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Laboratory of Climatology, Department of Geography and Environmental Studies, University of Haifa, Haifa, Israel

Rainfall uncertainty in the Mediterranean: definition of the rainy season – a methodological approach

H. Reiser, H. Kutiel

With 8 Figures

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Summary

Two different approaches exist for defining a rainy season; the *Meteorological year* (from January 1st till December 31st) is usually used in regions with rainfall all year round, and the *Hydrological year* is used in regions with a long dry period.

The Starting Analysis Date (*SAD*) refers to the beginning of a new rainy season and it characterizes a certain region, whereas, the Rainy Season Beginning Date (*RSBD*) and the Rainy Season Ending Date (*RSED*) determine the Rainy Season Length (*RSL*). The *RSBD* can be defined in two ways: on the day in which a certain threshold amount of rainfall is accumulated, or on the day in which a certain percentage of rainfall is accumulated. The *RSL* is influence by both the *SAD* and the *RSBD*/*RSED*. An unsuitable *SAD* will alter the analyses results and may lead to misleading conclusions. The goals of the present study are: to suggest a new approach for the determination of the *SAD* and to apply it to the Mediterranean region. For this end, daily rainfall data for the period of 1931–2006 were analyzed. The *RSL* was defined as the period that elapsed from the day on which 10% of the annual rain was accumulated till the day on which 90% was accumulated. In order to find the shortest *RSL*, it was calculated 365 times for each Julian day as the *SAD* and for every available year. The median *RSL* for each Julian day was determined. A Cluster and a Factor analyses were performed on a correlation matrix that included 365 *RSLs* at 41 stations.

Two distinguishable courses with uni-modal distribution appeared in all analyses and separated the area into two regions: a southern region with a minimum in the summer and a maximum in the winter, and a less pronounced annual course with a minimum in March and a maximum in June in the northern part of the area. Between these two regions, a transitional zone with a bi-modal course was identified. The main conclusions of the present study are that the *Hydrological year* should be adopted for rainfall analyses in all regions, regardless of their temporal distribution. It is suggested that the *SAD* should be set to July 1st, in the southern Mediterranean basin; February 1st in the transitional zone and to March 1st in the northern Mediterranean basin.

Correspondence: H. Reiser, Laboratory of Climatology, Department of Geography and Environmental Studies, University of Haifa, Haifa 31905, Israel, e-mail: hreiser@geo.haifa.ac.il

1. Introduction

The definition of a rainy season depends on the rainfall regime in the region under discussion, and there are two main approaches for that:

1. The so-called *Meteorological year* is usually used in regions in which rainfall is expected all year round. According to this approach, the analyzed period corresponds to the calendar year, starting on January 1st and ending on December 31st.
2. The so-called *Hydrological year* is usually used in places with a distinctive dry period, such as, for example, in Mediterranean regions. According to this approach, the analysis starts during the dry period in order to

avoid splitting of the rains into two different years.

The **Starting Analysis Date** (*SAD* hereafter) is defined as the date in which a new season starts, and therefore all analyses of all parameters regarding the annual rainfall regime start on that day. For example, in regions where the *Meteorological year* is used, the *SAD* is January 1^{st}, as aforesaid. However, even in these regions, this *SAD* should be tested, as January 1^{st} is an arbitrary date, like any other date, and may not reflect properly the rainfall regime in all regions. In regions were the *Hydrological year* is used, the *SAD* may be at any date within the dry period. It was customary to set it on March 1^{st}, August 1^{st}, or September 1^{st}, depending on the region under discussion.

Another factor that influences the determination of a rainy season is how one defines the **Rainy Season Beginning Date** (*RSBD* hereafter) and the **Rainy Season Ending Date** (*RSED*). Unlike the *SAD* that is fixed in a region for the entire data set, the *RSBD* and the *RSED* vary from one year to another and from one station to another. The time interval between *RSBD* and *RSED* consists, therefore, the **Rainy Season Length** (*RSL*):

$$RSL = RSED - RSBD \quad (1)$$

There are various approaches regarding the definition of the *RSBD* and the *RSED*. A partial list of these definitions may be found in Aviad et al. (2004). These can be grouped into two main definitions:

1. On the day in which a certain amount of rainfall is measured or accumulated. According to this approach, one can define the *RSBD* on the first day when, for example, 10 mm (or any other threshold value) is measured, or on the day when this amount is accumulated (usually this may happen a couple of days earlier). Gramzow and Henry (1972), Stern et al. (1981), Stern (1982) are few examples of adopting such an approach.
2. The day in which a certain percentage of the annual total is accumulated is the **Date of Accumulated Percentage** (*DAP*). According to this definition, the *RSBD* can be determined only after the rainy season is over and its annual total is known. This approach was proposed by Paz and Kutiel (2003).

In both approaches different threshold values can be set, depending on the purpose of the study.

As the Mediterranean rainfall regime consists of a long dry summer with hardly any rainfall, the *Hydrological year* is used rather than the *Meteorological year*. Either at the beginning of the rainy season or at its end, rains are sporadic events of a minute value for most purposes. These rains are followed (at the beginning of the season) or preceded (at the end of the season) by long dry periods (Paz and Kutiel 2003). Thus, if one considers the *RSL* as the period of time that elapsed from the first rainy day until the last one, he may obtain a very long *RSL* consisting of long dry periods in between. Therefore, the present study adopted the suggestion by Paz and Kutiel (2003) and the *RSBD* was defined to be equal to $DAP_{(10)}$ (the day in which 10% of the annual rainfall is accumulated). Similarly, the *RSED* equals $DAP_{(90)}$ (the day in which 90% is accumulated), and thus:

$$RSL = DAP_{(90)} - DAP_{(10)} \quad (2)$$

It is important to mention that an inappropriate selection of the *SAD* may alter completely the calculation of the *RSL* and other parameters regarding the rainfall regime. This may lead to obtaining misleading, non realistic values. If, for example, in a certain station, the rainy season ends in April and restarts in August, with a long dry period consisting of May, June and July, the longest expectable *RSL* should not exceed 9 months at the most. However, if the *SAD* is, for example, set on September 1^{st}, or October 1^{st}, the *RSL* may be as long as 12 months. This result may mislead one to believe that rainfall can be expected all year round although as has been above mentioned, there is a long dry season.

In recent years, many studies were focused on analyzing the relationships between the rainfall regime in the Mediterranean and pressure patterns, synoptic conditions or weather types. Some studies dealt with the entire basin (e.g. Air Ministry Meteorological Office, 1962; Kutiel et al. 1996a; Littmann 2000), several analyzed these relationships in some regions, e.g., Western-central Mediterranean (Conte et al. 1989); Southern Europe (Rodó et al. 1996); Eastern and Southern Mediterranean (Kutiel et al. 1996b; Ziv et al. 2006); the Iberian peninsula (Zorita et al. 1992; Trigo and DaCamara 2000), whereas, most studies focused on the analysis of such relationships in different countries, e.g., Italy (Brunetti et al. 2002); Greece (Anagnostopoulou et al. 2004; Houssos and Bartzokas 2006; Feidas et al. 2007); Turkey (Türkeş 1998; Kutiel et al. 2001; Kutiel and Türkeş 2005; Türkeş and Erlat 2005); Israel (Kutiel 1991, 1994; Kutiel and Paz 1998; Saaroni and Ziv 2000; Alpert et al. 2002); Iran (Ghasemi and Khalili 2005).

