GLOBAL MHD SIMULATION OF THE MAGNETOSPHERIC RESPONSE DUE TO TRANSIENT SOLAR WIND STUDIED AT LAPAN WATUKOSEK 2009: THE SPACE EARLY WARNINGS

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Abstract. *We have used a global magnetohydrodynamic simulation model to investigate the transient solar-wind events which occur in the magnetosphere. The magnetosphere reacts to automatically creates a bow-shock structure and deflects subsequent direct solar wind-flow away from the Earth. In the night-side of the magnetosphere, the plasma sheet recovers first along the flanks of the magnetosphere. The magnetic reconnection occurs at the midnight and the near-Earth neutral line shrinks toward midnight and then moves rapidly tail-ward as isolated plasma blob. Related space warning activity is discussed.*

Key words*: global MHD, solar wind, night reconnection, space early warnings*

1. Introduction

Taking a benefit from computer capability to aid non-linear physical interactions, physicist is now developing a new world of science that are the global magnetohydro-dynamics and the numerical computing techniques to discover and to explain new physical processes high above the Earth. This activity is considered as a modern approach to explain global and comprehensive physical constituent and characteristic of the magnetospheric physics derived from mosaic satellite data. Continous data from satellite is impossible to perform since it will incolve huge budget. Mosaic and wide spread data resulted from satellite readings are complemented by the innovation of dynamical-mathematics to represent the physics in related space and time to be considered.

The usage of a set of differential equations become more appriciable since in the outer space interactions of two or more physical systems are quoted to be highly non-linear and non-homogenous, and even more dynamic than scientist ever estimated before. Wave propagation from the Sun as the main source of the wave, and hence the energy transfer following the wave may impossible to separate each other. Wave and energy, including magnetic, momentum, thermal energies will always come to overwhelming the Earth environment after an explossion on the Sun's surface. The physical system around the Earth that will firstly interact with the wave is the magnetosphere. This paper is addressed to discuss the interaction of solar transient wind and reaction of magnetosphere of the Earth with some physical consequences in the night-side of the magnetosphere.

The Sun is known to continuously blowing a wind, and it is termed as solar wind blows. Even in quiet phase the Sun always blows this kind of wind which constitute of electron radiation, magnetic field slow escape, and electromagnetic energy radiation into interplanetary space. These 'energy' flows always interacts with the planetary physical system especially the outer most system that is the magnetosphere. Reaction of the magnetosphere with continuous wind blows is considered as initial dynamical condition of the magnetosphere. This condition is served as our initial magneto-hydrodynamical computation before a ‘transient’ solar wind hits the outer most computational boundary. The reaction of the magnetosphere in day-light and extends to mid-night are studied accordingly.

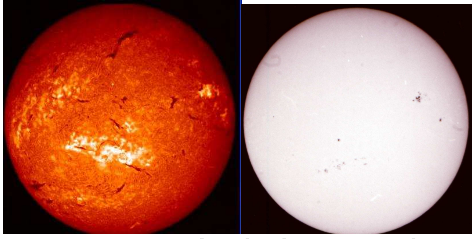
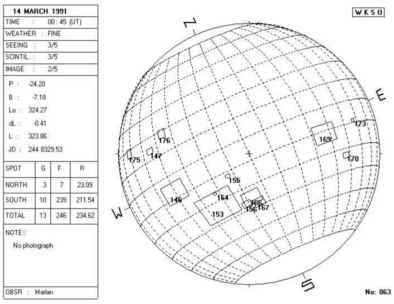


Figure 1. Corresponding bright areas on the Sun potentially producing the transient energy waves and give shocks in the magnetosphere, subsequently introduce disturbances to ionosphere and atmosphere. This photograph is resulted at LAPAN Watukosek when the Sun very active in middle of March 1991.



14 MARCH 1991
TIME : 00 : 45 (UT)
WEATHER : FINE
SEEING : 3/5
SCINTIL. : 3/5
IMAGE : 2/5
P : -24.20
B : -7.18
Lo : 324.27
dL : -0.41
L : 323.86
JD : 244 8329.53

SPOT	G	F	R
NORTH	3	7	23.09
SOUTH	10	239	211.54
TOTAL	13	246	234.62

NOTE::
No photograph
OBSR : Marlan

Figure 2. Our automatic heliographic position analyzer to recognize the potentially active region(s) on the Sun releasing huge energy in magnetohydrodynamical mode and transfer the waves through interplanetary space. The energy emerge from active regions number 146, 153, 156, 166, and 167 in LAPAN-ASCII Solar Data base system.

