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Link nature between low cloud amounts and cosmic rays through wavelet analysis

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ABSTRACT

Although much evidence implying correlations between low cloud cover variations and solar activity, the physical phenomenon explaining this is still poorly pronounced. Seventeen years of monthly averaged low cloud cover data from the International Satellite Cloud Climatology Project (ISCCP) are examined towards amplitude antipodal aa-index and sunspot number.

We have used in our previous study [24] Morlet wavelets to examine the processes and structures behind the variability of solar activity indicators and galactic cosmic rays variations. Morlet wavelets analysis continues to prove its power in this study field. Thus we invest in the present work Morlet wavelets tool to examine closely the possible links between solar activity and climate. The purpose of this work is to examine once for all the geomagnetic aa-index and sunspot number variations towards low cloud cover amounts variations. One of the procedures to analyse non-stationary series, to discern whether there is a linear relation or not between low cloud amounts variations on a side and the geomagnetic aa-index and the solar activity on the other side is by means of wavelet method. Thus we have analysed variations in time, we arose hidden periods and structures being able to highlight a physical causal link between solar, geomagnetic activity and low cloud cover.

Indeed besides of well-known 11 years cycle which was found common to all parameters, low cloud amounts, geomagnetic aa-index and sunspot number, three structures of 5–7 months, 12–13 months and 60–70 months (5–5.8 years) were found common to low cloud amounts variation and geomagnetic aa-index variations. Thus the iterative method used particularly in this study for extrapolation revealed more closely common hidden structures.

If relatively long periods such as 11 years cycles highlight globally the GCR-cloud connection, the community of structures and short periods highlighted through this Morlet analysis zoom prove closely the link between these parameters and low cloud amount as a measure of climate.

The Morlet wavelet analysis and our new iterative procedure for extrapolation prove with a good agreement that it is a suitable tool to reveal really hidden common structures and cycles. This analysis should be an answer to GCR-climate link around which several questions were discussed.

1. Introduction

Wavelet analysis have been employed to quantify variation and possible links between observed climate changes and solar activity around Moscow neutron monitor station.

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Wavelet tool emerged as a filtering and data compression method in the 1980s [21]. In the last decade autoregressive moving-average (ARMA) [22] and regression models [23] have also been used to evaluate possible climate change scenarios.

Looking for the contribution of significant periods, different research teams have analysed time variabilities in cosmic ray records [1,2]. Particularly continuous wavelet transform (WT) was recently used, and is useful for data series with non-stationary processes when dealing in terms of time–frequency decomposition [3–6]. In WT we use arbitrary scales and often arbitrary wavelets. However, the most important step is the wavelet choice, the wavelet type influences the time and frequency resolution of results. In fact while the derivative of Gaussian (DOG) wavelet provides a poor frequency resolution but a good time localization on the other hand we can expect that our Morlet (a plane sine wave with amplitude windowed in time by a Gaussian function) wavelet choice gives a high frequency resolution.

The continuous wavelet transform (CWT) 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 [1,2,7]. Wavelet analysis is more complicated than Fourier analysis in fact one must fully specify the mother wavelet from which the basis functions will be constructed. The mother wavelet can be complex or real, and it generally includes an adjustable parameter controlling the properties of the localized oscillation.

The wavelet theory involves general functions in terms of simple, fixed building blocks at different scales and positions. We use translations and dilations of one fixed function for wavelet expansion. Sophisticated wavelets are more powerful in revealing hidden detailed structures.

We have used in our previous study [24] for example Morlet wavelets to examine the processes, models and structures behind the variability of solar activity indicators and galactic cosmic rays variations.

However, in order to reveal new results and sustain previous ones regarding correlational analysis between the low cloud amounts and solar or geomagnetic activities and, respectively, between the solar indicators of activity and the galactic variations of radiations, we have invested in this work the Morlet wavelets mathematical zoom to highlight the possible links between low cloud cover amounts on one side, solar and geomagnetic activities on the other side.

Thus the hidden structures and unknown aspects in sunspot number, geomagnetic activity and low cloud amounts are discovered through this analysis particularly using the iterative method in extrapolation. Then they inspired us the well known searched correlation between low cloud amounts and cosmic rays.

2. Morlet analysis results and discussion

2.1. Geomagnetic activity: aa-index

The sunspot number being probably a good measure for solar irradiance [17] has decreased slightly from 1950 until mid-1970. More controversy has appeared about other parameters such as the open solar flux from the sun, the geomagnetic aa-index and the galactic cosmic ray (GCR) flux which varies inversely with solar activity.

The aa-index is based on the observations at two nearly antipodal observatories (Canberra, Australia, and hartland, United Kingdom) and is expressed in nanoteslas (nT).

