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Influence of the North Atlantic Oscillation on winter rainfall in Calabria (southern Italy)

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Abstract Seasonal rainfall amounts, directly responsible for availability of water resources on a specified area, are strongly dependent on the climate system. In order to highlight some features of such dependence, generally circulation indexes based on the difference in the sea level pressure between two geographic areas are taken into account. In the present study, the relationships between winter rainfall series observed in the Calabria region (southern Italy) and the North Atlantic Oscillation Index (NAOI) have been analysed. Firstly, a correlation analysis between precipitation and the NAOI was performed. Subsequently, the influence of the different phases of the NAO on the winter precipitation has been detected by a composite analysis, and by identifying changes in the behaviour of the probability density functions (gamma distribution) fitted on monthly rainfall. The results evidence a clear link existing between the phases of the climatic index and the amount of winter rainfall.

1 Introduction

In recent decades, understanding and predicting climatic variability and change have become key issues for the research community. In particular, there is great interest in assessing changes in precipitation due to their importance in economic activities such as agriculture, energy production and drinking water supply, and to their role in natural hazards such as droughts, floods, landslides and severe erosion.

With regard to the Mediterranean area, several studies have been carried out, which have often revealed negative trends for annual and winter precipitation (De Luis et al. 2000; Xoplaki et al. 2006; Feidas et al. 2007; del Rio et al. 2010). This trend behaviour has been also detected in Italy and, in particular, in some areas of southern Italian regions, as in the case of Campania (Diodato 2007; Longobardi and Villani 2010), Basilicata (Piccarreta et al. 2004), Calabria (Coscarelli et al. 2004; Ferrari and Terranova 2004; Caloiero et al. 2011; Brunetti et al. 2012) and Sicily (Aronica et al. 2002; Cancelliere and Rossi 2003; Cannarozzo et al. 2006).

Such regional changes in precipitation patterns are connected with changes in atmospheric circulation over the Atlantic Ocean (Hurrell 1995; Hurrell and van Loon 1997; Dai et al. 1998). In fact, 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 these mechanisms and, at regional level, it 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 between two geographic areas, tagged centres of climatic action. Such an approach, called teleconnection, shows that climatic conditions in different geographical areas, even relatively far from each other, are

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interdependent. The most important indexes on a large scale are: the Southern Oscillation Index, best known as El-Niño Southern Oscillation (ENSO) (Ropelewski and Jones 1987); the North Atlantic Oscillation Index (NAOI) (Hurrell 1995; Hurrell and Van Loon 1997); and the Arctic Oscillation Index (AOI) (Thompson and Wallace 1998, 2000).

In the last 20 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. In some areas of India, Australia, Peru and the USA, the impact of the climate variation in response to the ENSO is well documented (McBride and Nicholls 1983; Trenberth 1990; Zhang and Casey 1992; Stone and Auliciems 1992). With regard to the North Atlantic Oscillation (NAO), Durkee et al. (2008) highlighted its effects on temperature and precipitation regimes across the eastern USA during the winter season. As far as is concerned Central and Northern Europe, most of the inter-annual variability in precipitation is related to the NAO (Hurrell 1995), especially during winter season. When the NAO is in its positive phase, cold conditions

over the northwestern Atlantic and warm weather over Europe occur, as well as wet conditions from Iceland through Scandinavia and dry conditions over Southern Europe (Walker and Bliss 1932). Quadrelli et al. (2001), by studying only the Alpine region for the period 1971–1992, found a high negative correlation between winter precipitation and NAOI. Delitala et al. (2000) revealed the existence of a clear connection between NAO and Sardinian precipitation. Tomozeiu et al. (2002) have studied the winter average precipitation on Emilia Romagna (Italy), finding a strong correlation with the NAO index; they also explained how changes happened for winter precipitation around the year 1985 could be due to an intensification of the positive phase of NAO, especially after 1980.

Rodò et al. (1997) and Goodess and Jones (2002) showed that the NAO influenced the 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. Rodrigo and Trigo (2007), after analysing various simple rainfall indexes, concluded that the winter NAO governs fluctuations in number
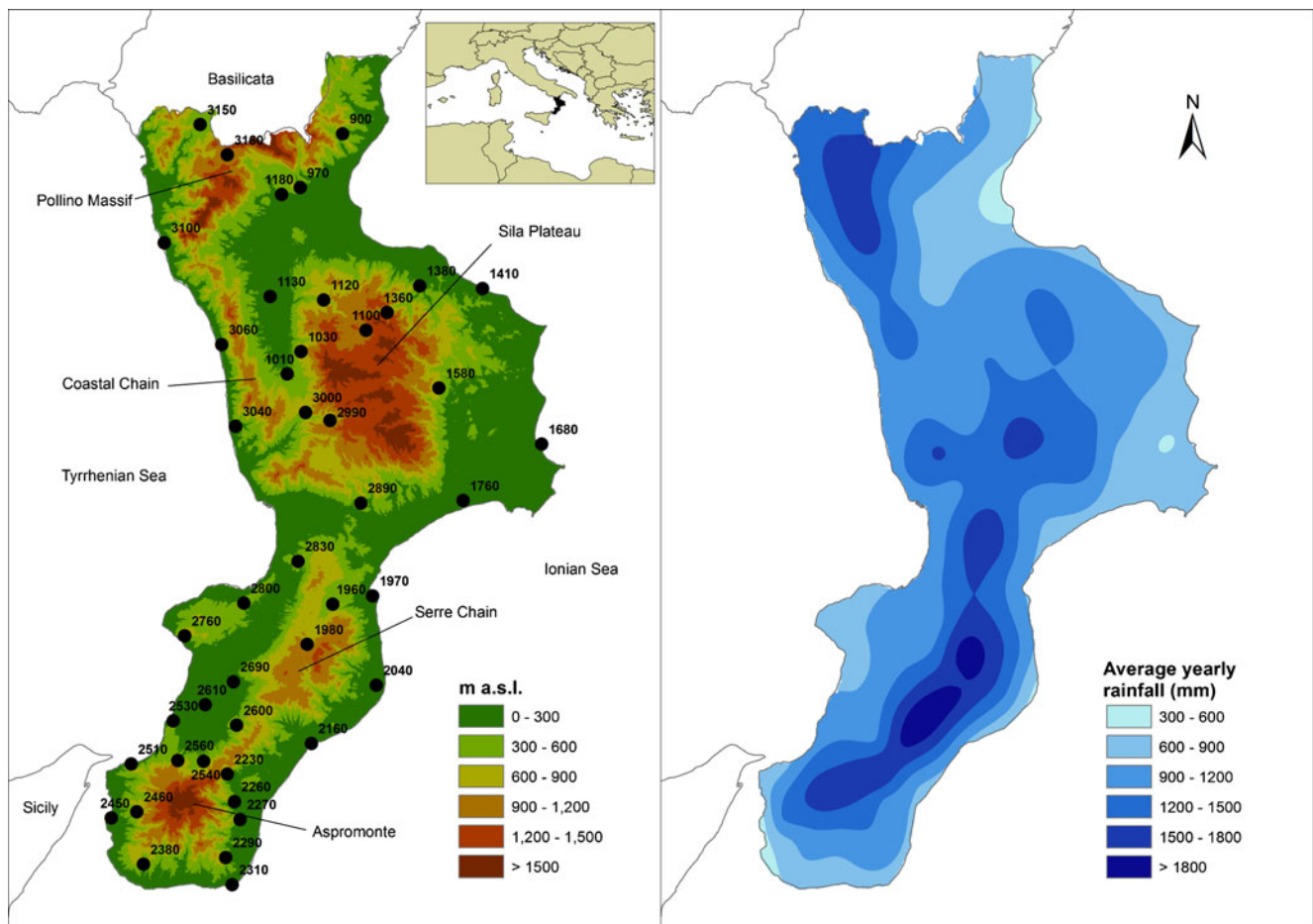
Fig. 1 Digital elevation model of the study area and location of the rain gauges (*left*) and spatial distribution of the average yearly rainfall (*right*)

Table 1 Results of the trend analysis (millimeters per decade) for the monthly and annual precipitation (*significant values are marked in bold*)

