Riadas e inundaciones en la provincia de Toledo. Análisis meteorológico e impacto social

Floods in the province of Toledo. Meteorological analysis and social impact

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RESUMEN
El objetivo de este trabajo es doble. Por un lado, se tratará de caracterizar desde el punto de vista climatológico la precipitación en la provincia de Toledo tomando como referencia un conjunto de estaciones pertenecientes a la Agencia Estatal de Meteorología (AEMET) que representen cada una su respectiva comarca geográfica. El segundo fin es el análisis sinóptico de las inundaciones históricas más severas que se han dado en la provincia de Toledo.
Palabras clave: Precipitación; inundación; Toledo; climatología histórica.

ABSTRACT
There are two main objectives in this work. On the one hand, it will be characterize, from the climatological point of view, the precipitation in the province of Toledo taking as a reference a set of stations belonging to the State Agency of Meteorology (AEMET) that represent each one its respective geographical zone. The second objective is the synoptic analysis of the severest historical floods that have happened in the province of Toledo.
Key words: Precipitation; floods; Toledo; historic climatology.

1. INTRODUCTION

The target of the Historical Climatology is the recovery and the meteorological analysis of situations of the past taking as a reference written papers (files, archives, newspapers, inscriptions …), press or oral tradition (Llasat et al., 2005; Domínguez-Castro et al., 2008; Rodrigo and Barriendos, 2008). For it, it is necessary, in some cases, to use historygraphical tools (as for example the paleography) to obtain the information that is useful from the climatological point of view (Llasat et al., 1999 ; Rodrigo, 2002).

The knowledge and the analysis of the meteorological phenomena of the past allow to know better the climatic mechanisms of a certain zone and to be able to characterize and to evaluate, with certain precision, current episodes of special virulence and more in the latter years where any minimally extraordinary phenomenon is imputed– especially by the media - to the Climatic Change (Barriendos et al., 2002).

In order to study the precipitation in the province of *Toledo*, it has been used seven meteorological stations of the network of the State Agency of Meteorology (AEMET) that could be representative of each of the geographical zones that form the province. The fundamental requisite for the selection of these stations has been the continuity in their series. It was observed that the period 1971-2005 did not have temporal gaps, and then it was used as a standard interval.

The principal sources of information used to make a list of historical floods in the province of *Toledo* have been principally the provincial press, and books on the local history of the different municipalities of the province.

We have initiated this compilation of floods at the beginning of the XIXth century; although it is true that in the archives and in the publications there are also previous floods, like that caused by the *Alcantarilla* dam (*Mazarambroz*) in the IVth century. The last flood reported belong to June, 2007 to include the most recent suffered in the whole region of *La Mancha* between 20 and 24 May, 2007.

2. CHARACTERIZATION OF THE PRECIPITATION IN THE PROVINCE OF TOLEDO

2.1. Physical geography of the province of Toledo and regional division

Located in the centre of the Iberian Peninsula, in the province of *Toledo* two zones can differ from the morphologic and lithologic point of view: the *Sierra of San Vicente*, to the north, and the *Montes of Toledo*, on the south.

Between both there spreads the valley of the *Tajo* river, flowing eastwards on clays, sand, slates, quartzites and granites that give place to formation of scrub and mounts - islands.

Our regional division of the province is represented in Fig. 1. The province is divided in two by the *Tajo* river: the north part is formed by the Valley of *Tiétar*, *La Sagra* and the *Mesa de Ocaña*; the southern part groups the south part of *La Mancha*, the Mounts of *Toledo and La Jara*.