We have used Morlet wavelet [9] which is defined as a complex sine wave, localized with a Gaussian. The frequency domain representation is a single symmetric Gaussian peak. The frequency localization is very good. This wavelet has the advantage of incorporating a wave of a certain period, as well as being finite in extent, it is given by

$$g(t) = \exp\left(i\omega_0 t - \frac{t^2}{2}\right), \quad (1)$$

Real parts of Morlet decomposition coefficients are given by

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

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

We have manipulated measured, limited and discrete time series. Indeed the measured yearly values of geomagnetic aa-index are given by Moscow neutron monitor [8] for 140 years period of study. Thus we need to discretise expression of Eq. (2) to be as follows:

$$w^R_{j,k} = j^{-1/2} \sum_{l=1}^{140} y(t_l) g^R_{j,k}(t_l) \quad (3)$$

The decomposition coefficients for yearly aa-index were calculated and their variation in time versus scale and translation parameters j and k were plotted (Fig. 1).

The most important periods for aa-index corresponding to highest Morlet decomposition coefficients are clear here. Indeed a period of about 20–25 years corresponding to highest decomposition coefficients is revealed in this analysis and is particularly showed in Fig. 1b,c.

How and when the periodicities of solar magnetic activity modulate the terrestrial climatic changes constitute already a main enigmas of solar-terrestrial physics. Some insights have been obtained: for one side, the solar Hale cycle (20–25 years). The studies of the solar activity changes with the aim of discovering contribution of solar activity to climatic variability. On the other hand, quasiperiodic climatic oscillations with periods of 20–25 years have been revealed in the analysis of parameters such as ground surface temperature, drought rhythm, variations in sea surface temperature, etc. [25,26].

We have also derived the Morlet decomposition coefficients corresponding to monthly variations of geomagnetic aa-index. The most important periods and structures of monthly aa are shown in Fig. 2. Primary maxima were detected for periods of 5–7 months, then 12 months.

We have reconstructed the geomagnetic aa-index variations function; we were interested to the real component of reconstructed function

