Moon to Mars Space Weather Analysis Office: SEP Validation Efforts

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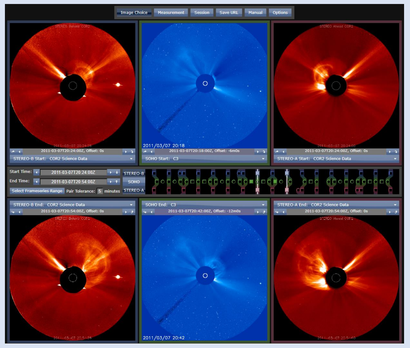
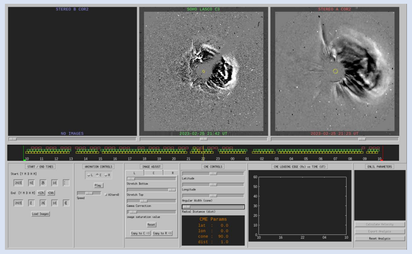
I. Introduction

Understanding space weather effects like space weather's impacts on satellites, GPS signals, communication systems, and power grids is important. For the NASA's Artemis program, it is also very important to understand the hazardous radiation environment the Sun can create for astronauts in space. As a result, improvements in space weather environment modeling capabilities, communication of radiation risks, and real-time analysis support is essential as NASA plans for missions beyond Low-Earth Orbit. The Moon to Mars (M2M) Space Weather Analysis Office located at NASA Goddard Space Flight Center supports NASA's Space Radiation Analysis Group (SRAG) at Johnson Space Center with human space exploration activities by providing novel capabilities to characterize the space radiation environment. M2M also supports NASA robotic missions with space weather assessments and anomaly analysis support. As part of this support, we work diligently with the research community to validate and understand the capabilities of the current space weather models. Below is an example of how M2M's capabilities were used to provide a set of quality and standardized CME inputs for future model development and validation efforts for solar energetic particle (SEP) events.

II. Measurement Techniques

There are two main measurement techniques we used to validate the parameters of all the CMEs. These two techniques include the StereoCAT tool (right) and the SWPC_CAT tool (below). The StereoCAT tool uses a geometric triangulation method. The main limitation of StereoCAT is the accuracy of halo CME analysis. However, it has the ability to show not only the real time data, but also work with STEREO Science data. This was proven to be a necessary ability to fill the gap of analyzing many of the CMEs in the final validation list.

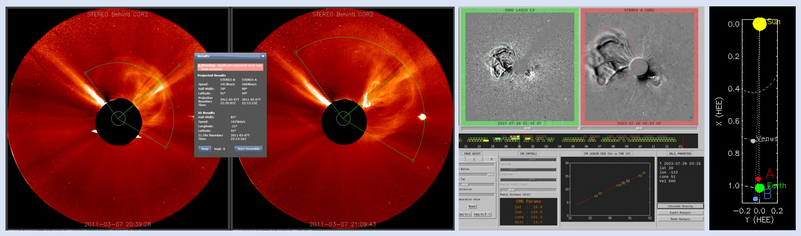




The SWPC_CAT tool uses a similar method to the StereoCAT tool, however SWPC_CAT uses a 3D-projected geometry with a lemniscate that can be adjusted to fit the CME more closely. The benefit of using the SWPC_CAT tool vs the StereoCAT tool is evident during the analysis of halo events as limitations decrease significantly.

III. Process & Challenges

- Data gaps in each spacecraft limiting triangulation techniques
- Missing imagery on SWPC_CAT and/or StereoCAT
- STEREO science data is only available on StereoCAT, not on SWPC_CAT
- No STEREO B imagery for events after 2014, limiting triangulation options
- Limited to no stereoscopic viewpoints during Solar Cycle 25



IV. Results

The M2M team was tasked with a list of over 60 CMEs to review, reanalyze, and if necessary, provide updated parameters. Below is a snippet of what that final list looked like. This list was then sent to model developers to use within their models to compare results to help validate and improve model performance.

