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Dynamics of beryllium-7 specific activity in relation to meteorological variables, tropopause height, teleconnection indices and sunspot number

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HIGHLIGHTS

- Four characteristic periods in the Be-7 surface concentrations are found.
- The investigated variables show mutual periodicities with Be-7.
- Be-7 long-range auto-correlation reversals occurred in 2000 and 2008.
- The reversals are preceded by correlation changes in teleconnection indices.

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ABSTRACT

The dynamics of the beryllium-7 specific activity in surface air over 1987–2011 is analyzed using wavelet transform (WT) analysis and time-dependent detrended moving average (tdDMA) method. WT analysis gives four periodicities in the beryllium-7 specific activity: one month, three months, one year, and three years. These intervals are further used in tdDMA to calculate local autocorrelation exponents for precipitation, tropopause height and teleconnection indices. Our results show that these parameters share common periods with the beryllium-7 surface concentration. tdDMA method indicates that on the characteristic intervals of one year and shorter, the beryllium-7 specific activity is strongly autocorrelated. On the three-year interval, the beryllium-7 specific activity shows periods of anticorrelation, implying slow changes in its dynamics that become evident only over a prolonged period of time. A comparison of the Hurst exponents of all the variables on the one- and three-year intervals suggest some similarities in their dynamics. Overall, a good agreement in the behavior of the teleconnection indices and specific activity of beryllium-7 in surface air is noted.

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1. Introduction

Beryllium-7 (half-life 53.22 days) is a naturally occurring radionuclide that is produced in the upper troposphere (around 30%) and lower stratosphere (around 70%) [1]. After formation ^{7}Be attaches to fine aerosols, and its residence time in the atmosphere is long [2–5]. The ensuing transport of the aerosols, and therefore of the radionuclide, is governed by the atmospheric circulation [6,7].

Concentration of ^{7}Be in any given location (altitude, latitude, longitude) depends on several factors [8]. First, the source of the radionuclide is its production in the higher layers of the atmosphere. Therefore, the production rate influences the total amount of the radionuclide. Second, transport can increase or decrease the radionuclide concentration at a particular location, depending on abundance of ^{7}Be in the transported air masses. Finally, the rate of the isotope removal influences its concentration in the atmosphere.

The above mechanisms have been investigated. Monthly ^{7}Be specific activities in surface air are inversely correlated with solar activity [6,9,10]. Air masses originating in the upper troposphere and lower stratosphere contain higher concentrations of ^{7}Be than surface air masses [11]. 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 [12,7]. Further, the ^{7}Be concentration maxima have been correlated with an enhanced vertical transport and the intrusion of the stratospheric air masses across the tropopause [13–16]. A positive correlation between the tropopause height and the ^{7}Be specific activity in surface air has been shown [17,18]. Longitudinal and latitudinal distribution of ^{7}Be in the air has been noted [8,19–21], and it is in part influenced by horizontal transport within the troposphere. Wet deposition is the most significant mechanism of ^{7}Be removal from the atmosphere [10,22,23], although different studies have shown no correlation or a negative correlation of the ^{7}Be specific activity with precipitation [6,10,24–27].

To further explain the behavior of ^{7}Be in surface air, its relation to local climate variables, including (but not limited to) temperature, atmospheric pressure, relative humidity, and sunshine hours, has been extensively studied [22,13,28–30,10, 31–34]. These studies, however, did not include an analysis of ^{7}Be relation with large-scale atmospheric circulation.

Variability in atmospheric circulation is described by teleconnection patterns, such as the North Atlantic Oscillation (NAO), Arctic Oscillation (AO) and Pacific/North American (PNA) [35,36]. These patterns are a measure of pressure oscillations over different locations, and have been shown to influence large-scale circulation [37–39], which further reflects on local weather conditions [40–43].

An influence of NAO on ^{7}Be has been implied [7,44], but only relatively recent studies have focused on the ^{7}Be specific activity in the air and large-scale transport. For example, the abundance of ^{7}Be in Fennoscandia is not only influenced by NAO [45,46], but the atmospheric conditions seem to play a more important role than production [47]. Further, AO can modulate the stratosphere–troposphere exchange, and as a consequence, the AO variability can explain a large part of ozone variability in the lower troposphere over North America [48]. This finding is also relevant for ^{7}Be which is, along with ozone, transported from the stratosphere into troposphere.

To summarize, there have been a number of studies on the ^{7}Be specific activity in surface air and its relation with local meteorological conditions, sunspot number, and tropopause height, and somewhat fewer studies on the influence of large-scale atmospheric transport. Most of these studies looked into linear relationship between the ^{7}Be specific activity and a set of chosen variables. However, there have been no in-depth statistical analysis encompassing meteorological variables, tropopause height, sunspot number and teleconnection indices (which quantify large-scale transport). The goal of our investigation is to look into common periodicities of the mentioned variables, whose existence could help to understand a relationship between the variables, even if it may not be linear in its nature. Two statistical analysis methods are used to investigate the dynamics of the ^{7}Be surface concentration: wavelet transform analysis and time-dependent Hurst exponent method.

2. Data

Time series of 11 measured variables were analyzed. The ^{7}Be specific activity in surface air, five meteorological variables, and the tropopause height were of local character—the data were recorded in Helsinki, Finland (60.21°N; 25.06°E; 12 m a.s.l). On the other hand, three teleconnection indices and sunspot number quantify hemispheric circulation, and sun activity, respectively. This set of variables was chosen in attempt to include as many as possible factors potentially influencing the ^{7}Be specific activity in surface air, but this choice was limited by the number of meteorological variables available for Helsinki, and by the temporal resolution of the available teleconnection indices. The length of the investigated time series differed, and the start and end date of the analysis were chosen to coincide with the available ^{7}Be specific activity data—from 1 January 1987 to 31 December 2011, thus spanning 25 years.

Beryllium-7 specific activity in surface air. The analyzed data are a subset of the Radioactivity Environmental Monitoring Database (REMdb) supported by REM group from the Institute of Transuranium Elements, of the DG Joint Research Centre (JRC). The ^{7}Be data prior to 2007 stored in the REMdb is public, and an access to the data over the 2007–2011 period can be granted only after explicit request. More information on the REMdb can be found on its web page (https://rem.jrc.ec.europa.eu/) and in [21,49,50]. The measurements conducted in Helsinki represent the largest set with more than 4000 data points over 1987–2011. The sampling frequency of the measurements varied: prior to 1999, the