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A Study on Global Analysis of Abnormal Rainfall through Various Spatiotemporal Scales and Basin characteristics

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ABSTRACT: In recent years, disasters induced by abnormal (extreme) rainfall have been reported around the world, and it has come out the necessity of estimating these disasters objectively. The purpose of this paper is to show how global analysis should be done by proposing new indexes of the abnormal rainfall event. Furthermore, as a part of realization of the proposal, this research defines an index using data from rain gauges around the world, and performs global analysis of abnormal rainfall with this index

1 INTRODUCTION

In recent years, disasters induced by abnormal (extreme) rainfall have been reported around the world, such as those of Mississippi in 1993, middle of South America in 1997, Yangtze in 1998, Venezuela in 1999, Mekong in 2000 and 2002, Elbe & Danube in 2002, and so on. Motivations of this research are questions such as;

1. Are those recent disasters related to the global warming?
2. Is distribution of the occurrences are related to the teleconnection of global atmospheric system?
3. In order to understand these, distribution of abnormal rainfall as external inputs for run-off system should be analyzed.
4. Are all abnormal rainfall events inducing disaster?
5. Are all so called disasters really abnormal? There are people who keep their smiles even in the timing of flooding.

This paper shows a strategy to answer the questions above and results of preliminary analysis for the first three questions. First, a strategy of investigating spatiotemporal distribution of occurrence of abnormal rainfall is described. Even if we simply say “abnormal rainfall”, we can think of various aspects of it. Here, we concentrate on the abnormality depending on duration of rainfall. In a view point of flooding, this aspect is very important because floods can be classified into the flush floods, the short-rain floods and the long-rain floods. Answer to “Which type of flood becomes serious for specified target point?” depends on the location of the target point, raging from location along mainstream of huge river basin to location along tributary with small river basin. Taking these as a background, we can understand that it is important to investigate combined global distributions of occurrence of abnormality of rainfall with various time durations. Although, of course, combination of abnormality of events with large (for floods) and small (for draught) amount of rainfall also is very important, however, application below is limited within the events with large amount of rainfall.

Second, a definition of an index of abnormality which can be commonly used through various time duration of rainfall will be shown. Here, the index is defined as the exceedance probability of each realized rainfall after identifying the probability density function of annually maximum one day, three days, seven days and fifteen days rainfall. The identification was done with respect to each available rain gauge station in the world. Total number of the stations is more than thirty thousand.

2 STRATEGY FOR ANALYSING ABNORMAL RAINFALL IN THE WORLD

2.1 Importance of types rainfall taking types of flooding into consideration

Floods can be classified into the flush floods, the short-rain floods and the long-rain floods (Ralf Merz et al., 2003), as table 1 shows. The long-rain floods occur due to lingering rainfall in a wide area brought by tropical cyclone and stationary atmospheric low pressure system and front. The short-rain floods occur due to localized heavy rainfall typically brought by meso-scale system along Baiu front. On the other hand, flush floods occur due to shower usually brought by thunder storms.

The main reason of the heavy floods broke out in Germany, Czech Republic and Austria in mid-August of 2002 is "long lasting rainfall in a very wide area". Direct reason for this long lasting rainfall in a very wide area was lingering of the large scale atmospheric low pressure system, which was caused by blocking by the stable high pressure that hung over Sahara-Barth region. This whether pattern is unusual in summer, while not in spring (Year 2002 European Flood Investigation Team of JSCE, 2003). As lower part of Figure 1 shows, if lingering rain in a wide area occurs, the areas along main-river channel would be inundated. This indicates that abnormality of time duration of rainfall also important even its intensity is not so strong. On the other hand, in many cases, urban area is located around merging point of tributaries into the main river. Therefore, inundation occurs also by localized heavy rainfall. In the case of Dresden, inundation occurred due to duplication of "long-rain floods" and "short-rain flooding of the tributary".

