International Journal on Science and Technology (IJSAT)

E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

Analysis of Coronal Mass Ejections (CMEs) Characteristics and Geomagnetic Impact During 2010-2024

Dr. Rohit Verma

Head, Department of Physics,
Sri Guru Tegh Bahadur khalsa College Jabalpur, India

Abstract:

This study examines the physical characteristics, geomagnetic consequences, and auroral reactions of coronal mass ejections (CMEs) linked to Magnetic Clouds that had place between 2010 and 2024. Key CME properties such propagation speed, type, magnetic field components (Bz and Bt), and related geomagnetic indices (Dst and Kp) are examined. Since magnetic clouds are among the most intense solar phenomena, special attention is paid to CMEs connected to them. Forty-five of the seventy nine CMEs that were investigated were halo CMEs, one was a multiple halo CME, and thirty-three were partial halo CMEs. 24.05% were classified as moderate, 56.96% as intense, 1.26% as super-intense, and 11.39% as weak in terms of geomagnetic intensity. Notably, intense geomagnetic storms (Dst < -100 nT) were linked to 65.82% of these occurrences. According to a statistical examination of CME speed, 75.55% of halo CMEs associated with magnetic clouds traveled faster than 1000 km/s, and around 39.24% of these high-speed occurrences caused notable geomagnetic disruptions. These results highlight how important magnetic clouds and high-speed CMEs are in causing space weather events.

Keywords: Coronal Mass Ejections; Magnetic Cloud; Geomagnetic Storms.

1. Introduction :

Numerous studies have been conducted recently to determine the elements that cause Geomagnetic Storms (GMSs) and to comprehend the solar-terrestrial interaction [1,2]. According to research conducted during the past three decades, Coronal Mass Ejections (CMEs) are energetic heliospheric phenomena. CMEs from the Sun generate magnetic field, speed, and density disruptions in the Solar Wind (SW), which in turn lead to geomagnetic disturbances on Earth.

Coronal mass ejections (CMEs) are massive structures that are ejected from the Sun into the atmosphere. These structures comprise magnetic fields and plasma. They are significant from a scientific and technical aspect. Their removal of accumulated magnetic energy and plasma from the solar corona makes them significant from a scientifically [3], and technologically, they are responsible for the most severe space weather effects on Earth, [4], as well as on other planets and spacecraft throughout the atmosphere.

A number of phenomena, including sprays, erupting loops, filaments, and Long Duration Events (LDEs), are intimately associated with CMEs. Therefore, it is necessary to track the CMEs from the solar surface via the interplanetary medium until they reach the earth in order to demonstrate a physical connection between the solar origin and the ultimate geomagnetic effect. The Solar and Heliospheric Observatory (SoHO) was launched more recently.

In sky-plane projection, the occulting disk of the observing coronagraph seems to be surrounded by a halo coronal mass ejection (CME). Howard et al. (1982)[5] were the first to report halo CMEs, although the Solwind coronagraph on the P78-1 mission only detected a small number of them [6]. Since most CMEs that trigger big solar energetic particle (SEP) occurrences and major geomagnetic storms are halos, halo CMEs make up just around 3% of all CMEs yet represent an energetic population [7]. According to Gopalswamy et al. (2010b) [8], halo CMEs often start around the disk center, whereas nearly 10% originate near the limb. The disruption that appears across the opposing limb in limb halos is probably a shock [8]

Parker first coined the term "Magnetic Cloud" (MC) in a considerably larger sense in 1957 when he conducted a theoretical investigation into the dynamics of hydromagnetic gas clouds that were ejected from the Sun and entered the IP space,[9]. Additionally, Burlaga et al. (1981) [10] used it to describe MCs as an area with low proton temperature, smooth magnetic field vector rotation, and improved magnetic field strength [10]. Interplanetary coronal mass ejections (ICMEs) are the term used to describe CMEs that are seen in the solar wind close to 1 AU. A subset of ICMEs with a particular configuration where the magnetic intensity is greater than the average magnetic field is known as MC. An MC is a brief occurrence that is seen in the solar wind. One potential expression of CMEs is MCs. Intense GMSs may result from MCs striking the Earth [11,12].

