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Annual and seasonal precipitation over Italy from 1961 to 2006

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ABSTRACT: Annual and seasonal precipitation series were derived from a set of 59 synoptic meteorological stations homogeneously distributed over Italy, in order to evaluate possible changes in precipitation behaviour and identifying areas of coherent variability. The time series were homogenized and standardized anomaly series were calculated for three areas: north, centre and south of Italy. Rotated principal component analysis (PCA) was applied to monthly data and the related loading maps were generated. The annual series do not show significant trends, while among the seasonal series only those of winter in northern and central Italy are non-stationary; they are characterized, respectively, by a decreasing trend for the entire period and by a positive trend since 1989. Seven common patterns were identified from clustered rotated principal components and linked with synoptical weather regimes. Copyright © 2009 Royal Meteorological Society

KEY WORDS precipitation; Italian climate

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1. Introduction

Time series analysis and trend estimate of precipitation are generally more problematic than temperature estimates. Due to its wide space and time variability, it requires a high-density network of meteorological stations, and a set of data characterized by high quality, completeness and temporal continuity and not affected by inhomogeneities; since it is very difficult to achieve these basic requirements, there is a risk of estimating changes at regional scale as the sum (sometimes inaccurate) of local changes, not giving a sound and a complete description of the precipitation trends and patterns.

At the global scale, as outlined by Huntington (2006), substantial uncertainties remain in the precipitation trend evaluation. The results obtained using different global dataset show significant discrepancies. The analysis of Global Historical Climatology Network [(GHCN); Peterson and Vose, 1997, constructed using only gauge data, does not reveal a significant linear trend in global annual land precipitation from 1900 to 2005 and in the sub-period 1951–2005. On the contrary, the analysis of the Precipitation Reconstruction over Land dataset (PREC/L, Chen *et al.*, 2002) and of the Global Precipitation Climatology Centre dataset [(GPCC) v3, Rudolf *et al.*, 1994] reveal significant trends in the period 1951–2005 (-5.10 ± 3.25 mm/decade and -6.63 ± 5.18 mm/decade, respectively), but with large uncertainties (for a complete description and review see Trenberth *et al.*, 2007).

At the European scale the Trenberth *et al.* (2007) report, using annual precipitation from GHCN dataset, indicates a significant precipitation increase in northern Europe from 1900 to 2005, and an opposite trend in the Mediterranean area; Norrant and Douguédroit (2006), inspecting the monthly and daily precipitation in the Mediterranean area in the period 1950–2000, report prevailing 'no trend' and 'non-significant trend' results at the monthly, seasonal and annual scale. Moberg *et al.* (2006) studied daily temperature and precipitation over Europe from 1901 to 2000, using a dataset of a particularly dense network of stations in Central Europe: for winter precipitation, a significant increasing trend in central and western Europe and a non-significant trend in Iberian Peninsula are shown, while for summer precipitation, no trend is found for the average value over the whole domain, although there are some notable regional differences.

In Italy, the very complex topography and its geographical position make the precipitation analysis even more difficult; Brunetti *et al.* (2006) investigated the behaviour of precipitation (and temperature) in Italy. They used 111 series from 1865 to 2003 (whereof 75 covering at least 120 years) with a good coverage in the south/east and north/west of Italy, mainly belonging to the Ufficio Centrale di Ecologia Agraria (UCEA). Their analysis, focused on six geographical areas, shows a significant negative linear trend, only for Central Italy and for the average over the whole: $-20 \pm 5\%$ and $-5 \pm 3\%$, respectively, as percentage per century relative to the period 1961–1990.

The aim of the present paper is the investigation of annual and seasonal precipitation over Italy, based

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on time series from 1961 to 2006, from a set of stations homogeneously distributed over the Italian territory, belonging to the Air Force Weather Service and to a few regional environmental protection agencies (ARPA). Data were collected and controlled through SCIA (Sistema nazionale per la raccolta, l'elaborazione e la diffusione di dati Climatologici di Interesse Ambientale), a computerized system for the collection, processing and diffusion of climatological data, developed by the Institute for Environmental Protection and Research (ISPRA; ex Italian agency for environmental protection, APAT) (www.scia.sinanet.apat.it; Desiato *et al*., 2007).

Having analysed the temperature in the last half-century in two previous works (Toreti and Desiato, 2008a,b), we would like to add more elements to the knowledge of the recent Italian climate trend. This is important for climate change impacts and vulnerability assessment at national and Mediterranean scale.

2. Data processing and homogenization

We analysed 59 monthly time series, derived from rough data recorded by meteorological stations from 1961 to 2006 (Table I and Figure 1). Before the construction of indicators, data underwent two types of quality controls: the so-called weak climatological control and the consistency control. The former checks that rough data belongs to a range of physically reasonable values and discards outliers; the latter cross-checks two or more variables: for example, if a SYNOP (surface synoptic observations) message reports a non-zero precipitation, the 'present weather' or 'past weather' field must report a phenomenon linked to precipitation. Then, ten-daily, monthly and annual indicators are calculated only if 90% of daily precipitations data are valid. The next step is the quality control of indicators, which is carried out through a procedure aimed to find climatological outliers, based on the inter-quartile range of the distribution and on spatial comparison (see for a complete explanation: Eischeid *et al*., 1995; Baffo *et al*., 2005). Non-valid data are discarded and do not contribute to the time series analysis. Missing monthly data have been reconstructed after time series homogenization.

In order to filter the effect of non-climatic factors, due to events like relocation of the stations, change of instrumentation or observational practices, we developed a procedure to check the homogeneity, and to eventually homogenize, monthly time series. The procedure is made up of various steps and methods, because the homogenization of precipitation data is still a tricky question and over-corrections should be avoided. First of all, we applied the Kolmogorov–Zurbenko Adaptive filter [(KZA); Zurbenko *et al*., 1996] to the log series, as an absolute method to check series behaviour. The KZA is an iterative moving average filter that dynamically adjusts its moving length:

$$Y_t = (q_{H(t)} + q_{T(t)})^{-1} \sum_{i=-q_{T(t)}}^{q_{H(t)}} X_{t+i} \quad (1)$$

Table I. List of the 59 selected stations.

