Analyses and images of hydrological extremes in Mediterranean environments
Proceedings of the AMHY-FRIEND International Workshop on Hydrological Extremes,
held at University of Calabria, Cosenza (Italy), July 10-12, 2008

SEASONAL RAINFALL TRENDS AND TELECONNECTIONS IN CALABRIA

T. Caloiero (1), *R. Coscarelli* (2), *E. Ferrari* (3), *M. Mancini* (1)

(1) DIIAR, Polytechnic of Milan, Italy
(2) CNR-IRPI, Rende (CS), Italy
(3) Department of Soil Protection, University of Calabria, Cosenza, Italy

ABSTRACT

The following work presents a trend analysis of seasonal precipitation observed in a region of Southern Italy (Calabria) through the Mann-Kendall non-parametric test and a correlation analysis between rainfalls aggregated at different time scales and two global circulation indexes, the North Atlantic Oscillation Index (NAOI) and the Mediterranean Oscillation Index (MOI). The results show a general negative trend in precipitation, with the exception of summer season, and links of the NAOI with autumn and winter rainfalls, observed in the north-western part of Calabria, and of the MOI with winter precipitation, revealing a more uniform distribution throughout the region.

1. INTRODUCTION

The conditions of the Atlantic, Pacific and Indian Oceans, which constitute heat and steam sources for the air masses crossing them, in the intertropical zone are related to the precipitation regime while, at the latitudes of the temperate zones, they modulate the circulation of the western winds, the high and low pressure zones distribution and the track of the low pressure areas responsible for atmospheric phenomena. The increase in sea temperature changes such mechanisms and, at regional level, influences meteorological variables such as precipitation, temperature and wind regime.

In order to highlight such phenomena, it is a common practice to adopt some indexes based on the difference in the sea level pressure (SLP) between two geographic areas, tagged centres of climatic action. Such approach, called teleconnection, shows that climatic conditions in different geographical areas, even relatively far from each other, are interdependent. The most important indexes are the Southern Oscillation Index (SOI), best known as El-Niño Southern Oscillation (ENSO), evaluated between Tahiti and Darwin on the opposite sides of the Pacific Ocean (*Ropelewski and Jones*, 1987), and the North Atlantic Oscillation Index (NAOI), which represents fluctuation in the difference of pressure between the Azores area and the Sea of Iceland (*Hurrell*, 1995; *Hurrel and van Loon*, 1997). Different choices are possible for the evaluation of the NAOI: the northern centre of action is always located in Iceland, whereas either Ponta Delgada (Azores) (*Rogers*, 1997), or Lisbon (Portugal) (*Hurrell and Folland*, 2002) or Gibraltar (*Jones et al.*, 1997) are used as the southern station. In addition to these indexes, which represent the atmosphere behaviour on a large scale, there are others concerning smaller spatial scales, such as the Mediterranean Oscillation Index (MOI) firstly described by *Conte et al.* (1989) as a teleconnection pattern with opposite pressure and rainfall anomalies between the western and eastern Mediterranean area. Particularly it is defined as the normalized pressure difference between Algiers and Cairo; a second version of the index can be calculated from Gibraltar and Israel (*Palutikof*, 2003).

In the last twenty years of the past century, and particularly in the last decade, a great number of these indexes have shown a clear variation of maximum values and consecutive sequences, closely linked to some regional phenomena.

As concerns Central and Northern Europe, most of the interannual variability in precipitation is related to the NAO (*Hurrell*, 1995). When the NAO is in its positive phase there are low pressure anomalies over the Icelandic region and throughout the Arctic, combined with high-pressure anomalies across the subtropical Atlantic producing stronger-than-average westerlies across middle latitudes. This phase of the oscillation is associated with cold conditions over the north-western Atlantic and warm weather over Europe, as well as wet conditions from Iceland through Scandinavia and dry conditions over Southern Europe. This pattern of climate anomalies, which has been recognized at least since *Walker and Bliss* (1932), is most pronounced during winter, when atmospheric teleconnection patterns such as the NAO are stronger. A remarkable feature of the NAO that has motivated numerous recent studies is its trend toward a more positive phase over the past 30 years of the last century (*Hurrell*, 1995).

The influences of the NAO on climatic changes and variability over the Mediterranean Basin and the surrounding regions were studied by many researchers. *Quadrelli et al.* (200la) observed that the largest fraction of variance, in the Mediterranean area for the period 1979-95, is explained by the NAOI. Moreover *Quadrelli et al.* (2001b), by studying the Alpine region for the period 1971-92, found a high negative correlation between winter precipitation and the NAOI. *Rodò et al.* (1997) and *Goodess and Jones* (2002) revealed respectively that the NAO influenced the seasonal and daily precipitation of the Iberian Peninsula. *Türkeş and Erlat* (2003) investigated the relationships between the variability of the NAOI and the normalized precipitation in Turkey noting a negative relationship, stronger in winter and weaker in spring, between interannual variability of the precipitation series and the NAO index.

