View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Lumbung Pustaka UNY (UNY Repository)

ISBN : 978-979-17763-3-2

SOLAR ERUPTION ON 4 JANUARY 2011:
CASE STUDY FOR SPACE EARLY WARNING

Bambang Setiahadi

Indonesian National Institute of Aeronautics and Space (LAPAN)
Watukosek, Gempol P.O. Box 04, Pasuruan67155, East Java
Fax: 0343 851 569. Tel: 0343 851 887
e-mail: bambangsetiahadi@rocketmail.com

Abstract. We perform intuitive analysis for solar eruption on 4 January 2011. Since we do not have magnetic observational data from the eruption, we perform first order calculation and expands it as interplanetary total effect of energy propagation by retro-inspect proximity data supplied from geomagnetic data. The Data suggested that the energy propagation may reach Earth proximity space environment within 48 hours. The work may constitute space early warning for the next solar activity maximum around July 2014.

Keywords: solar eruption, propagation, early warning.

ISBN : 978-979-17763-3-2

1. Introduction

The solar surface has sometimes exposes very exotic phenomena that may be recorded in many optical wavelength and other far infra-red, radio waves, and even in X-ray or high-energy particles detectors. Those phenomena are clearly energy liberation processes on the solar surface as results of slow but gigantic energy accumulation is relatively long time scale. The physical effect may propagates and arrives on the Earth within several hours to several days.

The abrupt changes exposes implicitly that a critical situation has passed and changed the relatively long time scale to much shorter time scale. The critical situations are assumed as energy buildup by basic processes manifested as one or more than one non-linear combination of the processes in sunspot flux-tube in active region (Setiahadi, 2005b): 1. Plasma pressure evolution. 2. Thermal evolution. 3. Plasma density evolution. 4. Shearing motions. 5. Twisting motion.

It is impossible to distinguish those processes one by one on the solar surface, and we only observed the total effect as an active region changes its observable appearance. For example, we will observe 'activation' of quiet dark filaments, fibrils, filament channels, and other global features such as bright points sudden appearance. As an example is the 4 January 2011 event as observed and recorded by Kamaruddin (2011) in Hα optical wavelength, a flaring region on the solar surface following dark filament activation (see Figure 2 and Figure 3). The disturbance arrived 2 days later as detected by the Kyoto geomagnetic detector (see Figure 5).

2. Data and Observation

The Watukosek Solar Observatory, belongs to LAPAN, has been observing and patrolling the solar surface activities in daily mode, from 23 October 1987 until present days. There are a lot of data resulting from consistent and persistent daily observation. The data has been written in most convenient data base and in a way that every operating system may be build around it. Moreover, every people may construct an algorithm to read or extract the data base for scientific purposes.

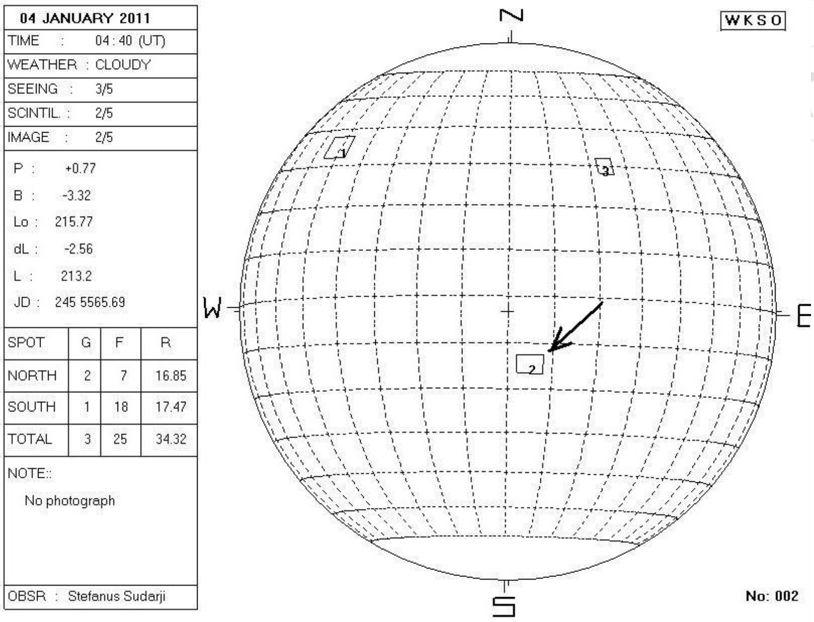
ISBN : 978-979-17763-3-2

After a daily observation a report can be generate to provide local environmental situation. There are weather, seeing, scintillation, and image stability. These parameters represent local atmospheric quality during one day observation, especially when the data is taken by an observer. Other slot is the heliographic coordinate system includes the Julian Date of astronomical time-forward counting procedure (Setiahadi, 2007).