Name	Lat	Lon	Height *m*
Arezzo	43.48	11.85	248
Bonifati	39.59	15.88	484
Brescia	45.42	10.28	102
Cagliari	39.25	9.07	4
Calderara di Reno	44.56	11.27	30
Campobasso	41.57	14.65	793
Capo Mele	43.95	8.17	220
Capo Palinuro	40.03	15.28	184
Casale Monferrato	45.13	8.51	118
Catania	37.40	14.92	22
Cozzo Spadaro	36.68	15.13	46
Cumiana	44.97	7.39	327
Dobbiaco	46.74	12.22	1222
Enna	37.57	14.28	940
Foggia	41.53	15.72	57
Forlì	44.02	11.88	286
Frontone	43.52	12.73	570
Frosinone	41.63	13.30	180
Gela	37.08	14.22	11
Gioia del Colle	40.77	16.93	345
Grazzanise	41.06	14.07	9
Grosseto	42.75	11.07	5
Guidonia	42.00	12.73	88
Latina	41.55	12.90	25
Latronico	40.08	16.02	888
Lecce	40.23	18.15	48
Marina di Ginosa	40.44	16.88	2
Messina	38.21	15.55	59
Monte S. Angelo	41.71	15.95	838
Monte Scuro	39.33	16.40	1710
Novafeltria	43.89	12.29	285
Pantelleria	36.82	11.97	191
Passo Rolle	46.30	11.78	2004
Piacenza	44.92	9.73	134
Pietramala	44.17	11.34	844
Pisa	43.68	10.38	2
Ponza	40.92	12.95	184
Potenza	40.63	15.80	829
Pratica di mare	41.65	12.43	6
Prizzi	37.72	13.43	1034
Propata	44.57	9.19	996
Punta Marina	44.45	12.30	2
Rimini	44.03	12.62	12
Roma/Ciampino	41.78	12.58	129
S. Maria di Leuca	39.82	18.35	104
S. Valentino alla Muta	46.75	10.53	1459
Santo Stefano d'Aveto	44.55	9.45	1007
Tarvisio	46.50	13.58	777
Termoli	42.00	15.00	16
Torino	45.03	7.73	709
Trapani	37.92	12.50	7
Trevico	41.06	15.23	1085
Treviso	45.68	12.10	45
Trieste	45.65	13.75	8
Ustica	38.71	13.18	250
Verona	45.38	10.87	67
Vicenza	45.57	11.52	39
Vigna di Valle	42.08	12.22	262
Viterbo	42.44	12.05	300

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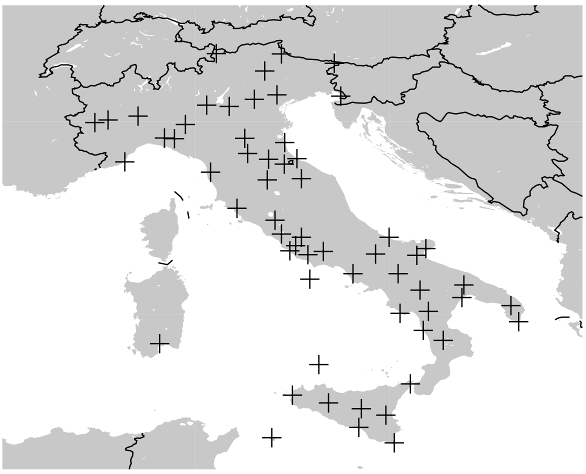

Figure 1. Map of the 59 stations.

where X denotes the original series, $q_{H(t)}$ and $q_{T(t)}$ depend on the rate of change of the following quantity: $D(t) = |Z(t+q) - Z(t-q)|$, where Z denotes the KZ filter (Zurbenko, 1986; Rao and Zurbenko, 1994) of the original series and q is the half-length of the simple moving average. When X_t is located in an area of increasing D (i.e. $D'(t) = D(t+1) - D(t)$ is positive), $q_{T(t)}$ is equal to q and $q_{H(t)}$ is reduced by a function of D (i.e. $q_{H(t)} = f[D(t)]q$ where $f[D(t)] = 1 - \{D(t)/\max[D(t)]\}$). On the contrary, if X_t is located in an area of decreasing D, $q_{H(t)}$ is equal to q and $q_{T(t)}$ is reduced. The plot of the filtered series and of the sample variance, defined by

$$\hat{\sigma}_t^2 = \frac{\sum_{i=q_t}^{q_h}(Y_i - \overline{Y}_t)^2}{q_t + q_h} \tag{2}$$

gives an idea of the position of possible inhomogeneities, located in correspondence of significant peaks of the sample variance. For example, Figure 2 (first plot) shows the log series of monthly precipitation recorded at Latronico, southern Italy (thin line), and the filtered series (thick line); the second plot of the same figure illustrates the sample variance with the peak of 1957–1958, that is a possible point of inhomogeneity. The next step is the application of a relative statistical test, i.e. the standard normal homogeneity test [(SNHT); Alexandersson and Moberg, 1997] in its single shift version. This test was implemented with a moving window approach, choosing a length of 12 years and excluding the shift detected in the first and in the last 4 years of such temporal interval, in order to avoid a well-known problem affecting the test at the beginning and the end of the series. The choice of the window length is a compromise between the need of a large number of data and the requirement of a single shift in the interval. The moving window-SNHT was applied to the series $Q = \log(Y/R)$, where Y denotes the 'candidate' series (i.e. the series to be tested) and R denotes the reference series, constructed using at least three series (until five) chosen using the best correlation criterion. The correlation coefficients were calculated

