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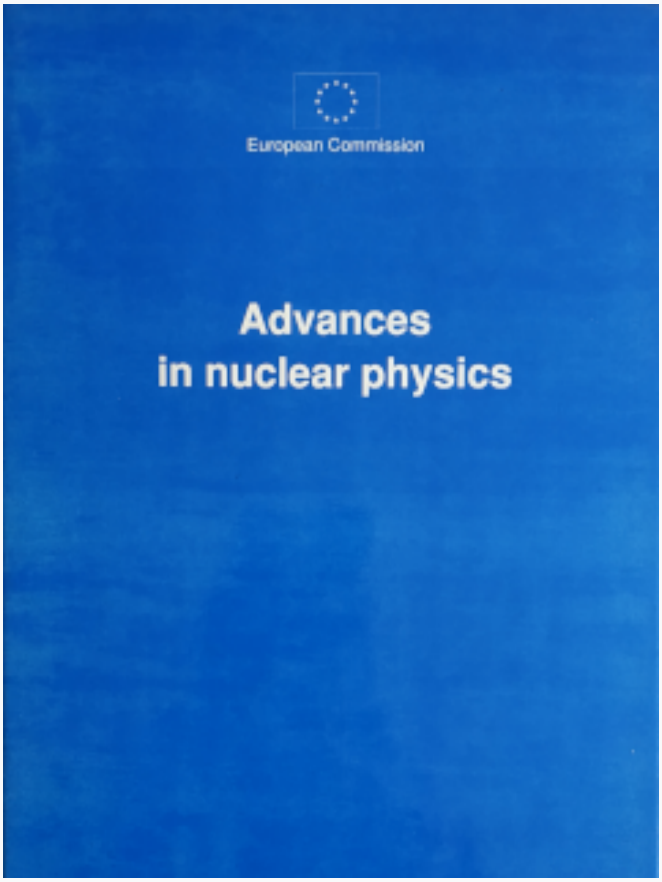


# Beryllium-7 Concentrations in the lower Atmosphere at the region of Thessaloniki (40°N)

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# Beryllium-7 Concentrations in the lower Atmosphere at the region of Thessaloniki (40°N)

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Atmospheric concentrations of $^{7}Be$ were measured over a 6-year period (July 1987 - December 1992) at the region of Thessalloniki, Greece (40°38'N, 22°58'E)in temperate latitude with very dry (precipitation-free) climate at east longitude in the European continent of the Northern Hemisphere. Our concern was focused in the variation of atmospheric concentrations of $^{7}Be$ and the main influencing factors.

Beryllium-7, a most important isotope in studying atmospheric processes because of its convenient half-life and sufficiently detectable radiation, has served principally 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.

Monthly, mean seasonal and mean annual values of $^{7}Be$ concentrations in the atmosphere, have been concerned for our study. Monthly values of $^{7}Be$ concentrations showed strong variation with time, while seasonal and mean annual values, showed slighter variations.

Local meteorological conditions were the most important factors that affected the monthly atmospheric concentrations of $^{7}Be$ at the region of Thessaloniki, especially the wind velocity and direction and the precipitation height. The lowest concentration 1.96 $mBq/m^3$ occurred during the winter of 1991, while the highest value 12.0 $mBq/m^3$ occured on September 1987.

Considering the mean seasonal concentrations of $^{7}Be$ for a long period as long as 51/2 years, the monthly variations become less noticeable and the differences are interpreted by large scale variations that are taken place at higher altitudes in the troposphere in combining with the regional meteorological conditions. The minima occurred during the winter, whereas the maxima occured during the summer and spring, each year.

Finally, the mean annual concentrations of $^{7}Be$ showed a small variation, each year.This was not a statistical phenomenon, but it was due to the strong relation between the eleven - year solar cycle and the cosmic-ray flux, and thus, to the production rate of cosmogenic radionuclides. The highest $^{7}Be$ concentration 6.29 $mBq/m^3$ during 1987 was related with the minimum of solar activity, while the lowest concentration 3.79 $mBq/m^3$ during 1991 was related with high solar activity.