2. Data Analysis :

.CMEs linked to magnetic clouds have been studied between 2010 and 2024. The information about Magnetic Clouds, which includes 79 events over the aforementioned time period, is sourced from https://www.srl.caltech.edu/ACE/ASC/DATA/level3/icmetable2.htm. The Dst index numbers are sourced from the World Data Center in Japan (http://swdcwww.kugi.kyoto-u.ac.jp). Information on the relevant CMEs is sourced from the CDAW data center's online SOHO/LASCO CME catalog (http://cdaw.gsfc.nasa.gov/CME_list). In the present investigation, the GMSs have been classified as : moderate (-50 nT > Dst ≥ -100 nT) and intense with Dst < -100 nT and superintense (Dst < -200 nT) .

3. Methodology :

The observational data of Coronal Mass Ejection (CME) events captured between 2010 and 2024 is used in this study. The dataset contains important information including the auroral impact, geomagnetic indices (Dst, Kp), magnetic field components (Bz and Bt), MC arrival date, CME date, speed, and type. Relationships between CME speed and geomagnetic indicators were investigated, and CME speed values were examined for distributional features. The impact of CME parameters on the intensity of geomagnetic storms was interpreted using statistical correlation and visual studies (such as column and scatter plots).

4. Result and Discussion :

A measure of association, the correlation coefficient is represented by the letter r. It is sometimes referred to as Pearson's correlation coefficient, after its creator. The scale on which the correlation coefficient is measured ranges from + 1 to 0 to -1. The correlation between two variables is positive when one rises as the other rises, and negative when one falls as the other rises. Complete absence of correlation is represented by 0.

The correlation coefficient calculation, where the values of the independent and dependent variables are denoted by x and y, respectively. The following formula should be used:

$$r = [n (\sum xy)- (\sum x)(\sum y)] / [\sqrt{(n \sum x^2-(\sum x)^2)][(n \sum y^2- (\sum y)^2)}]$$

4.1 CME Speed Distribution

The distribution of CME speeds from 2010 to 2024 revealed that moderate-speed events were more common, with occasional high-speed CMEs associated with strong geomagnetic storms. The speed of the CMEs varies from few hundred Km/s to 2700 Km/s. The minimum and maximum value of CME velocity is observed to be 500 and 2684 Km/s, respectively. The Average CME Speed is 1320.82 (approximately) Km/s. The majority of CMEs recorded exhibit speeds between 500 and 2000 km/s, with a few exceeding 2000 km/s. Faster CMEs are often associated with stronger geomagnetic responses.

4.2 CME Type Frequency:

The sample is dominated by Halo CMEs and partial Halo. Because of their Earth-directed paths, halo CMEs are frequently more geoeffective.