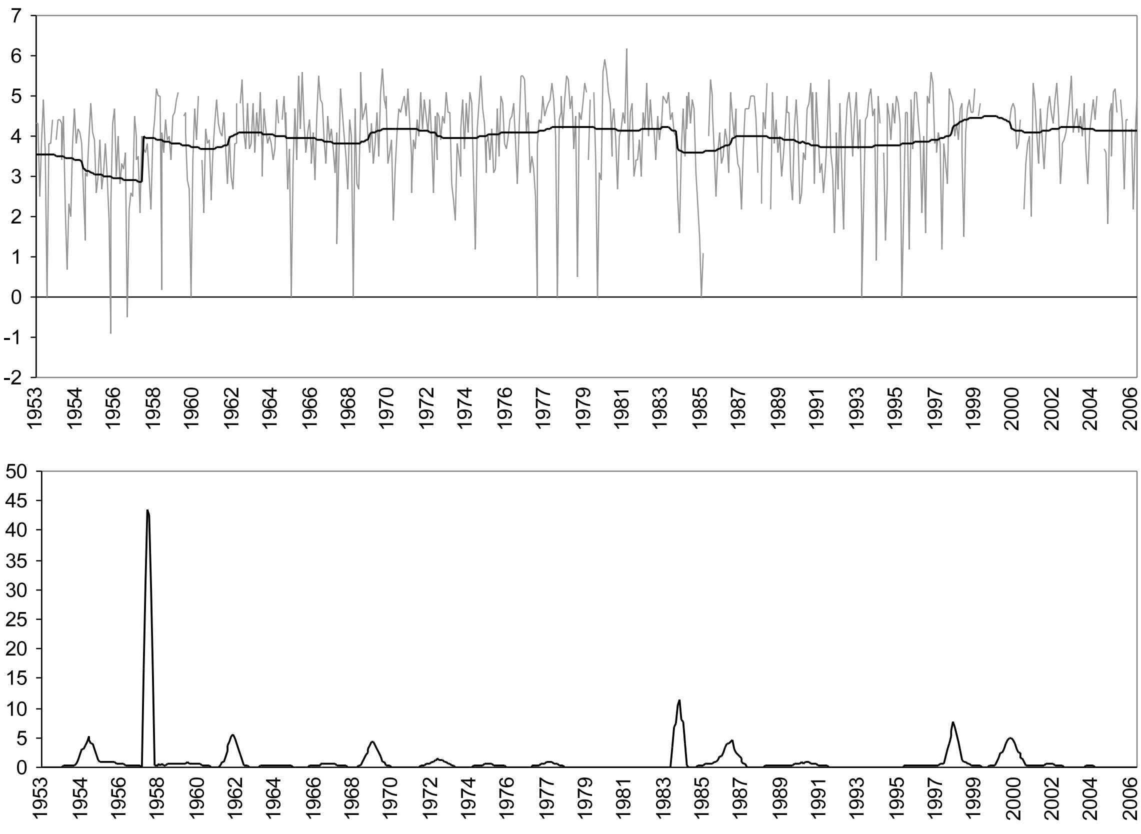

Figure 2. Upper plot: the log series of Latronico (thin line) and its filtered series (thick line). Lower plot: sample variance of the KZA filter.

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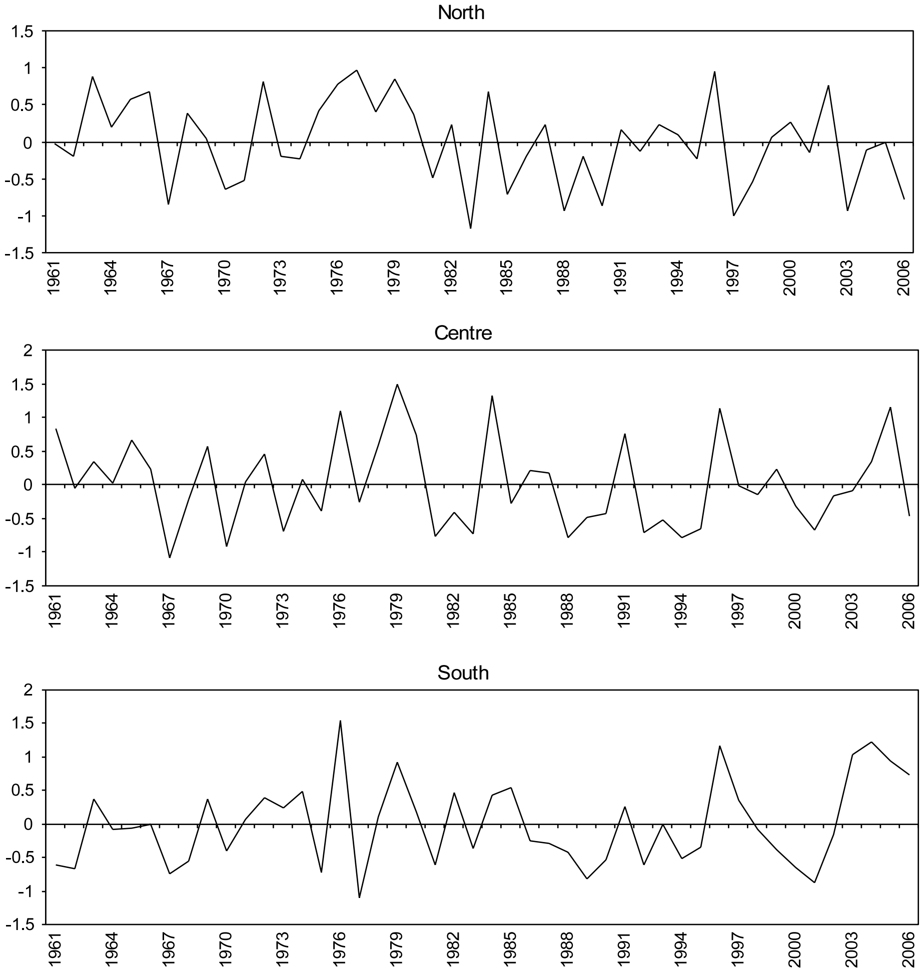

Figure 3. Annual standardized precipitation anomaly series for the three geographical areas: north, centre and south of Italy.

using the method of the first difference series (Peterson and Easterling, 1994). Finally, the significance of the identified shifts was tested using the non-parametric multi-response permutation procedure [(MRPP); Mielke *et al*., 1981; Easterling and Peterson, 1994]. This procedure, after an *a priori* subdivision into two groups, compares the Euclidean distances between members of the same group of data with the distances of all members of both groups; in our analysis, the two groups are data of the standardized series of Q before and after the potential shift (with a window length of 96 values centred at the shift point). Whenever the shift is significant, we correct the series using a month-by-month approach (calculating the monthly correction factors) if there is a strong evidence of seasonality of the adjustment and a large number of data, or using one correction factor for all months.

After homogenization, in order to avoid unreliable gap filling, we reconstructed missing data with two methods. The first one is based on the constancy of the distance between the series with missing data and the reference series determined during the homogenization process; this method was applied whenever reference series was available at the 'missing date' and no missing data were in a 10-value window centred at the missing point (i.e. we filled isolated gaps). In the other cases, we reconstructed monthly data using artificial neural network (ANN) techniques (Hertz *et al*., 1991): a feed-forward ANN (i.e. a multi-layer network without feedback) was applied, characterized by one intermediate layer with 30 neurons and by 1 neuron for the output layer; the training phase was performed with a resilient backpropagation algorithm. In order to guarantee a good training of the ANN, we limited the application of this method to the following cases: 2 years without missing data before and after the 'missing date', 5 complete months before and 3 complete years after, 5 complete months after and 3 complete years before.