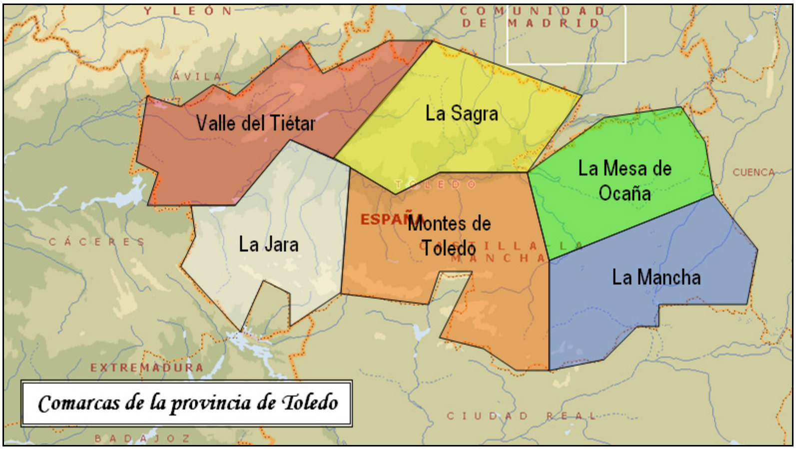

Figure 1. Regional division of the province of *Toledo*. This structure will be maintained during the whole study.

As for the hydrography, two are the hydrographic basins that exist in the province of *Toledo*: that of the *Tajo* (covering the major extension) and that of the Guadiana (in the zone of *La Mancha*).

2.2 Stations used for the study

The number of meteorological stations (including rain information) in the province of *Toledo* has not been constant throughout the years. The first observatory of the zone was the Observatory of *Toledo “ Lorenzana “* – called this way by its situation in the roof of the Palace of Lorenzana, in full historical city centre, which beginning of observations is September 1, 1908 (Aranda, 1984).

Gradually, the quantity of emplacements was increasing until the beginning of the Civil war (1936-1939) in which any meteorological routine activity was paralyzed. Data from this period exist, but with numerous gaps. From the 40s, it begins a growth of the points of observation, going so far as to reach the number 84 in 1973. Since then the number of stations, in general, has been drooping up to being located in 42 in 2005.

In order to compare precipitation in the diverse zones of the *Toledo* province, there have been chosen those stations, of the 93 available ones, with a long series of information (1971-2005) and that, also, are representative of the geographical zone where they are located. This period of time is common to all of them, except to *San Pablo* which is from 1981-2005, due to numerous temporal gaps in the decade of the 70s. Figure 2 shows the situation of every station in the province of *Toledo*.

Figure 2. Geographical location of the chosen stations.

2.3 Climatology of the total annual precipitation.

2.3.1 Annual distribution of the precipitation.

First of all, the basic parameters have been calculated: mean, standard deviation, variation coefficient, and the maximum and minimal values (the corresponding year appears in brackets) for every observatory (Table 1).

The maxima of average annual precipitation are located at the stations of zone of mountain (*San Pablo* and *El Real*), whereas the minimum is in *La Mancha* (*Villafranca*). Also, it is observed that the biggest variation coefficient, *CV*, corresponds to the stations located in the West of the province, with the highest values in the zones of mountain (*El Real* and *San Pablo*).

The years corresponding to the maximum of precipitation coincide at some stations, since it happens in 1977 at the stations of *Cabañas*, *Dosbarrios* and *Toledo*, whereas the driest year was a 2005 in all of them (except in *Villafranca*), coinciding with a strong drought which took place in the Iberian Peninsula.

	El Real	Cabañas	Dosbarrios	Villafranca	S. Pablo*	Belvís	Toledo
Annual meanl, $\overline{x}$	388,1	334,7	325,4	219,7	418,0	382,0	276,9
Standard deviation, S	132,90	86,37	95,01	68,00	168,6	115,3	68,06
C.V.= $s/\overline{x}$	0,342	0,258	0,292	0,310	0,328	0,300	0,250
Maxima (year)	695,3 (1989)	508,4 (1977)	566,4 (1977)	359,9 (1996)	797,4 (1989)	665,8 (2003)	445,2 (1977)
Minima (year)	104,7 (2005)	165,4 (2005)	134,1 (2005)	103,0 (1983)	284,1 (2005)	195,3 (2005)	109,7 (2005)

Table 1. Average annual precipitation, standard deviation, variation coefficient and extremes of annual precipitation. (period 1971-2005, except S. Pablo-1981-2005). Units in mm.

