7. Reconstruction of temperature and precipitation time series for Italy

7.1 Reconstruction of the temperature time series

As explained in Chapter 2, the superimposition of the anomaly grids obtained in *Brunetti et al. (2006b)* to the temperature high-resolution 1961-1990 climatologies constructed here, as built in Chapters 4 and 5, leads to the reconstruction of a minimum, mean, and maximum temperature time series. It also leads to a total precipitation time series for any grid cell of the Italian territory and for the 12 months. The so-called "anomaly approach" gives the possibility to reconstruct a minimum temperature, a mean temperature and a maximum temperature time series at a 30-arc-second horizontal spatial scale.

In the next pages, we show some examples of the reconstruction of temperature time series. First, we show some comparisons between our reconstructed time series and the corresponding secular homogenized historical records at the grid points where a complete secular record is available. Second, we show how a reconstructed series can complete a secular record with gaps. Third, we show a reconstructed time series for two grid points, where no secular data (or not even recent data) are available. Last, we make some comments on temperature trends.

7.1.1 Comparison between the reconstructed temperature series and the corresponding secular records

+ Reconstruction of the minimum temperature time series of Milano

Secular Record (name ; start year of data ; latitude ; longitude ; elevation)
Milano ; 1763 ; 45.470 °N ; 9.190 °E ; 64 m

Grid point for the reconstructed series (latitude ; longitude ; elevation)
45.471 °N ; 9.188 °E ; 110 m

Monthly T_N-T_M-T_X values for the grid point from the reconstructed temperature 1961-1990 climatologies:

(°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year AVG
T_N	-1.1	0.8	3.9	7.6	11.9	15.5	18.1	17.5	14.2	9.5	4.1	-0.1	8.5
T_M	2.0	4.4	8.4	12.5	17.0	21.0	23.7	22.7	19.1	13.6	7.3	3.0	12.9
T_X	5.1	8.0	12.9	17.4	22.2	26.4	29.2	27.8	23.9	17.7	10.5	6.1	17.3

Tab. 44: monthly temperature values for the grid cell used for reconstructing the time series of Milan0

In fig. 217-218 we show the reconstructed series versus the secular record for minimum temperature of May in the 1881-2000 period.

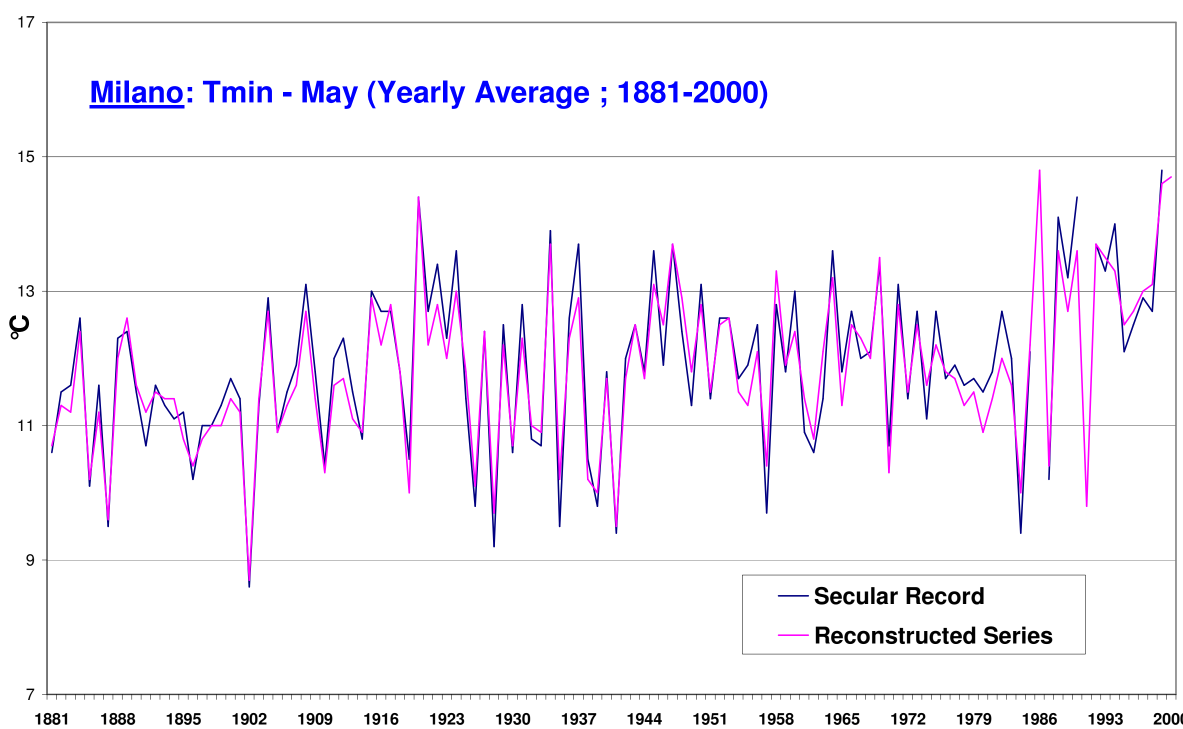

Fig. 217: May minimum temperature reconstructed series versus secular record for Milan

As we can see, the reconstructed series almost completely matches the corresponding secular record. If we compare the monthly values, the average *ME* is *-0.09* °C, the average *MAE* is 0.29 °C. In the following figure, we show the difference between the two series as the secular minus the reconstructed series.

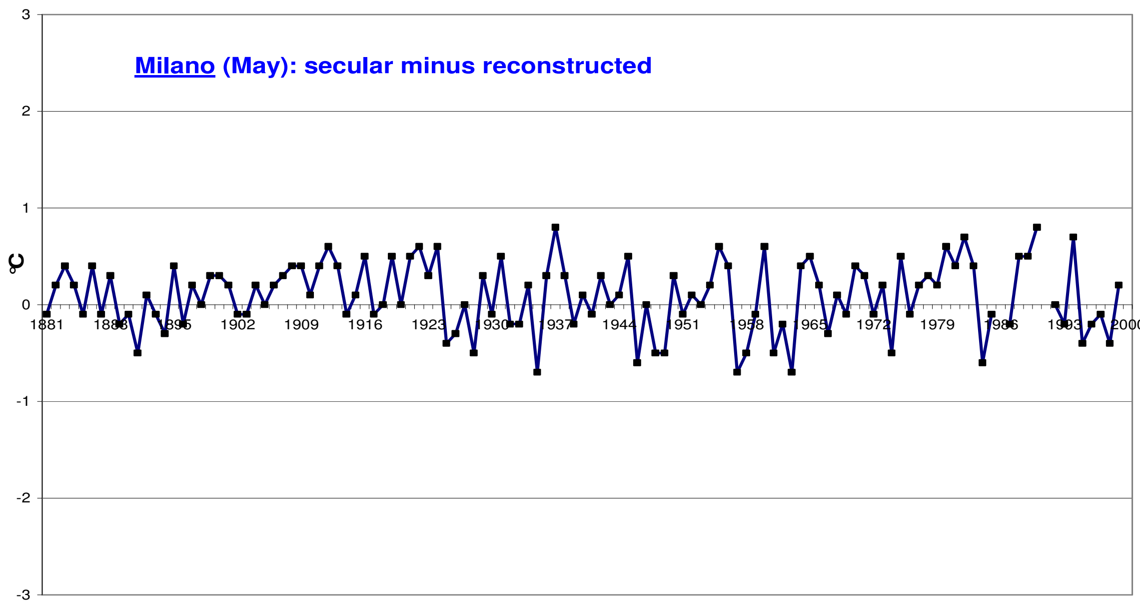

Fig. 218: differences between the reconstructed series and the secular record of Milano in May for T_N

The monthly differences never exceed, in absolute values, the optimal threshold of 1.0 °C.

• Reconstruction of the mean temperature time series of Roma

Secular Record (name ; start year of data ; latitude ; longitude ; elevation)
Roma ; 1862 ; 41.900 °N ; 12.470 °E ; 56 m

Grid point for the reconstructed series (latitude ; longitude ; elevation)
41.904 °N ; 12.471 °E ; 14 m

Monthly T_N-T_M-T_X values for the grid point from the reconstructed temperature 1961-1990 climatologies:

(°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year aVG
T_N	3.3	4.3	5.8	8.3	11.9	15.4	17.9	18.1	15.6	11.8	7.5	4.4	10.3
T_M	7.7	9.0	11.0	13.8	17.9	21.6	24.6	24.6	21.5	17.2	12.0	8.7	15.8
T_X	12.1	13.7	16.2	19.3	24.0	27.9	31.4	31.1	27.4	22.6	16.6	12.9	21.3

Tab. 45: monthly temperature values for the grid cell used for reconstructing the time series of Roma

In fig. 219-220, we show the reconstructed series versus the secular record for mean temperature of November in the 1881-2003 period.

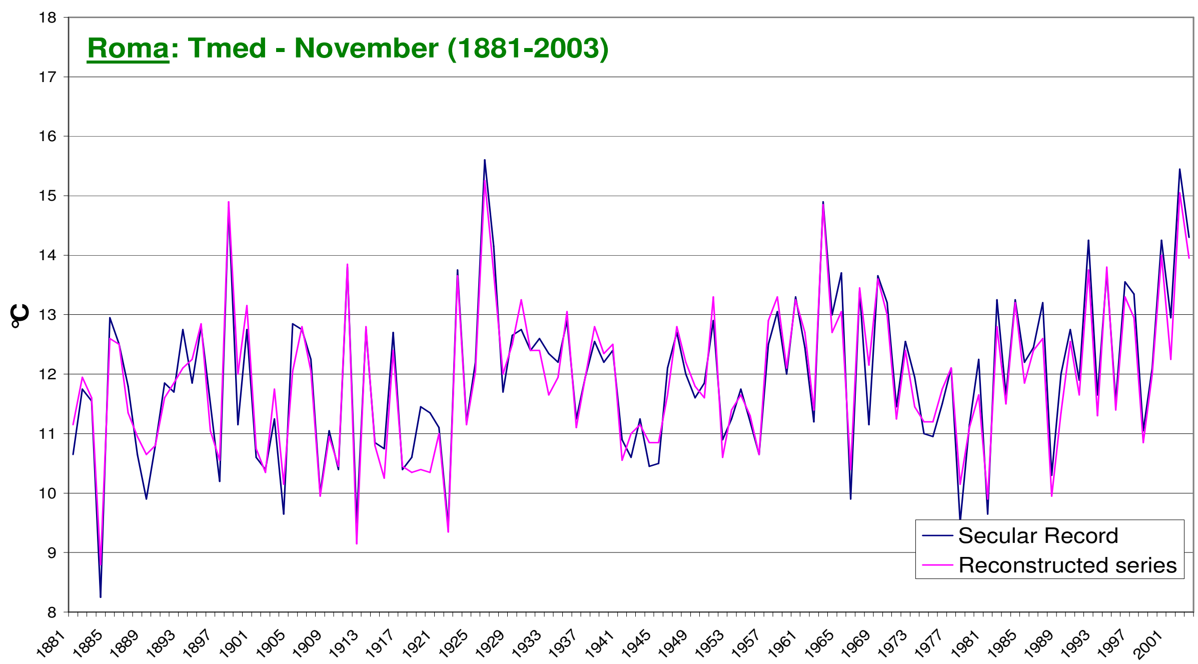

Fig. 219: November mean temperature reconstructed series versus secular record for Roma

As we can see, the reconstructed series matches the corresponding secular record well. If we compare the monthly values, the average *ME* is *-0.05* °C, the average *MAE* is *0.14* °C. In the following picture, we show the difference between the two series: the secular minus the reconstructed series.

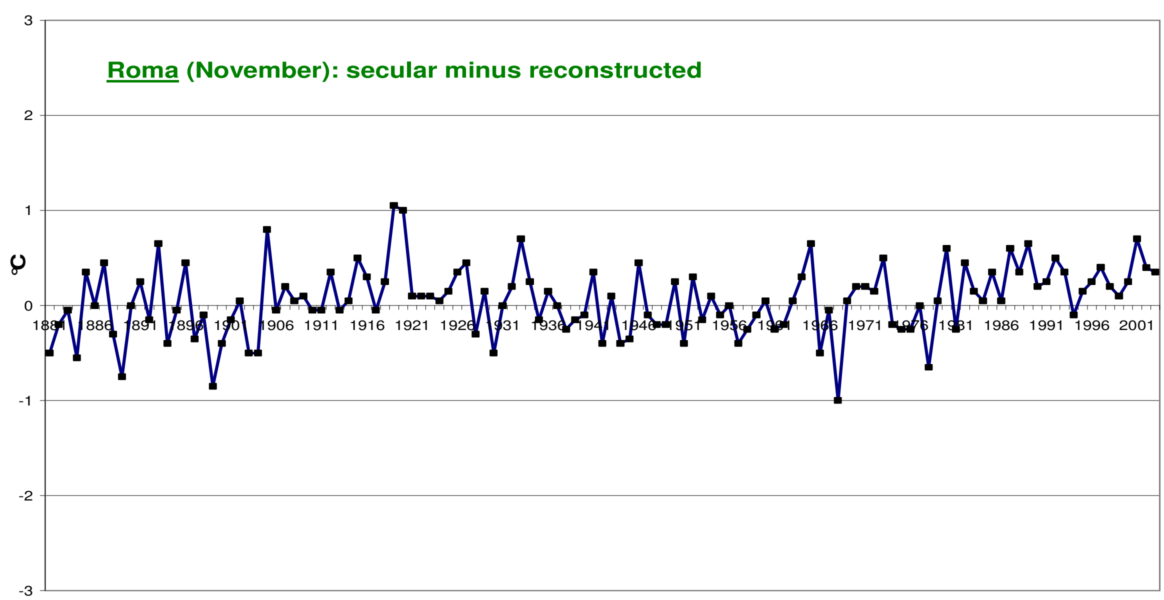

Fig. 220: differences between the reconstructed series and the secular record of Roma in November for T_M

The monthly differences exceed or equal, in absolute values, the threshold of 1.0 °C in three circumstances only: in 1919, in 1920 and in 1968.

• Reconstruction of the maximum temperature time series of Bologna

Secular Record (name ; start year of data ; latitude ; longitude ; elevation)
Bologna ; 1814 ; 44.480 °N ; 11.250 °E ; 60 m

Grid point for the reconstructed series (latitude ; longitude ; elevation)
43.479 °N ; 11.254 °E ; 87 m

Monthly T_N-T_M-T_X values for the grid point from the reconstructed temperature 1961-1990 climatologies:

(°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year AVG
TN	-0.4	1.4	4.5	8.2	12.2	15.9	18.5	18.1	15.0	10.4	5.1	0.9	9.2
TM	2.6	5.0	8.7	12.8	17.3	21.1	23.9	23.4	19.9	14.6	8.4	3.9	13.5
TX	5.7	8.6	13.0	17.4	22.3	26.3	29.3	28.6	24.7	18.8	11.6	6.9	17.8

Tab. 46: monthly temperature values for the grid cell used for reconstructing the time series of Bologna

In the following figures we show the reconstructed series versus the secular record for maximum temperature of April in the 1901-2003 period.