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

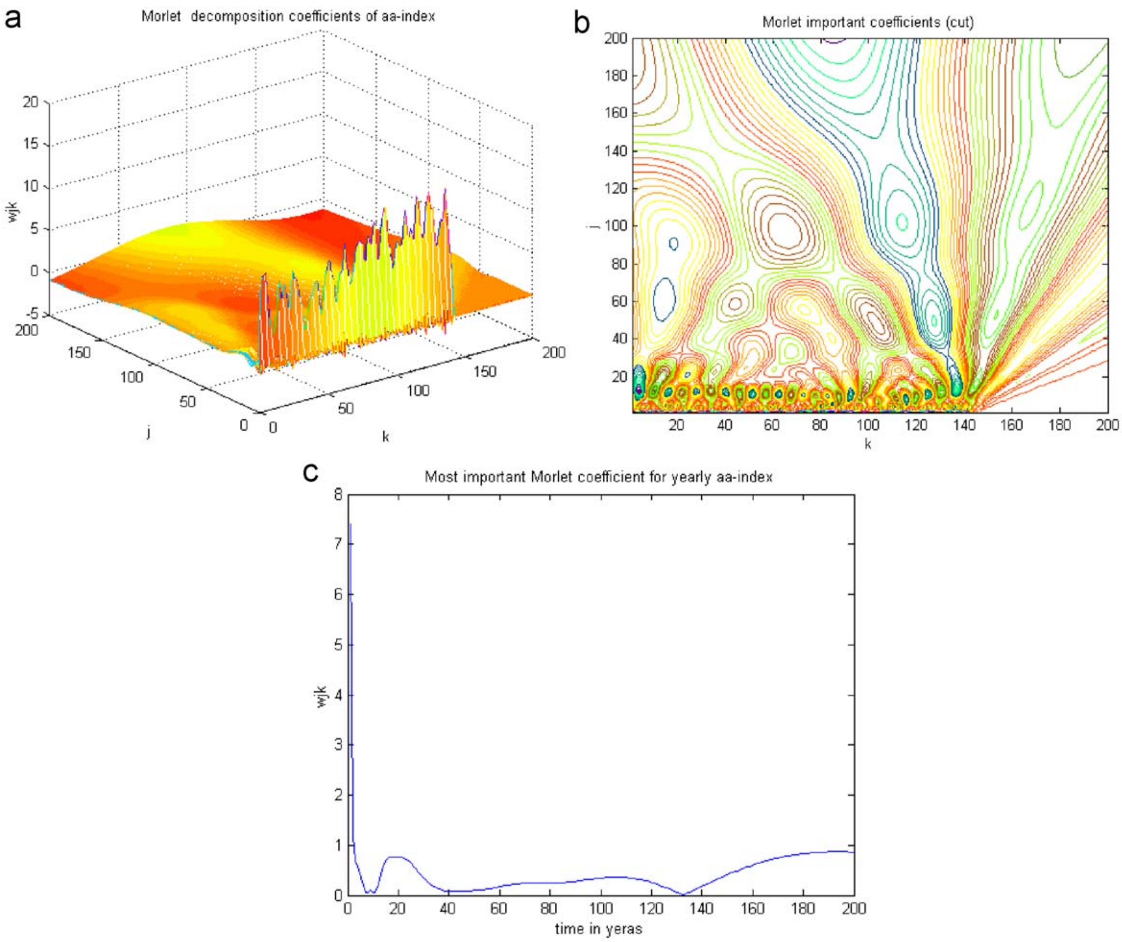

Fig. 1. (a) Morlet decomposition coefficients of yearly aa-index, (b) a cut of Morlet decomposition coefficients of yearly aa, and (c) most important coefficients.

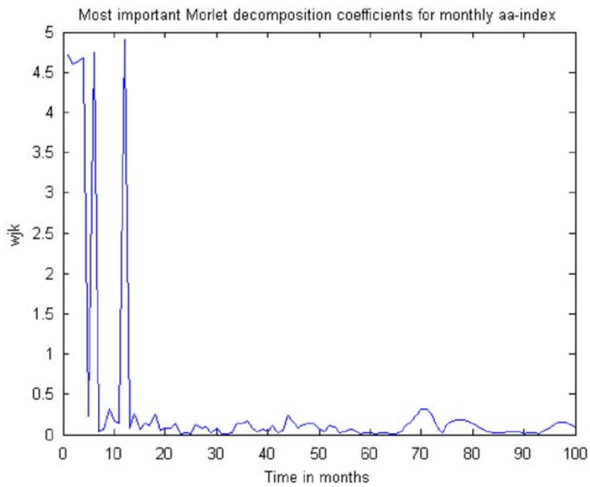

Fig. 2. Most important Morlet decomposition coefficients for monthly aa variations.

In yearly reconstruction case, scaling and shift parameter j and k vary from 1 to 140 with a step of 1 year. While for monthly reconstruction case of geomagnetic aa-index, scaling and shift parameter j and k vary from 1 to 1694 with a step of 1 month (Fig. 3).

The main 11-years cycle is evident in yearly and monthly ascertainment, as well for the original curves of aa-index variations around of Moscow station (Fig. 3a,d) as for Morlet reconstructed aa-index variations (Fig. 3b,c,e,f). We showed in Fig. 4 a zoom of the last two cycles between 1984 and 2009.

Starting from original and Morlet reconstructed curves (Fig. 3). We can notice particularly for the aa variations, a global and common increase in geomagnetic aa-index from 1868 until 2009.

After 1940 the global level of aa-index rose then fell around 1968 to increase again until now.

In our previous work [24], we have used a kind of pass band filter to obtain details and structures which are visible or even hidden in original signal.

However, in this work it is worth noting that our iterative method used for extrapolation provides us the details and quasiperiodicities in Morlet reconstructed part of the whole signal containing both reconstruction and extrapolation, this is clearly visible in Fig. 3c,f.

The Morlet extrapolation phase as well for yearly as for monthly geomagnetic aa-index values shows that the

