Adv. Geosci., 25, 45–50, 2010
www.adv-geosci.net/25/45/2010/

Advances in Geosciences

Cyclic modes of the intra-annual variability of precipitation in Greece

P. T. Nastos[1] **and C. S. Zerefos**[1,2,3]

[1]Laboratory of Climatology and Atmospheric Environment, Faculty of Geology and Geoenvironment, National and Kapodistrian University of Athens, Athens, Greece
[2]National Observatory of Athens, Athens, Greece
[3]Research Center for Atmospheric Physics and Climatology of the Academy of Athens, Athens, Greece

Received: 15 October 2009 – Revised: 28 January 2010 – Accepted: 7 February 2010 – Published: 9 March 2010

Abstract. The application of harmonic analysis to the annual variability of precipitation is the object of this study, so that the modes, which compose the annual variability, be elicited. For this purpose, monthly precipitation totals from 30 meteorological stations of the Hellenic National Meteorological Service (HNMS), for the period 1950–2000, were used.

The initial target is to reduce the number of variables and to detect structure in the relationships between the variables. The most commonly used technique for this purpose is the application of Factor Analysis (FA) resulted in five main factors (sub-regions) with common precipitation characteristics, explaining 77% of the total variance. For each sub-region, a representative station is selected for the analyses, mainly, as the station within the sub-region with the highest factor loading. In the process, the Fourier Analysis is applied to the mean monthly precipitation, so that 2 harmonic components are derived, which explain more than 90% of the total variability of each station, and are due to different synoptic and thermodynamic processes associated with Greece's precipitation regime. Finally the calculation of the time of the maximum precipitation, for each harmonic component, gives the spatial distribution of the appearance of the maximum precipitation in the Greek region.

1 Introduction

Greece is a country with a wide climatic variability due to its geographical position, the successive and high mountain ranges and also the multifarious and long coastlines. Precipitation, although mainly associated with cyclonic disturbances that originate in the Mediterranean basin, is also strongly influenced by local orographic effects. A characteristic pattern of the spatial variability of the precipitation in the Eastern Mediterranean appears in Greece, where within a distance of about 350 km the annual precipitation ranges from more than 2000 mm at the highlands of northwestern Greece to less than 400 mm in Attica and western Cyclades, while the intra-annual precipitation variability is high as well.

The temporal and spatial precipitation variability within the Mediterranean Sea and Greece has been investigated by many researchers (Maheras, 1981; Repapis, 1986, Nastos, 1993; Mantis et al., 1994; Brunetti et al., 2004; Nastos and Zerefos, 2008). Besides, the intra-annual variability of the precipitation for different time scales and sub-regions of Greece has been analysed using different multivariate methods (Kotini-Zabaka, 1983; Bloutsos, 1993; Metaxas et al., 1999; Fotiadi et al., 1999; Bartzokas et al., 2003). The Mediterranean climate is characterized by strong winter/summer rainfall contrast, which is associated with a well pronounced seasonal cycle with summertime warm, dry conditions. However, this simple pattern consists of secondary cycles, which appear with different amplitudes, significant in some cases, and could be attributed to the complex topography and the interchange between land and sea. These factors play an important role in the precipitation distribution, especially in the case of absence of advected air masses towards the country and presence of convection due to heat transfer from ground. This finding is partially hidden under the obvious Mediterranean pattern and especially during the warm period of the year, where an inverse relation between air temperature and precipitation has been found (Nastos et al., 2002). This period of the year the frequency of

Correspondence to: P. T. Nastos
(nastos@geol.uoa.gr)

Published by Copernicus Publications on behalf of the European Geosciences Union.