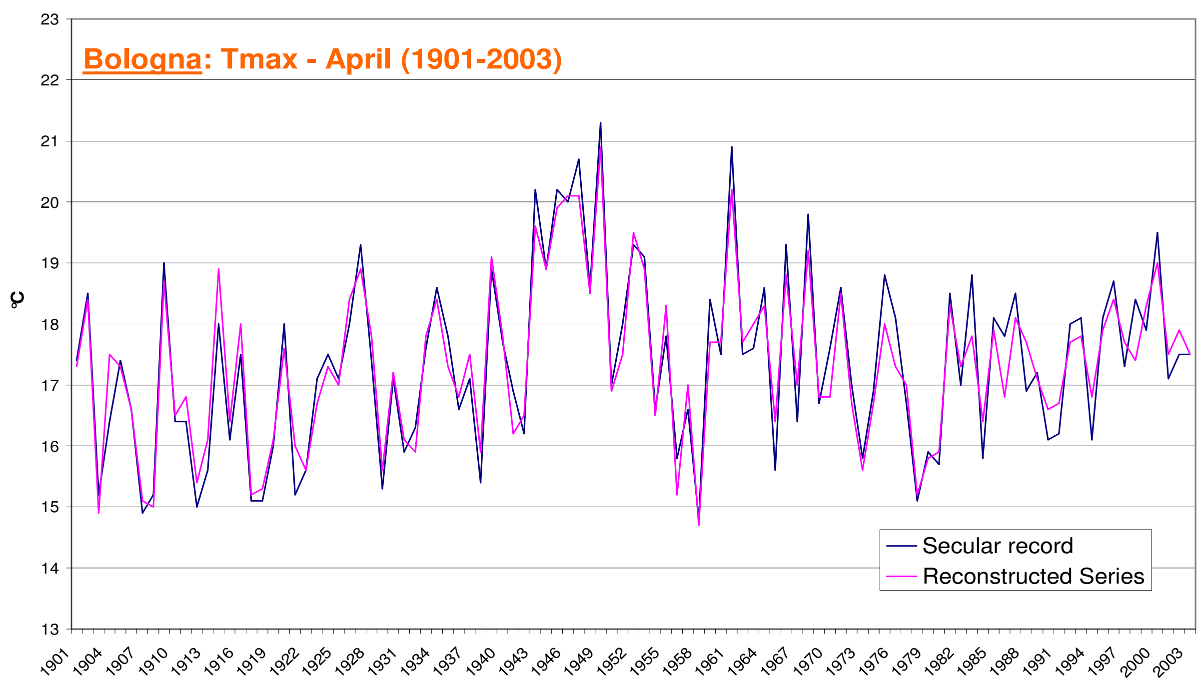

Fig. 221: April mean temperature reconstructed series versus secular record for Bologna

As we can see, the reconstructed series satisfactorily matches the corresponding secular record. If we compare the monthly values, the average *ME* is -0.02 °C and the average *MAE* is 0.37 °C. In the following picture, we show the difference between the two series: the secular minus the reconstructed series.

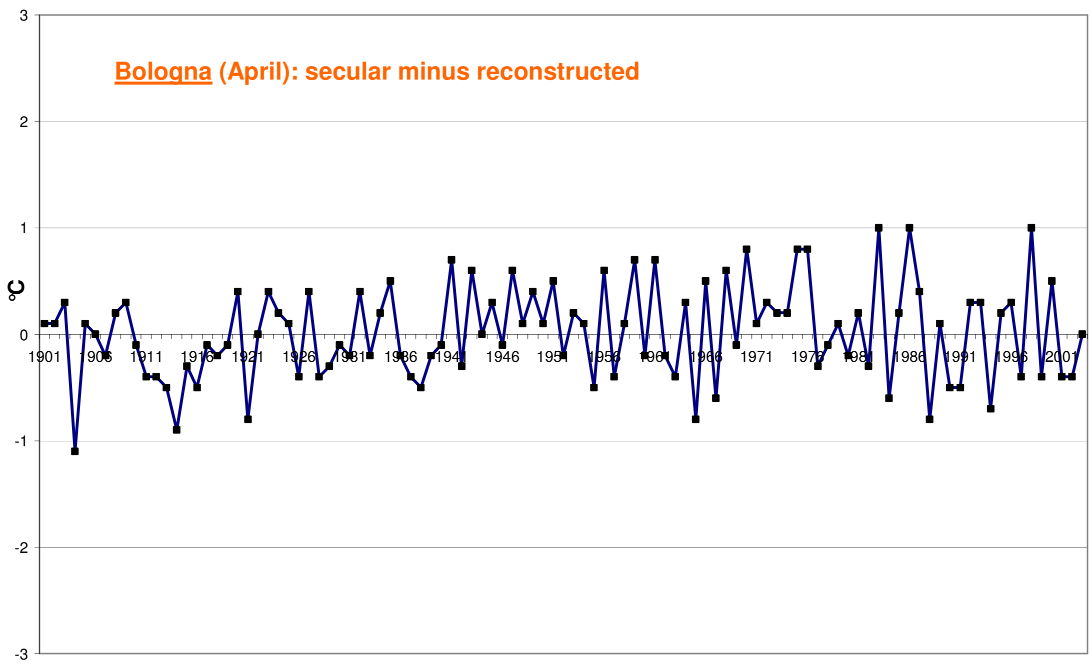

Fig. 222: differences between the reconstructed series and the secular record of April in November for T_X

The monthly differences exceed or equal, in absolute values, the threshold of *1.0 °C* in four circumstances only: in 1904, in 1983 and in 1986, 1998

7.1.2 The use of reconstructed time series to complete secular records

• Reconstruction of the temperature time series of Genova

Secular Record (name ; start year of data ; latitude ; longitude ; elevation)

Genova ; 1833 ; 44.400 °N ; 8.950 °E ; 21 m

Grid point for the reconstructed series (latitude ; longitude ; elevation)

44.396 °N ; 8.954 °E ; 13 m

Monthly T_N-T_M-T_X values for the grid point from the reconstructed temperature 1961-1990 climatologies:

(°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year AVG
TN	5.9	6.6	8.0	10.7	14.1	17.5	20.2	20.2	17.6	13.9	9.6	6.7	12.6
TM	8.2	9.0	10.8	13.6	16.9	20.4	23.1	22.9	20.3	16.5	12.2	9.3	15.2
TX	10.5	11.4	13.5	16.4	19.7	23.2	25.9	25.6	23.0	19.1	14.8	11.8	17.9

Tab. 47: monthly temperature values for the grid cell used for reconstructing the time series of Genova

In the following figures we show how the reconstructed series can be used in order to complete the secular record for minimum, mean and maximum temperature for June in the 1881-2008 period.

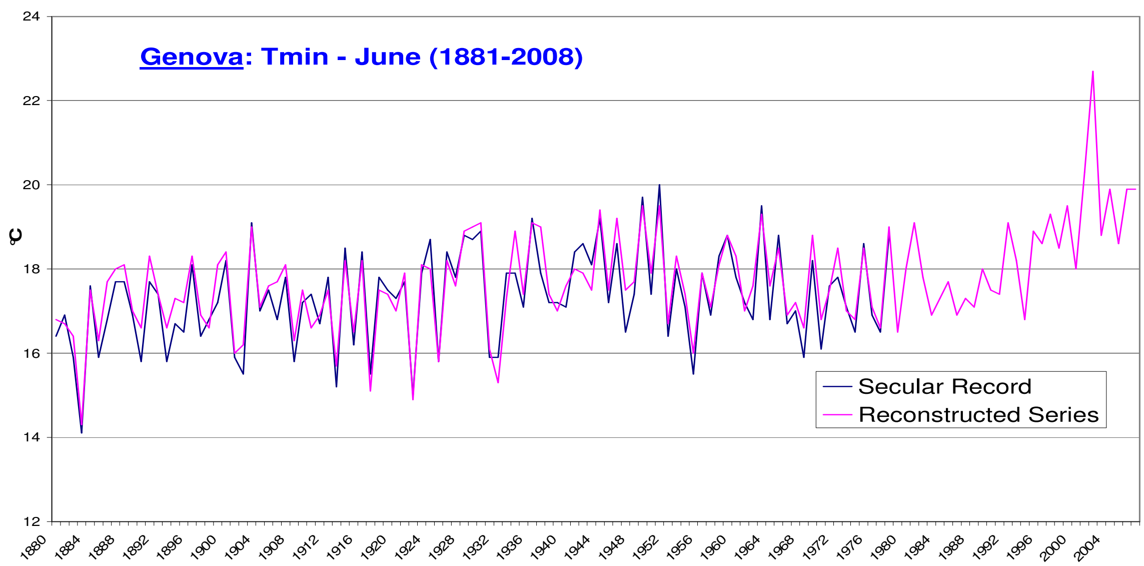

Fig. 223: June minimum temperature reconstructed series versus secular record of Genova

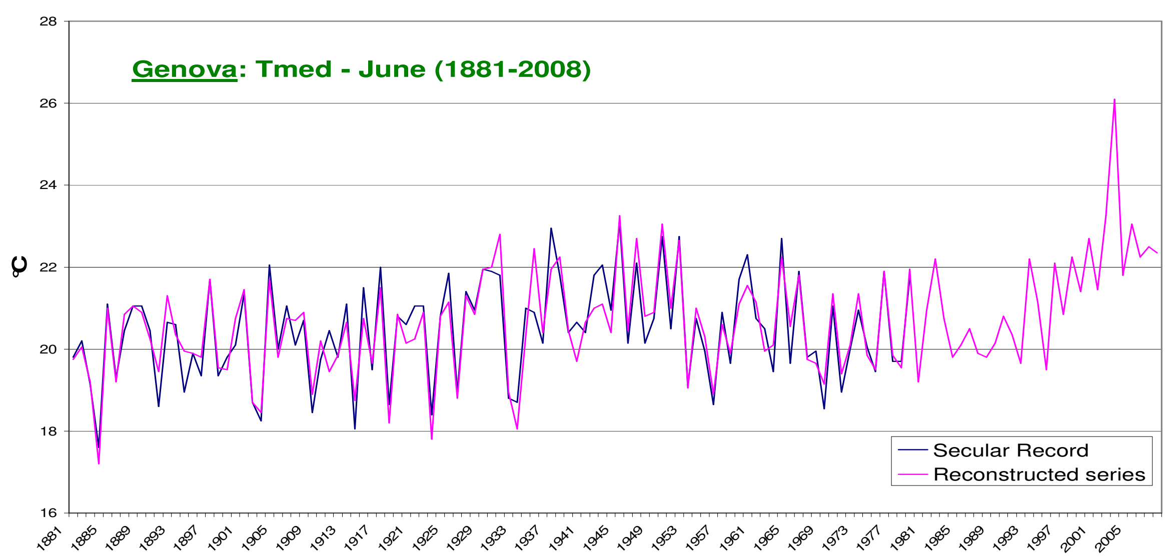

Fig. 224: June mean temperature reconstructed series versus secular record of Genova

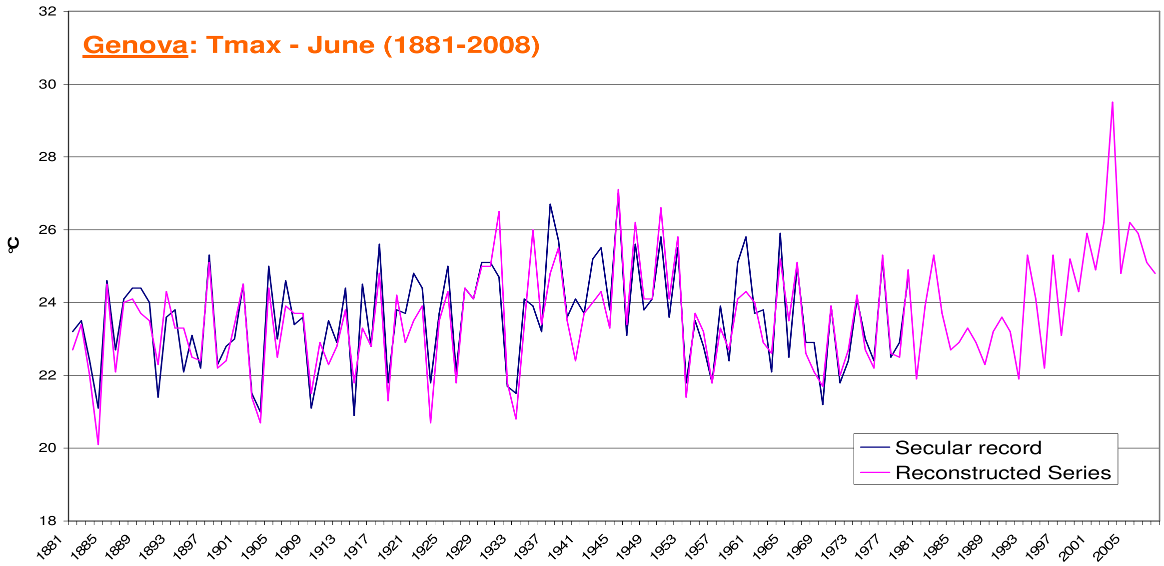

Fig. 225: June maximum temperature reconstructed series versus secular record of Genova

The temperature secular record of Genova Sestri ends in 1981.

In the reconstructed series, the extraordinarily hot June of 2003 is evident: T_N = 22.7 °C (anomaly of 4.8 °C related to the 1961-90 period), T_M = 26.1 °C (anomaly of 5.7 °C related to the 1961-1990 period), T_X = 29.5°C (anomaly of 6.2 °C related to the 1961-90 period).

Other examples of reconstructed temperature time series (Rovigo and Cortina d'Ampezzo), obtained in the framework of this PhD project can be found in *Brunetti et al. (2009).*

7.1.3 Construction of new secular time series

In this chapter we show some examples of the new T_N-T_M-T_X time series for Arona and Assisi. A new secular record for T_N-T_M-T_X (and precipitation) can be obtained by request for each month for each *30-arc second* (horizontal resolution) of the area under investigation.

• Reconstruction of the temperature time series of Arona (new series)

Arona is a small town (approximately 14,600 inhabitants) located on the western side of Lake Maggiore; no temperature data for Arona were found during the data search.

Grid point for the reconstructed series of **Arona** (latitude ; longitude ; elevation)
45.754 °N ; 8.554 °E ; 196 m

Monthly T_N-T_M-T_X values for the grid point from the reconstructed temperature 1961-1990 climatologies:

(°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year AVG
T_N	-0.8	0.6	3.3	6.6	10.4	13.8	16.1	15.6	12.6	8.3	3.5	0.1	7.5
T_M	2.7	4.5	8.0	11.6	15.6	19.3	21.8	21.0	17.6	12.7	7.2	3.5	12.1
T_X	6.2	8.4	12.7	16.5	20.8	24.9	27.6	26.5	22.6	17.1	11.0	6.9	16.8

Tab. 48: monthly temperature values for the grid cell used for reconstructing the time series of Arona

In the following figures, we show the new T_N-T_M-T_X series of January, July and the average yearly series in the 1881-2008 period.

