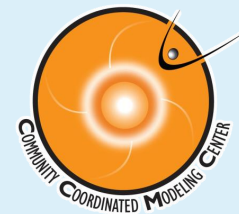


THE MOON TO MARS (M2M) SPACE WEATHER ANALYSIS OFFICE

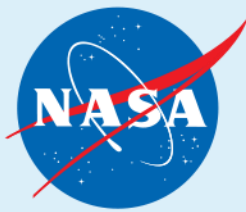
Dr. Yaireska (Yari) Collado-Vega and team
Moon to Mars Space Weather Analysis Office

Heliophysics Science Division
Space Weather Laboratory
NASA Goddard Space Flight Center

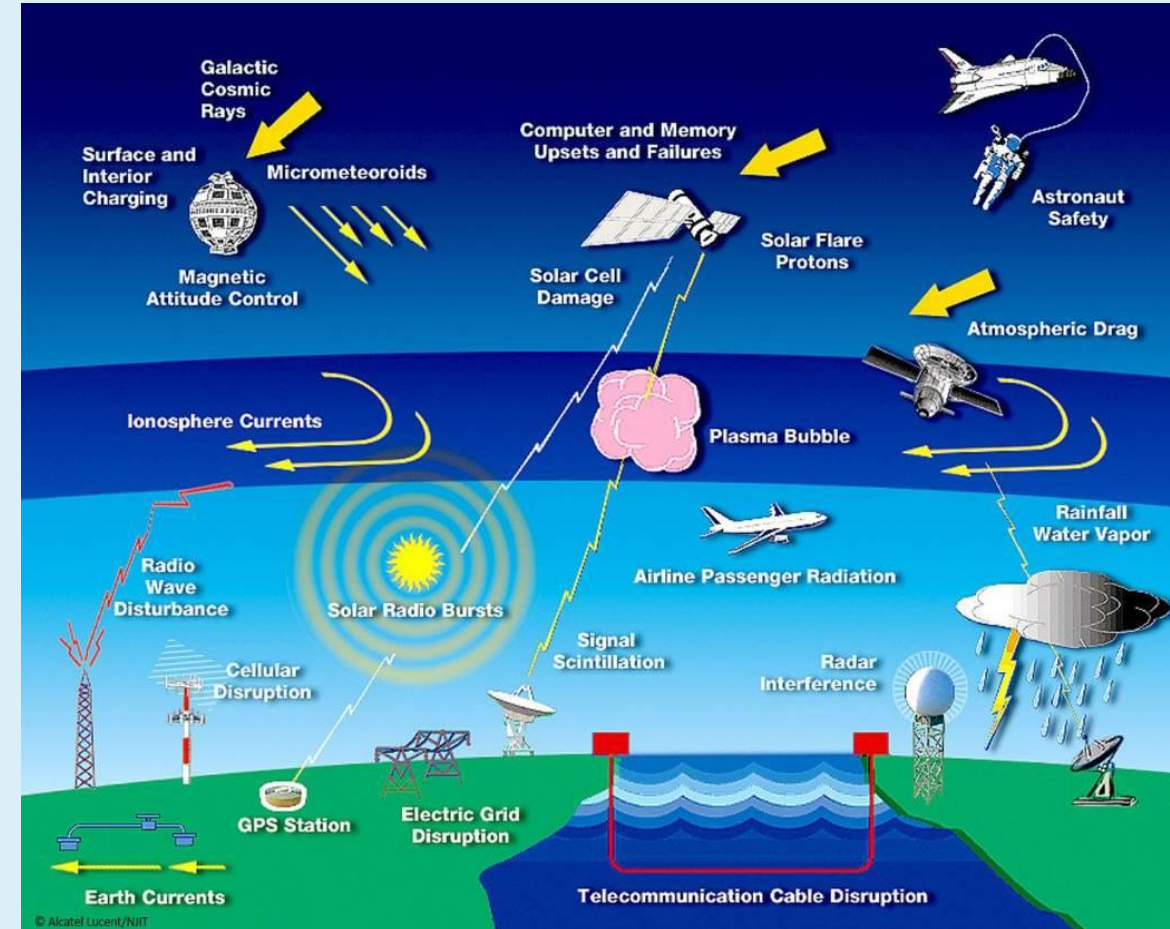
In close collaboration with the Community Coordinated Modeling Center (CCMC) and the Space Radiation Analysis Group (SRAG) from JSC.