The next is the sunspot counting number consist of sunspot group number, black dot number, relative sunspot number, northern sunspot number, and southern sunspot number. The situation is display as table in lower part of daily report. Every solar surface active region is numbered as number of appearance. The heliographic position is display automatically by our software and expose to computer screen as depicted in Figure 1.

The position of active region, for one or several active regions, can be determined automatically by this software as long as procedure to append the data for each new day is written correctly. The position is unique for every dark spot observed on the solar surface. We guarantee the uniqueness of the sunspot or active region position by using three-dimensional matrix as transformation from heliographic to observer coordinate and vice versa through expression below,

$$X^{\alpha} = P^{\alpha}_{\beta}\, B^{\beta}_{\gamma}\, L^{\gamma}_{\varepsilon}\, \bar{X}^{\varepsilon} \tag{1}$$



ISBN : 978-979-17763-3-2

Figure 1: Robotic sunspot observation and analysis, using sunspot telescope, on related day of 4 January 2011 taken at LAPAN Watukosek, East Java, Indonesia. Observation analysis had been performed by Sudarji (2011). This is the LAPAN's robotic analysis using tensorial heliographic coordinate system invented in late year 2000. The potential solar active region is in southern solar hemisphere with sunspot group number of appearance no. 2.

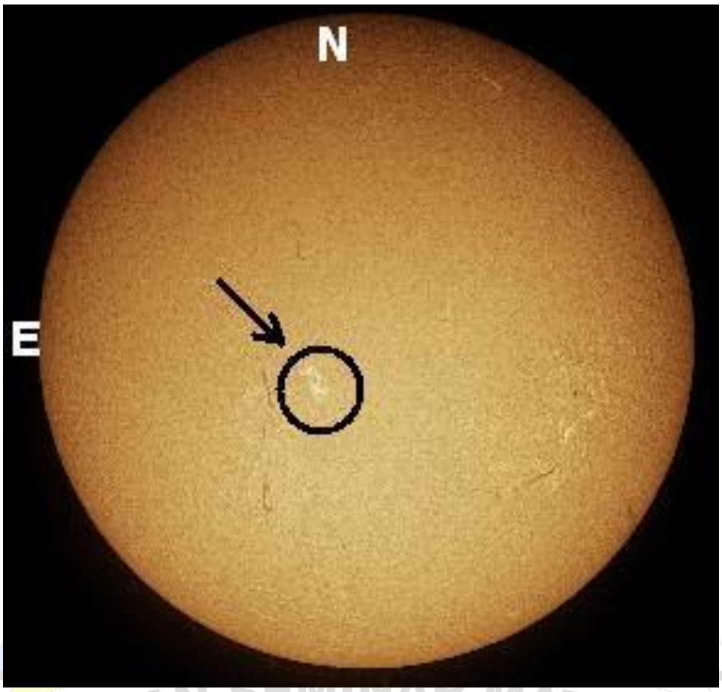


Figure 2: Solar Hα image at 4 January 2011 observed in Kuala Lumpur Solar Observatory by Angkasa Space Agency (Kamaruddin, 2011). The bright area shows clearly that a dark filament eruption proceeded the flaring region and a disturbance energy directed to the Earth.

ISBN : 978-979-17763-3-2

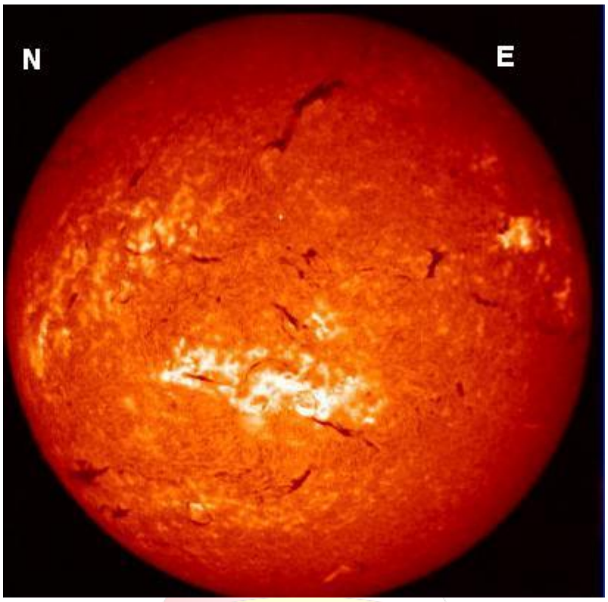


Figure 3: 14 March 1991, the very big explosion on the solar surface detected by the LAPAN's flare telescope at Watukosek, Pasuruan, East Java. Watch that various phenomena are appear as various dark filaments, filament channels, and active filament system. This image constitute maximum phase of solar activity cycle.

