ANALYSIS
1(1), January - March, 2015
ISSN 2394–8558
EISSN 2394–8566
Climate Change

Morlet Predictive Analysis of Earthquakes Modulations

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Publication History
Received: 13 October 2014
Accepted: 21 November 2014
Published: 1 January 2015

Citation
Neïla Zarrouk, Raouf Bennaceur. Morlet Predictive Analysis of Earthquakes Modulations. *Climate Change*, 2015, 1(1), 1-10

ABSTRACT
During an earthquake the dynamic behavior of inelastic structures is a complicated non-stationary process that is affected by the random characteristics of seismic ground motions. The earthquake records are the time-domain signals in all cases the earthquake waves change in a relatively short period of time. The link between cosmic rays, low cloud amounts and earthquakes as a measure of climate began to occur and becomes a considerable and effervescent research field in last-years. However, we have studied in our previous works on many faces of these links in many cases the most distinguished information is hidden in the frequency spectrum, which provides the energy, associated with a given frequency The conventional Fourier analysis describes the feature of a dynamic process by decomposing the signal into infinitely long sine and cosine series, which loses all time-located information. We focused our study in this time on links between earthquakes and low cloud amounts. The Morlet wavelet transform capability to give a full time–frequency representation of the earthquake record is demonstrated. In this method, the analysis of the original and reconstructed earthquakes time series of the earthquake record, demonstrates the ability of the wavelet transform technique to detect a complex variability of these signals in the time–frequency domain. Various spectral representations resulting from the

wavelet transform are discussed and their application for earthquake record is shown. In this paper, an analytical approach for seismic ground motions is developed by applying the Morlet wavelet transform, the well known 11 years cycle is present already found for low cloud amounts signs is present in the revealed Morlet modulations for earthquakes number and magnitude. Other structures are present as well in the present work for earthquakes as in present work for low cloud amounts. Our present Morlet extrapolation for earthquakes number and magnitude predict the presence of low magnitude earthquakes for the year 2015 which was already predicted to contain a maximum for low cloud amounts in our previous work.

Keywords: Morlet wavelets, earthquakes, low cloud amounts

1. INTRODUCTION

When waves start to break, the frequency content of signal changes rapidly in time due to nonlinear interaction between elementary wave components, resulting energy transfer, and energy dissipation[1]. In such cases, the Fourier transform provides information on the frequency content; however, the information on the frequency localization in time is essentially lost in the process. When the time localization of the spectral components is required, the transform of time series, which provides the time–frequency representation of the signal, should be developed. Transform of such type is the wavelet transform, which gives full time–frequency representation of the time series. In contrast to the Fourier transform, the wavelet transform allows exceptional localization in the time domain via translations of the so called mother wavelet, and in the scale domain via dilations [2]. While Fourier analysis uses complex exponential (sine and cosine) basis functions, wavelet decomposition uses a time-localized oscillatory function as the analyzing or mother wavelet. The mother wavelet is a function that is continuous in both time and frequency and serves as the source function from which scaled and translated basis functions are constructed. Wavelet transform uses narrow windows at high frequencies and wide windows at low frequencies which is impossible for Fourier analysis and then constitute a problem [22]. Wavelet analysis is a new mathematical technique and in the recent years enormous interest in application of engineering has been observed. This new technique is particularly suitable for non stationary processes as in contrast to the Fourier transform. The wavelet transform allows exceptional localization, both in time and frequency domains [3].

The Continuous Wavelet Transform (CWT) is an ideal tool for mapping the changing properties of non-stationary signals and also to determine whether or not a signal is stationary in a global sense. CWT is then used to build a time-frequency representation of a signal that offers very good time and frequency localization [4]. The mother wavelet can be complex or real, and it generally includes an adjustable parameter controlling the properties of the localized oscillation. The application of the wavelet transform to earthquake engineering is not frequent. Researchers demonstrated the usefulness of the wavelet transform in studying dispersion of the earthquake load [5]. Discrete and fast wavelet transforms are used for dynamic analysis of structures induced earthquake load. Then the discrete and fast wavelet transform are used for optimization of structures with earthquake loading [6-8]. The continuous wavelet transform was developed to analyze the energy balance in the equilibrium spectral subrange of the wind-generated gravity waves [9]. Wave growth and breaking in the time series were detected applying the wavelet transform [10]. In a first step we have decomposed in Morlet wavelets the original signals describing the world number of earthquakes versus years, the magnitudes of earthquakes as a function of time was decomposed in another side. We have used in a second step these MO coefficients to reconstruct the signs. Thus we have extrapolated with MO wavelets the earthquakes signs we have then obtained the predicted form of earthquakes signs for one to two years ahead.

2. RESULTS AND DISCUSSION

The sudden breaking of rock within the earth causes waves of energy which are the Seismic waves. The energy is stored as elastic strain in the rock along a fault. When the rock on either side of the fault ruptures, the force travels outward in waves. These waves of motion, which pass through the earth while spreading out from the point of fault rupture, are what we feel on the surface as an earthquake [1, 7].