It is important to notice that we chose only the most complete series: the original monthly series (i.e. before the homogenization and reconstruction procedures) have less than 20% of missing data on the entire period; 22% of total missing data were reconstructed with the 'reference method' and only 7% with the ANN technique.

The homogenized and reconstructed series were aggregated into three geographical areas (northern, central and southern Italy). Furthermore, we calculated seasonal and annual averaged indices in the form of standardized anomalies, that guarantee more robustness in relation to missing data, changing station configurations and

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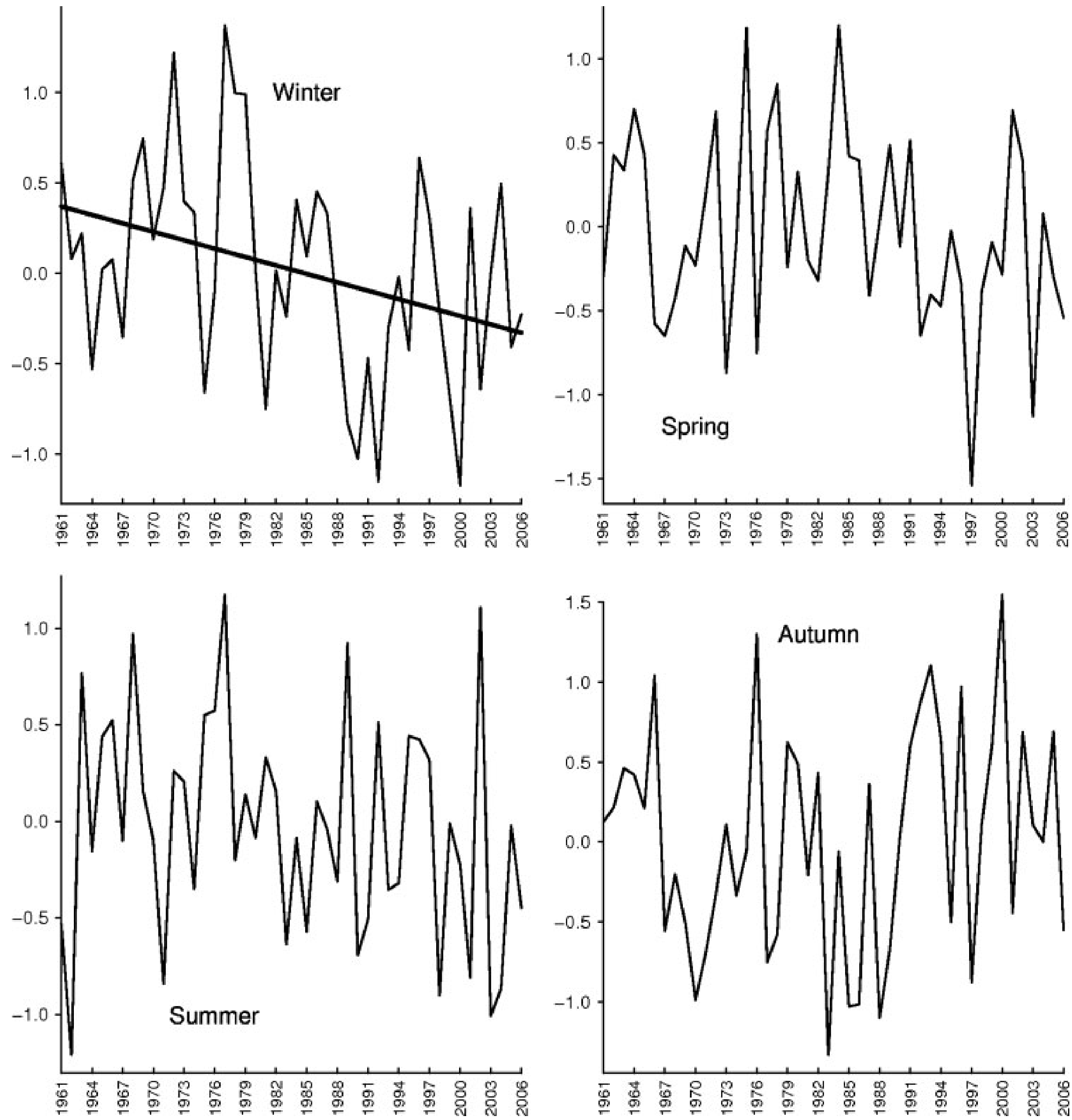

Figure 4. Seasonal standardized precipitation anomaly series for north of Italy. In the winter plot the thick line represents the trend.

large gradients of mean values and variances (Jones and Hulme, 1996). The 30-year reference period for the calculation of means and standard deviations is 1971–2000.

3. Analysis

In order to get distribution-free estimations, we focused on a non-parametric approach; additionally, we implemented tests and procedures that can catch trend and structural change, in order to consider a wide class of departures from stationarity.

Two tests were applied to detect the presence of a trend in each series. The first one is the well-known Mann–Kendall test (Sneyers, 1990), which is able to reveal the presence of a monotonic trend, but suffering the presence of serial correlation (Yue *et al.*, 2002) and structural changes; the second one is a test for stationarity *versus* deterministic trends and unit root, that can detect a large variety of deterministic trends (polynomial regression, abrupt changes, etc.) in the presence of a wide class of errors. It was developed by Giraitis *et al.* (2006) and is based on the rescaled variance $V_n/\hat{s}^2_{n,q}$, where:

$$V_n = n^{-2}\left[\sum_{k=1}^{n}(S_k^*)^2 - n^{-1}\left(\sum_{k=1}^{n}S_k^*\right)^2\right],$$

$$S_k^* = \sum_{j=1}^{k}(X_j - \overline{X}_n),\ \hat{s}^2_{n,q} = q^{-1}\sum_{i,j=1}^{q}\hat{\gamma}_{i-j} \quad (3)$$

n denotes the number of data, X the series, q a bandwidth and $\hat{\gamma}_i$ the sample covariances; the test function is