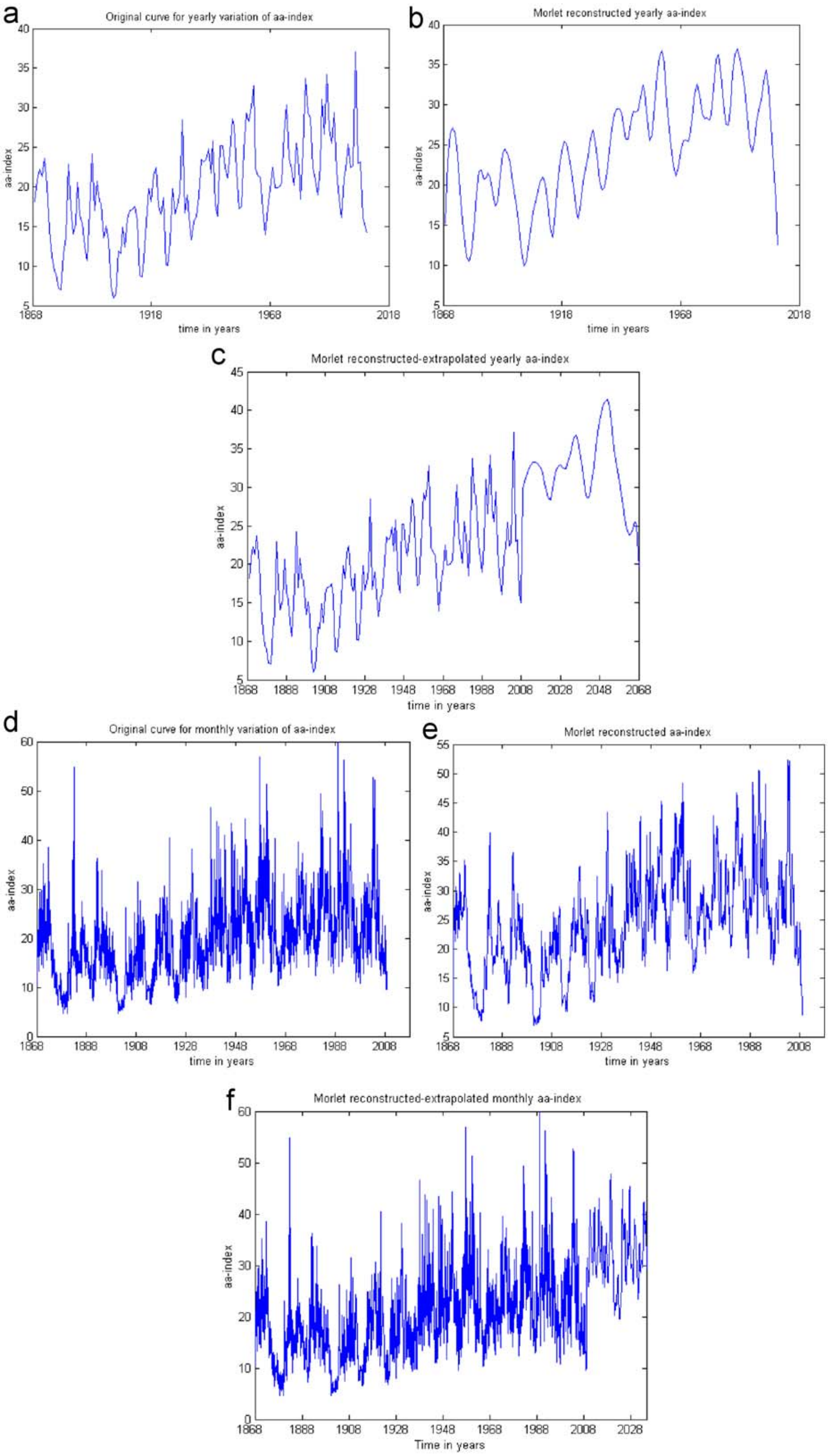

Fig. 3. (a) Original curve of yearly variations for aa-index, (b) Morlet reconstructed yearly aa, (c) Morlet reconstructed-extrapolated yearly aa; (d) original curve of monthly variations of aa, (e) Morlet reconstructed monthly aa, and (f) Morlet reconstructed-extrapolated monthly aa.

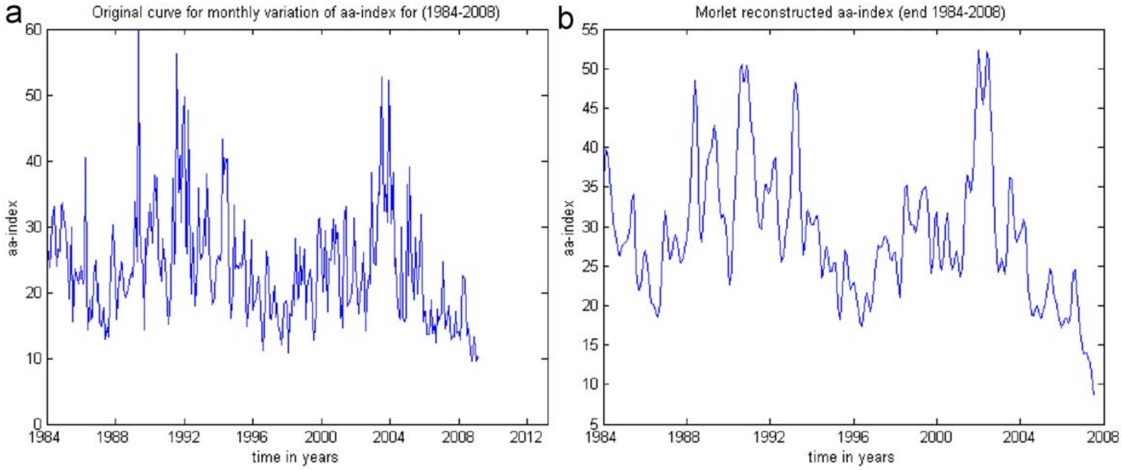

Fig. 4. (a) Original curve of last two cycles for aa variations, and (b) Morlet reconstructed aa.