Both the appropriate *SAD* and the *RSL* are determined by pressure patterns, synoptic conditions or weather types affecting each location. An example of such an influence is the dry late spring and summer period at the southern parts of the basin. This dry period is mainly caused by a subsidence of warm air over the sea and a constant flow into North Africa. The relatively low temperature of the SST compared with higher temperatures over the lands, produce stable condition which prevents rain producing system to develop (Air Ministry Meteorological Office, 1962).

The present study is not aiming at analyzing relationships between rainfall and pressure patterns or synoptic conditions, but rather:

1. To present a new approach for the definition of a rainy season that will be the most appropriate to the rainfall regime in a certain region.
2. To determine the most appropriate *SAD* at several stations within the Mediterranean basin and its vicinity.
3. To calculate the *RSL* at these stations according to the defined *SAD*.

2. Data and methodology

2.1 Study area, data and definitions

The study area is located in the Mediterranean basin, between the longitudes 10° W and 40° E and latitudes 30° and 46° N, excluding the North African coasts (Fig. 1). Forty-one rain stations were selected to represent the various rainfall regimes within the study area. Daily rainfall data within the period of 1931 and 2006 were obtained from *ECA&D – European Climate Assessment & Dataset*. For each station, a dataset of at least 40 years was used (Table 1). Each day, with a daily rainfall threshold of 1.0 mm, was defined as a rainy day.

2.2 Methodology

The analyses that were performed used the **Rainfall Uncertainty Evaluation Model** (*RUEM*), which was developed by the authors at the Laboratory of Climatology in the Department of Geography and Environmental Studies, University of Haifa. A detailed description of the model can be found at the following website: (http://geo.haifa.ac.il/∼geoweb/RUEM%204.pdf).

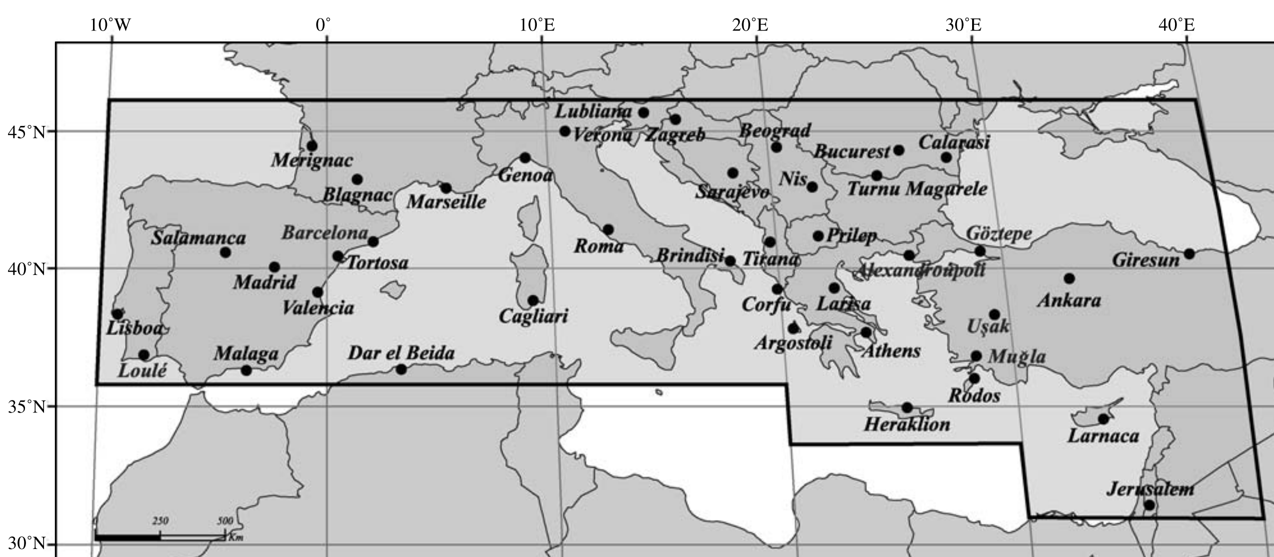


Fig. 1. Location of the rain stations in the study area

Table 1. Main characteristics of rain stations

Country	Station name	Longitude	Latitude	Available data	Mean annual rainfall [mm]*
Albania	Tirana	19° 47′E	41° 20′N	1946–1991	1224.1
Algeria	Dar el Beida	03° 15′E	36° 43′N	1940–2006	608.3
Bosnia Herzegovina	Sarajevo	20° 60′E	42° 70′N	1931–2005	909.0
Croatia	Zagreb	15° 59′E	45° 49′N	1931–2006	853.7
Cyprus	Larnaca	33° 38′E	34° 55′N	1931–2006	352.2
France	Blagnac	01° 23′E	43° 37′N	1947–2006	630.0
	Marseille	05° 23′E	43° 18′N	1931–2004	544.9
	Merignac	00° 41′W	44° 50′N	1931–2006	913.9
Greece	Alexandropoúli	25° 55′E	40° 51′N	1958–2000	531.8
	Athens	23° 40′E	38° 03′N	1955–2006	364.0
	Argostoli	20° 29′E	38° 11′N	1958–2000	895.0
	Corfu	19° 55′E	39° 37′N	1955–2006	1102.6
	Heraklion	25° 11′E	35° 20′N	1955–2006	477.7
	Larisa	22° 27′E	39° 39′N	1955–2006	423.0
	Rodos	29° 10′E	36° 23′N	1958–2000	695.6
Israel	Jerusalem	35° 13′E	31° 46′N	1950–2006	525.8
Italy	Brindisi	17° 56′E	40° 38′N	1956–2006	560.4
	Cagliari	09° 03′E	39° 14′N	1951–2006	396.3
	Genoa	09° 00′E	44° 24′N	1949–1996	1319.3
	Roma	12° 35′E	41° 47′N	1951–1998	748.6
	Verona	10° 52′E	45° 23′N	1951–2006	785.0
Macedonia	Prilep	21° 57′E	41° 33′N	1949–1995	523.2
Portugal	Lisboa	09° 09′W	38° 43′N	1947–2006	714.8
	Loulé[1]	08° 00′W	37° 15′N	1931–2005	658.3
Romania	Bucurest	26° 06′E	44° 25′N	1931–2006	589.5
	Calarasi	27° 20′E	44° 12′N	1938–2006	489.1
	Turnu Magurele	24° 53′E	43° 45′N	1938–2000	522.9
Serbia & Montenegro	Beograd	20° 28′E	44° 48′N	1936–2006	675.8
	Nis	21° 54′E	43° 20′N	1949–2006	567.2
Slovenia	Lubliana	14° 31′E	46° 04′N	1950–2006	1353.4
Spain	Barcelona[2]	02° 09′E	41° 23′N	1965–2001	609.2
	Madrid	03° 41′W	40° 25′N	1950–2006	435.1
	Malaga	04° 29′W	36° 40′N	1943–2006	540.9
	Tortosa	00° 29′E	40° 49′N	1946–2006	525.0
	Salamanca	05° 28′W	40° 56′N	1945–2006	384.9
	Valencia	00° 21′W	39° 28′N	1938–2006	435.0
Turkey[3]	Ankara	32° 53′E	39° 57′N	1948–2003	383.5
	Giresun	38° 23′E	40° 55′N	1948–2003	1233.3
	Göztepe	29° 05′E	40° 58′N	1948–2003	674.9
	Muğla	28° 22′E	37° 13′N	1948–2003	1151.7
	Uşak	29° 24′E	38° 41′N	1948–2003	525.6