## *Introduction*

Beryllium-7 is a relatively short-lived ($T_{1/2}$ = 53.3 days) naturally occurring radionuclide of cosmogenic origin that was formed by spallation reactions, disintegrations of nuclei of nitrogen and oxygen atoms that have been hit by cosmic-ray neutrons. The least endoergic routes for $^{7}Be$ production from nitrogen by neutrons and protons are given below.

$$^{14}N + n \longrightarrow {}^{7}Be + {}^{8}Li \qquad Q = -25.7MeV$$

$$^{14}N + p \longrightarrow {}^{7}Be + 2\,{}^{4}He \qquad Q = -10.4MeV$$

Beryllium-7, a most important isotope in studying atmospheric processes because of its convenient half-life and sufficiently detectable radiation, 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.

Once it is formed, it rapidly attaches to aerosol particles that are primarily removed from the troposphere by precipitation .

The concentration of $^{7}Be$ in the atmosphere presents variations with the geomagnetic latitude, with higher values occurring at high latitudes. The atmospheric concentrations of $^{7}Be$ in the lower atmosphere are varied with month, season and year.

In this work we report monthly concentrations of $^{7}Be$ in the atmosphere at the region of Thessaloniki in temperate latitude with very dry (precipitation-free) climate at east longitudes in the European continent of the Northern Hemisphere during a 6-year period from July 1987 to December 1992. We focused in the variation of atmospheric concentrations of $^{7}Be$ and the main influencing factors.

## *Instrumentation*

In the time interval between July 1987 and December 1992 66 samplings of atmospheric air filtered were made in the beginning of each month. The length of each collection period was 24 hours. A staplex high volume air sampler was used with Staplex type TFAGF 810 glass-fiber filter 8"x10" and having 99.28% collection efficiency for particles as small as 0.3μm. This design involves a regulated air-flow rate of 1.7 - 2.92 $m^3\ min^{-1}$ (60-68 $ft^3\ min^{-1}$). The measurements 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).

## *Beryllium-7 concentrations in air*

Monthly atmospheric concentrations of $^{7}Be$ for the time interval from July 1987 to December 1992 are presented in Table 1. The range of $^{7}Be$ concentrations varied between the minimum value 1.96 mBq/$m^3$ that have been observed during the winter of 1991 and January 1988 and the maximum value 12.0 mBq/$m^3$ that has been observed in September 1987 and 10.3 mBq/$m^3$ on May of 1992, respectively. Most of the values ranged between 3 to 5mBq/$m^3$.

The value of 1.13 mBq/$m^3$ that occured in April of 1991 has been rejected, because of the fact that the sampling has been carried out after a four-days rainfall.

In Table 3 the mean annual atmospheric concentrations of $^{7}Be$ for the period 1987-1992 are presented. These values are varied between 3.8 and 5.7 mBq/$m^3$ being in agreement with the production rate of $^{7}Be$ in the upper atmosphere over the $\lambda$=40°N, 5.18 mBq/$m^3$ [Feely et al., 1989].

Figures 1 and 2 show the monthly and seasonal values of atmospheric concentrations of $^{7}Be$.

The mode of presenting the data is calling "Box and Wisker plot" [Bowman and Robinson, 1987] according to which the data shows the range of values of concentrations of $^{7}Be$ in the atmosphere (vertical axes) for each month or season (horizontal axes). The upper and lower limits of the vertical line is the highest and the lowest values of $^{7}Be$ atmospheric concentrations for the month or season of interest, respectivelly . This is an easier and better way in presenting $^{7}Be$ data as a function of two parameters instead of the less usable three dimensional plotting.