3. Methods Determining Eruption

Subsequently after the heliographic position of an active region is uniquely determined, the region is followed day by day and determination for potential eruption from that active region is weighted by its Zurichal energy classification. The class of every active region is provide in the data base (Setiahadi, 2007). The extension of that region is followed later as well, and input to data base. The rest is estimation of growing magnetic flux tube in or around that active region under scrutiny. If there is significant number of spot appear and subsequently disappear in rather rapid time scale, it might be an eruption occurred.

The Zurichal Energy Classification Function ***Z(f)*** may interpreted as energy evolution function passes by an active region, marked by a sunspot group evolution, and represents energy build up and energy deposit near solar surface. If we consider the expected flare to occur as continuum processes then we may write it by integral processes.

ISBN : 978-979-17763-3-2

As a sunspot group passes through from A class to F class, and decline to J class, it certainly develop linear extension in heliographic longitude, from smaller than 2 heliographic degrees to 15 degrees, and declining back to 2 degrees. This is intuitively as a manifestation of a measure of energy build up, energy release, and energy declining in a sunspot group. Linear extension ***L(f)*** of a sunspot group is more gradual measurement of energy deposit and energy release.

The dynamics resulted from at least six processes, mention previously in Introduction, and it is symbolized by ***S(f)***. The first is the plasma pressure perturbation along a magnetic flux tube. This process is a result of restriction plasma motion inside the magnetic flux tube geometry. A magnetic flux tube is a very efficient pipe to flow plasma and keep the plasma moves back and forth along the flux tube. Plasma collisions within the magnetic flux tube may rise temperature consequently and rise thermal pressure instability as well.

The cover-all processes of energy build up in solar surface active region is then considered due to a long term solar magnetohydrodynamo estimation of 35 days time-scale ***To***. These two last equations below clearly expected the processes may be considered as frequency of occurrence of an active region potentially erupt since the equation is proportionally to $\boldsymbol{To}^{-1}$.

$$F_{ZLS} = \frac{1}{T_0} \frac{\int Z(f)\, L(f)\, S(f)\, df}{\int Z(f)\, L(f)\, df} \qquad (2)$$

$$F_{ZLS} = \frac{1}{T_0} \frac{\sum_{i=1}^{n} Z_i\, L_i\, S_i}{\sum_{i=1}^{n} Z_i\, L_i} \qquad (3)$$

Equation (2) is written to represent continuous form of the processes is assumed that the Zurichal Energy Classification and Linear Extension Function , are continuous function. But the data base consist of discrete quantities that equation (2) has to be represented by discrete expression as equation (3). The calculation is performed automatically, and when applying to January 2011 data base it resulted a number potentially erupted in 4 January 2011 in solar southern hemisphere (see Table 1 below).

ISBN : 978-979-17763-3-2

January 2011

Date	Time (UT) hhmm	North			South			Total			Obsr	No. Skt
				ZLS			ZLS					
01	----	----	----	----	----	----	----	----	----	----	NW	----
02	----	----	----	----	----	----	----	----	----	----	NE	----
03	0014										AS	001
04	0440						1				DR	002
05	0105										NW	003
06	0100										NE	004
07	----	----	----	----	----	----	----	----	----	----	AS	----
08	0031										DR	005
09	0105										NW	006
10	0013										NE	007
11	0135										AS	008
01	----	----	----	----	----	----	----	----	----	----	DR	----
13	0520										NW	009
14	0032										NE	010
15	0345										AS	011
16	0320										DR	012
17	0011										NW	013
18	----	----	----	----	----	----	----	----	----	----	NE	----
19	0132										AS	014
20	0221										DR	015
21	0040										NE	016
22	0130										NW	017
23	0026										AS	018
24	0346										DR	019
25	0017										NW	020
26	0134										NE	021
27	0043										AS	022
28	0031										DR	023
29	0131										NW	024
30	0104										NW	025
31	0108										AS	026

e

Table 1: Computation based on the results from plasma physics application in the solar magnetohydrodynamo processes in solar convective zone at LAPAN Watukosek. The table indicates that in 4 January 2011 a southern solar hemisphere had potentially eruption and releases some energy beam toward the Earth.

