EPJ Web of Conferences **24**, 05004 (2012)
DOI: 10.1051/epjconf/20122405004

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

A. Ioannidou[1,*], A. Vasileiadis[1] and D. Melas[2]

[1] Aristotle University of Thessaloniki, Physics Department
Nuclear Physics & Elementary Particle Physics Division
Thessaloniki 54124, Greece
[2] Aristotle University of Thessaloniki, Physics Department
Applied and Environmental Physics Division
Laboratory of Atmospheric Physics - Thessaloniki 54124, Greece

Abstract

The concentration of ^{7}Be at near surface air has been determined over 2009, a year of a deep solar minimum, in the region of Thessaloniki, Greece at 40°62′ N, 22°95′E. In geomagnetic latitudes over 40°N, the elevation of the 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. The positive correlation between the monthly activity concentration of ^{7}Be and the tropopause height (0.94, $p < 0.0001$), and also between ^{7}Be concentration and the temperature T (°C) ($R = 0.97$, $p < 0.001$), confirm that the increased rate of vertical transport within the troposphere, especially during warmer summer months, has as a result the descent to surface of air masses enriched in ^{7}Be. However, the ^{7}Be concentration levels in near surface air are not expected to respond immediately to the change of elevation of the tropopause. It was found that there's a time lag of ~ 3 days between the change in the daily surface concentrations of ^{7}Be the change in the elevation of the tropopause.

*E-mail: anta@physics.auth.gr

1. Introduction

Beryllium-7 ($t_{1/2} = 53.3\,\mathrm{d}$) 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 on 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, consequently, 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 [1]. The combined effects of high ^{7}Be production rates in the stratosphere (about 70%; [2]) 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 [3]. 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 it is on the order of a week [4]. The stratosphere serves as a reservoir of ^{7}Be -rich air injected into the troposphere via the global-scale Brewer–Dobson circulation [5] or during stratosphere-to-troposphere exchange events [6,7]. The concentration 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 troposphere and stratosphere. A fundamental characteristic of the tropopause is the change in its static stability (temperature lapse rate) across the interface. The WMO [8] definition of the tropopause is based on the lapse rate criteria (decrease of temperature with height becomes less than $2\,^{\circ}\mathrm{C\,km^{-1}}$), although the tropopause can also be defined by more general stability criteria, quantified by the potential vorticity (PV) [9].

In the tropics, the tropopause is relatively higher ($\sim 16\,\mathrm{km}$), reflecting a transition between radiative-convective balance in the troposphere and radiative balance in the stratosphere [10]. The tropopause in the extratropics is lower (8–12 km), with an equilibrium structure determined by baroclinic wave dynamics [11–13]. The extratropical tropopause is characterized by large dynamic variability, often with complex spatial structure (such as three-dimensional folds, see *e.g.* [14, 15]). There is a well-marked "tropopause gap" or break where the tropical and polar tropopause

overlap at 30°–40° latitude [16]. 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 a geomagnetic latitude of 40 °N during the year 2009, a year of a deep solar minimum, and as a consequence a year of maximum concentration of ^{7}Be in near surface air. During a year of solar minimum any fluctuation in ^{7}Be concentration is unaffected by the solar modulation and the differences in ^{7}Be fluctuations due to meteorological and seasonal variations are easily revealed. The main objective of the study is to define the time-lag between the elevation of tropopause and concentration of ^{7}Be in near surface air.

2. Instrumentation and methods

Be-7 atmospheric concentrations were measured by air sampling; using Staplex high-volume air samplers with Staplex type TFAGF 810 glass-fiber filters, $8'' \times 10''$, having 99.28% collection efficiency for particles as small as 0.3 μm. This design involves a regulated airflow rate of 1.7–1.92 $\mathrm{m^3\,min^{-1}}$ (60-68 $\mathrm{ft^3\,min^{-1}}$). The length of each collection period was 24 h. Air samplings were carried out once a week on the roof (20 m above the ground, and 52 m a.s.l.), at the Faculty of Science building in the center of the city of Thessaloniki, Greece.

After the collection procedure, the filters are folded and compressed by means of hydraulic press with up to 3 tons to make a cylinder with 5.8 cm diameter and 2 mm height. All samples were measured for their ^{7}Be activity (E_γ = 477 keV) using a high resolution (1.9 keV at 1.33 MeV; relative efficiency 42%), low-background high purity germanium (HPGe) detector. The 1σ counting uncertainty for ^{7}Be measurements is almost always smaller than 8%. Blank filters were regularly checked.

Meteorological data concerning temperature T (°C), and relative humidity (RH%) during sampling were obtained from a meteorological station on the roof of the faculty building.

Apart from the meteorological parameters, a daily tropopause height time series for the period of ^{7}Be observations was obtained from the NCEP/NCAR Reanalysis data [17].

