Climate Change and precipitation in Greece*

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ABSTRACT: This paper is a review, concerning the observed climatic changes in the precipitation regime of Greece, during the period 1956-2002, based on daily precipitation totals from 26 meteorological stations, assigned by the Hellenic National Meteorological Service. The annual trends of the precipitation time series were estimated using the Mann-Kendall rank statistic method. Besides, the probability of the extreme events was determined by the scale and shape parameters of the fitted Gamma distribution to the daily precipitation time series.

The findings extracted by the analysis showed that, decreasing trends, mostly statistically significant at 95% confidence level, regarding the total annual precipitation and the annual number of rain days appear all over Greece. The fitted Gamma distributions to the precipitation datasets within 10-year sub periods indicate that the scale parameter increases for the western and southern-eastern sub regions, while the annual precipitation presents a downward trend, especially during the last decade 1991-2000. The increase in the variance and the scale parameter, as well as the shift of the mean towards higher values reveal the incidence of extreme daily precipitation values since 1980s.

Key-words: *Precipitation variability, Gamma distribution, extremes, climate change, Greece.*

ΠΕΡΙΛΗΨΗ: Αυτή η εργασία είναι μια επισκόπηση, η οποία αφορά τις παρατηρούμενες κλιματικές μεταβολές στο βροχομετρικό καθεστώς της Ελλάδος, κατά την διάρκεια της περιόδου 1956-2002, βασισμένη σε ημερήσια δεδομένα βροχής από 26 μετεωρολογικούς σταθμούς, που παραχωρήθησαν από την Εθνική Μετεωρολογική Υπηρεσία. Οι ετήσιες τάσεις των χρονοσειρών της βροχής εκτιμήθηκαν εφαρμόζοντας την στατιστική μέθοδο Mann-Kendall. Επίσης, η πιθανότητα των ακραίων γεγονότων καθορίστηκε από τις παραμέτρους (scale και shape) της κατανομής Γάμμα που προσαρμόστηκε στις χρονοσειρές των ημερήσιων δεδομένων.

Τα εξαγόμενα συμπεράσματα από την ανάλυση έδειξαν ότι, σε όλη την Ελλάδα εμφανίζονται τάσεις μείωσης (στατιστικά σημαντικές σε επίπεδο εμπιστοσύνης 95%) στις χρονοσειρές της ετήσιας βροχής καθώς επίσης και στον ετήσιο αριθμό ημερών βροχής. Οι προσαρμοσμένες κατανομές Γάμμα στα ημερήσια βροχομετρικά δεδομένα 10-ετών υποπεριόδων έδειξαν ότι η παράμετρος “scale” αυξάνει στις δυτικές και νοτιο-ανατολικές περιοχές της Ελλάδος, ενώ η ετήσια βροχόπτωση παρουσιάζει τάση ελάττωσης, ιδιαίτερα την τελευταία δεκαετία 1991-2000. Η παρατηρούμενη αύξηση της μεταβλητότητας της βροχής και της παραμέτρου “scale” της κατανομής Γάμμα καθώς επίσης και η μετατόπιση της μέσης τιμής της ημερήσιας βροχής προς υψηλότερες τιμές αποκαλύπτουν την εμφάνιση ακραίων ημερήσιων ποσών βροχής από τη δεκαετία του 1980.

Λέξεις-κλειδιά: *Μεταβλητότητα βροχής, κατανομή Γάμμα, ακραίες τιμές, κλιματική μεταβολή, Ελλάδα.*

INTRODUCTION

According to the Koppen definition, the Mediterranean climate is characterized by winter rainfall which exceeds three times the summer rainfall totals. This strong winter/summer rainfall contrast is associated with a well pronounced seasonal cycle with summertime warm, dry conditions associated with a strong high-pressure ridge over Balkans. The axis of the ridge is displaced southward over Egypt by a trough which extends from the Persian Gulf area north-westwards towards Greece and which is associated with the Indian summer monsoon depression.