2. Basic mhd equations

Everything we feel and watch directly or through hardware-instrumentation from this physical universe are esentially material and wave propagations. In our relevan space and time to consider the wave and material can not be separated and always come togather as magnetohydro-dynamics transfer phenomena. There is a good representation of this situation, that is the Navier-Stokes concept of material transfer from one place to onather. Decreasing or increasing of a material is due to an outflow or an inflow of the material. This notion can be extanded to magnetic field as Navier-Stokes’ material to be transferred. In generally speaking the magnetic field will always come togather with ‘plasma’ material as they are frozen-in to each other. Only in a very special case the magnetic field deviate each other with plasma flow. That is in a so-called reconnection point.

We propose a Navier-Stokes type partial differential equations with left-hand side of the equation are written down with Lagrangian style to represent transfer or flow phenomena. Where the right-hand side are consist of our general concept of the cause of interaction, that are called the source function *S*. This newly expression we generally quote as Lagragian-Navier-Stokes partial differential equation. Written down with standard symbology are as follow

$$\frac{\partial\rho}{\partial t}+\nabla.\rho\vec{V}=\alpha\nabla^{2}\rho+0 \qquad (1)$$

$$\frac{\partial\rho\vec{V}}{\partial t}+\nabla.\rho\vec{V}\vec{V}=\upsilon\nabla^{2}\rho\vec{V}-\nabla P+\left(\nabla\times\vec{B}\right)\times\vec{B}+\rho\vec{G} \qquad (2)$$

$$\frac{\partial\vec{B}}{\partial t}+\nabla.\vec{B}\vec{V}=\eta\nabla^{2}\vec{B}+\left(\vec{B}.\nabla\right)\vec{V}+\vec{V}\left(\nabla.\vec{B}\right) \qquad (3)$$

$$\frac{\partial P}{\partial t}+\nabla.P\vec{V}=\kappa\nabla^{2}P-(\gamma-1)P\left(\nabla.\vec{V}\right) \qquad (4)$$

The quantities α, ν, η, and κ are the non-ideal coefficients controlling the degree of the non-ideal processes onto MHD system. They may be uniform and small or they will adjust their values automatically as the physical environment is turn to be possible. Therefore, the general expression of the non-ideal MHD system is written as follow

$$\boxed{\frac{\partial}{\partial t}Q+\nabla.Q\vec{V}=\xi\,\nabla^{2}Q+S} \qquad (5)$$

Where *S* is the source function. More over $\xi\equiv\xi(\alpha,\nu,\eta,\kappa)$ is a general function expressing the *general diffusive matrix* in our diffusive MHD equations. Components inside the matrix may be assigned as space and time dependent quantities to exhibit the highly non-linear, non-uniform, and non-homogeneous MHD interactions. For example, one of the matrix components may exhibit the magnetic reconnections of magnetic field of lines in the interplanetary and planet-proximity environments.

When the diffusive matrix ξ is essentially zero then the MHD system is the ideal system and the left-hand side of the Lagrangian materials are conventionally convected. This situation is always changes when the Sun's originated wave disturbance arrive to interact with the magnetosphere. Deeper the wave panetrates the magnetosphere the diffusive matrix ξ will deviate from its zero value and becomes decisive to the final solutions.

3. Initial model

A continuous solar wind actually pushes the planetary magnetosphere as a result of continuous radiation and particle pressure from the Sun. This kind of wind is known as background solar wind. Chapman and Ferraro proposed a model for magnetosphere for the quiet solar condition (see e.g. Chapman and Bartel,1940). That is a model for continuous and non-transient solar wind model imposed on initial conditions and boundary conditions magnetospheric model. According to the model, planetary magnetic fields have dipole magnetic fields structure and keeps this structure interacts with background solar wind. The solar wind blows do not change appreciably the dipole magnetic structure until a transient solar wind with higher momentum and energy push the dipole magnetic structure.