A new method to analyze signals is the wavelet transform, which overcomes the problems that other signal processing techniques exhibit [20, 21]. The main advantage gained by using the wavelet transform is the ability to perform the local analysis of a signal, to zoom in any interval of time or space. Wavelet analysis is thus capable of revealing some hidden aspects of the data that other signal analysis techniques fail to detect [11-14]. Thereby, this property is particularly important for damage detection of structures. Moreover, due to the availability of a fast transform version, the computational effort to perform the signal transformation is reduced. Because of these features, the wavelet transform is proposed as a promising new method for damage identification in structures. The application of the wavelet transform to earthquake analysis is rare.

Morlet revealing in earthquakes signs

Seismologists study and measure these seismic wave motions and their characteristics, including the period, the magnitude and the frequency. There are a number of different complex- and real-valued functions that are used as analyzing wavelets [12]. In many cases, the so-called progressive wavelet function is used, which is a complex-valued function that. The link between cosmic rays, solar activity and climate began to occur and becomes more considerable and effervescent in last years [23]. One of the most widely used functions in the wavelet analysis is the Morlet wavelet. Morlet wavelets are more powerful in revealing hidden detailed structures. This type of wavelets has been already used in our previous works [15-19] to examine the processes, models and structures of cosmic rays, solar activity and low cloud amounts modulations.

Morlet wavelet is defined as a complex sine wave, localized with a Gaussian. The frequency domain representation is a single symmetric Gaussian peak. This wavelet incorporates a wave of a certain period, it is finite in extent and it is given by:

$$g(t) = \exp\left(i\omega_0 t - \frac{t^2}{2}\right) \qquad \text{(Eq.1)}$$

Essentially, the Morlet wavelet in Eq.1 is a Gaussian windowed Fourier transform with sines and cosines oscillation at the central frequency, (ω_0 = 2π.f0) The Morlet wavelet is equivalently localized in the frequency domain, as evidenced by the Fourier transform of the dilated Morlet wavelet. Already Wavelets analysis is a useful tool both to find the dominant mode of variation and also to study how it varies with time [15].

Real parts of Morlet decomposition coefficients are given by

$$w^R{}_{j,k} = j^{-1/2}\int_{ti}^{tf} y(t) g^R_{j,k}(t)dt, \quad g^R_{j,k}(t) = g^R\left(\frac{t-k}{j}\right), \qquad \text{(Eq.2)}$$

$[t_i, t_f]$ is the study time interval

The resulting wavelet coefficients, means a measurement of the similitude between the dilated/shifted parent wavelet and the signal at time t and scale j. The dilation by the scale, j inversely proportional to the frequency, represents the periodic or harmonic nature of the signal. The normalization by the root of scale insures that the integral energy given by the wavelet is independent of the dilation. We have used 23 yearly values of earthquakes worldwide number and magnitudes [24] for the period around 1990 to 2012, these values constitute limited and discrete time series. Thus we have needed to discretise expressions of Morlet wavelets coefficients (Eq.2). We have then directly decomposed in Morlet wavelets the time series of worldwide earthquakes number and magnitudes, the correspondent MO coefficients are given by:

$$w^R{}_{j,k} = j^{-1/2}\sum_{l=1}^{23} y(t_l) g^R_{j,k}(t_l) \qquad \text{(Eq.3)}$$

The phase constant was taken $\omega_0 = 2\pi$. The period was fixed to $T = 1\ year$

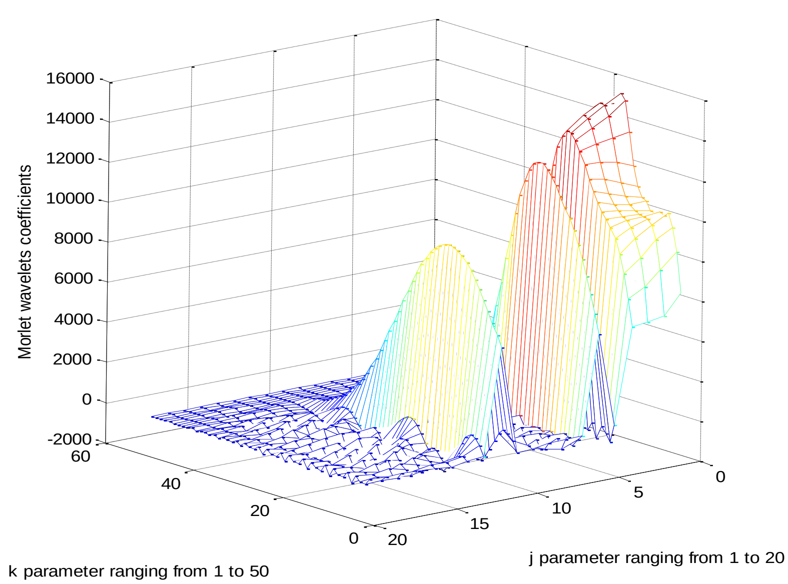

Figure 1 Morlet decomposition coefficients of earthquakes total number

The Morlet decomposition coefficients variation in time and versus scale and translation parameters j and k were plotted (Fig.1). We have then reconstructed the function describing earthquake total number variations; we were interested to the real component of reconstructed function:

$$y(t) = \sum_{j,k} w_{j,k} g_{j,k}(t) \qquad \text{(Eq.4)}$$

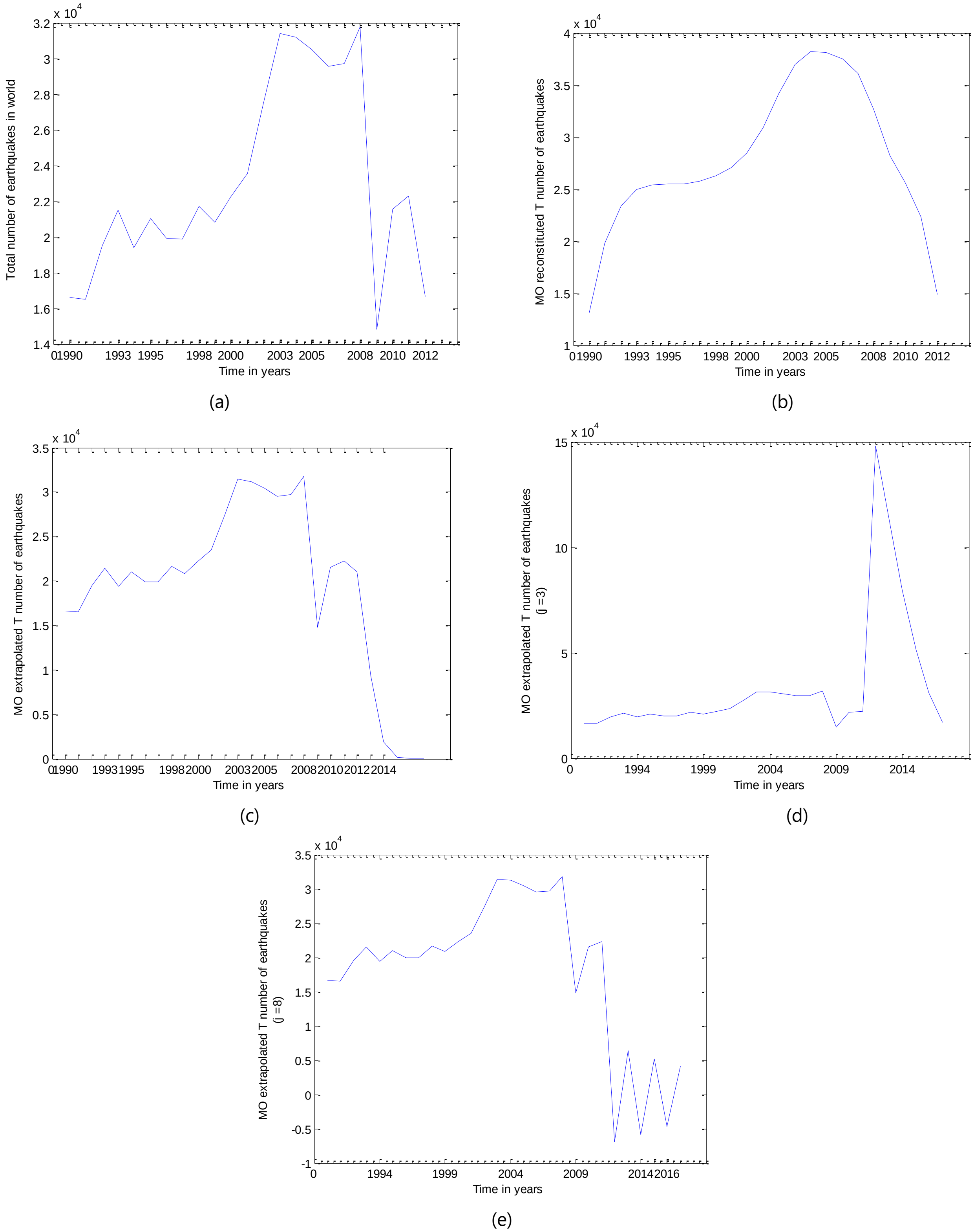

Figure 2

Reconstructed and extrapolated total number of earthquakes (a) original sign of earthquake total number, (b) MO reconstructed sign ,(c),(d), (e) : MO extrapolated signs (for different scale j)