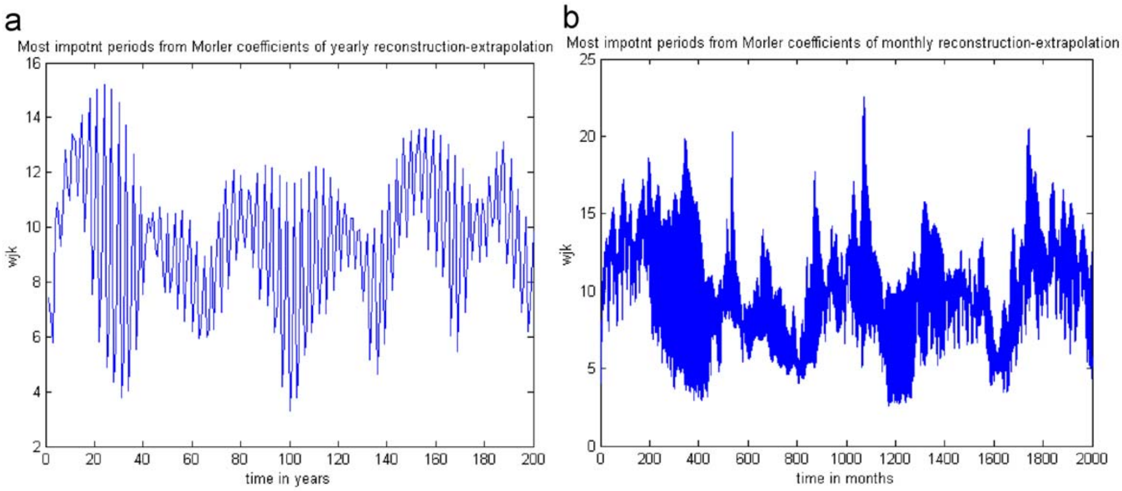

Fig. 5. Most important periods from Morlet coefficients of (a) yearly reconstruction–extrapolation aa, and (b) monthly reconstruction–extrapolation aa.

aa-index continue to increase all the period of extrapolation and we continue to detect 11 years cycle which has dilated to about 15 years Fig. 3c,f.

As we have mentioned, the innovation about the use of iterative method for extrapolation revealed the hidden cycles and structures which are also derived from Morlet important coefficients for the whole period of reconstruction–extrapolation (Fig. 5).

Indeed, in addition to 20–25 years cycle corresponding to an absolute maximum for Morlet decomposition coefficients relative to the whole period of yearly reconstruction–extrapolation, also secondary periods of 155 years then of about 190 years, a large maximum spread between 80 and 115 years and a 40 years period were revealed (Fig. 5a)

In the same way for monthly aa reconstruction–extrapolation phase, the study of most important coefficients proved the existence of periods around: 1050 months (87.5 years), 1750 months (145.8 years), 550 months (45.8 years), 360 months (30 years), 200 months (16.6 years), 850 months (70.8 years), 100–150 months (8.3–12.5 years), 1350 months (112.5 years), 60 months (5 years), 650 months (54 years), 1550 months (129 years)… organized, respectively, from most important and dominant periods to less frequent periods (Fig. 5b).

2.2. Low cloud amounts

Limited measured time series were used for low cloud cover variations provided by the International Satellite Cloud Climatology Project (ISCCP) [27] around Moscow station at 57° in latitude and 37° in longitude. Indeed, series of monthly measured values of low cloud amounts covering the period from 1983 to 2000 were decomposed in Morlet wavelets. The discretised real component of Morlet coefficients is given by

$$w_{j,k}^{R} = j^{-1/2} \sum_{l=1}^{204} y(t_l) g_{j,k}^{R}(t_l). \quad (5)$$

The study of Morlet decomposition coefficients for low cloud amounts variations (Fig. 6) revealed corresponding most marked structures around 6 months and 12–13 months, a secondary maximum is corresponding to 140 months which is equivalent to 11, 66 years period, a reduced pick occurred around 70 months corresponding to 5.8 years period.

We have reconstructed the low cloud cover amounts; the real component of reconstructed function is as follows:

$$y(t)=\sum_{j,k} w_{j,k} g_{j,k}(t). \quad (6)$$

Scale and translation parameters j and k vary from 1 to 204 with a step of one month.

The well known 11 years cycle is also apparent here through low cloud cover variations. The cycle is around 12–13 years which is visible as well for original curve as for Morlet reconstructed curve of monthly low cloud cover variations (Fig. 7b,c). The low cloud amount variations are in phase with a slight time lag with respect to cosmic rays variations (Fig. 7a,b). We can notice in this cycle and especially at the beginning of the signal a shorter period of about 5 years. A minimum for cloud amount variations is found around 1995 such as in geomagnetic aa-index and slightly shifted with respect to CR minimum (1991).

The cloud amounts cover extrapolation has been derived until 2020 as shown in Fig. 7d. The 12–13 years cycle was conserved. The extrapolation phase finished the last cycle and added another cycle. In first added cycle the original period of 1 year dilated to 1.6 years period while examining the second extrapolated cycle, only the 5 years period occurs again.

