Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 1 (SH), pages 717–720

30TH INTERNATIONAL COSMIC RAY CONFERENCE

ICRC'07 Mérida, México

The yearly and seasonal variations from 7-year data set of daily cosmogenic nuclide Be-7 concentrations in the atmosphere

SATOSHI KIKUCHI[1], HIROHISA SAKURAI[1], SHUICHI GUNJI[1], FUYUKI TOKANAI[1], EMIKO INUI[2], NATSUO SATO[3], AKIRA KADOKURA[3]
[1]*Department of Physics, Yamagata University*
[2]*Radioisotope Laboratory, Yamagata University*
[3]*National Institute of Polar Research*
kikuchi@ksprite.kj.yamagata-u.ac.jp

Abstract: We have been continuously observing the daily Be-7 concentrations at Yamagata, Japan (38.25° N, 140.35° E) since 2000 to study the relationship between the cosmogenic nuclides and solar activities. Based on the 7-year observation, the anti-correlation between the Be-7 concentrations and the sunspot numbers is obtained indicating the variability of 37.6 %. A clear seasonal variation with two peaks in spring and fall was shown over 7 years. Moreover, the Be-7 concentrations at Yamagata was 2.4 times greater than that in Iceland (64.67° N, 21.2° W).

Introduction

Be-7 is one of the cosmogenic nuclides in the atmosphere. It is produced by interactions between cosmic rays and nitrogen or oxygen in the atmosphere. The Be-7 is oxidized and then attaches to aerosols. The aerosols with the Be-7s fall down to the ground. Hence, the Be-7 concentrations in the air should indicate the variations of cosmic-rays intensities.

Solar activities affect the variation of heliomagnetic fields through solar winds. Galactic cosmic rays coming to the earth are modulated by the solar activities because they are traveling in the heliosphere. In fact, the cosmic-rays intensities are evidently modulated by the 11-year periodic variation of solar activities[1].

Moreover, the geomagnetic fields cut the cosmic rays with the energy less than the cut-off rigidity at each geomagnetic latitude. Hence, the latitude effect is appeared for the cosmic rays and in turn for the Be-7 concentrations.

The cosmogenic nuclides with the long half-life are useful for the estimation of the cosmic rays and/or the solar activities in the past. It is important to investigate the relationships between the Be-7 concentrations, the cosmic rays and the solar activities at the present time because Be-7 is a reliable cosmogenic nuclide with the half-life of 53 days. We describe the time variations of Be-7 concentrations by the daily sampling for 7 years at the solar cycle 23.

Experiment

The daily Be-7 concentrations in the atmosphere have been continuously observed at the top of the building (15 m in height) of Yamagata University since 2000. The building's location is at 38.25° N, 140.35° E, and its altitude from the sea-level is 168.33 m. A high-volume air sampler (HV-1000F) manufactured by Shibata-Kagaku Company, which is operational under all weather conditions, has been employed for the collection of the air containing aerosols. The volume intake rate of air is regulated to 1000 L/min (20 °C, 1 atm). The aerosols attaching the Be-7s are trapped in a sheet of the glass fiber filter with the cross-section of 203 × 254 mm (ADVANTEC GB-100R). The collection efficiency is 99.99 % for particles of 0.3 μm in diameter.

The filter is putted into the plastic capsule ($\phi\, 50 \times 35$ mm) and hold on for 10 days to reduce the influence of short-lived radionuclides. The radioactivity of the Be-7 (γ : 477.6 keV, HL:53.28 days) in the filter was measured with the high-purity germanium (HPGe) gamma-ray detector GEM-25185 (ORTEC). The detector is surrounded by shielding materials consisting of old lead, old iron, oxygen-free copper and acrylic plates to reduce the backgrounds. The measuring time is 6 hours for one sample.

Moreover, in order to investigate the latitude effect, we have been continuously observing the Be-7 concentrations in Iceland (64.67° N, 21.2° W) since Sep.2003 with the same method.

Results and Discussion

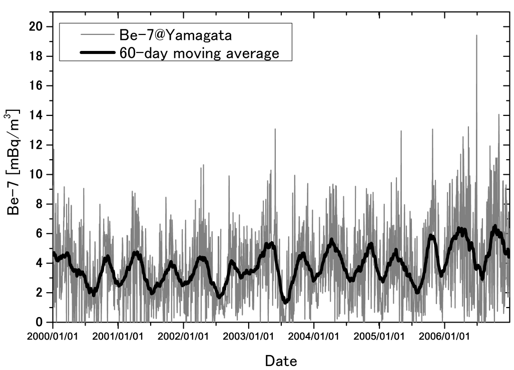

Figure 1: Daily profile of the Be-7 concentrations for 7 years

Figure 1 shows the daily profile of the Be-7 concentrations (BEC) at Yamagata for 7 years. The daily Be-7 concentrations are very variable and complex. The average and the standard deviation for 7 years are 3.80 mBq/m^3 and 2.44 mBq/m^3, respectively. In the figure, the seasonal variations are clearly shown as the smoothed curve with the two peaks in the spring and the fall.

