Dynamics and Topology of Coronal Mass Ejections

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Progress Report, Grant NNH05AB601, 1 Aug 2006 – 31 Jul 2007

Description: We are conducting state-of-the-art, three-dimensional, time-dependent, nonlinear numerical simulations of physics models for solar coronal mass ejections (CMEs) on massively parallel computers. The origin of these very energetic events is poorly understood, but the consequences for the earth's space and upper-atmosphere environment and for technological systems based there (satellites) or utilizing its properties (earth-bound communications and navigation systems) are well known and potentially highly detrimental. The events also pose particle and radiation hazards to astronauts and to occupants of high-altitude aircraft. Many CMEs originate in solar active regions, which are relatively compact structures with high magnetic field strengths. We intend to demonstrate that our successful breakout model for CMEs – which can explain the sudden triggering of energetic eruptions in vulnerable magnetic topologies on a global scale – can be extended to account for eruptions in compact active-region topologies, as well. Among the consequences that we will investigate in our research is the resultant magnetic structure and connectivity to the Sun and heliosphere of the simulated interplanetary CMEs (ICMEs). Our simulations and models are guided by observations and have been developed to predict signatures that can be sought in data from NASA space missions. As part of a team investigating the link between CMEs and ICMEs, we also are collaborating with other modelers and observers to advance our collective understanding of these phenomena.

Progress: FY07 is the second year of our three-year project. As described in our proposal and summarized above, our main objective is to demonstrate that breakout CMEs can occur in more compact, active-region-like, fully three-dimensional magnetic geometries than the quasi-two-dimensional cases we have considered heretofore. Our second objective is to analyze the results of these new CME simulations, to identify signatures of the eruption that can be sought in observational data in order to validate the model further. We have made major advances toward these objectives on two distinct configurations: a simple, idealized configuration susceptible to breakout initiation of a CME; and an approximate representation of the 12 May 1997 eruptive flare and CME event studied in detail by the SHINE (Solar-Heliospheric-INterplanetary Environment) community and selected for further investigation by our TR&T team. Results for our simple breakout configuration will be presented at the 2007 AAS/SPD meeting and prepared for publication in the Astrophysical Journal (DeVore & Antiochos, 2007), and are summarized in the figures below. This simulation is groundbreaking in that it exhibits *homology*, *confinement*, and *reformation* of solar eruptions in a single configuration. Our initially potential magnetic field is subjected to shearing motions that preserve the surface distribution of the Sun's radial magnetic flux as they continuously energize the field. The result is a sequence of distinct, similar (*homologous*) eruptions from the source region, with the characteristic breakout configuration reestablished after each event in preparation for the next. Although the outward motion of the sheared field lines in each eruption is quite vigorous, reaching 300 km s^{-1}, they do not escape the Sun as in an ejective event but are *confined*, coming to rest high in the corona and forming a large transequatorial loop. A byproduct of the eruption process is the creation of

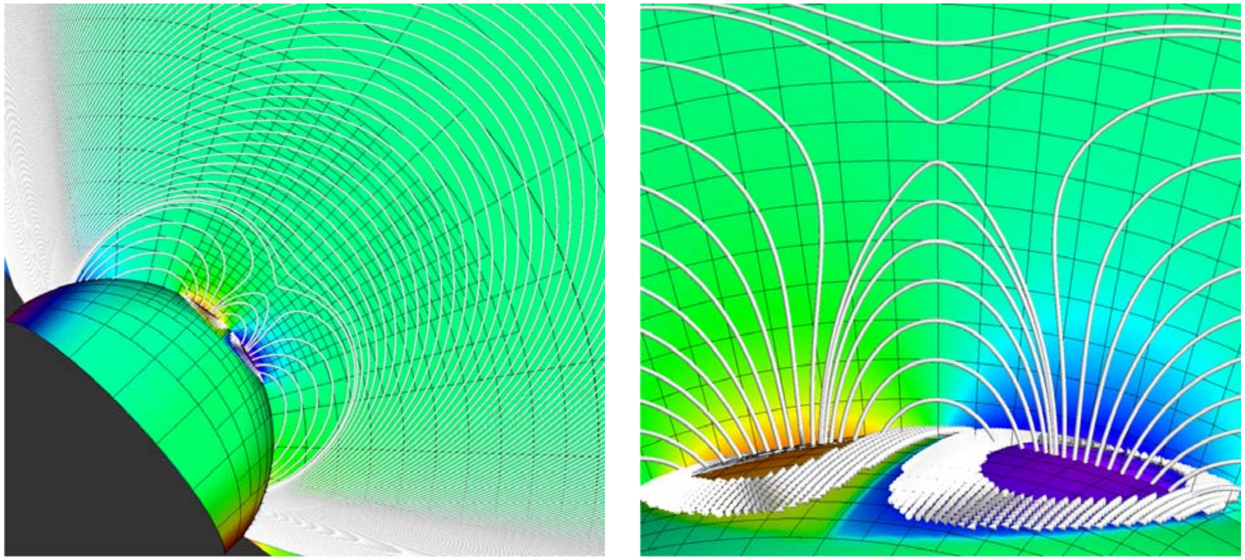

Figure 1. Global (*left*) and closeup (*right*) views of the *ARMS* adapted grid (*black*), surface flow vectors (*white*), radial magnetic field magnitude and sign (*red* to *blue* surface shading of negative to positive values), and selected magnetic field lines (*white*) showing the initial breakout configuration.

moderately sheared, low-lying field lines threading the core of the active region, marking the prompt *reformation* of structures that can support cool prominence or hot X-ray sigmoid material. All three of these features – homology, confinement, and reformation – are commonly observed in solar events. So far as we are aware, our simulation is the first to demonstrate either homology or reformation.