2.3. Sunspot number

Recent research shows that a closer relation exists between solar activity and climate changes than previously thought [10]. The Earth's cloud coverage has been shown to be affected by cosmic ray flux, thus correlated to solar activity which drives then space weather [11]. The latter can have a severe effect on technological system.

The 11-years cycle changes of the galactic cosmic ray intensity are inversely related with the similar changes of solar activity. They have shown that the time lag exists between the changes of the solar activity and the GCR intensity [12].

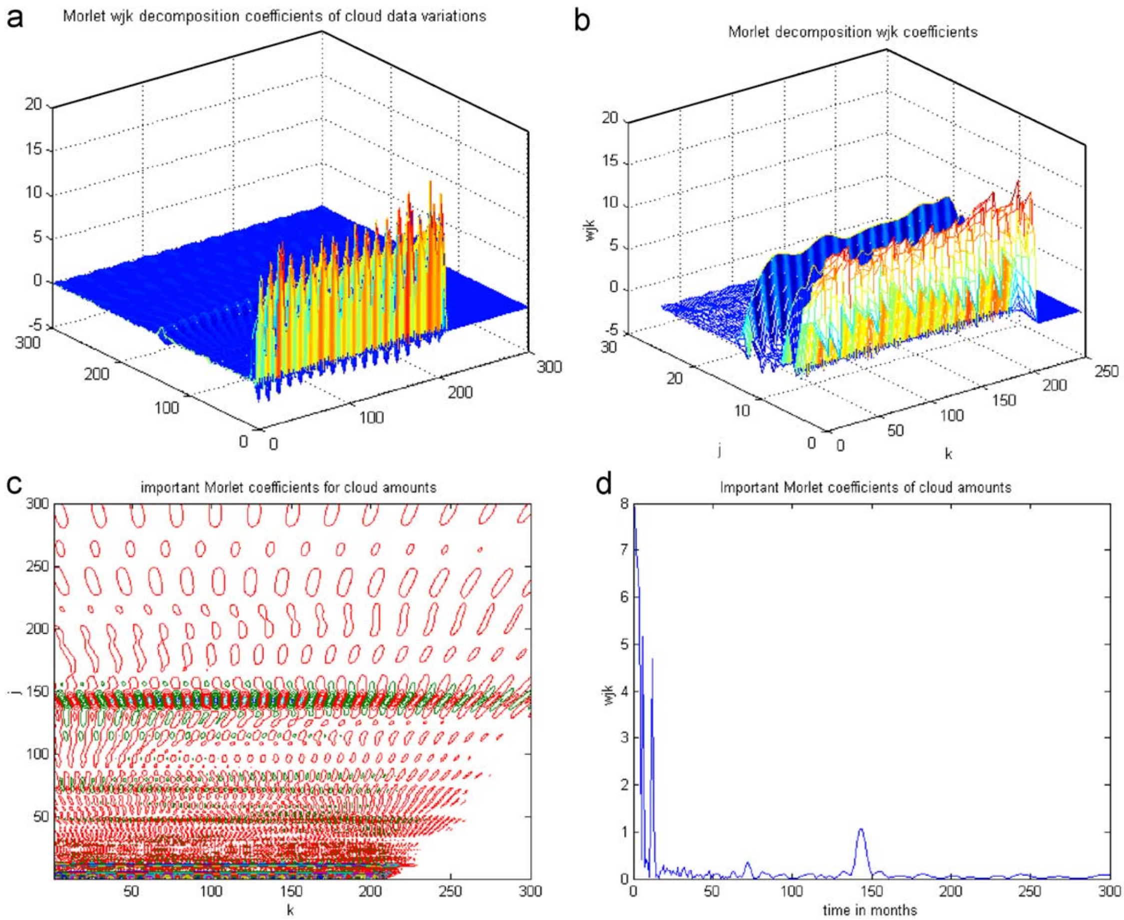

Fig. 6. (a) Morlet decomposition coefficients for low cloud amounts LCA variations, (b) zoom of Morlet decomposition coefficients, and (c) a cut of Morlet decomposition coefficients for LCA, and (d) most important coefficients for LCA.