The rainy season begins in October, associated with a change in the mean-wave pattern of the upper westerlies and an upper air flow which is characterized by a trough over Europe. Winter is characterized by cyclonic disturbances and low mean pressure in the Mediterranean, with higher pressure to the east associated with the Siberian high. In March and April, as the main features of the upper flow (e.g. jet streams) begin to move northward from their southernmost winter positions, the rainy season continues until May where the summer dry regime is established. A characteristic pattern of the spatial variability of the precipitation in the Eastern Mediterranean appears in Greece, where in 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 at Attica and western Cyclades, while the inter-annual precipitation variability is high as well.

Precipitation, although mainly associated with cyclonic disturbances that originate in the Mediterranean basin (Fig. 1), is also strongly influenced by local orographic effects. The winter mean surface pressure pattern shows features which result from these cyclogenetic aspects. The formation of Mediterranean depressions is partly determined by transitory excursions of the polar front jet and the European trough, modified by the land-sea temperature contrast which favors cyclogenesis over warm sea waters. Depressions over the eastern basin are often associated with cold northerly airflow and lee cyclogenesis. These relationships provide a link between the local rain-producing pressure systems and larger-scale aspects of the general circulation over Europe. The precipitation variability and the distribution of precipitation

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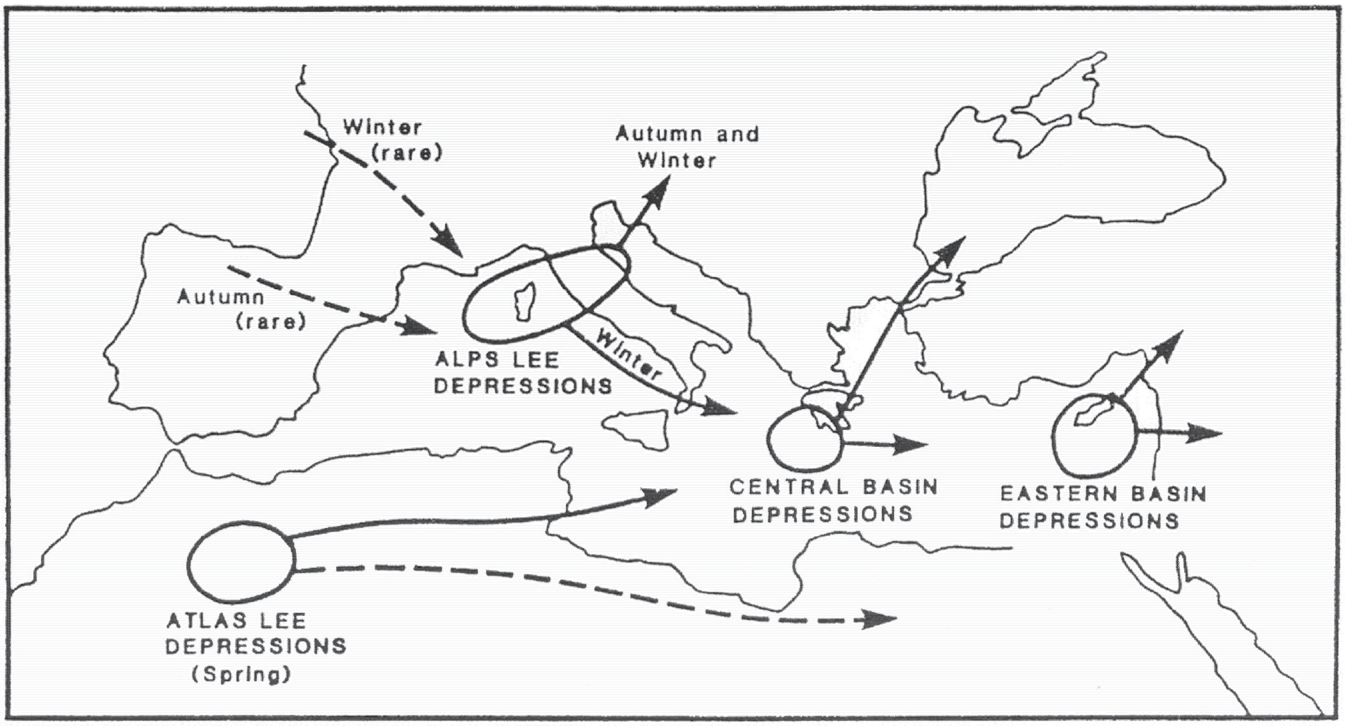

Fig. 1. Regions of cyclogenesis and principal cyclone tracks (from WIGLEY & FARMER, 1982).

frequency within the Mediterranean Sea and Greece have been carried out by many researchers (ZEREFOS *et al.,* 1977; MAHERAS, 1981; REPAPIS, 1986; NASTOS, 1993; MANTIS *et al.,* 1994; AMANATIDIS *et al.,* 1997; METAXAS *et al.,* 1999; MAHERAS & ANAGNOSTOPOULOU, 2003; NASTOS & ZEREFOS 2007).

