Chapter I
Introduction

Background and Motivation

Solar flares at the Sun's surface have been observed for more than a hundred years. Cosmic rays can be accelerated by flares and can propagate to the Earth. They can cause many effects (disturbing radio communications, causing radiation alarms on airplanes, etc.). No one knows the original causes of these events. The 11-year period of flare occurrences, the so-called solar cycle, is also not understood, nor is the mechanism of cosmic ray acceleration in solar flares.

Flares have been observed from electromagnetic waves (radio waves, infrared radiation, white light, ultraviolet light, x-rays and gamma rays) or from energetic particles such as cosmic ray protons (hydrogen ions), electrons, neutrons (Ruffolo 1991), pions, and heavy ions. Each method of observation will yield different information. Characteristics of flares were discovered in 1977 that separate flares into 2 classes by duration of x-ray emission. These are the impulsive and gradual flares (Pallavicini, Serio, &Vaiana 1977). Furthermore, these 2 classes of flares emit different particles, with differing ratios of electrons to protons and ^{3}He to ^{4}He (Reames & Stone 1986; Evenson 1990). Then the particle acceleration models are different (Cliver et al. 1989), but no clear conclusions have been drawn.

One aspect of the particle emission comparison between impulsive and gradual flares is the duration of particle emission. This is a very important analysis because some people think that if impulsive and gradual flares accelerate particles at different heights in the corona, the duration of emission from the corona will be different. However, there are no systematic analyses to support this idea.

This comparison is not clearly understood. It is hard to distinguish between a delay that depends on diffusion or transport from the corona and a delay that depends on pitch-angle diffusion in the interplanetary magnetic field. Interplanetary transport cannot be modeled by a simple diffusion equation because the mean free path can reach 0.5 AU (The distance from the Earth to the Sun is 1.0 AU). Thus more complex transport equations of a Fokker-Planck form (e.g., Jokipii 1966) have been used instead. Previous comparisons of the duration of emission (Reames & Stone 1986: Kallenrode & Wibberenz 1991) studied flares in which interplanetary diffusion was anomalously low and neglected effects of interplanetary transport. However, such assumptions are not valid for all flares, so no general conclusion results from their work.

Recently, computational techniques have been developed to find solutions of transport equations very accurately for the simulation of interplanetary cosmic ray transport. Successful results were obtained by research groups that worked separately, and used different calculation techniques (Ruffolo 1991). The results are quite similar. Ruffolo (1991) used a magnetic model to describe flux observations of neutron-decay protons from the June 3, 1982 and April 25,1984 flares. Further development was reported by Ruffolo (1995), who changed the computer program to calculate the effects of solar wind convection and adiabatic deceleration.

The other processes of transport might depend on the scattering mean free path vs. distance from the Sun (Kallenrode, Wibberenz, & Hücke 1992) and the effects of transverse drifts and diffusion. When particle transport from flares at the Sun to the Earth can be accurately calculated, one can attempt to do what no one has done before. This work aims to measure the duration of particle emission from the Sun by fitting cosmic ray data.

Summary of Related Research

1. Model of particle transport

The original of focused transport theory was developed by Earl (1976a,b). Numerical models using the finite difference method of Ng & Wong (1979) worked, but they had the problem of numerical diffusion. This was corrected by Ruffolo (1991). Two other methods (not finite difference methods) were developed by Earl (1976a;1987) that can be made similarly accurate. So far, only Ruffolo (1991) and Dröge, Ruffolo, and Klecker (1996) have compared such simulation results with observational data (of neutron-decay protons and electrons, respectively). Further recent work extended the transport equation by adding the effects of deceleration and convection (Ruffolo 1995). Ruffolo & Khumlumlert (1995) explored the simulated properties of coherent pulses of particles from the flares.

2. Duration of particle emission

The duration of particle emission has been estimated in the past. One example of a survey of many flares is the work of Ma Sung & Earl (1978). Now is a good time for a new estimation because

a) we can produce more accurate simulations.

b) the difference between gradual and impulsive flares (Pallavicini, Serio, & Vaiana 1977) can been checked.

c) recent data from the U. of Chicago instrument on the ISEE-3/ICE spacecraft include accurate measurements of solar flare protons and electrons.

Recently two papers have addressed the issue of the duration of particle emission and a possible difference between impulsive and gradual flares. Reames

& Stone (1986) showed only a 3-day sequence of flare data. They did not fit graphs of data. They only wrote that interplanetary transport had little effect.

3. Interpretation of the duration of particle emission

There is a difference between the duration of particle emission of impulsive and gradual flares. In the past three decades, time-intensity profile observation of cosmic rays have shown that diffusion perpendicular to the magnetic field in the inner solar system is probably negligible (Palmer 1982). Thus most transport is along magnetic field lines. However, there are many cases observed on a magnetic field line that is connected with a longitude on the Sun far from the flare site and thus it was initially supposed that transport is the physical motion of particles in the corona so it has the common term "coronal transport." The Reid (1964) model has been widely used to parameterize the injection profile from coronal transport.

Reames (1990), who was interested in interplanetary shocks, continued his work with this model. It is known that interplanetary shocks can be accelerators in the interplanetary medium. Cane wrote about interplanetary shocks associated with gradual flares and stressed that particle observations at Earth orbit can sometimes be classified as shock related (e.g., Cane 1985). Furthermore, these writers think that acceleration near the Sun might be due to the same shock while in the solar corona. Thus, coronal transport would not be necessary for gradual flares when particles had been accelerated on the magnetic field line that is connected with the observer. Furthermore, Reames (1990) claimed that cosmic rays with a high ratio of Fe to O are associated with impulsive solar flares and accelerated at the flare site with less azimuthal diffusion. He concluded that after gradual events, particles were only observed on field lines that were nearly directly connected with the flare site.

One important obstacle to finding whether the shock hypothesis is true is that the model had been modified to bring it in accord with new results, and the authors do not report quantitative predictions for observed fluxes. However, a group in Spain simulated shock acceleration for fitting cosmic ray fluxes from gradual flares which are associated with interplanetary shocks.

The Objectives of This Thesis

1. To develop computer programs for comparing the results from simulations with fluxes of cosmic rays from the solar flares that were measured by many spacecraft.

2. To improve the cosmic rays transport simulations for modeling the fluxes of cosmic rays that were measured by many detectors in many angles.

3. To compare the data from the detector in many spacecraft with the results from simulations for determining the particle injection at many longitude of the Sun.

Procedure and Outline of This Work

In this work, the author develops computer programs for comparing the results from simulations with fluxes of cosmic rays from the solar flares, as will be described in chapter 3. The results of comparisons between the simulation results and spacecraft data are discussed in chapter 4. Finally in the last chapter will be discussion and conclusions. The procedures in preparing this thesis were:

1. To study the research that is involved.
2. To study the computational simulations.
3. To develop computer programs and check the correction.
4. To improve the cosmic rays transport simulations.
5. To find the particle injection.

6. To conclude and write the thesis.

The Usefulness of This Work

In this research the author should develop the computer programs for comparing the results from simulations with fluxes of cosmic rays, so from this research we get the computer programs that make it possible to better interpret the data. Furthermore, this research will yield the data of cosmic ray emission at many longitudes of the Sun. This research will make the reader understand the solar flare events better.