Mass Calculation of Coronal Mass Ejection using Matlab

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Abstract

Computer programs have been written in this research to analyze the Coronal Mass Ejections (CMEs) information obtained from the Large Angle and Spectrometric Coronagraph (LASCO) aboard the Solar and Heliospheric Observatory (SOHO). The data, obtained from 2010 to 2014, were analyzed and discussed for 5166 different CME events. The relation between CME the width and mass was studied with details, for each exact event time, which was presented by the year, month, and day, such that the number of CME occurrences was related to their width. The rate of sunspot number was also calculated in this paper for part of the 24th cycle, for data collected from 2008 till 2016. Sunspot number was compared with the number of CMEs during that period, and the results showed that narrow CME is highly associated with sunspot number.

Keyword: coronal mass ejection, sunspot, solar cycle, magnetic field

1. Introduction

The Sun's differential rotation rates cause its surface magnetic field to become twisted and tangled, which in return can produce very strong localized magnetic fields. Places where ropes of bundled field lines break the surface of the Sun are active regions where sunspots form. These active regions often generate solar storms, solar flares and CMEs [1]. CMEs are large eruptions of plasma, magnetic field and energy from the Sun, releasing more than an order of magnitude of energy than the more popularly known solar flare. Much has been learnt about CMEs over the years regarding their composition, structure, onset and evolution [2]. While an interplanetary CME (ICME) impacts with the Earth's magnetosphere then solar storms are initiated, causing an enhancement of its ring current and aurora. A variety of damaging effects on Earth can result, including radiation hazards to polar air traffic, disruption of electric power grids, and telecommunication facilities. Thus, studying CME occurrence rates and general properties was of great interest in space physics. The calculation of the mass of CME it is needed to know:

1. Plasma density and temperature.

2. Intensity of magnetic field.

3. White light reflection from on plasma material in CME [3].

High brightness for CME mean that large reflection of the light of the Sun so, the density of is high, so, mass of CME is high, and vice versa. The solar corona is not stable, but is constantly escaping into space. Although the magnetic field of the Sun, some of the hot gases near the solar surface to make spectacular prominences, in other regions the magnetic field opens into interplanetary space and allows the million-degree gases to escape as a solar wind [4].

CMEs are observed by coronagraphs, which block out the main body of light from the Sun to reveal the faint surrounding corona [5]. The detection of huge ejections of plasma in the Sun's outer atmosphere, the ejections had speeds of a few tens of km/s up to more than 2000 km/s, an average outward propelled mass of ~ 10^{12} kg of solar material and an average width of ~ 45° heliolatitude. CME observed by today's most sophisticated space borne white-light coronagraph LASCO (Large Angle and Spectrometric Coronagraph) on board SOHO [6].

Shen et al., studies the projection effect would distort our understanding of coronal mass ejections (CMEs) and influence the space weather forecasting [7]. Liu et al., examined the Sun-to- Earth characteristics of the CMEs responsible for the geomagnetic storm with combined Heliospheric imaging and in situ observations [8]. In the recent paper, Selman and AL-Hakeem aimed to automatically detect and analyze CME events using images taken from LASCO. Few selected examples of CMEs were studied by means of the present method using LASCO archived images. Selected CMEs were a group of 20 events from the years 2000, 2002, 2003, 2007 and 2013 [9]. Bragain, his thesis aimed to study CMEs and their ICMEs using remove sensing observations from the solar corona, interplanetary in situ data and observations from ground-based cosmic ray detectors. He started the analysis by using a list of magnetic clouds (MCs) observed in the Earth-vicinity from 2008 to 2011 [10]. Jain et al., studied the effect of different types of full halo Coronal Mass Ejection on the cosmic ray intensity for the period of 1996-2004. It is found that the cosmic ray intensity depressed to minimum after three days of the onset of the symmetric and outlines asymmetric full halo CMEs and four days after the onset of brightness asymmetric full halo event of Coronal Mass Ejection [11]. Nicewicz et al., selected a large set of CMEs to study their dynamics seen with LASCO [12].

