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TEMPERATURE AND PRECIPITATION VARIABILITY IN ITALY IN THE LAST TWO CENTURIES FROM HOMOGENISED INSTRUMENTAL TIME SERIES

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ABSTRACT

The Italian monthly temperature (mean, maximum and minimum) and precipitation secular data set was updated and completely revised. Station density and metadata availability were greatly improved and the series were subjected to a detailed quality control and homogenisation procedure. The data homogenisation is described in detail. The bias affecting original data is quantified by studying the temporal evolution of the mean adjustments applied to the series and examined in the light of the stations history. The results stress the importance of homogenisation in climate change studies.

The final data set was clustered into climatically homogeneous regions by means of a Principal Component Analysis. Yearly and seasonal trend analyses were performed both on regional average series and on the mean Italian series. The results highlight a positive trend for mean temperature of about 1 K per century all over Italy; it is generally higher for minimum temperature than for the maximum temperature. The progressive application of trend analysis shows that, in the last 50 years, behaviour is the opposite; the maximum temperature trend being stronger than that of the minimum temperature. This has led to a negative trend in the daily temperature range that for the last 50 years has become positive. Precipitation shows a decreasing tendency, even if low and rarely significant, the negative trend being only 5% per century on a yearly basis.

KEY WORDS: Italy; data homogenisation; trend analysis; monthly temperature records; monthly precipitation records; minimum and maximum temperature; daily temperature range

1. INTRODUCTION

The awareness of the importance of data quality and homogeneity for the correct detection of climate change has increased rapidly in the last few years.

Most of the contributions concern upper-air data (e.g. Luers and Redder, 2003; Lanzante *et al*., 2003; Fu *et al*., 2004); however, errors and inhomogeneities also concern surface data. At surface level, it is often assumed that such inhomogeneities have a random distribution and by considering a sufficiently large number of series, average records with negligible bias can be obtained. This assumption is likely to be correct if global or hemispheric averages are considered, but it may not be correct on a regional scale. An interesting example of this problem is given by Böhm *et al*. (2001) in a paper investigating temperature variability in the Alps and their surroundings, based on instrumental series of monthly mean temperatures. In the frame of the EU-project ALPCLIM, they subjected about 100 secular temperature records of this area to a detailed quality control and homogenisation procedure and performed a systematic comparison between the original and the corrected records. The results clearly showed that the original series were biased by non-climatic noise and, even if the average over all the series was considered, the long-term temperature evolution of the original

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data was affected by an error of about 0.5 K over the last 150 years. Another interesting example is provided by Auer *et al.* (2005) in a paper concerning about 200 monthly secular precipitation records of the same area.

In the light of the results obtained within the ALPCLIM project, in the year 2000 we set up a research program with the aim of better investigating the impact of data quality and homogeneity issues on the detection of Italian temperature and precipitation trends in the last two centuries. The final goal was to enlarge, revise, improve and update the data sets of Italian monthly secular temperature and precipitation series presented in Maugeri and Nanni (1998), Buffoni *et al.* (1999) and Brunetti *et al.* (2000a,b), in order to give more reliable long-term trend estimates.

This paper summarises the main results obtained within this research program. The objectives are (1) to introduce the new data set, (2) to discuss the quality control and homogenisation procedures and (3) to analyse and discuss the new homogenised records.

2. DATA AND METADATA

Italy boasts of a role at the highest level in the development of meteorological observations. This role is well demonstrated by the invention of some of the most important meteorological instruments and the establishment of the first network of observations, the 'Rete del Cimento', which was set up by Galileo's scholars and operated from 1654 to 1667, with stations both in Italy and in some surrounding countries. The strong Italian presence in the development of meteorological observations is also testified by six stations that have been in operation since the eighteenth century (Bologna, Milan, Rome, Padua, Palermo and Turin) and other 15 stations where observations started in the first half of the nineteenth century (Aosta, Florence, Genoa, Ivrea, Locorotondo, Mantua, Naples, Parma, Pavia, Perugia, Trento, Trieste, Udine, Urbino and Venice). As a consequence, a heritage of data of enormous value has been accumulated in Italy over the last three centuries.

This heritage has been known for a long time and many attempts have been made to collect data into a meteorological archive. The first attempt to perform a systematic collection of Italian monthly precipitation data was made just after the National Central Office for Meteorology and Climate was founded (1880). This work was then updated and revised in different steps in the following decades. The same work was performed for mean temperatures, albeit concerning a lower number of stations and only some selected periods. Moreover, a very large number of monographic studies involving the collection of single Italian station records have been carried out in the last two centuries. Quite a complete list of the resulting publications is given in Narducci (1991). Unfortunately, a relevant fraction of them was published in grey literature and in the Italian language, thus the results were not easily available to the international scientific community. A list of the principal references reporting Italian monthly records is given in Table I, which also shows a list of the principal Italian meteorological yearbooks.

In spite of the huge heritage of data and even if most records were subjected to some sort of analysis, until a few years ago only a small fraction of Italian data was available in computer readable form.

The first step towards the digitisation of the Italian secular series was made in the 1970s when, in the frame of a national project funded by the Italian National Research Council (CNR), a set of 26 precipitation and minimum and maximum temperature records was transcribed from yearbooks to a digital support. The resulting data set, usually known as the UCEA (Ufficio Centrale di Ecologia Agraria, Rome) secular series data set (hereinafter referred to as the UCEA70s data set), consisted both of daily and monthly records, generally covering the 1870–1970 period (Lo Vecchio and Nanni, 1995). The main drawbacks of this data set were a rather high portion of missing data and the lack of any kind of metadata.

A further improvement in availability of digitalised data was made in the second part of the 1990s, in the frame of another CNR project (reconstruction of the past climate in the Mediterranean area), that allowed the UCEA secular series data set to be updated, completed, and revised. The resulting data set is extensively discussed in Buffoni *et al.* (1999) and in Brunetti *et al.* (2000b). In comparison with the UCEA70s, the new data set (hereinafter CNR90s), besides updating to 1996 and the inclusion of some new series, also presented both an extension of the covered period and a smaller fraction of missing data, thanks to extensive work on data digitisation performed by means of the data sources listed in Table I. Moreover, the previously available

Table I. Principal sources of Italian monthly records

Principal references reporting Italian monthly records

Millosevich E. 1882. Sulla distribuzione della pioggia in Italia. The study is included in Vol. 3 of the yearbooks of Italian Central Office for Meteorology and Climate (*Annali dell'Ufficio Centrale di Meteorologia. Serie II 3, anno 1881, Roma*).

Millosevich, E. 1885. Appendice alla memoria sulla pioggia in Italia. The study is included in Vol. 5 of the yearbooks of Italian Central Office for Meteorology and Climate (*Annali dell'Ufficio Centrale di Meteorologia. Serie II Vol. 5, anno 1883, Roma*).

Eredia F. 1908. Le precipitazioni atmosferiche in Italia dal 1880 al 1905. The study is included in Vol. 27 of the yearbooks of Italian Central Office for Meteorology and Climate (*Annali dell'Ufficio Centrale di Meteorologia e Geodinamica. Serie II Vol. 27 anno 1905, Roma*).

Eredia F. 1912. La temperatura in Italia. The study is included in Vol. 31 of the yearbooks of Italian Central Office for Meteorology and Climate (*Annali dell'Ufficio Centrale di Meteorologia e Geodinamica. Serie II, Vol. 31, anno 1905, Roma*).

Eredia, F. 1919. Osservazioni pluviometriche raccolte a tutto l'anno 1915 dal R. Ufficio Centrale di Meteorologia e Geodinamica. Edited by Ministero dei Lavori Pubblici (Servizio Idrografico Centrale), Rome.

Eredia, F. 1925. Osservazioni pluviometriche raccolte nel quinquennio 1916–1920. Edited by Consiglio Superiore lavori Pubblici (Libreria dello Stato), Rome.

Ministero Lavori Pubblici – Consiglio Superiore – Servizio Idrografico 1955–1961. Precipitazioni medie mensili ed annue e numero dei giorni piovosi per il trentennio 1921–1950. This publication (13 volumes published by Istituto Poligrafico dello Stato, Rome), reports monthly precipitation data of the 1921–1950 period for a very high number of Italian stations.

Ministero Lavori Pubblici – Consiglio Superiore – Servizio Idrografico 1966–1969. La distribuzione della temperatura dell'aria in Italia nel trentennio 1926–1955. This publication (3 volumes published by Istituto Poligrafico dello Stato, Rome), reports monthly temperature data of the 1926–1955 period for a high number of Italian stations.

Principal yearbooks reporting Italian data

Meteorologia Italiana (Ministero d'Agricoltura, Industria e Commercio – Direzione di Statistica, Roma). Published for the 1865–1878 period.

Annali ((R.) Ufficio Centrale di Meteorologia (e Geodinamica), Roma). Published for the 1879–1925 period, even if for some periods the yearbooks were published without the data.

Bullettino Meteorologico del R. Collegio Carlo Alberto in Moncalieri (then Bullettino della Società Meteorologica Italiana). Initially published by Father Francesco Denza and then by the Società Meteorologica Italiana, the yearbooks cover the 1865–1914 period, even if the last years they were published without the data.

Bollettino Meteorico Giornaliero del (R.) Ufficio Centrale di Meteorologia (e di Geodinamica) (then Bollettino Meteorologico Giornaliero/Bollettino Meteorologico ed Aerologico). Initially published by the Central Office then by Italian Air Force, the yearbooks cover the 1880–1940 (February) period.

Annali Idrologici (Ministero del Lavori Pubblici – Servizio Idrografico). Published for the Po basin from 1913 and for all Italy from 1924 the yearbooks mainly contain temperature and precipitation data. The publication of these yearbooks is still in progress, even if they are now published by the Regional Administrations. They are generally updated with some years' delay.

UCEA70s data were also checked by means of the same data sources. This comparison facilitated both the identification of typing errors and realisation that sometimes, in the UCEA70s data set, monthly precipitation amounts were calculated as a sum of daily precipitation even for months with incomplete data. This mistake, very common especially at the end of the last century, was eliminated either by invalidating the data or replacing them with the published ones.

In spite of significant improvements, the new CNR90s data set also had the fundamental limitation of very poor metadata availability. Moreover, the number of stations was still too low and some regions, especially in central and southern Italy, presented a very poor coverage. These deficits hampered subjecting the data to an extensive homogenisation procedure.

After the conclusion of the 1990s CNR project, some northern Italy monthly mean temperature records were shared within the EU ALPCLIM project to set up a data set covering a region centred on the Alps (Greater Alpine Region). Their comparison with the records of the other countries of this area showed some systematic differences.

The difficulties in subjecting the CNR90s data set to extensive homogenisation and the incomplete agreement of the northern Italy records with the others from the Greater Alpine Region clearly highlighted, at the end of the 1990s, that the collection of metadata and the improvement of station density were fundamental problems in the correct detection of temperature and precipitation trends over Italy.

Within this context, in the year 2000 a new research programme with the aim of obtaining homogenised Italian secular temperature and precipitation records was established. It was initially developed within a national project of the Ministry of Agriculture and Forests (CLIMAGRI – Climate Change and Agriculture, see www.climagri.it, complete but in Italian, or www.fao.org/sd/climagrimed/, less complete but in English), then an extension of the activities was performed within the EU-FP5 ALP-IMP project (see www.zamg.ac.at/ALP-IMP), within two more projects funded by the Italian Ministry for Education and Research (PRIN 2001 – Local climate variability in relation to global climatic change phenomena; FIRB 2001 – Frequency evolution of extreme precipitation events and droughts in Italy in the last 120 years and its impact on bioecosystems) and within the US–ITALY bilateral Agreement on Cooperation in Climate Change Research and Technology. Thanks to the availability of resources from these projects, and considering that other activities were in progress in Italy concerning both single stations (e.g. Bellumè *et al.*, 1998; Brunetti *et al.*, 2001; Camuffo, 2002; Maugeri *et al.*, 2002a) and Italian regional networks (e.g. Cortemiglia, 1999 for Piedmont), the initial goal of homogenising the existing records was extended and the construction of a completely new and larger set of data and metadata was also planned.

The metadata collection was performed with two main objectives: (1) to understand the evolution of the Italian meteorological network and (2) to reconstruct the 'history' of each available station in the data set.

The evolution of the national network was investigated both by analysing a number of reports and papers on this issue and by studying the proceedings of the principal conferences and meetings that led to the establishment and rapid growth of a national network of meteorological stations from the Italian political unity (1860) to the first decades of the twentieth century. References, results and methods are summarised in the final report of the first year of the CLIMAGRI project (Maugeri *et al.*, 2002b). The reconstruction of the network evolution is very important for data homogenisation, especially when homogenisation is mainly based on statistical methods, as they often fail in identifying breaks that affect a high fraction of stations within a short period. This happens when breaks are due to changes in instruments and methods caused by new standards imposed by the network management, for example, as a consequence of new national or international standards. A very good synthesis of the efforts produced in the last three decades of the nineteenth century to standardise the meteorological observations is given in the International Meteorological Codex of Hellmann and Hildebrandsson (1907) that was translated into Italian by Ciro Chistoni and published in the yearbooks of the Italian Meteorological Society (1912–1915). Two interesting examples on the effect of the introduction of new standards on data homogeneity are given in Böhm *et al.* (2001) and in Auer *et al.* (2005). The first study explains the disagreement between the northern Italy temperature records and the others of the Greater Alpine Region linked to a progressive substitution of the meteorological windows, initially suggested by the Italian Central Office (Figure 1, Tacchini, 1879), with ground-level Stevenson screens. The second estimates the impact of the progressive tendency to perform precipitation observation at ground level instead of at roof level.

The research on the history of the single stations was performed both by analysing a large amount of grey literature (monographic studies, bulletins, reports, etc.) and by means of the UCEA archive. This archive is very rich, since UCEA was, in the past, the National Central Office for Meteorology and Climate. All information was summarised in a document containing a card for each data series. Each card is divided into three parts. In the first part, all the information obtained from the literature is reported. In the second part, there are abstracts from the epistolary correspondence between the station and the Central Office. In the third part, the sources of the data used to construct the record are summarised. An example of these cards is reported in Maugeri *et al.* (2002b). They had a fundamental role in supporting data homogenisation.

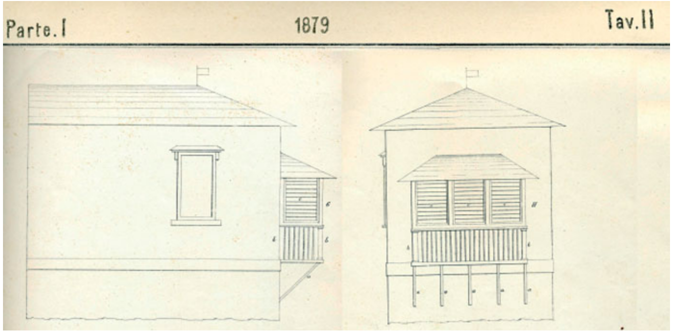

Figure 1. Meteorological window suggested by Italian Central Office for Meteorology and Climate in 1879 (Tacchini, 1879). In the last decades of the 19th century most of Italian observations were performed in urban environments, in screens located outside a north-facing window of the highest floor of a "meteorological tower". The purpose of using such towers was to perform observations above the level of the roofs of the surrounding buildings. This figure is available in colour online at www.interscience.wiley.com/ijoc

Figure 2 illustrates the spatial distribution of the stations included in the new data set. Not all the available series fulfilled the quality and completeness requirements, and some of them were classified as low quality and rejected from the final data set. From the original database comprising 105 mean temperature series, 57 minimum and maximum temperature series and 146 precipitation series, 38, 9 and 35 series were rejected for mean temperature, minimum and maximum temperature and precipitation respectively. So, the final homogenised data set comprises 67 mean temperature series, 48 minimum and maximum temperature series and 111 precipitation series. In Figure 2, accepted and rejected station locations are shown with filled and open circles respectively. Figure 3 shows the temporal development of the final data set we used in the following analysis, whereas Table II contains information on station location, covered period and the fraction of missing data for the different parameters (mean temperature, minimum and maximum temperature and precipitation).

