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Atmospheric Beryllium-7 Concentrations and Sun Spots

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Abstract—Atmospheric concentrations of Be-7 have been measured over an almost 7-year period from July 1987 to May 1994 in the region of Thessaloniki, Greece at a temperate latitude (40°38′N) with very dry (precipitation-free) climate at east longitude (22°58′E) in the European continent of the Northern Hemisphere. High Be-7 concentrations in air were related to the very low solar activity (1987–1988), while low Be-7 concentrations in air were related to the high solar activity (1989–1991). The atmospheric Be-7 concentrations and the number of sun spots correlated well ($r = -0.77$) in the last 11-year solar cycle which started in 1986.

INTRODUCTION

Beryllium-7 is a relatively short-lived ($T_{1/2} = 53.3$ days) naturally-occurring radionuclide of cosmogenic origin which is formed by spallation processes of light atmospheric nuclei such as nitrogen and oxygen when they absorb protons, and even neutrons, of the primary component of cosmic rays (Lal *et al.*, 1958; Lal and Peters, 1967). Examples of interactions of cosmic-ray neutrons and protons with atmospheric nitrogen are the following:

$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{7}_{4}Be + ^{8}_{3}Li \qquad Q = -25.7\ \text{MeV} \tag{1}$$

$$^{14}_{7}N + ^{1}_{1}p \rightarrow ^{7}_{4}Be + 2^{4}_{2}He \qquad Q = -10.4\ \text{MeV}. \tag{2}$$

Beryllium-7, is a most important isotope in studying atmospheric processes because of its convenient half-life and sufficiently detectable γ-radiation ($E_\gamma = 477$ keV) which has served for studying precipitation scavenging, vertical and horizontal removal of air masses, aerosol transit and residence times in the troposphere, aerosol deposition velocities and deposition patterns of airborne contaminants and exchange processes between the atmosphere and other global reservoirs, e.g. the biosphere and hydrosphere (Turekian *et al.*, 1983; Dutkiewicz and Husain, 1985; Dibb, 1989).

Once Be-7 is formed, it rapidly attaches to aerosol particles that are primarily removed from the troposphere by precipitation. The concentrations of Be-7 in the atmosphere presents variations with geomagnetic latitude with higher concentrations occurring at higher latitudes (Feely *et al.*, 1989). The atmospheric Be-7 concentrations also vary with month, season and year (Papastefanou and Ioannidou, 1991).

In this work we report monthly concentrations of Be-7 in the atmosphere in the region of Thessaloniki in a temperature latitude with a very dry (precipitation-free) climate at east longitude in the European continent of the Northern Hemisphere for an almost 7-year period from July 1987 to May 1994. We focussed on the annual variation of Be-7 concentrations in air with respect to the variation of the number of sun spots according to the 11-year solar cycle. The results obtained should help in the attempt to understand the behaviour of radionuclides in the atmosphere.

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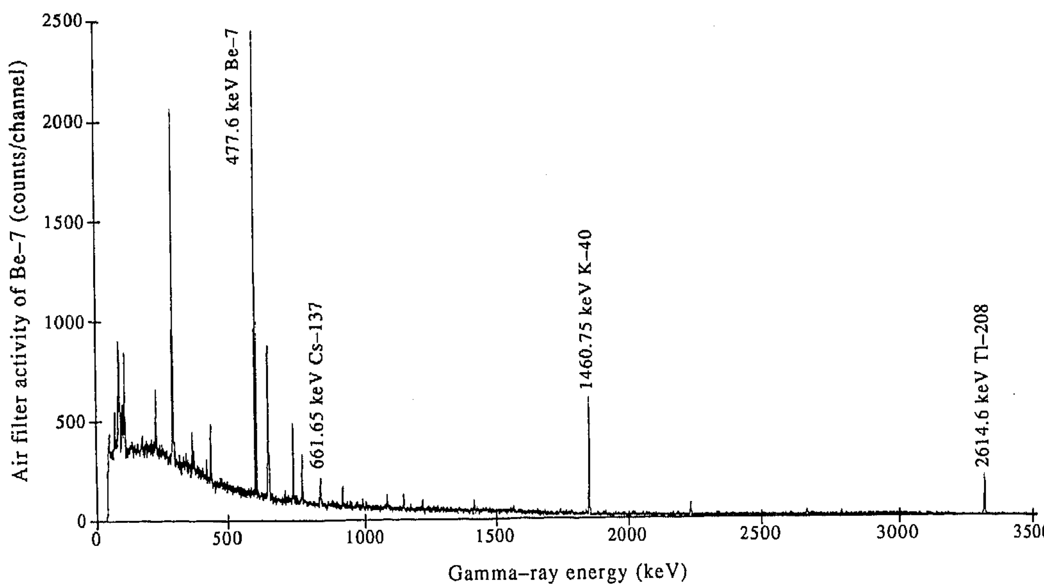

Fig. 1. A typical γ-spectrum of air filter obtained by a Ge detector on 1 February 1994.

