Earth-Affecting CMEs and Associated Geomagnetic Storms

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Initially Earth-directed coronal mass ejections (CMEs), which usually look like a halo from the Earth, are believed to be the most probable candidates of Earth-affecting CMEs. However, not all of initially Earth-directed CMEs can encounter the Earth, and moreover, not all of Earth-encountered CMEs can cause a geomagnetic storm. In this talk, starting from a sample of full halo CMEs during 1997 March –2012 May, we show that (1) even for full halo CMEs, they were not necessary to propagate along the Sun-Earth line; the deviation angle could be larger than 45 degrees, (2) the apparent speed observed in a coronagraph may differ largely from the true value for the CMEs propagating within 45 degrees of the Sun-Earth line and slower than 900 km/s, (3) the deflection and interaction of CMEs in interplanetary space may further influence the possibility of a CME encountering the Earth as well as their Earth-arrival time. Further, by investigating the ICMEs and Dst index from 1995 to 2015, we show the statistical properties of these Earth-encountered CMEs and their capability in causing geomagnetic storms. Although isolated CMEs are the major source of geomagnetic storms, shock-CME interacting structures demonstrate an increasing role in causing stronger geomagnetic storms.

Keywords: coronal mass ejections, geomagnetic storms, space weather

Deflection and distortion of CME internal magnetic flux rope due to the interaction with a structured solar wind

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The dynamics of CME propagation is strongly affected by the interaction with background solar wind. Wang et al. (2004) suggested that a fast CME that encounters a preceding slow wind stream subjects to eastward deflection due to parker spiral structure of the sola wind. This interaction strongly affects the arrival of a CME to the Earth, espeially the arrival of its internal magnetic flux rope.
To understand the interaction between a CME and background solar wind, we performed three-dimensional MHD simulations of the propagation of a CME with internal twisted magnetic flux rope into a structured bimodal solar wind. We compared three different cases in which an identical CME is launched into an identical bimodal solar wind but the launch dates of the CME are different. Each position relative to the boundary between slow and fast solar winds becomes almost in the slow wind stream region, almost in the fast wind stream region, or in vicinity of the boundary of the fast and slow solar wind streams, which grows to CIR. It is found that the CME is most strongly distorted and deflected eastward in the case near the CIR, in contrast to the other two cases. The maximum strength of southward magnetic field at the Earth position is also highest in the case near CIR. The results are interpreted that the dynamic pressure gradient due to the back reaction from pushing the ahead slow wind stream and due to the collision behind fast wind stream hinders the expansion of the CME internal flux rope into the direction of the solar wind velocity gradient. As a result, the expansion into the direction to the velocity gradient is slightly enhanced and results in the enhanced deflection and distortion of the CME and its internal flux rope. These results support the pileup accident hypothesis proposed by Kataoka et al. (2015) to form unexpectedly geoeffective solar wind structure.

Keywords: space weather, solar wind, coronal mass ejection, Corotation interaction region, MHD simulation

Earth-Affecting Coronal Mass Ejections Without Obvious Low Coronal Signatures

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We present a study of the origins of coronal mass ejections (CMEs) that were not accompanied by obvious low coronal signatures (LCSs) and yet were responsible for appreciable disturbances at 1 AU. These CMEs characteristically start slowly. In several examples, EUV images taken by the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO) reveal coronal dimming and large-scale brightening when we make difference images with long enough temporal separations, which are commensurate with the slow initial development of the CME. Data from the EUV Imager and COR coronagraphs of the Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) on the Solar Terrestrial Relations Observatory (STEREO), which provide the limb views of Earth-bound CMEs, greatly help us limit the time interval in which the CME forms and undergoes initial acceleration. For other CMEs, we find similar but weaker LCSs, and only with lower confidence. It is noted that even these less clear events may result in unambiguous flux rope signatures in in situ data at 1 AU. There is a tendency that the CME source regions are located near coronal holes or open field regions. This may have implications for both the initiation of the stealthy CME in the corona and its outcome in the heliosphere.

