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Consistency analysis of pluviometric information in Galicia (NW Spain)

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ABSTRACT

An important issue in pluviometric data analysis from rain gauges is the verification of their consistency. In general, this attribute is assessed using double-mass curves. This technique compares cumulative monthly rainfall from a gauge with that averaged from meteorological stations located nearby. The aim of this study was to analyze the quality of monthly rainfall data registered in Galicia (NW Spain) in a five year period (2002–2006). Initially, 159 meteorological stations were evaluated; however, 59 gauges were withdrawn because 10% of their data were missing. Double-mass analysis was performed following two procedures: a) data from each gauge were compared to those obtained in the nearby main station and b) data from each site were compared to the average from five nearby gauges, including data from neighboring regions. The second procedure proved to be more reliable. Rainfall data did not show any outlier for the study period. Determination coefficients were greater than 0.95 in all cases. A graphical analysis showed some deviations from the trend lines in certain stations. First, rainfall maps were obtained by inverse distances weighting. Furthermore, a comprehensive geostatistical analysis, centered in the characterization of the structure of rainfall spatial variability, was performed. Differences between two kriging methods, ordinary and kriging with an external drift, were confirmed, considering the later as a more appropriate technique for rainfall interpolation in the region.

1. Introduction

Precipitation data analysis is usually based on a network of meteorological stations each of which corresponds to a point. A well-distributed network is required to extrapolate point-scale results to the area-scale. Data from rain gauges cannot be disregarded in rainfall studies, and modern measurement techniques such as radars are also subjected to errors (Harrison et al., 2000; Jessen et al., 2005). Therefore, a good rainfall database will enhance further analysis and previsions, for instance, floodings or draughts. One of the basic requirements for the scientific use of rain data from rain gauges, and ground and space radars is data quality-control (Golz et al., 2005). Some works on rainfall-data quality-control from all over the world are: USA (Meek and Hatfield, 1994), China (Feng et al., 2004), Slovakia (Sevruk and Chvíla, 2005), Cyprus (Golz et al., 2006), etc. Many of these studies also intended to characterize spatial and temporal features of precipitation (Dahamsheh and Askoy, 2007; Ha et al., 2007), approaches that yield maps, by interpolation procedures, describing the rainfall phenomenon at regional scale.

The characterization of rainfall spatial variability is of great interest to water resources planners, regulators, and decision makers. As pointed out by Ali et al. (2000), such studies have direct applications in missing data estimation, water budget analysis, extreme events forecasting, hydrometeorologic network design, etc.

Traditional interpolation techniques (Thiessen polygon method, inverse distance weighting method) have many drawbacks, such as the necessity of an extensive rain gauge network or the impossibility of accounting for other factors that affect rainfall, such as elevation. Geostatistics, which is based on the theory of regionalized variables (Journel and Huijbregts, 1978), is preferred because it allows one to capitalize on the spatial correlation between neighboring observations to predict attribute values at unsampled locations, also providing an estimation of the interpolation errors. The results from different interpolations depend on the sampling density (Dirks et al., 1998); when it is low, geostatistical approaches proved to be

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Table 1
Distribution of altitude ranges in Galicia and percentage of rain gauges analyzed within those ranges.

Range of altitudes (m)	Surface in Galicia (%)	Rain gauges (%)
0–200	16	39
200–400	22	26
400–600	30	17
600–800	18	10
800–1000	8	6
>1000	6	2

more convenient than deterministic procedures (Phillips et al., 1992). Goovaerts (2000) described different geostatistical interpolation approaches to map rainfall and avoid the large installation and operational costs of a dense network.

The major advantage of geostatistical techniques, such as kriging, over simpler methods, is that the sparsely sampled records of rainfall can be complemented by secondary attributes that are more densely sampled. Several authors combined rain gauge with radar data using kriging techniques (Creutin et al., 1988; Raspa et al., 1997). However, a cheaper source of secondary information can be considered: digital elevation model (DEM). Precipitation tends to increase with increasing elevation, mainly because of the orographic effect of mountainous terrain, which causes the air to be lifted vertically, and condensation occurs due to adiabatic cooling. Thus, one approach consists in estimating rainfall at a DEM grid cell through a regression of rainfall versus elevation (Daly et al., 1994).

