Initiating Coronal Mass Ejection Based on Vector Magnetograms in the Alfvén Wave Solar Atmosphere Model

Looking for a Postdoc position!

Yifu An[1] (anyifu@umich.edu), **Gábor Tóth**[1] and Beatrice Popescu Braileanu[2]
[1]University of Michigan; [2] Universitetet i Bergen

EGU26-7878

Sharing is encouraged

Introduction

At a Glance

We have developed and implemented a new method to initiate a coronal mass ejection (CME) in the Alfvén Wave Solar atmosphere Model (AWSoM) using an HMI vector magnetogram observed prior to the CME eruption.

Motivation

The Space Weather Framework (SWMF) supports a few CME initiation methods, such as the Gibson-Low flux rope and the Titov-Démoulin flux rope. Neither utilizes the observed transverse magnetic field in the active region. Furthermore, previous study of CMEs using data-driven methods mostly focused on their local behavior. These reasons motivate us to implement a data-driven CME initiation method in the SWMF – a new bridge between vector magnetogram data and global CME simulations.

Objective and Tasks

The objective of this project is to experiment whether we can initiate CMEs from vector magnetograms. We reconstruct the pre-eruption magnetic field from observations using the magnetofriction method (Guo et al. 2016), and the corona using the AWSoM model. By running a simulation from the chromospheric surface to 1 AU, we compare the simulated results with observations. We mainly experiment with the *St. Patrick's Day Storm* (CME originating from AR12297 on 2015 March 15).

Challenges

- In typical active regions, the separation between opposite polarities is small compared to the typical grid resolution of AWSoM ($0.35°$). How to adequately resolve the field strength with the grid limitation?
- The stationary steady state implied by the magnetofriction method accumulates $\mathrm{div}\, B$. Is the solution physical?
- It is doubtful whether a pre-eruption solar corona in equilibrium can be found. How to trigger a CME?

The authors acknowledge support by the National Science Foundation grant PHY-2027555 and support from the NASA Space Weather Center of Excellence (CLEAR). Computational resources were provided by NSF on the Frontera supercomputer. Related paper is work in progress and can be expected soon.

Methodology

Data Preprocessing

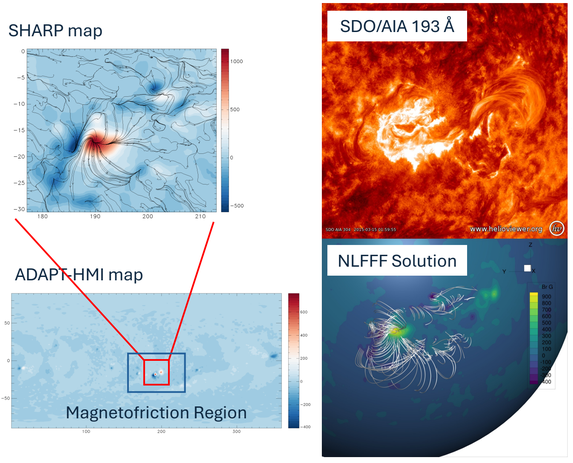
- Radial field B_r: merge ADAPT-HMI map with SHARP map before eruption
- Longitudinal and Latitudinal field B_{lon}, B_{lat}: merge HMI synoptic vector magnetogram with SHARP map
- Smooth B_r, B_{lon} and B_{lat} using a moving window averaging approach
- B_r produces a potential background field $\boldsymbol{B_0}$ by fitting spherical harmonics
- **Enlarge the active region but reduce $\boldsymbol{B}$ by a factor to better resolve field structures (at $0.35°$)**

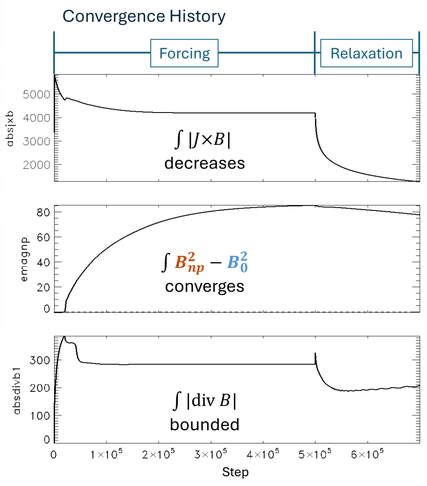
Magnetic Field Relaxation

- Evolve the magnetofriction equations with hyperbolic div B cleaning in a box enclosing the AR

$$\hat{v} = \Delta x\, \frac{J\times B}{|B|^2}, \quad v = \frac{c}{\max(|\hat{v}|)}\frac{\Delta x}{\Delta t}\hat{v} f_w(\vec{x}), \quad \frac{\partial B}{\partial t} = \nabla\times(v\times B)$$

