An application of spatiotemporal BME analysis to the estimation of rainfall in northwestern Greece

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Abstract. We study the rainfall distribution in a county region of northwestern Greece. The characteristics of the relief and the influence of various climate factors may cause a portion of the watershed to be under drought conditions while the remaining area is not. Human activity is intensive in the area; agriculture, hydropower generation and domestic supply rely heavily on surface water resources. A large database of accurate monthly rainfall data from the past 40 years is used for for this study, as we select monthly precipitation to be the drought determinant. Moreover, precipitation has a direct impact on agricultural activities, especially from October to January. The spatiotemporal distribution of droughts is studied within the framework of the Bayesian Maximum Entropy (BME) theory which allows merging spatial and temporal predictions in a single model. Study of model results indicates a decrease in rainfalls in the last 5 years of the studied period.

1 INTRODUCTION

Over the past few decades there has been an increasing concern that human actions and natural disasters have been adversely impacting the environment and posing serious ecological, economic and social problems. This concern has led to an increased emphasis on drought assessment at local and regional level. The spatiotemporal variability of droughts at regional scale is the main purpose of this study. The investigation of monthly rainfalls in the district of Kozani in NW Greece is assessed. Our interest is focused on the variability of drought over the records of 40 years. Generally, monthly precipitation is used as the drought-determining factor since it is usually considered to be the most relevant single hydro meteorological variable in drought estimation. The spatiotemporal distribution of monthly precipitation is studied within the framework of the Bayesian Maximum Entropy (BME) theory [2]. BME is a versatile extension of classical geostatistical methods that can use a variety of physical input, as well as hard and soft uncertain observations.

2 SITE DESCRIPTION

The climate of Greece in low altitude areas is Mediterranean, and characterized by dry and hot summers. The climate of mountainous regions of North, Central and South mainland is instead typical mountainous with high annual precipitations. The mean annual precipitation in Greece is about 900 mm, but there is a strong difference between rainfall amounts in western and eastern parts of the country. The western part receives more rainfall, while the eastern part receives at least 200 mm less on an annual basis [6].

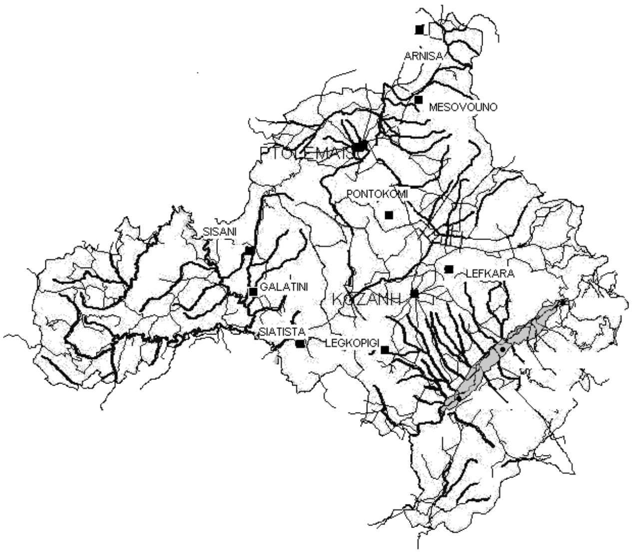

Figure 1. Spatial distribution of rain gauges (black squares) in the study area

The water district of Western Macedonia is the largest of the 14 water districts of Greece. On the basis of rainfall amounts, the territory of the region is classified in the first part of NW Greece and covers approximately 4.450 Km^2 [8]. Figure 1 shows the locations of the rainfall measuring stations in the study area.

3 MATERIALS AND METHODS

3.1 Samples and statistics

During the period from January 1962 to December 1997, monthly rainfall measurements were being recorded at a set of 10 meteorological stations in the broader area as shown in Figure 2. The sample values vary from 0 to 261 mm with an average of 49 mm and a standard deviation of 38 mm.

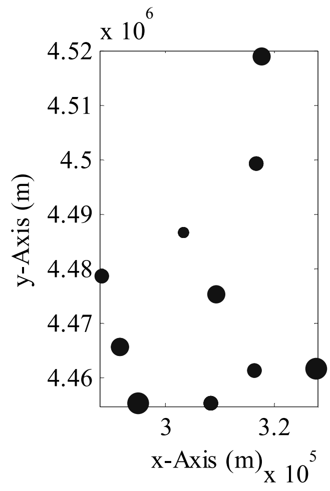

Figure 2. Distribution of average rainfall at sampling locations

We study rainfall in the area by considering monthly precipitation as a spatiotemporal random field (S/TRF). The observations in the data set are overall accurate, and are used as hard data for the prediction of precipitation at unsampled locations. The prediction grid is a subset of the spatiotemporal continuum where distances are based on the eucleidian metric. The spatiotemporal eucleidian metric δs = ds + v dt is expressed in spatial distance units and is the sum of two components. The first one is the spatial distance ds between two space/time points. The second component is the temporal distance dt of the same two points multiplied by a suitable spatiotemopral metric constant v that translates the product v dt into spatial distance units [3].