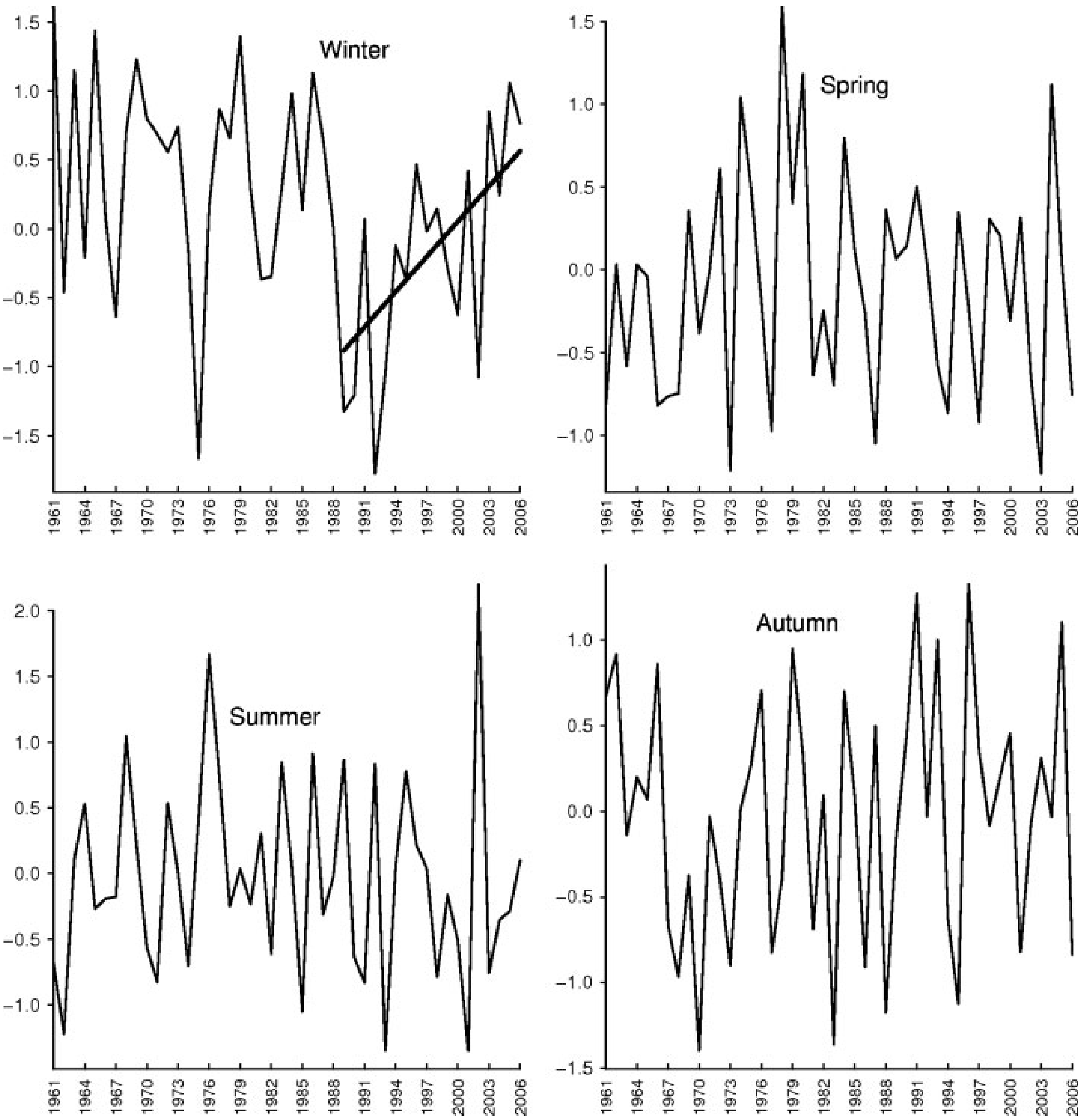

Figure 5. Seasonal standardized precipitation anomaly series for centre of Italy. In the winter plot the thick line represents the trend.

$T_n(\hat{d}) = (q/n)^{-2\hat{d}}(V_n/\hat{s}^2_{n,q})$. The parameter d was set to zero, because an error term with short memory is a reasonable hypothesis and under this condition the test performs better (see Giraitis *et al.*, 2006 for further details). The selection of q is more delicate; for large n the optimal choice is $n^{1/3}$, but our dataset is not so large. Therefore, we decided to perform the test under two reasonable different assumptions: $q = 0$ (independence assumption) and $q = 1$ (very weak dependence).

Furthermore, we implemented the iterated cumulative sums of squares (ICSS) algorithm, for the detection of changes in variances (Inclan and Tiao, 1994); in fact, we do not want to exclude *a priori* any possibility. The ICSS algorithm considers a sequence of independent zero-mean random variables $\{X_t\}_{t=1}^{n}$, and uses the quantity $C_k = \sum_{t=1}^{k} X_t^2$ to construct the statistic $D_k = (C_k/C_n) - (k/n)$. Under the null hypothesis of stationarity of the variance, the quantity $\sqrt{(n/2)}D_k$ converges in distribution to a standard Brownian motion, otherwise the point k_0, that maximizes $\sqrt{(n/2)}D_k$, is a breaking point for the variance. We use a p-value of 0.05 for the trend stationarity test.

If the hypothesis of trend stationarity is rejected, the algorithm of Bai and Perron (1998) is applied for the detection of change points in the trend function. Finally, the parameters of the trend component were estimated with the non-parametric method of Theil and Sen (Sen, 1968), that uses as slope estimator the median of the series $Y_{ij} = (X_j - X_i)/(t_j - t_i)$ with $t_j \succ t_i$. This method is very stable against gross errors and non-normality of data.

Based on the work of Serrano *et al.* (1999), we investigated monthly modes of variation of precipitation, i.e. its main spatial patterns of variability, through the application of a principal component analysis (PCA) (Wilks, 1995; Jolliffe, 2002; von Storch and Zwiers,

