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Brief communication "Calabria daily rainfall from 1970 to 2006"

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Abstract. This brief communication introduces a new quality-controlled precipitation database for Calabria, shows the precipitation trend for the period considered, and correlates daily rainfall with some common teleconnection patterns. The database consists of daily accumulated precipitation collected by 61 rain gauges from 1 January 1970 to 31 December 2006.

The 37-year trend in yearly rainfall shows a decrease of 4.7 mm/y, with a 17% reduction in the yearly mean value.

The correlation of the daily rainfall with large-scale patterns shows that the Mediterranean Oscillation Index (MOI a/c) is a useful predictor of daily precipitation over Calabria.

1 Introduction

The motivations of this brief note are to present a new precipitation database for the Calabria peninsula (Fig. 1a, b), to show the precipitation trend for the period analyzed, and to correlate daily precipitation with large-scale patterns. These goals are of interest to the general community because the literature on precipitation over the central Mediterranean is still rather poor and needs to be improved.

Contrary to the tendency in many areas of the world (Day et al., 1997), the Mediterranean Basin shows decreasing precipitation in the last 50 years, as reported in several studies (Xoplaki et al., 2000; Paz et al., 1998; Kostopoulou and Jones, 2005; Romero et al., 1998; Piervitali et al., 1998), with a reduction of 10 to 20% in the central-western Mediterranean Basin. Those studies considered only one or two raingauges in Calabria and focused their attention on different areas. This paper presents the precipitation trend over Calabria from 1970 to 2006 and discusses the result in the framework of previous findings, using a much greater number of rain gauges.

Variations in daily rainfall are often related to teleconnection patterns, expressing the global or regional circulations. The North Atlantic Oscillation (NAO) is well correlated with climate conditions over Europe and over the Mediterranean (Wallace and Gutzler, 1981; Hurrel, 1985). The El Niño Southern Oscillation (ENSO) is well correlated with North and Central Europe precipitation (Moron and Ward, 1998; van Loon and Madden, 1981). Conte et al. (1989) showed the importance of the Mediterranean Oscillation Index (MOI a/c, Algiers-Cairo) to precipitation over Italy and North Africa. This index is derived from the seesaw oscillation of the mean annual geopotential height at 500 hPa between Algiers and Cairo. Based on this concept, a similar seesaw pattern between Gibraltar and Israel is considered between the western and eastern Mediterranean (MOI i/g; Kutiel and Paz, 1998). Eastern Atlantic (EA) and Eastern Atlantic/West Russia (EA/WR) oscillations play an important role in the precipitation variability over the eastern Mediterranean (Krichak and Alpert, 2005).

In this short communication we correlate several teleconnection indexes (ENSO, NAO, MOI, EA, EA/WR) with daily precipitation over Calabria to find useful predictor(s).

2 Data and methodology

The initial database consisted of measurements from rain gauges provided by the Regional Agency for Environmental Protection. Rain gauges have different record lengths and all stations have missing data. At present, the number of rain

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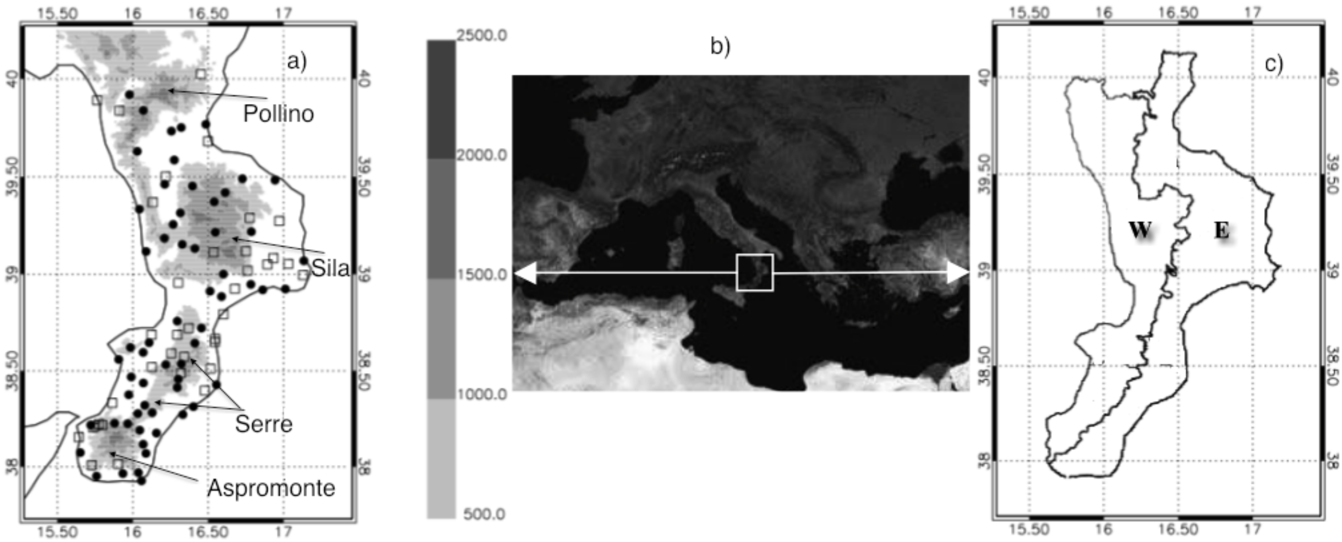

