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Recent changes in rainfall and air temperature at Agnone (Molise – Central Italy)

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Abstract
An exhaustive daily rainfall and extreme air temperature series (1883-2000) was reconstructed for Agnone, a small town in Molise (Central Italy). Long-term analysis identified an increasing trend of 1.3 ± 0.4°C per 100 years, statistically confident at the 95% level, only for minimum air temperature, and of a seasonal march, reasonably stationary along the entire investigated interval, explaining more than 50% of the corresponding monthly variance, with maxima in November and July for rainfall and air temperature, respectively. Daily clustering analysis evidenced scale-invariant properties, largely dependent on the threshold value, for all the investigated parameters.

Key words *Molise Region – climatic change – long-term instrumental series – fractal analysis – the Cantor dust method*

1. Introduction

The reconstruction and analysis of past climate is important not only in basic research, but also in land use management. Moreover, instrumental meteorological data constitute the reference basis for setting up indirect techniques in such fields as palynology and dendrochronology, which are commonly used to investigate the history of past climate.

It is widely held that a combined effect of natural and human causes could underlie recent climatic changes, even if great uncertainty still exists about their quantification (Ney, 1959; Kelly and Wigley, 1992; Halgh, 1994; Stouffer *et al.*, 1994; Lassen and Friis-Christensen, 1995; Mitchell *et al.*, 1995; Santer *et al.*, 1995; Friis-Christensen and Svensmark, 1997; Hegerl *et al.*, 1997; Lean and Rind, 1999; Rozelot, 2001).

Naturally, analysis which is carried out on a series of this kind requires great effort not only in collecting data, but also in verifying their homogeneity (Barriendos *et al.*, 2002; Camuffo, 2002a,b; Camuffo and Jones, 2002; Cocheo and Camuffo, 2002; Demarée *et al.*, 2002; Maugeri *et al.*, 2002a,b). This operation ensures that the time variations observed in the meteorological parameters can be identified as climatic signals and it is thus extremely important to collect the so-called *metadata*, *i.e.* all the information about the history of the station where measurements have been taken.

This study presents the results of the reconstruction and analysis of the daily precipitation and temperature series at Agnone, an upland town (800 m a.s.l.) in Molise, a small region in Central Italy. In analysing air temperature, only

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the daily maximum and minimum values were considered. Extreme air temperature is more suitable than daily mean temperature since: a) due to the *quasi*-sinusoidal nature of the diurnal temperature cycle, temperatures close to extreme values occur more frequently than those around the mean daily value; b) international methods of recording data across the world have only recently been standardized; therefore, when a historical series is examined, it must be ascertained that the data used for deriving mean values were observed at the same local times throughout. This problem obviously does not hold for extreme temperatures (Palumbo and Mazzarella, 1984).

2. Data collection

2.1. *Historical outline of the Molise climate*

In Molise, there is a substantial lack of climatic studies and this is the first in such a direction. In Molise, the earliest instrumental observations date back to the end of the 19th century, when in some areas of the region the first meteorological measurements began under the direction of private citizens who had a natural aptitude for recording such kinds of data, which were then sent to the Central Office of Meteorology (COM), as it was then known.

The longest daily rainfall and air temperature series concern the following towns: Agnone, where instrumental meteorological measurements were started by the de Horatiis family in 1875; Venafro, where Ludovico Giannini founded a meteorological observatory in 1883; Isernia, where Camillo D'Apollonio began meteorological observations in 1898; Campobasso, the main town of the region, where precipitation measurements began in 1886, and temperature observations in 1918, both carried out by Francesco Pesce.

There were various reasons behind our decision to choose the daily Agnone series. First of all, it goes the furthest back in time but, what is much more important, it shows a good completeness of data, a significant continuity in terms of station management and substantial constancy of the environment where measurements were taken. Furthermore, it should be recalled that over the years Agnone has not experienced a significant change in its urban nucleus, nor has there been human activity which could significantly affect precipitation and temperature. From this point of view, it is reasonable to state that the Agnone series does not suffer the so-called *heat-island effect* which commonly masks the meteorological variables measured in urban areas (Palumbo and Mazzarella, 1984).