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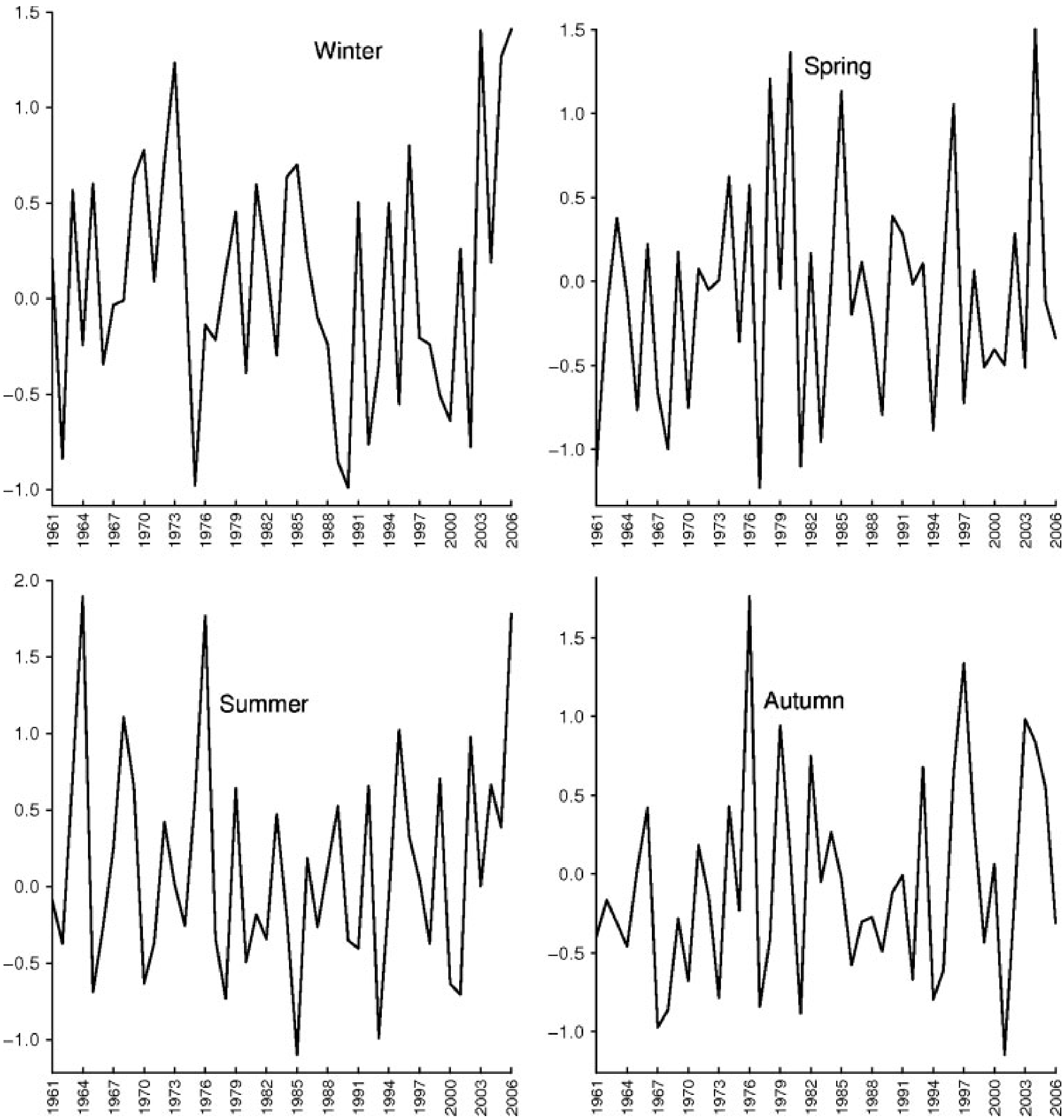

Figure 6. Seasonal standardized anomaly series for southern Italy.

2003). It is a multi-purpose technique, widely used in climate research for the identification of leading (physically relevant) patterns and for the reduction of data dimensionality (Hannachi *et al*., 2007).

Depending on which parameters are chosen as variables, PCA can be run in six different ways (from O-mode to T-mode). In this work, we performed an S-mode PCA (Richman, 1986), which 'clusters the stations with similar time behaviour' (Compagnucci and Richman, 2008). In other words, the monthly time series of each station were chosen as input variables for the analysis, so that each column of the data matrix represents a station. First of all, the precipitation series were standardized, i.e. time-centred and scaled, which correspond to the choice of a correlation matrix as dispersion matrix. Moreover, as sparse data might lead to loading maps suffering domain shape dependence and not properly interpretable, monthly data were interpolated on a regular $0.5^\circ \times 0.5^\circ$ grid, using the popular technique of splines with tension (Smith and Wessel, 1990). Therefore, the PCA was performed using these regular interpolated data.

The PCs were obtained through the 'prcomp' function of the R statistical language (R Development Core Team, 2006). The number of PCs, retained for the axis rotation procedure, was chosen through a comparison of different well-known strategies: scree-graphs, cumulative percentage of total variation, Kaiser–Guttman rule, and parallel analysis. Such decision rules are available in the n-Factors R-package (Raiche, 2007); as the number of retained PCs influences the outcome of axis rotation, different sizes were tested. Finally, we decided to keep

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four PCs for each month, which guarantees physically meaningful results and, at the same time, a sufficient amount of explained variance (around 70% for each analysis).

In order to improve the interpretation of the new variables, an axis rotation is usually performed on PCA results. In this study, following the suggestions of Dommenget and Latif (2002), we compared non-rotated solutions with two kinds of rotation: Varimax (Kaiser, 1958) and Quartimin (Carroll, 1953), both carried out with GPA rotation R-package (Bernaards and Jennrich, 2005). The former is an orthogonal rotation method, i.e. the PC orthogonality is kept; the latter, instead, belongs to the family of oblique rotation methods, which relax the orthogonality constraints in order to make axis interpretation more realistic. Here, Quartimin results were almost completely similar to Varimax results. Finally, loading maps [or empirical orthogonal functions (EOFs)] were generated by interpolating and plotting the Varimax results over the map of Italy; the contour plots were carried out using a linear interpolation algorithm from Akima R-package (Akima, 1978, 1996).

Keeping in mind that the aim of our analysis is the identification and interpretation of areas of coherent variability, PCs underwent a hierarchical cluster analysis using the average linkage method (Kalkstein *et al.*, 1987) and the congruence coefficients proposed by Harman (1976) as similarity measure:

$$G_{AB} = \frac{\sum_{i=1}^{n} a_i b_i}{\left(\sum_{i=1}^{n} a_i^2 \sum_{i=1}^{n} b_i^2\right)^{1/2}} \tag{4}$$

where A and B represent two PCs and a and b the associated EOFs. This approach can help to identify common patterns characterizing Italian precipitation.

4. Results

All the tests mentioned in the previous chapter, were applied using a p-value of 0.05. We present first the results on annual series, then those on the seasonal series for north, centre and south of Italy. The seasonal series were constructed using the definition of meteorological seasons: December–February as winter; March–May as spring; June–August as summer and September–November as autumn.

The annual series of standardized precipitation anomaly (Figure 3), calculated from December to November do not show a trend, as highlighted by the Mann–Kendall test that always gave p-values greater than 0.1. The same results are valid for the test of Giraitis *et al.* (2006). Furthermore no changes of the variance of the three series have been found with the ICSS test.