In Fig.1 which presents monthly values of $^{7}Be$ concentration, we can see that:

- during November, December and January, we observed the lowest atmospheric concentrations of $^{7}Be$ with more than 50% of the values to be less than 4 mBq/m3.
- during April and May, we observed very high values. Also, notable is the fact that during these months there is as a great range of $^{7}Be$ concentrations.
- during July and August, we observed the highest values of $^{7}Be$ concentrations in the 6- year period within 50% of the values to be higher than 6 mBq/m3.

After six years of collecting data, it is known that these monthly variations of $^{7}Be$ concentrations were due to local meteorological conditions. After a long period of precipitation rainfall, the concentrations of $^{7}Be$ in the atmosphere will decrease.The same effect occurred after the passage of a strong wind. In order to hide these small scale's variations, we calculated the mean values of $^{7}Be$ concentrations for each season. The results are shown in Table 2. In Table 2 and Fig. 2 we can see that:

- during the winter, we observed the lowest values of $^{7}Be$ concentrations. The range of values was small.

- during the spring, very high atmospheric concentrations of $^{7}Be$ were observed and the range of values was very large.
- during the summer, the highest values of $^{7}Be$ concentrations were observed and the range of values was also large.
- finally, during the autumn, the values of $^{7}Be$ concentrations did not present a large range.

The studies of other researchers gave that, the highest concentrations of $^{7}Be$ are expected during the spring because of the tropopause folding which results in stratospheric - tropospheric air mixing ([Rangarajan et al., 1970], [Dutkiewicz and Husain, 1985]). The precipitation is a factor that influences the concentration of $^{7}Be$ ( and other isotopes) in the lower atmosphere ([Olsen et al., 1985], [Dibb, 1989], [Turekian et al., 1983]). During different seasons, more than one process are taken place in the atmosphere, like rainfall, stratospheric - tropospheric air exchange, vertical and horizontal removal of air masses in the troposphere. So, each one of these processes is the most important and the seasonal cycle would have more than one maximum and not only in one season [Feely eta l.,1989].

More precisely, for the geographical position of Thessaloniki (40°38'N, 22°58'E), where the samplings were carried out and the results are presented in this work, the high values of $^{7}Be$ concentrations during the spring and the summer periods are in agreement with the variations of $^{7}Be$ concentrations that are taken place in the upper atmosphere in geomagnetic latitudes.

The stratospheric - tropospheric air exchange during the spring is greater for geomagnetic latitudes $\lambda$=50°N. For geomagnetic latitudes over $\lambda$=40°N, both the troposphere elevations during the summer months and the vertical removal of air masses from lower to upper levels of atmosphere are stronger [Parker, 1962]. So, as high temperatures reflect to an unstable troposphere with better mixing, we expect higher concentrations of $^{7}Be$ during the hot months of summer [Aegerter et al., 1966 as cited at Feely et al., 1989]. This fact, with the combination of the small precipitation rates that occurred during this period, has as a result highest concentrations of $^{7}Be$ in the atmosphere during the summer for a certain year. In Fig.4, the temperature and rainfall rates for the period 1998-1992 are presented. For the region of Thessaloniki, the observed spring values would be higher than those of the summer values, when the precipitation rates during spring were lower and the atmospheric stability was higher during the summer.

On the other hand, during the winter, where the temperatures are low, the atmosphere is more "stable" and the concentrations of $^{7}Be$ in the atmosphere are low. This period is also characterized by high precipitation rates , and a strong and frequent local wind, called "Vardaris", that clean the atmosphere.