Since the average values of total annual precipitation of some stations seem similar, it is convenient to add statistical significance to this result. Once verified that the histogram of precipitation data frequency follows approximately a Gaussian distribution for every station, we have tested the null hypothesis that the two independent population means are equal. As population variances are unknown, the statistic calculated from the samples is:

$$z = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} < 1{,}96 \qquad (1)$$

where $\bar{x}_1$ and $\bar{x}_2$ are the means of two samples with n_1 and n_2 data, respectively, and s_1^2 and s_2^2 are the corresponding variances. The z-statistic values obtained for each pair of the selected stations appear in the Table 2.

	El Real	Cabañas	Dosbarrios	Villafranca	San Pablo	Belvís	Toledo
El Real	0,000	2,021	2,303	6,768	**0,709**	**0,205**	4,469
Cabañas		0,000	**0,435**	6,277	2,154	**1,926**	3,154
Dosbarrios			0,000	5,428	2,360	2,226	2,490
Villafranca				0,000	5,524	7,088	3,567
San Pablo					0,000	**0,877**	3,748
Belvís						0,000	4,589
Toledo							0,000

Table 2. Contrast of hypothesis for the mean values of the different chosen stations. (Period 1971-2005).

In bold are highlighted those values with $z < 1.96$, critical value for a confidence level of 95% in the acceptance of the null hypothesis. Thus, results in Table 2 indicate that the null hypothesis of equal population means is statistically accepted, at 95% of confidence level, for stations placed in mountainous zones in the West (*San Pablo*, *El Real* and *Belvís*), as well as between *Cabañas* and *Dosbarrios*, stations located in the flatness of the East of the province of *Toledo*.

2.3.2 Temporal evolution of the annual precipitation in the different observatories.

If we represent the temporal evolution of the annual precipitation of all the observatories in the same graph (Fig. 3) it is observed that both the maximum extremes and minimal values, coincide for most of the cases. Also, it is necessary to highlight the sudden fall of the precipitation in 2005. The hydrometeorological year 2004-05 was the driest in Spain since the AEMET realizes these calculations (1947). The average national value of precipitation was of 411 mm (practically 40 % less than the climatological average value: 669 mm). The drought affected to all the regions except Canaries, being *Castilla-La Mancha* one of the Autonomous regions where there was major deficit, with precipitations lower than 50 % of the normal values. In the hydrometeorological year 2005-06 the average precipitation at national level was of 595 mm (11 % less than the average value), being especially dry in the west of *Castilla-La Mancha.*

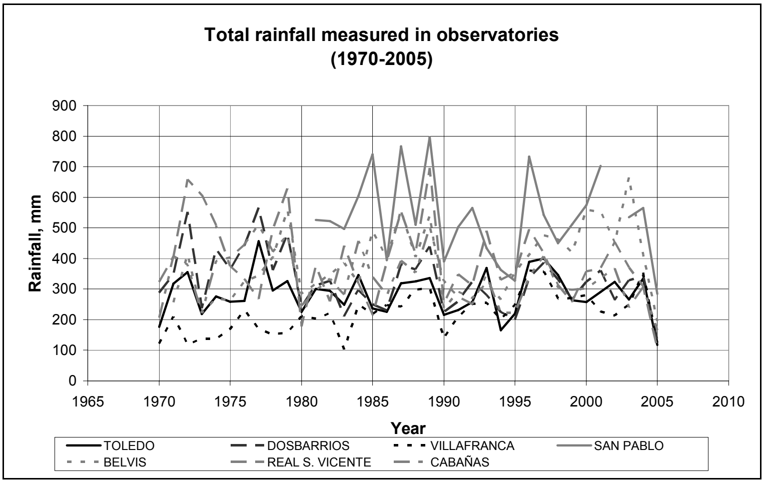

Figure 3. Evolution of the total annual precipitation in the chosen observatories.

2.4 Seasonal distribution of the precipitation

Next, the distribution of the precipitation is analyzed at four seasons: Winter (December, January and February), Spring (March, April and May), Summer (June, July and August) and Autumn (September, October and November).