Also the MO can be related to recent variability and trends in the Mediterranean precipitation (*Douguedroit*, 1998, *Maheras et al.*, 1999; *Dünkeloh and Jacobeit*, 2003); for instance, *Colacino and Conte* (1993) and *Piervitali et al.* (1999) used the MOI to explain the yearly precipitation variability above the Mediterranean Basin. The relationship between precipitation variability in Greece and atmospheric circulation was examined by *Feidas et al.* (2007) using a correlation analysis: the MOI was found to explain a significant proportion of annual precipitation variability.

In the present study, a trend analysis of seasonal precipitation observed in a region of Southern Italy (Calabria) through the Mann-Kendall non-parametric test has been firstly effected. Then the magnitude of the relationship between the normalized precipitation anomaly series observed in 109 rain gauges of Calabria region and the NAOI and MOI has been analyzed with reference to different temporal aggregations.

2. DATA AND METHODOLOGY

Calabria is in the furthest south of the Italian peninsula, with an area of 15080 km^2 and a perimeter of about 818 km. For its geographic position and its mountainous nature, Calabria is a region with high climatic contrasts. In fact Calabria has a typical dry summer subtropical climate, also known as Mediterranean climate: during the summer, precipitation are less frequent (except for some occasional thunderstorms), while in the winter rainfall and snow occur at highest elevations of lower latitudes in the Mediterranean Basin. Particularly the Ionian side of Calabria is influenced by the warm currents coming from Africa, causing high temperatures with short and heavy precipitation. On the contrary, the Tyrrhenian side is interested by western air currents and presents milder temperatures and many orographic precipitation. In the inland zones, colder winters with snow and fresher summer with some precipitation are observed.

The rainfall data set used in this work are monthly and annual precipitation values (mm) recorded by the former Italian Hydrographic Service, now “Centro Funzionale” of the Calabria Region. Until 2000, the historical rain gauge network of the Centro Funzionale consisted of 296 stations, with an average density of 1 station for 51 km^2. The year 2000 has been selected as the final year of observation because in 2001 many rain gauges have been dismantled, and new rain gauges have been installed. Based on an appropriate dimension of the undisturbed series, 109 rainfall series were finally selected, with an average density of 1 station for 138 km^2, as in *Caloiero et al.* (2009). The geographical distribution of the 109 rain gauges is shown in fig. 1.

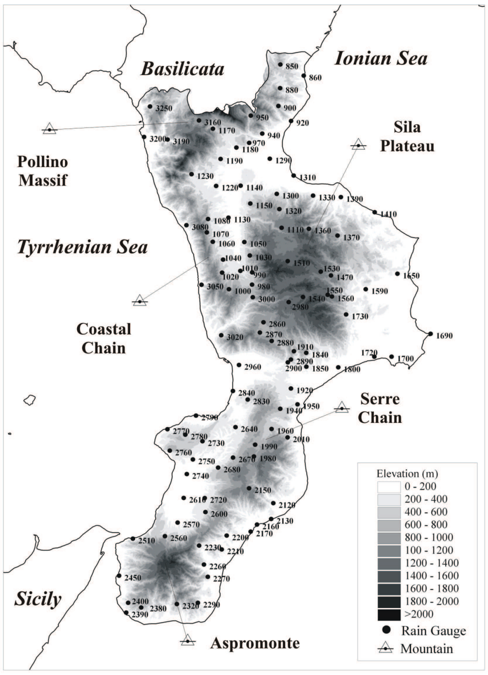

Figure 1. Localization of the rain gauges used in the study.

The NAOI and the MOI data used in the study are provided by the Climatic Research Unit, CRU, of the School of Environmental Sciences (ENV) of the University of East Anglia (UEA) in Norwich (http://www.cru.uea.ac.uk/cru/data/pci.htm).

2.1 Trend analysis of time series

The trend analysis of time series has been performed through the Mann-Kendall (MK) non-parametric test. The data are firstly ranked according to time and then each data point is compared to all the data points that follow in time. The MK statistic is given by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_i\right) \tag{1}$$

where x_i is the data value at time i, n is the length of the data set and sgn(z) is equal to +1, 0, -1 if z is greater than, equal to, or less than zero respectively. The null hypothesis is that the data are independently identically distributed random variables, that is, there is no existing trend in the data set. For the MK statistic holds:

$$E(S) = 0; \qquad \operatorname{Var}(S) = \left[n(n-1)(2n+5) - \sum_{i=1}^{n} t_i \, i(i-1)(2i+5) \right] \Big/ 18 \tag{2}$$

where t_i denotes the number of tied values of extent i. For n larger than 10, the test statistic Z_{MK}:

$$Z_{MK} = \frac{(S-1)}{\sqrt{\operatorname{Var}(S)}} \text{ for } S > 0; \quad Z_{MK} = 0 \text{ for } S = 0; \quad Z_{MK} = \frac{(S+1)}{\sqrt{\operatorname{Var}(S)}} \text{ for } S < 0 \tag{3}$$

follows a standard normal distribution. For a fixed significance level α, the test is verified if happens:

$$Z_{MK} > Z_{\alpha}; \qquad Z_{MK} < Z_{1-\alpha}; \qquad Z_{\alpha/2} < Z_{MK} < Z_{1-\alpha/2} \tag{4}$$

respectively for lower one-tailed test, upper one-tailed test and two-tailed test.