PRECIPITATION VARIABILITY AND EXTREMES IN GREECE

Extreme rain events, with a few exceptions, are associated with cyclones as humid Mediterranean air is advected against the slopes of the mountain ridges surrounding the Mediterranean basin. A small number of local flash floods has been associated with intense local convective cells. A heavy rain event is defined here as a day with more than 60 mm/day of precipitation in any point of a "territorial unit".

In Greece about 92% of rainfall during the rainy season (October to March) is produced by the cyclonic circulation types (MAHERAS & ANAGNOSTOPOULOU, 2003), while, during the summer period the intense precipitation and hail episodes are related to geostrophic vorticity advection (SPANOS, 2004). The cyclones responsible for precipitation in different areas do not share a common origin and generally a single system affects only part of the Mediterranean region. A study focused on Portugal, Italy and Greece has shown that precipitation over Greece is very rarely affected by Atlantic cyclones, but it is associated to cyclogenesis inside the Mediterranean region (LUTERBACHER *et al*., 2006). The transport of moisture from the Western to the Eastern Mediterranean corresponds to the generation (or intensification) of cyclones in the western Mediterranean and their following eastward motion. Air sea interaction and a large latent heat flux are playing an important role in this process (REPAPIS *et al*., 1978).

Fig. 2 shows that winter (DJF) averaged-mean Mediterranean precipitation anomalies (with respect to 1961-1990) from 1500 to 2002, defined as the average over the land area 10°W to 40°E and 35°N to 47°N (thin black line). The values for the period 1500 to 1900 are reconstructions (PAULING *et al*., 2006); data from 1901 to 2002 are derived from MITCHELL *et al.* (2004). The thick black line is a 30-year smooth 'minimum slope' constraint (mean squared error, MSE= 0.856) calculated according to MANN (2004). The dashed horizontal lines are the 2 standard deviations of the period 1961-1990. The driest and the wettest Mediterranean winters for the reconstruction and the full period are denoted. There is clear evidence of an extended dry period (with respect to the 1961-1990) at the turn of the twentieth century, followed by wet conditions with maximum in the 1960s (XOPLAKI *et al*., 2004). A striking phenomenon is the negative winter rainfall trend since the 1960s (CULLEN & DEMENOCAL, 2000; GOODESS & JONES, 2002; XOPLAKI *et al*., 2004), which seems to be unprecedented as inferred from reconstructed long-term time series. This negative trend can be at least partly explained by the observed positive trend of the NAO (DÜNKELOH & JACOBEIT, 2003; XOPLAKI *et al*., 2004; LUTERBACHER *et al*., 2006). XOPLAKI *et al.* (2004) has shown that the frequency and amplitude of intense anomalies from the long-term mean is steadily increasing between 1500 and 2002.

