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The analysis of the Standardized Precipitation Index in the Mediterranean area: regional patterns

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Abstract
In the present paper we propose a method to assess regional drought by using rain-gauge observations. In particular, we analyse the rainfall on the Marche region. We diagnose drought by means of the Standardized Precipitation Index, specifically analysing the period from January 1948 to December 1981. We present a preliminary comparison of these results with those obtained using large-scale precipitation data. We obtain a good agreement between the large-scale analysis and the local (regional scale) observations.

Key words *Rainfall observations – drought – climate variability*

1. Introduction

In Bordi *et al.* (2001) we analysed large-scale drought conditions in Italy using the Standardized Precipitation Index (SPI). In the last fifty years severe dry events have been shown as a recurrent condition on particular locations. We also gained insight into the diagnosis of drought events and demonstrated that the SPI is a useful tool that should be used operationally as part of a national drought watch system aimed at objectively monitoring climatic conditions.

A proposal for a monthly bulletin of drought over Italy was also presented. From a scientific point of view, results suggested that a global analysis, or a reanalysis like that of NCEP/NCAR used in Bordi *et al.* (2001), which has a typical grid spacing of about 200 km at middle latitudes, is not affected by any essential limitation in detecting climate behaviour. Large deviations of the climatic variables, in fact, are often related to large-scale atmospheric features.

However, a coarse resolution may be a more serious problem when drought warning must be delivered to the general public by an operational centre. Potential users, in fact, are usually interested in very local conditions. Moreover, when the input data are provided by global analysis, a limited number of observations are taken into account in processing the analysed data (see Kalnay *et al.*, 1996). As a consequence, the agreement between reanalysed fields and the interpolations of the same fields measured at local stations cannot be assessed *a priori*. This appears particularly relevant if the area in question is the Mediterranean basin. In this region, in fact, synoptical features are strongly modified by local moisture sources, complex topography and other local scale phenomena.

Thus, in this paper we present a preliminary analysis of the drought history as deduced from

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rain gauges measurements and, at the same time, make a comparison with the results reported in Bordi *et al.* (2001) for the large scale. Our main purpose being to lay the scientific ground for setting up a drought-watch system, the present study can be considered as a check on the reliability of local observations for climatic use.

The paper is organised as follows. In Section 2 we show the large-scale analysis of drought in Italy based on the SPI for December 1981. In particular, the historical reconstruction of drought from 1950 to 1981 is presented for the NCEP/NCAR grid-point nearest to the Marche region. In Section 3 we analyse the precipitation regime on Marche region and we present the method used for the comparison of the ensuing results with those obtained for the large-scale. In Section 4 we compare the regional analysis with that obtained using the reanalysed data. Some conclusions and suggestions for future work are drawn in the final section.

2. Large-scale analysis of drought in Italy

Following the methodology described in Section 3 of Bordi *et al.* (2001), we compute the SPI for Italy using the NCEP/NCAR reanalysis precipitation rates having $1.9° \times 1.9°$ grid spacing in longitude and latitude.

To compare the large-scale analysis of drought in a particular area of Italy (in the present paper we refer to the Marche) with that obtained using rain gauge data, we first set a common reference time-record to be used for the analysis. Since the station data for the Marche region were available from January 1948 to December 1981, in correspondence with the standard WMO climatic reference period, we restricted the large-scale analysis to this period. The drought condition is then evaluated as described in Bordi *et al.* (2001).

Figures 1a-d show the SPI for December 1981 on 3, 6, 12 and 24-month time scale respectively for the Italian area. For the classification of the SPI values see table II in Bordi *et al.* (2001). Figures show that on a 3-month time scale Northern and Central Italy are characterised by normal or wet conditions, while the remaining regions are affected by moderately dry events. The result for a 6-month time scale reveals that only Calabria and Sicilia are characterised by moderate or severe drought. On longer time scales, say a 12 and 24-month time scale, Central Italy remains in a near normal or moderately wet condition, while the other regions are in moderately or severely dry regimes. These results suggest that in some regions the occurrence of rainy periods balances the deficiency of precipitation on shorter time scales, but an imbalance remains for longer time scales (see for example the Alpine area).

In correspondence with the Marche region there is only one grid-point at 13.1°E longitude and 42.9°N latitude. For future comparison with rain-gauge data analysis, we show in figs. 2a-d the monthly SPI time history, for the above selected time scales, at the considered grid-point. Figures, which refer to the period spanning from January 1950 to December 1981, highlight several fluctuations, especially on relatively short time-scales. A cursory inspection of the figure for longest time scale (24-month) shows that during the periods 1950-1951, 1958-1960, 1972 and 1979 the region was characterised by extreme drought conditions (*i.e.* the index has values near or less than -2). This suggests that, during these periods, the region was affected by a hydrological drought with a consequent reduction of water resources.

3. Local precipitation on the Marche region and its comparison with the reanalysis

Monthly precipitation at 45 rain gauge stations distributed over the entire area of the Marche region is analysed for the period 1948-1981. The list of stations is reported in table I and their geographic distribution is shown in fig. 3. In the same figure a 100 m resolution altitude is also reported. It is clear that the altitude distribution of stations is not uniform in space. Such an impression is quantitatively confirmed by the analysis, shown in fig. 4a,b, of the statistical distribution of surface points and stations: fig. 4b clearly suggests that the stations do not uniformly cover areas of different altitude. In addition, areas at altitude higher than 1000 m are not covered at all. The question here

