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WAVELET SPECTRAL ANALYSIS OF TELECONNECTION INDICES AND ACTIVITIES OF BERYLLIUM-7 AND LEAD-210 IN GROUND LEVEL AIR IN BELGRADE, SERBIA

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Abstract. *Activities of beryllium-7 and lead-210 are monitored in ground level air in Belgrade, Serbia. The measuring sites are located at the Institute of Nuclear Sciences Vinča. The activities are determined on HPGe detectors by standard gamma spectrometry. Five teleconnection indices of large scale atmospheric circulation: North Atlantic Oscillation, East Atlantic Pattern, East Atlantic/West Russia Pattern, Scandinavia Pattern, and Polar/Eurasia Pattern are obtained from the data archive of the United States National Oceanic and Atmospheric Administration's Climate Prediction Center. The collected time series consist of monthly values and span more than two decades: beryllium-7 since 1991, lead-210 since 1985, and the teleconnection indices since 1950, thus offering data arrays of sufficient lengths for wavelet spectral analysis. A relation between the radionuclides' activities and the indices is first investigated using Pearson's correlation coefficients. The computed coefficients do not indicate a linear relationship between the variables. However, the wavelet spectral analysis shows a number of common characteristic frequencies in the data arrays. The annual cycle of all the variables is clearly evident. A common time period of two to three years is also found, as well as a higher frequency variability corresponding to five to six months.*

Key words: ***beryllium-7, lead-210, air, teleconnection indices, wavelet analysis***

1. INTRODUCTION

Beryllium-7 and lead-210 are naturally occurring radionuclides that can be used as tracers of air mass history. These isotopes have different origins: ^{7}Be (half-life 53.22 days) is produced in the upper troposphere and lower stratosphere, while the main source of ^{210}Pb (half-life 22.23 years) is its radioactive parent radon-222 that emanates from the soil.

The behaviour of ^{7}Be and ^{210}Pb after their formation is similar: they promptly get attached to aerosols, whose mean residence time in the atmosphere is longer than 30 days [1], and their ensuing transport is governed by atmospheric circulation. Furthermore, mechanisms of their removal from the atmosphere are the same, with wet deposition being most significant [2]. Concentrations of ^{7}Be and ^{210}Pb and their relation to local climate variables have been extensively studied [2, 3].

Due to their different origin, the concentrations of ^{7}Be and ^{210}Pb vary with height in the atmosphere. Air masses coming from the upper troposphere and lower stratosphere contain higher concentrations of ^{7}Be than surface air masses. Beryllium-7 can thus be used as a stratospheric tracer, and has been investigated as an indicator of exchange processes between the stratosphere and troposphere [4, 5]. On the other hand, surface air masses are richer in ^{210}Pb than air masses from higher altitudes. Moreover, the ^{210}Pb concentration is higher in continental air masses than in air masses originating over a body of water [6].

The behaviour of ^{7}Be and ^{210}Pb in surface air is influenced by large-scale atmospheric transport [4, 7], which is quantified by teleconnection indices.

The North Atlantic Oscillation (NAO) index is one of the most commonly used teleconnection indices to describe a large-scale circulation pattern over the North Atlantic Ocean and surrounding land masses [8]. The North Atlantic Oscillation can be described as a pressure dipole with one centre associated with the Icelandic low and the other with the Azores high pressure centre. Two oscillation phases, distinguished by the NAO index, induce differences in the position and strength of the North Atlantic jet stream and storm track in midlatitudes [9]. The changes in large-scale circulation patterns further reflect on local weather conditions especially over eastern North America and across Europe, including Serbia [10].

The Polar/Eurasia pattern (POL) is another teleconnection that has an impact on weather in Europe [11]. The POL index quantifies tri-pole anomalies centred over the Northern Hemisphere polar region, and Europe and north-eastern China [8].

