ESTIMATING EXTREME DRY-SPELL RISK IN THE MIDDLE EBRO VALLEY (NE SPAIN): A COMPARATIVE ANALYSIS OF PARTIAL DURATION SERIES WITH A GENERAL PARETO DISTRIBUTION AND ANNUAL MAXIMA SERIES WITH A GUMBEL DISTRIBUTION

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Abstract: This paper analyses fifty-year time series of daily precipitation in a region of the middle Ebro valley (northern Spain) in order to predict extreme dry-spell risk. A comparison of observed and estimated maximum dry spells (50-year return period) showed that the Generalised Pareto (GP) distribution combined with partial duration series (PDS) gives better results than the Gumbel distribution fitted to annual maximum series (AMS). Indeed, the classical Gumbel approach underestimated the empirical duration of dry spells. The PDS/GP approach was successfully applied in the study of extreme hydro-climatic variable values. The results reported here could be applied in estimating climatic drought risks in other geographical areas.

Keywords: Dry spells, return periods, drought, partial duration series, annual maximum series, Gumbel distribution, Generalized Pareto distribution, Ebro valley, Spain.

1- INTRODUCTION

There is great interest in determining the return periods of extreme hydrological events (precipitation or flows) so as to mitigate possible associated risks and considerable efforts have been made to develop stochastic methods to determine such risks accurately (WMO, 1989; Bobée and Rasmussen, 1995). The results of these probabilistic analyses are essential information in a range of activities including the construction of infrastructures, the expansion of population centres and land-use management .

Of all twentieth century natural hazards, droughts are those that have had the greatest detrimental impact (Obasi, 1994; Bruce, 1994). But droughts are not easily defined and need to be understood in terms of their hydrological, agricultural, and socio-economic impact (Dracup *et al*., 1980; Wilhite and Glantz, 1985). Although the causes of drought can be multiple (involving both human and physical factors), the on-set of a drought is usually caused by the decrease in, or absence of, precipitation.

Droughts cause major economic and human losses, affecting hundreds of millions of people, and numerous studies have highlighted the need for drought prevention and mitigation plans (Wilhite, 1991 and 1996; Wilhite and Wood, 1985; Wilhite *et al*., 1986; Sangoyomi and Harding, 1995). In order to protect agriculture and other socio-economic concerns the spatial and temporal assessment of droughts is necessary, while areas at risk from droughts of long duration and great intensity need to be determined. Sivakumar (1992) stresses the importance of recognising spatial patterns of extreme drought, which can then be used in the management of cultivated areas (crop selection, irrigation planning, etc.).

The study of hydrological extremes has typically focused on clearly defined episodes (principally floods), while other equally major but more *gradual* risks such as droughts – the on-set and termination of which are often unclear (Wilhite and Glantz, 1985) - have received less attention. Even less attention has been paid to the development of methods for studying extreme drought risk. And, although the consequences of a drought are more difficult to identify than those of an *instantaneous* risk, they can often be much worse. For this reason, advances in the development of methods that allow us to estimate more accurately the risk of occurrence are essential. Furthermore, the close links between crop types and agricultural productions and climatic characteristics mean the methods for estimating drought risk in agrarian planning are vital.

Many approaches have been adopted in the analysis of climatic droughts. Several studies have analysed droughts using monthly precipitation data, where droughts are considered as precipitation deficits with respect to average values (Gibbs, 1975). Recently, this approach has been improved, and better indices have been developed for a range of time scales (McKee *et al*., 1993 and 1995; Hayes *et al*., 1999). Some studies have looked at various factors in addition to precipitation, considering droughts as shortages in the soil water balance (Thornthwaite, 1948; Palmer, 1965). Other approaches analyse drought duration and intensity in relation to cumulative precipitation shortages (Chang and Kleopa, 1991; Estrela *et al*., 2000) .

The utility of these drought indices is greater in drought monitoring and management since they enable drought intensity, duration and magnitude to be identified, and the drought intensity in a number of areas to be compared at the same point in time. Yet, these indices are not so useful for identifying spatial patterns of drought risk, as they are based on

standardized or normalized shortages in relation to average conditions. Thus, even when the duration of the drought index series is long, the drought index values will occur with the same frequency (Lana *et al.,* 2001).

Sequences of days without precipitation, or dry spells, have frequently been used in the spatial analysis of drought risk. Drought duration and intensity are directly proportional to the number of days without precipitation (Dracup *et al.,* 1980). Several statistical methods have been used to determine the drought risk based on dry spells in the daily precipitation series. These include the Markov chain series (Lana and Burgueño, 1998a; Martín-Vide *et al.,* 1992; Pérez-Manrique *et al.,* 1984; Martín-Vide and Gómez, 1999) and different probability distributions, e.g., the exponential (Davy, 1978; Creus *et al*., 1981), the Eggenberger-Polya (Berger and Goosenes, 1983), and the truncated negative binomial (De Arruda and Pinto, 1980; Nobilis, 1986; Douguedroit, 1987 and 1990). These distributions are adjusted empirically to the original data series, and the return periods of dry spells of given duration are estimated. However, these distributions do not exhibit good fit to the extremes of the dry-spell series (Gabriel and Neumann, 1957; Flannigan and Harrington, 1988; Perzyna, 1994). As the time between events increases, their stochastic dependence falls, so that the most extreme dry spells in the series can be considered a random variable. The difficulties encountered in estimating the probability of occurrence of extreme dry spells is unfortunate because a better understanding of these phenomena might mean that the highly detrimental effects on the environment, water resources, and agriculture could be avoided.

Traditionally, the analysis of extremes in dry-spell series has been examined using annual maximum series (AMS) adjusted to a Gumbel distribution (Gupta and Duckstein, 1975;

Lana and Burgueño, 1998b; Ascaso and Casals, 1981). The AMS are constructed by determining the maximum dry spell for each year, so the series length equals the number of years for which records are available. However, this approach is not free of problems. The main drawback is the loss of the 2nd, 3rd, etc, largest annual dry spells, which might be considered extreme dry spells, and which might exceed the maximum dry spells of other years. An alternative approach is the partial duration series (PDS), which are constructed using the values above a selected threshold regardless of the year in which they occurred (Hershfield, 1973). Typically, the Generalized Pareto (GP) distribution has been used to model PDS (Bobée and Rassmussen, 1995). Although the PDS approach has obvious advantages over the AMS approach (Cunnane, 1973), it has been used only infrequently in precipitation dry-spell analysis (see, e. g., ARIDE, 2002).

The objectives of this paper are three: First, to determine whether the use of AMS with the Gumbel distribution (AMS/G approach) is suitable for modelling extreme daily dry-spell risk; second, to analyse if PDS with the Generalized Pareto (PDS/GP) is adequate for modelling extreme dry-spell risk; third, to compare both approaches with the observed maximum dry spells to determine the most suitable estimation of drought risk.

