Time Series Analyses of Climatological Records from a High Altitude Observatory in Southern Italy (Montevergine, AV)

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Abstract
In this work we show the results obtained from the homogenization and the analysis of a climatic time series (mean temperature and total precipitation) collected in the Southern Italy Apennines (Montevergine, AV). This climatological time series is one of the oldest of Apennines mountains and it’s very meaningful for the high altitude region climate study, being located at 1280 m asl (40° 56’N, 14° 43’E). The homogenization of time series is performed using the Standard Normal Homogeneity Test and its non-parametric version. Precipitation time series is characterized only by a discontinuity, occurred on 1950, while temperature time series is affected by multiple inhomogeneities, caused by changing in instruments location, human errors and instruments accuracy degradation. The analysis of homogenized time series is carried out through Wavelet Analysis, in order to investigate about series behavior in time-frequency spectrum, and LOWESS smoothing, aiming to highlight the decadal variability; moreover, we use a linear polynomial model to define trends. The results highlight an increase in annual mean temperature of 0.5°C/100 years and a decrease in annual total precipitation of 32%/100 years (667 mm/100 years). Positive temperature trend is evident on all season, except on autumn, while negative precipitation tendency is particularly sharp on spring. The signals are characterized by a strong oscillation between 1940 and 1950 on 2-4 years period. The opposite trends that characterize temperature and precipitation are very steep from mid-1970s up to early 2000s; in this period the two parameters are strongly anti-correlated, unlike previous decades, in which they show an unstable coupling. Mediterranean Circulation Index (MCI) captures a large portion of precipitation variability, while thermal regime is strongly related to Eastern Mediterranean Pattern (EMP).

Keywords: Climate Change, Temperature, Precipitation, Historical time series, High Altitude Climate
1. INTRODUCTION

In recent years climate change issues have taken high resonance, motivating the scientific community to carry out multiple research activities in order to understand the complex mechanisms that regulate atmospheric variability. The Mediterranean area is characterized by a climatic context of great interest, being affected both by atmospheric dynamics typical of Western Europe and by dynamics typical of sub-tropical areas [1]. Therefore, it was decided to restore and enhance the acquired records of Montevergine’s Observatory (AV), located at 1280 asl (40°56’N, 14°43’E) on the western side of Campania Apennines. This climatological time series is one of the oldest of Apennines Mountains and it’s very meaningful for the high-altitude regions climate; moreover, it is very representative of Central Mediterranean Climate. Montevergine’s Observatory, founded in 1884 at the behest of Padre Francesco Denza, was treated by the alternation of monks, military and government institution and actually is managed by the Benedictine Community of Montevergine’s Abbey. From 1892 to 2007 weather observations were performed in a screen located outside a north-facing window of the highest floor of “meteorological tower”, as suggested by Italian Central Office for Meteorology and Climate in 1879. Instead, from 2008 up to date the meteorological parameters are recorded by an Automatic Weather Station (AWS), installed on Observatory terrace. As often happens for this type of data, the original time series was recorded on paper and, consequently, required a huge main time to digitalize it. A sub data set of Montevergine’s precipitation time series was examined for the first time in a study concerning the 1884:1987 period [2]. More recently, the seasonal and yearly anomalies and trends in temperature, total precipitation (rain and melted snow), atmospheric pressure and snowfall for the 1884:1960 period were analyzed in [3], that pointed out a slight positive trend in annual-mean temperature (+ 0.2 K/50 years) and a negative tendency for annual precipitation (- 50 mm/50 years).

In this work we focus on the homogenization of time series, in order to detect abrupt changes of mean-level of climatic variables due to unnatural causes. After that we describe the variability and trends of mean-temperature and total precipitation (rain and melted snow) of whole time series (1884:2010); moreover, we analyze the relationship between Montevergine’s climatological time series and large-scale atmospheric patterns.
2. MATERIAL AND METHODS

The data availability of main meteorological parameters recorded at Montevergine’s observatory is shown in Fig.1. Maximum Temperature, Minimum Temperature and Precipitation are the only parameters characterized by near continuous observations.

