Chapter 6
Conclusions

In our work, we study spacecraft or ground-based data of solar energetic particles in different situations, such as the low energy protons of the solar event on July 9, 1996, the medium energy ions of the solar event on November 6, 1997, and adding the effect of bottleneck magnetic field lines for the solar event on July 14, 2000. In this work, we had to develop our simulation and fitting programs in order to apply them to the different conditions of solar events. These methods now make it easy to fit the data objectively (not by eye) and should be useful for analyzing the data from other spacecraft instruments as well. We can study the solar event by studying the data about the particles, energy, interplanetary medium, or the surrounding information in interplanetary space from spacecraft or ground-based data, which is publicly shown on websites.

We study the injection function of the solar particles as a function of time and energy by using the linear least squares technique to fit the data, and an automatic truncation of the piecewise linear technique. The joint times of the piecewise linear injection function are $t_\circ = t_{flare} + \delta$, and $t_i = t_\circ + 2^{i-1}\, \varepsilon\, dt$, where dt is the time spacing of the data, and (δ, ε) are optimized automatically. We developed a new technique for analyzing spacecraft data for the particles released from the Sun by taking non-statistical interplanetary fluctuations in account. This is useful to increase the accuracy of the fitting results because the χ^2 value which expresses the difference between the data and the transport simulation results (convoluted with the injection function) rely on the uncertainties of the data.

According to the fitting results for three solar events shown in the previous chapter, the scientific conclusions of this work are:

1. The CME-driven shock accelerates the particles as it moves outward from the Sun. The effects of acceleration by CMEs will be at a maximum when CMEs propagate near the Sun, and CMEs lose efficiency of the acceleration after they propagate outward from the Sun. We observed the effects of acceleration by CMEs in our derived injection profiles corresponding to the acceleration near the Sun, and the later due to acceleration by the CME-driven shock in the interplanetary medium.

2. The efficiency of acceleration by CMEs at a low energy persists longer than for high-energy particles, which we observe from the injection duration of the particles decreasing as the energy increases.

3. We can study the propagation of the particles released from the Sun by using the transport equation of Ruffolo (1995), which we can develop further in order to explain interplanetary mirroring effects on the events of interest.

4. This work tests our fitting technique by confirming our fitting results with those of other researchers. We can fit the spacecraft or ground-based data with the new uncertainty estimation, using the simulation results of the transport equation as well by the linear least squares fitting with the optimized automatic truncation of the piecewise linear injection function. The fits are objective, relying on χ^2 minimization (not by eye). This is the first time for using the fitting technique to systematically fit the spacecraft or ground-based data for various types of particles and energy bands.

5. This work provides important evidence for the explanation of mirroring by a magnetic bottleneck beyond the Earth.