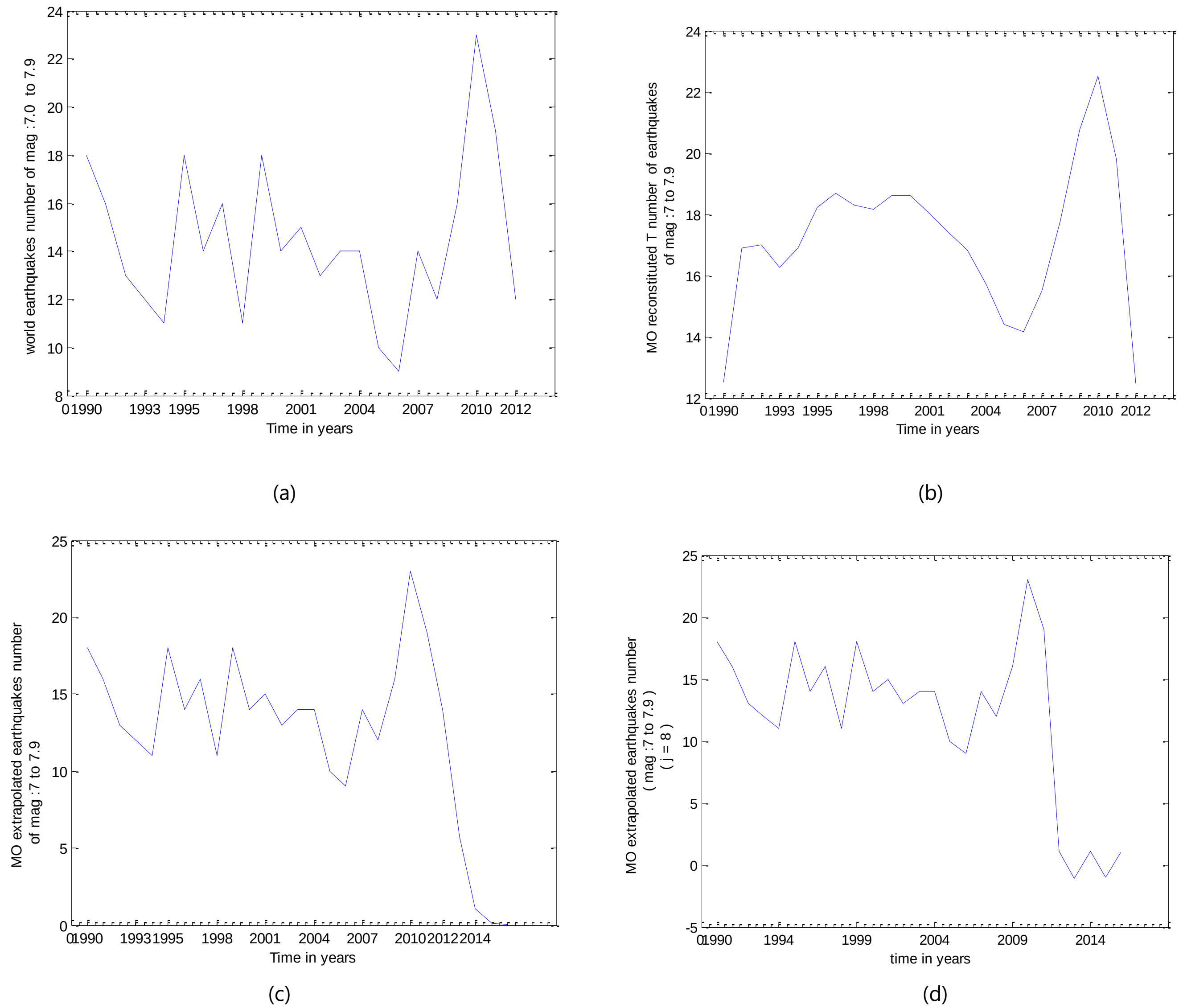

Figure 3

Reconstructed and extrapolated for earthquakes number of magnitude 7-7.9 (a) original sign, (b) MO reconstructed sign ,(c),(d) : MO extrapolated signs (for different scale j)

Thus we have analyzed variations in time, we arose hidden periods and structures being able to highlight a physical causal link between cosmic rays intensity, low cloud cover on a side and earthquakes on the other side. The original curve describing the total number of earthquakes in world has showed a largest number around the period 2004-2008 (fig.2a,2b). This period presents a global minimum particularly for the earthquakes number of magnitudes ranging from 3 to 3.9 and 7.0 to 7.9, this period correspond at the same time to a global minimum for low cloud amounts (fig.3, 4, 7). A secondary maximum has occurred around the year 2010 for all figures , this year is also a maximum for low cloud amounts which inversely correspond to minimum for cosmic rays flux. At 2006 the earthquakes number as well as low cloud amounts was minimum. the big modulation was always conserved after decomposition and reconstruction in Morlet wavelets, the absolute maximum describing the largest number of earthquakes is around 2004-2007. As well as for earthquakes number or magnitude, the years 1998 and 2010 have presented secondary low maxima which is the case also for low cloud amounts, the earthquakes number have globally decreased at 2000. Analyzing the Morlet modulations of earthquakes number, we have found conserved and revealed periods, indeed there are small periods varying from 2 to 4 years, for all types of earthquakes. The well-known 11 years cycle is present here particularly for total number of earthquakes and for weak earthquakes number, it is varying from 9 to 12 years, this known cycle was found in our previous work [18] common to low cloud amounts (fig.3- 7).