In the Table 3, the mean values appear for every season and the percentage with regard to the annual precipitation. The most rainy season of every observatory has been highlighted in bold.

		El Real	Cabañas	Dos barrios	Villa-franca	San Pablo*	Belvís	Toledo
Winter	$\overline{x}$	159,2	102,8	93,1	65,2	152,3	128,9	80,9
	%	**41,02%**	**30,71%**	28,62%	29,66%	**36,44%**	**34,12%**	29,20%
	s	16,75	9,65	4,92	7,18	10,14	5,65	6,10
Spring	$\overline{x}$	95,5	96,6	100,3	74,3	115,8	99,3	84,5
	%	24,61%	28,87%	**30,82%**	**33,80%**	27,70%	26,29%	**30,51%**
	s	4,40	7,65	4,82	5,70	10,44	8,50	7,74
Summer	$\overline{x}$	26,6	39,7	40,8	25,1	32,2	34,5	33,4
	%	6,82%	11,86%	12,54%	11,43%	7,71%	9,13%	12,07%
	s	6,11	7,74	6,16	7,20	9,10	7,40	6,81
Autumn	$\overline{x}$	106,8	95,6	91,2	55,2	120,4	115,1	78,1
	%	27,51%	28,56%	28,01%	25,11%	28,80%	30,45%	28,21%
	s	16,13	12,90	6,81	6,76	17,88	18,68	8,95

Table 3. Statistical parameters of the seasonal precipitation. Units in mm. (period 1975-2005).

A pattern of common behaviour at all the studied stations is that the minimum of precipitation happens in summer. As for the most rainy station, in the villages placed in the half West of the province it is the winter (*El Real de San Vicente, San Pablo de los Montes* and *Belvís de la Jara*), whereas in the located ones in the East (*Villafranca de los Caballeros* and *Dosbarrios*) is Spring. Also it is observed that the percentage of autumn precipitation is very similar in all the studied cases, and it is in winter when the differences are major: the percentage of *El Real de San Vicente* (41.02 %) overcomes in 13 % that of *Dosbarrios*, indicating the decisive role that there play the mountains of the Central System in the generation of the precipitations associated with Atlantic depressions that are the most common in this period of the year.

All the works contrasted with this one coincide in determining that the summer is the driest station in all the toledian regions and that when, exceptionally, some summer overcomes 100 mm it is due to episodes of strong convection activity (Muñoz, 1976; Aranda, 1984; Font, 2000).

2.5 Tendencies of the precipitation: results of the Mann test

In order to verify the possible existence of a tendency of the precipitation in the period of study, there has been applied the Mann test (Sneyers, 1975) to each of the chosen observatories.

The point of court between the direct series and the retrograde series indicates the possible origin of the tendency. In case of *El Real de San Vicente* it does not appreciate any tendency. For *Cabañas de la Sagra, Dosbarrios* and *Toledo* there is observed a negative tendency, which in case of *Toledo* might be due to the change of emplacement of the station in 1981, which coincides with the point of court. Finally, *Villafranca de los Caballeros* and *Belvís de la Jara* (all of them to the south of the province) present a positive tendency of the precipitation in the last years. Therefore, a clear and similar tendency is not seen for all the stations.

3. TWO EXAMPLES OF FLOODS IN THE PROVINCE OF TOLEDO ASSOCIATED WITH DIFFERENT SYNOPTIC SITUATIONS

In this part of the work it has been analyzed two floods that caused big losses in the province of *Toledo* and that are associated with two meteorological different situations. We can distinguish between:

- *Widespread episodes*. Generally they are associated with the passing of deep depressions over the Iberian Peninsula proceeding from the Atlantic Ocean, with a humid flow from W and from SW in surface and a trough at 500 hPa level. They usually are produced at the end of winter and in spring. The damages that provoke the floods spread at least over one of the regions in which the province has been divided. As example, we will study the storm of March, 1947.