The longest available time series of precipitation in

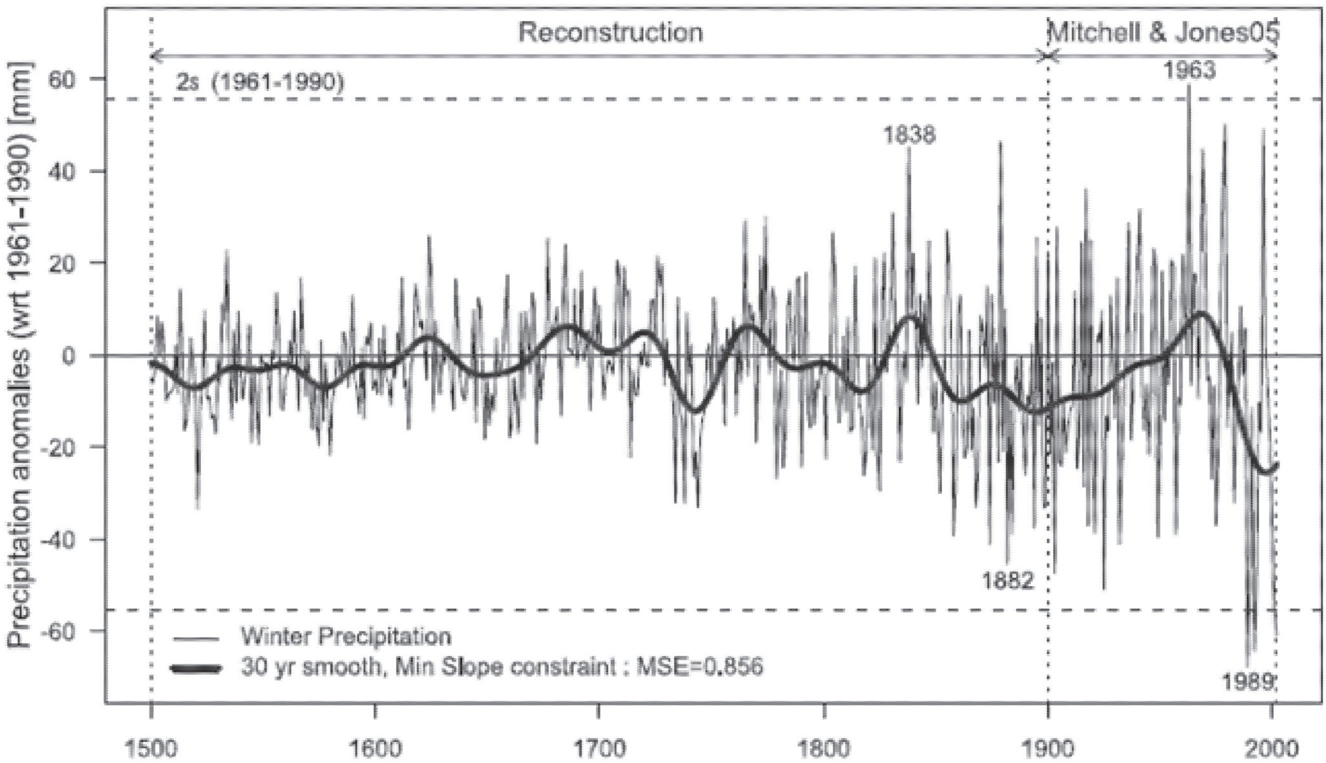

Fig. 2. Adopted from LUTERBACHER *et al.* (2006).

Greece is that recorded at the National Observatory of Athens. Fig. 3 depicts the course of the annual precipitation timeseries (upper graph) and the number of days with precipitation > 0.1 mm (lower graph), herewith rain days, along with linear and loess fitting, for the period 1891-2004.

Annual precipitation does not appear any statistically significant trend (p= 0.24) in the 1891-2004 period (the peak in the annual timeseries corresponds to the year 2002, and exceeds the average precipitation by over two standard deviations). On the other hand, the rain days series shows a slight negative trend, which is not statistically significant (p= 0.47), during the examined period. However, this trend becomes statistically significant (p= 0.03) during the last thirty seven years (1968-2004). The absence of a significant trend in annual precipitation and the negative trend in rain days, especially in the last three decades, may indicate an increase in the extreme daily precipitation. This temporal pattern is appeared over the northeastern quadrant of the contiguous United States, where during the last 30 years (exactly at the time when most of increase in very heavy precipitation started) a decrease in the number of rain days was observed (GROISMAN *et al*., 2005). Additionally, in several regions such as South Africa, Siberia, the Eastern Mediterranean Sea, central Mexico, and northern Japan, rainy days are becoming less frequent and an increase only in heavy precipitation is observed while total precipitation and/or the frequency of days with an appreciable amount of precipitation are not changing and/or are decreasing (EASTERLING *et al*., 2000; ALPERT *et al*., 2002; FAUCHEREAU *et al*., 2003; GROISMAN *et al*., 2005). Besides, this is in agreement with the results of BRUNETTI *et al.* (2001), who find a negative significant trend in the number of rain days all over Italy, and a positive trend in precipitation intensity, which is significant only in the northern regions.