- Steady state Forcing Stage: Enforce B_r, B_{lon} and B_{lat} at the bottom boundary
- Time accurate Relaxation Stage: Enforce B_r only, field lines bend/twist without moving foot points
- Obtain a local non-potential field $\boldsymbol{B_{np}}$ that nearly satisfies the force-free condition





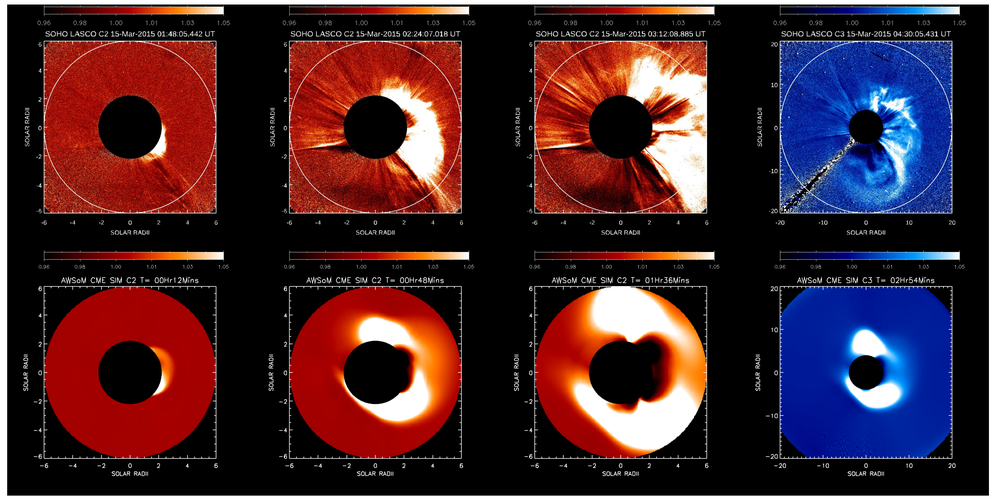
Steady State in AWSoM

- Only the magnetic field has been computed so far; solve for density, pressure, etc. in the corona
- Using $\boldsymbol{B_0}$ and $\boldsymbol{B_{np}}$ (locally in the active region) as the background, solve for the pre-eruption corona
- **Neglect $J := \nabla\times\boldsymbol{B_{np}}$ in the pre-eruption corona: move plasma in place without triggering an eruption**

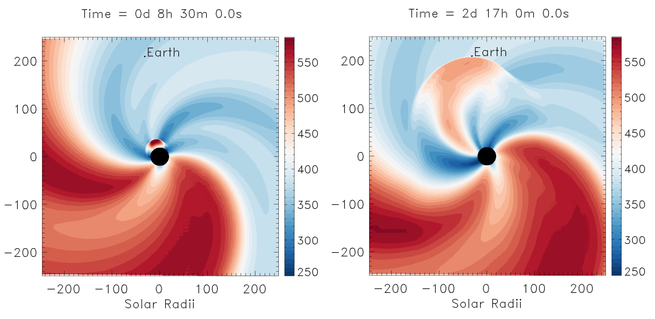
Time Accurate CME Simulation

- Use $\boldsymbol{B_0}$ as the background everywhere. Free energy in $\boldsymbol{B_{np}}$ is released. CME starts spontaneously.
- Solar Corona (SC) component coupled with Inner Heliosphere (IH) component extends domain to 1 AU
- Adaptive mesh refinement (AMR) in the CME path and Earth cone for better accuracy

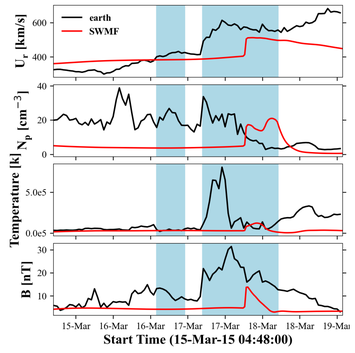
Results



Observed (top) vs. synthetic (bottom) C2/C3 white light images at various instants after eruption.



Left: Solar wind speed in IH showing CME propagation at 2 instants.



Right: CME impact at 1AU. Simulation vs. OMNI observations.

Conclusions

We successfully initiate a CME in AWSoM using a vector magnetogram observed prior to the eruption.

- Enlarge the active region but reduce the field strength to resolve the field structure
- Use a magnetofriction method to obtain the NLFFF: Guo et al. (2016) + div B cleaning + relaxation step
- Pre-eruption corona solved in AWSoM using the NLFFF, which then supplies energy to the eruption
- Synthetic images: qualitative agreements; 1 AU comparison: CME shock appears to be weaker & slower