Fig. 1. Panel **(a)** the regional rain gauge network; panel **(b)** Calabria region in the central Mediterranean; panel **(c)** the two sub-regions (see text).

gauges in the regional network is 127. Their positions are marked both by squares and filled circles in Fig. 1a.

All stations are equipped with a tipping-bucket rain gauge and have a sampling rate of 20 min. Daily accumulated rainfall is used in this work.

A compromise was necessary between considering as many stations as possible and retaining a considerable amount of valid data for each station. The final decision was to keep all stations having at least 80% of data available from 1 January 1970 to 31 December 2006. This choice reduces to 61 the number of suitable rain gauges (filled circles in Fig. 1a). The average of the minimum distance between rain gauges is 11 km, which can be assumed as a measure of the spatial resolution of our database.

The Regional Agency for Environmental Protection applies a data quality control procedure to the measurements. This procedure is based on a check of the physical internal coherence and spatial inter-comparison of data. Because all stations have missing data, the gap-filling procedure and data quality control reported in Federico et al. (2009) was also applied. This methodology generates a new time series for each station (target station) by interpolating the records of the surrounding stations within a search radius of 50 km. The weight assigned to each station is the square of the ratio between the precipitation correlation coefficient (computed between the interpolating and target stations) and distance. This functional form gave better performance compared to others (for details see Federico et al., 2009). A missing record of the target station is substituted with the interpolated value. Only stations that share at least 1000 days of common precipitation records with the target station are considered in the interpolation process, which uses all 127 rain gauges. Even if the data filling could smooth the precipitation field, we note that the algorithm is designed to preserve gradients because: a) the weights take into account the correlation between the interpolated and interpolating stations; and b) the precipitation of the interpolating station is scaled by the average ratio between the precipitation at the interpolated station and the precipitation at the interpolating station.

After the gap-filling procedure, there are no missing data for the 61 rain gauges for the whole period. The number of gaps filled for each station varies from 93 (0.7% of the 13 757 total data points) to 2511 (18% of the 13 757 total data points). Data filling over years varies from no gaps filled for 1970 to 3608 gaps filled for 1998 (16.2% of the 22 265 yearly total data).

The spatial distribution of the 61 rain gauges is rather homogeneous and covers both mountains and lowlands. None of the rain gauges were relocated.

In addition to the whole region, Calabria is divided in two sub-regions (Fig. 1c): western (W) and eastern (E). The western sub-region has 28 gauges and the eastern sub-region has 33 gauges (Fig. 1a, c). The two sub-regions are useful to assess, indirectly, if large-scale patterns play a role in the type of storms affecting the region. In a previous study (Federico et al., 2008) it was shown that: a) western Calabria is more exposed to storms originating in the lee of the Alps; and b) eastern Calabria is more exposed to African storms (originating in the lee of Atlas and propagating toward the central Mediterranean). So, correlations between large-scale patterns and precipitation over Calabrian sub-regions indirectly suggest a larger incidence of particular types of storms.