With respect to precipitation variability in Greece, Table 1 presents the trends of annual total precipitation and rain days; bold and italics figures for statistically significant trends at 95% confidence level. It is crystal clear that decreasing trends, mostly statistically significant at 95% confidence level, regarding the total annual precipitation and the annual number of rain days appear all over Greece. High decreasing trends appear mostly in western Greece (Kerkyra: -8.1 mm/year and -0.5 days/year).

The changes in daily precipitation totals in Greece, during the 45-year period (1956-2002) are also presented. The precipitation datasets concern daily totals recorded in 26 surface meteorological stations of the Hellenic National Meteorological Service, which are uniformly distributed over the Greek region. The probability of the extreme events is well determined by the scale and shape parameters of the fitted Gamma distribution to the daily precipitation time series. The results show that the shape parameter of the precipitation Gamma distributions remains rather stable in this period of study, independent of total precipitation, while the scale parameter, which characterizes the scale of the intensity of the daily precipitation (the higher the scale parameter is, the higher the intensity is), is most variable (Fig. 4). High figures of the scale parameter appear in the western, eastern and southeastern Greece, while low ones appear mainly in the central continental Greece. The fitted Gamma distributions to the precipitation datasets within 10-year sub periods indicate that the scale parameter increases for the western and southern-eastern sub regions, while the annual precipitation presents a downward trend, especially during the last decade 1991-2000.

The increase in the variance and the scale parameter, as well as the shift of the mean towards higher values reveal the incidence of extreme daily precipitation values since 1980s.

In order to present the trends of the extreme precipitation Factor Analysis is applied to all available daily datasets obtained from the Hellenic Meteorological Service and five sub regions with common precipitation characteristics were extracted. These represent the northern, southern, western, eastern and central regions of Greece. For each such 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 for central (5) sub region. Firstly, the annual number of precipitation days exceeding the specific thresholds such as 30 mm and 50 mm was estimated. In the process, these values were divided by the respective number of the rain days for each year, and thereafter the percentages (%) of the annual number of precipitation days exceeding these thresholds were calculated. Regarding the threshold of 30 mm, negative trends but statistically not significant (0.05 c.l.) appear in the western (Ioannina) and the northern (Mikra) sub regions, while rather stable trends appear in the southern (Iraklio) and the western (Mytilini) sub regions of Greece. Athens (National Observa-

