Altitude distribution of C-14 concentration by Geant-4

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Abstract

The altitude dependence of the ^{14}C production rate is simulated by Geant-4 using the cosmic primary proton spectra between 10 Mev and 1 TeV at the solar maximum and minimum. The simulation results indicated that the modulation at the troposphere is independent to the latitude but at the stratosphere it depends on the latitude.

1. Introduction

^{14}C is mainly produced in atmosphere by interaction between nitrogen and neutron generated with cosmic rays. The ^{14}C was taken in plant at biosphere as oxidized carbon. As ^{14}C is a radioisotope with the half-life of 5730 years, terrestrial materials including ^{14}C are useful samples to investigate cosmic rays over past a few ten thousand years [1]. Experimentally, the production rate of ^{14}C by cosmic rays can obtain from the concentration of ^{14}C using carbon cycle model between the atmosphere and the ocean. However, this is estimated under a postulate that the produced ^{14}C is uniformly mixed in the atmosphere. As the geomagnetic field modulates cosmic rays, the solar modulation at the polar region is greater than the low latitude region. Hence we have simulated ^{14}C production rate for each location in the global system applying the Geant-4 program with a cross section table of low energy neutron between 20 MeV to 10^{-5}ev [2]. The simulation was carried out for the energy spectrum of cosmic ray proton between 10 MeV and 1 Tev for the solar maximum and the solar minimum. We focused on the altitude distributions of ^{14}C production rates at each latitude, because the produced ^{14}C is affected by air mass flow at the troposphere and stratosphere.

2. Calculation

In calculations, we used a formula of the following differential energy spectra including the modulation parameter for galactic cosmic ray primary protons [3,4].

pp. 4151–4154

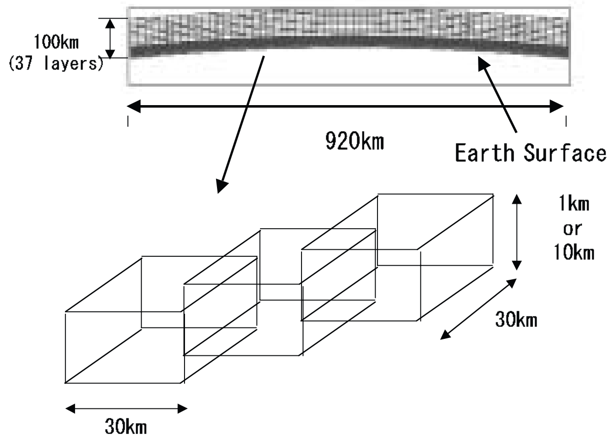

Fig. 1. The geometry structure of the atmosphere used in the Geant-4 simulation.

$$J(K,\Phi) = \alpha \frac{K(K+2M)(K+X)^{-2.65}}{(K+\Phi)(K+2M+\Phi)} \qquad (1)$$

where K is kinetic energy of the proton, Φ is the modulation parameter, α is 9.9×10^8, M is the rest mass energy of proton, X=780exp($-2.5 \times 10^{-4}K$). Although the proton energies injected to the atmosphere of the earth were ranged from 10 Mev to 1 Tev, most of ^{14}C are produced by the protons above 50 MeV.

In this calculation the target of the incident primary proton is the atmosphere from the grand to the altitude of 100 km, where the altitude distribution for the air-mass density was employed that of the U.S.- standard atmosphere. For the simulation, taking account of the air-mass distribution the atmosphere was divided to 37 layers for the altitude, where the thickness of the lower layers is 1 km each up to the altitude of 30 km and that of above layers is 10 km each. Moreover, to include the earth curvature in the geometry, a large box with the bottom area of 920 km $\times$30 km and the height of 100 km was constructed with many boxes in the size of 30 km $\times$ 30 km $\times$ 1 km or 10 km.

First of all, the proton coming to the top of the atmosphere from omnidirection is taken a test of the cut-off due to the geomagnetic fields [5]. And then, the proton that can go through the cut-off interacts with the elements in the geometry, and the interactions and productions by produced particles are traced by the Geant-4 supporting the production of ^{14}C due to the neutrons with the energies less than 20 MeV.