Table 1. Monthly Concentrations of Be-7 in Thessaloniki, Greece

| Month | 1987 mBq/m$^3$±σ | 1988 mBq/m$^3$±σ | 1989 mBq/m$^3$±σ | 1990 mBq/m$^3$±σ | 1991 mBq/m$^3$±σ | 1992 mBq/m$^3$±σ |
|---|---|---|---|---|---|---|
| Jan. | | 1.97±0.06 | 3.20±0.08 | 2.37±0.08 | 1.96±0.06 | 6.92±0.10 |
| Feb. | | 5.22±0.07 | 2.40±0.11 | 3.05±0.07 | 4.93±0.09 | 4.19±0.08 |
| Mar. | | 4.96±0.07 | 4.77±0.12 | 4.23±0.09 | 5.23±0.10 | 4.17±0.11 |
| Apr. | | 4.26±0.07 | 7.58±0.12 | 2.61±0.06 | *1.13±0.05* | 3.77±0.09 |
| May | | 9.58±0.10 | 3.75±0.08 | 4.37±0.09 | 3.14±0.08 | 10.3±0.16 |
| June | | 5.66±0.09 | 5.13±0.10 | 4.36±0.08 | 4.26±0.08 | 3.95±0.07 |
| July | 7.92±0.10 | 7.22±0.13 | 5.61±0.09 | 6.76±0.06 | 2.74±0.07 | 6.08±0.10 |
| Aug. | 6.22±0.22 | 7.40±0.12 | 3.01±0.07 | 7.08±0.10 | 4.24±0.08 | 7.69±0.12 |
| Sep. | 12.0±0.27 | 6.77±0.07 | 4.77±0.09 | 6.84±0.09 | 3.65±0.07 | 4.49±0.08 |
| Oct. | 3.36±0.12 | 5.62±0.08 | 3.32±0.10 | 3.66±0.06 | 5.05±0.08 | 5.52±0.09 |
| Nov. | 4.48±0.11 | 6.10±0.08 | 2.82±0.08 | 3.14±0.04 | 3.28±0.07 | 3.55±0.09 |
| Dec. | 3.81±0.08 | 3.81±0.09 | 3.84±0.09 | 4.58±0.08 | 3.16±0.08 | 3.27±0.06 |

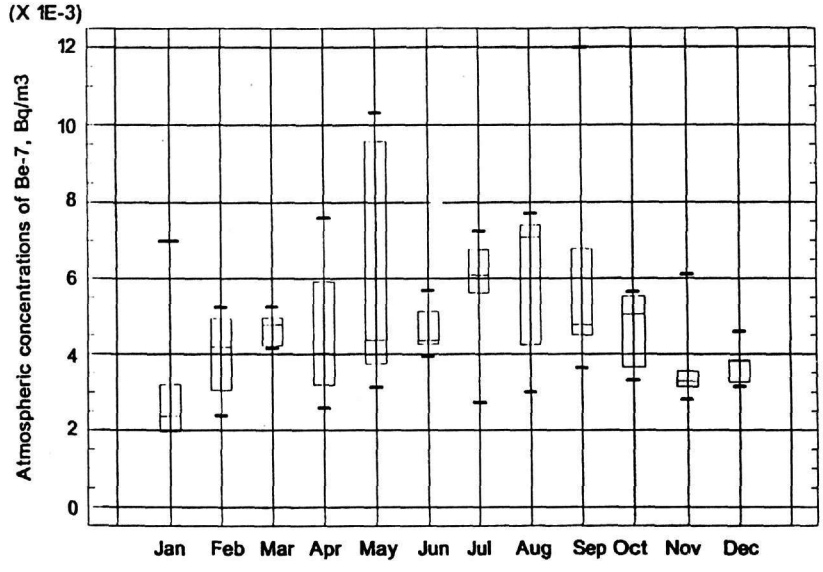


**Fig. 1. Monthly atmospheric concentrations of Be-7 vs time**

Table.2. Seasonal Be-7 ($mBq/m^3$) concentrations in the lower atmosphere at the region of Thessaloniki.

| Season | 1988 | 1989 | 1990 | 1991 | 1992 | 1988-1992 |
|---|---|---|---|---|---|---|
| Winter | 3.66 | 3.14 | 3.09 | 3.82 | 4.76 | 3.66 |
| Spring | 6.27 | 5.37 | 3.73 | 4.19 | 6.08 | 5.15 |
| Summer | 6.76 | 4.58 | 6.07 | 3.75 | 5.91 | 5.41 |
| Winter | 6.16 | 3.64 | 4.55 | 3.99 | 4.52 | 4.57 |