Precipitation was correlated with the NAO, EA, EA/WR, and MOI (a/c, Algiers and Cairo, i/g, Israel and Gibraltar) teleconnection patterns. Correlations with Niño 3, Niño 4 and Niño 3.4 were also studied but no significant

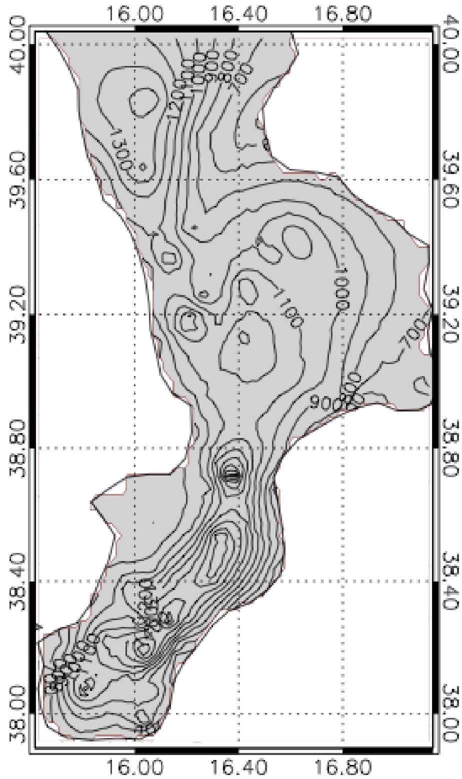

Fig. 2a. Annual precipitation over Calabria (average from 1970 to 2006). Contours from 600 mm to 1500 mm. Contour interval: 100 mm.

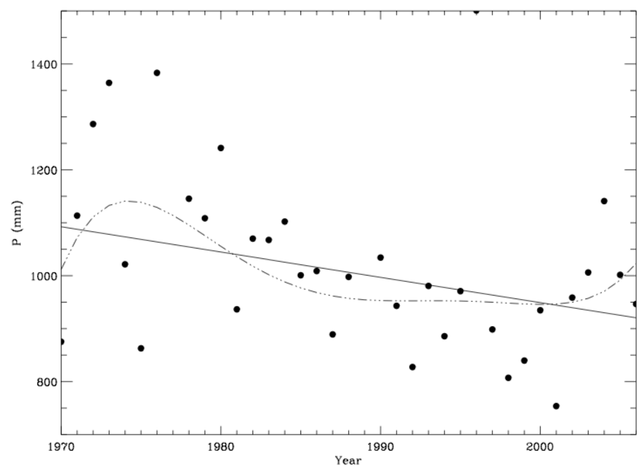

Fig. 2b. Linear trend of the yearly rainfall over Calabria. A fifth-order polynomial fitting is also shown. Among polynomials from the first to seventh degree, the fifth order minimizes the sum of squared differences between the interpolating curve and the original time series.

correlations were found. The monthly values of the NAO, EA, EA/WR, and Niño indexes were downloaded from the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center website (http://www.cpc.noaa.gov/data/teledoc/nao.shtml), and the MOI index monthly values were downloaded from the University of East Anglia website (http://www.cru.uea.ac.uk/cru/data/moi).

The *Spearman rank-order* (or nonparametric) correlation coefficient (r_s; Wilks, 1995) is used to measure the association between the precipitation and large-scale patterns. The nonparametric correlation is chosen because it is both robust and resistant in a statistical sense. Moreover, to assess the significance of the correlation, it does not require that the original data must follow any particular statistical distribution.

To evaluate the significance of the r_s value, a resampling method with bootstrap is used (Wilks, 1995). The basic idea is to build up a collection of artificial data batches (10 000 in our case) of the same size of the actual data at hand, in a manner consistent with the null hypothesis (i.e., that the precipitation and large-scale pattern index are uncorrelated), and then compute the Spearman correlation coefficient for each artificial batch. Taken together, these test statistics constitute an estimated null distribution against which to compare the test statistic computed from the original data.

3 Results

3.1 Precipitation trend

Before considering the correlation between daily rainfall and large-scale patterns, we introduce the precipitation field (annual mean) and trend for the 37 years considered.

The annual rainfall average from 1970 to 2006 is shown in Fig. 2a. The orographic signature is clear. From north to south there are maxima corresponding to the highest mountains of Calabria: Pollino (1400 mm), Sila (1200 mm), Serre (1500 mm) and Aspromonte (1400 mm).

There is a rainfall gradient from west to east. Minimum precipitation near the coastline is less than 600 mm east of Pollino and less than 700 mm east of Sila. These minima are a consequence of the shielding effect of the mountains because Mediterranean storms usually impinge Calabria from west to east (Federico et al., 2008, 2009).

