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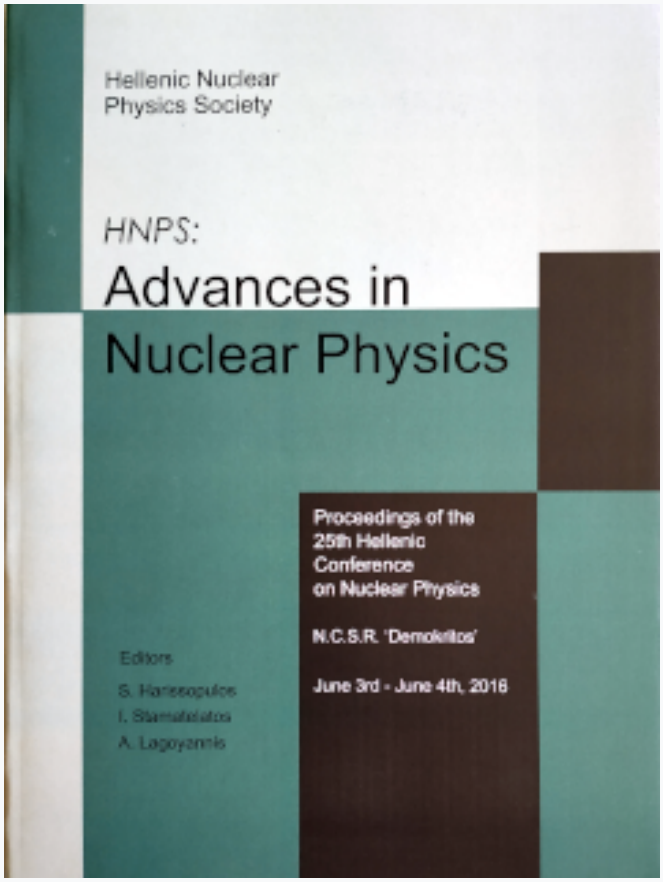

Time lag between the tropopause height and the levels of 7Be concentrations in surface air

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Time lag between the tropopause height and the levels of ^{7}Be concentrations in surface air

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Abstract The concentration of ^{7}Be at near surface air has been determined over 2009, which was a year of a deep solar minimum, at three different locations in Finland: Ivalo (68°64'N, 27°57'E), Rovaniemi (66°51'N, 25°68'E) and Kotka (60°48'N, 26°92'E). In geomagnetic latitudes over λ = 60° N, the elevation of tropopause during the warm summer months and the vertical exchange of air masses within the troposphere cause greater mixture of the air masses resulting in higher concentration levels for ^{7}Be in surface air. However, different climatic phenomena, such as air masses from the East, make the correlation between the monthly activity concentrations of ^{7}Be and the tropopause height fairly weak. For Ivalo and Rovaniemi it was found that changes in the daily surface concentrations of ^{7}Be lag the changes in the elevation of the tropopause by four days. In Kotka, the correlation is weakest.

Keywords ^{7}Be, atmosphere, tropopause, Solar cycle, correlation coefficient

INTRODUCTION

Beryllium – 7 ($t_{1/2}$ = 53.3 d) is a cosmic – ray produced radionuclide, which is formed in the upper troposphere and lower stratosphere by spallation reactions of light atmospheric nuclei. Its flux to the Earth's surface varies with the 11 – year solar cycle and has a latitudinal dependence with higher values around the magnetic poles and lower values in the equatorial region.

Besides the latitude, the cosmic ray flux and therefore the production rate of cosmogenic nuclides depends on the altitude. The production rate begins to increase at the top of the atmosphere, reaches a maximum at about 20 km in the stratosphere and finally decreases gradually down to the Earth's surface [Masarik and Beer, 1999]. The combined effects of high ^{7}Be production rates in the stratosphere (about 70%; [Lal and Peters, 1967]) and the relatively rapid removal of aerosol – associated species from the troposphere, produce stratospheric ^{7}Be concentrations about an order of magnitude higher than those just below the tropopause [Bhandari et.al., 1966]. Because of the thermal structure of the stratosphere and its separation from the troposphere by the tropopause, the residence time of aerosols in the stratosphere is substantially longer (about 1 – 2 years) than in the troposphere, where is in the

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order of week [Papastefanou and Ioannidou, 1995]. Stratosphere serves as a reservoir of ^{7}Be –rich air injected into the troposphere via the global – scale Brewer – Dobson circulation [Holton et al., 1995] or during stratosphere to troposphere exchange events [Feely et al., (1989), Zanis et al., (1999)]. The concentrations of ^{7}Be in the troposphere and near the ground level, show variations which are connected with exchange of air between the stratosphere and the troposphere in situation of tropopause folding events.