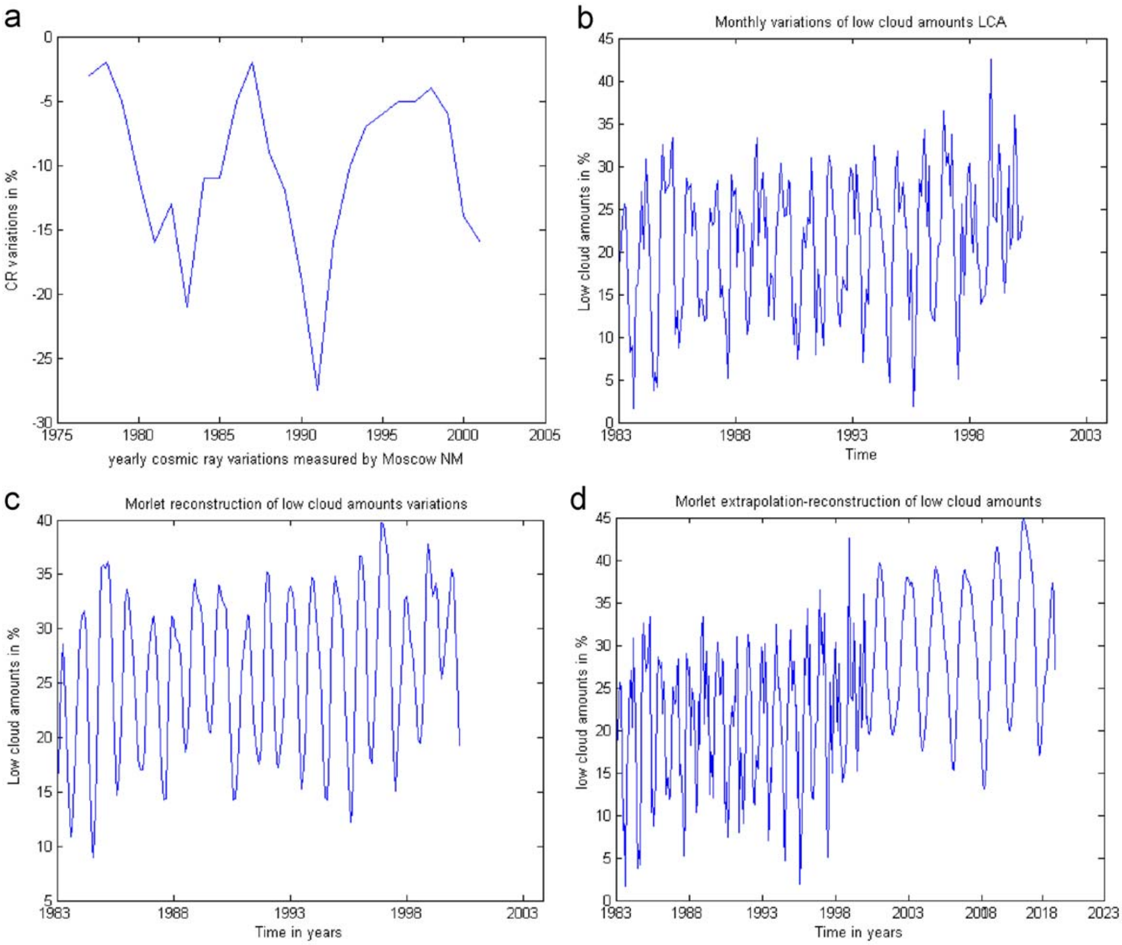

Fig. 7. (a) Yearly cosmic rays variation measured by Moscow NM, (b) monthly variations of LCA by ISCCP around Moscow station, (c) Morlet reconstructed LCA, and (d) Morlet extrapolation–reconstruction of LCA.

We have used yearly means of sunspot number (1810–2000) solar activity indicator given by Moscow NM. The original and Morlet reconstructed yearly sunspot variation, are shown in Fig. 8c,d.

As it was shown in Fig. 8a,b of decomposition coefficients the main 11–12 years already found for the cosmic rays modulation is found longer for this indicator of solar activity, it ranges from 10 to 15 years but it remains dominating for the whole period 1810 up to 2000, this is illustrated in original Moscow NM variations and Morlet reconstructed variations. A second main period is detected around 35–37 years and corresponds to an absolute maximum. We can also notice that the variability describing sunspot number is modulated with a period of 100 years.

The highest solar activities are found between 1940 and 1950 (Fig. 8c,d) as it has been claimed by Usoskin et al. [13].

The solar irradiance of which the sunspot number is a good proxy is illustrated here by steady rise in sunspot number in this period. However, the solar activity seems to drop around 1970 (Fig. 8c,d) and increase again sharply since 1982 already like the global level of aa-index which rose after 1940 and fell around 1968. Indeed after 1950 the global temperature fell slightly until the mid-1970s, while it has risen sharply since, in particular after about 1985. This warming was generally attributed to human activity [16], but we revealed through this study real connections between these cosmic rays indicators and climate.

