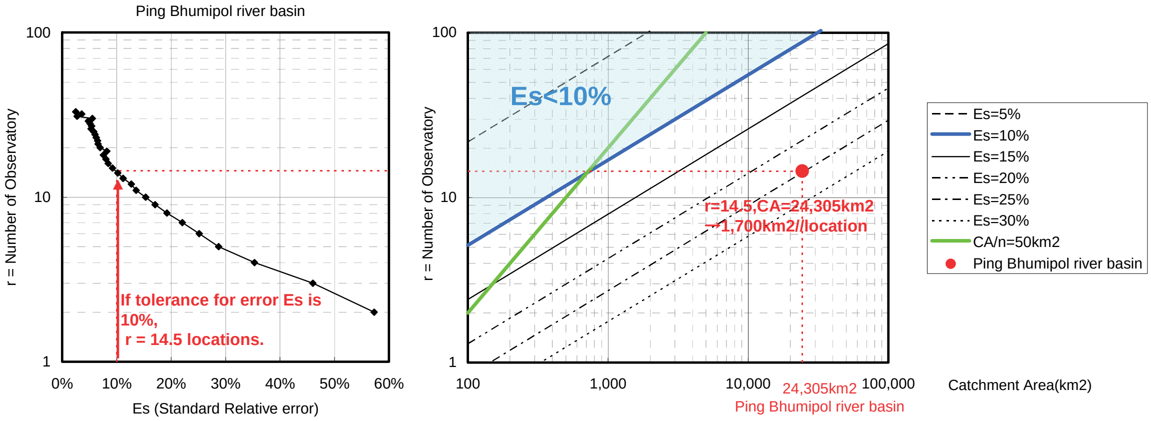


Fig. 1-6 Required concentration of gauging stations calculated by sampling plan method

The Technical Criteria for River Works of Japan describe that the standard relative error Es could be held to 10% or below in a basin of approximately 1000 km2 (700 km2 precisely) if the mean rainfall in the basin was calculated based on the rainfall amounts obtained at locations, placed one in every 50 km2. The gauging stations were therefore installed one in every 50 km2. *The line representing Es of 5 to 30% is a result of existing studies that is mentioned in the Technical Criteria for River Works. The red circle indicates the result of estimation in the Ping Bhumipol river basin.

Setting of the area to be covered using the sampling plan method

As a result of analysis using the sampling plan method, it was concluded that rainfall could be observed highly accurately if each rainfall gauging station covers 500 to 1500 km2.

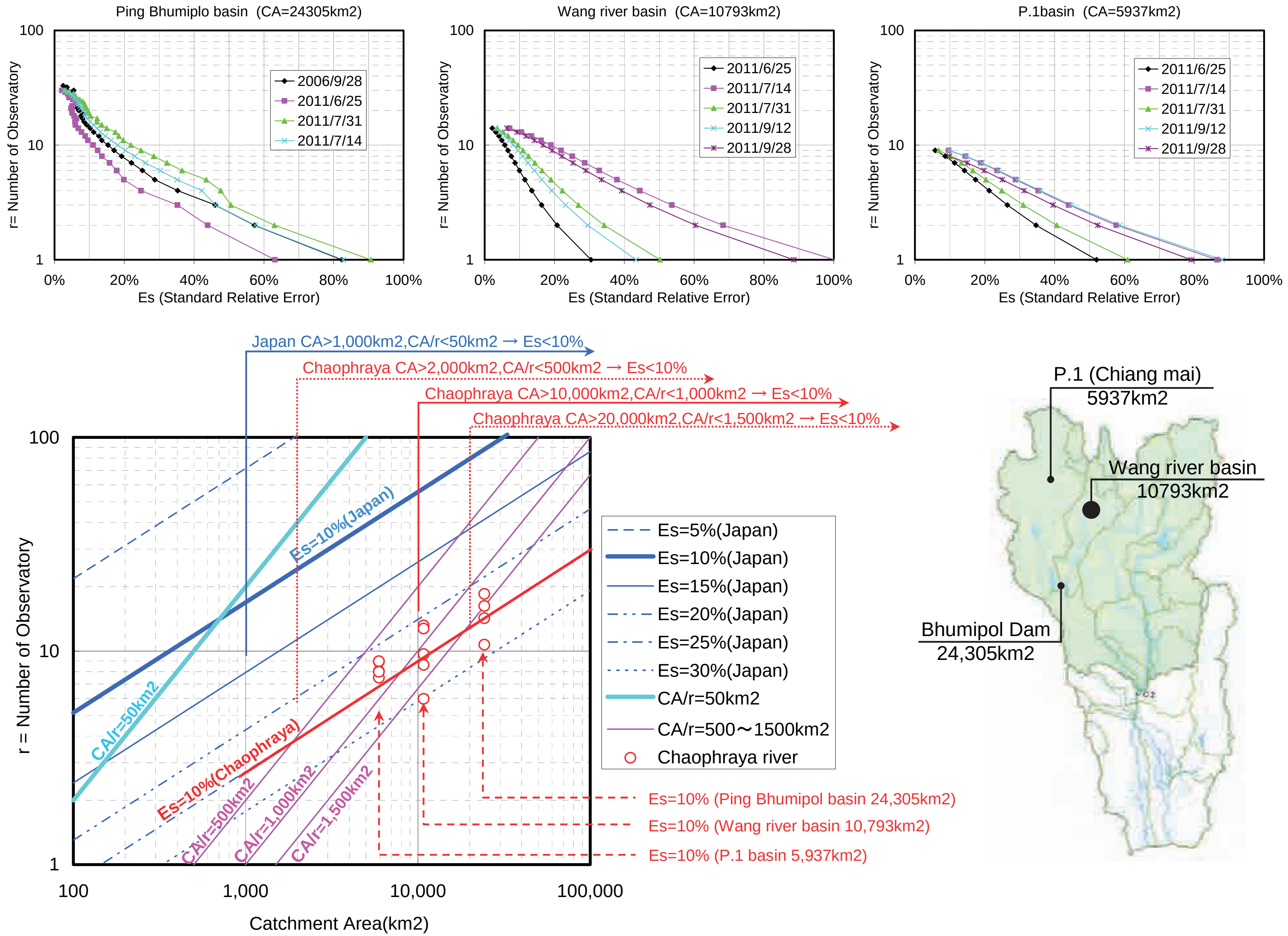


Fig. 1-7 Results of estimation of rainfall gauging station concentration identified by sampling plan method

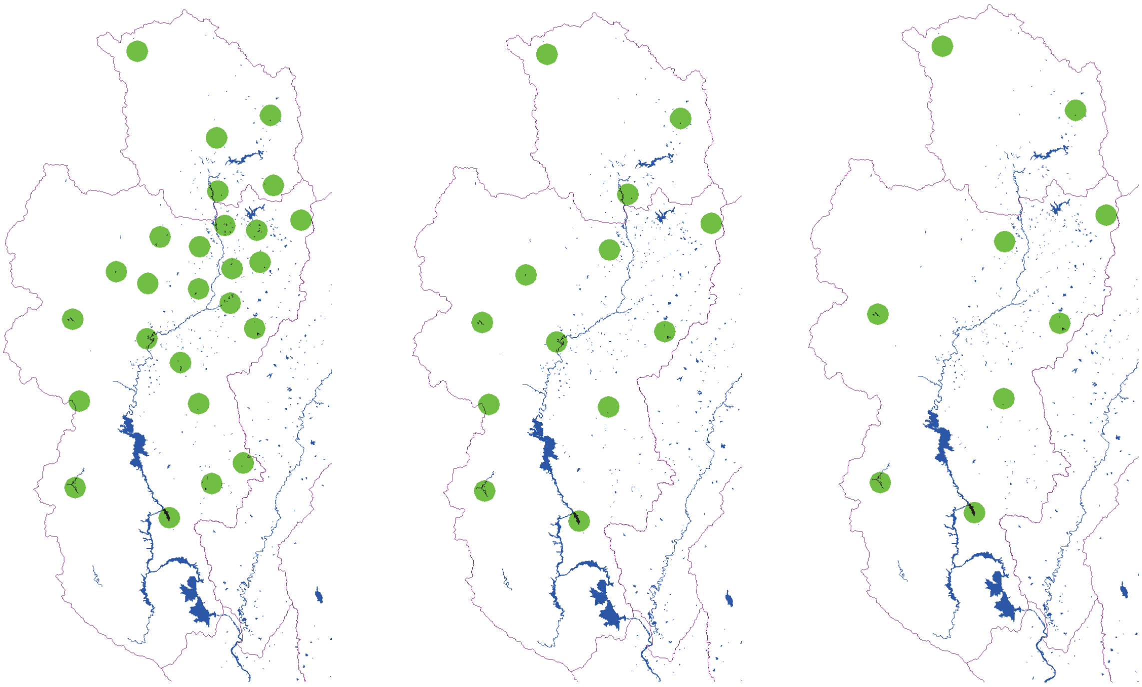
2) Setting the area to be covered using the results of RPI model analysis

The area to be covered by a rainfall gauging station was determined based on the results of RPI model analysis. The PRI model was analyzed using the following four patterns of rainfall as input data.

1) 51 rainfall gauging stations (each station covering a basin of approximately 500 km2)
2) 26 rainfall gauging stations (each station covering a basin of approximately 1000 km2)
3) 13 rainfall gauging stations (each station covering a basin of approximately 2000 km2)
4) 9 rainfall gauging stations (each station covering a basin of approximately 3000 km2)

26 rainfall gauging stations (1000 km2 per station)

26 rainfall gauging stations (3000 km2 per station)

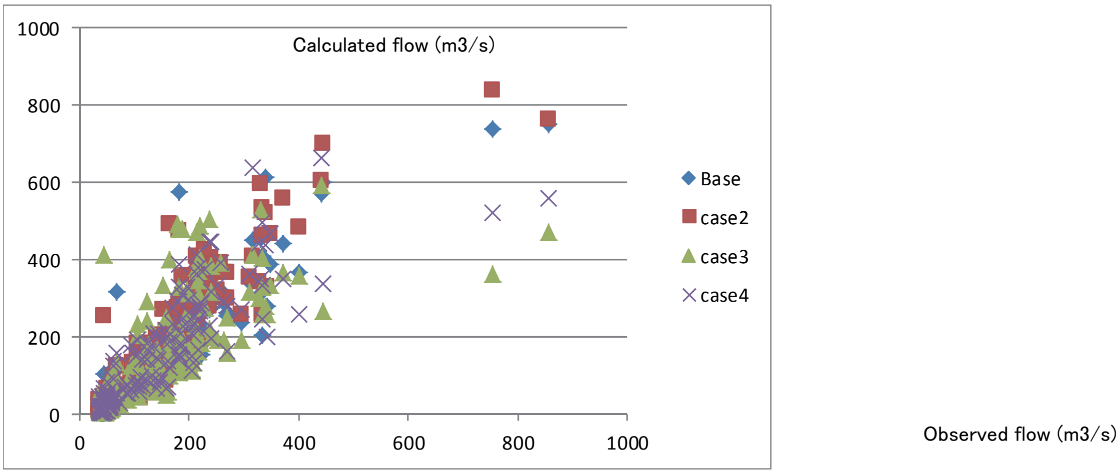


26 rainfall gauging stations (2000 km2 per station)

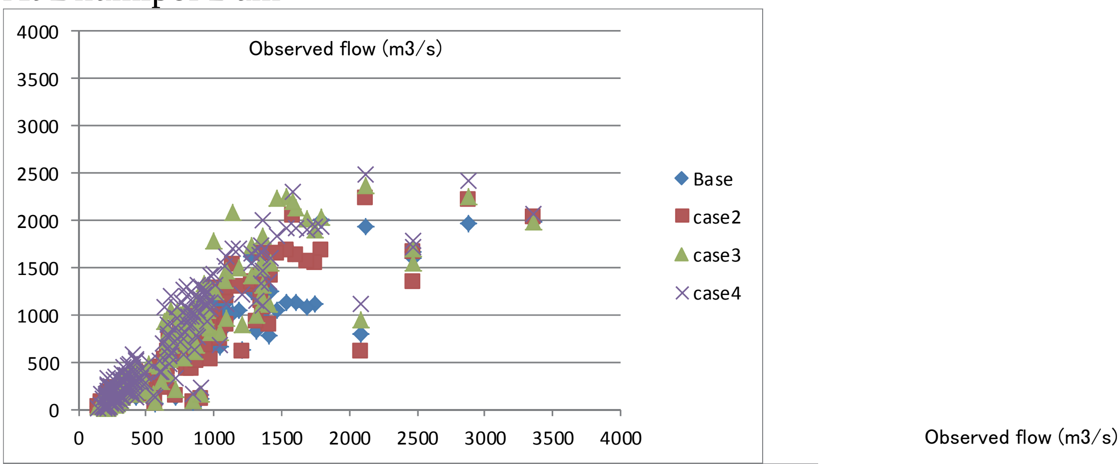
Results of setting the area to be covered by discharge calculation

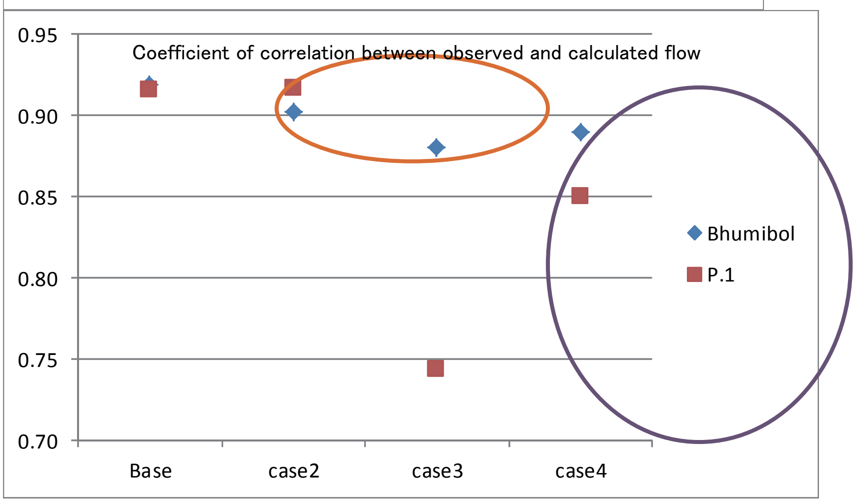
A correlation between the calculated and observed discharge (horizontal and vertical axes indicating observed and calculated discharge) and the coefficients of correlation identified using the RPI model are shown below. In the figure, Base represents 51 gauging stations (500 km2), case 2 26 stations (1000 km2), case 3 13 stations (2000 km2) and case 4 nine stations (3000 km2).

P.1



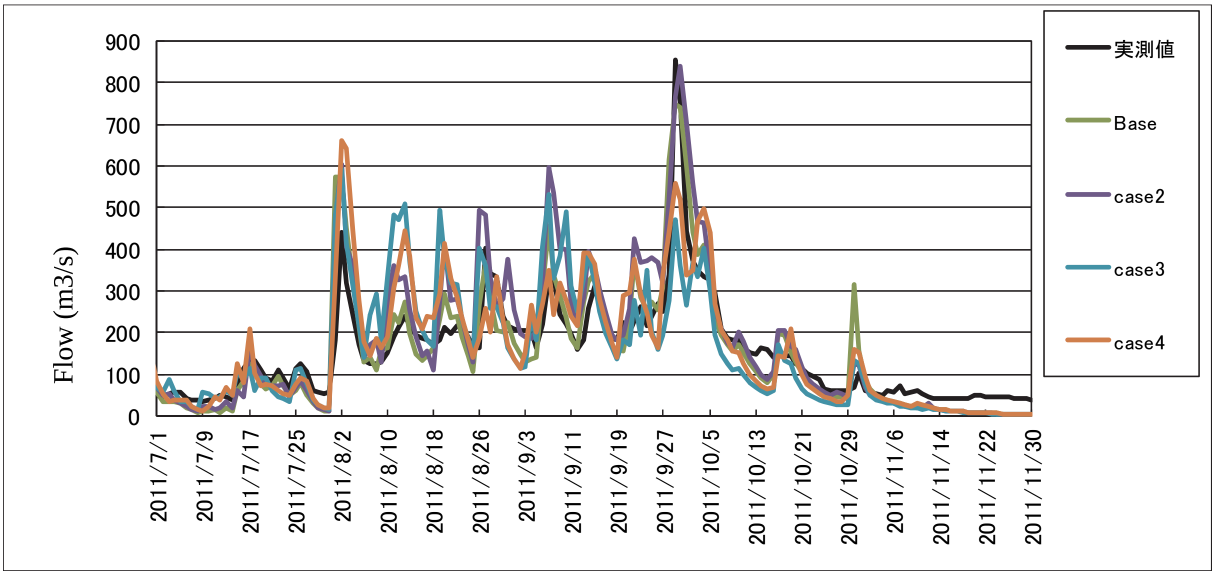
At Bhumipol Dam



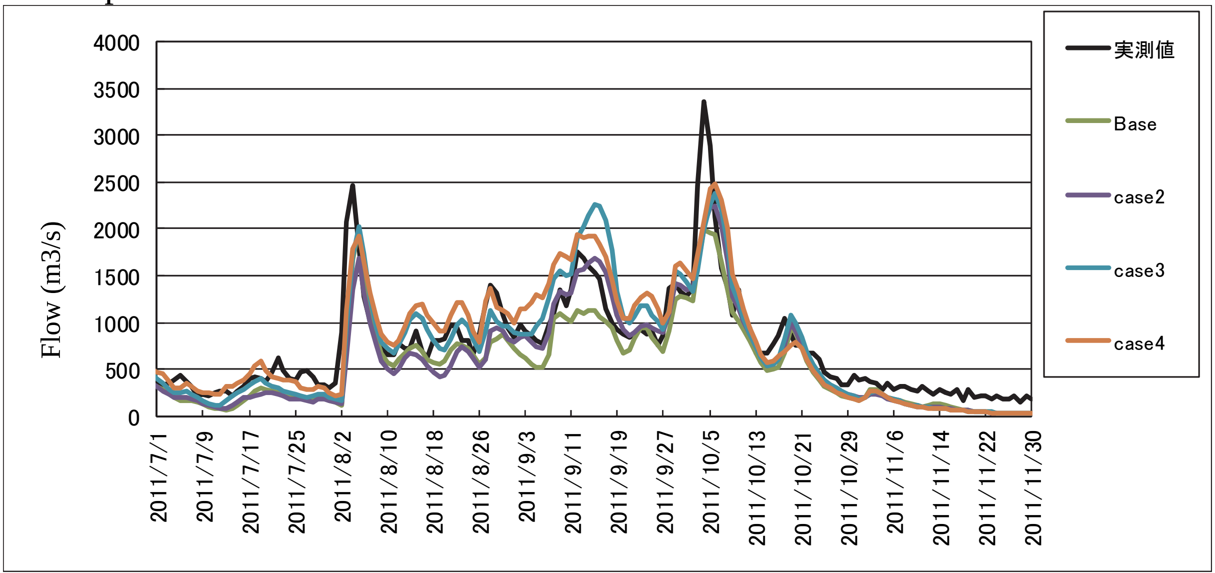


For reference, observed and calculated flow amounts are compared in the form of wave below.

P.1



Bhumipol Dam



As a result, no large variation was found at Bhumipol. If an average area covered by a single gauging station is 500 to 1000 km2, comparison is expected to lead to small errors. This is also true with respect to the area covered by a single rainfall gauging station.

In view of the above, the average area to be covered by a single rainfall gauging station was set at 500 km2 and the areas with no rainfall data were extracted in the Chaophraya River basin.

(2) Extraction of areas with no rainfall data

Areas with no rainfall data were extracted while setting the area to be covered by a single rainfall gauging station at 500 km^2 for the telemeter rainfall gauging stations controlled by RID, TMD and DWR.

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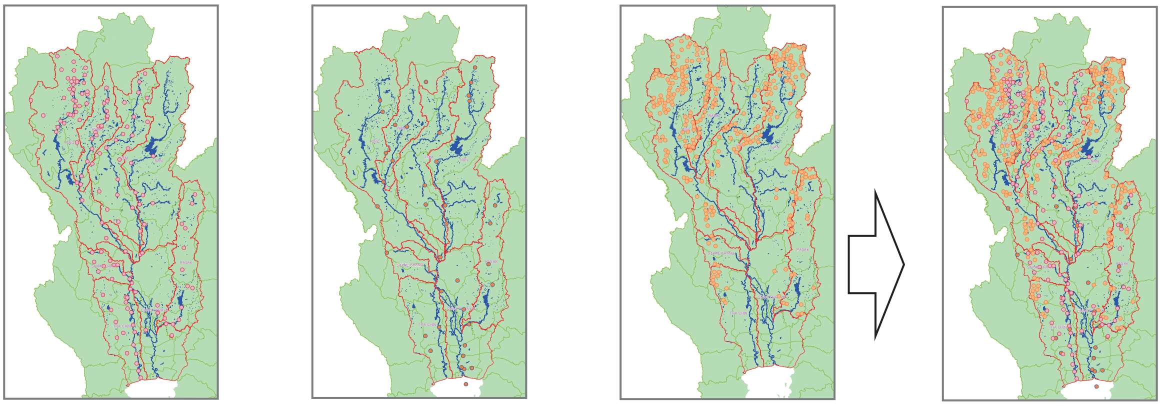


RID DWR TMD Integrated

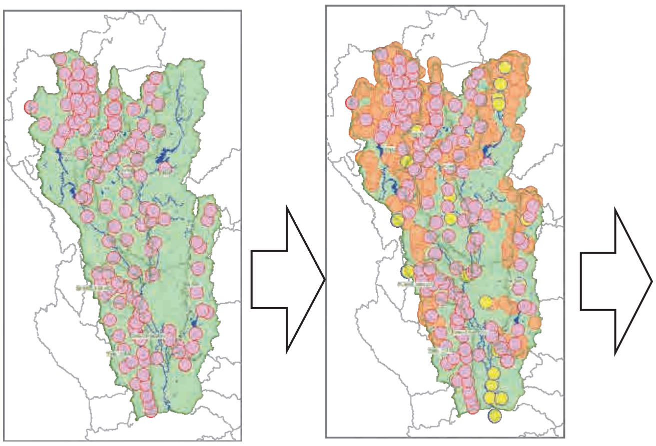
Fig1-8 Distribution of telemeter rainfall gauging stations

Table1 **Current situation of telemeter stations of different organizations**

(CA: average Covered Area per one station (km^2))

	RID		DWR		TMD		Integrated	
	Number	CA	Number	CA	Number	CA	Number	CA
Upper reaches	96	1,084	265	393	19	5,477	380	274
Lower reaches	55	1,065	42	1,395	18	3,265	115	510
Total	151	1,077	307	530	37	4,396	495	329

The area of each circle in the figure below is 500 km2. To fill the vacancies not covered by circles, telemeter gauging stations need to be installed at approximately 190 locations. At 160 thereof, existing automatic gauging stations may be equipped with telemeters.



1 org. (TLM: e.g. RID)　Integration of 3 orgs. (TLM)

Fig 1-9　Data vacant area indicated by 500km^2 circles

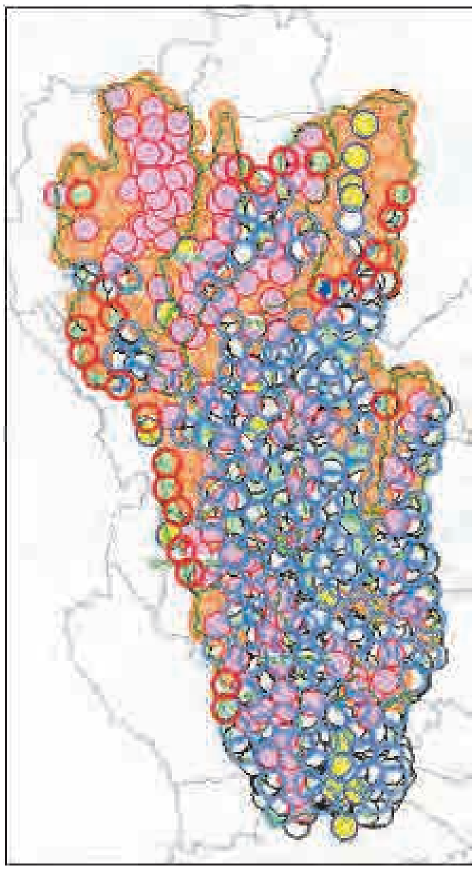


Table 2 Areas with no data (km2)

	RID (telemeter)		Three organizations (telemeter)	
Upper reaches	71,882	69 %	32,588	31 %
Lower reaches	38,677	66 %	27,813	48 %
Total	110,559	68 %	60,401	37 %

Fill vacant areas with new stations

New gauging stations will be installed (approximately 30 locations).
Existing automatic gauging stations will be equipped with telemeters (approximately 160 locations).

Review of radar rainfall observation

In order to enable the identification of conditions in a wide basin at first sight, and to grasp time-based changes in rainfall distribution and the occurrence of torrential rainfall, the accuracy of radar rain gauges is improved to collect more reliable data. Even if gauging stations are installed at ground level at a rate of one in every 500 km^2 (Section 1.1), ground-level rainfall gauging stations are located sparsely and data is collected only at certain points. Radar rainfall, which currently provides images only and is not converted to data, needs to be converted to data to enable the calculation of more precise flow based not only on the ground-level rainfall but also on the planar rainfall distributions.

Details of improvement

Present radar rainfall data contains considerable noise. To make better use of the data, facilities need to be maintained as described below to maintain data accuracy.

-Inspection and upgrading of radar facilities
--> Inspect radar facilities and identify the cause of noise
--> Select the equipment and facilities requiring upgrade and upgrade the selected equipment

-Refine regular inspection and maintenance systems
--> Examine items that need regular inspection
--> Examine methods of regular inspection and maintenance, and prepare relevant manuals

-Establish calibration systems based on the ground-level rainfall

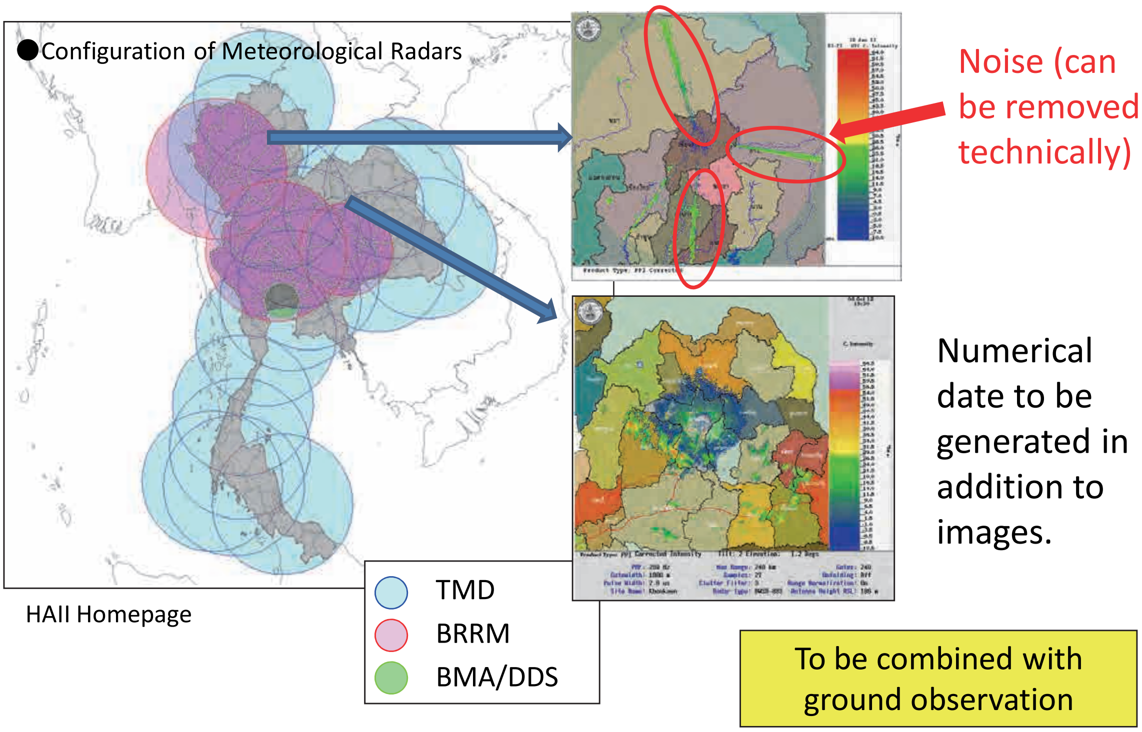


Fig 1-10 Distribution of Rainfall Radars

Identification of water level and flow

Water level and flow have been observed almost properly in the mainstream of the Chaophraya River and in large tributaries in the upper reaches such as the Ping, Wang, Yom and Nan Rivers. An on-line system is now being developed to integrate telemeter data.

Considerable amounts of flow are diverted from the mainstream to numerous tributaries and split flow and channels between Nakhon Sawan and Ayutthaya, and discharge capacity is smaller in lower reaches. Great floods therefore cause flood damage around the mainstream and split flow and channels. Under the present observation system, flow is not observed in all the split channels or flow. A system for observing flow and its influences in all split channels is therefore essential.

From a similar viewpoint, an observation setup should be established to examine the functions of facilities that may greatly affect the flow of mainstream such as the Monkey Cheeks, a new water reservoir that will be constructed.

Details of improvement

Water level and flow gauging stations will be additionally installed at locations between Nakhon Sawan and Ayutthaya along the mainstream where great changes in flow are expected to occur because of major tributaries, split flow and channels and the Monkey Cheeks, a new water reservoir that will be built. The objective is to observe the flow shared by tributaries and split channels and identify the effect in the Chaophraya River. Gauging stations and facilities will be installed for obtaining the water level and flow data in the tributaries and split flow and channels. On-line data collection will also be made possible

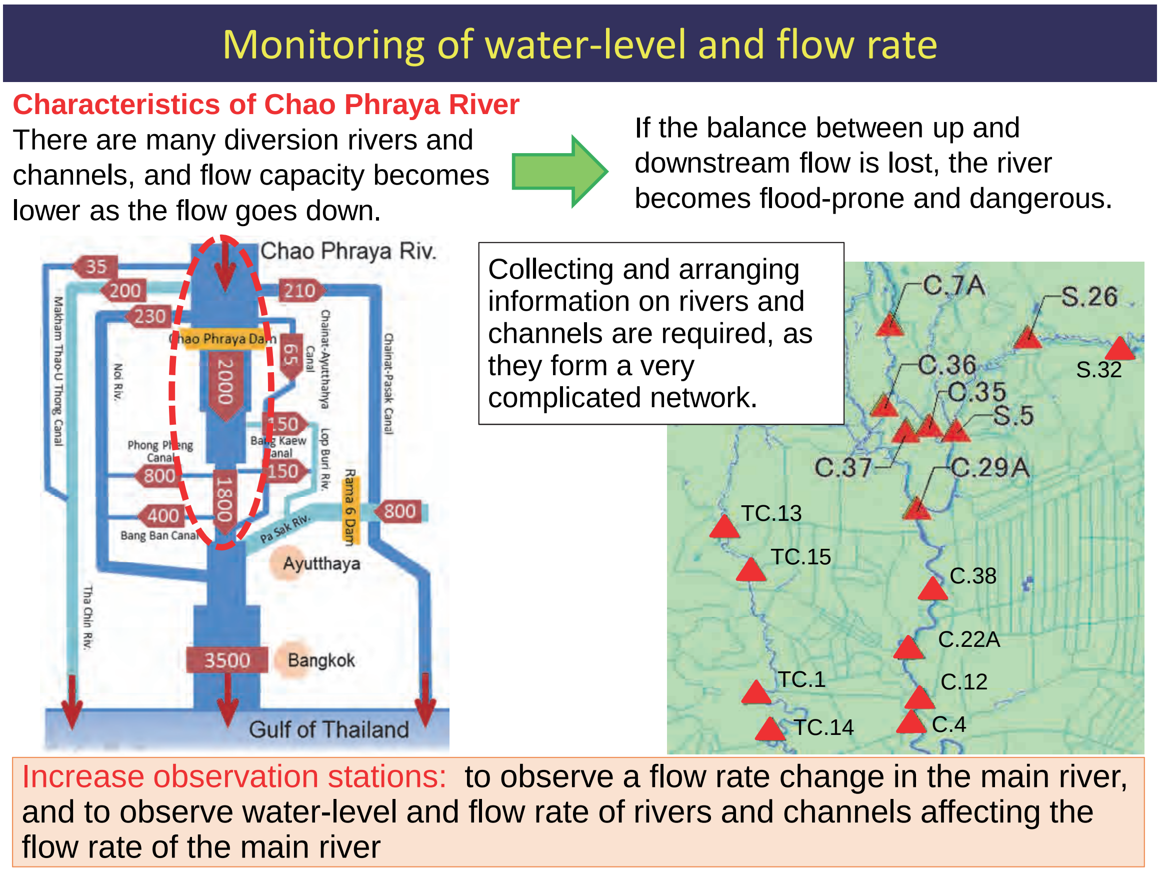


Fig 1-11Monitoring of Water-level and Flow-rate

Attachment 02

Forecast Rainfall Configuration

Contents

1 Outline of JMA forecast rainfall

Candidate forecast rainfall as input data for the Flood Risk Information System include TMD and JMA (Japan Meteorological Agency) rainfall forecasts. Obtaining TMD forecast rainfall was difficult as of September 2013, so it was decided to use JMA forecast rainfall. JMA forecast rainfall is obtained using a global meteorological model based on the data output at 720 and 361 locations along the longitude and latitude, respectively at pitches of 0.5 degree (approximately 50 km). There are about 60 output locations in the Chaophraya River basin. Cumulative forecast rainfall six to 84 hours later is publicized at intervals of six hours, or at 0:00, 6:00, 12:00 and 18:00 UTC (universal time coordinated). Cumulative forecast rainfall 96 to 192 hours later is publicized at 12:00 UTC at intervals of 12 hours. Hatched gray boxes in the table below indicate the time and period when forecast rainfall is publicized.

Table 1-1 JMA forecast rainfall

Forecast time (UTC)	Forecast Period（hr）																																		
	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126	132	138	144	150	156	162	168	174	180	186	192	198	204
0:00	0000	0006	0012	0018	0100	0106	0112	0118	0200	0206	0212	0218	0300	0306	0312																				
6:00		0000	0006	0012	0018	0100	0106	0112	0118	0200	0206	0212	0218	0300	0306	0312																			
12:00			0000	0006	0012	0018	0100	0106	0112	0118	0200	0206	0212	0218	0300	0306	0312		0400		0412		0500		0512		0600		0612		0700		0712		0800
18:00				0000	0006	0012	0018	0100	0106	0112	0118	0200	0206	0212	0218	0300	0306	0312																	

UTC：Universal time coodinated

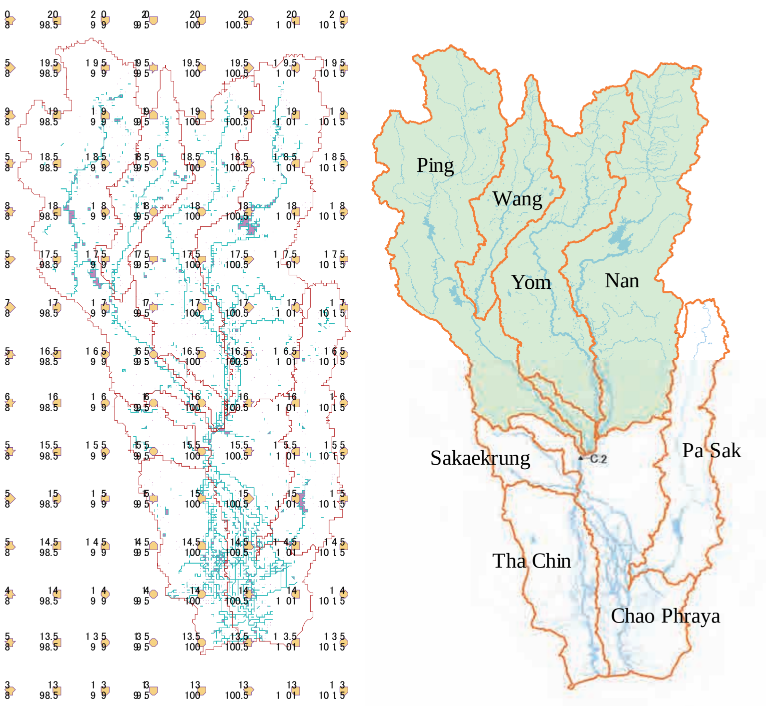


Fig. 1 Forecast rainfall output locations

2 Error in forecast rainfall

JMA forecast rainfall contains the following errors.

2.1 Errors with respect to rainfall intensity

When the observed rainfall is small, the forecast rainfall tends to exceed the observed rainfall (Fig. 4 through 6). This is ascribable to the difficulty in fully reproducing acute phenomena using meteorological models while in reality, rainfall of high and low intensities occur acutely. When using the forecast rainfall for predicting floods, therefore, corrections should be made so as to reduce the forecast rainfall in the case where the observed rainfall is small.

2.2 Errors with respect to regional distribution of rainfall

The Chaophraya River basin has a total catchment area of approximately 160,000 km^2. The catchment area at Nakhon Sawan is rather wide at approximately 100,000 km^2. Heavy rain never falls uniformly throughout the basin but occurs only in some areas in the basin. A distribution of observed rainfall on July 31, 2011 is shown below as an example. It is evident that relatively heavy rain concentrated in certain areas in the basin.

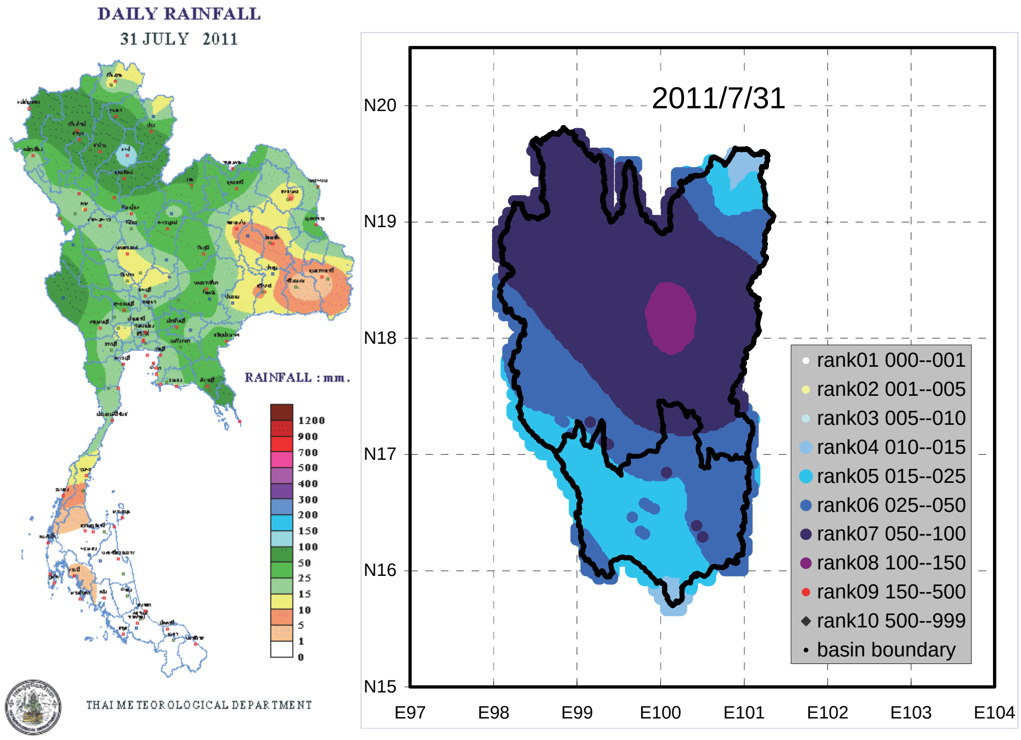
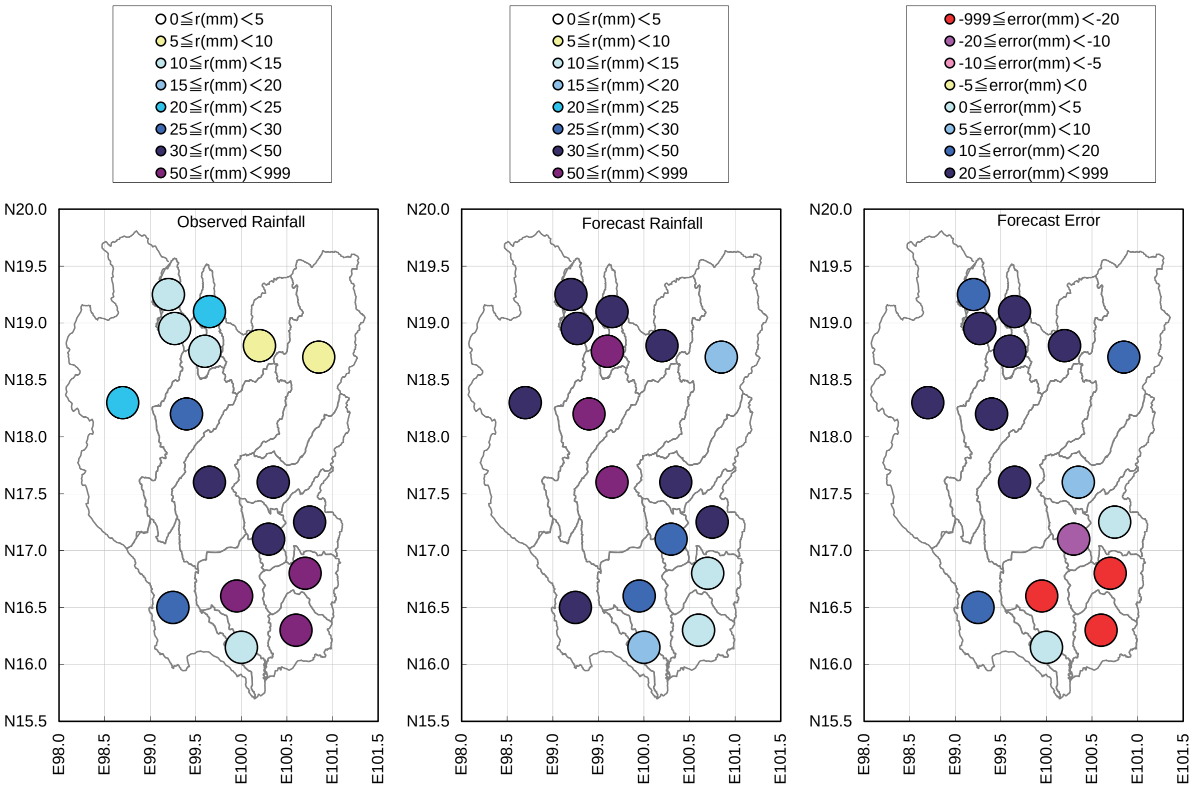


Fig. 2 TMD observed rainfall

Errors in forecast rainfall (forecast rainfall minus observed rainfall) are also regionally distributed in the basin around Nakhon Sawan (point C2), not uniformly throughout the basin. The following figures show the distributions of errors in forecast daily rainfall on September 12, 2011 as an example. The error in forecast rainfall has a negative value to the south of point C2 (forecast is lower than observation) but has a positive value to the north of the point (forecast is higher than observation).