- *Convective episodes.* The meteorological situation of this type is a centre of relative low pressures in surface and a cutoff low (cold air) in the peninsular SW reflected at the level of 500hPa. The most frequent period for this type of situations corresponds to the end of spring and summer and the beginning of autumn. These situations usually centralize the floods in a specific municipality, with insignificant damages in the surroundings. The case of May, 2007 (exceptional for its temporary and spatial extension) will be the one that we study.

3.1. Storm of beginning of March, 1947

Synoptic situation. March 1947 was one of the rainiest in the province of *Toledo* of the whole XXth century. The succession of a " train of depressions " (Fig. 4) did that in scarcely 4 or 5 days the accumulated rain reached values of 105 mm in *Calzada de Oropesa*. The episode begins with the pass of a strong Atlantic depression on March 4th, with warm and humid winds from SW and with generalized rains in the whole province. This day and the following, the most intense precipitations took place in the half west. In the following days, the synoptic situation did not present changes. On March 7th was the day of maximum precipitation in 24h in numerous observatories, being the most important precipitations: 38.8 mm of *Los Yébenes*, 38.5 mm in *La Puebla de Almoradiel* or the 37.7 mm in *La Villa de Don Fadrique*, all of them located in the East of the province.

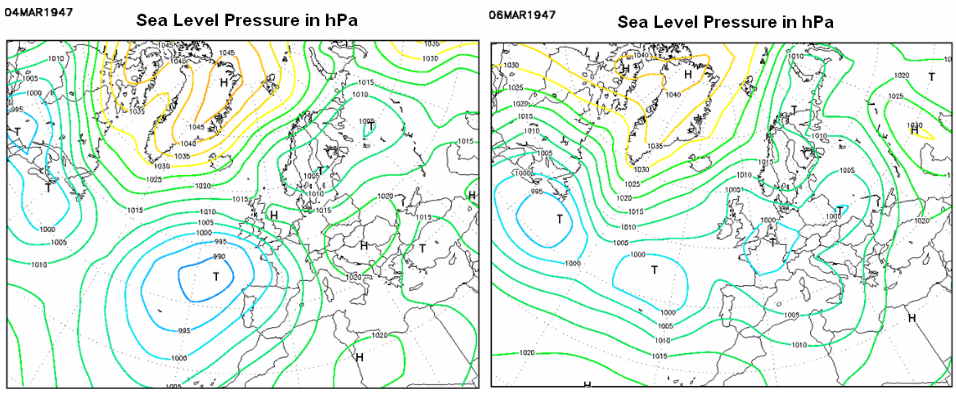

Figure 4. Maps of sea level pressure corresponding to the storm at the beginning of March, 1947. Left on March 4th and right on March 6th, 1947. The centres of low pressures are indicated by *T* and those of high pressures by *H*.

After a few days of anticyclonic weather, the rains returned at the end of the month with important quantities, but did not produce damages, according to the chronicles of the epoch.

Social impact . - The intense downpours that happened between 4 and 7 March provoked a rise of the river *Tajo* and of good part of its tributaries. The damages were numerous in the whole province. The press of the epoch published in detail the effects of the storm a few days after the most intense precipitations happened.

3.2 Floods in the zone of *La Mancha*, from May 20th until May 25th, 2007

Synoptic situation. - The episode of thunderstorms that happened between the 20th to May 25th, 2007 has been the most important in the last years as for the affected extension and the provoked damages. The most intense damages took place on the 20th and 23rd.

The situation at surface of the 23rd is marked by a wedge of the Atlantic anticyclone (1030 hPa in its centre) that spreads towards the interior of the continent. With this configuration, the wind is coming mainly from E and NE to the whole centre zone of the country. At 500 hPa an important cutoff low (cold air) exists to the SW of the Iberian Peninsula. Finally, in 850 hPa it can be seen a strong gradient of temperatures between the end of *San Vicente* and the Western Mediterranean (Fig. 5). This was the day with the most intense precipitations.