The data series studied correspond to the middle Ebro valley (North-East Spain). Forty-three daily precipitation series from 1951 to 2000 were used. In this area, the low annual precipitation and the frequent long dry spells are a major restrictive factor in crop growth. For this reason, this area is particularly suitable for testing these methods.

1- STUDY AREA

The location of the study area is shown in Figure 1. It is a heavily settled area with scant vegetation. The relief isolates the valley, largely impeding any maritime influences and giving it a continental climate. These features similarly determine the complexity of its climate, its principal feature being its aridity (Cuadrat, 1991; Creus and Ferraz, 1995; Creus 1996). The proximity of the Mediterranean sea, however, and the location of the study area in a climatic transition area (Balairón, 1997) give rise to significant temporal variability, alternating years of high precipitation associated with the polar fronts with years dominated by Mediterranean disturbances (Creus, 1983).

The annual precipitation oscillates between 300 and 450 mm in the valley bottom, and more than 800 mm in the northern and southern mountain areas (Figure 2). A high interannual variability is observed as a consequence of the alternation of dominant atmospheric patterns. There are years in which the precipitation greatly exceeds the mean value; in other years, the values are less than a third of the mean, and long drought periods are then particularly frequent (Saz and Creus, 1998; Cuadrat *et al.,* 2002). The mean annual temperatures oscillate between 14 and 16ºC in the valley bottom, and below 11ºC in the highest sectors.

The spatial distribution of the annual percentage of dry days is shown in Figure 3. Two thresholds are considered: 0.1 mm and 5 mm. In the case of the 0.1 mm threshold, a NW-SE gradation exists. In the north-west, just less than 80% of the days are dry, with a progressive increment in this value towards the east, with more than 88 % of the days recording precipitation at or below the threshold. At the 5 mm threshold, there is a N-S gradient with the largest percentage of dry days being recorded in the central valley (>93

%). The lowest values appear in the north (<88 %), whereas in the southern ranges a secondary minimum is reached where the influence of Mediterranean disturbances coincides with higher relief features.

2- METHODOLOGY

3.1- Data base elaboration

Of the 380 weather stations in the central Ebro valley, we selected those for which less than 15 % of values were missing for the period 1951-2000. This gave a total of 43 observatories (Figure 1). The weather stations were homogeneously distributed, although the density in the western and south-western sectors was lower.

Using data from neighbouring stations, Romero *et al.* (1998) outlined a method for completing daily precipitation series. In the observatories of the Ebro valley, the missing values were substituted by means of the weighted average of the daily precipitation of the stations located within a 15-kilometre radius of the candidate station:

$$P_i = \frac{\sum_{j=1}^{n} P_j d_{ij}}{\sum_{j=1}^{n} d_{ij}} \qquad (1)$$

where P_i is the precipitation at the candidate observatory, P_j is the precipitation at the neighbouring observatory and d_{ij} (the distance between points i and j) is the weighting factor. For the 43 weather stations, dry-spell series were obtained for two distinct thresholds. The dry-spell term refers to series of consecutive days with precipitation less than or equal to a given threshold ($\leq\alpha$ mm, Douguedroit, 1987; Nobilis, 1986; Ascaso and

Casals, 1981). Commonly, a threshold of 0.1 mm is applied (Lana and Burgueño, 1998a; Martin-Vide and Gómez, 1999; Pérez Manrique *et al.,* 1984), though a number of authors have used other thresholds. Hershfield (1981) used a 1 mm threshold in the analysis of the frequency of dry days in the USA. Harrington and Flannigan (1993) used a 1.5 mm threshold; given, they claim, that in forested areas the first 1.5 mm are intercepted by trees. Douguedroit (1987) considered a 1 mm threshold in Mediterranean climatic environments, since below that quantity the precipitation is not absorbed by soils in conditions of high evapotranspiration. The same threshold was used by Galliani and Filippini (1985) in the east of Italy. Martin-Vide and Gómez (1999) used a threshold of 10 mm. With this threshold, isolated days with low precipitation can be eliminated because these days can conclude a long dry-spell when defining the events, even when the drought has not ended. Sivakumar (1992), in an analysis of dry-spell frequency in Niger, established a range of thresholds from 1 to 25 mm. Perzyna (1994) used a 2 mm threshold in Norway. Finally, Alyamani and Sen (1997) used a 0 mm threshold in dry-spell analysis in Saudi Arabia.

Here, two thresholds were used: 0.1 mm and 5 mm, the former representing the minimum quantity of precipitation that the official pluviometer in Spain records. Higher thresholds were not considered, since in this semi-arid region the natural vegetation and cultivations are adapted to the climatic conditions. Thus, during drought periods, one isolated precipitation of more than 5 mm can allow vegetation growth provided that it takes place at the opportune moment (Austin *et al.,* 1998).

3.2. - Extreme dry-spell modelling with annual maximum series and Gumbel distribution.

The most commonly used distribution for extreme dry-spell frequency modelling is the AMS/G approach (Gumbel, 1958; Lana and Burgueño, 1998b; Ascaso and Casals, 1981; Perzyna, 1994). The Gumbel distribution is a two-parameter distribution with constant skewness. It is a particular case of the three-parameter Generalised Extreme Value distribution (GEV), that is the limit distribution for maxima series. The Gumbel is usually preferred to the GEV because of its ease of calculation. Its probability density function is:

$$f(x) = \frac{1}{\alpha} e^{-\left(\frac{x-\beta}{\alpha}\right) - e^{-\left(\frac{x-\beta}{\alpha}\right)}} \qquad (2)$$

and its cumulative distribution function is expressed:

$$F(x) = e^{-e^{-\left(\frac{x-\beta}{\alpha}\right)}} \qquad (3)$$

where x is the value of the variable, α and β are the parameters of the distribution. They are commonly estimated by the method of moments (Chow, 1964; Rao and Hamed, 2000), although they can also be estimated by L-moments (Greenwood *et al.,* 1979). The method of L-moments was preferred here because it yields more robust estimations than conventional moments (Sankarasubramanian and Srinivasan, 1999; Vogel and Fennessey, 1993). Hosking (1990) explains in detail the estimation of parameters using L-moments.