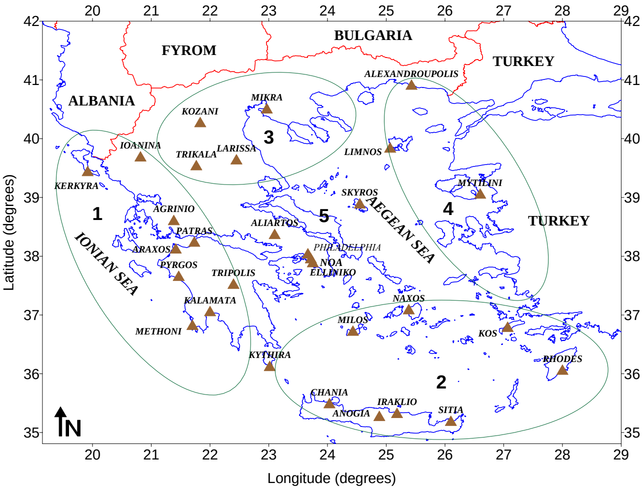

Fig. 1. Meteorological stations along with the sub-regions derived from FA.

depressions. moving over Greece decreases because of the NE Atlantic subtropical anticyclone expansions to the east basin of the Mediterranean Sea. For this reason, harmonic analysis is advisable for revealing these hidden cycles under the aforementioned dominant precipitation pattern.

The goal of this study is to determine the modes that constitute the intra-annual variability of precipitation in Greece and thus to interpret the different synoptic and thermodynamic processes associated with Greece's precipitation regime.

2 Data and methods

The data used in the analysis consists of the monthly precipitation totals from 30 meteorological stations of the HNMS for the period 1950–2000. The network of the meteorological stations is satisfactorily distributed within the Greek region (Fig. 1), representing well the precipitation regime of the country.

Firstly, the application of FA (S-mode) to all the available stations datasets was considered necessary in order to reduce the number of variables and to detect a structure in the relationships between them; resulting in the classification of the said variables. Therefore, FA is applied as a data reduction or a structure detection method. The data should have a bivariate normal distribution for each pair of variables, and observations should be independent. Each of the p initial variables X_1, X_2, ..., X_p can be expressed as a linear function of m ($m < p$) uncorrelated factors: $X_i = a_{i1}F_1 + a_{i2}F_2 + ... + a_{im}F_m$ where F_1, F_2, ..., F_m are the factors and a_{i1}, a_{i2}, ..., a_{im} are the factor loadings, which express the correlation between the factors and the initial variables. The values of each factor are called factor scores and they are presented in standardized form, having zero mean and unit variance (Jolliffe, 1986; Manly, 1986). The number m of the retained factors has to be decided, by using various rules (eigenvalue $\geq$1, scree plot) and considering the physical interpretation of the results. Another important point of the analysis is the rotation of the axes, which maximizes some factor loadings and minimizes some others; in that way a better separation among the initial variables is succeeded. Varimax rotation is generally accepted as the most accurate orthogonal rotation, which maximizes the sum of the variances of the square factor loadings, keeping the factors uncorrelated (Richman, 1986). In the process of the Harmonic Analysis of the intra-annual variability of precipitation, the following formula, which is the most common for meteorological and climatological research (Conrad and Pollak, 1950), is applied to the mean monthly values:

$$y = \alpha_0 + \alpha_1 \sin(\frac{2\pi t}{12} + \phi_1) + \alpha_2 \sin(\frac{2(2\pi t)}{12} + \phi_2) + ...$$
$$+ \alpha_\kappa \sin(\frac{k(2\pi t)}{12} + \phi_k) + ...$$
$$= \alpha_0 + \sum_{k=1}^{n} \alpha_k \sin(\frac{2k\pi t}{12} + \phi_k) \quad (1)$$

where α_o is the arithmetic mean of the mean monthly values, $\alpha_1, \alpha_2, \ldots, \alpha_\kappa$ are the amplitudes and $\phi_1, \phi_2, \ldots, \phi_\kappa$ are the phase angles of the respective harmonic terms with k=1, 2, 3, ...