2.2 Prewhitening procedure

The presence of a serial correlation in the hydrological time series changes the rate of rejecting the null hypothesis of no trend (*Yue and Wang*, 2004). It particularly alters the variance of the MK statistic, whereas it does not alter its mean and its distribution type (*Yue et al.*, 2002), thus leading to a disproportionate rejection of the null hypothesis of no trend when it is true.

In order to take into account the effects of serial correlation on the outcomes of trend identification tests, various approaches have been suggested in literature: the prewhitening procedure (PW), the trend-free prewhitening (TFPW), the variance correction (VC) and the block resampling techniques, a special version of which is the block bootstrap (BBS) (*Khaliq et al.*, 2009). In this study it is applied the pre-whitening procedure as suggested by *von Storch and Navarra* (1999):

$$Y_t = X_t - r_1 \cdot X_{t-1} \tag{5}$$

where r_1 is the lag-1 serial correlation coefficient of the sample data, that can be expressed as:

$$r_1 = \frac{\frac{1}{n-1} \sum_{t=1}^{n-1} \left[X_t - E(X_t) \right] \left[X_{t+1} - E(X_t) \right]}{\frac{1}{n} \sum_{t=1}^{n} \left[X_t - E(X_t) \right]^2} \tag{6}$$

where $E(X_t)$ is the mean of the sample data. *Von Storch and Navarra* (1999) demonstrated that pre-whitening operation is not necessary for $r_1 \leq 0.1$.

2.3 Normalized precipitation anomalies

The analysis of the influence of planetary scale climatic phenomena on local climatic conditions can be led through the estimation of the correlation of macroscopic climatic signals with local hydrological variables such as precipitation or temperatures. In order to establish the connections between precipitation and large-scale atmospheric patterns, in this study annual and seasonal normalized precipitation anomaly series have been used.

The normalized (standardized) precipitation anomaly A_{sy} for a station s and a specific year y (or a season) is defined by:

$$A_{sy} = \left(P_{sy} - \overline{P_s}\right) / \sigma_s \tag{7}$$

where P_{sy} (mm) is the total annual (or seasonal) precipitation, $\overline{P_s}$ and σ_s are the long-term average and standard deviation of annual (or seasonal) precipitation series, respectively.

Assuming that time series of total rainfall are available at N sites within a region, the Standardized Anomaly Index (SAI) for a given year can be evaluated as (*Kraus*, 1977):

$$A_y = \frac{1}{N} \sum_{s=1}^{N} \left[\left(P_{sy} - \overline{P_s}\right) / \sigma_s \right] \tag{8}$$

The anomalies of the precipitation have been correlated with the global climatic indexes for different temporal aggregation. The statistical significance of the regression has been checked by using the two-tailed test of the Student’s t distribution, evaluating the probability to reject the null hypothesis regarding absence of any relationship for values of t with (N−2) degrees of freedom.

3. RESULTS AND DISCUSSION

3.1 Trend analysis of annual and seasonal rainfalls

The MK test has been applied at 5% confidence level for the trend analysis of annual and seasonal precipitation series recorded in raingauges of Calabria region, previously prewhitened through expression (5). The seasonal aggregations considered for rainfalls are winter, spring, summer, autumn, autumn-winter (wet period) and spring-summer (dry period). A statistically significant negative trend has been detected for all the temporal aggregations, with the exception of the summer and the spring-summer rainfalls. As fig. 2 shows, the best results are registered in order for the autumn-winter, annual, autumn aggregations: statistically significant negative trends are evaluted for several rain gauges with a uniform spatial distribution on all over Calabria. Opposite trends are present for summer aggregation, but the series with statistically significant trends are few.

3.2 Correlation between precipitation and NAOI

The correlation analysis has been carried out between the NAO index and the normalized precipitation series observed at each rain gauge stations on a yearly, seasonal and six-month scale. The NAO index used in this application refers to Stykkilsholmur/Reykjavik and Gibraltar as centres of action.

Concerning the winter period, for all the rain gauges negative correlation coefficients (CCs) have been detected between the normalized precipitation series and the NAOI. Negative CCs are statistically significant for almost all the rain gauges, with the exception of 8 in the Ionian side of the region. Negative CCs means that winter precipitation, particularly where there are statistically significant CCs, are characterized by wetter than long-term average conditions during the negative NAO phase and drier than long-term average conditions during the positive NAO phase. The spatial distribution of the CCs (fig. 3a) clearly shows more relevant values in the Tyrrhenian side of Calabria probably due to the orography of Calabria, since the presence of the Sila Plateau, the Serre Chain and Aspromonte could reduce the effects of the NAO on the Ionian side of the region. The CC between the SAI and the NAOI is -0.51 (tab. 1).