4. Methods for Retro-inspect Proximity

The case study of 4 January 2011 is chosen for active region near center solar meridian heliographic position. Any eruption occurring in that region might certainly propagates and over whelming the Earth as proved by Dst index data as confirmation (see Figure 5).

The active region has rather ideal extension of less than 10^{0} heliographic degrees, it means that the energy will not wide spread but we still have a chance to catch the disturbance. More over, the disturbance propagates with less non-linear effect, since the energy beam is restricted in relatively small region. Calculation may be simplified and estimated Alfven mode propagation can be calculated easily (Setiahadi *et. al*, 2006)

LOMBA DAN SEMINAR MATEMATIKA
HIMA MATEMATIKA
LSM XIX

ISBN : 978-979-17763-3-2

We first consider simple propagation, that is the energy beam of the eruption directly toward us in linear straight line from the Solar surface to the Earth. Back calculation proves that the MHD propagation speed is much lower (868 km/sec) than the Alfvenic speed in interplanetary space around 1,000 km/sec.

The second approach is calculating the bending interplanetary magnetic field due to Solar rotation (see Figure 4). But it needs a rather sophisticated approach for calculation and needs additional assumption.

Parker (1958) considered the implication of a continuous coronal expansion with regard to the nature and configuration of the interplanetary magnetic field. The plasma ejected by the 4 January 2011 eruption would be expected to have an extremely high electrical (as well as thermal) conductivity. In such a fluid, the concept of "frozen-in" magnetic field lines, that is very slow diffusion of plasma transverse to the magnetic field, is applicable.

The continuous flow of coronal material into interplanetary space then must result in a transport of the solar magnetic field into the interplanetary region. If the sun did not rotate, the resulting magnetic configuration would be extremely simple; a radial coronal expansion as considered in the first model above, would produce magnetic field lines extending radially outward from the sun.

As the solar rotation is included, in our second Model of Archimedean interplanetary magnetic fields (see Figure 4), the bending-while-rotates has to be utilized in calculation that means we have to construct equation(s) or expression(s) that constitute the bending-while-rotates as follows,

$$B_r(r,\phi,\theta) = B_0\left(\frac{R}{r}\right)^2 \quad (4)$$

$$B_\phi(r,\phi,\theta) = -B_0\frac{\omega R}{V}\frac{R}{r}\sin\theta \quad (5)$$

$$B_\theta = 0 \quad (6)$$

Where ω is the Solar angular rotation at $12^0.5$/day. It is clearly that an energy beam will propagate in longer distance (172,800,000 km) more than geometrical distance (150,000,000 km) from the Solar surface to the Earth. Back calculation

ISBN : 978-979-17763-3-2

proves that the propagation speed attains Alfvenic speed characteristic 1,000 km/sec (see Table 2).

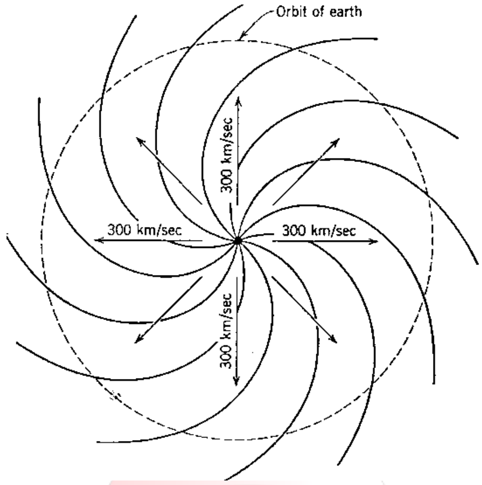


Figure 4: The Archimedean bending solar interplanetary magnetic fields according to interplanetary MHD theory. The solar atmosphere is ever expanding in a speed of propagation around 300 km/sec in quiet mode. An eruption may propagate in Alfvenic time-scale around 900 km/sec to 1,000 km/sec.