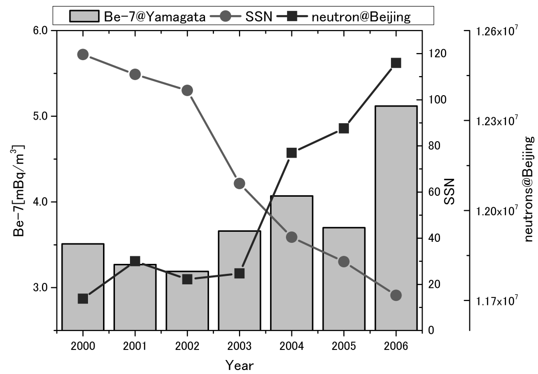

Figure 2: Yearly variations of the Be-7 concentrations, the SSN and the intensity of neutrons

Figure 2 shows the yearly variations of the Be-7 concentrations, the sunspot numbers (SSN)[2] and the neutron intensities[3] observed on the ground in Beijing (40.08° N, 116.26° E, alt.:47.81 m). The cut-off rigidity of Yamagata is approximately 10 GV and is similar to that of Beijing at 9.18 GV.

As shown in this figure, the Be-7 concentrations and the neutron intensities are anti-correlated to the SSN. The correlation coefficients between the Be-7s and the SSN, the neutrons are −0.79, 0.84, respectively. The correlation coefficient between the SSN and the neutrons is −0.92. They indicate that the solar activities affect the cosmic rays and the Be-7 concentrations with good correlation.

The rates of variability of the Be-7s, the SSN and the neutrons between the maximum and the minimum are 37.6 %, 87.3 % and 6.3 %, respectively. The variability of the Be-7s is much greater than that of the neutrons. The difference between both the variabilities is presumably caused by the air mass motions of the high concentrations of the Be-7 produced at lower cut-off rigidities. For instance, the variability of the neutron is approximately 15 % at Climax of 2.97 GV[1]. However, it is difficult to explain the variability of the Be-7s only by the cause of horizontal air-mass flow because of the variability of 20 % at most.

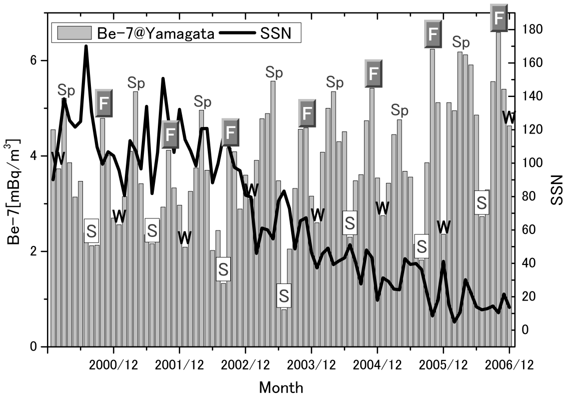

Figure 3: Seasonal variations of the Be-7 concentrations and the SSN

Figure 3 shows the monthly variations of the Be-7 concentrations and the SSN from 2000 to 2006. In this figure, “Sp”, “S”, “F” and “W” means the four seasons of spring, summer, fall and winter, respectively. As shown in the figure, the Be-7 concentrations in the spring and the fall are high and those in the summer and the winter are low.

In spring, the exchange of the air mass between the stratosphere and the troposphere is more active than the other seasons indicating the higher Be-7 concentrations. In summer, the pacific anticyclone becomes to be strong in Japan islands, and it provides to the islands the south winds which have less Be-7s because of the high cut-off rigidities at the lower latitude indicating the lower Be-7 concentrations. In fall, it is inferred that the Be-7s in the stratosphere and/or the upper troposphere directly fall down to the ground. The snows may wash out the Be-7s in the atmosphere because the Yamagata is snowfall area in winter.

The correlation coefficients between the Be-7 concentrations at each season and the SSN are −0.73 (spring), −0.62 (summer), −0.94 (fall) and −0.55 (winter), respectively. The Be-7 concentrations in fall are more strongly anti-correlated to the SSN than other seasons. It indicates that the Be-7s produced in fall are fallen down from the upper troposphere with a short residence time.