The aim of the present paper is to study the statistical of the relation between the width and mass of CME, and the relation between the number of occurrences and the width, so that a better understanding of the relation between the mass and number of occurrences of CME is done using Matlab.

2. Data

Five years of data (2010–2014, included) have been taken to understand the distribution of CME from LASCO catalogue's CDAW [13]. Total CME events number considered in this work was 5166 events. For sunspot, data were collected from 2008 till 2016 from [14].

3. Theory

3.1. Coronal Mass Ejection

That is a huge explosion of magnetic field and plasma from the Sun's Coronal. When CMEs impact the Earth's magnetosphere, they are responsible for geomagnetic storms and enhanced aurora. CMEs originate from highly twisted magnetic field structures on the Sun, often visualized by their associated filaments or prominences, which are relatively cool plasma trapped in the flux ropes in the corona [15]. It can contain a mass larger than 10^{13} kg and may achieve a speed of several thousand kilometers per second. A typical CME has a mass of around (10^{11}-10^{12}) kg and

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has a speed between 400 and 1,000 km/s [2]. An image of a CME is shown in Figure 1, illustrates a SOHO/LASCO image (with an EIT superposed).

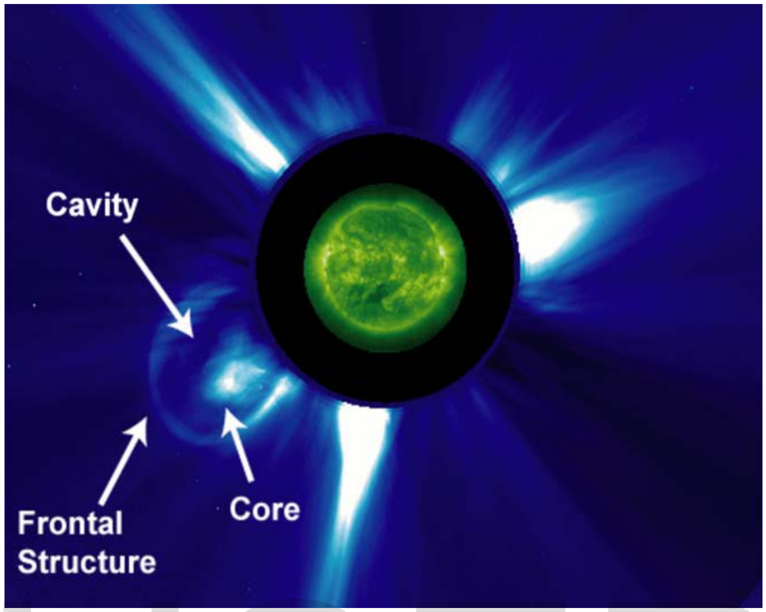


Figure 1: Image of a “classic” three-part CME as observed by the SOHO/LASCO (with an EIT 195 images superposed) obtained on 20 December 2001.

3.2. CME Classifications

Sheeley et al., devised a new method of generating CME height-time maps and applied it to LASCO CMEs. They then proposed the following two types of CMEs according to their speed:

- Gradual CMEs apparently formed when prominences and their cavities rise up from below coronal streamers and characterized by slow speeds and week, continuous acceleration of less than 20m/ s^2When seen broadside, their leading edges accelerate gradually to speeds in the range 400–600 km/s before leaving $30R_{sun.}$

- Impulsive CMEs often associated with flares on the visible disk. The extremely impulsive events with high speeds and strong, rapid acceleration of more than 1000 m/s^2. When seen broadside, these CMEs move uniformly across the 2–30 R_{sun}at speeds higher than 750km/s [16].

  The CME is driven by the energy stored in the magnetic field, which is built up over a long period of time (days to weeks) and is released in a short time (minutes to hours).

There are few more classifications used to categorize CME's. The first is the velocity classification which includes two types, gradual and impulsive CME as given earlier.

