Estimation of Geomagnetic Storm of Solar Cycle 24 Based on Solar Wind and Magnetic Field Parameters

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Abstract. Geomagnetic storms are important phenomena in space weather research and also one of the parameters provided in the LAPAN space weather service, SWIFtS (Space Weather Information and Forecast Service). Some of the geomagnetic storm prediction models have been developed. In 2017, a geomagnetic storm model was developed based on the behavior of the solar wind parameters and Southward interplanetary magnetic field (Bz(-)) by using data during 1996-2006, namely Dst(P_{Total}). In this paper, we estimate the geomagnetic storms event during 2015-2020 by using P_{Total} model. From analyzed obtained that the Dst(P_{Total}) model has a good in accuracy. This can be seen from the mean deviation value between Dst data and model output. The mean deviation value between Dst data and model outp This can be seen from the average value of deviation between data and model output (P_{Total}) is (-) 29.4%. Likewise, the average value of the lag time between data and model output is 2.4%.

Keywords: solar wind parameter, geomagnetic storm, space weather, interplanetary magnetic field.

1. Introduction

The Sun as the driving source of space weather is the Coronal Mass Ejection (CME) event. The CME ejects energetic particles that propagate toward to the Earth as the solar wind. A natural phenomenon that appears as a result of the CME is a geomagnetic storm after the "interplanetary shock". Its formation and intensity are determined by the behavior of the solar wind parameter and the southward interplanetary magnetic field (Bz(-)) when reconnection takes place. At this moment, there will be an injection of energetic particles carried by the solar wind into the Earth's magnetosphere. The amount of injection of energized particles can determine the intensity of the geomagnetic storm it forms (Burton et al., 1975; O'Brien and McPherron, 2000; Ballatore and Gonzalez, 2003, Russell, 2006; Mayaud, 1980; Gonzales et al., 1994; Nagatsuma, 2002; Crooker, 2000; Kivelson and Russell, 1995; Gopalswamy, 2009; Boudouridis, et al., 2004; Russel, 2006; Khabarova, 2007; Santoso, 2010; Guido, 2016). It illustration is as shown in Figure 1.

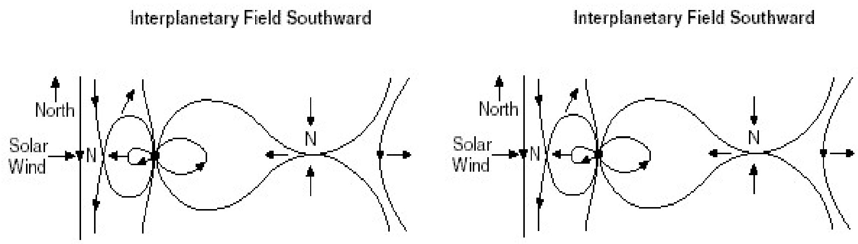

Fig. 1. The illustration of the formation of a geomagnetic storm after the "interplanetary shock". Bz IMF dominant play a role in the formation of geomagnetic storms (Ballatore and Gonzales, 2003)

Geomagnetic storms are an important space weather research so that many models of geomagnetic storms have been built (Lundtstedt and Wintoft., (1994); Burton et al., 1975; O'Brien and McPherron, 2000; Ballatore and Gonzalez, 2003; and Khabarova, 2007 and 2012; Friman, 2020; Kim et al., 2014; Gruet et al., 2018; Chakraborty and Morley, 2020; Uwamahoro and Habarulema, 2014; Myagkova et al., 2017).

So we assumed that solar wind behavior and Bz IMF before geomagnetic storm is important role plays. Khabarova (2007) was studied relation between solar wind before geomagnetic storm. She's result as shown in Figure 2.