2.2. *The Agnone climatic station*

In Agnone, meteorological observations were initiated by Pier Francesco Rufino de Horatiis, who founded an observatory in 1875, which was soon to become part of the national network of the State Central Office of Meteorology and Geodynamics (its name at that time).

This observatory continued its activity without interruption until 1977 (fig. 1), when it closed down and the task of carrying out precipitation and air temperature measurements was taken over by the State Forest Department, on whose premises at Agnone a pluviometer and a thermometer were set up. This station works to this day, even after the old instruments were replaced by electronic ones in March 2002.

The closing down of the de Horatiis station resulted in a huge loss, because it assured not only the collection of precipitation and air temperature, but also of other meteorological parameters (atmospheric pressure, wind speed and direction, state of the sky). Most of the documentation concerning the station and many of its instruments donated by the de Horatiis family can now be found in the Agnone municipal library.

The observatory was directed by its founder for 68 years, until 1942, when management passed first into the hands of his son Cesare, until 1957, and then of his nephew Pier Francesco junior, who was in charge of the station until 1977. This great continuity in station management, with well documented changes, makes the quality of the Agnone series data really appreciable.

We consulted the following sources for the acquisition of daily rainfall and air temperature data:

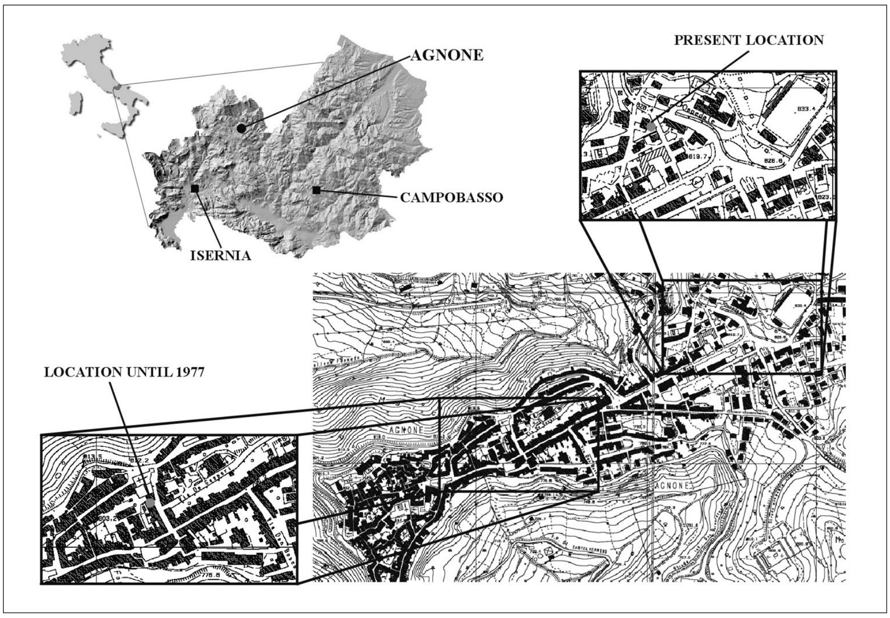

Fig. 1. Locations of the Agnone climatic station since 1883.

– For the 1883-1921 period, original handwritten registers available about UCEA and, in their absence, the Daily Meteoric Bulletins of the COM.

– For the 1922-2000 period, the Annals of the National Hydrographic Service (NHS) (at first in the department of Chieti and then in the department of Pescara).

According to a posthumous publication by de Horatiis (1967), the observations made in the 1875-1882 period were not included in those designated for publication, as they were carried out with old instruments, in different locations and in the early stages of the observer's experience, who was therefore not particularly confident about their quality.

In the analysis of the daily Agnone rainfall and air temperature series, problems arise when the original registers were missing. In their absence we analysed the Daily Meteoric Bulletin of the COM that attributed the record of the daily rainfall and of maximum air temperature to the previous day. Hence, considering the years for which mean monthly and annual data were obtained from this source, the daily rainfall and maximum air temperature series has been shifted back by one day.

The accuracy of the daily rainfall data and extreme air temperature is estimated to be equal to 0.1 mm and 0.1°C, respectively (De Horatiis, 1967).

