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Analysis of climatic trends in data from the agrometeorological station of Bologna-Cadriano, Italy (1952–2007)

Philipp Matzneller · Francesca Ventura · Nicola Gaspari · Paola Rossi Pisa

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Abstract Agriculture is highly exposed to climate change, as farming activities directly depend on climatic conditions. Knowledge of the extent of such change and of related phenomena will help to answer the questions posed by society about adaptation strategies. The global situation is well described by the Fourth IPCC assessment report (IPCC 2007), but local studies are important to understand the impact and the priorities to adopt in adaptation strategies. In this study a historical set of meteorological data, collected during the period 1952–2007 at the University of Bologna (Italy) agrometeorological station, was analysed. Several indexes, such as Frost Severity Index, number of hot days, number of rainy days, etc., were calculated, and their trends in time were analysed. The results show a scenario of increasing temperatures and evapotranspiration, a decrease in rainy days and a deepening of the watertable. The effect of these changes on agriculture will be a decrease in water availability, an increase in heat stress in plants and an increase in drought risk.

1 Introduction

In Earth's temperate zones climate is one of the most important limiting factors for agricultural production: frost risk during the growing period and low and irregular precipitation with high risk of drought during the cultivating period are common problems in agriculture.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change shows that the global average surface temperature increased by 0.74°C from 1906 to 2005. The linear warming trend over the 50 years 1956–2005 is 0.13°C per decade and eleven of the last 12 years (1995–2006) rank among the warmest years in the instrumental record of global surface temperature (since 1850) (IPCC 2007).

P. Matzneller · F. Ventura (✉) · N. Gaspari · P. Rossi Pisa
Department of Agroenvironmental Sciences and Technologies,
University of Bologna, via Fanin 44, 40127 Bologna, Italy
e-mail: fventura@agrsci.unibo.it

Trends in precipitation amount between 1900 and 2005 were observed in many large regions. Over this period, precipitation increased significantly in eastern parts of northern and southern America, northern Europe and northern and central Asia, whereas precipitation declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Globally, the area affected by drought has increased since the 1970s (IPCC 2007). Knowing the extent of changes at a global scale is not enough to understand the situation at a local scale, where it is important to comprehend its impact and make decisions about adaptation and mitigation strategies. The main interest lies in what happens in the boundary layer, where the climate is the result of the interaction between the atmosphere and the Earth's surface. In Italy various authors have reported an increasing trend of temperatures, with quite large differences depending on the site and the data treatment. For example, temperatures in the annual series have a positive trend of 1°C per century at national level (Brunetti et al. 2006), an increasing trend from 0.4°C/100 years for northern Italy and of 0.7°C/100 years in southern Italy (Brunetti et al. 2004), Colombo et al. (2007) described a negative trend in the spell 1961–1980 and a positive trend in 1980–2000, Ciccarelli et al. (2008) found an increase of 1°C/50 years in north western Italy. In the Emilia–Romagna region Tomozeiu et al. (2006), analyzing mean and extreme temperatures all over the region, found an increase, especially during winter and summer. This was accompanied by a reduction in the number of frost days. According to Brunetti et al. (2006) precipitation shows a decreasing tendency in the whole of Italy over the last two centuries. On a yearly basis a negative trend is evident for northern and southern Italy, with respectively −47 mm/100 years and −104 mm/100 years (Brunetti et al. 2004). Ciccarelli et al. (2008) found no significative variation in precipitation in the Piedmont and Valle d'Aosta area (north-west of Italy). Several authors analysed extreme events, such as droughts and torrential rainfalls. An increase in winter dry spells (Brunetti et al. 2002) and, in the frame of decreasing total annual precipitation, an increase in heavy to torrential rainfall events was observed (Brunetti et al. 2001; Alpert et al. 2002)

Within this varied framework, a 56-year data series was analysed to interpret the situation in the area of Bologna, where the experimental fields of the Agricultural Faculty of the University of Bologna are situated. Here, various kinds of experimentation related to agriculture are carried out, in particular several long term studies focused on the effects of agronomic practices and crop succession on soil fertility, water quality, and sustainability of plant production. Some experiments date back more than 40 years, and others are still in course or already finished. Long term experiments need to take into account changes in temperature and precipitation over time, and knowing them in detail would help the understanding of the experimental results. For this reason climate indicators suitable for monitoring changes important for their impact on agriculture were chosen.