There is also the observation- based classification which includes [10]:

1- Flux-rope: CMEs that exhibit a clear three-part structure: a bright leading edge, a dark cavity or (void) and a bright core as displayed in Figure 1. These CMEs is considered to have embedded magnetic flux ropes.

2- Loop: CMEs with a bright and filamentary loop, but without core and/or cavity.

3- Jet: narrow CMEs with a width of less than about 40° lacking a sharp front, circular morphology.

4- Outflow: similar than the jets, but wider.

5- Failed: events that are very bright in the corona close to the Sun but that disappear while they move outward.

Some CMEs are unknown events that cannot be classified in any of the other categories mainly due to poor observational data.

Besides that, there is also the width classification of CME which includes [17].

1. Spike CME: with width below 10°
2. Narrow CME: with width between 15° to ~ 60° and the speed distribution as ≤500 km/sec.
3. Wide CME: with width between 61° to ~ 120° and the speed distribution 501 ~ 1000 km/sec.
4. Partial Halo: with width between 121° to ~ 300° and the speed distribution 1000 ~ 1500 km/sec
5. Halo CME: with width between 300° to ~ 360° and the speed distribution > 1500 km/sec.

4. Results and Analysis

4.1. CME Results for Width vs. Occurrence

The first data had been taken for each month and then for each where year. The total number of occurrence CME result was of 5166 events considered, where a solar maximum took place in this period. These years have been taken too similar the research [12] where they studied CME from 1996 to 2004 and the result were for 9309 CME recorded during this period, but they chose 6621 CME, where these selected events have at least six heights-time measurements. It is also aimed to relate the results from this part with the number of sunspots.

The result of every graph was discussed as a relation between the width and the number of occurrences of CMEs, and was compared with previous research. The comparison showed that present results were in general close to earlier work. The advantage of the present work was the considerably higher number of CME events, where all events were collected for an included period of five years.

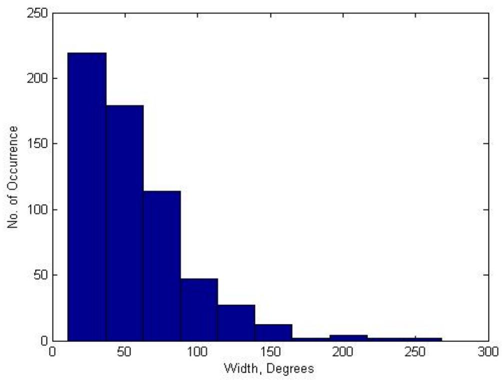
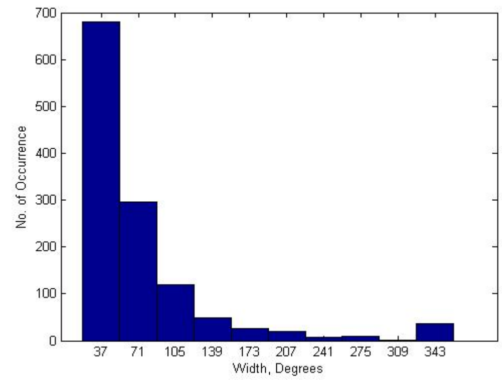
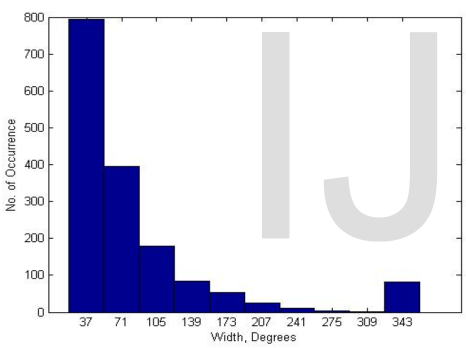


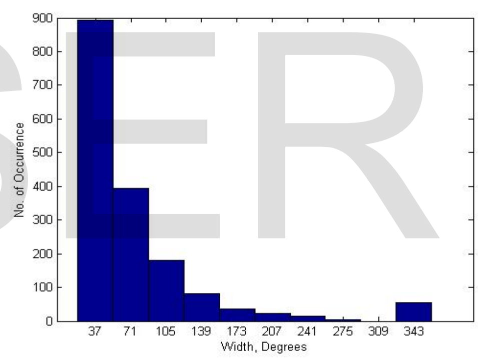
Figure (2): Number of CME as a function of width from 2010