Table 1. Types of rainfall with respect to types of floods

Rainfall type	Duration	Intensity	Scale
Long-rain floods	Several days or weeks	Low	Up to several thousands of square km
Short-rain floods	Short duration	High	Local or regional scale
Flush floods	Very short duration	Very high	Local

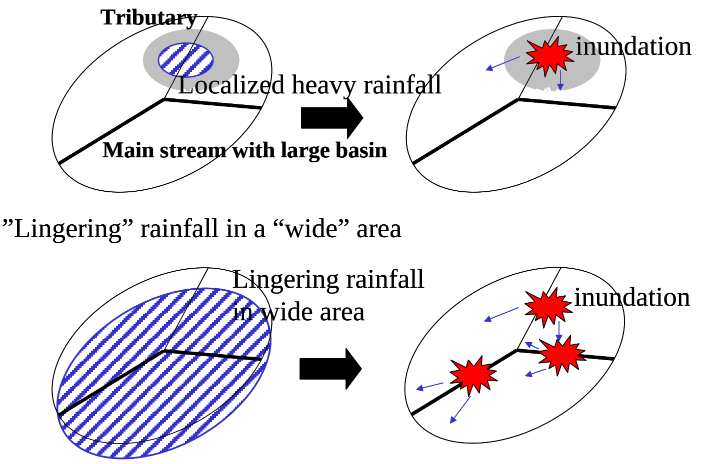


Figure 1. Types of rainfall with basin characteristics

2.2 *Necessity of taking abnormality of both spatial and temporal scales into consideration*

As discussed above, answer to "which type of flood becomes serious for specified target point?" depends on the location of the target point, raging from location along mainstream of huge river basin to location along tributary with small river basin. Taking these as a background, we can understand that it is important to investigate combined global distributions of abnormality of rainfall with various time durations.

Also, as mentioned above, abnormality of the floods in mid-Europe in 2002 mainly lies in abnormality of the time duration for such a very wide area. This means that abnormality of rainfall duration should be analyzed depending on its spatial scale. This paper, however, focuses on abnormality of time duration alone.

2.3 *How teleconnection can be detected?*

Figure 2 schematically shows an idea for detecting signature of the teleconnection of global atmospheric system. Here, P_1, P_2 and P_3 indicate, for example, abnormality (anomaly) of maximum daily rainfall, two-day rainfall, three-day rainfall in a specific year or decade. The lines means to contour of those indices.

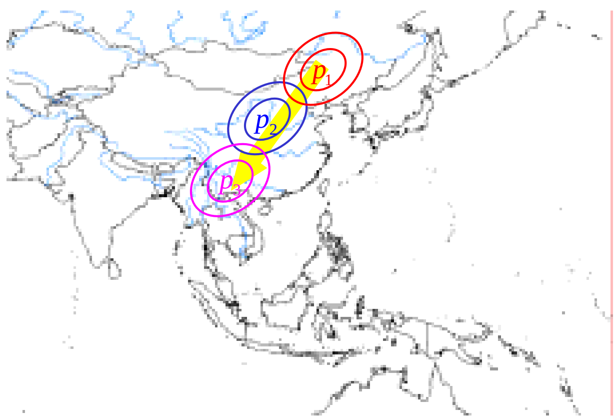


Figure 2. Schematic of combined map of abnormality of rainfall with various time durations.

Even if it is the case that spatial distribution of the contour for daily rainfall has no specific feature, distributions of the contour for all three types of the rainfall duration may show us some features of the global teleconnection.

2.4 Necessity of introducing natural coping and social coping

In order to answer to questions listed as the fourth motivation of this research in the first chapter, it is necessary to incorporate the natural coping such as the response time, the volume of basin storage and so on. These may roughly be represented by a parameter as basin area.

Also, in order to answer to questions listed as the fifth motivation of this research, it is necessary to incorporate the social coping such as culture, experience of flooding, and so on. Actually, there are people who keep their smiles even in the timing of large scale flooding over Mekong-delta in 2002, while people are so serious typically in Japan.

Taking these into consideration, an index of the abnormality of floods may be defined by

$$\text{People's Recognition of Abnormality by Flood Disaster Induced by Rainfall Phenomena } (F_D)$$
$$= \text{Abnormality of Rainfall Phenomena } (P_D) \times \frac{1}{\text{Natural Coping } (N_D)} \times \frac{1}{\text{Social Coping } (S_D)}. \quad (1)$$

Here, D denotes the time duration of rainfall. Although this equation only conceptually shows that higher the natural and social coping is, lower the abnormality of people's recognition is, it is, however, very important basic idea for analyzing influence of global warming in terms of flood disaster.