In the North (Figure 4) the spring/summer and autumn series do not show trend and variance changes: the p-values of the Mann–Kendall test were always >0.1. On the contrary, the winter series shows a significant decreasing trend for the entire period: this is revealed by the Giraitis and Mann–Kendall tests with a p-value <0.03. The slope and the confidence interval, estimated with the Theil–Sen technique, are -0.015/year and (-0.0283, -0.0024) respectively. In order to translate this trend estimate into millimeters, we used the method described in Jones and Hulme (1996), giving a result of -1.47 mm/year for the mean variation of winter precipitation in northern Italy.

Also in the Centre (Figure 5) only the winter series is not stationary although the situation is more complicated in this case. Indeed, the Mann–Kendall test does not recognize the presence of a trend (p-value equal to 0.103), while the Giraitis test reveals the presence of a significant trend that cannot be monotonic because it is not revealed by the Mann–Kendall test. Therefore, the application of the Bai and Perron procedure gives, as expected, a change point in 1988. Before 1988 the series is stationary with a mean of 253.97 mm, while after 1988 the trend is positive with a slope of 0.087/year, and a confidence interval equal to (0.0299, 0.1491). This trend corresponds to a precipitation increase of 7.73 mm/year. It is important to outline that after 1988 precipitation in Central Italy belongs to a climatic regime completely different from the previous, characterized by a positive trend component and a mean of the detrended series equal to123.35 mm. We think that this could be related to the yearly number of winter blocking episodes in European area (Trigo *et al.*, 2004), affecting positively monthly precipitation in Central Italy. However, we believe that an in-depth next study on this issue, using data until 2006 (because Trigo *et al.* performed their analysis with NCEP/NCAR re-analysis from 1958 to 1997), could give a better characterization/explanation.

Finally, in the South (Figure 6), all the series do not show trend or variance changes.

As for rotated PCA, the cluster analysis gives seven significant clusters (made up of more than two PCs/EOFs of different months) and other identified clusters (made up of only one PC/EOF) not physically interpretable and depending on local features. Hereafter, the four EOFs of each month will be indicated by the first three letters of the month and the number of the EOF (ordered using explained variance); for example Oct1 denotes the first EOF of October. In order to illustrate the physical interpretation of these clusters, we adopted the objective classification of synoptic weather regimes and results of James, although it concerns only winter and summer (2007; www.cost733.org/GWL//ObjGWL.html).

The first identified cluster is made up of the following EOFs: Oct1, Jun3, Dec3, Apr3, May3; Figure 7 shows an example of the common pattern of this cluster. It can be linked with the two types: TRM (trough over Central Europe) and NZ (cyclonic northerly). The second cluster (made up of Jan2, Sep2, Oct2, Apr4, and Nov2) involves mainly the central part of Italy, as shown in Figure 8; its pattern can be associated with TM (low over

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Central Europe) and HFZ (Scandinavian High, trough Central Europe). Mar3, Dec2, Feb3, Sep3, Apr1, Jun1 are included in the third cluster (Figure 9), concerning northwest of Italy and in relationship with: HNZ (Icelandic High, ridge Central Europe), HNFZ (High Norway–Iceland, ridge Central Europe) and SZ (cyclonic southerly). The fourth cluster (Sep1, Aug2, Feb4, Jul4, and Nov4) concerns especially the northeast of Italy and summer months (Figure 10) and shows possible links with summer types: WS (South-Shifted Cyclonic westerly) and NWZ (Cyclonic northwesterly). A more complex pattern is shown (Figure 11) by members of the fifth cluster (May4, Jul3, Oct4, and Nov3), linked to SEZ (Cyclonic southeasterly). The elements of the sixth cluster are: Mar1, Dec1, Feb1, May1, and Jun4; its pattern (Figure 12) is close to the pattern of the second cluster, but with some differences especially in the northern/central area; it could be associated with: TB (Low over British Isles) and TRW (trough over western Europe). The last cluster (Figure 13; made up of: Feb2, May2, Mar2, Nov1, Dec4, Jun2, and Jul2) has a pattern involving southern Italy with possible connections with BM (Zonal Ridge across Central Europe) and NA (Anticyclonic northerly).

The precipitation trend estimates are relevant for a sound evaluation of impacts and vulnerability to climate change on the Italian territory. In particular, national institutions, administrators and stakeholders are being more and more concerned with water resources availability, risk of draught and desertification processes, on which precipitation trends have a strong influence. In contradiction with the most common perception, our

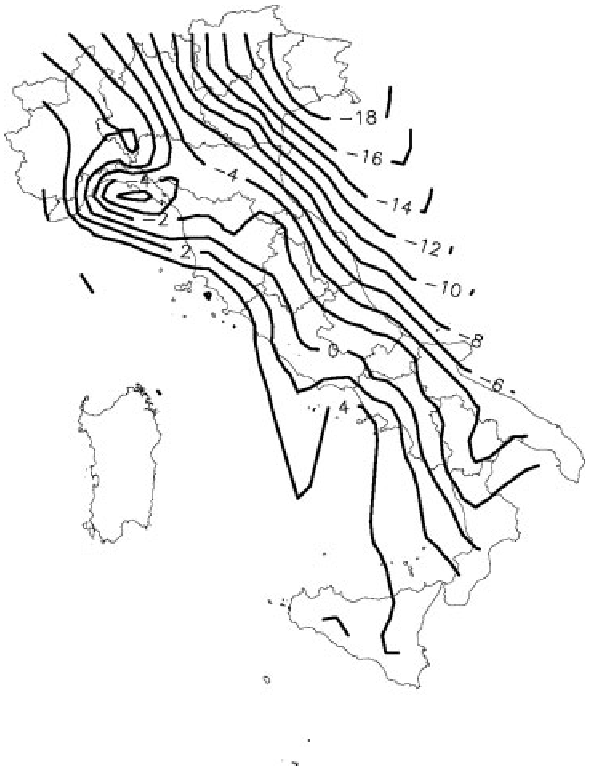

Figure 7. Third EOF map of April (first cluster).