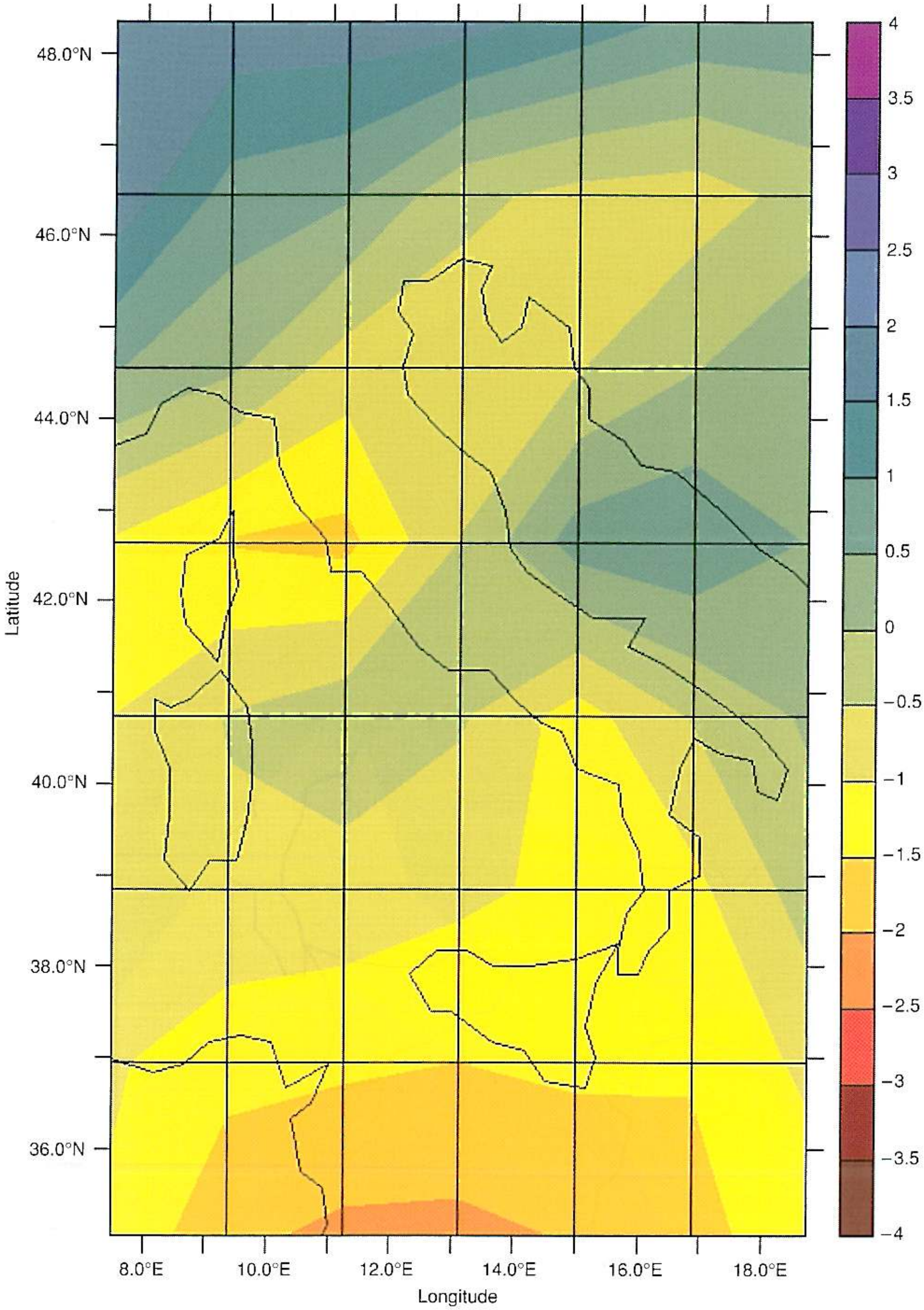


Fig. 1a. SPI for Italy on a 3-month time scale. Computation refers to December 1981 and data used for the analysis are NCEP/NCAR precipitation rates.

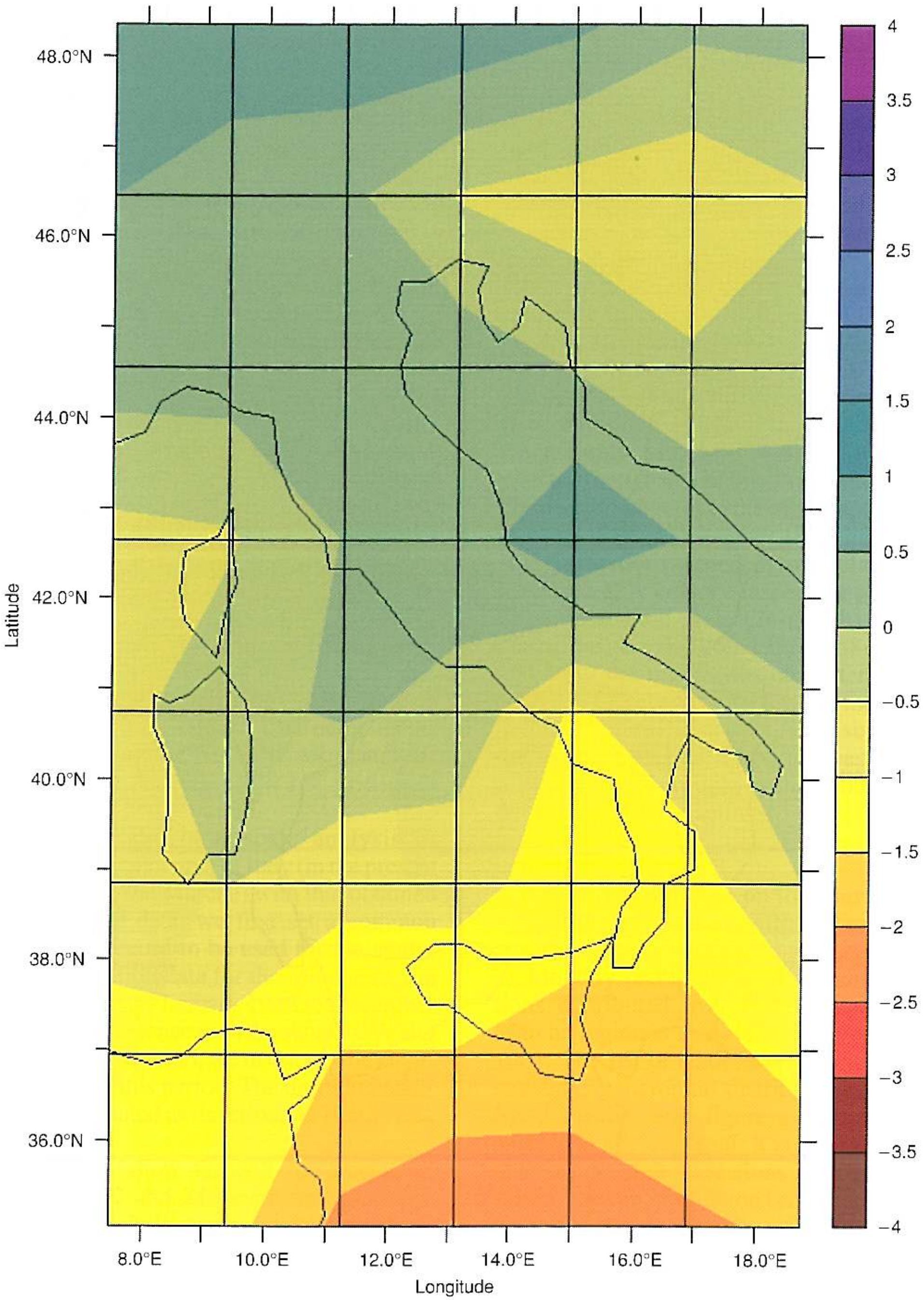


Fig. 1b. SPI for Italy on a 6-month time scale. Computation refers to December 1981 and data used for the analysis are NCEP/NCAR precipitation rates.