Precipitation has the best data availability: there are 111 records and 75 of them cover at least 120 years. There are 18 records that exceed 160 years, whereas 6 cover at least 200 years. There is also a very good availability of monthly minimum and maximum temperature records (48 series) that is probably unique in the world (70% of them are longer than 120 years). Finally, 67 mean temperature series are available, 80% of which are longer than 120 years. It is worth noting that for a significant fraction of the station records daily data also are available. This fraction is particularly high for minimum and maximum temperatures, whose daily data set almost coincides with the monthly one. On the contrary, for precipitation only 50% of the monthly data set is available with daily resolution. So, the data set of the monthly records is partially calculated from daily data and partially from data that are available only with monthly resolution. When daily records were available, a preliminary quality check was performed on a daily basis, both for temperature and precipitation, by self-consistency checks and intercomparison among different stations and parameters (for temperature, a comparison between minimum and maximum values was performed and daily temperature range (DTR) series were extracted and checked too). Details on the quality check of the daily data are given in Maugeri *et al*. (2002b, 2004).

3. HOMOGENISATION AND GAP FILLING

In the last decade, the scientific community has become aware of the fact that the real climate signal in original series of meteorological data is generally 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. So, at present, the statement that time series of meteorological data cannot be used for climate research without a clear knowledge about the state of the data in terms of homogeneity has very large consent.

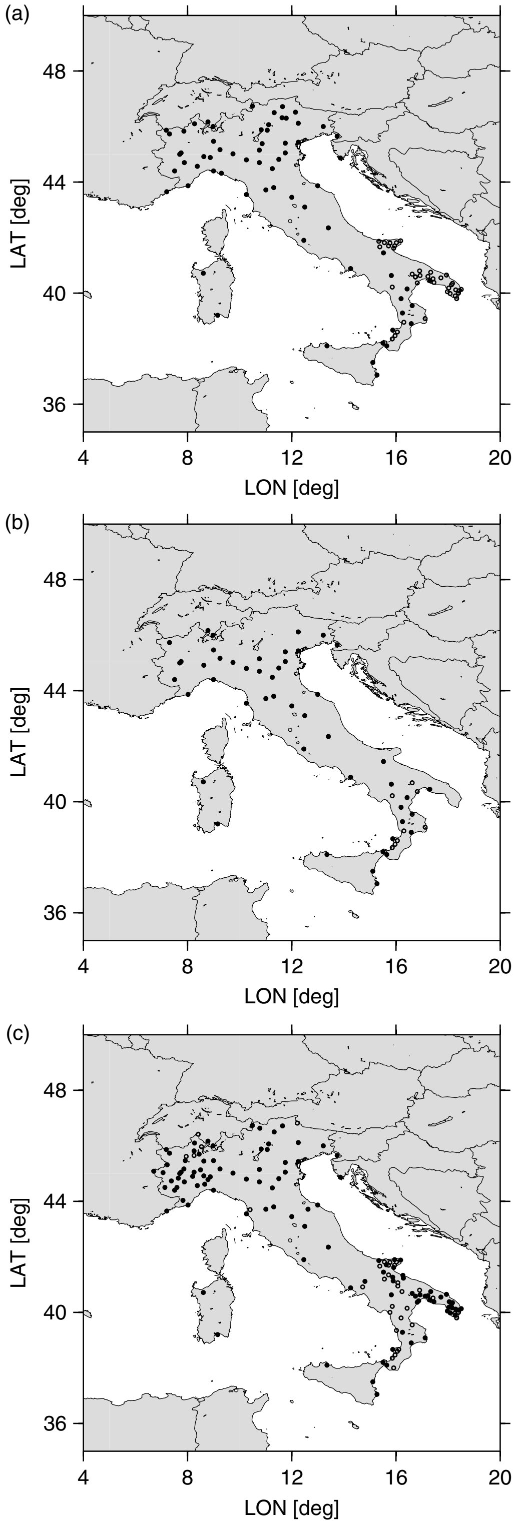

Figure 2. Station location for (a) mean temperature, (b) minimum and maximum temperature and (c) precipitation. Filled circles indicate stations that passed the quality and homogeneity procedures; open circles indicate rejected stations

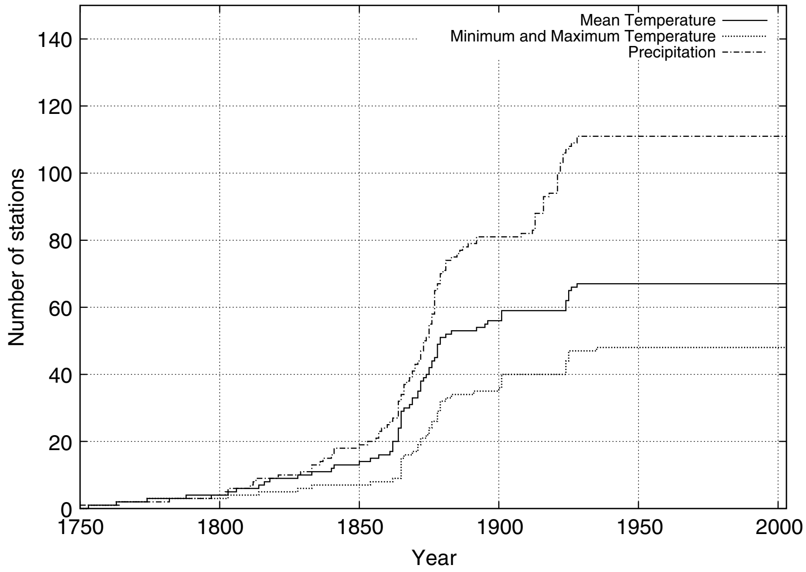

Figure 3. Development of the final homogenised temperature and precipitation networks

Table II. Names, locations, covered period and proportion of missing data of the series included in the final homogenised data set of Italian temperature and precipitation records

Station	Lon (°)	Lat (°)	z (*m*)	TMin–TMax covered period	TMin–TMax missing data (%)	TMed covered period	TMed missing data (%)	Precipitation covered period	Precipitation missing data (%)
Alessandria	8.63	44.92	98	1854–1985	9.4	1854–1973	4.5	1857–1986	2.4
Andria	16.28	41.23	151	–	–	–	–	1921–1996	0.0
Aosta	7.30	45.73	544	1891–2003	3.8	1840–2003	3.8	1841–2003	7.9
Arezzo	11.88	43.45	274	1876–2003	9.2	1876–2003	9.8	1876–2003	1.6
Asti	8.20	44.90	158	–	–	–	–	1881–1993	2.7
Balmè	7.22	45.32	1432	–	–	–	–	1913–2003	2.7
Bardonecchia	6.70	45.08	1340	–	–	–	–	1913–2002	1.8
Barletta	16.27	41.33	20	–	–	–	–	1921–1996	3.9
Belluno	12.25	46.12	404	1875–2003	9.5	1875–2003	8.3	1875–2003	6.3
Benevento	14.80	41.12	177	–	–	–	–	1870–1996	0.0
Bologna	11.25	44.48	60	1814–2003	0.0	1814–2003	0.0	1813–2003	0.0
Bolzano	11.33	46.50	272	–	–	1850–2003	15.2	1856–2003	17.6
Borgomanero	8.45	45.70	317	–	–	–	–	1881–1996	0.0
Brá	7.87	44.70	290	–	–	1862–1970	0.0	1862–2003	0.0
Brindisi	17.93	40.65	28	–	–	–	–	1877–2000	8.1
Brixen	11.65	46.72	569	–	–	1865–2003	30.4	1878–2003	5.4
Cagliari	9.15	39.20	55	1879–2003	3.8	1879–2003	4.3	1853–2003	0.0
Canosa	15.90	41.13	154	–	–	–	–	1922–1996	0.0
Casale Monferrato	8.50	45.13	113	–	–	–	–	1870–2003	12.9
Castellaneta	16.93	40.63	245	–	–	–	–	1877–1996	2.5
Castrovillari	16.20	39.80	353	1925–2002	10.5	1925–2002	12.8	–	–
Catania	15.11	37.50	75	1901–2003	5.5	1901–2003	6.6	1892–2003	1.0

(*continued overleaf*)

Table II. (*Continued*)

Station	Lon (°)	Lat (°)	z (*m*)	TMin–TMax covered period	TMin–TMax missing data (%)	TMed covered period	TMed missing data (%)	Precipitation covered period	Precipitation missing data (%)
Catanzaro	16.58	38.90	343	1924–2002	3.9	1924–2002	3.9	1868–2002	26.9
Cavour	7.37	44.73	290	–	–	–	–	1879–1993	0.0
Centallo	7.60	44.50	417	–	–	–	–	1883–1988	0.9
Cerignola	15.88	41.27	124	–	–	–	–	1922–1996	0.9
Chiavari	9.30	40.30	5	–	–	1883–2002	0.8	–	–
Chivasso	7.85	45.17	221	–	–	–	–	1892–1988	0.0
Cortina	12.12	46.52	1275	–	–	1878–2003	10.9	–	–
Cosenza	16.25	39.28	250	1925–2002	11.8	1925–2002	12.8	1873–2002	7.1
Crispiano	17.23	40.60	265	–	–	–	–	1916–1996	7.4
Crotone	17.12	39.08	6	–	–	–	–	1916–2002	7.1
Cuneo	7.50	44.40	536	1879–2003	2.3	1879–2003	2.8	1877–2003	0.0
Domodossola	8.27	46.10	300	–	–	1872–1997	0.0	1872–1998	9.9
Fenestrelle	7.06	45.04	1200	–	–	–	–	1912–1997	2.9
Ferrara	11.50	44.82	15	1865–2003	9.6	1865–2003	10.1	1865–2003	1.6
Firenze	11.30	43.80	51	1878–2003	0.3	1878–2003	0.5	1860–2003	2.6
Foggia	15.52	41.45	80	1901–2003	12.9	1901–2003	16.9	1873–2003	5.5
Fossano	8.38	44.57	351	–	–	1875–1973	0.0	1875–1997	0.2
Galat Ina	18.15	40.17	73	–	–	–	–	1923–1996	1.4
Gallipoli	17.98	40.05	31	–	–	–	–	1877–1996	7.6
Genova	8.93	44.40	21	1833–2003	0.2	1833–2003	0.3	1833–2003	0.0
Ginosa	16.75	40.58	257	–	–	–	–	1887–1996	20.2
Ginosa scalo	16.75	40.58	5	–	–	–	–	1928–1996	0.1
Imperia	8.02	43.87	54	1875–2003	0.8	1875–2003	1.1	1876–2003	0.0
Ivrea	7.91	45.46	267	–	–	–	–	1837–2002	12.4
Lago Gabiet	7.85	45.85	2340	–	–	1928–2003	0.8	–	–
L'aquila	13.40	42.35	753	1869–2003	16.1	1869–2003	17.3	1874–2003	3.5
Latiano	17.72	40.55	98	–	–	–	–	1925–1996	0.0
Lecce	18.17	40.35	78	–	–	–	–	1875–2000	0.1
Lesina	15.35	41.87	5	–	–	–	–	1928–1998	0.0
Livorno	10.25	43.55	3	1865–2001	7.8	1865–2001	8.8	1857–2002	0.7
Lizzano	17.45	40.38	67	–	–	–	–	1916–1996	0.0
Locarno	8.79	46.17	379	1935–1997	0.5	1864–1997	0.5	1886–2002	0.0
Locorotondo	17.33	40.75	420	–	–	–	–	1829–1996	1.9
Lombriasco	7.65	44.84	239	–	–	–	–	1913–1999	1.1
Lugano	8.97	46.00	276	1901–1997	0.0	1864–2003	0.0	1861–2002	0.0
Maglie	18.30	40.12	77	–	–	–	–	1908–1996	4.9
Manfredonia	15.92	41.62	2	–	–	–	–	1921–1996	3.9
Mantova	10.75	45.15	51	1828–2003	7.8	1828–2003	10.2	1840–2003	0.2
Massafra	17.12	40.58	116	–	–	–	–	1881–1997	2.6
Matera	16.62	40.68	401	–	–	–	–	1916–2002	18.8
Messina	15.50	38.20	54	1881–2003	2.0	1881–2003	2.0	1866–2003	2.0
Metaponto	16.82	40.37	3	–	–	–	–	1918–2000	4.5
Milano	9.19	45.47	64	1763–2003	0.2	1763–2003	0.3	1764–2003	0.1
Minervino Leccese	18.42	40.08	98	–	–	–	–	1926–1996	1.4
Moncalvo	8.25	45.05	297	–	–	–	–	1889–1988	0.0
Mondovi	7.82	44.04	44	–	–	–	–	1866–1995	0.0
Monte Maria	10.49	46.74	1323	–	–	1857–2003	36.1	1858–2003	0.0

Table II. (*Continued*)

Station	Lon (°)	Lat (°)	z (*m*)	TMin–TMax covered period	TMin–TMax missing data (%)	TMed covered period	TMed missing data (%)	Precipitation covered period	Precipitation missing data (%)
Napoli	14.25	40.88	149	1865–2003	1.6	1865–2003	1.6	1821–2003	0.1
Nardò	18.02	40.18	43	–	–	–	–	1923–1996	0.0
Nizza	7.20	43.65	4	–	–	1806–2003	29.3	1865–2002	7.2
Novara	8.62	45.45	181	–	–	–	–	1875–1996	0.0
Novi Ligure	8.78	44.78	186	–	–	–	–	1880–1979	0.0
Novoli	18.05	40.38	37	–	–	–	–	1924–1996	1.4
Otranto	18.50	40.13	52	–	–	–	–	1879–1996	3.5
Ovada	8.65	44.62	187	–	–	–	–	1913–1996	4.6
Padova	11.75	45.40	14	1774–2003	1.1	1774–2003	1.3	1750–2002	1.2
Palermo	13.35	38.10	71	1876–2003	0.7	1876–2003	1.4	1797–2003	2.9
Parma	10.25	44.80	57	1872–2003	1.0	1872–2003	1.0	1833–2002	0.0
Passo Rolle	11.28	46.28	2000	–	–	1895–2003	0.0	–	–
Pavia	9.25	45.17	75	1865–2002	15.1	1861–2002	15.5	1812–2002	3.2
Perugia	12.50	43.10	520	1865–2003	1.9	1865–2003	2.4	1811–2003	3.5
Pesaro	12.91	43.87	11	1871–2003	1.3	1871–2003	2.0	1866–2003	4.0
Piacenza	9.75	45.02	50	1871–2003	1.1	1871–2003	1.3	1872–2003	1.8
Potenza	15.82	40.63	826	1924–2002	2.1	1924–2002	2.1	1879–2002	3.2
Predazzo	11.60	46.30	1020	–	–	1896–2003	0.9	–	–
Presicce	18.27	39.90	114	–	–	–	–	1877–1996	2.2
Pula	13.87	44.86	30	–	–	1864–2003	14.6	1864–2002	7.7
Reggio Calabria	15.65	38.10	15	1878–2002	13.9	1878–2002	14.3	1877–2002	6.8
Reggio Emilia	10.75	44.70	62	1866–2003	14.5	1866–2003	15.6	1867–2003	4.1
Riva Torbole	10.83	45.88	70	–	–	1869–2003	23.2	1869–2003	5.1
Roma	12.47	41.90	56	1862–2003	0.0	1862–2003	0.0	1782–2003	0.0
Rossano	16.62	39.55	300	1925–1997	19.1	1925–1997	22.0	–	–
Rovereto	11.05	45.87	206	–	–	1862–2003	23.2	1864–2002	13.8
Rovigo	11.75	45.05	9	1879–2003	5.4	1879–2003	8.2	1878–2003	4.4
San Bernardo	7.18	45.87	2472	–	–	1818–1998	0.0	1864–1997	0.0
San Marco	15.62	41.72	560	–	–	–	–	1921–1998	0.0
San Pietro	18.13	40.30	160	–	–	–	–	1923–1996	0.0
Sassari	8.60	40.72	224	1874–2003	15.3	1874–2003	10.3	1876–2003	5.5
Silandro	10.77	46.63	706	–	–	–	–	1921–1999	0.8
Siracusa	15.28	37.05	23	1878–2003	16.7	1878–2003	17.3	1869–2003	12.0
Stroppo	7.12	44.50	1087	–	–	–	–	1913–1996	0.0
Taranto	17.30	40.45	22	1901–2003	3.5	1901–2003	4.3	1877–2003	1.4
Taviano	18.08	39.98	61	–	–	–	–	1885–1996	8.7
Torino	7.75	45.05	275	1753–2003	6.8	1753–2003	6.8	1802–2003	0.2
Torino Moncalieri	7.67	45.07	238	1865–2003	2.3	1864–2003	2.3	1864–2003	0.0
Tortona	8.87	44.88	199	–	–	1892–1965	0.9	1873–1998	0.5
Trento	11.12	46.07	199	–	–	1816–2003	0.7	1864–2003	12.7
Trieste	13.75	45.65	11	1883–2003	0.8	1841–2003	0.6	1841–2003	0.0
Tropea	15.88	38.67	51	1924–2002	21.0	1926–2002	24.1	1916–2002	21.4
Udine	13.20	46.06	51	1803–2003	12.7	1803–2003	12.8	1803–2002	12.6
Urbino	12.62	43.72	451	–	–	–	–	1850–2000	9.3
Vallombrosa	11.53	43.72	955	1872–2003	3.3	1872–2003	3.5	1872–2003	0.0
Valsinni	16.42	40.15	250	1924–2002	23.5	1924–2002	24.4	–	–