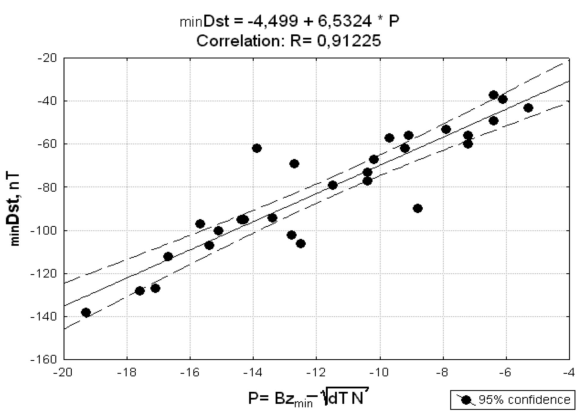

Fig. 2. The relationship between the minimum Dst to the increase in the solar wind pressure (Nsw) and southward Bz

Based on Figure 2, then equation (1) and equation (2) are obtained

$$P = B_{zmin} - \sqrt{NdT} \quad (1)$$

$$Dst = 4,5P + 6,5 \quad (2)$$

Where dT is timespand between N reach maximum with Bz southward reach minimum.
In 2010, Santoso also studied the behavior of solar wind components together with Bz IMF before geomagnetic storm using data during 1996-2001. He obtained 48 of geomagnetic storm events, 9 of them affected dominantly by solar wind speed (Vsw), 18 of them affected dominantly by solar wind density (Vsw) and 17 of them affected by solar wind speed and density with the strength.
Because of geomagnetic storms is one of the issued in the Space Weather Information and Forecst Service, (SWIFtS) Program at the Center for Space Science, Lapan. The research of geomagnetic storm predictions have been done too in Lapan. Santoso et al., (2017) were developed the estimation geomagnetic storm method using data from 1996-2006 based Khabarova's and Santoso's results. Santoso et al. adopted and then assumed equation (1) as function of Vsw, and get

$$P_{Bz-Vsw} = B_{z-min} - \sqrt{VdT} \quad (3)$$

Where P is a fit linier and dT is the time duration between minimum Bz and Vsw peak,

So, from equations (1) and (3), obtained Equation (4)

$$P_{tot} = P + P_{Bz-Vsw} \quad (4)$$

From equation (4), we calculated relation between P_{total} and minimum Dst. The result is as shown in Figure 3.

From Figure 3, we obtained,

$$Dst = 1{,}599(P_{total}) - 34{,}48 \quad (5)$$

Where P_{Total} is the parameter of the total fitting between Nsw and Vsw together with Bz IMF to Dst.

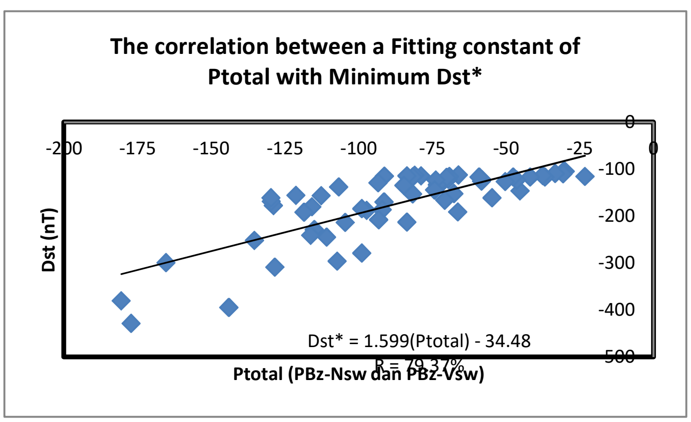

Fig. 3. The correlation between P_{total} ($P_{Bz-Nsw} + P_{Bz-Vsw}$) with minimum Dst

Meanwhile, for the time lag estimation between the time when Bz reaches minimum and Dst reaches minimum (Δt) by using 62 strong geomagnetic storm events (Dst < -100 nT) identified during 1996-2006. The results are as shown in Figure 4.

