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Trends of the daily intensity of precipitation in Italy and teleconnections(*)

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Summary. — Changes in daily precipitation frequency and distribution are studied by analyzing a daily precipitation data set covering the last 120 years for Italy. Data were homogenized on daily basis and completed by means of statistical methods. The following parameters were analyzed for each station record and averaged into some regional series for a synthetic description of the results: seasonal and yearly total precipitation, number of wet days, precipitation intensity and proportion and frequency of daily rainfall amounts, belonging to 6 precipitation class-intervals, defined on the basis of some percentiles of the precipitation distribution.

PACS 92.60.Ry – Climatology.
PACS 92.60.Jq – Water in the atmosphere (humidity, clouds, evaporation, precipitation).
PACS 92.60.Wc – Weather analysis and prediction.
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1. – Introduction

In recent climatological studies many efforts were made to characterize possible changes in climatic extremes, since they have the strongest impact on society. Modelling results have indicated increases in extreme precipitation in a warmer climate [20, 15, 18]. Observational studies also suggest changes in climatic extremes in many places of the globe [13, 14, 16, 19, 17, 7-9, 2, 4]. The authors of ref. [5], in a brief review of climate extreme, observed that the tendency in most countries that have experienced a significant increase or decrease in total precipitation has been directly related to the change in the amount of precipitation during the heavy and extreme events. The relationship between precipitation intensity and total precipitation is, however, not general. In some places,

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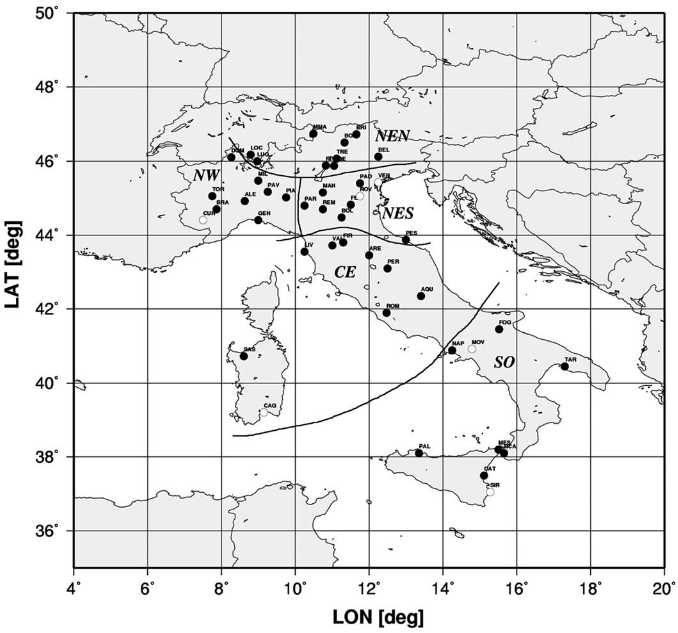

Fig. 1. – Map of the stations (black circles indicate stations that passed the homogenization procedure; white circles indicate stations rejected from the homogenization procedure). The 5 regions obtained from the PCA analysis (fig. 2) are indicated too.

an increase in heavy precipitation was observed together with a tendency toward a decrease in total precipitation [10]. A similar behavior was observed in Italy [1-3]. One of the biggest problems in examining the climate record for changes in the occurrence of extremes is a lack of high-quality and high temporal and spatial resolution long-term data [12, 6]. Furthermore, daily data are often not in digital form and for most countries the analysis period starts from the end of World War II. More effort from individual countries are necessary to set up national homogeneous daily resolution data bases to converge into wider international projects.