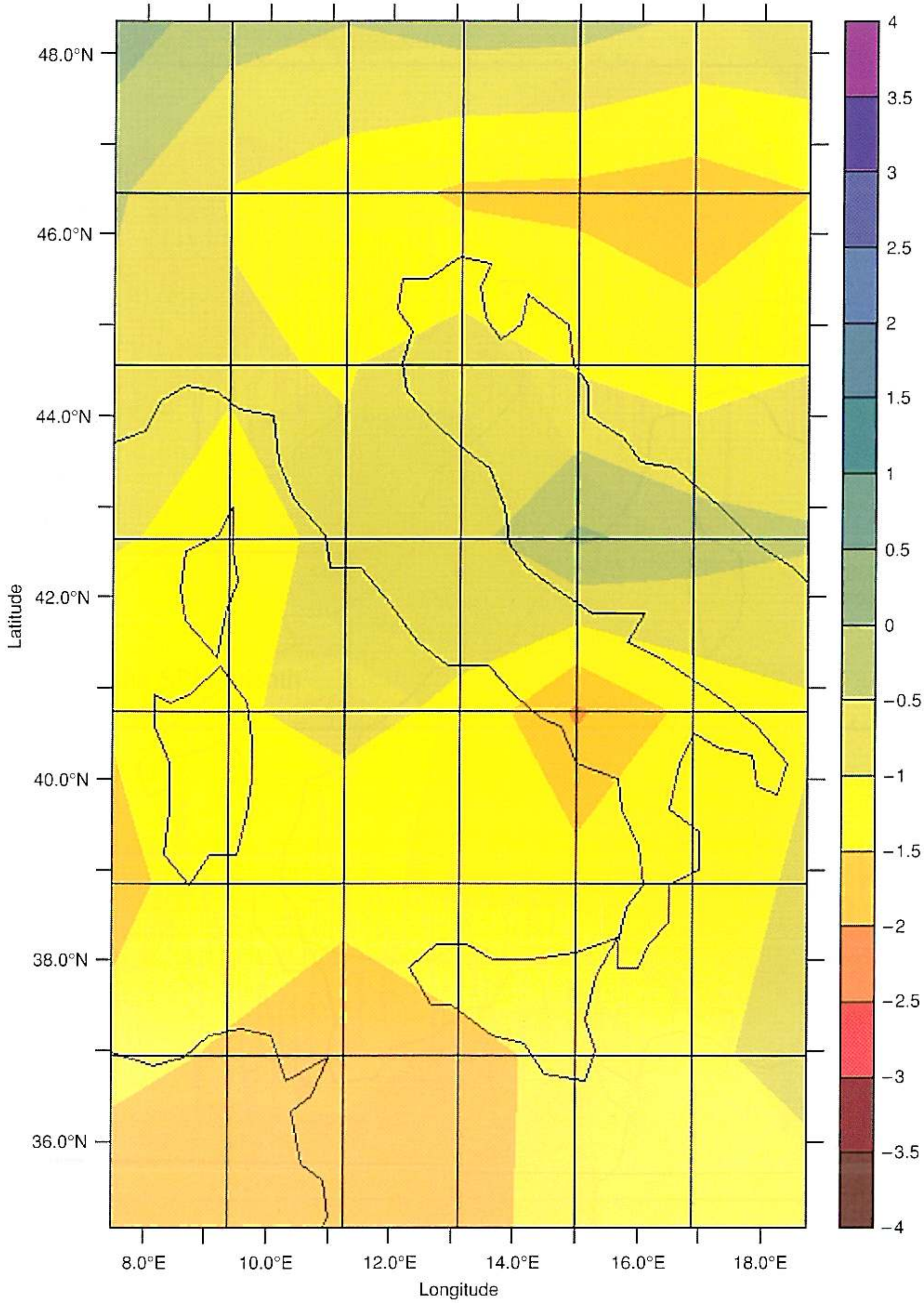


Fig. 1c. SPI for Italy on a 12-month time scale. Computation refers to December 1981 and data used for the analysis are NCEP/NCAR precipitation rates.