We define accordingly a primitive dipole structure as usual (see *e.g.* Jackson, 1975). In this structure the magnetic field inside the planet crust is not taken into account because the structure does not contribute for short time-scale events. It only becomes significance when we consider geological time-scale in millions of years. The initial dipole magnetic field is written directly with standard numerical algebra in two components as follow,

$$B_y(i,j) = -2.0\frac{B_0[x(i)-x_S]}{r^3} \qquad (6)$$

and,

$$B_x(i,j) = \frac{B_0[y(j)-y_S]}{r^3} \qquad (7)$$

where,

$$r(i,j) = \sqrt{x(i)^2 + y(j)^2} \qquad (8)$$

is the distance at any point outside the planet crust, B_0 is arbitrary magnetic numerical constant, x_S and y_S are the coordinate slots where the planet is placed. A distance scale ξ is introduced to discriminate points inside or outside the planet crust. The quantity ξ is generally larger than the planetary crust radius and represented lower atmosphere and ionosphere who do not change appreciably during the transient solar wind events. Higher than ξ the upper ionosphere and lower magnetosphere gradually become dynamics. Free boundary conditions are applied to all rectangular computational boundaries at where the wave propagations may flow through.

The gradual dynamics of the outer ionosphere and lower magnetosphere are introduced by a smoothing function f of external Q_e and internal Q_i quantity such that at each time step is connected as follow

$$f \equiv a_0 h^2\left(a_0 h^2 + 1\right) \qquad (9)$$

as

$$Q = fQ_e + (1-f)Q_i \qquad (10)$$

where,

$a_0 = 100$, $h = \left(\xi / \xi_0\right)^2 - 1$ for $\xi \geq \xi_0$ and $h = 0$ for $\xi < \xi_0$, where ξ_0 is the lower height limit for dynamical state for the ionosphere and lower magnetosphere. The quantity Q_e or Q has similar meaning with the general quantity Q in equation (5). It means that for all the magnetohydrodynamic quantities $Q \equiv (\rho, \rho\vec{V}, \vec{B}, P)$ are treated with the same rule.

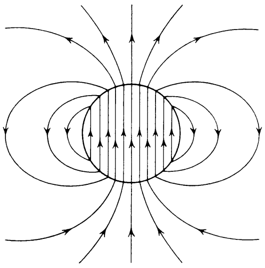


Figure 3. Explicit drawing of initial primitive dipole field of a planet including the general crust magnetic fields (Jackson, 1975). The crust magnetic fields are ignored for fast disturbance from the transient solar wind on the magnetosphere. The roots of magnetosphere's magnetic fields are assumed to anchor such that the fields do not change during dynamical interaction with transient solar wind. The lower ionosphere and magnetosphere follow this assumption.

4. Results

Simulated transient solar wind is blown into computational left-most free-boundary and move to the right. Mathematical physics assignment of the transient is expressed as momentum density $(\rho V)_{Transient}$, which brings magnetic fields through equation (2), (3), and (4). Duration of the transient is 50 minutes and after that time duration the magnetosphere is assumed to return its initial physical situation. From the graphical output of magnetic field evolutions show that the transient solar wind energy momentum gradually changes the symmetrical north-south axis to become asymmetrical. On Figure 4 is also shown at *t=0.0* minute the magnetosphere exhibits its initial primitive dipole magnetic structure similar as displayed on Figure 3. As the time goes on through *t=10,20,30,40,50* minutes, the primitive dipole magnetic field lost its dipole structure and becomes dynamically change to be a bow-shock structure. More intensive the wind is, more dense the bow-shock will be formed.

The plasma flow, following the solar wind transient magnetic field, will deviate to move further because the formation of the magnetic bow-shock. Instead, the plasma flow is deflected to move away and enter the night-side to reach the magneto-tail region. This plasma flows in accordance also brings waves and energy-momentum to the night side of the magnetosphere. As non-linear results of the dynamical pushes to the geomagneto-tail, and even more triggered another important process, that is the magnetic reconnection in the geomagneto-tail structure. A *300.0* km/hour solar wind transient will produce a *60.0* km/hour plasma blob speed and able to reach a distance Earth-Moon. A lower blob speed of about *60.0* km/hour indicates some non-linear energy absorption during the process.

There are other physical processes are related to this phenomena. For instance the magneto-pause region lies between incoming solar wind flux with the bow-shock region. In this region there is unstructured magnetic field formed by magnetohydrodynamic non-linear turbulence, such that in very short time scale the magnetic field and the plasma lost their chance to produce regular frozen-in magnetic structure. Other non-linear phenomenon is situated behind the bow-shock structure where strong magnetic concentration pushes low density ambient ionospherical plasma. Additional magnetic field energy may enter this region and add more magnetic energy to the ionosphere through a non-linear process called the Kelvin-Helmholtz instability (see e.g. Priest, 1981).