Mirás Avalos et al. (2007) reported that rainfall in Galicia is not necessarily stationary, namely its spatial structure may vary from one month to another, and it should be assessed for each month. Moreover, in the previous studied dataset, rainfall spatial variability could not always be described using geostatistical techniques, so another interpolation procedure must be used. Unlike this previous paper, in the current work, we checked the quality of the rainfall records using double-mass curves. A greater number of rain gauges (159) was available, although data from a part of them (59) were withdrawn due to missing data and some inconsistencies. Therefore, the quality of the data used for spatial interpolation was higher than in the previous study.

In this paper, first, a double-mass curve analysis of the precipitation data recorded in Galicia (NW Spain) from 2002 to 2006 was performed to check the quality of these observations. Second, rainfall for this period was statistically described and its relation with the altitude was checked. Third, a characterization of the spatial variability of the rainfall in this region was carried out. Then, monthly rainfall was mapped by two different kriging techniques: ordinary kriging and kriging with external drift using altitude as secondary information.

2. Materials and methods

2.1. Description of the study area and selection of rainfall data

Galicia is the northwestern region of Spain, with a surface area of approximately 29,570 km^2. It is bordered by the Cantabric Sea to the north and the Atlantic Ocean to the west. The region has a climate with local characteristics, due to the maritime environment and rough relief. The influence of the topography and distance from the coast on rainfall had previously been described from annual isohyets maps obtained by traditional interpolation methods (De Uña Álvarez, 2001). Annual rainfall amounts show a complex distribution because of the extent of the interactions between atmospheric and geographical variables (Carballeira et al., 1983). In this region, an increase in rainfall with elevation is expected because of the general circulation pattern, and from the orographic effect of mountainous terrain. The stations analyzed are heterogeneously scattered throughout the region with elevation ranges from 4 m at sea level for "Ferrol A Graña" station in the northwest coast to 1100 m at sea level for "Aira Padrón" station in the eastern mountains of the province of Lugo. Altitudes in Galicia range from 0 to 2060 m from sea level, the range from 400 to 600 m comprising the largest surface area (Table 1). The range of distances between the rain gauges extends from 5 to 280 km, approximately.

The dataset analyzed corresponded to total monthly rainfall in a period of five years, 2002 to 2006. This time period was chosen because most of the rain gauges analyzed were established in recent years. Initially, 159 rain gauges were evaluated, however, 59 were discarded since 10% of their data were missing. In addition, records from 44 stations located at boundary provinces (Asturias, León and Zamora) were considered for the double-mass analysis (Fig. 1).

2.2. Statistical characterization of rainfall data

The main statistical moments, generally accepted as indicators of the central trend and data spread, were analyzed. To decide whether or not data followed the normal frequency distribution, Shapiro–Wilk's test was used. The linear correlation between rainfall records and altitude of the rain gauges was examined using Pearson's r coefficient to justify the use of kriging with external drift (Webster and Oliver, 1990).

A correlation analysis between the data registered in every gauge was performed, namely data from one station was confronted to data from another station, then to another and so on until station 100 was reached. This analysis yielded different determination coefficients for each combination of stations. Then, these coefficients were plotted for Galicia and each of its provinces (A Coruña, Lugo, Ourense and Pontevedra provinces) and regression curves were fitted using the mean least-squares method to see if the gauges located close by presented greater determination coefficients than those further apart.

2.3. Double-mass curve analysis

Double-mass curve is one of the most useful techniques in paired-gauges analysis. After computing the cumulative values of rainfall for the treatment gauge and control gauge, and plotting the former on the y-axis versus the latter on the x-axis, a straight-line through the data points is called the double-mass curve (Searcy and Hardison, 1960). If there are no errors or changes in the data for the treatment gauge, all points will fall (approximately) on this straight-line, representing the constant of proportionality between the two quantities. Thus, double-mass analysis is often used to check quality of precipitation records. Rainfall data can be very inconsistent