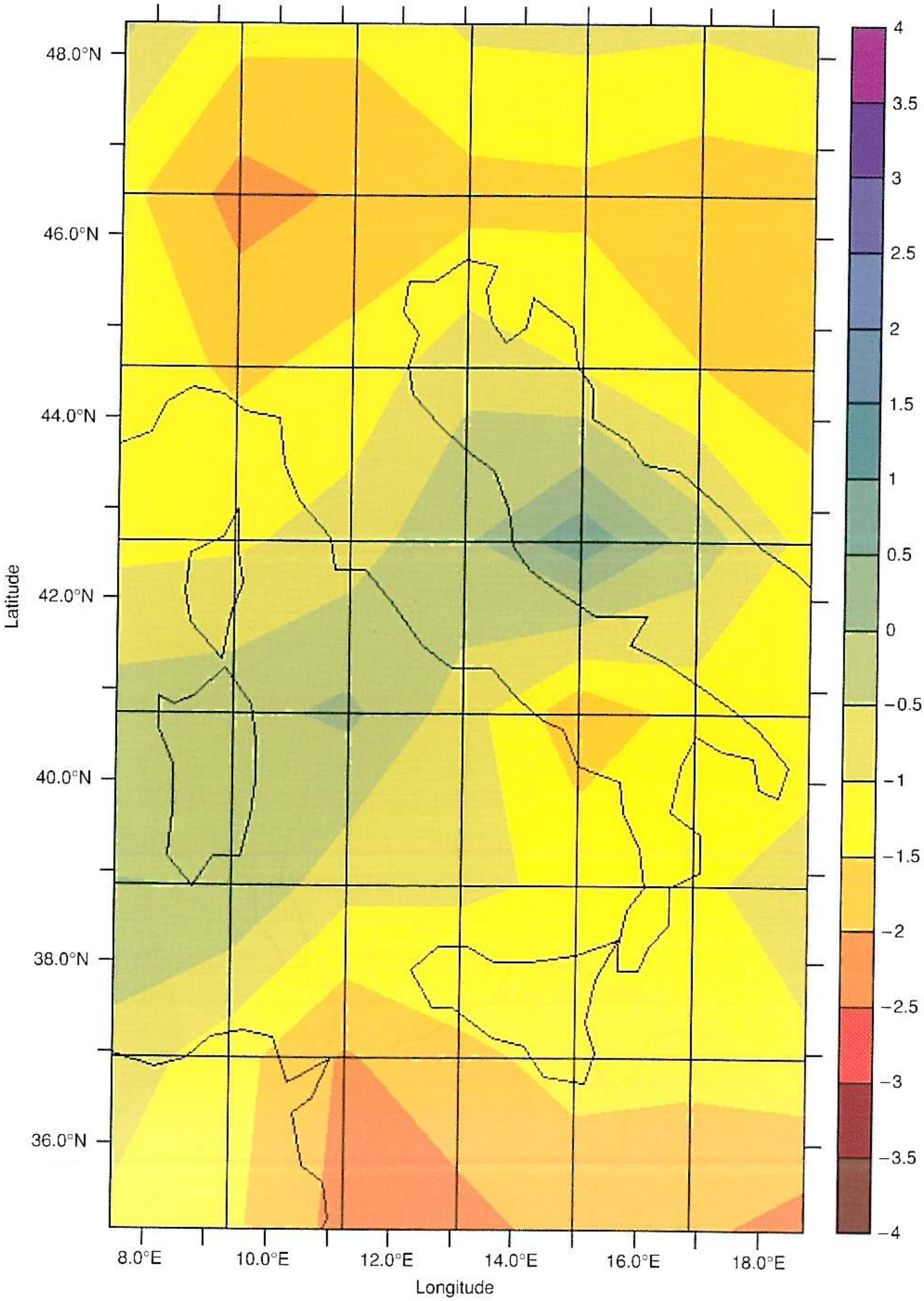
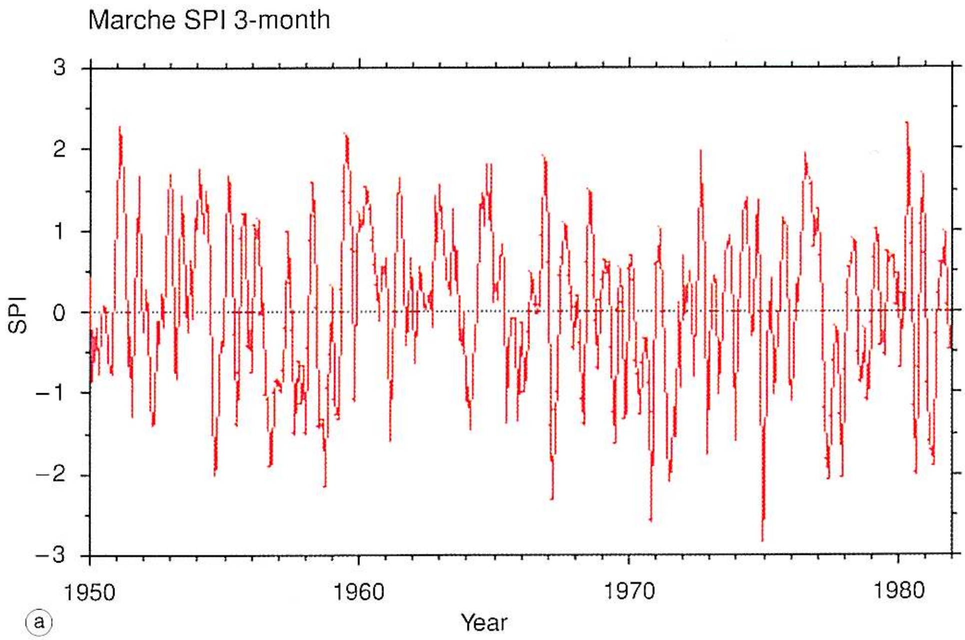


Fig. 1d. SPI for Italy on a 24-month time scale. Computation refers to December 1981 and data used for the analysis are NCEP/NCAR precipitation rates.



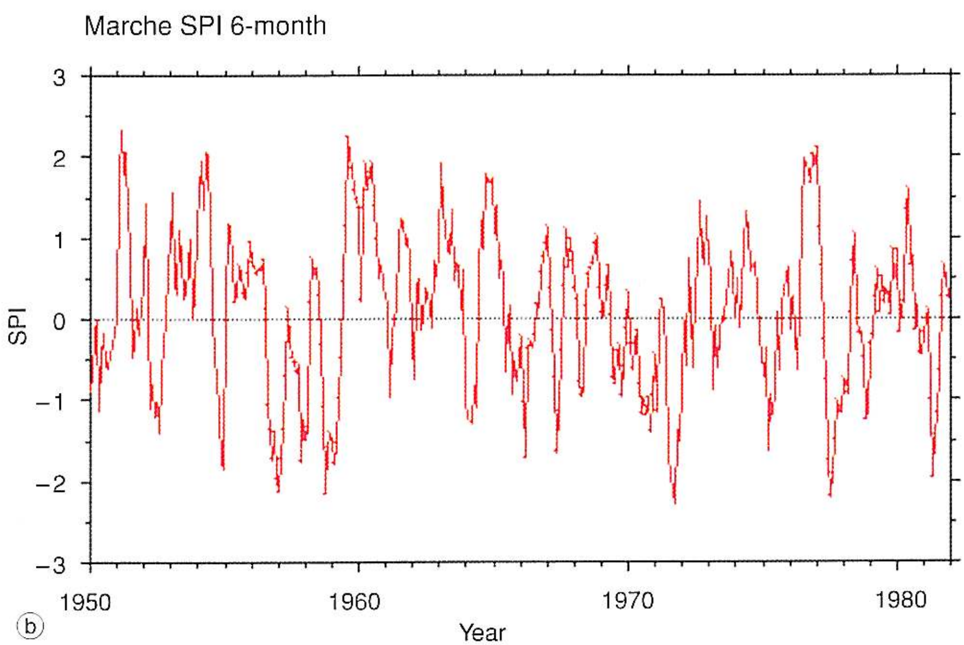
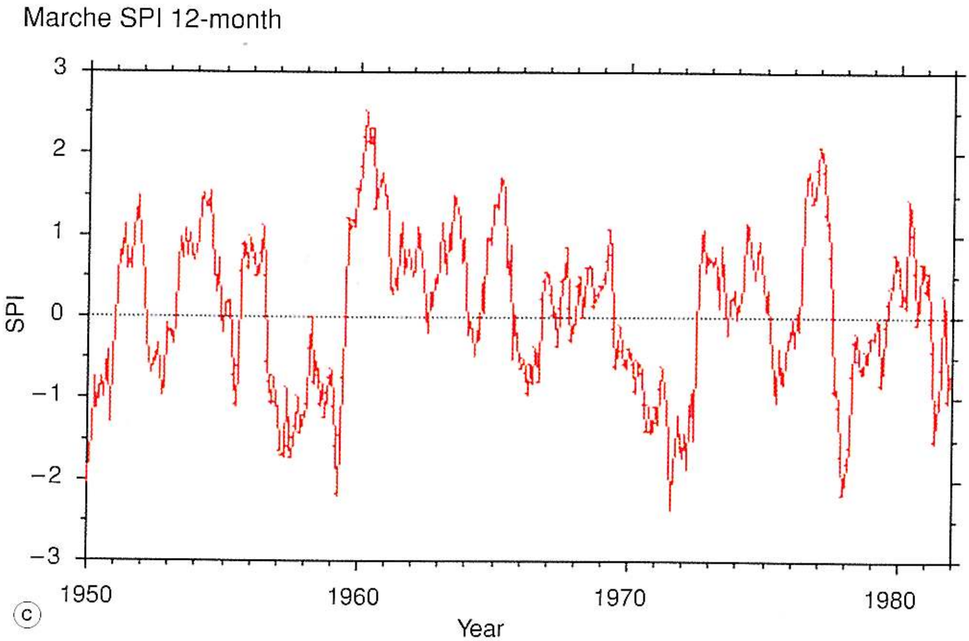


Fig. 2a,b. Time-behaviour of the monthly SPI on 3-month time scale for the grid-point nearest to Marche (a); 6-month time scale (b). The period considered goes from January 1950 to December 1981. Data used are NCEP/NCAR precipitation rates.