The prospective maximum dry-spell for a T year period X_T, can be calculated using:

$$X_T = \beta - \alpha \ln\left[-\ln(1 - (1/T)\right] \qquad (4)$$

3.3. - Estimation of extreme dry spells using partial duration series (PDS)

3.3.1- Characteristics of partial duration series

Although the preceding method has been widely used in the study of extreme dry spells, in the analysis of other hydrological and climatic variables (e.g. extreme rainfall, floods) many studies prefer to use PDS or series of peaks over an upper limit. Given the dry spell series $x = \{x_1, x_2,..., x_i\}$, for the station x, where x_n is the duration of a given dry spell, the PDS $y = \{y_1, y_2,..., y_j\}$ consists of all the values of the original series that exceed a predetermined upper limit, x_0:

$$y_j = x_i - x_0 \ \forall \ x_i > x_0 \qquad (5)$$

The size of the series obtained depends, therefore, on the upper limit, x_0. For this reason, PDS use the information contained in the original sample more efficiently, and permit the inclusion of more than one event per year, if they satisfy the conditions established in defining an extreme event (Kite, 1977; Chow *et al.,* 1988).

3.3.2- Probability distributions used to adjust partial duration series

Many probability distributions have been adjusted to PDS hydrological series, including lognormal, Pearson III, Gamma, General Extreme Value, Wakeby, Weibull, etc. (Bobee *et al.,* 1993; Rao and Hamed, 2000). Many recent studies have demonstrated the better performance of the Generalized Pareto (GP) distribution in the fit of extreme hydrological variables using PDS (Madsen *et al.,* 1997a and b). The GP is the limit distribution for excess over a lower bound series as is the General Extreme Value in the case of the AMS series.

The GP distribution function is:

$$F(x) = 1 - \left[1 - \frac{\kappa}{\alpha}(x - \varepsilon)\right]^{1/\kappa} \qquad (6)$$

where κ is the shape parameter and α is the scale parameter of the distribution, ε is the location parameter or distribution origin that corresponds to the lower bound of the PDS, x_0.

The parameters of the distribution can be obtained by L-moments (Hosking, 1990):

$$\alpha = \lambda_1 \left(\frac{1}{\tau_2} - 1 \right) \qquad (7)$$

$$\kappa = \frac{1}{\tau_2} - 2 \qquad (8)$$

The event X_T in a period of T years is obtained using:

$$X_T = \varepsilon + \frac{\alpha}{\kappa} \left[1 - \left(\frac{1}{\lambda T} \right)^{\kappa} \right] \qquad (9)$$

where λ is the average number of events per year above the upper limit.

Hosking (1990) gives parametric approximations to the relationships between τ_3 and τ_4 (L-skewness, and L-kurtosis, respectively), which permit comparison with the ratio estimations, and determine the suitability of the proposed distribution.

A major problem in using PDS is the selection of the lower bound, x_0. This value should be low enough to ensure the inclusion of as much relevant information as possible, without violating the assumption of independence of the peaks. Various methods have been proposed to determine the most appropriate lower bound (Ashkar and Rouselle, 1987; Madsen *et al.*, 1997a). However, Beguería (2003) has shown that the parameters and quantile estimations vary randomly with the threshold value, and no single value is entirely adequate. For this reason, in this paper the maximum dry spell in the 50-year period was calculated using different lower bounds in the PDS/GP approach. These bounds were

defined using the percentiles of the dry-spell series every 0.25 from the 90 to 99.75 percentiles. Dry spells were considered extreme above the 90 percentile.

3.4- Comparison of the AMS/G and PDS/GP series approaches

The maximum dry spell observed in each series in the period 1951-2000 was extracted. These were compared with the 50-year estimates using the AMS/G and PDS/GP approaches. It is clear that the maximum dry spell observed in a 50-year period does not necessarily correspond to a return period of 50 years. This limitation was partially overcome by using several weather stations in the same region. The goodness of fit was tested by means of the root mean square error (RMSE, Willmot, 1982), the lowest value indicating the best estimation.

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (z_i - \hat{z}_i)^2} \qquad (10)$$

z_i is the observed value and the circumflex ^ indicates estimation using annual maximum or partial duration series; n is the number of weather stations.

3- RESULTS

4.1- Performance of the AMS/G and PDS/GP approaches

In Figure 4, the L-moment ratios diagram is shown. The theoretical curve of GP distribution is shown along with the PDS ratios obtained using three different lower bounds (defined by percentiles 90, 95 and 97) using the dry-spell series defined at 0.1 mm. The Gumbel distribution ratios are also shown as a point, along with the data from the AMS. Figure 5 shows the same data, for the series of dry spells defined at 5 mm. The goodness of

fit of the PDS clouds was higher for the lowest lower bound (percentile 90) and for the 0.1 mm dry-spell series. Both effects were due to the reduction in the number of events as the lower bound and the dry-spell threshold increased.

The greater efficiency in the use of information in the PDS approach was reflected in the lower dispersion of the points in the L-moments ratios diagram. In comparison with PDS clouds, AMS showed a higher dispersion.

In addition, it was clear that a three-parameter distribution (GP) adapted better to the data series than a two-parameter distribution (Gumbel), as it was more flexible. This can be clearly seen in the figures, in which the GP distribution appears as a line, whereas the Gumbel is shown as a single point. The GP distribution proved to be a good model for the PDS series, as demonstrated by the closeness of the distribution line to the individual series, whereas the AMS cloud showed a higher dispersion with respect to the point representing the Gumbel distribution.

As mentioned earlier, the main problem in using PDS involves the selection of the lower bound. In theory, the method is invariant to the variation in the lower bound. In practice, however, the results may vary greatly, especially with the sample sizes that are common in hydro-climatic studies. This is exemplified in Figure 6, in which the maximum dry spells expected in 50 years are shown for six weather stations, in relation to the lower bound used. Whereas this value was expected to be similar independently of the lower bound chosen, it showed great random variation, as high as 20 % in some cases. In this paper we assumed that the average of the different values would provide a good estimate of the unknown true value, being less uncertain than using a unique, arbitrary, threshold.

4.2- Comparison of maximum dry spell estimations using the AMS/G and PDS/GP approaches with the observed maximum dry spells

Figures 7 and 8 compare AMS/G and PDS/GP estimates with the observed maximum dry spells for the 0.1 and 5 mm series. The AMS/G method clearly underestimated the duration of the observed maximum dry spells. The underestimation was greater than 30 days for the 5 mm dry-spell series, which severely limits the practical use of this method. The PDS/GP performed much more accurately for both the 0.1 and 5 mm dry-spell series.

The RMSE between the observed and estimated values is also highly indicative of the better performance of the PDS/GP distribution. There was a better adjustment for the 0.1 mm series (RMSE = 9.8 v. 17.3), while for the 5 mm dry-spell series, the adjustment was also better (RMSE = 19.8 v. 27.2).

Figure 9 shows the spatial distribution of the maximum dry spells observed in the study area between 1951-2000, and the estimations using the PDS/GP and AMS/G approaches for the 0.1 mm dry-spell series. The longest dry spells are located in the eastern areas, with values over 130 consecutive days of precipitation over below 0.1 mm. The same pattern is revealed by both estimations, but the Gumbel estimations are clearly lower than the observed figures. The PDS/GP map shows a much closer match to the observed data.