2011/9/12

Fig. 3 Regional distributions of errors in forecast rainfall

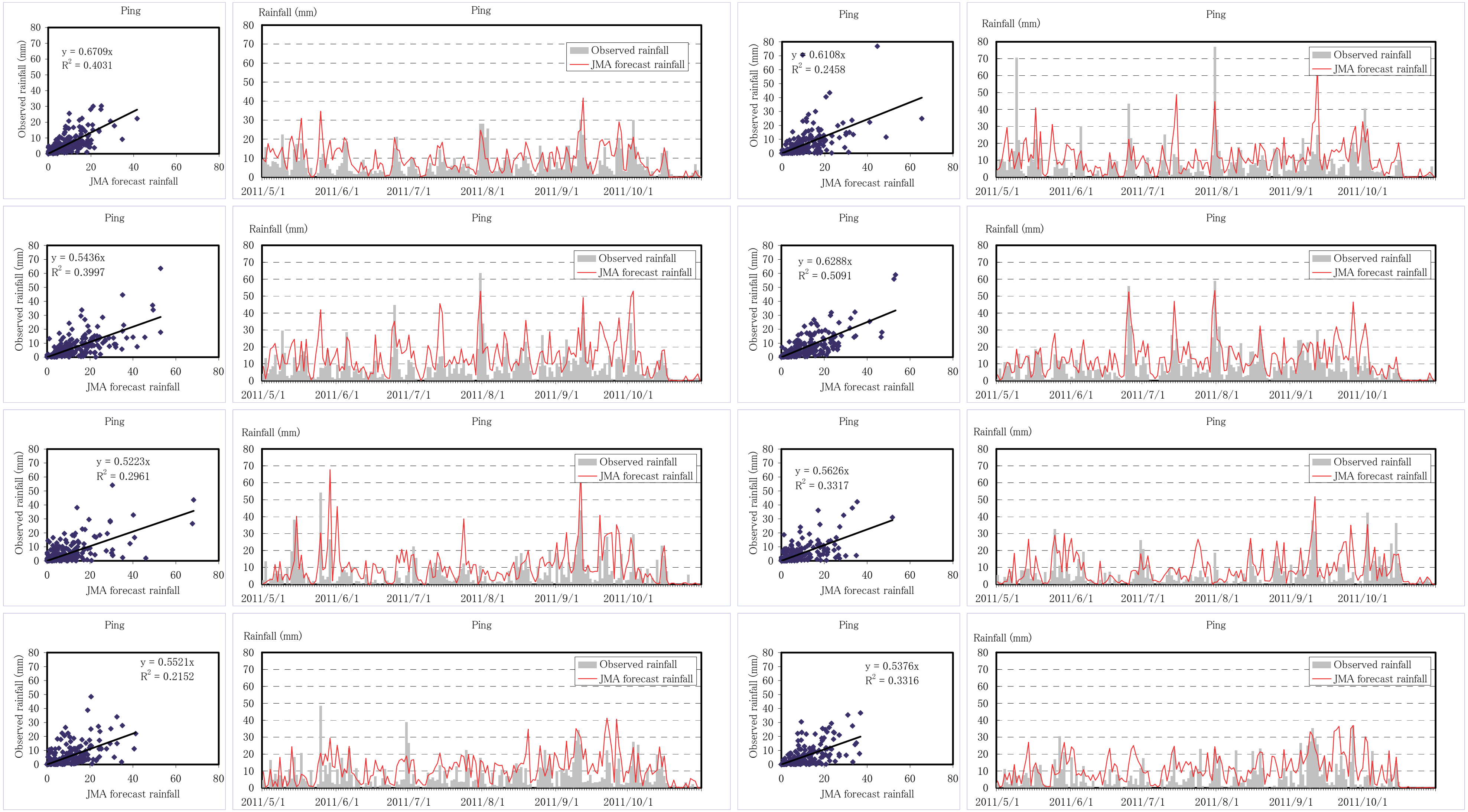


Fig. 4 JMA forecast rainfall and observed rainfall (daily rainfall at UTC0:00 as a daily boundary) May1 through Oct. 31, 2011

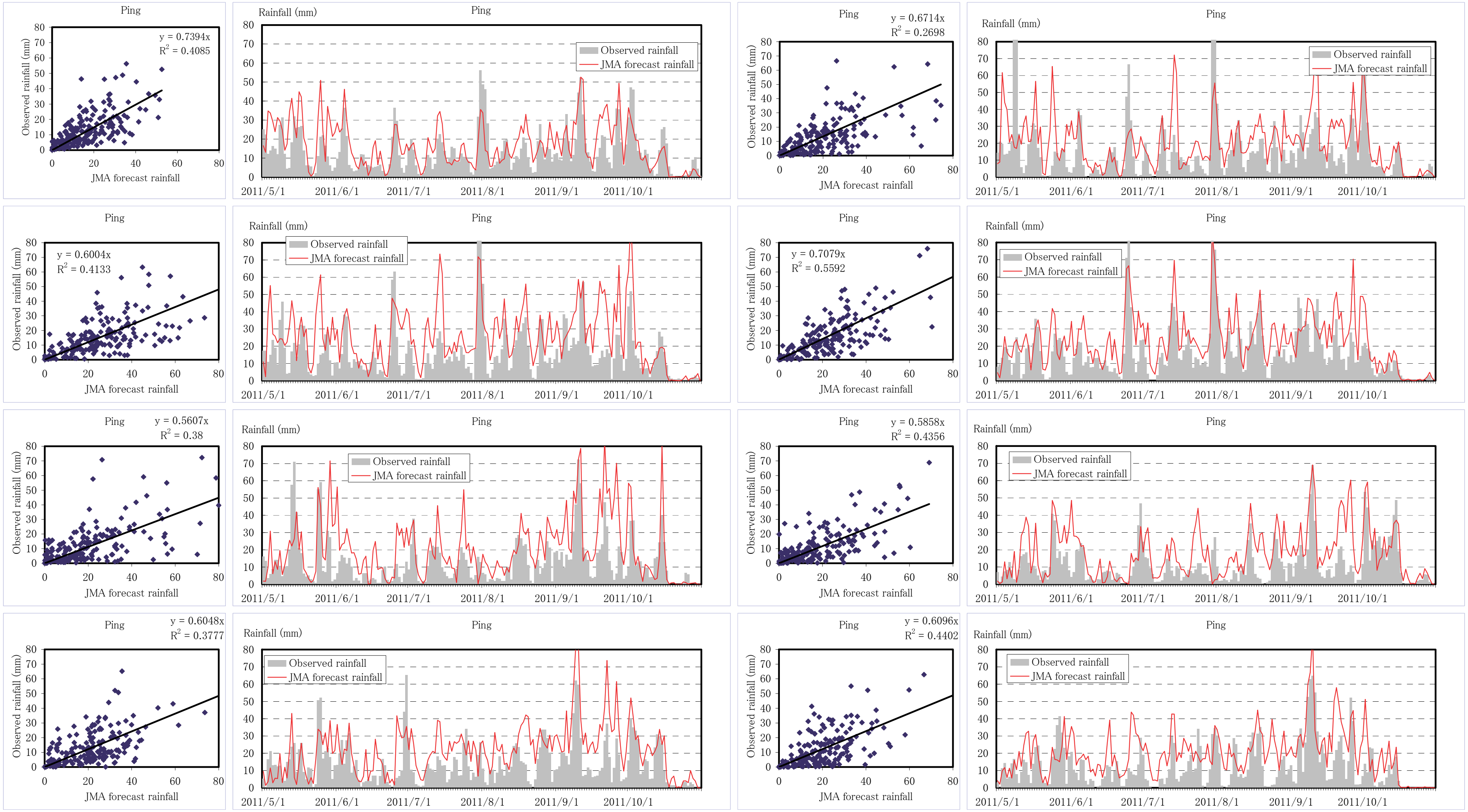


Fig. 5 JMA forecast rainfall and observed rainfall (two-day rainfall at UTC0:00 as a daily boundary) May1 through Oct. 31, 2011

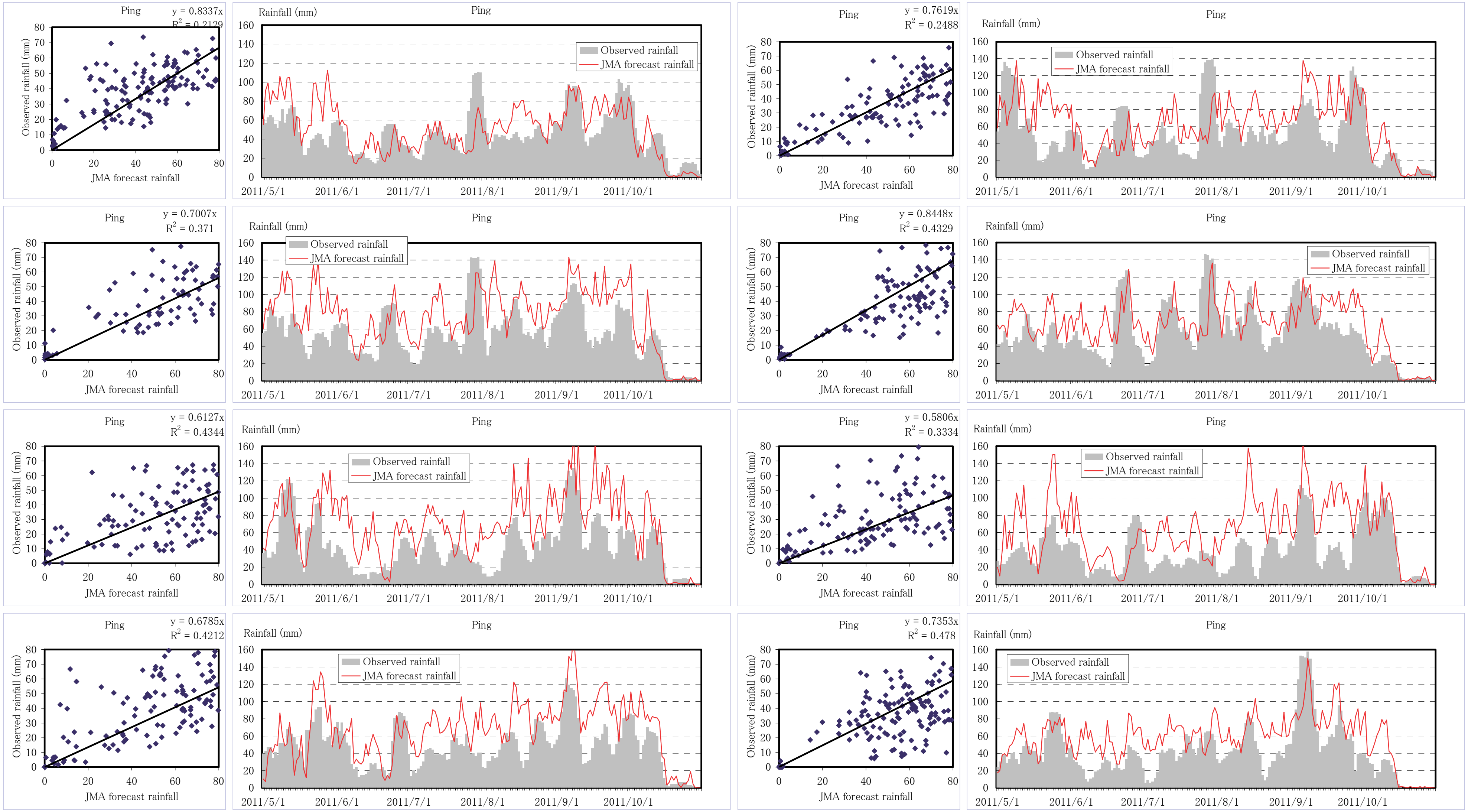
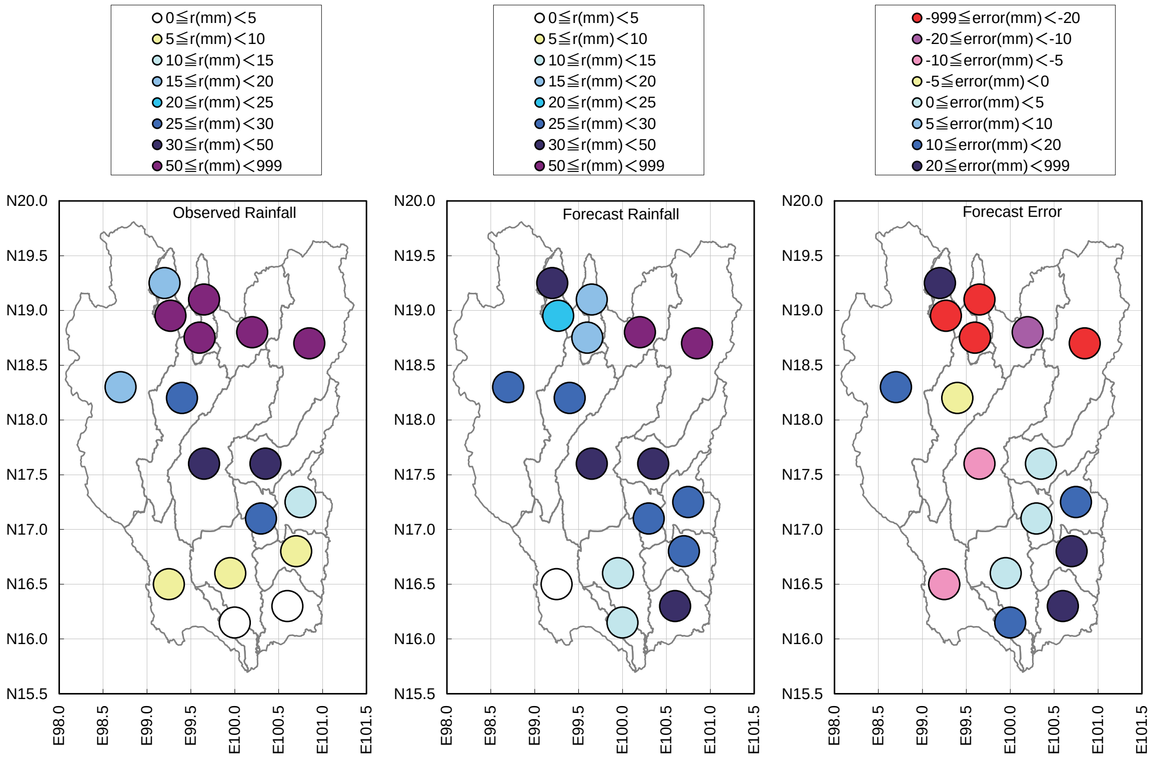
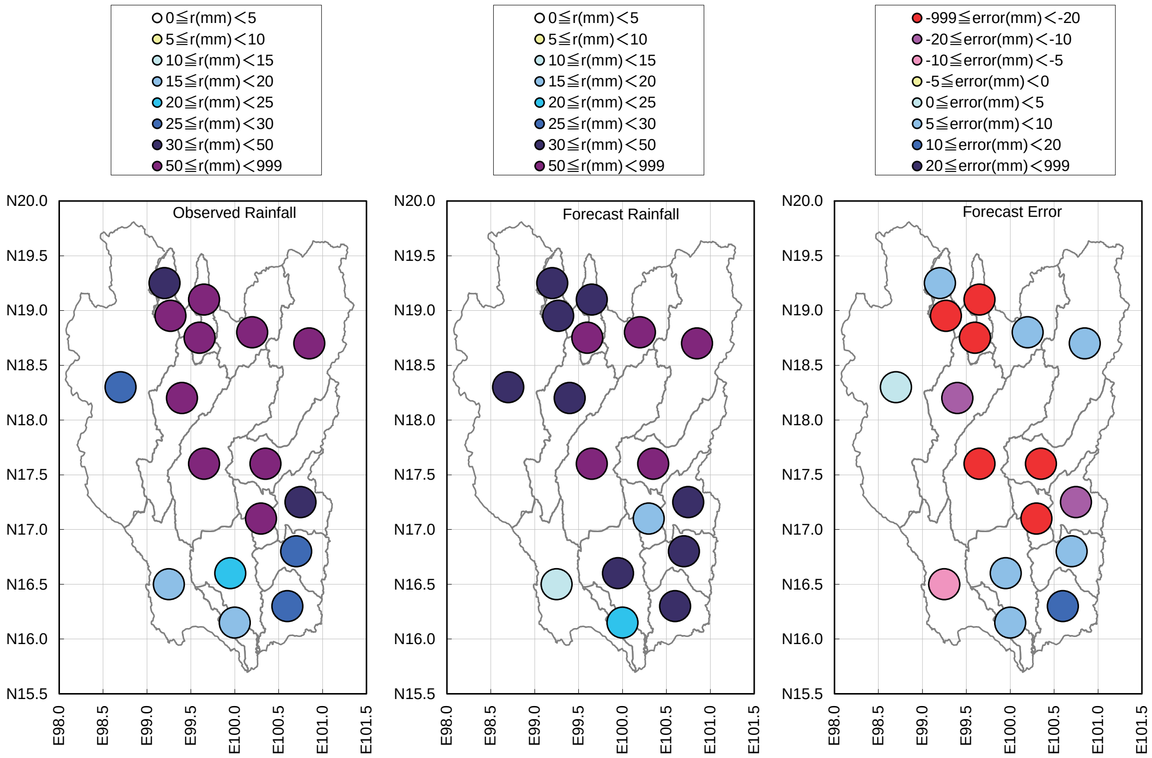


Fig. 6 JMA forecast rainfall and observed rainfall (seven-day forecast rainfall at UTC12:00 as a daily boundary and observed rainfall at UTC0:00 as a daily boundary) May1 through Oct. 31, 2011

Shown below for reference are the regional distributions of errors in forecast rainfall on the day when mean daily rainfall was large in the basin surrounding C2 in the period between October 24, 2007 and December 31, 2011.

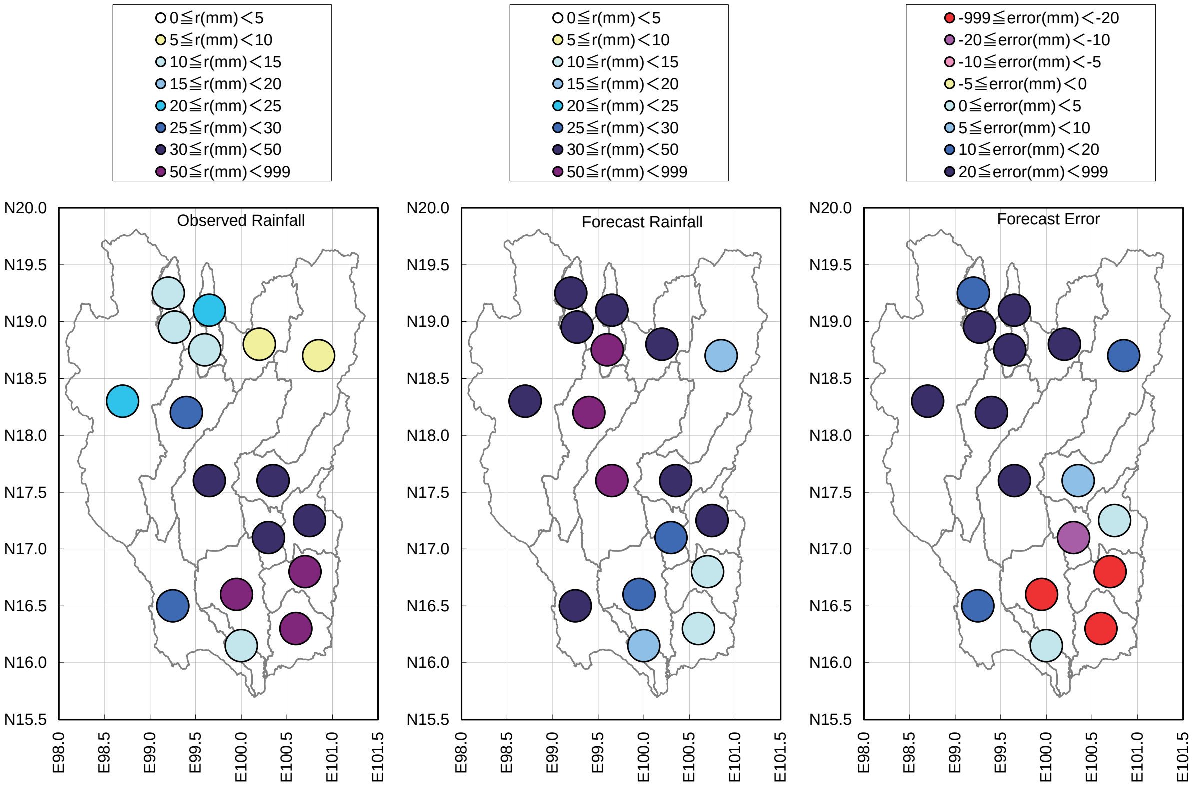


2011/6/25

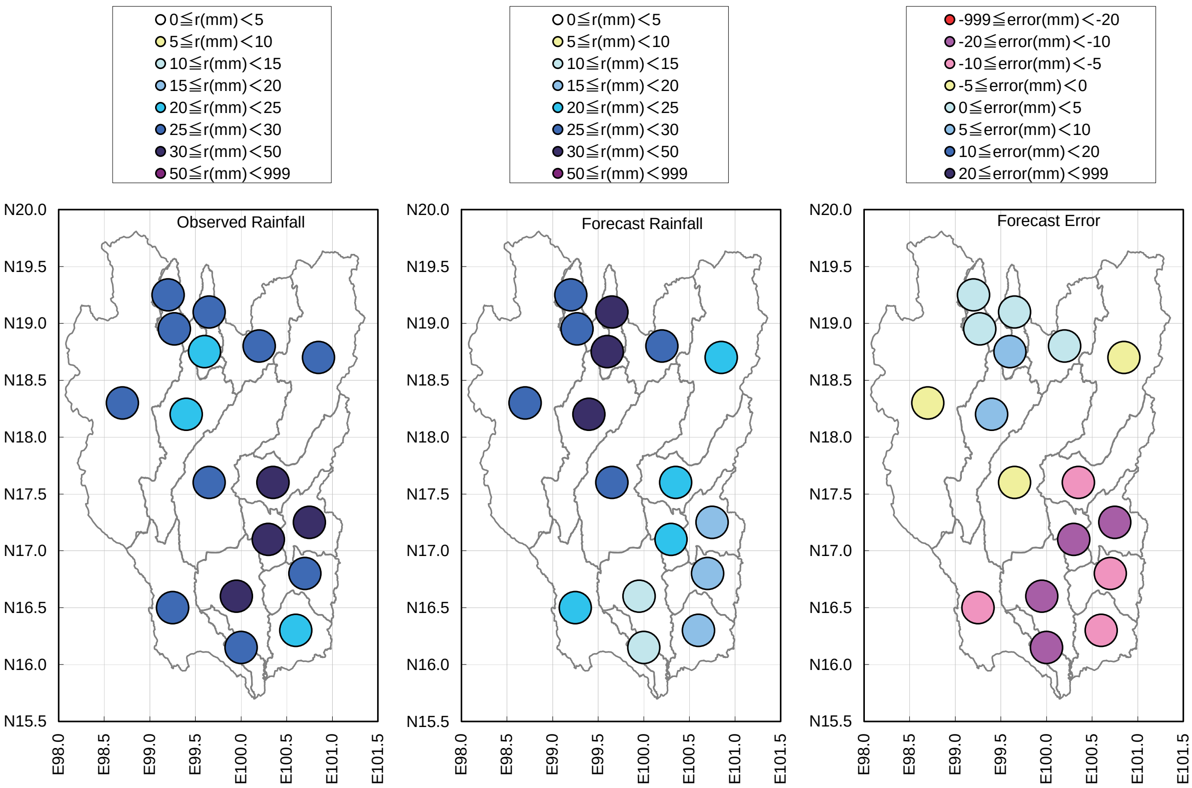


2011/7/31

Fig. 7 Planar distributions of errors in JMA forecast rainfall

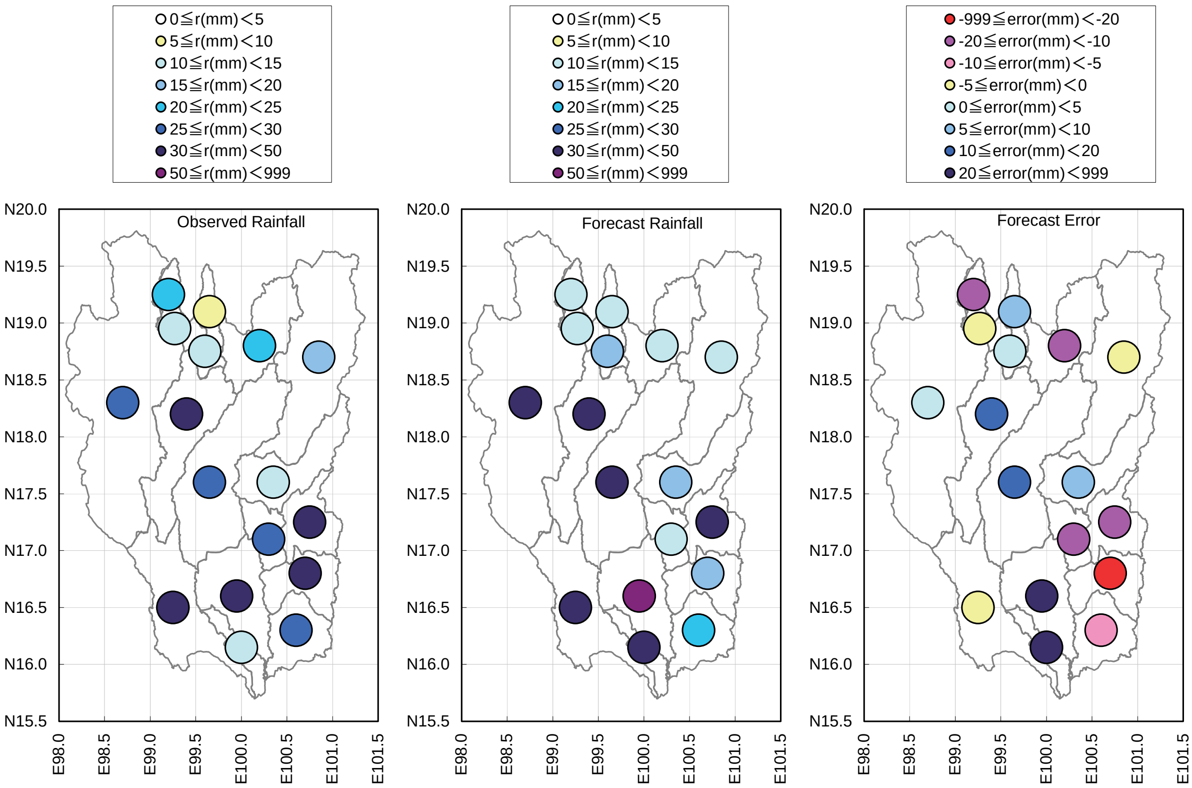


2011/9/12

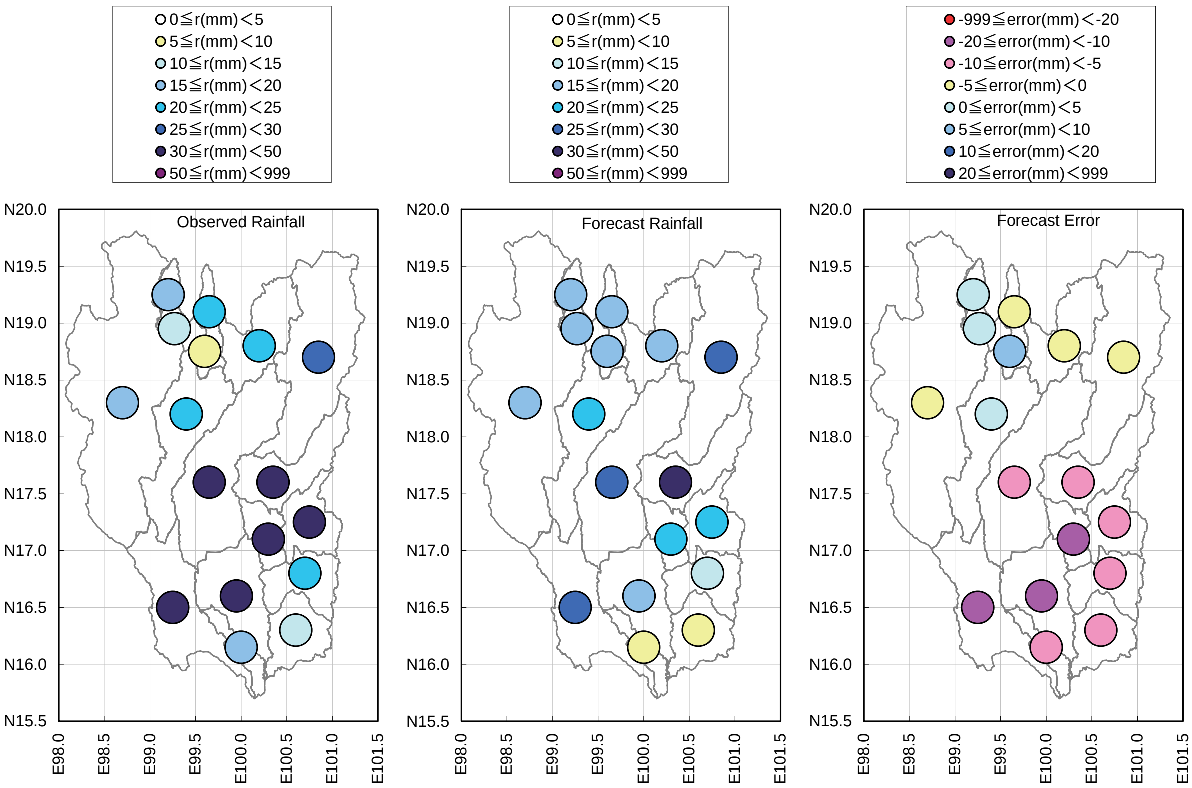


2011/3/16

Fig. 8 Planar distributions of errors in JMA forecast rainfall

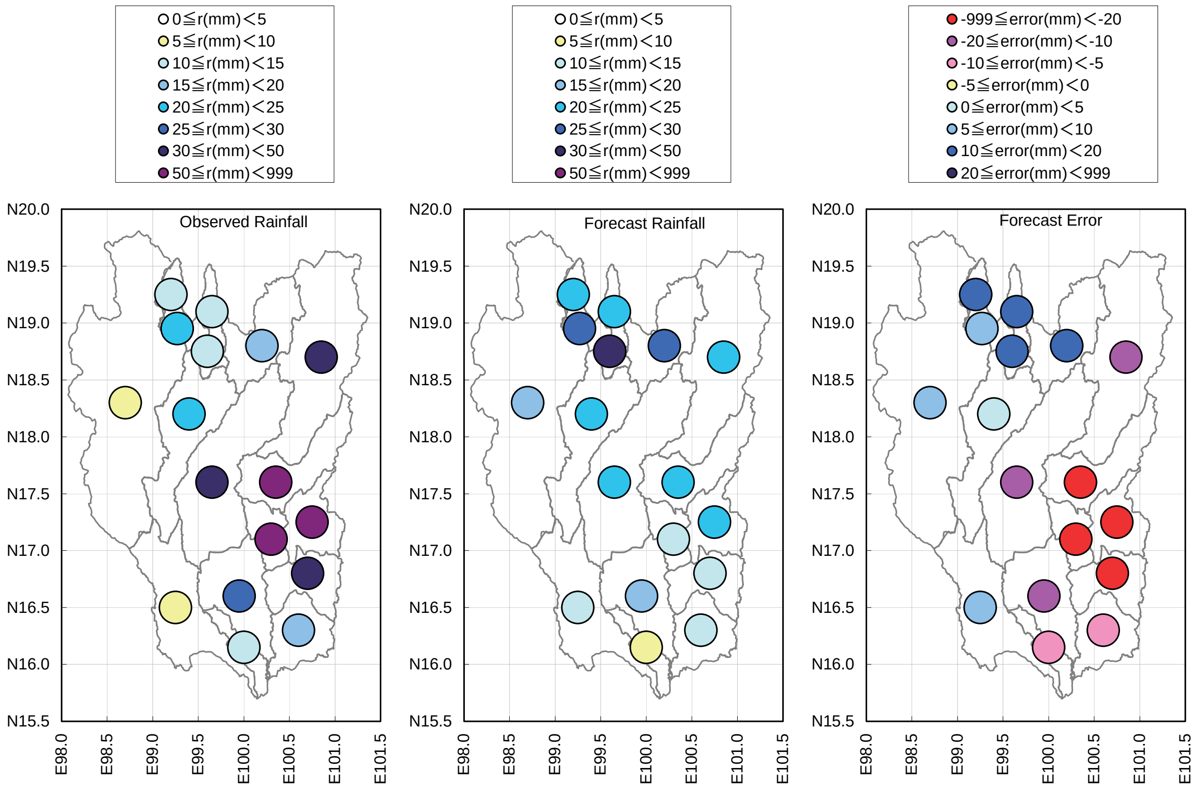


2009/9/26

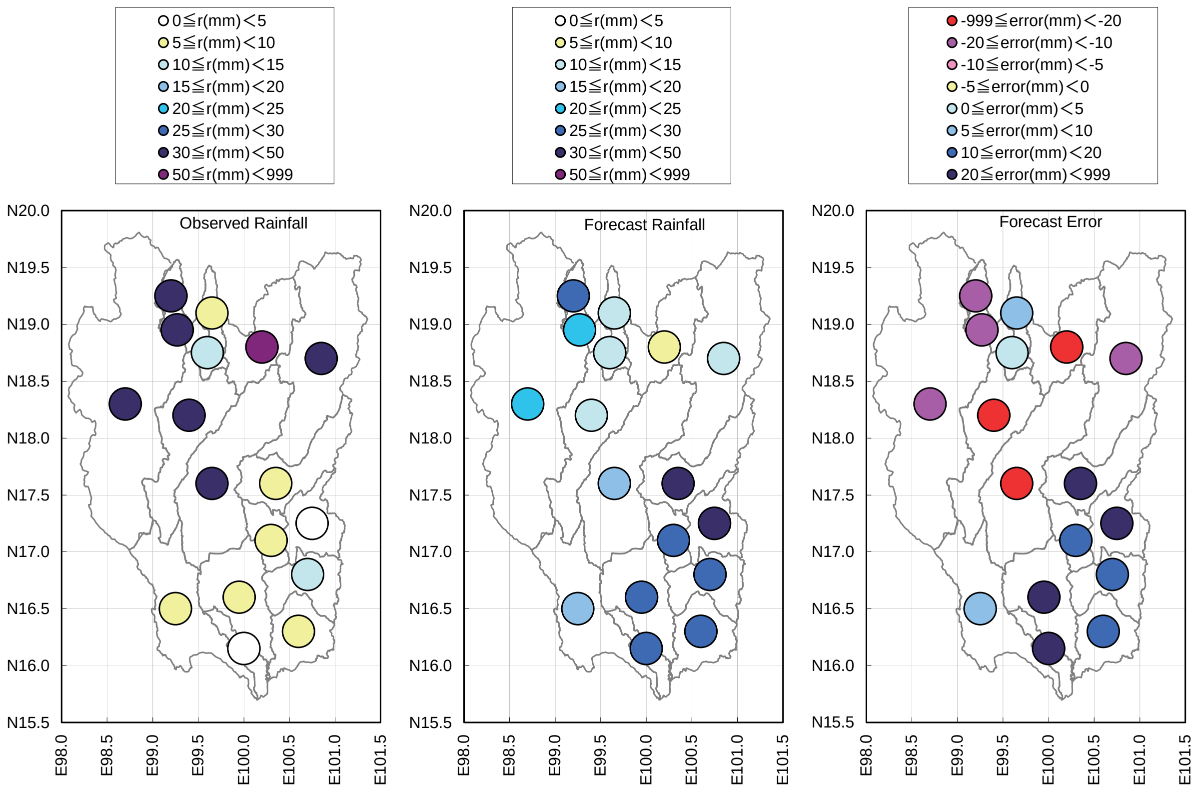


2011/3/17

Fig. 9 Planar distributions of errors in JMA forecast rainfall

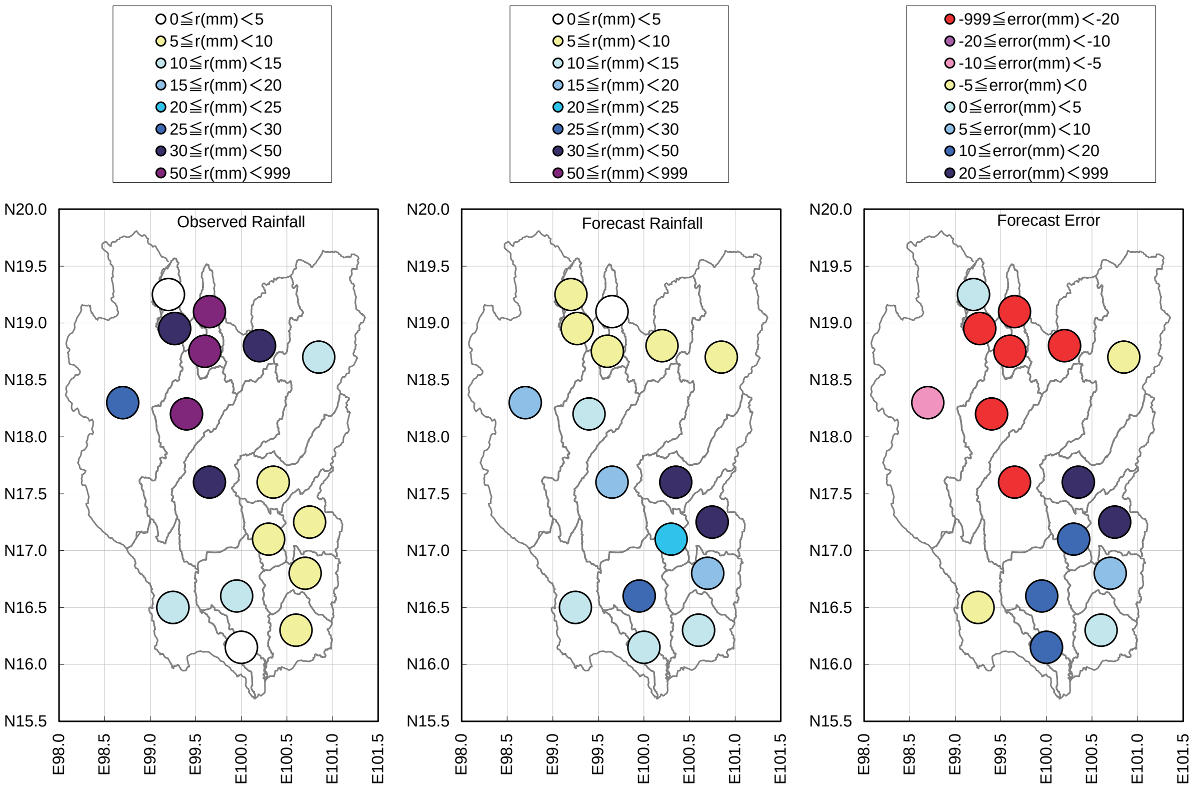


2010/9/14

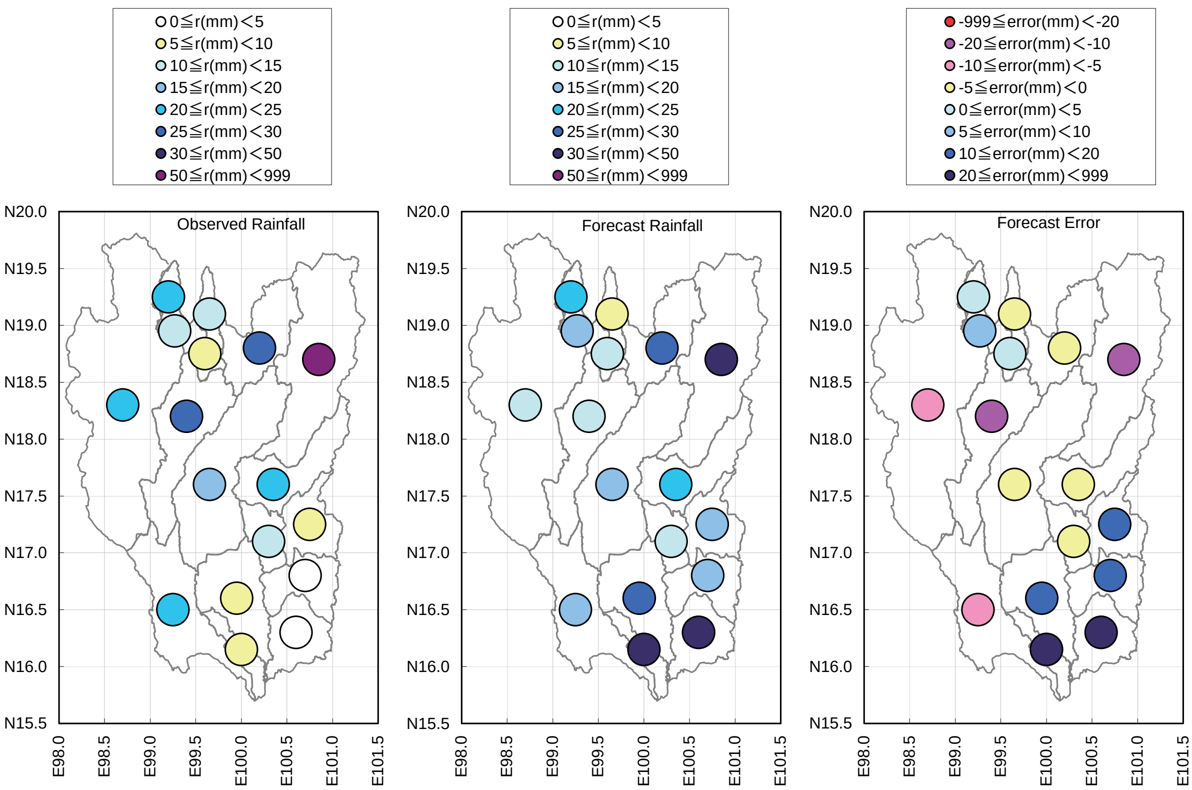


2011/8/1

Fig. 10 Planar distributions of errors in JMA forecast rainfall



2011/5/9



2011/6/26

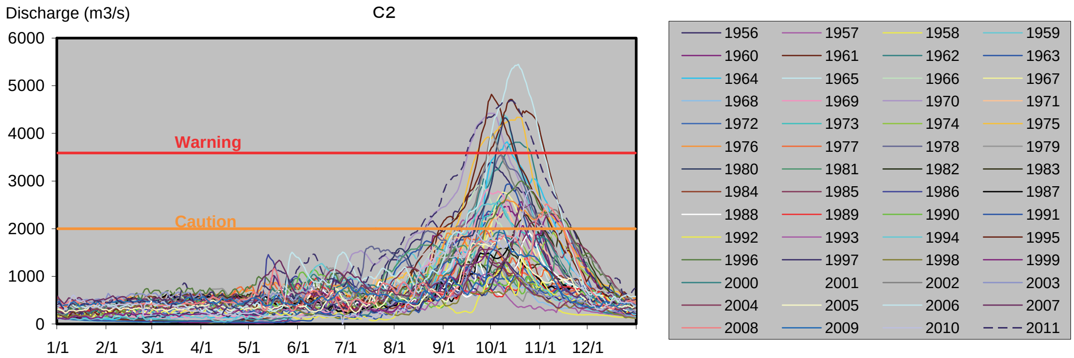
Fig. 11 Planar distributions of errors in JMA forecast rainfall

3 Increase in flow and rainfall at Nakhon Sawan

Predicting the flow at Nakhon Sawan is important to the Flood Risk Information System. Errors in forecast rainfall should be considered based on the importance. As the basic data for examination, data was organized on the occurrence of flood when the warning level was exceeded at Nakhon Sawan, and on the rainfall in the basin surrounding Nakhon Sawan when the flow increased rapidly at Nakhon Sawan during past floods.

(1) Flood exceeding the warning level (Nakhon Sawan)

Flow exceeded the warning level at Nakhon Sawan (C2) during the following eleven flood events in the period between April 1, 1956 and December 31, 2011, or eleven times during the 56-year period. (The warning and caution levels at Nakhon Sawan are 3500 and 2000 m^3/sec, respectively.) The average number of days from the point when the caution level was exceeded to that when the warning level was exceeded is 21 days. In 1964, the warning level was reached in ten days, fastest after the caution level was exceeded. The variance between the warning and caution levels varies according to the bed condition and the year. The variance was 2.5 m as of October 2012. Based on the variance, the rate of water level elevation since the caution level was reached in 1964 is estimated to be approximately 25 cm/day.



no.	Caution		Warning		Number of days*
	Day flood exceeded caution level	Flow on the day m3/s	Day flood exceeded caution level	Flow on the day m3/s	
1	1959/09/13	2,082	1959/10/04	3,623	21
2	1961/08/30	2,051	1961/09/30	3,620	31
3	1962/09/20	2,143	1962/10/11	3,689	21
4	1964/09/26	2,388	1964/10/06	3,614	10
5	1970/08/20	2,002	1970/09/17	3,702	28
6	1975/09/07	2,009	1975/09/22	3,612	15
7	1980/09/21	2,020	1980/10/04	3,650	13
8	1995/09/01	2,027	1995/09/23	3,660	22
9	2002/09/09	2,049	2002/09/29	3,742	20
10	2006/09/15	2,136	2006/09/30	3,810	15
11	2011/08/17	2,003	2011/09/16	3,670	30
ave.					21

*Number of days indicates the number of days from the point when the caution level was exceeded to that when the warning level was exceeded

Fig. 12 Floods exceeding the warning level at Nakhon Sawan

Shown below are the observed flow (mean daily flow), warning level and caution level at Nakhon Sawan in the period between April 1, 1956 and December 31, 2011.

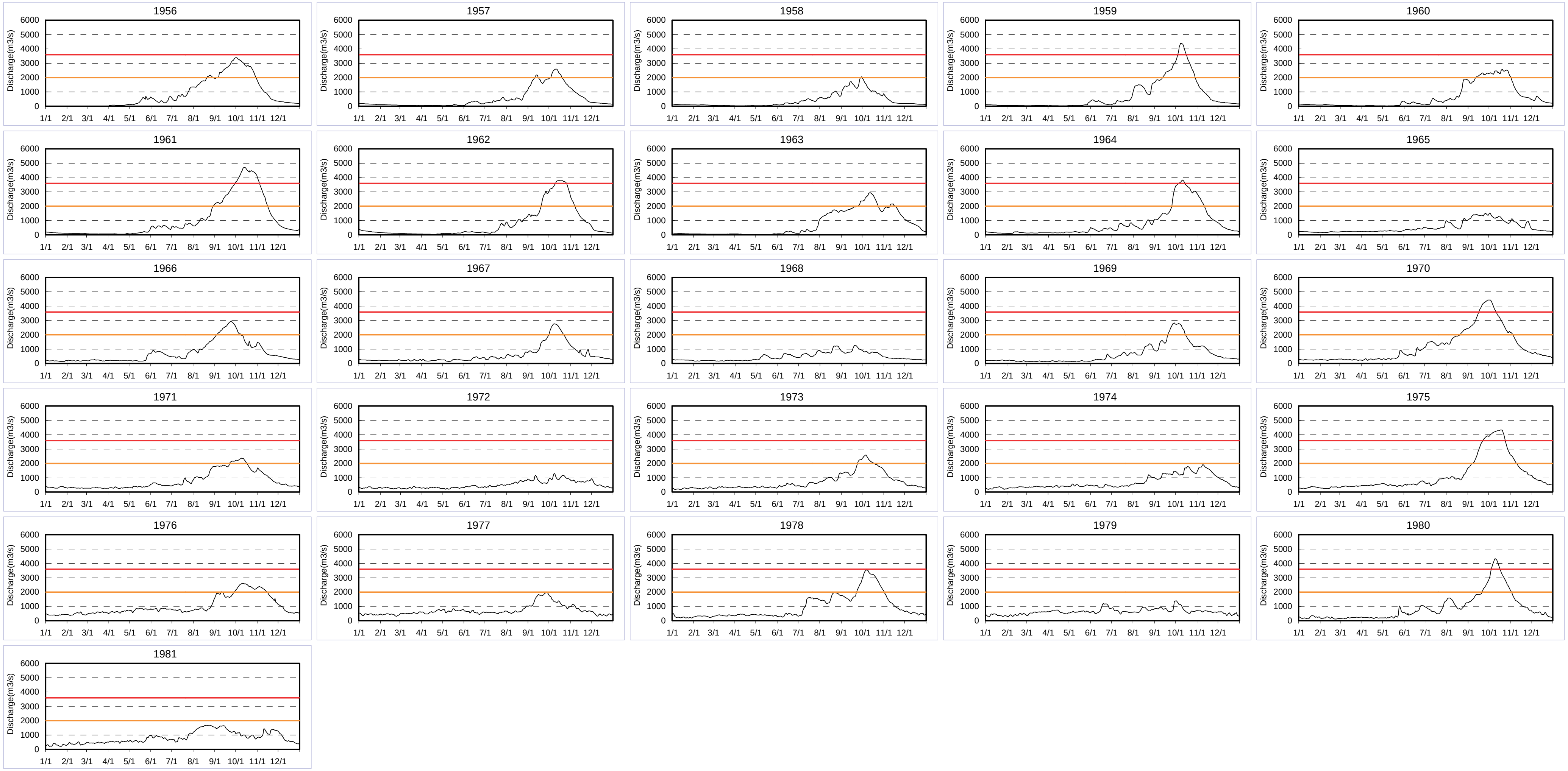


Fig. 3-13 Observed flow (Nakhon Sawan)

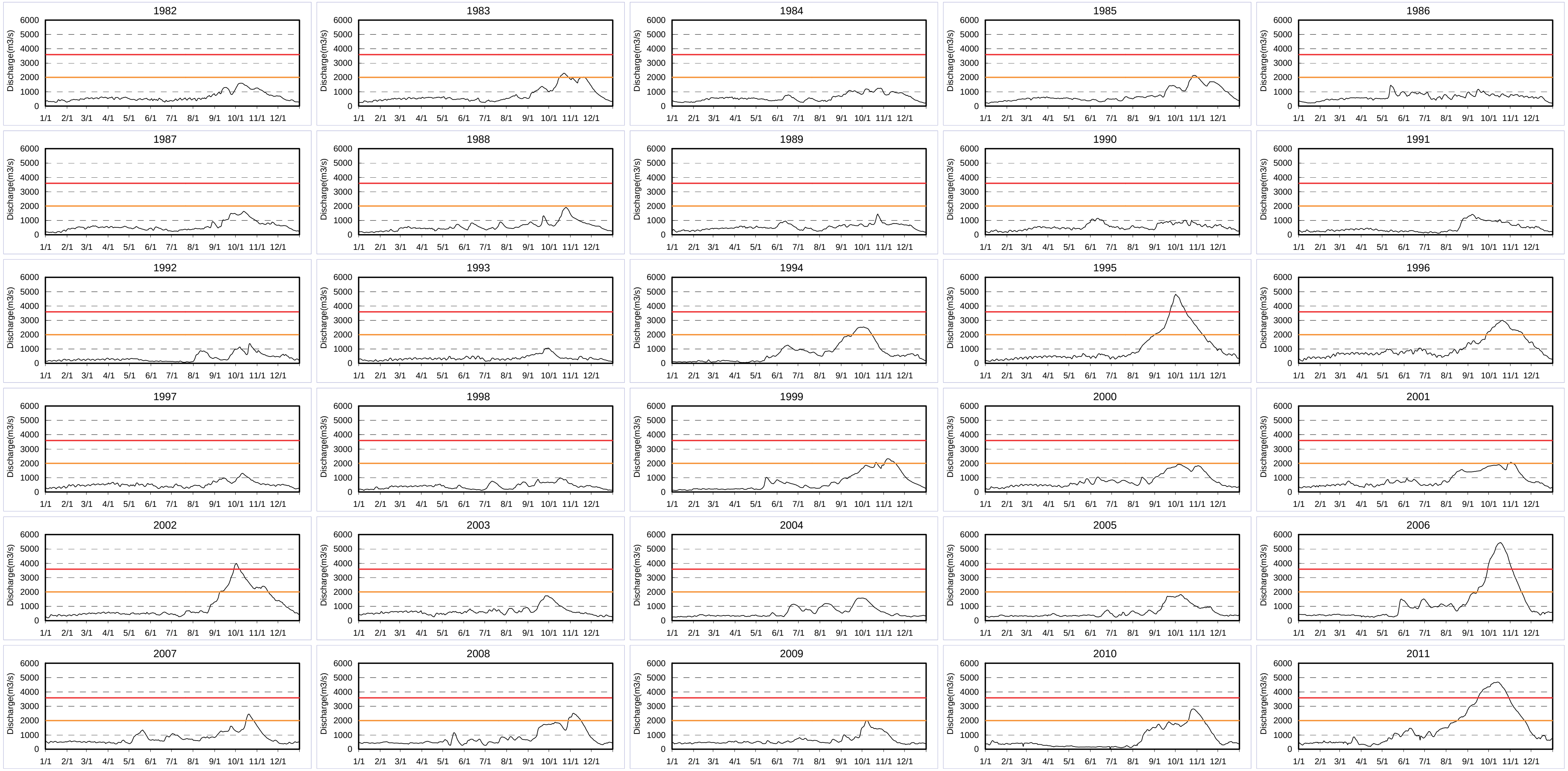


Fig. 3-14 Observed flow (Nakhon Sawan)

(2) Floods involving rapidly increasing flow (Nakhon Sawan)

The floods were extracted from the flow observation records during the period between April 1, 1956 and December 31, 2011 that caused rapid increase in flow at Nakhon Sawan (Table 3-1). Focus was placed on the increment in one, three and seven days. Rapid increase in flow was ranked relative to the increment in three days. Floods that caused rapid flow increase were defined as described above. Floods in September 1964 caused the flow to increase most rapidly, by 420 m^3/sec in a day, by 1,037 m^3/sec in three days and by 1,616 m^3/sec in seven days. The floods that caused rapid flow increase are ranked in Table 3-1.