2 Materials and methods

The surface meteorological observation data analysed in this paper were collected at the agrometeorological station of the Agricultural Faculty of the University of Bologna. The station was initially installed at the University Research Centre in Corticella, north of Bologna (44°32′59″ N, 11°32′59″ E, 30 m a.s.l., European

Datum 1950, UTM 32). The station was active at this site from 1951 to 1971. The meteorological variables measured were air temperature and humidity, using a mechanical hygrothermograph, and rainfall, using a raingauge, later replaced by a tipping bucket rainfall recorder. At the end of 1971 the meteorological station was moved to a new site at the University of Bologna experimental farm of Cadriano (44°33′03″ N, 11°24′36″ E, 33 m a.s.l. European Datum 1950, UTM 32). The two meteorological sites were very similar, both located on the plains, at a distance of 4 km from each other in a straight line, and in a similar morphological area (Fig. 1). In Cadriano, a grass-covered area of 30 × 40 m^2 was fenced off and a number of meteorological instruments were installed. The instruments included: hygrothermograph, rainfall recorder, phreatimeters to the depth of 2.5 m, as well as anemometers, radiometers and a class A pan evaporimeter. The mechanical instruments are still in use, together with new electronic sensors, and are periodically checked and calibrated. For this reason it was decided to analyse the complete series of mechanical data, using electronic data when the mechanical records were missing, and to consider the data series from the two stations as a single series. A homogeneity test (Kruskal–Wallis test; Sneyers 1990) was carried out on the data

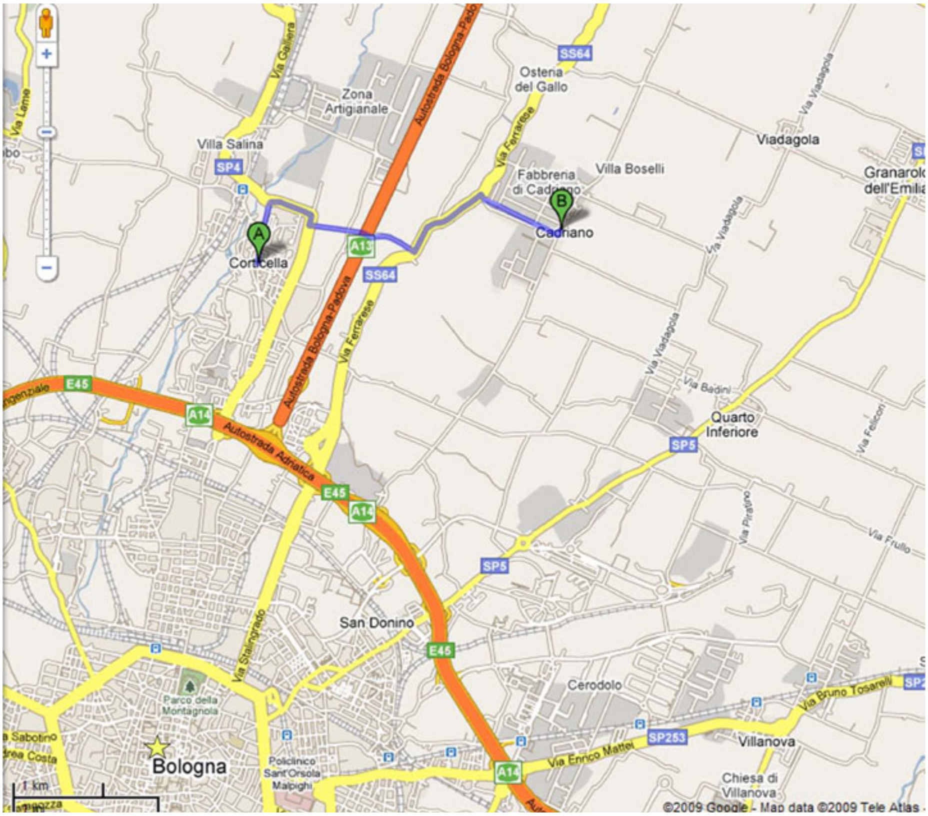

Fig. 1 Map illustrating the location of the first (*A*, Bologna–Corticella) and the second (*B*, Bologna–Cadriano) agrometeorological station. The station was moved from the first to the second site in 1971. The two sites are 4 km apart in a *straight line*. The *star* indicates the centre of the town

series in order to verify the suitability of this choice. The data series showed homogeneity for mean and maximum temperature and precipitations, but not for minimum temperature.

Subsequently, analyses were made on the whole data series, namely daily maximum and minimum air temperature and daily rainfall from 1952 to 2007, as well as on the weekly groundwater level from 1975 to 2007. Reference evapotranspiration was calculated starting from air temperature using the Hargreaves–Samani equation (Hargreaves and Samani 1982, 1985).