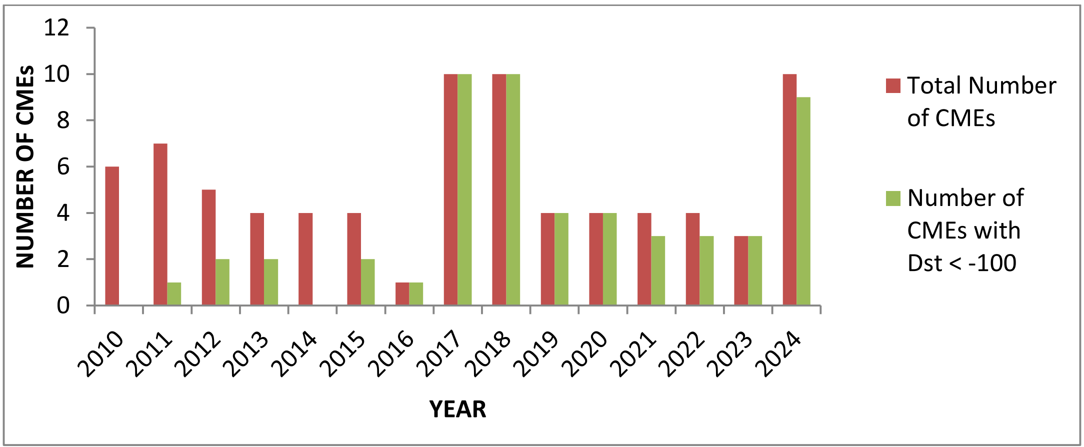


Figure 1: Yearly Distribution of CMEs has been plotted

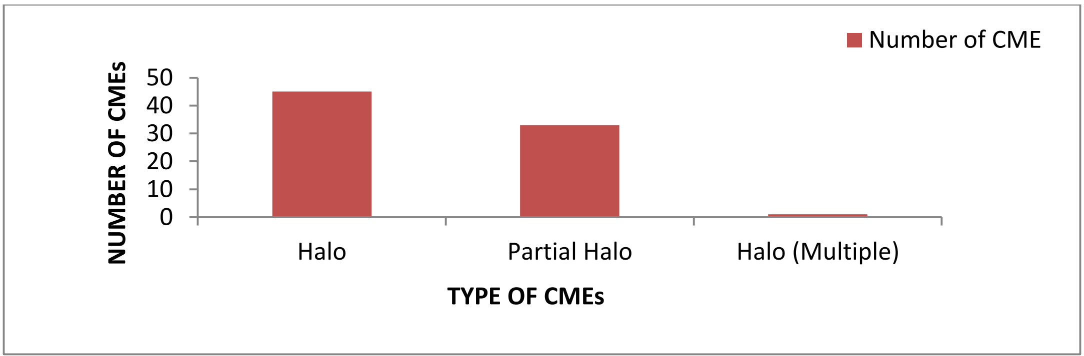


Figure 2: Frequency of CMEs type has been plotted

4.3 Correlation Between CME Speed and Geoeffectiveness

Analysis of the correlation between CME speed and geomagnetic indices (Dst, Kp index) indicated that faster CMEs generally induced more intense geomagnetic storms. There is a moderate inverse link between CME speed and Dst index, as shown by a scatter plot analysis. Stronger geomagnetic storms are indicated by lower Dst values, which are more negative. According to this, much faster CMEs are more likely to disrupt Earth's magnetosphere, particularly when they feature a significant southward Bz component.

4.3.1 CME Speed vs. Dst Index :

Between the Dst index and CME speed, the correlation coefficient is -0.457. Negative correlation, indicating that the Dst index tends to become more negative with increasing CME speed, indicating larger geomagnetic storms.The association is confirmed to be statistically significant by the highly significant ($p < 0.05$) p-value of roughly 2.29×10^{-5}. This confirms that stronger geomagnetic disturbances are typically linked to faster CMEs.

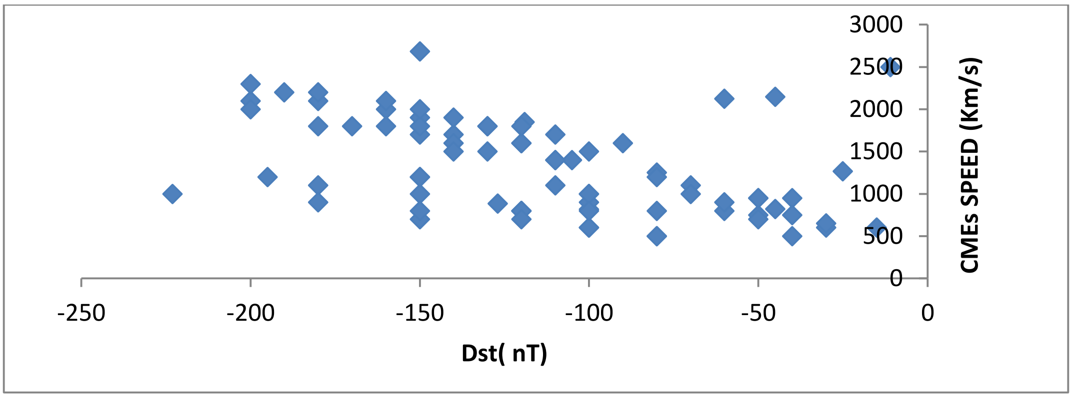


Figure 3: Scatter plot between Dst (nT) and CMEs (Km/s) with correlation coefficient **-0.457**

4.3.2 CME Speed vs. Kp Index :

CME Speed and Kp Index have a correlation coefficient of roughly +0.426. This suggests a moderately positive association, indicating that stronger geomagnetic activity, or higher Kp indices, are typically linked to higher CME speeds. The correlation's significance is confirmed by the statistically significant ($p < 0.05$) p-value of roughly 9.25×10^{-5}.