As regards the period after 1977, when the old station was closed down, no significant influence was exerted on precipitation and temperature measurements, so the whole series was analysed without differentiating between the period prior to closure and the period after it.

3. Methodology

3.1. *Long-term analysis*

Long-term analysis is performed here according to the least square regression line between the *N* available yearly values of each investigated parameter and time, only when it is found to be confident at a level not less than

95% (than 99%), *i.e.* when the following relationship is verified (Mazzarella, 1998):

$$\sqrt{N-3}\,/\,2\ln(1+r)/(1-r) \geq 1.96\,(\geq 2.58) \quad (3.1)$$

where r is the correlation coefficient between the series of N annual values of each meteorological series *versus* time.

3.2. *Seasonal analysis*

Seasonal analysis is performed here according to Fourier analysis, that provides the values of mean amplitude (A), phase (σ) of the 12 and 6 months harmonics. The confidence level of each harmonic is computed according to $1-\exp\cdot\cdot[-(0.833\ A/vpe)^2]$, where *vpe* is the vector probable error, *i.e.* the scattering of individual harmonics from the mean A (Mazzarella, 1998). The harmonic is found to be confident at 95% (99%) level when $A \geq 2.08$ *vpe* ($A \geq 3.00$ *vpe*). To ascertain the stationarity of the annual harmonic over the entire investigated interval, the same seasonal analysis is here applied to two non-overlapping subintervals (1883-1940, 1941-2000) and then the results compared.

3.3. *Fractal daily clustering analysis*

Analysis performed on 120 years of data showed the existence of dishomogeneity between daily values for the period 1883-1921. We therefore decided to postpone the daily analysis of this time interval and limit fractal analysis only to the period 1922-2000. Fractals (Mazzarella, 1998) are sets that are not topological. For sets that are topological the Hausdoff-Besicovitch dimension D is an integer (0 for points, 1 for any curve, 2 for any surface). For sets that are fractals D is not an integer but a real number in which the value of the whole number describes the topological nature of the data set under consideration and the size of the decimal fraction represents the irregularity exhibited within the data. The essential feature of fractal sets is their scale invariance. The basic concept of a fractal distribution is that a phenomenon will be repeated on different scales in the same manner, the major variable being the fractal dimension which is used as a measure of the nature of the phenomenon. The available daily rainfall and extreme air temperature events measured in Agnone over a period of 80 years provide a wide range of available timescales. This is why the fractal approach to time clustering of daily rainfall and extreme air temperature catalogue is here based upon a box-counting algorithm, like the Cantor dust method. To construct a Cantor set, start with the closed interval [0,1]; remove the middle third leaving two closed intervals each with a length 1/3; continue by deleting the middle third of these two intervals, leaving four closed intervals of length 1/9. The process of removing the open middle third of the remaining closed intervals is repeated an infinite number of times and defines the Cantor set. This set shows a scale-invariant clustering quantified by the fractal dimension D

$$D = \log\left(N_i/N_{i+1}\right)/\log\left(t_{i+1}/t_i\right) = \log 2/\log 3 = 0.6309 \quad (3.2)$$

where N_i is the number of events occurring in the interval of size t_i.

Different Cantor-like sets with the other fractal dimension D can be obtained simply by starting from different values of N_i and t_i. To compute the fractal time clustering of a catalogue, divide the time interval t_0, over which the N events occur, into a series of n smaller intervals of length $t = t_0/n$, with $n = 2, 3, 4 \ldots$ and compute the fraction $R = N/n$ of intervals of length t occupied by events. If the distribution of events has a fractal structure then

$$R = Ct^{(1-D)} \quad (3.3)$$

or, equivalently, on a log-log scaled plane

$$\log(R) = C + (1-D)\log(t) \quad (3.4)$$

where C is a constant of proportionality (Mazzarella, 1998, 1999).

