



## Atmospheric Transport Inferred from Seasonal Variations in Cosmogenic Be-7 Concentrations

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**Abstract:** A cosmogenic radionuclide Be-7 (half life 53.3 days) results from nuclear interactions of galactic cosmic rays in the Earth's atmosphere. Most of Be-7 is produced in the lower stratosphere and slowly transported to the surface. Be-7 plays a role of atmospheric tracer and its measurements provide an important clue on atmospheric air mass motions. We have continuously measured the Be-7 concentrations in Tokyo since 2002. The data in 2002-2006 indicated clear enhancements of Be-7 concentrations in spring and autumn every year. The seasonal variations are not associated with scavenging by precipitation because the surface Be-7 concentrations do not correlate with rainfall. We suggested a possibility that the stratospheric Be-7 are brought to the upper troposphere through a large-scale air mass exchange between the stratosphere and troposphere. The air mass exchange is inferred to occur in association with a periodic passage (a period of a few days) of a pair of traveling high pressure and extratropical low pressure over Japan in spring and autumn.

### Introduction

Be-7 results from nuclear interactions of galactic cosmic rays with atmospheric nitrogen and oxygen. About 70 % of Be-7 is produced in the lower stratosphere and about 30 % in the upper troposphere [1], [2], [3]. Once Be-7 is produced, it is attached to a small aerosol particle and transported to the surface by atmospheric motions. The half-life of Be-7 is 53.3 days, indicating that it is suitable for a study of the atmospheric motions with a time scale of an order of month. In the past the surface Be-7 concentrations were measured at several locations in the world and its complex temporal variations were reported so far [4], [5], [6], [7], [8], [9], [10]. The time scale of the variations ranges from within a single precipitation event (time scale of a day) to seasonal change (time scale of a few months). A few atmospheric transport processes were proposed to explain the previous variations in surface Be-7 concentrations: For example, (1) air mass exchange, mixing or circulation between the lower stratosphere and upper troposphere, (2) the vertical atmospheric air mass motion in the troposphere and (3) scavenging by precipitation (Be-7

borne small particles are efficiently attached to rain and brought to the surface). However, at present the variations in the surface Be-7 concentrations are not fully understood.

We started the experiment of Be-7 concentration on the roof of the building of Faculty of Science of Rikkyo University in Tokyo (35N, 139E) in January 2002. This measurement provides useful information on atmospheric motions in the upper atmosphere in the mid-latitude Asian Pacific region because surface Be-7 measurements were little reported in this region so far. The present Be-7 experiment in 2002-2006 indicated that the surface Be-7 concentrations were enhanced in spring and autumn regularly. This result suggests a possibility that air mass exchange or circulation takes place on a large scale between the lower stratosphere and upper troposphere in spring and autumn. Here we discuss the possibility from a viewpoint of seasonal meteorological conditions in the upper atmosphere in Japan.

### Measurement of Surface Be-7 Concentration

We started the measurement of surface Be-7 concentration in January 2002 and recorded the Be-7 concentrations per week for five years. Be-7 borne aerosol particles are collected on a special filter with a ground-based high-volume air sampler. Gamma-ray lines emitted from aerosol particles on the filter were detected with a high-resolution Ge spectrometer. The typical gamma-ray spectrum is shown in Figure 1. The Be-7 gamma-ray line at 477.59 keV is most intense in the natural radioactive nuclides, as shown in Figure 1. We determine the Be-7 concentration (in unit of  $\text{mBq}/\text{m}^3$ ) from a total count of photopeak of the Be-7 line taking account a detection efficiency of the spectrometer, a decay rate of Be-7 and a sampling air volume per week. The experiment is described in detail [11].

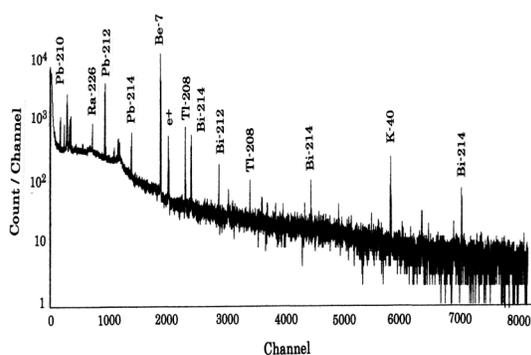


Figure 1: A typical gamma-ray spectrum of collected small aerosol particles.

We plot the surface Be-7 concentrations in 2002 to 2006 in Figure 2. Although there are differences in peaks of Be-7 concentrations from year to year, there is an apparent trend indicating the enhancements in spring and autumn. We fold the yearly data to see the detailed variations of the surface Be-7 concentrations. It is shown in Figure 3. There are clear peaks of the Be-7 concentration in spring (day of year is around 100 days) and autumn (day of year is around 300 days). The variations are thought to be caused by meteorological origin. Complex atmospheric air mass motions that vary from year to year influence the efficiency of transport of Be-7 borne aerosol

particles to the surface. The Be-7 concentration is minimum ( $\sim 2 \text{ mBq}/\text{cm}^3$ ) in summer and winter and is maximum ( $\sim 8 \text{ mBq}/\text{cm}^3$ ) in spring and autumn. The present Be-7 concentrations are roughly consistent with the results measured in Maryland, USA ( $3.3\text{--}5.0 \text{ mBq}/\text{m}^3$ ) [7], Alert in Canada ( $1.5\text{--}4.5 \text{ mBq}/\text{m}^3$ ) [12], Osaka in Japan ( $3\text{--}9 \text{ mBq}/\text{m}^3$ ) [13] and Tokyo in Japan [14].