* Mean rainfall with a daily rainfall threshold of 1.0 mm
[1] Data obtained from *LNEC*-Laboratorio Nacional de Engenaria Civil, Portugal
[2] Data obtained from University Politecnica de Catalunya
[3] Data obtained from *TSMS*-Turkish State Meteorological Service

It is essential to identify the shortest rainy season, or the longest dry period throughout the year in order to preserve the continuity of the rainy season. In order to achieve this goal, the *RSL* was re-calculated 365 times, using Eq. (2) for each Julian day as the *SAD*, for each available year. Then, the median *RSL* was calculated for each Julian day. This procedure was adopted in order to identify the *SAD* in which the *RSL* is the shortest. The 365 median *RSL* values from all 41 stations were set into a matrix of 41×365. Correlations between any possible pair of stations were calculated. The additional analyses that were performed on that matrix are: a Cluster Analysis (*Average linkage* method) and a Factor Analysis (*Varimax* rotation). These procedures enabled to divide the study area into sub-regions that differ from each other by their *SAD*.

In order to enable the use of the present results in future studies, in which only monthly data are available and not daily data, it is not convenient to set the *SAD* at the precise date of the minimum *RSL* (which can occur on any day of the year). The *SAD* was set to the first day of a month ac-

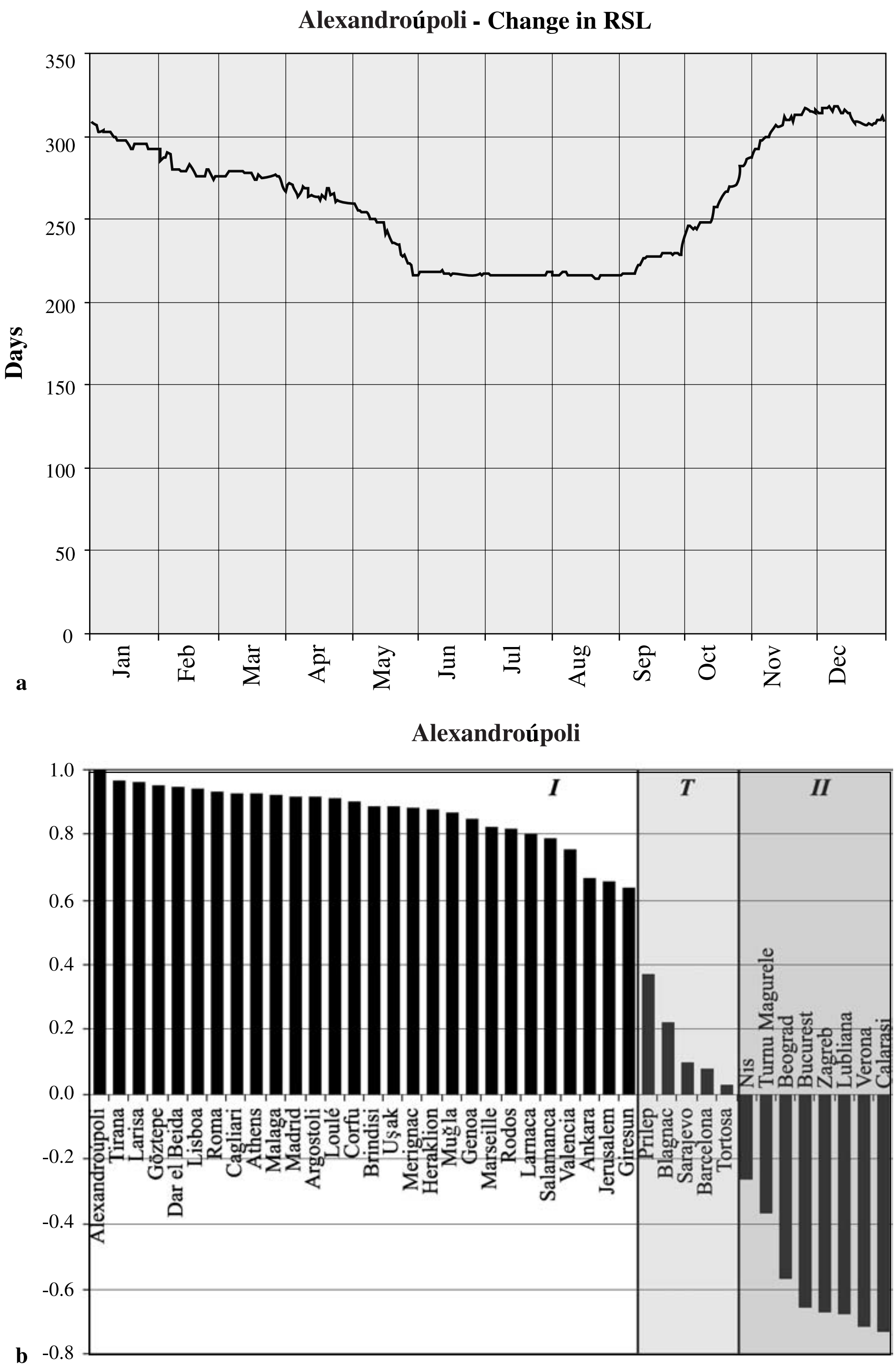


Fig. 2. An example from the station of Alexandroúpoli of change in *RSL* as a function of the *SAD* (**a**) and correlations with the other stations (**b**)