Figure(3): Number of CME as a function of width from 2011



Figure(4): Number of CME as a function of width from 2012



Figure(5): Number of CME as a function of width from 2013

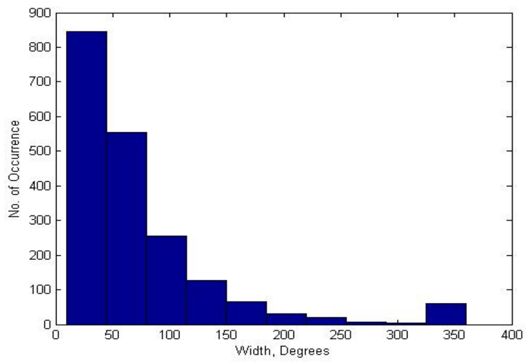


Figure (5): Number of CME as a function of width from 2014

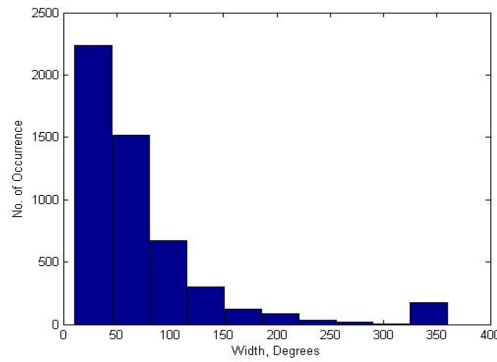


Figure (6): Represents the relation between no. of occurrence of CME and angular width through 2010, 2011, 2012, 2013, 2014

4.2. Analysis and Comparison of width Data

The relationship between the number of occurrence and width of CME is a systemic relationship. As the number decreases when width increase mean that the events with a small width is the largest number, and probability of occurrence was higher. While the wider events are less than to occur, but when the width is close to 360 the number became high again because of the nature of halo CME. When the number of CME occurrences increase, the percentage of error in the results decreases. The differences in angles among the results are not important because we are looking for distribution within a range of angles.

From Figures (1 to 5), the first event at narrow angles for the year 2010 are 219 numbers of occurrence at angle 25 degrees, in 2011 is 697 events at angle 37 degrees, while in year 2012 they are 799 in width 37 angles, and 899 total number at angle 37 degrees that calamities in year 2013, and for a year 2014 that angle at 25 degrees and numeral are 855 events. Note that the year 2013 has a large number of occurrences of CME from other years for 1st and high events. The second occurrence the number of CME for the same years 179 at angle 50 degrees, and (300, 400, 400 and 555) at an angle 71 degrees. The year 2014 has a large numeral from than 2010, 2011 and 2013 for narrower width.

The 3rdevents that have account 114 at 75° that narrow angle and the width at 105° (119, 180, and 181) events and 100 at angle 254° are partial halo of CME. Highest count occurrence for year 2011 and 2013 from than other years.

The numbers of occurrence of CME are 47 at angle 100°and (49, 84 and 82) at angle 139°, and 128 at angle 125 degrees from fourth events. The fifth events are 27 at angle 125°and (26, 53 and 37) at angle 173°and 66 numeral at angle 150 degrees. The 6ththat are events have 12 at angle 150 degrees and (20, 25 and 23) at angle 207 degrees, and 32 events at angle 200 degrees. The counts are 2 at angle 175°, (8, 10 and 15) at angle 241°and 20 at angle 250° for seventh event.

