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Atmospheric Air Mass Motions Studied from Measurement of Cosmogenic ^{7}Be Radionuclide

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We study atmospheric air mass motions in the upper atmosphere from a measurement of surface concentrations of the cosmogenic ^{7}Be (half life 53.3 days) produced by galactic cosmic rays (GCR) and solar energetic particles (SEP). ^{7}Be is a potentially useful tracer for atmospheric air mass motions that influence transport of ^{7}Be-borne small aerosol particle. The surface ^{7}Be concentrations in Tokyo (35N, 139E) have been continuously measured with a high-volume air sampler since 2002. The surface concentrations exhibit the enhancements in spring and autumn. The seasonal variations are thought to result from the stratosphere-troposphere air mixing that is caused by a pair of traveling anticyclone and extratropical cyclone.

1. Introduction

^{7}Be is produced from GCR and SEP nuclear interactions with atmospheric nuclei. The altitude distribution was calculated by a few authors [1], [2], [3]. Their results indicated that ~70% of ^{7}Be are produced in the lower stratosphere and ~30% in the upper troposphere. Once ^{7}Be is produced, it is attached to a small aerosol particle and brought to the surface by air mass motions. In particular, since the half life of ^{7}Be is 53.3 days, it is suitable for study of short-term air mass motions. A number of measurements of ^{7}Be were reported [4], [5], [6], [7] and the surface concentration of ^{7}Be showed complex temporal variation, depending on season, location and local meteorological conditions. Several simulations were carried out for explanation of the measured temporal variations [8], [9], [10]. A few processes were proposed: (1) The air mass mixing between the stratosphere and troposphere, (2) the vertical air mass transport in the troposphere, (3) the air mass transport from middle latitudes into high latitudes, and (4) scavenging by precipitation. We started a measurement of the surface ^{7}Be concentration in Tokyo in 2002. Japan is an important location for study of the short-term atmospheric motion in the Asian Pacific region.

2. Measurement

A high-volume air sampler is used for a collection of ^{7}Be-borne aerosol particles on the surface. It is of all-weather type and its air sampling rate is 1 m^{3} per minute. ^{7}Be is collected for one week. The gamma-ray spectrum of ^{7}Be (477.59 keV) is measured with a germanium detector shielded with a 10cm-thick lead that enables to reduced the background level. The experiment is described in detail [11]. In addition to ^{7}Be, numerous gamma-ray lines emitted from terrestrial radionuclides are detected: for example, uranium-series nuclides (^{210}Pb(46.50 keV), ^{214}Pb(351.92 keV), ^{226}Ra(185.99 keV) and ^{214}Bi(609.31, 1120.29 and 1764.49 keV)), thorium-series nuclides (^{212}Pb (238.62 keV), ^{208}Tl (510.72, 583.14 and 860.37 keV) and ^{212}Bi (727.17 keV)), and ^{40}K line at 1460.8 keV. In addition, the positron annihilation line at 511.0 keV is apparent. Taking account the photoefficiency of the detector at 477.59 keV, the decay rate of ^{7}Be and sampled air volume per 1 week, we determine the surface ^{7}Be concentration in unit of mBq/m3 from a total count of ^{7}Be photopeak. We show the yearly variations in the surface ^{7}Be concentration in Jan. 2002-June 2005 in Figure 1. There are seasonal variations that indicate the high surface concentration in spring and autumn (6-8 mBq/m^{3}).

The present value in Tokyo is comparable with the previous ones measured in the other locations: 3.3-5.0 mBq/m^3 in Maryland, USA [12], 1.5-4.5 mBq/m^3 in Northwest Territories, Canada [13] and 3-9 mBq/m^3, in Osaka, Japan [4]. The surface ^{7}Be concentration varies with season, location and meteorological conditions [14] and the time scale of variations ranges from within a single precipitation event to seasonal change [15]. In particular, the spring maximum was measured [12], [16], [4].

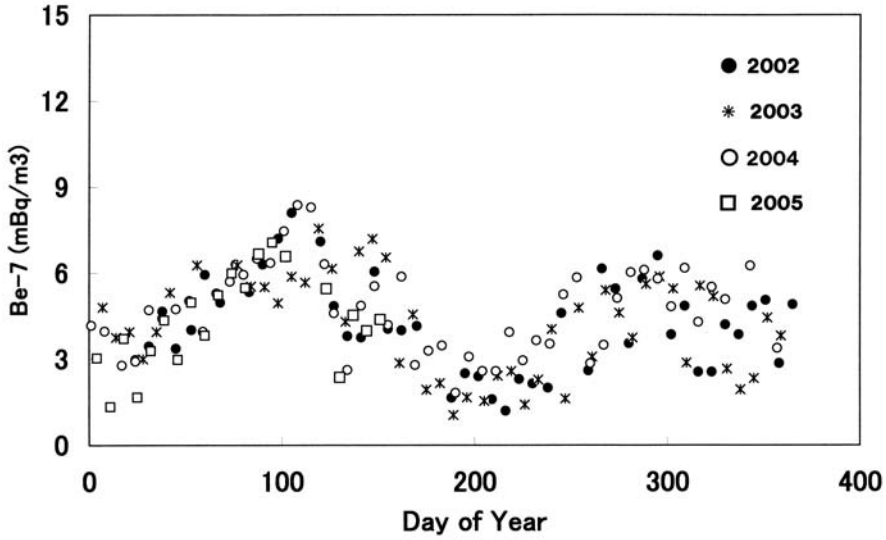

Figure 1. Temporal variations in the surface concentration in 2002-2005.