![Fig. 1: Annual availability of meteorological parameters recorded at Montevergine's Observatory in 1884-2010 period](image)

The homogenization of data-set was carried out adopting the Standard Normal Homogeneity Test [4], which allows to detect single shift in a climatological time series. This methodology requires the construction of a reference time series and the measure of correlation ($\rho$) between candidate station and reference stations. As suggested in [5], we compute correlation coefficients on the first difference series, $dT/dt$ (where $T$ is the climatological time series and $t$ is time). The degree of likelihood that the candidate time series is homogeneous can be determined by applying a statistical test to the ratio (adopted for precipitation), or difference (adopted for temperature) series $\{Q_t\}$. The size and timing of significant non-homogeneities can also be estimated with statistical test [6]. Given the observed series
and the year in which the break occurs \([a]\), the two levels of the ratio or differences before and after the possible break are:

\[
\begin{align*}
\bar{y}_1 &= \sigma_0 \bar{z}_1 + \bar{q} \\
\bar{y}_2 &= \sigma_0 \bar{z}_2 + \bar{q}
\end{align*}
\]

The data for the period \([1 \ldots a]\) should be corrected by \(\frac{a_2}{a_1}\) in the case of ratio and by \(\bar{y}_2 - \bar{y}_1\) in the case of differences. The Standard Normal Homogeneity Test is based on the assumption that the data set is distributed according to a Gaussian. In some circumstances this assumption fails, so we decided to compare the Alexandersson’s SNHT to a non-parametric version of SNHT, described in [7].

In order to investigate about the variability of climatological time series, we decomposed it into three components: trend, decadal and interannual component. The former was evaluated using a first-order polynomial model; we adopt the non-parametric Mann-Kendall method to test the statistical significance of trends. The second was determined from linear polynomials model’s residuals, using a LOWESS smoothing with a cut-off frequency of 10 years, while the latter is simply the difference between residuals and decadal component.

We used Wavelet Analysis [8] aiming to highlight the behavior of time series and to examine the relationship in time-frequency space between large-scale atmospheric pattern and Montevergine’s data set. The Wavelet Analysis was developed as an alternative approach to the short time Fourier transform and it’s very useful for geophysical time series examination. Most traditional mathematical methods that analyze periodicities in the frequency domain, such as Fourier analysis, have implicitly assumed that the underlying processes are stationary in time. Wavelet Transform expands time series into time-frequency space and can therefore find localized intermittent periodicities. Continuous Wavelet Transform (CWT) is the most commonly tool used for examining localized intermittent oscillations in a time series.

Moreover, Wavelet Analysis offers the possibility of examine whether regions in time-frequency space with large common power have a significant phase link and therefore are suggestive of cause-effect relationship between the time series. From two CWTs it’s possible to construct the Cross Wavelet Transform (XWT), which shows their common power and relative phase in time-frequency space. We used also the Wavelet Coherence (WTC), in order to find significant coherence even though the common power is low.
3. HOMOGENIZATION OF THERMO-PRECIPITATION TIME SERIES

Homogenization of a time series is a fundamental step for a study concerning meteorological observations recovery. However, as remarked in [9], the discontinuity identification can sometimes arise from subjective evaluation and is strongly dependent on the philosophy adopted by researchers. Our approach is based on the comparison between the results derived from SNHT and metadata, which provides a valuable aid in discerning between true and false breaks. Moreover, we gave particular relevance to the comparison with time series collected in a climatic context similar to that in which candidate station is located and with climatological series more correlated with Montevergine one.