Table 3-1 Floods causing rapid flow increase (at Nakhon Sawan during the period between April 1, 1956 and December 31, 2011)

Increase in flow									Caution → Warning				
Flow increase in three days (m3/s/3d)			Flow increase in seven days (m3/s/7d)			Flow increase in one day (m3/s/1d)			Caution		Warning		Number of days
rank	date	Increase in	rank	date	Increase in	rank	date	Increase in	Day flood exceeded caution	Flow on the day m3/s	Day flood exceeded caution	Flow on the day m3/s	
1	1964/09/28	1,037	1	1964/09/30	1,616	3	1964/09/26	420	1964/09/26	2,388	1964/10/06	3,614	10
2	2006/05/26	877	8	2006/05/28	1,180	9	2006/05/25	333					
3	1986/05/13	813	15	1986/05/13	925	2	1986/05/12	428					
4	1980/05/25	777	34	1980/05/25	759	1	1980/05/24	508					
5	2006/09/30	758	2	2006/10/02	1,441	14	2006/09/29	303	2006/09/15	2,136	2006/09/30	3,810	15
6	1960/08/25	750	6	1960/08/25	1,226	4	1960/08/24	396					
7	1992/10/20	744	55	1992/10/21	645	5	1992/10/19	377					
8	1959/08/28	721	22	1959/09/01	856	8	1959/08/27	351					
9	2008/10/29	716	16	2008/10/31	925	12	2008/10/28	307					
10	1980/10/04	698	4	1980/10/08	1,248	21	1980/10/04	277					
11	1979/09/30	694	37	1979/09/30	751	6	1979/09/28	367	1980/09/21	2,020	1980/10/04	3,650	13
12	1959/10/06	693	3	1959/10/08	1,254	16	1959/10/06	293	1959/09/13	2,082	1959/10/04	3,623	21
13	1962/09/22	670	5	1962/09/23	1,237	27	1962/09/21	257	1962/09/20	2,143	1962/10/11	3,689	21
14	1958/09/28	639	24	1958/09/30	832	19	1958/09/27	278					
15	1988/09/22	624	36	1988/09/23	755	15	1988/09/22	294					
16	2007/10/17	620	11	2007/10/19	1,032	20	2007/10/16	277					
17	2008/05/15	612	21	2008/05/17	860	28	2008/05/13	252					
18	1999/05/15	606	29	1999/05/16	796	29	1999/05/14	250					
19	2009/09/30	606	28	2009/10/04	814	23	2009/09/29	273					
20	2010/10/22	599	17	2010/10/24	900	32	2010/10/22	236					
21	1969/09/20	582	12	1969/09/24	1,016	10	1969/09/19	318					
22	1995/09/25	566	7	1995/09/29	1,223	26	1995/09/29	258	1995/09/01	2,027	1995/09/23	3,660	22
23	2002/09/30	565	10	2002/09/30	1,069	50	2002/09/28	210	2002/09/09	2,049	2002/09/29	3,742	20
24	1959/08/02	565	14	1959/08/03	935	43	1959/08/01	219					
25	1978/07/13	561	9	1978/07/13	1,076	13	1978/07/13	304					
26	1970/06/20	557				24	1970/06/19	261					
27	1961/08/28	544	25	1961/08/31	831	31	1961/08/27	241	1961/08/30	2,051	1961/09/30	3,620	31
28	2008/09/16	542	33	2008/09/17	760	36	2008/09/15	229					
29	1981/11/10	528	67	1981/11/11	596	7	1981/11/10	367					
30	1989/10/22	528	38	1989/10/23	740	53	1989/10/21	204					
31	1969/09/09	521	44	1969/09/11	716	40	1969/09/08	221					
32	1963/07/31	507	23	1963/08/02	843	35	1963/07/30	229					
33	2002/09/08	506	41	2002/09/09	727	34	2002/09/07	229					
34	1965/08/25	496	39	1965/08/26	732	39	1965/08/24	224	1970/08/20	2,002	1970/09/17	3,702	28
35	1970/05/26	491	74	1970/05/27	574	22	1970/05/26	274					
36	1974/10/14	484	71	1974/10/18	580	18	1974/10/13	279					
37	1978/10/02	480	18	1978/10/04	892	84	1978/10/02	174					
38	1973/09/24	464	19	1973/09/26	885	89	1973/09/23	170					
39	1958/09/03	463	43	1958/09/06	716	42	1958/09/02	219					
40	1973/08/29	462	73	1973/08/30	575	38	1973/08/28	228					
									1975/09/07	2,009	1975/09/22	3,612	15
									2011/08/17	2,003	2011/09/16	3,670	30

*Hatched boxes indicate top ten floods.

For the top five floods in terms of flow increase in three days, the distributions of rainfall in seven days preceding the date of rapid flow increase are shown in the figures below. The figures show that large amounts of rainfall were observed in areas relatively close to Nakhon Sawan (southern half of the basin upstream of Nakhon Sawan) in several days preceding the date of rapid flow increase.

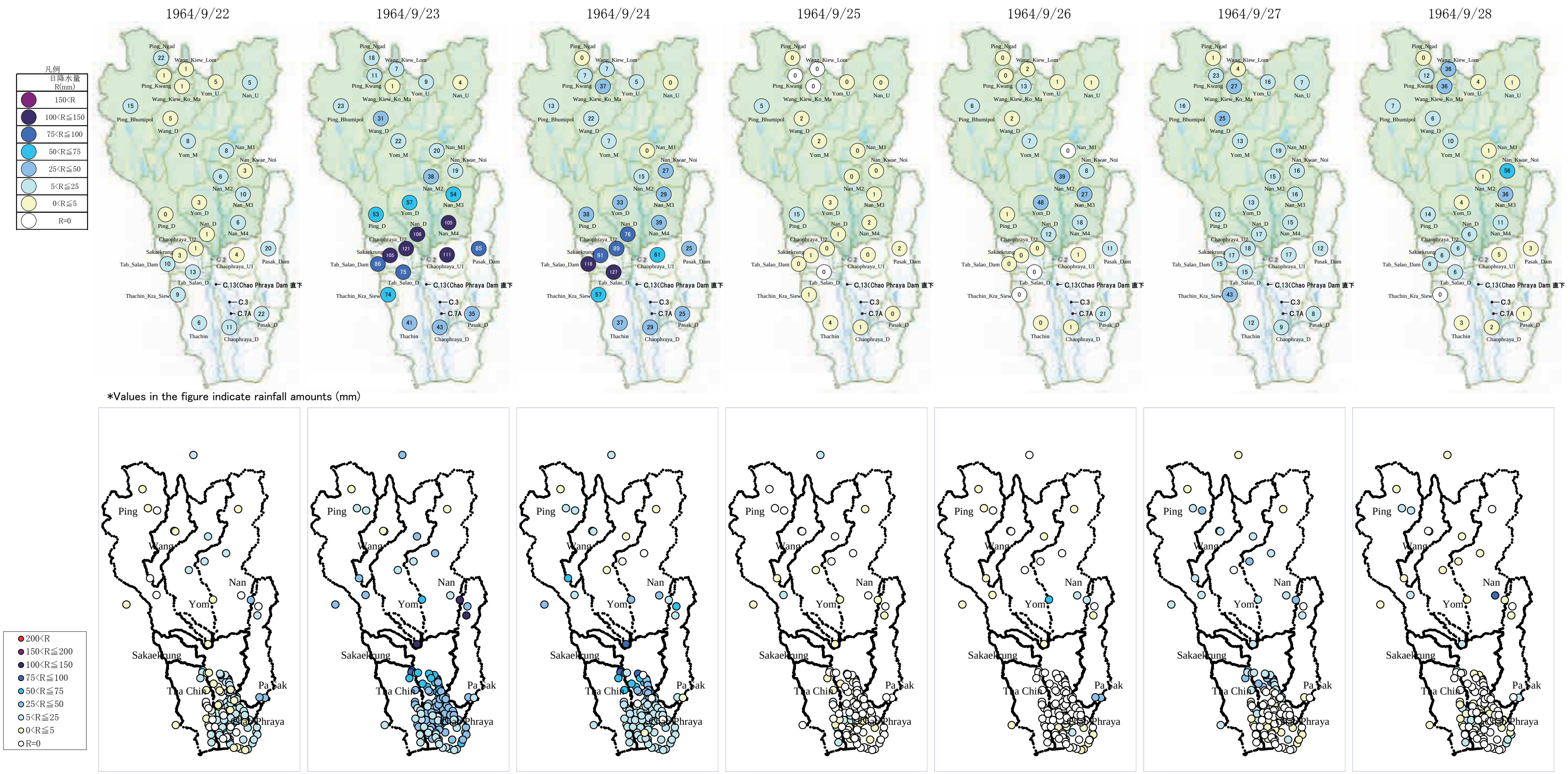
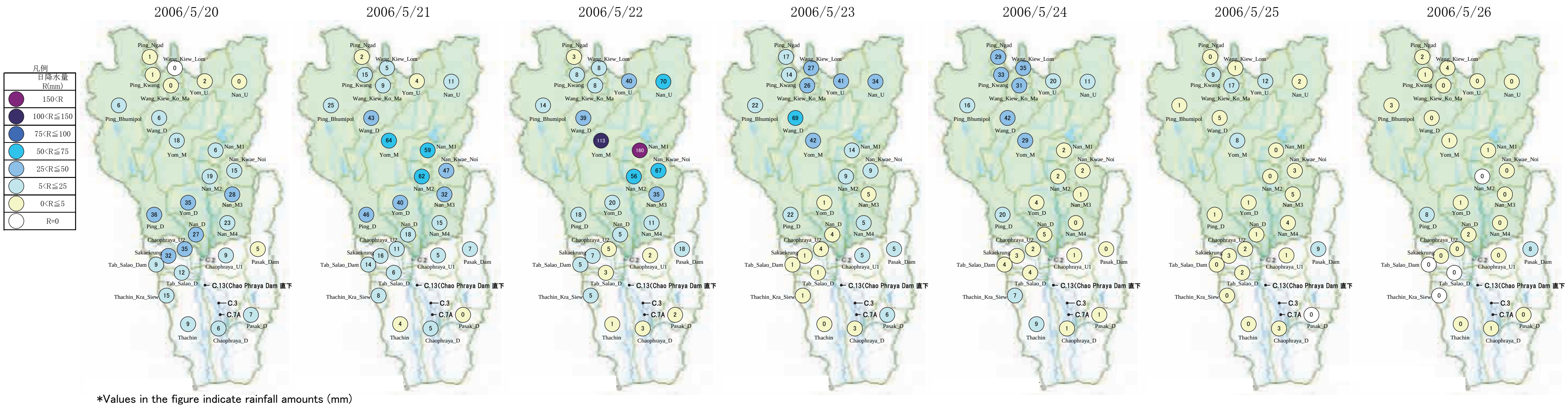


Fig. 3-15 Distributions of rainfall in seven days preceding the date of rapid flow increase at Nakhon Sawan (Sept. 28, 1964)



*Values in the figure indicate rainfall amounts (mm)

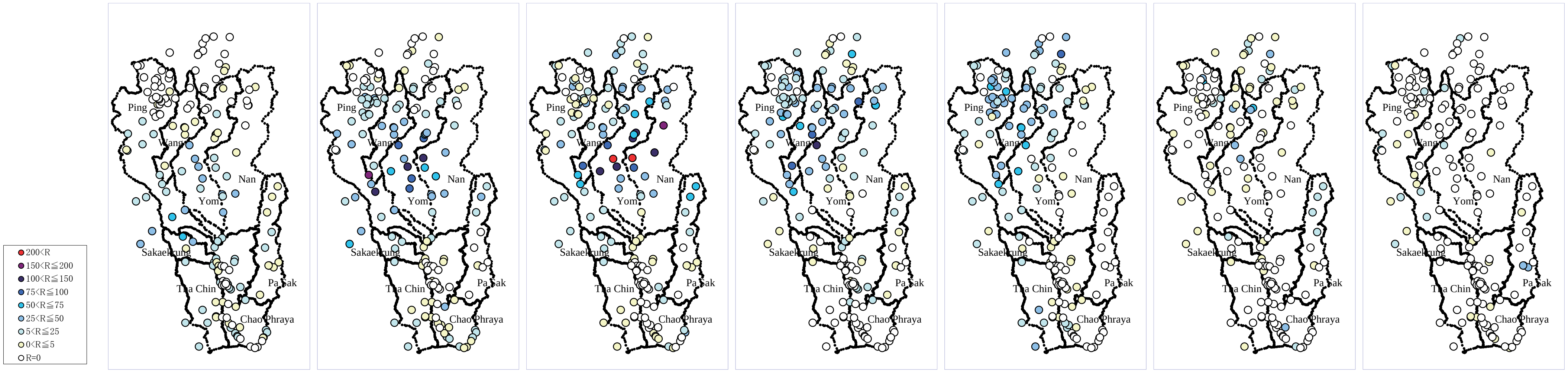


Fig. 3-16 Distributions of rainfall in seven days preceding the date of rapid flow increase at Nakhon Sawan (May 26, 2006)

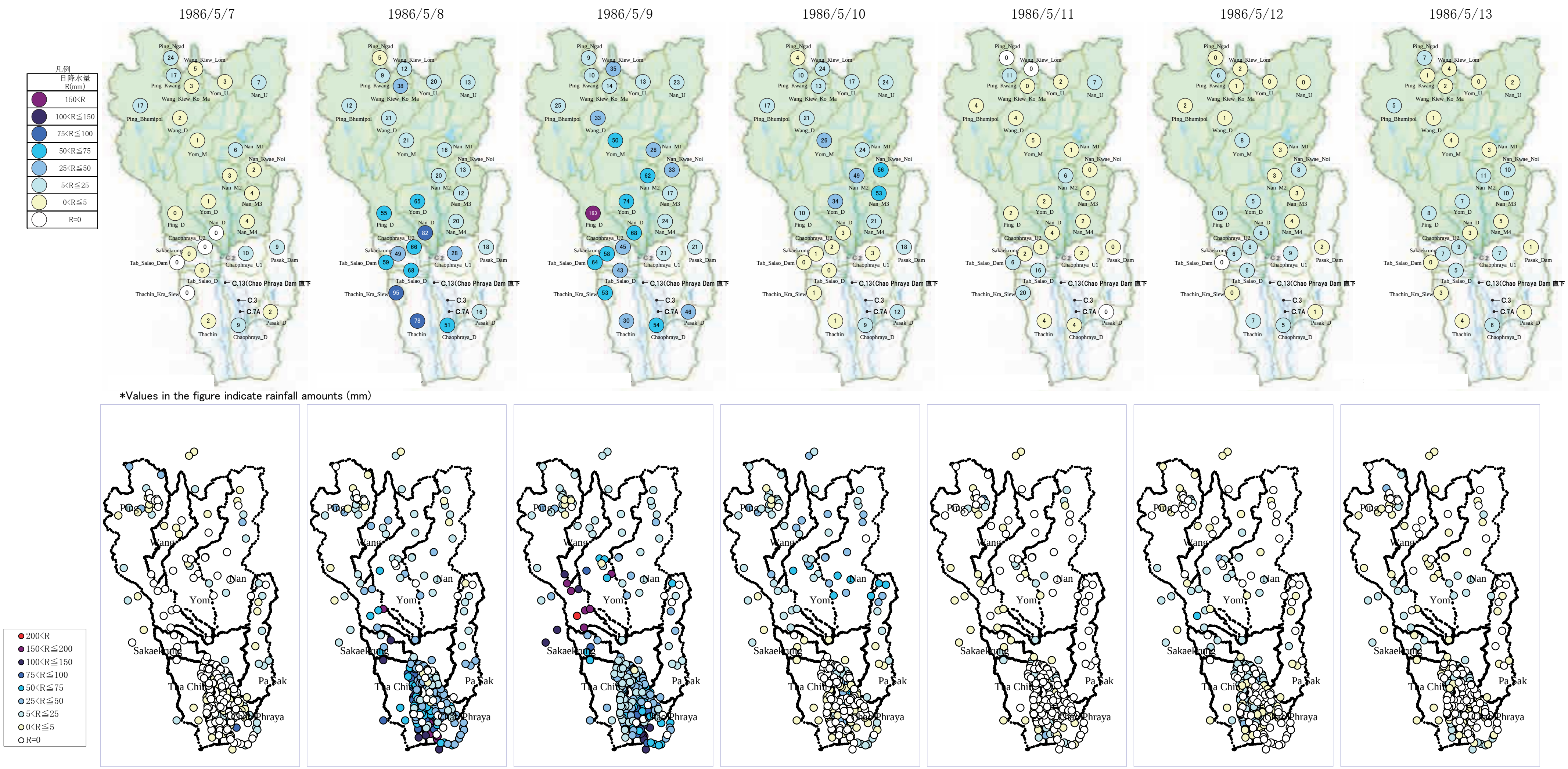


Fig. 3-17 Distributions of rainfall in seven days preceding the date of rapid flow increase at Nakhon Sawan (May 13, 1986)

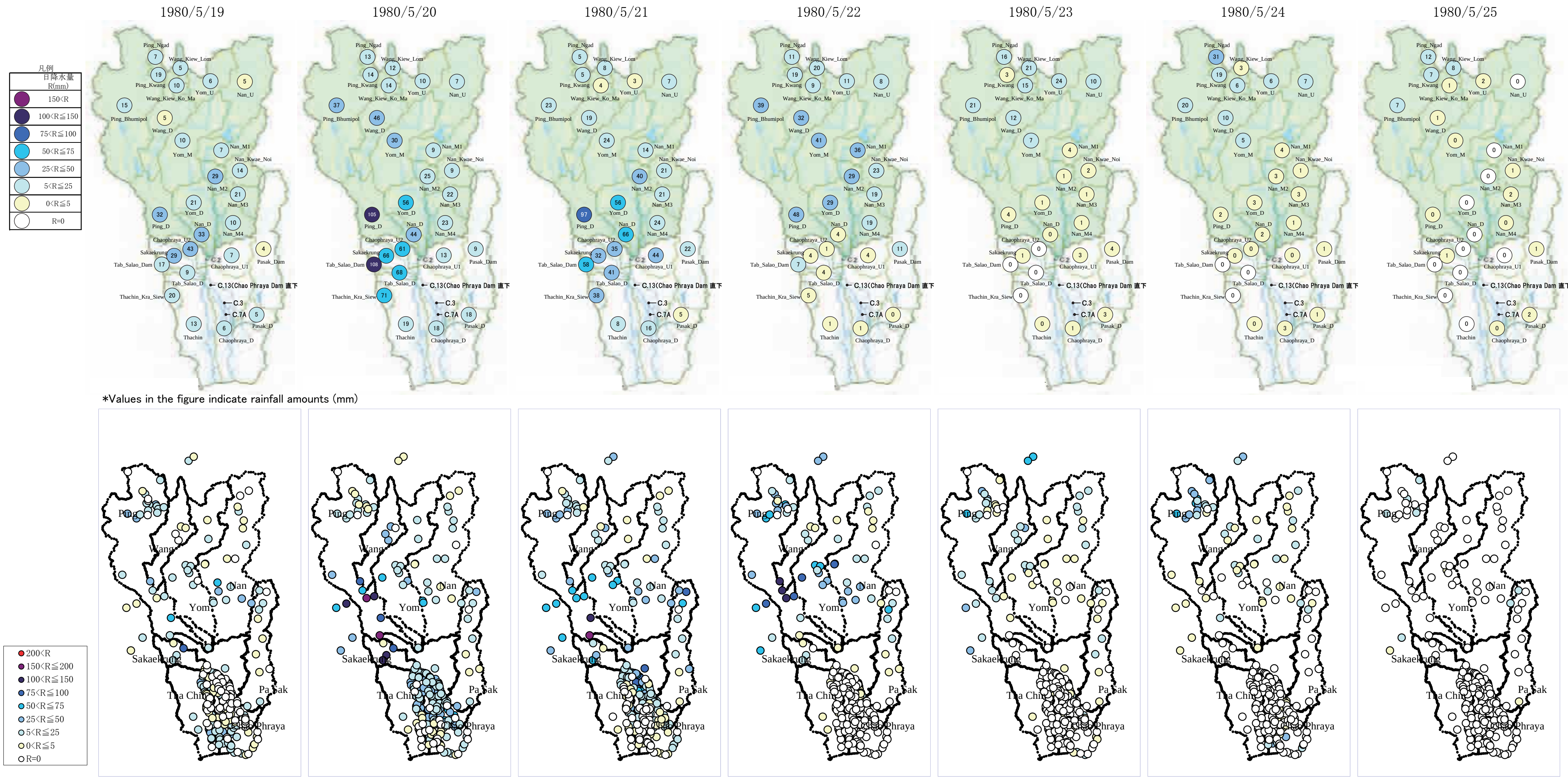


Fig. 3-18 Distributions of rainfall in seven days preceding the date of rapid flow increase at Nakhon Sawan (May 25, 1980)

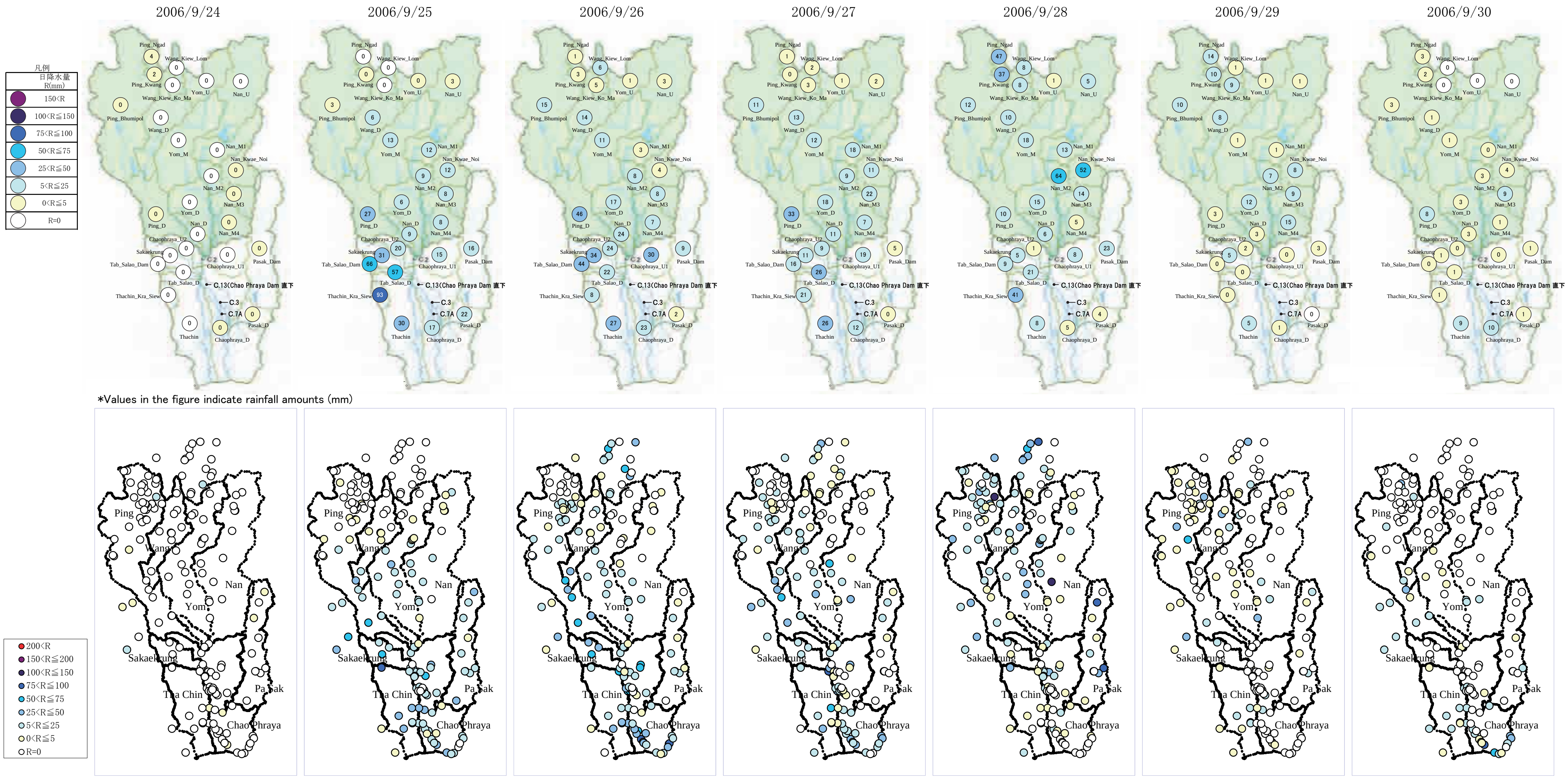


Fig. 3-19 Distributions of rainfall in seven days preceding the date of rapid flow increase at Nakhon Sawan (Sept. 30, 2006)

4 Division of basin for setting forecast rainfall

The basin was divided into sub-basins for setting forecast rainfall. Mean basin rainfall was specified in five sub-basins. The basin was divided into sub-basins based on the following principles.

-Heavy rainfall in an area south of C2 causes a rapid increase in flow at Nakhon Sawan. Forecast rainfall is set in the area as a sub-basin.
-Rainfall distributions are identified by major tributary in an area upstream of C2. Forecast rainfall is set in three sub-basins upstream of C2.
-An area downstream of C2 is relatively flat and has no topographic boundaries (watersheds). Forecast rainfall is set collectively in the area.

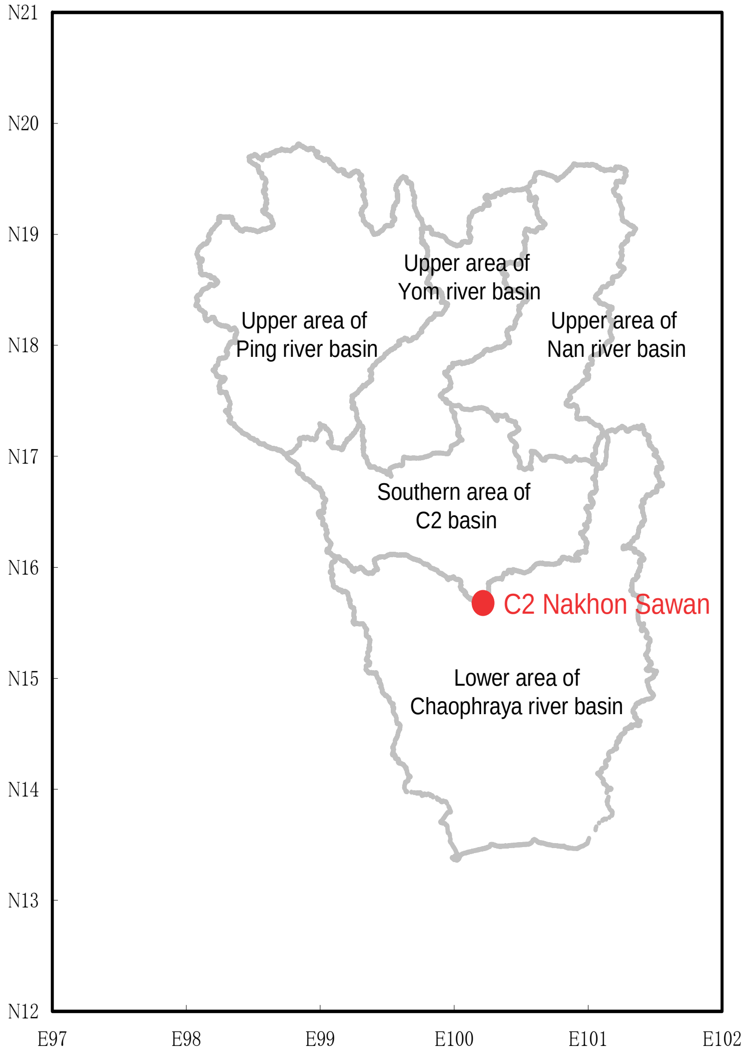


Fig. 20 Basin diagram

5 Observed and forecast rainfall on the day (one day ago)

There is a difference between JMA forecast and observed rainfall. When predicting floods, therefore, the maximum and minimum forecast rainfall should be set considering errors, as the rainfall that is input into the discharge calculation model. In order to set the maximum and minimum forecast rainfall, the relationship between JMA observed and forecast rainfall should be analyzed and the tendency of the relationship should be grasped. To that end, the following analysis was made.

Forecast rainfall is generally said to be publicized according to the present condition of rainfall. It is said that if a certain amount of rainfall occurs at present (when forecast is publicized), forecast rainfall at a consequently high level will be publicized. The rainfall one day ago was adopted to represent the present rainfall, and the relationship between the rainfall one day ago and the rainfall several days later (cumulative rainfall one, four and seven days later) was analyzed. If a certain tendency is confirmed concerning the difference between the rainfall one day ago and the forecast rainfall several days later (forecast rainfall/observed rainfall), the tendency may be used for setting the maximum and minimum errors in forecast.

JMA forecast rainfall has a certain degree of accuracy. A correlation was found between forecast and observed rainfall although with errors. The degree of error varies according to the scale of forecast rainfall or forecast period (the future period in which forecast is made). The ratio of observed rainfall to the forecast rainfall several days later was verified.

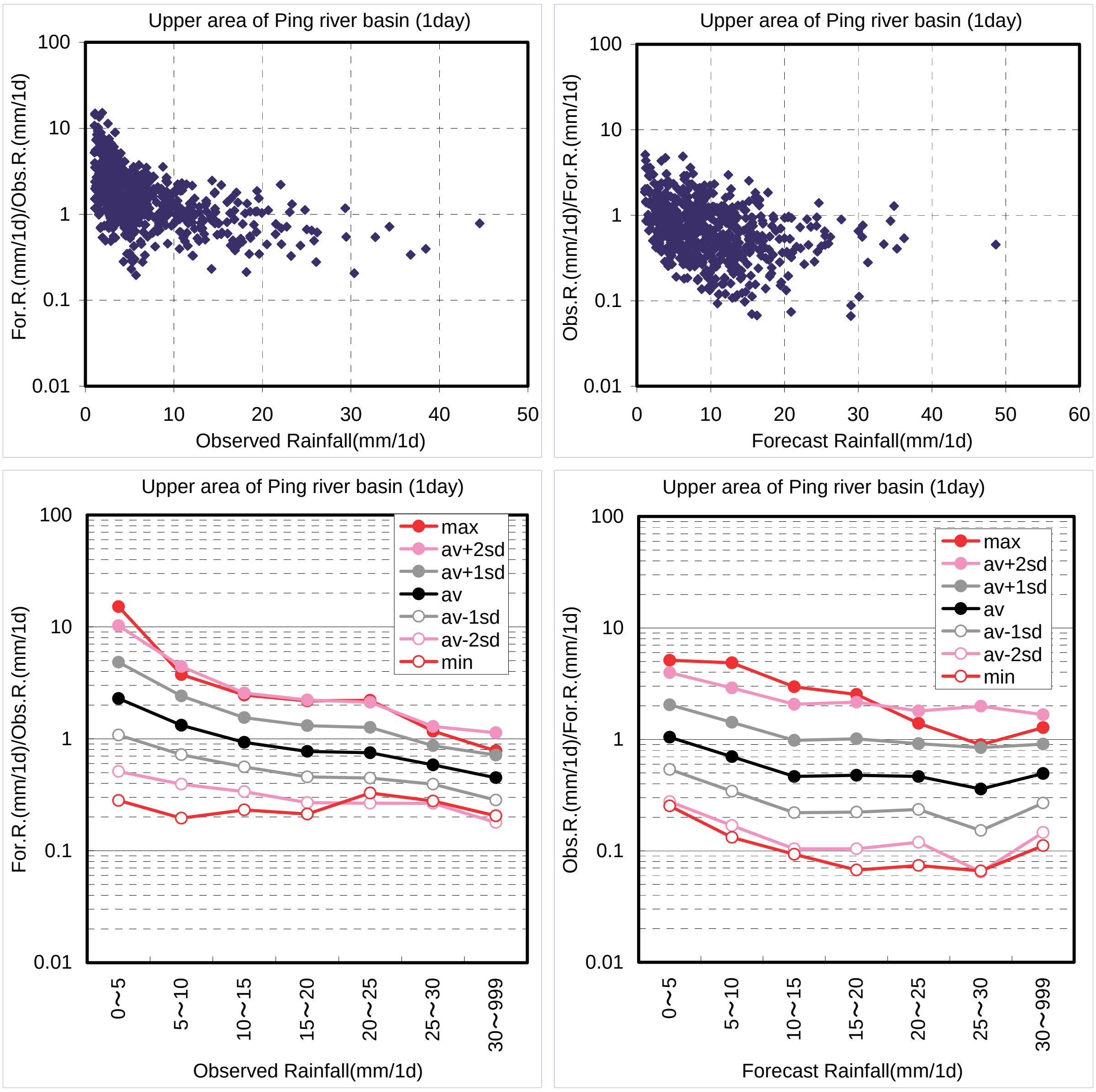
As a result of analysis, the following points were confirmed.

-The larger the rainfall one day ago, the smaller the maximum error in forecast rainfall (forecast rainfall/observed rainfall several days later) and the larger the minimum error. The maximum and minimum values gradually approached 1.

-The larger the forecast rainfall, the smaller the maximum ratio of observed rainfall to forecast rainfall and the larger the minimum value. The maximum and minimum values gradually approached 1.

The above tendency was reflected in the setting of the maximum and minimum forecast rainfall.

(1) Observed rainfall one day ago and forecast rainfall one day later



Rain(mm)	0～5	5～10	10～15	15～20	20～25	25～30	30～999
nod	287	173	67	38	13	7	6
max	15.14	3.74	2.46	2.18	2.21	1.17	0.78
av+2sd	10.22	4.42	2.57	2.23	2.12	1.29	1.13
av+1sd	4.83	2.41	1.55	1.31	1.26	0.87	0.71
av	2.29	1.32	0.93	0.77	0.75	0.58	0.45
av-1sd	1.08	0.72	0.56	0.46	0.45	0.39	0.28
av-2sd	0.51	0.39	0.34	0.27	0.27	0.26	0.18
min	0.28	0.20	0.23	0.21	0.33	0.28	0.21
sd	2.11	1.83	1.66	1.70	1.68	1.49	1.59

Rain(mm)	0～5	5～10	10～15	15～20	20～25	25～30	30～999
nod	142	195	139	70	25	9	11
max	5.12	4.87	2.97	2.53	1.39	0.89	1.28
av+2sd	3.97	2.90	2.07	2.17	1.80	1.98	1.67
av+1sd	2.04	1.42	0.98	1.01	0.91	0.84	0.91
av	1.05	0.70	0.46	0.48	0.46	0.36	0.49
av-1sd	0.54	0.34	0.22	0.22	0.24	0.15	0.27
av-2sd	0.28	0.17	0.10	0.10	0.12	0.06	0.15
min	0.25	0.13	0.09	0.07	0.07	0.07	0.11
sd	1.95	2.04	2.11	2.13	1.97	2.35	1.84

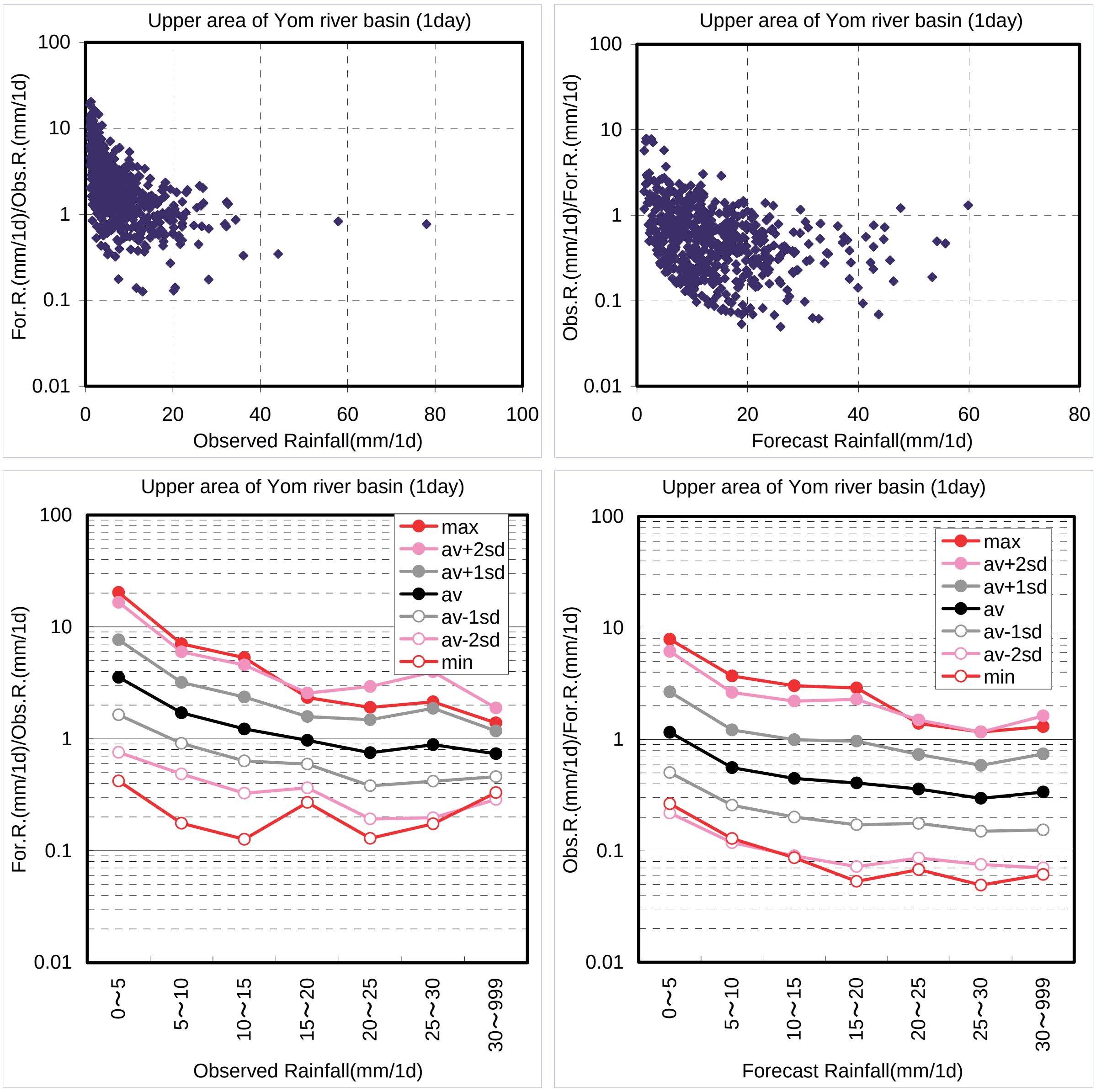
Fig. 21 Observed rainfall one day ago and forecast rainfall one day later (upper reaches of the Ping River)

Left figures show observed rainfall one day ago and (forecast rainfall one day ago/observed rainfall one day ago).

Right figures show forecast rainfall one day ago and (observed rainfall in one day/forecast rainfall in one day).