First of all, data were quality-controlled, with uncertain data compared to data from other instruments in the same station or from other stations close to it (Pavan et al. 2003). Average monthly data were considered only if less than three consecutive data were missing. In this case, the missing data were substituted by the average between the data of the previous and the following available day. When this standard was not possible to obtain, the month was considered as missing. The same criterion was used with annual data.

After performing this preliminary check, different data processing procedures were chosen for different kinds of data.

2.1 Air temperature

Air temperature data were prepared by calculating monthly and annual maximum, minimum, and mean air temperature values from daily data (annual values were calculated on a daily basis). To describe climatic variability, anomalies (an anomaly is defined as a departure from the average) are more accurate than absolute temperature and allow comparison between data from different climatological areas. To analyse anomalies in temperature, the average annual temperature was calculated. WMO suggested (Folland et al. 1999) 30 years as a standard period for calculating the average used to analyse anomalies. The climatological average was calculated on the period 1961–1990.

A series of temperature indices suitable for monitoring climate extremes and changes were presented by Ventura et al. (2002). Of these, we chose to calculate the following:

- Diurnal Temperature Range (DTR), defined as the difference between average maximum and minimum temperatures on a monthly and annual basis.
- Frost Severity Index (FSI), defined as the number of days per month with daily minimum temperature below zero ($T_{min} < 0°C$), and the percentage with respect to the month; the index was averaged over decades, with the exception of the first and the last period, for which data were averaged over 9 years (1952–1960), and 7 years (2001–2007).
- Frost Duration Index (FDI), the difference in days between the first and the last date for the frost season with minimum air temperature below 0°C (the "frost year "ranges from August the 1st to July the 31st).

Moreover, the maximum daily temperature 95th and 99th percentile (T_{95} and T_{99}) were calculated on the data series, and the number of days per year with $T_{max} > T_{95}$ and $T_{max} > T_{99}$ was counted.

2.2 Precipitation

The monthly and annual total rainfall was calculated for each year. The 56-year and 1961–1990 average were calculated in order to analyse rainfall anomalies. A seasonal amount was obtained by summing rainfall quantity during the quarters, starting from winter (seasons were defined using the standard meteorological definition, i.e. winter = December + January + February). The annual number of rainy days, P_n (days with $P \geq 2$ mm[1]), was chosen in order to study variation in rainfall patterns.

2.3 Groundwater table level

The southern Po plain has a shallow water table, very useful from the agricultural point of view because crops can directly uptake water when it is at a depth reachable by roots. For this reason the groundwater table level has been measured at the Bologna–Cadriano agrometeorological station since 1975 (Rossi Pisa and Kerschbaumer 1998). The weekly and annual minimum, mean and maximum groundwater depth was calculated for the 33-year period.

2.4 Reference evapotranspiration

Daily reference evapotranspiration was calculated to determine monthly and annual mean values for the period from 1952 to 2007. The reference evapotranspiration (ETo) was calculated with the Hargreaves–Samani equation (1982, 1985), based on the use of air mean, maximum and minimum temperature and latitude:

$$ET_o = 0.0023 \frac{R_a}{\lambda} \sqrt{DTR} \, (T + 17.8) \qquad [\text{mm/d}]$$

where R_a is the extraterrestrial radiation (MJ m^2 d^{-1}), λ is the latent heat of vaporization (MJ kg^{-1}), DTR is the difference between the daily maximum and minimum air temperature (°C), and T is the mean daily air temperature (°C). The daily temperature range (DTR) is used in the equation to assess the effect of cloudiness on ETo, on the basis that clear days have wider ranges than cloudy ones, whatever the season.

The Hargreaves–Samani equation was chosen instead of the more reliable Penman–Monteith equation, because some data are missing from the solar radiation, wind and humidity data series. Moreover, in this paper ETo is calculated for climatological considerations and it was decided that the error made is acceptable.

All the meteorological quantities time series considered were evaluated with the non-parametric Mann–Kendall test (Mann 1945; Kendall 1975), which reliably identifies monotonic linear and non-linear trends in non-normal data series with outliers (Helsel and Hirsch 1992). Data of air temperature, number of rainy days and reference evapotranspiration were found to have a significant trend, so they were also

[1] A limit of 2 mm for daily rainfall was adopted because Bologna–Cadriano has a quite humid climate, and it is common to have about 1 mm, or more, of wet deposition during the night and close to dawn, due to fog or dew.

evaluated with the algorithm for the analysis of discontinuity (change point) present in the library "STRUCCHANGE" of R and explained, for example, by Mariani (2006).