Metadata were retrieved from meteorological registers and from an old diary called “Le Cronache dell’Osservatorio”. The construction of reference time series was performed using historical data-set and reanalysis output [10, 11, 12, 13, 14]. According to metadata and reference time series availability, in order to homogenize precipitation time series the period we focus on was divided into five temporal segments (1884:1913, 1914:1943, 1944:1973, 1974:1999, 2000:2010). Because of the high spatial variability of rainfall, we used only stations located in a neighborhood of about 100 km.

Precipitation time series shows only a discontinuity, which occurred on 1950, as highlighted by Fig.2. According to metadata, the observations seem to suffer of frequent changes of operators and of errors in pluviograph measurements. The results obtained through this analysis are in agreement with those found in [2], in which the precipitation data acquired in 1946-1950 period were considered unreliable. We corrected the data recorded in this period decreasing monthly rainfall amount of 15%.
Fig. 2: Homogenization of Montevergine's precipitation time series. Standardized ratio time series and corresponding T-series for the non-parametric SNHT are shown. The 95 per cent critical level is indicated with a blue line.

Mean temperature (evaluated as the arithmetic average of max and min daily values) time series was characterized by several breaks, caused by various factors, such as instruments relocation, changes of observing practices, instruments accuracy degradation and human errors. The homogenization of data recorded in 1884:1961 period was carried out adopting mean temperature time series deriving from thermopsychrometric acquisitions as reference series. This approach required the homogenization of thermopsychrometric time series, which was performed using air-temperature at 850 mb level time series reconstructed by NOAA 20th Century Reanalysis. We constructed the reference series taking account the four grid points closest to the candidate time series, as highlighted by Fig.3a. The analysis showed a discontinuity on 1890 (Fig.3b), which was caused by the initial location of instruments, placed probably slight above the soil-level before the construction of meteorological tower. We correct monthly time series recorded in 1884:1890 period by a factor equal to +0.7°C. In the examined period precipitation time series don’t shows any discontinuity and it is in a good agreement with the reference one. Therefore, instruments relocation seems to have affected only the temperature observations.
Fig. 3: Spatial location of candidate station (blue star) and of grid points (red stars) adopted for the homogenization of thermopsychrometric time series (a). Homogenization of thermopsychrometric time series. Standardized difference time series and corresponding T-series for the SNHT are shown. The 95 per cent critical level is indicated with a blue line (b)

The comparison between homogenized thermopsychrometric time series and candidate time series showed initially only one significant discontinuity, which occurred on 1890. However, the subsequent subdivision of examined interval in three sub-periods (1884:1922, 1923:1944, 1945:1961) highlighted two further inhomogeneities, one on 1939 and the other on 1951 (Fig.4). The first break was caused by initial instruments location, while the other two, according to metadata, were probably caused by human errors and/or instruments accuracy degradation. The adjustment factors adopted to remove the
discontinuities, which emerged both in parametric and in non-parametric version of SNHT, are reported in Tab. 1.

<table>
<thead>
<tr>
<th>Period</th>
<th>Correction Factor [°C]</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1884:1890</td>
<td>+0.7°C</td>
<td>Initial instruments location</td>
</tr>
<tr>
<td>1939:1944</td>
<td>+0.3°C</td>
<td>Human errors and/or instruments degradation</td>
</tr>
<tr>
<td>1946:1951</td>
<td>-0.8°C</td>
<td>Human errors and/or instruments degradation</td>
</tr>
</tbody>
</table>

Table 1: Correction factors applied for homogenization of 1884:1961 mean-temperature (average of max and min daily values) time series and possible causes of discontinuities
Fig. 4: Standardized difference time series and corresponding T-series for 1884:1922 temperature series homogenization (a), for 1923:1944 temperature time series homogenization (b) and for 1945-1961 temperature time series homogenization (c)