2. – Data

In the frame of some national and international projects we set up a new data set of daily precipitation series. At the moment the data base consists of about 50 series distributed all over the Italian territory, but the data collection is still in progress to improve the area coverage. Station location is shown in fig. 1. A wide collection of metadata was set up too. Research activity concerning metadata was organized in order i) to understand the evolution of the Italian meteorological network and ii) to reconstruct the history of all the stations with secular series. Both the metadata on the evolution of the National network and that concerning the station history, contain a lot of information about instruments, station relocation and maintenance, changes of instruments and calibration problems, changes in the number of observations per day, in the observation time and in the people working at the station. All this information was very useful for a critical check of the quality of the data.

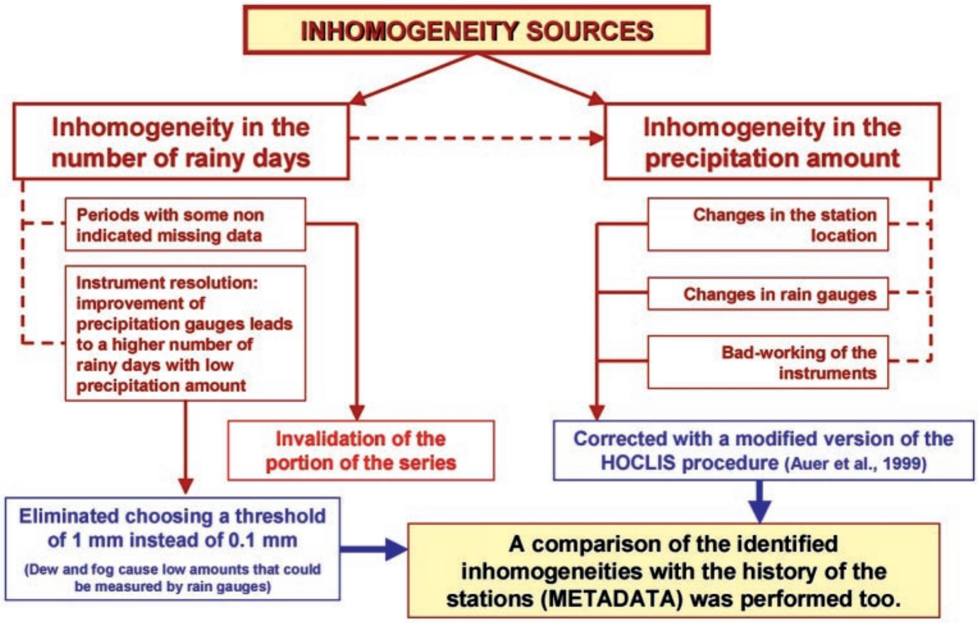

Fig. 2. – Sketch of the homogenization procedure.

3. – Data homogenization and gap filling

The real climate signal in original series is hidden behind non-climatic noise caused by station relocation, changes in instruments and instrument screens, changes in observation times, observers, and observing regulations, algorithms for the calculation of means, and so on, and many studies have demonstrated that climate variability research is not possible without clear knowledge about the state of the data in terms of homogeneity. One of the biggest problems concerning daily precipitation data is that the series could be affected by two kinds of inhomogeneities: i) in the precipitation amount and ii) in the number of rainy days. The latter can obviously generate an inhomogeneity also in the precipitation amount series. In fact, a period with some non-indicated missing data could be interpreted as a period with an underestimation of total precipitation and it could be badly corrected by increasing each single rainy day and originating some erroneous extreme events. So, we decided to check separately both total precipitation and the number of rainy days. Figure 2 shows a sketch of the homogenization procedure.

Six of the 45 series displayed so many homogeneity problems that they were classified "not homogenisable". At the end, a set of 39 single series constituted the final homogenized data base. It was possible to perform a comparison of the identified inhomogeneities with the history of the stations and a high percentage of the breaks were explained through metadata. A total of 36 breaks were homogenised: for 15 of them there was a relocation or some changes in the instruments, 4 correspond to the World War periods and 5 to a re-start of the data collection after an interruption. So, a total of 24 breaks out of 36 were supported by information about the history of the stations.