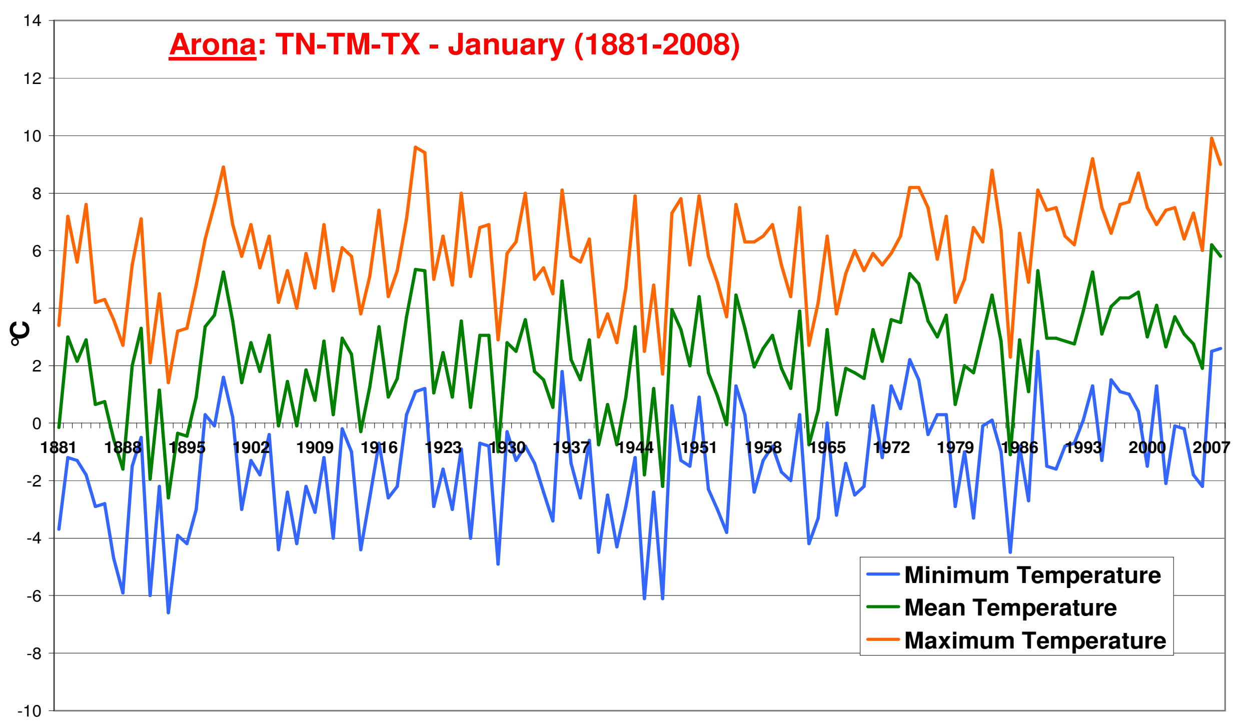

Fig. 226: January T_N-T_M-T_X new secular time series of Arona

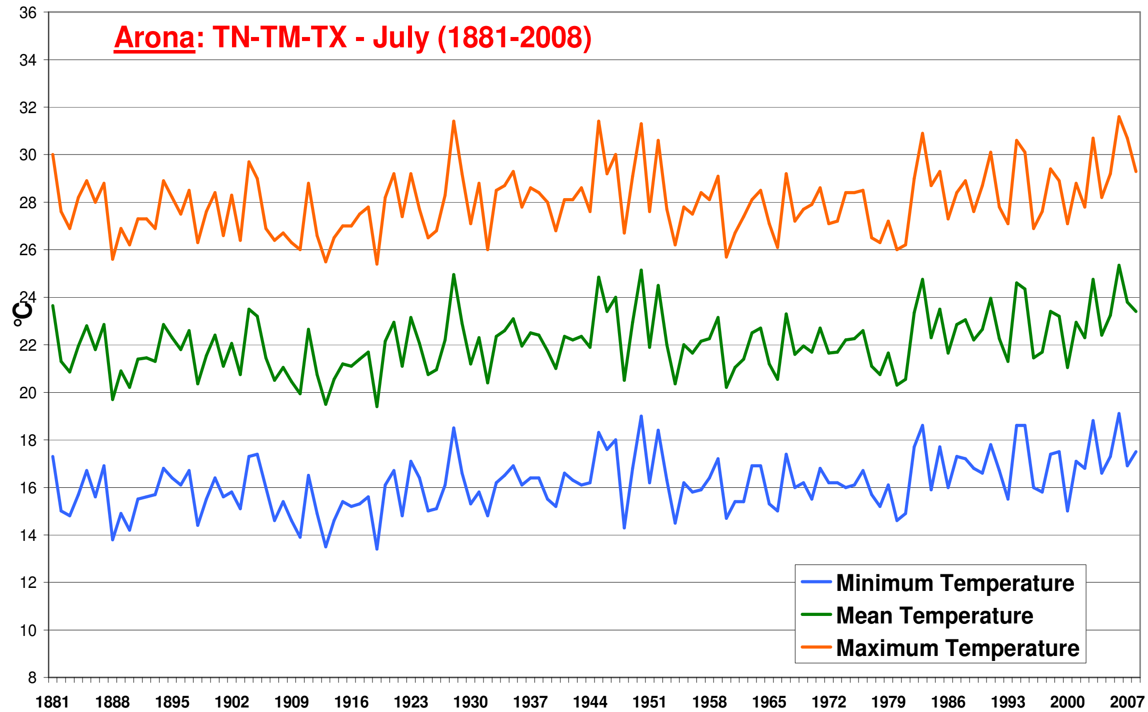

Fig. 227: July T_N-T_M-T_X new secular time series for Arona

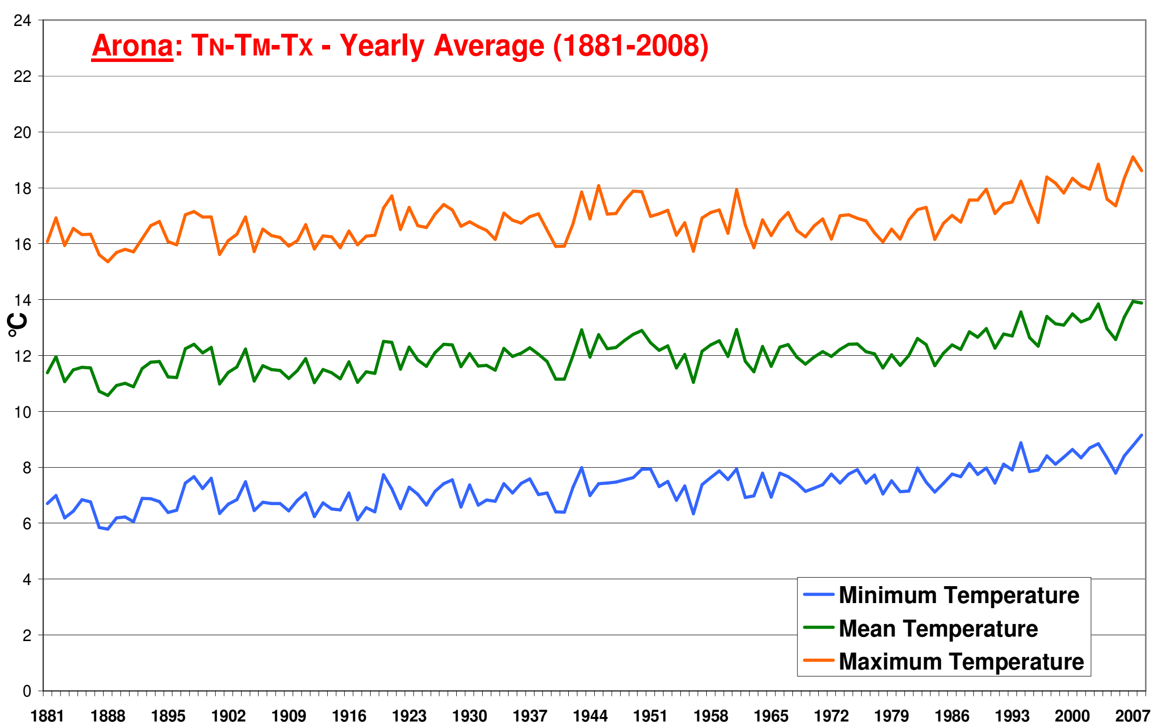

Fig. 228: Yearly average T_N-T_M-T_X new secular time series for Arona

The hottest January took place in 2008 (T_M = 6.2 °C), the coldest in 1893 (T_M = -2.6 °C); the hottest July took place in 2006 (T_M = 25.3 °C), the coldest in 1919 (T_M = 19.4 °C); the hottest month was August 2003 (T_M = 26.5 °C), the coldest was January 1893.

For maximum temperatures, the highest values can be found in August 2003 (T_X = 32.9 °C), the lowest in January 1893 (T_X = 1.4 °C); for minimum temperatures, the highest values can be found in August 2003 (T_N = 20.1 °C), the lowest in January 1893 (T_N = -6.6 °C).

The overall hottest year for Arona was 2008 (T_M = 13.9 °C) with an anomaly of 1.8 °C related to the 1961-1990 period; the overall coldest year was 1888 (T_M = 10.6 °C) with an anomaly of -1.5 °C related to the 1961-1990 period.

• Reconstruction of the temperature time series of Assisi (new series)

Assisi is located on the western side of Monte Subasio, near Perugia, in Umbria, and has approximately 27,000 inhabitants. It is known world wide because Saint Francesco of Assisi (Assisi: 1182, July 5th – Assisi: 1226, October 3rd), the patron saint of Italy, was born in Assisi, lived in Assisi and died in Assisi. Furthermore, Saint Chiara (Assisi: approximately 1193 – Assisi: 1253, August 11th) spent all her life in Assisi.

In Assisi, the "Basilica di San Francesco" is included in the list of the *UNESCO* World Heritage Centre (United Nations Education, Scientific and Cultural Organization, *http://whc.unesco.org/*).

Grid point for the reconstructed series of **Assisi** (latitude ; longitude ; elevation)
43.071 °N ; 12.613 °E ; 392 m

Monthly T_N-T_M-T_X values for the grid point from the reconstructed temperature 1961-1990 climatologies:

(°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year AVG
T_N	2.0	3.2	4.8	7.5	11.3	14.6	17.2	16.9	14.3	10.5	6.2	3.1	9.3
T_M	5.2	6.6	8.9	12.1	16.4	20.1	23.2	22.9	19.5	14.8	9.7	6.2	13.8
T_X	8.4	9.9	12.9	16.6	21.5	25.5	29.2	28.9	24.7	19.1	13.2	9.2	18.3

Tab. 49: monthly temperature values for the grid cell used for reconstructing the time series of Assisi

In the following figures we show the new T_N-T_M-T_X series for January, for July and the average yearly series in the 1881-2008 period.