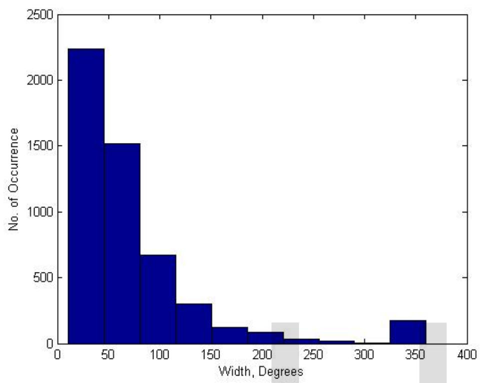
Either the 8thevents the width 200° are 4 events, and (9, 4, 4, 7) at angle 275 degrees.The numbers of occurrence of CME are 2 at angle 225 degrees and (1, 1, 0 and 3) at angle 309° for ninth events. The tenth events that have the numbers are 2 that the width is 275 degrees, (37, 81, and 54) at angle 343 degrees, and 60 at angle 350 degrees. The 4th , 5th, 6th, 7th, 9th, 10th event the year 2014 that is higher for other years in the number of occurrences of CME at a wide angle of CME, while the 8th events the year 2011 that are have large in number from 2010, 2012, 2013and 2014 for a wide angle.

4.3. Comparisons with Previous work

From Figures (6 and 7) a comparison between the present results with Nicewics and Michalik [12]. They chose at least six pictures while in our research all the values and readings have been taken from the CDAW table during these five years. That previous study was made for data at the end of solar cycle 23, while our study was for data during the middle of the solar cycle 24. The found results were similar in behavior to the previous results.

In their research", J. Nicewicz · G. Michalek" [12], data of nine years from (1996 to 2004) were taken and a statistical study were sixteen CME events.They recorded 6621 CMEs events during this period of time, these selected events have at least six height-time measurements, they carried out a statistical study of key CME parameters (acceleration, angular width, velocity, mass) for the different types of CMEs.

The maximum at an angle 62 degrees that angle its be narrower see in Figure (6), but in the first event at angle 10 degrees its smaller than from 1st in my paper for five years in width, and they chose 6621 but have been in my result 5166 events for their period, and less events in their research fourteen and fifteen at angle 270, 290 degrees that's been a partial halo CME, but in my paper that less calamities at angle 300 degrees. Then the width super from than their research in angle for less event of all their events. Halo CME in their research at an angle about 360 degrees, but in my thesis the width of 350 degrees. Halo is the last event in the forms and be anomaly where it rises or lower suddenly compared to the event that preceded it and the reason is to be headed vertically towards SOHO, showing at angle 360 degrees, so reading is not true because it is part of narrow or wide and appears in halo form because the camera is 2D where that image of LASCO does not give an impression of the volume of CME. LASCO discovered halo CME where in the form of a ring emitted by the sun.



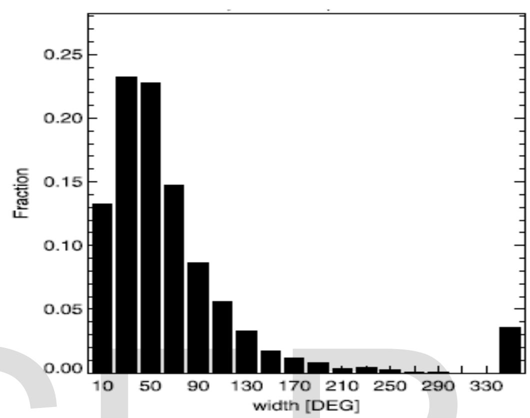


Figure (6): represents the relation between no. of occurrence of CME and angular width through 2010, 2011, 2012, 2013, 2014

Figure (7): represented the relation between the fraction and the angular width of CME from 1996 to 2004 years [11]

4.4. Discussion of mean total Sunspot number

The data have been taken from SILS (second version) [14]. The daily total sunspot numbers start from year 1818 to 2017 years that are integer number because they took total sunspot for every day. And data monthly mean total sunspot numbers begin from year 1749 to 2017 year. Data yearly mean total sunspot numbers initiate from year 1700 to 2017. In this paper, data have been taken monthly for the mean total sunspot number from 2008 to 2017 through solar

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cycles 24. And have been picking the data mean total sunspot number from (2010 to 2014) to compare with the total number of occurrences of CME for those five years to see in Figure (8).