Code	Rain gauge	January	February	March	April	May	June	July	August	September	October	November	December	Year
900	Albidona	−8.9	−4.4	**−6.2**	−1.4	−2.7	**−2.7**	0.6	1.4	1.2	−3.1	**−11.6**	−6.0	**−38.9**
970	Cassano allo Ionio	**−7.6**	−2.5	0.4	−1.0	**−2.4**	−0.6	1.5	0.6	1.3	−0.1	−2.0	−1.5	**−12.1**
1010	Cosenza	−1.1	−3.6	−0.6	−1.6	−2.0	0.2	−0.3	0.6	1.1	**−3.8**	−2.2	−5.4	**−13.5**
1030	San Pietro in Guarano	**−5.8**	−3.3	0.5	0.9	−3.0	0.1	0.9	**1.7**	**2.6**	−4.0	−1.4	−6.7	**−18.0**
1100	Cecita	−6.3	**−7.9**	−2.5	1.7	**−6.6**	−0.4	−0.3	1.9	−0.3	−3.9	**−9.2**	−4.4	**−34.5**
1120	Acri	−2.5	−3.8	1.5	3.0	**−3.1**	0.1	0.5	1.2	4.4	−1.3	−4.9	−4.9	−3.5
1130	Torano Scalo	−1.2	−2.3	−0.2	2.2	−0.7	0.9	0.9	1.4	**3.2**	−0.7	−2.4	−2.4	3.5
1180	Castrovillari	−4.0	−2.1	0.1	0.7	−1.9	0.4	0.8	0.5	1.7	−0.4	−4.2	−4.6	−8.8
1360	Longobucco	−7.2	−7.9	−3.9	3.3	−2.8	0.7	0.1	1.4	6.0	−5.4	**−12.8**	−1.1	**−39.1**
1380	Cropalati	**−11.0**	−5.6	−4.8	−0.8	−3.3	0.0	1.0	1.8	**7.3**	−8.4	**−14.5**	−7.1	**−52.9**
1410	Cariati Marina	−7.5	−4.3	**−9.5**	0.1	−4.3	0.1	0.4	1.3	5.2	**−22.0**	−13.3	−6.2	**−61.7**
1580	Cerenzia	−6.6	−4.5	−6.2	2.8	−1.3	0.7	**1.9**	**1.2**	**6.5**	−3.4	**−17.6**	−3.3	**−35.1**
1680	Crotone	−1.2	−2.4	0.4	1.9	0.4	0.1	**1.8**	0.4	2.7	−2.4	**−7.0**	−1.3	−3.2
1760	Botricello	−3.2	**−7.3**	−1.6	0.7	−1.6	−0.7	1.6	0.2	2.7	−3.0	**−15.3**	−4.1	**−30.2**
1960	Chiaravalle Centrale	−4.6	**−11.8**	**−6.9**	−2.7	−2.3	**−2.1**	1.3	**1.0**	7.2	**−10.2**	**−16.7**	−4.2	**−62.5**
1970	Soverato Marina	**−10.4**	**−8.2**	**−6.8**	−2.3	−1.8	**−1.6**	0.6	−0.7	3.1	**−11.2**	**−19.5**	**−13.4**	**−69.1**
1980	Serra San Bruno	−7.6	−10.3	**−9.7**	2.1	−3.1	−2.3	2.0	**3.3**	**7.0**	−4.7	**−15.0**	−4.6	**−38.5**
2040	Monasterace - Punta Stilo	−2.1	−0.8	**−6.5**	−0.3	−1.0	−0.4	1.0	1.0	**16.4**	**−22.7**	−9.4	−8.2	**−32.1**
2160	Gioiosa Ionica	2.3	−4.1	−2.3	−0.3	**−1.2**	−1.0	−0.1	0.1	5.7	−4.3	**−16.7**	−2.8	**−27.5**
2230	Plati'	−4.3	−1.7	−1.0	−0.4	−1.9	1.3	0.0	1.3	4.6	−7.1	**−14.2**	−10.6	−20.1
2260	San Luca	−6.2	−5.3	−7.0	−4.1	**−2.4**	−0.5	0.9	**1.4**	3.5	−7.0	**−14.4**	**−10.8**	**−52.5**
2270	Sant'Agata del Bianco	3.7	1.0	0.5	2.5	−0.4	−0.5	**0.6**	**1.8**	7.6	−2.7	**−11.0**	−1.7	−7.6
2290	Staiti	−11.4	1.0	−7.0	−0.3	−2.8	0.2	0.2	1.5	**5.7**	−13.6	−8.2	−5.7	**−45.2**
2310	Capo Spartivento	−0.7	−2.2	−0.2	0.2	−1.0	0.3	0.1	0.6	**3.6**	−1.8	**−8.7**	1.0	−5.4
2380	Montebello Ionico	**−4.6**	−2.9	−0.4	−0.2	**−3.0**	−0.1	0.4	−0.4	**4.4**	**−14.7**	−4.8	−0.6	−19.7
2450	Reggio Calabria	−0.4	−1.7	1.1	0.4	−0.6	−0.2	0.3	−0.2	**3.3**	1.6	−2.9	−1.1	4.8
2460	Reggio Calabria - Arasi'	−6.5	−9.1	−1.7	−1.9	−2.7	−1.2	0.8	**1.4**	0.0	−2.8	**−8.1**	−5.0	**−41.3**
2510	Scilla	**−12.7**	−2.2	−3.3	1.0	−2.3	0.8	1.9	−1.1	−1.0	**−8.5**	**−9.5**	**−8.5**	**−44.5**
2530	Palmi	−1.3	−1.4	−0.8	−1.2	−2.4	**2.7**	1.3	1.4	1.9	−2.3	−2.7	−1.5	−6.2
2540	Santa Cristina d'Aspromonte	**−13.2**	−3.6	−7.9	4.8	−4.7	1.7	−0.6	−0.5	2.2	−16.9	−9.6	−4.1	**−47.9**
2560	Sinopoli	**−4.8**	0.1	−1.7	−0.3	−0.4	−1.1	**1.9**	**2.8**	**6.6**	−1.3	2.6	−0.6	−13.2
2600	Cittanova	−1.3	−3.9	**−5.0**	−1.3	−3.2	−0.4	1.0	1.0	**4.2**	−5.1	**−10.0**	−2.6	**−24.2**
2610	Rizziconi	−2.0	1.0	2.3	2.5	−0.1	−2.3	2.6	1.2	**5.6**	3.3	−1.0	−3.2	13.9
2690	Fereleto della Chiesa	**−11.2**	**−7.8**	**−5.3**	1.8	−3.3	−2.9	**−0.1**	**1.5**	0.8	−3.7	**−5.0**	**−8.8**	**−37.9**
2760	Joppolo	**−5.0**	−1.4	−0.4	**4.7**	−2.7	**−2.6**	1.0	0.8	2.6	−0.2	−5.0	−5.0	−21.1

Table 1 (continued)

Code	Rain gauge	January	February	March	April	May	June	July	August	September	October	November	December	Year
2800	Vibo Valentia	**-5.7**	-2.1	0.3	-0.9	0.0	-2.8	**3.3**	1.1	3.0	**-4.7**	**-6.2**	-5.4	**-19.2**
2830	Filadelfia	**-14.1**	-6.2	-4.8	-0.3	-2.2	**-6.1**	**1.3**	0.9	**3.8**	**-6.8**	**-10.1**	**-9.0**	**-55.2**
2890	Tiriolo	**-29.5**	**-15.3**	**-15.9**	-2.6	**-6.2**	-1.7	0.9	0.6	1.3	**-11.9**	**-18.1**	-8.1	**-101.0**
2990	Parenti	-1.1	-1.5	1.6	-1.7	-2.4	0.3	1.2	**2.2**	0.7	-5.1	1.4	-1.9	-4.1
3000	Rogliano	-4.6	-5.5	-2.5	-1.4	**-3.7**	-1.6	**1.1**	1.8	**2.7**	-4.4	-1.1	-3.2	**-21.9**
3040	Amantea	**-5.1**	-4.7	2.1	3.1	-3.3	0.1	-1.4	-1.7	0.6	-0.4	-4.0	-0.9	-11.8
3060	Paola	**-11.2**	**-5.5**	-2.3	-0.9	**-6.5**	-1.3	**1.2**	1.6	3.0	**-6.1**	-4.7	**-8.9**	**-44.8**
3100	Belvedere Marittimo	-2.6	0.4	**5.6**	2.2	-1.9	1.1	**1.5**	2.1	4.6	-0.3	0.3	-3.7	-2.1
3150	Laino Borgo	-11.4	-13.5	0.1	-1.2	**-7.5**	0.1	1.3	-1.1	1.0	-8.2	1.4	-4.7	**-47.6**
3160	Campotenese	**-9.3**	-7.5	-1.4	1.8	-2.8	1.3	2.3	1.5	**3.4**	-3.1	-4.0	-10.8	-18.9
	Negative trend (%)	37.8	15.6	20.0	0	22.2	11.1	20.0	22.2	0	24.4	48.9	13.3	62.2
	Positive trend (%)	0	0	2.2	2.2	0	2.2	2.2	0	35.6	0	0	0	0

In the last rows, the percentages of the rain gauges with significant trend are reported

of wet days and daily rainfall intensity over a large part of the Iberian Peninsula, but only in southern areas it seems to influence significantly the extreme episodes. Jovanovic et al. (2008) have found that NAO has a dominant influence on the precipitation regime in Serbia, especially during winter.