The application of the aforementioned formula was succeeded for k=2, because the intra-annual variability of the precipitation is well described by two harmonic terms, which explain more than 90% of the total variance. In the process, the time of maximum precipitation is evaluated, for each station, using the formula:

$$t_{\max} = (\frac{\pi}{2} - \phi_\kappa)\frac{12}{2k\pi} \quad (2)$$

3 Results and discussion

The application of the FA (S-mode) to a table having as columns the meteorological stations-variables and rows the monthly precipitation values resulted in five main factors (sub-regions) with common precipitation characteristics, explaining 77% of the total variance of the precipitation in Greece. These sub-regions represent the northern, southern, western, eastern and central areas of Greece (Fig. 1). Relevant classifications have been adopted by other researchers (Loukas et al., 2001; Livada and Assimakopoulos, 2007). For each region, a representative station is selected for the analyses followed: Ioannina for western (1), Iraklio for southern (2), Mikra for northern (3), Mytilini for eastern (4) and Athens (National Observatory of Athens) for central (5) sub-region. The representative station for each sub-region was selected mainly as the station with the highest factor loading, extracted by FA.

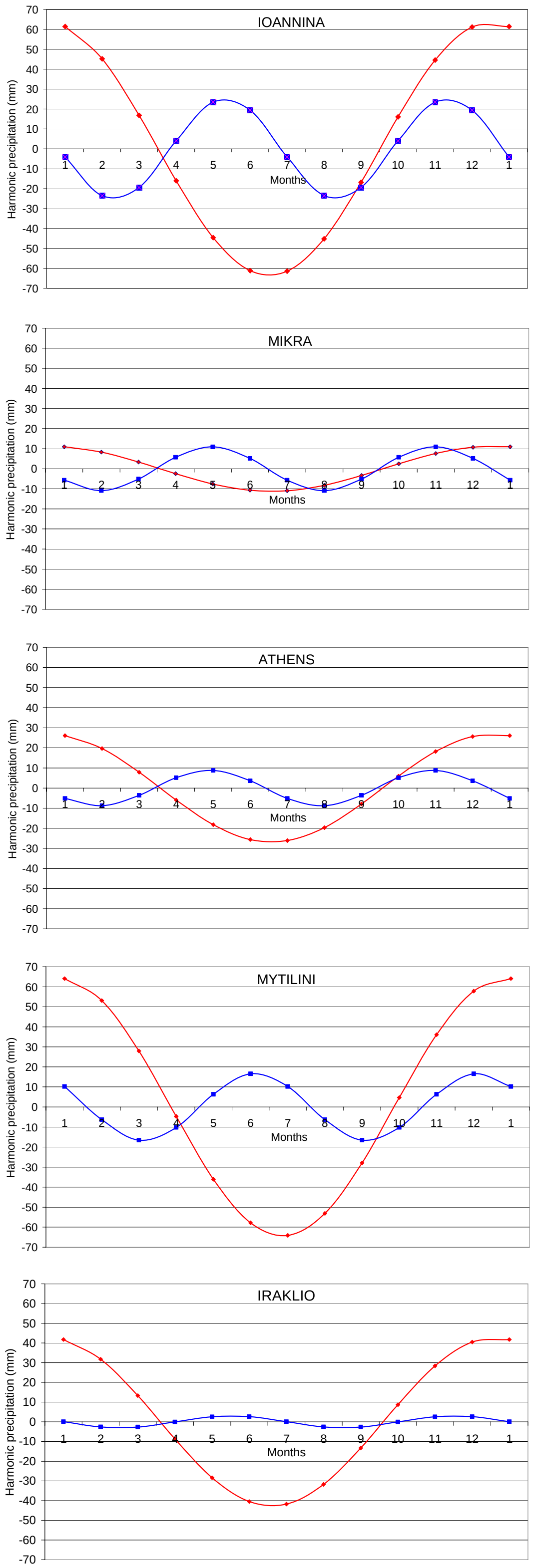

Fig. 2. Annual variation of the first harmonic (F1: red line) and the second harmonic component (F2: blue line) for representative stations within the sub regions extracted by FA.