3 DEFINITION OF ABNORMALITY OF RAINFALL PHENOMENA

A normalized index of abnormality is defined by the exceedance probability of rainfall amount. The maximum D-days rainfall amount in a year and the maximum D-days rainfall amount in a season will be focused on as the rainfall amount. When taking spatial scale of rainfall distribution into consideration, we can replace the rainfall amount by areal averaged rainfall amount. Because the exceedance probability will be calculated through common procedure for all types of rainfall amount, an explanation will be done for the annual maximum D-days rainfall at a point, as followed.

Let $P_{D,i,T}$ be the index of the maximum D-days rainfall at gauging station i in a year T and be defined by

$$P_{D,i,T} = \int_{r_{D,i,T}}^{\infty} f_{D,i}(x)dx, \quad (2)$$

where $f_{D,i}(x)$ is the probability density function (p.d.f.) of the maximum D-days rainfall at gauging station i, and $r_{D,i,T}$ is the maximum D-days rainfall amount at gauging station i in a year T. As type of $f_{D,i}(x)$, either of normal distribution, log-normal distribution, exponential distribution, Gumbel distribution, and log-Gumbel is selected independently for each point so that the SLSC value proposed by Takasao *et al.* should be smallest. The Wible plot is used as a plotting position formula. Namely, probability density function and its parameters are identified depending on each point i and each duration D, respectively.

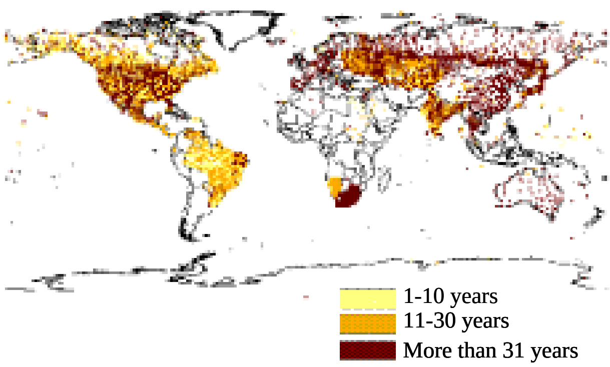
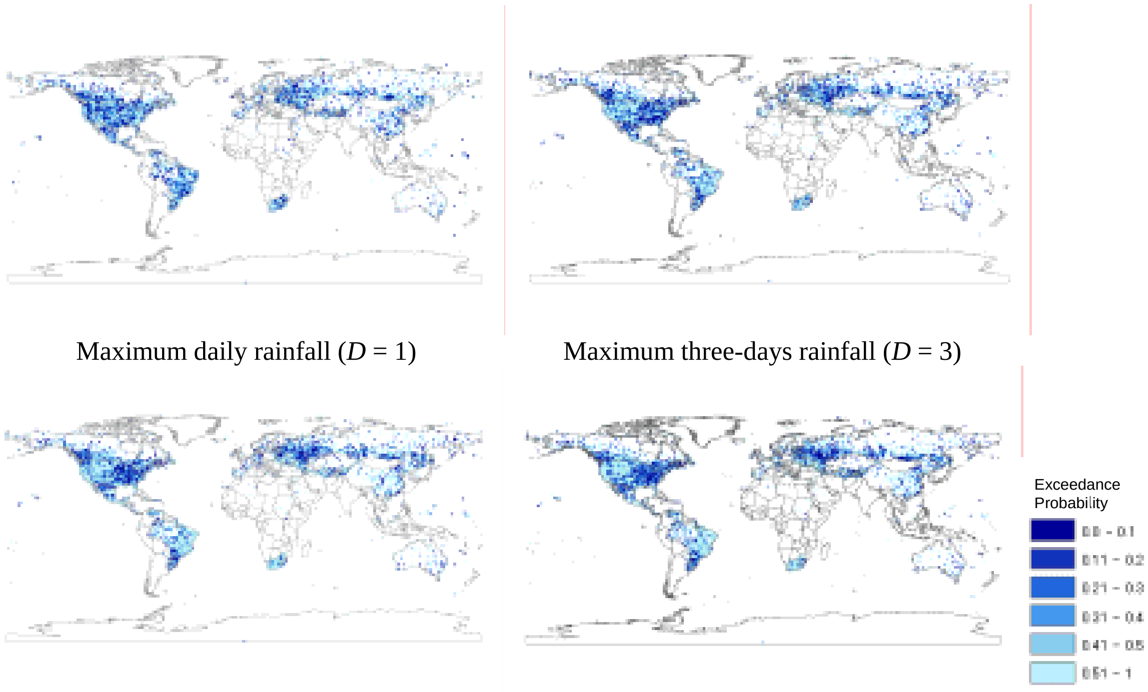