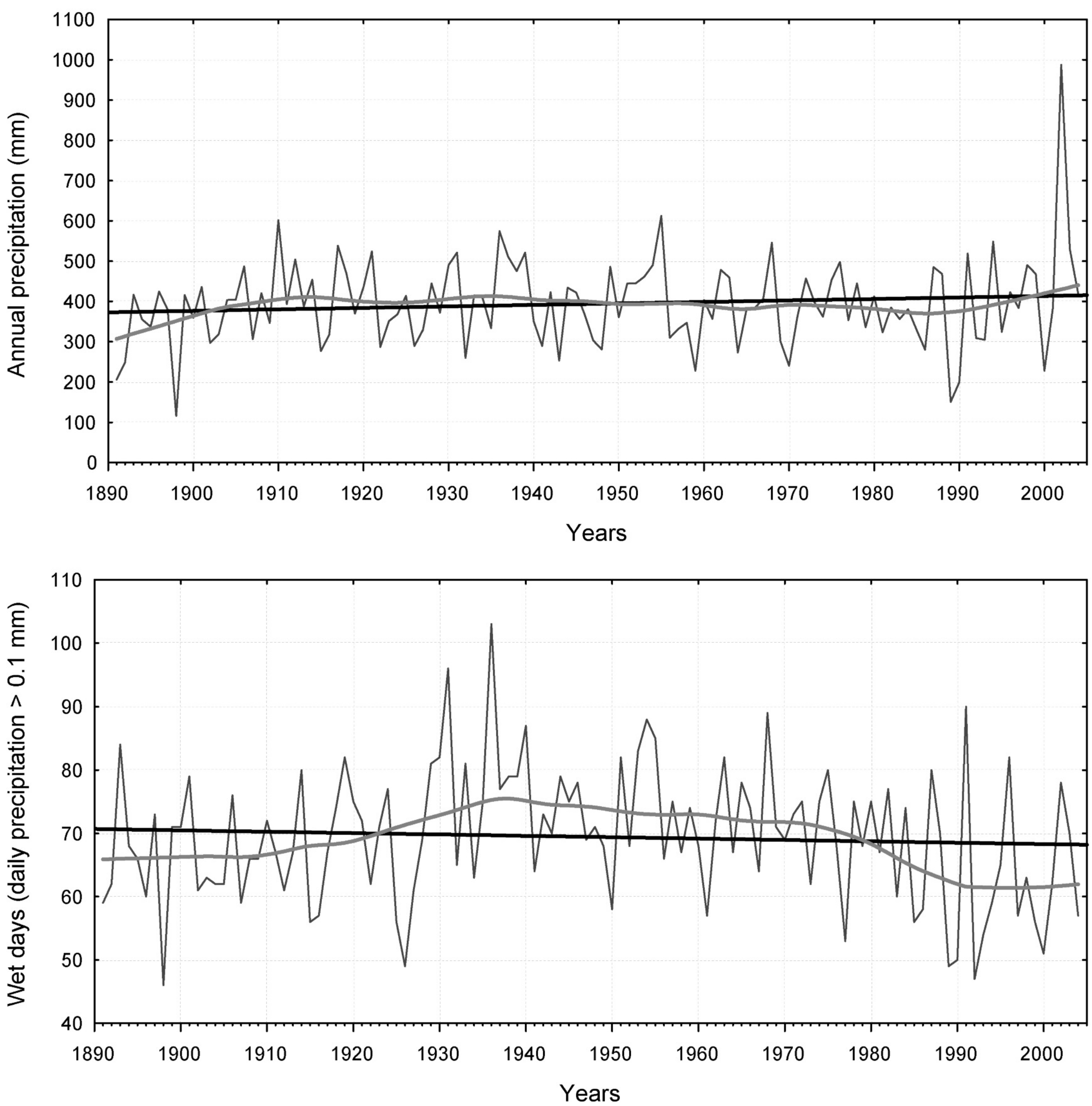

Fig. 3. Time series of annual precipitation (upper graph) and number of days with precipitation>0.1 mm (lower graph), along with linear and loess fitting (Adopted from Nastos & Zerefos, 2007).

tory of Athens, NOA) within the central sub region presents a statistically significant positive trend (0.05 c.l.), which has been pointed out in a previous study (Nastos & Zerefos, 2007). The application of the wavelet analysis to the time-series of the number of days exceeding the above thresholds resulted in significant quasi biennial and quasi decadal return periods, which could be attributed to North Atlantic Oscillation.

The monthly distributions of the percentages (%) of the number of days with precipitation greater than 30 and 50 mm, for the representative stations from the sub regions extracted, are depicted in the stacked graphs of the Fig. 5. The extreme and rare precipitation events appear mainly during winter months with respect to western and eastern sub regions and specifically the days (%) with precipitation greater than 50mm turn up more frequent within the eastern sub region (Mytilini) while are also more evident in August. Regarding the southern sub regions, the extreme events appear their peaks during autumn months (September to October) while their occurrence is minimized in summer. In northern sub regions the precipitation extremes are diminished and are obvious especially in July and September, while in Athens the peaks appear in January and October.

The consequent redistribution of the daily rainfall categories - torrential/heavy against the moderate/light intensities - is of paramount interest particularly in the semi-arid sub-tropical regions for purposes of water management, soil erosion and flash floods impacts. Specific isolated regions exhibit an increase of extreme rainfall in spite of the reduction of the total precipitation.

A final question is whether particularly dry and wet winters occurred more frequently during the twentieth century, when climate may be partly affected by human activity through emissions of GHGs (Houghton *et al*., 2001). The analysis of climate extremes and their changes requires a very careful procedure. There is large uncertainty in the estimate of extremes, simply because they represent infrequent events with small sample size.