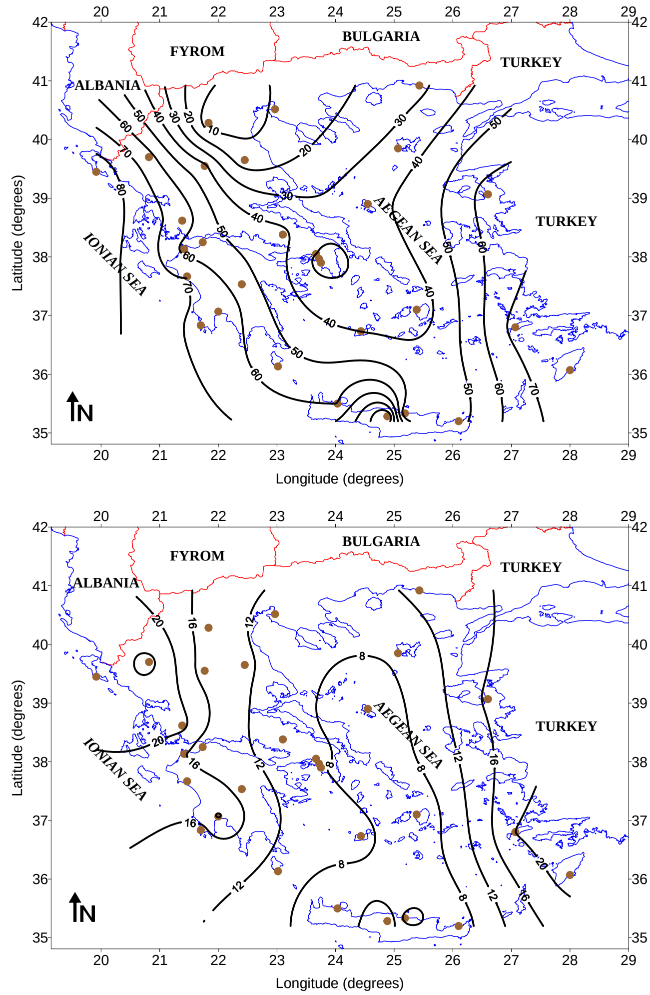

Fig. 3. Spatial distribution of the amplitude (a_1) for the first harmonic (upper graph) and the amplitude (a_2) for the second harmonic (lower graph).

The intra-annual variability of the precipitation is well described by two harmonic modes, which explain more than 90% of the total variance for almost all the under investigarion stations (Table 1). Figure 2 depicts the intra annual variation of the first harmonic (red line) and the second harmonic (blue line) for the representative stations, extracted by the FA. There is a significant variation for both the first and second modes for Ioannina and Mytilini stations, representing the western and eastern sub-regions of Greece, respectively. In this point, it is worthy to mention the equivalent role of the two harmonic modes in the case of Mikra station in the north of the country. Moving from north to south the second mode disappears (Iraklio), and this could be attributed to the mild influence of the sea, which prevents convective thunderstorms.

Table 1. Geographical position of the stations (Latitude, Longitude) and Harmonic Analysis results, (α_0: the arithmetic mean of the mean monthly values, a_1, a_2: the amplitudes of the first and second harmonic mode and t_1, t_2: the time of maximum for the first and second harmonic mode, respectively).