The homogenization of temperature observations acquired in 1974:2010 period was very critical and requires additional analytic steps involving minimum and maximum temperature trend examination. As highlighted by Fig.5, annual average maximum temperature is characterized by an anomalous increase in 1999-2001 period, while annual average minimum temperature shows a significant decrease in 1995-1999 period. In the former case, it’s reasonable to assume that observations quality was affected by human errors in maximum thermometer readings. In the latter case, the goodness of measurements is likely to have been affected by the accuracy degradation of instrument put into operation in 1989.
The different nature of discontinuities suggested us to adopt two distinct approaches for their removal. As regards maximum temperature, we used a direct approach, correcting the data observed in 1999-2001 period according to the extension of the index of maximum thermometer “SIAP”, corresponding to 3.2°C. We tested subsequently the series homogeneity through the SNHT: the results obtained validated the correction procedure adopted. Regarding minimum temperature, a classical indirect approach was used: the SNHT highlighted a break in 1990, statistically significant only in its non-parametric version. In order to investigate about the presence of other inhomogeneities, we have split the series in two parts, one before (1974 – 1989) and one after (1991 – 2010) the possible break. We have identified a break in 1999 and we corrected the data acquired in the period December 1993 – March 2000 applying a correction factor of +1.1°C. The subsequent application of SNHT to the entire period (1974:2010) did not reveal any discontinuities.
4. YEARLY AND SEASONAL VARIABILITY AND TRENDS

Yearly variability analysis of homogenized climatological time series highlights statistically significant trends: for mean-temperature, we found an increase of 0.5°C/100 years, while for total precipitation we discovered a drop of 667 mm/100 years (32%/100 years). These results show a partial agreement with those obtained in [9], where for whole Italian Peninsula a rise in mean-temperature of 1.0 K/100 years (1863:2003 period) was found, and with those got in [15], where for Southern Italy a decrease in yearly rainfall of about 21 mm/10 years (1916:2003 period) was discovered. As shown in Fig.6, mean-temperature is characterized by statistically significant oscillations between 1940 and 1950 and in 1920:1930 time intervals (period of ≈ 2-5 years). Wavelet Analysis performed for total precipitation (Fig.7) points out multiple oscillations in high frequency region between 1900 and 1970 (period ≈ 1-6 years). Instead in 1975:2010 period time-frequency spectrum shows a strong decrease in high frequencies energy and, therefore, a reduction of the interannual variability.
Fig. 6: Annual mean temperature recorded at Montevergine's observatory, with linear trend and LOWESS smoothing (a). Continuous Wavelet Transform of the signal (b)
The trends discovered are strongly influenced by anomalies in temperature and precipitation observed in the last three decades. In order to identify the pattern established between mid-1970s and 2000s, we correlated the first difference of the signals on five years step (Fig. 8). During the period just mentioned, mean-temperature and total precipitation show a strong anti-correlation, whose magnitude and persistence has never been observed in previous decades, in which the two variables are characterized by an unstable coupling. As remarked in [16], Western Mediterranean’s climate shows a similar behavior in the last three decades.
As regards as mean-temperature, seasonal variability analysis highlights a strong increase on winter, spring and summer, while no trend was detected on fall (Tab.2). Wavelet analysis performed for winter season shows high energy on multiple scales, although statistically significant oscillations were discovered only between 1930 and 1945 and in 1920:1930 periods. Spring season's CWT highlights a clear energy peak only between 1980 and 1990 (period ≈ 1-4 years), while Wavelet Analysis of summer and fall variability points out high energy at high frequencies (period ≈ 1-5 years) in 1900:1950 period. Regarding precipitation, we found strong negative trends in all seasons, particularly steep on spring (-41%/100 years) and on autumn (-32%/100 years). Seasonal Wavelet Analysis shows statistically significant oscillations in high frequencies regions (period ≈ 1-6 years) between 1890 and 1970, while in the last three decades a strong energy reduction was observed.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Year</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td></td>
<td>+ 0.5°C/100 years</td>
<td>+ 0.8°C/100 years</td>
<td>+ 0.8°C/100 years</td>
<td>+ 0.0°C/100 years</td>
</tr>
<tr>
<td>Precipitation</td>
<td></td>
<td>- 667mm/100 years</td>
<td>- 185 mm/100 years</td>
<td>- 218 mm/100 years</td>
<td>- 217 mm/100 years</td>
</tr>
</tbody>
</table>