Analysis period: Rainy season (May through October) in 2008-2011

Analysis data: Data on the day when forecast rainfall > 1 mm/d and observed rainfall > 1 mm/d

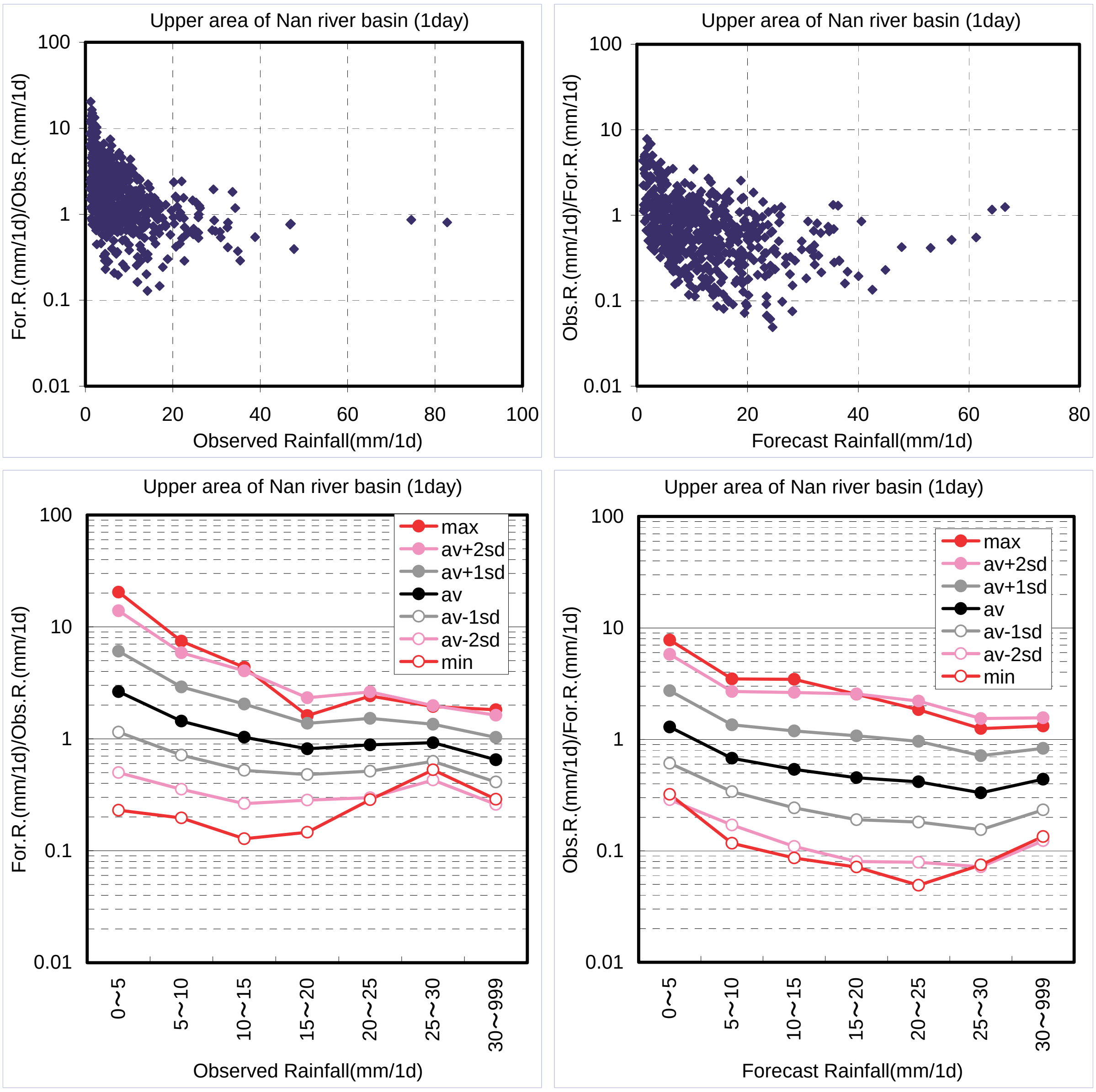


Rain(mm)	0～5	5～10	10～15	15～20	20～25	25～30	30～999
nod	247	162	88	35	22	9	9
max	20.28	7.07	5.30	2.34	1.91	2.13	1.39
av+2sd	16.59	5.98	4.57	2.57	2.93	3.97	1.88
av+1sd	7.66	3.19	2.37	1.58	1.48	1.87	1.18
av	3.54	1.70	1.22	0.97	0.75	0.88	0.73
av-1sd	1.64	0.91	0.63	0.59	0.38	0.42	0.46
av-2sd	0.76	0.49	0.33	0.36	0.19	0.20	0.29
min	0.42	0.18	0.13	0.27	0.13	0.17	0.33
sd	2.16	1.87	1.93	1.63	1.97	2.12	1.60

Rain(mm)	0～5	5～10	10～15	15～20	20～25	25～30	30～999
nod	68	151	139	92	59	26	37
max	7.91	3.71	3.03	2.90	1.39	1.16	1.30
av+2sd	6.16	2.63	2.21	2.29	1.49	1.16	1.63
av+1sd	2.67	1.21	0.99	0.96	0.73	0.59	0.74
av	1.16	0.56	0.45	0.41	0.36	0.30	0.34
av-1sd	0.50	0.26	0.20	0.17	0.18	0.15	0.15
av-2sd	0.22	0.12	0.09	0.07	0.09	0.08	0.07
min	0.26	0.13	0.09	0.05	0.07	0.05	0.06
sd	2.30	2.17	2.22	2.37	2.04	1.98	2.19

Fig. 22 Observed rainfall one day ago and forecast rainfall one day later (upper reaches of the Yom River)

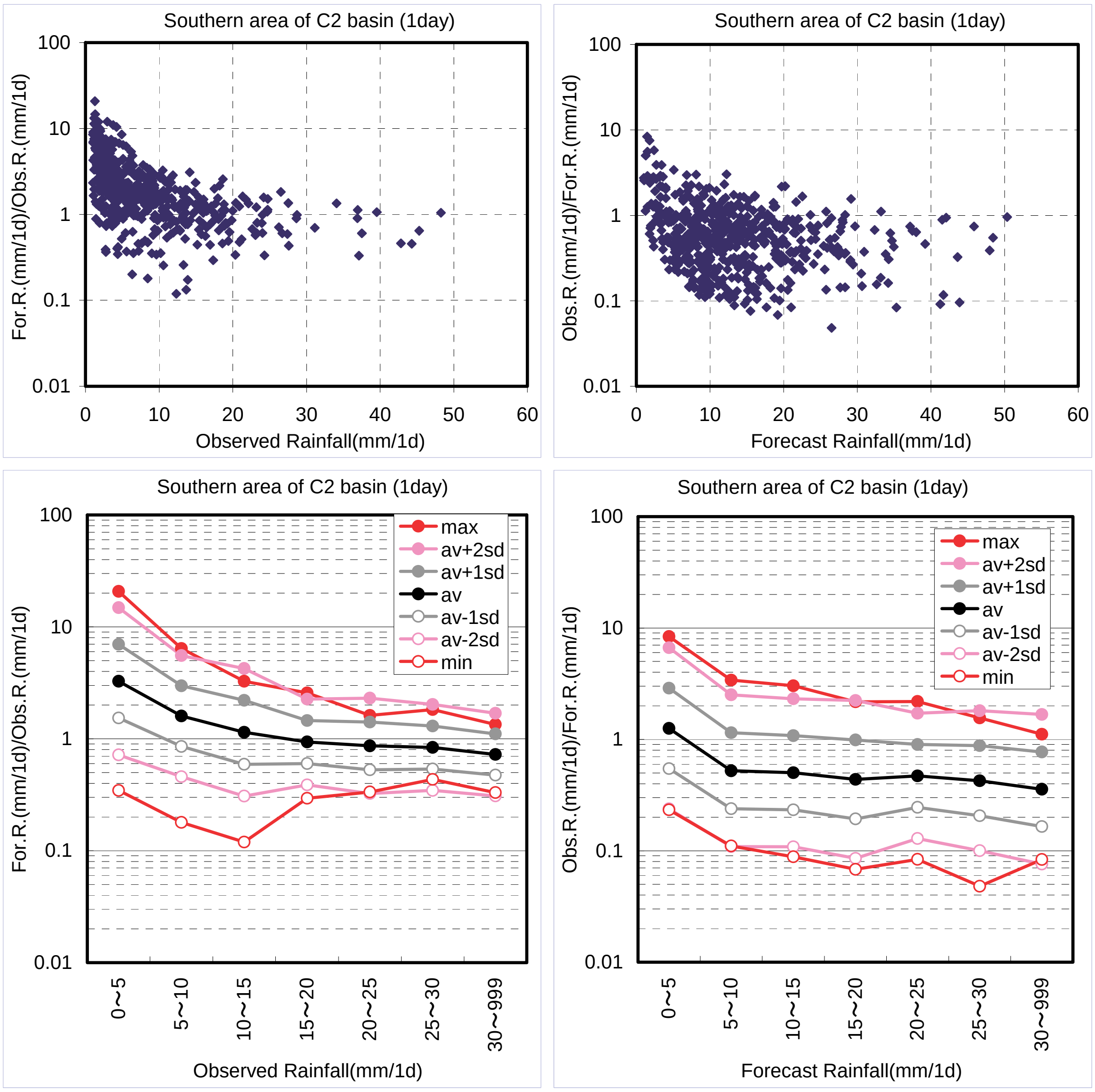
Left figures show observed rainfall one day ago and (forecast rainfall in one day/observed rainfall in one day).
Right figures show forecast rainfall one day ago and (observed rainfall in one day/forecast rainfall in one day).
Analysis period: Rainy season (May through October) in 2008-2011
Analysis data: Data on the day when forecast rainfall > 1 mm/d and observed rainfall > 1 mm/d



Rain(mm)	0~5	5~10	10~15	15~20	20~25	25~30	30~999	Rain(mm)	0~5	5~10	10~15	15~20	20~25	25~30	30~999
nod	215	161	91	33	22	11	15	nod	102	157	118	76	48	15	32
max	20.40	7.44	4.36	1.61	2.41	1.94	1.82	max	7.81	3.49	3.47	2.54	1.84	1.25	1.32
av+2sd	13.92	5.86	4.04	2.33	2.62	1.98	1.63	av+2sd	5.79	2.70	2.64	2.56	2.21	1.54	1.56
av+1sd	6.06	2.90	2.04	1.38	1.52	1.35	1.03	av+1sd	2.73	1.35	1.19	1.08	0.96	0.71	0.83
av	2.64	1.44	1.03	0.81	0.88	0.92	0.65	av	1.29	0.68	0.54	0.45	0.42	0.33	0.44
av-1sd	1.15	0.71	0.52	0.48	0.51	0.63	0.41	av-1sd	0.61	0.34	0.24	0.19	0.18	0.15	0.23
av-2sd	0.50	0.35	0.26	0.28	0.30	0.43	0.26	av-2sd	0.29	0.17	0.11	0.08	0.08	0.07	0.12
min	0.23	0.20	0.13	0.15	0.29	0.53	0.29	min	0.32	0.12	0.09	0.07	0.05	0.07	0.13
sd	2.30	2.02	1.98	1.69	1.72	1.47	1.58	sd	2.12	1.99	2.21	2.38	2.30	2.15	1.89

Fig. 23 Observed rainfall one day ago and forecast rainfall one day later (upper reaches of the Nan River)

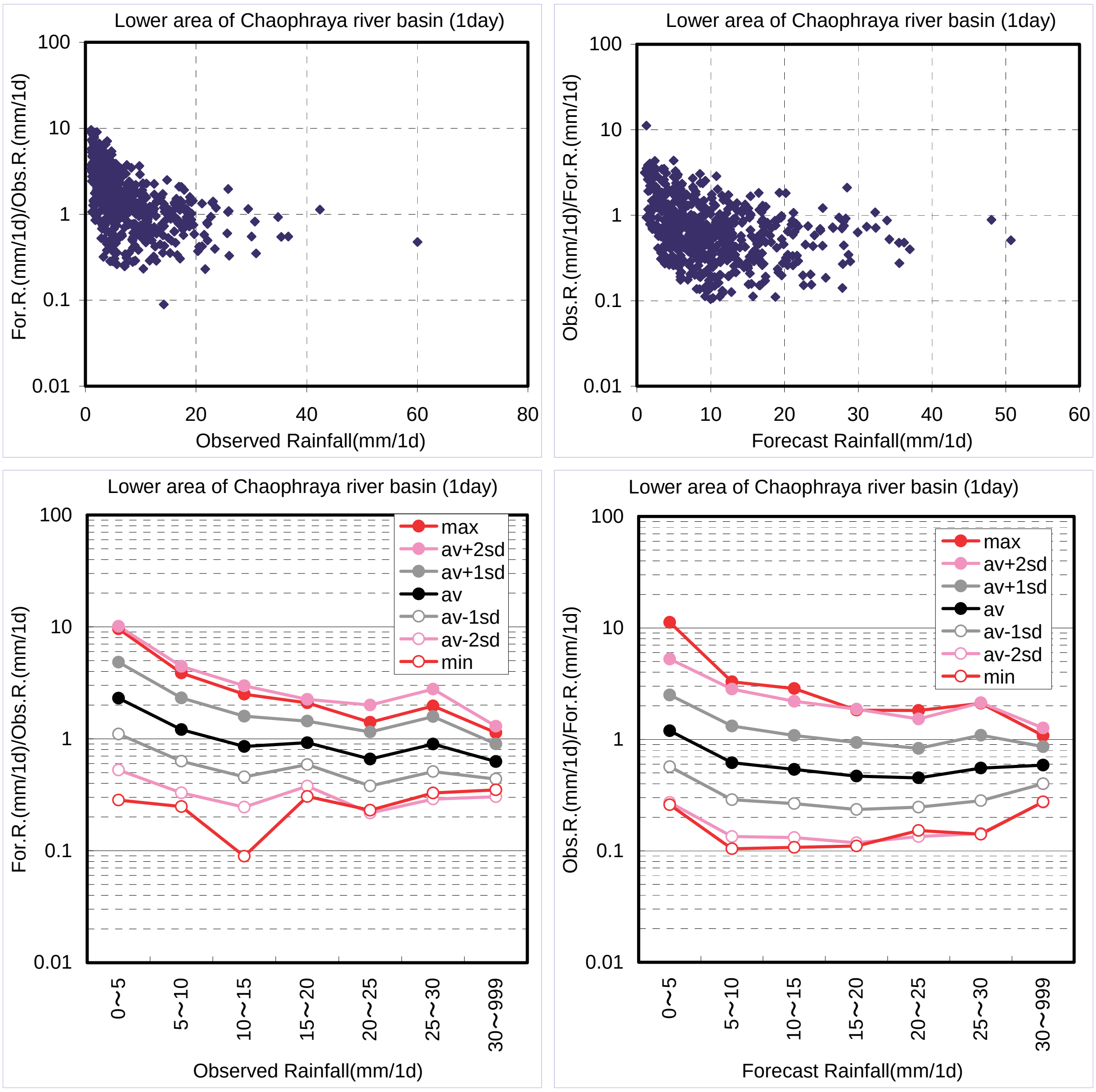
Left figures show observed rainfall one day ago and (forecast rainfall in one day/ observed rainfall in one day).
Right figures show forecast rainfall one day ago and (observed rainfall in one day/forecast rainfall in one day).
Analysis period: Rainy season (May through October) in 2008-2011
Analysis data: Data on the day when forecast rainfall > 1 mm/d and observed rainfall > 1 mm/d



Rain(mm)	0～5	5～10	10～15	15～20	20～25	25～30	30～999	Rain(mm)	0～5	5～10	10～15	15～20	20～25	25～30	30～999
nod	234	156	84	45	21	8	11	nod	64	155	146	91	45	30	28
max	20.80	6.42	3.26	2.58	1.62	1.83	1.35	max	8.38	3.41	3.03	2.17	2.19	1.55	1.11
av+2sd	14.88	5.55	4.25	2.26	2.30	2.02	1.69	av+2sd	6.64	2.51	2.32	2.23	1.72	1.81	1.67
av+1sd	6.97	2.98	2.20	1.46	1.41	1.30	1.11	av+1sd	2.89	1.15	1.08	0.99	0.90	0.88	0.77
av	3.27	1.60	1.14	0.94	0.86	0.84	0.72	av	1.26	0.52	0.50	0.44	0.47	0.43	0.36
av-1sd	1.53	0.86	0.59	0.60	0.53	0.54	0.47	av-1sd	0.55	0.24	0.23	0.19	0.25	0.21	0.16
av-2sd	0.72	0.46	0.31	0.39	0.32	0.35	0.31	av-2sd	0.24	0.11	0.11	0.09	0.13	0.10	0.08
min	0.35	0.18	0.12	0.29	0.33	0.43	0.33	min	0.23	0.11	0.09	0.07	0.08	0.05	0.08
sd	2.13	1.86	1.93	1.55	1.63	1.56	1.53	sd	2.30	2.19	2.15	2.26	1.91	2.06	2.16

Fig. 24 Observed rainfall one day ago and forecast rainfall one day later (south of C2)

Left figures show observed rainfall one day ago and (forecast rainfall in one day/ observed rainfall in one day).
Right figures show forecast rainfall one day ago and (observed rainfall in one day/forecast rainfall in one day).
Analysis period: Rainy season (May through October) in 2008-2011
Analysis data: Data on the day when forecast rainfall > 1 mm/d and observed rainfall > 1 mm/d



Rain(mm)	0~5	5~10	10~15	15~20	20~25	25~30	30~999
nod	274	169	65	45	14	6	8
max	9.60	3.87	2.50	2.10	1.40	1.96	1.13
av+2sd	10.10	4.43	2.98	2.25	2.00	2.77	1.29
av+1sd	4.83	2.31	1.59	1.44	1.15	1.58	0.90
av	2.31	1.21	0.85	0.92	0.66	0.90	0.63
av-1sd	1.10	0.63	0.46	0.59	0.38	0.51	0.44
av-2sd	0.53	0.33	0.25	0.38	0.22	0.29	0.30
min	0.28	0.25	0.09	0.30	0.23	0.33	0.35
sd	2.09	1.92	1.87	1.56	1.74	1.76	1.44

Rain(mm)	0~5	5~10	10~15	15~20	20~25	25~30	30~999
nod	136	204	119	67	27	17	11
max	11.20	3.28	2.86	1.83	1.82	2.11	1.08
av+2sd	5.25	2.83	2.20	1.87	1.52	2.14	1.27
av+1sd	2.50	1.32	1.09	0.94	0.83	1.09	0.86
av	1.19	0.62	0.54	0.47	0.45	0.55	0.59
av-1sd	0.57	0.29	0.27	0.23	0.25	0.28	0.40
av-2sd	0.27	0.13	0.13	0.12	0.13	0.14	0.27
min	0.26	0.10	0.11	0.11	0.15	0.14	0.27
sd	2.10	2.14	2.02	2.00	1.84	1.97	1.47

Fig. 25 Observed rainfall one day ago and forecast rainfall one day later (lower reaches of the Chaophraya River)

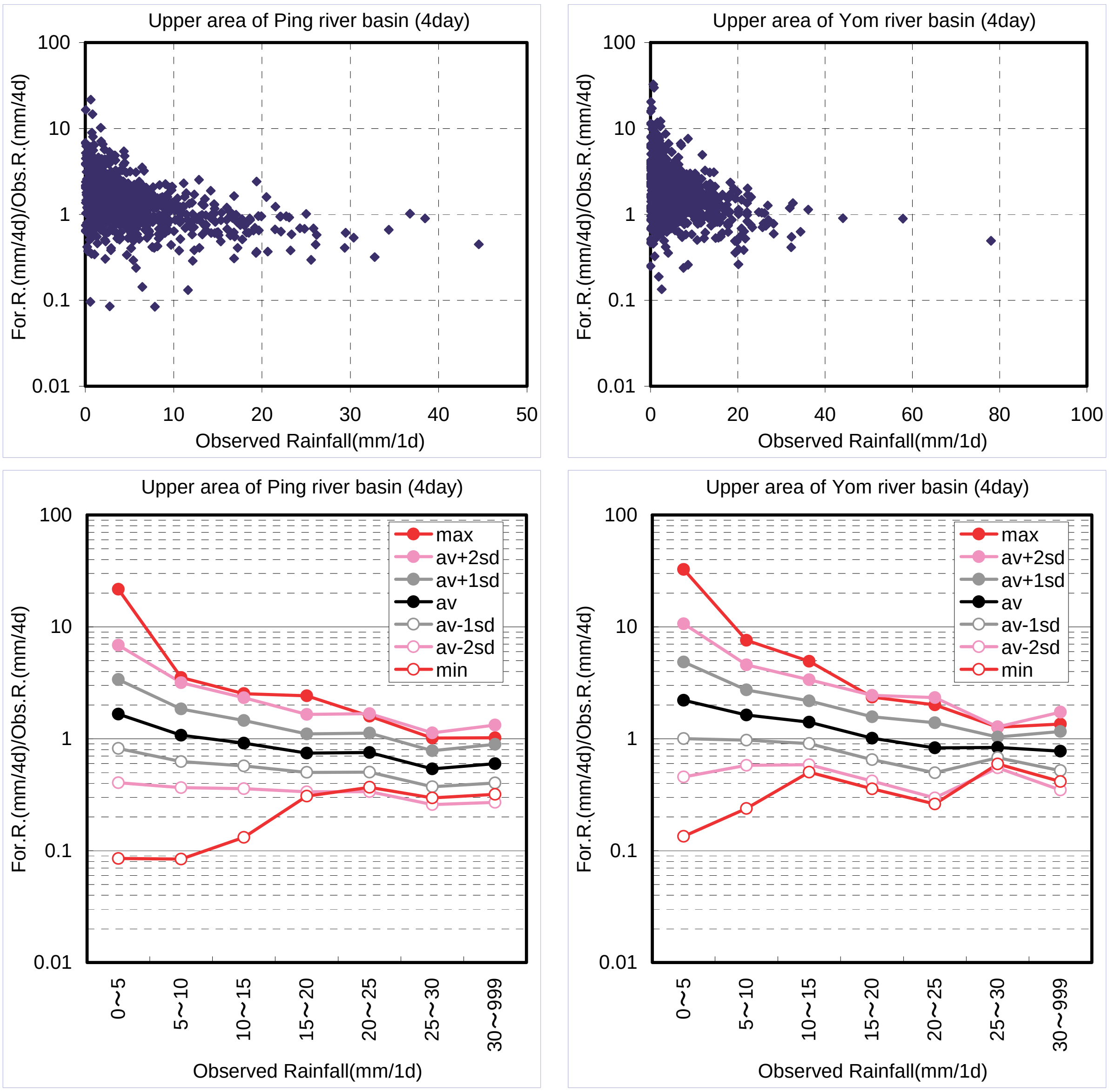
Left figures show observed rainfall one day ago and (forecast rainfall in one day/ observed rainfall in one day).

Right figures show forecast rainfall one day ago and (observed rainfall in one day/forecast rainfall in one day).

Analysis period: Rainy season (May through October) in 2008-2011

Analysis data: Data on the day when forecast rainfall > 1 mm/d and observed rainfall > 1 mm/d

(2) Observed rainfall one day ago and forecast rainfall four days later



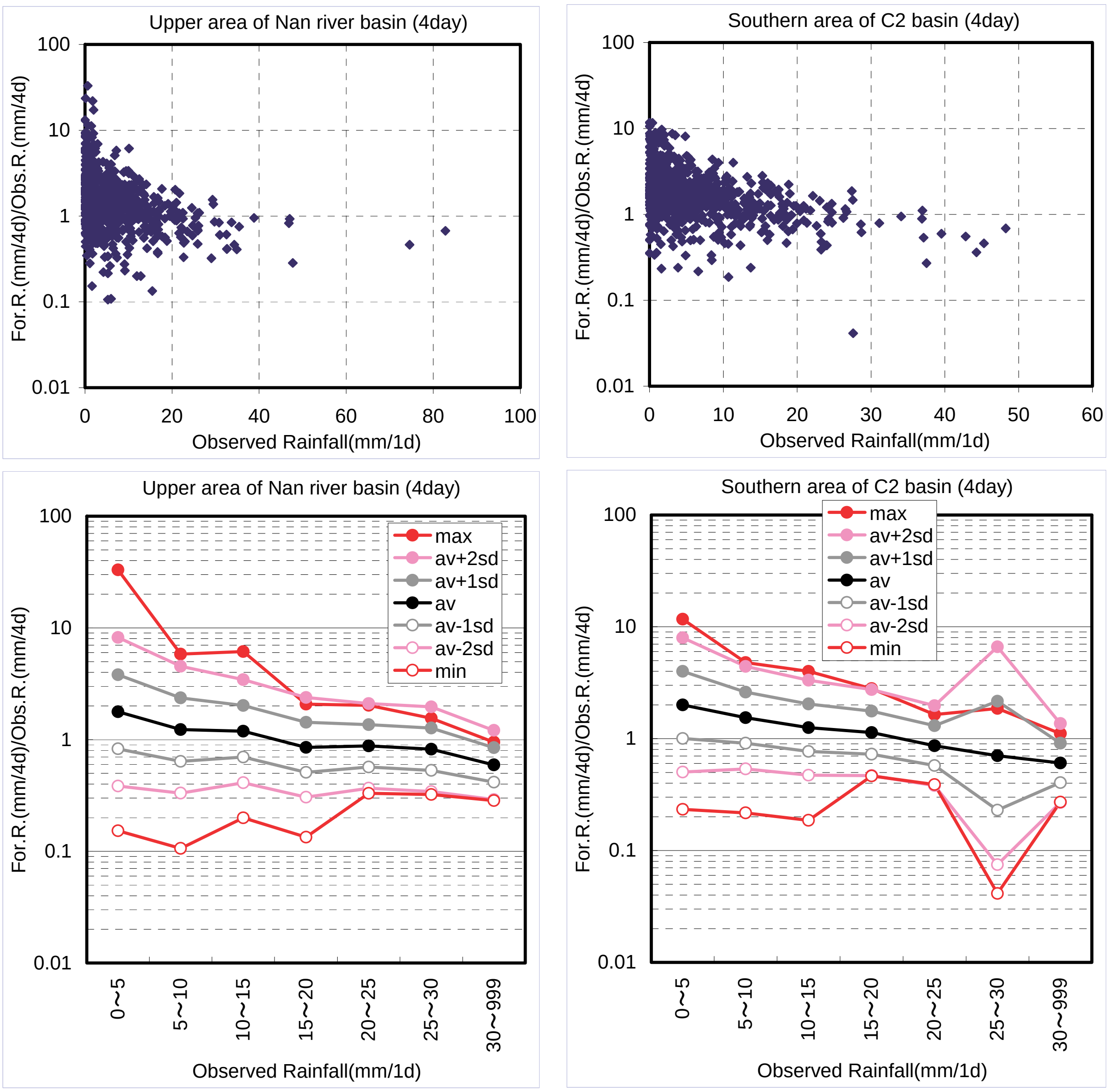
Rain(mm)	0～5	5～10	10～15	15～20	20～25	25～30	30～999
nod	411	174	68	38	13	7	6
max	21.68	3.53	2.53	2.42	1.59	1.02	1.02
av+2sd	6.86	3.18	2.32	1.65	1.68	1.13	1.33
av+1sd	3.38	1.85	1.46	1.11	1.12	0.78	0.89
av	1.67	1.08	0.91	0.74	0.75	0.54	0.60
av-1sd	0.82	0.63	0.57	0.50	0.50	0.37	0.40
av-2sd	0.40	0.37	0.36	0.34	0.34	0.26	0.27
min	0.09	0.08	0.13	0.31	0.37	0.30	0.32
sd	2.03	1.72	1.60	1.49	1.49	1.45	1.49

Rain(mm)	0～5	5～10	10～15	15～20	20～25	25～30	30～999
nod	378	162	89	35	22	10	9
max	32.66	7.61	4.93	2.35	2.01	1.27	1.36
av+2sd	10.68	4.59	3.38	2.44	2.33	1.28	1.73
av+1sd	4.86	2.73	2.18	1.57	1.39	1.04	1.16
av	2.21	1.63	1.41	1.01	0.83	0.84	0.78
av-1sd	1.00	0.97	0.91	0.65	0.50	0.68	0.52
av-2sd	0.46	0.58	0.59	0.42	0.30	0.55	0.35
min	0.13	0.24	0.50	0.36	0.26	0.60	0.41
sd	2.20	1.68	1.55	1.55	1.67	1.23	1.49

Fig. 26 Observed rainfall one day ago and (forecast rainfall in four days/observed rainfall in four days)

Analysis period: Rainy season (May through October) in 2008-2011

Analysis data: Data on the day when forecast rainfall > 1 mm/4d and observed rainfall > 1 mm/4d



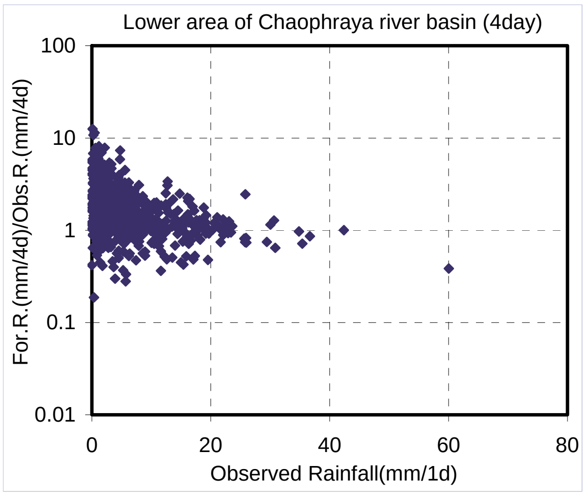
Rain(mm)	0～5	5～10	10～15	15～20	20～25	25～30	30～999
nod	367	161	91	35	22	11	15
max	33.02	5.82	6.13	2.08	2.02	1.55	0.95
av+2sd	8.20	4.54	3.44	2.38	2.11	1.97	1.21
av+1sd	3.81	2.36	2.02	1.43	1.36	1.27	0.85
av	1.77	1.23	1.19	0.85	0.88	0.82	0.59
av-1sd	0.83	0.64	0.70	0.51	0.57	0.53	0.42
av-2sd	0.38	0.33	0.41	0.30	0.37	0.34	0.29
min	0.15	0.11	0.20	0.13	0.33	0.32	0.28
sd	2.15	1.92	1.70	1.67	1.55	1.55	1.43

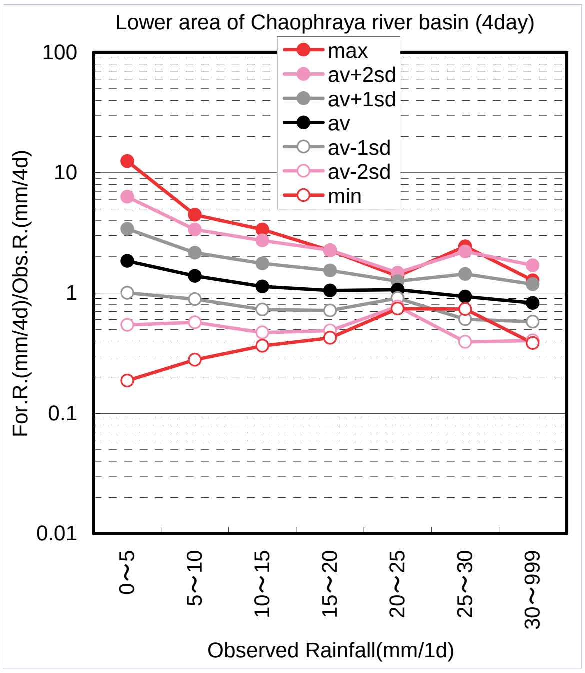
Rain(mm)	0～5	5～10	10～15	15～20	20～25	25～30	30～999
nod	377	157	85	46	21	8	11
max	11.69	4.80	4.00	2.81	1.64	1.86	1.11
av+2sd	7.98	4.42	3.34	2.74	1.97	6.62	1.37
av+1sd	4.00	2.61	2.05	1.76	1.31	2.16	0.91
av	2.00	1.54	1.26	1.13	0.87	0.70	0.61
av-1sd	1.00	0.91	0.77	0.73	0.57	0.23	0.40
av-2sd	0.50	0.54	0.47	0.47	0.38	0.07	0.27
min	0.23	0.22	0.19	0.46	0.39	0.04	0.27
sd	2.00	1.69	1.63	1.56	1.51	3.07	1.50

Fig. 27 Observed rainfall one day ago and (forecast rainfall in four days/observed rainfall in four days)

Analysis period: Rainy season (May through October) in 2008-2011

Analysis data: Data on the day when forecast rainfall > 1 mm/4d and observed rainfall > 1 mm/4d





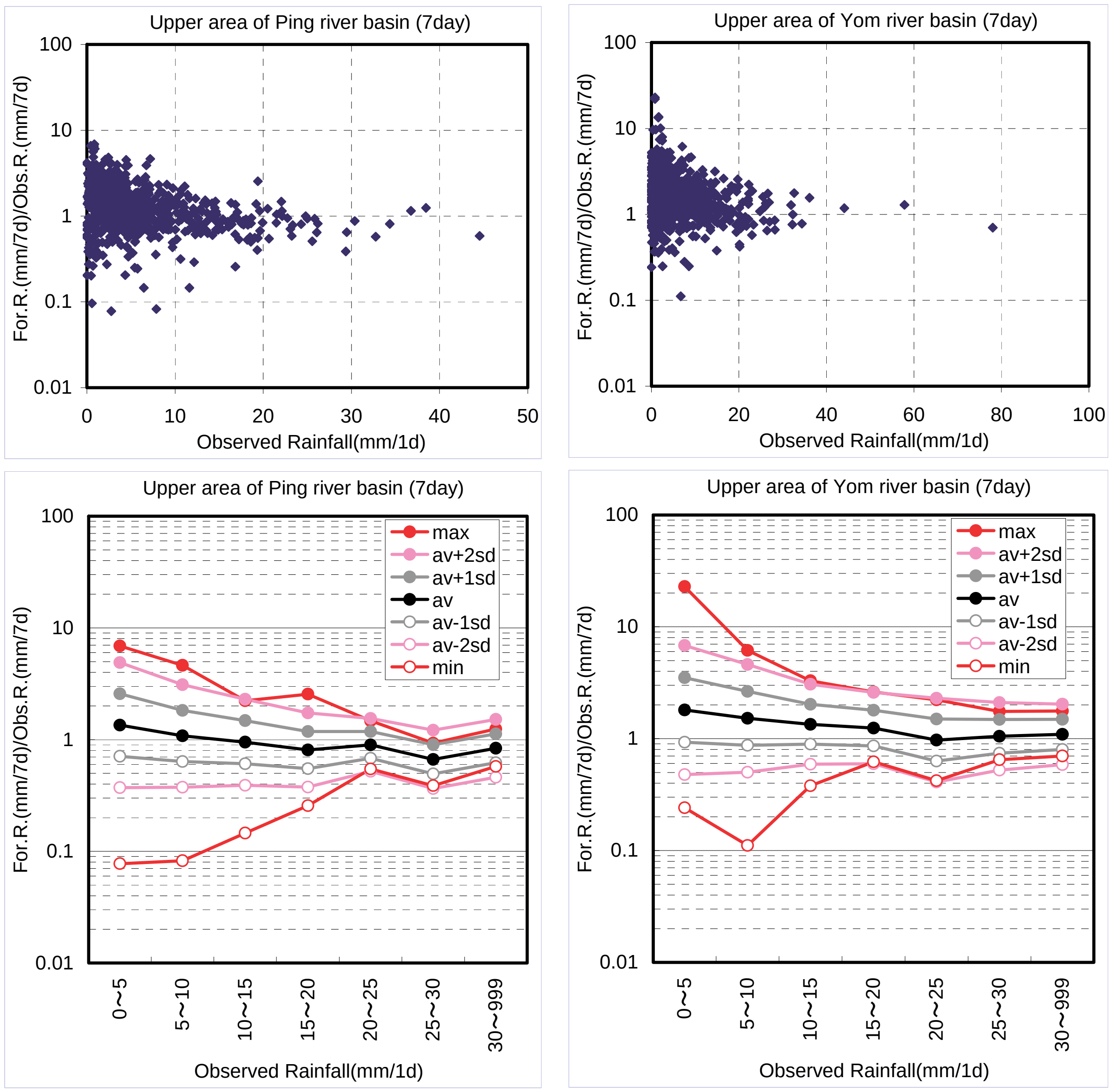
Rain(mm)	0～5	5～10	10～15	15～20	20～25	25～30	30～999
nod	402	172	65	45	14	6	8
max	12.51	4.48	3.38	2.26	1.38	2.45	1.28
av+2sd	6.31	3.38	2.73	2.27	1.47	2.22	1.70
av+1sd	3.42	2.16	1.76	1.54	1.25	1.44	1.18
av	1.85	1.39	1.13	1.05	1.07	0.94	0.83
av-1sd	1.00	0.89	0.73	0.72	0.91	0.61	0.58
av-2sd	0.54	0.57	0.47	0.49	0.77	0.39	0.40
min	0.19	0.28	0.36	0.42	0.74	0.74	0.38
sd	1.85	1.56	1.55	1.47	1.18	1.54	1.43

Fig. 28 Observed rainfall one day ago and (forecast rainfall in four days/observed rainfall in four days)

Analysis period: Rainy season (May through October) in 2008-2011

Analysis data: Data on the day when forecast rainfall > 1 mm/4d and observed rainfall > 1 mm/4d

(3) Difference between observed rainfall one day ago and forecast rainfall seven days later



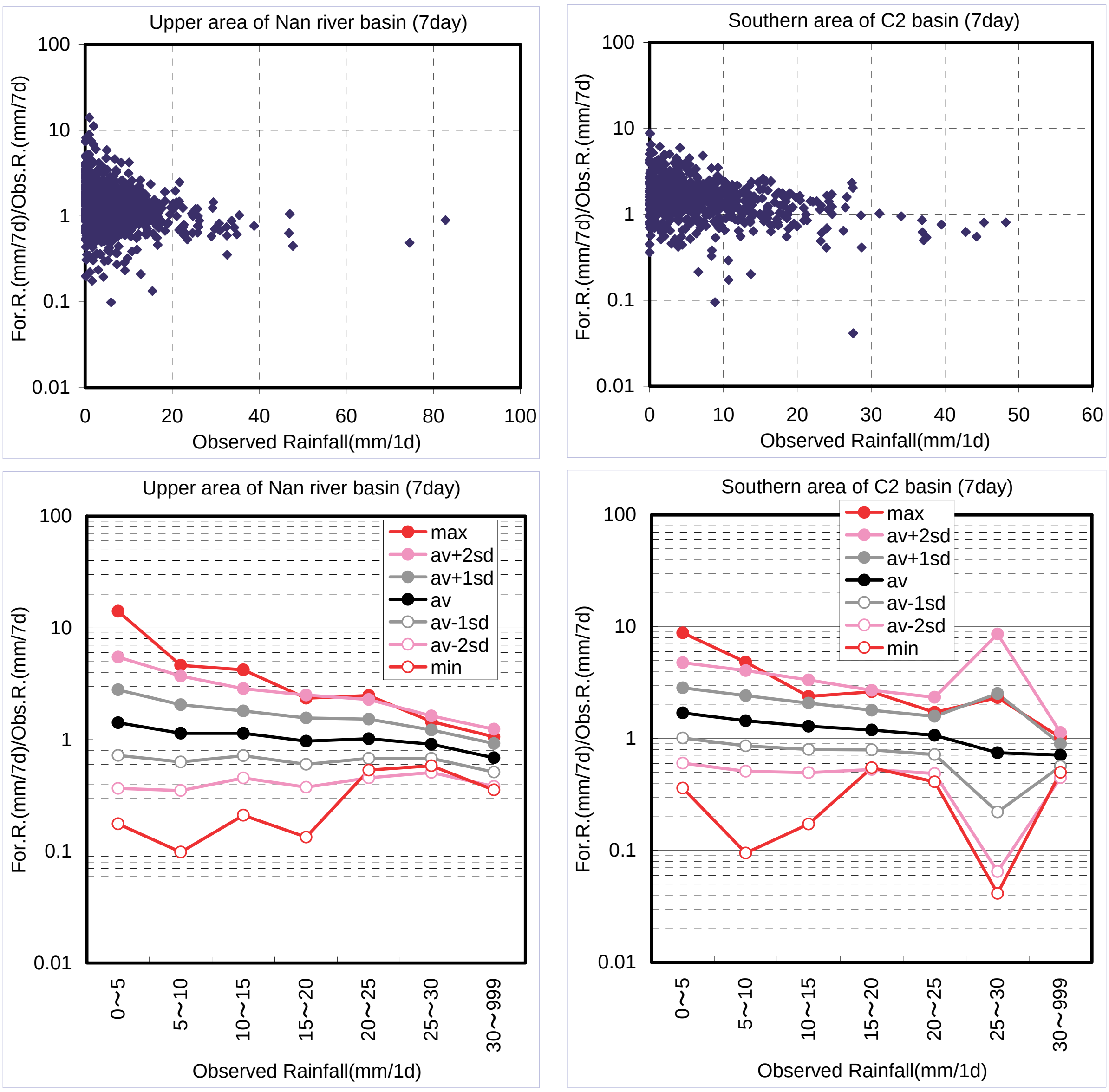
Rain(mm)	0～5	5～10	10～15	15～20	20～25	25～30	30～999
nod	417	174	68	38	13	7	6
max	6.89	4.63	2.22	2.55	1.48	0.93	1.25
av+2sd	4.89	3.10	2.30	1.73	1.55	1.22	1.52
av+1sd	2.57	1.83	1.48	1.18	1.18	0.90	1.13
av	1.35	1.08	0.95	0.81	0.90	0.67	0.84
av-1sd	0.71	0.64	0.61	0.55	0.68	0.49	0.62
av-2sd	0.37	0.38	0.39	0.38	0.52	0.36	0.46
min	0.08	0.08	0.15	0.26	0.55	0.39	0.57
sd	1.90	1.70	1.56	1.47	1.31	1.35	1.35

Rain(mm)	0～5	5～10	10～15	15～20	20～25	25～30	30～999
nod	391	163	89	35	22	10	9
max	22.92	6.15	3.29	2.61	2.23	1.75	1.77
av+2sd	6.81	4.61	3.07	2.60	2.30	2.10	2.03
av+1sd	3.51	2.65	2.03	1.80	1.49	1.48	1.49
av	1.81	1.52	1.35	1.25	0.97	1.05	1.09
av-1sd	0.93	0.87	0.89	0.86	0.63	0.74	0.80
av-2sd	0.48	0.50	0.59	0.60	0.41	0.52	0.59
min	0.24	0.11	0.38	0.62	0.42	0.65	0.70
sd	1.94	1.74	1.51	1.44	1.54	1.41	1.36

Fig. 29 Observed rainfall one day ago and (forecast rainfall in seven days/observed rainfall in seven days)

Analysis period: Rainy season (May through October) in 2008-2011

Analysis data: Data on the day when forecast rainfall > 1 mm/7d and observed rainfall > 1 mm/7d



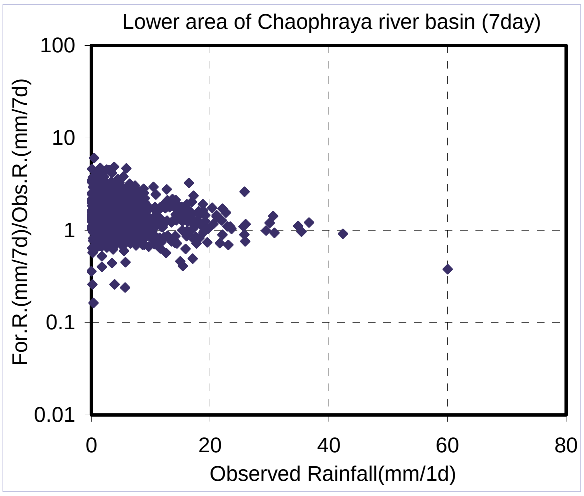
Rain(mm)	0~5	5~10	10~15	15~20	20~25	25~30	30~999
nod	384	161	91	35	22	11	15
max	14.09	4.61	4.22	2.35	2.48	1.45	1.06
av+2sd	5.48	3.70	2.86	2.51	2.28	1.63	1.24
av+1sd	2.79	2.05	1.81	1.56	1.52	1.22	0.92
av	1.42	1.14	1.14	0.97	1.02	0.91	0.69
av-1sd	0.72	0.63	0.72	0.60	0.68	0.68	0.51
av-2sd	0.37	0.35	0.45	0.37	0.45	0.51	0.38
min	0.18	0.10	0.21	0.13	0.53	0.58	0.35
sd	1.97	1.80	1.59	1.61	1.50	1.34	1.34

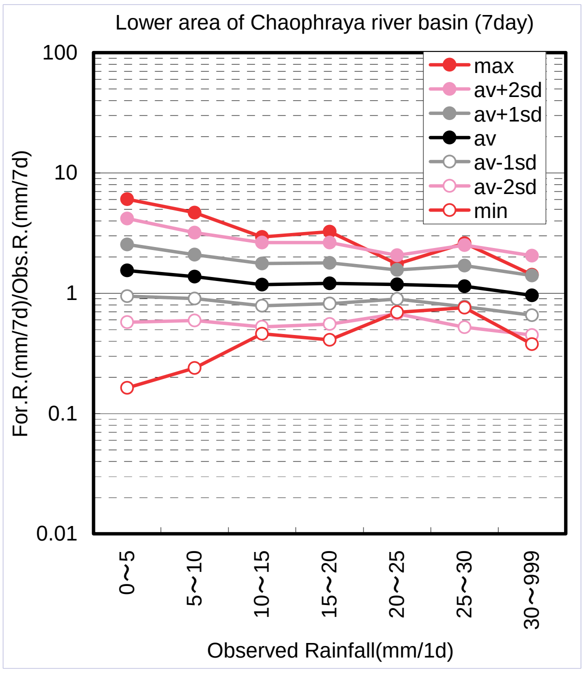
Rain(mm)	0~5	5~10	10~15	15~20	20~25	25~30	30~999
nod	384	158	85	46	21	8	11
max	8.81	4.84	2.39	2.62	1.72	2.33	1.02
av+2sd	4.78	4.06	3.34	2.70	2.35	8.60	1.13
av+1sd	2.85	2.42	2.07	1.80	1.58	2.54	0.90
av	1.70	1.44	1.29	1.20	1.07	0.75	0.71
av-1sd	1.01	0.86	0.80	0.80	0.72	0.22	0.57
av-2sd	0.60	0.51	0.50	0.53	0.49	0.07	0.45
min	0.36	0.09	0.17	0.55	0.41	0.04	0.50
sd	1.68	1.68	1.61	1.50	1.48	3.39	1.26

Fig. 30 Observed rainfall one day ago and (forecast rainfall in seven days/observed rainfall in seven days)

Analysis period: Rainy season (May through October) in 2008-2011

Analysis data: Data on the day when forecast rainfall > 1 mm/7d and observed rainfall > 1 mm/7d





Rain(mm)	0～5	5～10	10～15	15～20	20～25	25～30	30～999
nod	410	172	65	45	14	6	8
max	6.06	4.68	2.94	3.25	1.75	2.61	1.43
av+2sd	4.18	3.19	2.64	2.64	2.07	2.52	2.05
av+1sd	2.54	2.09	1.77	1.79	1.57	1.70	1.40
av	1.55	1.38	1.18	1.21	1.18	1.14	0.96
av-1sd	0.94	0.90	0.79	0.82	0.90	0.77	0.66
av-2sd	0.57	0.59	0.53	0.55	0.68	0.52	0.45
min	0.16	0.24	0.46	0.41	0.69	0.76	0.38
sd	1.64	1.52	1.50	1.48	1.32	1.48	1.46

Fig. 31 Observed rainfall one day ago and (forecast rainfall in seven days/observed rainfall in seven days)

Analysis period: Rainy season (May through October) in 2008-2011

Analysis data: Data on the day when forecast rainfall > 1 mm/7d and observed rainfall > 1 mm/7d

6 Approximate equations for obtaining the maximum and minimum forecast rainfall

6.1 Approximate equations for obtaining the maximum and minimum forecast rainfall from the present condition of rainfall

In relation to the mean rainfall in the five sub-basins, scatter diagrams (Fig. 32 and 33) were developed that show the relationship between the present rainfall (observed rainfall one day ago) and (observed rainfall/forecast rainfall). Approximate lines were developed in the figures that envelope the areas near the maximum and minimum (observed rainfall/forecast rainfall). The approximate line enveloping the maximum value could be used to obtain the ratio of maximum rainfall forecast one to seven days later to the observed rainfall one day ago (observed rainfall/forecast rainfall). The ratio was multiplied by the observed rainfall one day ago to create the maximum forecast rainfall. Similarly, the minimum forecast rainfall was created using the approximate line enveloping the minimum value.

Table 2 Approximate equations for obtaining the maximum and minimum forecast rainfall from the present condition of rainfall (rainfall one day ago)

Maximum Forecast Rainfall $y = a \cdot x^b$

y: Observed Rainfall (mm) / Forecast Rainfall (mm)
x: Observed Rainfall 1 day ago (mm)

basin	Coefficient	1d-Rain.	2d-Rain.	3d-Rain.	4d-Rain.	5d-Rain.	6d-Rain.	7d-Rain.
Upper area of Ping river basin	a	60.000						
	b	-0.896						
Upper area of Yom river basin	a	60.000						
	b	-0.781						
Upper area of Nan river basin	a	60.000						
	b	-0.835						
Southern area of C2 basin	a	60.000						
	b	-0.877						
Lower area of Chaophraya river basin	a	60.000						
	b	-0.901						

Minimum Forecast Rainfall $y = a \cdot x^b$

y: Observed Rainfall (mm) / Forecast Rainfall (mm)
x: Observed Rainfall 1 day ago (mm)

basin	Coefficient	1d-Rain.	2d-Rain.	3d-Rain.	4d-Rain.	5d-Rain.	6d-Rain.	7d-Rain.
Upper area of Ping river basin	a	0.039						
	b	0.854						
Upper area of Yom river basin	a	0.019						
	b	0.912						
Upper area of Nan river basin	a	0.034						
	b	0.764						
Southern area of C2 basin	a	0.010						
	b	1.188						
Lower area of Chaophraya river basin	a	0.023						
	b	0.926						

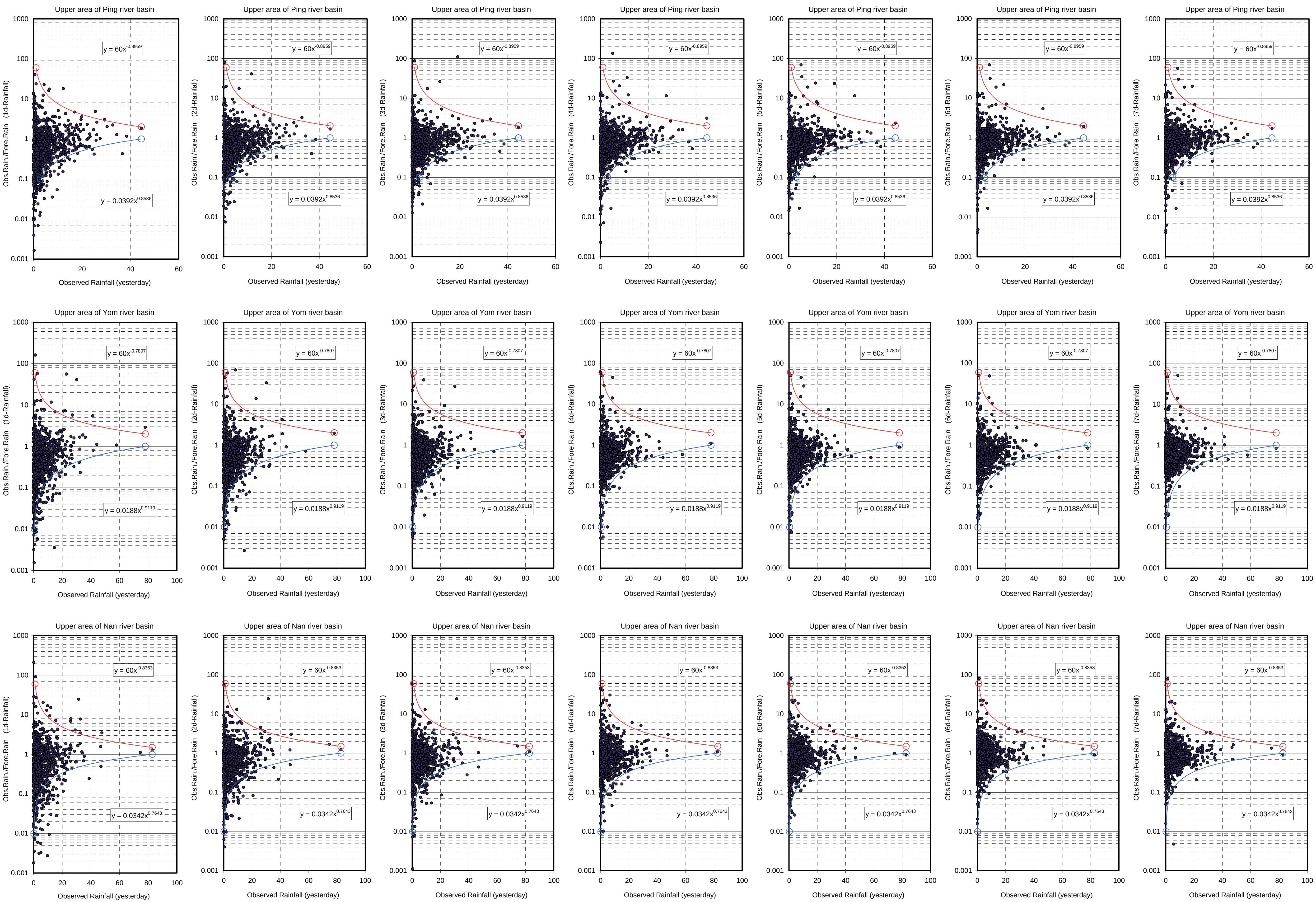


Fig. 32 Approximate equations for obtaining the maximum and minimum forecast rainfall based on the present condition of rainfall (rainfall one day ago)

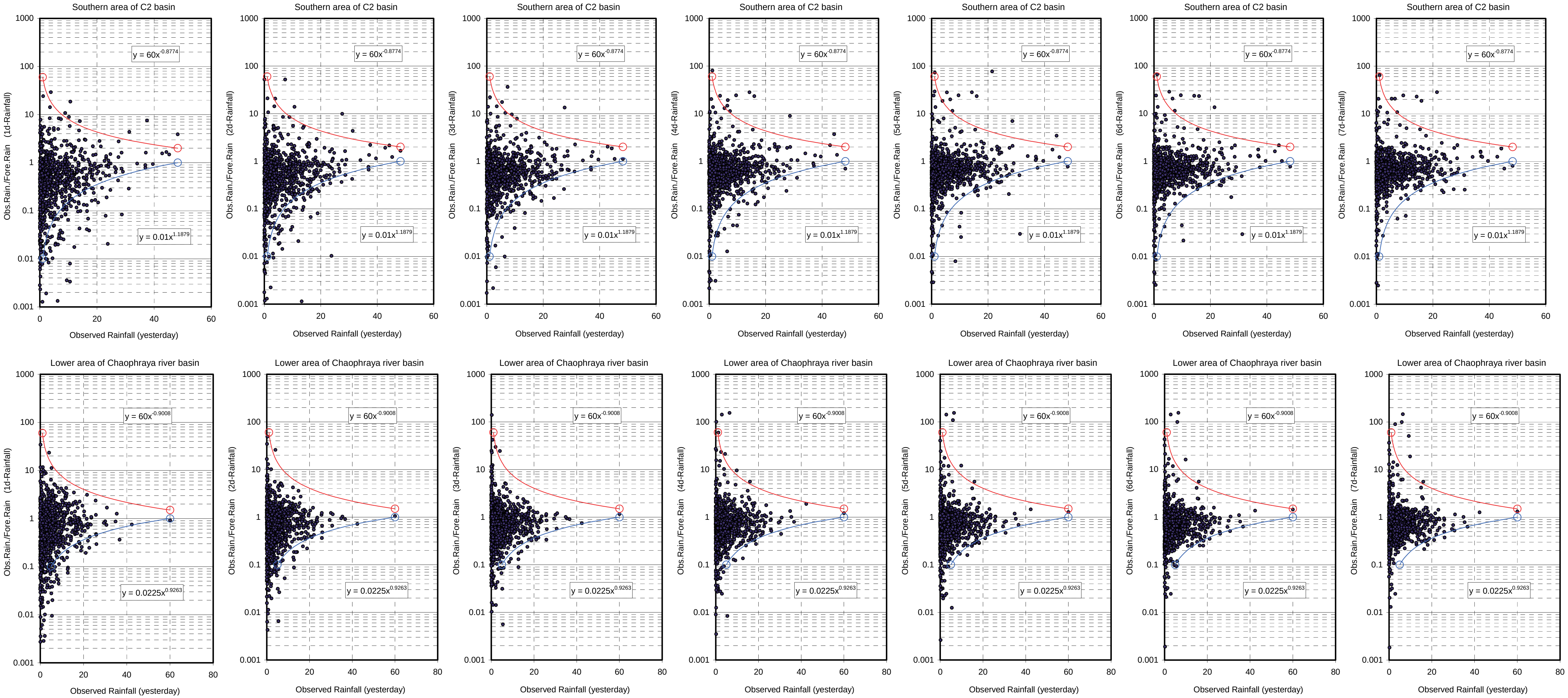


Fig. 33 Approximate equations for obtaining the maximum and minimum forecast rainfall based on the present condition of rainfall (rainfall one day ago)

6.2 Approximate equations for obtaining the maximum and minimum forecast rainfall based on the present condition of rainfall

In relation to the mean rainfall in the five sub-basins, scatter diagrams (Fig. 34 and 35) were developed that show the relationship between the forecast rainfall and (observed rainfall/forecast rainfall). Approximate lines were developed in the figures that envelope the areas near the maximum and minimum (observed rainfall/forecast rainfall). The approximate line enveloping the maximum value could be used to obtain the ratio of the maximum possible rainfall to the forecast rainfall (observed rainfall/forecast rainfall) when the forecast was publicized. The ratio was multiplied by the forecast rainfall to create the maximum forecast rainfall. Similarly, the minimum forecast rainfall was created using the approximate line enveloping the minimum value.