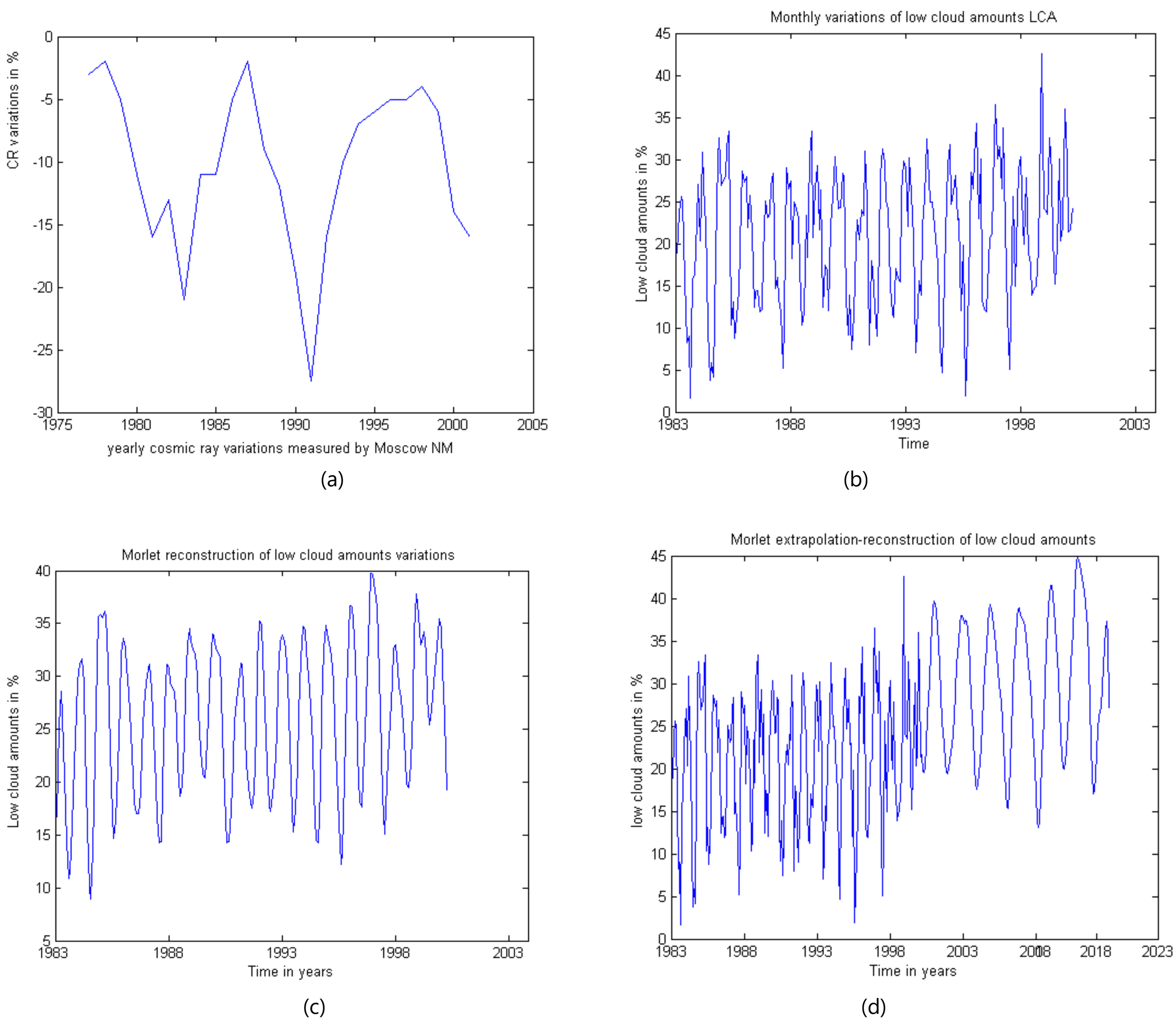

Figure 4 (a) Yearly cosmic rays variation measured by Moscow NM, (b) monthly variations of LCA by ISCCP around Moscow station, (c) Morlet reconstructed LCA, and (d) Morlet extrapolation–reconstruction of LCA.

The Morlet decomposition in time of largest earthquakes was applied to a discrete serie of 54 values of largest earthquakes during the period 1575 to 2014. The correspondent MO coefficients are given by:

$$w^{R}{}_{j,k} = j^{-1/2} \sum_{l=1}^{54} y(t_l) g^{R}_{j,k}(t_l) \qquad \text{(Eq.4)}$$