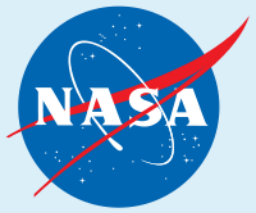


BACKGROUND

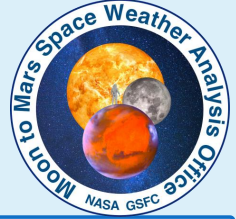


- As NASA plans for missions beyond Low-Earth Orbit (LEO), the need for improvements in **space weather environment modeling capabilities, communications of radiation risks to crew health and safety, and space weather real-time analysis support** has been identified as essential.
- The NASA Johnson Space Center (JSC) Space Radiation Analysis Group SRAG serves as the main space weather monitoring support for all US crew members aboard the International Space Station (ISS) and operates a console that includes analyses of satellite imagery and energetic charged particle measurements.
- Given the new challenges with deep space exploration missions, **additional** support is needed in analyzing the space weather environment beyond the Sun-Earth line.



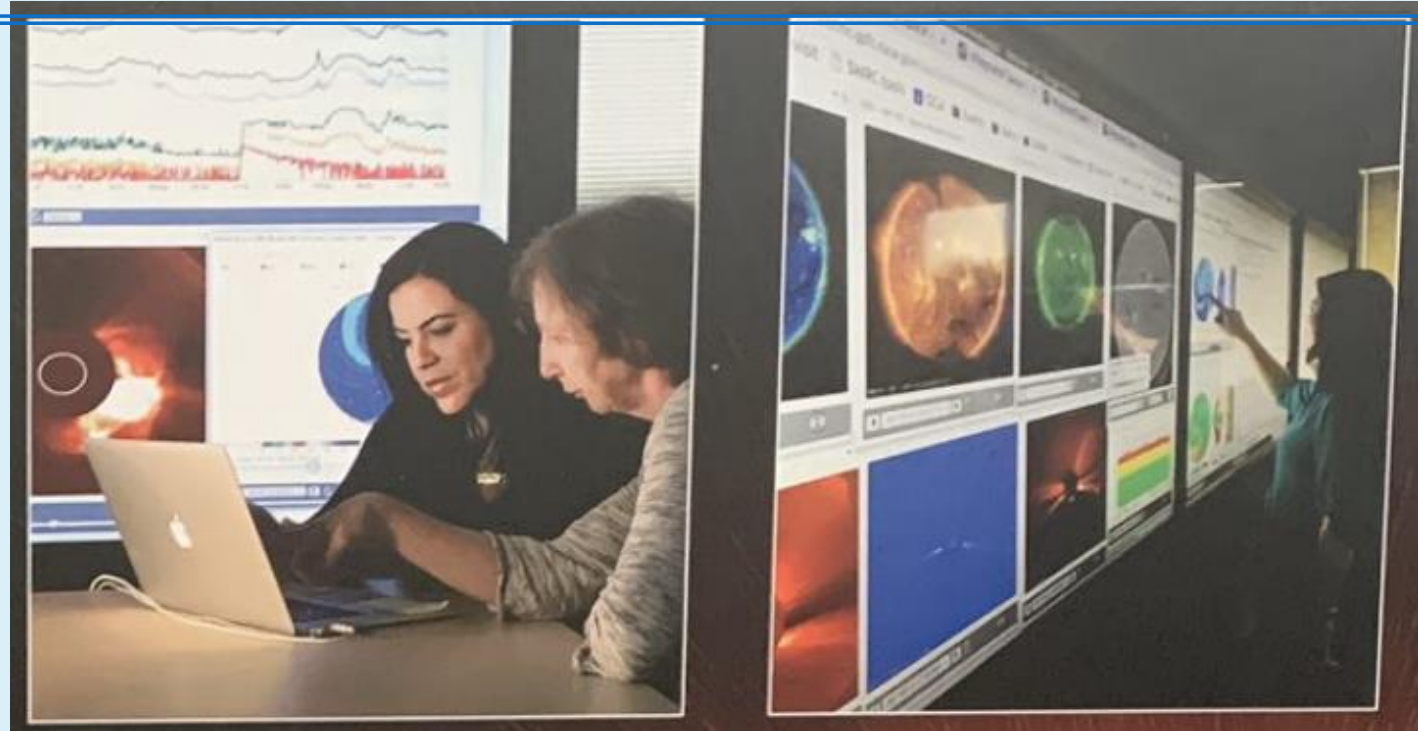


M2M SPACE WEATHER ANALYSIS OFFICE

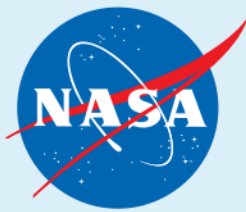


Mission Statement: The Moon to Mars Space Weather Analysis Office (M2M) was established to support NASA's Space Radiation Analysis Group (SRAG) with human space exploration activities by providing additional expert analysis of the space radiation environment.

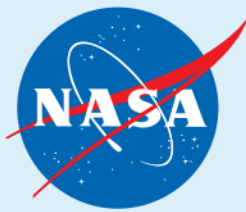
- **NOAA Space Weather Prediction Center remains the primary forecasting operations office for SRAG.**