The year 2014 mean total sunspot number that have larger than from 2010, 2011, 2012 and 2013 where the mean total sunspot number is 113 for all month for every day, but in 2010 are 24, 2011 are 80, 2012 are 84 and 2013 are 94. That's mean in the year 2014 that solar cycle maximum through 24 cycles, where the 24 solar cycles started from 2008 and end in 2019, where the sunspot number are associated with the solar cycle.

In 2010 year that smaller than from 2011, 2012, 2013, and 2014 for mean total sunspot number, but in 2011 and 2012 years that are approximate in mean total sunspot number were in 2011 that are 80 but in 2012 that are 84 see in Figure (8). In Figure 9, the relation between the mean total sunspot number and years from 2008 to 2016 through 24 cycles was, we noted that maximum value was in 24 solar cycles in year 2014 and minimum value in the year 2008 for the mean total sunspot number. The smallest mean total sunspot number was in 2008 and 2009 where that's 4.2 and 4.8, and increased in 2010, 2011, 2012, 2013 and 2014 respectively, and begin to decrease in 2015 and 2016 in the mean total sunspot number. We did not take the year 2017 data because data is not yet complete.

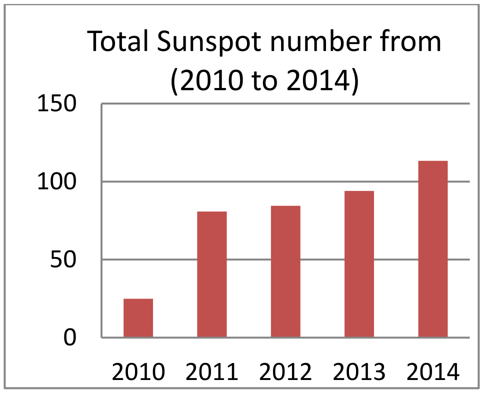

Figure (8): Represent the relation between the mean total sunspot number and five years

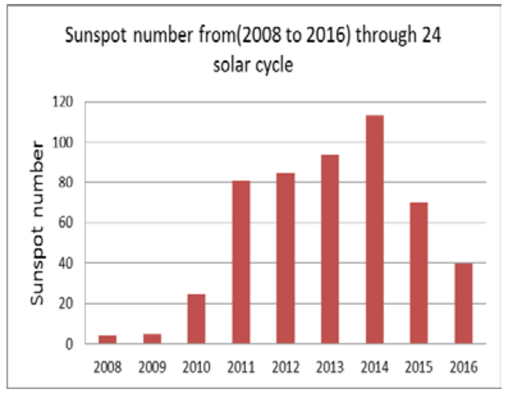

Figure (9): Represent the relation between mean total sunspot number and years (2008 to 2016).

4.5. Comparison between sunspot number and CME number

The total number of occurrences of CME for all months in 2014 the result was 1970 events, but when we sum the mean total sunspot number for all months in 2014 the result was 1363.3 numbers. Those are more solar activity from in 2010, 2011, 2012, 2013 years. The total sunspot number without the average, then we calculate by sum total sunspot number for five years and the result were 145214 numbers, while the total number of occurrence of CME for five years its 5166 events.So, it is noted that the total number of occurrences of CME it's smallest from the total sunspot number for five years. Its importance is to know the exact relationship between sunspot number and CME and provide a tool to replace the study of one of these events.

The number of occurrences of CME slightly increases towards Sunspots maximum and slightly decreases towards Sunspots minima. The number of occurrences of CME increases with solar activity and arrived peaks around solar maximum.

5. Conclusion

a- When sunspot number increased the number of CME slightly increased and vice versa.

b- When CME that width 30° or less angle and a large number of CME is associated with streamers that's mean the narrow CME proportional to the solar activity and not with halo CME.

c- Halo CME in the year 2012 that are more than events from the years 2010, 2013 and 2014.

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