The power law (3.4) is further verified to be significantly different from the relative uniform distribution in which the same number N of events is equally spaced in time (no time clustering). As a mathematical representation, the relation (3.4) could be valid over an infinite range; however, for physical applications, there will be upper and lower limits on the applicability of the fractal distribution (scaling region). The fractal dimension $D=1-s$ is estimated from the slope s that provides the best fitting of the least square regression line of $\log(R)$ on $\log(t)$ when it is found to be confident at a level not less than 99%, *i.e.*, when the relationship (3.1) is verified, with r representing the correlation coefficient between $\log(R)$ and $\log(t)$. It is worth noting that an increasingly clustered distribution of events causes an increase of D up to the limiting value $D=1$ that is the topological dimension of a line; on the other hand, a concentration of events at a definite time corresponds to the limit $D=0$, *i.e.*, to the dimension of a point. The fractal dimension characterises the data distribution globally and, in general, does not reflect the situation in the different time subsets. Thus, to investigate the change in D with time, one can calculate D for catalogue subsets with a fixed number of events or choose a fixed-length time window and calculate consecutive values of D shifting the window through the catalogue. Here both options are adopted using windows containing no less than 100 events, the minimum for sound fractal analysis (Smith, 1988).

4. Results

4.1. *Rainfall*

The yearly values of rainfall measured in Agnone (1883-2000) show a wide interannual variability (fig. 2) and the least square regression analysis on time shows no significant time trend. Seasonal analysis of the available monthly values (table I) shows that the annual and semiannual harmonics are determined at a level greater than 99%, with maxima occurring at the beginning of January for the annual wave and at the beginning of March for the semiannual wave. Analysis performed on the two non-overlapping subintervals (1883-1940 and 1941-2000) shows a small increase in the amplitude of annual harmonic.

To compute the daily clustering of rainfall according to the Cantor dust method, fraction R (the fraction of time intervals including a rainy day) is computed as a function of the interval t, on a log-log scaled plane, for different intensity thresholds T. The smallest time interval is chosen to be 1 day, gradually increased by a factor of 2.

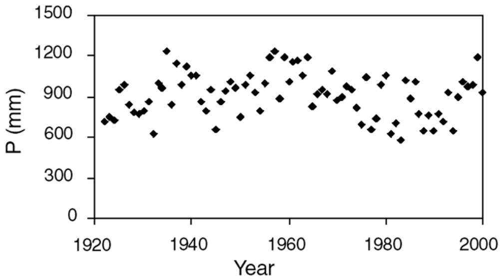

Fig. 2. Interannual variation of rainfall measured at Agnone in the 1883-2000 interval.

Table I. Seasonal analysis of monthly rainfall measured in Agnone for the 1883-2000 interval and for the two different non-overlapping subintervals (1883-1940, 1941-2000). A, *vpe* and σ represent the mean amplitude, the vector probable error and the phase of the harmonic, respectively.

Interval	Total mean monthly value	Period	A	*vpe*	σ
1883-2000	75.7 mm	12 months	23.6 mm	2.6	81.8°
		6 months	12.6 mm	2.2	177.0°
1883-1940	75.1 mm	12 months	21.1 mm	4.0	78.2°
		6 months	14.1 mm	3.0	189.9°
1941-2000	76.2 mm	12 months	26.0 mm	3.5	84.6°
		6 months	12.0 mm	3.1	162.1°

