
ANALYZING CORONAL MASS EJECTION OF JULY 10, 2005 AND ITS EFFECT ON THE EARTH'S MAGNETOSPHERE

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Abstract

A large coronal mass ejection (CME) was occurred on July 10, 2005 08:54 UT at the South-West solar limb. This was a partial type of CME as the ejected coronal plasma covered partially around the occulting disk of coronagraph. The Large Angle and Spectrometric Coronagraph (LASCO) aboard Solar and Heliospheric Observatory (SOHO) data were used in detecting CME. The data taken by the Extreme-ultraviolet Imaging Telescope (EIT) as well as Michelson Doppler Imager (MDI) that observes the active regions in white-light wavelength and maps the magnetic field of the photosphere are used to identify the source region of CME. The projected speed of CME perpendicular the Sun-Earth line is determined to estimate the arrival time at the Earth's orbit. The speed and location of the source region of CME are used to study the effect of CME to the Earth's magnetosphere (geo-effectiveness). It is concluded that the CME's effect to the Earth's space environment was relatively small (Dst index greater than -100 nT) due to the source region was located close to the West solar limb. This work supports the efforts in establishing space weather service at LAPAN.

Keywords: coronal mass ejection, geo-effectiveness, space environment, space weather.

1. Introduction

The Sun is very dynamics in nature when it is seen in X-ray or extreme ultraviolet (EUV) [4]. There is a rapid change in minutes in active regions but there is also a gradual change of solar corona globally more than one solar rotation (27.3 days) as seen in EUV or X ray synoptic maps [2]. The intensity change of transient event such a flare can be even as fast as in seconds order due to a sudden liberation of magnetic energy of an active region into radiation in electromagnetic waves. Some large flares of

M or X class are accompanied with a huge coronal mass ejection (CME) that may caused severely disturbance at the interplanetary space and the Earth's space environment as well [1, 5, 6, 7, 10]. In this case, the active region that releases a flare with coronal mass ejection (CME) is the source region of CME.

A CME may be initiated by a dark filament at the solar disk or prominence eruption at the solar limb. Instability in one or both of the foot points of filament may init eruption of the filament, trigger further instability in the corona above the filament and therefore cause ejection of solar coronal plasma. The dark filament or prominence eruption plays an important role in triggering the coronal mass ejection in middle or high latitude of the Sun. A dark filament may form at or close to or far from the active regions. During a minimum phase of solar cycle in which the appearance of active regions is very rare, dark filament or prominence eruption mostly controls the occurrence of CME.

Other possible the source region of CME is a helmet streamer [12, 13]. This is a coronal structure which looks like a helmet or dome with a tail structure at the top. This structure may form over a large active region or outside the active region. The helmet streamer that formed above an active region is the potential source region of a powerful CME such as 'halo' type when it is directed to the Earth. Location of active region that produced a CME at solar disk can be used to forecast whether a CME has a strong impact to the Earth's space environment or not [8, 11, 14].

Identifying the source region of a CME is very crucial as it will provide more precise in forecasting the arrival of CME related disturbance at the Earth orbit. This is part of space early warning system to be developed at LAPAN [3, 9,13]. Based on a statistical study, a CME may reach the Earth as early as one day or longer up to 6 days. It depends upon the position of the source region of CME in solar disk, its initial speed, as well as mechanisms of acceleration or deceleration during its propagation in the interplanetary space [7]. This work deals with analyzing a large CME at the South-West solar limb that occurred on July 10, 2005. The effects of this CME on the Earth's space environment will also be studied.

Section 2 provides observational data taken from the SOHO spacecraft, while the methods in analyzing the data are given in section 3. Data processing and analysis are provided in section 4, while the results and discussions are presented in section 5. Finally, conclusion of the work is given in section 6.