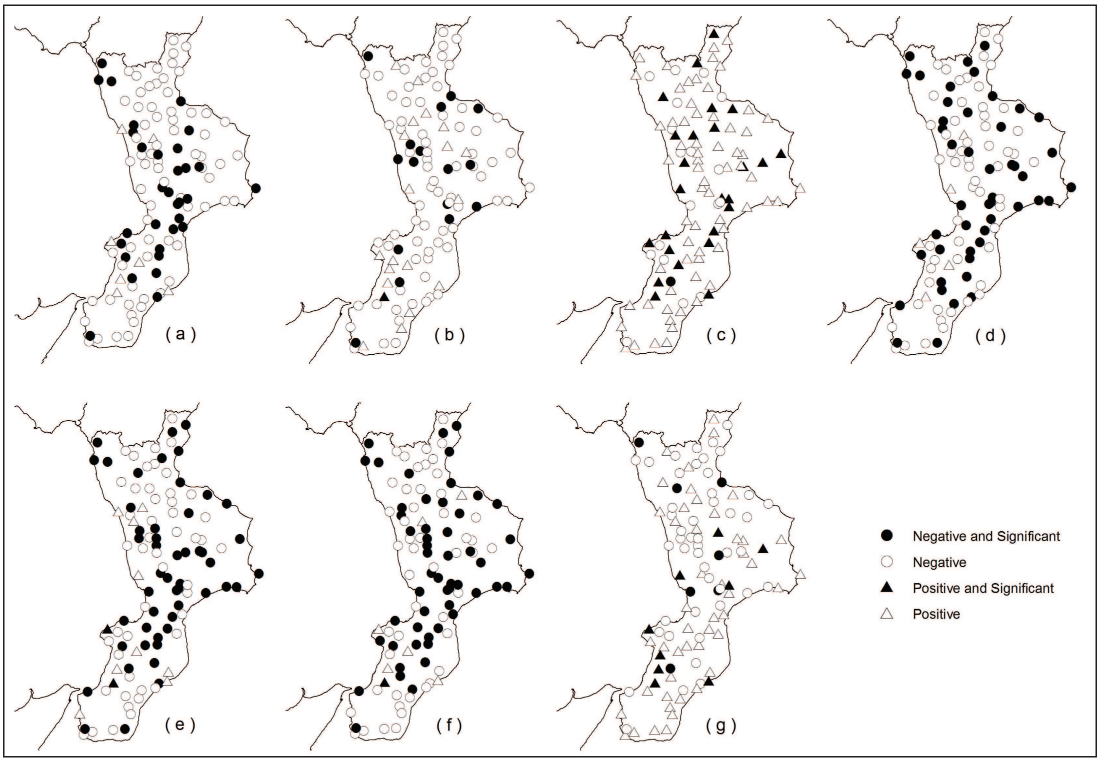

Figure 2. Spatial distributions of the trend for the winter (a), spring (b), summer (c), autumn (d), annual (e), autumn-winter (f) and spring-summer (g) precipitation.

Both negative and positive CCs have been obtained between the normalized spring precipitation series and the NAOI in the same period. In particular 49 series have shown positive CCs and 60 series negative CCs; however only the positive CC relative to the Trebisacce rain gauge (code 920) is statistically significant. The spatial distribution of the CCs (fig. 3b) demonstrates that spring precipition and NAOI are not well related. The mean value of the CCs between the SAI and the NAOI is -0.03 (tab. 1).

Table 1. Correlation coefficients between normalized precipitation anomaly series and NAOI.

	Winter	**Spring**	**Summer**	**Autumn**	**Annual**	**Aut-Win**	**Spr-Sum**
Mean value of the CCs	-0.51	-0.03	-0.35	-0.15	-0.32	-0.45	-0.24
Significant NAOI signals	101	1	72	31	54	78	29

In the summer, negative CCs have been detected for all the rain gauges, but those statistically significant are for 72 rain gauges. The 37 rain gauges which don't show statistically significant CCs are almost all located in the Ionian side of the region. In fig. 3c the distribution of the CCs between the normalized precipitation series and the NAOI appears to be uniform. The mean value of the CCs between the SAI and the NAOI is -0.35.

In the autumn period, negative CCs have been detected for 84 rain gauges, out of which 30 CCs are statistically significant. Among the 25 series which show positive CCs, only for 1 rain gauge (code 2290) the CC is statistically significant. The spatial distribution of the CCs (fig. 3d) clearly shows more relevant values in the northern Tyrrhenian side of the region. The mean value of the CCs between the SAI and the NAOI is -0.15.

Negative CCs have been detected between the normalized yearly precipitation series and the NAOI anomalies in almost all the rain gauges, except for only 4 rain gauges in the Ionian side of the region. Negative CCs are statistically significant for 54 rain gauges. Like for the winter period, the spatial distribution of the CCs (fig. 3e) shows higher values in the Tyrrhenian side of Calabria. The mean value of the CCs between the SAI and the NAOI is -0.32.