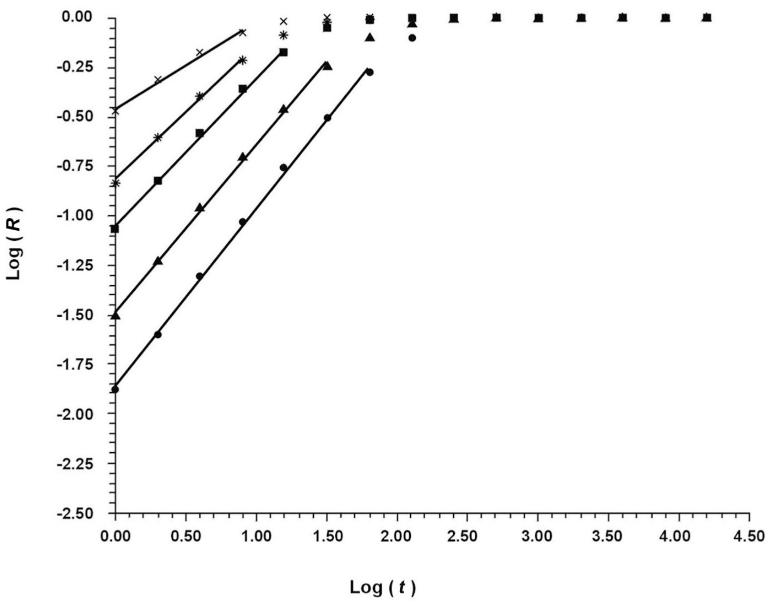

Fig. 3. The logarithm of the fraction R of time intervals t (in days) including the rainfall events for Agnone Observatory, as a function of $\log(t)$ (interval: 1922-2000); the values relative to daily rainfall events equal to or greater than 0.2 mm, 5 mm, 10 mm, 20 mm, and 30 mm, respectively, are plotted from the top of the graph downwards.

Table II. Fractal dimension and scaling region values of the rainfall recorded in Agnone in the 1922-2000 interval, found to be confident at a level not less than 95% for different intensity threshold values.

Intensity threshold	Fractal dimension	Scaling region
≥ 0.2 mm	0.5 ± 0.1	1-8 days
≥ 5 mm	0.31 ± 0.08	1-8 days
≥ 10 mm	0.25 ± 0.07	1-16 days
≥ 20 mm	0.16 ± 0.05	1-32 days
≥ 30 mm	0.10 ± 0.03	1-64 days

The fractal dimension and the specific scaling region of the daily rainy events is found to be strongly dependent on the chosen intensity threshold: the higher this value, the lower the fractal dimension and the wider the relative scaling region. As a result, the rainfall process is characterised by an infinite hierarchy of intensity-dependent dimensions. Some typical plots of $\log(R)$ on $\log(t)$ for different intensity thresholds ($T \geq 0.2$ mm, $T \geq 5$ mm, $T \geq 10$ mm, $T \geq 20$ mm, $T \geq 30$ mm) are reported in fig. 3. Table II shows the relative values of fractal dimension and of specific scaling region, found to be confident at a level not lower than 95% and significantly different from the relative uniform distribution. The time variation of D, computed according to both different time variable windows enclosing successive daily events and to a time fixed windows, show substantial stability over the period 1922-2000 with no significant time trend.

4.2. *Air temperature*

The yearly values of minimum and maximum air temperature measured at Agnone (1883-2000) show wide interannual variability and least square regression analysis on time shows an increasing time trend equal to 1.3 ± 0.4°C per 100 years, confident at least at 95% level, only for T_{min} (fig. 4). Seasonal analysis of the monthly values of T_{max} and T_{min} (table IIIa,b) shows that the annual and semiannual harmonics are determined at a level greater than 99%, albeit with a large dominance of the annual wave whose maximum occurs at the end of July. Analysis performed on the two non-overlapping subintervals (1883-1940 and 1941-2000) shows no significant differences.

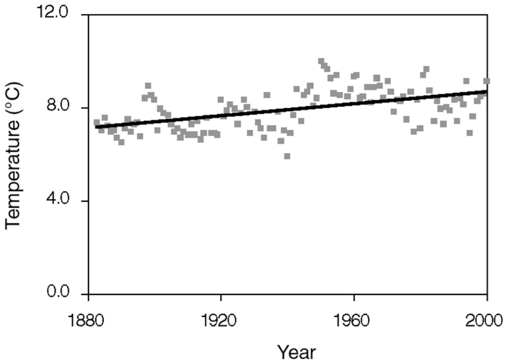

Fig. 4. Interannual variation of minimum air temperature measured at Agnone in the 1883-2000 interval. The line represents the least square regression line of T_{min} on time, calculated at 95% level of confidence.

The continuous daily series of T_{min} and T_{max} measured at Agnone has been transformed into a daily series of events simply considering daily values of T_{min} lower than 5°C, 0°C and −5°C and daily values of T_{max} higher than 25°C and 30°C. Hence, the same fractal methodology applied to rainy days is applied to lowest and highest daily minimum and maximum air temperature, respectively. As regards minimum temperature, the lower this value, the lower the fractal dimension; for maximum temperature, the higher the threshold value, the lower the fractal dimension and the wider the relative scaling region (fig. 5).