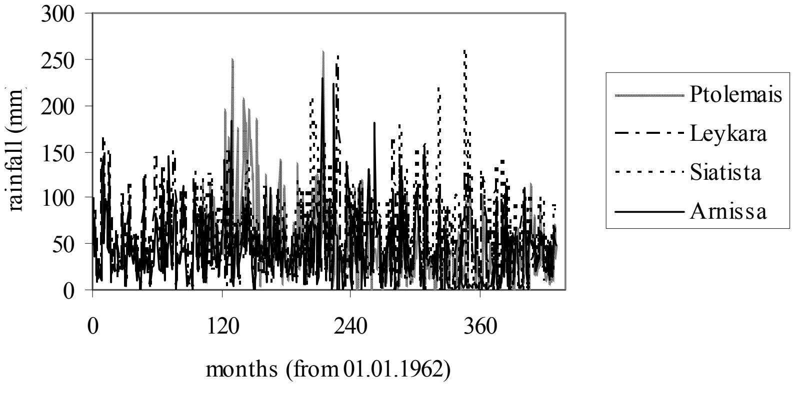

Figure 3. Monthly rainfall at selected sampling stations

The SEKS-GUI software library [7] was used for the stochastic analysis in our study. The spatial prediction grid was set to a 40 x 65 points parallelogram spaced by 1000 m in each axis, as shown in Figure 2. The temporal grid features prediction points at every month for a total of 179 months.

Within the decades-long time scale that we are interested in, a simple plot of sample values on the time axis (Fig. 3) does not reveal any significant long temporal trend, though the annual seasonality of rainfall is evident at smaller time scales. On the contrary, a spatial trend analysis indicates an underlying trend of increasing rainfall values towards the South. Proper calculation of the covariance function should consider a spatially homogeneous and temporally stationary S/TRF so that its average value is constant over the entire study area.

Detrending of the dataset was accomplished with the application of a Gaussian kernel transformation [4]. The outcome of this transformation for all space-time rainfall data was an estimated mean spatiotemporal trend, as for example seen in Figure 4 for two selected instances. Similar plots (not shown) were derived for all other temporal nodes in the prediction grid. Subtraction of trend from the original values leads to a homogeneous S/TRF, and the trend is restored in the analysis results following the completion of the prediction process.

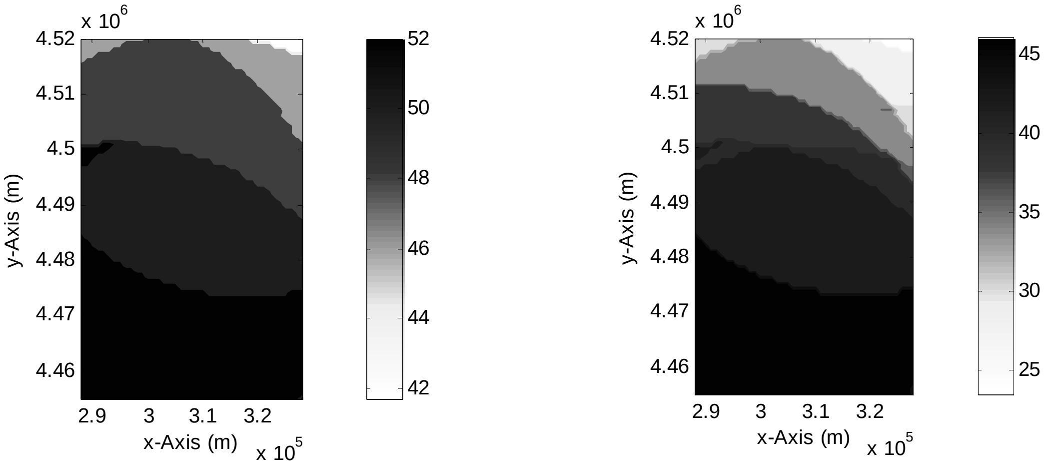

Figure 4. Estimated rainfall mean trend (mm) for 1982 Feb (left) and 1993 Sep (right)

Our analysis considers the first (means) and second (covariances) moments of the rainfall S/TRF, hence we assume that it follows a Gaussian distribution. However, the rainfall data distribution histograms were negatively skewed. Normality was assessed by applying a normal scores transformation to the detrended data [1], [5].