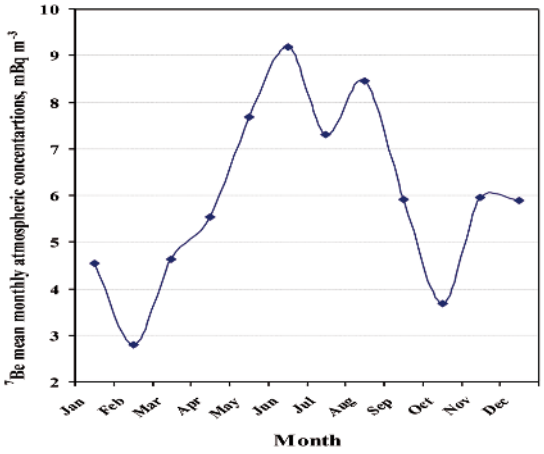

Fig. 1: Mean monthly atmospheric concentration of ^{7}Be during the year 2009 at Thessaloniki, Greece 40 °N.

3. Results and discussion

3.1. ^{7}Be concentration levels in near surface air

The mean annual activity concentration of ^{7}Be during the year 2009 was $6 \pm 3\,\mathrm{mBq\,m^{-3}}$. The periodic pattern of the mean monthly ^{7}Be concentration in near surface air over year 2009 presents a strong seasonal variation with the highest values being observed in summer, and the lowest ones in winter (Figure 1). High values were also observed during spring. This is a typical seasonal profile for Thessaloniki, Greece (40 °N) [18]. However, during November and December 2009 abnormally high ^{7}Be concentrations were observed, which can be attributed to a particular meteorological characteristic during these months. Atmospheric processes and meteorological parameters that may contribute to these variations are discussed below.

3.2. ^{7}Be concentration levels in near surface air and the influence of meteorological and atmospheric parameters

In order to obtain information concerning the main mechanism controlling the summer peak in the ^{7}Be surface concentration, correlation coefficients were calculated between the monthly means of ^{7}Be and the meteorological and atmospheric parameters.

^{7}Be concentration in near surface air is correlated clearly with temperature T (°C). Regression analysis shows that the correlation coefficient

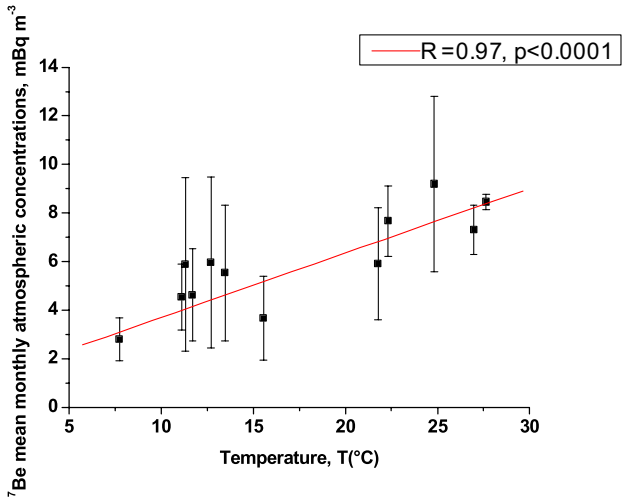

Fig. 2: Mean monthly atmospheric concentration of ^{7}Be *vs.* temperature, T (°C).

between the mean monthly activity concentrations of ^{7}Be and the temperature T (°C) is 0.97 and the significance of the regression is given by $p < 0.0001$ (Figure 2). The observed strong positive correlation coefficient between the mean monthly activity concentration of ^{7}Be, and temperature T (°C), confirms that the increased rate of vertical transport within the troposphere, especially during warmer months, has as a result the descent to the surface layer of air masses enriched in ^{7}Be.

The high ^{7}Be activity values observed during warm summer months could well be explained by the solar heating of the Earth-atmosphere system. The solar heating of the surface of the Earth has a result of heating of air masses that are in contact with the surface while turbulent eddies transport the surface air to higher altitudes. A convective circulation is produced, carrying surface air upward and bringing downward air from higher levels [6]. This convective circulation is connected with higher ^{7}Be activity concentrations in near surface air, described by positive correlation between the activity of ^{7}Be and the temperature T (°C).

A negative correlation coefficient was found between the mean monthly activity concentration of ^{7}Be and relative humidity RH% ($R = -0.65$ $p < 0.02341$). The most probable explanation for this anti-correlation is that the condensation during high relative humidity conditions becomes more intense, resulting in increased particle sizes of atmospheric aerosols. But, greater aerosol particle sizes mean higher scavenging rates of aerosols and as a result lower activity concentration of ^{7}Be in the atmosphere [19]. On

the other hand low relative humidity conditions can be explained as events of downward transport of dry upper tropospheric air [20].