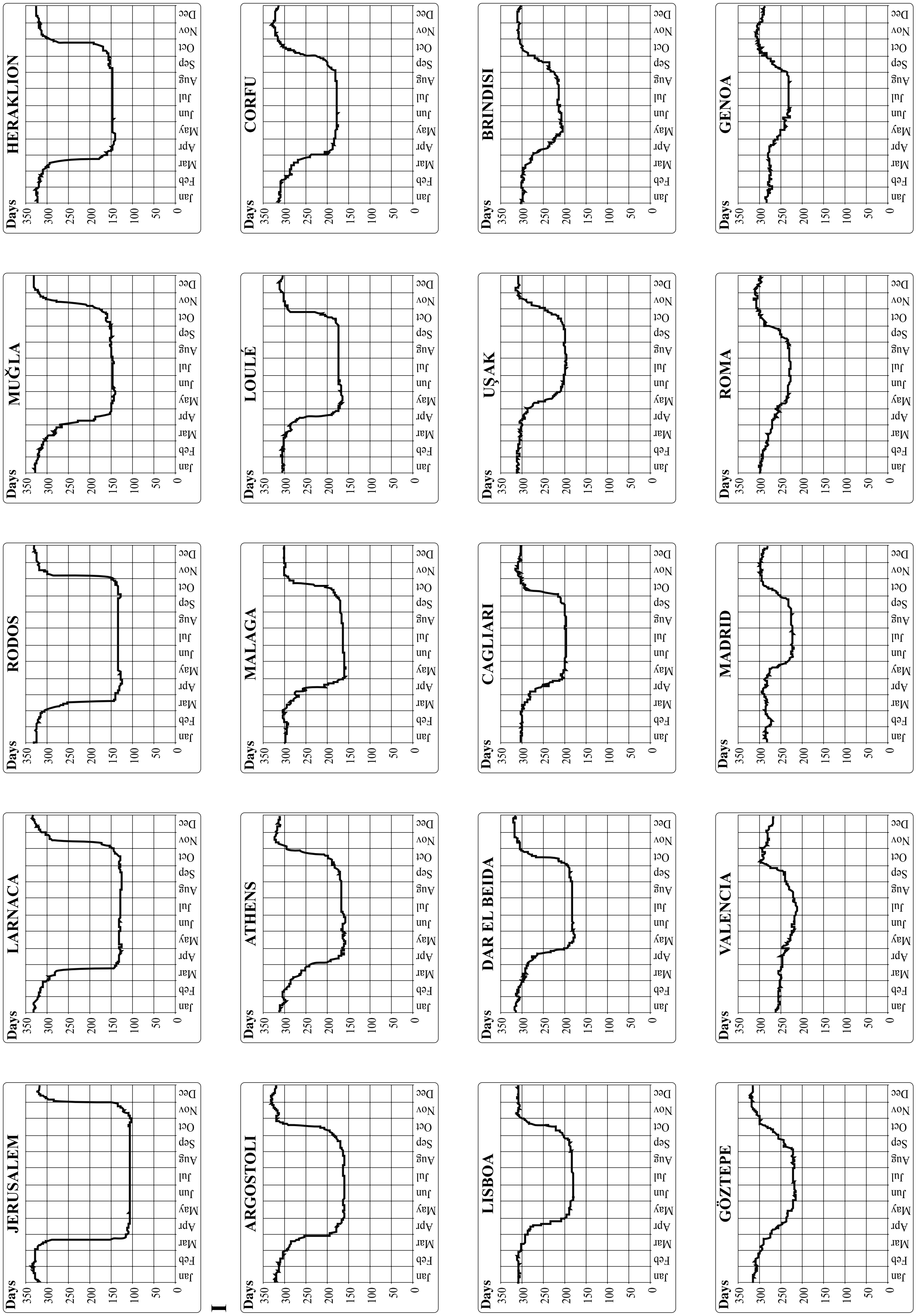


Fig. 3. The annual course of the *RSL*

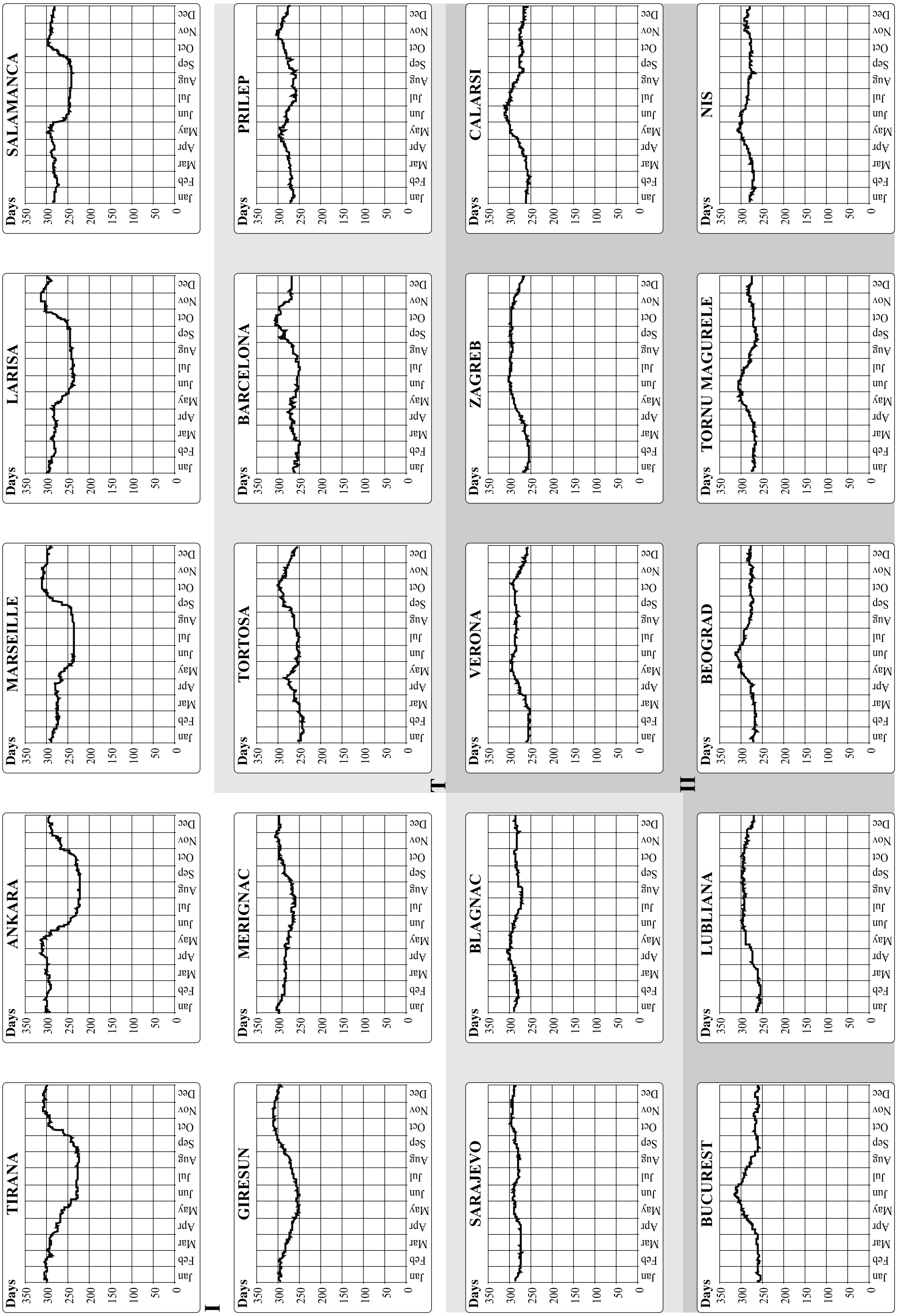


Fig. 3. *(continued)*

cording to the following procedure: the difference between the minimum annual *RSL* (or the shortest median *RSL*) and the median *RSL* of the first day of each month was calculated. The *SAD* of the rainy season was set therefore, to the first day of the month, in which this difference was the smallest.

