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Geant4 simulation of geomagnetic field

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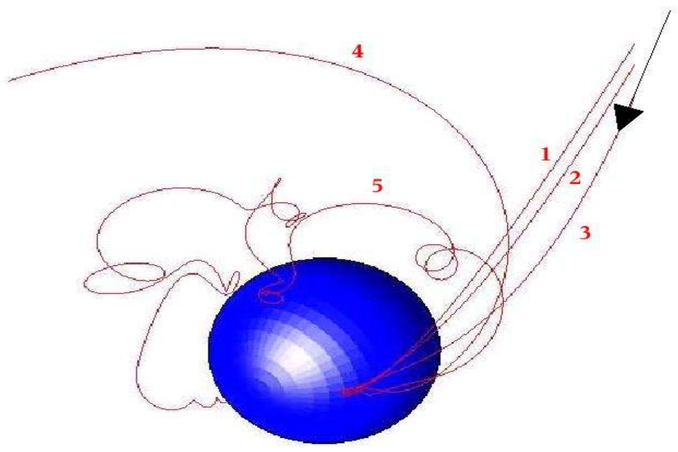
Abstract

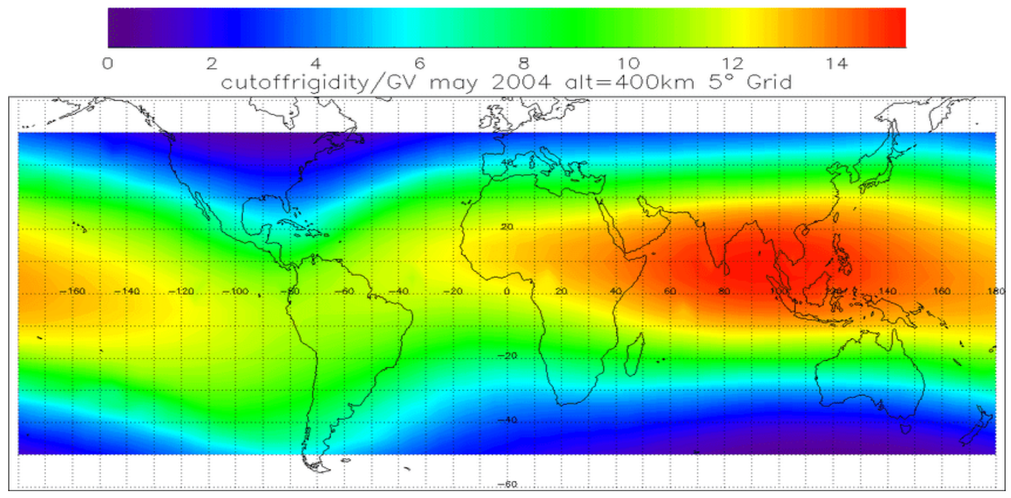
Modern experimental techniques, such as Accelerator Mass Spectrometry (AMS), allow us to analyze environmental samples with high sensitivity and resolution. The concentration of cosmogenic nuclides in these samples is the result of the interplay between three processes: production, transport, and deposition. The knowledge about the process became production. The Monte-Carlo method is a very helpful method to understand such processes. Our model of extraterrestrial production of cosmogenic nuclide was described in [1]. Model is a powerful tool for investigation of cosmogenic production. On the other hand, its important component is missing allowing calculation of production on the Earth. The model could be used also for simulation of cosmic rays' irradiation of terrestrial objects. But the secondary cosmic ray at the Earth highly depends on modulation with a geomagnetic field. The field simulation is not included I our model yet.

This presentation will be dedicated to the description of the geomagnetic extension of our model. Geant4 toolkit is suited to simulation of simple magnetics field. On the other hand, the geomagnetic field is highly non-uniform. Modeling non-uniforms field is possible by definition of many small uniform fields in Geant4. The global field will be modeled using Geant4 routines. The results will be compared with existing published works. The extension of our model allows the investigation of Earth samples.

[1] Čechvala, P., Breier, R. & Masarik, J. Production rates of cosmogenic nuclides in extraterrestrial material using GEANT4 software. J Radioanal Nucl Chem 332, 4403–4411 (2023). https://doi.org/10.1007/s10967-023-09135-5