A suitable permissible covariance model was then selected to describe the spatiotemporal systematic dependencies of the precipitation S/TRF based on the empirical covariance from the rainfall observations. Figure 5 shows the average experimental spatiotemporal covariance of the detrended and transformed data in all directions, as well as the fitted theoretical model, which is exponential in the spatial part with a range of 90 km and spherical in the temporal part with a range of 4 months.

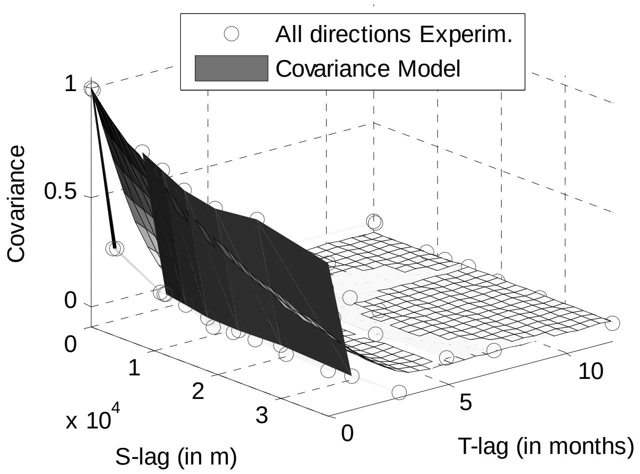

Figure 5. Rainfall experimental and model spatiotemporal covariance in units of normalized rainfall variance.

It is seen from this figure that rainfalls exhibit spatial and temporal dependencies and even though the range of influence covers all the area in the spatial part, it is very short in the temporal part. This result comes to validate the first impression of absence of long term temporal correlation in Figure 3.

3.2 Spatiotemporal mapping

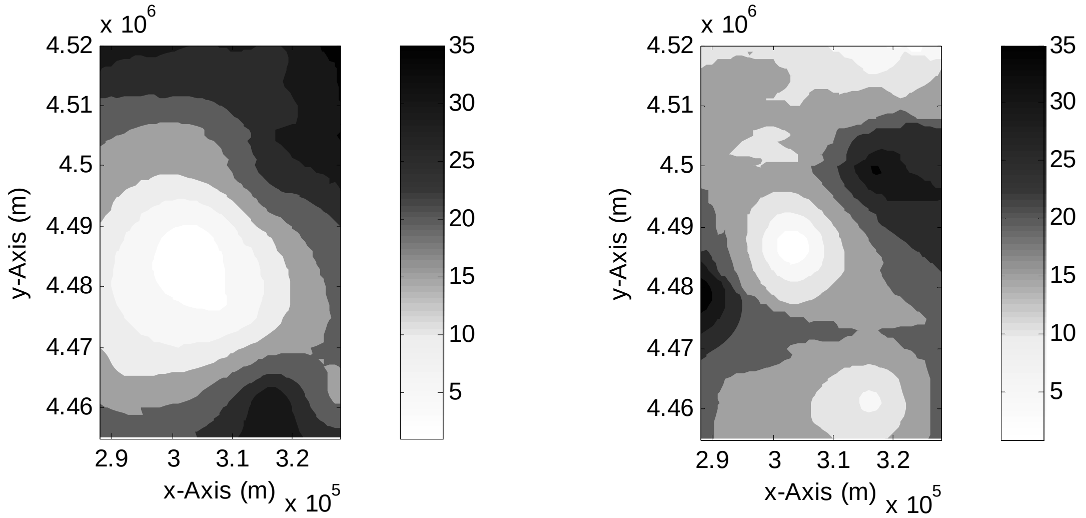

Figure 6. Predicted rainfall map (mm) for 1982 May (left) and 1992 Aug (right)

In the prediction stage we used the available rainfall measurements as well as the aforementioned structural model to obtain maps of the rainfall spatiotemporal distribution. Figure 6 displays the rainfall mode (predictor of the most probable values) maps for two selected instances in the spatiotemporal grid.

The area climate is mostly affected by weather fronts and much less by local atmospheric disturbances that could result in brief, extreme weather phenomena like thunderstorms and torrential downpours. In that sense, our study is largely unaffected by the smoothing effect that monthly rainfall prediction can have on extreme precipitation events. Instead, within the current spatial and temporal scales the produced maps provide a near-seasonal depiction of rainfall intensity that can be very useful for agricultural and water resources analysis and planning.

Specifically, model results show rather lower rainfall intensity in the central part of the study area. There is also an indication of decreased rainfalls in the last 5 years of the studied period.

4 CONCLUSIONS

Employment of BME theory allows merging spatial and temporal precipitation data in a single stochastic model.

The range of influence of the covariance model in the study area is very short in the temporal part, not allowing for long term predictions.

Study of model maps indicates a decrease in rainfalls in the last 5 years of the studied period.

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