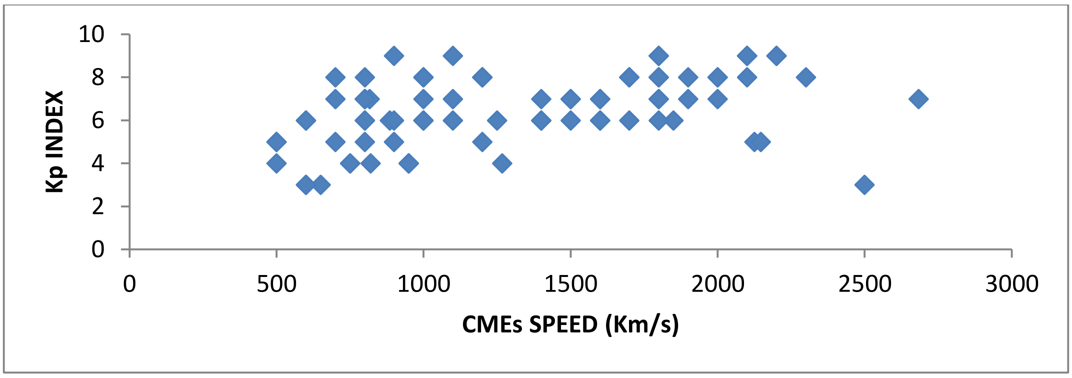


Figure 4: Scatter plot between CMEs (Km/s) and Kp Index with correlation coefficient **+0.426**

Most events show moderate geomagnetic activity (Kp ~3 to 6), with a few reaching higher levels during intense CME events.

4.4 Magnetic Field Characteristics :

Both the Bt (total magnetic field) and Bz (southward component) values vary throughout the collection. A stronger geomagnetic coupling is generally linked to more negative Bz values, which results in higher Kp indices and lower Dst. This highlights the importance magnetic orientation and CME speed are in determining the consequences of space weather.

4.4.1 Dst (nT) and Bz (nT) :

The Dst index and Bz component have a strong positive linear relationship, as seen by the correlation of +0.819. This means that as Bz moves southern, the Dst index also moves southward, indicating larger geomagnetic storms. A stronger storm is indicated by a larger negative Dst value.The amount of solar wind energy that enters the Earth's magnetosphere is largely determined by the Bz component of the interplanetary magnetic field (IMF). When Bz is southerly (negative), it combines strongly with Earth's magnetic field, causing geomagnetic activity. The well-known space weather physics that states that "Southward IMF (negative Bz) is a key driver of geomagnetic storms" is supported by this substantial association. The effectiveness of the southward IMF tilt in generating strong storm responses (Dst decreases) is indicated by the strong relationship ($r \approx 0.82$).

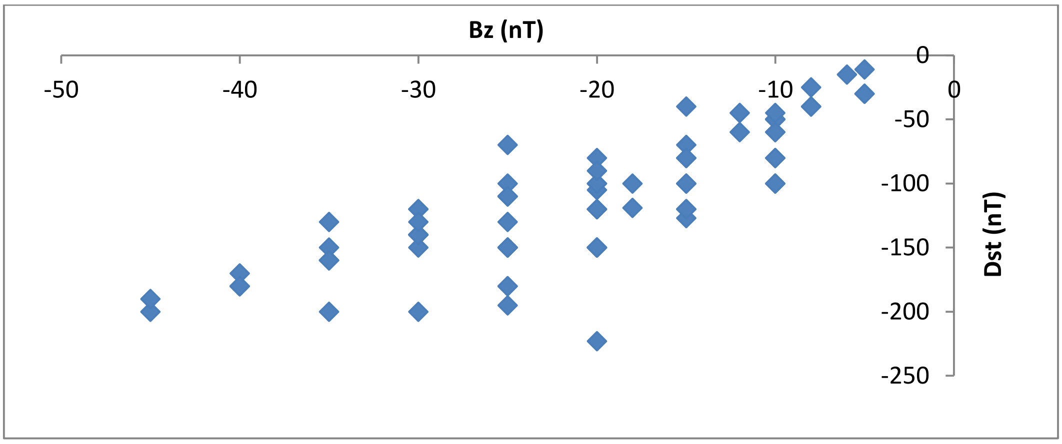
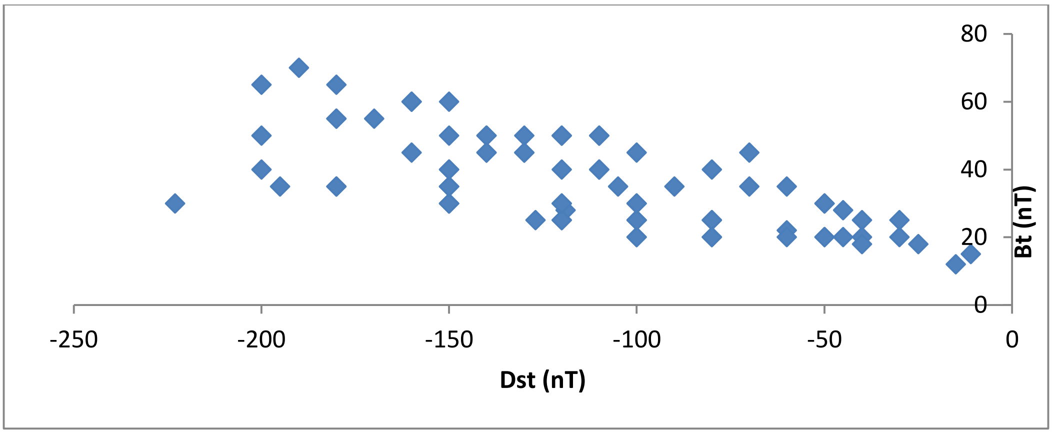


