Anisotropy and mean free path of solar energetic particles: simulation study

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As solar energetic particles (SEPs) cause severe radiation hazards such as satellite malfunctions, radiation exposure for astronaut, high radiation doses of air crew, and lost of communications by high-frequency radio waves, forecasting of SEP is one of the most important topics in space weather research.

SEPs are non-thermal ions with energy MeV-GeV/nucleon accelerated at solar flare and/or shock wave, and sometimes called solar cosmic rays. SEPs having energy over 100 MeV, which are accelerated near the Sun (namely at solar flare and/or coronal shock waves), are propagated in solar wind followed by being observed at the Earth. Therefore, to comprehensively understand SEP events, it is essential to investigate SEP propagation as well as acceleration.

Although Parker's transport equation is often used to describe energetic particle transport problems such as cosmic ray transport in heliosphere, the Parker's equation, which postulates isotropic pitch angle distribution of energetic particles, cannot describe SEP transport correctly. The reason is that as a mean free path of SEP in solar wind can be comparable to a distance from the Sun to the Earth, a strong anisotropy appears in pitch angle distribution. Therefore, Focused Transport Equation (FTE), which can describe evolution of pitch angle distribution of particles, must be used to describe SEP transport in solar wind. Solving the FTE, the strong anisotropy of SEP can be reproduced correctly. Actually, previous simulation studies of SEP transport show that solution of the FTE with adjusting mean free path value can reproduce observed SEP intensity and anisotropy well. Therefore, the FTE model may be used to predict SEP intensity time profile if the adjustable values such as mean free path can be estimated as soon as SEP event was observed at the Earth.

Shalchi et.al. (2009) derived analytically a relation between an SEP anisotropy and a mean free path by using FTE under many approximations. However, the relation is not valid for initial time of SEP event when anisotropy is strong. For a purpose of forecasting, we want to know a relation between anisotropy and a mean free path at initial phase of an SEP event. In this study, we analyzed data of FTE simulation to find out a method to estimate a mean free path of SEP in solar wind from anisotropy data.