3 Results

3.1 Air temperature

Changes in the mean annual air temperature in the Bologna–Cadriano area during the second half of the twentieth century (1952–2007) are shown in Fig. 2. During this period the mean annual temperature increased by about 1.2°C, corresponding to 0.21°C per decade. The correlation coefficients were calculated using a linear regression model, with the rate of change defined by the slope of the linear regression line. The Mann–Kendall test confirmed that the positive trend observed is significant, with a 99% confidence limit. Other studies found that annual mean air temperature increased by 0.4°C in northern Italy during the last century (Brunetti et al. 2004), in north-west Italy temperature increased by 1°C in the period 1952–2007 (Ciccarelli et al. 2008), while in Emilia–Romagna over the last 45 years the increase was of 0.8°C (Cacciamani 2007), results not so different from the Bologna–Cadriano data series.

The occurrence of a significative trend in time suggested the application of the breakpoint test. The change point was identified in the year 1987. In Fig. 2 the dotted lines represent respectively the means for the periods before and after the change point, the difference between them being 1.0°C.

Figure 3 illustrates the variation of temperature using the anomalies. The base-average was the 30-year period from 1961 to 1990, as suggested by the WMO

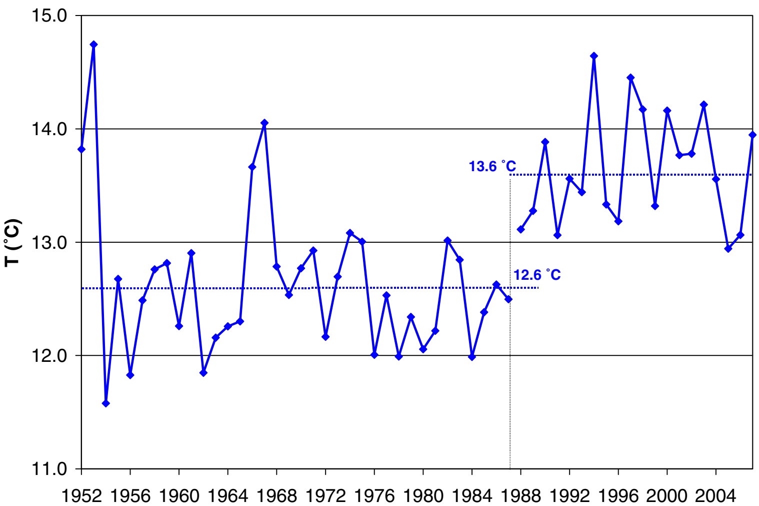

Fig. 2 Mean air temperature: annual average trend in the period 1952–2007. The *dotted lines* represent respectively the mean for the periods before and after the change point

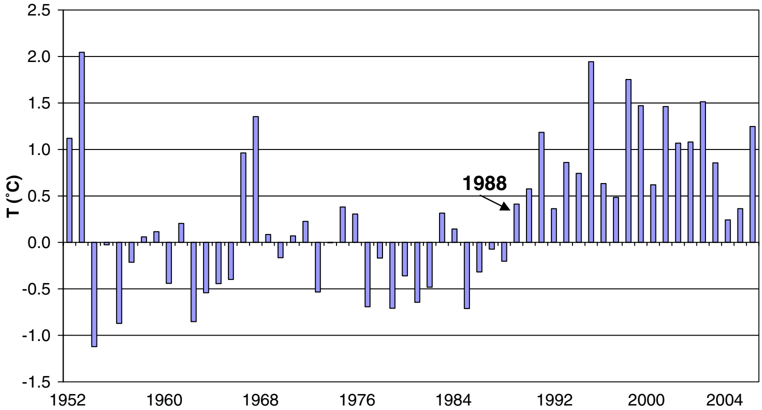

Fig. 3 Mean air temperature anomalies (1952–2007) with respect to the climatological mean 1961–1990. 1988 is the first year after the change point

(Folland et al. 1999). During the period from the 1950s till the early 1970s it was not possible to observe a trend. In the 1970s the values were generally below the mean and the last 20 data, from 1988 to 2007 were all positive. The result is in line with temperature trends, showing a local increase.

In order to account for the potential effects of climatic changes on agricultural crops and practices, it is important to analyse the temperature change in detail.