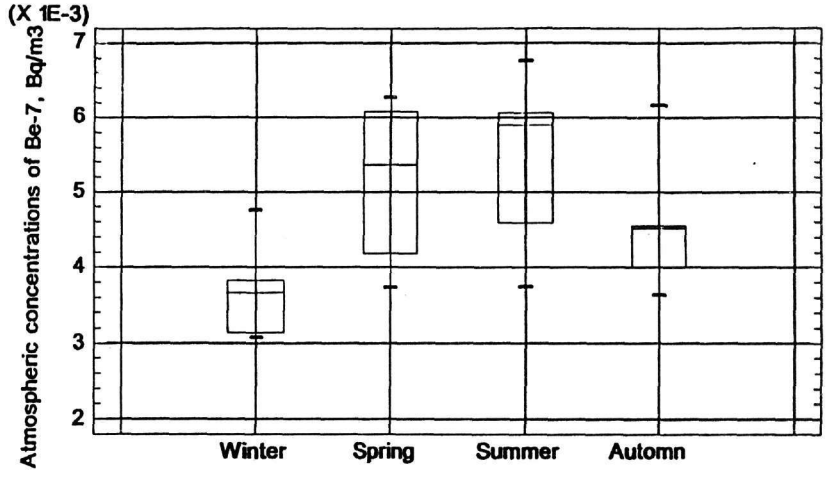


Fig. 2. Seasonal atmospheric concentrations of Be-7 (Period 1988 - 1992)