Non-linear processes such as the Kelvin-Helmholtz instability produced plasma kinetic energy absorption and plasma will be attracted gravitationally downward to approach near ground sky. One of the results is the glowing of atmospheric region near the planet polar region. This is one of many other explanations of the onset of Aurora-Borealis or Aurora-Australis. Other explanations of this non-linear absorption is from diffusion processes through the Geomagneto-tail and return back gravitationally to near ground sky and amplified by higher magnetic flux in polar region. This process may also create the Aurora phenomena.

Other interesting non-linear process during the transient event is formation of equatorial-electro-jet or the EEJ. The height of formation and density of EEJ dynamically depends on the total energy-momentum brought by the transient solar wind minus non-linear absorption processes. This phenomenon may affect high altitude flight in communications and navigations. The phenomenon of the EEJ is still rarely studied by people.

Even the transient solar wind interacts with the day side of the magnetosphere in some cases have shown that the disturbance will propagate to enter the night-side. It means that the transient solar wind gives physical impact surrounding a planetary physical system, in the day-side or in the night-side. Impacts to satellite and communication, and other technological system will also happen surrounding the planet. It may interfere transportations and other infra-structure for transportations. Computational results on Figure 5 shown that after the first impact with magnetosphere, several minutes later reaction of magnetosphere in the night-side is begun and the magnetic reconnection begun to produce plasma blob. Several minute later the plasma blob begun to escape to deep night-side sky, reaching the Moon distance. Historically this plasma blob was hampered the IEEE satellite.

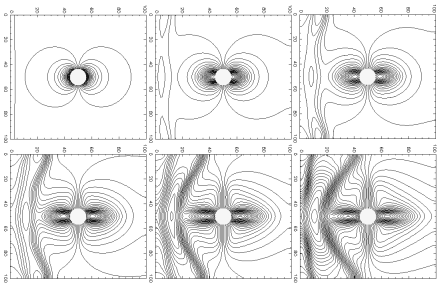
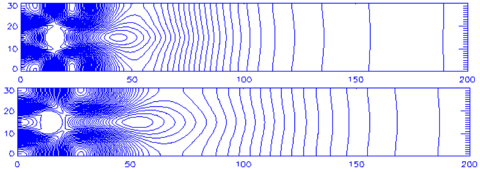


Figure 4. Output of time sequence of magneto-hydrodynamics computer simulation of the magneto-sphere response. The initial condition when *t=0* is the upper left where initial primitive dipole magnetic topology is clearly shown. Proceed to right is *t=10, 20,30,40,50* minutes. The solar-wind transient has average speed of *300.0* km/hour, with magnetic field strength *5.0* Gauss. (Setiahadi, 2005). See similar paper by Ogino (1986).



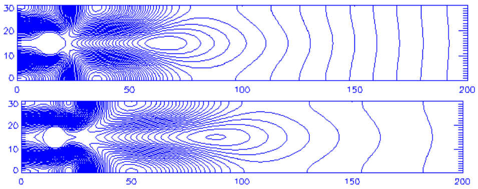


Figure 5. The night-side response in the magnetosphere due to transient solar-wind event with the same momentum and magnetic strength. High above night sky at least *100.0* km cool magnetic reconnection is occur. Time sequence is *t=20,30,40,50* minutes after first day-side impact. Subsequently a blob of magnetized plasma is moving away with a speed around *60.0* km/hour (Setiahadi, 2005). Historically this kind of plasma flow hampered the IEEE satellite, some years ago.

5. Discussions

Transient solar wind has long been known to produce some physical impacts in our modern life and activities. During that time some space missions around the Earth orbital were performed to gather data. Many valuable data could be gathered, though lack of global scale explanations made difficult to had a comprehensive picture of the interactions of the magnetosphere it self with the transient solar wind. The satellite and other orbital missions only provide us mosaic of data rather than easily interpreted data. After the numerical technique is applied to reconstruct the mosaic data we have a plenty of more systematical explanations of the interactions and consequences of the interaction between transient solar wind and the magnetosphere.

The difficulties lie on the nature of highly non-linear interaction of magnetic field and the plasma. Both the solar wind and magnetosphere brought their own magnetic field and plasma. This is impossible if we do not implemented point by point solution provided by numerical approximations to reach global and dynamical description over mosaic data.

Warning of the event is important that many non-linear interactions could interfere down to the ground activity. Such as navigation and communication, and even more navigation and communication using satellite system.

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