Figure 3. Time length of record at each point.

Data observed by ground-based rain gage is used. The name of data set used in this paper, is "Global Dairy Climatology Network, Version1.0" and daily precipitation for period from March 1, 1840 to November 30, 2001 is archived. Although the total number of observation station is 32,857, the time length of record varies by station to station. Figure 3 shows location of the stations and the time length of resord. Only records from the stations of which record length is more than thirty years are used in this paper.

As the value for *D*, one day (daily), two days, three days, seven days (one week), fifteen days (half month), and thirty days (one month) were selected. In this paper, results from *D* of one day, three days, seven days, and fifteen days are shown because, in the part of large extreme rainfall amount, the fitting to observed values of even optimal p.d.f.-models for two days and thirty says was not necessary good.



Maximum daily rainfall (D = 1) Maximum three-days rainfall (D = 3)

Maximum seven days rainfall (D = 7) Maximum fifteen-days rainfall (D = 15)

Figure 4. Global map of abnormality (exceedance probability) of annual maximum rainfall in 1990.

4 ABNORMALITY IN A GLOBAL POINT OF VIEW

4.1 Spatial distribution of abnormality

Spatial distributions of $P_{D,i,T}$ for T from 1990 to 1999 were computed and global maps were produced by showing the smallest value in every 1.5 degree times 1.5 degree mesh in latitude and longitude. Figure 4 shows results for the year of 1990. Features in other years are almost same.

Features of the spatial distribution are as follows;

1. The maximum seven-days rainfall and the maximum fifteen-days rainfall have tendency to be abnormal at locations where the maximum three-days rainfall is abnormal. In other words, characteristic for the maximum daily rainfall are that the feature of the distribution is quite different from that of other time durations.
2. There is a tendency that longer the rainfall duration *D* is, higher the spatial correlation is.

The second feature means that shorter the time duration is, more local the occurrence of the abnormality is. Therefore, both features indicate the uniqueness of occurrence of the extreme “short-rain”. It may be said that both features support the difficulty in predicting statistics of influence of the global warming only by GCMs.

The second feature indicates also importance of taking both spatial extent and temporal duration into consideration as mentioned in the section 2.2.

4.2 Time series of abnormality

Time series of area-percentage of abnormal rainfall $R_{D,T,x}$ for exceedance probability x of 0.01 and 0.02 for year T from 1990 to 1999 were computed. Here, $R_{D,T,x}$ is defined by

$$R_{D,T,x} = \frac{N_{D,T,x}}{M_T}, \tag{3}$$

where M_T is number of meshes inside which at least one rain gauge data is available for year T, and $N_{D,T,x}$ is number of meshes inside which the smallest $P_{D,i,T}$ is less than x. The size of each mesh is set as 1.0 degree times 1.0 degree in latitude and longitude taking the size of spatial correlation of rainfall distribution. Figure 5 shows results in the case that the exceedance probability x is 0.01. In the figure, x is expressed as return period of hundred years. Features in the case of return period of fifty years are almost same.

Features of the time series are as follows;

1. Time series of the index for daily rainfall $R_{1,T,x}$ is quite different from those for other time durations. On the other hand, time series of other time durations are quite similar.
2. Indices for time durations of one, three and seven days increase in 1990's beyond each variance before the decade.