- M2M provides secondary expert support for SRAG by analyzing state-of-the-art space radiation models tailored to SRAG's needs.



M2M SPACE WEATHER ANALYSIS OFFICE



- M2M support will help SRAG make informed decisions to the Flight Control Team about the projected SEP event likelihood, intensity, and duration during the human exploration missions to the Moon, and subsequently, to Mars.
- M2M Office capabilities encompass both lunar and Mars missions. This is a unique capability that only an in-house NASA space weather analysis office can offer.



M2M SPACE WEATHER OFFICE TEAM



Yaireska (Yari) Collado-Vega, PhD
Director



Anna Chulaki
Deputy



Robert Loper, PhD
Analyst



Carina Alden
Analyst



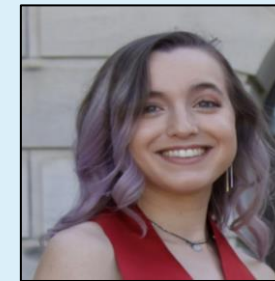
Michelangelo Romano
Analyst/IPM



Mary Keenan, PhD
Scientific Software Developer



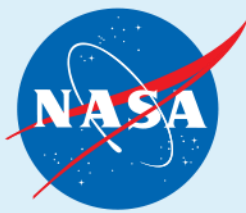
Mary Aronne
Analyst



Mattie Anastopulos
Analyst



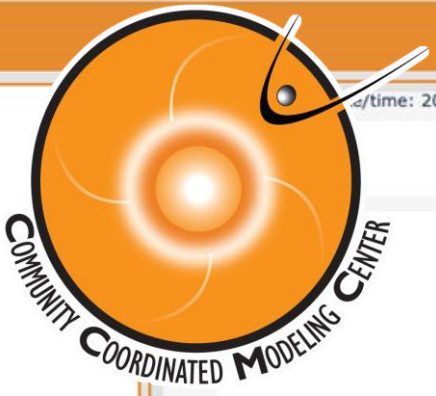
Chris Stubenrauch
Analyst



ACTIVITIES AND CHAIN OF EVENTS

- **Monitor models and activity 8am-4pm daily**
- **Notifications are sent out to users when thresholds are exceeded**
- **10am video and in-person “tag-up” meetings each weekday**
- **10:45am Tag ups with SRAG/Practice Support to EVAs**
- **Weekly Space Weather Reports**