3. Conclusion

The warming of earth's climate before 1950 was believed to be a result of several factors combination [14,15] such as increased greenhouse gas concentrations, little volcanic activity and enhanced solar irradiance. However, as it was suggested by Svensmark et al. [18], the Earth's total cloud cover is modulated by variations in the GCR flux. This hypothesis was subsequently modified by Marsh et al. [19] to a link between GCR flux and low clouds, which have a particularly strong cooling effect on climate. But because of insufficient understanding of aerosol formation and growth in atmosphere, it was

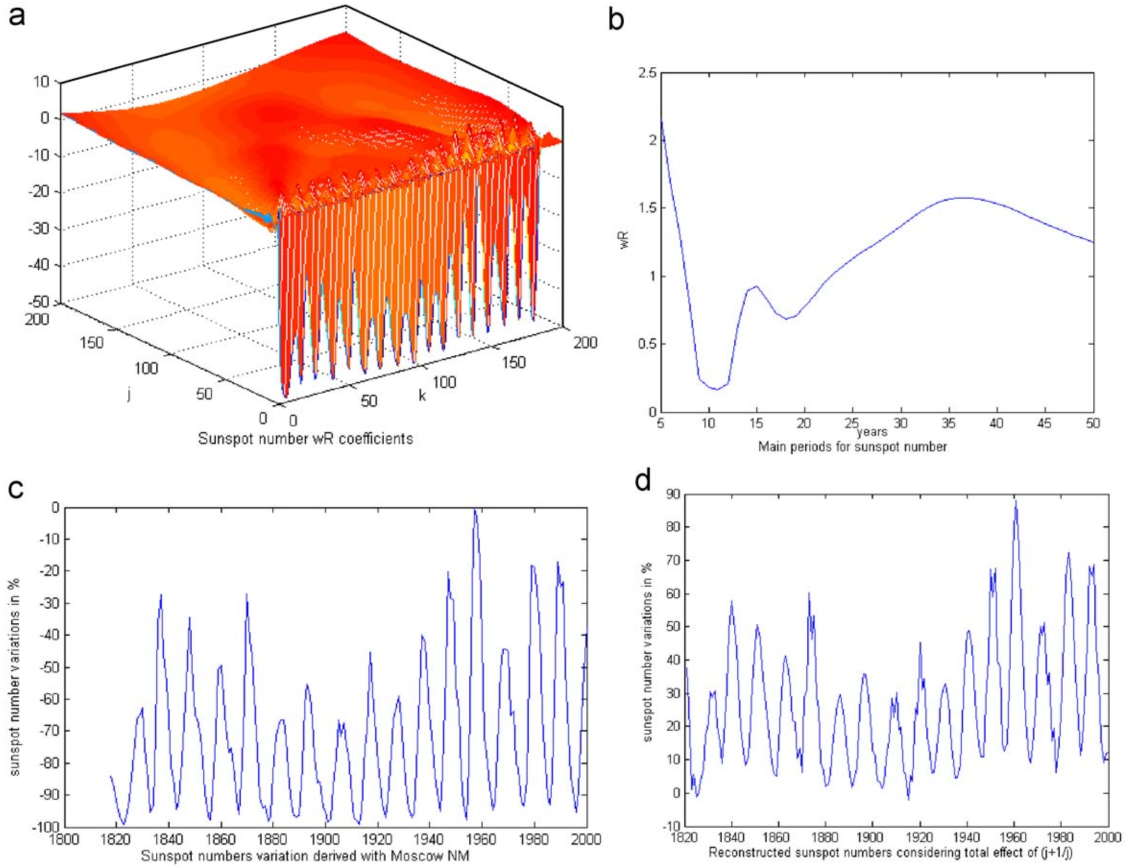

Fig. 8. (a) Morlet decomposition coefficients of sunspot number 1810–2000, (b) most important decomposition coefficients for sunspot number, (c) sunspot number variations derived with Moscow NM, and (d) Morlet reconstructed sunspot number variations.

difficult to build final improvements for firm conclusions at this point [20].

We have refined through this study the link between climate and galactic cosmic rays. The proposed Morlet physical explanation and analysis for a GCR-cloud connection through these parameters has been subject to controversy.

Indeed besides of well-known 11 years cycle which was found common to all parameters, three structures of 5–7 months, 12–13 months and 60–70 months (5–5.8 years) were found common to low cloud amounts and geomagnetic aa-index variations. Thus the iterative method used particularly in this study for extrapolation revealed more closely common hidden structures.

The 17 years period of study for low cloud amounts was not sufficient to confirm the absence of 25 years and 35–40 years cycles and more long other cycles obtained in aa-index and sunspot variations.

Finally, we would like to state that if relatively long periods such as 11 or 100 years cycles highlight the GCR-cloud amounts connection, revealing of common structures and short periods through this Morlet analysis zoom prove closely the link between these parameters: geomagnetic aa-index and sunspot number on one side and low cloud amounts as a measure of climate on the other side.

The Morlet wavelet analysis with all its stages decomposition, reconstruction and our new procedure for extrapolation proves with a good agreement that it is a strong and suitable tool to reveal really hidden common structures and cycles. Although in another way, this analysis should be an answer and finer ascertainment to GCR-climate link around which several questions were discussed.

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