(*continued overleaf*)

Table II. (*Continued*)

Station	Lon (°)	Lat (°)	z (*m*)	TMin–TMax covered period	TMin–TMax missing data (%)	TMed covered period	TMed missing data (%)	Precipitation covered period	Precipitation missing data (%)
Varallo	8.25	45.82	454	–	–	–	–	1871–1995	0.0
Venezia	12.25	45.43	21	1900–2002	6.3	1900–2002	11.2	1836–2003	0.1
Verona	10.97	45.42	60	–	–	1788–2003	33.8	–	–
Vico Garganico	15.95	41.90	450	–	–	–	–	1922–1998	1.2
Vieste	16.17	41.88	25	–	5.4	–	5.5	1921–1998	0.3

There are different ways of solving homogeneity problems, and the choice of the most suitable one is strictly related to the data set characteristics (metadata availability, station density and so on) and to the examined region (Peterson *et al*., 1998; HMS-WMO, 1997, 1999, 2001; Aguilar *et al*., 2003).

Meteorological series can be tested for homogeneity and homogenised both by direct and indirect methodologies. The first approach is based on objective information that can be extracted from the station history or from some other sources, the latter uses statistical methods, generally based on comparison with other series. Direct methods have the advantage of providing detailed information about the time location of the inhomogeneities and the sources that caused them. Unfortunately, metadata are not always available and complete. Moreover, it is generally difficult to convert them into quantitative values useful to correct the discontinuities. On the other hand, indirect methods are more suitable to calculate correcting factors to eliminate the breaks, but the identification of inhomogeneities is not always easy and unambiguous, as (1) inhomogeneities and errors are present in all meteorological series, making it difficult to objectively assign the breaks to one or another of them and (2) correlation among data series depends on various factors (regional patterns, climate elements under analysis, time resolution of data and so on) and when the common variance (squared correlation coefficient) between the test series and the reference series is too low, the potential discontinuity signal in an homogeneity test disappears into statistical noise.

In Figure 4, the scatter plot of the common variance (on a monthly basis) *versus* station distance is shown for temperature and precipitation records. The figure gives evidence that, on a monthly basis, temperature has a high spatial coherence, and also for distances greater than 400 km many records have more than 50% of common variance. The decrease in common variance *versus* station distance is higher for minimum and maximum temperature and lower for the mean one. On the contrary, for precipitation, it is difficult to have more than 50% of common variance for distances greater than 100 km. This threshold distance is lower in central and southern Italy (Figure 5), whose correlation shows a faster decrease with distance. So, in spite of the strong increase in the station density, the application of indirect homogenisation methods to Italian records has still some setbacks that can be overcome only by means of strong metadata information support.

In some previous works (Buffoni *et al*., 1999; Brunetti *et al*., 2000b), an attempt aimed at homogenising precipitation and temperature data for Italy was made. Because of the low amount of metadata and the rather low station density, the homogenisation was performed by considering weighted averages among some neighbouring series as reference series (Alexanderson, 1986; Alexanderson and Moberg, 1997), with the confidence that the average procedure could eliminate or reduce the inhomogeneities in the reference series. Unfortunately, this is not always true, in particular for limited regions or single networks, where some simultaneous changes in the instruments or measurement methods can occur. By following this procedure, only the most relevant breaks were eliminated, but some minor (but not negligible) problems persisted. This was highlighted when some data from northern Italy were shared, within a wider data set covering the Greater Alpine Region.

In the last years, as previously mentioned, the Italian data set was remarkably enlarged with the collection of many new series, and a rich metadata archive was set up. This heritage of data and metadata together with the improvement of the homogenisation techniques led us to reconsider the entire homogenisation procedure.

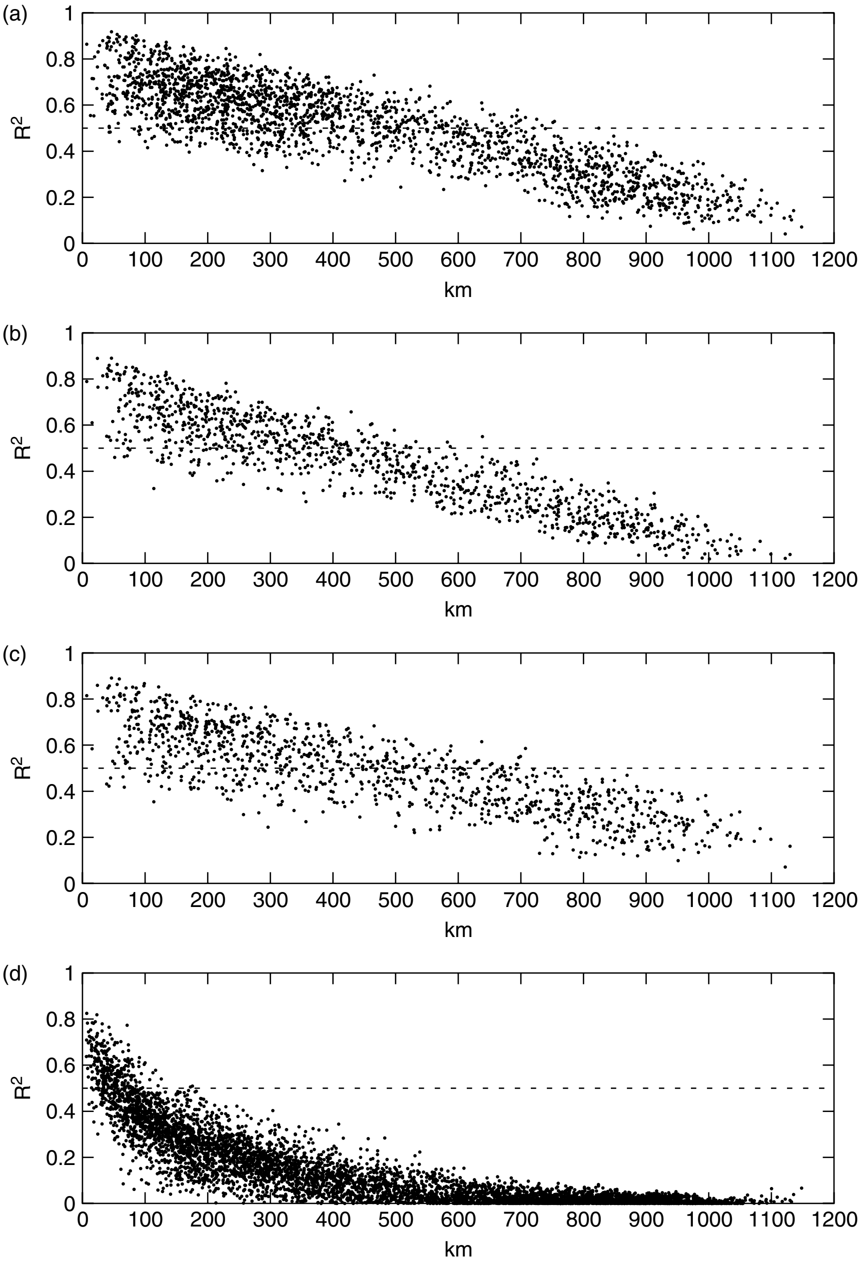

Figure 4. Scatter plot of the common variance among pairs of series *vs* station distance for (a) mean temperature, (b) maximum temperature, (c) minimum temperature and (d) precipitation. The squared correlation is calculated by means of the monthly anomalies of the period 1880–2003. They remove the yearly cycle from the records and allow evidence to be given only to displacements from climatological monthly normals

Within this new homogenisation, testing and adjusting were performed in regional sub-groups of 10 series using a revisited version of the HOCLIS procedure (Auer *et al.*, 1999). HOCLIS rejects the *a priori* existence of homogeneous reference series. It consists of testing each series against other series, by means of a multiple application of the Craddock test (Craddock, 1979), in sub-groups of 10 series. The test is based on the hypothesis of the constancy of temperature differences and precipitation ratios. The break signals of one series against all others are then collected in a decision matrix and the breaks are assigned to the single series

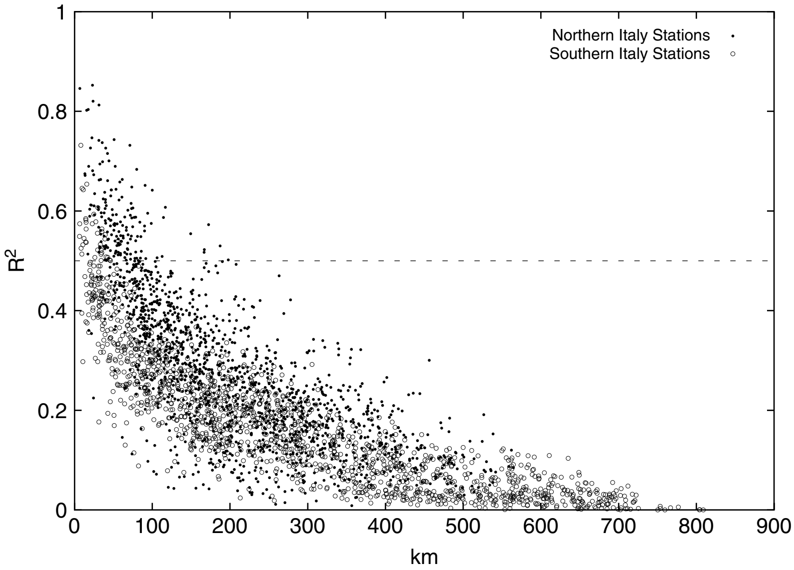

Figure 5. Scatter plot of the common variance among pairs of precipitation series *vs* station distance for northern (filled circles) and central-southern (open circles) stations. The squared correlation is calculated by means of the monthly anomalies of the period 1880–2003

according to probability. This system avoids trend imports and an inadmissible adjustment of all series to one or a few 'homogeneous reference series'. However, even if this method overcomes most of the problems concerning the hypothesis of the *a priori* existence of a homogeneous reference series, a margin of subjectivity in break identification persists, especially when discontinuities are not very high. In this case, the signal in the homogeneity test is not so clear and, as at present there is not a universal approach to the use of the indirect homogenisation methods, the choice of whether to homogenise or not may be strictly linked to the researcher's 'philosophy'. This point is an important open question of research concerning the reconstruction of the past climate.

When the signal is not clear, our 'philosophy' is to homogenise the data only in the following cases: (1) when there is some information in the metadata or (2) when more reference series give coherent adjustment estimates, and their scattering around the mean value is lower than the break amount. In our opinion, only in these cases the corrections really improve the data quality, whereas in other cases there is a high risk of introducing corrections whose associated errors are higher than the corrections.

Once we decide to correct one break, the series used to estimate the adjustments are chosen among the reference series that result homogeneous in a sufficiently long sub-period centred on the break year, and that correlate well with the candidate one. We chose to use several series to estimate the adjustments to be sure about their stability and to avoid unidentified outliers in the reference series from producing bad corrections. Moreover, it often happens that homogeneous sub-intervals between two detected breaks are so short that the signal-to-noise ratios of the adjustments obtained with only one reference series are very low. So, using more series allows us to correct a great number of short sub-periods that would have to be left unchanged otherwise. The adjustments from each reference series are calculated on a monthly basis, and then they are fitted with a trigonometric function in order to smooth the noise and to extract only the physical signal (the adjustments often follow a yearly cycle). The benefits of using smoothed adjustments instead of the rough ones are well described in Auer *et al.* (2005). The final set of monthly adjustments is then calculated by averaging all the yearly cycles, excluding from the computation those stations whose set of adjustments shows an incoherent behaviour compared with the others. When a clear yearly cycle is not evident, the adjustments used to correct the monthly data are chosen as constant through the year and are calculated as the average among the monthly values for temperature and as the weighted average for precipitation, where the weights are the ratios between monthly mean precipitation and total annual precipitation.

Generally, in our data, temperature adjustments (additive) resulted in more or less pronounced, but rather steady, annual courses. The monthly adjustment factors for precipitation series, in contrast, showed in many cases a non-evident annual course and, in the majority of cases, a constant correction was made. Some exceptions were those stations with a predominant snowy winter precipitation.

Table III summarises some statistical characteristics of the homogenisation.

Precipitation series present a lower number of breaks per series. Moreover, many series remained unchanged as they were classified homogeneous. The reason is not only a better quality of the precipitation data set, but also a lower signal-to-noise ratio that characterises this meteorological variable. As a consequence, it was often difficult to obtain coherent correcting factors from the different reference series in case of discontinuities below 5–10%.

The number of breaks in mean temperature series is given by the sum of the breaks identified in minimum and maximum temperatures, plus more breaks located in periods or series for which minimum and maximum values were not available (9 series have some periods with non-available minimum and maximum temperatures and for 19 series, only mean temperatures are available). Minimum temperatures show a higher number of breaks per series than maximum temperatures.