Concerning the autumn-winter period, negative CCs have been detected in all the rain gauges between the normalized precipitation series and the NAOI, although these values are statistically significant for 78 rain gauges. Also for the autumn-winter period the spatial distribution of the CCs (fig. 3f) clearly shows relevant values in the northern Tyrrhenian side of Calabria. The mean value of the CCs between the SAI and the NAOI is -0.45.

In the spring-summer period, negative CCs have been detected in 105 out of 109 rain gauges (29 statistically significant CCs). The nonuniform spatial distribution of the CC values is shown in fig. 3g. The mean value of the CCs between the SAI and the NAOI is -0.24.

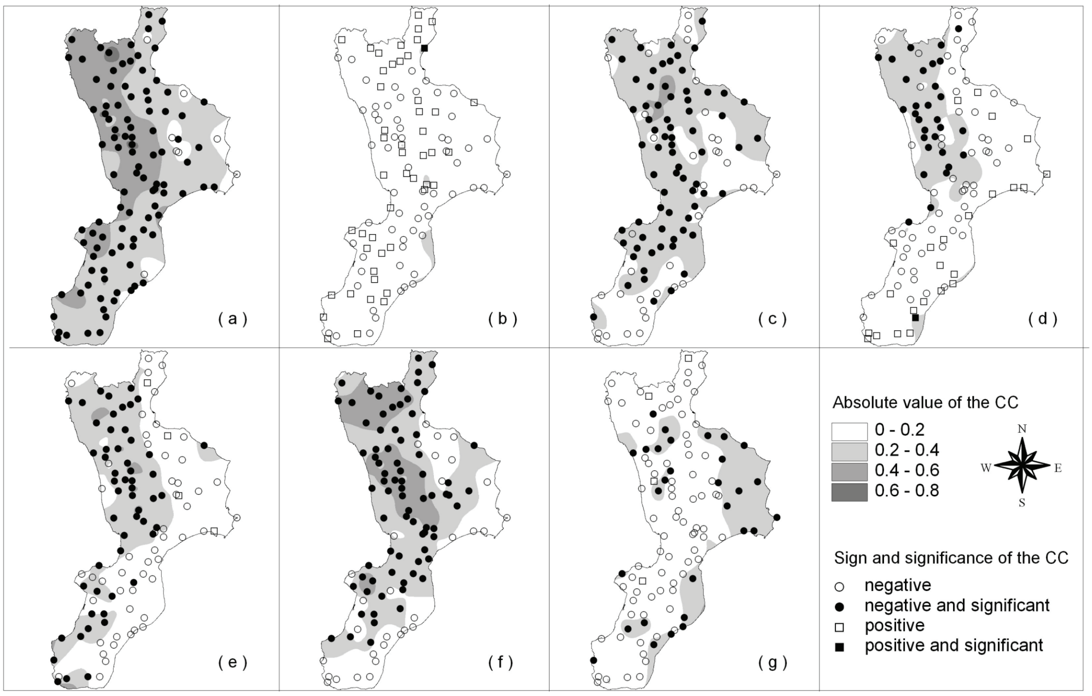

Figure 3. Spatial distributions of the correlation coefficient between normalized precipitation series and NAOI for winter (a), spring (b), summer (c), autumn (d), annual (e), autumn-winter (f) and spring-summer (g) periods *(significance level: 5%).*

3.3 Correlation between precipitation and MOI

Due to the importance and the influence of the MOI in the Mediterranean basin, both the expressions of the index have been used. In fact, even if the MOIs calculated between Algiers and Cairo (MOI-AC) and between Gibraltar and Israel (MOI-GI) are very similar in behaviour, they are different in values. As for the NAOI, the correlation analysis has been carried out between the MOI and the normalized precipitation series on a yearly, seasonal and a six-month scale.

For the winter period, for all the rain gauges, negative CCs have been detected between the normalized precipitation series and the MOI-AC. Negative CCs are statistically significant for almost all the rain gauges with the exception of 2 rain gauges in the Ionian side of the region. Also, the correlation analysis between the normalized precipitation series and the MOI-GI for all the rain gauges shows negative CCs, 98 of which statistically significant. The spatial analysis of the CCs for both the MOI-AC and the MOI-GI (figs. 4a and 5a) shows higher values distributed all around the region and not only in the Tyrrhenian side, as previously obtained for the NAOI. As shown in tab. 2, the mean value of the CCs between the SAI and the MOI-AC (MOI-GI) is -0.58 (-0.48).

Table 2. Correlation coefficients between normalized precipitation anomaly series and MOIs.

