International Symposium on Solar Terrestrial Physics
ASI Conference Series, 2013, Vol. 10, pp 67 – 71
Edited by N. Gopalswamy, S. S. Hasan, P. B. Rao and Prasad Subramanian

Solar eruptive filament studies at USO for the COMESEP project

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Abstract. The Coronal Mass Ejections and Solar Energetic Particles (COMESEP) project is developing tools for forecasting geomagnetic storms and solar energetic particle (SEP) radiation storms. By analysis of historical solar and interplanetary data, complemented with the extensive data coverage of solar cycle 23, the key ingredients that lead to geomagnetic storms, SEP events and the factors that are responsible for false alarms are being identified. Based on the insights gained, and making use of algorithms for the automated detection of CMEs, forecasting tools for geomagnetic and SEP radiation storms will be developed and optimised. Validation and implementation of the developed tools into an operational Space Weather Alert system will be performed. COMESEP is a unique cross collaboration effort and bridges the gap between the SEP, CME and terrestrial effects scientific communities. The role of the Udaipur Solar Observatory (USO) in addressing some of the goals of this project are highlighted in this paper. In particular, USO is engaged in studying the CMEs associated with eruptive filaments. We describe the studies undertaken to understand space weather effects related to these CMEs.

Keywords : CME – filaments – ICMEs – geomagnetic activity

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1. Introduction

Eruptive filaments are known to be associated with Coronal Mass Ejections (CMEs). Some of these CMEs can be the drivers of major geomagnetic storms at the Earth. Most of the earlier studies have focused on the geomagnetic effects of CMEs associated with major flares with little attention on those associated with eruptive filaments. Udaipur Solar Observatory is involved in addressing some of the important questions related to identification of filaments in Interplanetary CMEs (ICMEs) and their role in geomagnetic activity as part of the COronal Mass Ejections and Solar Energetic Particles (COMESEP) project (http://comesep.aeronomy.be/). COMESEP is a 3 year collaborative project funded by the European Commission FP7 project 263252 which commenced on 1 February 2011. The primary objective of COMESEP is to improve our understanding on forecasting geomagnetic storms and solar energetic particle (SEP) radiation storms. This is done in a two fold way. By analyzing the historical data, complemented with the extensive data coverage of solar cycle 23, the key parameters leading to magnetic storms and SEP events are being identified. To improve the forecasting of the arrival time, 3D kinematics and interplanetary (IP) propagation of CMEs are also being examined. In parallel, the sources and propagation of SEPs are being examined and modeled. Apart from the above goals, algorithms for the automated detection of CMEs, forecasting tools for geomagnetic and SEP radiation storms are being developed. It is also envisaged to validate these models leading into an operational Space Weather Alert system. In order to achieve the overall science objectives, cross collaboration between various SEP, CME and terrestrial effects scientific communities is highly desirable. The participation of USO as an external collaborator finds significant importance, as some of the research problems that are being pursued at USO, viz., CME propagation and consequences, filament eruptions, are in line with the ones outlined in the COMESEP project. Besides the common scientific objectives, active collaborations and participation in analysis of historical data and development of forecasting tools will be instrumental towards establishing a forecasting center for space weather in India.

2. Accomplished studies at USO

The building components; of the COMESEP project have been, divided into 3 main subjects: (i) basic science; (ii) model optimisation; and (iii) alert tools. Basic science is sub-divided into three work-packages covering CMEs, SEPs and Space Weather Impact. The main objectives of the CME work-package are to (i) Study the 3D kinematics and IP propagation of ICMEs (ii) Test and compare analytical and numerical ICME propagation models (iii) Study the evolution of the ICME magnetic structure. In the SEP work-package the main objectives are: (i) enhance our understanding of the source of SEP events and acceleration processes, as well as SEP propagation; (ii) advance SEP modelling to include CME propagation effects, cross field diffusion and heavy ions. Key parameters of solar events that define the space weather impact are identified and the impact for prediction purpose quantified in the space weather impact work-package. USO has actively participated towards realisation of CME and space weather impact work-packages; in particular, two important studies completed in the first year of the project are:

1. *Identification of filament plasma in ICMEs*: Although most of the CMEs are known to be associated with eruptive prominences, the associated ICMEs do not always contain prominence material that can be identified easily. After the launch of SOHO and ACE, compositional signatures have been used to identify filament plasma in ICMEs (Burlaga et al. 1998; Gopalswamy et al. 1998; Lepri & Zurbuchen 2010; Lee & Raymond 2012). In a study undertaken at USO, we detected filament plasma in two ICMEs using magnetic, plasma and compositional signatures. One of these events was associated with an active region eruptive filament and an M3.9/2N flare on November 18. 2003. while the other with a quiescent filament eruption on 01 August 2010. The investigation of plasma properties for filaments in ICMEs showed low temperature, high proton and electron densities coinciding with pressure balanced regions in magnetic clouds. Further, compositional signatures such as depressed ion charge states, high ion and helium densities and presence of He+ ions were also detected in this region. The two ICMEs showed a mixture of cold and hot plasma with presence of He+ ions. The rarity of finding cold, low charge state ions at 1AU as an indicator of filament plasma, suggests partial ionization of elements during transit through corona. It also shows that filament plasma is regularly observed in ICMEs but no longer distinguishable as ionizationally cold (Skoug et al. 1999: Sharma and Srivastava, 2012).

2. *IP and geomagnetic consequences of January 05, 2005 CMEs associated with solar eruptive filaments:* We carried out a cradle-to-grave study of two solar filament eruption events of 05 January 2005 based on multi-instrument, multi-technique remote-sensing observations and in-situ measurements of ICMEs. These eruptions occurred at 04:21 UT and 13:06 UT and resulted in two distinct magnetic clouds. These magnetic clouds embedded with filament plasma merged together in IP medium and formed complex magnetic structure at their interface region. These features impacted the Earth's magnetosphere - ionosphere system and resulted in a moderate geomagnetic storm (Dst ~ -96 nT). During the main phase of this storm on 07 January, polarity reversals in the Y-component (dawn-to-dusk) of IP electric field seem to trigger two major auroral substorms with concomitant changes in the polar ionospheric electric field. However, similar polarity reversal on 08 January during the recovery phase of the storm did not trigger any substorm activity highlighting complex relationship between storms and substorms. The study provides the most comprehensive view of the CMEs of 05 January 2005 (Sharma et al. 2013).

3. Ongoing studies in the project

1. *Estimating the arrival time of CMEs using STEREO/SECCHI observations:* Prediction of the arrival time and transit speed of CMEs near the Earth is one of the key problems in understanding the solar terrestrial relationship. We have used the

3D triangulation on the J-maps constructed from images obtained from Heliospheric Imagers HI1 and HI2 for 8 CMEs observed during 2008-2010. Based on the reconstruction, and applying the Drag Based Model (Vršnak et al. 2010) for the distance where the CMEs cannot be tracked unambiguously in the IP medium, the arrival time of these CMEs have been estimated. These have also been compared with the actual arrival time. The analysis reveals the importance of heliospheric imaging in forecasting the arrival time and direction of propagation of CMEs in the IP medium (Mishra and Srivastava 2013). In another study, we evaluate the performance of different techniques used with HI observations to obtain kinematics of a CME in the heliosphere. We also plan to quantify the errors and understand the limitations involved in each technique in order to improve the prediction of the arrival time of CMEs (Mishra & Srivastava, 2013b, in preparation).

2. *Onset time estimation of eruptive filaments and associated CMEs:* One of the major constraints in investigating the driving force of these CMEs is the difficulty of estimating their correct onset time. Particularly, in the case of eruptive filaments, monitoring their activation is crucial for forewarning of its disappearance in H_α and/or in EUV for defining the onset time of the associated CME lift off. We are studying a filament that underwent recurrent partial eruptions before its complete eruption on August 8, 2012. We implement an automated detection algorithm for estimating different attributes of this filament in order to study its evolution during these eruptions. Our results show the importance of such studies in understanding the mechanism of CME initiation and possible role of eruptive filaments for the same (Srivastava, Joshi and Mathew 2013).

4. Summary

Several studies have been undertaken under the COMESEP project at USO, in particular, for the problems outlined in the CME work-package as well as those concerning space weather impact. The scientific results thus obtained will be useful for optimising detection and forecasting tools to be developed for space weather alerts and forecasting systems.

Acknowledgements

The authors acknowledge all members of the COMESEP Project Consortium. COMESEP project has received funding from the European Commission FP7 Project (263252).

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