Keywords: Coronal Mass Ejections, Solar Corona, Extreme Ultraviolet Radiation, Solar Dynamics Observatory, Solar Terrestrial Relations Observatory, Geomagnetic Storms

All CMEs Originating Near the Disk Center of the Sun Do Not Arrive at Earth: Why?

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Coronal Mass Ejections (CMEs) originating from close to the disk center of the Sun are expected to arrive at Earth and cause space weather effects. However, not all such CMEs arrive at Earth (Gopalswamy et al. 2012, JGR 117, A08106). In this paper, we consider all wide CMEs (width 60 degrees) in the period 2009 October to 2012 July. During this period, STEREO A/B spacecraft had side views of these CMEs at angles from +/- 60 to +/- 120 degrees, so the CME kinematics can be measured accurately. The solar sources of the CMEs had Central Meridian Distance 30 degrees. We tracked 232 such CMEs using SOHO and STEREO coronagraph data to see whether or not they impacted Earth. We also used in situ data from SOHO/Wind/ACE to check Earth arrival. We found that 1) 34% (79/232) of CMEs faded out before reaching Earth, 2) 29% (67/232) of CMEs arrived at Earth, 3) 25% (57/232) were captured by following faster CMEs, and 4) 13% (29/232) of CMEs left the ecliptic plane. The Earth-arriving CMEs (603 km/s) were faster (in the COR1 to COR2 FOV) than the fading-out CMEs (307 km/s). The Earth-arriving CMEs show a wider range (64-2046 km/s) speeds than the fading out events (98-790 km/s). Among the Earth-arriving CMEs, 45% (30/67) had magnetic cloud signatures based on ACE data. ICME ejecta and complex signatures were found in 37% (25/67) and 9% (6/67), respectively. Six Earth-arriving CMEs did not show any in situ signature. We also investigated the geoeffectiveness of the Earth-arriving CMEs and found that only 3% (2/67) and 27% (18/67) had Dst index -100 nT and -50 nT, respectively.

Keywords: Coronal Mass Ejections, Space Weather

Sheath-Accumulating Propagation of Interplanetary Coronal Mass Ejection

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Fast interplanetary coronal mass ejections (interplanetary CMEs, or ICMEs) are the drivers of strongest space weather storms such as solar energetic particle events and geomagnetic storms. The connection between space weather impacting solar wind disturbances associated with fast ICMEs at Earth and the characteristics of energetic CMEs observed near the Sun is a key question in the study of space weather storms as well as in the development of practical space weather prediction. Such shock-driving fast ICMEs usually expand at supersonic speed during the propagation, resulting in the continuous accumulation of shocked sheath plasma ahead. In this paper, we propose the "sheath-accumulating propagation" (SAP) model that describe the coevolution of the interplanetary sheath and decelerating ICME ejecta by taking into account the process of upstream solar wind plasma accumulation within the sheath region. On the basis of the SAP model, we discussed (1) ICME deceleration characteristics, (2) the fundamental condition for fast ICME at Earth, (3) thickness of interplanetary sheath, (4) arrival time prediction and (5) the super-intense geomagnetic storms associated with huge solar flares. We quantitatively show that not only speed but also mass of the CME are crucial in discussing the above five points. The similarities and differences between the SAP model and the drag-based model are also discussed.