Finally, the various regions were delimited and mapped according to their *SAD*.

3. Results

3.1 The annual changes in RSL depending on the SAD

Figure 2a presents an example of the annual changes in *RSL* as a function of the *SAD* in Alexandropoúli. It can be seen that the *RSL* is much shorter during the period June 1st – September 1st. The annual courses of the *RSL* in other stations are presented in Fig. 3. Three different courses can be noticed:

1. A uni-modal annual course with shorter *RSL* values in summer (marked as I).
2. A bi-modal course (marked as T).
3. A uni-modal course with shorter *RSL* values between February and March (marked as II).

Charts are arranged from the shortest *RSL* to the longest within each group, as in Table 2.

3.2 Correlation of the annual course

A correlation matrix between all possible pairs of stations was calculated, based on their 365 *RSL* values for each *SAD*. For each station, the 40 correlation coefficients with all other stations were sorted in a descending order, thus, yielding 41 different sorting orders, one for each station. Figure 2b presents an example of these correlations in Alexandropoúli. Stations are arranged according to their correlations in a descending order. Three groups of correlation coefficients are noticeable:

1. Large positive correlations ($r>0.6$ marked I).
2. Poor positive correlations ($r<0.4$ marked T).
3. Negative correlations (marked II).

The correlations for all other stations are presented in Fig. 4. The stations order within each chart is identical to the stations order in Fig. 2b, i.e., Alexandropoúli, Tirana... Calarasi. The various charts are arranged in the same order as in Fig. 3.

Table 2. The median $DAP_{(10)}$, $DAP_{(90)}$ and the median *RSL* over the entire period, at the various stations

Region	Station name	*Median* $DAP_{(10)}$	*Median* $DAP_{(90)}$	*Median RSL* [days]*
I	Jerusalem	29/11	21/03	106
	Larnaca	14/11	21/03	130
	Rodos	06/11	18/03	132
	Muğla	09/11	04/04	146
	Heraklion	26/10	22/03	147
	Argostoli	18/10	27/03	156
	Athens	27/10	03/04	159
	Malaga	22/10	07/04	165
	Loulé	21/10	13/04	176
	Corfu	01/10	27/03	178
	Lisboa	16/10	22/04	181
	Dar el Beida	17/10	22/04	182
	Cagliari	03/10	22/04	196
	Uşak	16/10	07/05	203
	Brindisi	19/09	14/04	209
	Alexandropoúli	01/10	23/05	218
	Göztepe	23/09	19/04	218
	Valencia	18/09	07/05	222
	Madrid	02/10	15/05	226
	Roma	17/09	05/05	229
	Genoa	08/09	29/04	231
	Tirana	15/09	09/05	231
	Ankara	06/10	25/05	232
	Marseille	09/09	06/05	233
	Larisa	20/09	14/05	234
	Salamanca	21/09	23/05	245
	Giresun	25/08	08/05	257
	Merignac	24/08	13/05	264
T	Tortosa	31/03	08/12	244
	Barcelona	04/04	06/12	256
	Prilep	19/03	09/12	272
	Sarajevo	19/03	20/12	275
	Blagnac	14/03	23/12	280
II	Verona	11/04	27/12	252
	Zagreb	21/04	02/01	255
	Calarasi	20/04	05/01	258
	Bucurest	18/04	10/01	261
	Lubliana	18/04	02/01	261
	Beograd	18/04	13/01	267
	Turnu Magurele	17/04	10/01	267
	Nis	16/04	15/01	272

Stations are sorted within each region in an ascending order of their median *RSL*

* The median *RSL* is the median of all annual *RSL*s and not the difference between the median $DAP_{(90)}$ and median $DAP_{(10)}$. This was done in order to reduce the loss of information. Therefore, median *RSL* is not always equal to median $DAP_{(90)}$-$DAP_{(10)}$

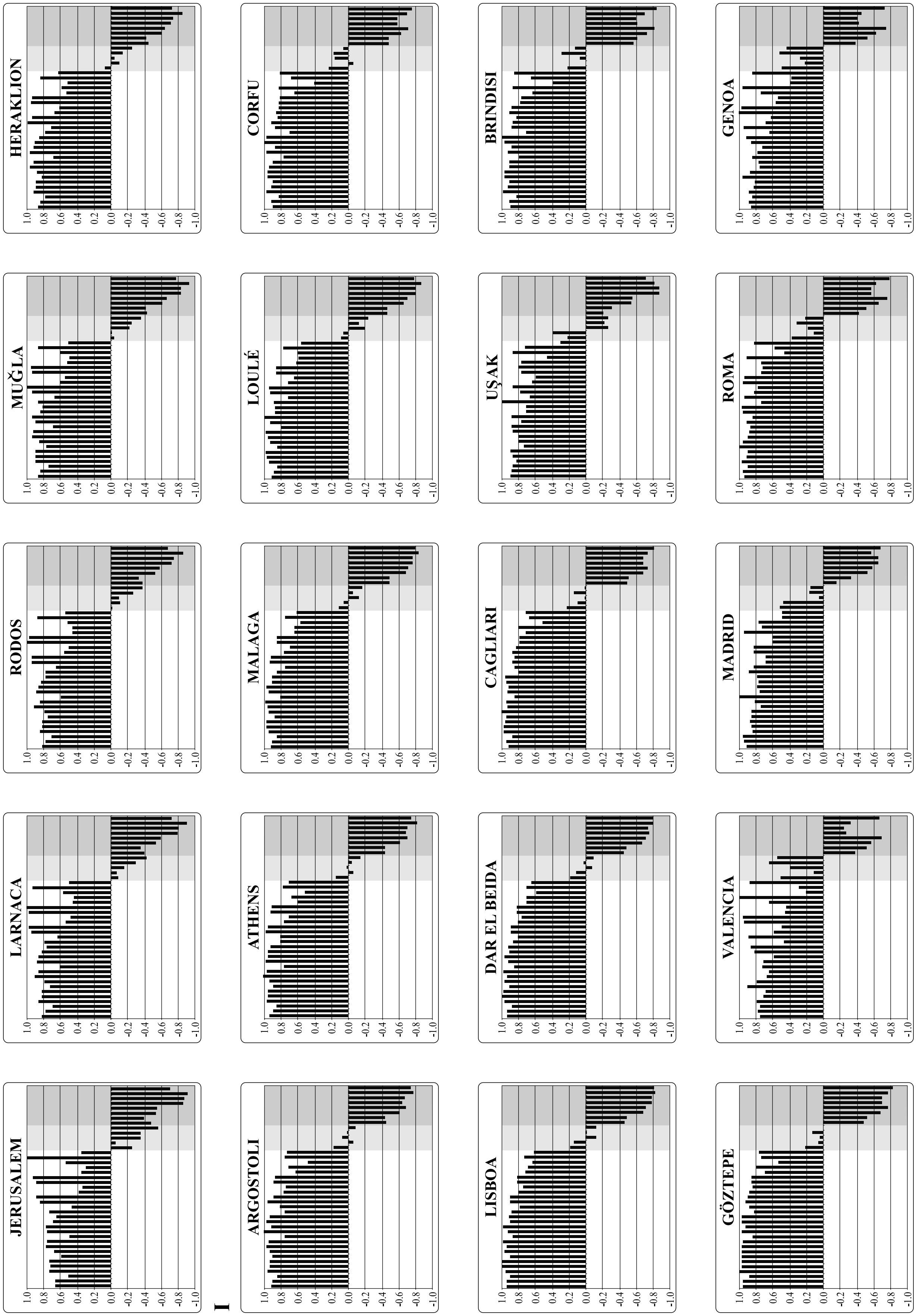


Fig. 4. Correlation between all the rain stations regarding the annual course of the *RSL*