Tab. 2: Yearly and seasonal linear trend of temperature and precipitation observed in 1884:2010 period

5. LARGE SCALE VARIABILITY CONNECTIONS

As remarked in [17], in order to understand local climate variability features, is necessary to link it to large-scale climate atmospheric phenomena. So, we have focused our study on the analysis of links...
between Montevergine's time series and atmospheric pattern better able to influence Mediterranean and Europe climate. We represent atmospheric circulation by five indexes: the North Atlantic Oscillation index (NAO), defined as the difference between Lisbon and Stykkisholmur/Reykjavik normalized sea level pressure, the Mediterranean Circulation index (MCI), defined by the difference between Marseille and Jerusalem sea level pressure, the Western European Zonal Circulation Index (WEZCI), defined by Madrid + Barcelona and Trondheim + Lund surface pressure record, the Eastern Mediterranean Pattern (EMP), defined by the difference in geopotential height at 500 hPa between Northeastern Atlantic (52.5°N 25°W) and the Eastern Mediterranean (32.5°N 22.5°E), and the North Sea Caspian Pattern Index (NCPI), proposed by [18], which is calculated from the difference in the normalized 500 hPa geopotential between averages of North Sea (0°E, 55°N and 10°E, 55°N) and North Caspian (50°E, 45°N and 60°E, 45°N) centers of action. For NAO index we used data provided by NCEP/NCAR, while the other indexes were reconstructed for the 1884:2010 period means of [14]. Montevergine precipitation regime is largely influenced by Mediterranean atmospheric circulation, which is represented by Mediterranean Circulation Index (MCI), proposed in [19]. As showed by Fig.9, MCI explains a portion of variance greater than other indexes in the October-April period: the highest correlation values were found on January ($\rho = -0.67$), on December ($\rho = -0.64$) and on February ($\rho = -0.62$).

![Fig. 9: Monthly correlation between Montevergine's precipitation time series and teleconnections indices in 1884:2010 period](image_url)
In order to identify the atmospheric pattern more favorable to precipitation events in Montevergine during autumn and winter, we selected MCI October-November-December (OND) and January-February-March (MAM) values below the 10th percentiles. The sea-level pressure pattern and the relative anomalies (with respect to 1981-2010 mean) are shown in Figure 10a and 10b (OND) and in Figure 10c and 10d (JFM).
Fig. 10: Sea level pressure pattern and relative departures with respect to the 1981-2010 period for the OND seasons (Fig. 10a and Fig. 10b) and JFM season (Fig. 10c and Fig. 10d) characterized by MCI values below the 10th percentiles.

Autumnal and winterly sea-level pressure patterns associated to MCI values below the 10th percentiles show very similar features: they are characterized by a low-pressure center between Corsica and Sardinia, which pumps moist air masses from south-west in the southern Italy, by a weakening of
Icelandic low-system and by two strong anomalies centers, one located in Northern Atlantic, the other situated in Western European sector.

Wavelet Coherence between MCI and winter precipitation highlights a large area of covariance in 1940-2010 time interval (period ≈ 1-8 years), while in 1884-1930 period there is high covariance only on periods of 1-4 years and of 8-16 years (Fig.11a). The drop in precipitation observed at Montevergine’s observatory in the last three decades can be related to the significant change in atmospheric circulation, which was caused both by an increase in north-south pressure gradient, represented by the shift into the positive phase of NAO, and by an increase in difference between western and eastern Mediterranean pressure, represented by the shift into the positive phase of MCI. This coupling between NAO and MCI is well captured by the WTC of two signals (Fig.11b), which shows a covariance area in 1970:2010 time over 8-10 years periods.
Fig. 11: Wavelet Coherence of MCI and Montevergine's winter precipitation (a) and Wavelet Coherence of NAO and MCI winter variability (b)