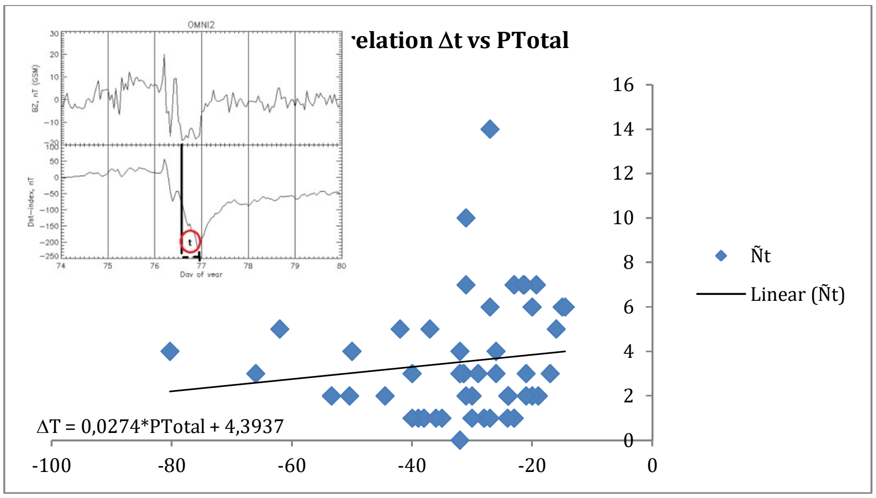

Fig. 4. The correlation value between ΔT and P_{Total}

From Figure 4, obtained equations:

$$\Delta t = 0{,}0274(P_{Total}) + 4{,}3937 \qquad (6)$$

So, equations (4), (5), and (6) will test to estimation geomagnetic storm.

In this paper, will doing the estimation of geomagnetic storm during 2015-2020 uses a model based on equations (4), (5) and (6). It is hoped that the result can providing decision support system tool for help SWIFtS activities.

2. DATA AND METHOD

2. 1. Data

The data used are the Dst index from http://wdc.kugi.kyoto-u.ac.jp/dst_final/index.html, the solar wind component (Speed, V_{SW}, density, N_{SW}, and pressure, P_{SW}) and the Bz IMF component. from http://omniweb.gsfc.nasa.gov/form/dx1.html during 2015-2020.

2.2. Method

Evaluating Dst data to collect geomagnetic storm during 2015-2020. Then determined the P_{TOT} using equation (4) furthermore, estimation geomagnetic storm using equation (5). For determine the time lag used equation (6). The model ouput was compared with data statistically to see its deviation.

3. **Results and Disscussion**

The identification of Dst index during 2015-2020 obtained 9 geomagnetic storm events with a scale strong (Dst <-100 nT), as shown in Table 1.

Table 1. List of strong geomagnetic storm events (Dst < -100 nT) during 2015-2020

No	Date of the geomagnetic occured	Intensity (nT)	T-DstMin (UT)
1	17-March-15	-222	23.00
2	23-Jun-15	-204	05.00
3	7 Oct 2015	-124	23.00
4	20 Dec 2015	-155	23.00
5	1-Jan-16	-110	01.00
6	13 Oct 2016	-104	24.00
7	28 May 2017	-125	08.00
8	8-Sep-17	-124	02.00
9	26 Aug 2018	-174	07.00

From 9 of strong geomagnetic storm events for case study, 9 of strong geomagnetic storm events will used as case studies.

Case study I: Geomagnetic Storm event on March 17, 2015

The geomagnetic storm on 17 March 2015 was categorized as a major geomagnetic storm with an intensity of Dst = -222 nT and minimum Dst was occurred at 23.00 UT on 17 March 2015 (06.00 West Indonesia Time (WIT) on 18 March 2015). This geomagnetic storm assumed triggered by Halo CME event on March 15, 2015 at 01:36 UT (07:36 WIT on March 15, 2015) with class M. Furthermore, 70.5 hours later it major geomagnetic storm (Major Storm) type SC has generated with Dst = -222 nT on March 17, 2015 at 23:00. UT (06.00 WIT on 18 March 2015).