	Winter	**Spring**	**Summer**	**Autumn**	**Annual**	**Aut-Win**	**Spr-Sum**
Mean values of the CCs	-0.58	0.13	-0.35	-0.41	-0.34	-0.63	-0.07
Significant MOI-AC signals	107	20	69	89	74	105	15
Mean values of the CCs	-0.48	-0.18	-0.24	-0.15	-0.21	-0.49	0.04
Significant MOI-GI signals	98	36	39	29	41	96	19

In the spring period, both negative and positive CCs have been obtained. In particular, 83 series have shown positive CCs (statistically significant for 20) and 26 negative CCs between the normalized spring precipitation series and the MOI-AC, while 89 series have shown positive CCs (statistically significant for 35) and 20 negative CCs between the normalized spring precipitation series and the MOI-GI. As for the NAOI, the spatial distribution of the CCs (figs. 4b and 5b) demonstrates that spring precipitation and both the MOIs are not well related. The mean value of the CCs between the SAI and the MOI-AC (MOI-GI) is 0.13 (-0.18).

In the summer, negative CCs for 107 rain gauges (statistically significant for 69) have been detected between the normalized precipitation series and the MOI-AC. The correlation analysis between the normalized precipitation series and the MOI-GI shows negative CCs for 100 rain gauges, 39 of which show statistically significant CCs. By comparing figs. 4c and 5c, the CCs related to the MOI-AC seem to assume higher values and to be better distributed all over the region than the ones related to MOI-GI. The CCs between the SAI and the MOI-AC (MOI-GI) is -0.35 (-0.24).

In the autumn period, if the MOI-AC has been taken into account, negative CCs have been detected for 108 rain gauges (statistically significant for 89), while when the CCs refers to the MOI-GI, 89 rain gauges show negative values (statistically significant for 28). For this time aggregation, the spatial distribution of the CCs (figs. 4d and 5d) confirms a behaviour similar to the one detected for the winter period. The mean value of the CCs between the SAI and the MOI-AC (MOI-GI) is -0.41 (-0.15).

For the annual period, negative CCs (statistically significant for 74) between the normalized precipitation series and the MOI-AC have been detected for 106 rain gauges.

The correlation analysis between the normalized precipitation series and the MOI-GI shows negative CCs (statistically significant for 41) for 101 rain gauges. The spatial analysis of the CCs for both the MOIs (figs. 4e and 5e) does not show higher values distributed on the Tyrrhenian side, as previously obtained for the NAOI. The mean value of the CCs between the SAI and the MOI-AC (MOI-GI) is -0.34 (-0.21).

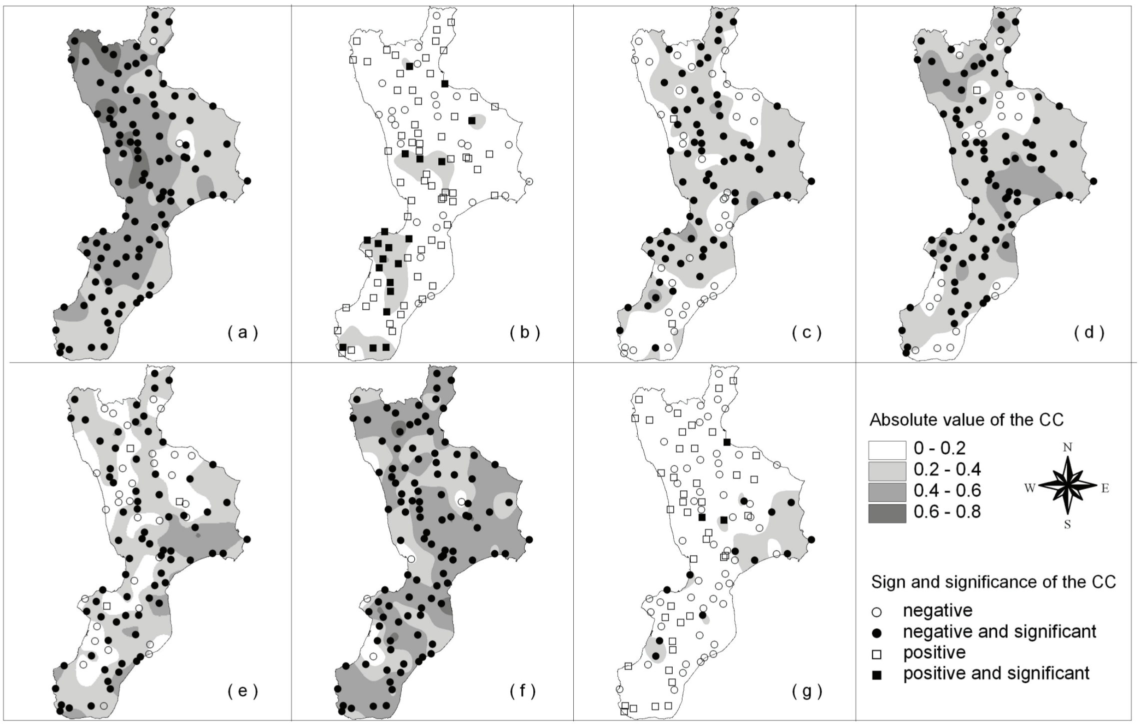

Figure 4. Spatial distributions of the correlation coefficient between normalized precipitation series and MOI-AC for winter (a), spring (b), summer (c), autumn (d), annual (e), autumn-winter (f) and spring-summer (g) periods *(significance level: 5%).*

For the autumn-winter period, for all the rain gauges, negative CCs have been detected between the normalized precipitation series and the MOI-AC. Negative CCs are statistically significant for almost all the rain gauges with the exception of 4. Also, the correlation analysis between the normalized precipitation series and the MOI-GI shows negative CCs for all the rain gauges (statistically significant for 96). For this period the spatial distribution of the CCs (figs. 4f and 5f) clearly shows for both the MOIs high CC values distributed all around the region. The mean value of the CCs between the SAI and the MOI-AC (MOI-GI)is -0.63 (-0.49).