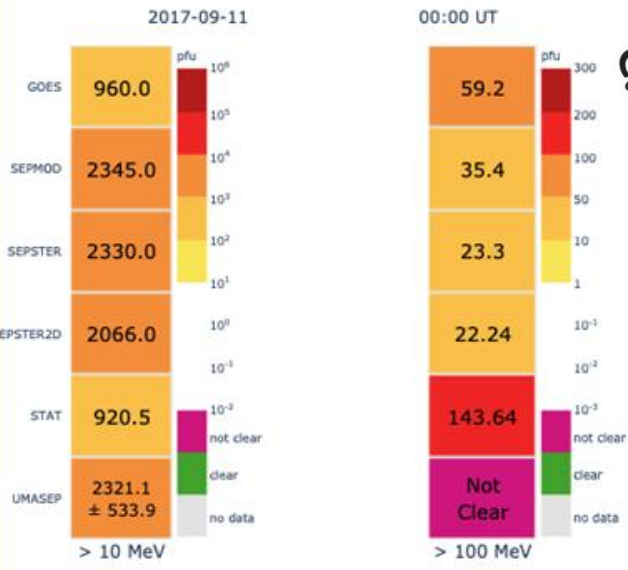
- Flare (M5 or above) – SDO, GOES
- CME (Depending on the speed notifications will be send as fast as possible first with measurements and then with the simulation) – SOHO, STEREO A coronagraphs
- Solar Energetic Particle (if any) – SOHO, GOES, STEREO A
- CME arrival (in-situ data) – DSCOVR, ACE/STEREO A
- Geomagnetic storm (indicated by Kp index) – Global index
- Radiation belt electron flux enhancement - GOES
- Magnetopause Crossing (SWMF Model)



SEP Scoreboard

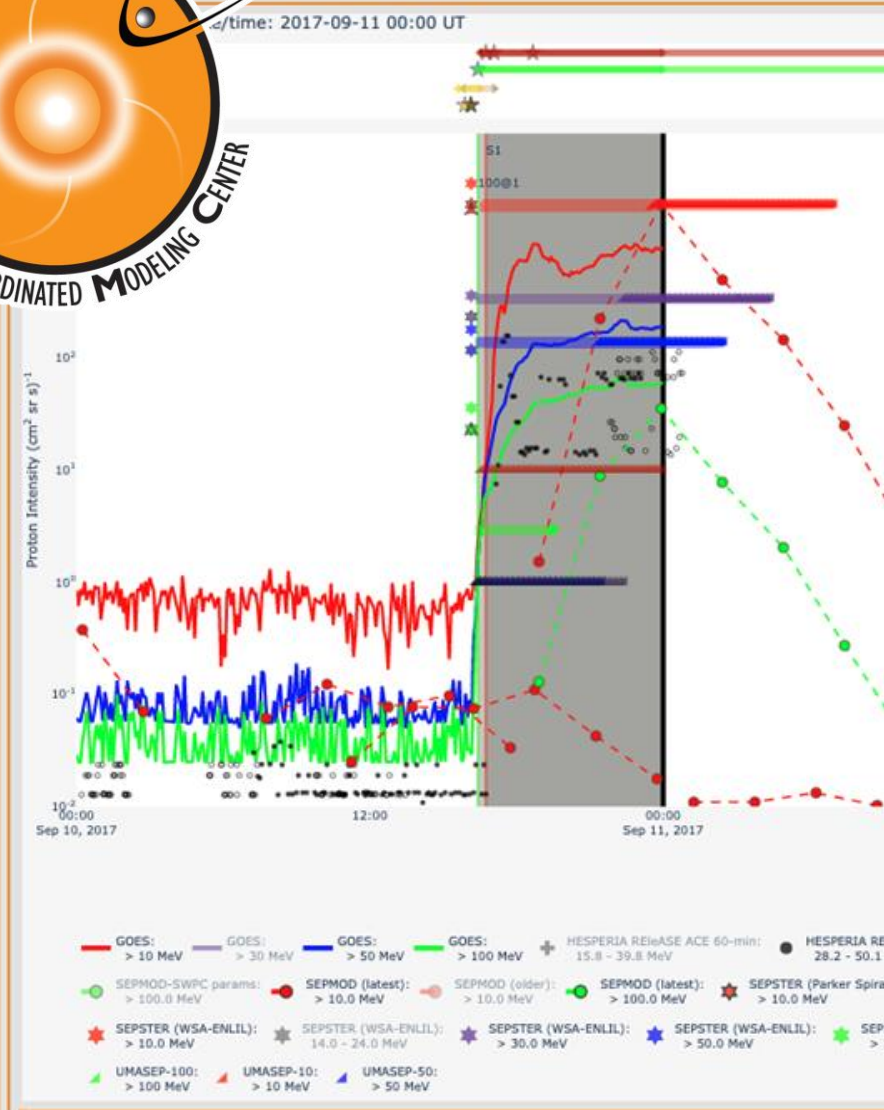
- ★ Publicly available Dec 2020
- ★ Supports SRAG console operators and M2M analysts
- ★ Forecasts from multiple models are collected and uniformly displayed in real time
- ★ Ability to go back in time
- ★ Engages participation from the scientific community
- ★ 6+ participating models