The spatial distribution and the estimations for the 5 mm dry-spell series are shown in Figure 10. The spatial patterns differ markedly from those in Figure 9. The most extreme dry spells (e.g. 170 days of precipitation below 5 mm) were located in the centre of the study area. There were significant contrasts between the centre and depression borders, with differences of more than 50 days. The differences between modelled and observed values were again lower for the PDS/GP approach than for the AMS/G approach.

The absolute errors of the estimations are shown in Figures 11 and 12. The high magnitude of the errors resulting from the AMS/G approach is evident. Here, the positive errors indicate the underestimation provided by this approach. By contrast, the errors of the PDS/GP approach include low positive and negative values and the estimation is, in general, better.

4- DISCUSSION AND CONCLUSIONS

Daily precipitation dry-spell series are commonly used in the stochastic analysis of drought occurrence. Extreme values correspond to long spells of consecutive days without precipitation that generate episodes of climatic drought. To date, the frequency analysis of these extreme values has been carried out using AMS adjusted to the Gumbel distribution (Lana and Burgueño, 1998b; Ascaso and Casals, 1981, Perzyna, 1994).

In this paper, we have used a PDS sampling in conjunction with a Generalized Pareto distribution, adopting a similar approach to that used in other studies that have sought to model extreme precipitations (Alila, 2000), floods (Mkhandi *et al.,* 2000) or hydrological droughts (ARIDE, 2002). The results obtained have been compared to those obtained when adopting the AMS/G approach for the maximum dry spell series observed in the study area.

The use of PDS for the stochastic modelling of extremes has yielded good results in the analysis of hydrological variables (Moreno and Roldan, 1999; Alila, 2000; Mkhandi *et al.,* 2000), whereas numerous studies have pointed out that AMS produces a significant loss of data for extreme modelling (Cunnane, 1973; Madsen *et al.,* 1997a and b). In this paper, the greater efficiency of PDS has been demonstrated for dry-spell series by the lower

dispersion of the points in the L-moments ratios diagram. In comparison with PDS clouds, AMS show a higher dispersion, yielding greater uncertainty.

Different probability distributions can be used to fit both AMS and PDS. The Gumbel distribution is a two-parameter extreme values distribution widely used in modelling AMS. It has been compared to the three-parameter Generalized Pareto distribution fitted to PDS. Generalized Pareto is the limit distribution for excesses over an upper limit, and is the most frequently used model with PDS (Kjeldsen *et al.,* 2002; Madsen *et al.,* 1997a and b). It is obvious that a three-parameter distribution would fit the observed data better than a two-parameter one. Nevertheless, the need to estimate a greater number of parameters introduces an extra source of uncertainty that can affect the final estimates.

In spite of this, the RMSE obtained by the PDS/GP is lower than that obtained by the AMS/G when analysing the empirical maximum dry spells for a 50-year time series. Moreover, in common with the findings reported in several studies (Neyman and Scott, 1971; Cowpertwait *et al.,* 1996; Beguería, 2002), the AMS/G clearly underestimates the empirical extreme dry spells. For this reason, the PDS/GP approach is recommended for estimating drought risk for longer recurrence intervals, and which therefore exceed the longitude of the data set.

One shortcoming of the method proposed is the selection of the upper limit used to define the PDS. We found that the final quantile estimates vary significantly when only small changes are made in the upper limit used. To deal with this problem we propose the use of different upper limits when constructing a set of PDS, and then taking the average quantile estimates obtained with them. A set of PDS with limits ranging from 90 to 99.75 centiles rising by 0.25 steps was used in this paper. This proved to stabilize the variability of the

quantile estimates. However, if this methodology is to used on a more general scale, the upper limit range used needs to be defined more accurately, as it can differ for each data set.

This paper has demonstrated that the widely used AMS/G approach underestimates the observed extreme dry-spell risk. By contrast, the PDS/GP approach produces more accurate estimates. The shortcomings of this methodology have been discussed, and a modified sampling method proposed. There are sufficient theoretical indications suggesting that this methodology can be exported to other regions. However, this needs to be confirmed by other studies.

The methodological improvement described here is of potential importance for agrarian planning, since it yields more precise estimations of extreme drought risks. The method should also be of benefit in crop management as it facilitates the drawing of risk maps and the drafting of preventive and palliative plans for the mitigation of the effects of drought.