Beniston and Jungo (2002), in their study of climate variables change in the Alpine region, proposed to investigate the extent to which NAO influences the probability distribution function of the climate variables. The question is, therefore, if the changes in the distribution parameters are due to the oscillations of the NAO. Some investigations have been performed in order to examine the influences of the extreme phases of the teleconnection indexes on the changes in the probability for climatic categories of monthly rainfall, typically drought and abundant rainfall. These analyses could be highly useful for agriculture and water management. Muñoz-Díaz and Rodrigo (2003) explored the changes produced by the different phases of the NAO on the probability of the local monthly rainfall in the southern Iberian Peninsula. The authors evidenced a certain asymmetry detected in January with more extremes linked to the negative NAO phase. Rodrigo (2010) analysed the correlations between the teleconnection indexes and the parameters of the gamma distribution, which were applied to data from 22 stations in the Iberian Peninsula from 1951 to 2002. The author showed the existence of significant relationships between the winter NAO index and the scale parameter, but not with the shape parameter of the gamma distribution. Wan et al. (2012) described the spatial patterns of the extreme monthly precipitation in China by means of the scale and shape parameters of the generalized Pareto distribution, whose regional features depend on the ENSO activities.

In the present study, in order to point out some features of the dependence between rainfall amounts and climate system, the relationships between winter rainfall series observed in the Calabria region (southern Italy) during the period 1916–2010 and the North Atlantic Oscillation Index (NAOI) have been analysed. Firstly, a correlation analysis between precipitation and the NAOI was performed. Subsequently, a composite analysis has been implemented considering only the winter precipitation and the NAOI. Finally, the influence of the different phases of the NAO on the winter precipitation has been detected through a probabilistic approach, which aims at identifying possible changes in the behaviour of the probability density functions (gamma distribution) fitted on monthly rainfall.

2 Case of study

2.1 Area

The Calabria region occupies the southern part of the Italian peninsula (Fig. 1). It has a surface of 15,080 km^2 and a

coastline of 738 km on the Ionian and Tyrrhenian seas. In the North, it borders the Basilicata region for 80 km.

Calabria has an oblong shape with a length of 248 km and a width ranging between 31 and 111 km. Although it does

Table 2 Correlation coefficients between P and NAOI (*significant CCs are marked in bold*)

Code	Rain gauge	December	January	February	Winter
900	Albidona	**−0.268**	−0.013	**−0.292**	**−0.319**
970	Cassano allo Ionio	**−0.376**	**−0.218**	**−0.407**	**−0.474**
1010	Cosenza	**−0.354**	**−0.413**	**−0.593**	**−0.518**
1030	San Pietro in Guarano	**−0.260**	**−0.331**	**−0.530**	**−0.526**
1100	Cecita	**−0.229**	**−0.303**	**−0.306**	**−0.347**
1120	Acri	**−0.277**	**−0.291**	**−0.475**	**−0.331**
1130	Torano Scalo	**−0.345**	**−0.365**	**−0.601**	**−0.573**
1180	Castrovillari	**−0.440**	**−0.362**	**−0.521**	**−0.537**
1360	Longobucco	−0.096	**−0.241**	**−0.379**	**−0.291**
1380	Cropalati	−0.080	−0.079	**−0.255**	−0.160
1410	Cariati Marina	−0.122	−0.187	**−0.300**	−0.124
1580	Cerenzia	−0.046	−0.107	**−0.298**	−0.086
1680	Crotone	−0.091	−0.113	**−0.215**	−0.135
1760	Botricello	−0.172	−0.071	0.002	0.052
1960	Chiaravalle Centrale	−0.167	−0.139	**−0.304**	**−0.260**
1970	Soverato Marina	**−0.208**	−0.145	**−0.305**	−0.200
1980	Serra San Bruno	−0.164	−0.113	**−0.317**	**−0.272**
2040	Monasterace - Punta Stilo	−0.162	−0.190	−0.153	−0.264
2160	Gioiosa Ionica	−0.150	−0.180	**−0.310**	**−0.337**
2230	Plati'	**−0.192**	−0.162	**−0.390**	**−0.421**
2260	San Luca	−0.098	−0.050	**−0.188**	**−0.258**
2270	Sant'Agata del Bianco	−0.105	−0.039	−0.105	**−0.200**
2290	Staiti	−0.131	−0.126	−0.168	−0.207
2310	Capo Spartivento	−0.068	−0.016	0.016	−0.034
2380	Montebello Ionico	−0.155	−0.091	**−0.301**	**−0.257**
2450	Reggio Calabria	**−0.216**	−0.179	**−0.332**	**−0.299**
2460	Reggio Calabria - Arasi'	−0.049	0.066	−0.198	−0.131
2510	Scilla	0.056	**−0.212**	**−0.475**	**−0.358**
2530	Palmi	**−0.215**	−0.149	**−0.379**	**−0.270**
2540	Santa Cristina d'Aspromonte	−0.084	0.016	**−0.398**	**−0.207**
2560	Sinopoli	−0.125	**−0.204**	**−0.412**	**−0.408**
2600	Cittanova	**−0.255**	−0.170	**−0.372**	**−0.490**
2610	Rizziconi	−0.055	−0.185	**−0.452**	**−0.375**
2690	Feroleto della Chiesa	−0.177	**−0.233**	**−0.465**	**−0.291**
2760	Joppolo	−0.104	−0.185	**−0.435**	**−0.308**
2800	Vibo Valentia	−0.119	**−0.215**	**−0.475**	**−0.276**
2830	Filadelfia	−0.131	−0.149	**−0.408**	**−0.225**
2890	Tiriolo	**−0.223**	**−0.416**	**−0.437**	**−0.483**
2990	Parenti	**−0.357**	**−0.495**	**−0.520**	**−0.524**
3000	Rogliano	**−0.312**	**−0.405**	**−0.487**	**−0.436**
3040	Amantea	−0.098	**−0.295**	**−0.535**	**−0.388**
3060	Paola	−0.179	**−0.272**	**−0.484**	**−0.318**
3100	Belvedere Marittimo	**−0.436**	**−0.239**	**−0.441**	**−0.335**
3150	Laino Borgo	**−0.332**	**−0.298**	**−0.553**	**−0.608**
3160	Campotenese	**−0.369**	**−0.378**	**−0.449**	**−0.475**
	Significant negative CCs (%)	33.3	31.1	73.3	57.8

In the last row, the percentages of the rain gauges with significant negative CCs are reported