One aspect of climate change that is receiving increasing attention is the potential difference between changes for daily maximum (T_{max}) and minimum (T_{min}) temperatures, and resulting changes in the diurnal temperature range. We observed a more significant increasing trend in annual mean minimum air temperature than in mean maximum air temperature (Fig. 4), statistically significant at a 99% level. Annual

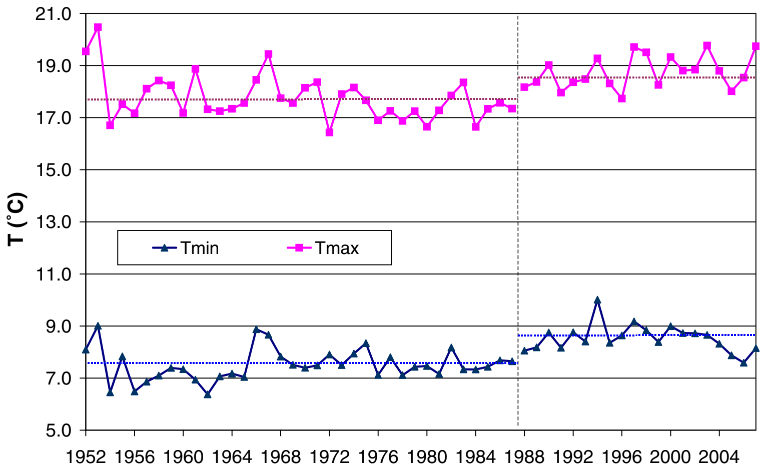

Fig. 4 Minimum and maximum air temperature: annual average trends in the period 1952–2007

maximum temperature increased from 17.7°C at the beginning of the 1950s to the current 18.7°C, while the minimum temperature went from 7.1°C to 8.5°C in the same period. Discontinuities in daily maximum and minimum temperature were identified, and breakpoints were both in 1987, as for the mean annual air temperature. Again, the average of data before and after the change points differs by 1°C.

DTR showed a reduction of about 0.4°C. A positive trend can be observed in December, January, February and March and a negative trend in the other months. Other studies showed a decrease in DTR over a period of 100 years of 1–1.3°C in Cyprus (Price et al. 1999), an increase of 0.22°C in northern Italy and of 0.12°C in southern Italy (analysed data-series from 1896–1996, Brunetti et al. 2004).

A different trend in the two temperature data-sets, T_{max} and T_{min}, suggested that they should be analysed separately, with examination of changes in extremes, such as the number of frost or high temperature days.

Frost risk is a topic of great interest in Emilia–Romagna, a region rich of orchards, as confirmed by the regional project DIsGELO (Zinoni et al. 2002; Zinoni and Antolini 2002) but few climatological analyses are available in the literature. The annual number of frost days from 1952 to 2007 showed a negative variation of 8 days, but the trend is not statistically significant.

Table 1 shows the mean Frost Severity Index (FSI) for the months with frost days and its average over selected decades. The time series did not show a clear trend, the 1970s and the 1990s had the lowest index of the whole period, while the 1980s have the highest FSI. In the first 7 years of this century the FSI had high values, similar to the 1950s and 1960s. Tomozeiu et al. (2006) found a distinct pattern for Emilia–Romagna, with a decrease of 6d/decade of frost days at regional level, mainly due to agrometeorological stations in the hilly area, but also in the plain, where the Bologna–Cadriano station lies, in the examined period (1958–2000).

The number of frost days is a good index of low temperature effects on crops, but the dates of beginning and ending of frost periods are more important, since late spring frost determines a particularly high risk of damage to crops and fruit trees. The investigation of the frost duration index (FDI) show a mean value of 122 days, not changing, with a maximum of 183 and a minimum of 75 days, respectively in 1957 and 2001. The frost period now starts a little earlier, in autumn rather than in winter, but this has no impact on agriculture. In springtime the frost finished a little earlier and so the risks caused by late frost for autumn–winter crops and fruit trees decreased. It should not be forgotten that vegetation reacts to variations in its atmospheric environment, and several authors have found that phenological events

Table 1 Frost Severity Index (FSI), or number of days per month with $T_{min} < 0°C$, for each month and annual total: average for decade and for 56-year period

Period	November	December	January	February	March	April	Year
1952–1960	3.8	11.6	20.3	17.3	10.1	0.6	63.6
1961–1970	1.9	16.4	22.6	14.6	6.3	0.5	62.3
1971–1980	5.2	16.8	12.0	8.3	4.9	0.3	47.5
1981–1990	5.8	16.2	21.8	17.0	6.1	0.1	67.0
1991–2000	3.4	12.3	14.4	12.6	5.1	0.2	48.0
2001–2007	3.6	14.1	19.5	15.8	5.9	0.6	59.5
1952–2007	4.0	14.6	18.3	14.1	6.3	0.4	57.7

Table 2 Number of days with maximum temperatures higher than 95th percentile ($T_{95} = 34.1°C$) and with temperature higher than 99th percentile ($T_{99} = 35.5°C$)

Period	Days	
	$T_{max} > T_{95}$	$T_{max} > T_{99}$
1952–1960	86	52
1961–1970	59	21
1971–1980	20	3
1981–1990	38	10
1991–2000	83	23
2001–2007	107	50

(first leaf, flowering) have been occurring earlier in recent years (Scheifinger et al. 2002; Sparks and Menzel 2002; Cleland et al. 2007; Ventura et al. 2008, 2009). This could counteract the beneficial effect of an early ending of the frost season, but some authors found that the end of the frost season moved faster towards earlier occurrence than phenological phases, at least in Central Europe (Scheifinger et al. 2003; Schwartz et al. 2006).

