A Numerical Simulation
of a Geomagnetic Sudden Commencement

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Magnetospheric response to a solar wind pressure impulse is studied by using a numerical simulation based on a MHD model of the solar wind–magnetosphere–ionosphere system as a model of a geomagnetic sudden commencement (SC). We find that a SC period is divided into three phases; the preliminary impulse (PI) phase, the first stage of the main impulse (MI) phase, and the second stage of the MI phase. We also investigate plasma processes occurred in the magnetosphere–ionosphere compound system in the three phases of a SC period. In the context of the magnetosphere–ionosphere compound system in which plasma convections, field-aligned current (FAC), and current generators associated with the magnetosphere–solar wind interaction are self-consistently dependent, a SC is regarded as state transition from a ground state in the pre-SC period to another ground state in the post-SC period via a transient state in the second MI phase. In addition, plasma disturbances in the PI phase and the first MI phase are regarded as a MHD wave superposed in the compound system.

1. Introduction

Many Japanese scientists have conducted SC researches so far through a theoretical approach and through an observational approach [Araki, 1994, and references therein]. However, to understand completely global phenomena like a SC requires the global model in which plasma processes and their interactions are treated physically consistent in a given topology of the magnetosphere–ionosphere regime. Therefore, we must use a global MHD numerical simulation [Tanaka, 1994,1995]. Thus, in order to explain physical processes in a SC period, we conduct a numerical simulation of magnetospheric response to a solar wind pressure impulse using an MHD model of the solar wind–magnetosphere–ionosphere system.

2. Results

The numerical simulation has been conducted under the condition of positive (northward) IMF Bz because we intend to extract pure effects of a solar wind impulse to the magnetosphere. The simulation successfully reproduced geomagnetic variation and plasma disturbances in a SC period. Details should be referred to Fujita et al [2003a].

We discuss here characteristic features of plasma disturbances and their physical properties in a SC period. It is noted that plasma processes in a SC period are divided into three phases, although a geomagnetic variation in a SC period is categorized into the preliminary impulse and the main impulse [Araki, 1994]. In the last part of this section, we propose a new model of a SC in the context of the magnetosphere–ionosphere compound system [Tanaka, 2003].

2.1 The PI phase

First, we consider propagation of the signal launched by impinging of a solar wind pressure impulse and generation of FAC that causes geomagnetic variations detected as the preliminary impulse (PI) [Fujita et al., 2003a]. It is revealed that the current in the PI phase is first generated as the enhanced Chapman-Ferraro current in the magnetopause, next turns to the magnetosphere along a wavefront of a compressional MHD signal launched by the impulse. It is finally converted to FAC via mode coupling due to plasma non-uniformity. The current is inertia current in the wavefront region. We present a quantitative model of the plasma disturbances in the PI phase presented by Araki [1994] by using a numerical simulation.

2.2 The first MI phase

After the PI phase, there appears FAC that flows oppositely against FAC in the PI phase. We designate this phase as the main impulse (MI) phase.

We investigate generation mechanism of FAC in the MI phase [Fujita et al., 2003b]. There are two successive current generators of FAC and two current systems in the magnetosphere – ionosphere regime. Therefore the MI phase is divided into the first and second stages.

The current generator in the first stage appears behind the wavefront of the magnetospheric compressional disturbance launched by the impulse. Energy of the generator is supplied through deceleration of plasma flows behind the wavefront region. An azimuthal current induced by this generator is converted into FAC in a plasma non-uniform region. Thus, the MHD wave process is dominant in this phase. The magnetospheric flows and the ionospheric flows are not yet connected self-consistently to each other.

2.3 The second MI phase

The current generator in the second stage of the MI phase is located in the nightside cusp region. This generator is the same as the current generator of the Region 1 (R1) current and transiently activated due to compression of the magnetosphere
associated with passing of the solar wind impulse. This generator drives a current system similar to the R1 current. On the other hand, a small-scale pressure enhancement in the morning and evening sectors of the magnetospheric equatorial region is induced due to compression of the magnetosphere flank by the solar wind impulse. This pressure enhancement moves slowly toward nightside magnetosphere. This pressure structure modifies the R1 current system. Geomagnetic variation that exhibits a peak and recovery in the MI phase \cite{Araki,1994} is explained with combination of the temporally activated current generator in the cusp region and modification of the magnetosphere–ionosphere current system due to the small-scale pressure enhancement.

At the same time, there appear plasma convection vortices both in the magnetosphere and in the ionosphere, which are correspondent to each other. The magnetospheric convection is closed within the magnetosphere. This convection system is peculiar to the second MI phase. We call this convection as the SC transient cell convection \cite{Fujita et al.,2003b}

### 2.4 Recovery of a SC

It is noted that the Region 2 (R2) current appears when plasma disturbances associated with a SC (for example, the peculiar plasma convection vortices in the second MI phase) almost disappear. Since the current system in the second MI phase is basically the R1 current system, this fact indicates that the R2 current is established after the R1 current system when the magnetosphere–ionosphere stationary current system is once disturbed by a solar wind impulse.

### 2.5 State transition in a SC period

Our numerical simulation shows that a stationary convection system in the pre-SC period is disturbed by a solar wind impulse and recovered to another stationary convection system in the post-SC period. In the course of recovery, there appear two characteristic states; the PI phase and the first MI phase when MHD wave processes are dominant as well as the second MI phase with the SC transient cell convection. In the context of the magnetosphere–ionosphere compound system in which the magnetosphere–ionosphere plasma convections, FAC, and the current generator associated with the magnetosphere–solar wind interaction are self-consistently dependent \cite{Tanaka,2003}, a SC is regarded as state transition from a ground state in the pre-SC period to another ground state in the post-SC period via a transient state in the second MI phase. The PI phase and the first MI phase are regarded as a phase of the magnetospheric response to a sudden impulse like generation of an elastic wave by hitting a hard body.

### 3. Conclusion

We conducted a numerical simulation of a magnetospheric response to a solar wind impulse. The simulation successfully reproduced geomagnetic variation and plasma disturbances in a SC period. Through analysis of the numerical results, we found that a SC period is categorized into the PI phase, the first MI phase, and the second MI phase. Finally, we propose that a SC is interpreted in terms of the magnetosphere-ionosphere compound system as state transition from a ground state in the pre-SC period to another ground state in the post-SC period through two transient phases of essential convection transition in the second MI phase and elastic response in the PI and the first MI phase.

### References