Table 3 Results of the composite analysis for the winter P series

Code	Rain gauge	Negative NAO conditions				N	P_m	Positive NAO conditions			
		CNA	CA	p_m	n			CNA	CA	p_m	n
900	Albidona	0.24	45.0	372.3	10	72	327.3	−0.36	−68.0	259.2	20
970	Cassano allo Ionio	0.68	71.4	**356.5**	10	77	285.2	−0.57	−59.8	**225.3**	26
1010	Cosenza	0.82	126.5	**542.4**	11	86	415.9	−0.64	−99.1	**316.8**	26
1030	San Pietro in Guarano	0.84	112.1	**519.0**	10	83	407.0	−0.59	−79.5	**327.5**	27
1100	Cecita	0.47	80.8	532.1	10	83	451.4	−0.41	−70.2	**381.1**	25
1120	Acri	0.55	77.6	512.5	10	81	434.8	−0.26	−36.3	398.5	25
1130	Torano Scalo	0.65	84.1	445.3	10	84	361.3	−0.68	−88.0	**273.3**	29
1180	Castrovillari	0.89	125.6	**452.0**	10	85	326.4	−0.57	−80.6	**245.8**	28
1360	Longobucco	0.49	88.1	614.2	8	73	526.1	−0.24	−42.3	483.8	27
1380	Cropalati	−0.05	−10.1	405.9	9	78	416.0	−0.17	−35.2	380.8	28
1410	Cariati Marina	−0.09	−45.0	1,518.5	8	56	1,563.5	−0.26	−124.9	1,438.6	19
1580	Cerenzia	−0.04	−24.9	1,943.7	8	71	1,968.6	−0.26	−155.3	1,813.4	22
1680	Crotone	−0.01	−2.3	1,246.0	9	71	1,248.3	−0.26	−92.7	1,155.6	24
1760	Botricello	−0.73	−288.4	969.4	8	65	1,257.8	−0.28	−109.5	1,148.3	20
1960	Chiaravalle Centrale	0.27	73.6	687.3	11	88	613.7	−0.24	−65.8	547.9	26
1970	Soverato Marina	−0.10	−16.3	345.5	8	64	361.8	−0.38	−59.7	**302.1**	21
1980	Serra San Bruno	0.09	28.2	818.4	10	84	790.1	−0.15	−45.6	744.5	27
2040	Monasterace - Punta Stilo	0.01	7.3	1,427.3	7	45	1,420.0	−0.50	−267.0	1,153.0	11
2160	Gioiosa Ionica	0.31	49.3	413.3	11	83	364.0	−0.21	−34.2	329.8	27
2230	Plati'	0.34	103.7	897.6	10	83	793.9	−0.33	−100.4	**693.5**	28
2260	San Luca	0.14	33.7	519.1	10	77	485.4	−0.12	−30.5	454.9	25
2270	Sant'Agata del Bianco	−0.10	−20.5	399.1	9	72	419.6	−0.04	−8.9	410.7	22
2290	Staiti	0.21	39.0	484.0	9	64	445.0	−0.16	−30.0	415.1	20
2310	Capo Spartivento	−0.11	−14.4	228.8	10	77	243.3	0.09	11.1	254.4	27
2380	Montebello Ionico	0.25	40.3	400.8	8	65	360.5	−0.15	−24.2	336.2	22
2450	Reggio Calabria	0.18	14.3	247.7	9	82	233.4	−0.34	−26.5	206.9	25
2460	Reggio Calabria - Arasi'	0.04	5.6	499.0	9	55	493.4	−0.01	−2.0	491.4	15
2510	Scilla	0.37	39.5	321.5	8	69	282.0	−0.49	−52.0	**230.0**	22
2530	Palmi	−0.04	−5.2	373.3	9	60	378.5	−0.50	−62.3	**316.2**	17
2540	Santa Cristina d'Aspromonte	0.15	43.5	667.6	9	65	624.2	−0.13	−37.2	587.0	21
2560	Sinopoli	0.09	17.1	559.9	11	79	542.8	−0.46	−85.8	**457.0**	27
2600	Cittanova	0.46	109.8	690.0	11	84	580.2	−0.33	−77.9	**502.3**	28
2610	Rizziconi	0.18	29.2	464.3	10	77	435.1	−0.35	−58.4	**376.7**	24
2690	Feroleto della Chiesa	0.52	77.8	491.3	9	81	413.6	−0.31	−45.9	367.6	27
2760	Joppolo	0.41	43.3	381.8	9	74	338.6	−0.33	−34.7	303.9	22
2800	Vibo Valentia	0.21	26.1	394.7	9	80	368.6	−0.32	−39.0	329.6	25
2830	Filadelfia	0.35	72.7	587.4	8	86	514.7	−0.32	−66.6	**448.1**	30
2890	Tiriolo	0.63	137.1	651.9	8	67	514.8	−0.43	−92.9	**421.9**	22
2990	Parenti	0.96	214.0	**813.7**	8	77	599.7	−0.59	−131.0	**468.6**	26
3000	Rogliano	0.95	170.6	**685.0**	10	85	514.4	−0.47	−83.5	**431.0**	27
3040	Amantea	0.79	325.0	**2,149.3**	8	51	1824.3	−0.72	−296.0	**1,528.3**	15
3060	Paola	0.48	73.0	498.7	9	80	425.6	−0.46	−69.5	**356.1**	26
3100	Belvedere Marittimo	0.49	71.6	451.2	8	66	379.6	−0.45	−65.2	**314.4**	19
3150	Laino Borgo	1.07	230.4	**791.0**	9	61	560.6	−0.63	−134.5	**426.0**	19
3160	Campotenese	1.01	235.8	**837.5**	9	84	601.7	−0.61	−141.0	**460.7**	28
	Negative CNA (%)	20.0						97.8			
	Positive CNA (%)	80.0						2.2			

In the last rows, the percentages of the rain gauges with positive and negative CNA are reported

CNA composite normalized anomaly, *CA* composite original anomaly (millimeters), p_m composite mean (millimeters) (with significant values in *bold*), *n* number of years corresponding to the extreme NAOI phase, *N* total number of years, p_m long-term precipitation average (millimeters)

not have many high summits, Calabria is one of the most mountainous regions in Italy: 42 % of the land is mountainous, 49 % hilly and only the 9 % is flat. The maximum elevation is 2,267 m a.s.l., while the average elevation is 597 m a.s.l. Because of its geographic position and mountainous nature, this region has a high climatic variability with a typically dry summer subtropical climate, also known as the Mediterranean climate. The average regional annual rainfall is about 1,100 mm, ranging between 500 mm (northeastern Calabria) and 2,000 mm (Serre Chain). The coastal zones are characterised by mild winters and hot summers with little precipitation (Caloiero et al. 1990).

Colacino et al. (1997) showed that the interaction between the orography and mesoscale circulations leads to a precipitation gradient between the Tyrrhenian and Ionian side of the Calabrian peninsula. In particular, the Ionian side, which is influenced by the currents coming from Africa, has short and heavy precipitation, while the Tyrrhenian side is influenced by western air currents, and it presents considerable orographic precipitation. Numerical simulations of severe weather showed the crucial role

played by orography, which enhances rainfall in localized spots (Federico et al. 2003a, b) or forces secondary cyclogenesis which persists over the Ionian side of the peninsula (Federico et al. 2007).

2.2 Data

The data used in this study are a set of daily precipitation series relative to the period 1916–2010, registered in Calabria by the former National Hydrographic Service. Particular attention has been given to the problems arising from the inhomogeneities of the data series. In this study, each series was tested against the other series, in sub-groups of ten series, by means of a multiple application of the Craddock test (Craddock 1979). This homogenization approach is similar to the one presented in Brunetti et al. (2012), which was applied on monthly rainfall observed in Calabria up to the year 2000. At the end of this procedure, a total of 45 monthly rainfall series resulted homogenous, or have been homogenized, for the period 1916–2010 and are available for analysis, with a mean number of 70 years
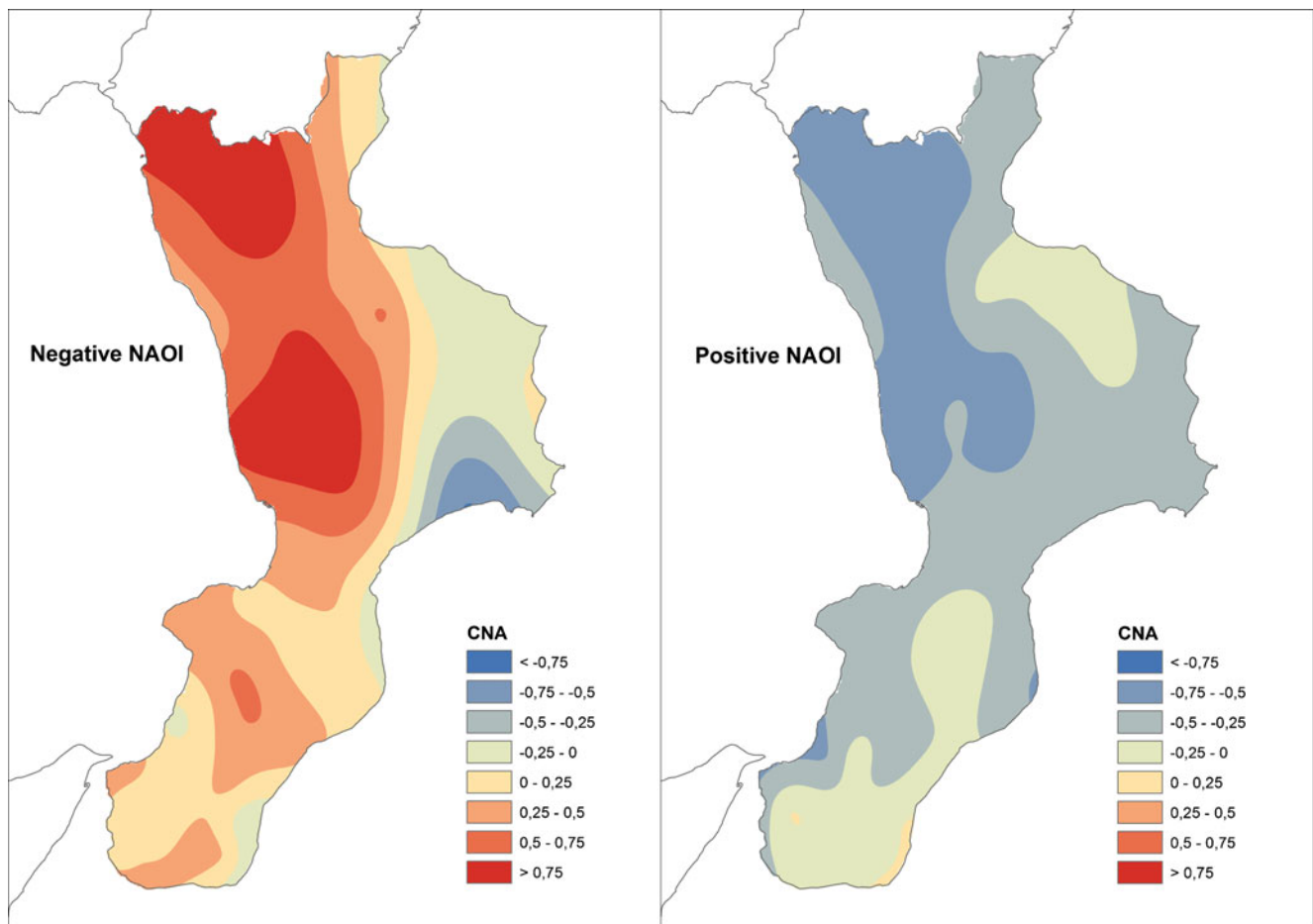
Fig. 2 Spatial distribution of the composite normalized anomaly (CNA) for winter precipitation, with reference to both the extreme negative (<−1) phase (*left*) and extreme positive phase (>1) of the NAOI (*right*)