Keywords: coronal mass ejections, solar wind, space weather

Towards the Prediction of Solar Flare by Analysing Magnetic Twist Based on the Nonlinear Force Free Field

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As the largest eruption in the solar system, solar flare can release enormous amount of energy to the interplanetary space, including the Earth. It is essentially important to study the solar flare mechanism in order to be able to anticipate severe impacts of flare to the near-Earth space environment. Since the flare releases magnetic energy during its process, the distribution of the accumulated magnetic energy before the onset of flare must be informative for predicting flares. Active region that contains large amount of excess magnetic energy shows non-potential configuration of magnetic fields in the region around the polarity inversion line (PIL). This non-potential magnetic field manifests as a highly-twisted magnetic field line. It is well-known that the highly-twisted field is subject to kink instability. However, it is still not clear how to extract the information of magnetic twist from the observation for the flare prediction. Here, we propose a non-dimensional parameter that contains information of twist distribution and magnetic flux of an active region to predict the occurrence of a solar flare. We use SDO/HMI (SHARP) data to evaluate the evolution of this parameter for the active region (AR) NOAA 11158. Non-linear Force-Free Field (NLFF) modelling is used to reconstruct the coronal structure from the vector magnetogram data. We then calculated a new parameter which is the averaged twist of magnetic field lines normalised by the total magnetic flux within AR from the NLFF model. We found that our proposed parameter increased before large flares and dramatically decreased after the onset of the flares. Our study shows that this parameter can be used as a proxy of the stability of an active region. It suggests that the combination of this new parameter and the magnetic free energy is usable to estimate the probability of large flares, and we will devise a new scheme of solar flare prediction using them.

Keywords: Solar Flare, Magnetic Twist, NLFFF, Prediction

Jet-Producing Minifilament Eruptions as Keys to Understanding CME-Producing Large-Scale-Filament Eruptions

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Coronal Jets are a common phenomenon on the Sun, occurring at a rate of several tens per day in polar coronal holes, with many more covering the entirety of the Sun. They are observed at EUV and X-ray wavelengths, and can reach heights of ˜50,000 km with widths ˜10,000 km, with transient lifetimes of only about 10 min. Recent investigations suggest that coronal jets result when small-scale (<˜10,000—20,000 km) miniature filaments, which we call ``minifilaments,’’ erupt from near the solar surface and into the corona (Sterling et al. 2015, Nature, 523, 437). Several studies (e.g., Panesar et al. 2016, ApJ, 832L, 7) demonstrate that minifilament eruptions share many characteristics with larger-scale filament eruptions: Prior to eruption, both minifilaments and filaments reside at locations where the photospheric magnetic field reverses direction (magnetic neutral lines); minifilament eruptions produce expulsions of cool chromospheric and warmer transition-region material in the form of a coronal jet, while the larger-scale-filament eruptions expel material that can form part of a Coronal Mass Ejection (CME); and a jet-producing minifilament eruption occurs along with an EUV/X-ray brightening near the solar surface that we call a jet-base bright point (JBP), and this corresponds to the situation where a CME-producing large-scale filament eruption accompanies a typical solar flare occurring on the neutral line beneath the erupting filament. Therefore the jet-producing erupting minifilaments appear to be small-scale analogues to typical CME-producing erupting filaments. The smaller size scale and apparent shorter lifetimes of minifilaments offers an opportunity to study with high-resolution instruments, e.g. with DKIST and with coronal imagers with the resolution of Hi-C that might fly on the next generation solar space mission, the buildup to and the onset of minifilament eruptions. These anticipated observations of minifilament eruptions may well reveal how the eruption is initiated in filament eruptions of all size scales, including large ones that produce geophysically-important CMEs.

Keywords: Sun, Solar Filament Eruptions and Flares, Coronal Mass Ejection (CME) Onset

Magnetic Source Region Characteristics Influencing the Coronal Velocity of Solar Eruptions