After the homogenization, to prevent missing data from introducing any bias we used a procedure described in [13] and widely used in many works [14, 1-3] to estimate them.

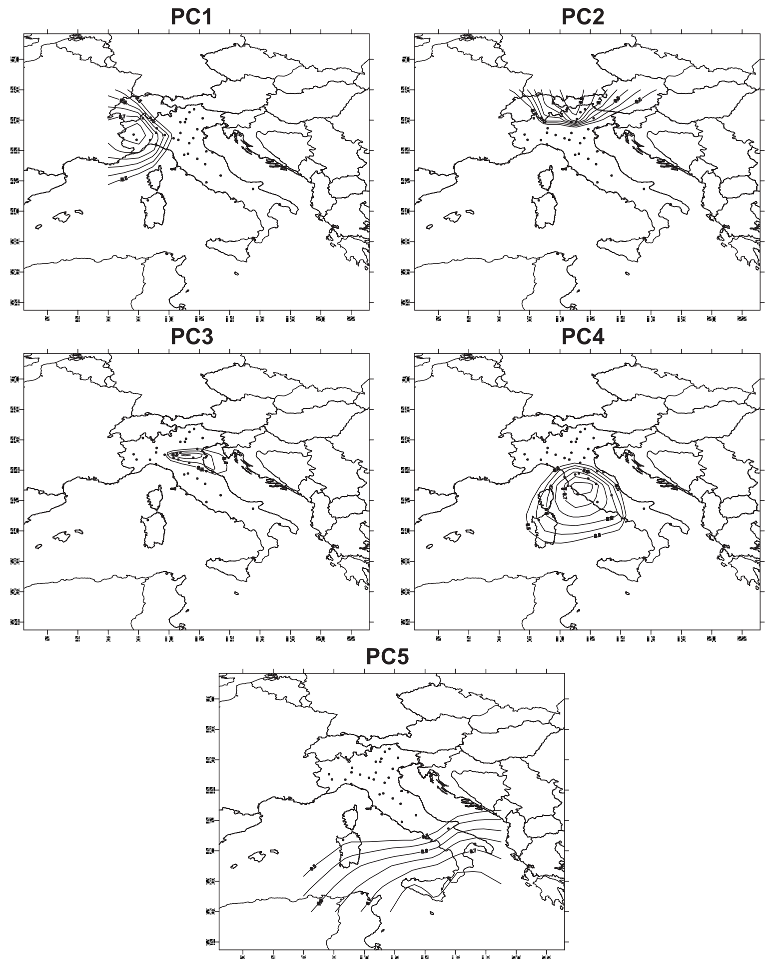

Fig. 3. – Factor loading patterns of the first five rotated Principal Components obtained from the PCA.

Basically, a gamma function is fit to each station's daily data for each month of the year. To determine if precipitation occurs on any missing day, a random number generator is used such that the probability of precipitation is set equal to the empirical one on that day. If precipitation occurs, then the gamma distribution is used to determine the amount that falls for that day, again using a random generator.

4. – Data analysis

The final data base was clustered into homogeneous precipitation areas by means of Principal Component Analysis (PCA) applied to monthly total precipitation series. The eigenvalues of correlation matrix reveal that only 5 principal components (PCs) account for more variance than the original variables (having eigenvalues greater than 1) and that these 5 PCs account globally for 65% of the variance of the standardised data. The resulting loadings are 5 vectors of the 39 components. We represent the loadings on