Table 4 Parameters of the gamma distribution for the February monthly rainfall sub-series related respectively to negative and positive NAO phases

Rain gauge	Negative NAO				Positive NAO			
	α	β	n	D	α	β	n	D
900	2.89	36.48	17	0.114	1.04	62.15	31	0.0603
970	5.06	23	16	0.1575	1.52	44.27	32	0.0815
1010	5.16	34.58	20	0.0915	1.94	42.58	38	0.0438
1030	4.53	35.25	19	0.0671	2.67	29.34	34	0.0734
1100	3.51	47.5	20	0.0653	3.03	31.24	33	0.0476
1120	4.62	34.63	19	0.062	1.84	46.78	34	0.066
1130	5.4	28.4	20	0.0919	1.73	37.98	37	0.07
1180	3	51.38	18	0.182	1.66	40.19	36	0.0553
1360	3.61	42.88	16	0.0641	1.85	58.32	36	0.0663
1380	2.58	44.99	18	0.1183	1.31	68.29	33	0.1422
1410	1.82	46.09	13	0.125	1.19	54.4	21	0.1753
1580	2.98	34.53	20	0.1019	1.02	73.27	30	0.0942
1680	3.19	15.37	20	0.0951	1.18	38.01	36	0.0842
1760	2.26	19.25	16	0.1596	1.31	33.86	24	0.0615
1960	2.31	74.86	21	0.0499	1.86	72.62	37	0.0952
1970	2.63	34.2	16	0.0994	1.89	37.6	28	0.0429
1980	3.05	76.51	19	0.0753	1.53	116.32	34	0.085
2040	1.92	41.61	15	0.2114	1.83	34.43	24	0.0963
2160	2.19	49.94	19	0.1299	1.82	37.86	35	0.0517
2230	2.98	70.88	16	0.0681	1.85	96.03	36	0.0749
2260	3.95	27.58	16	0.118	1.59	64.26	32	0.0434
2270	3.72	23.31	17	0.1212	1.55	56.23	30	0.0344
2290	4.2	22.49	15	0.0733	1.38	62.03	25	0.0884
2310	2.29	20.65	18	0.0519	1.43	39.54	32	0.0353
2380	4.74	17.57	16	0.0806	1.55	36.91	24	0.0815
2450	7.26	8.77	19	0.0866	1.72	26.25	37	0.0494
2460	3.17	39.1	17	0.0388	1.28	68.17	22	0.0686
2510	5	18.07	16	0.0474	1.57	27.47	27	0.0851
2530	4.1	27.17	17	0.0596	1.42	46.8	26	0.0651
2540	2.53	66.37	16	0.0955	1.3	68.02	25	0.1121
2560	2.82	61.01	20	0.0974	1.77	65.69	38	0.0619
2600	4.12	43.98	18	0.0602	1.84	71.26	35	0.0635
2610	4.06	35.54	18	0.0664	2.02	41.88	31	0.077
2690	2.6	54.56	19	0.0767	1.35	63.1	35	0.0667
2760	3.32	33.25	18	0.1148	1.55	38.85	28	0.0497
2800	3.29	37	20	0.0896	1.86	34.95	32	0.0547
2830	2.86	63	19	0.0515	1.86	63.3	37	0.0545
2890	2.72	57.71	16	0.0635	1.96	44.94	26	0.0542
2990	3.74	55.06	18	0.0531	1.6	72.47	33	0.0549
3000	3.86	49.41	19	0.0759	1.77	63.82	35	0.0615
3040	3.56	41.36	13	0.0805	1.62	53.31	17	0.0539
3060	4.12	34.72	17	0.0568	1.67	49.38	33	0.0681
3100	3.21	40.52	17	0.0772	1.32	56.04	25	0.078
3150	3.24	61.93	15	0.0798	1.71	46.2	23	0.0957
3160	2.22	94.02	20	0.0951	1.75	62.45	33	0.0785

α shape parameter, β scale parameter, n number of data, D statistic of the Kolmogorov–Smirnov test

of observation (Fig. 1). The NAOI values used in this study were provided by the Climatic Research Unit of the School of Environmental Sciences of the University of East Anglia at Norwich (http://www.cru.uea.ac.uk/cru/data/pci.htm).

The rainfall dataset was preliminarily analysed for trend, and statistical significance assessed with the Mann–Kendall non-parametric test (Mann 1945; Kendall 1962) which is highly recommended for general use by the World Meteorological Organization (Mitchell et al. 1966) because it can test trends in a time series without requiring normality or linearity (Wang et al. 2008). Table 1 shows the results of the trend analysis applied to the monthly and yearly series of precipitation for each station. On a yearly basis, the statistically significant trends (significance level, 95 %) in the 1916–2010 period are only negative (62.0 % of the whole set of rain gauges). Only three stations present a positive, but not significant, trend. The general negative tendency ranges from −2.1 to −101.0 mm/decade (Table 1). On a monthly basis, the most remarkable negative trends were detected in November and January, with respectively 48.9 and 37.8 % of the rain gauges showing a significant trend. The maximum decreasing rate for January and November are −29.5 and −19.5 mm/decade, respectively (Table 1). Conversely, summer precipitation shows a diffuse positive trend. In particular, in July and August significant trends (5 % confidence level) were detected in the 20 and 22.2 % of the rain gauges. Also, in September a diffused significant positive trend has been detected (35.6 % of the rain gauges), with a maximum increasing rate equal to 16.4 mm/decade.

3 Analysis and results

3.1 Relationships between winter rainfall and North Atlantic Oscillation Index

With the aim to investigate the relationships between winter rainfall series and the NAOI, first a correlation analysis has been carried out; then, the composite means and the composite normalized anomalies for seasonal rainfall, which correspond to the extreme (negative and positive) NAO phases, have been computed for each station.

The correlation analysis has been carried out between the NAOI and the winter precipitation series for three months (December, January and February) and the entire season with reference to the whole observation period 1916–2010. The winter period has been chosen because previous studies revealed a higher correlation than other seasons (Caloiero et al. 2011). At seasonal aggregation, for all the rain gauges (with the only exception of Botricello rain gauge, code 1760) negative correlation coefficients (CCs) have been

detected between the precipitation series and the NAOI (Table 2). Negative CCs are statistically significant for almost all the rain gauges, with the exception of nine stations localized in the Ionian side of the region. Negative CCs have also been obtained for monthly scales, in particular for February, in which 87 % of the rainfall series present significant CCs (max value, −0.601). The analogous percentages for December and January are 42 and 44 %, respectively. In other words, the results obtained in terms of negative CCs, particularly where there are statistically significant values, mean that the Calabria region is characterized by wetter conditions during the negative NAO phase, and drier conditions during the positive one.