Proton Intensity Forecasts:



Proton All Clear Forecasts:

Model	> 10 MeV	> 100 MeV	> 500 MeV
GOES	Not Clear	Not Clear	N/A
SEPMOD	Not Clear	Clear	N/A
SEPSTER	Not Clear	No Data	N/A
SEPSTER2D	Not Clear	Not Clear	N/A
UMASEP	Not Clear	Not Clear	Clear

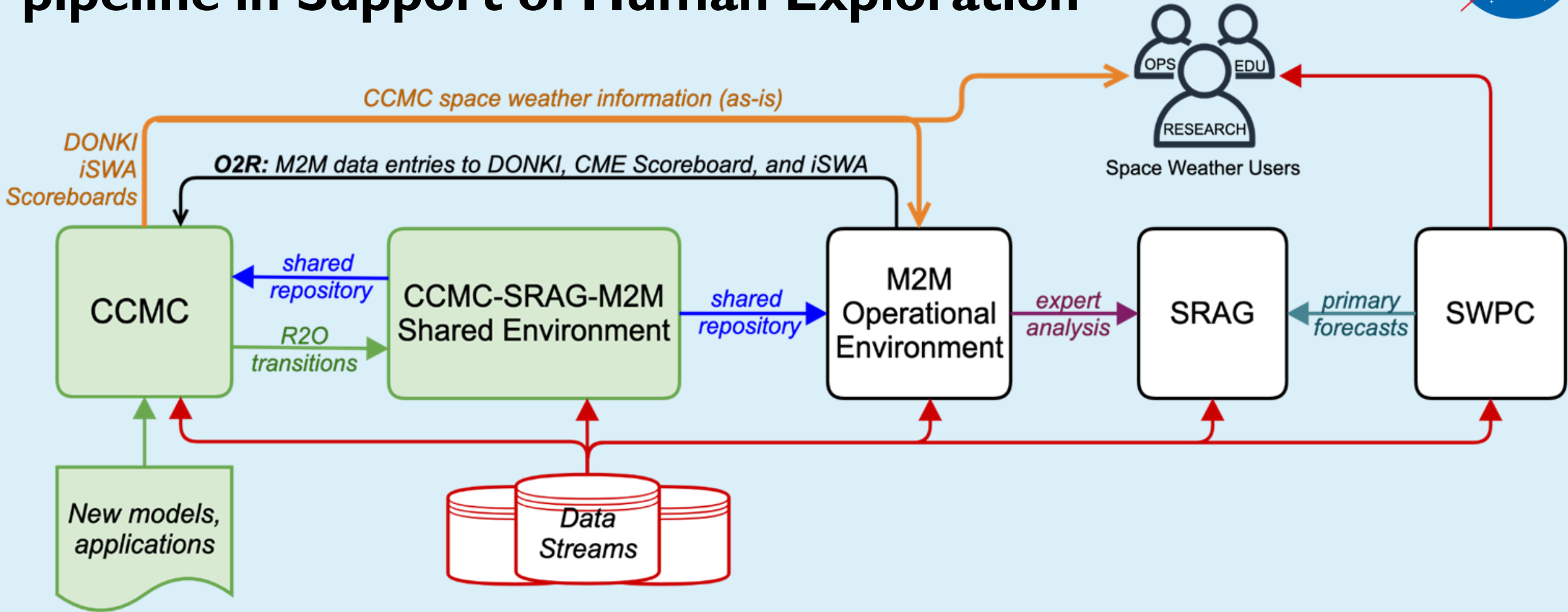
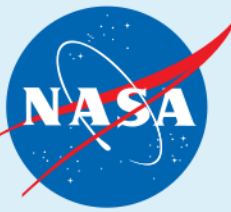


Additional Information for Selected Point:

Graph Show Options

Auto Refresh

CCMC – M2M partnership: NASA in-house R2O2R pipeline in Support of Human Exploration



- The CCMC-SRAG-M2M shared cloud environment, maintained by CCMC, is accessible by all CCMC, SRAG, and M2M staff.
- CCMC transitions ISEP models/software to the shared environment. M2M staff then transitions the models/software from the shared environment and maintains them within the M2M operational environment, serving SRAG as secondary expert support.