However, another phenomenon that contributes to higher ^{7}Be levels during summer at mid-latitudes is the elevation of the tropopause during warm summer months. The analysis gave that the tropopause reaches its highest level, (up to 16 km, monthly average 14 km), during the summer period, especially during June and August. On the other hand, during the winter months, when the temperatures are low, the tropopause height is lower and the concentration of ^{7}Be in near surface air is low. The relatively high values of ^{7}Be concentration observed during November and December could well be explained by a slight increase of the tropopause height during this month. A positive correlation was defined between the mean monthly activity concentration of ^{7}Be and the tropopause height ($R = 0.74$, $p < 0.0001$).

Gerasopoulos *et al.* [21] reported also a strong negative correlation between ^{7}Be concentration at three high-altitude Alpine stations and relative humidity, and a strong positive correlation with tropopause height on the other hand, indicating that wet scavenging and downward transport from the upper/middle to lower troposphere within anticyclonic conditions are the main controlling mechanisms throughout the year.

3.3. Time delay between ^{7}Be concentration levels in near surface air and the tropopause height

As already discussed previously, the positive correlation between the activity concentration of ^{7}Be and the tropopause height (0.94, $p < 0.0001$), and also between ^{7}Be concentration and the temperature T (°C) ($R = 0.97$, $p < 0.001$), confirms that the increased rate of vertical transport within the troposphere, especially during warmer months, has as a result the descent to the surface layer of air masses enriched in ^{7}Be. However, the atmosphere does not respond immediately to the change of the controlling meteorological factors. So, we are expecting a time lag between these two maximums that might be ranging from hours (highly unlikely) to days or weeks. The time lag between the elevation of the tropopause and levels of ^{7}Be surface concentration represents the time required for the ^{7}Be concentration levels in the near surface air to respond to the change of the tropopause height.

The daily values of the tropopause height for the latitude of investigation were calculated for the year 2009 (Figure 3). The correlation coefficient (R) between ^{7}Be and the tropopause height was successively calculated for different time lags between 0 and 7 days. The results are shown in table 1.

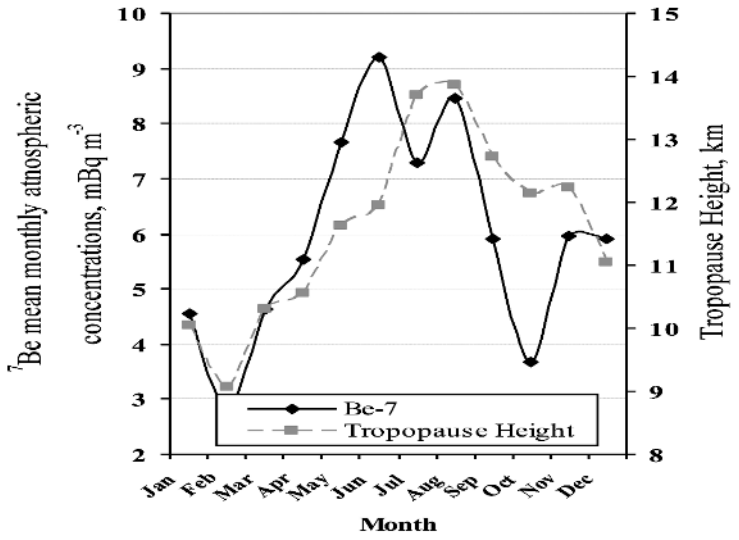

Fig. 3: Mean monthly atmospheric concentration of ^{7}Be and tropopause height variations during the year 2009 at Thessaloniki, Greece 40 °N.

Table 1: The correlation coefficients corresponding to different time lags between 0 and 7 days.

Time lag (days)	R (correl. coeffic.)
0	0.437
1	0.429
2	0.428
3	0.439
4	0.411
5	0.347
6	0.304
7	0.266