	Station	Latitude	Longitude	Altitude (m)	a_0 (mm)	a_1 (mm)	t_1 Date	%	a_2 (mm)	t_2 Date	%
1.	Alexandroupolis	40.92	25.43	3	45.6	27.6	3 January	80	12.9	27 May	17
2.	Mikra	40.52	22.97	5	37.1	11.2	3 January	50	10.9	17 May	48
3.	Kozani	40.28	21.83	626	43.5	4.6	9 December	8	13.8	16 May	76
4.	Limnos	39.85	25.07	3	40.4	33.9	5 January	92	8.7	10 June	6
5.	Ioannina	39.70	20.82	484	92.8	63.4	1 January	85	25.1	28 May	13
6.	Larissa	39.65	22.45	74	36.4	14.4	22 December	52	12.8	11 May	42
7.	Trikala	39.55	21.77	149	61.9	41.8	5 January	86	14.1	10 May	10
8.	Kerkyra	39.45	19.92	4	93.0	87.0	21 December	94	20.8	11 May	5
9.	Mytilini	39.07	26.60	5	54.8	64.2	12 January	92	16.7	21 June	6
10.	Skyros	38.90	24.55	4	38.6	38.1	6 January	96	5.5	21 June	2
11.	Agrinio	38.62	21.38	47	78.6	66.5	29 December	89	21.2	22 May	9
12.	Aliartos	38.38	23.10	110	51.9	42.5	2 January	92	9.4	13 May	5
13.	Patras	38.25	21.73	1	56.5	54.2	1 January	93	14.5	24 May	7
14.	Araxos	38.13	21.42	15	56.4	56.9	26 December	91	16.1	21 May	7
15.	N. Philadelphia	38.05	23.67	138	35.8	30.1	3 January	87	9.6	22 May	9
16.	Athens	37.97	23.72	107	32.1	26.8	3 January	86	8.9	15 May	9
17.	Elliniko	37.90	23.75	10	30.7	26.6	1 January	86	8.1	17 May	8
18.	Pyrgos	37.67	21.47	13	68.4	69.6	24 December	92	17.6	22 May	6
19.	Tripolis	37.53	22.40	622	66.7	54.7	5 January	93	14.5	4 June	6
20.	Naxos	37.10	25.38	10	29.1	33.8	11 January	94	4.9	3 July	2
21.	Kalamata	37.07	22.00	5	66.7	69.0	26 December	90	20.5	26 May	8
22.	Methoni	36.83	21.70	33	59.5	66.3	25 December	94	14.6	28 May	5
23.	Kos	36.80	27.07	10	58.4	73.7	8 January	91	20.1	13 July	7
24.	Milos	36.73	24.43	182	34.9	39.9	5 January	92	9.4	8 June	5
25.	Kythira	36.13	23.02	167	45.5	54.0	1 January	94	10.5	13 June	4
26.	Rodos	36.07	28.00	35	60.9	79.3	7 January	91	21.7	28 June	7
27.	Chania	35.50	24.03	62	52.4	59.9	7 January	95	4.6	16 July	<1
28.	Iraklio	35.33	25.18	39	39.4	42.6	4 January	95	3.0	3 June	<1
29.	Anogia	35.28	24.88	740	91.0	101.6	5 January	95	11.5	28 June	1
30.	Sitia	35.20	26.10	28	41.2	47.1	3 January	95	6.0	11 June	2

Table 1 presents the results of the Harmonic Analysis applied to the mean monthly precipitation totals for each one of the meteorological stations. It is crystal clear that the percentage of the total variance explained by the first harmonic is high enough, so that its variation is quite similar to the annual variation of the original data. The first harmonic mode interprets almost 90% of the total variance with the exception in Kozani station, where the second mode accounts for 76% of the total variance and in Mikra and Larissa stations where both modes explain equivalent percentages of the total variance. The spatial distributions of the amplitudes of the two extracted modes are depicted in Fig. 3.

Concerning the first mode (Fig. 3, upper graph), high amplitudes appear in the western and southeastern sub-regions of Greece. This is in agreement with Bartzokas et al. (2003), who studied the intra-annual variation of the precipitation amount and duration in Greece using FA on 10-day precipitation totals. They found that Factor 1 (59% of the total variance) includes stations in the islands of the central and southern Aegean Sea, as well as areas of the northern Aegean and Ionian Sea. The second mode (Fig. 3, lower graph) presents high amplitudes in stations, which are located in the continental sub-regions of northern Greece. This pattern is similar to the one described by the Factor 2 (29%) in the work of Bartzokas et al. (2003).

It is very likely that, the first mode refers in fact to the eastward moving Mediterranean depressions, releasing the larger amount of precipitation on the west coasts of Greece and Anatolia during the cool season southward withdrawal of the subtropical anticyclone.

while the second one represents the precipitation caused mainly by upper barometric lows in combination with instability and powerful breeze cells.