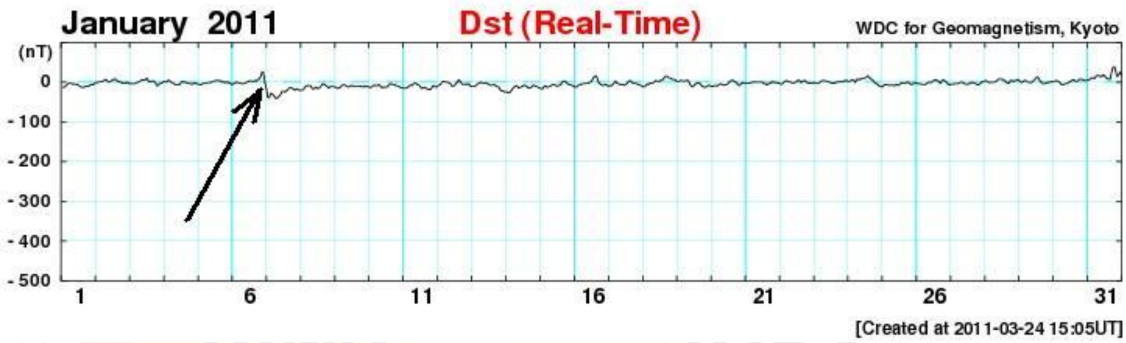


Figure 5: Dst index taken from KyotoUniversity for January 2011. Watch that the disturbance arrived on the Earth's proximity in 6 January 2011. It is detected as a blip within several hours in the time versus magnetic fields strength in [nT] unit.

Model	Distance [km]	Speed [km/sec]	Speed [km/hour]
Linear Model	150,000,000	868	3,125,000
Archimedean Model	155,520,000	900	3,240,000
	172,800,000	1,000	3,600,000

ISBN : 978-979-17763-3-2

Table 2: Resume of MHD calculation model for the 4 January 2011 solar surface eruption. Note that the speed propagation of the interplanetary MHD waves may propagate with a speed around 1,000 km/sec. As the real physical distance is longer than 150,000,000 km, that is 172,000,000 km, the disturbance arrived in about 2 days or in 6 January 2011 as display in Figure 5.

5. Discussions

Time estimation arrival of a solar originated disturbance is very important to initially perform since it provides the early warning mission of LAPAN (Setiahadi, 2005a). The warning so important in modern life due to implementation of satellite based technology and wireless technology for communications and navigation, and much further to warn astronaut or cosmonaut who works in international orbital space station. The solar disturbance might be harmful to the astronaut or cosmonaut biological system.

Precise computation for the time arrival is difficult since the propagation is not simply linear physics. It may consist of electron plasma embedded by strong magnetic field supplied from the eruptive active region magnetic fields. Or in other words the disturbance might consist of plasma MHD and moreover, interaction with Archimedean interplanetary magnetic fields will be highly dynamical and non-linear propagation (see for example Setiahadi *et. al*, 1998)

References:

Kamaruddin, F. (2011), Private communication

Parker, E.N. (1958), *Dynamics of the Interplanetary Gas and Magnetic Fields*, Astrophysic Journal, **128**, p. 664.

Setiahadi, B., Anwar, B., Akioka, M., Sakuari, T. (1998), *Non-Linear Evolution of Erupting Coronal Magnetic Fields*, *Observational Plasma Astrophysics: Five Years of Yohkoh and Beyond*, in Astrophysics and Space Science Library, Watanabe, T., Kosugi, T, and Sterling, A.C. (Eds), Kluwer Academic Publisher, p. 353.

Setiahadi, B. (2005a), *Advances and Frontiers in Solar-Terrestrial Magnetohydro-dynamics*, *Computer Simulation and Space EarlyWarningsat Lapan Watukosek 2005*, Prosiding Semiloka Teknologi Simulasi dan Komputasi serta Aplikasi III, P3TIE-BPPT, p. 32.

ISBN : 978-979-17763-3-2

Setiahadi, B. (2005b), *Problems of Equilibria and Instabilities on Solar Coronal Magnetic Fields and Its Evolution Towards Energetic Energy Liberation: Effect to Interplanetary Space,* Seminar Nasional Matematika Univ. Diponegoro, Semarang, p. E. 1.

Setiahadi, B., Sakurai, T., Miyazaki, H., and Hiei, E. (2006), *Research on Magneto-hydrodynamic Transport Phenomena in Solar-Terrestrial Space at LAPAN Watukosek 2006*, *Proc. National Seminar in Space Science III*, LAPAN-Bandung, p. 17.

Setiahadi, B. (2007), *Daily Observational Sunspot ASCII Data for Long-Term Solar Magnetohydrodynamo Studies at LAPAN Watukosek*, National Conference on Computer Science and Information Technology, University of Indonesia, (ISSN 0126-2866), p. 137.

Sudarji, S. (2011), Private communication.

UNY LSM LOMBA DAN SEMINAR MATEMATIKA HIMA MATEMATIKA