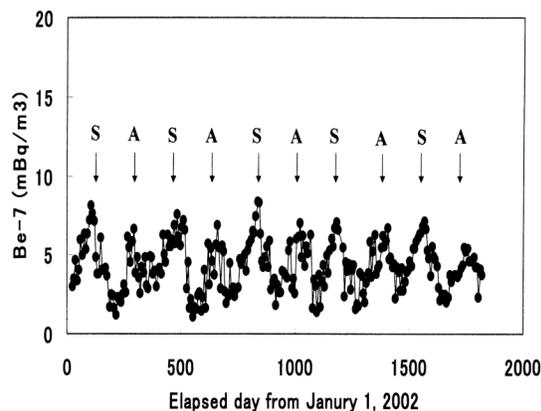


Figure 2: Variations in the surface Be-7 concentration in 2002-2006. Here S and A stand for spring and autumn, respectively.

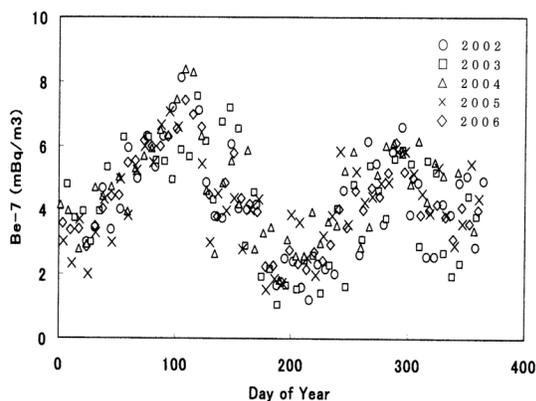


Figure 3: Variations in the surface Be-7 concentrations in 2002-2006 ( $\circ$ : 2002,  $\square$ : 2003,  $\triangle$ : 2004,  $\times$ : 2005,  $\diamond$ : 2006).

## Discussion

We discuss the enhancements of surface Be-7 concentrations in spring and autumn shown in Figure 3. The data show clear enhancements in spring and autumn every year. The seasonal variations are not related to the solar activity and are due to the meteorological effect. There are two possibilities that cause the seasonal variations. The first one is the influence of scavenging by precipitation. It is believed to be the efficient process that brings Be-7 borne aerosol particles to the surface [7], [13], [15]. In Figure 4 we show the variations in the monthly average precipitation in Tokyo in 2002-2006 to study the influence of precipitation to the surface Be-7 concentration [16]. Precipitation does not indicate enhancements in spring and autumn and there is not a positive correlation between the Be-7 concentration and precipitation, as shown in Figure 4. It implies that scavenging by precipitation does not explain the measured variations shown in Figure 2.

The second one is characteristic atmospheric motions in the upper atmosphere. If the efficient air mass exchange or mixing takes place between the lower stratosphere and upper troposphere in spring and autumn, a large quantity of Be-7 produced in the lower stratosphere are brought into the troposphere, resulting in the enhancements of

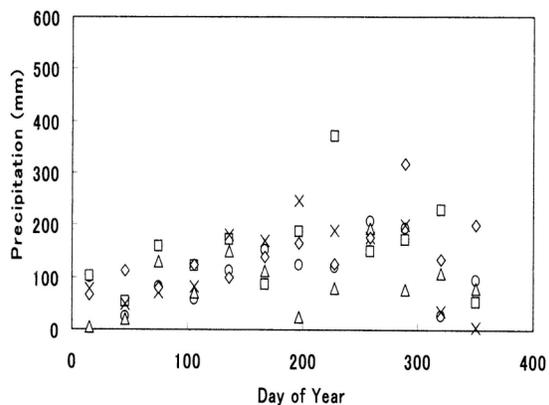


Figure 4: Variations in monthly average precipitation in Tokyo in 2002-2006.

the surface Be-7 concentrations. Recently, measurements of the Be-10 to Be-7 ratio were proposed to provide an important clue for a study of the stratosphere-to-troposphere exchange [17], [18]. Here we suggest a possibility of the air mass exchange or circulation between the stratosphere and troposphere in spring and autumn.

It has been well known that a westerly carries a pair of a traveling high pressure and extratropical low pressure over Japan in spring and autumn. A distance between the high and low pressures is about 1000 km and they pass through Japan in a period of a few days. The traveling high pressure is formed between a ridge and trough in the large-scale meander of the jet-stream (altitude of ~300 mb). On the other hand, the extratropical low pressure is formed between a trough and ridge. Cold air flows downwardly from a convergence of the jet-stream to a divergence of the surface high pressure. On the contrary, warm air flows upwardly from the convergence of the surface low pressure to the divergence of the jet-stream. The atmospheric pressures, jet-stream and air flows are schematically shown in Figure 4. These atmospheric downward and upward motions cause a circulation or mixing between the lower stratosphere and upper troposphere. This atmospheric motion results in the enhancement of the surface Be-7 concentrations in spring and autumn.

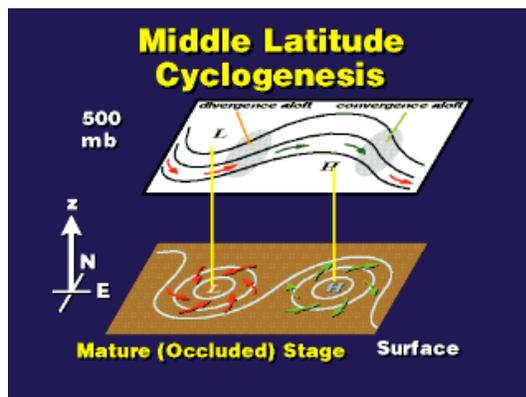


Figure 5: Schematic meteorological conditions in spring and autumn in Japan.

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