Table 3 Approximate equation for obtaining the maximum and minimum forecast rainfall based on the forecast rainfall

Maximum Forecast Rainfall $y=a \cdot x^b$

y: Observed Rainfall (mm) / Forecast Rainfall (mm)
x: Forecast Rainfall (mm)

basin	Coefficient	1d-Rain.	2d-Rain.	3d-Rain.	4d-Rain.	5d-Rain.	6d-Rain.	7d-Rain.
Upper area of Ping river basin	a	5.000	10.000	15.000	20.000	25.000	30.000	35.000
	b	-0.414	-0.563	-0.583	-0.637	-0.662	-0.689	-0.713
Upper area of Yom river basin	a	5.000	10.000	15.000	20.000	25.000	30.000	35.000
	b	-0.393	-0.507	-0.558	-0.603	-0.645	-0.666	-0.688
Upper area of Nan river basin	a	5.000	10.000	15.000	20.000	25.000	30.000	35.000
	b	-0.383	-0.473	-0.530	-0.592	-0.633	-0.664	-0.690
Southern area of C2 basin	a	7.000	10.000	15.000	20.000	25.000	30.000	35.000
	b	-0.496	-0.514	-0.563	-0.599	-0.643	-0.679	-0.693
Lower area of Chaophraya river basin	a	5.000	6.000	7.000	8.000	9.000	10.000	11.000
	b	-0.410	-0.409	-0.423	-0.424	-0.444	-0.461	-0.476

Minimum Forecast Rainfall $y=a \cdot x^b$

y: Observed Rainfall (mm) / Forecast Rainfall (mm)
x: Forecast Rainfall (mm)

basin	Coefficient	1d-Rain.	2d-Rain.	3d-Rain.	4d-Rain.	5d-Rain.	6d-Rain.	7d-Rain.
Upper area of Ping river basin	a	0.0032						
	b	1.015						
Upper area of Yom river basin	a	0.0045						
	b	0.913						
Upper area of Nan river basin	a	0.0044						
	b	0.918						
Southern area of C2 basin	a	0.0042						
	b	0.932						
Lower area of Chaophraya river basin	a	0.0036						
	b	0.981						

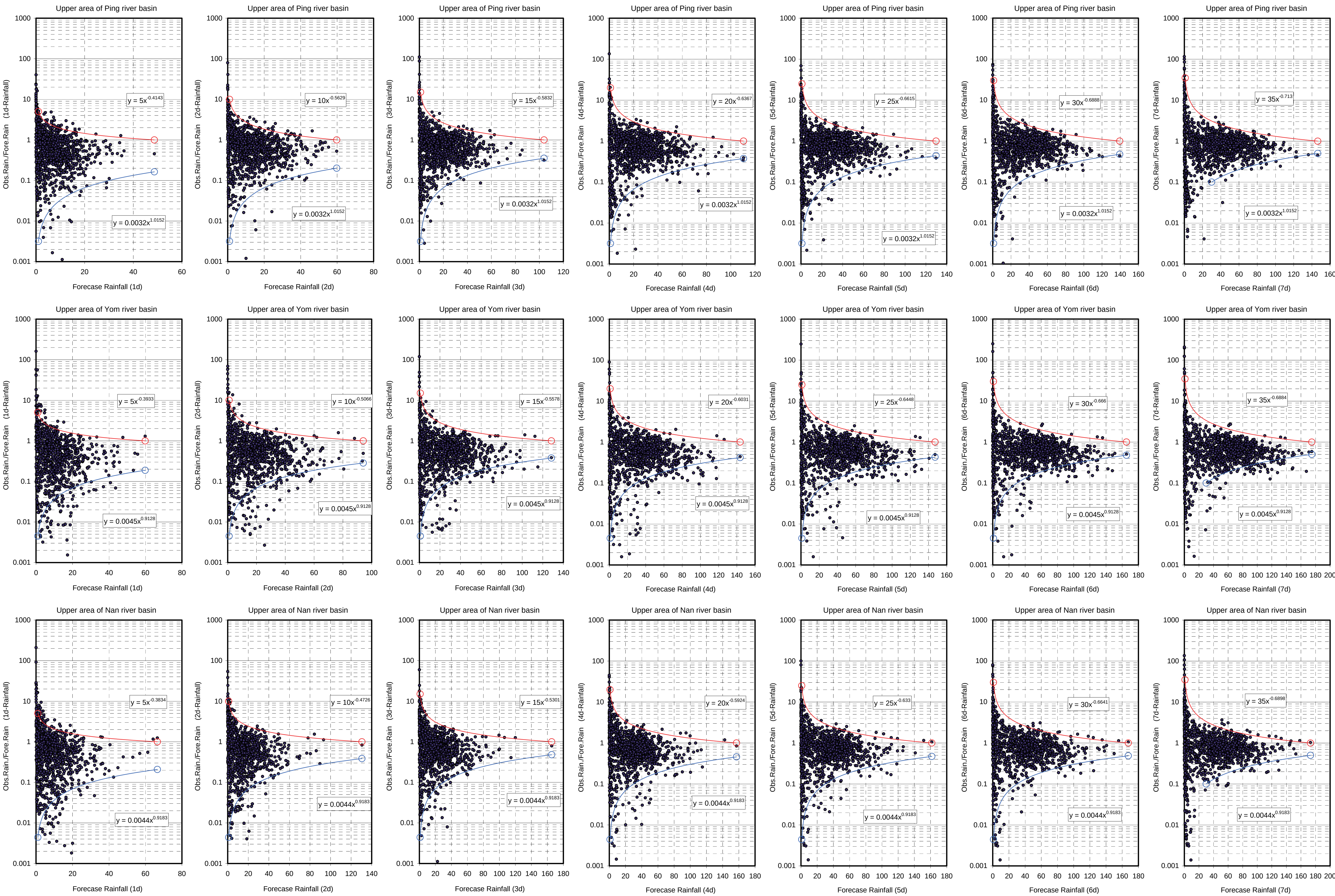


Fig. 34 Approximate equation for obtaining the maximum and minimum forecast rainfall based on the forecast rainfall

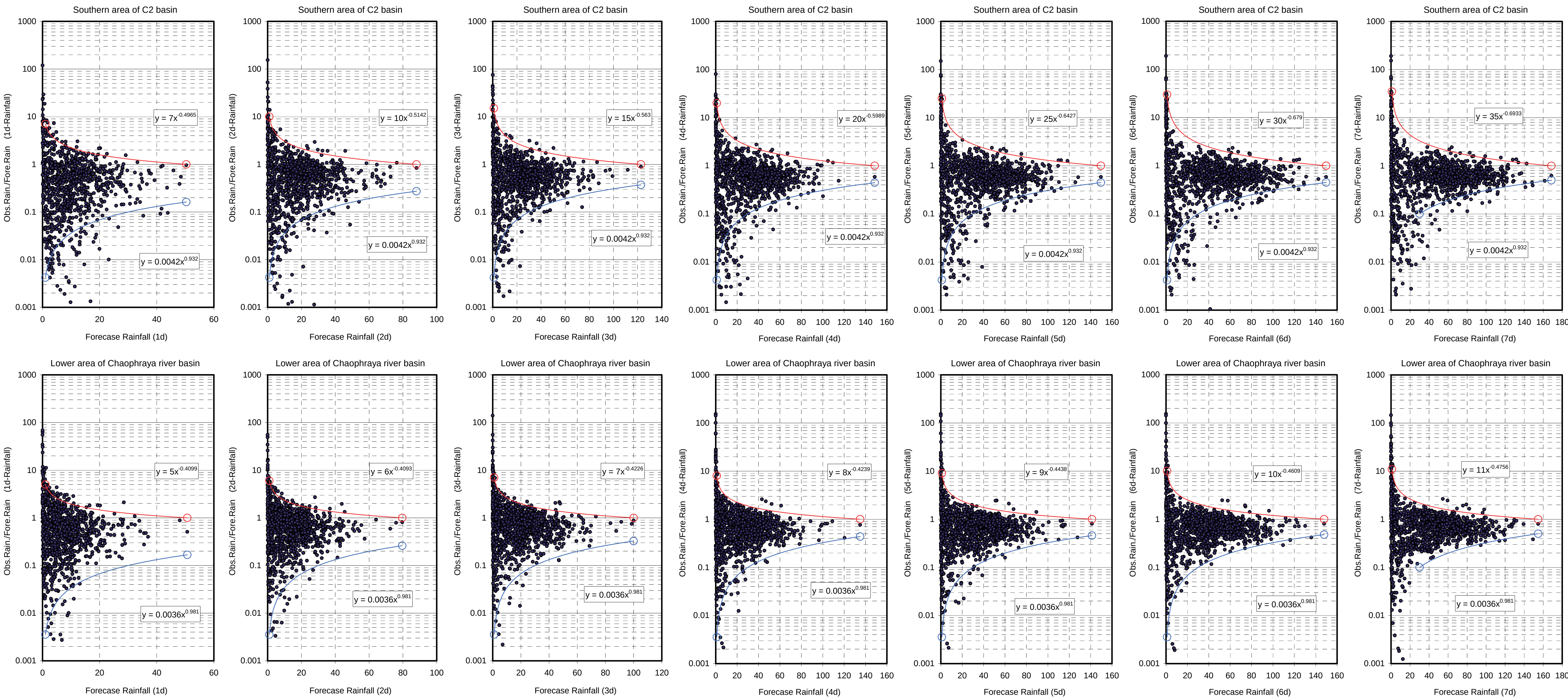


Fig. 35 Approximate equation for obtaining the maximum and minimum forecast rainfall based on the forecast rainfall

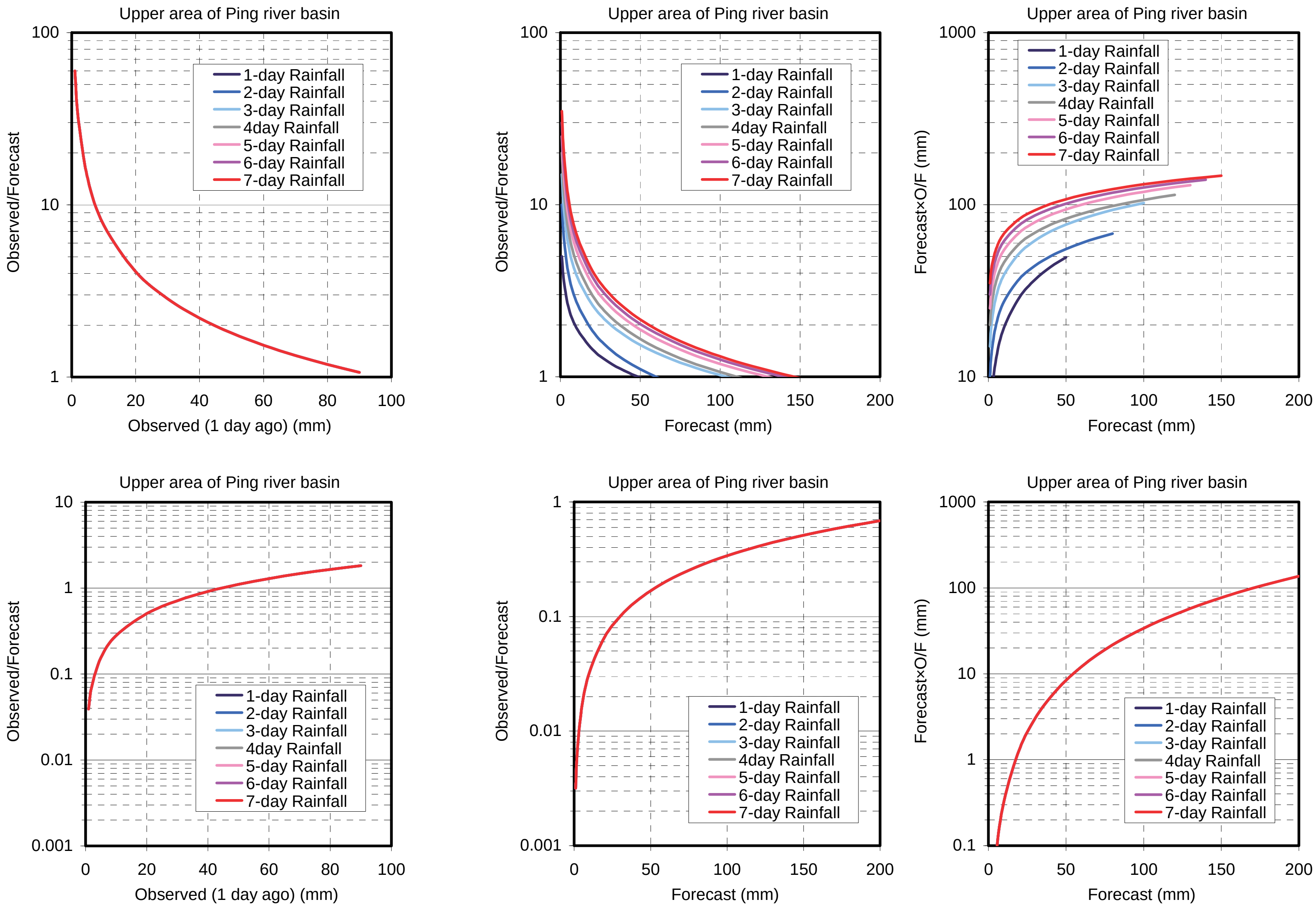


Fig. 36 Approximate equation for obtaining the maximum and minimum rainfall (Upper reaches of the Ping River)

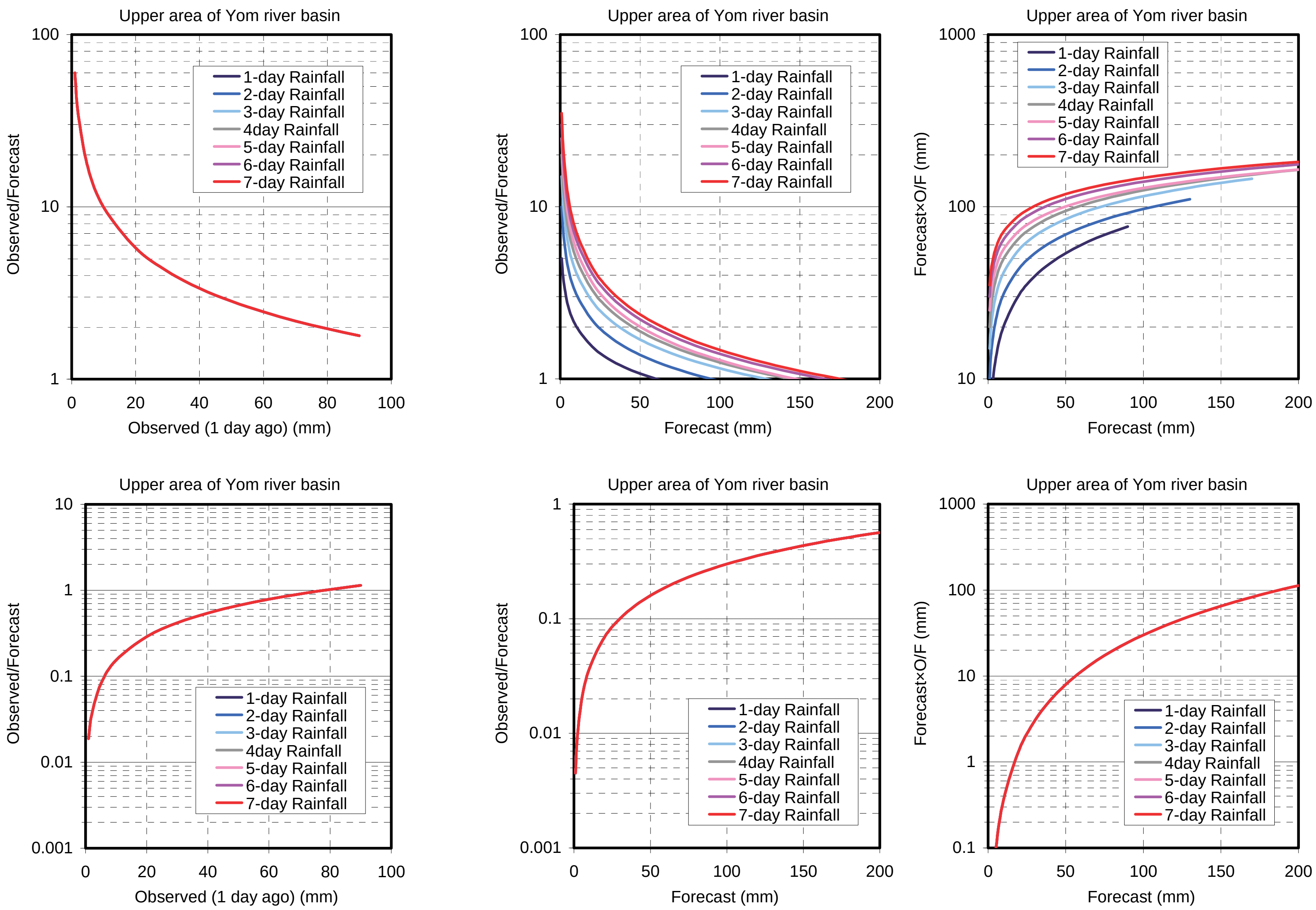


Fig. 37 Approximate equation for obtaining the maximum and minimum rainfall (Upper reaches of the Yom River)

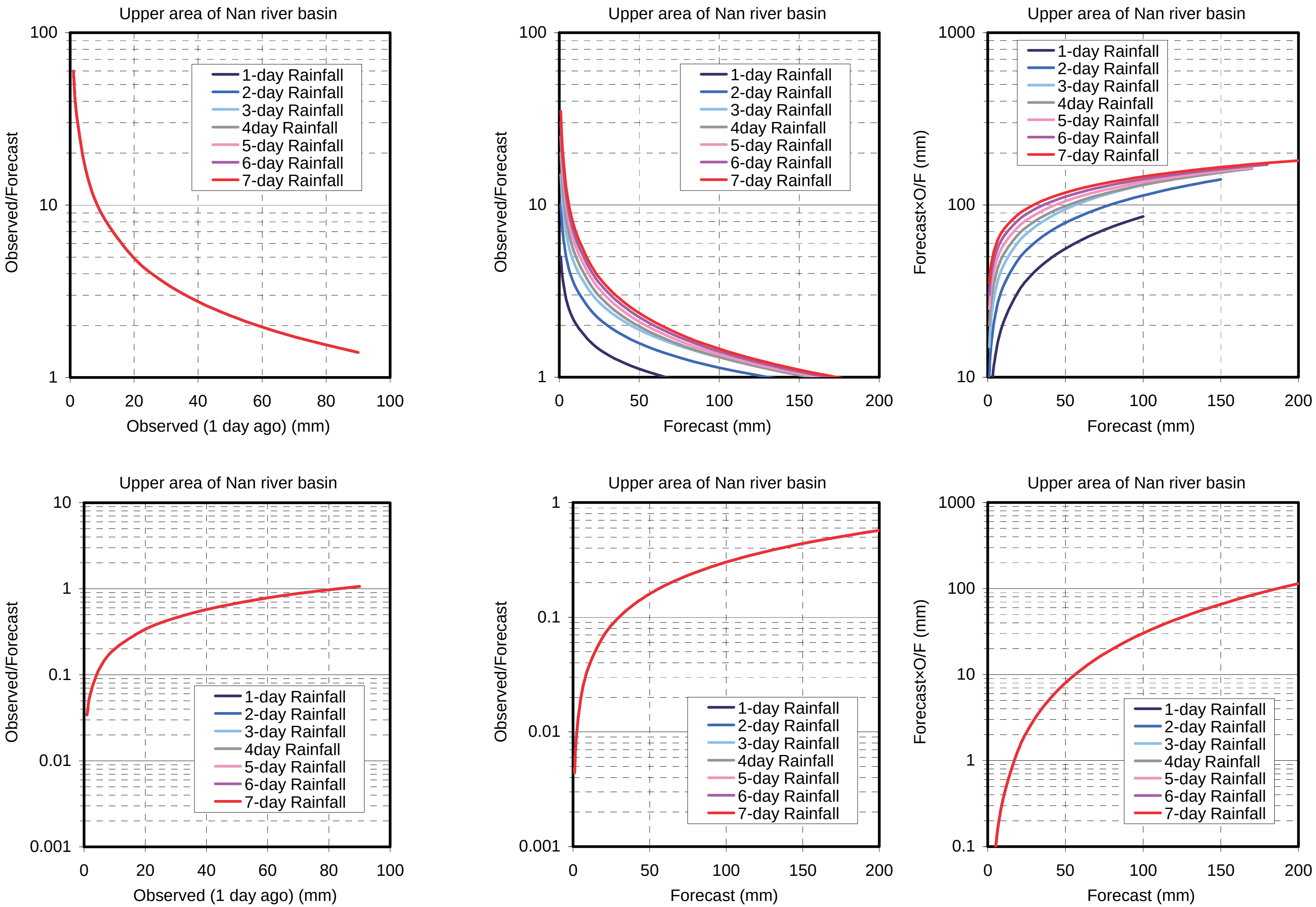


Fig. 38 Approximate equation for obtaining the maximum and minimum rainfall (Upper reaches of the Nan River)

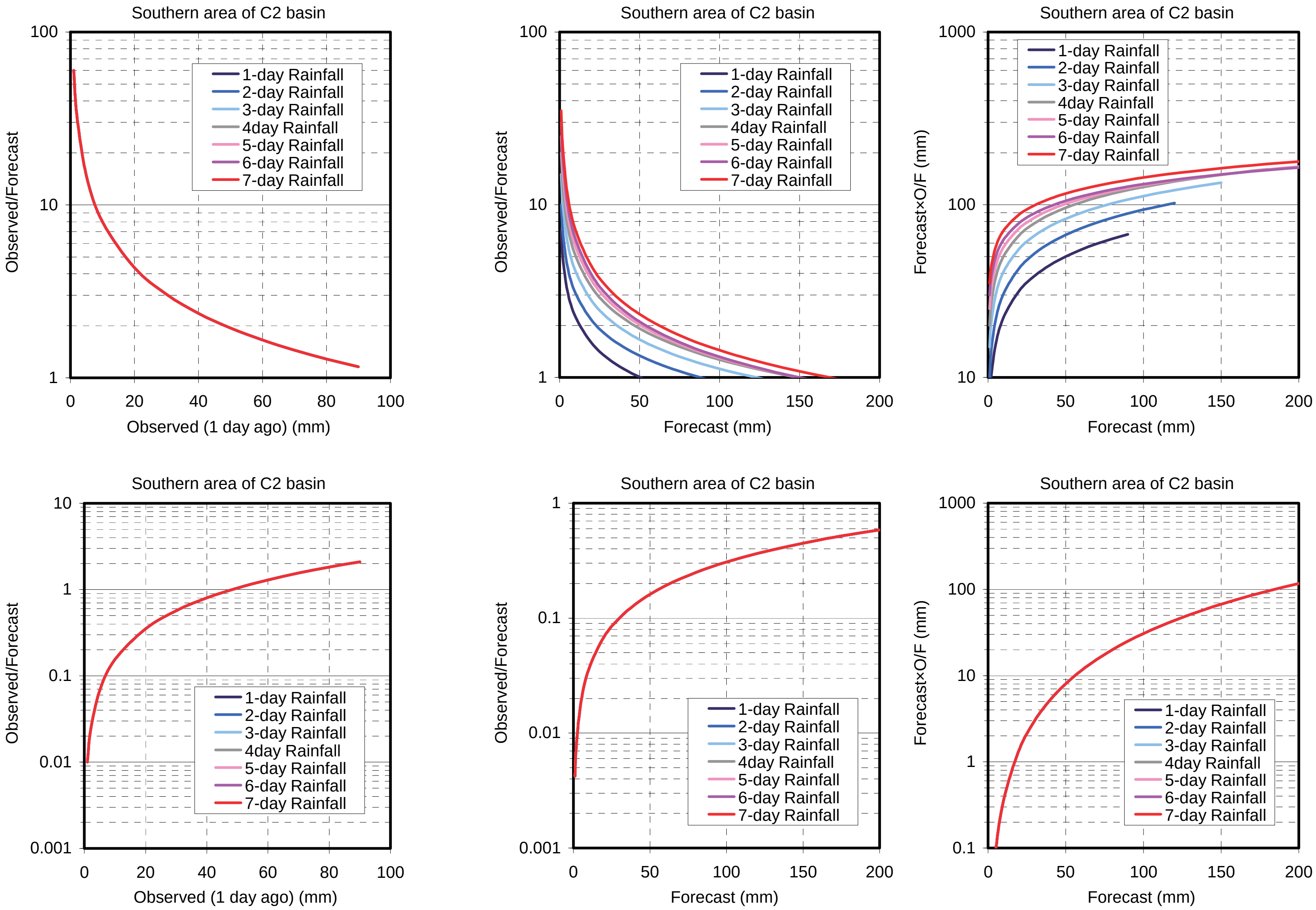


Fig. 39 Approximate equation for obtaining the maximum and minimum rainfall (South of C2)

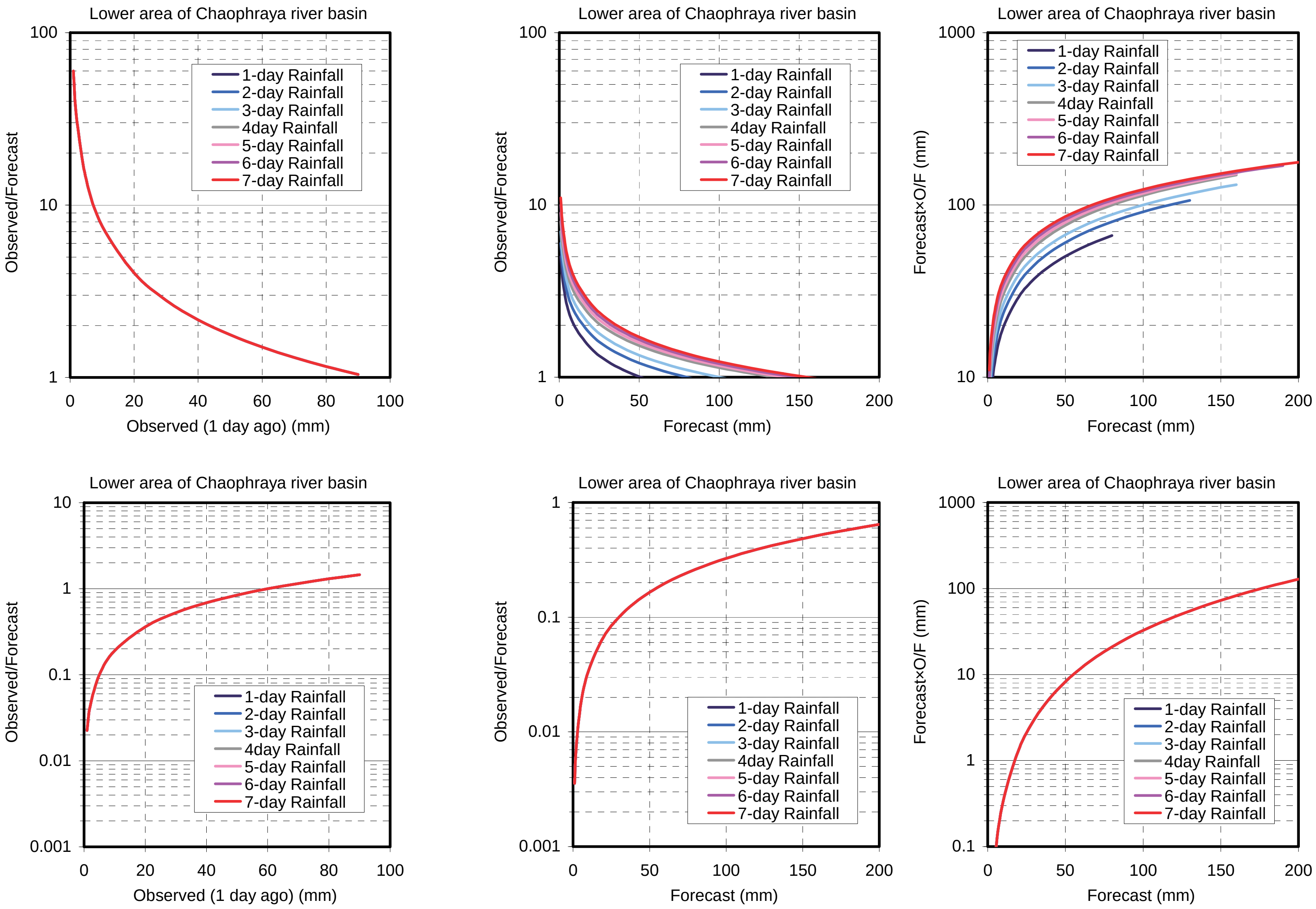


Fig. 40 Approximate equation for obtaining the maximum and minimum rainfall (Lower reaches of the Chaophraya River)

7 Setting of the maximum and minimum forecast rainfall using an approximate equation

7.1 Outline of methods for calculating the maximum and minimum forecast rainfall using an approximate equation

The maximum and minimum forecast rainfall is calculated using an approximate equation as described below. The maximum and minimum forecast rainfall is calculated as mean rainfall in each sub-basin (rainfall in each sub-basin is assumed to be spatially uniform).

-Maximum forecast rainfall
(i) Cumulative rainfall one to seven days later is calculated based on the present condition of rainfall (observed rainfall one day ago) using an approximate equation.
(ii) Cumulative rainfall one to seven days later is calculated based on the forecast rainfall using an approximate equation.
(iii) The smaller of the cumulative rainfall obtained in (i) and (ii) above is defined as the primary forecast.
(iv) The primary forecast is corrected using continuous rainfall or mean rainfall at C2.
(v) Corrected value is defined as the flood prediction model (input into the discharge calculation model).

*Correction using continuous rainfall: Corrections are made so that one- to seven-day rainfall forecast one to seven days later (cumulative rainfall) might not exceed the maximum rainfall ever observed in each sub-basin. When the primary forecast exceeds the maximum rainfall ever observed, corrections are made to make the primary forecast equal the maximum rainfall ever observed. For details, refer to the sample calculations below.

*Correction using the mean rainfall at C2: Corrections are made so that cumulative rainfall forecast one to seven days later might not exceed the maximum rainfall ever observed. For specific correction methods, refer to the sample calculations below.

-Minimum forecast rainfall
(i) Cumulative rainfall one to seven days later is calculated based on the present condition of rainfall (observed rainfall one day ago) using an approximate equation.
(ii) Cumulative rainfall one to seven days later is calculated based on the forecast rainfall using an approximate equation.
(iii) The larger of the cumulative rainfall obtained in (i) and (ii) above is defined as the primary forecast.
(No correction is made to the minimum forecast rainfall.)

7.2 Maximum rainfall ever observed

The maximum rainfall ever observed is listed in Table 4 and shown in Fig 41. The maximum rainfall ever observed means the maximum rainfall observed in the 1960-2011 period.

The maximum mean rainfall in the basin becomes smaller as the basin area increases in the basin of tens of thousands of square kilometers because the area of heavy rainfall is relatively small as compared with the basin area. The maximum mean rainfall ever observed in the basin at C2 is therefore relatively small. The value is relatively small in the upper reaches of the Ping River, which is considered to be characteristic of the sub-basin.

Table 4 Maximum rainfall ever observed (1961-2011)

	1d-Rain.	2d-Rain.	3d-Rain.	4d-Rain.	5d-Rain.	6d-Rain.	7d-Rain.
Upper area of Ping river basin	53	80	99	124	130	142	152
Upper area of Yom river basin	90	135	177	204	217	226	232
Upper area of Nan river basin	100	150	162	170	175	186	212
Southern area of C2 basin	93	128	155	183	203	223	229
LOWER	90	132	160	162	167	196	209
C2 (NakhonSawan) basin	52	81	107	124	137	142	157

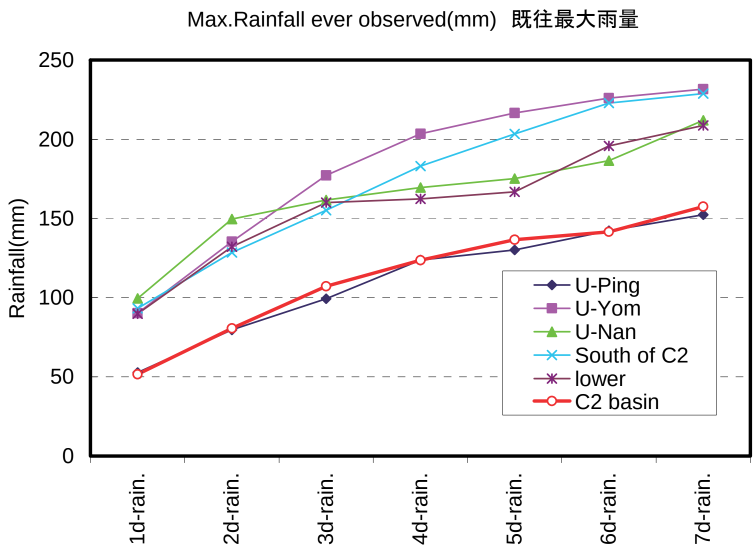


Fig. 41 Maximum rainfall ever observed (1961-2011)

7.3 Method of correction using continuous rainfall

(1) Method of correction

When setting the maximum forecast rainfall for a relatively short period such as one to two days on the assumption of the maximum error in forecast, it should be verified that the forecast is not extremely larger than the maximum rainfall ever observed as compared with the continuous rainfall for the past several days. Rainfall is verified as described below.

For the forecast rainfall one to seven days later, it is verified that continuous rainfall including the observed rainfall up to six days ago is smaller than the maximum rainfall ever observed. The method of verification is described below for the forecast two days later as an example.

-Daily rainfall on the day, and one and two days later than the time of forecast (present) is obtained based on the forecast rainfall up to two days later (cumulative rainfall).

-It is verified that the daily rainfall up to two days later is smaller than the maximum daily rainfall ever observed.

-It is verified that the two-day rainfall one and two days later is smaller than the maximum two-day rainfall ever observed.

-Verifications are made similarly up to seven-day rainfall two to four days later.

If the n-day rainfall (n = 1 to 7) including the forecast rainfall is larger than the maximum rainfall ever observed, daily rainfall is reduced so that n-day rainfall will equal the maximum rainfall ever observed.

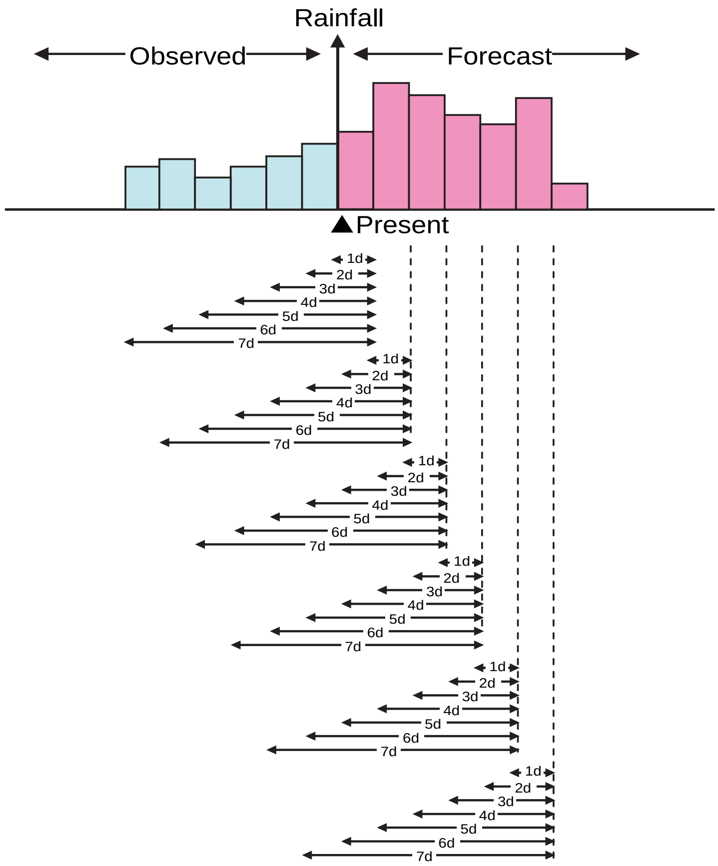


Fig. 42 Conceptual view of continuous rainfall

(2) Example of correction

Correction procedure is described below in the SC2 sub-basin (south of C2)

(i) Daily rainfall forecast three days later 100 mm/d is large. Then, the forecast rainfall up to three days later exceeds the maximum rainfall ever observed (hatched box).

(ii) Forecast rainfall up to three days later exceeds the maximum rainfall ever observed as shown below.
One-day forecast rainfall three days later 100 mm/d exceeds the maximum rainfall ever observed 93 mm/d by 7 mm/d.
Three-day forecast rainfall up to three days later 157 mm/d exceeds the maximum rainfall ever observed 155 mm/d by 2 mm/d.

(iii) Then, the daily forecast rainfall three days later is reduced by 7 mm/d (larger of the variances obtained in (ii) above) to 93 mm/d.

Maximum Rainfall Ever Observed (mm)						
1day	2days	3days	4days	5days	6days	7days
93	128	155	183	203	223	229

	Daily Rainfall(mm/d)
6days ago	4
5days ago	22
4days ago	4
3days ago	3
2days ago	10
1day ago	6
present→ 1days later	33
2days later	25
3days later	100
4days later	50
5days later	7
6days later	11
7days later	23

	Maximum Forecast Rainfall (mm)						
	1day	2days	3days	4days	5days	6days	7days
1days later	33	39	49	52	57	79	83
2days later	25	57	63	74	77	81	104
3days later	100	125	157	163	174	177	181
4days later	50	150	175	207	213	224	227
5days later	7	57	157	182	214	220	231
6days later	11	17	67	167	192	225	231
7days later	23	33	40	90	190	215	248

	Difference with Maximum Rainfall Ever Observed (mm)							
	1day	2days	3days	4days	5days	6days	7days	max.
1days later	-61	-90	-106	-131	-147	-144	-146	-61
2days later	-69	-71	-92	-109	-126	-141	-125	-69
3days later	7	-4	2	-20	-29	-46	-47	7
4days later	-43	22	19	24	10	1	-2	24
5days later	-86	-72	2	-2	11	-2	2	11
6days later	-83	-111	-88	-16	-11	2	2	2
7days later	-70	-95	-115	-93	-13	-8	19	19

Fig. 43 Example of correction using continuous rainfall (before correction)

(iv) Even if the daily forecast rainfall three days later is reduced to 93 mm/d, the daily forecast rainfall up to four days later exceeds the maximum rainfall ever observed because the forecast daily rainfall on the fourth day 50 mm/d is large (hatched box)

(v) Forecast rainfall up to four days later exceeds the maximum rainfall ever observed as shown below.

Two-day forecast rainfall up to four days later 143 mm/d exceeds the maximum rainfall ever observed 128 mm/d by 15 mm/d.

Three-day forecast rainfall up to four days later 168 mm/d exceeds the maximum rainfall ever observed 155 mm/d by 13 mm/d.

Four-day forecast rainfall up to four days later 201 mm/d exceeds the maximum rainfall ever observed 183 mm/d by 18 mm/d.

Five-day forecast rainfall up to four days later 207 mm/d exceeds the maximum rainfall ever observed 203 mm/d by 4 mm/d.

(vi) Then, the daily forecast rainfall four days later is reduced by 18 mm/d (largest variance in (v) above) to 32 mm/d.

Maximum Rainfall Ever Observed (mm)						
1day	2days	3days	4days	5days	6days	7days
93	128	155	183	203	223	229

	Daily Rainfall(mm/d)
6days ago	4
5days ago	22
4days ago	4
3days ago	3
2days ago	10
1day ago	6
present→ 1days later	33
2days later	25
3days later	93
4days later	50
5days later	7
6days later	11
7days later	23

	Maximum Forecast Rainfall (mm)						
	1day	2days	3days	4days	5days	6days	7days
1days later	33	39	49	52	57	79	83
2days later	25	57	63	74	77	81	104
3days later	93	118	151	157	167	170	175
4days later	50	143	168	201	207	217	220
5days later	7	57	150	175	208	214	224
6days later	11	17	67	161	185	218	224
7days later	23	33	40	90	184	208	241

	Difference with Maximum Rainfall Ever Observed (mm)							
	1day	2days	3days	4days	5days	6days	7days	max.
1days later	−61	−90	−106	−131	−147	−144	−146	−61
2days later	−69	−71	−92	−109	−126	−141	−125	−69
3days later	0	−10	−5	−26	−36	−52	−54	0
4days later	−43	15	13	18	4	−6	−8	18
5days later	−86	−72	−5	−8	4	−9	−5	4
6days later	−83	−111	−88	−22	−18	−5	−5	−5
7days later	−70	−95	−115	−93	−20	−15	12	12

Fig. 44 Example of correction using continuous rainfall (after first correction)

As a result of corrections, the forecast rainfall is reduced to the maximum rainfall ever observed.

Maximum Rainfall Ever Observed (mm)						
1day	2days	3days	4days	5days	6days	7days
93	128	155	183	203	223	229

	Daily Rainfall(mm/d)
6days ago	4
5days ago	22
4days ago	4
3days ago	3
2days ago	10
1day ago	6
present→ 1days later	33
2days later	25
3days later	93
4days later	32
5days later	7
6days later	11
7days later	23

	Maximum Forecast Rainfall (mm)						
	1day	2days	3days	4days	5days	6days	7days
1days later	33	39	49	52	57	79	83
2days later	25	57	63	74	77	81	104
3days later	93	118	151	157	167	170	175
4days later	32	126	150	183	189	200	203
5days later	7	39	133	157	190	196	207
6days later	11	17	50	143	168	200	207
7days later	23	33	40	73	166	191	223

	Difference with Maximum Rainfall Ever Observed (mm)							
	1day	2days	3days	4days	5days	6days	7days	max.
1days later	−61	−90	−106	−131	−147	−144	−146	−61
2days later	−69	−71	−92	−109	−126	−141	−125	−69
3days later	0	−10	−5	−26	−36	−52	−54	0
4days later	−61	−3	−5	0	−14	−23	−26	0
5days later	−86	−89	−23	−26	−13	−27	−22	−13
6days later	−83	−111	−105	−40	−36	−22	−22	−22
7days later	−70	−95	−115	−110	−37	−32	−5	−5

Fig. 45 Example of correction using continuous rainfall (after second correction)

7.4 Method of correction using mean rainfall in the basin at C2

(1) Method of correction

For the maximum forecast rainfall set using an approximate equation based on the present condition of rainfall (observed rainfall in the past one day) and the forecast rainfall, the maximum error that could occur independently in each sub-basin is estimated. In reality, heavy rainfall never occurs uniformly throughout the basin at C2 but relatively heavy rainfall occurs in areas occupying approximately 20% of the basin at C2. The mean rainfall in the basin at C2 with the maximum error being estimated in each sub-basin was checked using the maximum rainfall ever observed. The process of checking is described below.

The mean rainfall in the basin at C2 is checked as shown below.

-The mean rainfall in the basin at C2 is obtained from the maximum forecast rainfall calculated in the four sub-basins upstream of C2 Rmax (mean rainfall in the sub-basins) by weighted averaging using the catchment area CA.

Mean rainfall in the sub-basins = (Σ(Rmax x CA))/ ΣCA

-If the mean rainfall in the sub-basins exceeds the maximum rainfall ever observed, the rainfall in upper reaches (U-P, U-Y and U-N) is reduced.