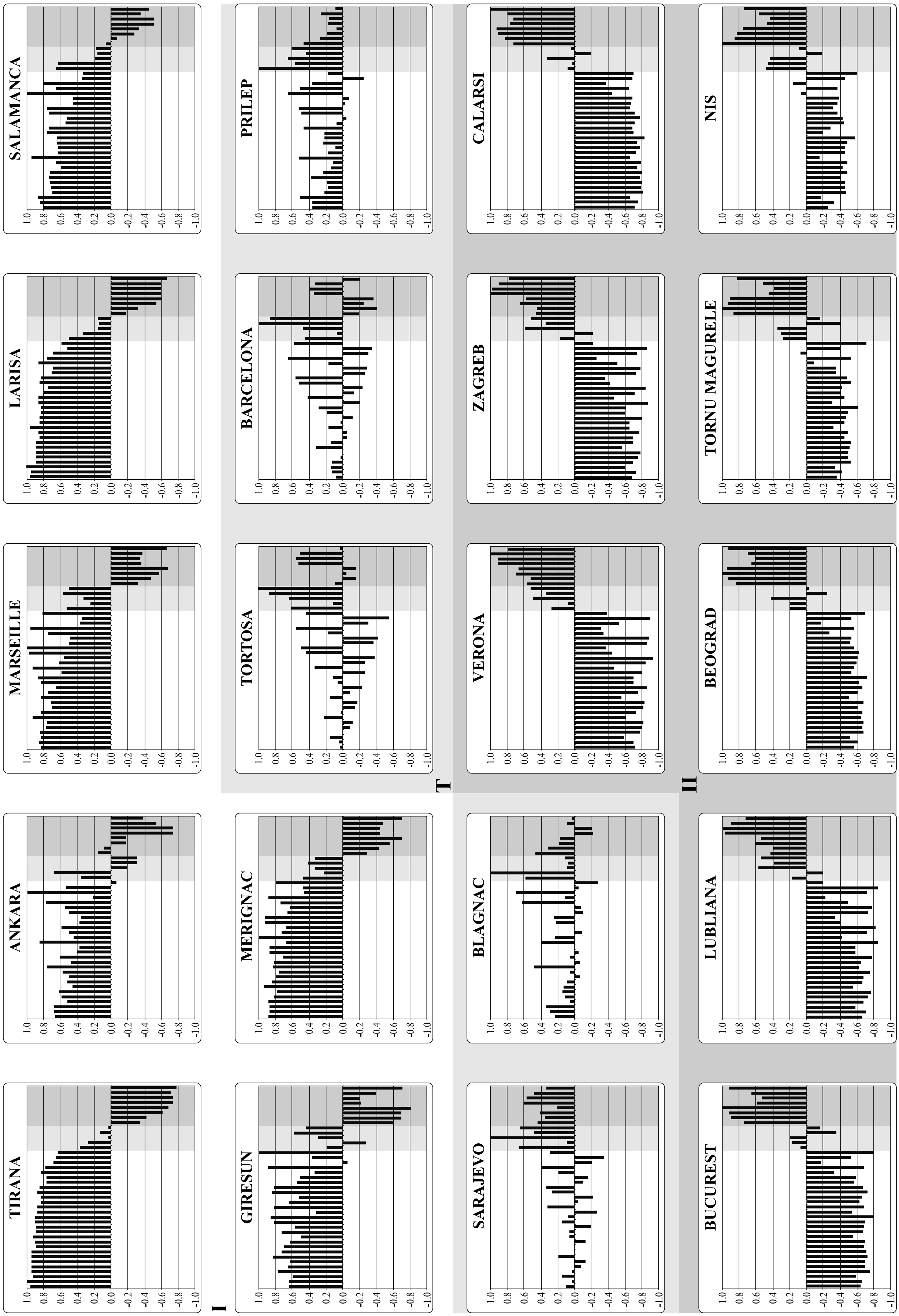
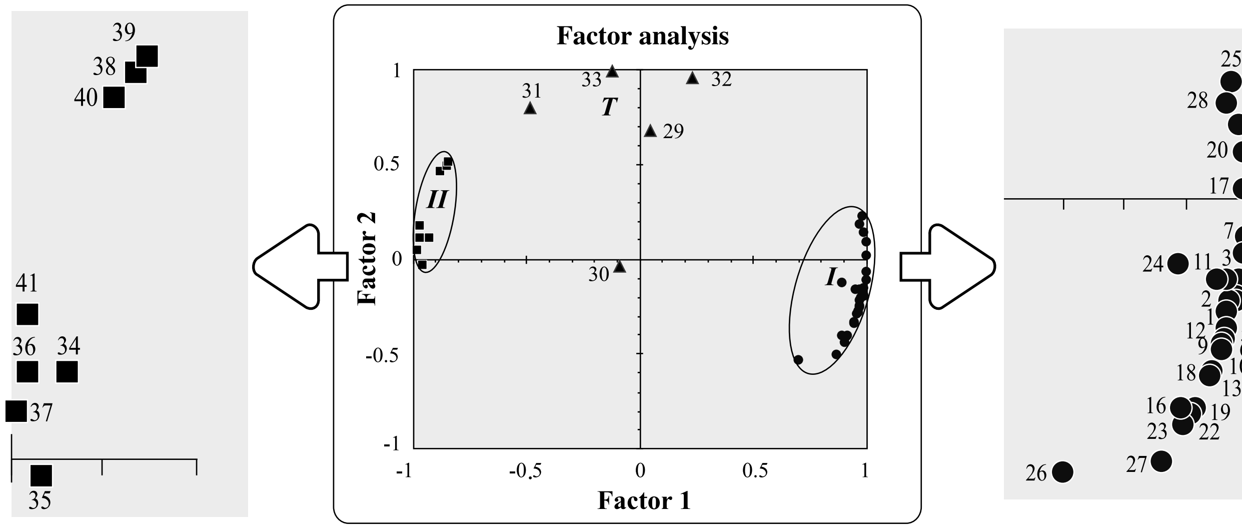
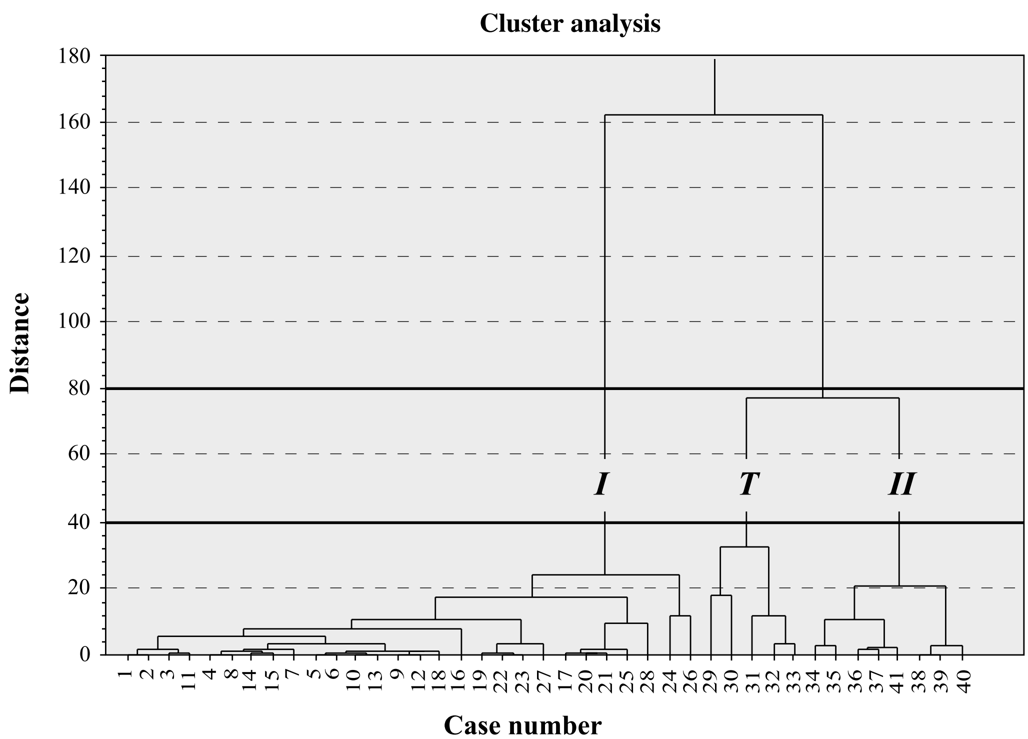