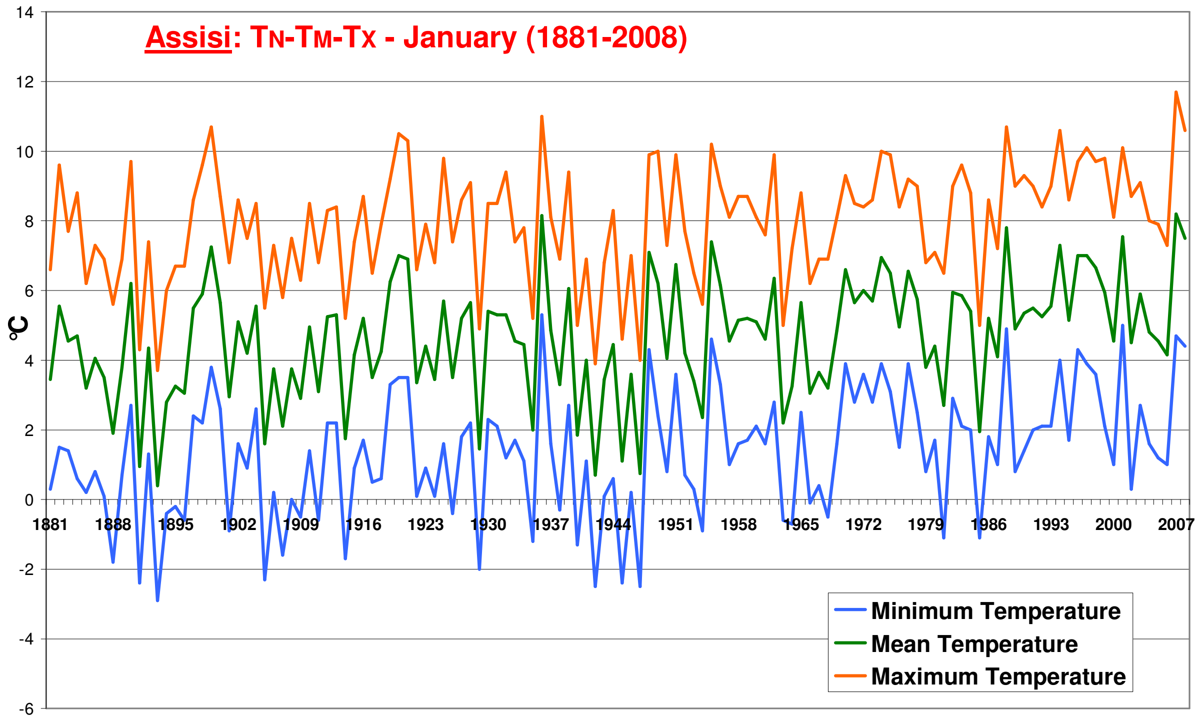

Fig. 229: January T_N-T_M-T_X new secular time series of Assisi

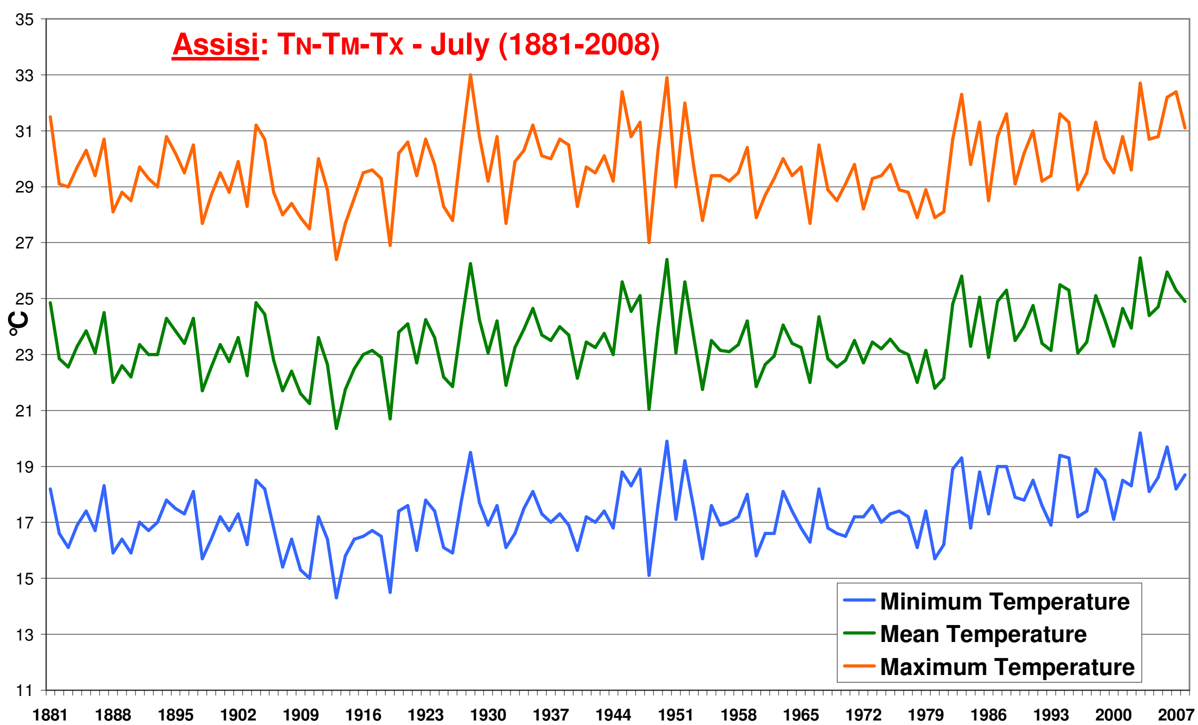

Fig. 230: July T_N-T_M-T_X new secular time series of Assisi

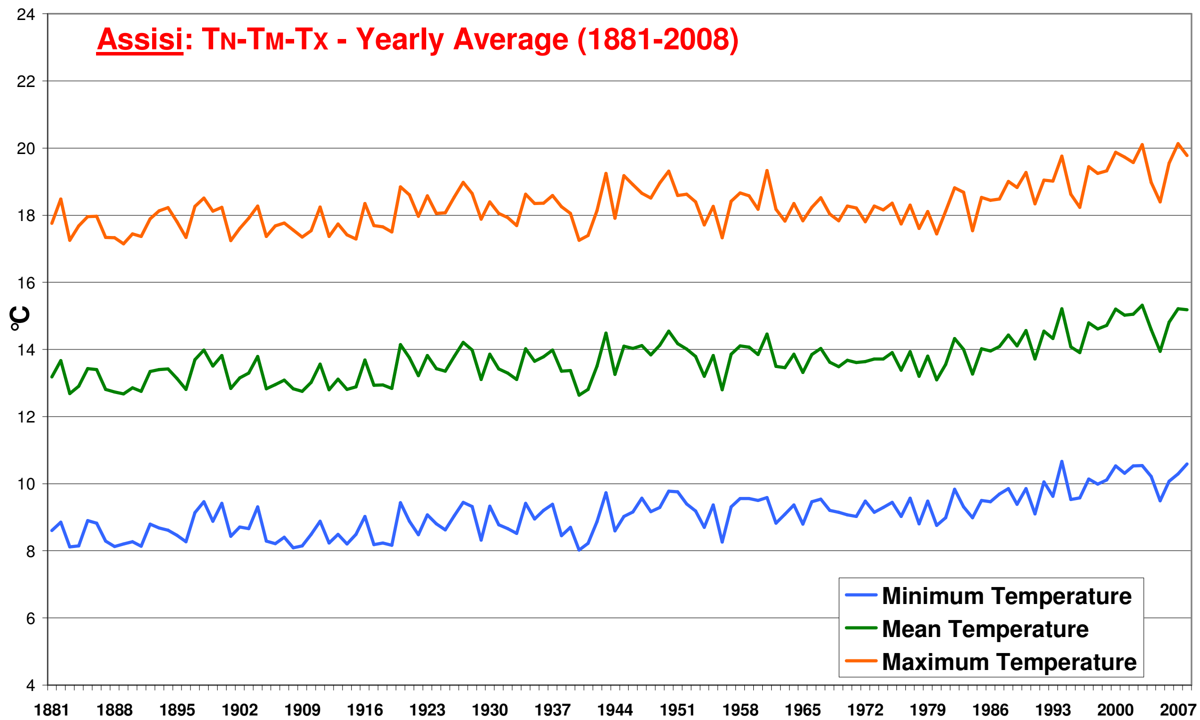

Fig. 231: Yearly average T_N-T_M-T_X new secular time series of Assisi

The hottest January took place in 2007 (T_M = 8.2 °C), the coldest in 1893 (T_M = 0.4 °C); the hottest July took place in 2003 (T_M = 26.5 °C), the coldest in 1919 (T_M = 20.7 °C); the hottest month was August 2003 (T_M = 28.0 °C), the coldest was January 1893.

For maximum temperatures, the highest values can be found in August 2003 (T_X = 34.5 °C), the lowest in January 1893 (T_X = 3.7 °C); for minimum temperatures, the highest values can be found in August 2003 (T_N = 21.5°C), the lowest in January 1893 (T_N = -2.9 °C).

The overall hottest year for Assisi was 2003 (T_M = 15.3 °C) with an anomaly of 1.5 °C related to the 1961-1990 period, the overall coldest year was 1889 (T_M = 12.7 °C) with an anomaly of -1.1 °C related to the 1961-1990 period.

7.1.4 Some considerations about temperature trends

The temperature trends that can be found by means of statistical analyses of the reconstructed secular time series are a very evolved and much more complete version of the computational techniques used in *Brunetti et al. (2006b)*.

To see the improvements, we show some examples. For the reconstructed series: in the following figures we show the mean temperature trend of Milan and Rome.

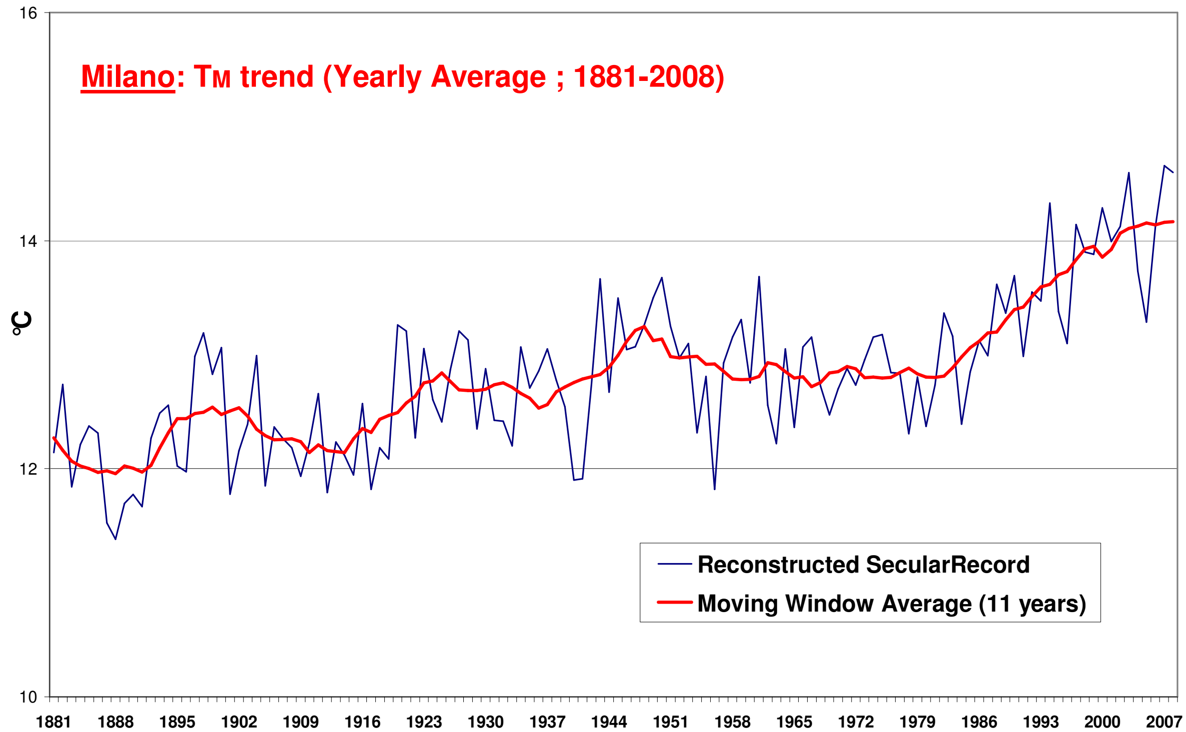

Fig. 232: Yearly average T_M trend of Milano

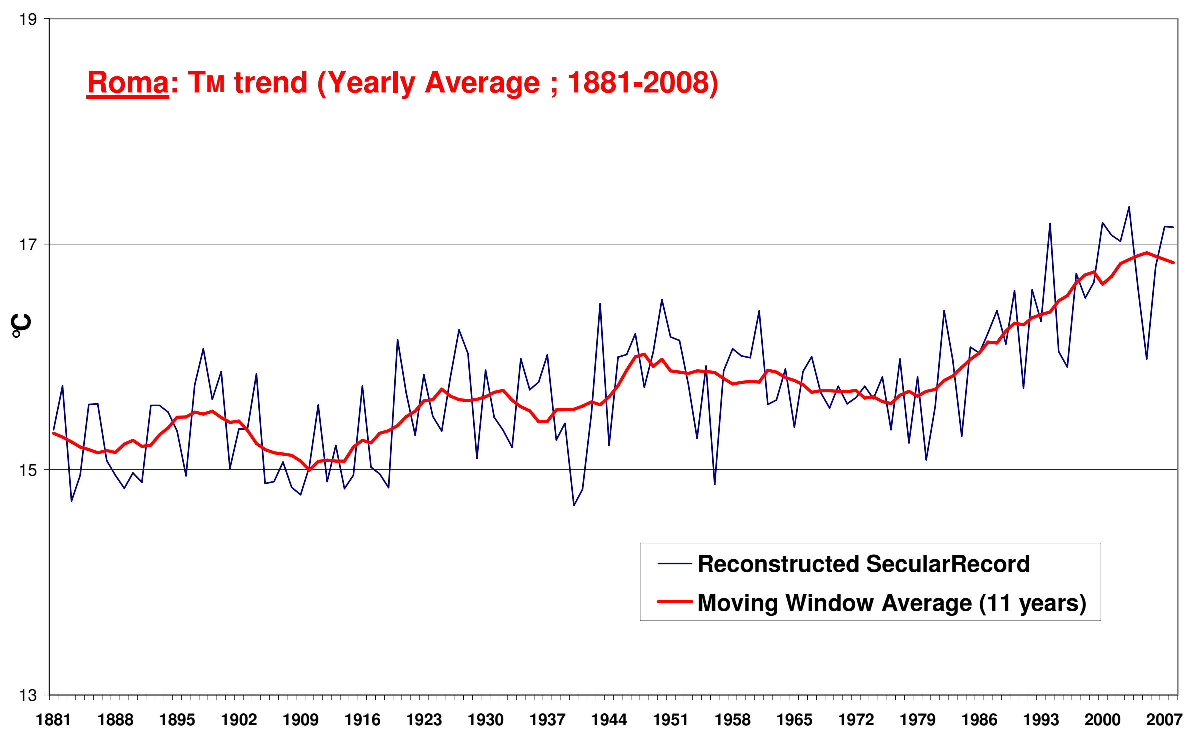

Fig. 233: Yearly average T_M trend of Roma

If we use a linear regression, we find that for Milan, the mean temperature has an increase of 0.13 °C *per decade* in the 1881-2008 period; for Rome, the mean temperature has an increase of 0.11 °C *per decade* in the 1881-2008 period. If we look at the last 30 years, we can see that these temperature trends are stronger. For Milan, mean temperature shows an increase of 0.59 °C *per decade* in the 1979-2008 period; for Rome, mean temperature shows an increase of 0.49 °C *per decade* in the 1979-2008 period, after some levelling or decrease.

If we consider Arona, as an example, the yearly average minimum temperature in the 1979-2008 period was 8.0 °C, with an anomaly of 0.5 °C related to the 1961-1990 reference period. The yearly average mean temperature in the 1979-2008 period was 12.8 °C, with an anomaly of 0.7 °C related to the 1961-1990 reference period. The yearly average maximum temperature in the 1979-2008 period was 17.6 °C, with an anomaly of 0.9 °C related to the 1961-1990 reference period.

7.2 Reconstruction of the precipitation time series

As for temperatures, we show some examples of reconstruction of the precipitation time series. In this case, we show some comparisons between the reconstructed series and the corresponding secular homogenized records for grid points where a complete secular record is available. Second, we show how a reconstructed series is able to complete a secular record with gaps. Third, we show a reconstructed time series for a grid point where no secular data (or not even recent data) are available. Last, we make some commentaries on precipitation trends.

Because the monthly 1961-1990 precipitation climatologies are provisional to some extent yet, and can be subjected to slight variations, especially in some regions with a complex geography and orography as, e.g., Liguria, we do not show the tables that exhibit the 1961-1990 reconstructed total monthly precipitation values for the grid points considered.

We however show the plots of the reconstructed and observed time series.

7.2.1 Comparison between the reconstructed precipitation series and the corresponding secular records

• **Reconstruction of the precipitation time series of Milano**

Secular Record (name ; start year of data ; latitude ; longitude ; elevation)
Milano ; 1764 ; 45.470 °N ; 9.190 °E ; 64 m

Grid point for the reconstructed series (latitude ; longitude ; elevation)
45.471 °N ; 9.188 °E ; 110 m
(The same point for the reconstruction of the temperature time series).

In the following figures we show the reconstructed series versus the secular record for precipitation for January, for July and for the yearly total in the 1881-2008 period, and the comparisons in the 1881-2003 period.

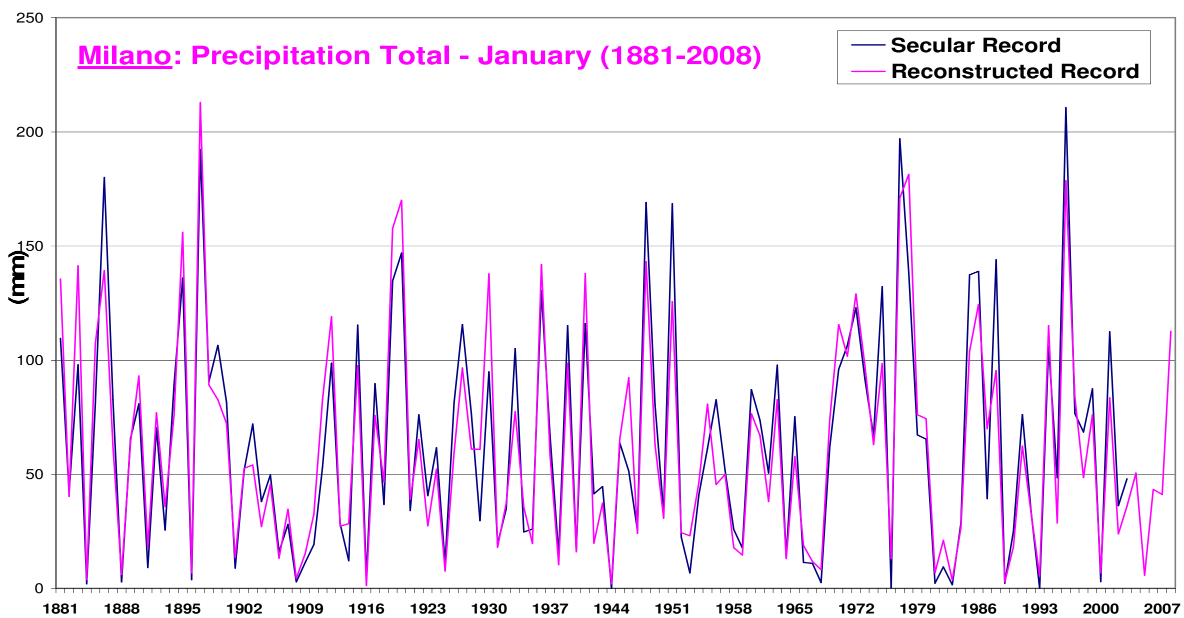

Fig. 234: January precipitation total reconstructed series versus secular record of Milano

As we can see, the reconstructed series well reproduces the corresponding secular record. If we compare the monthly values in the 1881-2003 period, the average *ME* is 1.2 mm and the average *MAE* is 13 mm. The driest January took place in 1993 (0 mm), the wettest in 1996 (211 mm).

In the next page, in fig. 235, we show the difference between the two series as the secular minus the reconstructed series.

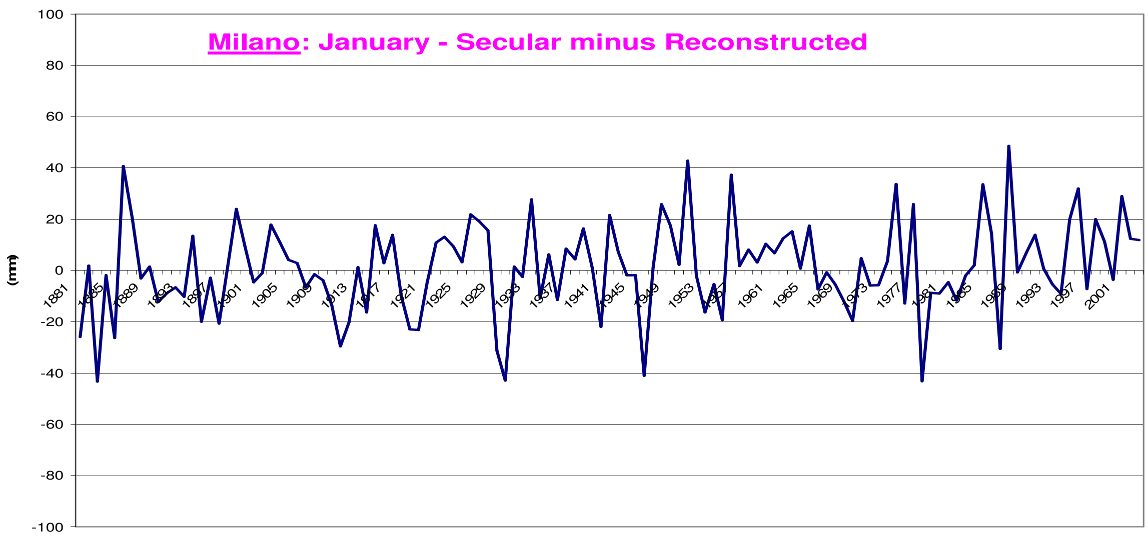

Fig. 235: differences between the reconstructed and the secular series of Milano in January for precipitation.