The yearly precipitation amount, i.e., the average of the stations' yearly rainfall, shows an average decrease of 4.7 mm/y, with a reduction of 17% in the yearly mean value (1006 mm, Fig. 2b). The linear trend is significant at 90% level. The decrease depends on the season: it is 2.5 mm/y in winter and 1.5 mm/y in fall and spring, while the summer rainfall trend is positive (0.5 mm/y). This result is expected because Calabria has a typical Mediterranean climate (Federico et al., 2009) characterized by rainy winters and dry summers. Since precipitation is low in summer, we expect that the yearly precipitation reduction should occur mainly in other seasons and especially in the cold semester (from 1 October to 31 March), which accounts for 80% of the yearly total rainfall.

Table 1. Significant correlations (bold and italic: 99% level, plain text: 95% level) between the cold-season rainfall categories and the teleconnection indexes, for the two sub-regions of Calabria (W, E) and for the whole region (C). The value of the Spearman regression coefficient is also reported for each significant correlation (rows: R_NAO, R_EA/WR, R_MOI a/c, R_MOI i/g).

Rain/ index	0–4 (mm/d)	4–16 (mm/d)	16–32 (mm/d)	32–64 (mm/d)	> 64 (mm/d)	Total rainfall
NAO	–	W,***E***,***C***	E,C	W	–	W,C
R_NAO	–	−0.39,***−0.47***,***−0.43***	−0.35,−0.31	−0.31	–	−0.35,−0.31
EA/WR	–	W	–	–	–	–
R_EA/WR	–	−0.37	–	–	–	–
MOI a/c	E	***W,E,C***	***W,E,C***	***W,E,C***	W,***E***,C	***W,E,C***
R_MOI a/c	−0.34	***−0.58,−0.63,−0.62***	***−0.51,−0.59,−0.58***	***−0.50,−0.52,−0.54***	−0.39,***−0.42***,−0.41	***−0.61,−0.68,−0.65***
MOI i/g	–	***W,E,C***	W,***E***,C	W,E,C	W,E,C	***W,E,C***
R_ MOI i/g	–	***−0.46,−0.50,−0.50***	−0.35,***−0.43***,−0.41	−0.39,−0.40,−0.40	−0.34,−0.35,−0.35	***−0.48,−0.53,−0.51***

The linear trend is in agreement with previous findings in the Mediterranean Basin (Xoplaki et al., 2000; Paz et al., 1998; Kostopoulou and Jones, 2005; Romero et al., 1998; Piervitali et al., 1998). Piervitali et al. (1998), in particular, divided their analysis of the Mediterranean Basin into three belts: northern (>42° N), central (38° N–42° N), and southern (<38° N), and found a reduction in the yearly precipitation amount of 13, 20, and 26%, respectively. Considering the difference in the years analyzed, our result compares reasonably well with previous findings.

The polynomial fitting is useful to illustrate changes in the precipitation regime within the 37-year period. It shows that the yearly precipitation increased from 1970 to 1975, decreased from 1976 to 1988, and was then almost constant until 2004, when it started to increase again.

3.2 Correlation with large-scale patterns

This section shows the correlation between the daily precipitation and large-scale patterns. To study whether correlations are particularly important for selected pairs of precipitation-geographical area, in addition to the total daily precipitation and to the whole region, we define five rainfall intensities and two geographical sub-regions.

Rainfall intensities are defined as: light (0–4 mm/d); moderate (4–16 mm/d); moderate-heavy (16–32 mm/d); heavy (32–64 mm/d); and severe (>64 mm/d). The usefulness of the power of 2 thresholds, i.e., 2^n as indicated above, and its comparison with thresholds adopted in other studies is discussed in Alpert et al. (2002). We remark that thresholds allow the evaluation of the contribution of different rainfall categories to the rainfall totals. Considering the daily rainfall over the whole region, the moderate category has the highest contribution (32%). The second-highest contribution is from the moderate-heavy category (28%). The third-highest contribution is from the heavy category, accounting for 21% of the total yearly rainfall. Severe rainfall follows (12%), while the remaining 7% is from the light category.

The daily precipitation was correlated with several teleconnection patterns both for the cold semester and for winter (DJF). The same behaviour was found for cold semester and for winter, which supports the robustness of the analysis. In the following discussion we consider the correlation with the cold semester.