CCMC-M2M PARTNERSHIP

- The M2M team populates CCMC's DONKI and CME Scoreboard during their real-time analysis of space weather conditions, and sends real-time simulation results to CCMC's iSWA.



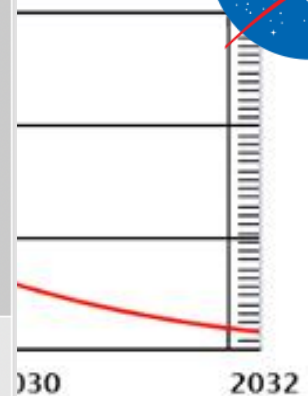
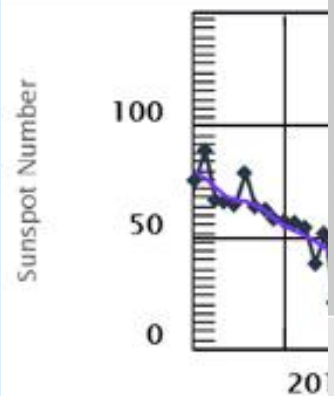
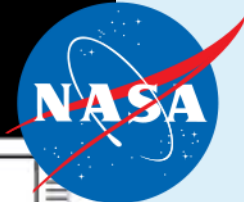
DONKI:

CCMC's real-time SW
Event Catalog-Populated
by M2M



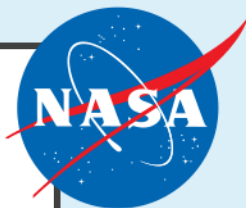
CCMC CME Arrival Time Scoreboard

- M2M will continue to support NASA robotic missions with space weather notifications and anomaly analysis support.
- SRAG, CCMC, and M2M partner together on model validation.
- The goal of the partnership between CCMC and M2M is to establish and maintain an effective NASA in-house Research-to-Operations-to-Research (R2O2R) pipeline.



Missions	SRAG (Primary Support)	M2M (Secondary Support)
Normal ISS Operations + Free Space Mission	<ul style="list-style-type: none"> Operators monitor ISS radiation instruments and data. Participate as active member of Flight Control Team (FCT). Maintain situational awareness of the space environment with support from the Space Weather Prediction Center (SWPC). Issue Alert and Warnings according to SRAG solar activity thresholds. Take advantage of the uncrewed mission to test whatever new operational tools we and communications amongst teams. 	<ul style="list-style-type: none"> The M2M Office will use these events as training opportunities to learn how space weather events are addressed in FCT. Utilize NASA-specific models to provide SRAG with operational expert assessment of any solar activity that may occur. Take advantage of the uncrewed mission to test whatever new operational tools are available and communications amongst teams.
Normal ISS Operations + Free Space Mission + Space Weather Event	<p>In addition to above duties:</p> <ul style="list-style-type: none"> SRAG will monitor multiple missions. SRAG will interface with multiple FCTs. SRAG operations will require 24/7 presence in Mission Control during higher exposure risk to free space missions. Recommend shelter protocols as required. 	<p>In addition to above duties:</p> <ul style="list-style-type: none"> M2M will be relied upon as the experts in the space weather models. M2M analysts will distill Moon to Mars output into an actionable operational format. M2M will leverage NASA-specific tools and models to create visualizations to support SRAG operations. Support SRAG 24/7 operations.
Normal ISS Operations + Free Space Mission + Space Weather Event + Lunar Surface	<p>In addition to the above duties:</p> <ul style="list-style-type: none"> SRAG operations are supporting missions on two different spacecraft and a lunar surface crew. Lunar surface operations will be dependent on lower energy proton fluxes than previous spacecraft operations. Alert FCT of any forecasted space weather events that could require astronauts back to shelter. 	<p>In addition to above duties:</p> <ul style="list-style-type: none"> Provide SRAG operators with M2M products that communicate the probabilities of severe space weather events.
All the Above + Planetary Surface	<p>In addition to the above duties:</p> <ul style="list-style-type: none"> SRAG operations extend beyond Earth centric/cis-lunar space. New operational resources and methods may be required to support mission operations. 	<p>In addition to above duties:</p> <ul style="list-style-type: none"> M2M will be essential for the forecasting support due to the need for non-Earth modeling for mission support. Integrate mission operational space weather monitoring and models to support Mars mission operations. Provide Mars/spacecraft centric forecasts for SRAG mission evaluation.