Figures 6(a)–(d) show the number of detected breaks per year for the whole data set. Obviously, the number of corrections increases with the station number. In Figures 6(e)–(h), the number of breaks per year in relation to the available series is also shown. In this case, the number of detected breaks is almost constant in time, with only some evidence of a higher number of breaks per series in the early and the last periods. However, because of the low spatial density of the available series in the early instrumental period that makes the identification of breaks more difficult, we cannot conclude that the quality of the data set is unchanged from the beginning till today; on the contrary there could be a probable underestimation of the inhomogeneities of the early period, especially for temperature. In fact, the homogenisation of the initial part of the temperature records was very difficult, not only as a consequence of low station density but also because all records were affected by severe errors depending on a number of factors. The most important factor seems to be the progressive introduction of the minimum and maximum thermometers that have allowed a much more accurate estimate of the daily extremes than the previous observations at sunrise and in the afternoon. Another very important factor is the progressive substitution of the initial thermometer metal screens with meteorological windows, such as the one shown in Figure 1 (for a general discussion of the homogeneity problem of the most ancient thermometer records see Camuffo and Jones, 2002). Unfortunately, metadata concerning the first part of the records are available only in some cases. So, in many cases, especially for minimum and maximum temperature, the lack of corrections in the early period of the records is more a consequence of the difficulties of the homogenising method than an effect of high data quality. The main consequence of these difficulties is that we have a lower confidence of the results of data homogenisation for the years before 1865, i.e. before the Italian Ministry of Agriculture, Industry and Trade began to define instruments and standards and to collect data for the whole national territory. So, as the aim of our research is to give reliable long-term estimates, only minimum and maximum temperature data after 1865 will be considered for trend analysis, whereas for mean temperature, the trend will be given for the full period, even though in this case also the initial data might contain some unsolved inhomogeneities. The situation is

Table III. Break statistics

	Mean T	Maximum T	Minimum T	Precipitation
No of years (excluding filled gaps)	8292	5848	5848	13 355
No of breaks	766	347	398	170
No of breaks per series	11.43	7.23	8.29	1.53
No of breaks per year per series	0.092	0.059	0.068	0.013
Mean homogeneous sub-period (years)	10.8	16.9	14.7	78.6

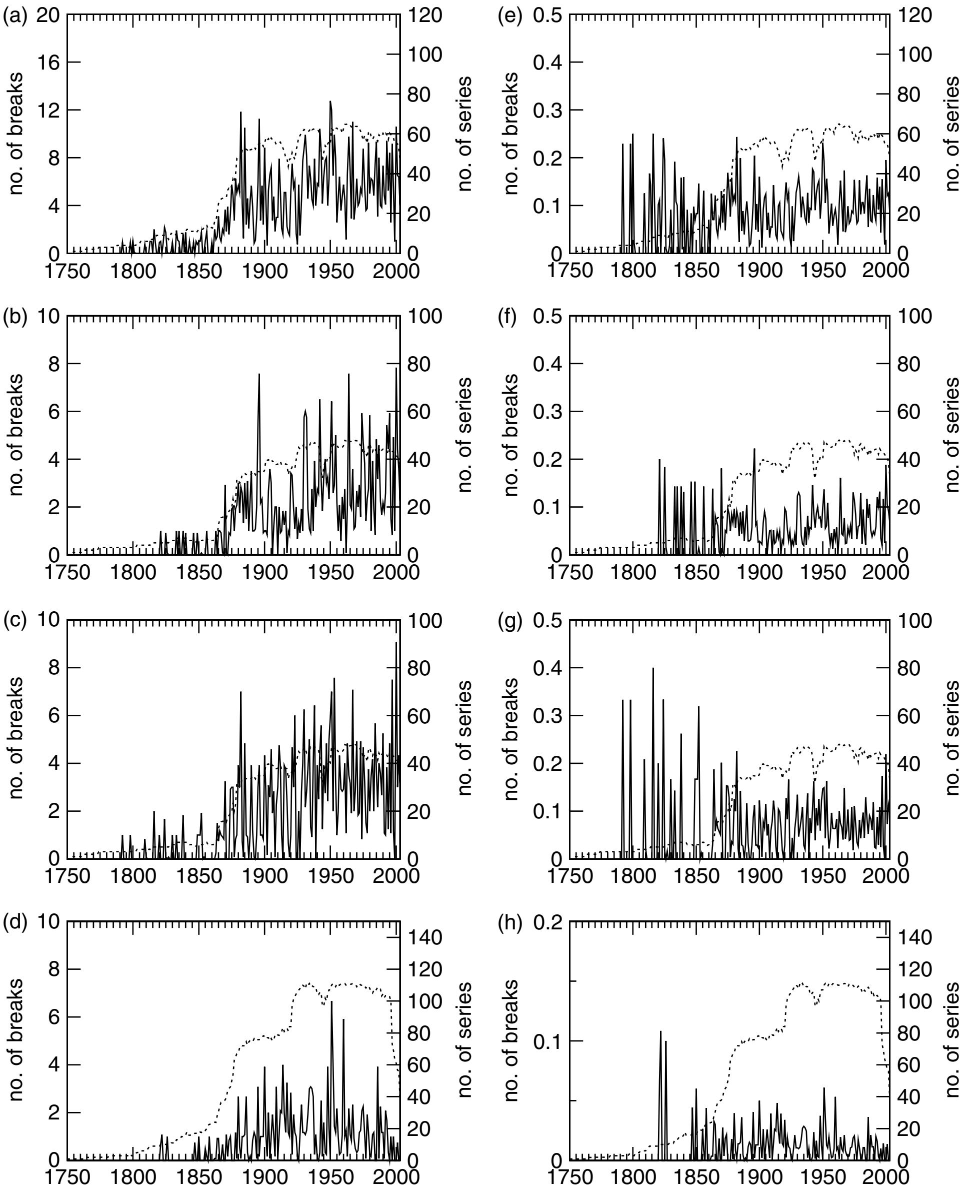

Figure 6. Number of detected breaks per year. From (a) to (d) absolute values (for mean temperature, maximum temperature, minimum temperature and precipitation respectively); from (e) to (h) in relation to the available series (for mean temperature, maximum temperature, minimum temperature and precipitation respectively)

better for precipitation records, as they do not present so many homogeneity problems in the initial period. However, also in this case, station density is rather low before 1865 and the results of homogeneity testing and adjusting have a lower confidence than in the following period.

As far as the higher break frequencies of the last few years are concerned, they are probably due to the recent (around year 2000) transfer of the management of many stations to the regional administrations, which in many cases corresponded to a station relocation.

Before starting with the analysis of the homogenised data, the comparison among homogenised and original series is discussed to highlight the degree of bias of the original data set. This issue can be investigated by analysing the adjustment series. As these series contain the values that were added to (multiplied by) the original temperature (precipitation) records in order to produce homogeneous data, this analysis will reveal any systematic errors in the original records. Figure 7 shows the mean adjustment curves averaged over all single series, the standard deviation and the absolute range of the adjustments for all the different variables. The large absolute ranges of adjustments (the dotted lines) as well as the standard deviation ranges underline again the absolute necessity to homogenise in order to get any reasonable single station series.

Because of the low number of available stations in the early period (see Figure 3), before around 1865 the adjustment curves present a high variability, reflecting single site peculiarities more than general systematic evolutions. For temperature (Figures 7(a), (b) and (c)), however, the means of all adjustments (the bold lines) are often significantly different from zero, also where the samples reach the maximum availability of data, indicating that the temperature inhomogeneities are not completely random. Moreover, they display an evident positive trend.

The trend in the adjustment series is higher for minimum temperature and lower for the maximum one (0.8 and 0.3 K over the last 140 years respectively). It is probably due to a progressive evolution of thermometer location from meteorological windows as the one in Figure 1 to ground-level Stevenson screens. This evolution began in the late nineteenth century and continued in the following decades, being particularly important around World War II.

So, the analysis of the adjusting series reveals that the use of the original data in estimating long-term temperature evolution gives negatively biased results. This result is in agreement with the findings of Böhm *et al.* (2001) and Begert *et al.* (2005).

After the homogenisation procedure, missing months were filled with estimates based on the highest correlated reference series. The method is based on the assumption of the constancy of the differences (ratios) between incomplete and reference temperature (precipitation) series. The algorithm works as follows for each missing monthly value: each month is considered separately; when one value is missing, a window large enough to hold 30 available values for that month is considered (for precipitation we considered a window with 50 available values to obviate its lower spatial coherence); then all the series that are complete within that window are considered and the one that better correlates with the candidate one is chosen to evaluate the missing value.

For each series, all the gaps comprised between its first available year and December 2003 were filled. The fraction of estimated data is around 6% for precipitation, around 7% for minimum and maximum temperatures and around 10% for mean temperature.

4. DATA ANALYSIS

4.1. Clustering of the stations into climatic regions

The first step in data analysis was clustering the stations into climatologically homogeneous regions by means of Principal Component Analysis (PCA). PCA allows the identification of a small number of linearly independent variables (Principal Components, PCs), obtained as linear combinations of the original variables that explain most of the variance of the original data. The technique (e.g. von Storch, 1995 or Hanssen-Bauer and Nordli, 1998) consists of solving the eigenvalue problem for the covariance or the correlation matrix. We used the correlation matrix R based on the monthly anomalies (in order to avoid the dominance of the annual course of temperature and precipitation) for the sub-sample 1928–2003, for which all the series were available. For temperature, the analysis was applied to the full data set, whereas for precipitation, as the spatial density of the stations was particularly inhomogeneous, a homogeneously distributed subset of 73 stations was considered.

Table IV shows the eigenvalues, the explained variances, and the cumulative explained variances of the first 10 base vectors (Empirical Orthogonal Functions, EOFs), both for temperature and precipitation. It is evident that, for temperature, only three EOFs have eigenvalues greater than 1 (i.e. account for more variance than the original variables). These account for 85% of the variance of the mean temperature data set and 82% of the variance of the minimum and maximum data set. For precipitation, the spatial coherence is lower and there are nine EOFs with eigenvalues greater than 1. In this case, however, we considered only the first

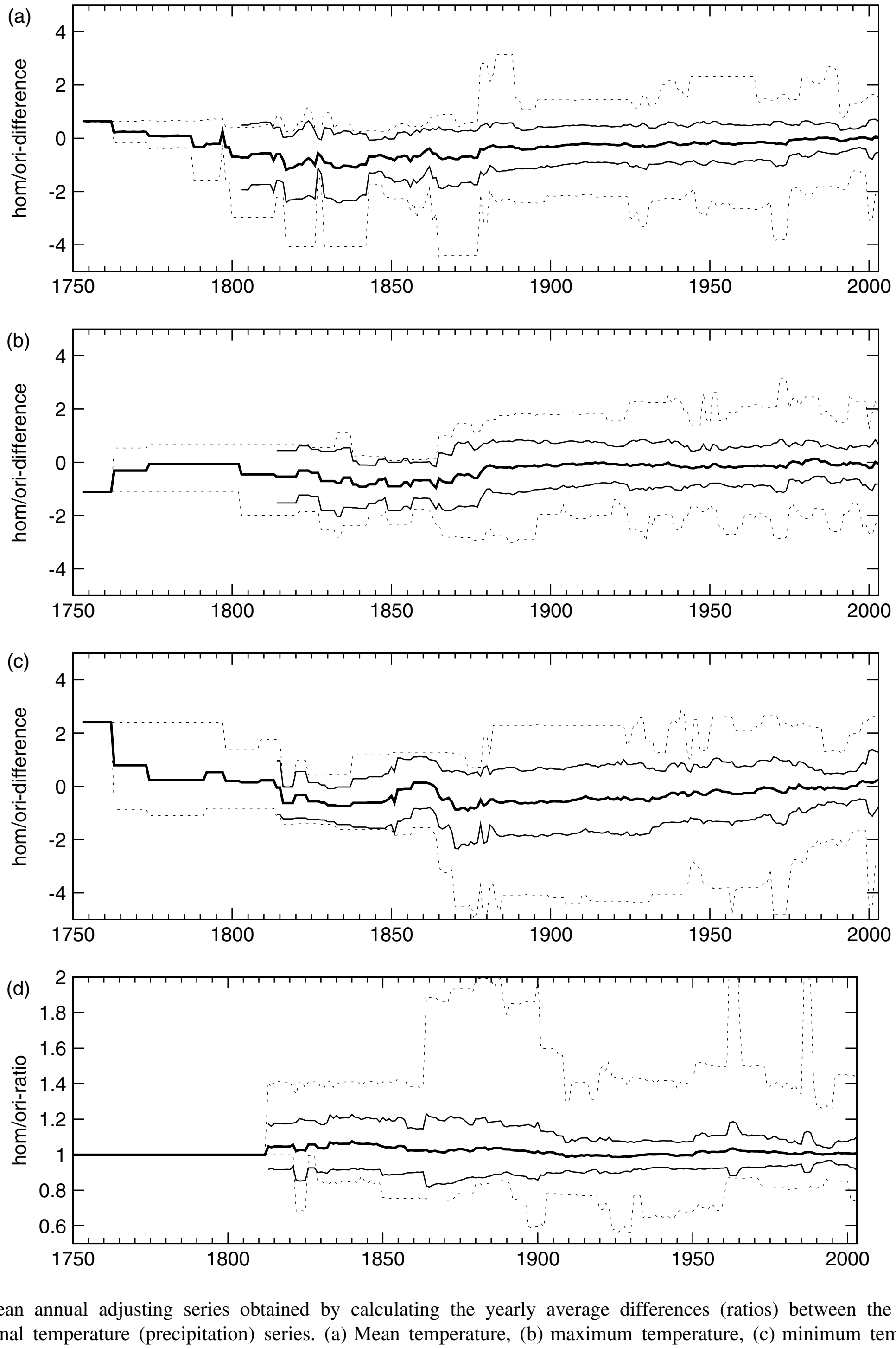

Figure 7. Mean annual adjusting series obtained by calculating the yearly average differences (ratios) between the homogenised and the original temperature (precipitation) series. (a) Mean temperature, (b) maximum temperature, (c) minimum temperature, and (d) precipitation. Standard deviations (thin lines) and total correction ranges (dotted lines) are indicated too. The standard deviations were not calculated before 1803 for mean temperature and before 1814 for minimum and maximum temperature, because of a sample size fewer than 5 stations

Table IV. Eigenvalues, explained variances and cumulative explained variance of the first 10 EOFs for mean, maximum and minimum temperature and precipitation

Tmed			Tmax			Tmin			Prec.		
Eig. val.	Var. (%)	Tot. Var. (%)	Eig. val.	Var. (%)	Tot. Var. (%)	Eig. val.	Var. (%)	Tot. Var. (%)	Eig. val.	Var. (%)	Tot. Var. (%)
48.67	72.65	72.65	32.27	67.24	67.24	34.23	71.30	71.30	25.60	35.07	35.07
6.31	9.42	82.06	5.89	12.26	79.50	3.85	8.03	79.33	10.70	14.66	49.73
1.77	2.65	84.71	1.13	2.36	81.85	1.33	2.76	82.09	5.24	7.18	56.92
0.99	1.49	86.19	0.87	1.80	83.66	0.74	1.53	83.63	3.47	4.75	61.67
0.75	1.11	87.31	0.68	1.42	85.08	0.50	1.05	84.67	2.19	3.00	64.67
0.61	0.92	88.23	0.61	1.27	86.35	0.48	1.00	85.67	1.74	2.39	67.06
0.42	0.62	88.85	0.47	0.99	87.33	0.40	0.83	86.50	1.29	1.76	68.82
0.40	0.60	89.45	0.39	0.81	88.14	0.39	0.81	87.31	1.18	1.61	70.43
0.36	0.53	89.98	0.35	0.73	88.87	0.35	0.74	88.05	1.15	1.57	72.00
0.30	0.45	90.43	0.34	0.71	89.58	0.35	0.72	88.77	0.99	1.36	73.36

six functions, as the EOFs out of the first six account for a low amount of the total variance and give no additional information. The first six EOFs explain 67% of the variance of the precipitation data set.

Non-rotated solutions of the PCA are more useful when pure data reduction is sought and where PCs will be used for regression, without individually interpreting each mode. Otherwise, when the goal is station clustering, simple structure rotations are helpful to better interpret the results. Therefore the selected EOFs were rotated by means of aVARIMAX rotation, and the variance was re-distributed among them.