The tropopause marks the boundary between the troposphere and stratosphere, and a fundamental characteristic of the tropopause is a change in static stability (temperature lapse rate) across the interface. The WMO [World Meteorological Organization, 1957] definition of the tropopause is based on lapse rate criteria (decrease of temperature with height becomes less than 2° C/km), although the tropopause can also be defined by more general stability criteria, quantified by potential vorticity (PV) [Hoerling et al., 1991].

In the tropics the tropopause is relatively high (~16 km), reflecting a transition between radiative – convective balance in the troposphere and radiative balance in the stratosphere [Thuburn and Craig, 2002]. The tropopause in the extratropics is lower (8 – 12 km), with an equilibrium structure determined by baroclinic wave dynamics [Held, (1982), Haynes et al., (2001), Schneider, (2004)]. The extratropical tropopause is characterized by large dynamic variability, often with complex spatial structure (such as three – dimensional folds, e.g. [Bithel et al., (1999), Nielsen-Gammon, (2001)]). There is a well – marked ‘’tropopause gap’’ or break where the tropical and polar tropopauses overlap at 30° - 40° latitude [Kochanski, 1955]. The break is in the region of the subtropical jet stream and is of major importance for the transfer of air and tracers (humidity, ozone, radioactivity) between stratosphere and troposphere. The height of the tropopause varies seasonally and also daily with the weather systems, being higher and colder over anticyclones than over depressions.

The current study presents an analysis of ^{7}Be data at geomagnetic latitudes over 60° N in Finland, during the year 2009, a year of a deep solar minimum, and as a consequence a year of maximum concentrations of ^{7}Be in near surface air. During a year of solar minimum any fluctuation on ^{7}Be concentrations are unaffected by the solar modulation and the differences in ^{7}Be fluctuations due to meteorological and seasonal variations are becoming easily to be revealed. The main objective of this study is to define the time – lag between the elevation of tropopause and concentrations of ^{7}Be in near surface air for three different regions in Finland.

INSTRUMENTATION AND METHODS

Atmospheric concentrations of Beryllium – 7 were measured by air sampling, using Staplex high – volume air samplers with Staplex type TFAGF 810 glass – fiber filters 8’’x10’’ and having 99.28% collection efficiency for particles as small as 0.3 μm. This design involves a regulated air – flow rate of 1.7 – 1.92 m^3 min^{-1} (60 – 68 ft^3 min^{-1}). The length of each collection period was one week.

After the collection procedure, the filters are folded and compressed by means of hydraulic press at up to 3 tons to give a cylinder 5.8 cm diameter and 2 mm height. All the samples were measured for ^{7}Be activity (E_γ = 477 keV) using a high resolution (1.9 keV at

1.33 MeV) and high efficiency (42%) low – background HPGe detector. The 1σ counting uncertainties for ^{7}Be measurements were almost always smaller than 8%. Blank filters were regularly checked.

Meteorological data concerning the temperature T (°C), Relative Humidity (RH%), during sampling dates were obtained from a meteorology station at the roof of the Faculty of Science building.

Apart for the meteorological parameters, a tropopause height time series of daily values for the period of ^{7}Be observations was obtained from the NCEP/NCAR Reanalysis data.