The composite analysis starts by selecting from the whole rainfall series the values corresponding to some prefixed classes of the climatic index (Türkeş and Erlat 2003). Particularly, the composite analysis performed in this study refers to winter series selected according to a negative (or weak) climatic index anomaly phase corresponding to normalized index values <−1.0 and a positive (or strong) climatic index anomaly phase corresponding to normalized index values >+1.0 (Caloiero et al. 2011).

Each entire winter rainfall series, characterized by a mean value P_m and a standard deviation σ, has been, therefore, divided into two subseries which correspond to the two different climatic index anomaly phases. Then, for each subseries, the mean precipitation (p_m), the Composite Anomalies (CA)—which is the difference between P_m and p_m—and the Composite Normalized Anomalies (CNA), given by the ratio between CA and the standard deviation σ, have been calculated. This procedure allows to evidence the influence of the extreme NAO phases on the winter
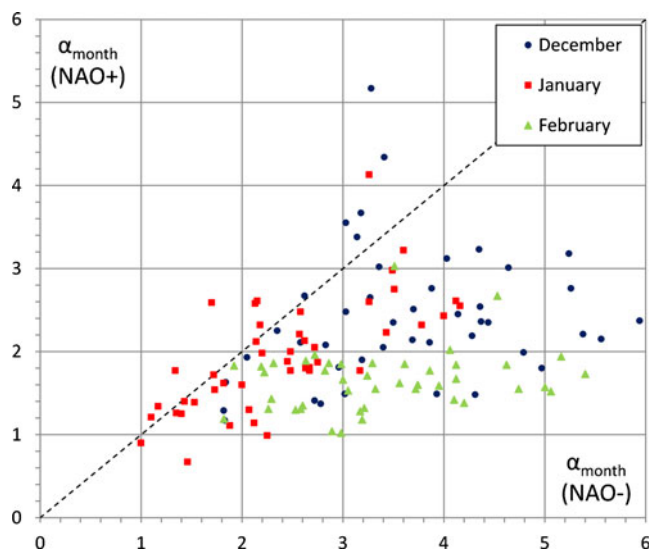
Fig. 3 Values of shape parameter of gamma distribution estimated for the sub-series of monthly rainfall of corresponding to different NAO phases

precipitation amounts. The statistical significance of the CNA values can be verified through the Cramer's t_k test

(Türkeş and Erlat 2003), based on the null hypothesis of no significant difference between a composite mean of the
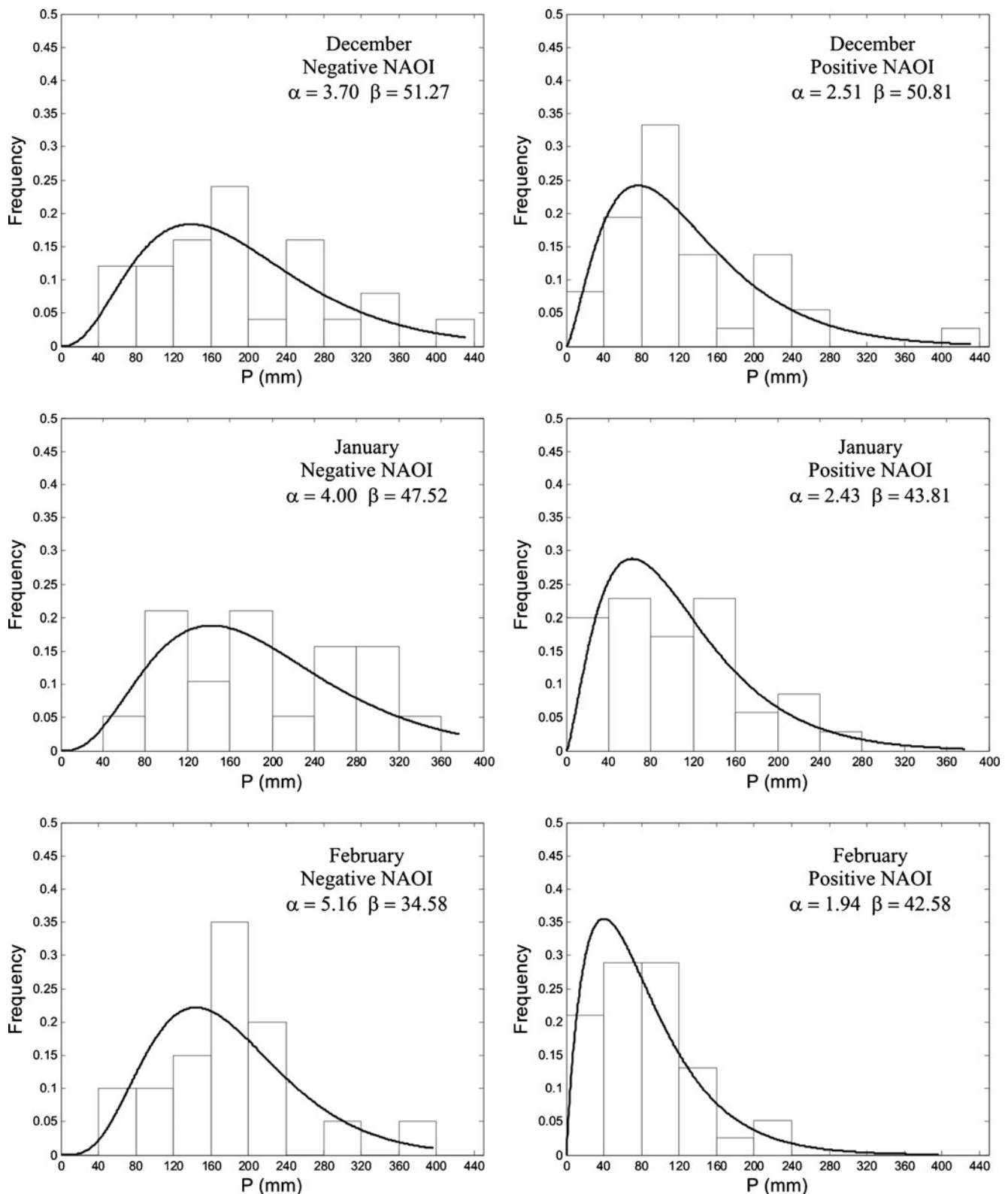
Fig. 4 Gamma distribution (α shape parameter, β scale parameter) fitted to monthly winter rainfall series corresponding to each extreme NAO phase over the period 1916–2010 in Cosenza rain gauge (code 1010)

negative (or positive) NAO phase and the long-term average of the whole period. The t_k statistic is computed as follows:

$$t_k = CNA \cdot \sqrt{\frac{n \cdot (N-2)}{N - n - n \cdot CNA^2}}$$

with N total number of years and n number of years corresponding to the extreme NAOI phase. The test statistic t_k is distributed as the Student's t with $N-2$ degrees of freedom. The null hypothesis of the test is rejected with the two-tailed test for large values of $|t_k|$. Any composite precipitation mean

of a station is considered as a dry (or wet) 'signal' only if the test statistic of t_k computed for that station is significant at the 0.05 level of significance.