For precipitation, more evidently than for temperature, the anomaly approach shows its Achilles' heel, that is the inability to reconstruct the extreme events. The highest precipitation values are worst reconstructed. Nevertheless, the reconstructed series differs, in absolute values, by more than 30 mm from the secular records only in 11 months out of 123.

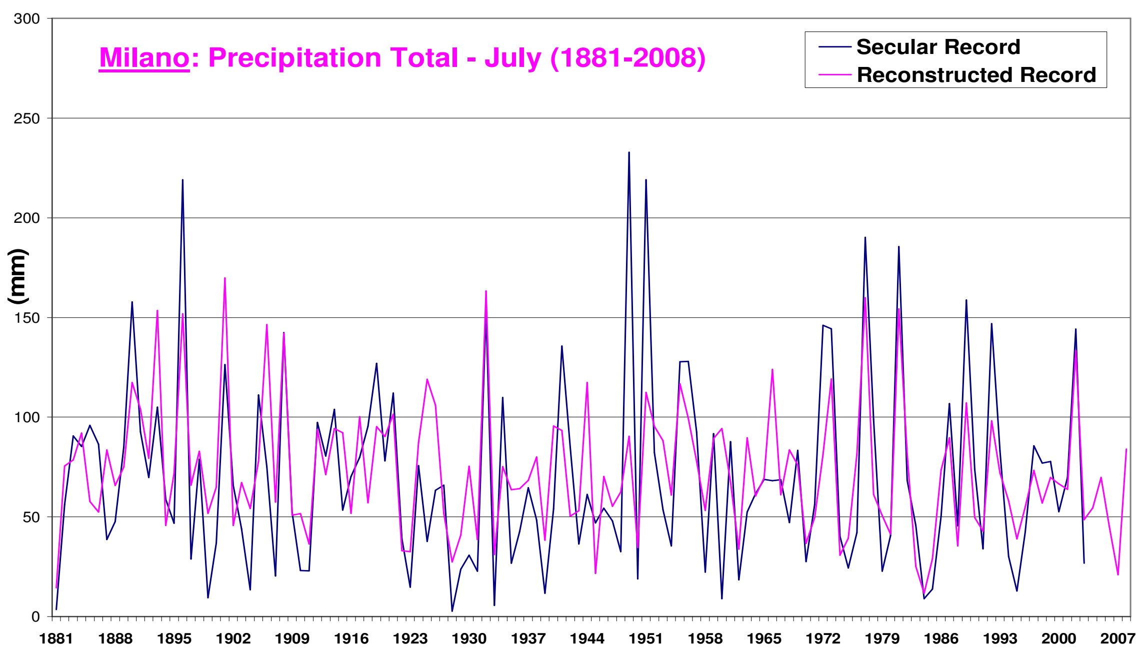

Fig. 236: July precipitation total reconstructed series versus secular record for Milano

As we can see, the reconstructed series reproduces the corresponding secular record less accurately than for January. If we compare the monthly values in the 1881-2003 period, the average *ME* is -4 mm and the average *MAE* is *26* mm. The driest July took place in 1882 (0 mm), the wettest in 1949 (243 mm).

In the following figure, we show the difference between the two series (the secular minus the reconstructed series.

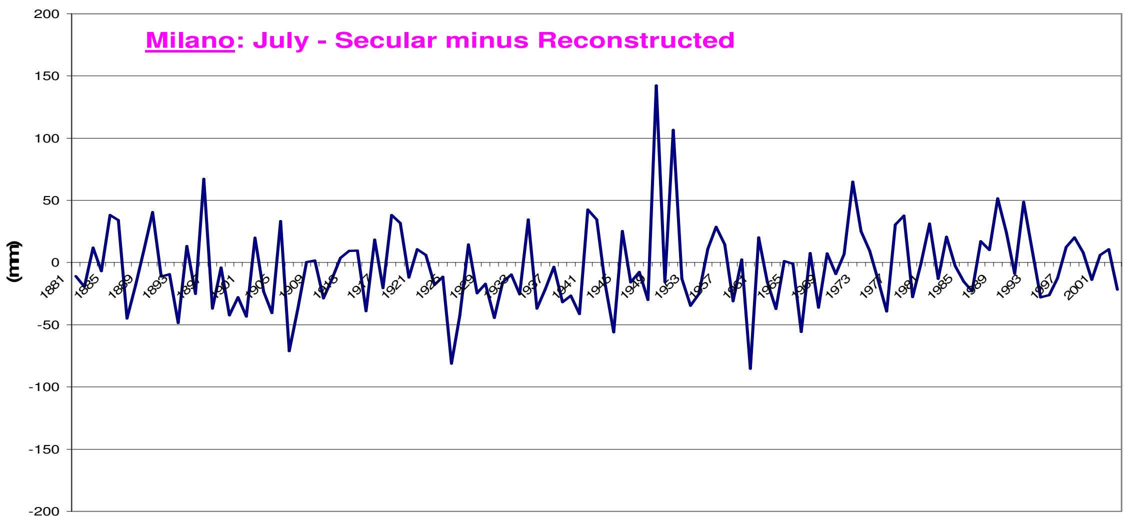

Fig. 237: differences between the reconstructed and the secular series of Milano in July for precipitation.

Even for July, the highest precipitation values are worst reconstructed; this is particularly evident for 1949 (*MAE* is 142 mm) and 1951 (*MAE* is 107 mm). Nevertheless, the reconstructed series differs, in absolute values, more than 30 mm from the secular records only in 19 months out of 123.

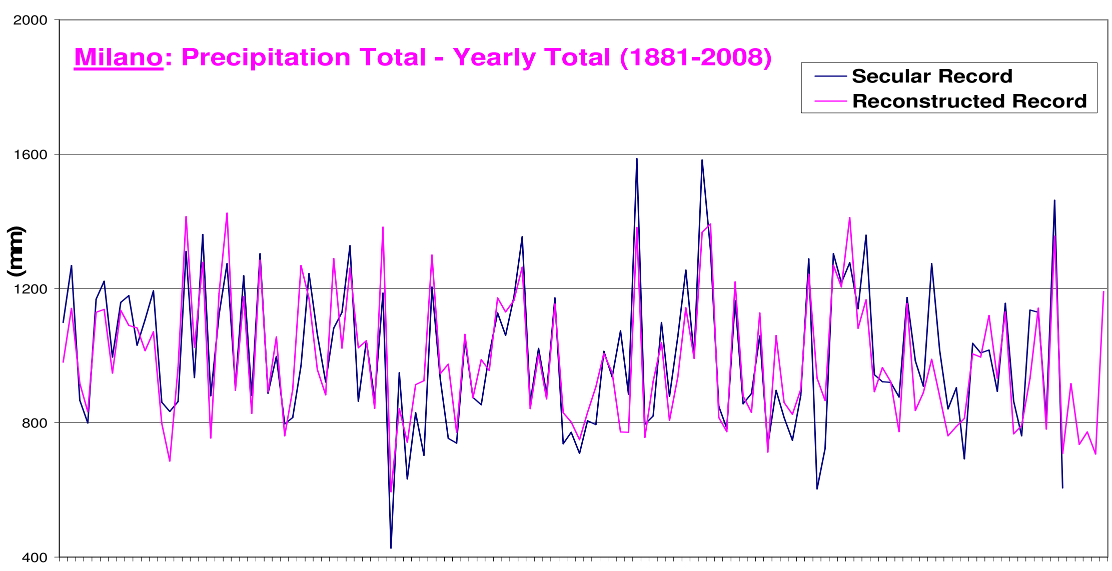

Fig. 238: Yearly precipitation total reconstructed series versus secular record for Milano

As we can see, the reconstructed series reproduces the corresponding secular record more accurately than for July and for January. If we compare the monthly values in the 1881-2003 period, the average *ME* is 3 mm and the average *MAE* is 82 mm. If we consider that the average yearly total precipitation for Milan in the 1881-2003 period was 998 mm (value calculated using the secular record) the relative mean absolute error is 8.2%. The driest year was 1821 (427 mm) and the wettest was 1951 (1,587 mm).

In the following figure, we show the difference between the two series as the secular minus the reconstructed series

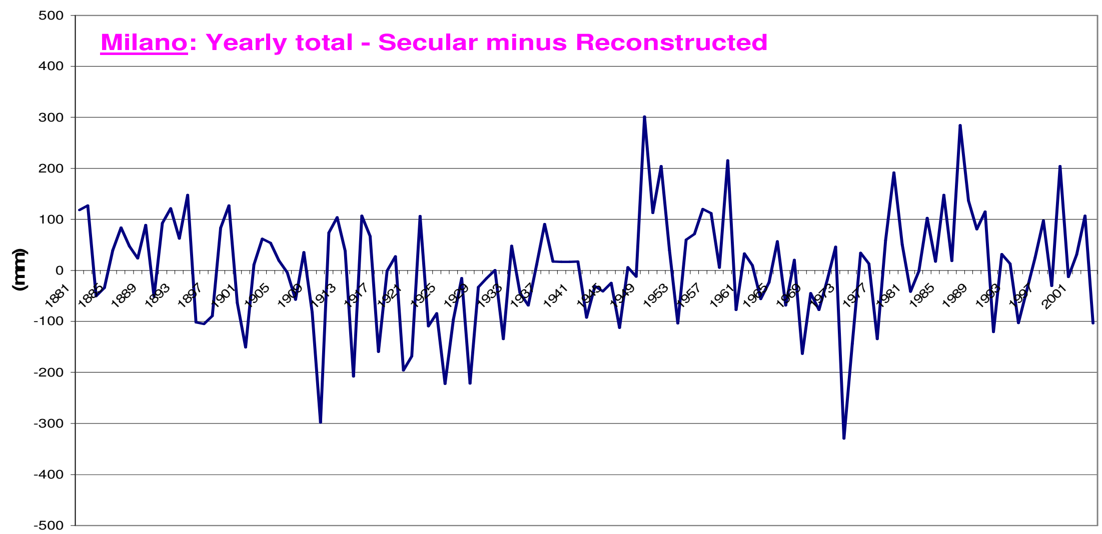

Fig. 239: differences between the reconstructed and the secular series of Milano in July for precipitation.

Even for the yearly total, as for the single months, the highest precipitation values are worst reconstructed. Nevertheless, the reconstructed series differs, in absolute values, by more than 250 mm from the secular records only in 4 months out of 123.

• Reconstruction of the precipitation time series of Roma

Secular Record (name ; start year of data ; latitude ; longitude ; elevation)
Roma ; 1782 ; 41.900 °N ; 12.470 °E ; 56 m

Grid point for the reconstructed series (latitude ; longitude ; elevation)
41.904 °N ; 12.471 °E ; 14 m
(The same point for the reconstruction of the temperature time series).

In the following figures we show the reconstructed series versus the secular record for precipitation for March in the 1881-2008 period, and the comparisons in the 1881-2003 period.

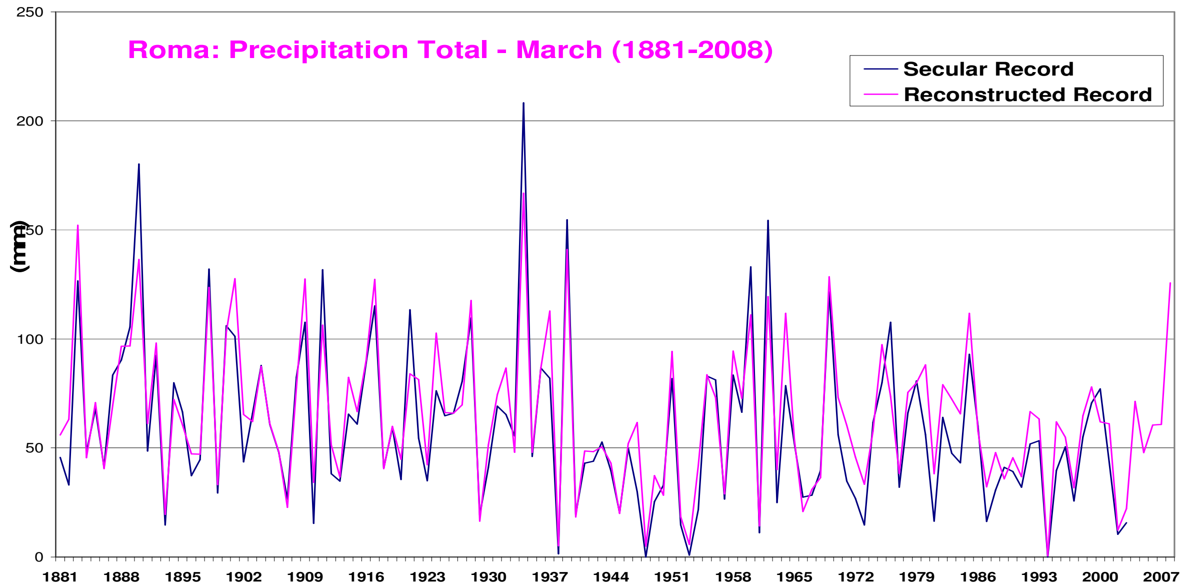

Fig. 240: March precipitation total reconstructed series versus secular record for Roma

If we compare the monthly values in the 1881-2003 period, the average *ME* is -5 mm and the average *MAE* is 11 mm. The driest March took place in 1834, in 1948 and in 1994 (*0* mm), the wettest in 1935 (208 mm).

In the following figure, we show the difference between the two series as the secular minus the reconstructed series.

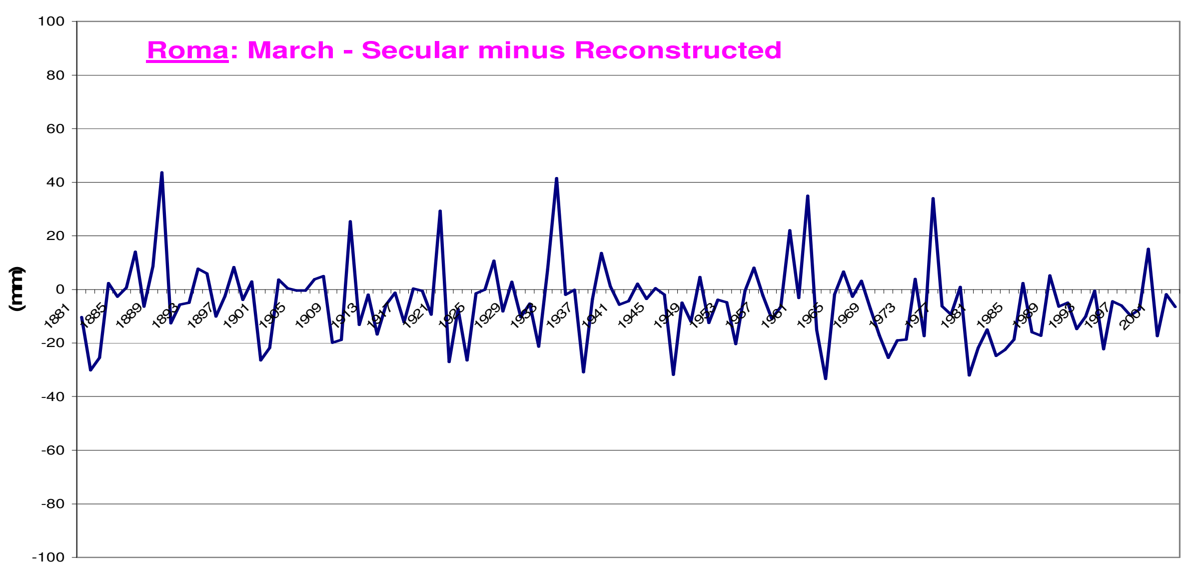

Fig. 241: differences between the reconstructed and the secular series of Roma in March for precipitation.