ACKNOWLEDGEMENTS

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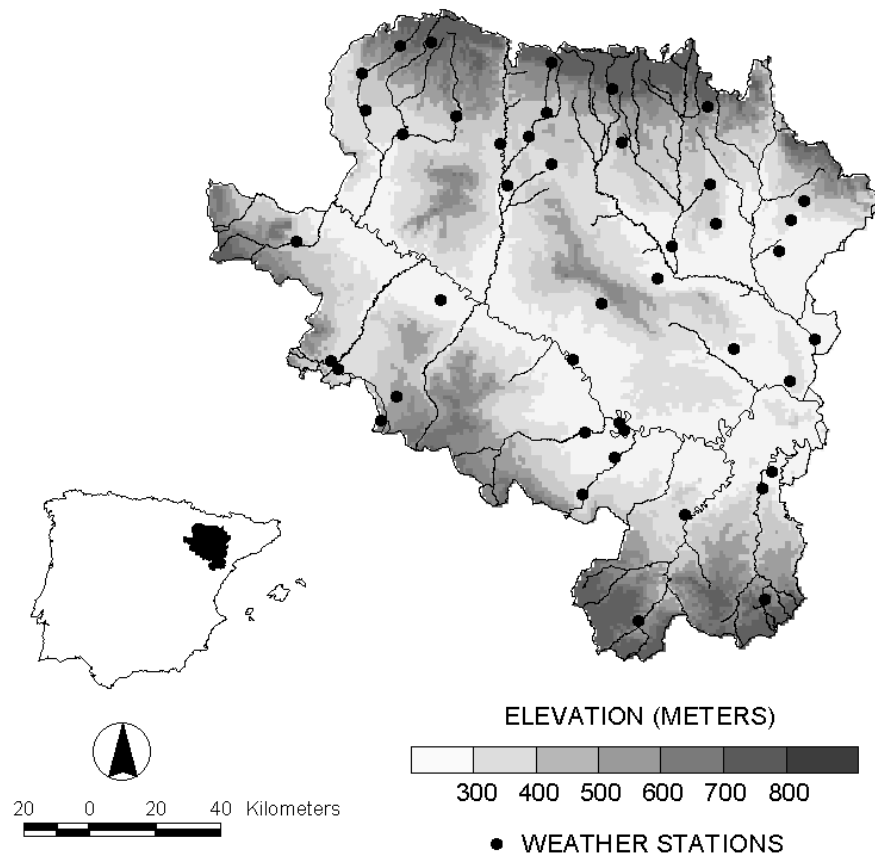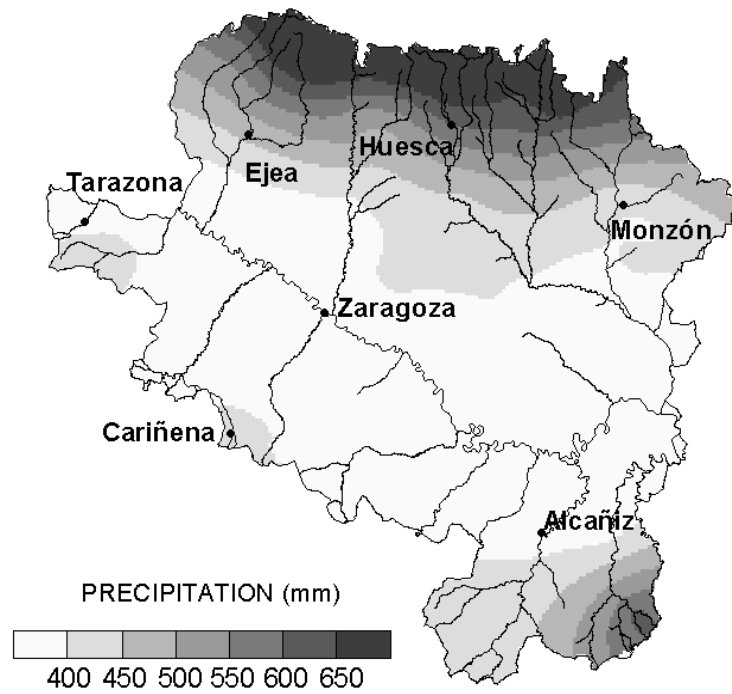
Figure 1: Study area
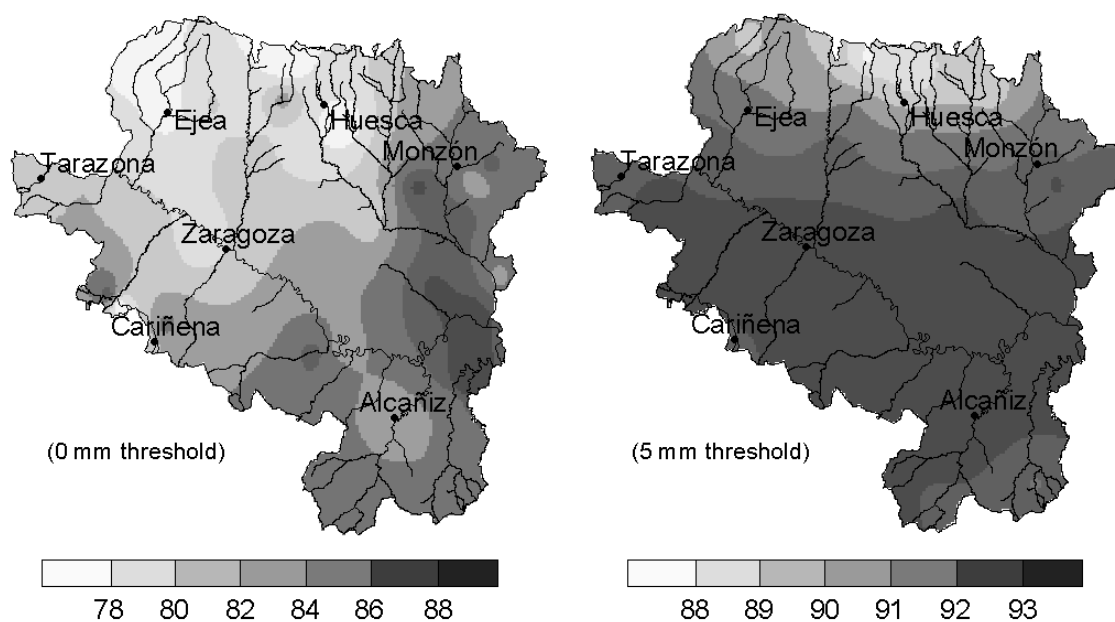
Figure 2: Annual mean precipitation

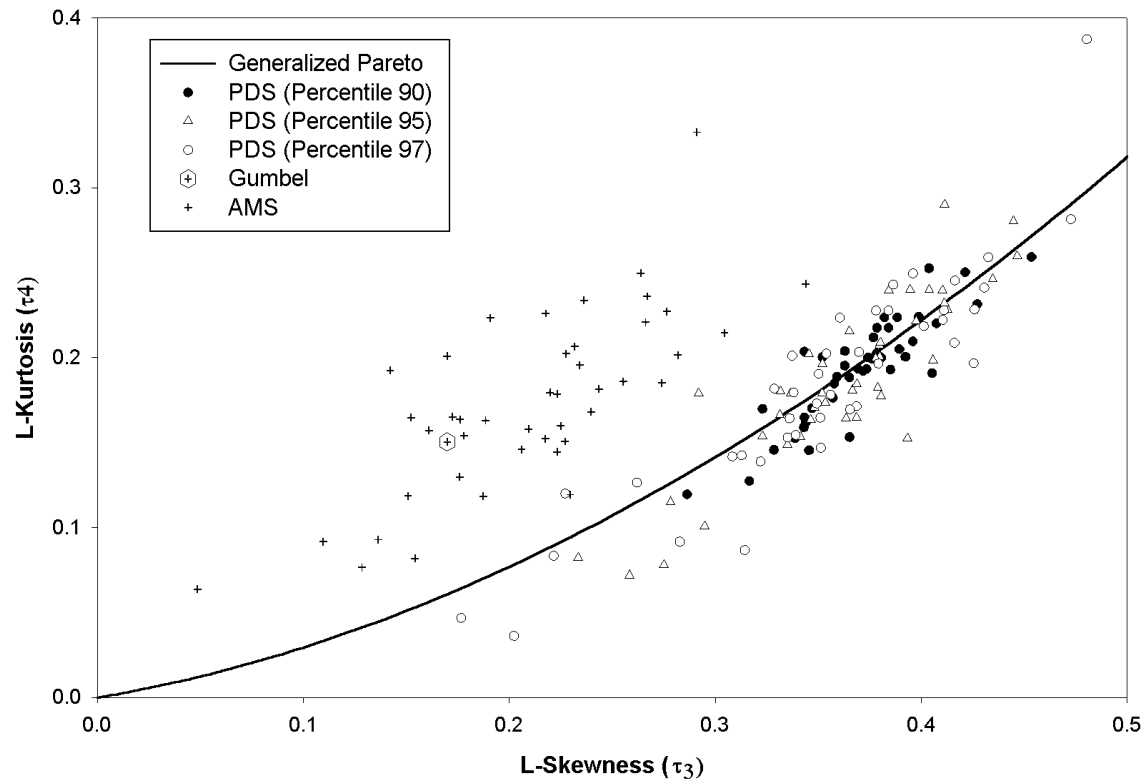Figure 3: Percentage of dry days at 0.1 and 5 mm thresholds (1951-2000)