Another important issue is the spatial distribution of the time of maximum precipitation extracted by the Harmonic Analysis. As far as the first mode is concerned, maximum

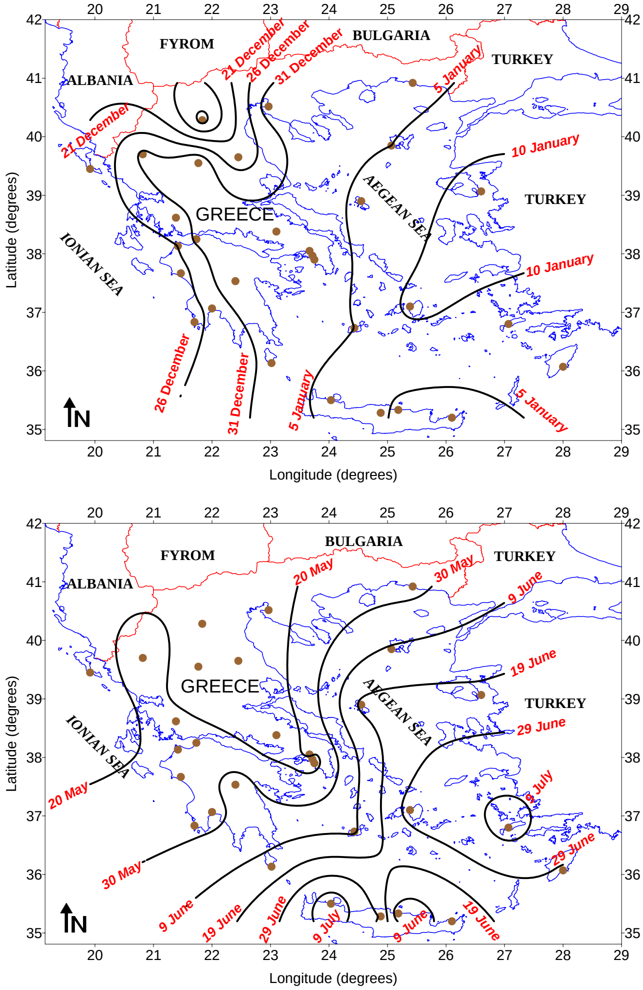

Fig. 4. Spatial distribution of the time of maximum precipitation for the first harmonic (upper graph) and for the second harmonic (lower graph).

precipitation appears in late December at the northern continental and the western sub-regions of Greece, while the eastern part of the country is under maximum precipitation in the first ten days of January (Fig. 4, upper graph). This pattern shows an approximately 20-day shift from the west to the east of Greece. The spatial distribution of the primary maximum of the second mode (Table 1) is shown in Fig. 4 (lower graph). It appears in late May, mainly in the continental sub-regions and it is shifted to late June in the southeastern sub-regions, attributed to the sea thermal capacity. The secondary maximum has a similar pattern (not shown) and appears in late November-early December preceding the maximum of the first mode, which follows in late December-early January, as mentioned. This is attributed to the during the winter occasional stationary of moving anticyclones of central Europe extended over Balkan peninsula, which prevent the passage of depressions interrupting the winter rains.

4 Conclusions

The intra-annual variation of the precipitation totals in Greece is well described by two harmonic modes, which explain more than 90% of the total variance. The first mode appears to have high amplitudes in the western and southeastern sub-regions of Greece, influenced by the sea, while the second one represents the continental sub-regions of northern Greece. The first mode could be attributed to the depressions moving eastwards, affecting western Greece and the East Aegean islands, during winter period, while the second mode interprets the well known thermal thunderstorms in the inlands, which occur during summertime mainly.

Concerning the time of maximum precipitation for the first mode, the established pattern shows that there is about 20-day shift between the west and east sub-regions of Greece, while significant time shift appears from northwest to southeast, as far as the maxima of the second mode are concerned.