INSTRUMENTATION

In the time interval between July 1987 and May 1994, samplings of atmospheric air were made at the beginning of each month. The length of each collection period was 24 h. Staplex high volume air samplers were used with Staplex type TFAGF 810 glass-fibre filters 8 × 10 in. having 99.28% collection efficiency for particles as small as 0.3 μm. This design involves a regulated air-flow rate of 1.7–2.92 $m^3 min^{-1}$ (60–68 $ft^3 min^{-1}$). Air samplings were carried out on the roof (20 m height) of the Faculty of Science building, University of Thessaloniki at Thessaloniki, Greece (40°38′N, 22°58′E).

The glass-fibre filters, after each sampling, were measured for Be-7 activity ($E_\gamma = 477$ keV) by γ-ray spectrometry using a high resolution (1.9 keV at 1.33 MeV, ^{60}Co), high efficiency (42%), low-background HPGe detector.* Uncertainties in counting the Be-7 activity were <5% for the geometry ("filter geometry") used (Papastefanou and Ioannidou, 1991). A typical γ-ray spectrum of an air filter obtained by using a HPGe detector is shown in Fig. 1. The peak corresponding to the 477 keV γ-rays of Be-7 is very strong. The γ-ray spectrum was obtained after several days, less than a week to decay radon and thoron daughter products.

RESULTS AND DISCUSSION

Monthly atmospheric concentrations of Be-7 for the time period July 1987 to May 1994 are illustrated in Fig. 2. The data of Fig. 2 shows that Be-7 concentrations in air varied between the minimum value of 0.4 $mBq\,m^{-3}$ observed on December 1993 and the maximum value of 12.0 $mBq\,m^{-3}$ observed on September 1987. The variability in tropospheric Be-7 concentrations os most likely due to mixtures of stratospheric and tropospheric air, by direct transfer of air across the tropopause. Monthly changes of Be-7 concentrations in surface air are associated with air masses of stratospheric origin and the changes of the tropopause height, see Fig. 3. The tropopause heights in Fig. 3 were determined from the National Meteorological Center's (EMY) archived data.

Since the production of Be-7 and other cosmogenic radionuclides, such as Na-22, is directly dependent on the cosmic-ray intensity, a relationship between the production rate and, or the

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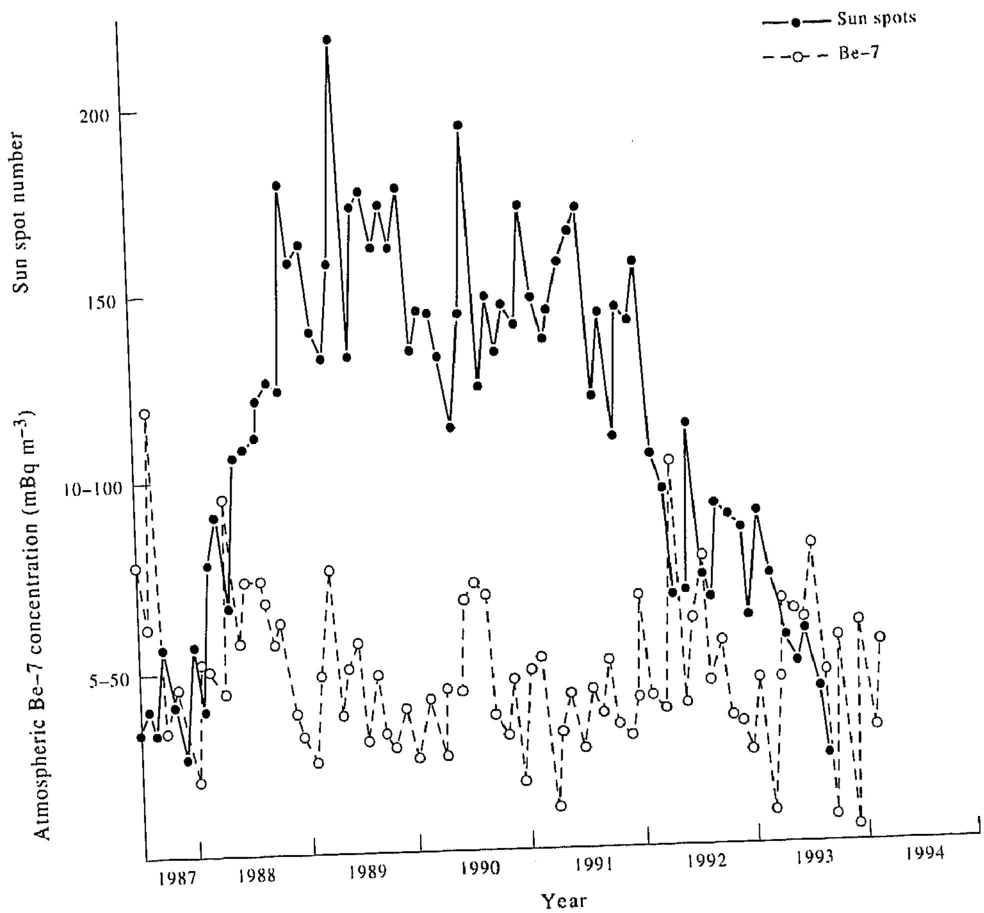

Fig. 2. Beryllium-7 concentrations of air and mean number of sun spots each month for the period July 1987–May 1994.