2. Observations

SOHO spacecraft observes the Sun at multi-wavelengths based on optical imaging taken by the Large Angle and Spectrometric Coronagraph Experiment (LASCO) and Michelson Doppler Imager (MDI), as well as extreme ultraviolet (EUV) taken by the Extreme ultraviolet Imaging Telescope (EIT). LASCO is used to take images of outer solar corona up to 30 solar radii. MDI observes the features at photosphere such as active region (sunspot group) to follow its morphological evolution as well as mapping the magnetic pattern of the Sun. The occurrence of CME is sensed by LASCO instrument while EIT images are used to study the evolution of coronal structure which can be used to find the source region of CME. EIT is able to detect a sudden increase in intensity that may correspond to the occurrence of flare or coronal wave of CME.

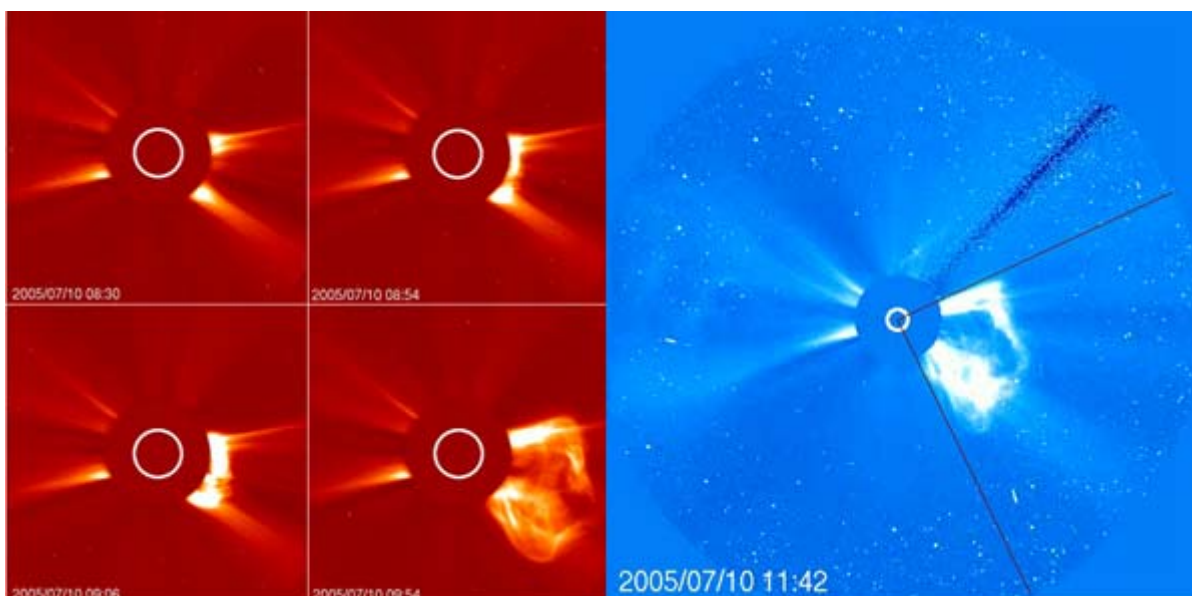


Figure 1. A coronal mass ejection was observed by SOHO/LASCO-C2 (left) and LASCO-C3 (right) at the South-West solar limb on July 10, 2005. The angular span of CME plasma is shown by lines in LASCO-C3 image.