Figure 4: L-moments ratios diagram. Dry spell series at 0.1 mm threshold. The L-moments of AMS and PDS at three upper limit (defined by centiles 90, 95 and 97) are shown.
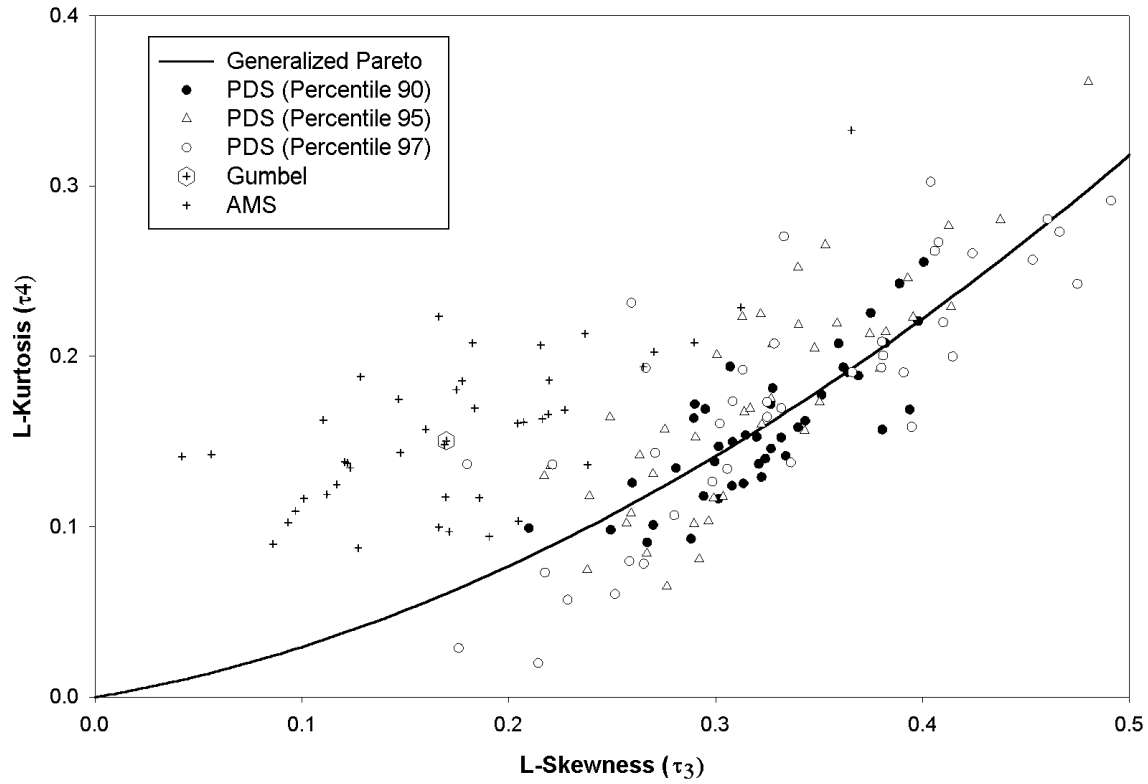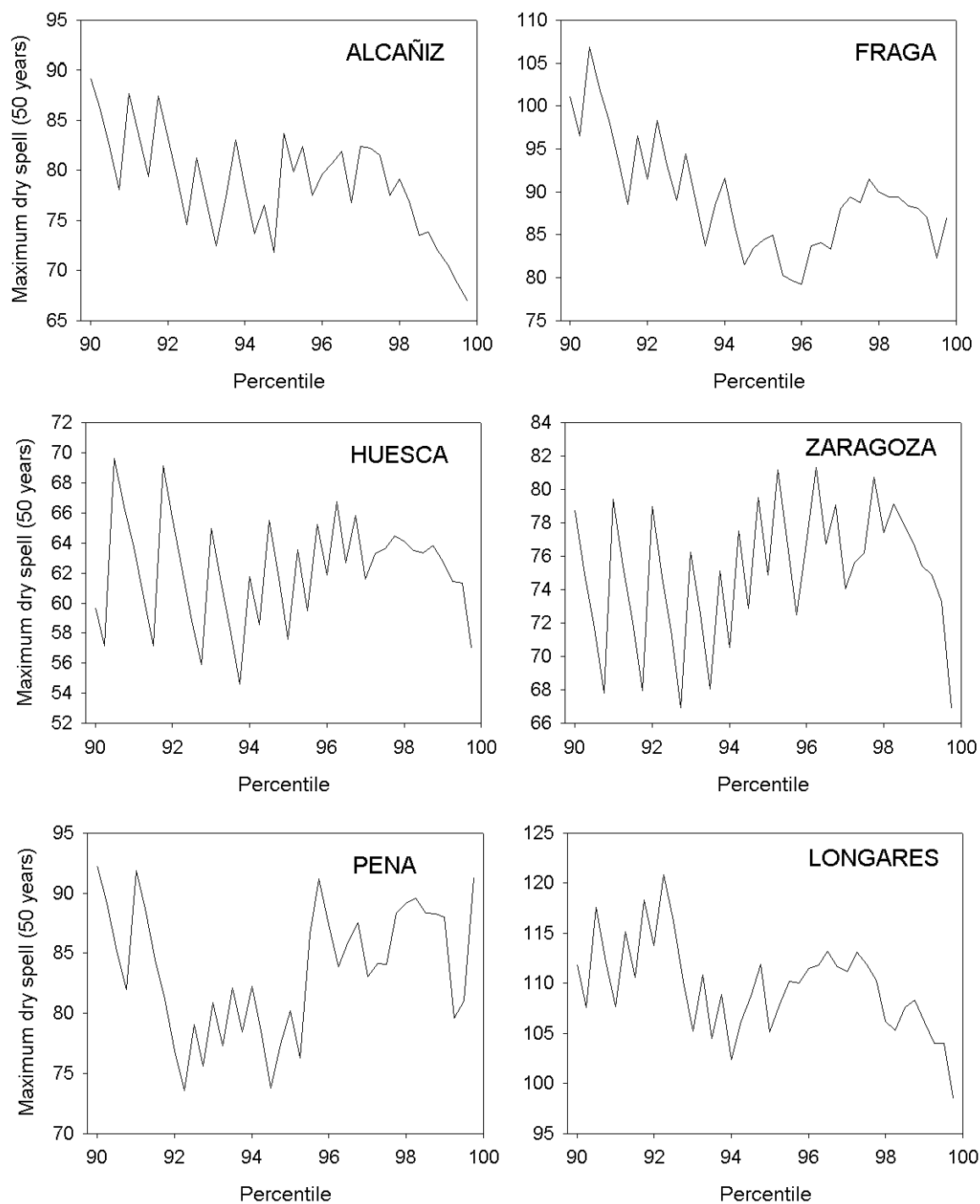
Figure 5: L-moments ratios diagram. Dry spell series at 0.1 mm threshold. The L-moments of AMS and PDS at three upper limit (defined by centiles 90, 95 and 97) are shown.