We were interested to the real component of reconstructed function the Morlet reconstructed function describing largest earthquakes is as follows;

$$y(t) = \sum_{j,k} w_{j,k} g_{j,k}(t) \qquad \text{(Eq.5)}$$

The original and reconstructed curves describing the largest earthquakes in the world and in California present many types of maxima and minima, the magnitudes have generally ranged from 4.4 to 7.9. We can note biggest period or envelop of 45 years (fig.5-7). Indeed maxima of this period correspond to an earthquake of 7.1 at region of Santa Barbara [24] in 1812 and to a second largest earthquake on California on the area of Parkfield-Wrightwood in 1857. Medium cycles modulating earthquakes magnitudes in California are of 20, 16, 15 years (fig.6). The known cycle of 11 years characterizing particularly solar activity and cosmic rays intensity signs is present here modulating the largest earthquakes magnitudes in California, this cycle have dilated and seems to be of 11 to 13 years. Short cycles of 3 to 7 years have occurred also. We can note small structures of 2 years to 4 months. Periods of 23, 25 and 39 years occurred at Imperial Valley, earthquakes have happened in 19 years at San Jacinto. Cape Mendocin was generally a hot area of frequent earthquakes, there was small cycles of 4,5 years, the well known 11 years which have varied from 9 to 13 years , earthquakes happened even in periods of 22, 26 and 50 years. We can note that earthquakes have occurred after long period at some area in California, at Santa Barbara an earthquake has occurred the second time after 113 years recalling the 100 years cycle highlighting the galactic cosmic rays-cloud amounts connection.

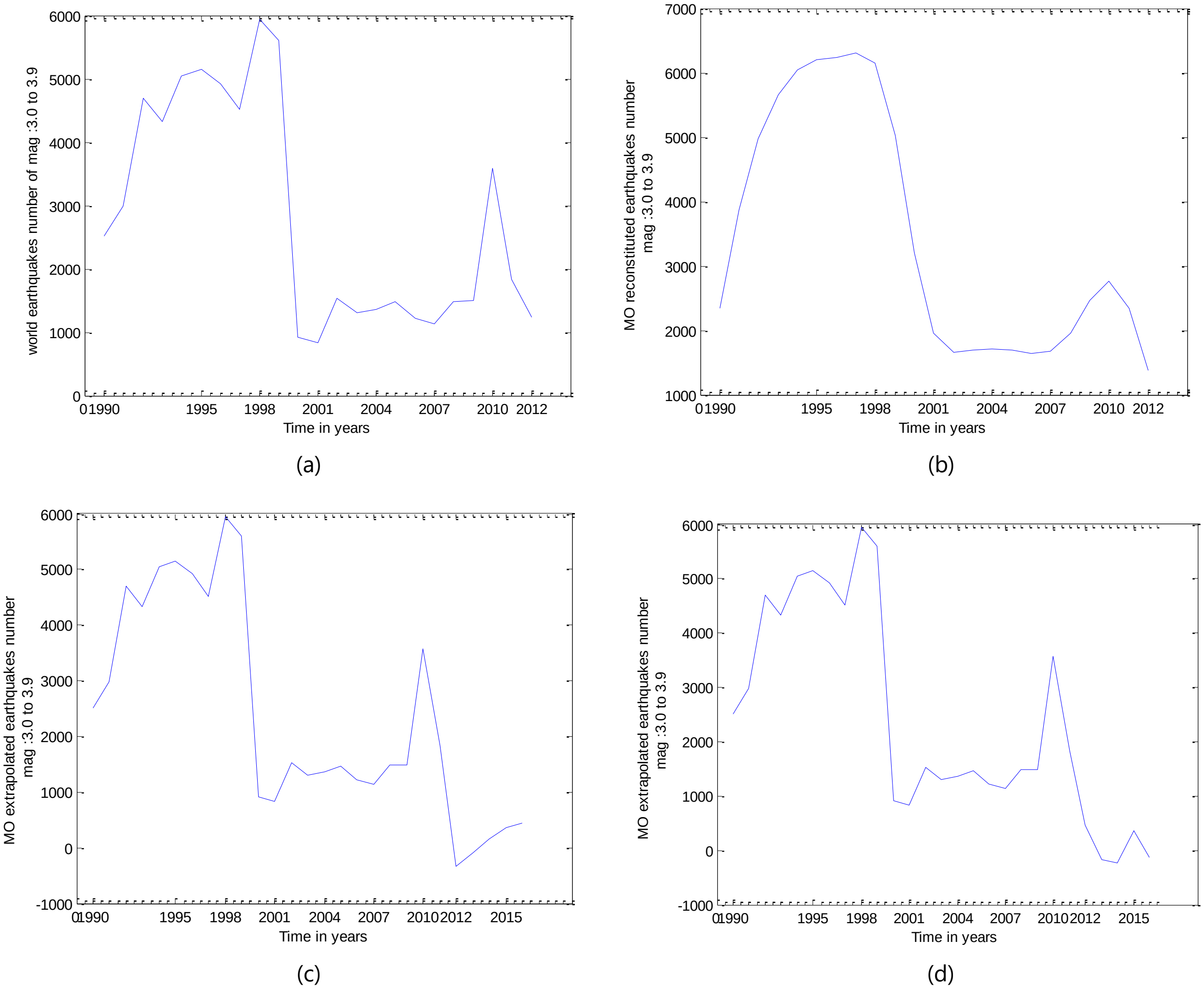

Figure 5

Reconstructed and extrapolated earthquakes number of magnitude 3-3.9 (a) original sign, (b) MO reconstructed sign ,(c),(d) : MO extrapolated signs (for different scale j)