Both negative and positive CCs have been obtained between the normalized spring-summer precipitation series and the MOIs in the same period. In particular, 64 series have shown positive CCs and 45 negative CCs between the normalized spring-summer precipitation series and the MOI-AC. Relative to the MOI-GI, 68 series have shown positive CCs and 41 negative. Anyway, for this temporal aggregation, the rain gauges with statistical significant CCs are very few. The spatial distribution of the CCs (figs. 4g and 5g) demonstrates that spring-summer precipitation and both the MOIs are not well related. The mean value of the CCs between the SAI and the MOI-AC (MOI-GI) is -0.07 (-0.04).

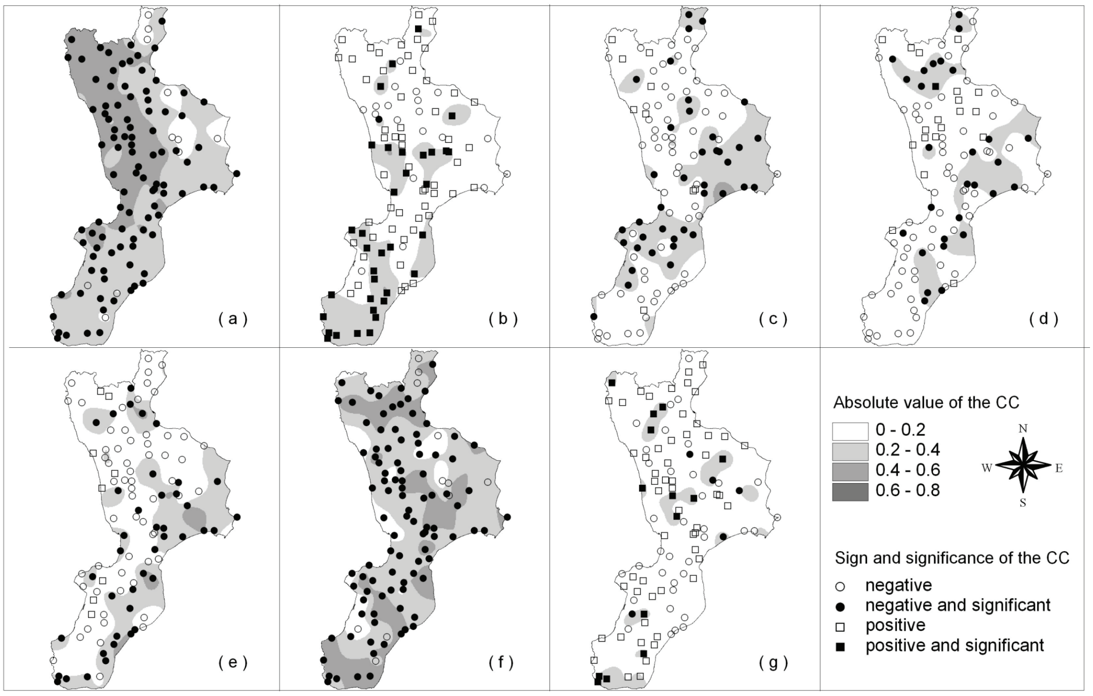

Figure 5. Spatial distributions of the correlation coefficient between normalized precipitation series and MOI-IG for winter (a), spring (b), summer (c), autumn (d), annual (e), autumn-winter (f) and spring-summer (g) periods *(significance level: 5%).*

4. CONCLUSIONS

The analysis of the annual and seasonal rainfall series has shown statistically significant negative trends for about half of the rain gauges as regards the autumn-winter, the annual and the autumn aggregations. On the contrary, the summer rainfall has shown a significant positive trend for about 25% of the series. The investigation of the correlation between precipitation observed in Calabria and large scale teleconnection indexes (NAOI and MOI) has provided useful information regarding the dependence of precipitation on the global climatic fluctuations. Particularly, the NAOI and the MOI have shown a good correlation with the pluviometric regime observed in autumn and winter. The spatial distribution of the CCs has revealed a greater link with the NAOI on the Tyrrhenian side, probably due to the typical elevation distribution of the region which could minimize the effects of the climatic oscillation on the Ionian side. The correlations with both the MO indexes appear to be stronger than those calculated with the NAOI, and to be uniformly distributed throughout the whole region. Given the correlations existing between precipitation and such indexes, the latter ones might be used in a predictive way for an advance estimation of the seasonal rainfall amounts over a specific territory or, at least, to provide qualitative knowledge of the future seasonal rainfall behaviour.