At the other temperature extreme, the number of days with high T_{max} influences crops health and yield, and is an indicator of dry periods. An index to determine extreme events is obtained by calculating T_{95} and T_{99}, which were found to be 34.1°C and 35.5°C, respectively. The number of days with $T_{max} > T_{95}$ and $T_{max} > T_{99}$ was counted and the results are shown in Table 2. The index tended to increase in the 1990s and is very high in the last 7 years. Moreover, the 1950s had a high number of hot days: the year 1952 had 35 and 28 days with temperature over 34.1°C and 35.5°C, respectively whereas in 2003, considered one of the hottest summers ever, there were 45 and 24 days, respectively. The trend with $T_{max} > T_{99}$ was statistically significant at a level of 99% and the trend $T_{max} > T_{95}$ was statistically significant with 95% confidence limit (Mann–Kendall test). Similar results were found by Tomozeiu et al. (2006) with a significant increase of the 90th percentile of maximum air temperature at regional level.

3.2 Precipitation

DTR variations were often strongly correlated with changes in precipitation, where higher rainfall was associated with greater cloud cover, which tends to reduce DTR (Lobell 2007). Changes in temperature are asymmetric, characterised by a strong heightening in minimum night-time temperature and a stable or even decreasing maximum day-time temperature (Folland et al. 1999). This asymmetric warming is characteristic of a climate influenced by increased cloud cover (Moot et al. 1996).

If this phenomenon is really taking place in the study area, are changes in cloudiness affecting rainfall patterns? The average annual rainfall of the area was recorded as 742 mm and Fig. 5 shows the annual total rainfall for the period 1952 to 2007. A great variability among years was recorded, with a standard deviation of 163 mm. The site showed a decreasing trend in annual precipitation amount of about 132 mm over the whole period, but the Mann–Kendall test was not significant. Annual rainfall averages in the period 1952–1969, 1952–1979, 1952–1989 and 1952–1999 were calculated as 827, 786, 750 and 750 mm, respectively, with a variation of 11%, 6%, 1% and 1% with respect to the 1952–2007 base.

For a better understanding of these trends and their effects on agriculture, Table 3 shows decade averages for the annual and seasonal totals. The results revealed that

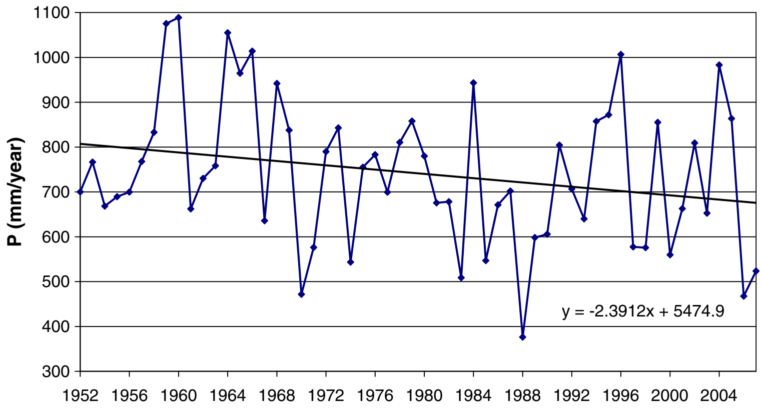

Fig. 5 Annual precipitation in Bologna–Cadriano from 1952 to 2007

the seasonal variations of the decadal values are much larger than the annual values. The trend showed a decrease of seasonal mean precipitation in winter and springtime, with 68 mm (significance 95%) and 70 mm (significance 93%) respectively, while in summer and in autumn there was no trend. This result agreed with other studies in Emilia–Romagna (Tomozeiu et al. 2002; Cacciamani 2007). Data showed a general decrease in rainfall from the beginning of the study-period till the late 1980s, an increase in the 1990s and a decrease again more recently, in line with other studies (Colombo et al. 2007). This suggests that the data-series is not long enough to allow significant consideration on precipitation trends.

Global warming produces an increase in atmospheric energy which can be dissipated through the occurrence of stronger atmospheric events, such as heavy precipitations (Alpert et al. 2002; Colombo et al. 2007). An analysis of the number of rainy days (days with $P \geq 2$ mm) is an indicator of this effect. Our results revealed a significant decrease (confirmed by Mann–Kendall test with 99% confidence) in the period under study, as shown in Fig. 6. In this case the change point was found in 1980 and the difference in the average before and after the break is 10 days. However, the distribution of days with precipitation over the year did not seem to change. In fact, no variation in the maximum length of dry spells during the year was observed.