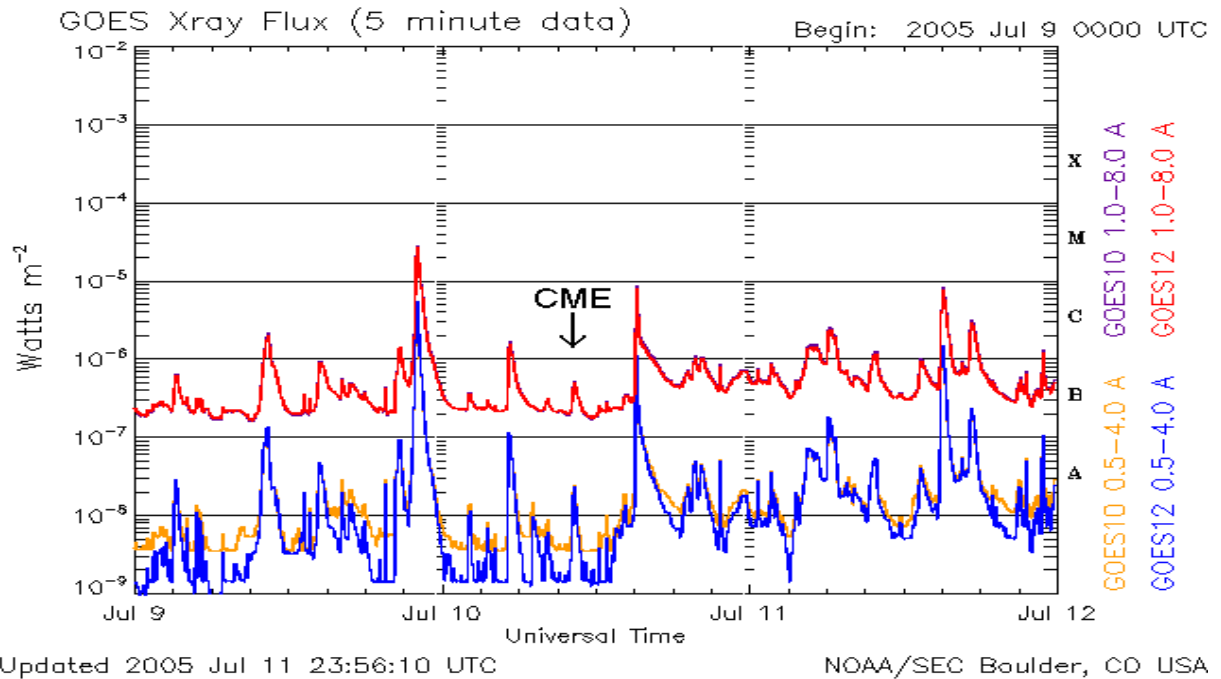


Figure 2. Soft X ray flux of GOES satellite showing a solar activity in July 9 – 11, 2005. A possible sudden increase of X-ray flux that may correspond to CME event is shown by an arrow.

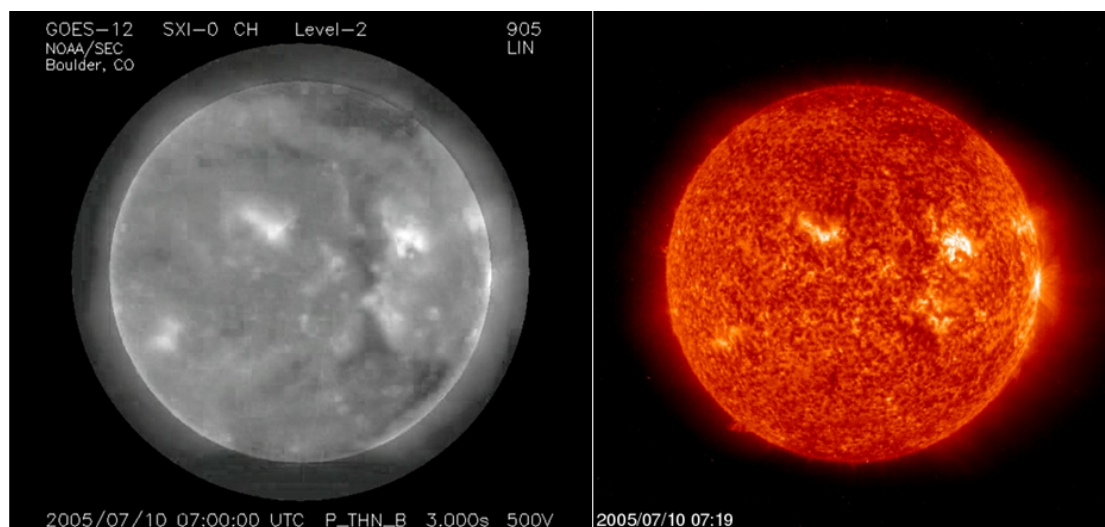


Figure 3. The GOES/SXI image taken in July 10, 2005 at 07:00:00 UTC (left) is compared with the SOHO/EIT 304Å (right). The bright area corresponds to active regions while the dark parts are coronal holes.

