RESEARCH AND OBSERVATIONS ON SOLAR STORM: SOLAR WARNING ON 11 MARCH 2015

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Abstract. On early morning on 11 March 2015 a solar exceptionally energy release was calculated by MHDo-observational parameters and showed there would be energy liberated by the Sun. Later we observed on 17 March 2015, we did notice geomagnetic large deviation. As preliminary conclusion we supposed that on 11 March 2015 the Sun did release huge energy into interplanetary space.

Keywords: Solar storm, energy liberated, interplanetary effects

1. Introduction

Every solar energetic event has some unique characteristics in freeing its energy to space surrounding and it is always attract solar physicist to analyze further. One of the event is the solar flare that is an explosion on the Sun happens when energy stored in sunspot magnetic fields is suddenly liberated [2]. The total amount of the energy liberated is supposed very huge. This may be roughly traced by coronal sudden temperature increasing from $2x10^6$ K to $20x10^6$ K in a matter of seconds.

The radiative energy from the solar thermonuclear energy generated from very center of the sun is gradually blocked by increasing optical depth in outer most radiative layer. It makes the next layer become convective. The huge energy that sometimes releases from the solar surface is the resulting of slow motion in the solar convective layer that always involved the dynamics of magnetic fields. This layer was derived from the magnetohydrodynamo model [8], has a depth of 20,000 km and what solar physicist termed it as solar isoclines. Migration of solar coronal holess to solar equator might also a manifestation of the migraton of magnetic fields in solar convection layer in global sense.

Active solar region is generally manifest as appearance of sunspots. A group of sunspot which has complex structure both in magnetic polarities and has concentrated plasma confinement might be the region of potentially energy build-up and flare-strom productive region. A powerful X2.2 solar flare blasts towards Earth from sunspot number AR2297 or WK0049 number was erupting with M and C class flares before the magnetic energy finally gave way to the x-flare on 11 March 2015, causing HF radio blackouts.

2. Observation

Observation in X-ray wavelength is popular since the use of X-ray satellite such as the Japanese Hinotori X-ray satellite. Since then classification of solar flares according to their X-ray brightness in the wavelength range 1 to 8 Angstroms are 3 categories: X-class flares are biggest energy. The events can trigger planet-wide radio blackouts and long-lasting radiation storms. M-class flares are intermediate, they can cause brief radio blackouts that affect Earth's polar regions. Minor radiation storms sometimes follow an M-class flare. Compared to X- and M-class events, C-class flares are small with few noticeable consequences on Earth.

A powerful X2.2 Solar Flare explosion towards the Earth from sunspot number AR2297 or number WK0049 was erupting with M and C class flares before the magnetic energy finally gave way to the x-flare on 11 March 2015, causing HF radio blackouts. The execptionally X-class flare emitted from a relatively small active region needed explanations. At least intuitive explanation have to be proposed.

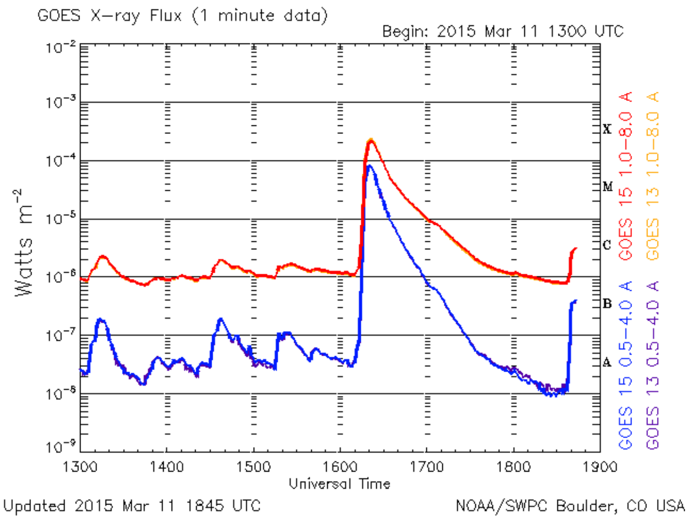


Figure 1: X-ray flux energy release from AR2297 or WK0049 on 11 March 2015 at 16:22 UTC or 23:22 WIB. The GOES X-ray data was taken from NOAA/SWPC Boulder CO USA, clearly shows the X-ray energy release from the suspected AR2297 or WK0049 active region in Universal Time Coordinate (UTC).