3. Discussion

^{7}Be in the surface air consist of two components of stratospheric and tropospheric origin. The surface ^{7}Be concentration depends on the production rate, the mean residence times in the stratosphere and troposphere and the decay rate. The ^{7}Be production rate in the stratosphere is about 2.4 times as large as that in the troposphere. The residence time of ^{7}Be in the stratosphere is about 1 year [17] that is much longer than the half life of ^{7}Be (53.3 days), while that in the troposphere is about 10 days [18]. It indicates that most of the stratospheric ^{7}Be do not reach the Earth's surface unless there is an efficient transport process from the stratosphere to the troposphere. In order to explain the measured seasonal enhancements of the surface ^{7}Be concentration, the vertical downward transport within the troposphere was studied [19], [15], [20]. O the other hand, the air mass mixing process between the stratosphere and troposphere was suggested [21]. Further, measurements of the ^{10}Be/^{7}Be ratio were carried out for the study of the air mass exchange between stratosphere and troposphere [22], [3].

The temporal variations in the surface ^{7}Be concentration were suggested to be due to the influence of scavenging by precipitation [12], [14]. In order to study whether there is a correlation between the surface ^{7}Be concentration and the precipitation in the present measurement, we show the temporal variations in the monthly average ^{7}Be concentration and the monthly precipitation in Figure 2. There is not clear relation between these two in the present measurement.

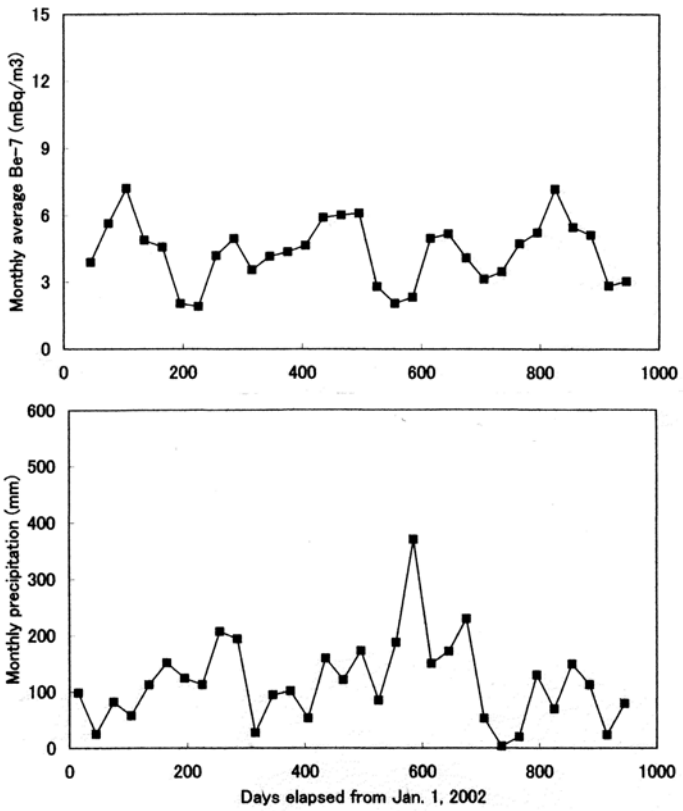

Figure 2. Temporal variations in the monthly average ^{7}Be concentration and precipitation.

Here we suggest the possibility of vertical air mass transport in the troposphere in order to explain the enhancements of the surface concentrations in spring and autumn. It has been well known that a pair of a traveling anticyclone and extratropical cyclone usually passes over Japan in a spring and autumn. A period of the passing is a few days. The traveling anticyclone is formed between the ridge and trough in the Rossby waves (large-scale meaders of the jet stream) at ~300 mb, while the extratropical cyclone is formed between the trough and ridge. The surface pressure, airflow, front systems and the locations of troughs and ridges in the Rossby waves are schematically shown in Figure 3. The cold air flows downward from convergence in the surface anticyclone to divergence in the Rossby waves. On the other hand, the warm air flow s upward from convergence in the surface cyclone to divergence in the Rossby waves. Such air mass circulation in the troposphere is thought to cause the enhancements of the surface ^{7}Be concentration in spring and autumn.

4. Acknowledgements

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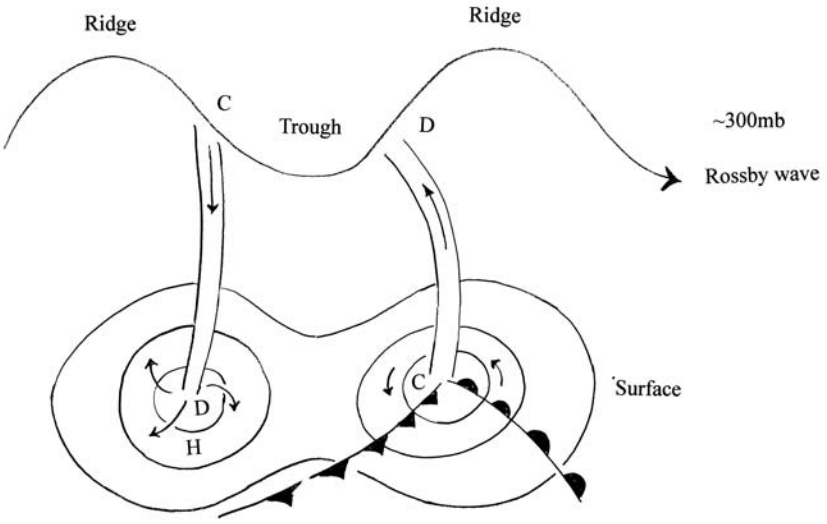

Figure 3. Schematic air mass mixing in spring and autumn.

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