The results of the rotation of the temperature EOFs are shown in Figure 8, where loading patterns are plotted on geographic maps (drawing contours through the points with the same loadings) for mean temperature (Figure 8(a)–(c)), maximum temperature (Figure 8(d)–(f)) and minimum temperature (Figure 8(g)–(i)). These loading patterns allow the following regions to be identified:

- The Po plain (PP): a region surrounded northward and westward by the Alps, southward by the Apennines and eastward by the Adriatic sea. It comprises the larger northern Italy valleys: the Po valley as far as Alexandria, and the Adige valley up to Bolzano.
- The Italian Alpine region, Liguria and western Piedmont (AL): a region framing Italy in the north and west, it mainly consists of high valley and pied-mountain stations. This region extends to the south up to the edge between the Alps and Apennines, comprising also the costal region of the gulf of Genoa.
- Peninsular Italy (PI): a region surrounded by the Mediterranean and comprising central and southern Italy and the two main islands (Sardinia and Sicily). It consists of both maritime and Apennine stations.

These three regions are indicated in Figure 9 where topography and major rivers are also drawn.

It is worth noting that for mean temperature there is quite a uniform distribution of the stations within the 3 regions, with 23 stations in PP and 22 stations in AL and PI, whereas for minimum and maximum temperatures the number of stations is significantly lower in AL (10 stations) than in the other areas (PP: 16 stations; PI: 22 stations). Moreover, most of these 10 stations are in the western part of northern Italy, and only one has an altitude higher than 1000 meters. So, data availability is not completely suitable for a correct description of minimum and maximum alpine temperatures.

The results of the rotation of the precipitation EOFs are shown in Figure 10. The identified regions are:

- Northwestern Italy (NW, Figure 10(a)): a region covering the western Alps and the western part of the Po Plain. It extends southward to the gulf of Genoa and comprises mountain, pied-mountain and plain stations.
- Southeastern Italy (SE, Figure 10(b)): a region of maritime influence, comprising Apulia and Basilicata.

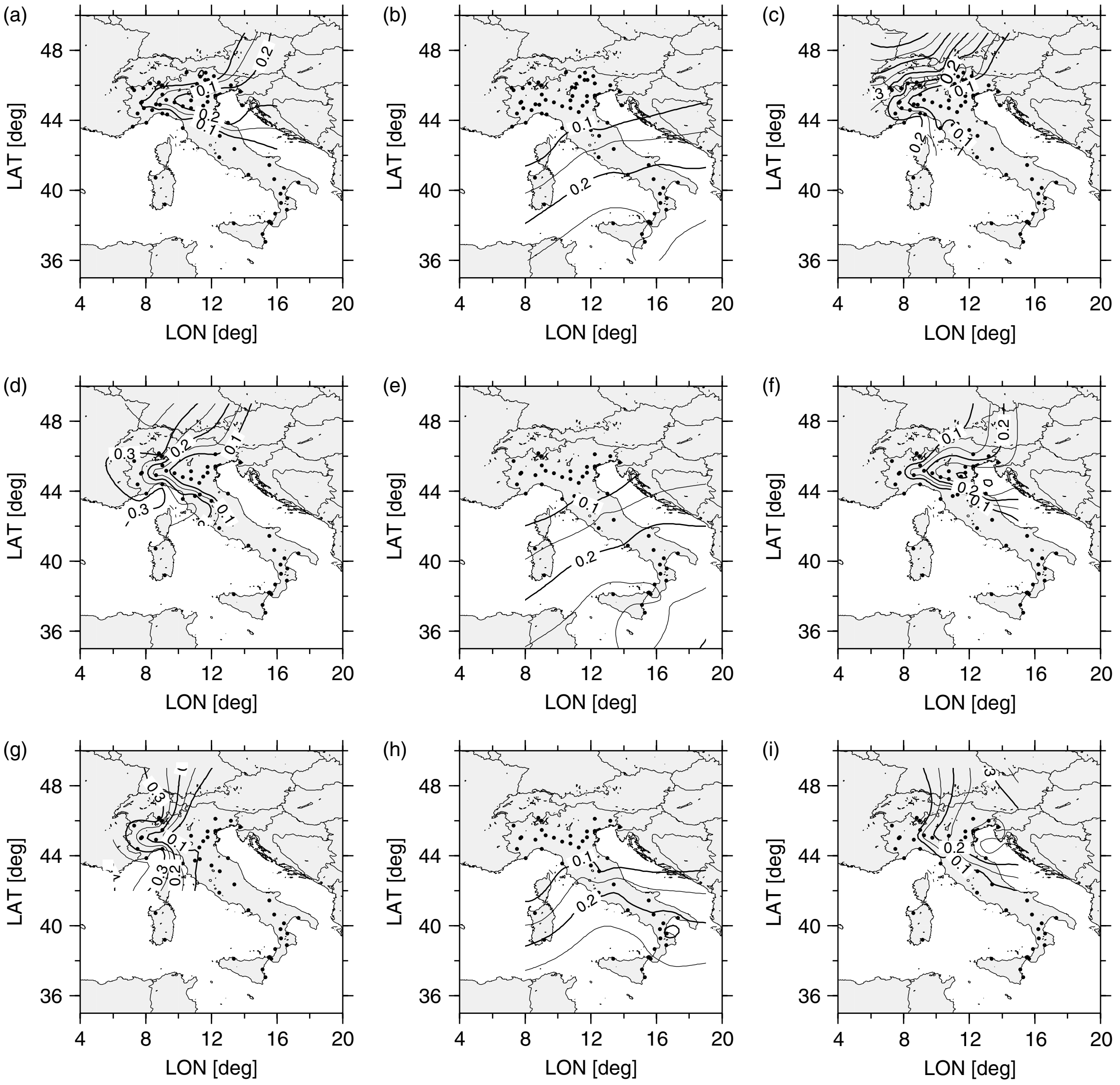

Figure 8. Maps of the three rotated EOFs for mean (a–c), maximum (d–f), and minimum (g–i) temperature

- The southern part of northeastern Italy (NES, Figure 10(c)): a region which is similar to that identified by the first temperature EOF, even though it includes only plain stations and has minor extension both to the north and to the west.
- The northern part of northeastern Italy (NEN, Figure 10(d)): a region covering the central and eastern Alps. It mainly comprises mountain stations.
- Southern Italy (SO, Figure 10(e)): a region covering the extreme southern part of Italy. It comprises all stations below 39° latitude.
- Central Italy (CE, Figure 10(f)): a region comprising the core of the Apennines, the coastal areas of the Tyrrhenian sea and the northern part of Sardinia.

The borders of the six regions are indicated in Figure 11, where the stations used for the PCA are indicated with open circles, while those excluded to obtain a uniform station density are indicated with black full circles.

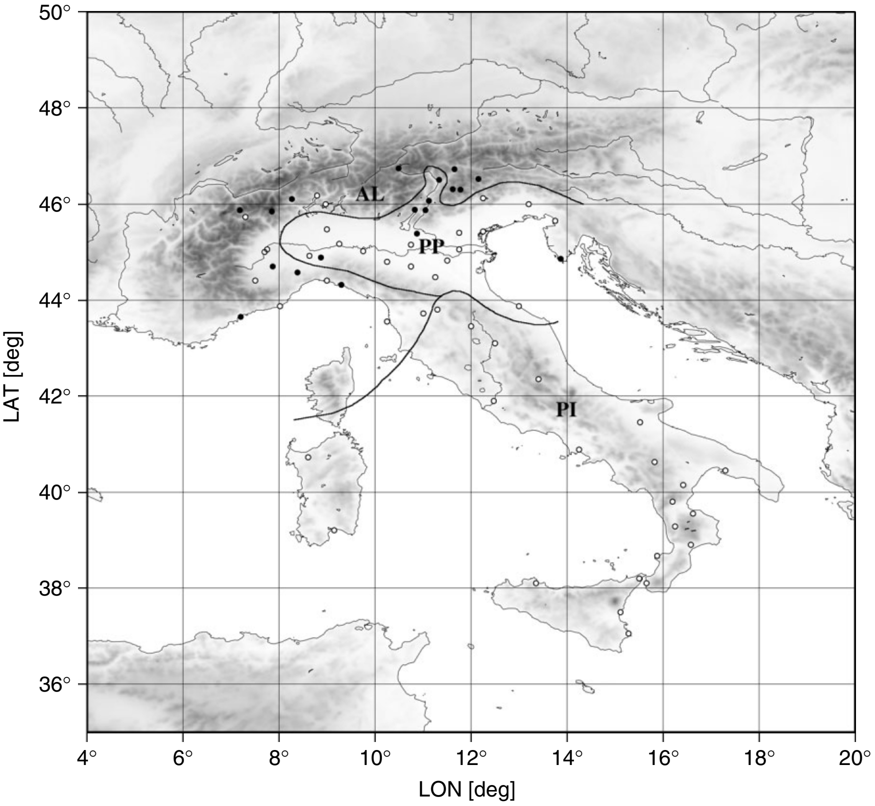

Figure 9. Map of the temperature sub-regions based on PCA. Black circles indicate stations with only mean temperature data available, open circles indicate stations with both mean and extreme temperature data available

As for minimum and maximum temperatures, for precipitation also there are significant differences in the number of stations in the regions: NW and SE have the highest number (33 stations), then there are 13 stations in CE, 12 stations in NEN, 11 stations in NES, and 9 stations in SO.

4.2. Calculation and analysis of seasonal and annual mean regional records

After clustering the stations, we computed seasonal and annual mean regional records. These records give a more synthetic description of the climatic signal than the single station series and permit a higher signal-to-noise ratio, allowing a better identification of long-term trends. They were obtained by first considering for each station the anomalies from the 1961–1990 seasonal and annual means for temperature and the ratios with the means of this period for precipitation, and then by simply calculating the arithmetic means over all the available data of each region. The use of the anomalies/ratios instead of the absolute values allows the regional mean records to be unbiased by the time evolution of the number of available series. Besides the average regional records, we also computed average national records (ITA) both for temperature and precipitation series.

Regional series were calculated only if at least three series were available within the region, while ITA series were calculated if at least five series were available all over Italy. Under these restrictions the starting years are: 1818, 1788, 1865 and 1803 for AL, PP, PI and ITA mean temperature series; 1865, 1803, 1865 and 1814 for AL, PP, PI and ITA minimum and maximum temperature; and 1812, 1856, 1833, 1821, 1875, 1866 and 1802 for NW, NEN, NES, CE, SE, SO and ITA precipitation. It is, however, worth noting that up to the 1850s, ITA temperature records only represent AL and PP regions, the longest PI series starting in the 1860s.

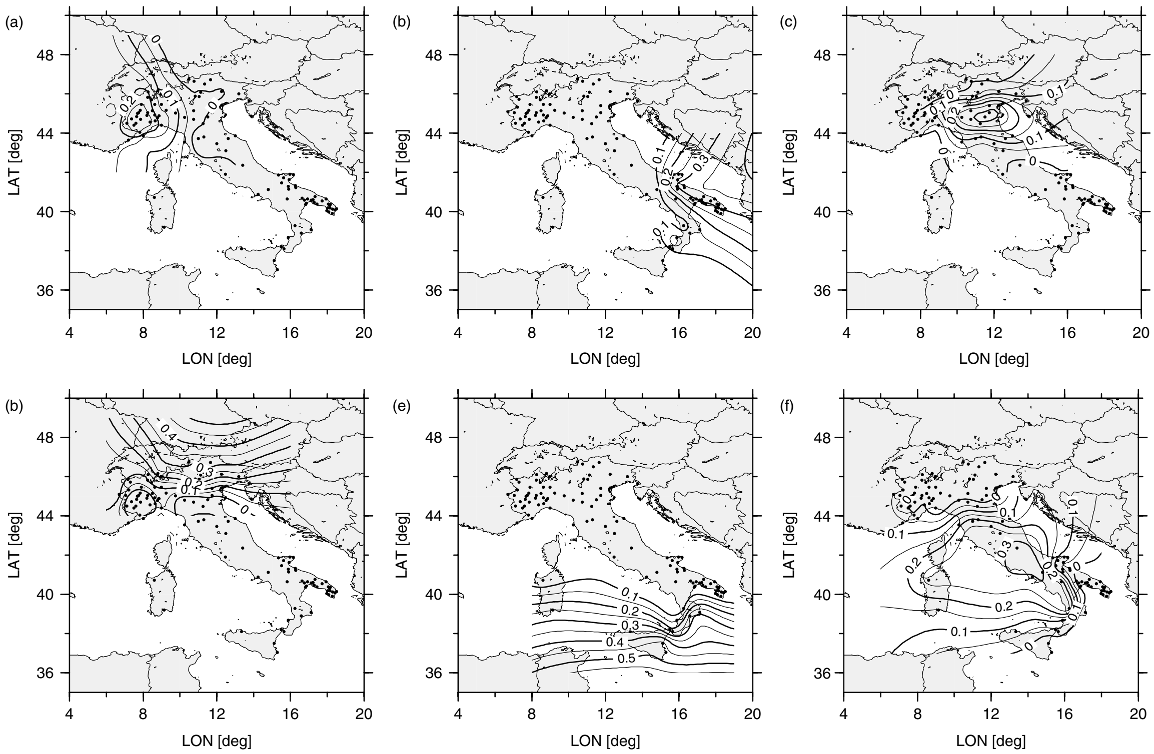

Figure 10. Maps of the six rotated EOFs for Precipitation

Annual values correspond to the period from December to November and are dated by the year in which January is included. Thus, the annual means cover the same months as the seasonal means, where winter values refer to the December–February interval, spring to March–May, summer to June–August and autumn to September–November.

It is interesting to observe from Table V that there is rather a high correlation between the different temperature regional average series, with correlation coefficients ranging from 0.73 (AL–PI, maximum temperature) to 0.93 (AL–PP, mean and maximum temperature) for the annual series and from 0.73 (AL–PI, autumn maximum temperature) to 0.96 (AL–PP, winter maximum temperature) for the seasonal ones. So, most of the temperature signal can be captured by considering the average record over all Italian stations, i.e. ITA series. Correlation coefficients between ITA and regional temperature records are greater than 0.90 both at seasonal and annual level.

The correlation between precipitation regional records is rather low (Table VI). Nevertheless, also in this case, ITA annual and seasonal records explain a significant portion of the variance of the regional series and can be considered as representative of a significant portion of the signal.

Figure 12 shows the seasonal and annual AL, PP and PI mean, maximum and minimum temperature series filtered with a 3-year σ Gaussian low-pass filter. It is evident that the regional temperature anomalies are highly correlated, not only concerning year-to-year variability (Table V) but also on secular timescale. The high similarity among the regional series allows us to give a preliminary representation of the whole area by means of the national average records that are presented in Figure 13 together with their 3-year σ Gaussian low-pass filters.

The ITA annual mean temperature series starts with rather low values before 1860s, with 1816 being the absolute minimum of the 1803–2003 period. After this period, there is a gradual trend towards higher values with the strongest contribution coming from the 1860s, 1890s, 1920s and 1940s. After the relative maximum reached around 1950 (which is the most important besides the last two decades) and up to the 1970s there is a stationary situation followed by the strongest increase of the whole period, with 2003 being the warmest year of the series.