Fig. 4. (*continued*)



1	Alexandropoúli	8	Cagliari	15	Brindisi	22	Rodos	29	Prilep	36	Beograd
2	Tirana	9	Athens	16	U¸ ak	23	Larnaca	30	Blagnac	37	Bucurest
3	Larisa	10	Malaga	17	Merignac	24	Salamanca	31	Sarajevo	38	Zagreb
4	Göztepe	11	Madrid	18	Heraklion	25	Valencia	32	Barcelona	39	Lubliana
5	Dar el Beida	12	Argostoli	19	Muˇ la	26	Ankara	33	Tortosa	40	Verona
6	Lisboa	13	Loulé	20	Genoa	27	Jerusalem	34	Nis	41	Calarasi
7	Roma	14	Corfu	21	Marseille	28	Giresun	35	Turnu Magurele		

Fig. 5. Results of Factor Analysis. Numbers refer to the different stations as listed in the legend



1	Alexandropoúli	8	Cagliari	15	Brindisi	22	Rodos	29	Prilep	36	Beograd
2	Tirana	9	Athens	16	U¸ ak	23	Larnaca	30	Blagnac	37	Bucurest
3	Larisa	10	Malaga	17	Merignac	24	Salamanca	31	Sarajevo	38	Zagreb
4	Göztepe	11	Madrid	18	Heraklion	25	Valencia	32	Barcelona	39	Lubliana
5	Dar el Beida	12	Argostoli	19	Muˇ la	26	Ankara	33	Tortosa	40	Verona
6	Lisboa	13	Loulé	20	Genoa	27	Jerusalem	34	Nis	41	Calarasi
7	Roma	14	Corfu	21	Marseille	28	Giresun	35	Turnu Magurele		

Fig. 6. Results of Cluster Analysis. Numbers refer to the different stations as listed in the legend

3.3 Factor analysis (FA) and cluster analysis (CA)

A Factor Analysis and a Cluster Analysis were performed in order to divide the study area into sub-regions according to similar annual changes in *RSL*.

Figures 5 and 6, present the results of these analyses. In Fig. 5, stations with a similar annual course are grouped into two distinguishable groups. Twenty eight stations are grouped in Factor I that explains 83.2% of the variance. Eight stations belong to Factor II that adds 10.2% to the explained variance, which amounts to 93.4% of the total variance explained by these two factors. The remaining five stations (the same stations belonging to group T in Figs. 2b, 3 and 4) do not belong to neither Factor I, nor Factor II, and are marked as T (Transitional) on Fig. 5.

Figure 6 presents a dendrogram obtained from the *CA*. One can observe two clusters at a distance of 80. Cluster I, consisted of 28 stations and Cluster II – the remaining 13 stations. However, at a shorter distance, e.g., 40 (which means a greater resemblance between the grouped stations), Cluster II is divided into two sub-clusters. Cluster II comprises now only 8 stations which are identical to the stations grouped in Factor II. Cluster I remains the same, whereas, five stations (the same stations that did not belong to any Factor in Fig. 5) are grouped together into a new cluster (marked as T).

3.4 Starting analysis date (SAD)

Figure 7 presents the average differences between the shortest median *RSL* and the median *RSL* of the first day of each month for Regions I, II and the Transitional T, which correspond to Factors/Clusters I, II and T in Figs. 5 and 6, respectively.

In both Regions I and II, a uni-modal course is observed, whereas the transitional Region T has a bi-modal course. In Region I, there are minimum differences during the summer month of July (5 days), and the maximum in the winter months from December to March (values longer than 100 days, 113 and 114 days in December and January, respectively), while in Region II the minimum is obtained in March (5 days) and the maximum in June (43 days). The range, however, between the maximum and the minimum annual values is much larger in Region I (109 days) as compared with Region II (38 days). In the transitional Region T, two minima exist in February and August (8 days) and two maxima, in May (27 days) and