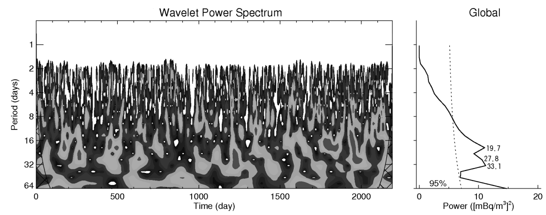

Figure 4: Periodic analysis by Wavelet for 6-year daily Be-7 concentration data set from 2000 to 2005

The results of the periodic analysis for 6-year daily Be-7 concentration data set (the number of data is 2192) by wavelet[4] are shown in Figure 4. In this figure, the power spectrum is plotted by the two-dimensional data transformed from one-dimensional time-series data, and the global spectrum is the projection of this power spectrum. We used “Morlet” as the mother wavelet. The global spectrum has three peaks (period [days]: 19.7, 27.8, 33.1). The 27.8-day may correspond to the rotation period of the sun. Some kinds of meteorological elements may cause the other periods.

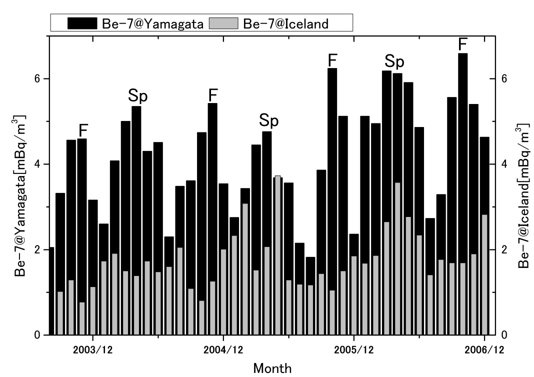

Figure 5: Monthly variations of the Be-7 concentrations at Yamagata and in Iceland

Figure 5 shows the monthly variation of the Be-7 concentrations at Yamagata and in Iceland from Sep.2003 to Dec.2006. The cut-off rigidity of Iceland is approximately 0.5 GV, which is much smaller than that at Yamagata. The variation of Be-7 concentrations at Yamagata has two peaks, but that in Iceland has only one peak in spring.

The average Be-7 concentrations at Yamagata and in Iceland for approximately 3 years are

4.3 mBq/m^3 and 1.8 mBq/m^3, respectively. Considering the latitude effect of cosmic rays, this result should be reversed. However, the height of the tropopause gradually lowers from low latitude to high latitude. The heights of the tropopause in the vicinity of the equator and that in the vicinity of the pole are 17 km and 9 km, respectively. Hence, at higher latitude the production rate of Be-7 is smaller than at lower latitude. As a result, the Be-7 concentration in middle latitude is higher than that in high latitude.

The calculated production rates[5] of the Be-7 in the troposphere at the latitude at Yamagata and in Iceland are approximately 1.25 and 0.4 [$\times 10^{15}$ atoms s^{-1} deg^{-1}], respectively. The Be-7 concentration at Yamagata is 2.4 times greater than that in Iceland. As the production rate at Yamagata is 3.1 times greater than that in Iceland, the ratio of the Be-7 concentrations is greater than that of the calculated production rate.

Conclusion

We have been studying the relationship between the cosmogenic nuclides and solar activities observing continuously the concentrations of cosmogenic nuclides Be-7 at Yamagata and in Iceland.

The time profile of the daily Be-7 concentrations for 7 years showed the seasonal variation and the yearly variation with anti-correlation to the SSN indicating the average Be-7 concentration of 3.80 mBq/m^3.

The variability of the Be-7 concentrations is 37.6 % for 7 years and it is greater than that of the neutron. The Be-7 concentrations in the spring and the fall are high and those in the summer and the winter are low. The Be-7 concentrations in fall are more strongly anti-correlated to the SSN than other seasons.

We analyzed the daily data set of the Be-7 concentrations for 6 years from 2000 to 2005 by wavelet. The global spectrum has three peaks of the periods, 19.7, 27.8 and 33.1 days. The 27.8-day may correspond to the rotation period of the sun.

The seasonal variation of Be-7 concentrations at Yamagata has two peaks, but that in Iceland has only one peak in spring. The Be-7 concentration at Yamagata is 2.4 times greater than that in Iceland indicating the height effect of the tropopause for the latitude.

References

[1] Space physics data system : Climax and haleakala neutron monitor datasets. `http://ulysses.sr.unh.edu/NeutronMonitor/neutron_mon.html`.

[2] Solar influences data analysis center. `http://sidc.oma.be/`.

[3] World data center for cosmic rays. `http://www.env.sci.ibaraki.ac.jp/database/html/WDCCR/`.

[4] C. Torrence and G. Compo. A practical guide to wavelet analysis. `http://paos.colorado.edu/research/wavelets/`.

[5] Hisao Nagai, Wataru Tada, and Takayuki Kobayashi. Production rates of ^{7}Be and ^{10}Be in the atmosphere. *Nuclear Instruments and Methods in Physics Research B*, 172:796–801, 2000.