Climatic analysis of some places of Sicily using simple graphics tools and wavelet.

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Abstract

The aim of this work is to analyse the temperature time series of some Sicilian weather stations by using special graphical tools and a powerful mathematical instrument like the Wavelet Transform, in order to better understand the climatic dynamics. In the work, both the methodologies are described. The first, due to its simplicity, can be used by users with few mathematics or physics knowledge, while the wavelet analysis require a medium to high scientific background.The need to go forward deeper in the analysis, after the emerged considerations using the easier graphic analysis, require more robust mathematics instrument and tools like wavelet analysis.

Keywords: Time series analisys, temperature, wavelet, climate, Sicily.

1. Introduction

Any climate signal can be interpreted as a results of interactions between physical and dynamic processes that occur on a wide range of spatial and temporal scales. The scale of the processes involved, extends into the space between a few meters and thousands of kilometres and in time in a few hours and millions of years (Lau and Weng, 1995). The analysis of the time series of a locality temperature, can provide information on the major climatic and physical processes involved in determining the evolution of the climate. Thermometric series also allow us to understand the current warming of localities with respect to the Global warming and show how this warming proceeds. In the present paper, carried as part of the PhD school in Physics at Universit di Messina, we analyse the thermometric data of some Sicilian places. After acquiring some preliminary information, we have chosen to use three weather stations of the Italian Air Force Meteorological Service, because they have the longest and continuous database.

Data

The weather stations are located at the three corner of Sicily (Fig.1), few hundred meters from the costal line and, for this reasons, they can be considered as a good indicator of the mean Mediterranean climate. The data collected starts on 1951 for Cozzo Spadaro and Messina, while on 1962 for Trapani. To uniform the time series for wavelet analysis we decided to analyse the 1962-2014 temperature time series, because the three stations show continue and regular observations. All the weather stations are under the responsibility of the Italian Air Force Meteorological Service and have a high quality standard comparable with W.M.O. standards. Furthermore, they have never been moved, and have done regular Synoptic observation every 3 hours since they were constituted.

Station name	Latitude	Longitude	Altitude s.l.m.
1) Messina	38°12′02″	15°33′11″	54
2) Trapani	37°54′50″	12°29′28″	4
3) Cozzo Spadaro	36°41′10″	15°07′57″	44

Figure 1: Weather Stations position

Using simple graphic tools

For the purpose of this paper, we've analysed only the temperature recorded at 12 UTC. As a first step, we calculated the annual linear trend of warming starting from mean monthly temperature. The results are the following: 0,0157 C/year for Trapani, 0,0255C/year for Cozzo Spadaro and 0,0304C/year for Messina.

	Trapani	Cozzo Spadaro	Messina
Trend °C/10 years	+0,157	+0,255	+0,304
Total warming °C 1962-2014	+0,81°C	1,32°C	1,58°C

Figure 2: Table of trends of analized stations

It is quite clear that Messina temperature has over warming due to the anthropogenic impact and the urban heat island effect. The aim of the next step is a better understanding of how this warming developed. In order to do this, we put temperature at 12 UTC data in a matrix 365 row for 65 column where each row is the day of the year and the column the year. We plot the matrix using a contour graph, assigning a colour to each temperature. The advantages of this kind of graph have been described since 2001 (Colombo, 2001) and are immediately clear by looking at the figure (Fig. 3).

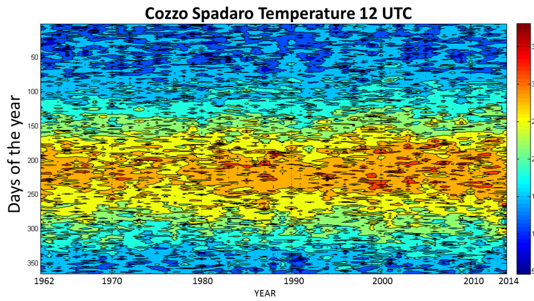

Figure 3: Matrix of temperature of Cozzo Spadaro

This kind of representation allows, first of all, to have evidences of the number of hot days or heat wave. Their number increased both in absolute value and in length of single event starting from 1980 and, more sharply, in the last years of the 90s. More in detail, the figure of the summer months (Fig.4) shows how these events get wider in time, meaning that the higher temperature starts earlier and ends later in the year. The same picture also shows how the length of the summer season get longer in time and is caracterized by an increasing of summer heat wave.