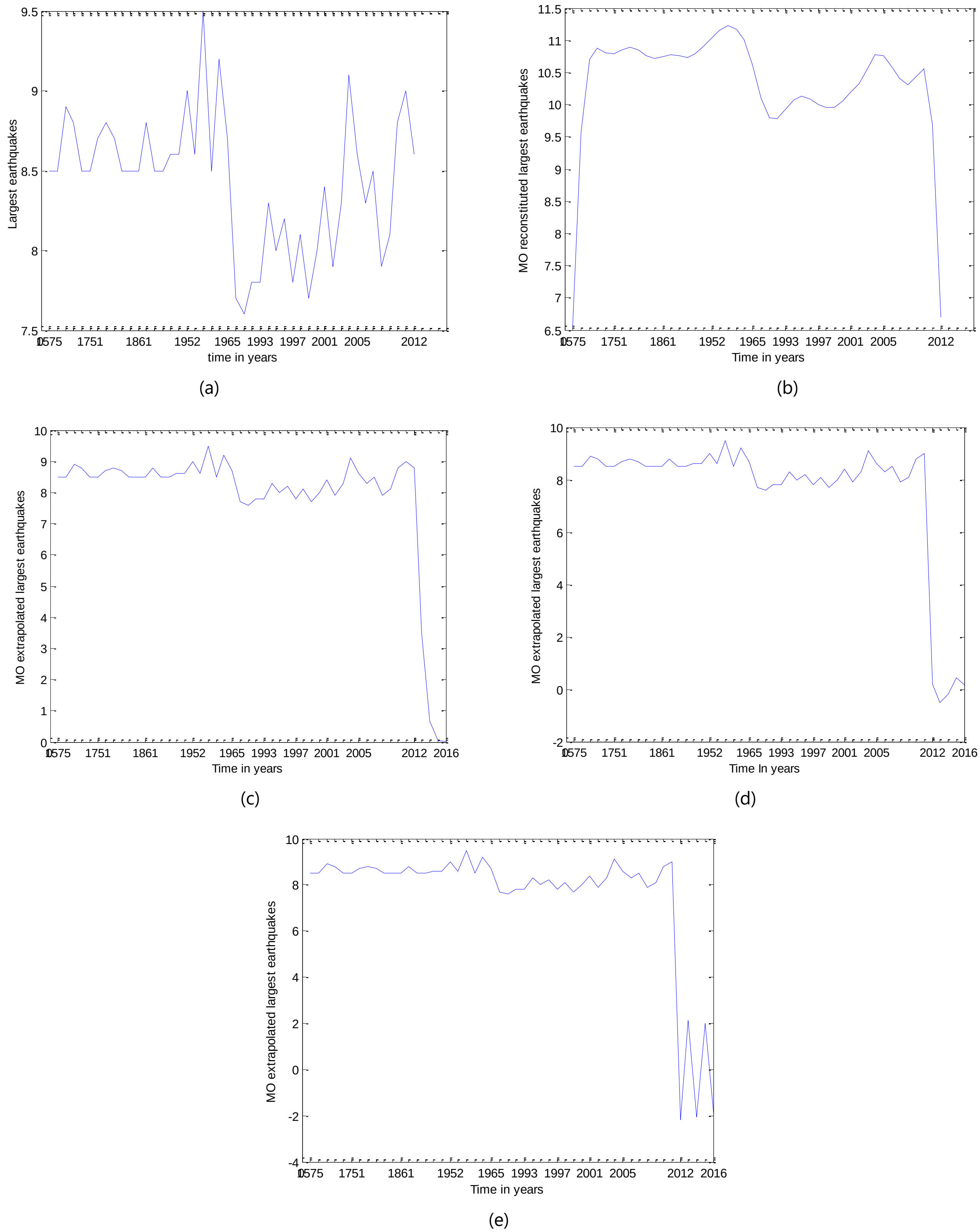

Figure 6

Reconstructed and extrapolated largest earthquakes: (a) original sign, (b) MO reconstructed sign ,(c),(d),(e) : MO extrapolated signs (for different scale j)