The correlation was computed as follows. For each category and sub-region (including the total daily rainfall and the whole region), the daily precipitation is the sum of the daily rainfall recorded in that category by all rain gauges belonging to that sub-region. For example, if one day in sub-region W, 3 mm are recorded at one station, 5 mm at four other stations, and 0 mm in the remaining stations, the daily precipitation is 3 mm for the light category, 20 mm for the moderate category, and 0 mm for the other categories. A monthly rainfall value is then computed for each category/sub-region by adding all the daily precipitation in the category/sub-region. The cold semester rainfall is computed by adding monthly data from October to March. Finally, cold semester rainfall is transformed into a standardized anomaly (SA, Wilks, 1995) and correlated with the average of pattern indexes for cold semester for each category/sub-region. Results are shown in Table 1.

No significant correlations were found with pattern EA.

The spatial correlation between the EA/WR index and precipitation over Europe was considered in Krichack and Alpert (2005). They found a significant relationship over wide areas of the eastern Atlantic and southeastern Mediterranean. The correlation was not significant for the central Mediterranean and our result confirms this for Calabria. Nevertheless, sub-region W shows a significant (95%) negative correlation for the moderate category.

The NAO shows a significant negative correlation with precipitation in several sub-regions of Calabria. Significant correlations were found for the total rainfall and for all precipitation categories with the exception of light and severe. Table 1 shows that correlation coefficients never reach the absolute value of 0.5 and the regression is not very strong because the proportion of the variation of the predictand described by the linear regression never reaches 25%. Precipitation in western Calabria is more correlated with the NAO compared to eastern Calabria. A negative NAO implies, among other things, an increase in cyclones that develop in the lee of the Alps (Serreze et al., 1997), and the W sub-region is more exposed to these storms. The correlation weakens with increasing precipitation thresholds because values have a larger year-to-year variability and their scatter around the regression line is larger. On the opposite side, the light precipitation threshold exhibits a lot of noise, which explains the low correlation with all indexes.

The MOI a/c has a negative correlation with precipitation over Calabria. Total rainfall has significant (99%) correlations with MOI for all sub-regions. The same result is obtained for the moderate, moderate-heavy, heavy, and severe categories. For some pairs of category/sub-region the absolute value of the correlation coefficient is larger than 0.6, showing a rather strong correlation. Sub-region E is particularly well correlated with the MOI a/c (99% for all categories). This is expected because the position of the MOI a/c poles, Algiers and Cairo, takes well into account the development of African storms that are important for the precipitation over eastern Calabria.

The correlation with the MOI i/g is similar to the MOI a/c, however the strength of the correlation is lower. This is expected because the poles of the MOI a/c are closer to the target area compared to the MOI i/g.

4 Conclusions

This short communication introduces a new quality-controlled daily precipitation database for the Calabria peninsula, presents the precipitation trend from 1970 to 2006, and studies the correlation of daily rainfall with large-scale patterns. Its aim is to improve the literature on precipitation over the Central Mediterranean. After applying a data quality control apt to retain the largest number of stations while preserving a reliable dataset, 61 of the 127 rain gauges were selected. The database consists of daily accumulated rainfall from 1 January 1970 to 31 December 2006. Its spatial resolution (11 km) and distribution are enough to study the differences between western and eastern Calabria.

As reported in several studies, the Mediterranean precipitation shows a decrease over the last 50 years (20% of the yearly total amount for the latitude of Calabria). This paper confirms this trend for the 37 years analyzed, because we found a 17% reduction of the yearly mean value (1006 mm).

We correlated, using the Spearman rank correlation coefficient, the daily rainfall of the cold semester and DJF with the atmospheric patterns ENSO, EA, EA/WR, NAO, and MOI (a/c, Algiers-Cairo and i/g, Israel-Gibraltar). The NAO shows several significant (95–99%) negative correlations with precipitation over Calabria, especially for the moderate category, which accounts for the largest proportion of the rainfall. The MOI i/g is well correlated with precipitation over Calabria for all categories, with the exception of light. However, the best (negative) correlation was found with the MOI a/c index. In particular, all sub-regions show significant correlations (99%) of their total rainfall with the MOI a/c and all sub-regions show significant correlation (95–99%) for moderate, moderate-heavy, heavy, and severe precipitation categories with the MOI a/c. Eastern Calabria rainfall is well correlated with the MOI a/c (99% for all categories with the exception of light).

A significant negative correlation between the MOI a/c index and the precipitation in southern Italy and the southern Mediterranean has already been found (Conte et al., 1989; Piervitali and Colacino, 2003). Our study confirms this result for Calabria using a different dataset and a much greater number of rain gauges.

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