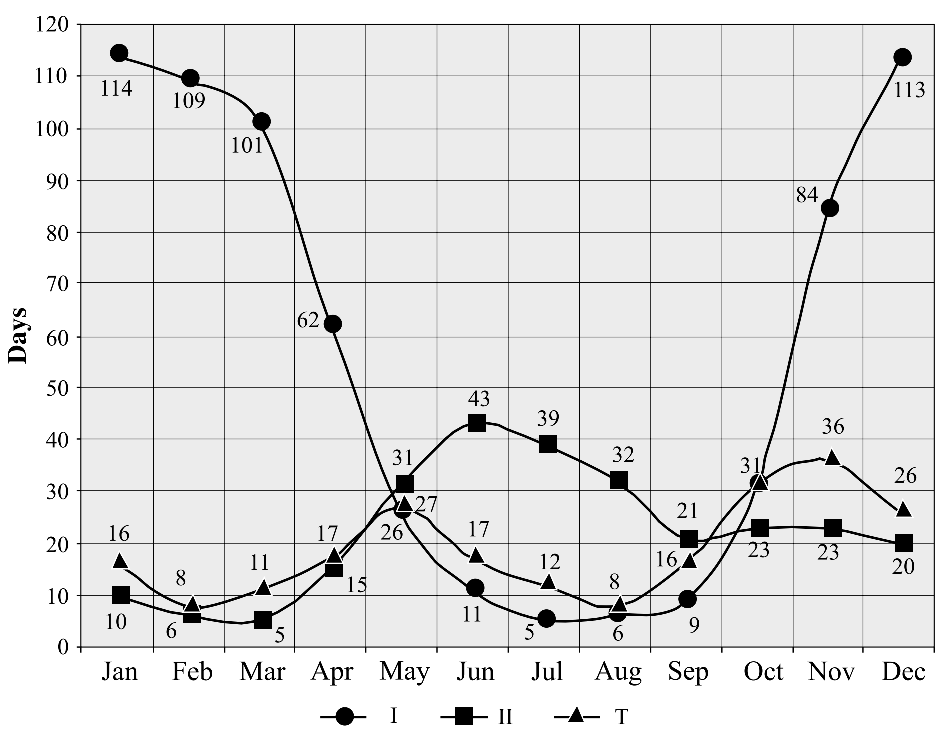


Fig. 7. Differences between the shortest median *RSL* and the shortest median *RSL* of the first day of each month

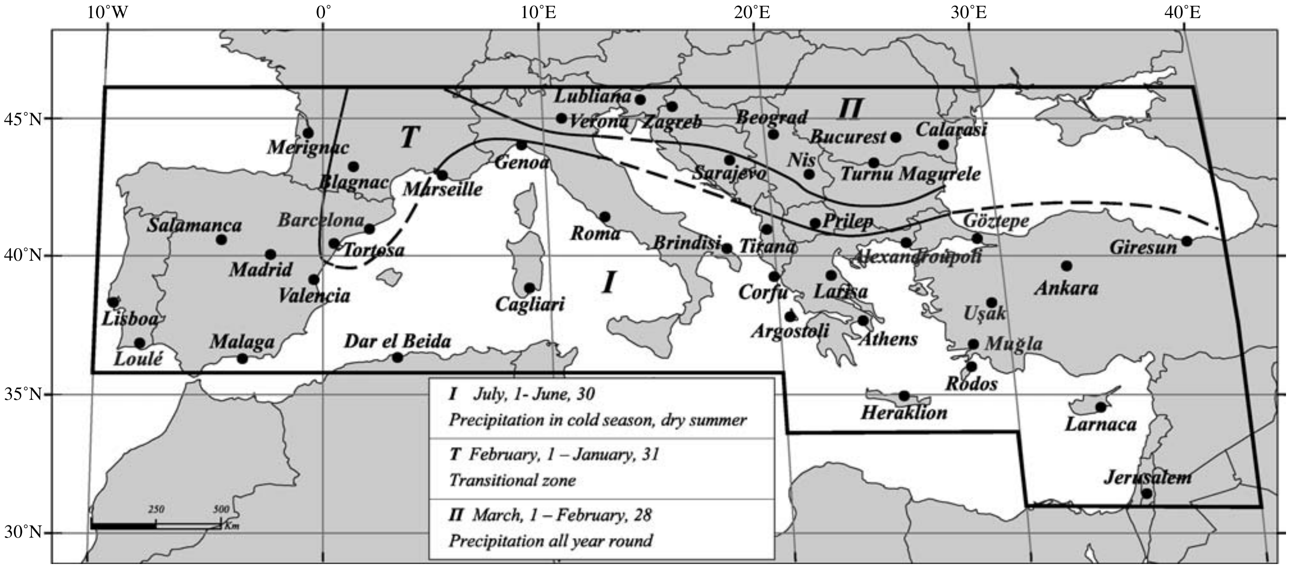


Fig. 8. Spatial distribution of the *SAD* within the study area

November (36). The annual range between November and February is the smallest among the three regions (28 days).

The *SAD* for the various regions was set as follows:

1. July 1st in Region I.
2. February 1st in the Transitional Region T.
3. March 1st in Region II.

Figure 8 presents the spatial distribution of the *SAD* within the study area.

3.5 Rainy season length (RSL)

Table 2 lists the median $DAP_{(10)}$, $DAP_{(90)}$ and the *RSL* over the entire period, at the various stations calculated according to the defined *SAD* pertaining to the respective regions. It can be noticed that all stations with *RSL* shorter than 240 days (8 months), belong to Region I.

4. Discussion and conclusions

The results presented above show very clearly the existence of two distinguishable regions in terms of their annual rainfall course. All stations in Region I have a uni-modal annual course with a summer minimum. They are highly positively correlated amongst themselves and negatively correlated with all stations belonging to Region II. Stations in Region II, have also a uni-modal course with its minimum in March, and are positively correlated amongst themselves (Figs. 3 and 4). These two groups of stations were very clearly evident in both *FA* and *CA*, in which exactly the same stations belonged to either Factor I or II, and Cluster I or II, respectively (Figs. 5 and 6). Five stations did not fit in either one of these two groups in all analyses. In Fig. 4, while all stations belonging to Region I have a similar correlation pattern, and all stations belonging to Region II show an opposite pattern, these 5 stations have not a clear pattern. These stations were grouped in a separate cluster between clusters I and II, in Fig. 6. However, these stations cannot be considered as a third region, due to the fact that the correlations among them are not highly positive and they do not appear as a separate Factor in the *FA*. They rather show a transition from a region with rains mainly in autumn, winter and spring to a region with rains all year round and slightly dryer in February and March. Therefore, these stations, which are geographically located between the two defined regions, were considered as a transitional zone.

It should be emphasized that unlike previous studies, which proposed new repartitions of the seasons according to various factors, such as astronomical, meteorological, synoptic and the temperature regime (e.g., Alpert et al. 2004), the present study is not aiming at a new repartition of the year into seasons. On the other hand, it proposes a new methodology for the definition of the most appropriate *SAD* for each rainfall regime.

Figure 8, presents the spatial distribution of the rainfall regimes that were defined according to their annual courses:

1. Region I, which comprises mainly the southern Mediterranean basin, demonstrates two distinguishable seasons: a dry period during the summer months, mainly between May and September, and a rainy season during the rest of the year.
2. Region II, which comprises the northern part of the study area; Adriatic, northern Balkans and further northward, precipitations occur all year round.

Between these two regions there is a Transitional zone T, which is characterized by a bimodal frequency of the precipitations.

The main conclusion of the present study is that from a climatological point of view, the use of a *Meteorological year*, for rainfall analyses, even in regions with a rainfall regime consisting of rains all year round, is less appropriate and therefore the *Hydrological year* should be preferred. Hence, in Region II, the period of March 1st–February 28th is more appropriate than the period of January 1st–December 31st for rainfall analysis, whereas, in Region I the period of July 1st–June 30th is the most appropriate. The methodology presented in this study enables to define the most appropriate *SAD* at any region in the world in a relatively simple way.

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