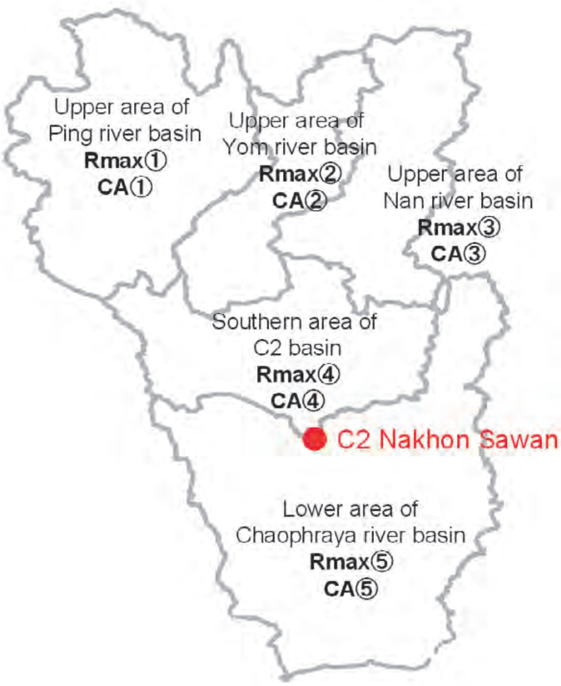


Fig. 46 Sub-basins

(2) Example of correction

(i) Daily forecast rainfall four days later in the U-P sub-basin 100.0 mm/d is large, so the mean rainfall in the basin at C2 53.0 mm/d also becomes large.

(ii) The mean forecast rainfall up to four days later in the basin at C2 therefore exceeds the maximum rainfall ever observed (hatched box).

(iii) Forecast rainfall up to four days later exceeds the maximum rainfall as described below.

The daily rainfall four days later 53.0 mm/d is 1.03 times the maximum daily rainfall ever observed 51.6 mm/d. The four-day rainfall four days later 128.9 mm/d is 1.04 times the maximum daily rainfall ever observed 123.7 mm/d.

(iv) Then, the daily rainfall upstream of C2 for four days up to the fourth day when the rate of exceedance is maximum is corrected. (All of the daily rainfall amounts upstream of C2 (U-P, U-Y and U-N) up to four days later are reduced by the same factor so that the mean rainfall in the basin at C2 may equal the maximum rainfall ever observed.)

The rainfall in upstream areas is reduced in the case where the mean rainfall in the basin at C2 exceeds the maximum rainfall ever observed for the following reasons.
-The rainfall upstream of C2 has relatively small effects on flow increase at C2 while the rainfall south of C2 directly affects flow increase at C2.
-Only the rainfall in the upstream areas is therefore reduced to assume the worst case of flow increase at C2.

	U-P	U-Y	U-N	SC2	LOW	C2
6days ago	9.6	7.3	11.8	3.8	10.8	8.2
5days ago	35.9	32.7	26.2	22.0	12.2	29.7
4days ago	15.5	22.6	21.4	4.5	7.9	15.2
3days ago	24.6	6.4	2.0	3.0	1.8	11.0
2days ago	7.8	5.2	5.9	10.5	6.1	7.7
yester day	2.0	1.1	6.5	6.1	2.9	3.9
present→ 1days later	22.1	16.5	28.4	32.7	18.8	25.2
2days later	17.0	34.3	32.4	24.7	17.2	25.3
3days later	24.0	29.6	25.0	24.7	21.1	25.3
4days later	100.0	25.1	22.3	32.7	28.2	53.0
5days later	13.1	6.9	10.9	6.9	15.4	9.9
6days later	6.7	13.2	13.9	10.5	15.9	10.4
7days later	15.2	21.0	15.1	22.9	14.7	18.2

U-P :Upper area of Ping river basin
U-Y :Upper area of Yom river basin
U-N :Upper area of Nan river basin
SC2 :Southern area of C2 basin
LOW :Lower area of chaophraya river basin

Maximum Rainfall Ever Observed (mm) C2 Basin						
1day	2days	3days	4days	5days	6days	7days
51.6	80.7	107.2	123.7	136.6	141.6	157.5

Cumulative Rainfall (mm) C2 Basin	1day	2days	3days	4days	5days	6days	7days
1days later	25.2	29.1	36.8	47.8	63.0	92.7	100.9
2days later	25.3	50.5	54.4	62.1	73.1	88.3	118.0
3days later	25.3	50.6	75.8	79.7	87.4	98.4	113.6
4days later	53.0	78.4	103.7	128.9	132.8	140.4	151.5
5days later	9.9	63.0	88.3	113.6	138.8	142.7	150.4
6days later	10.4	20.3	73.3	98.7	123.9	149.2	153.1
7days later	18.2	28.5	38.4	91.5	116.8	142.1	167.3

Ratio to Maximum Rainfall Ever Observed (mm) C2 Basin	1day	2days	3days	4days	5days	6days	7days
1days later	0.49	0.36	0.34	0.39	0.46	0.65	0.64
2days later	0.49	0.63	0.51	0.50	0.54	0.62	0.75
3days later	0.49	0.63	0.71	0.64	0.64	0.70	0.72
4days later	1.03	0.97	0.97	1.04	0.97	0.99	0.96
5days later	0.19	0.78	0.82	0.92	1.02	1.01	0.95
6days later	0.20	0.25	0.68	0.80	0.91	1.05	0.97
7days later	0.35	0.35	0.36	0.74	0.86	1.00	1.06

Fig. 47 Example of correction of mean rainfall in the basin (before correction)

Equations to correct the mean rainfall in the basin at C2 are shown below.

Table 5 Equations for correcting means rainfall in the basin at C2

α: Ratio to maximum rainfall ever observed (Ratio to Maximum Rainfall Evere Observed)

β :Ratio of correction

R :Rainfall before correction (mean rainfall in C2 basin)

R': Rainfall after correction (mean rainfall in C2 basin)

$$R' = R/\alpha$$

$$R = \frac{R_{U\cdot P}\times CA_{U\cdot P}+R_{U\cdot Y}\times CA_{U\cdot Y}+R_{U\cdot N}\times CA_{U\cdot N}+R_{SC2}\times CA_{SC2}}{CA_{U\cdot P}+CA_{U\cdot Y}+CA_{U\cdot N}+CA_{SC2}}$$

$$R' = \frac{\beta\times(R_{U\cdot P}\times CA_{U\cdot P}+R_{U\cdot Y}\times CA_{U\cdot Y}+R_{U\cdot N}\times CA_{U\cdot N}) + R_{SC2}\times CA_{SC2}}{CA_{U\cdot P}+CA_{U\cdot Y}+CA_{U\cdot N}+CA_{SC2}}$$

RU-P: U-P rainfall (mm) CA U-P: U-P basin area (km2)

R U-Y: U-Y rainfall (mm) CA U-Y: U-Y rainfall (km2)

R U-N: U-N rainfall (mm) CA U-N: U-N basin area (km2)

RSC2: SC2 rainfall (mm) CASC2: SC2 basin area (km2)

(v) As a result of correction, the rainfall up to four days later does not exceed the maximum rainfall ever observed. The six-say rainfall up to six days later 143.4 mm/6d is 1.01 times the maximum rainfall 141.5 mm/6d.

(vi) Daily rainfall in the upstream areas (U-P, U-Y and U-N) for six days up to six days later is corrected.

	U-P	U-Y	U-N	SC2	LOW	C2
6days ago	9.6	7.3	11.8	3.8	10.8	8.2
5days ago	35.9	32.7	26.2	22.0	12.2	29.7
4days ago	15.5	22.6	21.4	4.5	7.9	15.2
3days ago	24.6	6.4	2.0	3.0	1.8	11.0
2days ago	7.8	5.2	5.9	10.5	6.1	7.7
yester day	2.0	1.1	6.5	6.1	2.9	3.9
present→ 1days later	21.1	15.7	27.1	32.7	18.8	24.5
2days later	16.2	32.8	31.0	24.7	17.2	24.4
3days later	22.9	28.3	23.9	24.7	21.1	24.5
4days later	92.5	23.2	20.6	32.7	28.2	49.7
5days later	13.1	6.9	10.9	6.9	15.4	9.9
6days later	6.7	13.2	13.9	10.5	15.9	10.4
7days later	15.2	21.0	15.1	22.9	14.7	18.2

U-P :Upper area of Ping river basin
U-Y :Upper area of Yom river basin
U-N :Upper area of Nan river basin
SC2 :Southern area of C2 basin
LOW :Lower area of chaophraya river basin

Maximum Rainfall Ever Observed (mm) C2 Basin						
1day	2days	3days	4days	5days	6days	7days
51.6	80.7	107.2	123.7	136.6	141.6	157.5

Cumulative Rainfall (mm) C2 Basin	1day	2days	3days	4days	5days	6days	7days
1days later	24.5	28.4	36.0	47.1	62.3	92.0	100.2
2days later	24.4	48.9	52.8	60.5	71.5	86.7	116.4
3days later	24.5	48.9	73.4	77.3	85.0	96.0	111.2
4days later	49.7	74.2	98.6	123.7	127.0	134.7	145.7
5days later	9.9	59.6	84.1	108.6	133.0	136.9	144.6
6days later	10.4	20.3	70.0	94.5	118.9	143.4	147.3
7days later	18.2	28.5	38.4	88.1	112.6	137.1	161.5

Ratio to Maximum Rainfall Ever Observed (mm) C2 Basin	1day	2days	3days	4days	5days	6days	7days
1days later	0.47	0.35	0.34	0.38	0.46	0.65	0.64
2days later	0.47	0.61	0.49	0.49	0.52	0.61	0.74
3days later	0.47	0.61	0.68	0.63	0.62	0.68	0.71
4days later	0.96	0.92	0.92	1.00	0.93	0.95	0.93
5days later	0.19	0.74	0.78	0.88	0.97	0.97	0.92
6days later	0.20	0.25	0.65	0.76	0.87	1.01	0.94
7days later	0.35	0.35	0.36	0.71	0.82	0.97	1.03

Fig. 48 Example of correction of mean rainfall in the basin (after first correction)

(vii) As a result of correction, the rainfall up to six days later does not exceed the maximum rainfall ever observed. The seven-day rainfall up to seven days later 159.5 mm/7d is 1.01 times the maximum rainfall 157.5 mm/7d.

(viii) Daily rainfall in the upstream areas (U-P, U-Y and U-N) for seven days up to seven days later is corrected.

	U-P	U-Y	U-N	SC2	LOW	C2
6days ago	9.6	7.3	11.8	3.8	10.8	8.2
5days ago	35.9	32.7	26.2	22.0	12.2	29.7
4days ago	15.5	22.6	21.4	4.5	7.9	15.2
3days ago	24.6	6.4	2.0	3.0	1.8	11.0
2days ago	7.8	5.2	5.9	10.5	6.1	7.7
yester day	2.0	1.1	6.5	6.1	2.9	3.9
present→ 1days later	20.7	15.4	26.6	32.7	18.8	24.2
2days later	15.9	32.2	30.4	24.7	17.2	24.1
3days later	22.5	27.7	23.4	24.7	21.1	24.1
4days later	90.7	22.8	20.2	32.7	28.2	48.9
5days later	12.8	6.7	10.7	6.9	15.4	9.8
6days later	6.6	12.9	13.6	10.5	15.9	10.2
7days later	15.2	21.0	15.1	22.9	14.7	18.2

U-P :Upper area of Ping river basin
U-Y :Upper area of Yom river basin
U-N :Upper area of Nan river basin
SC2 :Southern area of C2 basin
LOW :Lower area of chaophraya river basin

Maximum Rainfall Ever Observed (mm) C2 Basin						
1day	2days	3days	4days	5days	6days	7days
51.6	80.7	107.2	123.7	136.6	141.6	157.5

Cumulative Rainfall (mm) C2 Basin	1day	2days	3days	4days	5days	6days	7days
1days later	24.2	28.1	35.7	46.8	62.0	91.7	99.9
2days later	24.1	48.3	52.2	59.8	70.9	86.0	115.7
3days later	24.1	48.2	72.4	76.3	84.0	95.0	110.2
4days later	48.9	73.1	97.1	121.3	125.2	132.9	143.9
5days later	9.8	58.7	82.8	106.9	131.1	135.0	142.7
6days later	10.2	20.0	68.9	93.0	117.1	141.6	145.2
7days later	18.2	28.4	38.1	87.1	111.2	135.3	159.5

Ratio to Maximum Rainfall Ever Observed (mm) C2 Basin	1day	2days	3days	4days	5days	6days	7days
1days later	0.47	0.35	0.33	0.38	0.45	0.65	0.63
2days later	0.47	0.60	0.49	0.48	0.52	0.61	0.73
3days later	0.47	0.60	0.68	0.62	0.61	0.67	0.70
4days later	0.95	0.91	0.91	0.98	0.92	0.94	0.91
5days later	0.19	0.73	0.77	0.86	0.96	0.95	0.91
6days later	0.20	0.25	0.64	0.75	0.86	1.00	0.92
7days later	0.35	0.35	0.36	0.70	0.81	0.96	1.01

Fig. 49 Example of correction of mean rainfall in the basin (after second correction)

As a result of correction, the rainfall up to seven days later does not exceed the maximum rainfall ever observed.

	U-P	U-Y	U-N	SC2	LOW	C2
	3.1	9.7	6.6	1.5	1.3	
	9.9	11.9	2.1	1.9	4.7	
6days ago	9.6	7.3	11.8	3.8	10.8	8.2
5days ago	35.9	32.7	26.2	22.0	12.2	29.7
4days ago	15.5	22.6	21.4	4.5	7.9	15.2
3days ago	24.6	6.4	2.0	3.0	1.8	11.0
2days ago	7.8	5.2	5.9	10.5	6.1	7.7
yester day	2.0	1.1	6.5	6.1	2.9	3.9
present→ 1days later	20.3	15.1	26.1	32.7	18.8	23.9
2days later	15.6	31.6	29.8	24.7	17.2	23.7
3days later	22.1	27.2	23.0	24.7	21.1	23.8
4days later	89.0	22.3	19.8	32.7	28.2	48.1
5days later	12.6	6.6	10.5	6.9	15.4	9.6
6days later	6.5	12.7	13.3	10.5	15.9	10.1
7days later	14.9	20.6	14.8	22.9	14.7	17.9

Maximum Rainfall Ever Observed (mm) C2 Basin						
1day	2days	3days	4days	5days	6days	7days
51.6	80.7	107.2	123.7	136.6	141.6	157.5

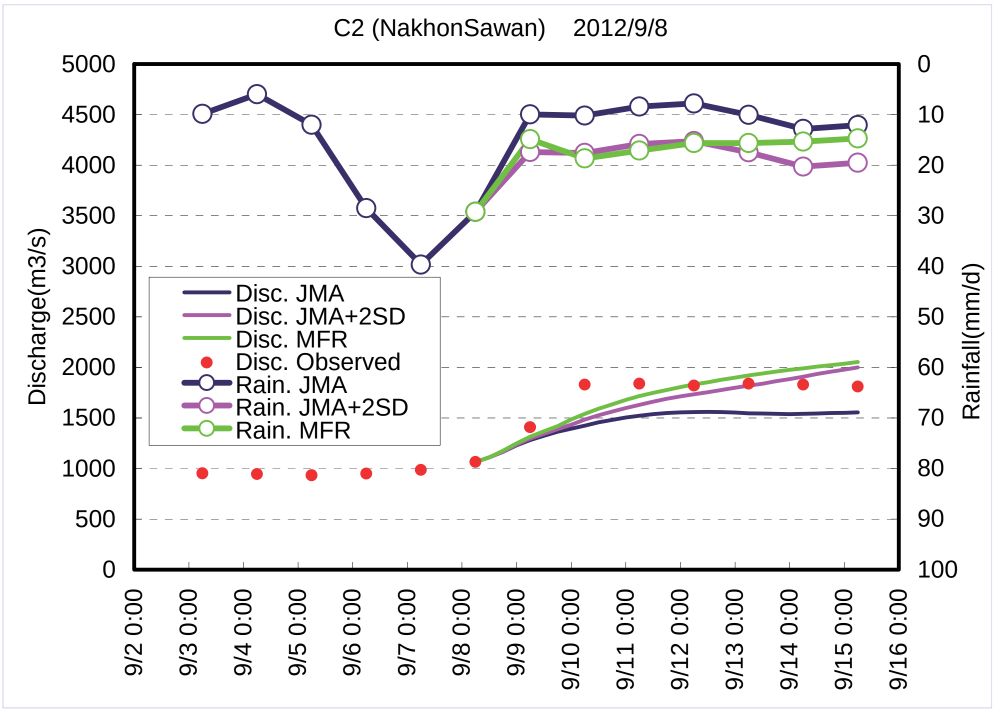
Cumulative Rainfall (mm) C2 Basin	1day	2days	3days	4days	5days	6days	7days
1days later	23.9	27.8	35.4	46.5	61.7	91.4	99.6
2days later	23.7	47.6	51.5	59.2	70.2	85.4	115.1
3days later	23.8	47.6	71.4	75.3	83.0	94.0	109.2
4days later	48.1	71.9	95.7	119.6	123.5	131.1	142.2
5days later	9.6	57.8	81.6	105.3	129.2	133.1	140.8
6days later	10.1	19.7	67.8	91.6	115.4	139.3	143.2
7days later	17.9	28.0	37.6	85.8	109.6	133.3	157.2

Ratio to Maximum Rainfall Ever Observed (mm) C2 Basin	1day	2days	3days	4days	5days	6days	7days
1days later	0.46	0.34	0.33	0.38	0.45	0.65	0.63
2days later	0.46	0.59	0.48	0.48	0.51	0.60	0.73
3days later	0.46	0.59	0.67	0.61	0.61	0.66	0.69
4days later	0.93	0.89	0.89	0.97	0.90	0.93	0.90
5days later	0.19	0.72	0.76	0.85	0.95	0.94	0.89
6days later	0.19	0.24	0.63	0.74	0.84	0.98	0.91
7days later	0.35	0.35	0.35	0.69	0.80	0.94	1.00

Fig. 50 Example of correction of mean rainfall in the basin (after third correction)

7.5 Results of discharge calculation using the maximum forecast rainfall set by an approximate equation

Discharge (flow at C2) was calculated using the maximum forecast rainfall (MFR) set by an approximate equation. The discharge calculated using JMA forecast (with no correction) was compared with the discharge using conventional maximum rainfall (JMA forecast plus 2SD) (Fig. 51 and 52).



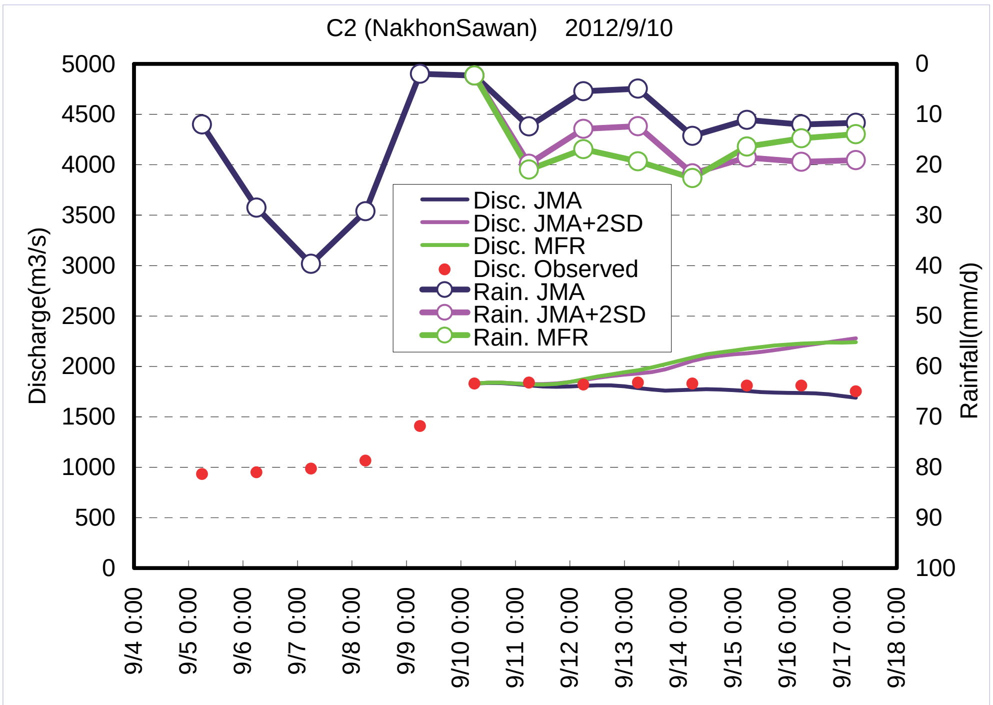
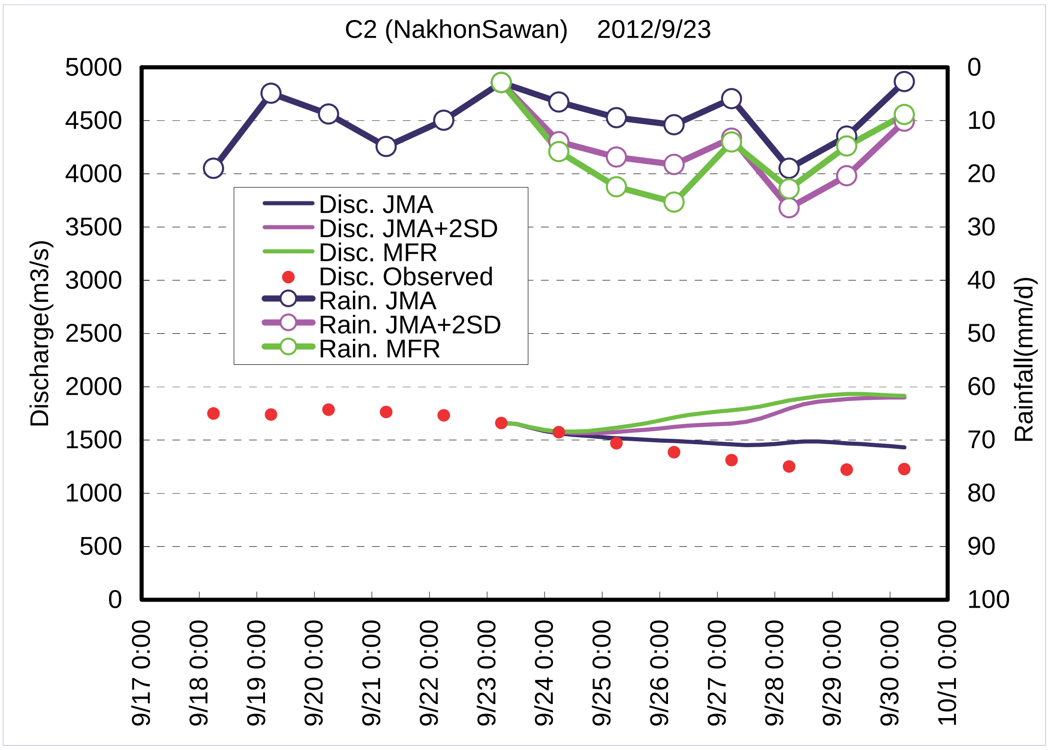


Fig. 51 Mean rainfall in the basin at C2 and flow at C2



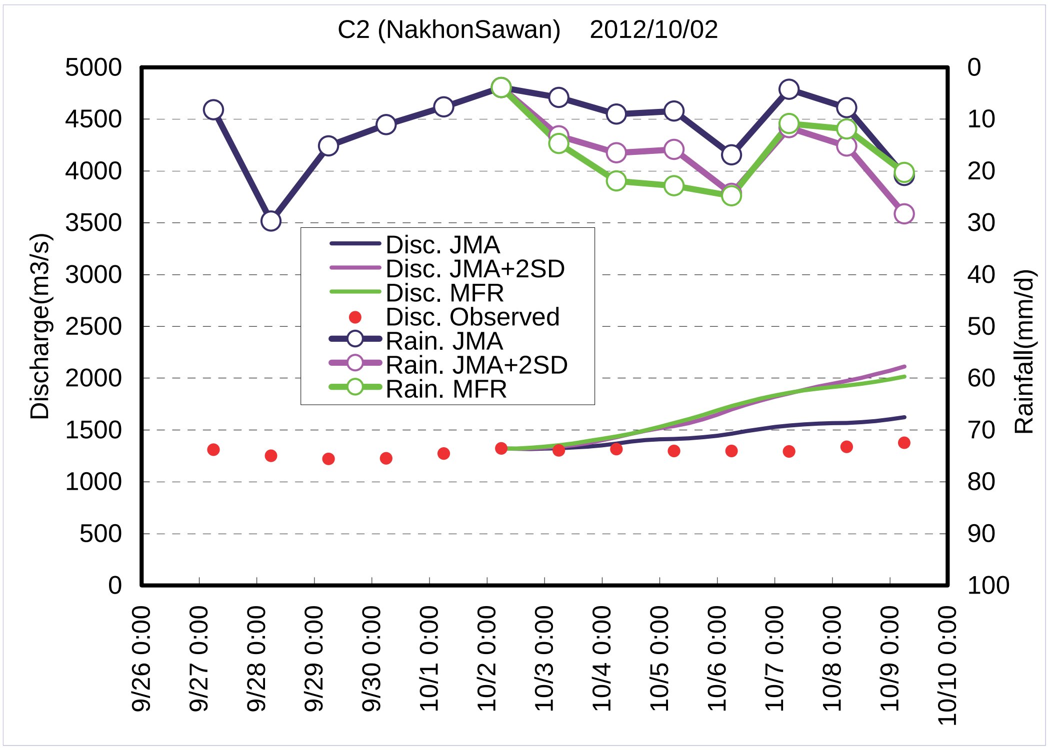


Fig. 52 Mean rainfall in the basin at C2 and flow at C2

Subsequent descriptions are for reference.

8 Method of setting forecast rainfall in temporary operation

8.1 Comparison of JMA forecast rainfall and observed rainfall

JMA forecast rainfall was compared with observed rainfall for one-, two- and seven-day rainfall. For the observed rainfall, the mean rainfall in the basin obtained by TMD and RID was adopted. The daily boundary of the observed rainfall (daily rainfall) is 7:00 hours Thai time (UTC0:00). Comparing with JMA forecast at UTC0:00 enables comparison in rainfall without time difference. For seven-day rainfall, however, JMA made forecast only at UTC12:00. There is a twelve-hour difference in rainfall observation period between observed and forecast rainfall. Comparison was made for one- and two-day rainfall during the period between May 1 and July 1, 2011. The results of comparison are shown in Table 8-1 and Fig. 53. The coefficient of correlation between JMA forecast and observed rainfall is 0.58 for one-day rainfall, 0.64 for two-day rainfall and 0.60 for seven-day rainfall.

Table 8-1 Correlation between JMA forecast and observed rainfall

Basin	Coefficient of correlation		
	Daily rainfall	Two-day rainfall	Seven-day rainfall
Ping	0.635	0.639	0.461
Wang	0.496	0.519	0.499
Yom	0.632	0.643	0.609
Nan	0.714	0.748	0.658
Sakaekrung	0.544	0.616	0.659
ThaChin	0.576	0.660	0.577
Chaophraya	0.464	0.615	0.649
PaSak	0.576	0.663	0.691
Mean rainfall	0.580	0.638	0.601

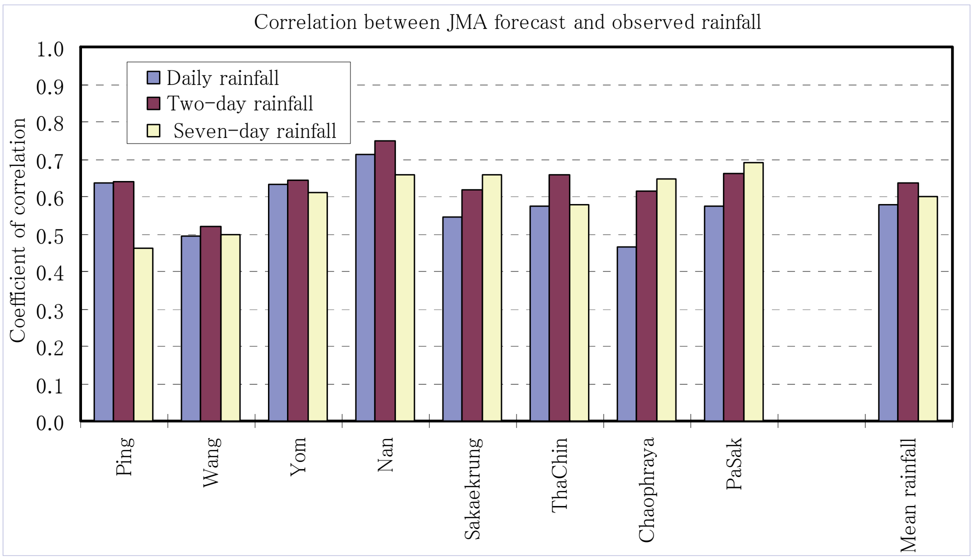


Fig. 53 Correlation between JMA forecast and observed rainfall

8.2 Standard deviation of error in JMA forecast rainfall

Standard deviations of difference between JMA forecast and observed rainfall (forecast rainfall minus observed rainfall) were calculated in eight sub-basins. The mean standard deviation in each sub-basin is 8 mm for one-day rainfall, 12 mm for two-day rainfall and 26 mm for seven-day rainfall. In each of the eight sub-basins, the percentage of error in forecast in the mean error in forecast plus or minus standard deviation ($\mu \pm \sigma$) was calculated. The mean percentage in eight sub-basins was 74%. The percentage of error in forecast in the mean error in forecast plus or minus double the standard deviation ($\mu \pm 2\sigma$) was 95%.

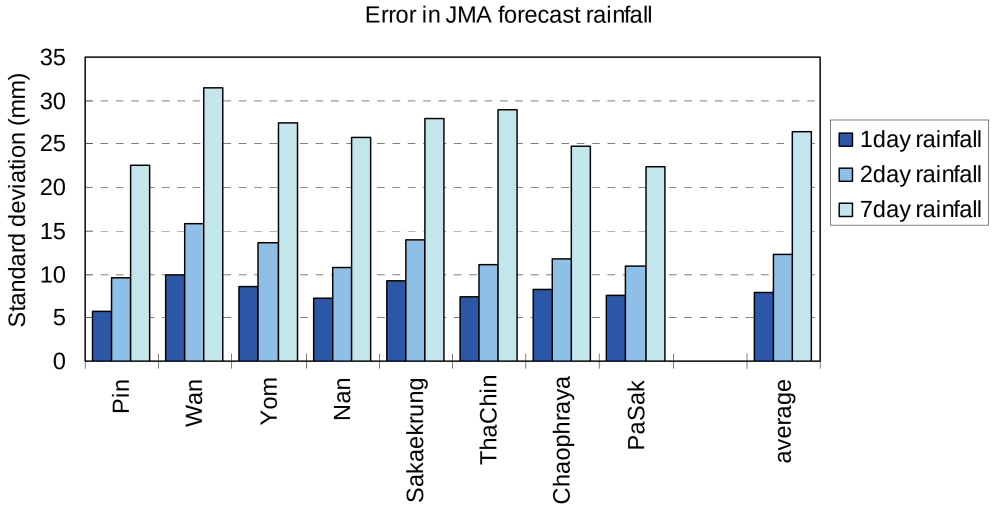


Fig. 54 Standard deviation of error in JMA forecast

Fig. 1 Standard deviation of error in JMA forecast

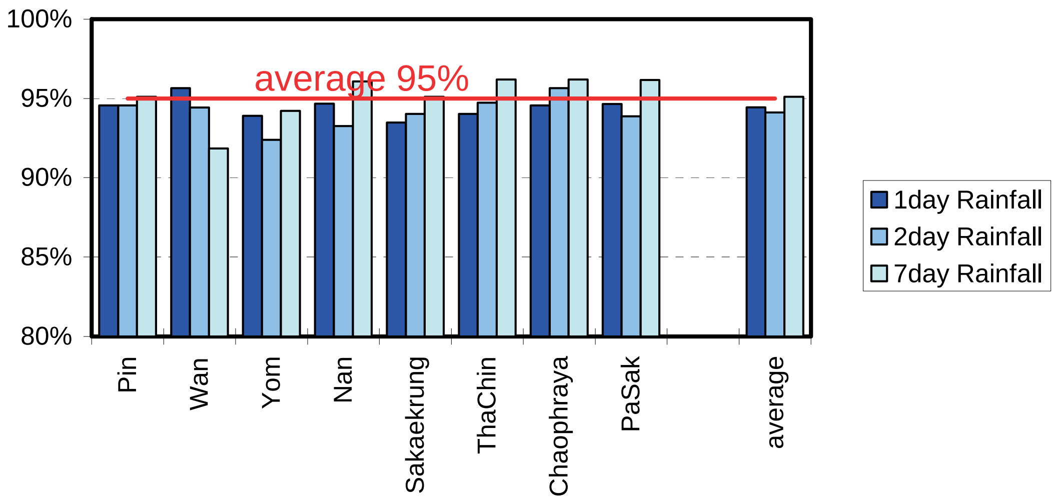


Fig. 55 Percentage of error in JMA forecast in the mean error in forecast plus or minus double the standard deviation ($\mu \pm 2\sigma$)

Based on the above discussion, the maximum and minimum forecast rainfall was set at forecast rainfall $\pm$ 2σ. The maximum and minimum forecast rainfall was specifically set as described below.

Daily forecast rainfall is obtained based on the difference in JMA cumulative forecast rainfall in each day up to seven days later (for example, the value obtained by subtracting cumulative forecast rainfall up to two days later from the cumulative forecast rainfall up to three days later is defined as the forecast rainfall on the third day).

The error was set at ± 52 mm for seven days and ± 52 mm divided by seven was distributed as the rainfall in each day. The maximum and minimum forecast rainfall was set as described below.

Table 8-2 Method of setting forecast rainfall

Maximum forecast rainfall on the first day (from present to 24 hours later)
= Forecast rainfall one day later + 52/7 mm
Minimum forecast rainfall on the first day (from present to 24 hours later)
= Forecast rainfall one day later - 52/7 mm
Maximum forecast rainfall on the second day (from 24 hours later to 48 hours later)
= Forecast rainfall two days later - forecast rainfall one day later + 52/7 mm
Minimum forecast rainfall on the second day (from 24 hours later to 48 hours later)
= Forecast rainfall two days later - forecast rainfall one day later - 52/7 mm
Subsequently, the maximum and minimum forecast rainfall up to the seventh day is set similarly on a daily basis.

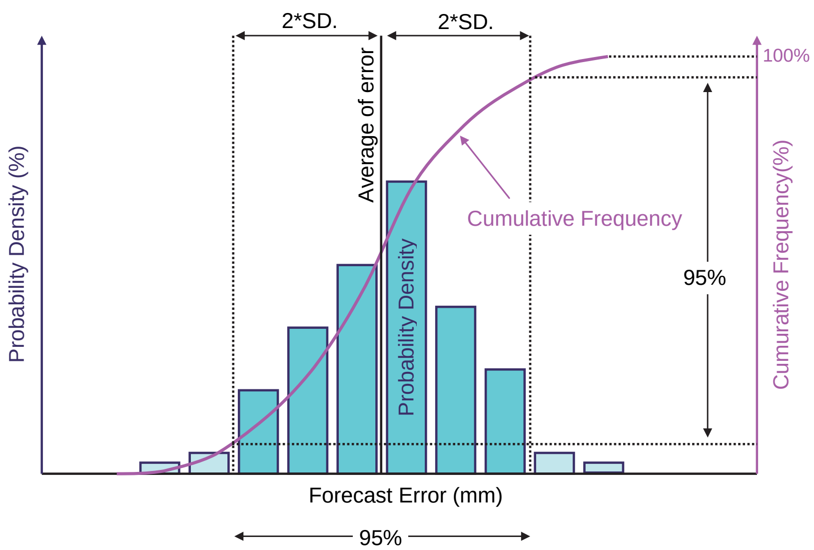
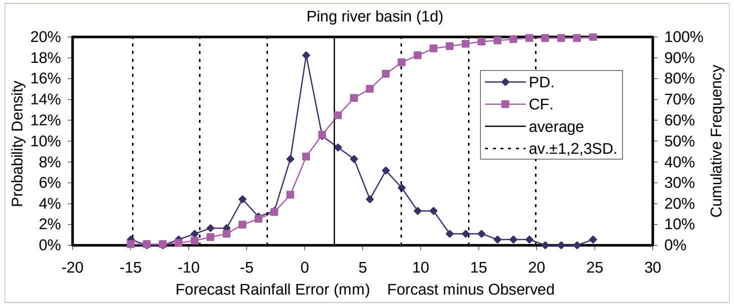
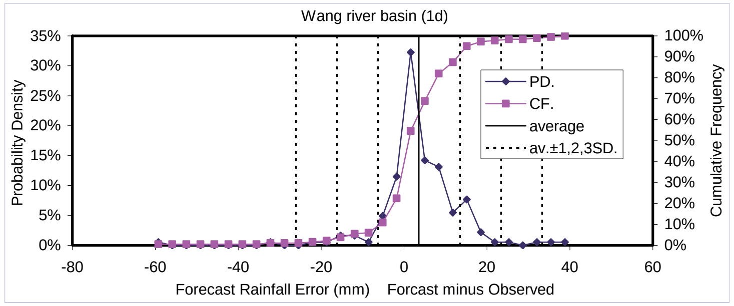


Fig. 56 Conceptual view of distribution of errors in forecast and percentage of error in ($\mu \pm 2\sigma$)

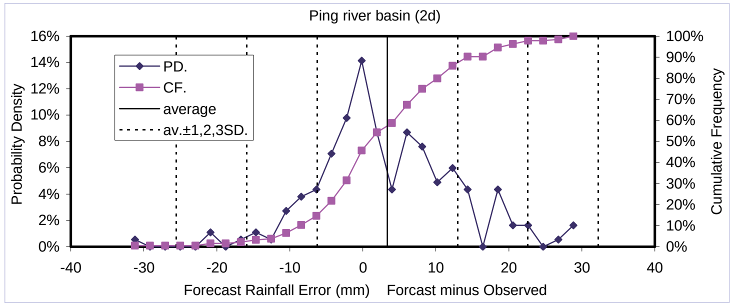
The above conceptual view shows the distribution of errors in forecast (forecast rainfall minus observed rainfall) used for setting forecast rainfall, and the percentage of error in the errors in mean forecast rainfall plus or minus double the standard deviation ($\mu \pm 2\sigma$). Errors in $\mu \pm 2\sigma$ account for 95% of all. The probability of rainfall occurring outside the range of forecast rainfall area (between maximum and minimum forecast rainfall) may be set at 5%.



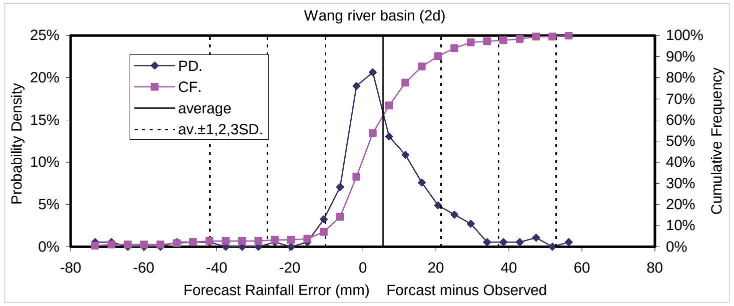
n	181
max	25.5
min	-15.7
average	2.6
SD	5.8
2*SD	11.6
3*SD	17.4
Abundance ratio	
-SD to SD	73.2%
-2SD to 2SD	94.1%
-3SD to 3SD	98.9%



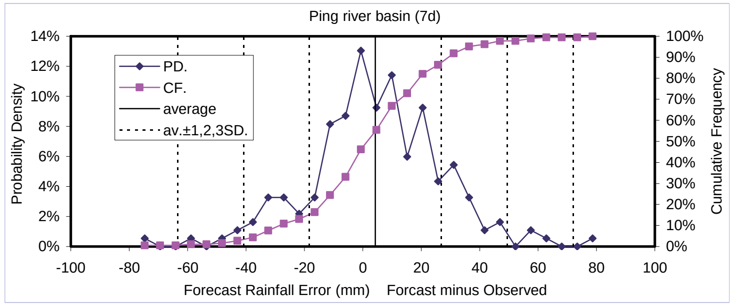
n	183
max	40.5
min	-61.0
average	3.6
SD	9.9
2*SD	19.8
3*SD	29.6
Abundance ratio	
-SD to SD	82.0%
-2SD to 2SD	94.6%
-3SD to 3SD	98.0%



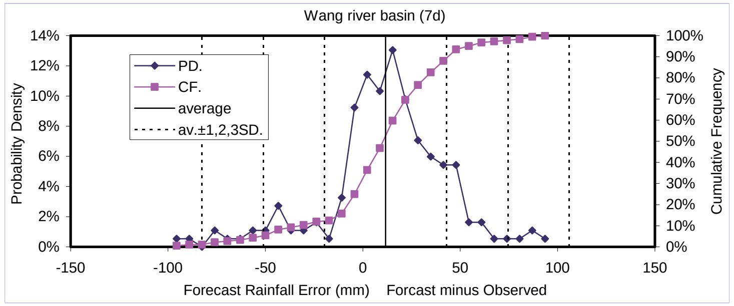
n	184
max	29.9
min	-32.2
average	3.4
SD	9.6
2*SD	19.3
3*SD	28.9
Abundance ratio	
-SD to SD	72.4%
-2SD to 2SD	95.2%
-3SD to 3SD	99.5%



n	184
max	58.7
min	-75.5
average	5.6
SD	15.8
2*SD	31.6
3*SD	47.4
Abundance ratio	
-SD to SD	83.1%
-2SD to 2SD	94.6%
-3SD to 3SD	96.9%



n	184
max	81.3
min	-77.3
average	4.3
SD	22.6
2*SD	45.1
3*SD	67.7
Abundance ratio	
-SD to SD	72.3%
-2SD to 2SD	94.5%
-3SD to 3SD	98.8%



n	184
max	96.8
min	-98.9
average	11.7
SD	31.4
2*SD	62.8
3*SD	94.3
Abundance ratio	
-SD to SD	77.2%
-2SD to 2SD	92.6%
-3SD to 3SD	98.9%

Fig. 57 Distribution of errors in JMA forecast rainfall (Ping river basin and Wnag river basin)

Analysis period: May 1 through Oct. 31, 2011 (except days with observed rainfall of 0 mm and forecast rainfall of 0 mm)

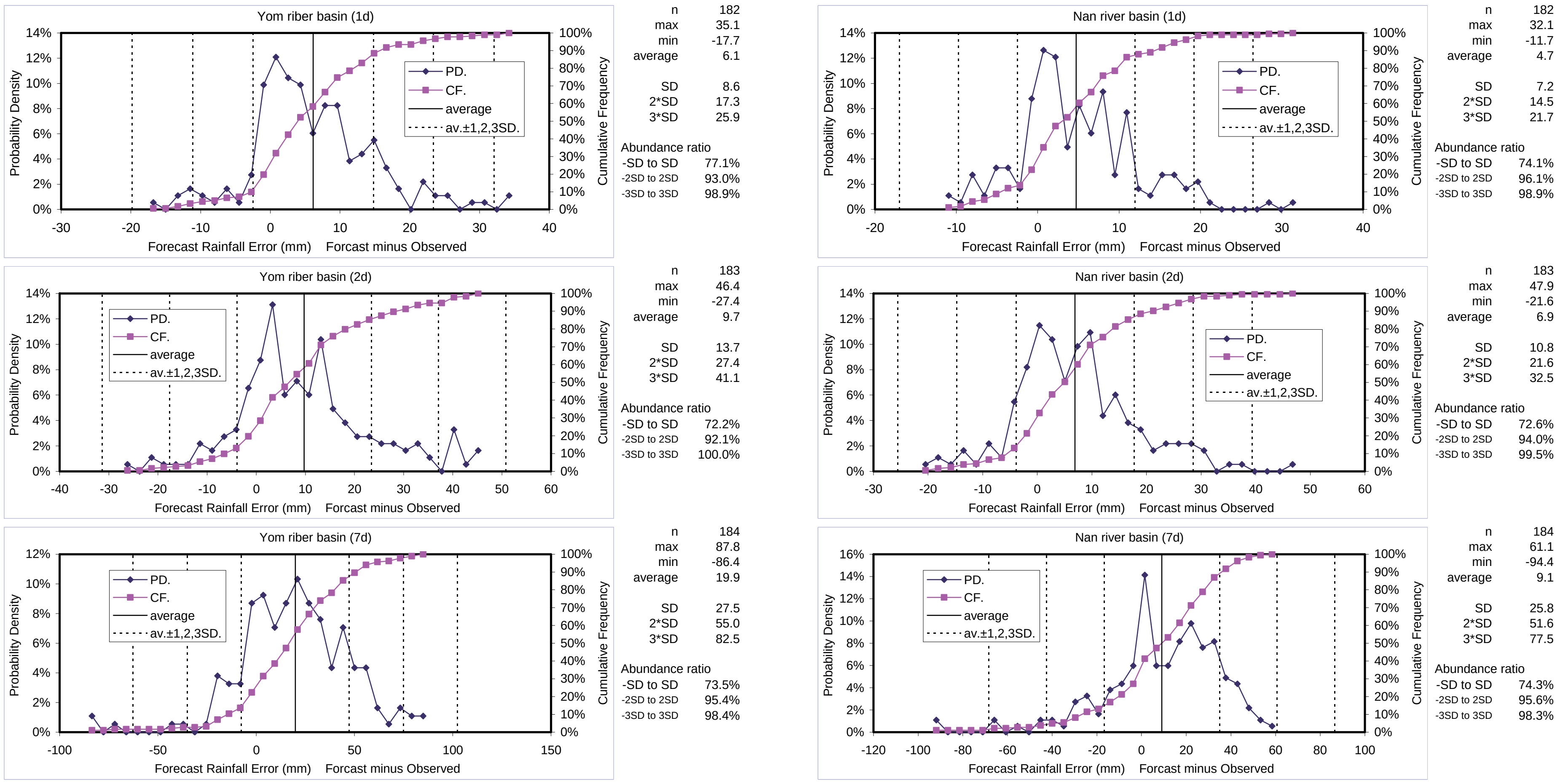
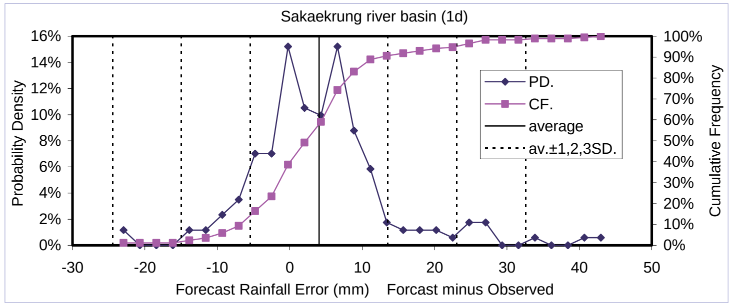
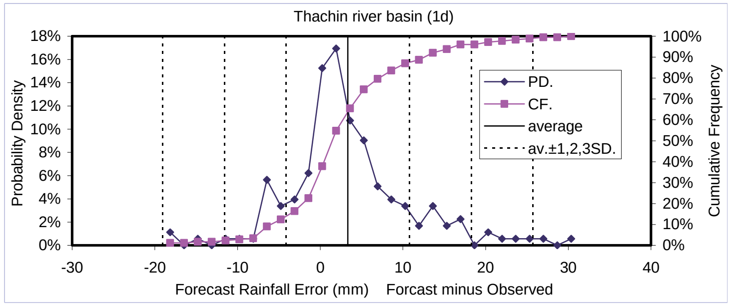