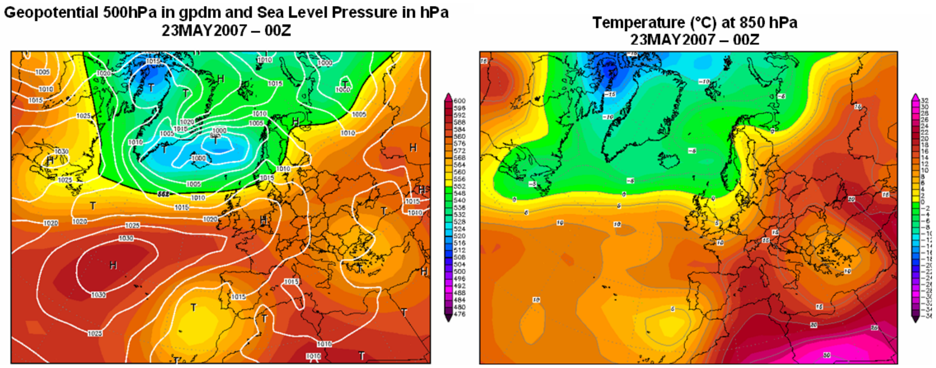

Figure 5. Sea level pressure and 500 hPa geopotential maps (left) and 850 hPa temperature (right) for May, 23th 2007.

As for the precipitations of this episode, it sould be underlined the 117 mm gathered in *Tembleque* (to the E of the province), 59.8 mm of *El Real de San Vicente* (to the NW) and 52 mm measured in *Polán* (centre).

Social impact.- The thunderstorms from the 20th until May 25th 2007 caused ravages in multitude of municipalities of the provinces of *Ciudad Real, Cuenca* and *Toledo*, for what the Regional government of *Castilla-La Mancha* included 78 municipalities as harmed with a fund for 300 million euros by way of helps.

4. METEOROLOGICAL SITUATIONS ASSOCIATED WITH THE HISTORICAL MAXIMA

Of the analyses of the meteorological situations associated with the floods, we have verified that the maxima of precipitation for the whole province are located in the third W and in winter and are associated at the arrival of Atlantic depressions. On the other hand, the maxima of the half E are tied to the presence of stormy proper phenomena of the summer season. The centre of the province behaves as zone of transition, without a clear situation that provokes the maxima (Table 4).

	Half West	**Centre**	**Half East**
Synoptic situation	In general, depression to the W of the British Isles, accompanied of a trough at 500 hPa. W flow at surface. Preferably from October until March.	Certain preference in situations of relative low pressures. At 500 hPa cutoff low (cold air) to the SW. SE Flow at surface. Regular frequency along the whole year.	Relative low pressures. At 500 hPa, cutoff low (cold air) to the SW. E flows at surface surface. Especially often, from May to October.

Table 4. Summary of the meteorological situations that caused the historical maxima precipitation.

5. SUMMARY AND CONCLUSIONS

In this work, an analysis of the precipitation has been realized in the province of *Toledo* (Spain) taking as a base the information which the AEMET has. The mean values of precipitation obtained are slightly lower than those appeared in other studies, due to the presence of the strong drought produced in the Iberian Peninsula during the years 2004-2006. With regards to the study of tendency, we have to indicate that a similar and global behaviour is not observed between the different analyzed observatories, presenting some stations positive tendency and others negative.

The episodes of intense precipitations have been classified in two types, according to the meteorological situation that accompanies them and of the geographical dimension of the produced damages. This way, the floods associated with Atlantic storms coming from W affect, especially, to the most western zone of the province and present a major extension of damages (*widespread episodes*). On the other hand, those due to summer convective situations or corresponding to the beginning of the autumn are located in the E zone of the province, with major quantity of precipitation, and affecting fewer municipalities (*convective episodes*).

Finally, there have been analyzed the meteorological situations associated with such floods. As conclusion we emphasize that the floods in the W zone of the province are associated with storms coming from the Atlantic Ocean with a W through in the level of 500 hPa and happen, preferably, in winter season. On the other hand, in the zone E the floods are produced by E wind situations at surface, and a cutoff low (cold air) in 500 hPa placed in the SW of the Peninsula and an important gradient of temperature at 850 hPa along the north of Africa.

6. ACKNOWLEDGEMENTS

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