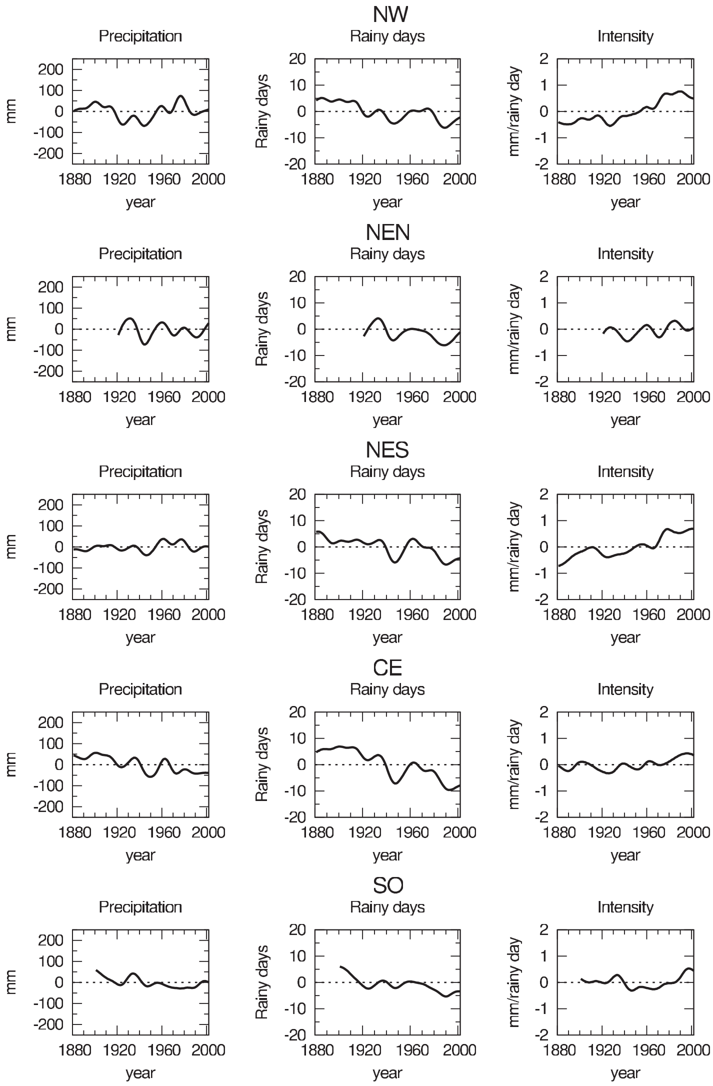

Fig. 4. – Yearly TP, WDs and PI series for the 5 regions. The data were smoothed with a 31-year width window and 5-year σ Gaussian filter.

geographic maps, drawing contours through the points with the same loadings (fig. 3).

The loadings patterns allow the regions indicated in fig. 1 to be identified. The longest series starts in 1787, but most of them have data only since 1880. Moreover, there are also some stat ions that start in only in 1920s. Sometimes the starting year is linked to the basin to which the station belongs, so we have different series lengths for the different regions: NW, NES and CE have data starting from 1880, but for NEN and SO most of the s eries have data only since 1920 and 1900 respectively. For each station, some simple statistics of the precipitation series: the total seasonal precipitation (TP), the number of wet days per season (WD) and the mean amount of precipitation per wet day (precipitation intensity, hereinafter PI). Then we calculated the proportion of daily