Table: SRAG



ANOMALY ANALYSIS SUPPORT FOR NASA ROBOTIC MISSIONS

- Anomaly Analysis are requested by NASA missions several times a month.
- An assessment is prepared and sent to the mission team for their evaluation and decision.
- Sometimes face to face meetings are required when an evaluation board is conducted, and the space weather environment is presented by our team.
- Critical decisions are made that take into account the space weather assessment.

- Supported missions include:

MMS, ACE, STEREO, IBEX, Aqua, Aura, Terra, Landsat, VAP, GPM, Spitzer, DSCOVR, GOES, TDRSS, OSIRIS-Rex, SDO, etc.

We also work closely with the GSFC Space Asset Protection Program (SAPP) and we are part of the procedures for mission anomalies.

The support has been very important for the development of new missions, like GOES series.

During Shutdown:

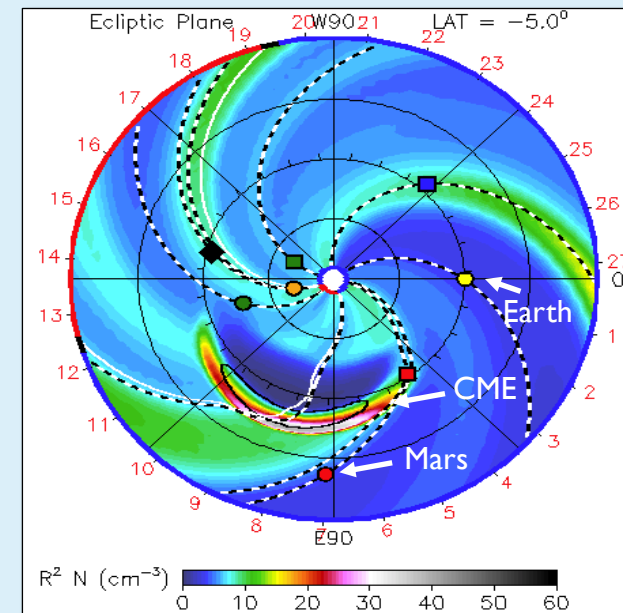
Space weather Analysis services were critical and excepted. A mission had an anomaly that needed to be evaluated for an orbit departure and spacecraft health and safety.

SPACE WEATHER AND INGENUITY'S FIRST AND SECOND FLIGHTS



- Two days before Ingenuity's first flight, a solar flare was observed that produced a Mars-directed CME (coronal mass ejection). *Images to left.*
- Moon to Mars Space Weather Analysis Office (SMD, GSFC) and Space Radiation Analysis Group (HEOMD, JSC) teams immediately began providing PSD leadership and the JPL mission team situational awareness information and potential radiation impacts that could be felt on the surface of Mars.

- NASA space weather models predicted (*image to right*) that the CME would arrive at Mars on the day of Ingenuity's second flight. A combination of the CME parameters and NASA/ESA missions' observations showed that the CME would not produce a harmful radiation environment for operations. Observations from Solar Orbiter and RAD (Curiosity) confirmed these predictions.



Plasma density results from the WSA-Enlil+Cone model for the 17 April 2021 Mars-directed CME.

SUMMARY

- Given the new challenges with deep space exploration missions, additional support is needed in analyzing the space weather environment beyond the Sun-Earth line. **The Moon to Mars (M2M)** Space Weather Analysis Office will address these space weather needs by conducting and providing additional model-based predictions and analyses as well as new tools and service development in support of SRAG.
- CCMC and M2M are collaborating to create an effective NASA in-house R2O2R pipeline for space radiation environment predictive capabilities in support of human missions beyond LEO.
- M2M will continue to support NASA robotic missions with space weather notifications and anomaly analysis support.

We look forward to additional collaborations with NASA missions/groups to further analyze and validate predictions of the space weather environment at different locations. We are also looking forward to strengthen our collaboration with NOAA.