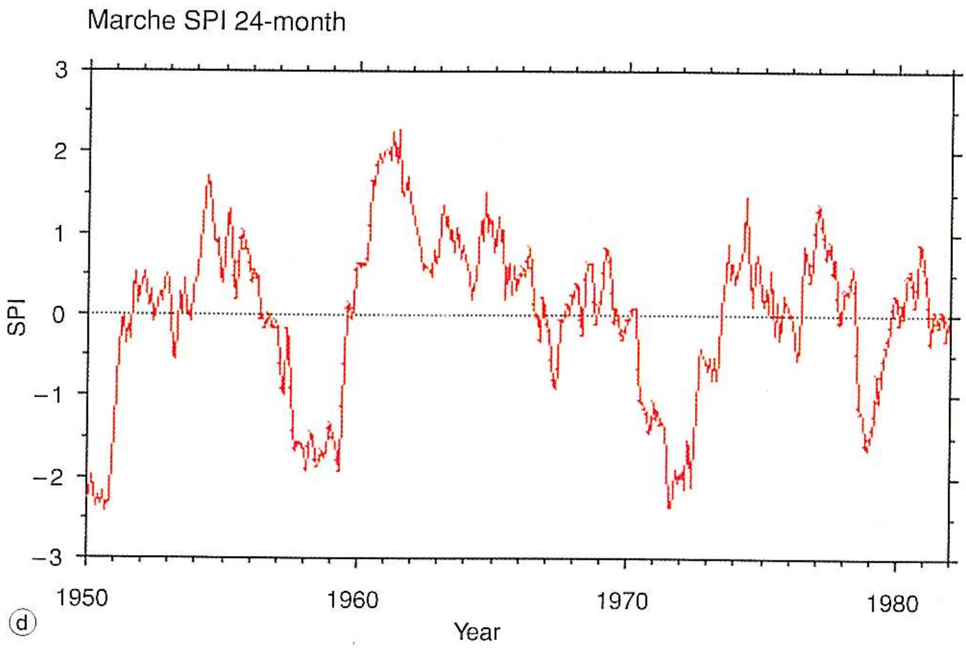


Fig. 2c,d. Time-behaviour of the monthly SPI on 12-month time scale for the grid-point nearest to Marche (c); 24-month time scale (d). The period considered goes from January 1950 to December 1981. Data used are NCEP/NCAR precipitation rates.

Table I. Rain gauge stations with the corresponding altitude in metres.

Stations	No. Station	Altitude	Stations	No. Station	Altitude
Arcevia	1	535	Montemonaco	24	988
Ascoli	2	135	Montottone	25	277
Bagnara	3	613	Morrovalle	26	245
Barbara	4	219	Nereto	27	163
Barchi	5	319	Nocera	28	548
Bargni	6	273	Osimo	29	265
Camerino	7	622	Ostra	30	199
CapoColle	8	539	Pergola	31	309
Capodacqua	9	819	Pesaro	32	11
Cingoli	10	631	Petriolo	33	271
Fabriano	11	325	Piagge	34	201
Fano	12	750	Pioraco	35	441
Fermo	13	279	Recanati	36	268
Foresta	14	641	Ripatransone	37	494
Fossomb.	15	116	SAngelo	38	473
Gelagna	16	711	SLorenzo	39	209
Gualdo	17	535	Sassoferrato	40	312
Jesi	18	97	Serravalle	41	647
LoroPiceno	19	436	SorgenteScirca	42	750
Macerata	20	315	Sorti	43	716
Mercatello	21	429	Teramo	44	300
Montecarotto	22	388	Urbino	45	485
Montecassiano	23	215			

is: how to obtain from such an inadequate sampling an average precipitation from which to compute a «regional» SPI (to be compared with that derived from global products, like that discussed in the previous section)? Though this is a classical problem, it has no standard solution.

In the case in question, we have found the systematic use of the altitude-distribution to be an efficient approach. Figure 5a,b show the distribution of the averaged monthly precipitation as a function of the station altitude for the months of December and August respectively. The month of August displays (here not shown) a unimodal dependence of precipitation on altitude, while that related to the month of December is bimodal. Note that the two branches are statistically well distinct, as can be seen looking at the vertical bars representing the dispersion of monthly precipitation around the average. All the other months (here not shown) are intermediate between the two shown here.

On these grounds, we may proceed to compute for each month, from 1948 to 1981, the spatial averaged cumulated precipitation to be compared with that derived from the reanalysis. We divide the altitude up to 1000 m into 100 m thick layers. For each layer and for each month we compute the spatial mean precipitation by averaging the data of those stations that are within the altitude layer considered. Then, the mean is weighted by the territory extension at that altitude assumed as measured by the number of grid points of the digital topographic model. For altitudes up to 1000 m, we compute the average precipitation by using the best-fit regression line for each month of the year, weighting the mean by the extension of the territory (computed as above).

The result is shown in fig. 6, where the time history of the regional cumulated precipitation (blue line) is compared with the NCEP/NCAR precipitation (red line) at the selected grid-point.