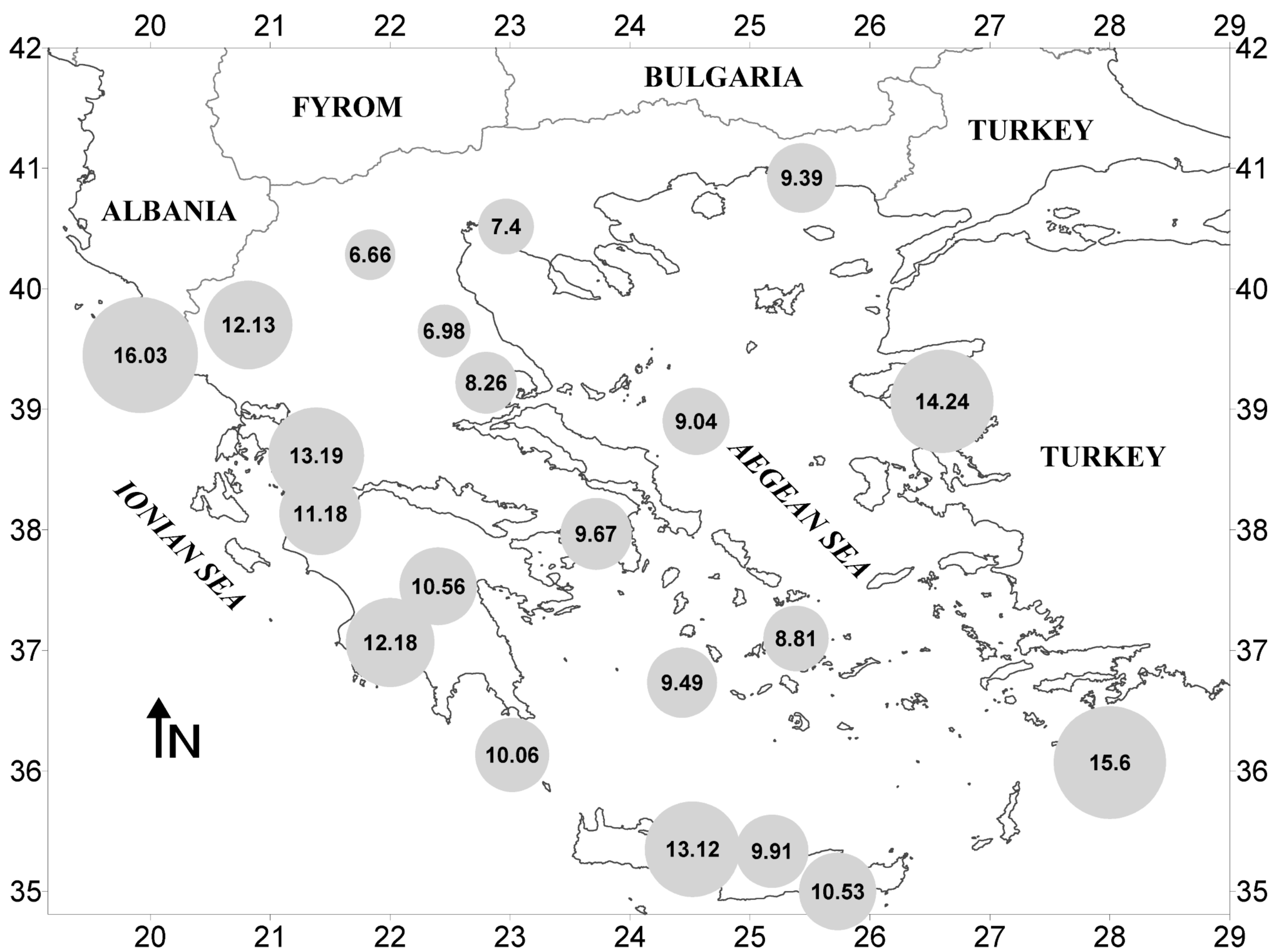

Fig. 4. Spatial variability of the scale parameter of the Gamma distribution fitted to daily precipitation totals (adopted from Nastos & Zerefos, 2008).