Table IV shows the relative fractal dimension and scaling region values obtained at a level of confidence not lower than 99% and significantly different from the relative uniform dis-

Table IIIa,b. Seasonal analysis of monthly maximum (T_{max}) (a) and minimum (T_{min}) (b) air temperature measured in Agnone for the 1883-2000 interval and for the two different non-overlapping subintervals (1883-1940, 1941-2000). *A*, *vpe* and σ represent the mean amplitude, the vector probable error and the phase of the harmonic, respectively.

Interval	Total mean monthly value	Period	*A*	*vpe*	σ
(a)					
1883-2000	15.7 °C	12 months	9.5 °C	0.1	−113.9°
		6 months	0.9°C	0.1	−36.4°
1883-1940	15.7°C	12 months	9.4°C	0.2	−114.1°
		6 months	0.9°C	0.1	−37.2°
1941-2000	15.6°C	12 months	9.5°C	0.2	−113.7°
		6 months	0.9°C	0.1	−35.6°
(b)					
1883-2000	7.9°C	12 months	7.6°C	0.1	−117.4°
		6 months	0.4°C	0.1	−29.7°
1883-1940	7.3°C	12 months	7.5°C	0.1	−118.2°
		6 months	0.4°C	0.1	−30.9°
1941-2000	8.4°C	12 months	7.6°C	0.1	−116.7°
		6 months	0.5°C	0.1	−28.8°

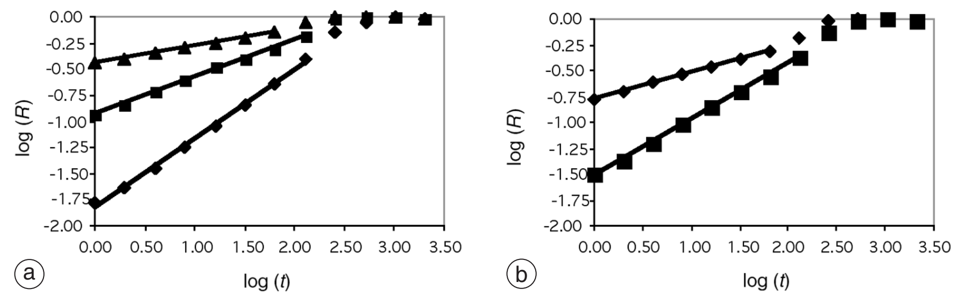

Fig. 5a,b. The logarithm of the fraction R on t (in days) (interval: 1922-2000) including: a) the daily minimum temperature events for Agnone Observatory as a function of $\log(t)$; the values relative to daily events of T_{min} lower or equal to 5°C, 0°C and −5°C respectively, are plotted from the bottom of the graph upwards; b) the daily maximum temperature events for Agnone Observatory as a function of $\log(t)$; the values relative to daily events with T_{max} greater than or equal to 25°C and 30°C respectively, are plotted from the bottom of the graph downwards.

Table IV. Fractal dimension and scaling region values of daily extreme air temperatures recorded in Agnone from 1922 to 2000, found to be confident at a level not less than 99% for different threshold values.

Intensity threshold	Fractal dimension	Scaling region
≤−5°C	0.34±0.05	1-128 days
≤0°C	0.64±0.03	1-128 days
≤5°C	0.84±0.01	1-64 days
≥25°C	0.74±0.03	1-64 days
≥30°C	0.46±0.02	1-128 days

tribution. Investigation of the time variation of D shows, over the entire 1922-2000 interval, no significant time trends for T_{max} with a substantial stability of the value of D and a decreasing time trend for T_{min}, representative of an ever rarer occurrence of lowest values of minimum air temperature.

The different trend of the minimum temperature in comparison with the maximum is also confirmed by the time analysis of the daily thermal excursion (the difference between the daily maximum temperature and the daily minimum temperature) averaged over the period of a year. It shows a decreasing rate of 1.3±0.7°C per 100 years, confident at a level just below 99%.

5. Discussion

Long-term analysis shows no time trend for rainfall and maximum air temperature and a statistically significant increase in yearly values of minimum air temperature equal to 1.3±0.4°C per 100 years. Such values are more accurate than rainfall and maximum air temperature as they are measured at the end of the night, in the absence of convective motions. Monthly rainfall and extreme air temperature show high seasonal variation that remains substantially unchanged over the entire interval of observation. Fractal analysis gave results which agree with those obtained in other studies (Mazzarella, 1999).