The results evidence a clear link existing between the phase of the climatic index and the amount of winter rainfall. In fact, for almost all the rain gauges, the rainfall anomalies present an opposite sign compared with the phase of the NAO (Table 3). In particular, when the latter is negative, the average winter rainfall (p_m) is greater than the average winter rainfall of the whole period (P_m) for 36 out of a total of 45 rain gauges (only 9 statistically significant, according to the Cramer's t_k test). The opposite happens when
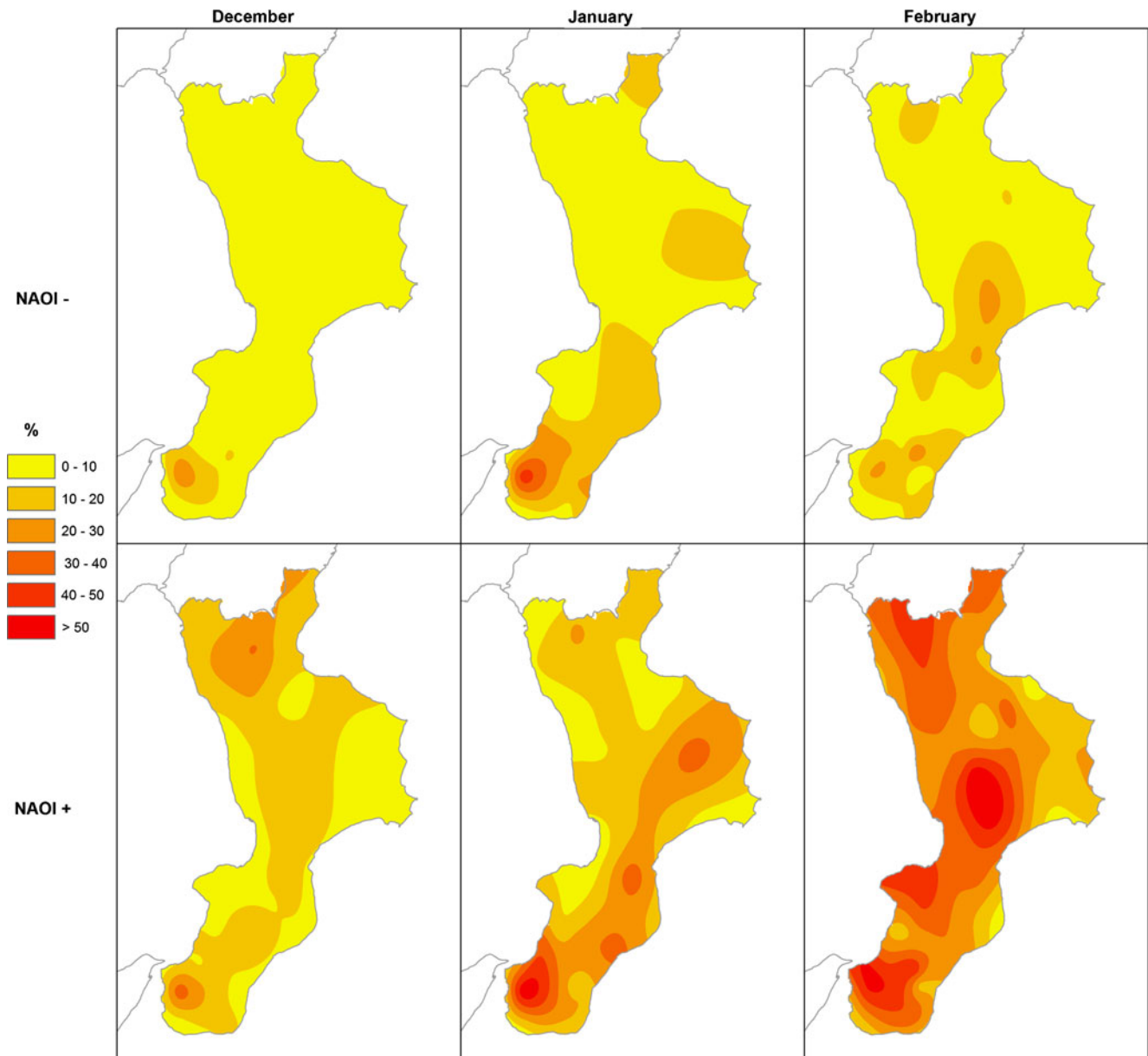
Fig. 5 Distribution of gamma probability values (percentage) related to a dry ($P<P10$) month corresponding to December, January and February rainfall, respectively, for the negative and the positive NAO phases ($P10$ used as threshold value is the 10th percentile of the monthly rainfall for the whole reference period 1961–1990)

the NAOI is positive: 44 rain gauges, out of which 22 statistically significant, present negative values of CNA (Table 3) and only one rain gauge a positive value. The highest absolute values of the CNA (up to +1.07) occur during the negative phase of the NAO and are mainly localized in north-western Calabria. In the same areas, the highest absolute values of CNA, though lower than the previous ones, have been observed for positive NAOI values (Fig. 2). This confirms the influence of the NAO extreme phases on the precipitation amount in winter, particularly as regards the positive phase.

3.2 Use of gamma distribution for assessing change in monthly rainfall

The influence of the different phases of the NAO on the winter precipitation can also be detected through a probabilistic approach aiming at identifying changes in the behaviour of the probability density functions fitted on monthly rainfall (Lucero 1998). In order to adequately fit highly skewed data such as monthly rainfall, the gamma distribution can be assumed (Horton et al. 2001). The general form of the gamma density function is the following:
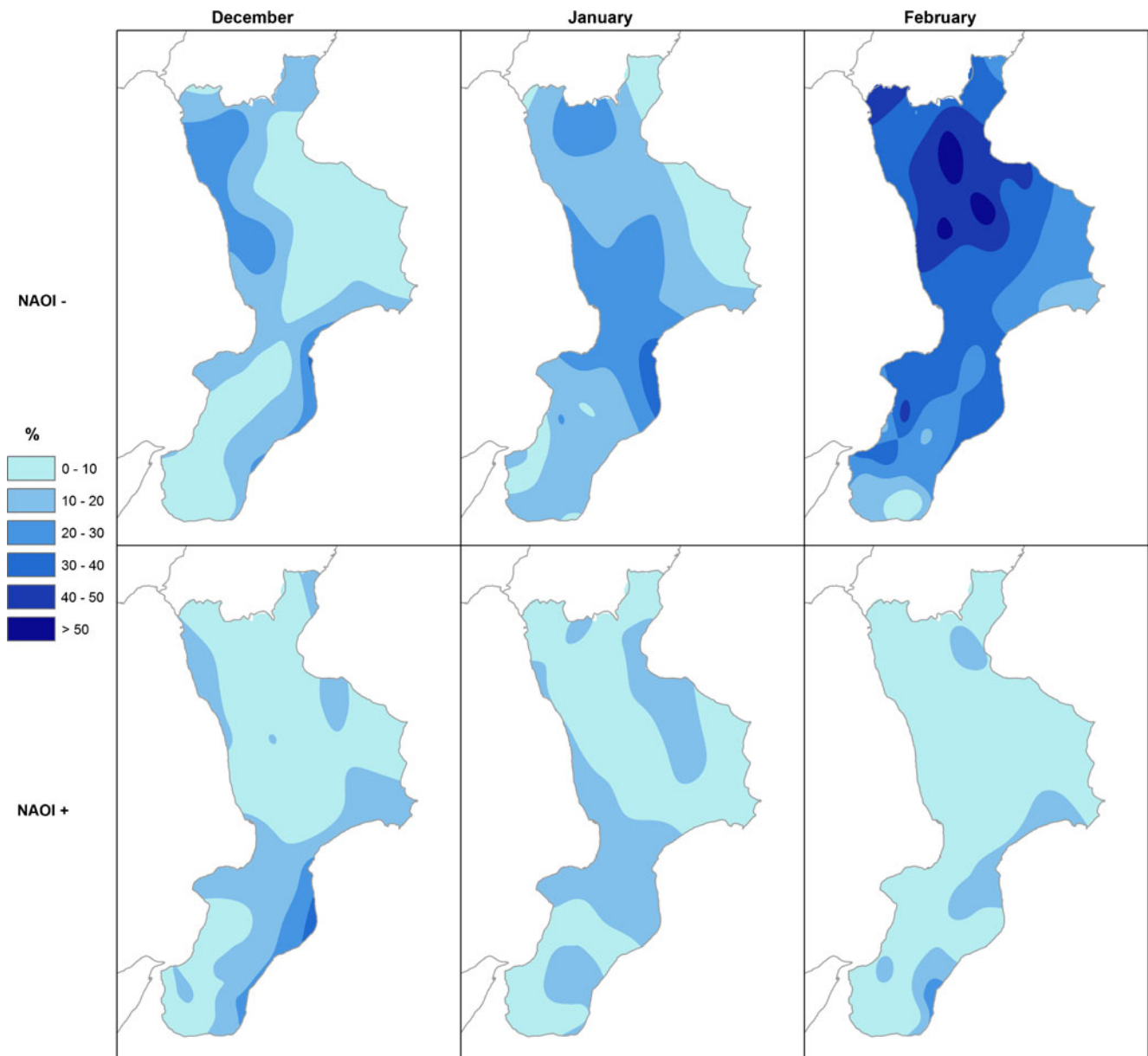
Fig. 6 Distribution of gamma probability values (percentage) related to a wet ($P>P_{90}$) month corresponding to December, January and February rainfall, respectively, for the negative and the positive NAO phases (*P90 used as threshold value is the 90th percentile of the monthly rainfall for the whole reference period 1961–1990*)

$$f(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta}$$

where x is the monthly rainfall, $\Gamma(\alpha)$ is the complete gamma function, α is the shape parameter and β is the scale parameter. The α parameter influences the peak in the curve since it is constrained to be positive. The β parameter has a stronger influence on the width. In particular, small values of α tend to sharpen the peak of the function, while high values of α smooth the skewness, approaching the gamma function to a Gaussian distribution. For highly skewed distributions, the method of moments is less reliable; thus, it is better to adopt the maximum likelihood method for estimating α and β parameters (Sneyers 1990). To test the fit of the gamma distribution on observed data, a Kolmogorov–Smirnov test was performed, and the null hypothesis has been accepted for all the rain gauges.