2. Materials and Methods

In Belgrade, Serbia, at the Vinča Institute of Nuclear Sciences, continual measurements of the ^{7}Be and ^{210}Pb activities in surface air started in 1991 and 1985, respectively. The monthly mean activities of ^{7}Be and ^{210}Pb in composite aerosol samples were determined on HPGe detectors by standard gamma spectrometry. The activities of ^{7}Be and ^{210}Pb were determined by using the gamma energies of 477.6 keV and 46.5 keV, respectively. A detailed description of the measurement procedure is given in [3].

The monthly values of five teleconnection indices of large scale atmospheric circulation: North Atlantic Oscillation, East Atlantic Pattern, East Atlantic/West Russia Pattern, Scandinavia Pattern, and Polar/ Eurasia Pattern were obtained from the data archive of the United States National Oceanic and Atmospheric Administration's Climate Prediction Center (http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml visited on 18 October 2013). A description of the procedure used to identify the Northern Hemisphere teleconnection patterns and indices is given in [8]. The monthly values of teleconnection indices since 1950 were available.

An investigation of a relation between the time series was conducted in two steps. First, Pearson's linear correlation coefficients were used to quantify a degree of linear correlation between the variables. Second, wavelet transform analysis was performed to investigate similar periodicities in the time series which could imply a causal relationship between the radionuclides' activities and teleconnection patterns, even if that relationship is not linear in its nature.

Wavelet transform (WT) is a useful tool in investigation of time series that contain nonstationarities on a number of different frequencies [12]. Transforming a signal $s(t)$ with a set of wavelet functions $\psi_{a,b}(t)$ gives a set of coefficients (wavelet amplitudes):

$$W(a,b) = \int \psi_{a,b} \cdot s(t) \cdot dt \qquad (1)$$

Using WT, a global wavelet power spectrum (which corresponds to Fourier power spectrum) can be obtained by integrating wavelet amplitudes over time parameter b:

$$E_W(a) = \int W(a,b) \cdot db \qquad (2)$$

A set of Morlet wavelets (with ω_0=4) was used to calculate WT and then the wavelet scale a was recalculated into a corresponding Fourier period T. In contrast to Fourier spectra, wavelet spectra are smooth and can therefore be used to estimate characteristic times (periods) in the data sets containing the radionuclides' activities and teleconnection indices.

The calculated spectra represent variations of the analysed signals on different time scales, and show increased values for the events occurring at a characteristic time scale. To detect those characteristic scales, a standard peak analysis was performed by searching the maximum and saddle (for hidden peaks) points in the global wavelet power spectra of the radionuclides' activities and teleconnection indices.

3. Results and Discussion

Pearson's linear correlation coefficients were first calculated by pairing the data points from the activities and teleconnection indices for each given month. The computed coefficients did not indicate a linear relationship between the variables.

Next, a time lag of 1 to 12 months was introduced in the calculations, thus allowing a possible shift in the correlation. For example, a linear correlation with a time lag of 1 month would imply that changes in one variable took about a month to reflect on the changes in the second variable. However, the obtained coefficients again indicated that there was no linear correlation between the variables.

To further investigate a relation between the teleconnection patterns and the activities, wavelet transform was used to calculate characteristic periods in each of the data sets separately. Characteristic periods correspond to a time coordinate of the local maxima in the power spectrum. For example, the power spectra for ^{7}Be, ^{210}Pb, North Atlantic Oscillation and Polar/Eurasia indices are given in Fig. 1.

The characteristic frequencies were then examined to find similarities in different data sets. The aim of this analysis, however, was only to suggest a possible direction in which to search for a potential causality between the radionuclides' activities and atmospheric circulation.

Short characteristic periods of 2-3 and 5-6 months were found in all of the data sets. These seasonal and biannual periodicities are well known in the behaviour of ^{7}Be and ^{210}Pb [2, 3, 13].

The time periods of 11-13 months, corresponding to an annual cycle, were also found. A longer time period of 30-36 months, was evident in the isotopes' activities, as well as in the NAO and POL time series (Fig. 1). For example, a 36-month period found in the NAO series agrees well with the period of 2-4 years noted by [14].