RESULTS AND DISCUSSION

The periodic pattern of mean weekly ^{7}Be activity concentrations in near surface air over year 2009 presents a strong seasonal variation with the highest values being observed in the summer months and the lowest in the winter months. Also, high values were observed during the spring period. For the area of Ivalo the largest concentration of ^{7}Be was 5.428 mBq/m^{3} and was observed in January. For Rovaniemi the largest concentration was 4.3574 mBq/m^{3} and was observed in August and finally the highest concentration of ^{7}Be in Kotka region was 6.93 mBq/m^{3} and was presented in June. Also, we applied the method of deviation from the moving average, for the calculation of average weekly values of ^{7}Be. (Fig. 1). The production rate of ^{7}Be depends on the flow of cosmic radiation. Furthermore, the concentrations of ^{7}Be are known that are formed by large – scale atmospheric phenomena (such as NAO and ENSO).

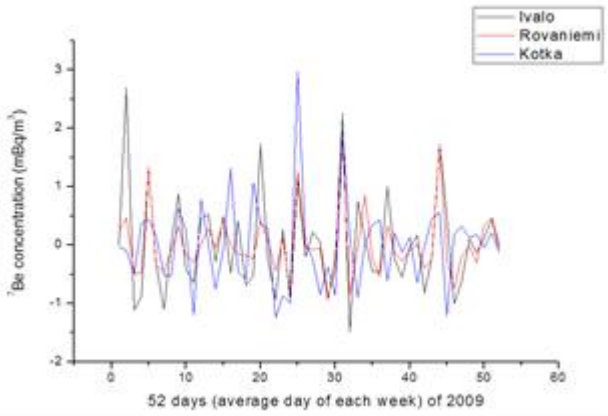

Fig. 1. Weekly variation of ^{7}Be activity concentrations for the three areas.

According to our knowledge, in mid latitudes there is a strong positive correlation between the seasonal changes of the tropopause height and the concentrations of ^{7}Be in surface air and in case of 40°N has defined a time – lag between tropopause height and ^{7}Be surface concentrations of 3 – 4 days [Ioannidou et al., 2014]. For higher latitudes, the elevation of tropopause in the summer months, which are warmer, along with the vertical exchange of air masses in the troposphere, lead to higher concentrations of ^{7}Be in surface air.

In this work we examine the influence of tropopause height on ^{7}Be concentrations in surface air at latitudes above 60°N. The concentration of ^{7}Be at near surface air has been determined over the year 2009, at three different locations in Finland: Ivalo (68°64'N, 27°57'E), Rovaniemi (66°51'N, 25°68'E) and Kotka (60°48'N, 26°92'E). Year 2009 was a year of solar minimum, ie. a year of high production rate, and at the same a period when the cosmogenic flux was stable. So it was the ideal period to study atmospheric changes and reveal the differences in ^{7}Be fluctuations due to any meteorological and seasonal variations.

For our analysis, the tropopause height was determined for a small shell that covers each one region for year 2009 daily (Fig. 2, 3, 4).

The equation used in order to find the height of the tropopause is given here.

$$TropoHeight = \frac{Z_1 + Z_2}{2}$$

$$Z_1 = \frac{287 Temp_{1i}}{9{,}81 \log\left(\frac{Pr_{1i}}{Tropopres_i}\right)} + GH_{1i}$$

The number 1 refers to the one isobaric surface and (i) runs from 1 to 365 days of 2009. The same is for the second surface. (Temp) and (Tropopres) refer to the temperature and pressure of the air at the tropopause levels. (GH) and (Pr) refer to the geopotential height and pressure of the closest isobaric levels. Holding the same column of data for ^{7}Be we calculate the correlation coefficient (R) for each new column of daily data of the tropopause height. The new columns are created by going back in time with a step of one day in order to find how many days we have to wait until the concentrations of ^{7}Be responds to the elevation of the tropopause height.

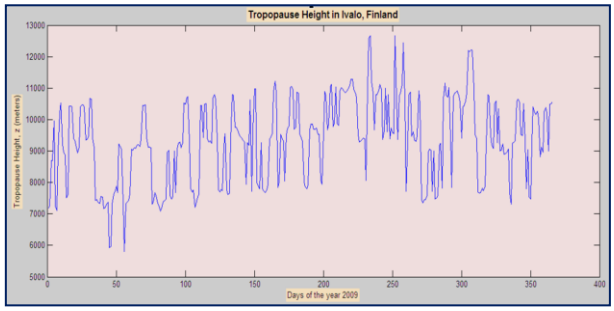

Fig. 2. Tropopause height for Ivalo.