The initial state of our idealized breakout configuration is shown in Figure 1; images obtained during the second of three simulated eruptions comprise Figure 2 (*top*), along with images of the reformed configuration after each of our three eruptions (*bottom*).

Our collaborative work with the TR&T team on the 12 May 1997 event is designed to address critically important issues associated with the required magnetic topology and the effectiveness of alternative means of initiation in launching CMEs. We have completed and are now analyzing one of two planned simulations on this topic, in which the participating active region is rotated relative to its observed orientation so that it possesses a magnetic null in the corona (like our idealized example just discussed) and so is susceptible to breakout initiation. We have confirmed that this topology indeed gives rise to an eruption when breakout reconnection temporarily removes the active region's restraining field lines. The more complex geometry of this field produces a strongly nonradial eruption through a null point displaced off to the side of, rather than directly above, the active region. Our second simulation for this study is

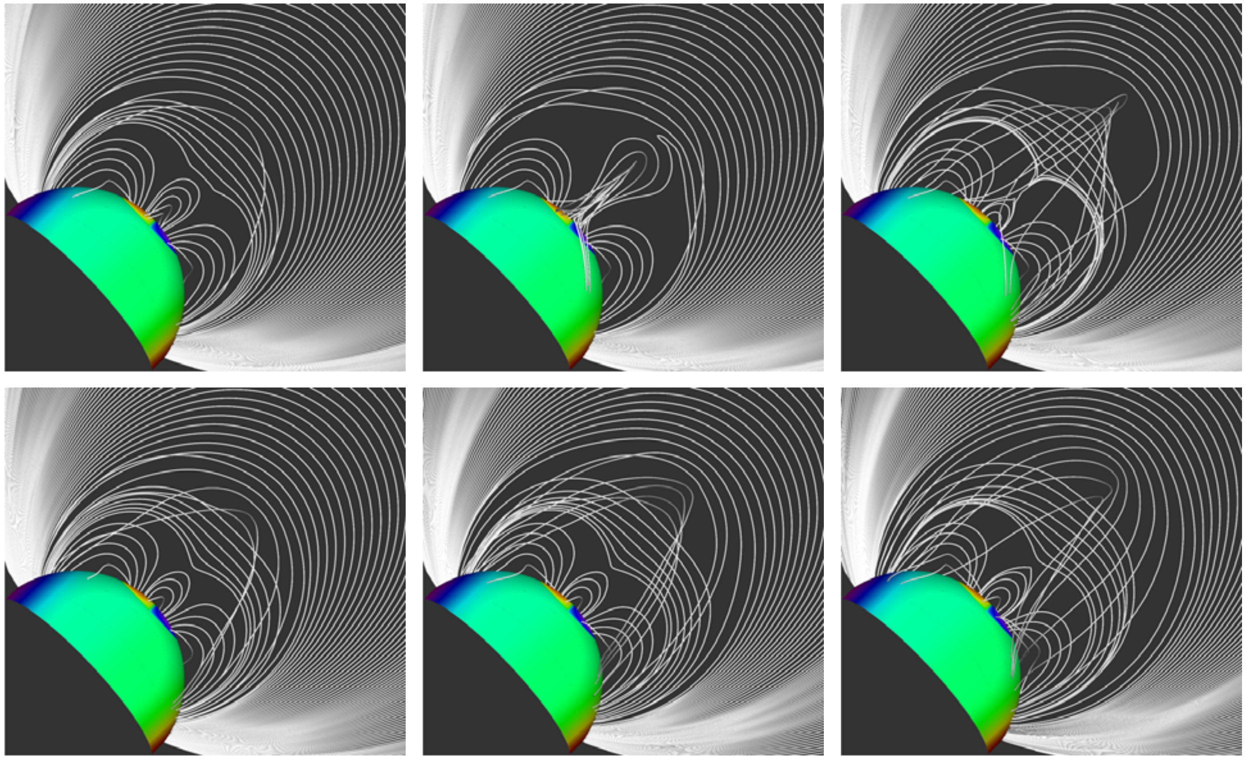

Figure 2. Top: Global views of magnetic fields during the second of three eruptions, showing the flattening of the breakout current sheet (*left*), the radial expansion of the sheared core flux of the active region and the formation of new transequatorial loop field lines (*middle*), and the ejection of the latter field lines into the high corona and the reformation of the equatorial arcade and null point in the low corona following the flare reconnection (*right*). Bottom: Global views of the post-eruption magnetic fields following homologous eruptions #1 (*left*), #2 (*middle*), and #3 (*right*), showing the accumulating and rising transequatorial loop in the high corona and the restored breakout configuration in the low corona. The three top panels occur between the bottom left and middle panels.

now underway, with the active region oriented as observed in 1997. In this case, there is no coronal magnetic null, although the direction of the magnetic field changes very rapidly across quasiseparatrix surfaces in the active region. It remains to be seen whether magnetic breakout can occur in this topology and launch an eruption, as it does in the modified orientation already simulated.

References and publications:

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