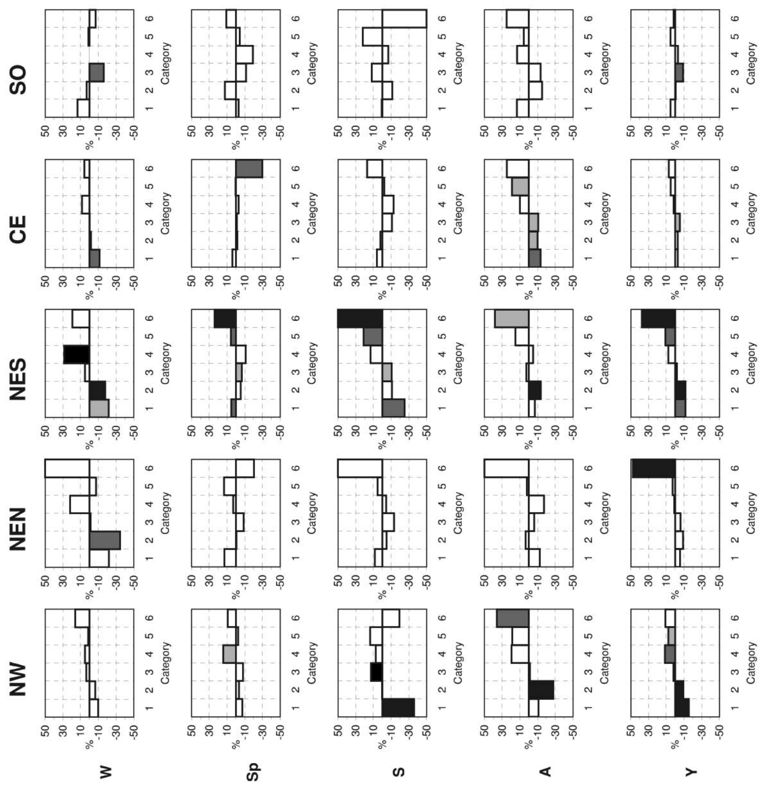

Fig. 5. – Trends (expressed as percentage variation per century relative to the mean value of the 1961-1990 standard period) of the relative contribution to TP of the 6 precipitation class categories. (Black bins= $s.l. > 99\%$; grey bins = $s.l. > 95\%$; light grey bins = $s.l. > 90\%$)

rainfall amounts, belonging to 6 precipitation class-intervals for each season and each year (C1, ..., C6), compared with the corresponding total precipitation, and the numb er of events falling into these six classes (C1, ..., C6). These categories were defined on the basis of some percentiles of the precipitation distribution of each series as follows:

C1: precipitation lower than the 50th percentile,
C2: precipitation between the 50th and the 75th percentiles,
C3: precipitation between the 75th and the 90th percentiles,
C4: precipitation between the 90th and the 95th percentiles,
C5: precipitation between the 95th and the 99th percentiles,
C6: precipitation greater than the 99th percentile.

All these statistics were averaged over the 5 regions and the regional series were analyzed for trend with the Mann-Kendall non-parametric test.

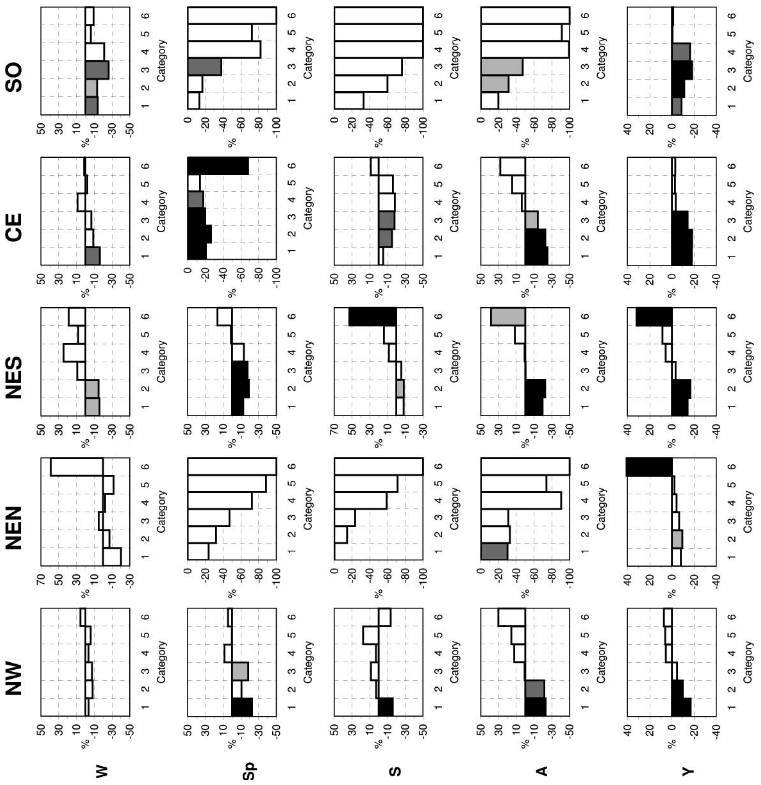

Fig. 6. – Like fig. 5, but for the number of events belonging to each class category.

