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Statistical and geostatistical analysis of rainfall in central Japan

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Abstract

Precipitation data have been analyzed statistically and geostatistically in order to obtain fundamental information for assessing water resources and predicting natural hazards caused by heavy rains. The study area is the mountainous Chubu and plain Kanto districts, central Japan. For the statistical distribution of hourly, daily and annual precipitations, lognormal distributions were fitted well in both districts, but exponential distribution was more suited for monthly precipitations. Weibull distribution illustrates also hourly and monthly precipitations well. Spatial variograms of annual precipitations show clearly nuggets and sills as well as ranges. The range is about 130 km in both districts. This range value, which is about seven times of the average station distance, indicates that the station density is sufficient for assessing water resource. Temporal variograms of hourly precipitations through a year have ranges of 8 h. In the analysis of heavy rain on August 14, 1999, when severe floods attacked some areas in Kanto, variograms of hourly precipitations show clear ranges (50–70 km), if it rains heavy in a wide area on a series of rainfall. Ranges of variograms increase with increasing accumulation time, and become constant as 120–150 km over 3–5 h. This range value is two or three times of the average station distance, and the accumulation time is three to five times of the measuring intervals. It concluded, accordingly, that the station density and the measuring interval of AMeDAS are insufficient for predicting natural hazards.

Keywords: Rain; Water resources; Water flood; Statistics; Variogram; Japan

1. Introduction

Water is essential for all living things including human beings, and hence one of the most important resources. All necessary water for life on land originates for rain. Estimation of precipitation, accordingly, is very important for assessing water resources. The result of the assessment contributes to not only water supply but also making plans to keep the environmental conditions. Many environmental problems are caused by water pollutions in rivers, lakes and sea. The estimation of precipitation is also important for predicting natural hazards caused by heavy rain.

To estimate precipitation properly, it is necessary to have optimally distributed locations of rain gauges, and to apply an appropriate technique for the estimation. We have used geostatistical approach to overcome the problem. In geostatistical approach, the variogram can suggest how to optimally set rain gauges, and the kriging should be able to estimate precipitation. Many papers have tried to apply geostatistics to these themes. For example, Delhomme and Delfiner (1973) draw a variogram of water heights (measured in rain

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gauges) after rain showers in the Kadjemeur basin in Tchad (Central Africa), and simulated rainfalls, although it is unbelievable that the variogram increased linearly. Takara and Oka (1992) applied variogram and kriging to rainfall in Yasu Basin, Central Japan using data of only nine stations. Lynch and Schulze (1995) compared daily rainfalls estimated by interpolation techniques of inverse distance weight, Schäfer, Thiessen, SACLANT (1979) and kriging using data of 90 rain gauges in the province of KwaZulu-Natal (ca. 10,735 km^2), South Africa, and concluded that variograms needed to be analyzed for before the kriging technique was used, though variograms were not shown. Lynch (1998) estimated daily rainfalls using data of 27 automatic weather stations in the winter rain region (ca. 15,000 km^2), South Africa, by interpolation techniques of inverse distance weight, root mean square error, Schäfer, regression, spline and kriging, and compared the estimates with data of 159 daily rainfall stations. The conclusion is that kriging did not produce better estimates of the daily rainfall surfaces, though variograms are not also shown. Çetin and Tülücü (1998) calculated variograms of monthly precipitations in Eastern Mediterranean Region, and showed that ranges changed from 25 to 270 km depending on months. Pardo-Igúzquiza (1998) compared the areal average climatological rainfall mean estimated by the classical Thiessen method, ordinary kriging, cokriging and kriging with an external drift (the first two methods used only rainfall information, while the latter two used both precipitation data and orographic information) in the Guadalhorce river basin in southern Spain, and concluded that kriging with an external drift seemed to give the most coherent results in accordance with cross-validation statistics and had the advantage of requiring a less demanding variogram analysis than cokriging. Campling et al. (2001) analyzed temporal and spatial rainfall patterns to describe the distribution of daily rainfall across a medium-sized (379 km^2) tropical catchment, and concluded that although distinct wet season phases could be established based on the temporal analysis of daily rainfall characteristics, the interpolation of daily rainfall across a medium-sized catchment based on spatial analysis was better served by using the global rather than the wet season phase climatological variogram model.

All of the previous papers introduced above aim to estimate rain precipitations accurately. It is said really that this is the final goal of the geostatistical application for rainfall. Before the estimation, however, spatial and temporal continuities of rainfall should be revealed clearly. Accordingly, this paper aims to comprehend spatial and temporal continuities of rainfall, especially special continuities of hourly, daily, monthly and annual precipitations on the basis of their variograms.

2. Data and areas

Japan Meteorological Agency has established an automated meteorological observation system named AMeDAS (Automated Meteorological Data Acquisition System). AMeDAS has 1536 stations in the whole area of Japan (377,800 km^2). Each station records precipitation and other meteorological data such as temperature, velocity of wind, and so on at every hour. The station density is about 1/250 station/km^2 (41 stations in $100 \times 100\,km^2$). If the stations are arranged on a tetragonal grid, the average distance between the neighboring stations is 16 km. If they are arranged on a trigonal grid, the average distance is 17 km. The Japan Meteorological Agency has published data of AMeDAS every year as a CD-ROM. The present study uses the data in 1999.

One of the main purposes of this study is to evaluate the station density. Japan is surely one of the most densely networked areas of the meteorological observation in the world. If we can show that the station density in Japan is still too coarse, then we cannot estimate accurately precipitation anywhere in the world. In contrast, if the station density of AMeDAS is sufficiently dense, we can suggest an optimal station density for newly established observation systems.

In order to compare with rain patterns in mountainous area and plain, the Chubu district characterized by many mountains, and the Kanto district characterized by the widest plain in Japan are selected for the analysis (Fig. 1). Both districts are next of each other, and the former is situated west of the latter. Accordingly, it rains sequentially or contemporarily in both districts.

The Chubu district consists of many folding mountains and volcanoes including Mt. Fuji, which is the highest in Japan. In order to obtain the characteristics of rainfall in the mountainous district, only the stations higher than 100 m above the sea level are selected in the district. The elevation of the highest station is 2730 m. The district is about $5.1 \times 10^4\,km^2$ in area, and includes