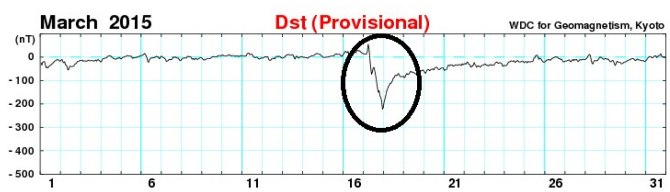

Fig. 5. A strong geomagnetic storm (Dst = -222 nT) on 17 March 2015 at 23:00 UT (18 March 2015 at 06.00 WIT) was detected by the Dst data index (http://wdc.kugi.kyoto-u.ac.jp/dst_provisional/201503 /index.html)

Using equations (4), (5) and (6) then estimation of the intensity and time lag of geomagnetic storm is done. The results are as follows:

Table 2. Values of Dst and ΔT from the observation data and values of P_{Total}, Dst(P_{Total}), and T(P_{Total}) as output of the geomagnetic storm event model on 17 March 2015

Bz	N	V	T1	T2	PBz-Nsw	PBz-Vsw	Ptot
-18,1	33,7	614	9	3	-35,5155	-61,0185	-96,534
ÑT Data = 8 hour							
17-19 March 2015							
Dst-Data	Dst*						
-222	-226,351	Dst*(PBz-Nsw)			DTPBz-N	3,289335	
	-188,838	Dst*(Ptotal)			DTPTotal	1,748667	

Case study II: Geomagnetic storm event on June 23, 2015

The geomagnetic storm on June 23, 2015 was categorized as a strong geomagnetic storm (Major Storm) with an intensity of Dst = -204 nT and time of minimum Dst was occurred at 05.00 UT (12.00 WIT) on 23 June 2015. This geomagnetic storm is estimate triggered by Halo CME event on June 21, 2015 at 02:36 UT with class M with speed 1366 km/s. Furthermore, 10.5 hours later it generated a strong-scale geomagnetic storm (Major Storm) type SC with Dst = -204 nT on June 23, 2015 at 05:00. UT (12.00 WIT on June 23, 2015)

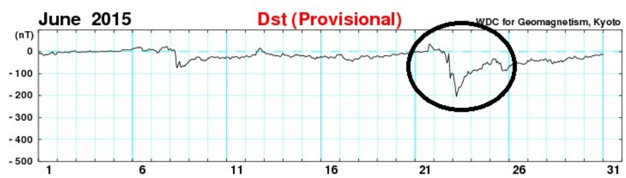

Fig. 6. A strong geomagnetic storm (Dst = -204 nT) on June 23, 2015 at 05:00 UT (June 23, 2015 at 12.00 WIT) was detected by the Dst data index (http://wdc.kugi.kyoto-u.ac.jp/dst_provisional/201506 /index.html)

By using equations (4), (5) and (6) an estimation of the intensity and time lag of geomagnetic storm is done. The results are as follows:

Table 3. Values of Dst and ΔT from the observation data and values of P_{Total}, Dst(P_{Total}), and T(P_{Total}) as output from the geomagnetic storm event model on June 23, 2015

Bz	N	V	T1	T2	P1	P1	Ptot
-22,2	40,4	673	0	0	-22,2	-22,2	-44,4
ÑT Data = 9 hour							
22-24 June 2015							
Dst	Dst*						
-204	-139,8	Dst*(PBz-Nsw)			DTPBz-Nsw	3,00596	
	-105,476	Dst*(Ptotal)			DTPTotal	3,17714	

Case study III: Geomagnetic storm event on December 20, 2015

The geomagnetic storm on December 20, 2015 was categorized as a strong geomagnetic storm (Major Storm) with an intensity of Dst = -155 nT and time of a minimum Dst occurring at 23.00 UT on December 20, 2015 (06.00 WIT on December 21, 2015). This geomagnetic storm is estimate triggered by double Halo CME, namely on December 16, 2015 at 09.36 UT and at 14.24 UT, both are C classes. Furthermore, 135.5 hours later they generated a strong scale geomagnetic storm (Major Storm) type SC with Dst = -155 nT on December 20, 2015 at 23.00 UT (06.00 WIT on December 21, 2015).