Tabel 1: X-ray flare classification [10].

Class	*Peak (W/m^2)between 1 and 8 Angstroms*
B	$I < 10^{-6}$
C	$10^{-6} <= I < 10^{-5}$
M	$10^{-5} <= I < 10^{-4}$
X	$I >= 10^{-4}$

Even though the X-ray radiation from the Sun gives severe impact on Earth, but from ground based observation the X-ray ceased to observed because of lower layer Earth's atmospheric strong absorption in short wavelengths. At Watukosek Solar observing site, ground based observation is performed by optical wavelength able to observe solar photospheric layer. Sunspot is usually very clear to observe on the ground when the sky condition is good with minimum atmospheric stray lights.

The photospheric observation is performed every day in two kinds of data retrieve mode. The first is a direct-draw mode that takes image of the photosphere in classic-manual international procedure to have the international sunspot number R=k(10g+f). Each day one sunspot data sheet is resulted [3]. This data is further processed to yield ASCII data system in our data base [4]. The results are presented in a data template as shown in Figure 2, or in tabular as Figure 5(a) and Figure 5(b).

Our ASCII data provide position of any points on the solar surface (photosphere) in a graphical mode in a way that if a region on solar surface other than region on focus, the scientist may immediately able to know the position. It is including the positions of solar coronal holes that eventually migrate through and toward solar equator as depicted on Figure 3.

The second is tracking the sun with fully automatic mode and data is taking every one minute in digital form using a CCD camera. Sunspot active region number WK0049 was tracking continously since the sun rise in the east horizon. The sun is observed from 00:00 UTC until 08:00 UTC provides enough data for analysis.

The existence of solar coronal holes were migrating toward solar equator exposed on WDC-Geomagnetic data, Kyoto. It may be inspected on Figure 6 that shows the geomagnetic index did not zero since the beginning of March 2015, but oscillated around zero within ±50.0 nT. The nearly constant particle beam was suspected from solar coronal holes.

Coronal holes have lower density relative to other regions of the sun and a source of fast solar wind of solar particles. It may surround the Earth with relatively long duration. The magnetic field in these regions extends far out into space rather than quickly looping back into the solar surface. In MHD terminology is called open magnetic topology which shown in Figure 8. The corresponding image is shown on Figure 4. On pixels around 80, the intensity and hence the density is low; marks the solar coronal holes.

Within ±40° solar latitude the magnetic fields are in closed magnetic topology where sunspots and many other solar surface MHD phenomena could take place. This situation may be inspected in Figure 8. Since the sunspots have closed magnetic fields topology, the sunspots can only co-exist in a belt on solar surface within which the magnetic topology is the same, that is within ±40° solar latitude.

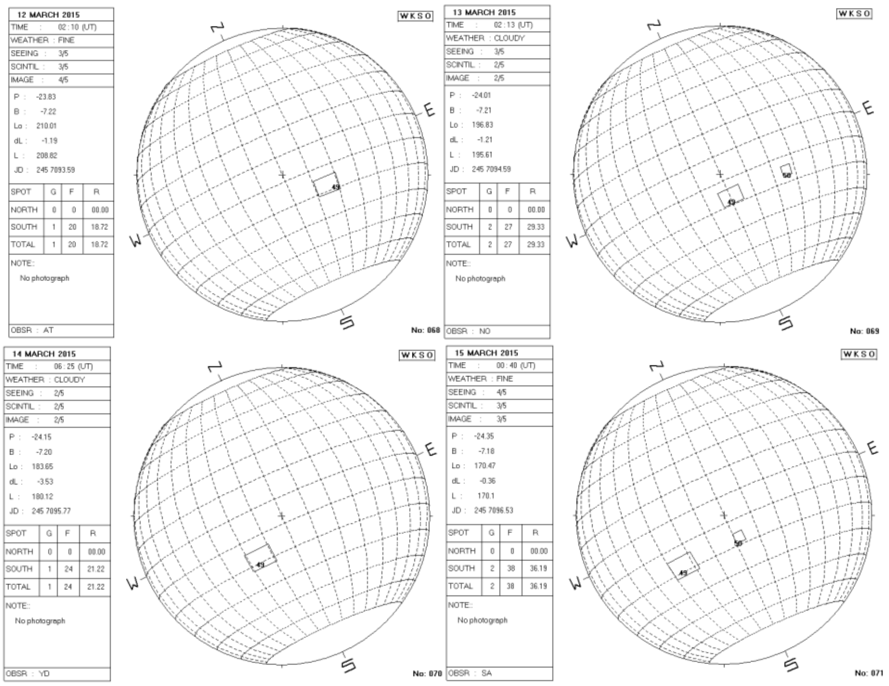
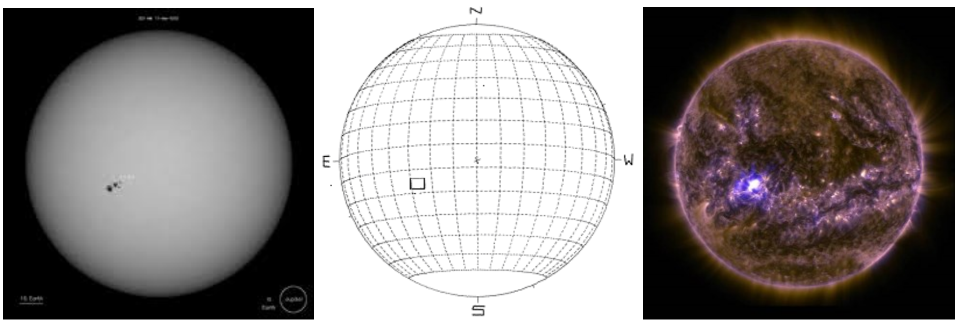