In most cases, flares are occurred in active regions. Therefore, morphological evolution of active region and its magnetic field pattern are important to be studied to understand why a flare has been occurred. Predicting the occurrence of flare and CME is crucial part of space weather to avoid or minimize the damage that may occur [9]. Figure 1 shows an example of CME event detected by LASCO/SOHO on July 10, 2004. It is important to identify the source region of this CME. Therefore, other data such soft X-ray flux and images are utilized as shown in Figures 2 and 3.

3. Methods

In order to analyze the CME event of July 10, 2005 at 8:30 UT and study its effects to the Earth's space environment, the following steps have been done:

1. Compile the SOHO data (EIT, MDI, LASCO) from the SOHO website.
2. Identify the CME occurrence (start and end time) from LASCO images.
3. Inspect the soft X ray flux from GOES to determine the start time of transient event (flare) close to the appearance time of CME. It is used to find the relationship whether this flare was related to the identified CME.
4. Inspect the GOES/SXI movie to find the location of active region related to flare in X ray. This is used to find a possible source region of CME, if the CME related to a flare..
5. Find the facts whether the CME and flare occurrence were related or not.
6. Identify an increase of intensity or coronal loop motion in SOHO/EIT 195Å images before the appearance of CME to confirm the finding in step 5.
7. Create difference images of SOHO/EIT 195Å to enhance the intensity change in corona. Locate whether the change or plasma flow were originated from the solar disk facing to or away from the Earth.
8. Identify a dark filament or prominence eruption from SOHO/EIT 304Å, if any.

9. Determine the source region of CME using SOHO/EIT and SOHO/MDI [1].
10. Do measurement of the sky-projected speed of CME [4, 5].
11. Determine the arrival time of CME at the Earth's orbit.
12. Confirm the arrival time of CME at the Earth using Dst (Disturbance storm time) index.

Construction of a movie from sequence of images taken by SOHO's instrument involves an alignment of the center position of the Sun at each image to avoid motion in the movie caused by a jitter motion of the spacecraft. Suppose that the center of solar disk of the first image is (X_0, Y_0) , the center position of the subsequence solar images are represented as (X_1, Y_1) , (X_2, Y_2) , ..., (X_n, Y_n) , where n is the number of subsequence images. To align the images to the first one, the subsequence images should be shifted to amount of ΔX_i and ΔY_i , as follows:

$$\begin{aligned} \Delta X_i &= X_i - X_0 \\ \Delta Y_i &= Y_i - Y_0 \quad \text{where } i=1, n. \end{aligned} \tag{1}$$

Note that the shift of image involves operation of all pixels. In this work, the size of image is 512 x 512 pixels.

To enhance a weak flow in coronal images (EIT or LASCO), a difference technique was utilized. A difference image was simply constructed from two images taken in a close in time (less than 2 hours), where the second image was subtracted from the first one.

4. Data processing and analysis

In order to find the source region of CME, the SOHO/EIT195Å and GOES/SXI are utilized. The flow of coronal plasma seen in sequence images of EIT195Å may very weak and therefore is difficult to be detected visually. In order to enhance this weak flow, a technique namely "running difference" is used. In this method, the two sequence images taken at relatively close in time are subtracted. An example of the difference image taken by SOHO/EIT 195Å in July 10, 2005 at 08:48 UT is given in

Figure 4 (bottom-left), along with the corresponding LASCO-C2 difference image at 08:54 UT (bottom-right). These two images fit each other in time sequence as the EIT 195Å represents lower part of corona while LASCO-C2 image observes outer part of corona. Their positions at the occulting disk of coronagraph (South-West) also fit as well. By measuring the width of CME in angle the center position can be estimated. Careful inspection on two images reveals that the plasma flow did not obscure the solar limb. This means that the flow was originated from a region behind the solar limb. This active region was observed at the solar limb in July 8, 2005 as shown in Figure 4 (top).