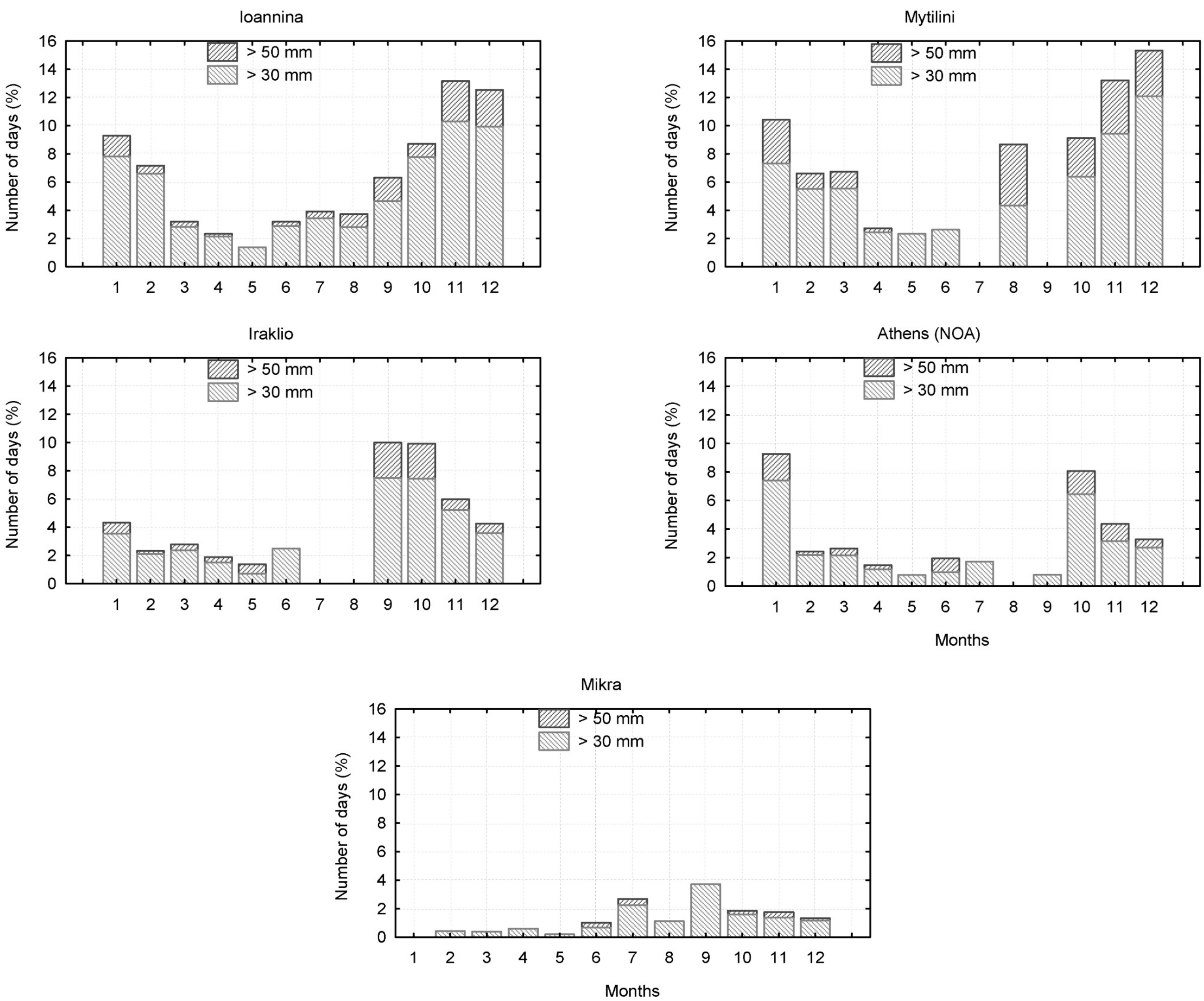

Fig. 5. Monthly distribution of the number of days (%) with precipitation greater than 30 mm and 50 mm (monthly number of days exceeding the specified thresholds divided by the number of rain days of the respective month) (Adopted from NASTOS & ZEREFOS, 2008).

CONCLUSIONS

To summarize, from the above discussion it appears that in the past few decades precipitation over Greece displays generally a larger variance and has a tendency of becoming dryer, compared to long-term climatic normals. This is in agreement with the preliminary analysis of IPCC model output that indicates the potential for strong precipitation decreases in the Mediterranean region and this may well be related with a shift towards more positive NAO index values as climate warms (TSELIOUDIS *et al*., 2006). Besides, the results show that the shape parameter of the precipitation Gamma distributions remains rather stable in the examined period (1956-2001), independent of total precipitation, while the scale parameter, which characterizes the scale of the intensity of the daily precipitation, is most variable.

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