Figure 2: Observation is focused on active region number WK0049 according to Watukosek (WKSO) active region numbering system. It is AR2297 by NOAA active region numbering system. At initial, on 11 March 2015, position of the region suspected to liberate flare is 26E15S on our heliographic coordinate system (LAPAN, Watukosek, Pasuruan).



(a). (b). (c).

Figure 3: Three different data exposed the storm potential region of WK0049 sunspot group. (a). Sunspot appearance on 11 March 2015 observed at Watukosek Solar observing site. The LAPAN sunspot group number WK0049 or the NASA AR2297 had no simple magnetic fields that probably under-went huge magneto-plasma instability. (b). Heliographic position of the AR2297 situated on solar southern hemisphere at about 14° latitude near solar equator, meant any propagation of disturbance escaping from the region might severe impact on planets. (c). Extremely short optical wavelength imaging gave confirmation on the area from AR2297 or WK0049 did expose huge energy (NASA).

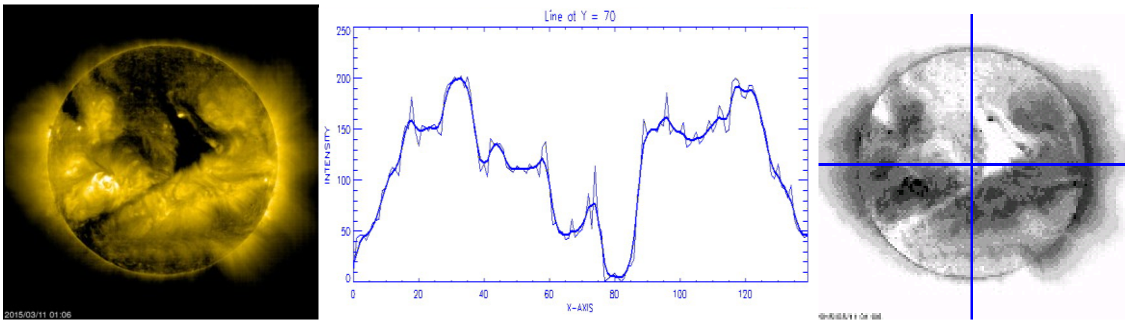


Figure 4: Existence of the 11 March 2015 storm event accompanied by the coronal holes. The marching solar coronal holes toward solar equator, indicated by very low intensity on the image, contributed into solar flare from sunspot number WK0049. The low intensity of the coronal holes was due to direct particle escape in open magnetic fields.

3. Warnings Method

At Watukosek Solar Observing site the scientist has been developed warning method based on solar magnetohydrodynamo (MHDo) observational parameters [7]. The MHDo method has given us greater improvement in forecasting and predicting solar surface potentially active regions which will be storm-productive regions. In this case we consider that active region is represent by appearance of sunspots. Sunspots always appear in a group that is manifestation of very strong and concentrated magnetic fields in closed loop geometry and high density plasma confinement inside the magnetic fields.