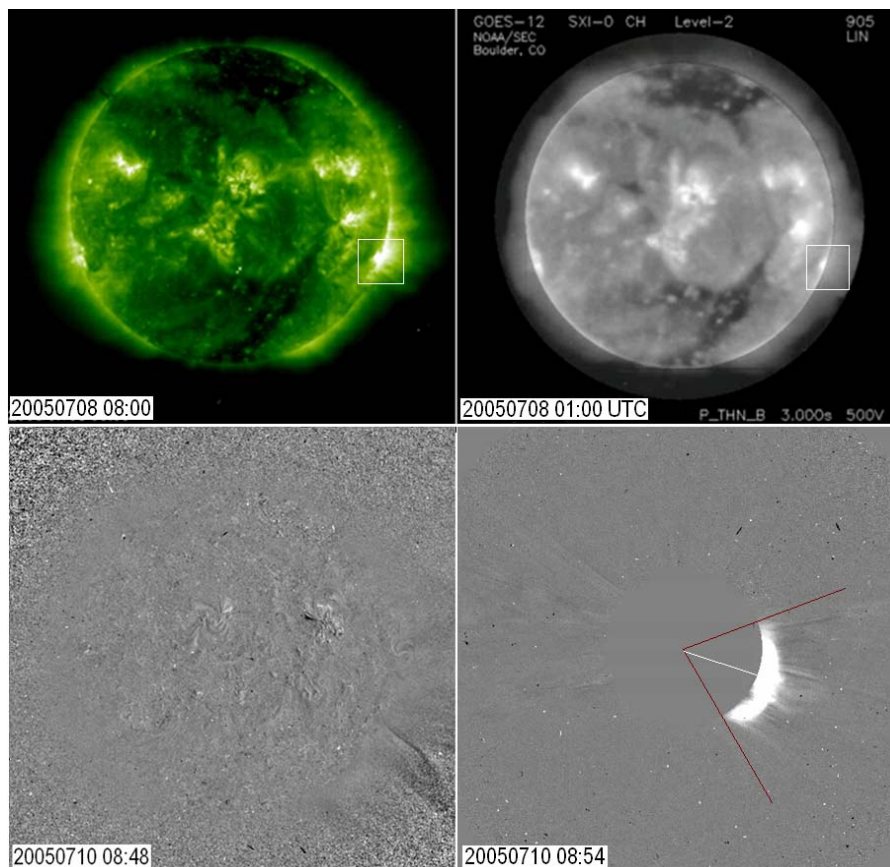


Figure 4. SOHO/EIT 195Å and GOES/SXT showing an active region at the South-West limb on July 8, 2005. The region released a CME on July 10, 2005. The difference of EIT 195Å images that shows an enhance a weak plasma flow at the South-West limb close to solar surface (bottom-left) and the difference image of LASCO-C2 that shows an ejection plasma at a large distance.

Low latitude CME is mostly related to active regions. Therefore, we need to seek the active region that released the CME of July 10, 2005. Figure 4 (upper) shows SOHO/EIT 195Å image taken on July 8, 2005 at 08:00 UT (left) and GOES/SXI at 01:00 UTC (right). The position of active region that may release a CME two days later (July 10) is indicated by a box located at the South-West solar limb. This position is fit well with the position of the center of CME shown in Figure 4 (bottom-right). From these facts, it is concluded that the source region of CME on July 10, 2005 was an active region. Probably, a flare was occurred accompanied with CME.