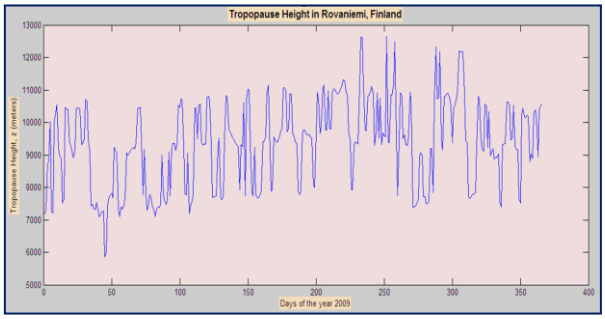

Fig. 3. Tropopause height for Rovaniemi.

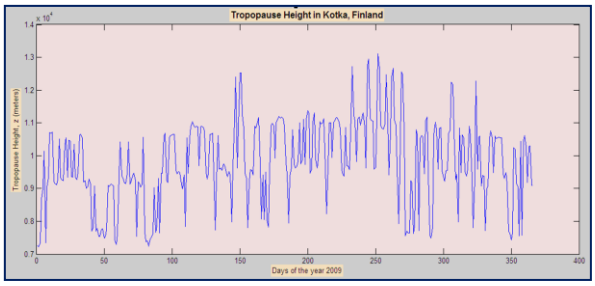

Fig. 4. Tropopause height for Kotka.

What is necessary to study and understand are the factors that affect the time delay of the interdependence of the height of tropopause and ^{7}Be concentrations, knowing in advance that the ^{7}Be located in the surface layer of the atmosphere did not immediately responds to changes of the height of the tropopause. Analysis gave that at latitudes over 60°N the correlation between the tropopause height and ^{7}Be concentrations is weak.

For Ivalo and Rovaniemi it was found that changes in the daily surface concentrations of ^{7}Be lag the changes in the elevation of the tropopause by four days (Fig. 5).

In Kotka station, the influence of tropopause height on the surface concentrations of ^{7}Be is the weakest (Fig. 5). In Kotka region it seems that the influence of air masses from the East has greater influence on ^{7}Be concentrations instead of the influence of the tropopause height.

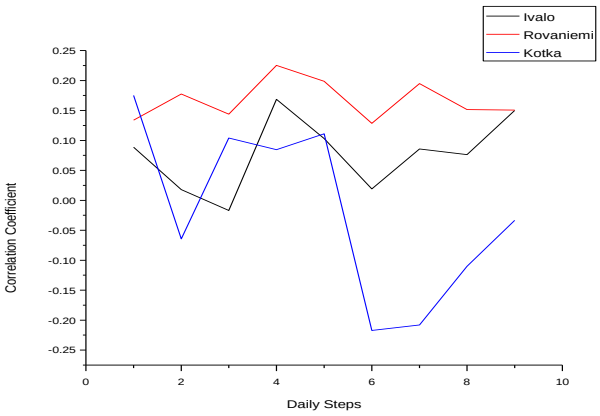

Fig. 5. Day lag plot for the three locations in Finland.

CONCLUSIONS

One year of ^{7}Be data obtained during a year of a deep solar minimum were analyzed together with a set of meteorological parameters and tropopause height in order to define the time – lag between the elevation of tropopause height and the ^{7}Be concentrations in near surface air.

^{7}Be concentrations were found to have a distinct annual cycle with a clear maximum during warm summer months.

In general the large fluctuations in the values of the correlation coefficients show a weak correlation between the ^{7}Be and tropopause height for latitudes above 60°N. The factors

affecting ^{7}Be surface air concentrations in Finland are mainly of atmospheric origin and the observed differences in ^{7}Be concentrations in surface air are mainly caused by the different climate/weather patterns during the time of observations [Leppänen and Paatero, 2013]. The changes in air mass transport patterns associated with NAO (North Atlantic Oscillation) and AMO (Atlantic Multidecadal Oscillation) were determined to be the main contributor to the interannual variability of surface air ^{7}Be activities in Finland [Leppänen et al., 2012].

This is the first approach of determining the data and further analysis is needed for more accurate conclusions.

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