The sunspots in a group has observationally at least three parameters that a manifestation of MHDo processes in convective layer. The first is enegertic class of a sunspot group symbolised by Z. we may use the classic Zurich classification or the newer McIntosh classification. Large complex sunspot group manifest high Z value. A growing complex group usually has growing area. We symbolized this by L. The larger area usually parellel with large Z value. The number of sunspot in group will eventually increase in number and we symbolized as S. larger S means large number of closed magnetic topology existed in the group.

The Z, L, and S are weighted relative to Z and L, because the Z and L are decesive parameters where the sunspots magnetic fields S are rooted in active region as sunspot group. The three parameters are all in the MHDo time domain ot the convective layer. This time domain is represented by $1/\boldsymbol{T_o}$, that is the time length of sunspot appear on solar surface and after several days disappear due to MHD instability and explosions. Roughly $\boldsymbol{T_o} \sim 30$ days to 35 days. Results of computation may be accomodated by reading the ASCII sunspot data base belongs to scientist at Watukosek Solar Observing site. With same template as in Figure 5(a), the Figure 5(b) is the template of date of storm potential solar hemisphere. It was obvious that solar southern semi-hemisphere was more active on March 2015. The total decesive warning is symbolized as F, and following to utilise with ASCII data, the expressiion is,

$$F = \frac{1}{To} \frac{\sum_{i=1}^{n} Z_i \, L_i \, S_i}{\sum_{i=1}^{n} Z_i \, L_i}$$

The computation yielded that on 12 March through 16 March on southern semi-hemisphere are potential to explode as flare or storm. While the X2.2 flare did explode on 11 March 2015. This discrepancy of one day can be justified since the burst of flare from WK0049 was occurred at 16:22 UTC or 23:22 WIB (Western Indonesian Zone Time). It means that the burst occurred near mid-night at Watukosek, that the sun below Watukosek horizon. At tomorrow morning on 12 March 2015 at 02:10 UTC we computed afterwards. The activity was persistent several days ahead until on 16 March 2015 as computed by MHDo method as seen on Figure 5(b).

Other indicator of solar storm of 11 March 2015 can be deduced graphically from template Figure 5(a), the result is plotted on Figure 6. The sunspot number R is increasing after 11 March 2015 and decreasing very soon until zero on 20 March 2015. From Figure 5(b) shown that after 20 March 2015 the WK0049 was decaying as it set on the solar west limb. The next increasing value of sunspot number R is not relevant to the AR2297 or WK0049 since the sunspot number belong to other new sunspot groups.

March 2015

Date	Time (UT) hhmm	North			South			Total		
		g	f	R	g	f	R	g	f	R
01	0320	1	26	22.46	2	15	21.84	3	41	44.3
02	0113	1	16	16.22	1	9	11.86	2	25	28.08
03	0105	1	8	11.23	1	16	16.22	2	24	27.46
04	0301	1	3	8.11	1	5	9.36	2	8	17.47
05	0448	1	6	9.98	0	0	0.00	1	6	9.98
06	0235	1	5	9.36	1	2	7.49	2	7	16.85
07	0425	0	0	0.00	1	5	9.36	1	5	9.36
08	0113	0	0	0.00	1	5	9.36	1	5	9.36
09	0141	0	0	0.00	1	12	13.73	1	12	13.73
10	0442	0	0	0.00	1	15	15.6	1	15	15.6
11	0330	0	0	0.00	1	17	16.85	1	17	16.85
12	0210	0	0	0.00	1	20	18.72	1	20	18.72
13	0213	0	0	0.00	2	27	29.33	2	27	29.33
14	0625	0	0	0.00	1	24	21.22	1	24	21.22
15	0040	0	0	0.00	2	38	36.19	2	38	36.19
16	0100	1	2	7.49	2	28	29.95	3	30	37.44
17	0029	0	0	0.00	2	13	20.59	2	13	20.59
18	0132	2	13	20.59	1	2	7.49	3	15	28.08
19	0445	2	7	16.85	1	4	8.74	3	11	25.58
20	0208	2	7	16.85	0	0	0.00	2	7	16.85
21	0046	1	2	7.49	1	2	7.49	2	4	14.98
22	0040	2	4	14.98	3	11	25.58	5	15	40.56
23	0039	3	13	26.83	3	22	32.45	6	35	59.28
24	0100	5	20	43.68	2	22	26.21	7	42	69.89
25	0023	3	9	24.34	1	34	27.46	4	43	51.79
26	0013	3	8	23.71	2	31	31.82	5	39	55.54
27	0050	4	14	33.7	2	25	28.08	6	39	61.78
28	0030	1	2	7.49	1	31	25.58	2	33	33.07
29	0025	1	1	6.86	4	19	36.82	5	20	43.68
30	0231	2	6	16.22	2	21	25.58	4	27	41.81
31	0034	1	1	6.86	2	14	21.22	3	15	28.08
Mean				11.33			19.1			30.44