Acknowledgements. The authors would like to acknowledge the Hellenic National Meteorological Service for providing the monthly precipitation datasets.

Edited by: S. C. Michaelides
Reviewed by: A. Paliatsos and H. D. Kambezidis

References

Bartzokas, A., Lolis, C. J., and Metaxas, D. A.: A study of the intra-annual variation and the spatial distribution of precipitation amount and duration over Greece on a 10 day basis, Int. J. Climatol., 23, 207–222, 2003.

Bloutsos, A. A.: Harmonic analysis of the annual variation of precipitation over Greece. In Water Deficiency and Floods, Symposium Organized by the Geotechnical Chamber of Greece, Thessaloniki, 17–18 March 1992, 181–191, (in Greek) 1993.

Brunetti, M., Maugeri, M., Monti, F., and Nanni, T.: Changes in daily precipitation frequency and distribution in Italy over the last 120 years, J. Geophys. Res., 109, D05102, doi:10.1029/2003JD004296, 2004.

Conrad, V. and Pollak, L. W.: Methods in Climatology. Harvard University Press, Cambridge, Massachusetts, 118–133, 1950.

Fotiadi, A. K., Metaxas, D. A., and Bartzokas A.: A statistical study of precipitation in NW Greece, Int. J. Climatol., 19, 1221–1232, 1999.

Jolliffe, I. T.: Principal Component Analysis. Springer-Verlag, New York, 1986.

Kotini-Zabaka, S.: Contribution to the study of the climate of Greece. Normal weather per month, Publication of the Research Centre of Climatology of the Academy of Athens, Publication no. 8, (in Greek), 1983.

Livada, I. and Assimakopoulos, V. D.: Spatial and temporal analysis of drought in Greece using the Standardized Precipitation Index (SPI), Theor. Appl. Climatol., 89, 143–153, 2007.

Loukas, A., Vasiliades, L., Dalezios, N. R., and Domenikiotis, C.: Rainfall-frequency mapping for Greece, Phys. Chem. Earth Pt. B, 26(9), 669–674, 2001.

Maheras, P.: La variabilite des precipitations dans la mer Egee, Archiv. Met. Geoph. Bioklim., Series B, 29, 157–166, 1981.

Manly, B. F. J.: Multivatiate Statistical Methods: A Primer, Chapman & Hall, London, 1986.

Mantis, H. T., Repapis, C. C., Philandras, C. M., Paliatsos, A. G., and Amanatidis, G. T.: The spatial and temporal structure of the precipitation climate the Eastern Mediterranean; Background for a study of Climate Change, EUR 17458 – Eastern Europe and Global Change, Kassandra, Halkidiki, Greece, edited by: Ghazi, A., Mathy, P., and Zerefos, C. 3–10 October 1994, 125–131, 1994.

Metaxas, D. A., Philandras, C. M., Nastos, P. T., and Repapis, C. C.: Variability of precipitation pattern in Greece during the year, Fresen. Environ. Bull., 8, 1–6, 1999.

Nastos, P. T.: Changements de la pluviosite en region Hellenique pendant la periode 1858–1992, Proceedings of the 6th Colloque International de Climatologie, 22–25 September 1993, Thessaloniki, Greece, Vol. 6, 183–190, 1993.

Nastos, P. T. and Zerefos, C. S.: Decadal changes in extreme daily precipitation in Greece, Adv. Geosci., 16, 55–62, 2008, http://www.adv-geosci.net/16/55/2008/.

Nastos, P. T., Philandras, C. M., and Repapis, C. C.: Application of canonical analysis to air temperature and precipitation regimes over Greece, Fresen. Environ. Bull., 11(8), 488–493, 2002.

Repapis, C. C.: Temporal fluctuations of precipitation in Greece, Rivista Meteor. Aeron., XLVI, 1–2, 19–25, 1986.

Richman, M. B.: Rotation of principal components. J. Climatol., 6, 293–335, 1986.