As for Milan, the highest precipitation values are reconstructed worst. Nevertheless, the reconstructed series differs, in absolute values, by more than 30 mm from the secular records only in 7 months out of 123.

• Reconstruction of the precipitation time series of Palermo

Secular Record (name ; start year of data ; latitude ; longitude ; elevation)
Palermo ; 1797 ; 38.100 °N ; 13.350 °E ; 71 m

Grid point for the reconstructed series (latitude ; longitude ; elevation)
38.104 °N ; 13.346 °E ; 51 m

In the following pictures we show the reconstructed series versus the secular record for precipitation for April in the 1881-2008 period, and the comparisons in the 1881-2003 period.

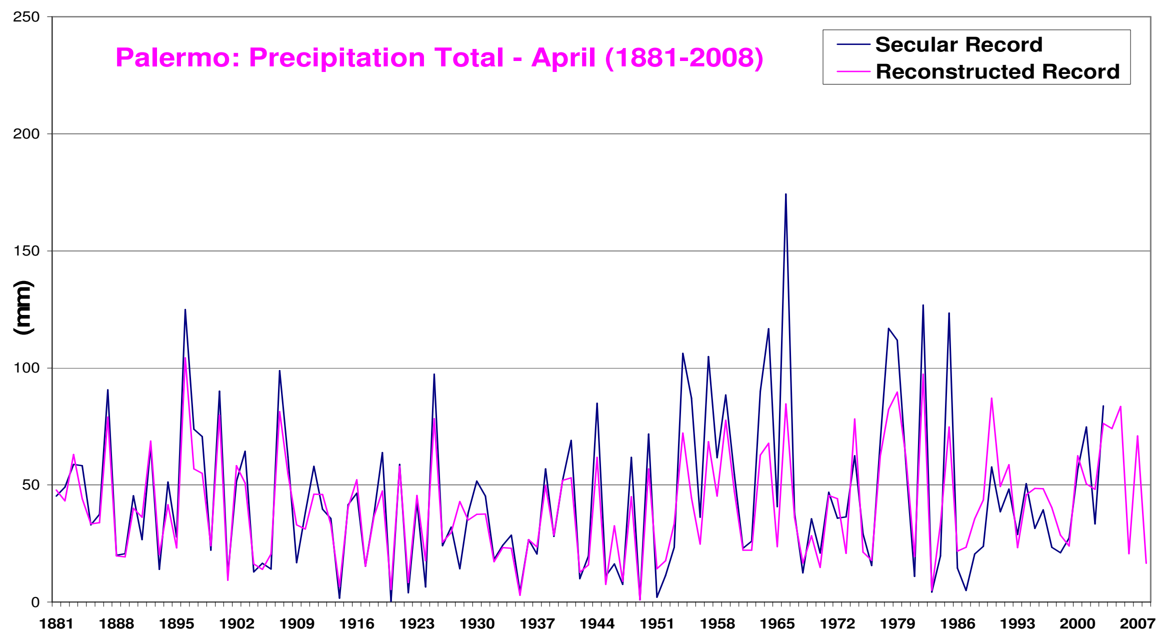

Fig. 242: April precipitation total reconstructed series versus secular record for Palermo

As we can see from the picture, in this case the reconstructed series tends to underestimate the precipitation total. In fact, if we compare the monthly values in the

1881-2003 period, the average *ME* is 4 mm and the average *MAE* is 11 mm. The driest April took place in 1830, in 1847 and in 1860 (427 mm), the wettest in 1834 (209 mm).

In the following figure, we show the difference between the two series as the secular minus the reconstructed series.

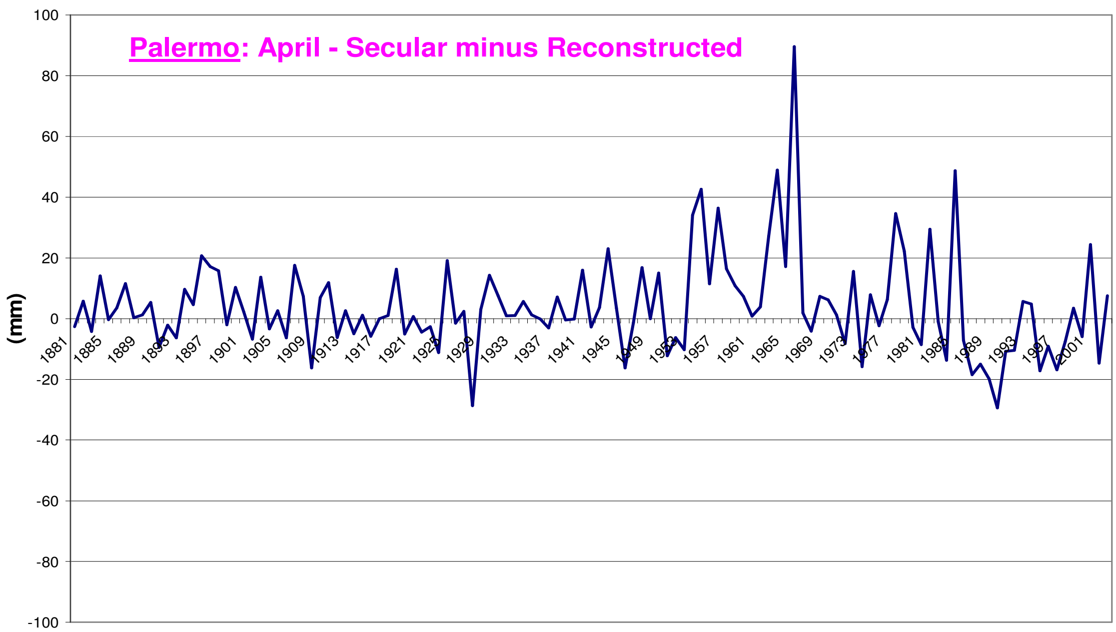

Fig. 243: differences between the reconstructed and the secular series of Palermo in April for precipitation.

As for Milan and Rome, the highest precipitation values are reconstructed worst. Nevertheless, the reconstructed series differs, in absolute values, by more than 30 mm from the secular records only in 6 months out of 123.

7.2.2 The use of reconstructed time series to complete secular records

+ Reconstruction of the precipitation time series of Rovigo

We show the results obtained for Rovigo in the framework of this PhD project and published in *Brunetti et al. (2010)*. Such a reconstruction of the precipitation time series of Rovigo was obtained in the frame of the collaboration between *ISAC-CNR* and the University of Milan, which contributed to completing this PhD project.

Secular Record (name ; start year of data ; latitude ; longitude ; elevation)
Rovigo ; 1879 ; 45.050 °N ; 11.770 °E ; 9 m

Grid point for the reconstructed series (latitude ; longitude ; elevation)
45.054°N ; 11.771 °E ; 5 m

In the following figures we show how the reconstructed series can be used in order to complete the secular record for precipitation for winter (December, January, and February) and for summer (June, July and August) in the 1800-2008 period. In this case the reconstructed series is in blue, whilst the secular record is in red.

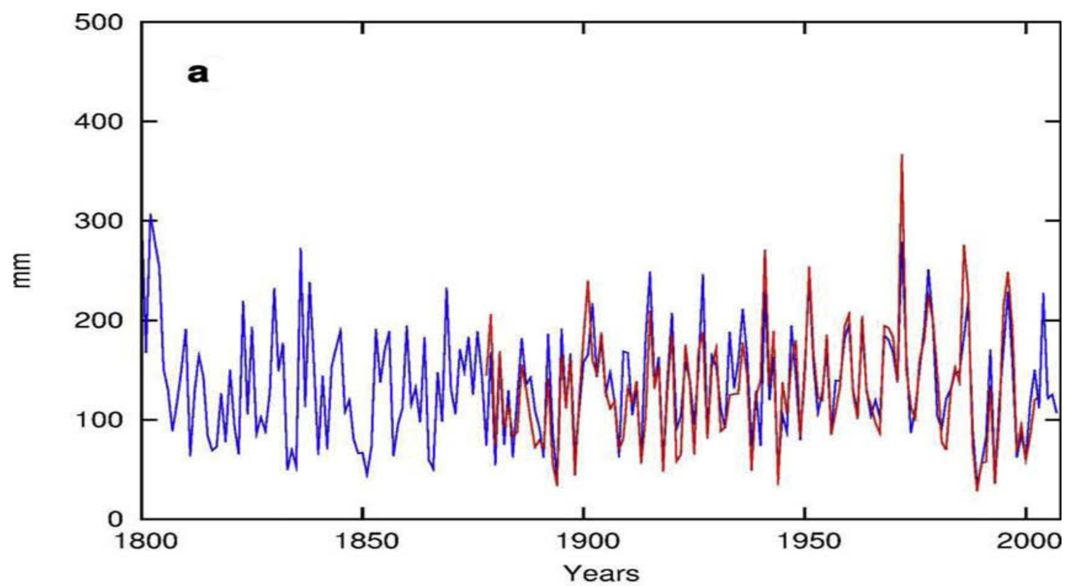

Fig. 244: winter precipitation total reconstructed versus secular record of Rovigo (Brunetti et al., 2010)

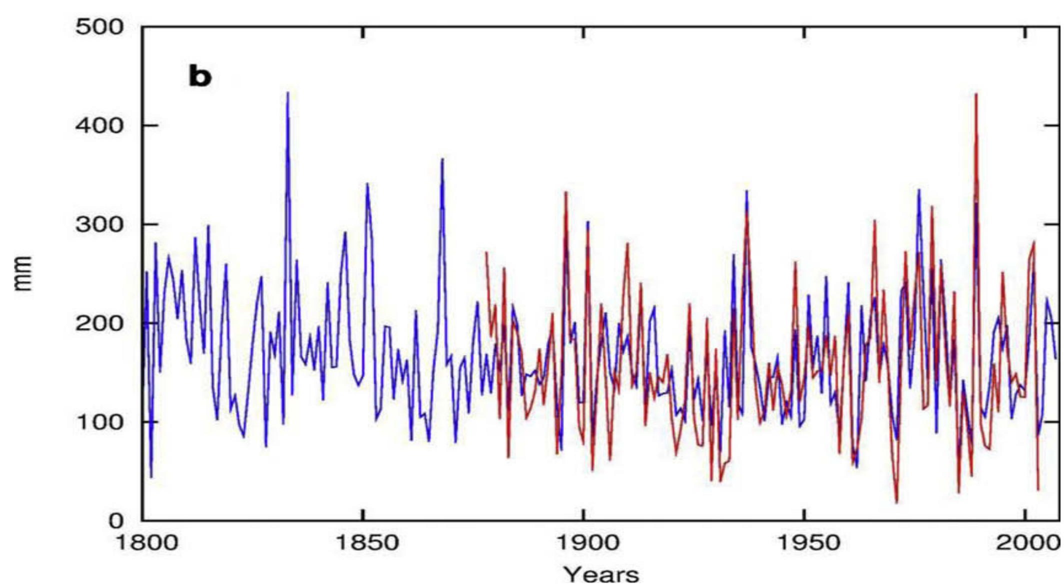

Fig. 245: summer precipitation total reconstructed versus secular record of Rovigo (Brunetti et al., 2010)

Using the anomaly approach, the precipitation time series of Rovigo was reconstructed for the 1800-2008 period.

7.2.3 Construction of new secular time series

In this chapter we show some examples of new precipitation time series for Arona. As for temperature, a new secular record for precipitation can be obtained by request for each month for each 30-arc second (horizontal resolution) of the area under investigation.

• Reconstruction of precipitation time series for Arona (new series)

We used the same grid point used for the reconstruction of the temperature time series (see Chapter 7.1.3 for details).

In the following figures we show the new precipitation time series of January, July, and the yearly total precipitation series in the 1881-2008 period.