Fig. 58 Distribution of errors in JMA forecast rainfall (Yom river basin and Nan river basin)

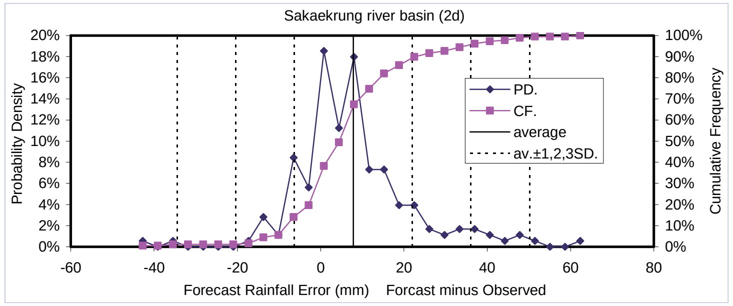
Analysis period: May 1 through Oct. 31, 2011 (except days with observed rainfall of 0 mm and forecast rainfall of 0 mm)



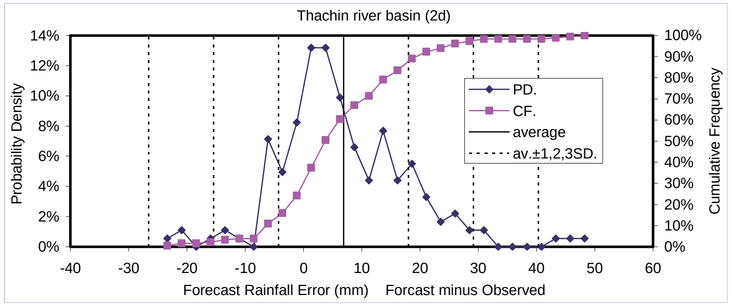
n	171
max	44.1
min	-24.1
average	4.1
SD	9.5
2*SD	19.0
3*SD	28.5
Abundance ratio	
-SD to SD	76.4%
-2SD to 2SD	93.4%
-3SD to 3SD	98.5%



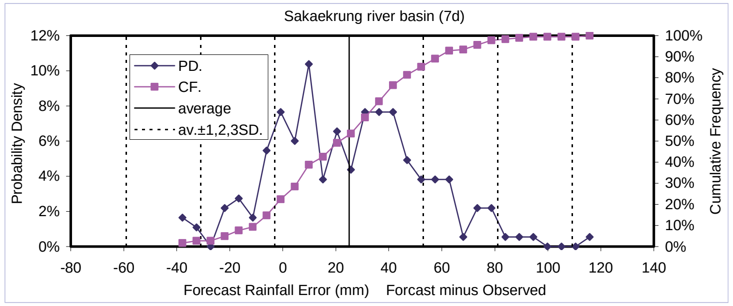
n	177
max	31.2
min	-19.0
average	3.3
SD	7.5
2*SD	14.9
3*SD	22.4
Abundance ratio	
-SD to SD	73.6%
-2SD to 2SD	93.8%
-3SD to 3SD	99.0%



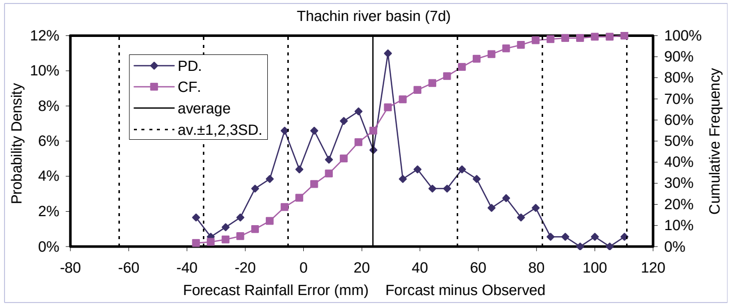
n	178
max	64.1
min	-44.5
average	7.8
SD	14.1
2*SD	28.2
3*SD	42.3
Abundance ratio	
-SD to SD	74.9%
-2SD to 2SD	94.4%
-3SD to 3SD	98.1%



n	182
max	49.5
min	-24.6
average	6.9
SD	11.2
2*SD	22.3
3*SD	33.5
Abundance ratio	
-SD to SD	73.1%
-2SD to 2SD	95.1%
-3SD to 3SD	98.4%



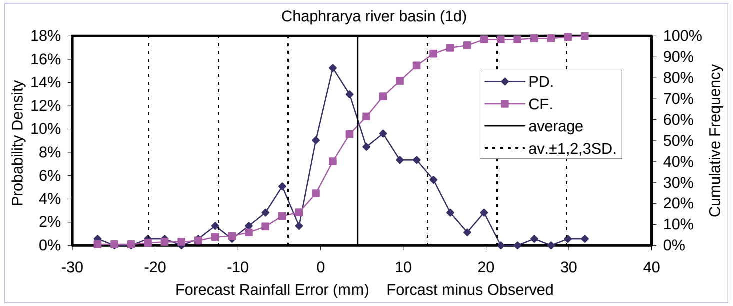
n	183
max	118.4
min	-40.5
average	25.0
SD	28.0
2*SD	56.1
3*SD	84.1
Abundance ratio	
-SD to SD	66.7%
-2SD to 2SD	95.3%
-3SD to 3SD	99.5%



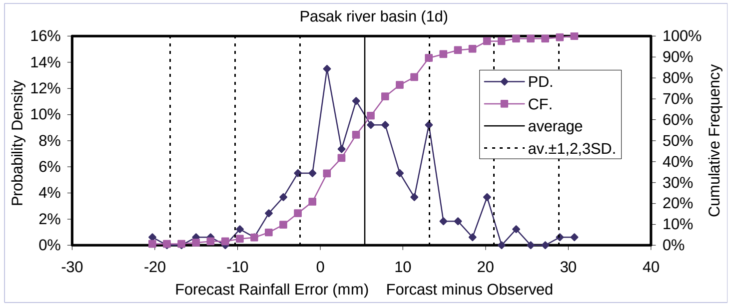
n	182
max	112.7
min	-39.4
average	23.8
SD	29.1
2*SD	58.1
3*SD	87.2
Abundance ratio	
-SD to SD	64.1%
-2SD to 2SD	96.1%
-3SD to 3SD	100.0%

Fig. 59 Distribution of errors in JMA forecast rainfall (Sakaekrung river basin and Tha Chin river basin)

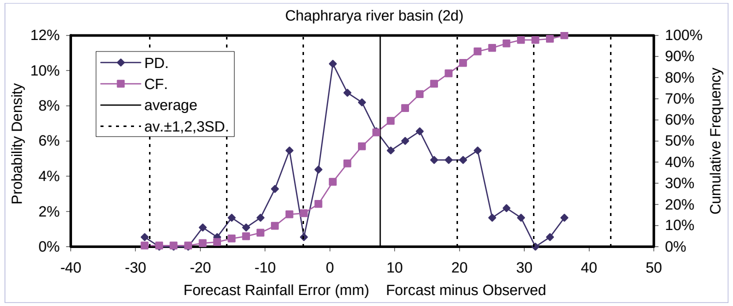
Analysis period: May 1 through Oct. 31, 2011 (except days with observed rainfall of 0 mm and forecast rainfall of 0 mm)



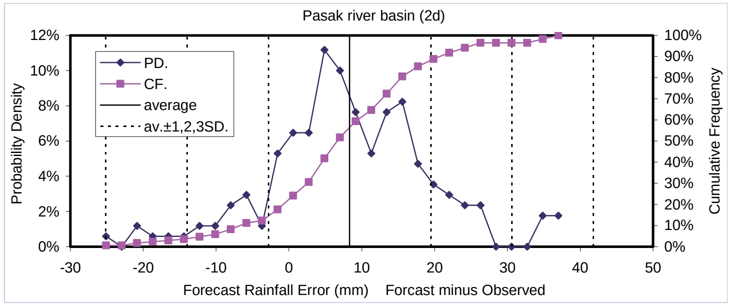
n	177
max	32.9
min	-28.0
average	4.5
SD	8.4
2*SD	16.8
3*SD	25.3
Abundance ratio	
-SD to SD	74.7%
-2SD to 2SD	94.2%
-3SD to 3SD	98.2%



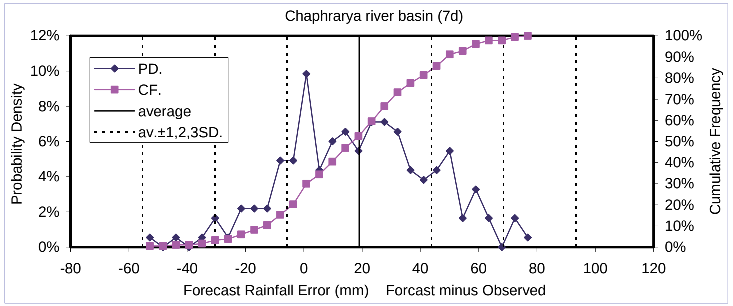
n	163
max	31.6
min	-21.2
average	5.4
SD	7.8
2*SD	15.7
3*SD	23.5
Abundance ratio	
-SD to SD	73.6%
-2SD to 2SD	94.9%
-3SD to 3SD	98.7%



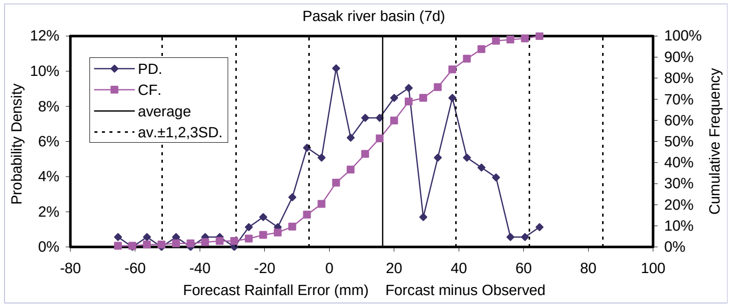
n	183
max	37.3
min	-29.7
average	7.8
SD	11.9
2*SD	23.7
3*SD	35.6
Abundance ratio	
-SD to SD	69.0%
-2SD to 2SD	94.6%
-3SD to 3SD	99.5%



n	170
max	38.1
min	-26.2
average	8.3
SD	11.2
2*SD	22.3
3*SD	33.5
Abundance ratio	
-SD to SD	73.7%
-2SD to 2SD	92.7%
-3SD to 3SD	100.0%



n	183
max	79.1
min	-55.0
average	19.0
SD	24.8
2*SD	49.5
3*SD	74.3
Abundance ratio	
-SD to SD	66.2%
-2SD to 2SD	94.8%
-3SD to 3SD	100.0%



n	177
max	67.2
min	-67.6
average	16.5
SD	22.7
2*SD	45.4
3*SD	68.0
Abundance ratio	
-SD to SD	69.4%
-2SD to 2SD	96.3%
-3SD to 3SD	98.8%

Fig. 60 Distribution of errors in JMA forecast rainfall (Chaophraya river basin and PaSak river basin)

Analysis period: May 1 through Oct. 31, 2011 (except days with observed rainfall of 0 mm and forecast rainfall of 0 mm)

8.3 Validity of dividing the error in seven-day rainfall equally into seven

In temporary operation, the standard deviation of error in seven-day forecast rainfall was calculated and, based on the standard deviation, the maximum and minimum forecast rainfall up to seven days later was set on a daily basis. The validity of dividing the error set based on the seven-day rainfall equally into seven is analyzed as described below.

Error in forecast rainfall (=forecast rainfall minus observed rainfall) was calculated for JMA forecast rainfall (cumulative rainfall) up to one, two, three, four, five, six and seven days later in the April-November period between October 24, 2007 and November 30, 2011. A distribution of errors in forecast rainfall was verified. Fig. 61 shows mean error in forecast rainfall ± maximum error in forecast rainfall, mean error in forecast rainfall ± minimum error in forecast rainfall and mean error in forecast rainfall ± double the standard deviation of error in forecast rainfall (mean value in eight sub-basins) in each of the eight sub-basins of the Chaophraya river basin. The thin red lines indicating mean error in forecast rainfall ± 2SD (at 7d)/7 show daily values obtained by dividing equally into seven the mean error in forecast rainfall ± 2σ. Comparing the thin and thick red lines enables the verification of the validity of dividing an error concerning seven-day rainfall equally into seven. Fig. 61 shows that the error (exactly mean error ± 2SD, which is represented by thick red lines) calculated based on the one- to seven-day forecast rainfall according to the period of forecasting is larger than the error calculated based on the seven-day forecast rainfall and divided by seven. This may be because time-series errors (differences between forecast and observed rainfall depending on the time of rainfall) are eliminated in long-term forecasts. In view of the above results, errors should be set based on the forecast rainfall up to one to seven days later.

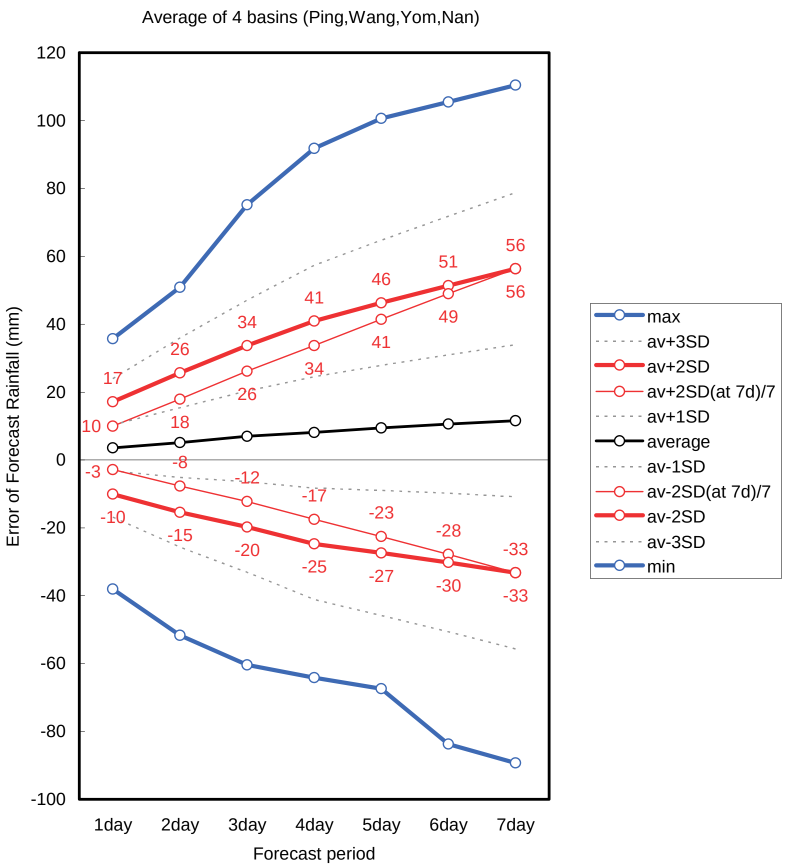


Fig. 61 Comparison in error in forecast rainfall (mean error calculated in four sub-divisions)

Fig. 62 compares the error calculated for mean rainfall upstream of Nakhon Sawan based on the forecast rainfall one to seven days later according to the period of forecast (exactly mean error ± 2SD, which is represented by thick red lines) with the error calculated based on the seven-day forecast rainfall and divided by seven. The relationship is similar to that in the case where the mean error is calculated in four sub-basins (Ping, Wang, Yom and Nan). The error was smaller in the case where errors were calculated throughout the area upstream of Nakhon Sawan that in the case where the errors calculated in four sub-basins were averaged.

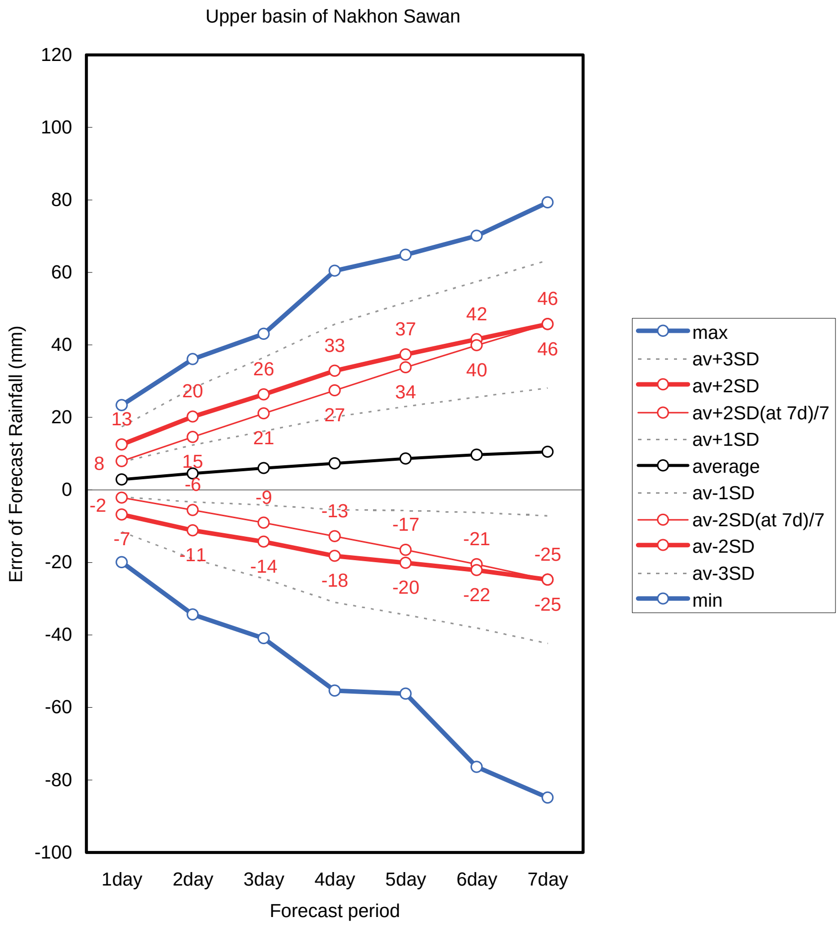


Fig. 62 Comparison in error in forecast rainfall (mean error calculated in the basin at Nakhon Sawan)

Fig. 63 shows the percentages of error in JMA forecast rainfall in the mean error in forecast rainfall plus or minus standard deviation, double the standard deviation and triple the standard deviation (mean forecast rainfall ± 1, 2, 3SD) calculated in nine sub-basins (eight sub-basins of the Chaophraya basin and an area upstream of Nakhon Sawan). Approximately 75% of all errors in forecast rainfall are in the area of the standard deviation. Approximately 95% are in the area of double the standard deviation and approximately 98% in the area of triple the standard deviation.

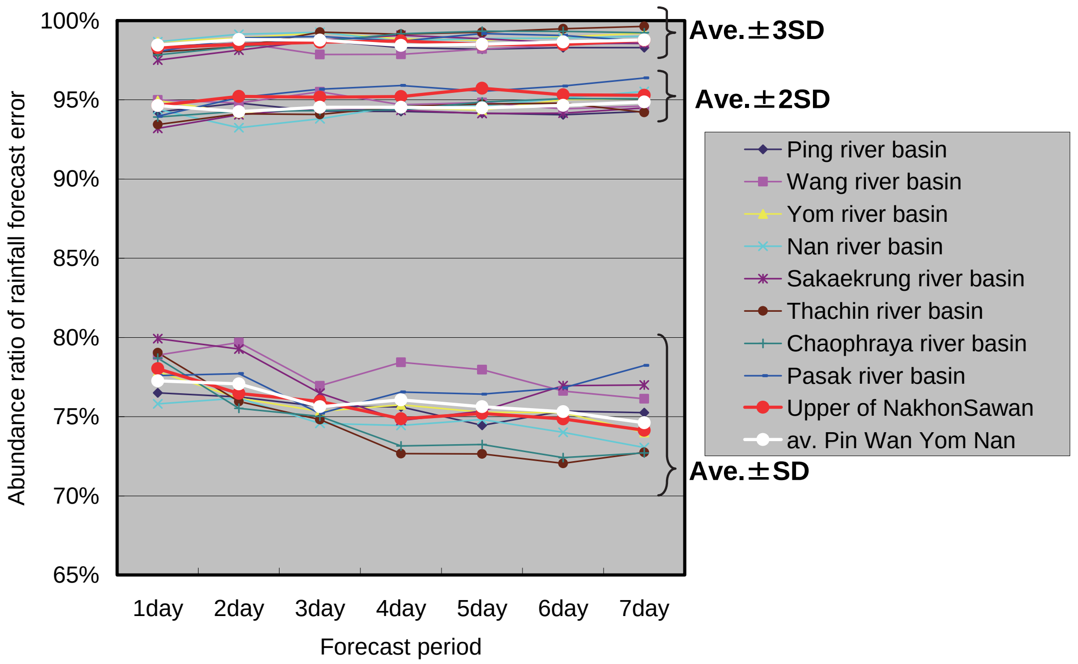
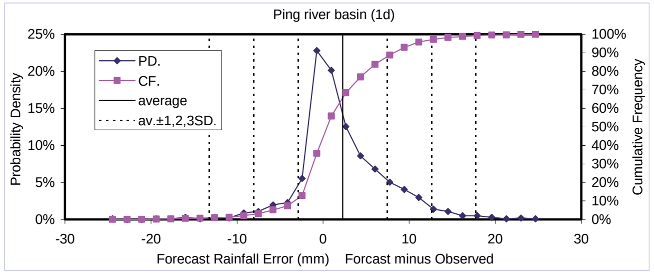


Fig. 63 Percentage of mean error in forecast rainfall in standard deviation (in nine sub-basins)

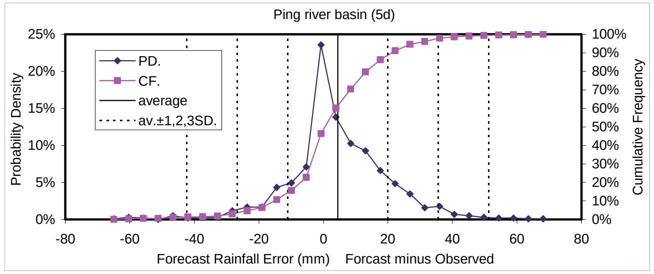
Analysis period: Apr. through Nov. between Oct. 24, 2007 and Nov. 30, 2011



n 1013
max 25.5
min -25.3
average 2.3

SD 5.2
2*SD 10.3
3*SD 15.5

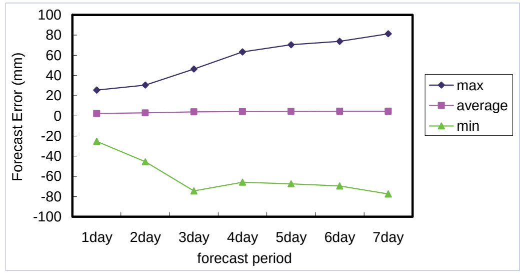
Abundance ratio
-SD to SD 76.5%
-2SD to 2SD 94.2%
-3SD to 3SD 98.4%

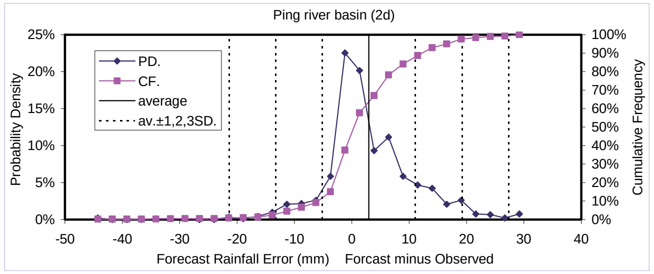


n 1014
max 70.4
min -67.3
average 4.5

SD 15.6
2*SD 31.2
3*SD 46.7

Abundance ratio
-SD to SD 74.5%
-2SD to 2SD 94.2%
-3SD to 3SD 98.2%

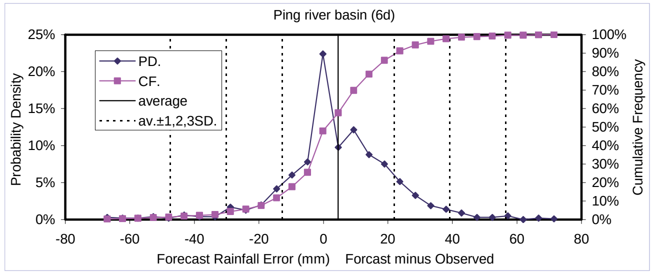




n 923
max 30.5
min -45.5
average 3.0

SD 8.1
2*SD 16.2
3*SD 24.4

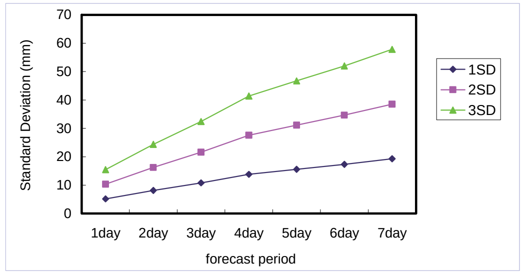
Abundance ratio
-SD to SD 76.2%
-2SD to 2SD 94.8%
-3SD to 3SD 98.6%

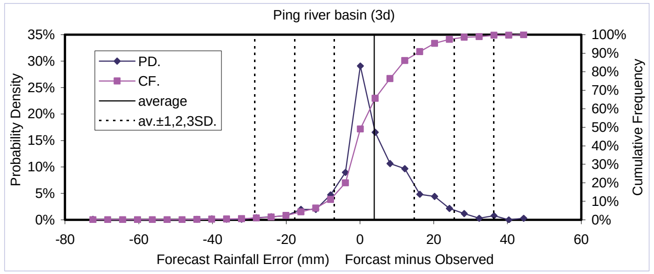


n 1014
max 73.9
min -69.4
average 4.6

SD 17.3
2*SD 34.7
3*SD 52.0

Abundance ratio
-SD to SD 75.4%
-2SD to 2SD 94.1%
-3SD to 3SD 98.3%

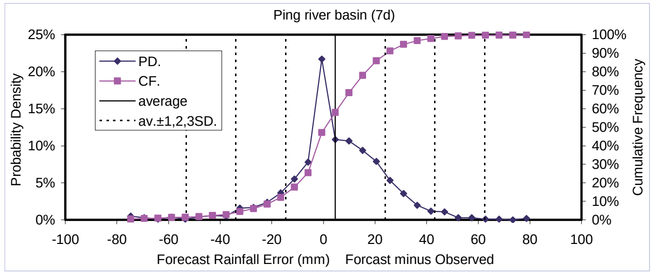




n 1014
max 46.4
min -74.4
average 3.9

SD 10.8
2*SD 21.6
3*SD 32.4

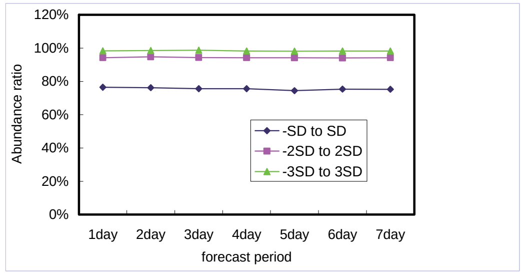
Abundance ratio
-SD to SD 75.6%
-2SD to 2SD 94.3%
-3SD to 3SD 98.7%

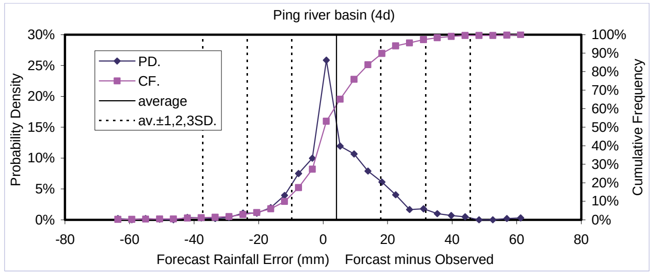


n 1014
max 81.3
min -77.3
average 4.6

SD 19.3
2*SD 38.6
3*SD 57.8

Abundance ratio
-SD to SD 75.3%
-2SD to 2SD 94.3%
-3SD to 3SD 98.3%





n 1013
max 63.4
min -65.8
average 4.1

SD 13.8
2*SD 27.6
3*SD 41.4

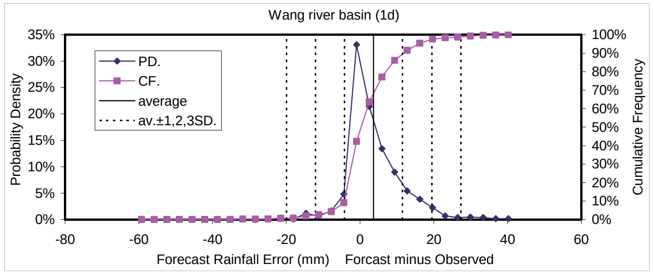
Abundance ratio
-SD to SD 75.6%
-2SD to 2SD 94.3%
-3SD to 3SD 98.3%

forecast period	Forecast Error (mm)			Standard Deviation (mm)			Abundance ratio		
	max	average	min	1SD	2SD	3SD	-SD to SD	-2SD to 2SD	-3SD to 3SD
1day	25.5	2.3	-25.3	5.2	10.3	15.5	76.5%	94.2%	98.4%
2day	30.5	3.0	-45.5	8.1	16.2	24.4	76.2%	94.8%	98.6%
3day	46.4	3.9	-74.4	10.8	21.6	32.4	75.6%	94.3%	98.7%
4day	63.4	4.1	-65.8	13.8	27.6	41.4	75.6%	94.3%	98.3%
5day	70.4	4.5	-67.3	15.6	31.2	46.7	74.5%	94.2%	98.2%
6day	73.9	4.6	-69.4	17.3	34.7	52.0	75.4%	94.1%	98.3%
7day	81.3	4.6	-77.3	19.3	38.6	57.8	75.3%	94.3%	98.3%

Fig. 64 Distribution of errors in forecast rainfall (JMA forecast rainfall - observed rainfall)

Ping river basin

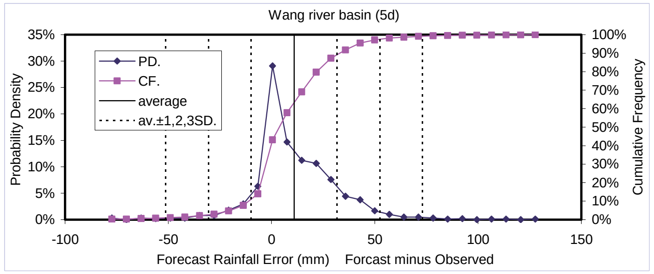
Analysis period: Apr. through Nov. between Oct. 24, 2007 and Nov. 30, 2011Study rainfall: one-, two-, three-, four-, five-, six- and seven-day rainfall



n 1013
max 41.9
min -61.0
average 3.7

SD 7.9
2*SD 15.8
3*SD 23.6

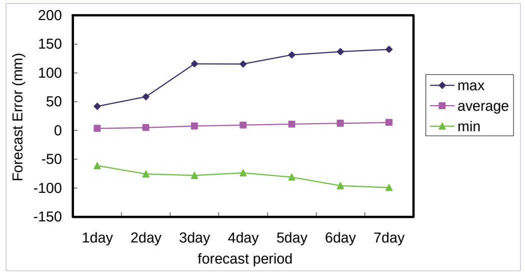
Abundance ratio
-SD to SD 78.9%
-2SD to 2SD 95.0%
-3SD to 3SD 98.1%

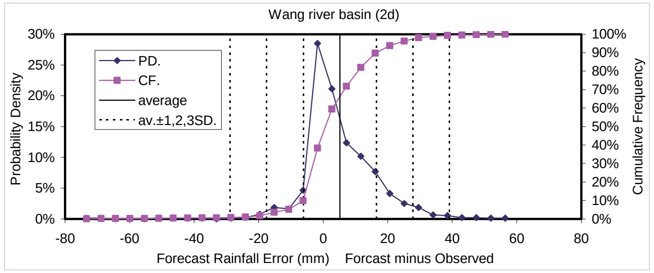


n 1014
max 131.3
min -80.9
average 10.9

SD 20.7
2*SD 41.5
3*SD 62.2

Abundance ratio
-SD to SD 78.0%
-2SD to 2SD 94.8%
-3SD to 3SD 98.2%

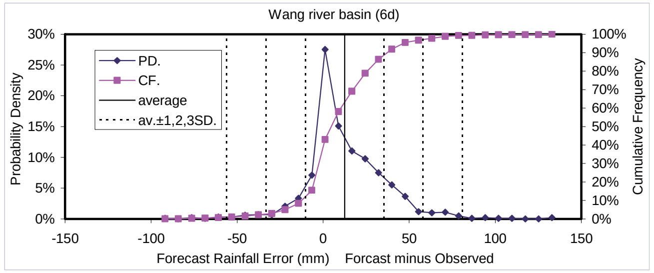




n 923
max 58.7
min -75.5
average 5.2

SD 11.3
2*SD 22.6
3*SD 33.9

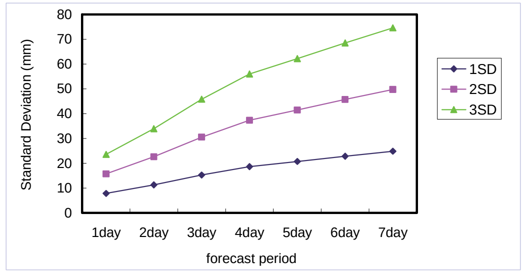
Abundance ratio
-SD to SD 79.7%
-2SD to 2SD 94.8%
-3SD to 3SD 98.6%

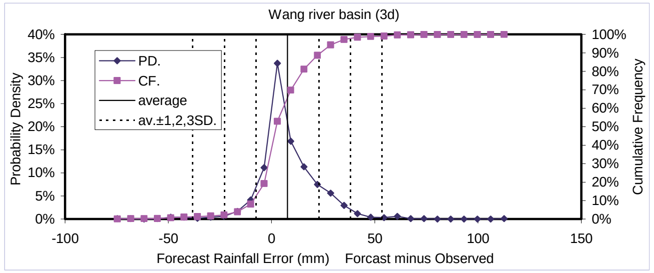


n 1014
max 136.8
min -95.8
average 12.4

SD 22.8
2*SD 45.7
3*SD 68.5

Abundance ratio
-SD to SD 76.6%
-2SD to 2SD 94.4%
-3SD to 3SD 98.5%

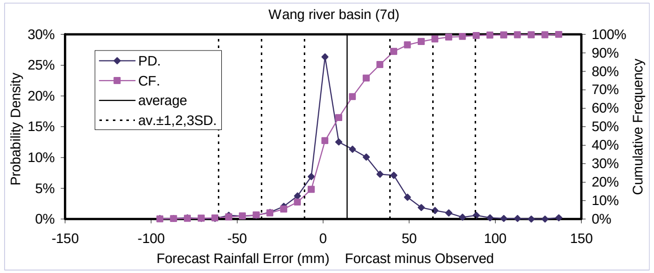




n 1014
max 115.8
min -77.9
average 7.7

SD 15.3
2*SD 30.6
3*SD 45.8

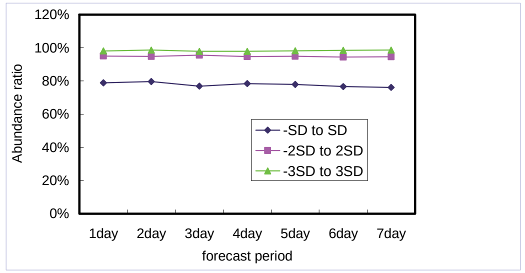
Abundance ratio
-SD to SD 76.9%
-2SD to 2SD 95.5%
-3SD to 3SD 97.9%

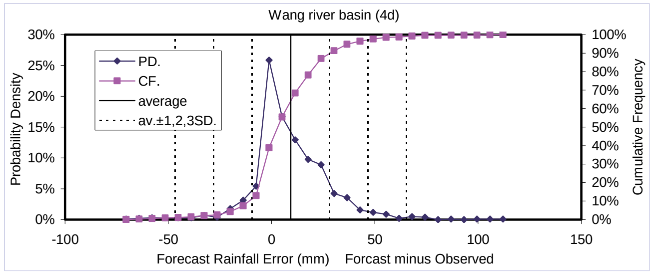


n 1014
max 140.9
min -98.9
average 13.9

SD 24.9
2*SD 49.7
3*SD 74.6

Abundance ratio
-SD to SD 76.1%
-2SD to 2SD 94.6%
-3SD to 3SD 98.6%





n 1013
max 115.2
min -73.5
average 9.3

SD 18.7
2*SD 37.3
3*SD 56.0

Abundance ratio
-SD to SD 78.4%
-2SD to 2SD 94.7%
-3SD to 3SD 97.9%

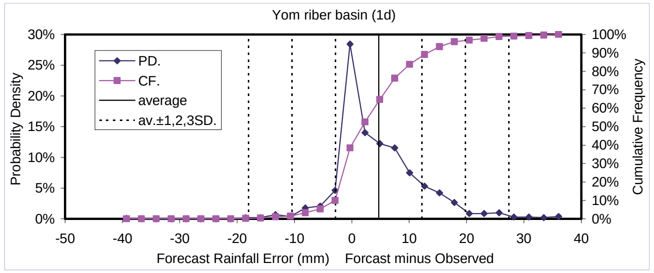
forecast	Forecast Error (mm)			Standard Deviation (mm)			Abundance ratio		
period	max	average	min	1SD	2SD	3SD	-SD to SD	-2SD to 2SD	-3SD to 3SD
1day	41.9	3.7	-61.0	7.9	15.8	23.6	78.9%	95.0%	98.1%
2day	58.7	5.2	-75.5	11.3	22.6	33.9	79.7%	94.8%	98.6%
3day	115.8	7.7	-77.9	15.3	30.6	45.8	76.9%	95.5%	97.9%
4day	115.2	9.3	-73.5	18.7	37.3	56.0	78.4%	94.7%	97.9%
5day	131.3	10.9	-80.9	20.7	41.5	62.2	78.0%	94.8%	98.2%
6day	136.8	12.4	-95.8	22.8	45.7	68.5	76.6%	94.4%	98.5%
7day	140.9	13.9	-98.9	24.9	49.7	74.6	76.1%	94.6%	98.6%

Fig. 65 Distribution of errors in forecast rainfall (JMA forecast rainfall - observed rainfall)

Wang river basin

Analysis period: Apr. through Nov. between Oct. 24, 2007 and Nov. 30, 2011

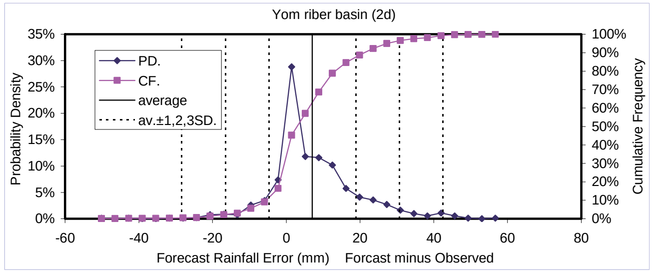
Study rainfall: one-, two-, three-, four-, five-, six- and seven-day rainfall



n 1013
max 37.4
min -40.6
average 4.7

SD 7.6
2*SD 15.1
3*SD 22.7

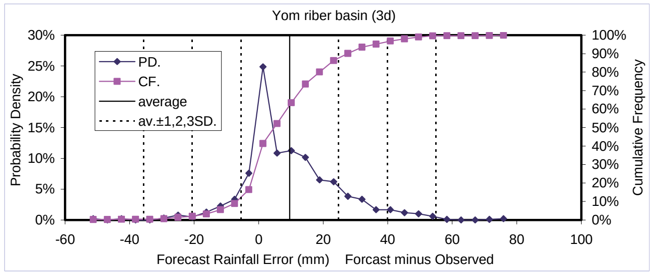
Abundance ratio
-SD to SD 77.8%
-2SD to 2SD 95.0%
-3SD to 3SD 98.7%



n 923
max 58.5
min -52.0
average 7.1

SD 11.8
2*SD 23.6
3*SD 35.4

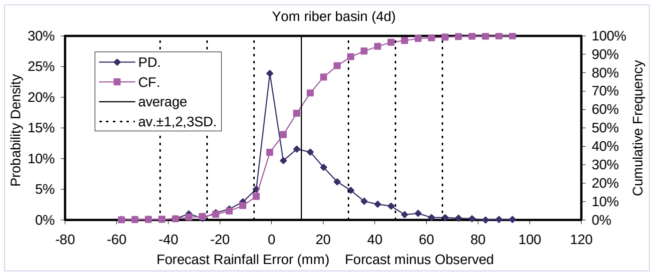
Abundance ratio
-SD to SD 76.2%
-2SD to 2SD 94.2%
-3SD to 3SD 98.9%



n 1014
max 78.1
min -53.5
average 9.6

SD 15.1
2*SD 30.2
3*SD 45.3

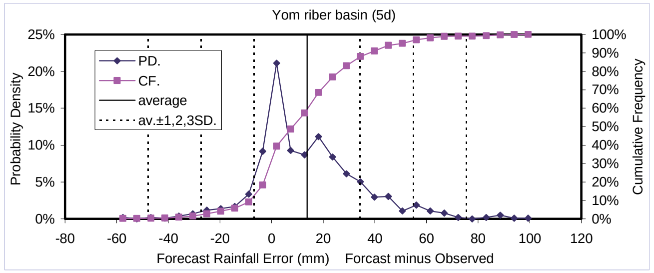
Abundance ratio
-SD to SD 75.3%
-2SD to 2SD 94.5%
-3SD to 3SD 99.2%



n 1013
max 95.9
min -60.7
average 11.5

SD 18.2
2*SD 36.4
3*SD 54.7

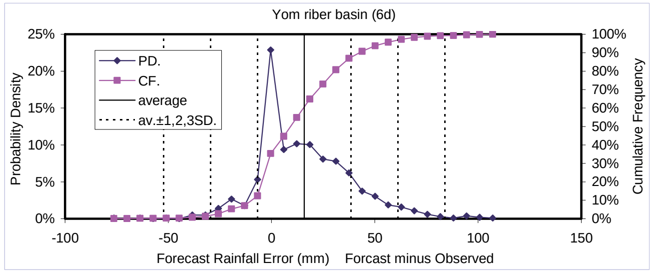
Abundance ratio
-SD to SD 75.7%
-2SD to 2SD 94.5%
-3SD to 3SD 98.8%



n 1014
max 102.1
min -60.3
average 13.8

SD 20.6
2*SD 41.1
3*SD 61.7

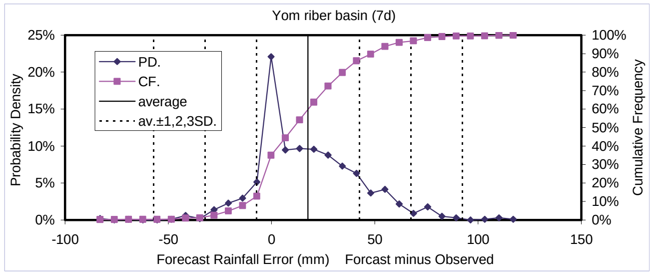
Abundance ratio
-SD to SD 75.3%
-2SD to 2SD 94.4%
-3SD to 3SD 98.8%



n 1014
max 110.2
min -79.5
average 15.8

SD 22.7
2*SD 45.4
3*SD 68.1

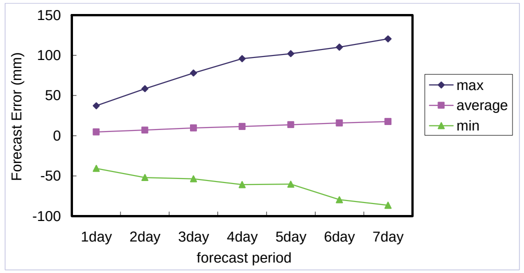
Abundance ratio
-SD to SD 75.2%
-2SD to 2SD 95.0%
-3SD to 3SD 99.0%

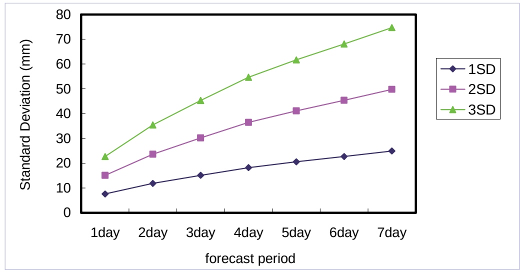


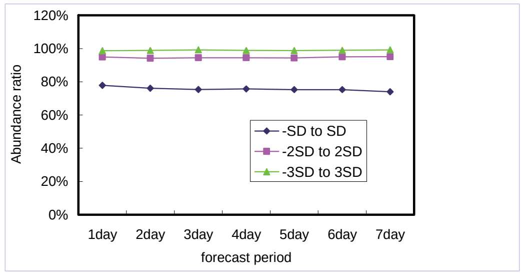
n 1014
max 120.5
min -86.4
average 17.7

SD 24.9
2*SD 49.8
3*SD 74.7

Abundance ratio
-SD to SD 74.0%
-2SD to 2SD 95.1%
-3SD to 3SD 99.2%







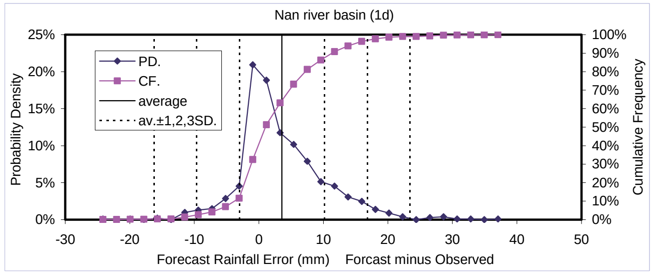
forecast	Forecast Error (mm)			Standard Deviation (mm)			Abundance ratio		
period	max	average	min	1SD	2SD	3SD	-SD to SD	-2SD to 2SD	-3SD to 3SD
1day	37.4	4.7	-40.6	7.6	15.1	22.7	77.8%	95.0%	98.7%
2day	58.5	7.1	-52.0	11.8	23.6	35.4	76.2%	94.2%	98.9%
3day	78.1	9.6	-53.5	15.1	30.2	45.3	75.3%	94.5%	99.2%
4day	95.9	11.5	-60.7	18.2	36.4	54.7	75.7%	94.5%	98.8%
5day	102.1	13.8	-60.3	20.6	41.1	61.7	75.3%	94.4%	98.8%
6day	110.2	15.8	-79.5	22.7	45.4	68.1	75.2%	95.0%	99.0%
7day	120.5	17.7	-86.4	24.9	49.8	74.7	74.0%	95.1%	99.2%

Fig. 66 Distribution of errors in forecast rainfall (JMA forecast rainfall - observed rainfall)

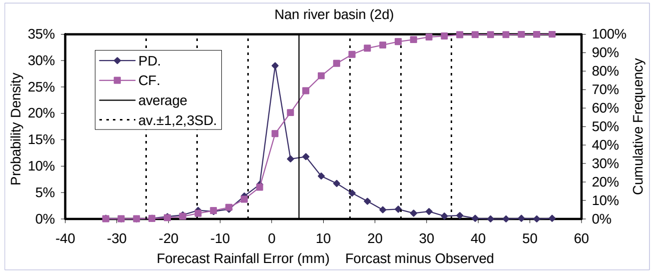
Yom river basin

Analysis period: Apr. through Nov. between Oct. 24, 2007 and Nov. 30, 2011

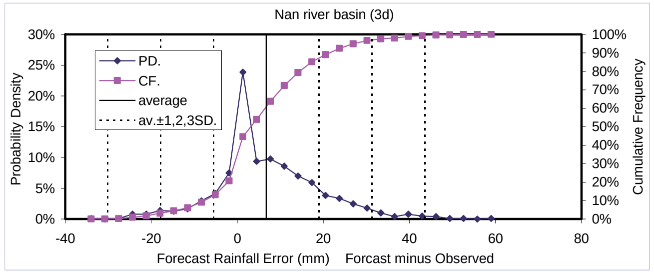
Study rainfall: one-, two-, three-, four-, five-, six- and seven-day rainfall