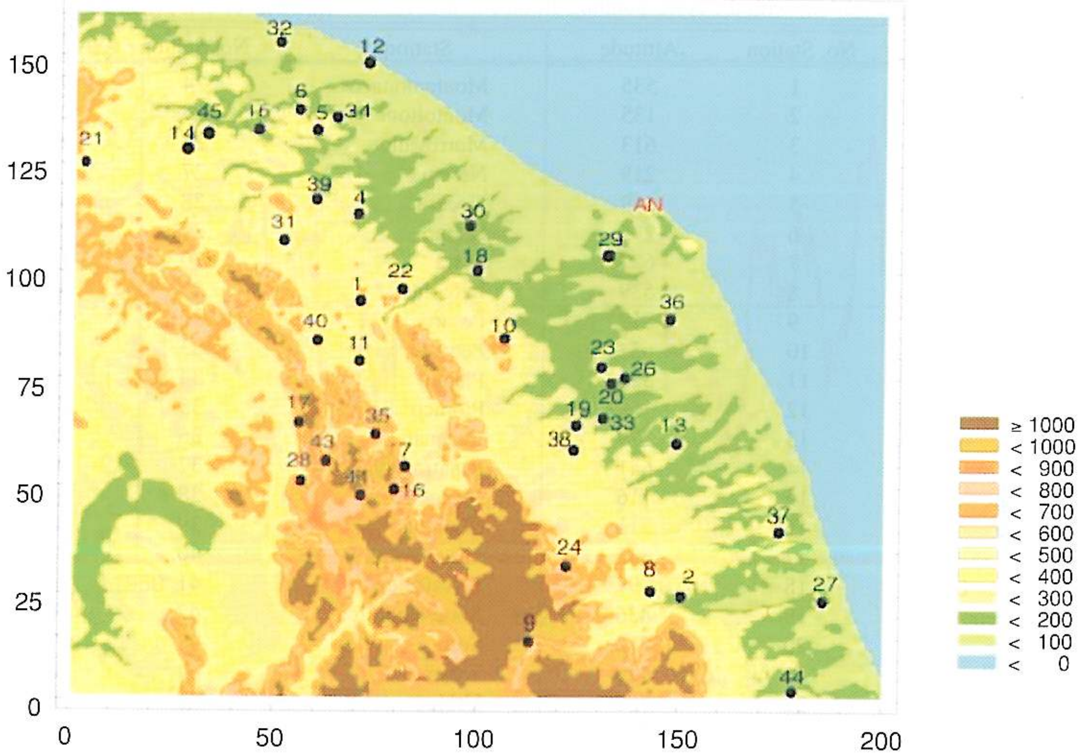


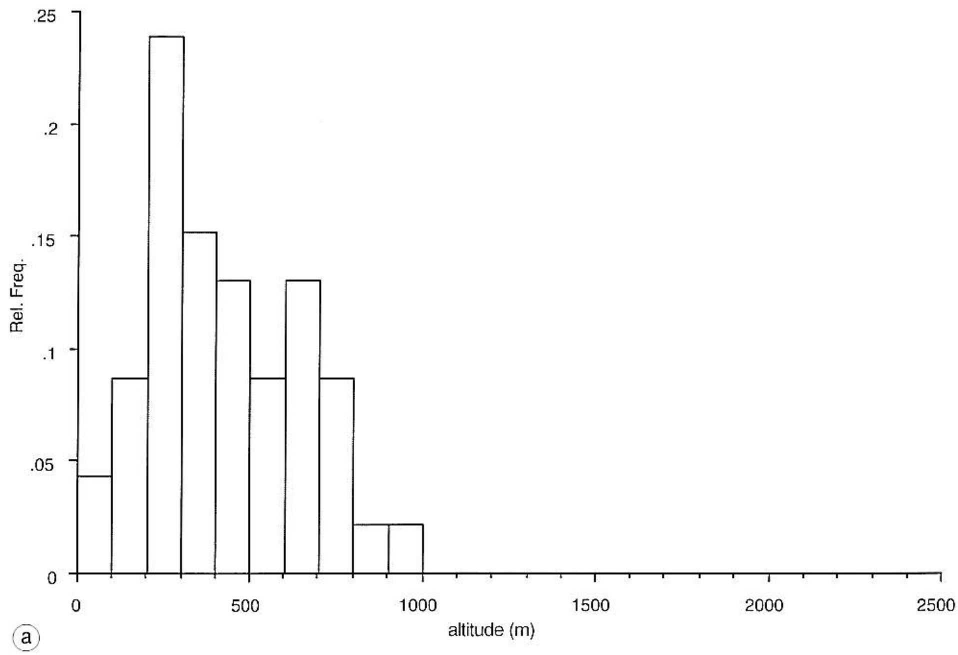
Fig. 3. Spatial distribution (over the Marche region) of the 45 rain gauge stations used for the analysis. Full contours display the altitude from 0 m up to values greater than 1000 m. Contour intervals are in hundreds of metres.

The figure displays a satisfactory overall agreement between the two curves (the correlation coefficient is 0.6) and a general tendency of the reanalysis data to have greater values than the observed ones (both for the mean value and the standard deviation of the record). Despite some discrepancies, the agreement between the two records is surprisingly high if the differences in the sources of precipitation estimates are taken into account. The regional monthly precipitation record is, in fact, obtained directly from local observations, while the NCEP/NCAR precipitation data are derived from the primary meteorological fields by means of a re-analysis procedure. Moreover, the grid-point selected as representative of the Marche region really accounts for the precipitation of a larger area that covers not only the Marche, but also part of Abruzzo, Lazio and Toscana (at the grid box in figs. 1a-d, consider a rectangle centred at the selected grid-point).

4. Regional analysis of drought on the Marche region

From the averaged precipitation defined in the preceding section we are able to compute the SPI according to the procedure defined in Section 3 of Bordi *et al.* (2001).

Comparison of the Marche regional SPI with the global one computed at the nearest grid-