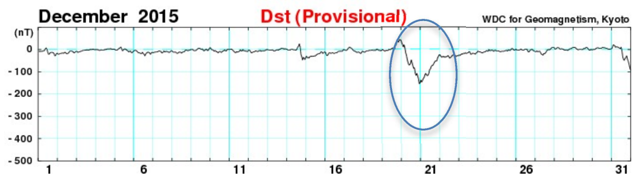

Fig. 7. A strong geomagnetic storm (Dst = -155 nT) on December 20, 2015 at 23:00 UT (December 21, 2015 at 06.00 WIT) was detected by the Dst data index (http://wdc.kugi.kyoto-u.ac.jp/dst_provisional/201512/index.html)

By using equations (4), (5) and (6) an estimation of the intensity and time lag of geomagnetic storm is done. The results are as follows:

Table 4. Values of Dst and ΔT from the observation data and values of P_{Total}, Dst(P_{Total}), and T(P_{Total}) as output from the geomagnetic storm event model on December 20, 2015

Bz	N	V	T1	T2	P1	P1	Ptot
-17	62,7	418	12	7	-44,429911	-71,0925	-115,522
ÑT Data = 1 hour							
19-21 Des 2015							
Dst	Dst*						
-155	-284,294	Dst*(PBz-Nsw)			DTPBz-Nsw	3,362875	
	-219,2	Dst*(Ptotal)			DTPTotal	1,228386	

By using the same method as shown in the case studies above, estimation for 9 of strong geomagnetic storm events are done. The results are summarized and as shown in Table 5.

Table 5. Values of Dst and ΔT from the observation data and values P_{Total}, Dst(P_{Total}), and T(P_{Total}) as output from 9 of geomagnetic storm as case study.

No	Date of Geomagnetic storm	Intensity (nT)	Time of Dst min	PBz - Nsw	Ptotal	Output Model Dst		Dev Dst Model-Data (%)		Time lag of data (Hour)	Time of output model (Hour)		Dev ΔT Model-Data (%)	
						Dst (PBz-Nsw)	Dst (Ptotal)	PBz-Nsw	Ptotal		PBz-Nsw	Ptotal	PBz-Nsw	Ptotal
1	17-Mar-15	-222	23.00	-35,5	-96,5	-226	-188,8	1,80	-14,69	8	3,3	1,8	-58,8	-77,5
2	23-Jun-15	-204	05.00	-22,2	-44,4	-140	-105,5	-31,37	-70,36	9	3,3	1,8	-63,3	-80
3	7 Oct 2015	-124	23.00	-16,6	-84,7	-104	-169,9	-16,13	44,15	8	3,3	1,8	-58,8	-77,5
4	20 Dec 2015	-155	23.00	-44,4	-115,5	-284	-219,2	83,23	22,60	1	3,3	1,8	230	80
5	1-Jan-16	-110	01.00	-31	-107,7	-197	-206,8	79,09	49,14	4	3,3	1,8	-17,5	-55
	13 Oct 2016	-103	18.00	-39,1	-115,2	-250	-218,8	142,72	46,32	1	3,3	1,2	230	20
6	28 May 2017	-125	08.00	-40,4	-91,54	-258	-180,9	106,4	21,67	6	3,1	1,9	-48,3	-68,3
7	8-Sep-17	-124	02.00	-32,2	-56,4	-205	-124,7	65,32	0,34	1	3,1	2,9	210	190
8	26 Aug 2018	-174	07.00	-24,6	-91,1	-155	-180,2	-10,92	4	1	3,4	1,9	240	90
	Average Value							46,68	11,46				73,71	2,41

From Table 5, obtained that the geomagnetic storm method namely Dst(P_{Total}) has has good accuracy. This can be seen from the average value of deviation between data and model output (Dst(P_{Total})) is (-)29.4%. Likewise, the average value of the lag time between data and model output ($\Delta t(P_{Total})$) is 2.4%. The results obtained in above also show that the superposition of the density and speed of the solar wind became complements for the results. Although in some geomagnetic storm events there are the model results that have low accuracy. This requires further analysis to find the answer.

4. **Conclusion**

The behavior of the solar wind parameters with Bz IMF before a geomagnetic storm can determine intensity and formation of a geomagnetic storm. Estimation of geomagnetic storm by using Dst(P_{Total}) method has a good in accuracy. This can be seen from the average value of deviation between data and model output Dst(P_{Total}) is (-)29.4%. Likewise, the average value of the lag time between data and model output $\Delta t(P_{Total})$ is 2.4%.

ACKNOWLEGEDMENT

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