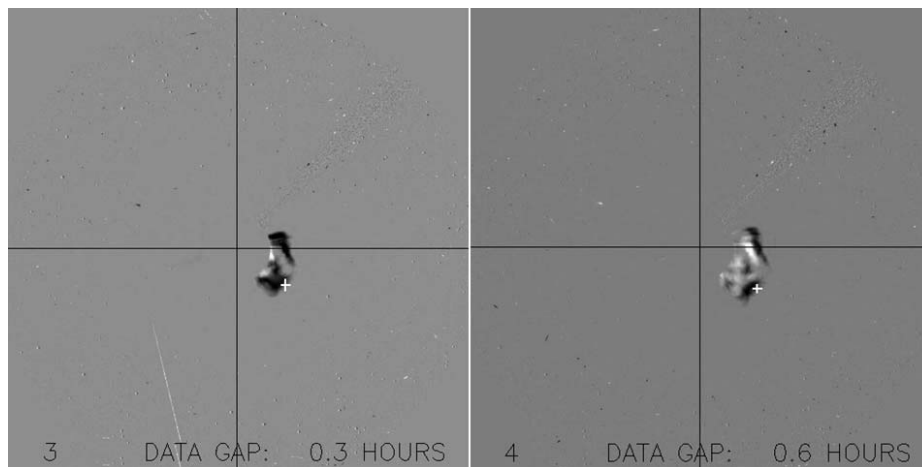


Figure 5. Measurement of the height of the CME loop top (+ sign) relative to the center of the Sun (the center of coordinate) based on LASCO-C3 difference images. The occulting disk is disappeared in the difference image.

5. Results and discussions

In this section, we provide the results of analyzing the CME events on July 10, 2005, as well as discussions. Identification of the source region of CME is crucial part in analyzing the effects of CME on the Earth's magnetosphere. A CME is ejection of magnetized plasma solar corona in nature and it will turn into an interplanetary coronal mass ejection (ICME) during its propagation in the interplanetary space. The CME trajectory in general follows the solar magnetic field lines in the interplanetary space which has a spiral-like pattern. The speed of CME may as low as 10 km/s up to

2400 km/s for a super-fast CME. In order to study the effects of CME on magnetosphere, determination of CME speed is required. This can be performed by measurements of the CME loop tops in the difference image of LASCO-C2 sequentially as shown in Figure 6. The results of the measurements of the loop top are given in Figure 6: (a,b) positions of the loop top in X and Y axis (a,b); the height of the loop top relative to the center of the Sun (c); and the final projected speed in the sky plane (d). The initial speed when the CME appeared at the LASCO-C3 was 500 km/s. There was an acceleration of the CME plasma at the first one hour to 700 km/s and then decreased gradually during the next 2.5 hours to about 400 km/s. Other acceleration was occurred about two hours later to reach a top speed of about 900 km/s. The CME plasma was decreased again to about 700 km/s. This is the final speed as the CME loop top was dimmed before reached the outer boundary of the field of view of LASCO-C3 coronagraph.