Geomagnetic field

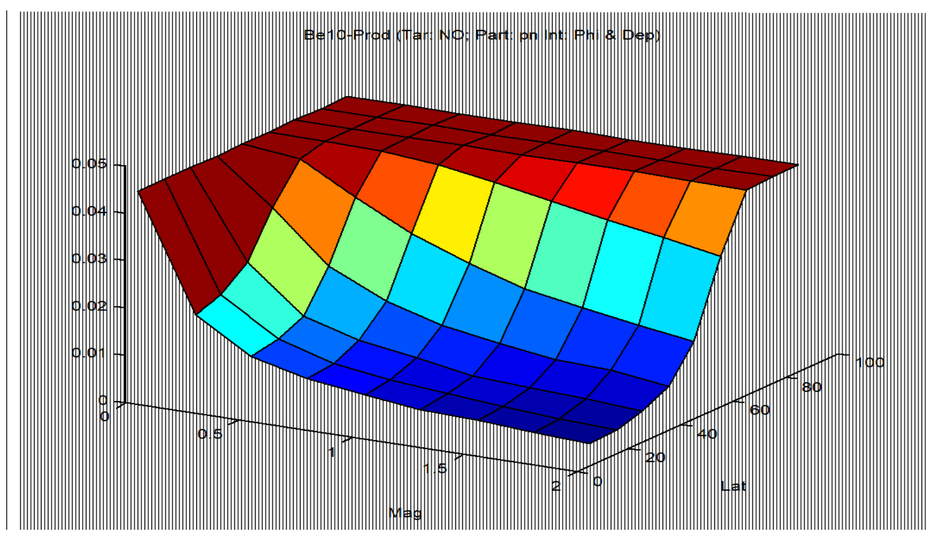




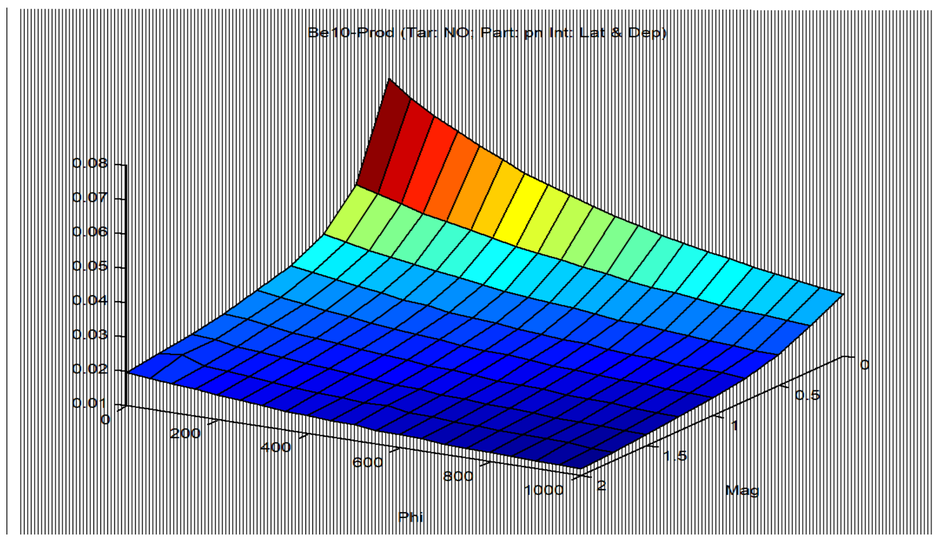
Geant 4 simulation

For our simulations we have been using Geant4 (GEometry ANd Tracking) Monte Carlo simulation toolkit. Geant4 is free to download and available at the webpage site https:// geant4. web.cern.ch/. This software simulates the propagation of high-energy particles through matter, Geant4 is very versatile and multifunctional software which enables to the user to develop his own geometrical object and the environment exposed to the flux of high-energy particles.The application of Geant4 code also to calculation of production rate of nuclides can optimize and automatize our calculation approach. The extension of model to simulation of geomagnetic field allows investigation of Earth sample.

Results



Production rate 10Be versus magnetic field and latitude M=550



Dependence of 10Be production rate on geomagnetic field and solar modulation.

10Be production rate depends on the geomagnetic field intensity (relative to the present) and the geomagnetic latitude. The latitude dependence upon dipole moment is strongly non-linear. Note that the "magnetic modulation" is strongest in equatorial regions, and non-existent at geomagnetic latitudes > 70°. If the geomagnetic field is switched off (M = 0), as it may occur during a geomagnetic reversal, the production rate is constant over the globe. Note however that the persistence of non-dipole terms in the geomagnetic field at such times will result in some small regional magnetic modulation.

Finally, the mean global 10Be production rate depends upon solar modulation and the strength of the geomagnetic dipole. First of all it shows the mean global production rate has a dynamic range of almost an order of magnitude from a maximum when the geomagnetic field is zero and the sun quiet (M = 0 MV) to a minimum when the magnetic field is doubled and the sun very active. As M increases, so the geomagnetic cut-off energy increases, removing the lower energy cosmic rays that suffer the strongest solar modulation. Thus the amplitude of the solar modulation is a relatively strong function of strength of the geomagnetic dipole.