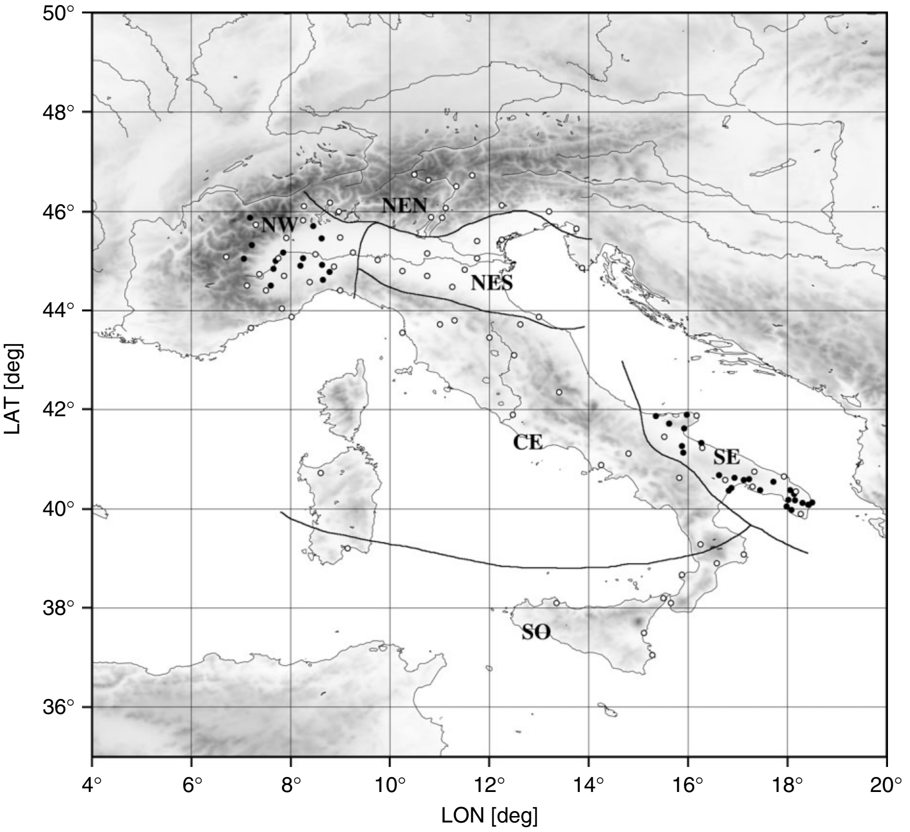

Figure 11. Map of the precipitation sub-regions based on PCA. Open circles indicate stations used for the PCA computation, black circles indicate stations excluded to obtain a uniform station density for the PCA

Table V. Correlation coefficients among regional temperature series and among regional and ITA series

		Mean temperature			Maximum temperature			Minimum temperature		
		PP	PI	ITA	PP	PI	ITA	PP	PI	ITA
Y	AL	0.93	0.76	0.95	0.93	0.73	0.92	0.92	0.79	0.93
	PP		0.84	0.98		0.79	0.96		0.87	0.98
	PI			0.91			0.93			0.95
W	AL	0.94	0.78	0.96	0.96	0.77	0.94	0.92	0.80	0.93
	PP		0.84	0.98		0.81	0.97		0.87	0.98
	PI			0.91			0.93			0.94
Sp	AL	0.94	0.77	0.96	0.95	0.74	0.94	0.92	0.79	0.93
	PP		0.83	0.98		0.78	0.96		0.88	0.98
	PI			0.90			0.91			0.95
S	AL	0.94	0.79	0.96	0.94	0.77	0.93	0.92	0.80	0.93
	PP		0.85	0.98		0.82	0.96		0.89	0.98
	PI			0.92			0.94			0.95
A	AL	0.93	0.76	0.95	0.93	0.73	0.92	0.93	0.80	0.93
	PP		0.84	0.98		0.79	0.96		0.88	0.98
	PI			0.91			0.93			0.95

Table VI. Correlation coefficients among regional precipitation series and among regional and ITA series

		Precipitation					
		NEN	NES	CE	SE	SO	ITA
Y	NW	0.64	0.66	0.48	0.16	−0.02	0.73
	NEN		0.57	0.47	0.05	−0.06	0.56
	NES			0.80	0.39	0.06	0.78
	CE				0.62	0.30	0.83
	SE					0.68	0.75
	SO						0.47
W	NW	0.65	0.63	0.23	0.03	−0.15	0.72
	NEN		0.50	0.30	0.06	−0.10	0.62
	NES			0.66	0.28	−0.05	0.74
	CE				0.45	0.07	0.60
	SE					0.82	0.67
	SO						0.40
Sp	NW	0.67	0.64	0.42	0.12	−0.03	0.74
	NEN		0.62	0.48	0.10	−0.02	0.64
	NES			0.77	0.43	0.17	0.82
	CE				0.53	0.28	0.76
	SE					0.74	0.71
	SO						0.48
S	NW	0.65	0.66	0.47	0.18	−0.02	0.71
	NEN		0.56	0.40	0.03	−0.08	0.51
	NES			0.78	0.39	0.08	0.76
	CE				0.65	0.38	0.83
	SE					0.75	0.79
	SO						0.54
A	NW	0.63	0.65	0.47	0.15	−0.03	0.72
	NEN		0.56	0.45	0.03	−0.08	0.54
	NES			0.80	0.40	0.06	0.78
	CE				0.62	0.31	0.83
	SE					0.69	0.76
	SO						0.47

The analysis of seasonal series gives evidence that, besides some common features, there are also significant differences. In particular, the strong increase characterising the last two decades observed on an annual basis does not have the same importance in all seasons: it is evident in spring and summer, but not in autumn and winter, where the trend is less steep. During winter in particular, the behaviour is even opposite in the last few years. Also the relative maximum observed around 1950 in the annual series is mainly due to summer and spring seasons, where the temperatures are comparable to the 1990s values. Moreover, it is interesting to note that the two extremes of the yearly series, 1816 and 2003, are mainly due to the summer season. They correspond to two widely studied events: the strong heatwave of summer 2003 (Schär *et al.*, 2004) and the cold summer of 1816 (Harington, 1992; Chenoweth, 1996; Briffa *et al.*, 2001), known as *year without a summer*, that followed a four year period of particularly strong volcanic eruptions, the most violent being the Tambora (Indonesia) in April 1815 (Harington, 1992), whose explosion is believed to have lifted 150 to 180 cubic kilometres of material into the atmosphere (for a comparison, the infamous 1883 eruption of Krakatau ejected ‘only’ 20 cubic kilometres of material).

As far as ITA maximum and minimum temperatures are concerned, Figure 13 gives evidence that, besides a rather similar long-term evolution, the most interesting differences between the two parameters regard the

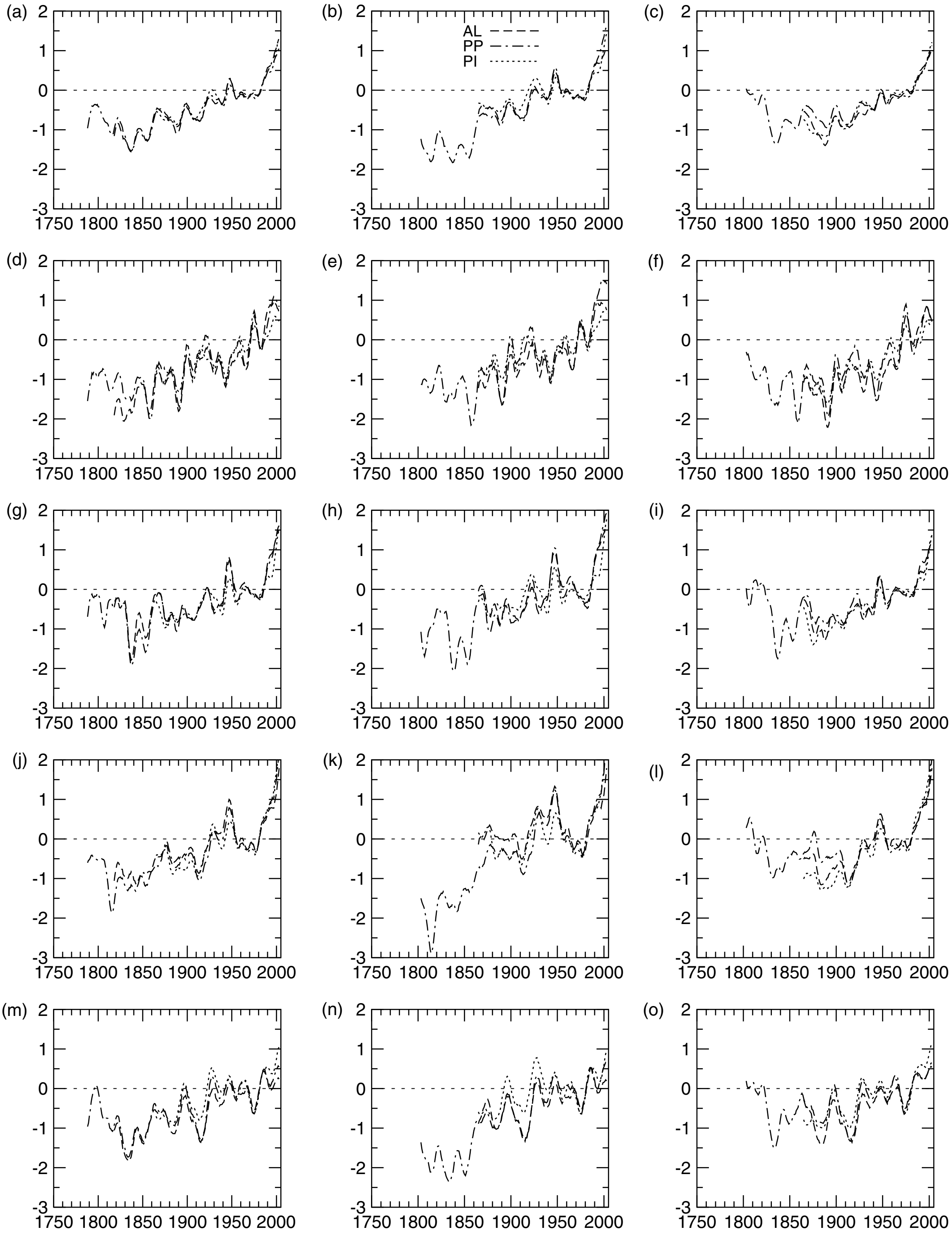

Figure 12. Average regional series for (from left to right) mean, maximum, and minimum temperature. (a–c) yearly series; (d–f) winter series; (g–i) spring series; (j–l) summer series; (m–o) autumn series. The series were filtered with an 11-year window 3-year σ Gaussian low-pass filter. (AL: dashed line; PP: dashed–dotted line; PI: dotted line)

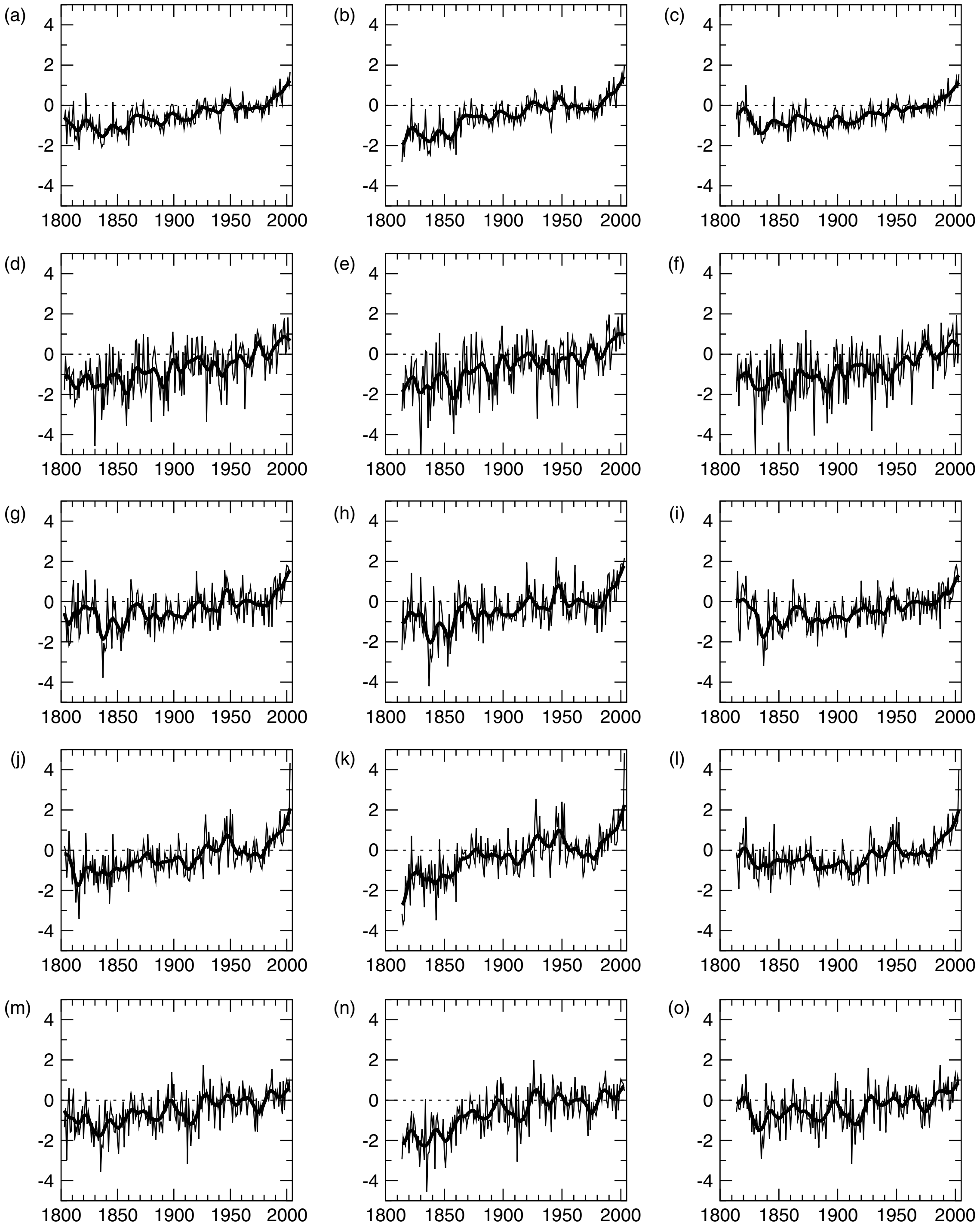

Figure 13. Average national series for (from left to right) mean, maximum, and minimum temperature. (a–c) yearly series; (d–f) winter series; (g–i) spring series; (j–l) summer series; (m–o) autumn series. The series are displayed together with an 11-year window 3-year σ Gaussian low-pass filter

last decades with a steeper trend in the maximum temperature rather than in the minimum one and the earlier period. The latter one, as discussed in the homogenisation section, may be a consequence of the lower confidence on the maximum and minimum data quality in the earlier period, since the data are not really extreme temperatures but day and nighttime values (the maximum and minimum thermometer being widely introduced all over the network only after the 1850s). The bias caused by the absence of the daily extreme observations is very evident in the original series, which show in the initial period higher-than-normal minimum temperatures and lower-than-normal maximum temperatures. The problem was partially solved by homogenisation, but it was probably not completely eliminated.

It is worth noting that the mean temperature extreme values are remarkable events also for minimum and maximum temperatures: 1816 is the second coldest summer of both the minimum and maximum series, and 2003 is the warmest summer of both series with values 4.8 and 4.0 K higher than the 1961–1990 average for maximum and minimum temperature, respectively.

Figure 14 shows annual and seasonal regional precipitation series filtered with a 3-year σ Gaussian low-pass filter. Besides strong differences in the high-frequency variability, there is quite a similar long-term behaviour that, together with the results of the correlation between ITA and regional series shown in Table VI, suggests that we use the Italian average to give a preliminary representation of the whole area.

Figure 15 presents the annual and seasonal ITA precipitation series together with the filtered series (again with a 3-year σ Gaussian low-pass filter). The annual data show a sequence of relative maxima and minima without any evident tendency towards an increase or decrease in total precipitation. Highest precipitation values were reached in the 1800s, between the 1840s and the 1850s and around 1900, 1960 and 1980. The lowest values in total precipitation amount can be observed around 1990 and in the 1940s plus two secondary minima between the 1820s and the 1830s and in the 1860s. On a seasonal basis, besides some common characteristics both in the long-term behaviour and in the high-frequency variability, there are many differences in the location of the periods with minimum and maximum precipitation amounts.