Precipitation as recorded in Bologna–Cadriano showed a general tendency, though not significant, towards a decrease in the amount of rainfall and of days with

Table 3 Annual and seasonal rainfall: average over 56 years and 10-years sub-periods

Period	(mm/year)	(mm/3 months)			
	Annual rainfall	P winter	P spring	P summer	P autumn
1952–1960	810	181	253	153	223
1961–1970	807	162	222	190	234
1971–1980	744	155	172	144	273
1981–1990	631	112	183	165	170
1991–2000	746	125	178	185	258
2001–2007	709	145	186	133	244
1952–2007	742	146	199	163	233

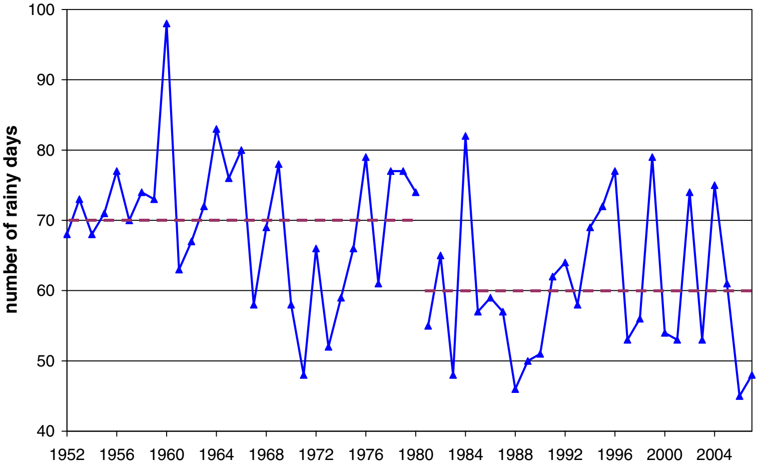

Fig. 6 Annual number of rainy days (with $P \geq 2$ mm) in the period 1952–2007

rainfall, but the decrease in rainy days was greater, so the occurrence of extreme events or longer drought periods was probable. As for the annual precipitation, no clear results are found, probably because the data series is not long enough to allow significant considerations. This is quite unfortunate because the precipitation variability can have strong impacts on agricultural production, forcing farmers to adopt new agricultural practices in response to altered conditions.

3.3 Groundwater table level

The decreasing trend in precipitation amount and the presence of heavy rainfall, together with the increase in air temperature, can be the cause of a significant decrease in the groundwater table level. A shallow water table can be used by crops, directly uptaking water when it is at depth reachable by roots. A change in depth can influence results obtained over time in the long term trials carried out in the experimental farm of Cadriano, in particular when studying the effects of agronomic practices and crop succession on soil fertility, water quality, and sustainability. This phenomenon has therefore been monitored in Cadriano over the last 33 years. Observations made at the study site showed that the level dropped on average by 36 cm (Fig. 7), and the negative trend was significant with a 99% confidence level determined by Mann–Kendall test. In the analysed period the winter depth had a mean value of 64 cm under the soil surface, corresponding to the typical ditches depth in the Po valley. The maximum phreatimeter length was never reached during the 33-year period: the maximum observed depth was 241 cm in the summer of 2003. The maximum annual depth showed a negative trend of 43 cm during the study period, significant with 99% confidence limit (Mann–Kendall test).

3.4 Reference evapotranspiration

Reference evapotranspiration was calculated using the Hargreaves–Samani equation. In this equation ETo is proportional to the product of mean air temperature and

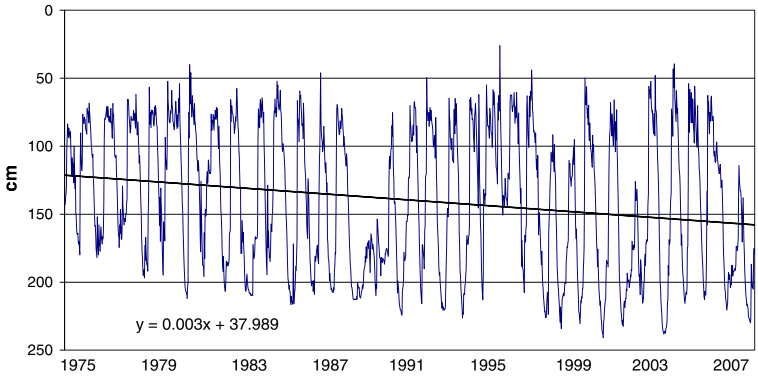

Fig. 7 Groundwater table depth recorded weekly at the Bologna–Cadriano station from 1975 to 2007

the square root of the DTR. The first of these two quantities showed an increase, the second a slight decrease in the considered period, and as a result we expect to find an increase in the annual ETo.