5. – Results

In fig. 4 yearly TP, WD and PI series are shown. TP shows significant trends only in southern regions (CE and SO) with a decrease of about the 10% per century of the average total annual precipitation.

WD presents a highly significant negative trend all over Italy, with the strongest decreases between 1930s and 1940s and between 1960s and 1980s. The trend values range from -7% per century in NEN to -15% per century in CE (corresponding to -6 and -14 days per century). Also on seasonal basis trend is always negative and significant, being the strongest contributes coming from spring and autumn. As a consequence of the strong negative trend in WDs in all regions and of the not uniform behavior of TP, PI presents a positive trend about everywhere, but with quite different significant levels from region to region. On yearly basis it reaches significant values only in some northern regions (NW and NES). This is caused by the fact that in southern regions (CE and SO) both WDs and TP have significant decreases. By studying the above defined precipitation categories behavior it is evident that precipitation intensity increase is due to a decrease in the contribution of low precipitation categories to total precipitation and to an increase in that of higher categories corresponding to heavy precipitation events (fig. 5). This is more evident in northern regions (NW, NEN and NES) with highly significant t rends and in CE even if the significance is low, while no clear signal is present in SO. Considering

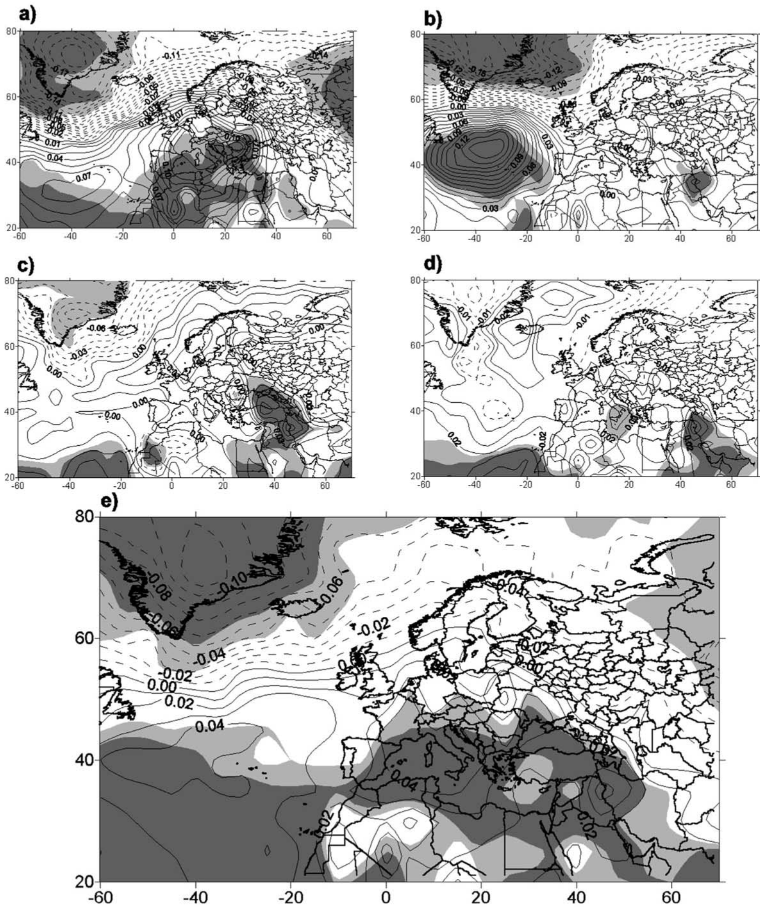

Fig. 7. – Maps of pressure trends (hPa/y) and SLs (light grey areas indicate a SL greater than 95%, the dark gray ones a SL greater than 99%). a) winter, b) spring, c) summer, d) autumn, e) year.