4.3. Trend analysis of the regional mean records

The regional and national average temperature and precipitation series were analysed for trend by means of the Mann–Kendall non-parametric test (Sneyers, 1990). The slopes of the trends were calculated by least-square linear fitting.

Yearly and seasonal temperature trends for the 1865–2003 period are shown in Table VII, both for the three regions and all Italy.

With regards to mean temperature, the situation is quite uniform among the different regions, with a trend of 1 K per century all over Italy on a yearly basis. Also on a seasonal basis the situation is quite uniform and no significant differences are evident, neither for the different regions nor for the different seasons, as all trend values are comparable within one standard error. It is however interesting to highlight the lower autumn values because of the uniformity of the signal through all the regions.

The trend is generally higher for minimum temperature than for maximum temperature for all the seasons and the year, the only exception being the PP region, whose trend is always higher for maximum temperature. As for mean temperature, also maximum and minimum temperatures show a lower trend in autumn, the only exception being the maximum temperature series of AL that has a minimum trend value in summer.

Table VIII shows the yearly and seasonal trends of the precipitation regional average series over the 1865–2003 period. Trends are generally negative, even if the decreases are very low and rarely significant. Considering the average all over Italy there is a decrease of 5% per century in the annual precipitation amount, which is mainly due to the spring season (–9% per century). The region with the most evident negative trend in total precipitation is CE, with a decrease of 10% per century on a yearly basis, and 20 and 13% per century in spring and summer respectively. Among the other regions, only SE shows significant trend even if only in the total annual precipitation (−8% per century).

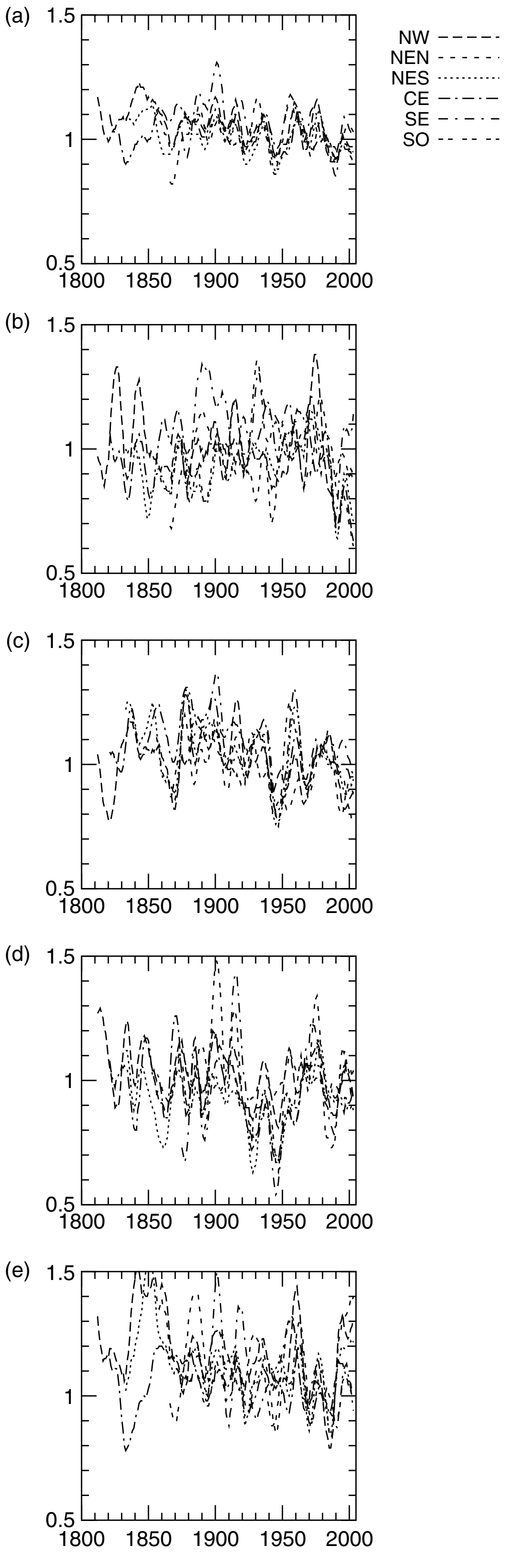

Figure 14. Average regional precipitation series. (a) yearly series; (b) winter series; (c) spring series; (d) summer series; (e) autumn series. The series were filtered with an 11-year window 3-year σ Gaussian low-pass filter

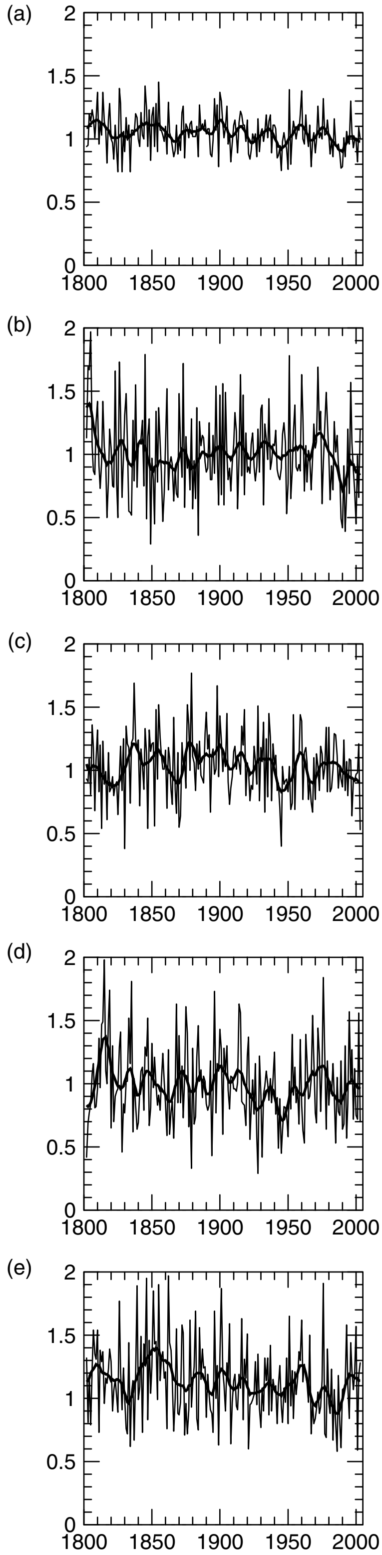

Figure 15. Average national precipitation series. (a) yearly series; (b) winter series; (c) spring series; (d) summer series; (e) autumn series. The series are displayed together with an 11-year window 3-year σ Gaussian low-pass filter

Table VII. Trends of mean, maximum and minimum temperatures over the 1865–2003 period. The values are expressed in K per century. Bold values indicate trends with significance level higher than 99%, values in italics indicate trends with significance level higher than 95%

	Tmed				Tmax				Tmin			
	AL	PP	PI	ITA	AL	PP	PI	ITA	AL	PP	PI	ITA
Y	**1.0 ± 0.1**	**1.0 ± 0.1**	**1.0 ± 0.1**	**1.0 ± 0.1**	**0.8 ± 0.1**	**1.1 ± 0.1**	**0.7 ± 0.1**	**0.9 ± 0.1**	**1.2 ± 0.1**	**0.9 ± 0.1**	**1.3 ± 0.1**	**1.1 ± 0.1**
W	**1.2 ± 0.2**	**1.0 ± 0.3**	**1.0 ± 0.2**	**1.1 ± 0.2**	**1.2 ± 0.2**	**1.2 ± 0.3**	**0.8 ± 0.2**	**1.0 ± 0.2**	**1.4 ± 0.2**	**1.1 ± 0.3**	**1.2 ± 0.2**	**1.2 ± 0.2**
Sp	**1.0 ± 0.2**	**1.0 ± 0.2**	**1.0 ± 0.2**	**1.0 ± 0.2**	**0.9 ± 0.2**	**1.2 ± 0.2**	**0.7 ± 0.2**	**0.9 ± 0.2**	**1.2 ± 0.1**	**0.9 ± 0.2**	**1.2 ± 0.1**	**1.0 ± 0.1**
S	**1.0 ± 0.2**	**1.1 ± 0.2**	**1.2 ± 0.2**	**1.1 ± 0.2**	*0.4 ± 0.2*	**1.1 ± 0.2**	**0.7 ± 0.2**	**0.9 ± 0.2**	**1.2 ± 0.2**	**0.9 ± 0.2**	**1.6 ± 0.2**	**1.2 ± 0.2**
A	**0.8 ± 0.2**	**0.8 ± 0.2**	**0.9 ± 0.2**	**0.8 ± 0.2**	**0.6 ± 0.2**	**0.9 ± 0.2**	**0.6 ± 0.2**	**0.8 ± 0.2**	**1.0 ± 0.2**	**0.8 ± 0.2**	**1.1 ± 0.2**	**0.9 ± 0.2**

Table VIII. Precipitation trends over the 1865–2003 period. The values are expressed in percentage per century relative to the mean of the standard period 1961–1990. Only values with significance level greater than 90% are indicated; for lower values of significance only the sign of the trend is indicated. Bold numbers indicate trends with significance level higher than 99%, numbers in italics indicate trends with significance level higher than 95%. For SE and SO, trends are referred to the periods 1875–2003 and 1866–2003 respectively (because of the restrictions that were used in the calculation of the regional series, see Section 4.2)

	NW	NEN	NES	CE	SE	SO	ITA
Y	−	−	−	**− (10 ± 3)**	− (8 ± 5)	+	*− (5 ± 3)*
W	−	+	+	−	−	+	−
Sp	−	−	−	**− (20 ± 5)**	−	−	− (9 ± 5)
S	−	−	+	− (13 ± 8)	−	−	−
A	−	−	−	−	−	+	−

Significance and slope of the trends strictly depend on the selected period. For this reason a progressive trend analysis was also performed, by applying the trend analysis to the series starting from the i-th year and ending with the last one, with i running from 1865, 1803 and 1802 (for maximum and minimum temperature, for mean temperature and for precipitation, respectively) to 1974 (we chose 1974 as the last starting year in order to have series not shorter than 30 years to calculate the trends). So we decided to use the whole data available for mean temperature and precipitation, whereas for minimum and maximum temperatures, due to poorer data availability and greater homogeneity problems, we considered only the data of the 1865–2003 period.

Figure 16 shows the results of the progressive trend analysis performed on ITA mean, maximum and minimum temperature series, both for the year and for the seasons. As in Table VII they are expressed as slopes, in K per century. In the yearly series, the most relevant peculiarities are the quite stationary slopes of the sub-series starting before the 1920s, and the slopes then become progressively steeper the later the sub-series start. The trends are always significant at 95%. This behaviour is evident both in mean temperature and in maximum and minimum temperatures and is mainly due to spring and summer seasons. In winter the temporal evolution has an opposite tendency, the slopes being lower and the trends not significant for sub-series starting after 1960s.

The very high slopes of the final periods in the summer and in the yearly series are partially influenced by the 2003 event, as if rather short periods are considered least-square linear fitting is very sensitive to an extreme in the final year. Figure 17 quantifies the contribution of the 2003 event to the mean temperature trends, by comparing the result of the progressive trend analysis performed on the sub-series ending in 2003 and that performed on the sub-series ending in 2002. The most relevant trend differences are in summer (the only season affected by the 2003 heat wave event), since the difference is 0.8 K/100 years over the last 50 years and 1.8 K/100 years over the last 30 years. These differences are evident, but less relevant, also in the yearly series.

It is very interesting to compare the results of the progressive trend analysis of maximum and minimum temperature shown in Figure 16. On the yearly basis, the positive trend is stronger in minimum temperature than in the maximum one for all the sub-series starting before the 1950s. For sub-series starting after this date the situation is opposite, with the maximum temperature trend being higher than that of minimum temperature. This behaviour is evident in all seasons but autumn.

This turning in the relative slopes of maximum and minimum temperatures around 1950 suggested that we analyse the temporal evolution of the DTR.

Studies performed by many authors highlight a general tendency towards a negative trend in DTR (Easterling *et al*., 1997; Rebetez and Beniston, 1998; New *et al*., 2000; Türkeş and Sümer, 2004), since the twentieth century positive trend of minimum temperature is generally higher than that of maximum temperature, even if, on a local scale, many exceptions can be observed. Examples concern Canada, parts of south Africa, south-west Asia, part of Europe, interior Australia and western tropical Pacific islands (Easterling *et al*., 1997). Both observational studies (Rebetez and Beniston, 1998; Huth, 2001; New *et al*., 2000) and analyses of sensitivity of climate models to climate forcing (Hansen *et al*., 1995, 1997; Braganza *et al*., 2004) link the observed DTR decrease to an increase in cloudiness.

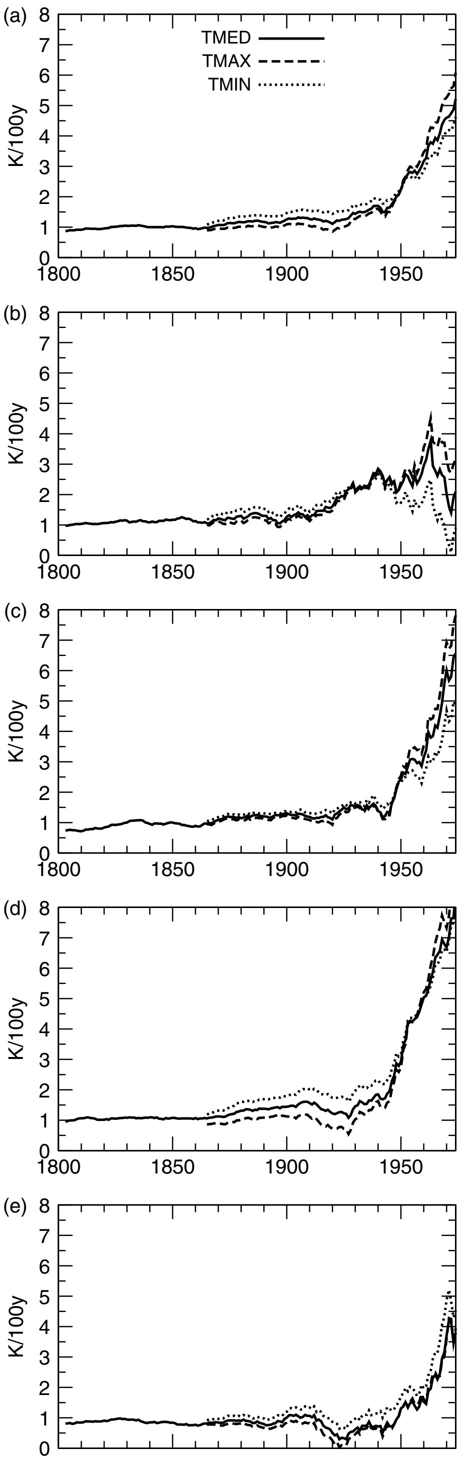

Figure 16. Progressive trend analysis for mean temperature (continuous line), maximum temperature (dashed line) and minimum temperature (dotted line). Each point of a curve represents the regression coefficient (expressed in K per century) calculated for the series beginning from the year in which it is located and ending with the last one (2003). Thick portions of the curves indicate trends with s.l. > 95%. (a) year; (b) winter; (c) spring; (d) summer; (e) autumn

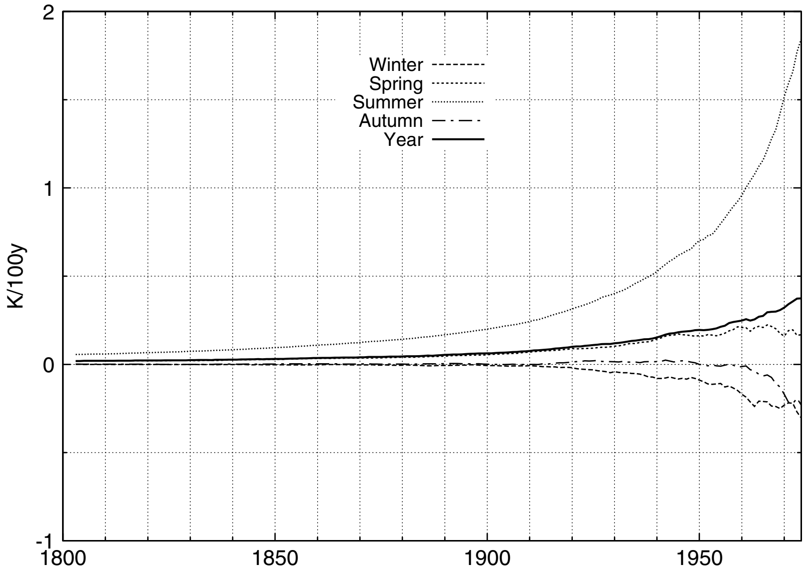

Figure 17. Differences between the results of the progressive trend analysis (as shown in figure 16) for mean temperature sub-series ending in 2003 and mean temperature sub-series ending in 2002

As far as ITA records are concerned, the DTR behaviour strongly highlights the dependence of the results of trend analysis on the study period.