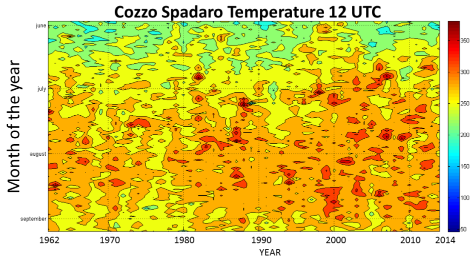

Figure 4: Matrix of summer temperature of Cozzo Spadaro and heat wave (red spot)

The Wavelet analisys

The Wavelet analysis is a powerful mathematical tool able to provide a time-frequency representation of every signal analysed in the time domain (Percival and Valden, 2000). It can be used to analyse time series that contain nonstationary power at many different frequencies (Daubechies 1990). In the case of meteorological and climatological series, this type of analysis is particularly appreciated because it is able to extract valuable information from the signal. For example, if compared to the simple Fourier transform,the wavelets analysis allows to find not only in the value of certain frequencies in a non-stationary series, but also to identify the time interval in which these frequencies are present and predominant. These sophisticated tools have been used in several studies of climatology, and the scientific literature contains many examples. (Baliunas et al. 1997 Torrence and Compo 1998 Park and Mann 2000 etc). For the purpose of this paper, we used the continuous wavelet transform CWT. The continuous wavelet transform of a discrete sequence x_n with a scaled and translated version of $\Psi_0(\eta)$ is : $W_n(s) = \sum_{n'=0}^{N-1} \chi_{n'} \Psi * \left[\frac{(n'-n)\delta t}{s}\right]$ where the (*) indicates the complex conjugate. By varying the wavelet scale s and translating along the localized time index n, one can construct a picture showing both the amplitude of any features versus the scale, and how this amplitude varies with time (Torrence and Compo 1997). To approximate the continuous wavelet transform, the convolution (1) should be done N times for each scale, where N is the number of points in the time series (Kaiser 1994). The wavelet function should reflect the kind of features in the time series. For time series with sharp jumps or steps, one would choose a boxcar-like function such as the Harr, while for smoothly varying time series one would choose a smooth function such as the damped cosine. If one is primarily interested in wavelet power spectra, then the choice of wavelet function in not critical and one function will give the same qualitative results as another (Torrence and Compo 1997). The choice of the mother wavelet to perform the analysis of the temperature has been done by taking in account the shape of the signal and, for this reason, we choose a Morlet wavelet. The first operation we did over the signal of all three weather stations was its decomposition in order to evaluate trends and dominant frequencies. The decomposition of signal at level A4 shows the interdecadal trend comparable with the values obtained with simple liner trend. At the same level, all the stations shows a peak in correspondence of years 1982, 1993 and 1998 (Fig.5).

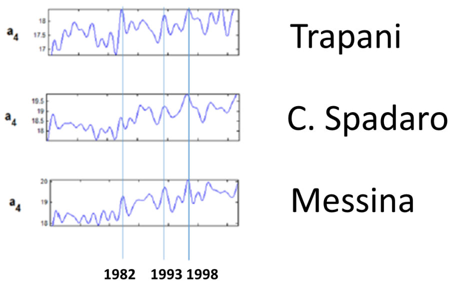

Figure 5: Peak of 1982, 1993 and 1998 years

Then we calculated and plotted the CWT. Before proceeding in this operation, we calculated the mean monthly temperature anomaly in order to eliminate the strong annual periodicity and allow the longer periodicity to be visible in the graph. The results obtained are the following: Cozzo Spadaro CWT of temperature anomaly (Fig. 6) shows a long time interval starting from 1962 until 1979, where only signals with periods between 9 months and 2 years are present. Starting from 1970, a signal with an initial period of about 1 year is present and continuous until 1981, shifting in period to 2 years.

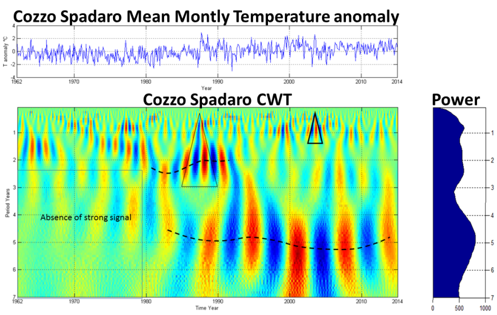

Figure 6: Cozzo Spadaro CWT of temperature anomaly

Since 1982, there are two new signals: the first with a period of about 2 years between 1983 and 1992, with a strong discontinuity in the summer of 1987 (remarked by the triangle in the figure), and a second one with mean period of 5 years extending from 1983 and 2014. Moreover, in this last range of time, another discontinuity is present in correspondence of summer 2003. For period longer than 7 years, the wavelet analysis of Cozzo Spadaro shows an important signal with a period of 10-11 years extending from 1980 and 2014 (not in figure). Messinas CWT (Fig.7) shows a long time interval from 1962 to 1980 in which only signal with period shorter than 2 years are present. Starting from 1980, two signals with period 2,5 and 4,5 years appear, and partly overlap. The first develops from 1994, reducing its period at about 1,5 years.