the frequency of events falling into each category, rather than their relative contribution to total precipitation, a more uniform behavior all over Italy was observed (fig. 6): there is a highly significant decrease in the number of events falling into lower categories in all regions. In northern regions there is also evidence of a significant increase in the number of events falling into the highest class-interval (comprising events above the 99th percentile).

6. – Conclusions

Italy, due to its orography, is particularly exposed to the negative effects of high intensity precipitation events. It is one of the European countries with the greatest human loss due to flood events. At the same time droughts are a frequent problem for agriculture, in particular during summer, when the lack of water resources often compromise the crop in large regions, especially in Southern Italy. The results of this paper highlight both

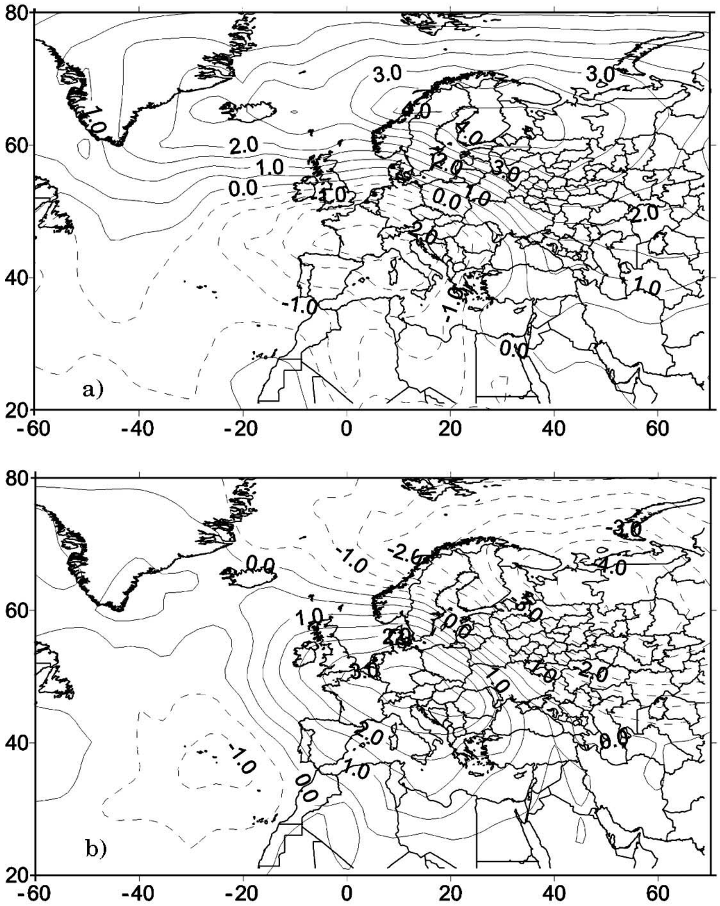

Fig. 8. – Average among the anomalies (hPa) of the mean monthly pressure patterns associated to the five highest (a) and lowest (b) number of WD per season.

these two aspects, indicating the last decade as the one with the lowest number of rainy days per year and the highest amount of precipitation per rainy day. However, the tendency toward a decrease in the number of rainy days, and an increase in intensity, that was already observed in a previous study for the last 50 years [2], is not a peculiarity of recent decades, but it has persisted since the end of the 19th century. From this study, it is evident that most of this negative trend is explained by the marked decrease in the frequency of low intensity precipitation events (below the 75th percentile).