3. Results and Discussion

It is necessary to know the altitude distribution of the produced ^{14}C for the investigation of the short-term time variation such as the 11-year solar variation

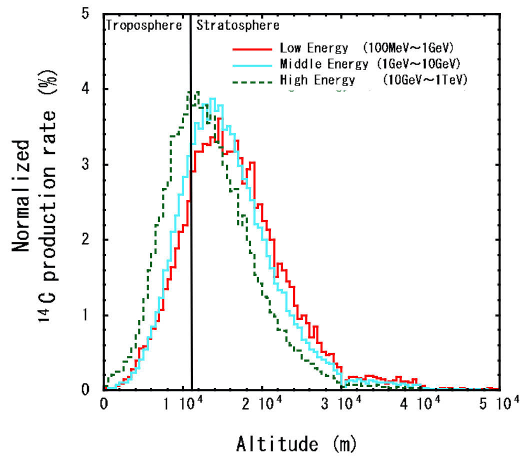

Fig. 2. The simulated ^{14}C production rate as a function of altitude for the three kinds of incident proton energy ranges in the whole of the earth atmosphere.

of cosmic rays, because the residence time (3 yr) of $^{14}CO_2$ in the stratosphere is different from that ($\leq$ 1 yr) in the troposphere [6]. Fig. 2 shows the simulated ^{14}C production rate as a function of altitude for the three kinds of incident proton energy ranges in the whole of the earth atmosphere. Most of ^{14}C are produced independently to the proton energy at the altitude less than 30 km. However, the production rates in the troposphere at which the altitude is typically 11 km at middle latitude, were 22%, 26%, and 41% for the low, middle, and high energy range, respectively.

Naturally, the altitude distribution depends on the latitude because the geomagnetic cut-off rigidity is different at each one. It, also, depends on the primary proton energy spectra. Fig. 3 shows the average altitude of ^{14}C production rate at each latitude of the earth for the solar Maximum (Φ=1000 MeV) and the solar minimum (Φ=400 MeV). The altitude gradually increases with the latitude from the equatorial region of 13 km to the polar regions of 16 km. In the high latitude region above 60 degree, the average altitude at the solar minimum is approximately 0.5 km higher than that at the solar maximum. In Table 1, the solar modulations of the ^{14}C production rate at each latitude are shown for the troposphere and the total atmosphere. The simulation results indicate that the solar modulation at the troposphere is independent to the latitude but at the stratosphere it depends on.

4. Conclusion

The simulation of the ^{14}C production rate was carried out for the energy spectrum of cosmic ray proton between 10 MeV and 1 Tev for the solar maximum and the solar minimum, using Geant-4. Taking account of the earth curvature in

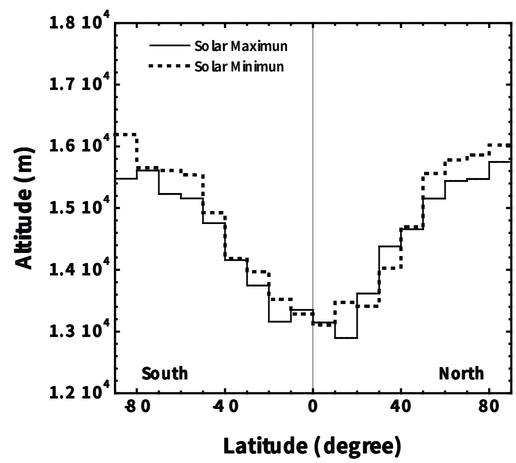

Fig. 3. The simulated average altitude of ^{14}C production rate at each latitude of the earth for the solar Maximum (Φ=1000 MeV) and the solar minimum (Φ=400 MeV)

Table 1. Simulated results of the solar modulation for the ^{14}C production rate

latitude	Troposphere	Total
Low	11%	12%
Middle	11%	17%
High	12%	29%

the geometry for the simulation, a large box with the bottom area of 920 km ×30 km and the height of 100 km was constructed with many boxes in the size of 30 km × 30 km × 1 km or 10 km.

The ^{14}C production rate in the troposphere increases with the incident primary proton energy. Also, the simulation indicate that the solar modulation of the ^{14}C production rate at the troposphere is independent to the latitude but at the stratosphere it depends on the latitude.

5. References

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