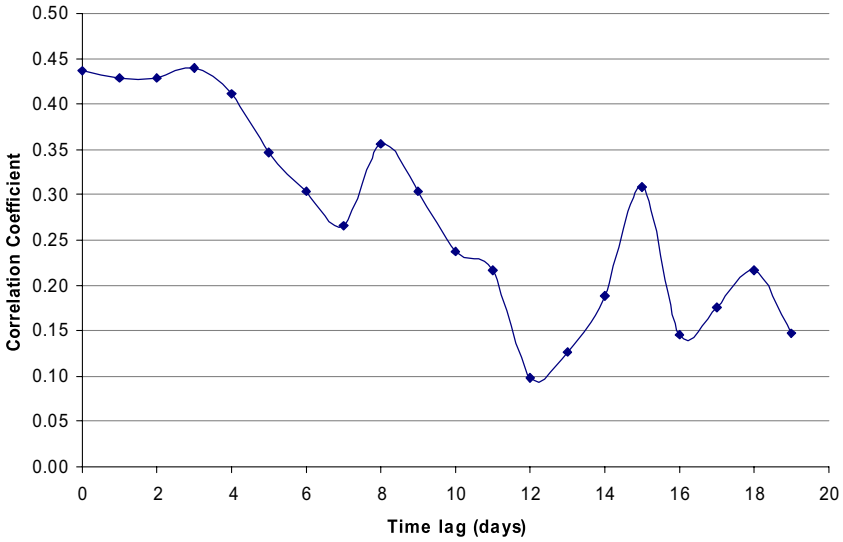

Fig. 4: Correlogram between ^{7}Be surface concentration and tropopause height.

Figure 4 presents the pattern of the cross-correlation analysis of ^{7}Be surface concentration values and tropopause height. It is clearly shown that after the third day the Correlation Coefficient falls dramatically. The $R_{\max}$ was found in the third day (~ 0.44).

The abnormal high values of ^{7}Be concentration up to $13\,.\mathrm{mBq\,m^{-3}}$ observed during November 2009 could well be explained by the increase of the tropopause height (up to 15.4 km, mean height 12.2 km) during this month (Figure 3).

4. Conclusions

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

^{7}Be concentration was found to have a distinct annual cycle with a clear maximum during warm summer months. The positive correlation between the mean monthly activity concentration of ^{7}Be and the tropopause height (0.94, $p < 0.0001$) and also between ^{7}Be concentration and the temperature T (°C) ($R = 0.97$, $p < 0.001$), confirms that the increased rate of vertical transport within the troposphere, especially during warmer months, has as

a result the descent to the surface layer of air masses enriched in ^{7}Be.

However, the atmosphere does not respond immediately to the change of the tropopause height. The analysis of the daily data revealed that the time delay between the elevation of the tropopause and the ^{7}Be concentration in surface air is about 3 days.

References

[1] MASARIK J. and BEER J., *Journal of Geophysical Research*, **104**(D0) (1999) 12.099.

[2] LAL D. and PETERS B., *In: Handbuch der Physik*, **46** (1967) 551.

[3] BHANDARI N., LAL D. and RAMA, *Tellus*, **18** (1966) 391.

[4] PAPASTEFANOU C. and IOANNIDOU A., *Journal of Environmental Radioactivity*, **26** (1995) 273.

[5] HOLTON J. R. *et al.*, *Review of Geophysics*, **33** (1995) 403.

[6] FEELY H. W., LARSEN R. J. and SANDERSON C. G., *Journal of Environmental Radioactivity*, **9** (1989) 223.

[7] ZANIS, P, SCHUEPBACHE E., GÄGGELER, H. W, HÜBENER S. and TOBLER L., *Tellus*, **51B** (1999) 789.

[8] WORLD METEOROLOGICAL ORGANIZATION, *Meteorology — A three dimensional science: Second session of the Commission for Aerology* (1957).

[9] HOERLING, M. P., SCHAACK T. K. and LENZEN A., *Journal of Monthly Weather Review*, **126** (1991) 3303.

[10] THUBURN, J. and CRAIG G. C., *Journal of Geophysical Research*, **107**(D2) (2002) 4017.

[11] HELD I., *Journal of the Atmospheric Sciences*, **39** (1982) 412.

[12] HAYNES, P., SCINOCCA J. and GREENSLADE. M., *Geophysical Research Letters*, **28**(22), (2001) 4179.

[13] SCHNEIDER T., *Journal of the Atmospheric Sciences*, **61** (2004) 1317.

[14] BITHEL, M., L. J. GRAY and COX B. D., *Journal of the Atmospheric Sciences*, **56** (1999) 673.

[15] NIELSEN-GAMMON J. W., *Bulletin of the American Meteorological Society*, **82** (2001) 1151.

[16] KOCHANSKI A., *Journal of Meteorology*, **12** (1955) 95.

[17] KALNAY E. *et al.*, *Bulletin of the American Meteorology Society*, **77** (1996) 437.

[18] IOANNIDOU A., MANOLOPOULOU M. and PAPASTEFANOU C., *Applied Radiation and Isotopes*, **63**(2) (2005) 277.

[19] IOANNIDOU A. and PAPASTEFANOU C., *International Aerosol Conference 2010, Helsinki, Finland* 28/8-3/9/2010.

[20] GERASOPOULOS E. *et al.*, *Atmospheric Environment*, **35**(36) (2001) 6347.

[21] GERASOPOULOS, E. *et al.*, *Proceedings: VIIth Int. Symp. On the NRE*, **7** (2005) 863.