REFERENCES

Caloiero, T., Coscarelli, R., Ferrari, E., and M. Mancini (2009). Trend detection of annual and seasonal rainfall in Calabria (Southern Italy). *Int. J. Climatol.* (in press), DOI: 10.1002/joc.2055.

Colacino, M., and M. Conte (1993). Greenhouse effect and pressure patterns in the Mediterranean Basin. *Il Nuovo Cimento C 16*, 67–76.

Conte, M., Giuffrida, S., and S. Tedesco (1989). The Mediterranean oscillation: impact on precipitation and hydrology in Italy. In: Proceedings of the Conference on Climate and Water. Publications of Academy of Finland: Helsinki, vol. 1, 121–137.

Douguedroit, A. (1998). Que peut-on dire d'une oscillation Méditerranéenne?. In *Climate and Environmental Change*, Alcoforado MJ (ed). Evora, 135–136.

Dünkeloh, A., and J. Jacobeit (2003). Circulation dynamics of Mediterranean precipitation variability 1948-98. *Int. J. Climatol. 23*, 1843–1866.

Feidas, H., Noulopoulou, Ch., Makrogiannis, T., and E. Bora-Senta (2007). Trend analysis of precipitation time series in Greece and their relationship with circulation using surface and satellite data: 1955–2001. *Theor. Appl. Climatol. 87*, 155–177.

Goodess, C.M., and P.D. Jones (2002). Links between circulation and changes in the characteristics of Iberian rainfall. *Int. J. Climatol. 22*, 1593–1615.

Hurrell, J.W. (1995). Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation. *Science 7*, 676–679.

Hurrell, J.W., and C.K. Folland (2002). A change in the Summer Atmospheric Circulation over the North Atlantic. *CLIVAR Exchanges 25*, 52–54.

Hurrell, J.W., and H. Van Loon (1997). Decadal variations in climate associated with the North Atlantic Oscillation. *Climatic Change 36*, 301–326.

Jones, P.D., Jonsson, T., and D. Wheeler (1997). Extension of the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and south-west Iceland. *Int. J. Climatol. 17*, 1433–1450.

Khaliq, M.N., Ouarda, T.B.M.J., Gachon, P., Sushama, L., and A. St-Hilaire (2009). Identification of hydrological trends in the presence of serial and cross correlations: a review of selected methods and their application to annual flow regimes of Canadian rivers. *J. Hydrol. 368*, 117–130.

Kraus, E.B. (1977). Subtropical droughts and cross-equatorial transports. *Mon. Weather Rev. 105*, 1009–1018.

Maheras, P., Xoplaki, E., and H. Kutiel (1999). Wet and dry monthly anomalies across the Mediterranean basin and their relationship with circulation 1860–1990. *Theor. Appl. Climatol. 64*, 189–199.

Palutikof, J.P. (2003). Analysis of Mediterranean climate data: measured and modelled. In: *Mediterranean Climate-Variability and Trends*, Bolle H.J. (Ed.). Springer-Verlag: Berlin; 133–153.

Piervitali, E., Colacino, M., and M. Conte (1999). Rainfall over the central–western Mediterranean basin in the period 1951–1995. Part II: precipitation scenarios. *Il Nuovo Cimento C, 22*, 649–661.

Quadrelli, R., Lazzeri, M., Cacciamani, C., and S. Ribaldi (2001a). Observed winter Alpine precipitation variability and links with large-scale circulation patterns. *Climate Res. 17*, 275–2854.

Quadrelli, R., Pavan, V., and F. Molteni (2001b). Wintertime variability of Mediterranean precipitation and its links with large-scale circulation anomalies. *Clim. Dynam. 17*, 457–466.

Rodò, X., Baert, E., and F. Comin (1997). Variations in seasonal rainfall in Southern Europe during the present century: relationships with the NAO and the ENSO. *Clim. Dynam. 13*, 275–284.

Rogers, J.C. (1997). North Atlantic storm track variability and its association to the North Atlantic Oscillation and climate variability of Northern Europe. *J. Climate 10*, 1635–1647.

Ropelewski, C.F., and P.D. Jones (1987). An extension of the Tahiti-Darwin Southern Oscillation Index. *Mon. Weather Rev. 115*, 2161-2165.

Türkeş, M., and E. Erlat (2003). Precipitation changes and variability in turkey linked to the North Atlantic oscillation during the period 1930-2000. *Int. J. Climatol. 23*, 1771–1796.

Von Storch, H., and A. Navarra (1999). *Analysis of Climate Variability*. Applications of Statistical Techniques. Springer Verlag: Berlin.

Walker, G.T., and E.W. Bliss (1932). World Weather. V. *Memoirs of the Royal Meteorological Society 4*, 53–84.

Yue, S., and C.Y. Wang (2004). The Mann-Kendall test modified by effective sample size to detect trend in serially correlated hydrological series. *Water Resour. Manag. 18*, 201–218.

Yue, S., Pilon, P., and G. Cavadias (2002). Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *J. Hydrol. 259*, 254–271.