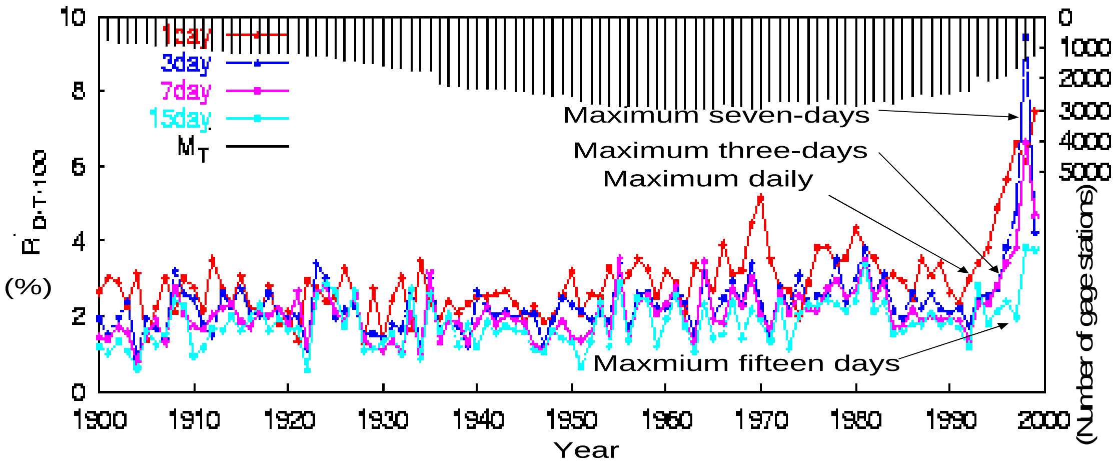


Figure 5. Time series of percentage of area in which the return period of annually maximum rainfall is longer than hundred years. Bars from top indicate number of available stations.

The first feature is similar to that of spatial distribution of $P_{D,i,T}$. Regarding the second feature, although the increasing in 1990's seems to be influenced by the Global Warming at a glance, the rate of increasing, however, seems to be too high to be directly caused by the Global Warming. Therefore, there is a possibility that the rapid increase was caused by the EL Nino in 97/98 because indices decrease in 1999 corresponding to the La Nina in 1999.

5 APPLICATION INTO THE CASE OF THE FLOODS IN THE MISSISSIPPI RIVER BASIN IN 1993

The abnormality $P_{D,i,T}$ defined by equation (1) is applied into the case of the floods around upper and middle reaches of Mississippi river in June and July in 1993. In this chapter, T denotes a specific season in a specific year. Figure 5 shows spatial distribution of the exceedance probability of seasonally maximum D-days rainfall for D of one, three and seven. In the figure, the selected series of months for different seasons are shown. Here, rectangular area roughly corresponds to the area where abnormal rainfall in this area brought the floods.

Features of the spatiotemporal distribution are as followed;

1. Abnormality of the rectangular area gradually increases and becomes highest in summer which corresponds to the season of the floods. Also the abnormality suddenly decreases in autumn.
2. Most of the meshes inside the rectangular area show high abnormality in summer.

3. Abnormality for seven days is highest among the three time durations.

It can be said that these features means that an abnormality of this flood case lies in the abnormality of lingering rainfall in the wide area as well as the case of the mid-Europe in 2002.