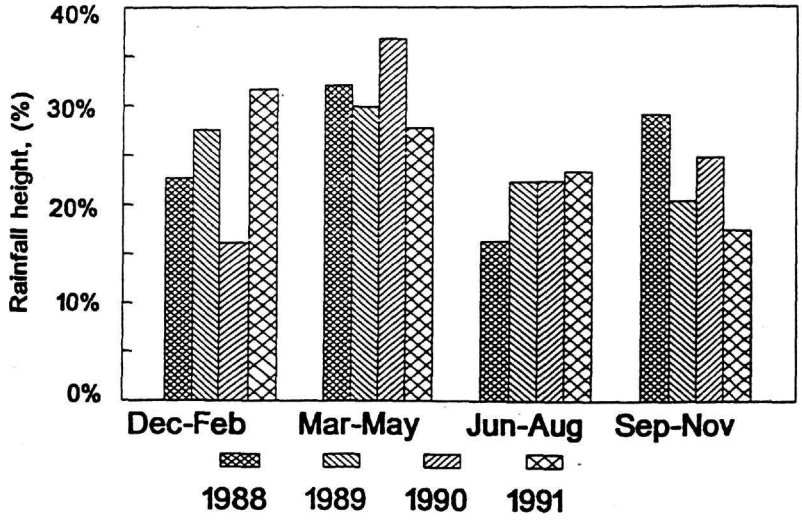


Fig.3. Precipitation heights (% of total) for the period 1988-1991

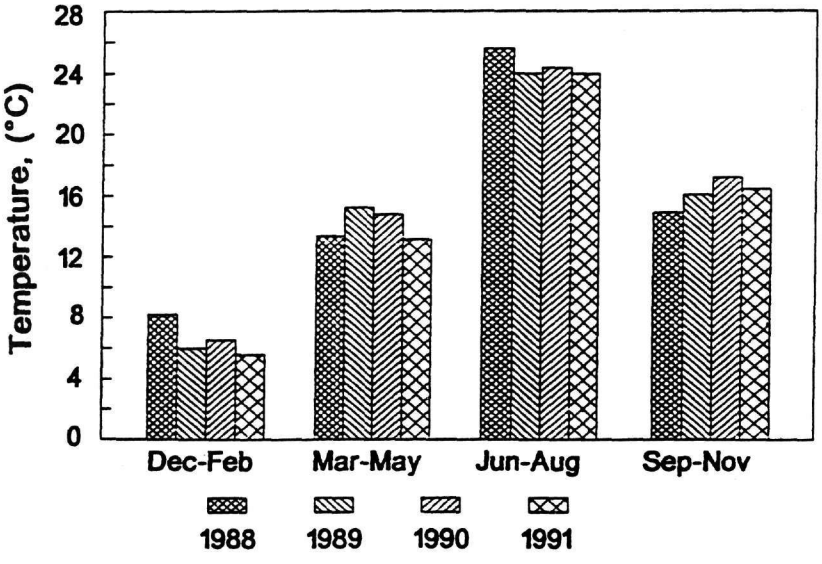


**Fig.4. Seasonal Variations of Temperature for the period 1988-1991**

## Annual concentrations of $^{7}Be$ in the atmosphere and their dependence from the eleventh year solar cycle

One can notice that, during the years 1987, 1988, 1992 high values of $^{7}Be$ concentrations occurred during over the above years and not only for the period of a certain month or season. So we have to examine variations that occur in the upper atmosphere and, of cource, variations of the flux of cosmic neutrons' component [Lal and Peters, 1967].

The high values of $^{7}Be$ concentrations during the years 1987, 1988 and 1992 can be explained only if we take into concideration the eleven - year solar cycle. The year 1987 was of minimum solar activity, moreover the years 1988 and 1989 were of low solar activity also. On the other hand, during 1989, 1990, 1991 low values of atmospheric concentrations were observed and interpreted by the high solar activity during these years, Figs 5 and 6.

This effect can be explained 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 (reduce) the production rate of cosmogenic radionuclides.

In Fig.6, the variations both of annual atmospheric concentrations of $^{7}Be$ and the mean annual number of solar flares are presented. Because of the fact that we have only 6-year measurements in regard to the 11-year cycle, its not so clear the fact that these two magnitudes are reversibly corellated W.S Houston, 1961-1992]. We examined, if there is any relation between these two magnitudes. Analysis with the method of least squares show that there is a strong linear relationship between them. More precisely, the atmospheric concentrations of $^{7}Be$ at the region of Thessaloniki decrease as the number of solar flares increases , Fig.6, Table 3.

In a recent paper of Larsen (1993) similar variations of $^{7}Be$ concentrations in eight representative stations (four for each hemisphere) for the period 1985-1990 were presented. From the data of Larsen's paper, we examined if there is a linear relationship between the number of solar flares and the atmospheric concentrations of $^{7}Be$ with that found in our observations, Fig.7.

For each of the eight stations of $^{7}Be$ measurements (Larsen 1993) we found that there is a strong linear relationship between these two magnitudes, and it supports our results and our hypothesis that, long scale variations of $^{7}Be$ atmospheric concentrations are affected by global variations of $^{7}Be$ in the upper atmosphere.

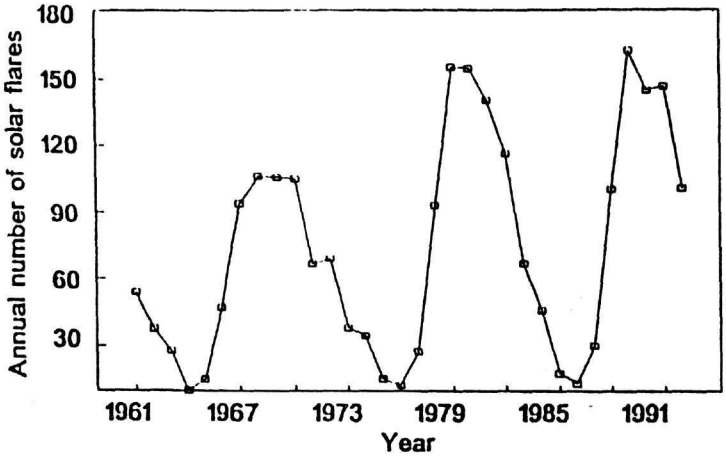


Fig.5. Eleven - year solar cycle for the time period 1961 -1991 [Sky&Telescope, 1993].