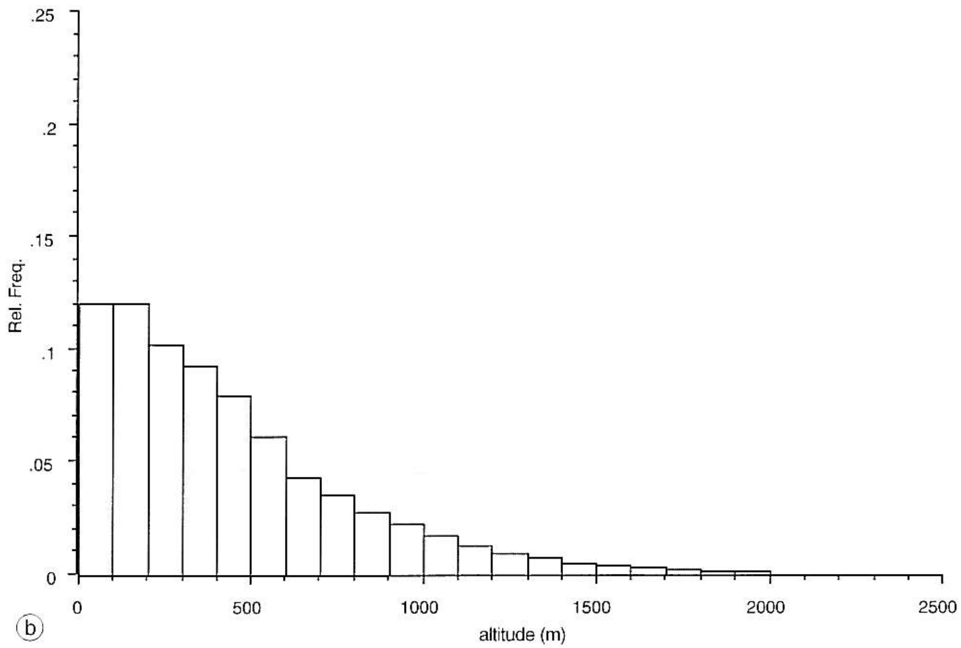
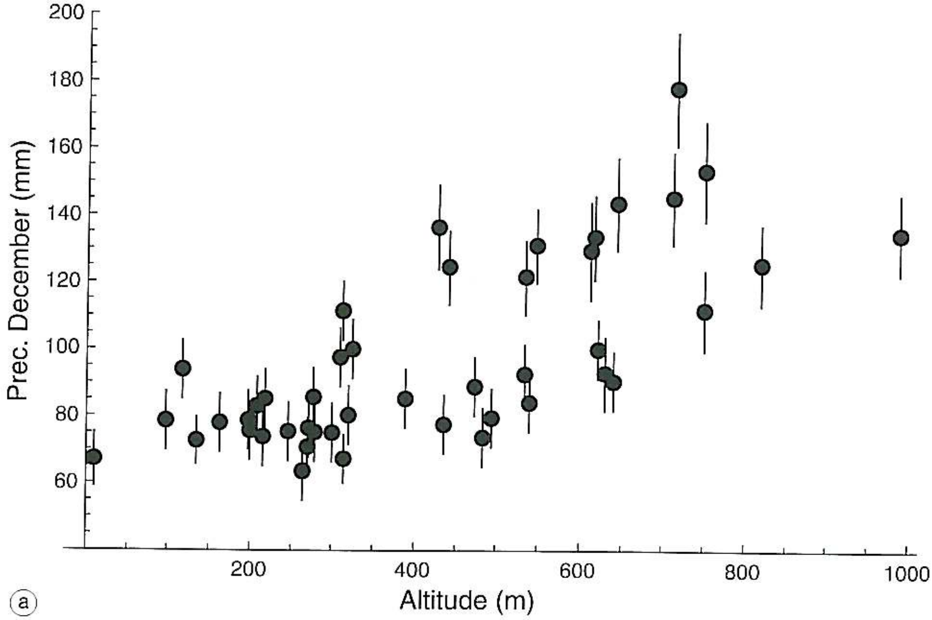


Fig. 4a,b. Statistical distribution of surface points (a) and altitude (b) of stations. Altitudes are in metres.



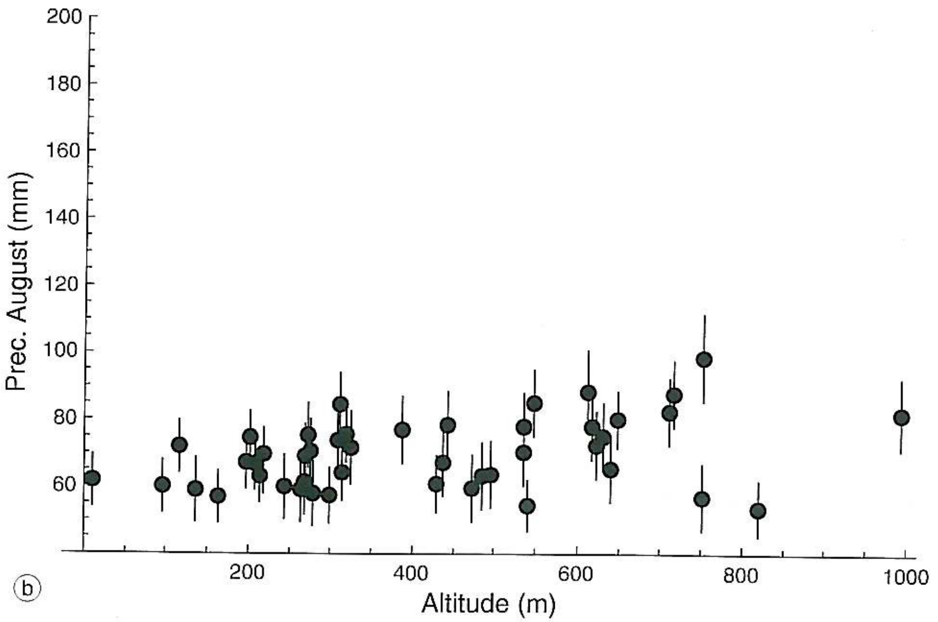


Fig. 5a,b. Distribution of the averaged (from 1948 to 1981) monthly precipitation as a function of the station-altitude for the month of December (a) and for August (b). Vertical bars represent the scatter of the monthly precipitation around the average. The altitude is in metres and precipitation is in millimetres.

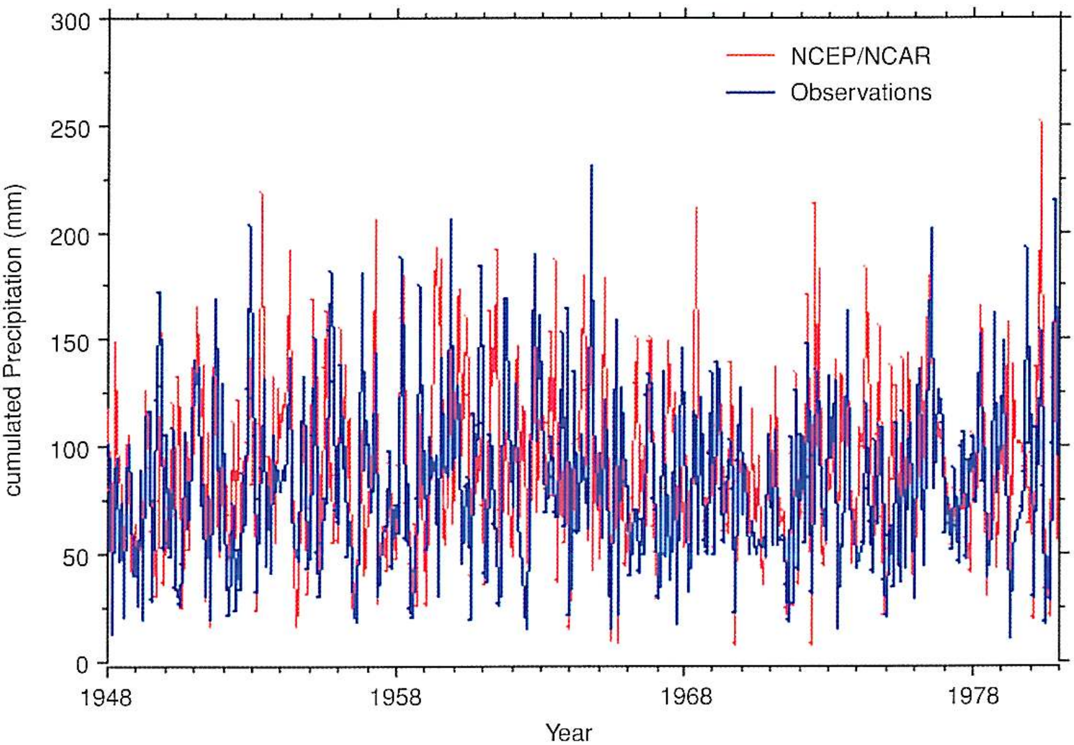


Fig. 6. Comparison between the temporal behaviour (from 1945 to 1981) of the monthly cumulated precipitation as derived from NCEP/NCAR reanalysis (red line) and from observations (blue line). Precipitation is in millimetres.