Figure 5: Scatter plot between Bz (nT) and Dst (nT) with correlation coefficient **+0.819**

4.4.2 Dst (nT) and Bt (nT) :

Bt (nT) and Dst (nT) have a correlation coefficient of $r = -0.682$. Dst tends to become more negative as Bt rises, indicating larger geomagnetic storms. The association is statistically significant, as indicated by the p-value of $\approx 4.70 \times 10^{-12}$, which is significantly less than 0.05. A higher Bt value typically indicates stronger interplanetary magnetic fields and the potential for stronger interaction with the Earth's magnetosphere, especially when accompanied by a southward Bz.



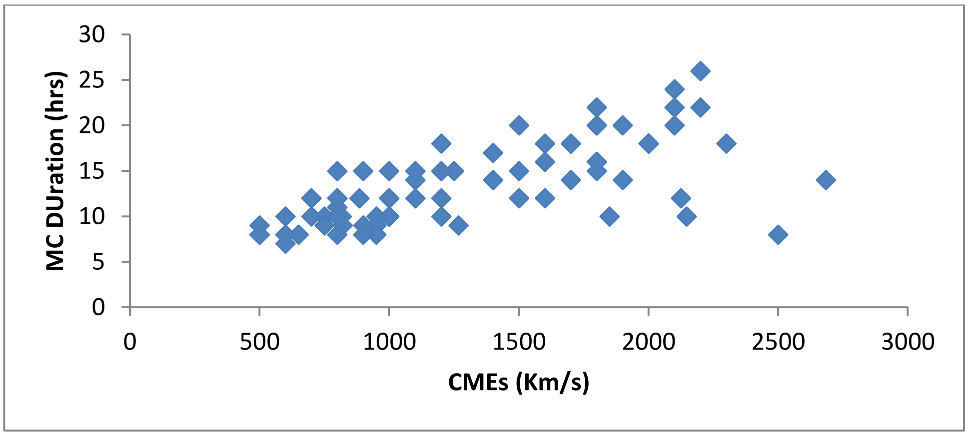
. **Figure 6:** Scatter plot between Dst (nT) and Bt (nT) with correlation coefficient **-0.682**

4.5 Auroral Impact :

According to the auroral impact data, CMEs with higher speeds and larger negative Dst values tended to exhibit moderate auroral activity. Slower CMEs with lesser magnetic fields, on the other hand, produced no influence on Earth or weak auroras.

4.6 CME Speed vs MC Duration:

There is a modest relationship between CME speed and magnetic cloud duration, with longer durations often occurring with faster CMEs.



