Coupled Model Simulation of CME Effects on the Geospace Environment

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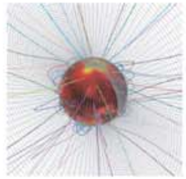
This paper describes the 3D simulation of a space weather event using the coupled model approach adopted by the Center for Integrated Space Weather Modeling (CISM). The simulation employs coronal, solar wind, and magnetosphere MHD models, and a thermosphere/ionosphere fluid dynamic model, with interfaces that exchange parameters specifying each component of the connected solar terrestrial system. A coronal mass ejection is launched from the Sun by a process emulating photospheric field evolution, and an ejected magnetic flux rope propagates into the solar wind, producing an interplanetary shock and magnetic cloud. These reach 1 AU where the solar wind and interplanetary magnetic field parameters are used to drive the magnetosphere-ionosphere-thermosphere coupled model. The simulated magnetosphere responds with a magnetic storm, producing auroral ionization and enhanced convection in the ionosphere. These results demonstrate the potential for future studies using a modular, systemic numerical modeling approach to space weather research.

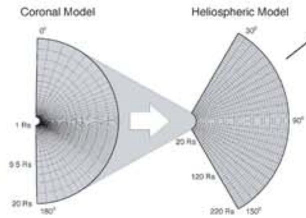
Solar Corona Model
Magnetohydrodynamics Around a Sphere (MAS)
Linker et al., 1999; Mikic et al., 1999; Riley et al., 2002

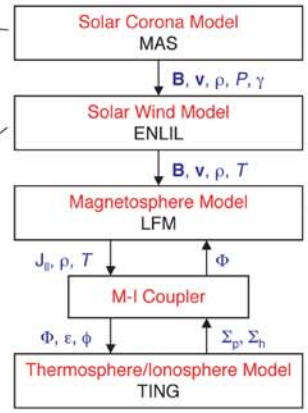
3D MHD model extends from the photosphere to 30 solar radii.
Passed to solar wind model: magnetic field vector, plasma velocity vector, plasma density, plasma pressure, ratio of specific heats.



Solar Wind Model
ENLIL (Sumerian wind deity)
Odstrcil and Pizzo, 1999; Odstrcil et al., 2002

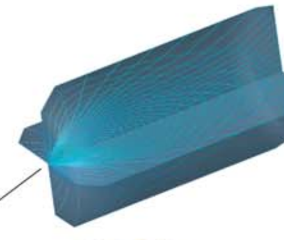
3D MHD model extends from 20 solar radii to > 1 AU
Passed to magnetosphere model: magnetic field vector, plasma velocity vector, plasma density, plasma temperature.

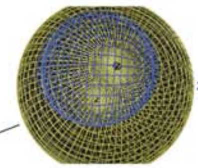




Magnetosphere Model
Lyon-Fedder-Mobarry (LFM)
Fedder and Lyon, 1995; Fedder et al., 1995; Lyon et al., 1998

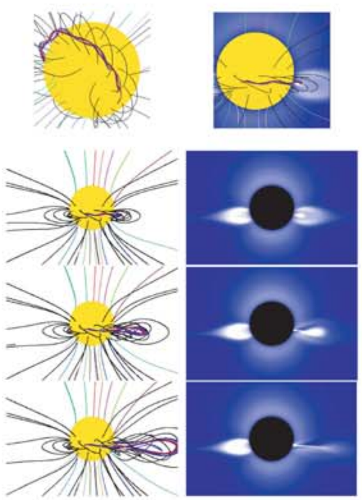
3D MHD model extends from 30 R_E upstream to 300 R_E downstream
Lateral dimension is 100 R_E, Inner boundary is at 2 R_E
Passed to magnetosphere/ionosphere 2-way coupler: electric current parallel to B, plasma density, plasma temperature
M-I coupler passes to thermosphere/ionosphere model: electric potential, precipitating electron characteristic energy & flux