Summertime rainfall is partially well captured only by WEZCI and by NCPI: in both cases correlation degree is maximum on August ($\rho = -0.51$ and $\rho = 0.47$, respectively). Summer seasons characterized by NCPI value above the 90$^{th}$ percentile (Fig. 12a) show a pattern in geopotential heights anomalies similar to that observed for those marked by a WEZCI (Fig. 12b) value below the 10$^{th}$ percentile, with strong positive anomalies in North Sea and negative anomalies in Southern Italy.
Fig. 12: Geopotential heights anomalies at 500 hPa level (with respect to 1981-2010 mean) for summer season (JJA) characterized by WEZCI values below the 10th percentiles (Fig.12a) and by NCPI values above the 90th percentiles (Fig.12b)
As marked in [19], there is a significant influence of ENSO on rainfall in regions of Euro-Mediterranean sector, especially on spring and on autumn season. Monthly correlation analysis between Montevergine’s precipitation time series and Nino3.4, defined as SST anomaly in 5S-5N, 120W-170W, didn’t show any perceptible relationship. However, the XWT performed for the autumn season (Fig.13) revealed areas of common power between 1890 and 1895 (period ≈ 2-3 years), 1910 and 1920 (period ≈ 5-8 years), 1935 and 1940 (period ≈ 3-6 years) and between 1970 and 1985 (period ≈ 4-6 years). In the latter two areas Nino3.4 seems to lead Montevergine’s rainfall variability.

![Cross Wavelet Transform of Nino3.4 index and Montevergine precipitation](image)

Fig. 13: Cross Wavelet Transform of Nino3.4 index and Montevergine’s autumn precipitation

Montevergine’s temperature variability is in a good agreement with EMP, particularly on winter season ($\rho = -0.63$). The strong oscillation of temperature signal between 1940 and 1960 is strongly related to the EMP, as pointed out by the XWT of the two signals performed for winter season (Fig.14a). WTC shows a strong and stable area of covariance on 8-16 years periods on the whole time interval considered (Fig.14b).
Fig. 14: Cross Wavelet Transform (a) and Wavelet Coherence (b) of EMP and Montevergne’s winter temperature time series
6. CONCLUSIONS

In this study we focused on the homogenization and the analysis of Montevergine’s climatological time series for the period 1884-2010. Precipitation data are affected by errors only between 1946 and 1950, while temperature time series is characterized by multiple discontinuities, due to various causes, such as instrument relocation, changing in observers, human errors and instrument accuracy degradation. This study has pointed out an increase of annual mean temperature (0.5°C/100 years) and a huge drop in total precipitation (32%/100 years). Positive trend in mean temperature emerged in all season, except on fall, while negative trend in total precipitation is particularly strong on spring and autumn. Both signals are characterized by a strong oscillation between 1940 and 1950. The analysis of relationship with large-scale patterns suggested that behind the decrease in precipitation there’s an enhancement both of north-south pressure gradient (represented by North Atlantic Oscillation Index) both of eastern-western Mediterranean pressure gradient (synthetized by Mediterranean Circulation Index), which has determined a weakening of the energy associated to atmospheric transients. Montevergine’s precipitation time series is in a good agreement with Mediterranean Circulation Index in the October-April period, while summer rainfall variability is partially captured only by Western European Zonal Circulation Index and North Sea Caspian Pattern Index. ENSO irregular oscillations have affected autumn rainfall variability, especially in early 1900s and in 1970-1985 period. Temperature series shows a good correlation degree with Eastern Mediterranean Pattern, particularly on winter season.

There isn’t yet a full comprehension of how high-altitude regions have responded to recent change in atmospheric circulation, so in near future our purpose is to extend the study to other mountain stations located in Central-Southern Apennines.

7. ACKNOWLEDGMENTS

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