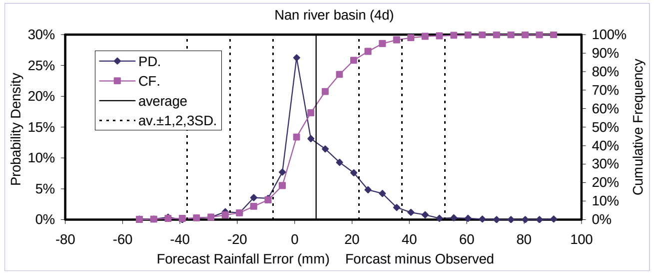
n	1013
max	38.1
min	-25.2
average	3.6
SD	6.6
2*SD	13.2
3*SD	19.8
Abundance ratio	
-SD to SD	75.8%
-2SD to 2SD	94.4%
-3SD to 3SD	98.7%



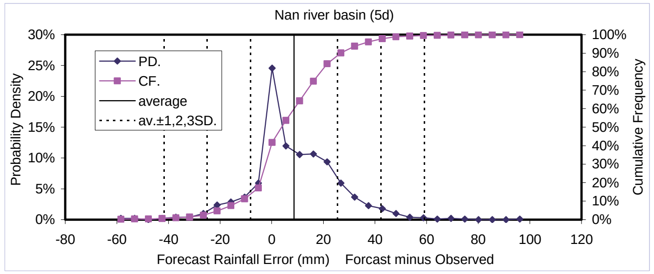
n	923
max	55.8
min	-33.6
average	5.3
SD	9.9
2*SD	19.7
3*SD	29.6
Abundance ratio	
-SD to SD	76.2%
-2SD to 2SD	93.2%
-3SD to 3SD	99.2%



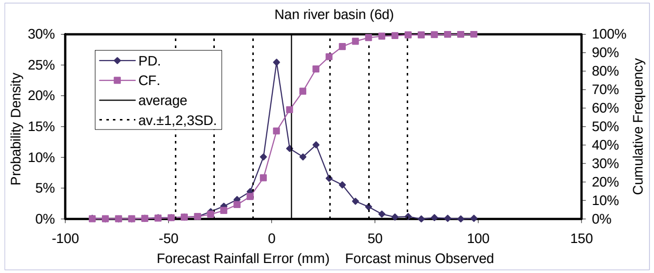
n	1014
max	60.6
min	-35.6
average	6.7
SD	12.3
2*SD	24.6
3*SD	36.9
Abundance ratio	
-SD to SD	74.6%
-2SD to 2SD	93.8%
-3SD to 3SD	99.3%



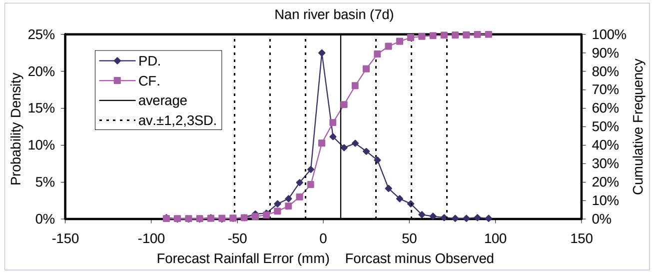
n	1013
max	92.8
min	-56.6
average	7.5
SD	15.0
2*SD	29.9
3*SD	44.9
Abundance ratio	
-SD to SD	74.4%
-2SD to 2SD	94.6%
-3SD to 3SD	98.7%



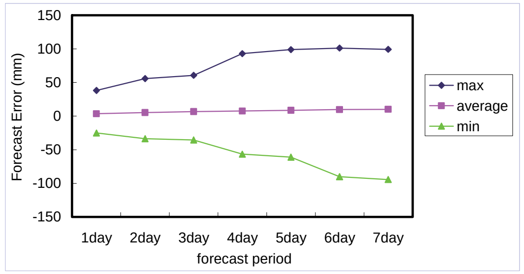
n	1014
max	98.8
min	-61.1
average	8.7
SD	16.8
2*SD	33.6
3*SD	50.4
Abundance ratio	
-SD to SD	74.8%
-2SD to 2SD	94.6%
-3SD to 3SD	98.9%

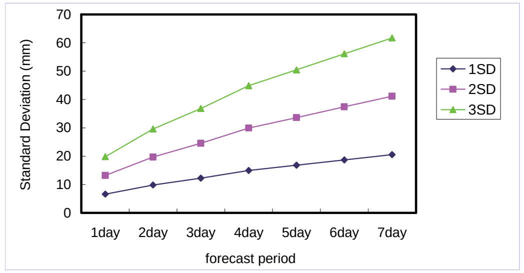


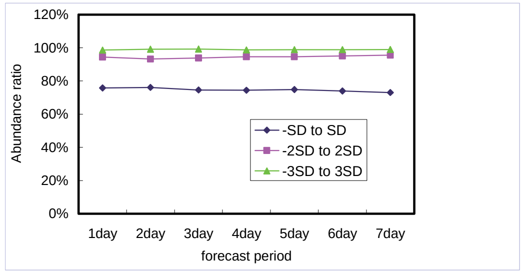
n	1014
max	101.1
min	-90.1
average	9.6
SD	18.7
2*SD	37.4
3*SD	56.1
Abundance ratio	
-SD to SD	74.0%
-2SD to 2SD	95.1%
-3SD to 3SD	98.9%



n	1014
max	99.2
min	-94.4
average	10.1
SD	20.6
2*SD	41.1
3*SD	61.7
Abundance ratio	
-SD to SD	73.0%
-2SD to 2SD	95.5%
-3SD to 3SD	99.0%







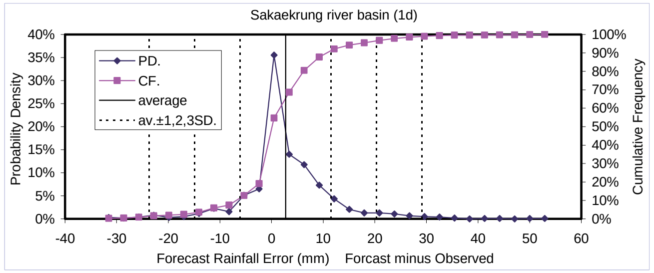
forecast	Forecast Error (mm)			Standard Deviation (mm)			Abundance ratio		
period	max	average	min	1SD	2SD	3SD	-SD to SD	-2SD to 2SD	-3SD to 3SD
1day	38.1	3.6	-25.2	6.6	13.2	19.8	75.8%	94.4%	98.7%
2day	55.8	5.3	-33.6	9.9	19.7	29.6	76.2%	93.2%	99.2%
3day	60.6	6.7	-35.6	12.3	24.6	36.9	74.6%	93.8%	99.3%
4day	92.8	7.5	-56.6	15.0	29.9	44.9	74.4%	94.6%	98.7%
5day	98.8	8.7	-61.1	16.8	33.6	50.4	74.8%	94.6%	98.9%
6day	101.1	9.6	-90.1	18.7	37.4	56.1	74.0%	95.1%	98.9%
7day	99.2	10.1	-94.4	20.6	41.1	61.7	73.0%	95.5%	99.0%

Fig. 67 Distribution of errors in forecast rainfall (JMA forecast rainfall - observed rainfall)

Nan river basin

Analysis period: Apr. through Nov. between Oct. 24, 2007 and Nov. 30, 2011

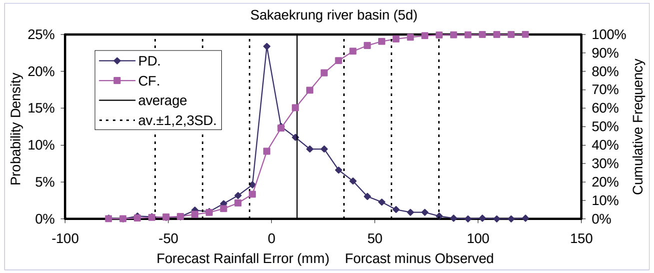
Study rainfall: one-, two-, three-, four-, five-, six- and seven-day rainfall



n 1013
max 54.4
min -33.0
average 2.7

SD 8.8
2*SD 17.6
3*SD 26.5

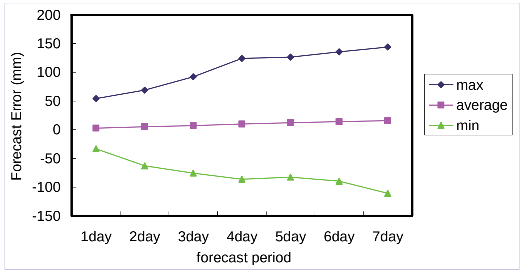
Abundance ratio
-SD to SD 79.9%
-2SD to 2SD 93.2%
-3SD to 3SD 97.5%

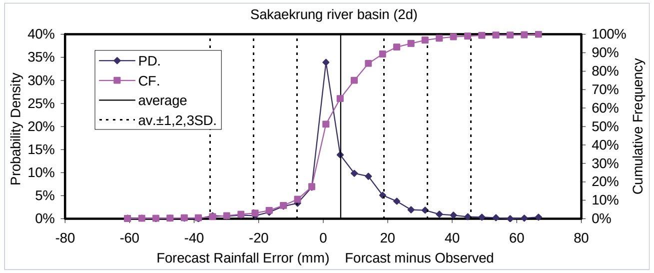


n 1014
max 126.5
min -82.4
average 12.3

SD 22.9
2*SD 45.8
3*SD 68.7

Abundance ratio
-SD to SD 75.4%
-2SD to 2SD 94.1%
-3SD to 3SD 98.9%

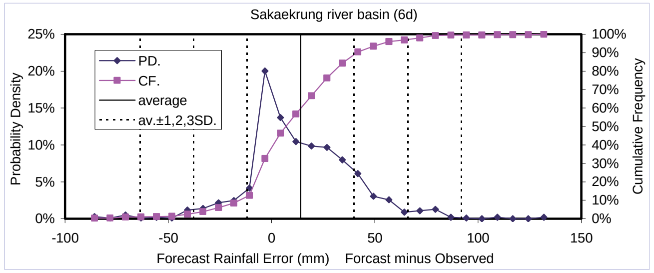




n 923
max 68.9
min -62.8
average 5.4

SD 13.5
2*SD 27.0
3*SD 40.4

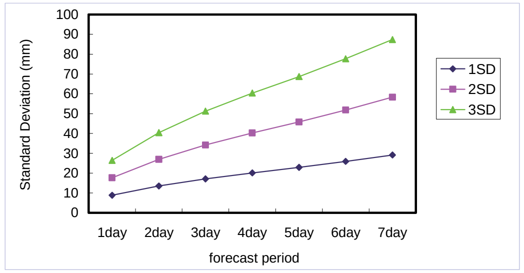
Abundance ratio
-SD to SD 79.3%
-2SD to 2SD 94.1%
-3SD to 3SD 98.1%

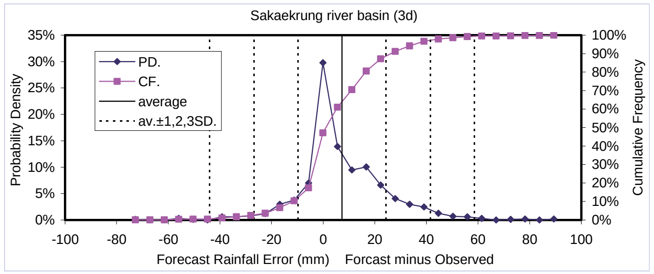


n 1014
max 135.6
min -89.5
average 14.1

SD 25.9
2*SD 51.8
3*SD 77.7

Abundance ratio
-SD to SD 77.0%
-2SD to 2SD 94.2%
-3SD to 3SD 98.6%

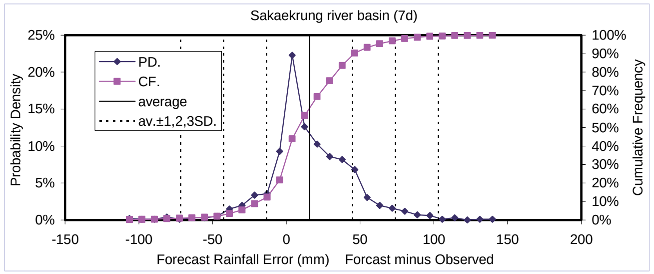




n 1014
max 92.2
min -75.5
average 7.3

SD 17.1
2*SD 34.2
3*SD 51.2

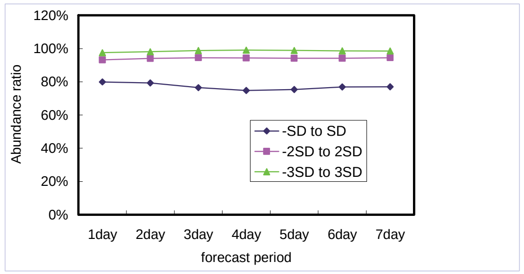
Abundance ratio
-SD to SD 76.5%
-2SD to 2SD 94.5%
-3SD to 3SD 98.8%

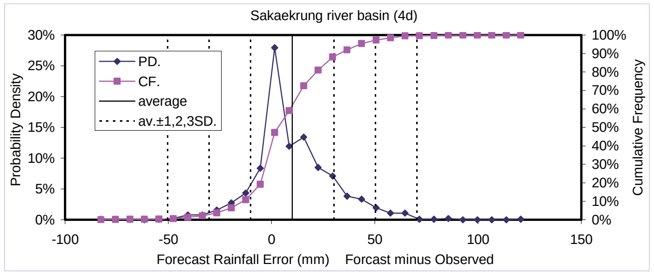


n 1014
max 143.9
min -110.6
average 15.8

SD 29.1
2*SD 58.3
3*SD 87.4

Abundance ratio
-SD to SD 77.0%
-2SD to 2SD 94.5%
-3SD to 3SD 98.6%





n 1013
max 124.2
min -86.1
average 10.0

SD 20.1
2*SD 40.3
3*SD 60.4

Abundance ratio
-SD to SD 74.8%
-2SD to 2SD 94.3%
-3SD to 3SD 99.1%

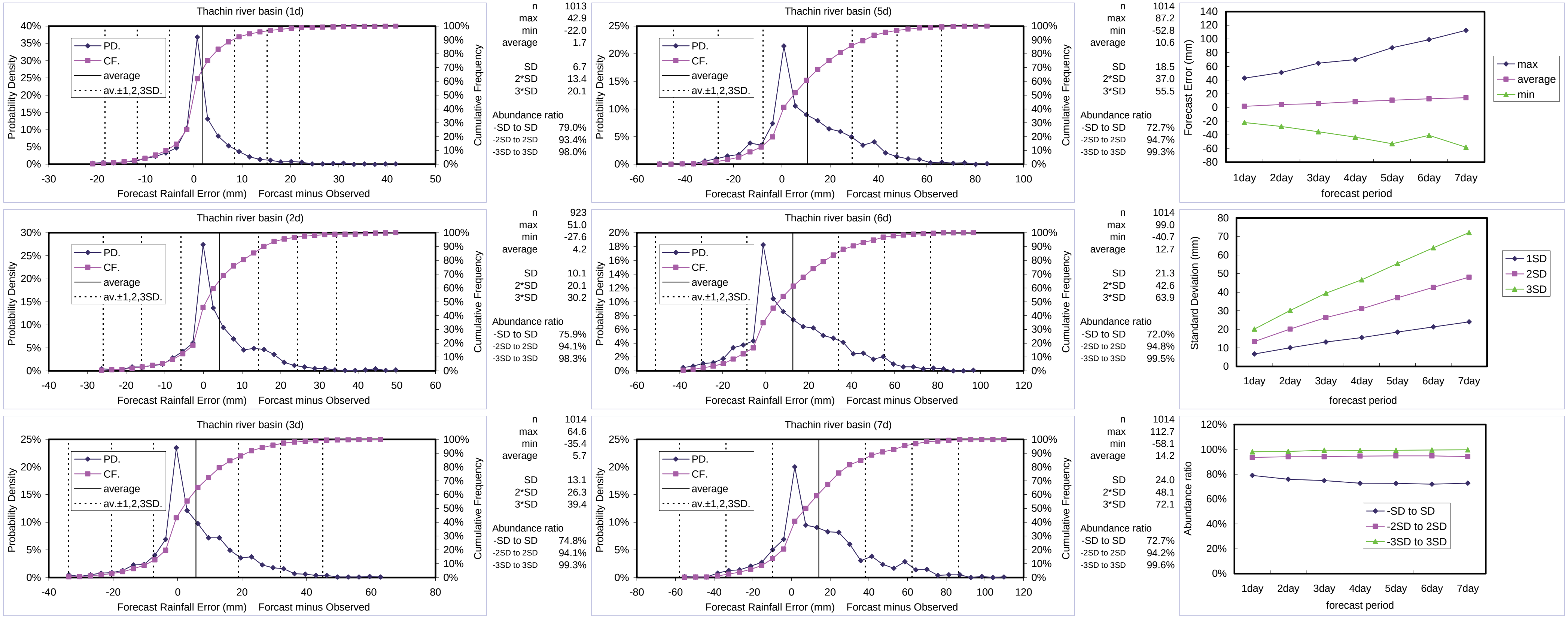
forecast period	Forecast Error (mm)			Standard Deviation (mm)			Abundance ratio		
	max	average	min	1SD	2SD	3SD	-SD to SD	-2SD to 2SD	-3SD to 3SD
1day	54.4	2.7	-33.0	8.8	17.6	26.5	79.9%	93.2%	97.5%
2day	68.9	5.4	-62.8	13.5	27.0	40.4	79.3%	94.1%	98.1%
3day	92.2	7.3	-75.5	17.1	34.2	51.2	76.5%	94.5%	98.8%
4day	124.2	10.0	-86.1	20.1	40.3	60.4	74.8%	94.3%	99.1%
5day	126.5	12.3	-82.4	22.9	45.8	68.7	75.4%	94.1%	98.9%
6day	135.6	14.1	-89.5	25.9	51.8	77.7	77.0%	94.2%	98.6%
7day	143.9	15.8	-110.6	29.1	58.3	87.4	77.0%	94.5%	98.6%

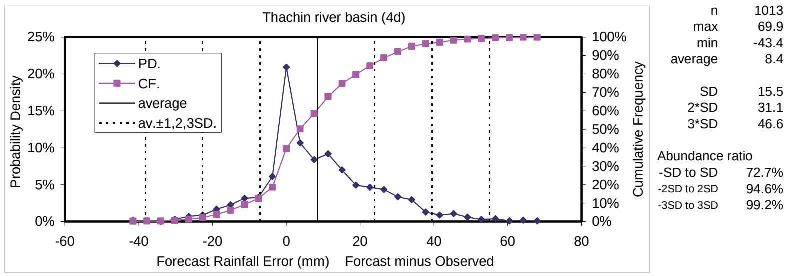
Fig. 68 Distribution of errors in forecast rainfall (JMA forecast rainfall - observed rainfall)

Sakaekrung river basin

Analysis period: Apr. through Nov. between Oct. 24, 2007 and Nov. 30, 2011

Study rainfall: one-, two-, three-, four-, five-, six- and seven-day rainfall





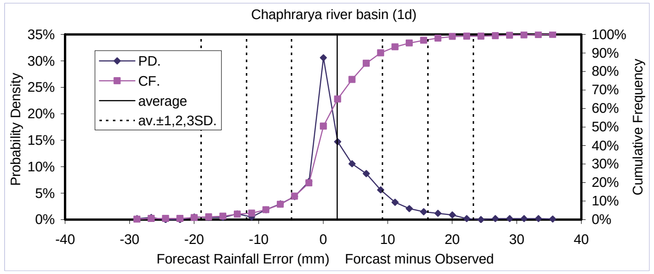
forecast period	Forecast Error (mm)			Standard Deviation (mm)			Abundance ratio		
	max	average	min	1SD	2SD	3SD	-SD to SD	-2SD to 2SD	-3SD to 3SD
1day	42.9	1.7	-22.0	6.7	13.4	20.1	79.0%	93.4%	98.0%
2day	51.0	4.2	-27.6	10.1	20.1	30.2	75.9%	94.1%	98.3%
3day	64.6	5.7	-35.4	13.1	26.3	39.4	74.8%	94.1%	99.3%
4day	69.9	8.4	-43.4	15.5	31.1	46.6	72.7%	94.6%	99.2%
5day	87.2	10.6	-52.8	18.5	37.0	55.5	72.7%	94.7%	99.3%
6day	99.0	12.7	-40.7	21.3	42.6	63.9	72.0%	94.8%	99.5%
7day	112.7	14.2	-58.1	24.0	48.1	72.1	72.7%	94.2%	99.6%

Fig. 69 Distribution of errors in forecast rainfall (JMA forecast rainfall - observed rainfall)

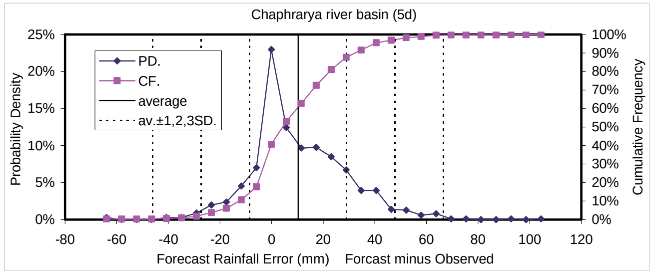
Tha Chin river basin

Analysis period: Apr. through Nov. between Oct. 24, 2007 and Nov. 30, 2011

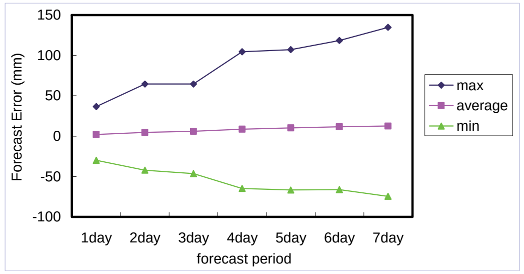
Study rainfall: one-, two-, three-, four-, five-, six- and seven-day rainfall

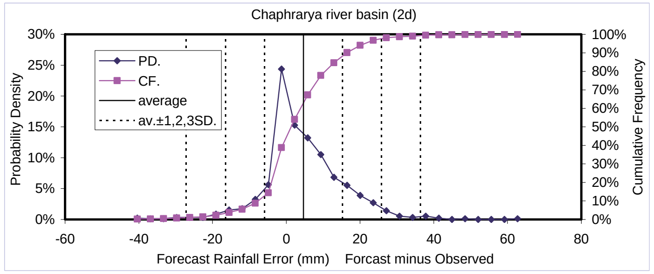


n 1013
max 36.7
min -30.0
average 2.2
SD 7.0
2*SD 14.1
3*SD 21.1
Abundance ratio
-SD to SD 78.7%
-2SD to 2SD 93.9%
-3SD to 3SD 97.8%

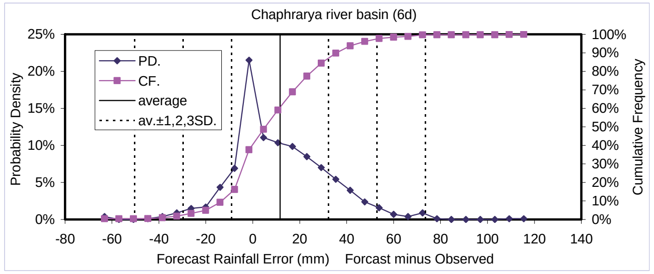


n 1014
max 107.3
min -66.8
average 10.3
SD 18.8
2*SD 37.5
3*SD 56.3
Abundance ratio
-SD to SD 73.2%
-2SD to 2SD 94.9%
-3SD to 3SD 99.3%

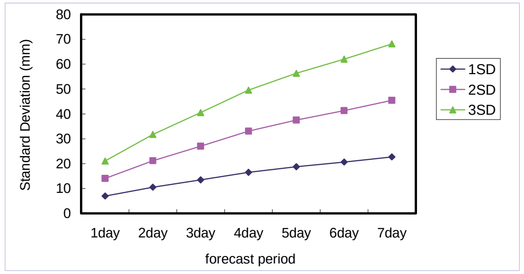


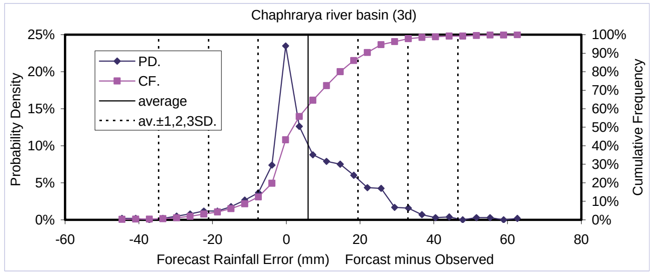


n 923
max 64.5
min -42.2
average 4.6
SD 10.6
2*SD 21.2
3*SD 31.8
Abundance ratio
-SD to SD 75.5%
-2SD to 2SD 94.3%
-3SD to 3SD 98.4%

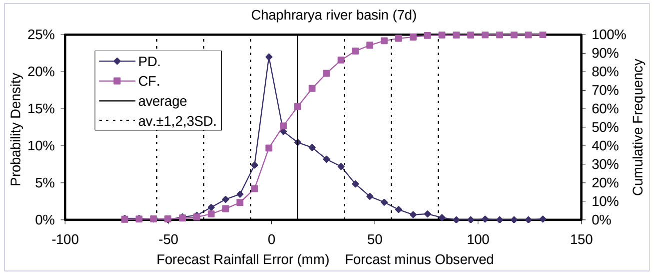


n 1014
max 118.5
min -66.3
average 11.6
SD 20.7
2*SD 41.3
3*SD 62.0
Abundance ratio
-SD to SD 72.4%
-2SD to 2SD 95.1%
-3SD to 3SD 99.3%

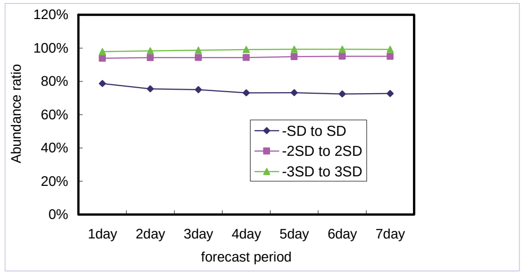


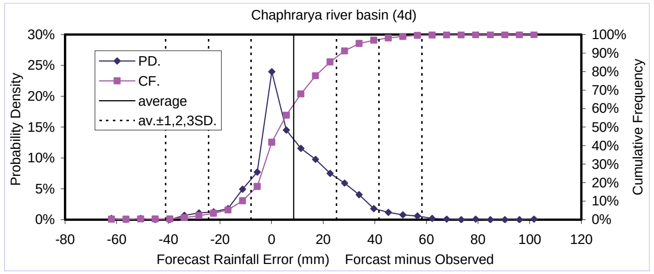


n 1014
max 64.5
min -46.4
average 5.9
SD 13.5
2*SD 27.0
3*SD 40.5
Abundance ratio
-SD to SD 75.0%
-2SD to 2SD 94.3%
-3SD to 3SD 98.7%



n 1014
max 134.9
min -74.6
average 12.5
SD 22.7
2*SD 45.5
3*SD 68.2
Abundance ratio
-SD to SD 72.7%
-2SD to 2SD 95.1%
-3SD to 3SD 99.2%





n 1013
max 104.5
min -64.8
average 8.6
SD 16.5
2*SD 33.1
3*SD 49.6
Abundance ratio
-SD to SD 73.2%
-2SD to 2SD 94.4%
-3SD to 3SD 99.2%

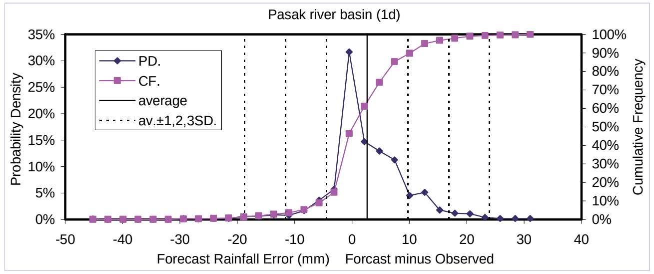
forecast	Forecast Error (mm)			Standard Deviation (mm)			Abundance ratio		
period	max	average	min	1SD	2SD	3SD	-SD to SD	-2SD to 2SD	-3SD to 3SD
1day	36.7	2.2	-30.0	7.0	14.1	21.1	78.7%	93.9%	97.8%
2day	64.5	4.6	-42.2	10.6	21.2	31.8	75.5%	94.3%	98.4%
3day	64.5	5.9	-46.4	13.5	27.0	40.5	75.0%	94.3%	98.7%
4day	104.5	8.6	-64.8	16.5	33.1	49.6	73.2%	94.4%	99.2%
5day	107.3	10.3	-66.8	18.8	37.5	56.3	73.2%	94.9%	99.3%
6day	118.5	11.6	-66.3	20.7	41.3	62.0	72.4%	95.1%	99.3%
7day	134.9	12.5	-74.6	22.7	45.5	68.2	72.7%	95.1%	99.2%

Fig. 70 Distribution of errors in forecast rainfall (JMA forecast rainfall - observed rainfall)

Chaophraya river basin

Analysis period: Apr. through Nov. between Oct. 24, 2007 and Nov. 30, 2011

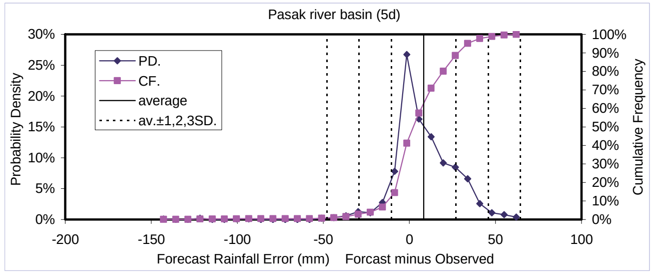
Study rainfall: one-, two-, three-, four-, five-, six- and seven-day rainfall



n 1013
max 32.4
min -46.5
average 2.6

SD 7.1
2*SD 14.2
3*SD 21.3

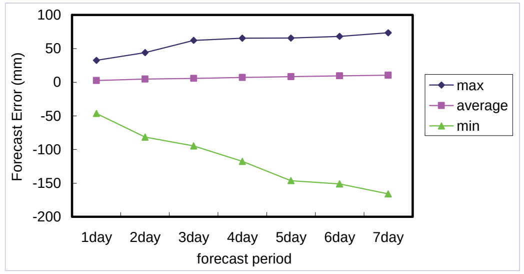
Abundance ratio
-SD to SD 77.6%
-2SD to 2SD 94.0%
-3SD to 3SD 98.0%

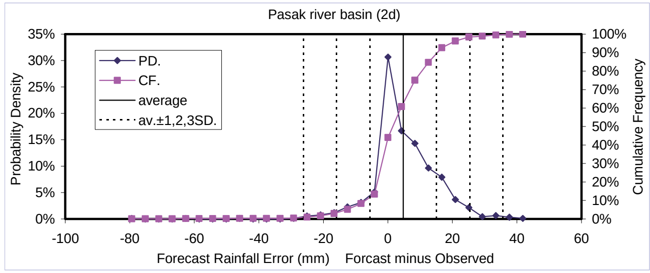


n 1014
max 65.6
min -146.4
average 8.3

SD 18.8
2*SD 37.5
3*SD 56.3

Abundance ratio
-SD to SD 76.4%
-2SD to 2SD 95.5%
-3SD to 3SD 99.2%

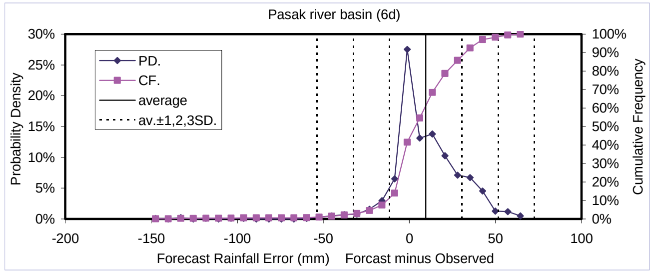




n 923
max 43.9
min -81.5
average 4.7

SD 10.3
2*SD 20.6
3*SD 30.9

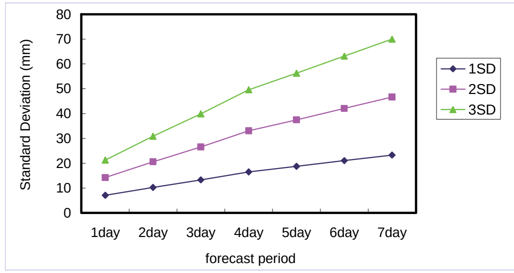
Abundance ratio
-SD to SD 77.7%
-2SD to 2SD 95.1%
-3SD to 3SD 98.9%

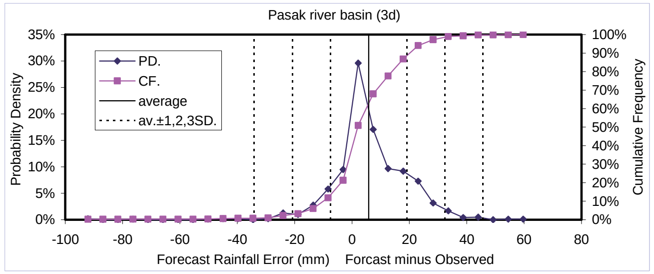


n 1014
max 68.2
min -151.1
average 9.5

SD 21.1
2*SD 42.1
3*SD 63.2

Abundance ratio
-SD to SD 76.8%
-2SD to 2SD 95.9%
-3SD to 3SD 99.1%

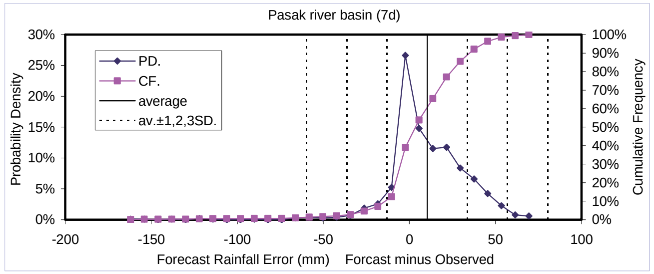




n 1014
max 62.3
min -94.7
average 5.8

SD 13.3
2*SD 26.6
3*SD 39.9

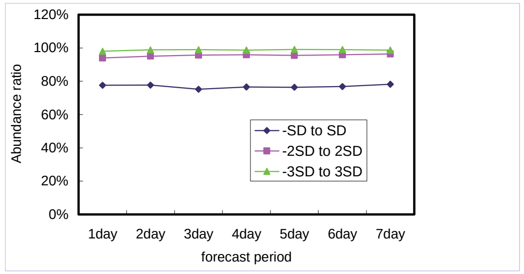
Abundance ratio
-SD to SD 75.2%
-2SD to 2SD 95.7%
-3SD to 3SD 99.0%

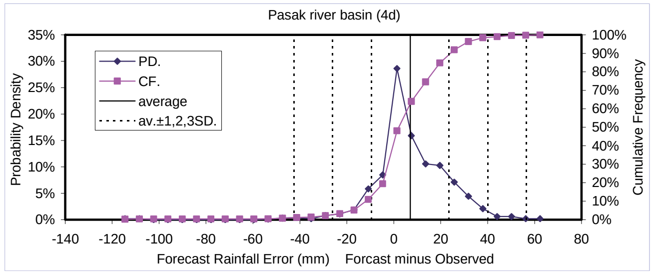


n 1014
max 73.5
min -166.0
average 10.3

SD 23.3
2*SD 46.7
3*SD 70.0

Abundance ratio
-SD to SD 78.2%
-2SD to 2SD 96.4%
-3SD to 3SD 98.7%





n 1013
max 65.4
min -117.5
average 7.0

SD 16.5
2*SD 33.1
3*SD 49.6

Abundance ratio
-SD to SD 76.5%
-2SD to 2SD 95.9%
-3SD to 3SD 98.7%

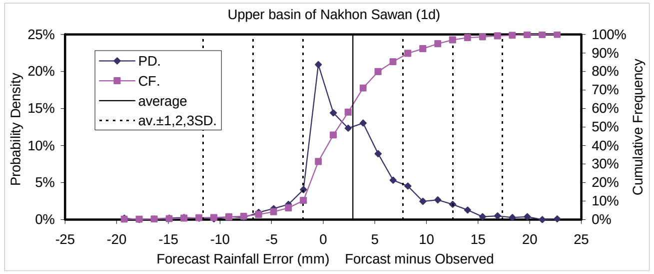
forecast	Forecast Error (mm)			Standard Deviation (mm)			Abundance ratio		
period	max	average	min	1SD	2SD	3SD	-SD to SD	-2SD to 2SD	-3SD to 3SD
1day	32.4	2.6	-46.5	7.1	14.2	21.3	77.6%	94.0%	98.0%
2day	43.9	4.7	-81.5	10.3	20.6	30.9	77.7%	95.1%	98.9%
3day	62.3	5.8	-94.7	13.3	26.6	39.9	75.2%	95.7%	99.0%
4day	65.4	7.0	-117.5	16.5	33.1	49.6	76.5%	95.9%	98.7%
5day	65.6	8.3	-146.4	18.8	37.5	56.3	76.4%	95.5%	99.2%
6day	68.2	9.5	-151.1	21.1	42.1	63.2	76.8%	95.9%	99.1%
7day	73.5	10.3	-166.0	23.3	46.7	70.0	78.2%	96.4%	98.7%

Fig. 71 Distribution of errors in forecast rainfall (JMA forecast rainfall - observed rainfall)

PaSak river basin

Analysis period: Apr. through Nov. between Oct. 24, 2007 and Nov. 30, 2011

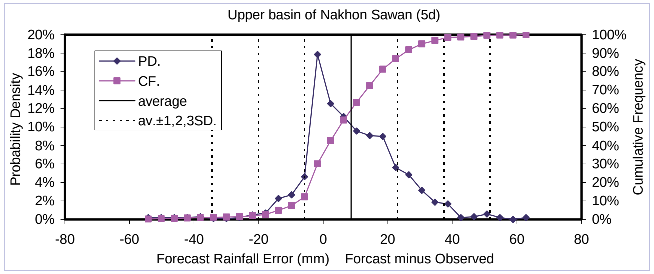
Study rainfall: one-, two-, three-, four-, five-, six- and seven-day rainfall



n 1013
max 23.4
min -20.0
average 2.9

SD 4.8
2*SD 9.7
3*SD 14.5

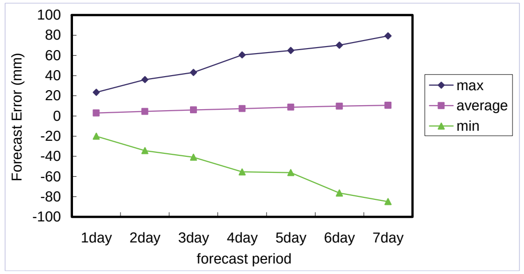
Abundance ratio
-SD to SD 78.0%
-2SD to 2SD 94.6%
-3SD to 3SD 98.3%

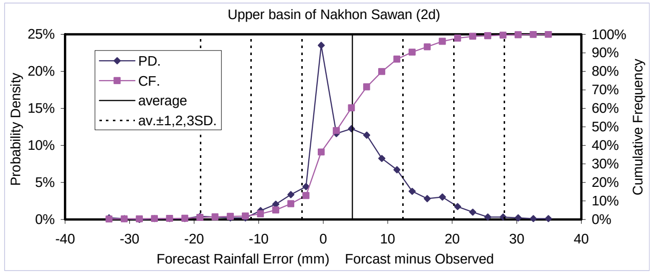


n 1014
max 64.8
min -56.2
average 8.7

SD 14.4
2*SD 28.7
3*SD 43.1

Abundance ratio
-SD to SD 75.2%
-2SD to 2SD 95.7%
-3SD to 3SD 98.5%

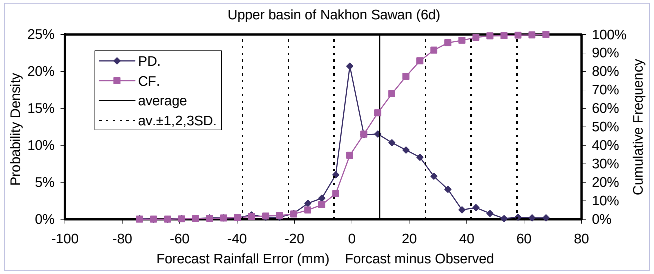




n 923
max 36.1
min -34.3
average 4.5

SD 7.8
2*SD 15.7
3*SD 23.5

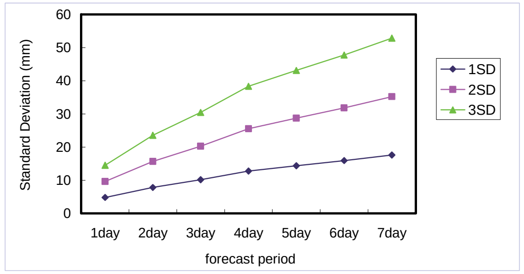
Abundance ratio
-SD to SD 76.5%
-2SD to 2SD 95.2%
-3SD to 3SD 98.5%

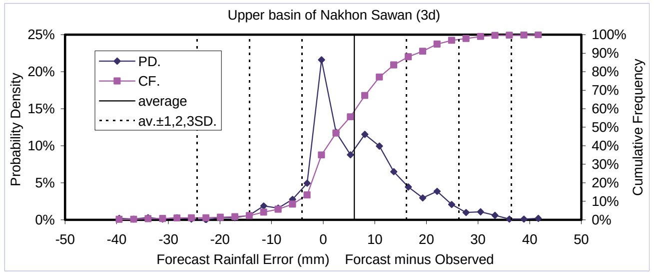


n 1014
max 70.1
min -76.4
average 9.7

SD 15.9
2*SD 31.8
3*SD 47.8

Abundance ratio
-SD to SD 74.8%
-2SD to 2SD 95.3%
-3SD to 3SD 98.5%

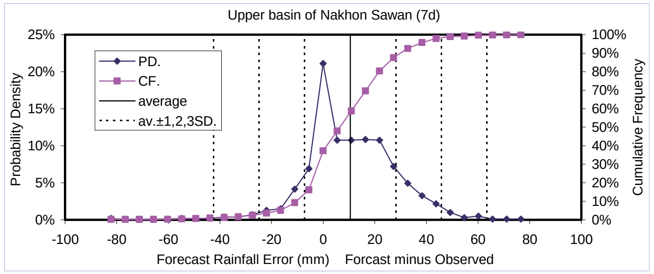




n 1014
max 43.1
min -40.9
average 6.0

SD 10.1
2*SD 20.3
3*SD 30.4

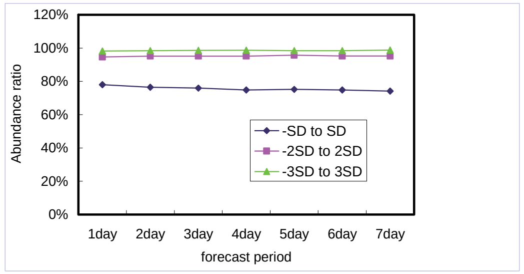
Abundance ratio
-SD to SD 76.0%
-2SD to 2SD 95.2%
-3SD to 3SD 98.6%

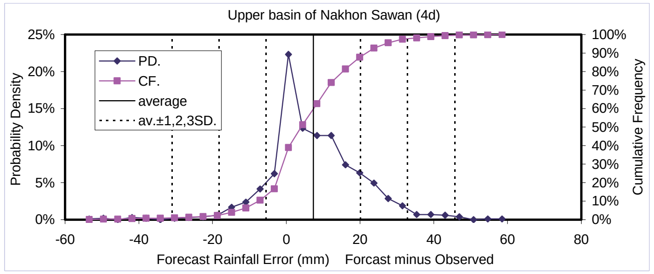


n 1014
max 79.3
min -84.9
average 10.5

SD 17.6
2*SD 35.2
3*SD 52.9

Abundance ratio
-SD to SD 74.1%
-2SD to 2SD 95.3%
-3SD to 3SD 98.8%





n 1013
max 60.4
min -55.4
average 7.3

SD 12.8
2*SD 25.6
3*SD 38.3

Abundance ratio
-SD to SD 74.9%
-2SD to 2SD 95.2%
-3SD to 3SD 98.7%

forecast period	Forecast Error (mm)			Standard Deviation (mm)			Abundance ratio		
	max	average	min	1SD	2SD	3SD	-SD to SD	-2SD to 2SD	-3SD to 3SD
1day	23.4	2.9	-20.0	4.8	9.7	14.5	78.0%	94.6%	98.3%
2day	36.1	4.5	-34.3	7.8	15.7	23.5	76.5%	95.2%	98.5%
3day	43.1	6.0	-40.9	10.1	20.3	30.4	76.0%	95.2%	98.6%
4day	60.4	7.3	-55.4	12.8	25.6	38.3	74.9%	95.2%	98.7%
5day	64.8	8.7	-56.2	14.4	28.7	43.1	75.2%	95.7%	98.5%
6day	70.1	9.7	-76.4	15.9	31.8	47.8	74.8%	95.3%	98.5%
7day	79.3	10.5	-84.9	17.6	35.2	52.9	74.1%	95.3%	98.8%

Fig. 72 Distribution of errors in forecast rainfall (JMA forecast rainfall - observed rainfall)

Nakhon Sawan basin

Analysis period: Apr. through Nov. between Oct. 24, 2007 and Nov. 30, 2011

Study rainfall: one-, two-, three-, four-, five-, six- and seven-day rainfall

8.4 Improvements required for setting forecast rainfall in temporary operation

The maximum and minimum forecast rainfall were set in temporary operation considering errors in forecast rainfall for convenience sake. The following improvements, however, need to be made to this method.

1) Setting of errors according to the scale of forecast rainfall
The maximum and minimum rainfall is given considering a certain level of error regardless of the amount of JMA forecast rainfall. The certain level of error is assumed to include 95% of differences between JMA forecast and observed rainfall for cumulative rainfall for seven days. The errors in large-scale rainfall are therefore included. In the case where JMA forecast rainfall is small, excessively large errors are considered. (For example, even in the case where JMA forecast rainfall is 0 mm/7d, a difference of 52 mm/7d, equivalent to the error in the maximum-class heavy rainfall in the past, is given.) To solve the problem, methods should be examined to set errors according to the scale of JMA forecast rainfall.

2) Setting of errors considering the regional distribution of rainfall
Same errors are given uniformly throughout the basin. The total catchment area of the Chaophraya River is 162,660 km^2 and the catchment area upstream of Nakhon Sawan is 104,059 km^2. There are considerable regional differences in rainfall distribution during heavy rainfall upstream of Nakhon Sawan. If maximum-level errors are considered uniformly throughout the basin, excessive errors will be given. Methods should be examined to set errors considering the regional distribution of rainfall.

3) Setting of maximum and minimum forecast rainfall considering the mean error in forecast rainfall
The maximum and minimum forecast rainfall should be set by subtracting the mean error in forecast rainfall from the forecast rainfall and considering a value equivalent to 95% of the error in forecast rainfall as shown below. In temporary operation, however, the subtraction of the mean error in forecast rainfall is eliminated. Improvements should also be made concerning this point.

Maximum forecast rainfall = Forecast rainfall - mean error in forecast rainfall + 95% of error in forecast rainfall (2σ = 52 mm/7d)
Minimum forecast rainfall = Forecast rainfall - mean error in forecast rainfall - 95% of error in forecast rainfall (2σ = 52 mm/7d)

4) Division of error obtained from seven-day rainfall equally into seven
As shown in the results in the case where the error obtained from seven-day rainfall is equally divided into seven, no errors in forecast rainfall up to one to seven days later can be set accurately using this method. Improvement should also be made with this respect.