point is displayed in fig. 7a-d for 3, 6, 12 and 24-month time scale respectively. The correlation coefficient between the two SPI series for each time scale is denoted as r in the figures. The coefficients range between 0.63 and 0.69 and the maximum correlation is obtained for 3 and 12-month time scale. On a longer time scale (24-month), the periods when the two results lead to different behaviours of drought in the region (for example periods 1950-1951, 1958-1960, 1974-1976 and 1978-1980) appear more marked. The differences during the first two periods are probably due to the different amount of the cumulated precipitation accounted for (the behaviour is similar, but the curves differ roughly by a constant value). During the second period the SPI computed using raingauge data seems to precede the NCEP SPI, it rapidly goes down toward negative values and then rises up to positive values. This suggests that observations are more sensitive to local variations in the precipitation amount than the large-scale pluviometry is. The last period, instead, reveals an opposite behaviour between the two curves, meaning that the drought assessment is totally different for this period (*i.e.* NCEP analysis gives near normal conditions, while the regional analysis moderately dry conditions).

Despite these differences, results show a surprisingly good general agreement if we take into account the fact that the two pluviometries are computed quite differently and refer to different areas. Some of the major differences can, probably, be smoothed if we were to work within the same area.

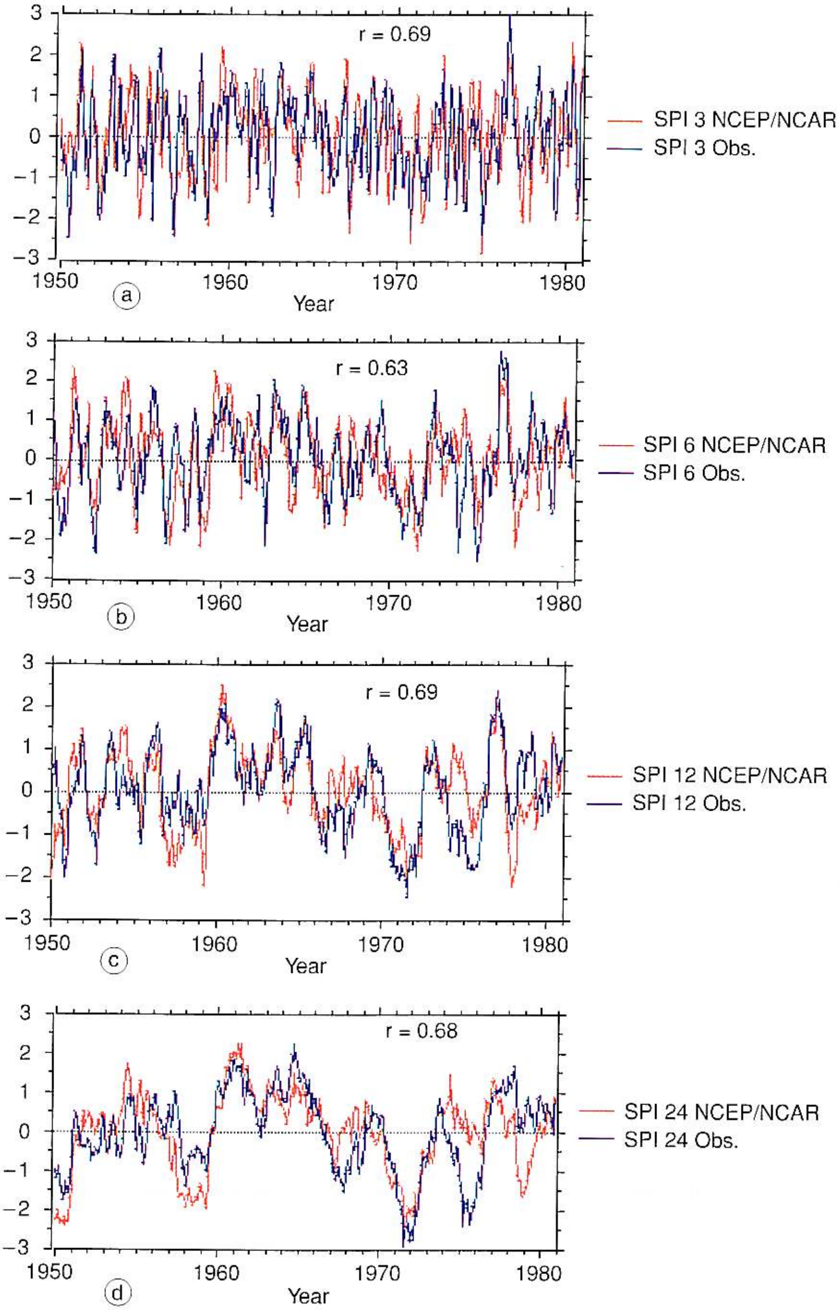


Fig. 7a-d. Comparison between the time behaviour of the monthly SPI as derived from NCEP/NCAR reanalysis (red line) and from observations (blue line) for 3-month time scale (a); 6-month time scale (b); 12-month time scale (c), and 24-month time scale (d).

5. Summary and conclusions

An evaluation of drought conditions on the Marche region from 1948 to 1981 is described using both the NCEP/NCAR gridded data set and rain-gauge observations. On the grounds of an analysis based on altitudes, we computed the monthly regional cumulated precipitation from local observations and compared it with the large-scale precipitation record of the NCEP/ NCAR grid-point nearest to the region where the rain gauges are located. The overall agreement is good. Moreover, the SPI computed by using the above two different precipitation records shows satisfactory agreement. Such results suggest that it is both possible and desirable to perform a systematic analysis of rainfall observations over the entire national territory to produce regional rainfall climatologies to be compared with large-scale ones.

In the context of the above procedure, we also illustrated the benefits of relating local scale rainfall to topography. In fact, convergence zones, organised convective systems and rainbands have been largely documented as phenomena involving orographic effects. In perspective, however, other local features (such as land-coverage, marine influence, etc.) should also be considered.

As an additional outcome of our study, the relation between precipitation and altitude here illustrated might be a useful tool to determine a basic network for rainfall observations over Italy.

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