(a)

March 2015

Date	Time (UT) hhmm	North			South			Total		
				ZLS			ZLS			
01	0320			1						
02	0113									
03	0105									
04	0301									
05	0448									
06	0235									
07	0425									
08	0113									
09	0141									
10	0442									
11	0330									
12	0210						1			
13	0213						1			
14	0625						1			
15	0040						1			
16	0100						1			
17	0029									
18	0132									
19	0445									
20	0208									
21	0046									
22	0040									
23	0039									
24	0100						1			
25	0023						1			
26	0013						1			
27	0050						1			
28	0030						1			
29	0025									
30	0231									
31	0034									

(b)

Figure 5: Solar activity data templates. (a). Solar influence data analysis performs daily at Watukosek LAPAN, provides numerical table to ease scientist for inferring the International sunspot Number R (LAPAN, Watukosek, Pasuruan). (b). Possibility of liberating energy in solar southern semi-hemisphere is calculated using MHDo observational parameters developed at Watukosek Solar Observing Site [7]. The results are tabulated in a table using the same template as in Figure 5(a). Calculation shows potential active region to liberate flare is on southern solar hemisphere on 12 March 2015 (LAPAN, Watukosek, Pasuruan). But outcome number "1" noticed that the flare wolud not so big.

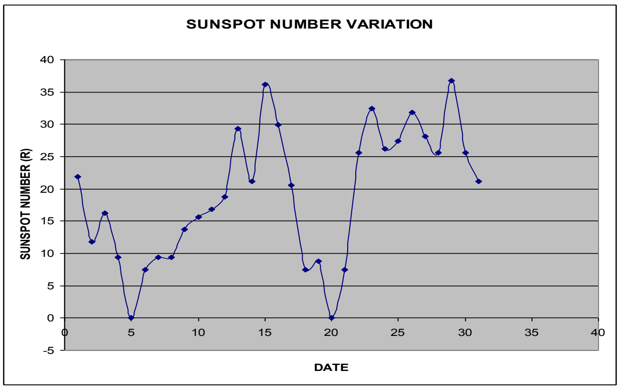


Figure 6: Sunspot number (R) variation during March 2015. It is obvious for WK0049 or AR2297 the sunspot number increased and attained highest value at 15 March 2015 as pointed out on Figure 5(a). It then decreased very soon until zero at 20 March 2015. It means the explosion might bring a great deal of sunspot magnetic fields.

4. Conclusions

In the beginning of March solar activity was at low levels with only low level C-Flares detected. The Region 2297 or WK0049 was start to appear on 7 March 2015 at 14° south of solar equator. As the WK0049 evolve to became complex sunspot group, while solar coronal holes migrated toward lower latitudes approaching the WK0049 position. The migrating solar coronal holes indicated by periods of proximity geomagnetic storm may persist as shown in Figure 7 as solar wind stream continues to flow past Earth as earlier as 1 March 2015.

The WK0049 was relatively small active region. Instead, strong Earth-directed X-flare erupted from a large active region of AR2297 or WK0049 on 11 March at 16:22 UTC. Radio emissions from the sun indicate a possible coronal mass ejection or CME emerging from the blast site at speeds exceeding 1,400 km/s.