. **Figure 7:** Scatter plot between CMEs (Km/s) and MC Duration (hrs)

5. Conclusion :

This study looked at the geomagnetic impacts of Coronal Mass Ejection (CME) events that occurred between 2010 and 2024. Faster CMEs and those with strong southward magnetic fields (negative Bz) have been found to cause more intense geomagnetic storms, as indicated by lower Dst and higher Kp index values. This was identified through an analysis of CME characteristics, including speed, type, magnetic field components, and arrival time. Partial Halo and Halo During that period, CMEs which are most certainly Earth-directed were prevalent and frequently associated with auroral displays and observable geomagnetic activity. Results indicate the significance of CME speed and magnetic configuration are for forecasting space weather phenomena. The identified correlations between CME characteristics and geomagnetic indices enhance our understanding of space weather phenomena and support advancements in forecasting geomagnetic storms.

6. Acknowledgements :

The authors are highly indebted to various experimental groups for providing data online through Internet. The CME catalog is generated and maintained at the CDAW Data Center by NASA and The Catholic University of America in cooperation with the Naval Research Laboratory. SOHO is a project of international cooperation between ESA and NASA. The authors thank NOAA, ISGI, CDAW Data Center, OMNIWEB for the databases. They are also grateful to Prof. N. Gopalswamy and other authors for providing valuable information on MCs and GMSs directly or indirectly. The authors acknowledge the contributions from several of his colleagues.

References

1. Gopalswamy N, Akiyama S, Yashiro S, Michalek G and Lepping R P " Solar sources and geospace consequences of interplanetary magnetic clouds observed during solar cycle 23" J. Atmos. Sol. Terr. Phys. (2008) Vol. 70 245.
2. Verma R, Kumar S, and Dubey S K "Coronal Mass Ejection, Magnetic Cloud and their Geoeffectiveness During 1996-2009" International Journal of Science and Research (IJSR) May (2016) Volume 5 Issue 5, 1832.
3. Low B C "Solar activity and the corona" Solar Phys. (1996), 167, 217.
4. Baker D N, Balstad R, Bodeau JM, Cameron E, Fennell JF, Fisher GM, Forbes K F, Kintner P L, Severe Space Weather Events - Understanding Societal and Economic Impacts: A Workshop Report, The National Academies Press, Washington DC (2008).
5. Howard, R. A., Michels, D. J., Sheeley, Jr., N. R., & Koomen, M. J. "The observation of a coronal transient directed at earth",The Astrophysical Journal, (1982) 263:L101-L104.
6. Howard, R. A., Sheeley, N. R., Jr., Michels, D. J., J. M., Koomen, Jr., " Coronal mass ejection :1979-1981", Jouranal of Geophysical Research – Space Physics, (1995), 8173-8191.
7. Gopalswamy N., Akiyama S., Yashiro S, and Mäkelä P., "Coronal Mass Ejections from Sunspot and Non-Sunspot Regions, Magnetic Coupling between the Interior and Atmosphere of the Sun", Astrophysics and Space Science Proceedings, ed S. S. Hasan and R. J Rutten (Berlin Heidelberg: Springer), (2010a) 289.
8. Gopalswamy N., Yashiro S., Michalek G., Xie H., Mäkelä P., Vourlidas A. and Howard R.A., A Catalog of Halo Coronal Mass Ejections from SOHO. SunGeo 5, 7 (2010b).
9. Parker E N, "The Gross Dynamics of a Hydromagnetic Gas Cloud" Astrophys. J. Supp., (1957) Vol. 3, 51.
10. Burlaga L F, Sitter E, Mariani F and Schwenn R "Magnetic loop behind an interplanetary shock: Voyager, Helios, and IMP 8 observations" J. Geophys. Res.,(1981), Vol. 86, 6673.
11. Bothmer V and Schwenn R, "The structure and origin of magnetic clouds in the solar wind" Annales Geophysicae, (1998) Vol. 16,1-24.
12. Kumar S, Verma R and Dubey S K "Geospheric Effects of Magnetic Clouds during 1996-2008" International Journal of Science and Research (IJSR) Volume 5 Issue 1, January (2016) 1434.

13. Gopalswamy, N. et al., “An Overview of Solar Cycle 24: Space Weather Perspective” Journal of Space Weather and Space Climate. (2015).
14. Zhang, J. et al., “Solar and Interplanetary Sources of Major Geomagnetic Storms (Dst ≤ -100 nT) during 1996–2005”, Journal of Geophysical Research, (2007).
15. Schwenn, R. “Space Weather: The Solar Perspective”. Living Reviews in Solar Physics,(2006).