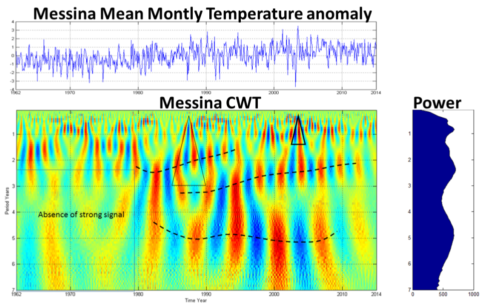

Figure 7: Messina CWT of temperature anomaly

Also in this case, a strong discontinuity is present in the summer of 1987. The second signal, with an average period of about 5 years, is present till 2010. A third signal, starting from 1986 till 2012, shows a period of about 3,5 years and ends its cycle with a period of about 2 years. During the summer 2003, a new discontinuity is well visible and it is marked in figure with a small triangle. The signal analysis of Trapanis weather station (Fig 8), once again shows a long interval of time of about 20 years during which only signal with period shorter than 2 years are present. Since 1980, two signal, the first stronger than the second, appear and are partly overlapped. The first signal, with period of about 2,5 years, extends its influence till 1994, with a strong shift to shorter periods. The second one starts in 1980 and arrive until 2014 with a mean period of 5 years. Finally, a third signal develops since 1992 and arrives till 2014, with a period of about 2,5 years at the beginning and less than 2 years at the end. Once again, the picture shows two strong discontinuities during the summer 1987 and 2003. In CWT a significant signal with period of about 11 years (not in figure) is also presents from 1962 to 1990.

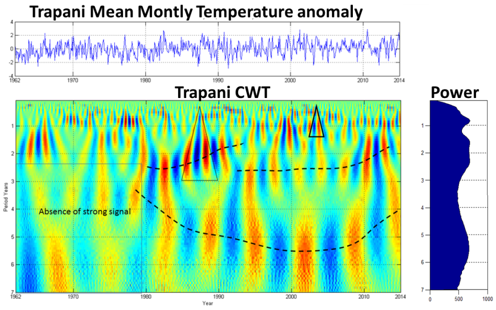

Figure 8: Trapani CWT of temperature anomaly

Discussion and conclusion

In this paper, we show two different way to analyse a climatic signal. The use of graphical tools coupled with specific elaboration strategies, allows a generic user to elaborate meteorological data to extract much climatologic information from a simple signal, such as temperature. In particular, the graphical analysis provides an immediate visual impact and remarks some specific aspect of the current warming process (i.e. the increasing number and the extension of the summer heat wave or the lengthening of warm season, which is quantifiable in about 25 days in the course of the last 65 years). The second approach we uses is the wavelet analysis. The compared analysis of CWT spectra allows us to find some common features as well as some unique characteristics of the analysed localities. In detail, the three CWT power spectra show a power peak with a period of about 1 year, a second peak with a period of two and a half years, and a last peak with a periodicity of four to six and a half years. Furthermore, all the three CWT show an almost clean area from 1962 to 1980, with just the annual or quasi-biannual periodicity active. During this period, none or very weak signals were present. Then, starting from 1980, all the CWT show a sequence of signals with initial periodicity of about two and a half years. In addition to that, a strong and continuous signal with periodicity 4 to 6 years is present and persists until nowadays. Two strong discontinuity are also common for all three CWT spectra, and they are indicated in the figures with big and small triangles. The first discontinuity occurs during the summer 1987, and is well visible in the row thermic anomaly signal. In fact, a sharp jump in high temperature occurred during that summer. That year was characterized by the greatest increase in temperature of the analysed time series. On this purpose, analysing again the matrix of temperature in Fig. 2, it is possible to observe how high temperature expand toward autumn months and how the number of red spots (hot days/heat wave) increase during the summer in correspondence on those years. A second break point is present in all three signals during the summer 2003, the so-called killer summer. Thousands of people died that summer in Central Europe due to strong and long heat wave. The matrix shows how the high temperature expands toward spring months, anticipating the summer season. Also in this case, a high number of red spots are present during summer season. In conclusion, we demonstrated how this kind of analysis could help the research in the field of climatology to better understand the climate dynamics by studying simple signals such as temperature.

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