From MHDo warning method the number “1” appear on Figure 5(b) means AR2297 or WK0049 potentially to be a flare but not so big flare. According to Zurich energy classification the AR2297 or WK0049 had “D” class which would not produced big flare, thus would not be observed as X-flare class. For storm type classification other than Zurich classificatiion can be read in [1]. Other energy release mechanism must be taken into account. The only possible additional mechanism is the magnetic reconnection. We suspected the closed magnetic topology of AR2297 or WK0049 reconnected with open topology of the solar coronal holes that migrated and approached, and than interact subsequently. The process is usually termed as magnetic reconnection [10]. In seconds magnetic reconnection able to rise temperature to $20x10^6$ °K.

On 18 March 2015 the only noticed was an extended period of minor geomagnetic storming of continuing solar coronal migation. On 19 March 2015 the AR2297 or WK0049 set in solar west limb.

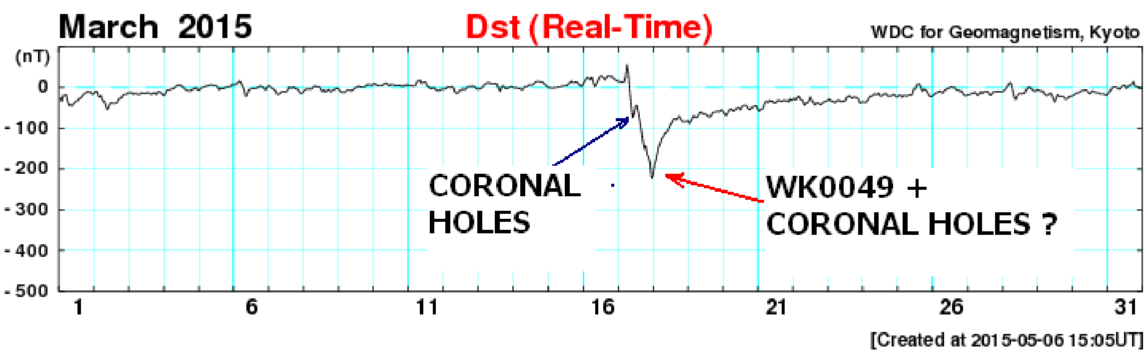


Figure 7: In 17 March 2015 magnetohydrodynamics (MHD) waves of plasma and magnetic fields of the solar storm 11 March 2015 arrived on Earth environment. It introduced high frequency radio black-out over geographical high latitude sites (WDC for Geomagnetic, Kyoto).

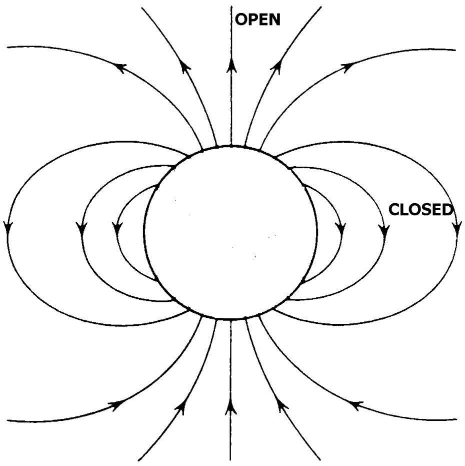
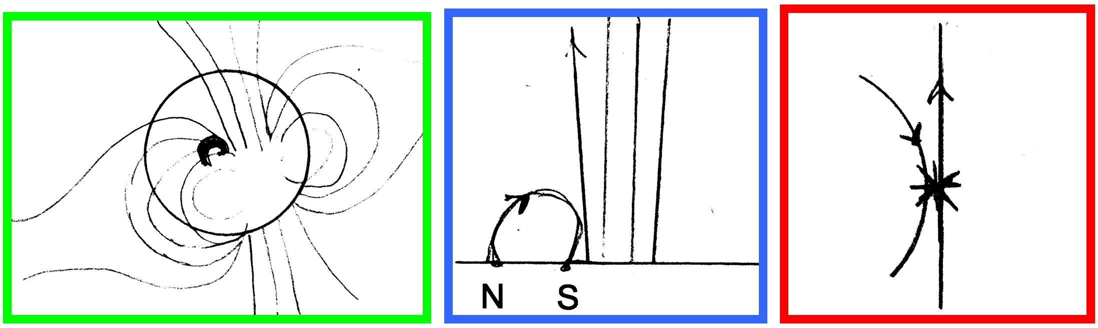


Figure 8: Global magnetic structure of the Sun. Around Solar south pole and north pole the structure of magnetic fields are open and are termed as the Solar Coronal holes. Along the Solar equator from zero latitude to about ±40° the magnetic fields are in closed configuration. The Sunspot where the Solar flares occur usually comes from closed configuration magnetic fields. While the coronal holess have open magnetic configurations are the source of continuous high energy particles such as high energy electron plasmas.