From Figure 18 we observe that, considering the whole series 1865–2003, there is a significant negative trend in the DTR in the year (−0.2 K per century), and in winter (−0.2 K per century), summer (−0.3 K per century) and autumn (−0.2 K per century). The strongest negative trends in DTR are observed for sub-series starting in the 1920s, with a trend of −0.6 K per century for the year, the most relevant contribution coming from summer, having a trend of −1.1 K per century. Considering the sub-series starting after the 1940s, trend is no more significant, either in the seasonal or in the yearly series, and considering those starting after 1950 there is even a reversal in the sign of the trend that becomes positive and, for sub-series starting a few years later, significant in the yearly series and in the winter and spring series. The only exception to the behaviour of DTR in the recent period concerns autumn (in agreement with Figure 16).

Also for precipitation a progressive trend analysis was performed on the ITA average series.

The results are shown in Figure 19. On a yearly basis there is a low negative trend that reaches significant values only for the sub-series starting before 1900. In the last period the trend becomes steeper, but it is rarely significant. A similar behaviour, but with lower significance level, is evident also in all seasons but autumn, which shows a turning in the last period, with the tendency towards a positive trend (albeit not significant).

The negative trend of precipitation and the positive one of DTR in the most recent period are probably due to the strong decrease in cloud cover that was observed in Italy over the last 50 years (Maugeri *et al.*, 2001). Unfortunately, it is not possible to extend the comparison with cloud cover to the whole period as the recovery of secular records of sky condition is still in progress.

Also, pressure evolution over the last 50 years agrees with DTR and cloud cover behaviour; Brunetti *et al.* (2002) observed a significant positive trend in sea-level pressure over the whole Mediterranean basin for that period. Like sky condition, secular sea-level pressure series collection also is still in progress for Italy.

5. GRIDDING

We decided to produce also a gridded version of the data set to make the data available to the scientific community. The grid has 1° resolution both in latitude and in longitude and was realised with a Gaussian

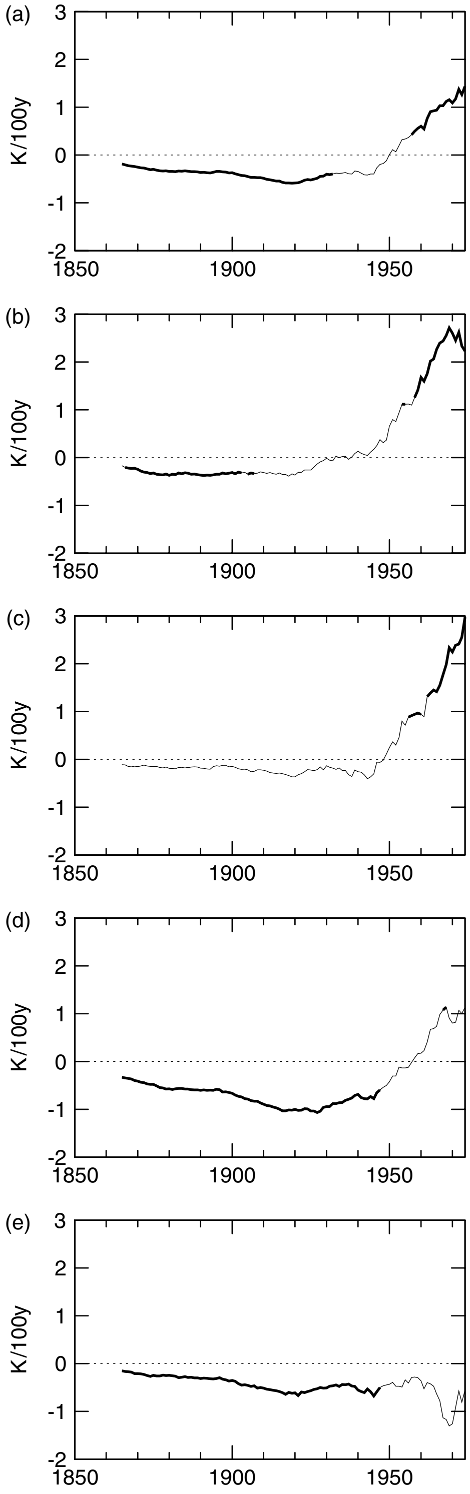

Figure 18. Progressive trend analysis for DTR. Each point of a curve represents the regression coefficient (expressed in K per century) calculated for the series beginning from the year in which it is located and ending with the last one (2003). Thick portions of the curves indicate trends with s.l. > 95%. (a) year; (b) winter; (c) spring; (d) summer; (e) autumn

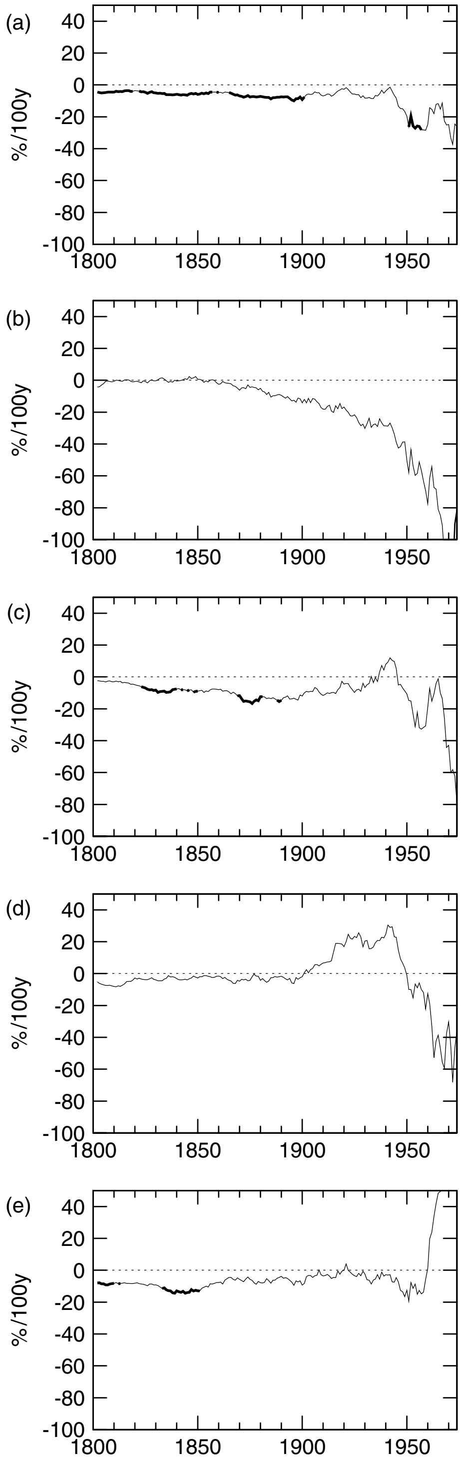

Figure 19. Progressive trend analysis for precipitation. Each point of a curve represents the regression coefficient (expressed in percentage per century relative to the mean of the standard period 1961–1990) calculated for the series beginning from the year in which it is located and ending with the last one (2003). Thick portions of the curves indicate trends with s.l. > 95%. (a) year; (b) winter; (c) spring; (d) summer; (e) autumn

weighting function with the following form:

$$w_i(x, y) = e^{-\frac{d_i^2(x,y)}{c}}$$

with

$$c = -\frac{\overline{d}^2}{\ln 0.5}$$

where i runs along the stations and $d_i(x, y)$ is the distance between the station i and the grid point (x, y). With this choice of the c parameter, we have weights of 0.5 for station distances equal to $\overline{d}$ from the grid point we want to calculate. $\overline{d}$ is defined as the mean distance of one grid point from the next one obtained by increasing both longitude and latitude by one grid step (it is a sort of mean length of the grid mesh diagonal). $\overline{d}$ depends on the grid resolution, so we have weights decreasing faster with distance for a higher resolution (that would require a higher station density).

Each grid point was calculated under one of the following conditions: (1) a minimum of two stations at a distance lower than $\overline{d}$, or (2) a minimum of one station at a distance lower than $\overline{d}/2$. The grid value computation was then performed by considering all stations within a distance of $2\overline{d}$.

In order to avoid biases due to the different lengths of the station records, for temperature we calculated the grid values starting from the anomalies, whereas for precipitation we started from the relative deviations from the means. The conversion of these anomalies (relative deviations) into absolute values requires the knowledge of the monthly normals at the grid point.

The grid was constructed from 7 to 18° longitude and from 37 to 47° latitude only when the above conditions were satisfied. Obviously, not the whole box has adequate station coverage, because of the large portion of sea areas. A total of 63 grid points over a box of 132 were calculated for minimum and maximum temperatures, 71 grid points for mean temperatures and 75 grid points for precipitation. In Figure 20 the starting year of each grid point is indicated for minimum and maximum temperature (Figure 20(a)), for mean temperature (Figure 20(b)) and for precipitation (Figure 20(c)).

6. CONCLUSIONS

The data set of Italian monthly temperature and precipitation secular records was updated to 2003 and greatly improved, both in station density and in metadata availability. Moreover, it was subjected to a detailed quality control and homogenisation procedure and analysed for trends.

Most of the series turned out to be inhomogeneous, containing one or several shifts that, in the case of temperature series, systematically biased the original data, the mean adjustment series being affected by a relevant trend, higher for minimum temperature and lower for the maximum one (0.8 and 0.3 K, over the last 140 years). So, using the original data in estimating long-term temperature evolution gives negatively biased results.

The homogenised and gap filled data set was clustered into climatically homogeneous regions, three for temperature and six for precipitation. The main results are as follows:

- Quite a uniform temperature trend was observed in the different regions, with a trend of 1 K per century all over Italy on a yearly basis. Also on a seasonal basis the situation is quite uniform and no significant differences are evident, either for the different regions or for the different seasons. The trend is generally higher for minimum temperature than for maximum temperature for all the seasons and the year, the only exception being the PP region, whose trend is always higher for maximum temperature.
- Precipitation trend analysis showed a decreasing tendency, even if the decreases are very low and rarely significant. Considering the average all over Italy, there is a 5% decrease per century in the annual precipitation amount, mainly due to the spring season (−9% per century);

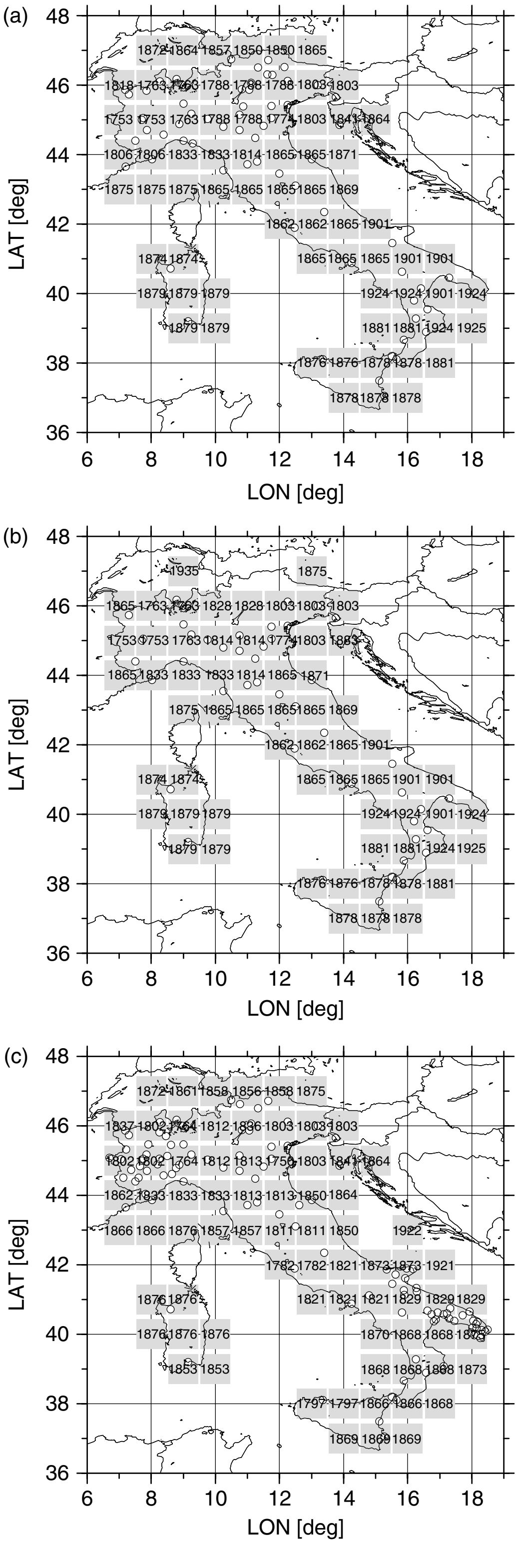

Figure 20. Starting year of each grid point for (a) mean temperature, (b) maximum and minimum temperature and (c) precipitation

- A progressive trend analysis revealed that, both for temperature and precipitation, the significance and the slope of the trends strictly depended on the selected period. In particular, for minimum and maximum temperatures, a turning in the relative behaviour was highlighted, minimum temperature trend over the whole series length being higher than that of maximum temperature, and lower if the last 50 years are considered. This suggested that we investigate DTR progressive trends too. The results showed that, considering the whole series length 1865–2003, there was a significant negative trend in the DTR that, in the last 50 years, became positive and significant, the only exception being autumn;

Temperature and precipitation trends obtained by analysing the new data set show significant differences from the results presented in Maugeri and Nanni (1998), Buffoni *et al.* (1999) and Brunetti *et al.* (2000a, b), the old trend assessments being characterised by a lower temperature increase (around 0.5 K per century), a greater precipitation decrease (around 10% per century) and a low but significantly positive DTR trend (0.1–0.2 K per century). These differences are partially due to the improved data coverage of Italy, both in increased station number (67 against 27 mean temperature series, and 111 against 32 precipitation series) and in territorial distribution (in the old data set, northern Italy was represented almost only by PP stations, the peninsular part of Italy was represented by only 15 stations, and large areas such as the southeast region had no station) and partially to a better homogenisation, even though the updating of the records (previous results were updated to 1996) also plays an important role, as the temperatures of the last years are the highest of the 1865–2003 period.

A gridded version of the new data set was produced. The grid has 1° resolution, both in latitude and in longitude, and was realised with a Gaussian weighting function. The gridded data, as well as average regional and national series, will be available to the scientific community on the Internet (http://www.isac.bo.cnr.it/~climstor/).

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