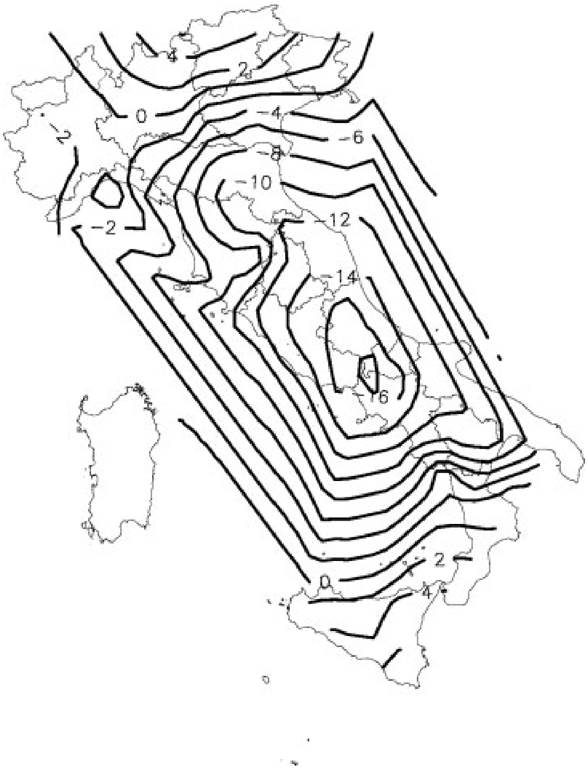

Figure 8. Second EOF map of October (second cluster).

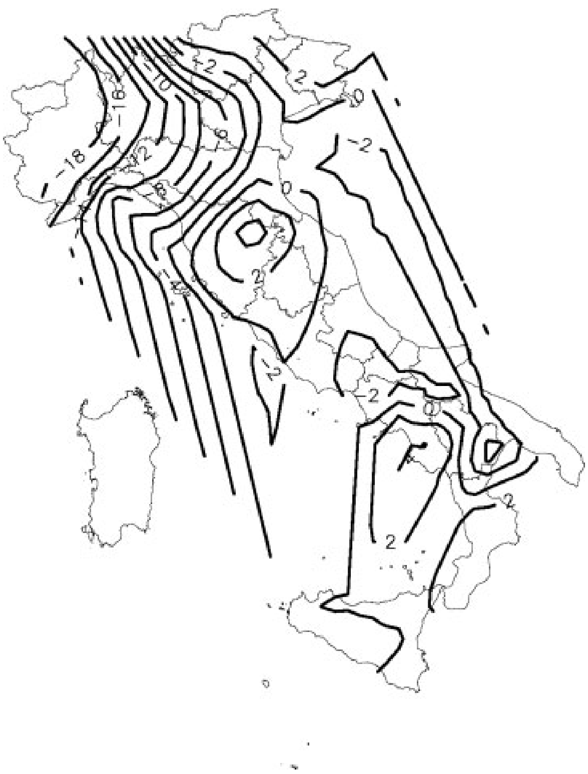

Figure 9. Second EOF map of December (third cluster).

results indicate that nowadays and in the near future the stronger warning concerning water resources availability, could regard the north of the country more than the south; Also the most recent data are in this direction:

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Figure 10. Second EOF map of August (fourth cluster).

Figure 12. First EOF map of February (sixth cluster).

Figure 11. Third EOF map of November (fifth cluster).

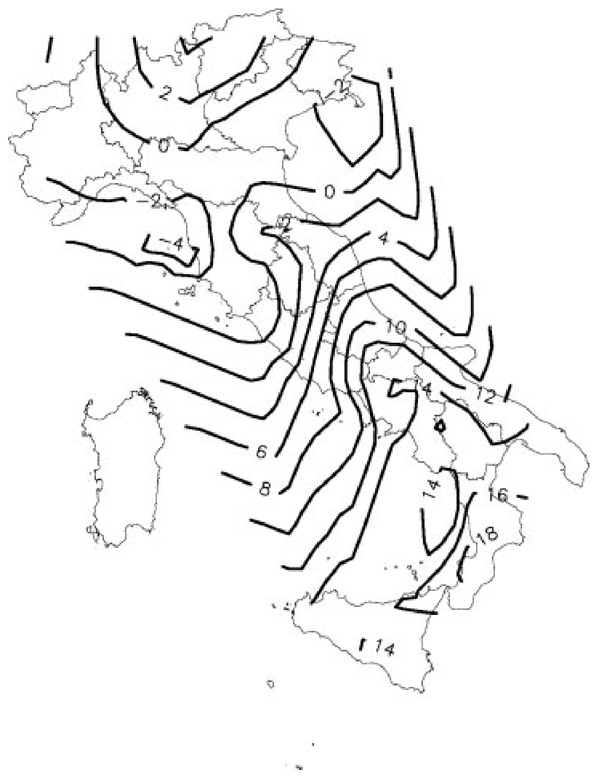

Figure 13. Second EOF map of May (seventh cluster).

2006 has been the fourth year in-a-row with negative precipitation anomalies for the North (and specially in the Northwest) and positive anomaly in the south of Italy. On the other hand, it must be outlined that in the long term the scenarios calculated by most global and regional climate models depict a stronger precipitation reduction descending with latitude in the Mediterranean area (Meehl *et al.*, 2007).

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The detected trend could be linked to increasing split events of the jet stream, which strongly influence the precipitation regime in our Peninsula especially in the winter season. At the moment, our analysis only gives an overview of the spatial patterns of precipitation over Italy. In order to get a more rigorous classification of precipitation regimes and their possible relations with atmospheric circulation patterns, further analysis needs to be carried out in the future, trying to involve a larger number of data series and other variables representing circulation characteristics like geopotential height (see for example Trigo *et al*., 2006).

5. Conclusions

A set of 59 monthly cumulated precipitation series from meteorological stations, homogeneously distributed over the Italian territory, was analysed. Data underwent a quality control procedure and series were homogenized, in order to filter the influence of non-climatic factors; furthermore, two reconstruction methods were applied. Annual and seasonal series of standardized precipitation anomaly were derived for three geographical areas: north, centre and south of Italy. Annual cumulated precipitation series do not show significant signals of change. Among the seasonal series, only in winter a trend is detected for the northern and Central Italy. In the North, precipitation decreased from 1961 to 2006 at a rate of −1.47 mm/year; in the Centre, precipitation was stationary form 1961 to 1988, and increased from 1989 to 2006 at an average rate of 7.73 mm/year. These results are relevant for climate change impacts and vulnerability assessment over Italy, highlighting that in the next future water resource availability may be a reason of concern also, if not mainly, in northern Italy.

The multi-variate technique of rotated PCA was performed on monthly data; the retained PCs were clustered using a hierarchical approach. Seven patterns, associated with typical synoptical regimes obtained by James (2007) were identified; they highlight the complex spatial behaviour of Italian precipitation.

Summarizing, this article provides, through high-quality monthly series, a characterization of Italian precipitation in the last 46 years, highlighting some important features (not pointed out in other works), useful for the definition of appropriate plans for the management of water resource availability. Nonetheless, it would be very important to update regularly this kind of information, in order to verify (and improve) the identified behaviour.

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