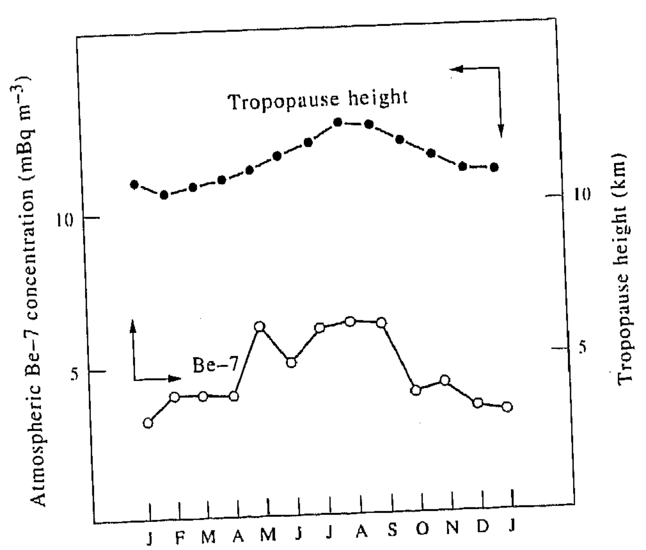

Fig. 3. Monthly variations of Be-7 concentrations of air and tropopause height, for the period July 1987–May 1994.

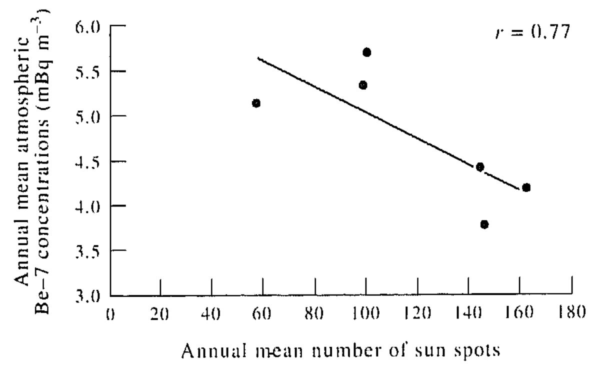

Fig. 4. Annual mean concentrations of Be-7 in air vs annual mean number of sun spots for the period of six complete annual cycles (1988–1993).

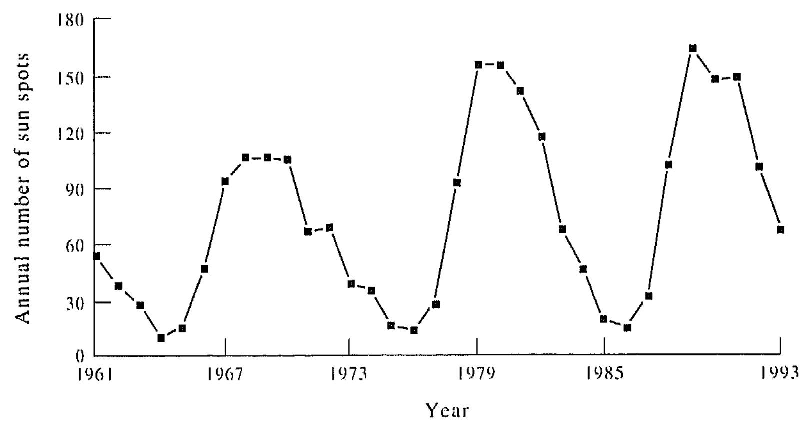

Fig. 5. Three 11-year solar cycles of sun spot changes for the period 1961–1993.

concentration of these radionuclides and the 11-year solar cycle can be expected. It is well known that the galactic cosmic-ray intensity at the earth's orbit is inversely related to solar activity (O'Brien, 1979). This effect can be interpreted as follows: the solar wind that is consistent with the relatively low-energy particles eliminates the passage of the galactic cosmic radiation through the solar system to the earth and therefore, it influences by reducing the production rate of cosmogenic radionuclides. A negative correlation is therefore expected between the atmospheric Be-7 and sun spots. In fact, an inverse relationship between the atmospheric Be-7 concentrations and the sunspot numbers is evident from the plot of Fig. 2. On the other hand, for six complete annual cycles the annual mean atmospheric Be-7 concentrations and the annual numbers of sun spots correlated well with each other, with $r = -0.77$, as shown in Fig. 4.

The last three 11-year cycles of solar activity, showing the changes in the number of sun spots from 1961 to 1993, are illustrated in Fig. 5. Data based on sunspot numbers were derived from observations by members of the American Association of Variable Star Observers' Solar Division at Duluth, Minn., U.S.A.

CONCLUSIONS

As the cosmic-ray intensity varies with solar activity and Be-7 concentrations depend on the cosmic-ray neutron flux to earth, a decrease in cosmic-ray intensity is accompanied with the increase in solar activity. A decrease in the production rate of the cosmic-ray-produced Be-7 is accompanied by an increase in sun spots, establishing an inverse relationship between the atmospheric Be-7 concentration and the number of sun spots (solar activity).

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