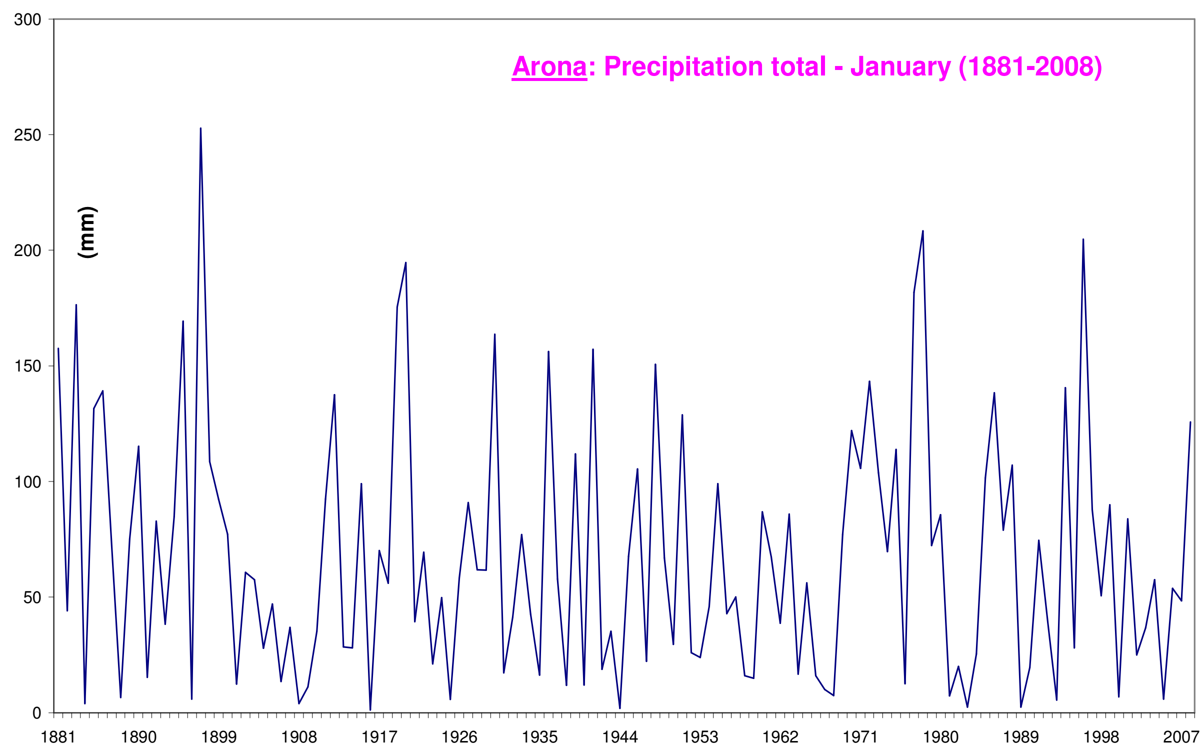

Fig. 246: January precipitation new secular time series for Arona

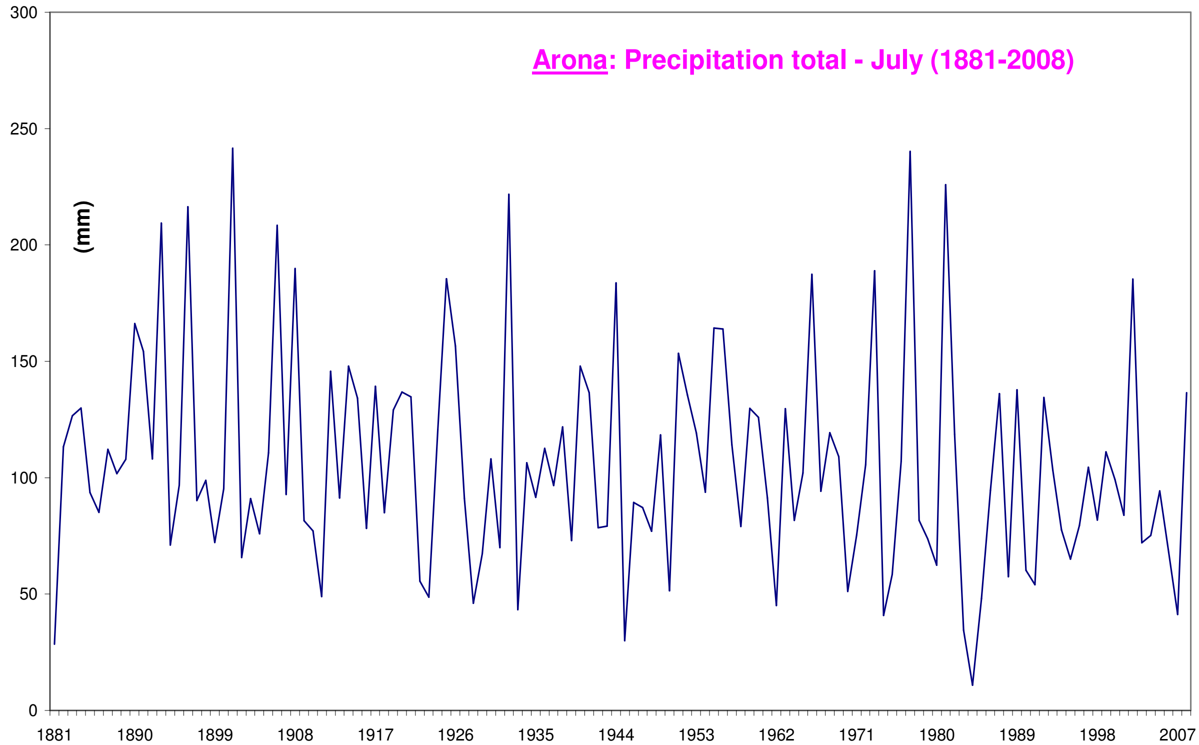

Fig. 247: July precipitation new secular time series for Arona

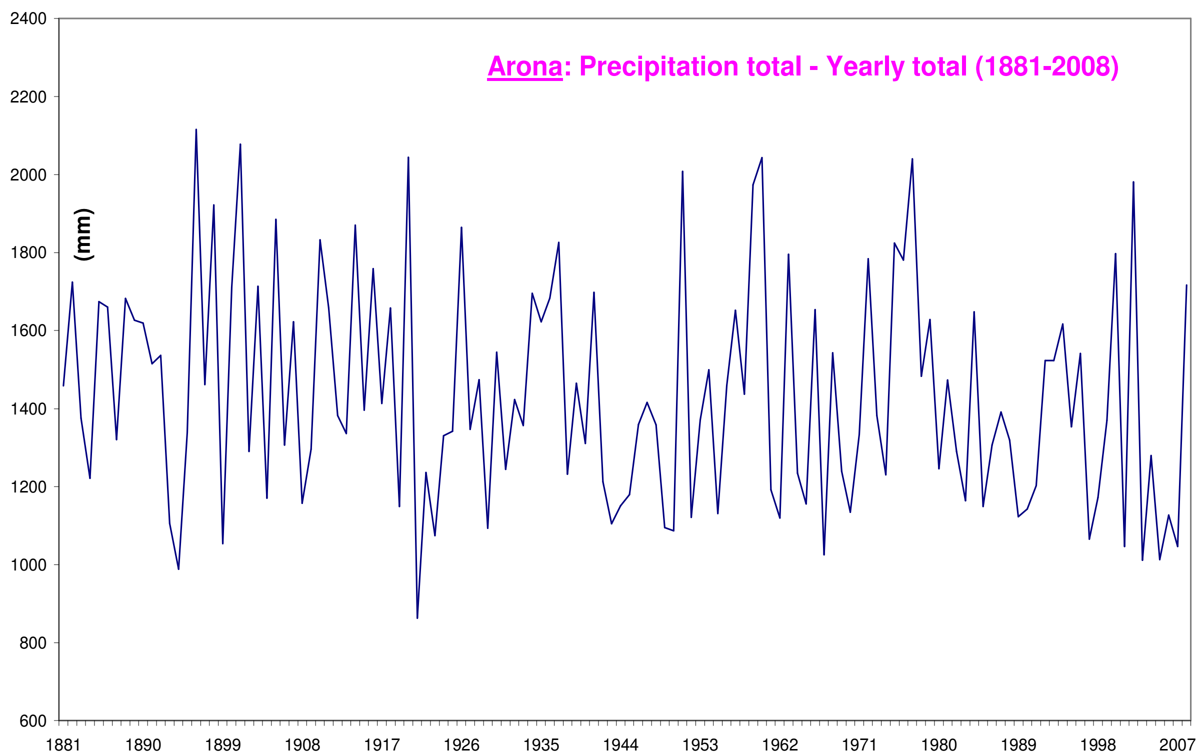

Fig. 248: Yearly total precipitation new secular time series for Arona

The driest January took place in 1916 (1 mm), the wettest in 1897 (253 mm). The driest July took place in 1984 (11 mm), the wettest in 1901 (242 mm). The overall driest month for Arona was February 1984 (0.9 mm), the overall wettest month was October 1907 (575 mm). The overall driest year for Arona was 1921 (863 mm), the overall wettest year was 1896 (2,116 mm). The driest month is February (average precipitation total: 65 mm), the wettest month is October (average precipitation total: 172 mm). Seasonally, winter has a precipitation total of 206 mm, spring of 411 mm, summer of 377 mm, fall of 441 mm.

7.2.4 Some considerations about precipitation trends

As for temperature and for the same reasons, the precipitation trends that can be found by means of statistical analyses of the reconstructed secular time series are similar to the results found by *Brunetti et al. (2006b).*

In fig. 249 and in fig. 250 we show some examples for the reconstructed series. In the following figures we show the total precipitation trend of Milan and Rome.

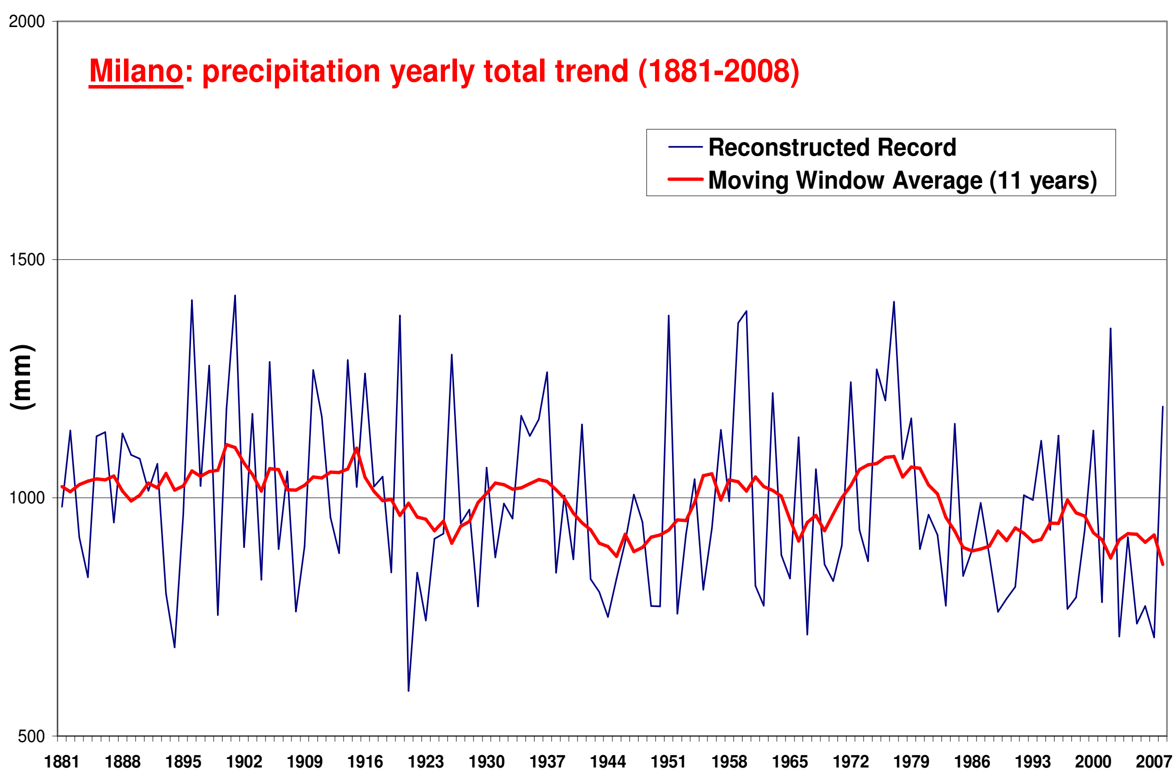

Fig. 249: Yearly precipitation total trend of Milan

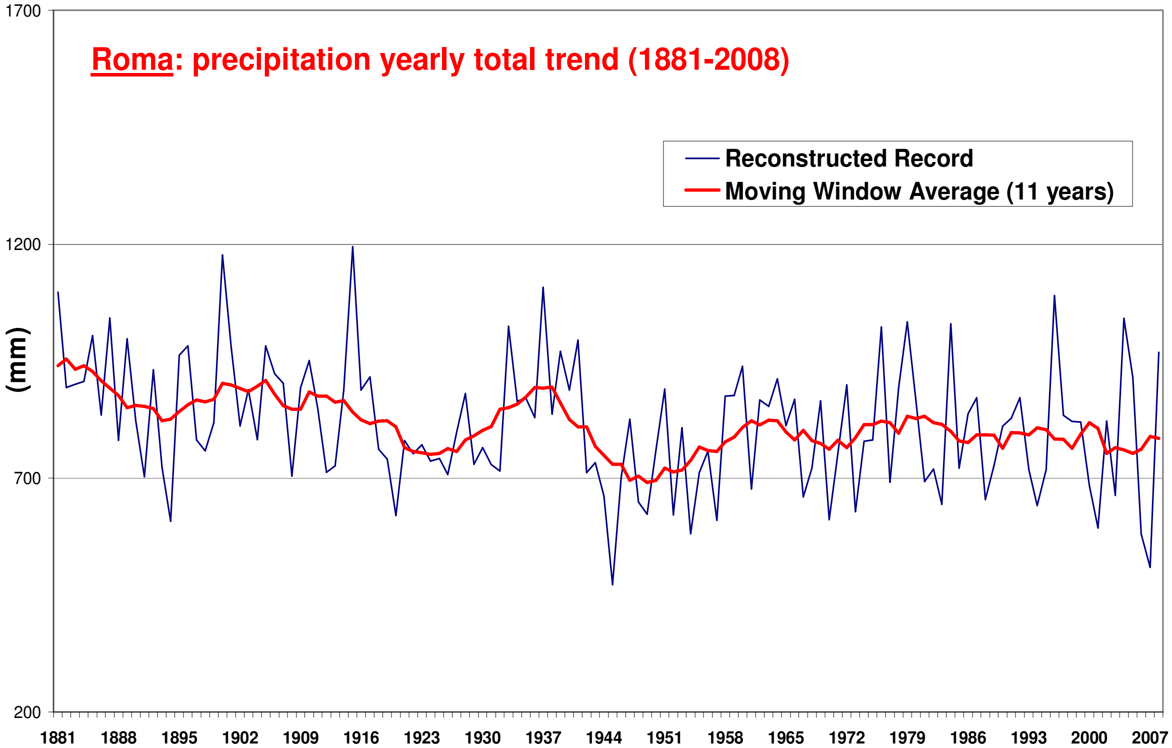

Fig. 250: Yearly precipitation total trend of Rome

If we use a linear regression, we find that, for Milan, the yearly precipitation total shows a negative trend of 8 mm *per decade* in the 1881-2008 period. For Rome, the yearly precipitation total shows a negative trend of 9 mm *per decade* in the 1881-2008 period and no significant variations in the last 50 years.

As for temperature, we also consider Arona as a further example for a reconstructed precipitation time series. The average yearly precipitation total in the 1881-2008 period is 1,436 mm, with an anomaly of 42 mm related to the 1961-1990 reference period. In the last years, the average yearly precipitation total in the 1979-2008 period is 1,342 mm, with an anomaly of -52 mm related to the 1961-1990 reference period. The yearly precipitation total shows a negative trend of 14 mm *per decade* in the 1881-2008 period.

In fig. 251, we show the yearly precipitation total trend for Arona in 1881-2008.

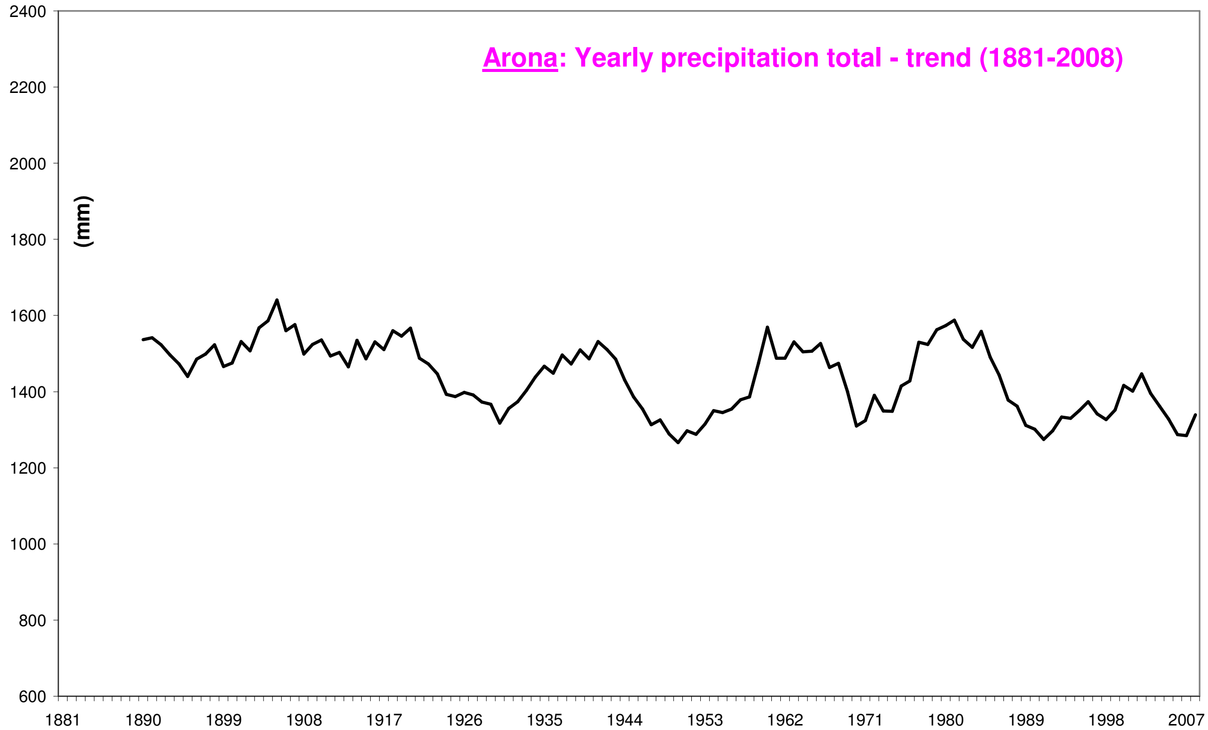

Fig. 251: Yearly precipitation total trend for Arona

8. Conclusions and further developments

8.1 Temperature

Within a scientific collaboration between the Department of Physics of the University of Milan and the *ISAC-CNR* of Bologna, I **achieved** the following **goals** in the framework of this PhD project:

- the improvement of the Italian temperature database to 1,494 T_M stations and 1,179 T_N-T_X stations related to different time intervals between 1850 and 2010 ;
- the development of a spatialization model based on *MLR* plus local improvements plus a *GIDS* interpolation of the residuals for gridding the temperature data on the Italian area ;
- the creation of 12 high-resolution monthly (and a yearly average) 1961-1990 climatologies for minimum temperature, mean temperature, maximum temperature and daily temperature range for Italy on the high-resolution grid of the *USGS GTOPO30 DEM*;
- the possibility, by means of the "anomaly approach", to obtain a reconstructed mean, maximum and minimum temperature time series for each grid cell (resolution: *30-arc second*) of the Italian territory for the period 1850-2010.