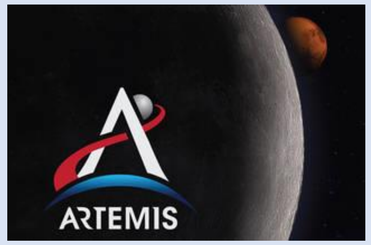
SEP Event Date	Checked by:	Update Measurement (Y/N)	Coronagraphs used?	Bulk, Shock, or both?	SOHO's Timestamp of last CME image used in measurement	STEREO's Timestamp of last CME image used in measurement	UPDATED CME Time a 21 Rsun
#Original SHINE Challenge Events							
2012-03-07	Hannah	Yes	COR2A, COR2B	Bulk	n/a	2012-03-07T00:54Z	2012-03-07T01:38Z
2012-03-07	Hannah	No	COR2A, COR2B	Bulk	n/a	2012-03-07T02:09Z	
2012-05-17	Hannah	No	C3, COR2A	Bulk	2012-05-17T03:18Z	2012-05-17T03:24Z	
2012-07-12	Chris	No	COR2A, COR2B		n/a	2012-07-12T18:24Z	
2013-04-11	Chris	No	C3, COR2B		2013-04-11T10:06Z	2013-04-11T10:09Z	
2014-01-06	Chris	Yes	C3, COR2A	both	2014-01-06T08:24Z	2014-01-06T09:24Z	2014-01-06T10:59Z
2014-01-07	Chris	No	C3, COR2A		2014-01-07T19:30Z	2014-01-07T19:24Z	
2017-07-14	Chris	No	C3, COR2A		2017-07-14T03:30Z	2017-07-14T03:24Z	
2017-09-04	Chris	No	C3, C2		2017-09-04T23:30Z	n/a	
2017-09-06	Chris	Yes	C3, C2, COR2A	Shock	2017-09-06T15:30Z	2017-09-06T15:34Z	2017-09-06T14:21Z
2017-09-10	Chris	Yes	C2, C3, COR2A	Shock	2017-09-10T17:18Z	2017-09-10T16:54Z	2017-09-10T17:26Z
#New events in Solar Cycle 25							
2021-05-29	Carina	Yes	C3, COR2A	Shock Bulk	2021-05-29T00:54Z	2021-05-29T00:53Z	2021-05-29T02:29Z 2021-05-29T02:54Z
2021-10-28	Carina	No	C3, COR2A	Bulk	2021-10-28T17:30Z	2021-10-28T16:53Z	
2022-01-20	Carina	No	C3, COR2A	Shock/Bulk (somewh	2022-01-20T07:30Z	2022-01-20T07:23Z	
2022-03-28	Carina	No	C2, COR2A	Bulk	2022-03-28T13:36Z	2022-03-28T13:53Z	
2022-04-02	Carina	No	C2, C3, COR2A	Shock	2022-04-02T15:06Z	2022-04-02T14:38Z	
2022-08-27	Carina	No	C2, C3, COR2A	Shock	2022-08-27T03:42Z	2022-08-27T03:38Z	
2023-02-25	Carina	No	C3, COR2A	Bulk	2023-02-25T22:06Z	2023-02-25T21:23Z	
#Added Events in Solar Cycle 24							
2011-03-08	Hannah	No	COR2B, C3		2011-03-07T20:54Z	2011-03-07T20:54Z	
2011-06-07	Hannah	No	COR2A, COR2B	Bulk	n/a	2011-06-07T08:24Z	

CME list includes ones that triggered SEP events and ones that did not trigger SEP events.

V. Applications & Future Work

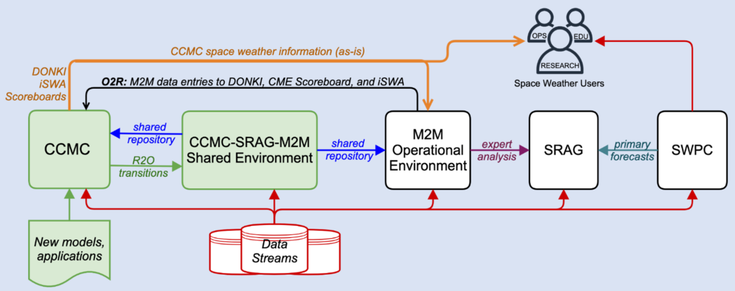
With the CME list validated and available for use, modelers can use the CME parameters in their models in hopes of working together to provide more accurate predictions of the intensity and energy distribution of energetic particles during different events. This becomes particularly important as we look forward to returning humans to the moon and beyond.

During ARTEMIS I, the M2M team worked 24/7 to analyze CMEs and validate SEP model performance as a wet dress rehearsal for future ARTEMIS missions in collaboration with NOAA Space Weather Prediction Center to support SRAG. This work will be detrimental for predicting SEP events and non-events more accurately with the safety of astronauts as one of the highest priorities.



VI. ISEP Project

The validation efforts presented here are part of the ISEP project. The Integrated Solar Energetic Proton Alert/Warning System (ISEP) project, a collaborative partnership between NASA's Moon to Mars Space Weather Analysis Office (M2M), Community Coordinated Modeling Center (CCMC), and the Space Radiation Analysis Group (SRAG), works to identify, transition, and evaluate research Solar Energetic Particle models that can be developed into an operational software tailored for SRAG.



The CCMC has built the SEP Scoreboard and transitioned 6+ real-time models into the application so far. Currently, M2M conducts an event-based validation in which the real-time model outputs for events of interest (e.g., SEPs and ICME arrivals) are evaluated. The ISEP models are then validated in a real-time operational setting as a collaborative effort.

The 6+ models that have already been transitioned are visible in the SEP Scoreboard (right), a tool that is used to view model outputs in a one-stop-shop view. M2M's human-in-the-loop analysis of CMEs is used in some of these models which then populate the SEP Scoreboard.

The SEP Intensity Scoreboard application displaying an SEP event which occurred March 8-9th, 2023.

M2M, CCMC, and SRAG plan to develop an automated validation technique to evaluate real-time model outputs over a continuous period. Such a technique will enable end-users to gauge model accuracy during specific periods of time and will offer continuously updated assessments of model performance.

VII. Summary

Given the new challenges with deep space exploration missions, additional support is needed to analyze the space weather environment beyond the Sun-Earth line. The Moon to Mars (M2M) Space Weather Analysis Office will help address these space weather needs by conducting and providing model-based predictions and analyses as a proving grounds of tool development in support of SRAG. CCMC and M2M are in close collaboration to create an effective NASA in-house R2O2R pipeline for space radiation environment predictive capabilities in support of human missions beyond LEO. M2M also supports NASA robotic missions with space weather assessments and anomaly analysis support. The Office is always looking on how to support model development and validation as an effort to improve SEP and CME arrival predictions. **We look forward to additional collaborations with organizations/missions/groups to further analyze and validate predictions of the space weather environment.**