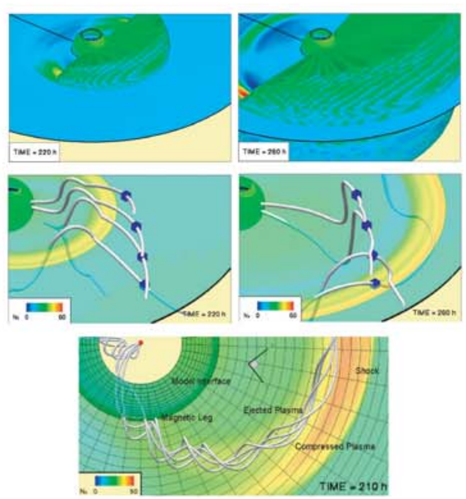


Thermosphere/Ionosphere Model
Thermosphere-Ionosphere Nested Grid (TING)
Roble et al., 1988; Wang et al., 1999

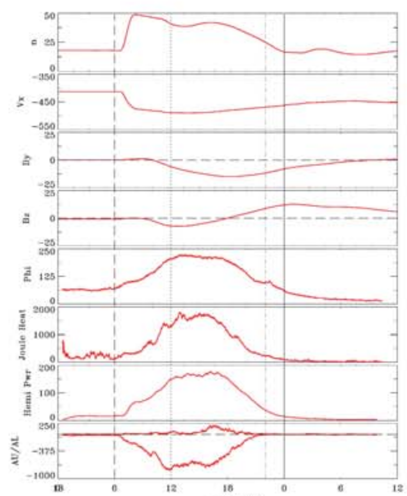
3D fluid dynamic model extends from 97 km to ~600 km altitude
Geographic grid is 5° in latitude and longitude
Passed to M-I coupler: Pederson and Hall conductances
M-I coupler passes to magnetosphere model: electric potential field



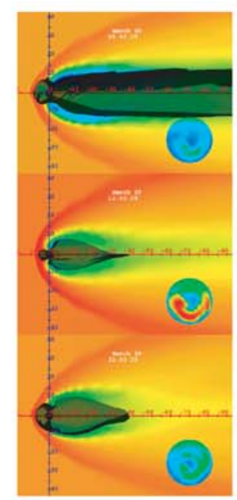
3D MHD simulation of a CME triggered by emerging flux. Top: emergence of opposite polarity flux leads to formation of a stable flux rope. Bottom: Further emergence causing eruption is illustrated by a sequence of snapshots of selected coronal magnetic field lines. Scattered white light coronagraph images constructed from the simulation as if the eruption were viewed on the limb are also shown.



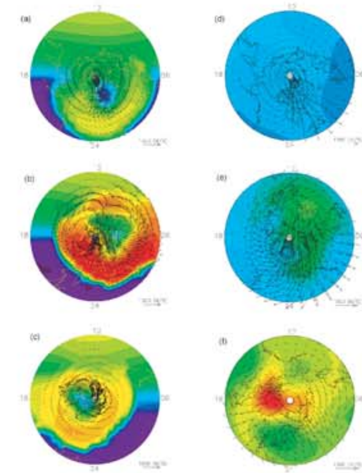
The shape and progression of an evolving coronal transient simulated by the ENLIL model. (a) The shock, identified by its density jump. (b) the ambient interplanetary field compressed and deflected out of the plane containing the moving flux rope, producing a north-south interplanetary field component of enhanced magnitude. (c) The ejecta fields, exhibiting a subsequent rotating north-south component as viewed by a stationary observer.



Key solar wind parameters at L1 plotted as a function of model time, and parameters representing the global response (northern hemisphere) to the simulated event. Top to bottom: solar wind density, cm^{-3}; solar wind velocity x-component, km s^{-1}; IMF y and z components, nT; cross-tail potential, kV; hemispheric Joule heating, GW; hemispheric power of precipitating electrons, GW; simulated AU and AL indices, nT. The vertical dashed lines represent the times of the model output shown at right.



Configuration of the magnetosphere at 6, 12, and 22 UT as simulated by the LFM/TING coupled model. Plasma density is plotted as a color image with the "last closed field line" surface superimposed.
Inset: ionospheric conductance as calculated by the TING model.



Response of the thermosphere/ionosphere system calculated by the LFM/TING coupled model at 6, 12, and 22 UT. (a,b,c): E-region electron densities at ~120 km with the ion drift pattern superimposed. (d,e,f): F-region neutral temperatures at ~250 km with the neutral winds superimposed.