(a) (b) (c)

Figure 9: Schematic diagram for easy understanding the 11 March 2015 solar storm phenomena. (a). The Open magnetic fields of the coronal holes is marching toward the closed magnetic fields of the WK0049 sunspot. (b). At the same occasion, the sunspot had attained critical situation and potentially will explode as flare. (c). At near by region above solar surface, a magnetic reconnection works on contact region of opposite magnetic polarity between closed sunspot magnetic fields and open coronal holes magnetic fields.

5. Discussions

The flare that happened on 11 March 2015 at 16:22 UTC or 23:22 WIB might generated extreme ultraviolet radiation. The explosion might ionized the upper layers of Earth's atmosphere, causing HF radio fade-outs and other propagation effects on the dayside of our planet. Radio operators have noticed complete blackout conditions at frequencies below 10 MHz.

The sun has started year 2015 with a long been proposed that approaching to the end of solar activity cycle, there will be solar polar magnetic fields migration. Observationally the migration appears as moving dark area or hole. A huge hole has appeared since the last December 2014 and continued to year 2015. At the initial area the phenomenon occurred near the north and south solar pole and was seen as a dark area covered all of its base. The exact shape changes all the time.

Planet proximity responses of such gigantic energy releases may be simulated by using fully consistent numerical simulation in quoted references [5], [6], and warning capabilty of MHDo observational method had been tested [9].

References

[1]. Budhi, G.S., Adipranata, R., Setiahadi, B., Adrian, H.N. (2012), Solar Storm Type Classification Using Probabilistic Neural Network Compared with the Self-Organizing Map, Journal Ilmiah Kursor, V. 6, No. 4, pp. 211-220.

[2]. Setiahadi, B. (2005), Problems of Equilibrium and Instabilities on Solar Coronal Magnetic Fields and Its Evolution Towards Energetic Energy Liberation: Effects to Interplanetary Space, National Seminar on Mathematics, Diponegoro University, p. E.1.

[3]. Setiahadi, B. (2007), Daily Observational Sunspot ASCII Data for Long- Term Solar Magnetohydrodynamo Studies at Lapan Watukosek,

[4]. Setiahadi, B. (2007), Solar Observation Procedures to Obtain the Watukosek White Light Solar ASCII Data for Statistical Space Warnings, Proceedings of International conference on Rural Information and Communication Technology 2007, ITB Research Center on ICT, pp. 101-105. (ISBN 978-979-15509-1-8).

[5]. Setiahadi, B. (2007), MHD Numerical Simulation of Interactions Between the Solar Storm and the Planet, Prosiding Seminar Nasional Sistem dan Teknologi Informasi (SNASTI), STIKOM, Surabaya, pp. III 1-5, (ISBN 978-979-8968-30-3).

[6]. Setiahadi, B. (2009), Global MHD Simulation of the Magnetospheric Response due to Transient Solar Wind Studied at LAPAN Watukosek 2009: The Space Early Warnings, Prosiding Nasional Pascasarjana IX – ITS, Surabaya, ISBN: 978-979-96565-5-1

[7]. Setiahadi, B. (2010), Solar Flare Occurrence by Considering the Zurich Classification, Area of Active Region and Magnetic Topology: Warning to Solar Activity, Univ. Negeri Yogyakarta, pp. 375-385.

[8]. Setiahadi, B. (2010), Magnetohydrodynamo Solar Activity Simulation Toward the Next Maunder Minimum: Interplanetary Global Cooling, Prosiding Seminar Nasional Matematika, Universitas Sebelas Maret, Surakarta, pp. 158-170, (ISBN 979-978-3456-79-1).

[9]. Setiahadi, B. (2011), Solar Eruption on 4 January 2011: Case Study for Space Early Warning, Seminar Nasional Pendidikan Matematika, LSM XIX, Univ Neg Yogya, pp. 139-149, (ISBN 978-979-17763-3-2).

[10]. Tandberg-Hanssen, E., Emslie, A.G. (2009), The Physics of Solar Flares, Cambridge Astrophysics Series, Cambridge Univ. Press, (ISBN 978-0-521- 11552-0).