Figure 6: Oscillation of the maximum dry spell estimations in function of the selected percentile in the creation of the dry spell PDS. Six representative weather stations are shown.

Figure 7: Differences between maximum dry spells observed and estimated using PDS modelled using the Generalized Pareto distribution.

Figure 8: Differences between maximum dry spells observed and estimated using AMS modelled using Gumbel distribution.
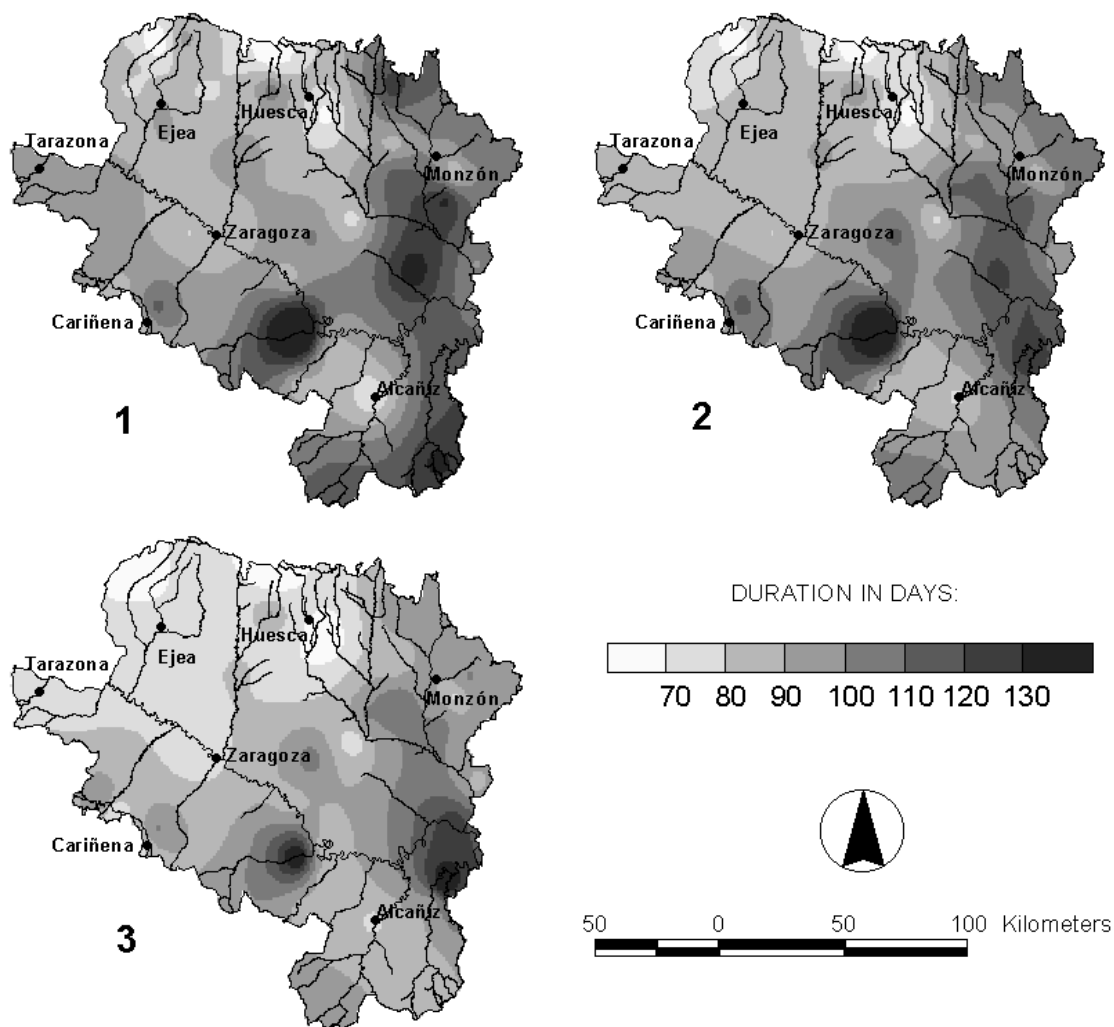
Figure 9: Dry spells at 0.1 mm threshold: 1 Observed maximum dry spells in 50 years (1951-2000). 2 Predicted maximum dry-spell using the Generalized Pareto distribution. 3. Predicted maximum dry-spell using Gumbel distribution.
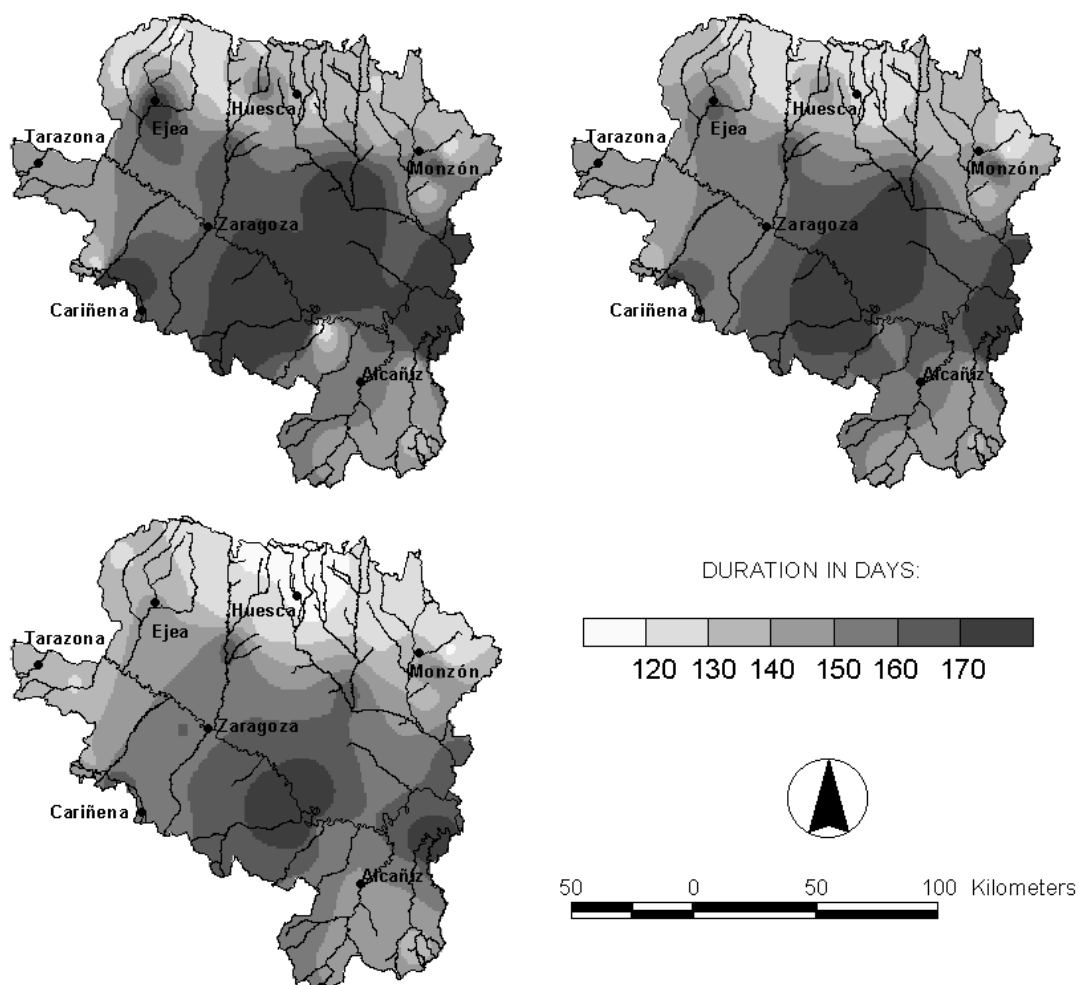