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The velocity of coronal mass ejections (CMEs) is one of the primary parameters determining their potential geoeffectiveness. A great majority of very fast CMEs receive their main acceleration already in the corona. We study the magnetic source region structure for a complete sample of 15 very fast CMEs (v > 1500 km/s) during 2000--2006, originating within 30 deg from central meridian. We find a correlation between CME speed and the decay index profile of the coronal field estimated by a PFSS extrapolation. The correlation is considerably weaker for a comparison sample in which slower CMEs are included. We also study how the decay index profile is related to the structure of the photospheric field distribution. This is complemented by a parametric simulation study of flux-rope eruptions using the analytic Titov-Demoulin active-region model for simple bipolar and quadrupolar source regions. The simulations provide simple relationships between the photospheric field distribution and the coronal decay index profile. Very fast, moderate-velocity, and even confined eruptions are found and the conditions for their occurrence quantified.
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A statistical study of the association of coronal mass ejections with filament disappearances using H-alpha full disk images observed with the Solar Magnetic Activity Research Telescope (SMART)

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Forecasting space weather comes to be important because humans' space exploration is rapidly increasing recently. Coronal mass ejections (CMEs) strongly affect the space weather. In order to forecast CMEs, studies of filament disappearances are important. An erupted filament is sometimes observed as a core of a CME. Filament disappearances are closely connected with CMEs. Accordingly, filament disappearances were studied using the H-alpha full disk images of the Solar Magnetic Activity Research Telescope (SMART), Hida Observatory. 1276 filament disappearance events were found in about 10 years (from 1-April-2005 to 9-October-2014). The number of filament disappearance events were correlated with the relative sunspot number. SMART observes not only the H-alpha center images but also the H-alpha wing images (+/-0.5A, +/-0.8A, +/-1.2A, +3.5A). 274 out of 1276 events were observed with SMART during their disappearances. We classified the 274 filament disappearance events into eruption type and non-eruption type, using -0.5A images. If disappearing filaments can be observed in -0.5A images, the events were regarded as eruption type filament disappearance. On the contrary, if there were no signals in -0.5A images during filaent disappearances, we think of the events as non-eruption type filament disappearances. We found large (more than 200,000 km) and eruption type filaments are easy to be associated with CMEs. In addition, we investigated the precursors of filament disappearances.

Keywords: Space weather, the Solar Magnetic Activity Research Telescope (SMART), Filament disappearance

Using Interplanatery Scintillation Data to Improve Ensemble Modeling of Coronal Mass Ejections

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The impact of the coronal mass ejections (CMEs) on the Earth’s magnetosphere-ionosphere system can cause widespread anomalies for satellites from geosynchronous to low-Earth orbit and produce effects such as geomagnetically induced currents. At the NASA/GSFC Community Coordinated Modeling Center we have been using ensemble modeling of CMEs since 2012. In this work we use interplanetary scintillation (IPS) observations from the Ooty Radio Telescope facility in India to track CMEs and compare to an ensemble of CME forecasts. This allowes downselection of the ensemble members and helps to improve forecasting of CME arrival times. The inclusion of observations of the solar wind density and velocity using IPS from hundreds of distant sources in ensemble modeling of CMEs can be a game-changing improvement of the current state of the art in CME forecasting. Moreover, the same method can be applied to ensemble simulations of the magnetosphere that suffer from the same scarcity of input data with similar degree of uncertainty.

Keywords: Coronal Mass Ejections, Ensemble Modeling, Interplanetary Scintillation Observations

CME Propagation and How It Affects Their Geo-effectiveness

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The Sun-to-Earth propagation of coronal mass ejections (CMEs) take between 1 and 4 days. In the past decade, we have gained deeper understanding in the physical processes occurring during the propagation thanks to remote observations by STEREO, in-situ measurements by planetary missions at Mercury and Venus and missions at 1 AU (Wind, ACE and STEREO) and large MHD simulations. These have revealed that processes such as expansion, erosion, deflection, rotation and interaction, that routinely occur, affect the properties of CMEs and their potential impact on Earth's magnetopshere. Here, we present two particular cases, one when the ongoing interaction of two CMEs at Earth enhanced the geomagnetic response of Earth's magnetosphere, and one where the CME expansion resulted in an unusual coupling between the solar wind and the magnetosphere.

Keywords: CMEs, Geomagnetic storms