In previous work, based on greater data availability for the last 50 years, we obtained similar results and it was possible to link the observed climate changes (in particular the rainy days decrease) to some changes in atmospheric circulation. Figure 7 shows the map of the UKMO sea level pressure trend slope over Europe, for individual seasons and full year, for the last 50 years. The significance level was calculated using the Mann-Kendall non-parametric test. The light grey areas indicate a significance level (SL) greater than 95%, the dark grey ones a SL greater than 99%. A positive trend (up to 0.04 hPa/y) below the 50 latitude with highly significant values over all the Mediterranean basin and

TABLE I. – *Seasonal and yearly correlation values of P and WD with circulation indices. All indicated values have SL greater than 95%; ∗∗ indicates values with a SL greater than 99%.*

		NORD		SUD	
		NAOI	MCI	NAOI	MCI
Precipitation	Y		-0.48^{**}	-0.27	-0.34
	W	-0.38^{**}	-0.71^{**}	-0.54^{**}	-0.60^{**}
	Sp		-0.26		
	S	-0.36	-0.38^{**}		-0.46^{**}
	A		-0.45^{**}		-0.46^{**}
Wet days	Y	-0.32	-0.43^{**}	-0.48^{**}	-0.42^{**}
	W	-0.47^{**}	-0.69^{**}	-0.62^{**}	-0.60^{**}
	Sp			-0.32	-0.30
	S		-0.30		-0.35
	A		-0.52^{**}	-0.41^{**}	-0.60^{**}

a negative trend above 60 latitude, with highly significant values in the eastern north Atlantic, in particular over Iceland and Greenland, are evident on yearly bases. The positive trend over the Mediterranean is almost completely due to the winter season, where the slope is up to 0.12 hPa/y (fig. 7a). The positive trend over Azores and the negative one over Greenland are mostly due to spring (with slopes up to 0.14 and −0.17 hPa/y) and winter (0.7 and −0.19 hPa/y) (figs. 7a and 7b). These trends, negative in the eastern North Atlantic and positive in the eastern Central Atlantic (the two regions where the NAO cells are located), are consistent with the increase in the westerlies accompanied by the strengthening of the NAO observed for the last decade [11]. This kind of variation in the European pressure patterns can justify an increase in precipitation at the higher latitudes (*i.e.* north of the Alps) and a decrease in the Mediterranean region, due to a northward shift of the jet-stream, especially in winter. The positive trend of the pressure over the Mediterranean also agrees with the hypothesis of an increase of the number and the persistence of anticyclones in this region.

The NAO is the dominant mode of variability of the surface atmospheric circulation over the North Atlantic [11] and many studies have been aimed at relating climate variability to this pattern. Figure 2, however, shows a different behavior of pressure trends over the Atlantic areas and the Mediterranean basin. This led us to look for a circulation index, aimed at characterising the link between Italian precipitation variability and atmospheric circulation better than NAO, that explains a significant proportion of the Italian P and WD variance but only in winter.

In order to obtain an index more suitable for Italy, we calculated, for each region, the average among the anomalies of the mean monthly pressure patterns associated to the months with the highest and lowest number of WDs. Results are shown in fig. 8. We decided to define a new index, the Mediterranean circulation index (MCI), as the normalized pressure difference between one station lying in the northwestern Mediterranean and another in the southeastern Mediterranean. According to the quality (homogeneity and length) of the series, we selected the stations of Marseille and Jerusalem. To verify if the results of our analyses depended critically on the stations selected, we compared all the results with the result obtained by selecting other pairs that characterize the same circulation features. No significant differences were found. High values of MCI correspond to positive pressure anomaly over the central-western Mediterranean basin with anticyclones located over the central-western Mediterranean basin. On the contrary, low values of MCI correspond to negative pressure anomaly over the central-western Mediterranean basin with anticyclones located far away from the central- western Mediterranean basin.

MCI explains the P and WD variances better than the NAOI. A highly significant correlation is evident for all seasons and for the year, with the proportion of explained variance being up to 50% for the N in winter P and 48% in winter WD (table I).

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