Figure 10: Dry spells at 5 mm threshold: 1 Observed maximum dry spells in 50 years (1951-2000). 2 Predicted maximum dry-spell using the Generalized Pareto distribution. 3. Predicted maximum dry-spell using Gumbel distribution.
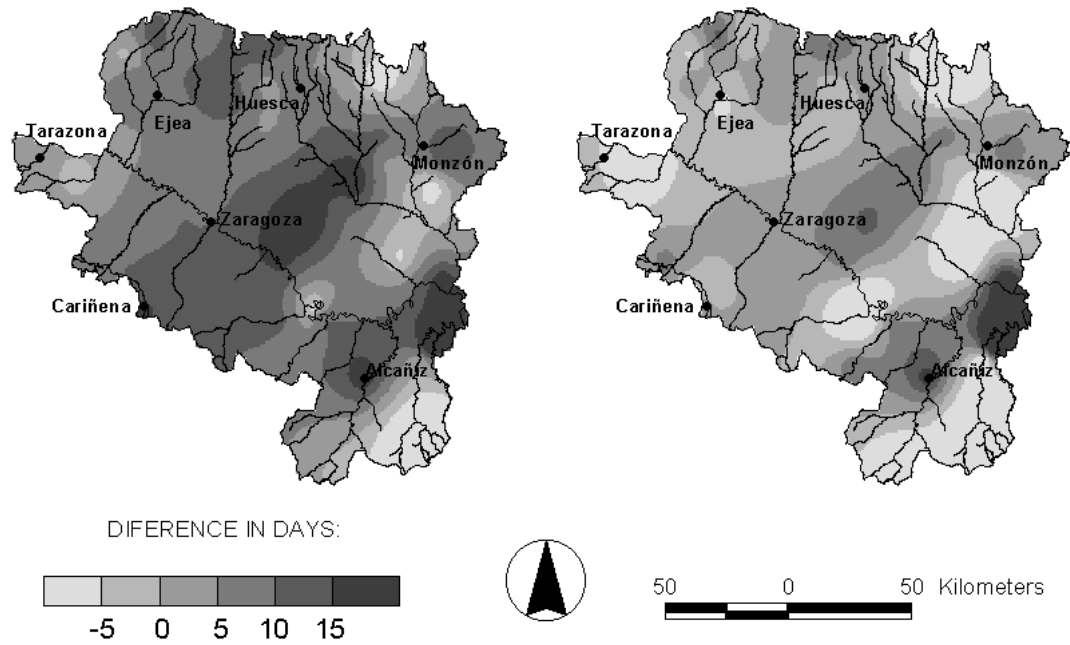
Figure 11: Differences between maximum dry spells observed and estimated at 0.1 mm threshold: 1- Observed-Estimated using Gumbel distribution. 2- Observed-Estimated using a Generalized Pareto distribution.
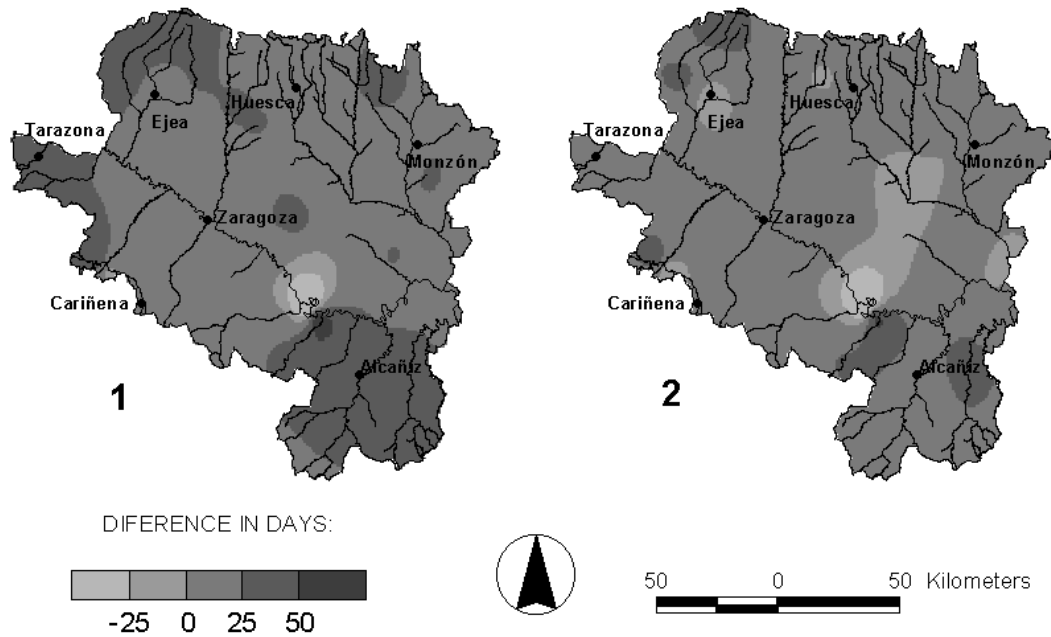
Figure 12: Differences between maximum dry spells observed and estimated at 5 mm threshold: 1- Observed-Estimated using Gumbel distribution. 2- Observed-Estimated using a Generalized Pareto distribution.