Our results further showed a somewhat shorter time period of 20-30 months in the ^{7}Be concentrations. This period was also found in the analysis of [7] and was attributed to quasi-biennial oscillation.

The North Atlantic Oscillation is considered a dominant teleconnection in the Northern Hemisphere, but its specific frequencies did not match the ^{7}Be and ^{210}Pb frequencies as well as the POL pattern (Fig. 1). An explanation may lie in the fact that one of the three poles of the POL is centred over central Europe, and the pressure anomalies associated with it can have a rather direct influence on weather in Serbia. Over Europe, a positive phase of POL is accompanied by an anticyclonic pressure field, which is often characterised by dry weather condition, air subsidence and temperatures higher than the average. Since the ^{7}Be and ^{210}Pb activities show correlation with this type of weather condition [3], it could be expected that they are also correlated with POL. This type of correlation between the NAO index and the radionuclides' activities is less evident because the NAO poles are positioned westward of Serbia. Still, a frequency of stratospheric intrusions over the Apennines was related to the NAO phases [4] implying an indirect, but possibly localised, influence of NAO on the ^{7}Be concentration.

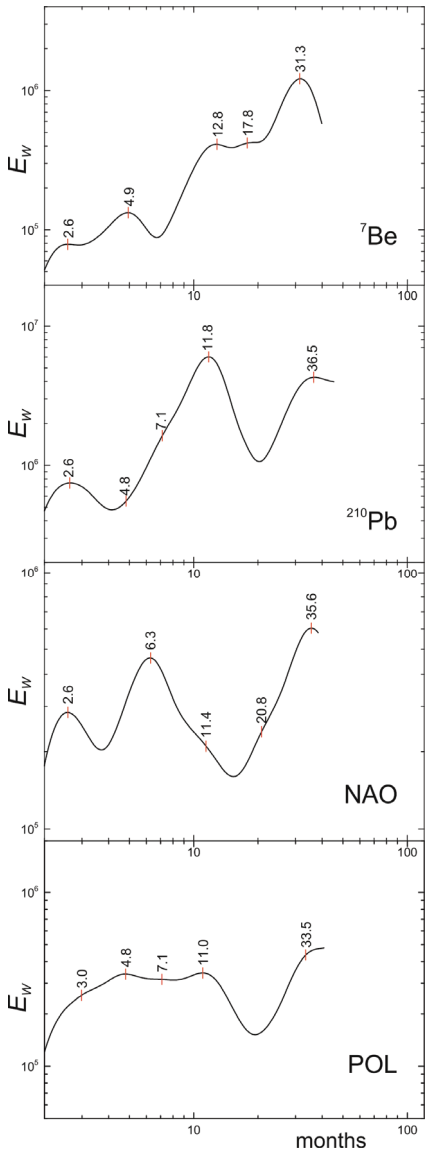

Fig. 1 Power spectra of the ^{7}Be and ^{210}Pb activities, NAO and POL teleconnection indices. Positions of the maximum and saddle points are marked with the assigned values of characteristic time in months.

The availability of the aerosol samples (a composite monthly sample) limited the shortest time periods that could be captured in our analysis to an order of a month, not allowing examination of higher frequencies such as 19 and 36 days that were found in a wavelet analysis of daily ^{7}Be concentrations by [15].

At the other end of the time scale, the longest time periods, of about 40 months, were limited by the length of the time series. Thus, the 11-year solar cycle whose signature on the ^{7}Be concentration has been found [2, 16], could not be observed in our analysis.

4. Conclusions

A relation between the ^{7}Be and ^{210}Pb activities measured in Belgrade, Serbia, on one hand, and five teleconnection indices representative of large-scale atmospheric circulation, on the other hand, was investigated. Linear correlation between the variables was not found. Similar periodicities in the activities and the teleconnection indices were calculated in the wavelet transform analysis. Apart from the seasonal, biannual and annual behaviour, an oscillation of 30-36 months was also found. Further, the characteristic time periods of the Polar/Eurasia pattern seemed to match the periods of the radionuclides' activities better than the other investigated indices.

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