Here is a list of **further developments** that can be introduced:

- a further improvement of the temperature database with data from new providers (when possible) ;
- the homogenization and the completion of new secular records in order to improve the resolution of the anomaly grids ;
- the construction of a data net that may update the database every month ;
- a further validation of the spatialization model with the introduction of the new data ;
- the development of spatialization models based on different methodologies (especially kriging, splines, PRISM) in order to have a further validation of our temperature models.

8.2 Precipitation

As for temperature, within a scientific collaboration between the Department of Physics at the University of Milan and the *ISAC-CNR* of Bologna, I **achieved** the following **goals** in the framework of this PhD project:

- the improvement of the Italian precipitation database to more than 4,000 precipitation stations related to different time intervals between 1850 and 2010 ;
- the development of a spatialization model based on a improved version of the *PRISM* methodology ;
- the creation of 12 high-resolution monthly (and a yearly average) 1961-1990 climatologies for precipitation totals for Italy ;
- the possibility, by means of the "anomaly approach", to obtain a reconstructed precipitation time series for each grid cell (resolution: *30-arc second*) of the Italian territory for the period 1850-2010.

As for temperature, **further developments** can be planned:

- a further quality-check procedure on the precipitation database, especially in some regions where the data density is smaller;
- a further enlargement of the precipitation database with data from new providers;
- the homogenization and the completion of new secular records in order to improve the resolution of the anomaly grids ;
- the construction of a data net that may update the database every month ;
- a further refinement of the spatialization model in order to obtain definitive monthly precipitation climatologies for the whole Italy ;
- the development of spatialization models based on different methodologies (especially *MLR*, splines, kriging) in order to have a further validation of our temperature models.

8.3 Solar radiation and other climatic variables

In the framework of this PhD project, I also dealt with solar radiation and I **achieved** the following **goals**:

- the construction of a provisional sunshine radiation database for Italy of more than 200 records related to different time intervals between 1950 and 2010 ;
- the development of a solar radiation model by means of an original mixed approach, based on sunshine duration data, decomposition formulas, parameterization of the turbidity of the atmosphere and calculations on astronomical quantities ;
- the creation of 12 high-resolution monthly (and a yearly average) 1961-1990 climatologies for global, direct, diffuse, reflected, and absorbed solar radiation for Italy ;
- the possibility, by means of slight variations in the Fortran codes, to obtain a solar radiation model that provides high-resolution climatologies for any period where sunshine radiation data are available.

In this case, the **further developments** may be:

- the homogenization of the sunshine radiation database in order to obtain 1951-2010 anomaly grids for sunshine duration and consequently the possibility to re-scale our solar radiation model to any 30-year interval between 1951 and 2010 ;
- the construction of a secular sunshine duration dataset for Italy in order to evaluate the sunshine duration and global radiation trends in the last century ;
- an enlargement of the sunshine duration database with data from new providers (when possible) ;
- the creation of a spatially dense dataset of solar global radiation and cloudiness data ;
- the development of a solar radiation model based on cloudiness data and global radiation data in order to compare the solar radiation climatologies obtained by means of different approaches ;

Furthermore, the anomaly approach may be applied in the future to other climatic variables in the Italian area, as the relative humidity, the atmospheric pressure, the cloudiness, the wind and so on.

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9.3 Web sites

ArcGIS ArcView
http://www. esri.com/software/arcview/index.html

AMI Dataset
http://www.meteoam.it/

American Meteorology Society Glossary
http://amsglossary.allenpress.com/glossary

ANUSPLIN
http://fennerschool.anu.edu.au/publications /software/anusplin.php

ARPA Emilia Romagna
http://www.arpa.emr.it/

ARPA Liguria
http://www.arpal.org/

ARPA Lombardia
http://ita.arpalombardia.it/ita/index.asp

ARPA Piemonte
http://www.arpa.piemonte.it/

ARSO Slovenia
http://www.arso.gov.si/

AVHRR
http://noaasis.noaa.gov/NOAASIS/ml/avhrr. html

CNR Lazio
http://usr-lazio.artov.rm.cnr.it/concluse/scienza2001/modulo-snaturali/dimenno/irraggiamento.htm

CORINE Land Cover Project
http://www.eea.europa.eu/publications/COR0-landcover

DBT-ENEA
http://clisun.casaccia.enea.it/Pagine/Index.htm

ECSN-HRT GAR
http://www.zamg.ac.at/forschung/klimatologie/ klimamodellierung/ecsn_hrt-gar/

ENAS
http://www.enas.sardegna.it/

ENEA Solar Tool for Italy
http://www.solaritaly.enea.it/

ENEL
http://www.enel.it/it-IT/

Forest Encyclopedia
http://www.forestencyclopedia.net/

GMT Generic Mapping Tools
http://gmt.soest.hawaii.edu/

Google Earth
http://earth.google.com/intl/it/

GRASS GIS
http://grass.itc.it/

JRC
http://ec.europa.eu/dgs/jrc/index.cfmJRC

JRC GEM GLC2000 Project
http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php

JRC PVGIS
http://sunbird.jrc.it/pvgis/

JRC r.sun Project
http://sunbird.jrc.it/pvgis/solrad/index.htm

Kansas Geological Survey
http://www.kgs.ku.edu/

Kyoto Project Lombardia
http://www.kyotolombardia.org/

Idropisa
http://www.idropisa.it/

ISPRA SINTAI PLUTER
http://193.206.192.243/storico/index.html

Meteo France
http://france.meteofrance.com

Meteo Swiss
http://www.meteoswiss.admin.ch/web/en/ weather.html/

Meteo Trentino
http://www.meteotrentino.it/

MIPAF
http://www. politicheagricole.it/default.html/

MODIS
http://modis.gsfc.nasa.gov/

NCDC - GSOD - NOAA
http://www.ncdc.noaa.gov/oa/about/whatsnew.htm

Ortelio ECM Cartographic Maps.
http://www.ortelio-ecm.it/

Power From the Sun website
www.powerfromthesun.net

PRISM
http://www.prism.oregonstate.edu/docs/index.phtml

Protezione Civile Calabria
http://www.protezionecivilecalabria.it/

Protezione Civile Marche
http://www.protezionecivile.marche.it/

Protezione Civile Puglia
http://www.protezionecivile.puglia.it/

Provincia Autonoma di Bolzano
http://www.provincia.bz.it/

R Project for statistical computing
http://www.r-project.org/

Regione Abruzzo
http://www.regione.abruzzo.it/xIdrografico/ index.asp/

SCIA-APAT SINANET
http://www.scia.sinanet.apat.it/

SIAS Sicilia
http://www.sias.regione.sicilia.it/

Ubuntu OpenOffice (Ubuntu Website)
http://www.ubuntu-it.org/

UCEA dataset
http://www.cra-cma.it

UNESCO
http://whc.unesco.org/

UNFCCC
http://unfccc.int/2860.php

University of Colorado at Boulder (Sea Level Change)
http://sealevel.colorado.edu

University of Kansas (KU Kansas Geological Survey)
http://www.kgs.ku.edu/

University of Washington (Applied Mathematics)
http://www.amath.washington.edu/

University of Washington (Polar Science Center – Applied Physics)
http://psc.apl.washington.edu/

USGS GTOPO30
http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30_info

WGMS
www.wgms.ch/

Windows Office (Microsoft Website)
http://office.microsoft.com/it-it/

Wikipedia
http://www.wikipedia.org/

WRDC WMO
http://wrdc.mgo.rssi.ru

ZAMG
http://www.zamg.ac.at/histalp/

Appendix - List of acronyms and abbreviations

ADW = Angular Distance Weighted

AGDC = Alaska Geospatial Data Clearinghouse

ANN = Artificial Neural Networks

AMI = Aeronatuica Militare Italiana

AMS = American Meteorological Society

APAT = Agenzia per la Protezione dell'Ambiente e per i Servizi Tecnici

ARPA = Agenzia Regionale per la Protezione dell'Ambiente

ARSO = Agencijea Republike Slovenije za okolje

Asp = Aspect

AVG = Average

AVHRR = Advanced Very High Resolution Radiometer

BLUE = Best Linear Unbiased Estimation

BLUP = Best Linear Unbiased Prediction

BMLR = Baesian Multivariate Linear Regression

CAMS = Climate Anomaly Monitoring System

CCK = Collocated Co-Kriging

CD = Compact Disc

CK = Co-Kriging

CNR = Consiglio Nazionale delle Ricerche

CORINE = Coordination of information on the environment

CV = Cross Validation

DBT-ENEA = Database Temperature Ente Nazionale Energia e Ambiente

DEM = Digital Elevation Model

DJK = Disjunctive Kriging

DTR = Daily Temperature Range

ECSN HRT-GAR = European Climatic Support Network High Resolution Temperature climatologies for the Greater Alpine Area project

EF = Model Efficiency

ELEV = Elevation

ENAS = Ente Acque della Sardegna

ENEA = Ente Nazionale Energia e Ambiente

ENEL = Ente Nazionale Energia eLettrica

ENSO = El-Nino Southern Oscillation

EROS = Earth Research Observation and Science

ESRA = European Solar Radiation Atlas

EUMETNET = Network of European Meteorological Services

GAR = Greater Alpine Region

GCV = General Cross Validation

GEM = Global Environment Monitoring

GHCN = Global Historical Climatology Network

GHG = GreenHouse Gases

GIDS or **GIDSW** = Gradient or Geographical plus Inverse Distance Square Weighting

GIDW = Gradient or Geographical plus Inverse Distance Weighting

GIS = Geographic Information System

GISS = Goddard's Institure for Space Studies

GLC2000 = Global Land Cover 2000 Joint Research Centre project

GLM = Generalized Linear Models

GLS = Generalized Least Squares

GMT = Generic Mapping Tools

GMT = Greenwich Mean Time

GPCP = Global Precipitation Climatology Project

CRUT = Climate Research Unit Temperature databases of the East Anglia University

GWR = Geographic Weighted Regression

$\mathbf{H_0}$**=** Exo-atmospheric solar radiation

$\mathbf{H_T}$**=** Global solar radiation

Hi-res = High resolution

HISTALP = Historical Instrumental climatological Surface Time series of the greater ALPine region

JRC = Joint Research Centre

$\mathbf{K_{dir}}$ **=** Direct Fraction of solar radiation

$\mathbf{K_{dif}}$ **=** Diffuse Fraction of solar radiation

$\mathbf{K_t}$ **=** Clearness Index

KBS = Knowledge-Based System

KED = Kriging with External Drift

KNN = K-Nearest Neighbour

ID = Inverse distance

IDW = Inverse Distance Weighting

IES = Institute for Environment and Sustainability

IPCC = International Panel on Climate Change

IK = Indicator Kriging

IRFK = Intrinsic Random Function Kriging

ISAC = Istituto di Scienze dell'Atmosfera e del Clima

ISDW or **IDSW** = Inverse Squared Distance Weighting

ISPRA = Institute for Environmental Protection and Research

IST = Italian Standard Time

LAT = Latitude

LCOV = Land Cover

LLR = Local Lapse Rate Regression

LNK = Log-Normal Kriging

LON = Longitude

LR = Linear Regression

LRK = Local Regression Kriging

LT = Local Time

MAE = Mean Absolute Error

MAER = Relative Mean Absolute Error

MBE = Mean Bias Error

ME = Mean Error

MIK = Multiple Indicator Kriging

MIPAF = Ministero delle Politiche Agricole e Forestali

MLR = Multiple Linear Regression

MODIS = MODerate Resolution Imaging Spectrometer

MVR = MultiVariate Regression

MSE = Mean Squared Error

MWLR = Multiple Weighted Linear Regression

NLR = Non Linear Regression

NN = Nearest Neighbour

NAO = North Atlantic Oscillation

NCDC = National Climatic Data Centre

NCDC-GSOD = National Climatic Data Center, Global Surface Observation of the Day

NOAA = National Oceanic and Atmospheric Administration

OK = Ordinary Kriging

OI = Optimal Interpolation

OLS = Ordinary Least Squares

PELCOM = Pan-European Land Use and Land Cover Monitoring

PhD or **Ph.D.** = Doctor of Philosophy (In Italy it means "Dottorato di Ricerca")

PRISM = Parameter Regression Independent Slope Model

PVGIS = Photovoltaic GIS

QBO = Quasi-Biennal Oscillation

R_s = Sun hours ratio

RCM = Regional Circulation Models

RES = Residual

ResK = Residual Kriging

RK = Regression Kriging

RMSE = Root Mean Square Error

RSwT = Regularized tplines with Tension

SCAS = Spatial Climate Analysis Service (University of the Oregon State)

SCIA = Sistema nazionale per la raccolta, l'elaborazione e la diffusione di dati Climatologici di Interesse Ambientale

SDS = Smart Distance Searching

SE = Standard Error

SEADIST = Distance from the Sea

SeqK = Sequential Kriging

SK = Simple Kriging

SIAS = Servizio Informativo Agrometeorologico Siciliano

SIMN = Servizio Idrografico e Maereografico Nazionale

SINANET = Rete del Sistema Informativo Nazionale Ambientale

SINTAI PLUTER = Sistema Informativo Nazionale per la Tutela delle Acque Italiane, database Pluviometrtico e Termometrico

SLR = Stepwise Linear Regression

SMI = Società Meteorologica Italiana

SSE = Sum of Squared Residuals

T_L = Turbidity Linke's Factor

T_M = Mean Temperature

T_N = Minimum Temperature

T_X = Maximum Temperature

TPS = Thin Plate Splines

TS = Trend Surface

UCEA = Ufficio Centrale di Ecologia Agraria

UGM-ENAV = Ufficio Generale per la Meteorologia-Ente Nazionale di Assistenza al Volo

UNESCO = United Nations Education, Scientific and Cultural Organization

UHI = Urban Heat Island

UK = United Kingdom

UNFCCC = United Nations Framework Convention on Climate Change

UnK = Universal Kriging

UniMi = University of Milan

USA = United States of America

USGS = United States Geological Survey

UT = Universal Time

WDRC = World Radiation Data Center

WGMS = World Glacier Monitoring Service

WGS84 = World Geodetic System 1984

WLR = Weighted Linear Regression

WMO = World Meteorological Organization

ZAMG = Zeltral-Anstalt fur Meteorologie und Geodinamik

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