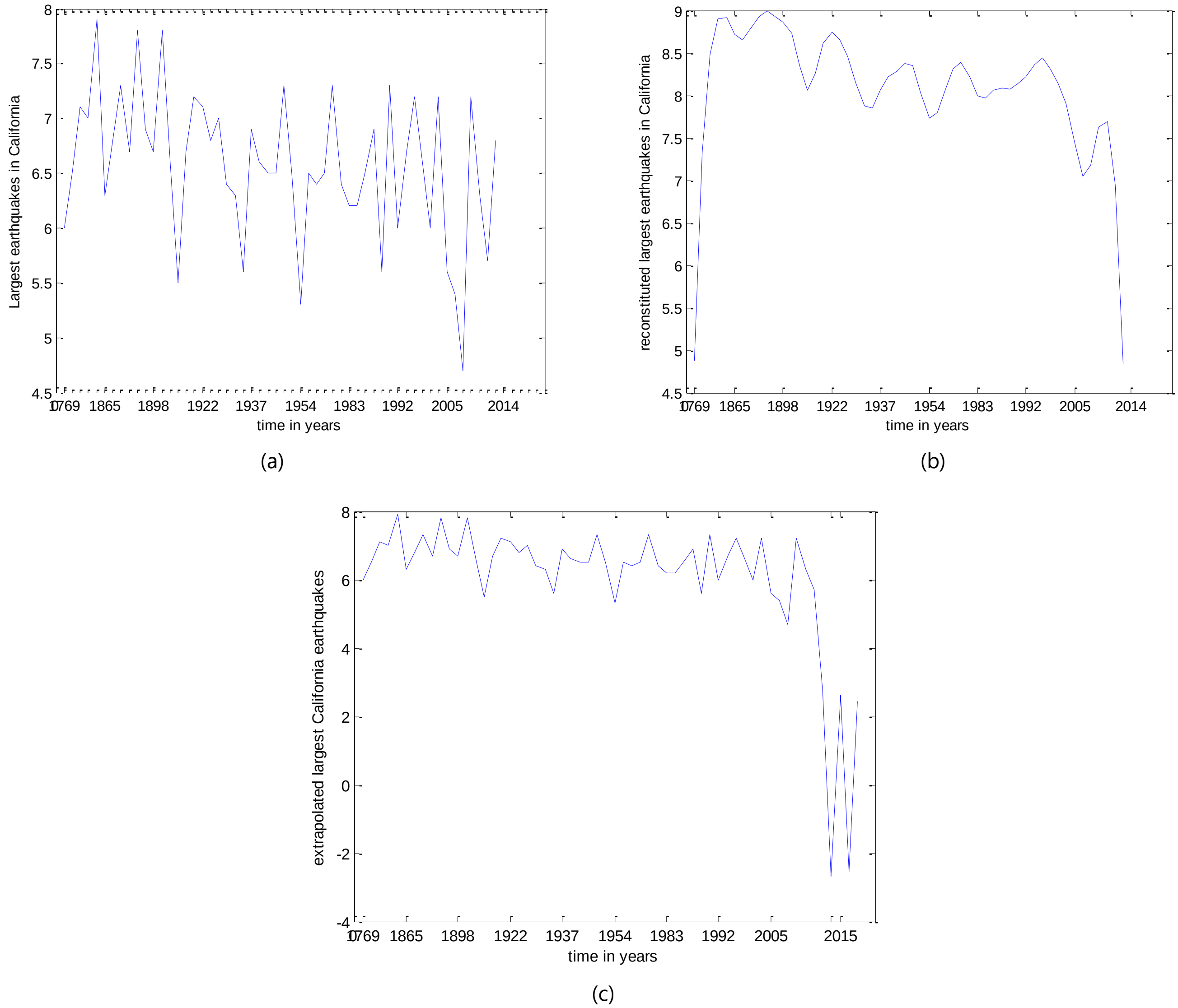

Figure 7
Reconstructed and extrapolated largest earthquakes in California: (a) original sign, (b) MO reconstructed sign ,(c), MO extrapolated signs (for different scale j)

Thus the iterative method used particularly in this study for extrapolation revealed more closely common hidden structures. The Morlet extrapolated curves concerning the earthquakes total number have shown the original modulations. As well as in our previous work in which we have revealed a maximum for low cloud amounts in 2015 (fig.7), extrapolating the original signal once again we have found in this work that, the year 2015 seems to hide a secondary maximum for number of earthquakes or for magnitude earthquakes reported to 2014 which is clear in all extrapolations figures. This means that the year 2015 will be hotter in earthquakes and hide a largest number of earthquakes than 2014, it is worth to note that particularly they are the earthquakes of weak magnitudes which will be the largest at 2015.

3. CONCLUSION

When the earth is rapidly displaced or distorted at some point, the energy imparted into the earth by the source of the distortion can be transmitted in the form of elastic waves. A wave is a disturbance that propagates through, or on the surface of, a medium. Elastic waves propagate through the medium without causing permanent deformation of any point in the medium. The wavelet transform technique is particularly suitable for non-stationary signals. In contrast to the Fourier transform, the wavelet transform allows exceptional localization, both in the time domain via translation of the wavelet, and in the frequency domain via dilations scales, which can be changed from minimum to maximum, chosen by the user. The Morlet wavelet analysis with all its stages decomposition, reconstruction and our procedure for extrapolation proves with a good agreement that it is a suitable tool to reveal really hidden common structures and cycles. The variations of the frequencies corresponding to the maximum of the wavelet transform at particular time are very similar to the recorded frequencies. It is interesting to note that wavelet transform shows the influence of the some low frequency components which are not clearly seen in the original signs. It was difficult to build terminal improvements for firm conclusions at this point. We have revealed and focused through this study the link between earthquakes and low cloud amounts as climate measure. The year 2015 seems to be hotter in earthquakes and hide a largest number and magnitudes for earthquakes than 2014, it is worth to note that particularly they are the earthquakes of weak magnitudes which will be the largest at 2015.

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