The gamma distribution has been fitted to the winter monthly rainfall observed at the whole set of rain gauges, with the original precipitation series subdivided, as in the case
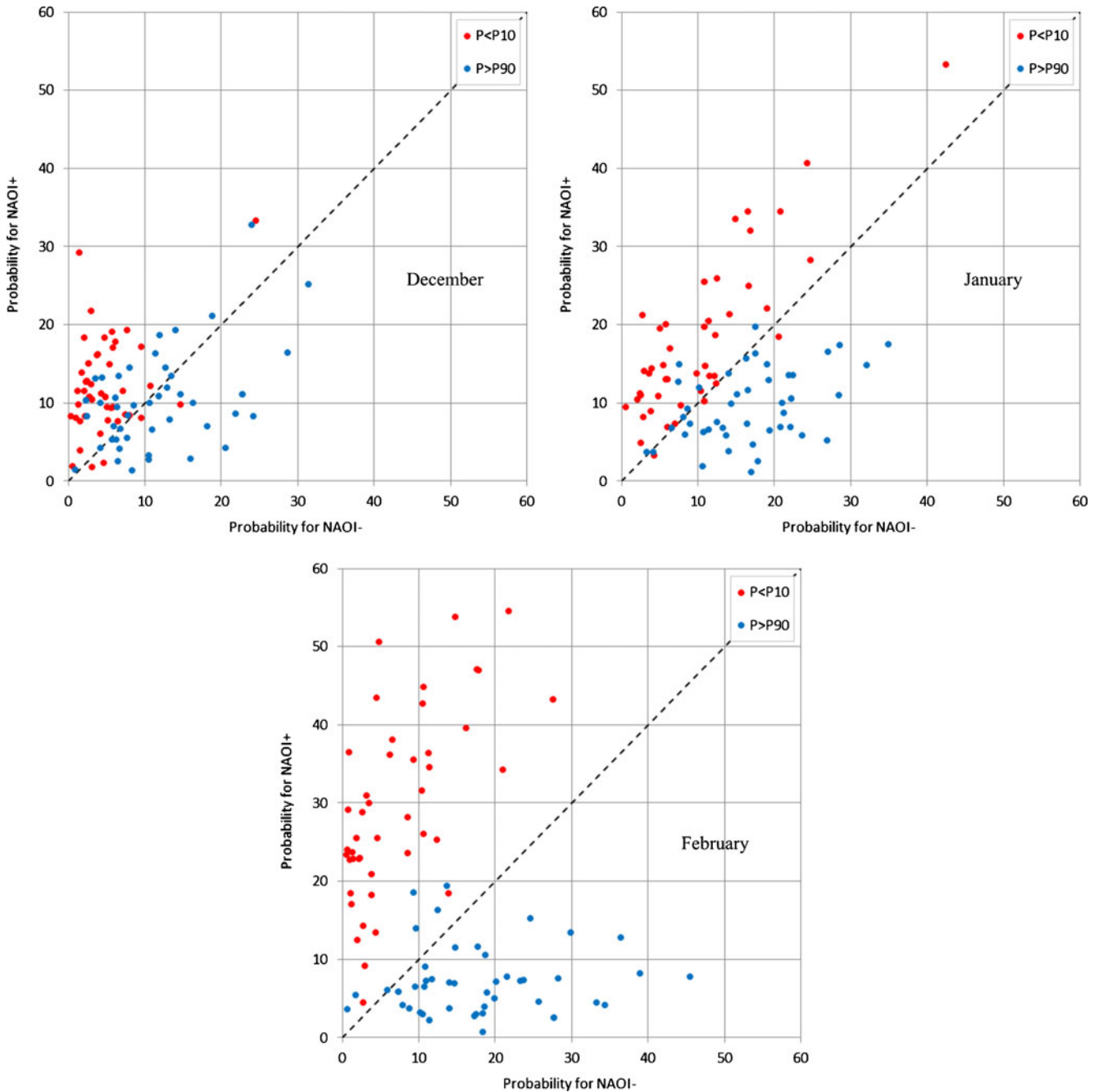
Fig. 7 Comparison of the probabilities of having a dry or a wet winter month, corresponding to the different NAO phases

of composite analysis, into two sub-series corresponding to extreme NAO phases. Table 4 presents the estimated values of the gamma distribution parameters for February rainfall, which shows the best correlation with NAO (Table 2). In general, the results in Table 4 present higher values of the α shape parameter corresponding to the negative phase of the NAO, whereas the β scale parameter does not show a defined behaviour under different NAO phases. In other terms, the peak of the gamma distribution, closely linked to the α parameter, shifts to lower values when the NAOI changes from negative to positive phase, in accordance with the negative correlation detected between the climatic index and the monthly rainfall. The values of the shape parameter estimated for the three analysed monthly rainfall corresponding to the different extreme NAO phases are plotted in Fig. 3. As it can be seen, the greatest part of estimated values of α parameter for the extreme negative NAOI is greater than the correspondent values estimated for the extreme positive NAOI, particularly as to what concerns the values estimated in February when all the points are under the bisector of the quadrant (no-shift line). Consequently, the skewness of the gamma distribution changes when comparing different NAO phases (Fig. 4).

According to the gamma distributions fitted to monthly rainfall subseries correspondent to the different NAO phases, and using as thresholds the percentiles P10 and P90 of the reference period 1961–1990, it is possible to estimate, for each station and month, the probabilities of having a dry (P<P10) or a wet (P>P90) month. Figures 5 and 6 show the spatial distribution of the probabilities of dry and wet months corresponding to the NAO phases during the winter months. In December, the probability of drought (P<P10) ranges between 1.9 to 33.3 % for the positive NAO phase, with an average value of 12.3 %, while the average probability of abundant rainfall (P>P90) is around 11.5 % when the NAO phase is negative, with a maximum value of 31.4 % and a minimum one of 0.9 %. In January, the mean probability is 18 % (range, 3.4÷53.4) for droughts during a positive NAO, and 16.6 % (range, 3.3÷34.8) for abundant rainfall during a negative NAO. In February, the probability of dry months during a positive NAO ranges between 4.5 and 54.6 % (mean value, 29.7 %), and the probability of wet months during a negative NAO phase is around 17.7 % (range, 0.6÷45.4).

Figure 7 clearly shows, for all the rain gauges and relatively to February, the influence of the different NAO phases on the probability of having a dry or a wet month. This influence is particularly evident for all the rain gauges as regard the probability of having a dry month (P<P10).

4 Conclusions

The aim of the present study was an analysis of the relationships between winter rainfall series observed in the Calabria region and the North Atlantic Oscillation Index. Preliminarily, a correlation analysis between monthly and seasonal winter precipitation and the NAOI has shown a general negative correlation, with statistically significant values of CCs for almost all the rain gauges at a seasonal scale, and at a monthly scale particularly for February (87 % of significant CCs). Subsequently, a composite analysis implemented considering only the winter seasonal precipitation and the extreme NAO phases has evidenced that, for almost all the rain gauges, the rainfall anomalies and the NAO phases are in opposition.

The influence of these different phases of the NAO on winter precipitation has also been confirmed through a probabilistic approach aiming at identifying changes in the behaviour of the probability density functions (gamma distribution) fitted on monthly rainfall. More specifically, the probability of having a dry month is lower when the extreme NAOI is negative, while it is clearly higher for the extreme positive phase of the NAO. On the contrary, the occurrence probability of a very wet month is more remarkable during extreme negative NAOI than during the extreme positive phase of the NAO. Such behaviour is highly marked for February.

This study evidences that the relationship between rainfall and NAO cannot only be limited to an increase or a decrease in precipitation amounts related to the NAO phase, but also imply significant changes in the monthly rainfall probabilities. Nevertheless, the clear correlation between wet/dry conditions in the Calabria region and extreme phases of the NAO index, in this phase of the study it is not possible to use the teleconnections for seasonal forecasts since the available data for the extreme NAOI are very few (8–10 years) in comparison with the whole dataset (about 70 years). If these tendencies will be confirmed in the next years with a longer database, the corresponding results could be implemented and used as predictive tools in integrated systems devoted to water management and civil protection actions.

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