Table 3. Annual Be-7 concentrations in air and solar flares for the period 1987 - 1992

| Year | Be-7 ($mBq/m^3$) | Solar Flares |
|---|---|---|
| 1987 | 6.29 | 30.2 |
| 1988 | 5.71 | 100.0 |
| 1989 | 4.18 | 162.4 |
| 1990 | 4.42 | 144.9 |
| 1991 | 3.79 | 146.5 |
| 1992 | 5.32 | 100.5 |

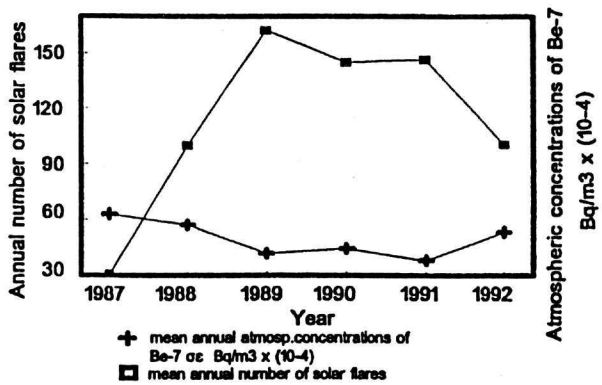


Fig.6. Illustration of annual Be-7 concentrations in air and solar flares vs time

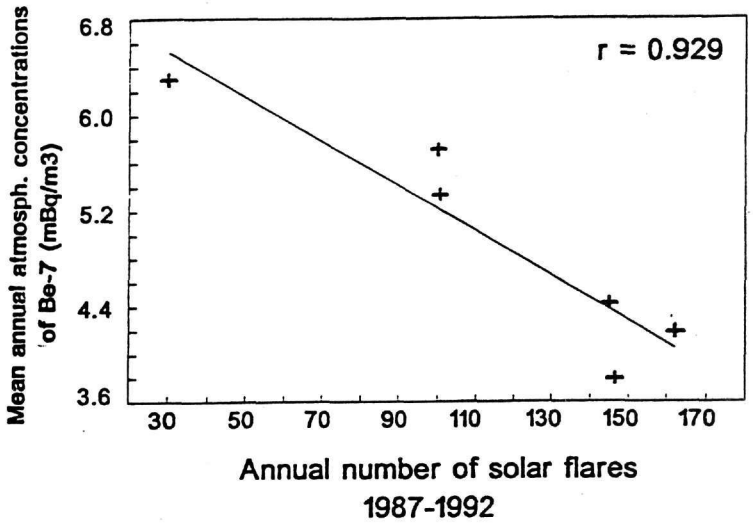


Fig.7. A plot of a mean annual concentrations of Be-7 versus the annual number of solar flares, for the time period 1987-1992.

Table.4. Corellation coefficients of dependence of Be-7 annual concentrations on solar flares (from data of Larsen, 1993)

North Hemisphere

| Latitude | Cor.Coefficient |
|---|---|
| 26°N Miami | 0.995(6) |
| 41°N Chester | 0.975 (6) |
| 51°N Moosonee | 9.922 (5) |
| 71°N Barrow | 0.810 (4) |
| 40°38'N Thessaloniki | 0.929 (6) |

South Hemisphere

| Latitude | Cor.Coefficient |
|---|---|
| 12°S Lima | 0.847 (5) |
| 32°S Perth | 0.938 (6) |
| 41°S Cape Grim | 0.892 (6) |
| 53°S Punta Arenas | 0.942 (5) |

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