Variability in D with the threshold may provide insights into the nature of rain and the thermal field over Agnone, as the observed catalogue of rain and extreme air temperature also reflects the intermittency of the field, *i.e.* its three-dimensional structure organised in eddies and subeddies and changeable in time for the same points. Research in intermittency (Berndtsson and Niemczynowicz, 1988; Fraedrich and Larnder, 1993; Lovejoy and Schertzer, 1999; Mazzarella, 1999) shows that cascade processes, where the large scale multiplicatively modulates the small, when carried out over wide enough ranges of scales with a repeating (scale invariant) mechanism, generally tend to multifractal structures.

As regards precipitation and maximum air temperature, the higher the intensity threshold, the lower the fractal dimension and longer the relative scaling region. The opposite holds for minimum temperature: the lower the threshold value, the lower the fractal dimension. Thus the different intensity thresholds reveal different properties of the physical process: when using a higher threshold, the low-intensity parts are «cut-off» and only the properties of the high-intensity events (the opposite occurs for $T_{\min}$) are taken into account. This gives evidence of the so-called multifractality in which a multiplicative cascade process is responsible for the concentration of energy fluxes into successively smaller parts of the atmosphere (Lovejoy and Schertzer, 1990; Olsson *et al.*, 1993).

The time variation of the fractal dimension of daily rainfall does not reveal any significant trend for any intensity threshold, which suggests that Agnone exhibits no trend towards the climatic *tropicalization* which seems to be characteristic of the coastal areas (Mazzarella, 1999; Brunetti *et al.*, 2000).

The time variation of the fractal dimension shows a decrease, confident at the 99% level, only in minimum air temperature lower than -5°C. This means that in Agnone there has been a significant reduction in the occurrence of lowest temperatures. This seems to be perfectly compatible with a world which is heating up increasingly. According to various estimates, there has been a global increase in surface mean temperature between 0.3 and 0.6°C in the last century (data from NCDC; Jones *et al.*, 1991).

The asymmetric trend of the minimum and maximum temperatures, underlined, among other thing by the decreasing trend in daily thermal excursion, may have a major effect on local ecosystems, given the physiological effects which the minimum temperature has on living beings. Consequently, it would be well worth investigating the contemporary evolution of vegetation at Agnone, in order to discover any changes that may be related to climatic evolution.

Furthermore, given the influence on evaporation and evapotranspiration rates, it cannot be excluded that in future this asymmetry in temperature trends could also affect precipitation.

A preliminary analysis conducted on other stations in Molise, shows a general tendency towards an increase in temperature, particularly in the minima. However, the situation throughout Molise is by no means uniform due to the fact that, besides stations which experienced substantial stability in the period examined, such as Chiauci, there are others, such as Campobasso (the Region's capital) and Guardiaregia which show positive trends, even more so than Agnone, both in mean temperature and minimum temperature.

6. Conclusions

Reconstruction of the instrumental climatic series constitutes a fundamental step in understanding climatic evolution. The importance of reconstructing a historical series such as that of Agnone lies in the fact that 120 years of climatic history constitutes a valid starting point for comparisons with results from the analysis of other stations, both within and outside the region, and for setting up other analytical techniques which allow us to investigate the history of climatic trends more deeply.

In this sense, the Agnone series is also an important point of reference for further analysis which will involve other long-term stations in Molise: it could be useful to identify the heat-island effect in the Campobasso series, as Campobasso, more than other stations in Molise, should allow us to clearly underline and quantify it. Analysis of the Agnone series produced important results particularly if they are inserted into a wider context, enabling us to discover similarities and differences with other places.

Application of fractal analysis confirmed the validity of this method in describing precipitation events and temperature extremes and enhancing our knowledge of them. Hence this study is a valid basis for further analysis, with the aim, amongst others, of in-depth investigation.

By extending the analysis to other places, within and outside Molise, it will be possible to establish whether or not there is a zonal distribution of the change and, in the event of a positive answer, try to determine the causes of the specific pattern. Furthermore, one of the main objectives is to go increasingly further back in time, in order to establish whether climatic change has always occurred in the same way and with the same structure.

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