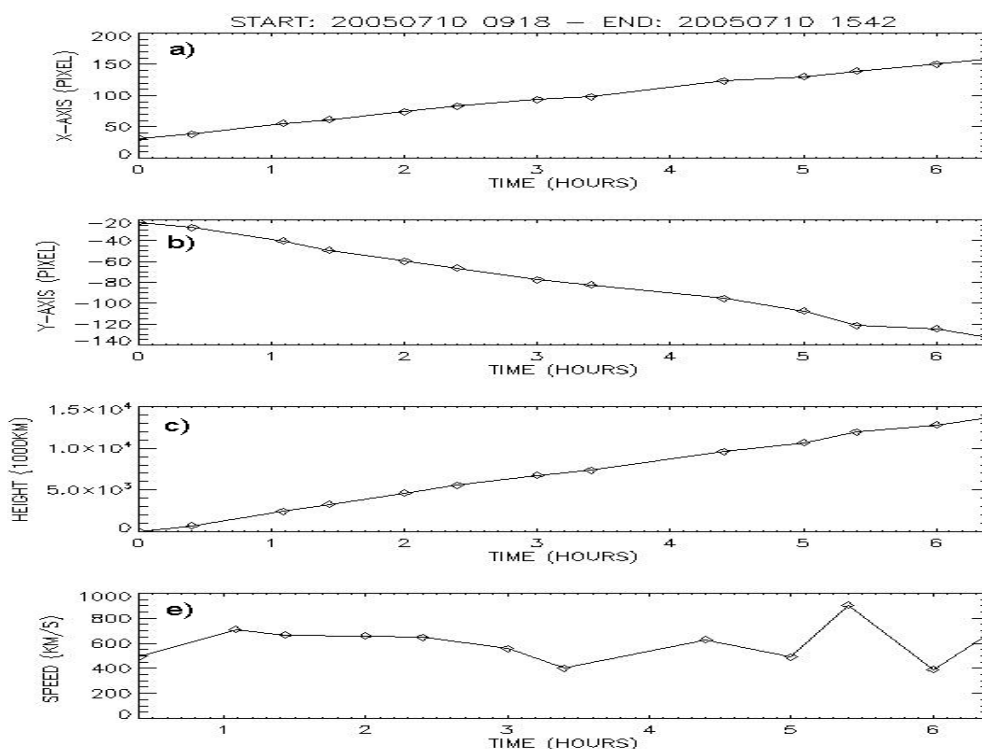


Figure 6. Determination of CME speed projected to the sky plane based on the measurements of the loop top positions. The final speed is accounted to about 700 km/s.

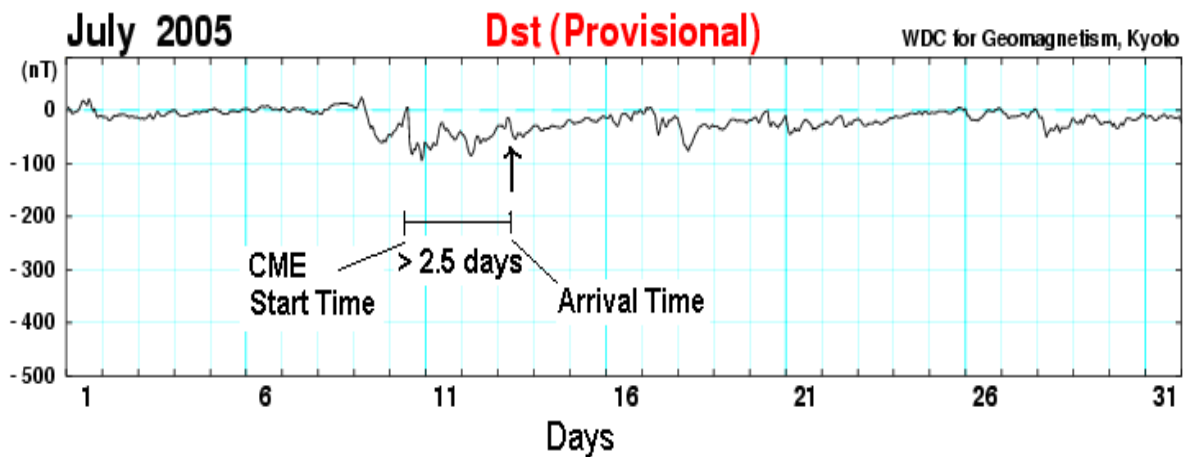


Figure 7. The Dst index showed a decrement after the observed CME on July 10, 2005 at about 08:30 UT. Though, the peak was greater than -100 nT indicating that the CME's effect on the Earth's magnetosphere was minor.

In order to estimate the arrival time of CME at the Earth's orbit, the average distance of Sun-Earth of 150 millions km is assumed. Furthermore, there was no acceleration and deceleration during its propagation in the interplanetary space, the arrival time of CME at the Earth's orbit is about 2.5 days since it launched from the Sun. The actual CME speed toward the Earth may smaller than 700 km/s and therefore the traveling time of CME may be longer (about 3 days). Based on the global index of magnetic field (Disturbance storm time/Dst) compiled by World Data Center for Geomagnetism, Kyoto University, the decrease in Dst index was occurred in July 13 as show by arrow in Figure 7.

6. Conclusion

We have described the methods and analysis of the CME event that occurred on July 10, 2005 at about 8:48 UT. The source region of CME was located at the unseen hemisphere or behind the South-West solar limb. The CME was related to an active region, a possibly a flare, although it can not be detected directly by X-ray flux of GOES. The effect of this CME was minor as shown by Dst index (greater than -100 nT). Therefore, it is concluded that the CMEs located at West solar limb cause a minor geomagnetic storm. This conclusion can be applied to a space weather service at

LAPAN, meaning that if there is a CME at the West limb in the future, a space alert will not be necessary issued to public.

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