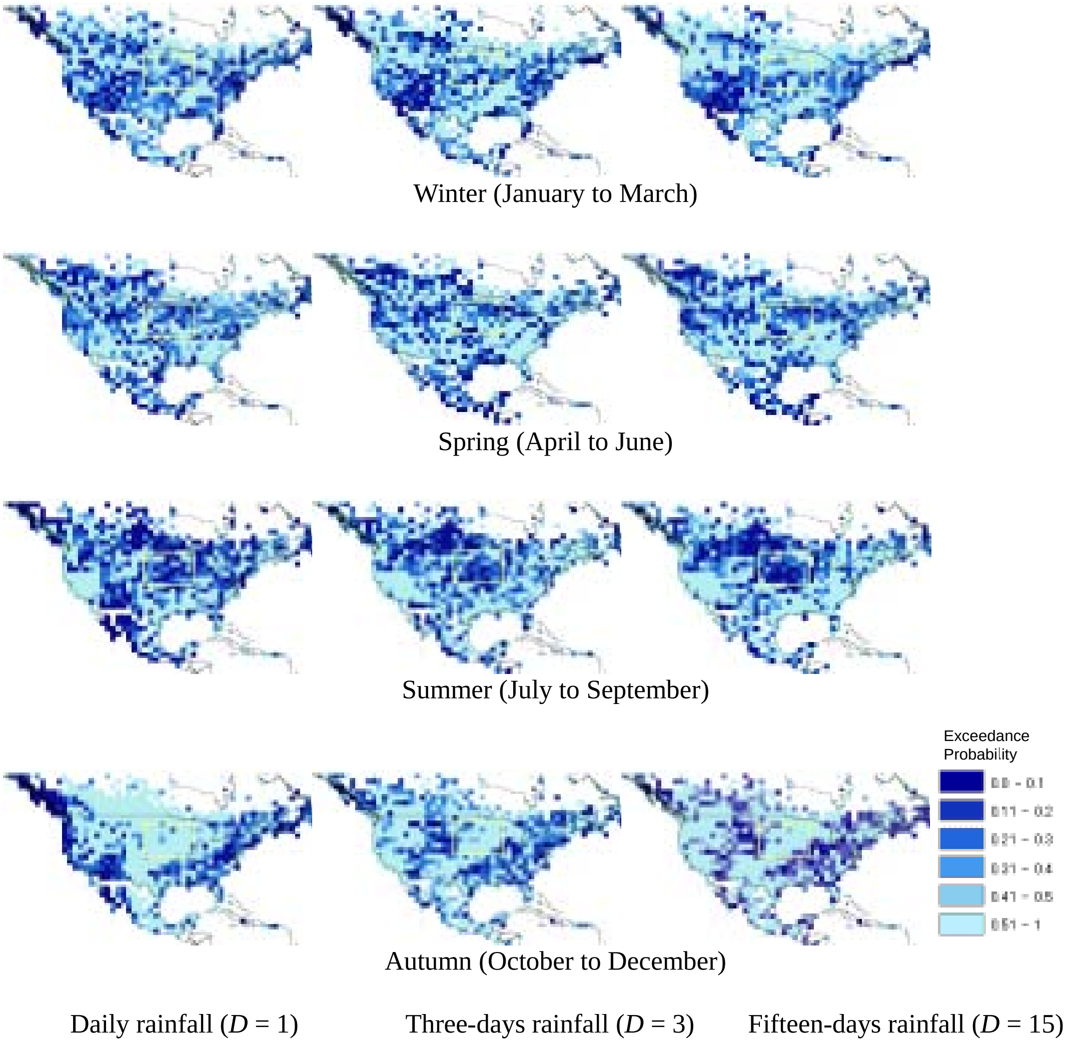


Figure 6. Abnormality (exceedance probability) of seasonally maximum rainfall in 1993.

6 CONCLUSIONS

Fisrt, a strategy for analyzing abnormal rainfall in the world was proposed. Next, as parts of strategy, a abnormal index of abnormality was defined as the exceedance probability of event and applied it into analyses on the spatiotemporal distribution of abnormality in both global and regional senses. As a result, it was found that the defined index clearly explains phenomena occurred and, therefore, shows that it can be used in further analyses. The next step would be definition of abnormality of areal-averaged rainfall amount and its application.

REFERRENCES

Year 2002 European Flood Investigation Team of JSCE, Summary Report of Year 2002 Flood Disaster in Europe, *Journal of Hydroscience and Hydraulic Engineering*, Vol. 21, No.2, pp.1-10, 2003.

Takasao, T., K. Takara and A. Shimizu, A Basic Study on Frequency Analysis of Hydrologic Data in the Lake Biwa Basin, *Annuals, Disas. Prev. Res. Inst., Kyoto Univ.*, No.29B-2, pp.157-171, 1986 (in Japanese).