The average annual ETo of the study area was estimated as 1,022 mm and the data are shown in Fig. 8. There was much variability among the years, with a maximum of 1,154 mm in 1952 and a minimum of 925 mm in 1972. Looking at the graph it was decided to analyse the data series with the algorithm of change point, present in the library STRUCCHANGE of R. The statistical test confirmed a trend with a change point in the year 1971, and the whole time series was divided into two sub-sets. The presence of a breakpoint in ETo data can be related to the inhomogeneity of the minimum temperature recorded in 1971, corresponding to the agrometeorological station movement from Corticella to Cadriano.

The first data series, from 1952 to 1971, showed no significant trend, with a mean value of 1042 mm/year, the second had an increasing trend of 35 mm per decade,

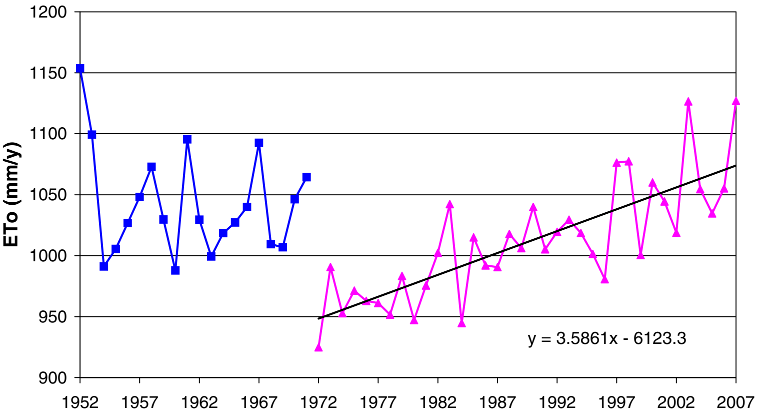

Fig. 8 Annual reference evapotranspiration in Bologna–Cadriano from 1952 to 2007

starting from about 950 mm/year in 1972 to about 1074 mm/year in 2007. The trend is significant with a confidence limit of 99%.

For a more detailed analysis of the annual trends, the annual data of the second period were separated into seasons. The results revealed that the seasonal variations were much larger than the annual variations. The trends showed an increase for all the seasonal mean ETo (for the 1972–2007 period), with a increase of 13 mm in winter, 39 mm in springtime, 60 mm in summer and 14 mm in autumn. Mann–Kendall test shows a not statistically significant trend for the autumn (with 90% confidence limit), while in the other seasons the trends were significant with a 99% confidence limit.

This was congruent with the general rise in temperatures, which resulted in a large increase in evapotranspiration. Most of the increase is concentrated within the crop growth season, with high impact on agriculture and irrigation water management. Practically speaking, this will result in changes in cultivated species, anticipate sowing date and negative effects on yields.

4 Conclusions

Analysis of a 56-year series of meteorological data, including daily air temperature, rainfall and weekly groundwater table depth, collected at the University of Bologna agrometeorological station, allowed us to draw the following conclusions:

- Mean annual temperature showed a significant increase during the period, up to 1.2°C/56 years. A shift point was found in 1987. Anomalies with respect to the climatological average were all positive in the last 20 years.
- Yearly DTR showed a significant decrease, mainly due to the raising of the minimum air temperature.
- The Frost Severity Index did not show any important variations, and the Frost Duration Index suggested a diminished risk of frost damages for agriculture in springtime.
- The number of hot days ($T_{max} > T_{95}$, $T_{max} > T_{99}$) increased dramatically in the last 7 years of the data series.
- No clear signs of a decrease in precipitation or of an increase in the number of extreme events were detected.
- The number of rainy days per year decreased.
- The maximum groundwater table level deepened by 42 cm.
- The reference evapotranspiration showed a significant increasing trend from 1972 to 2007, mainly concentrated during the crop growth season.

Climate change has an impact on several aspects of society, in particular it influences agriculture in multi-dimensional ways and acts across all time scales, ranging from short-term weather events, such as damaging frosts, to seasonal average weather, such as precipitation quantity and patterns during the crop growing season, to multi-year effects, such as in the vigour of specific types of crops or changes in plant phenology (Ventura et al. 2008). Temperature and precipitation trends are already influencing agriculture, and a better knowledge of the extent of the correlated phenomena will help to answer questions posed by society about possible adaptation strategies.

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