# THE MOON TO MARS SPACE WEATHER ANALYSIS OFFICE; CONCEPT OF OPERATIONS AND SPACE WEATHER ANOMALY ANALYSIS SUPPORT

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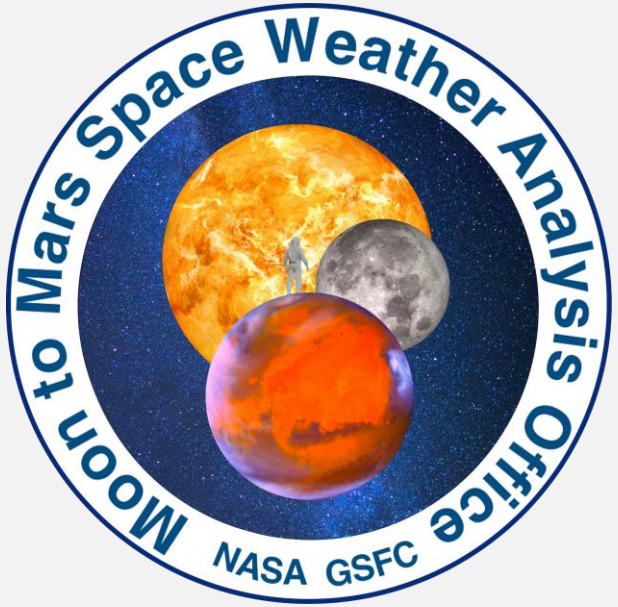
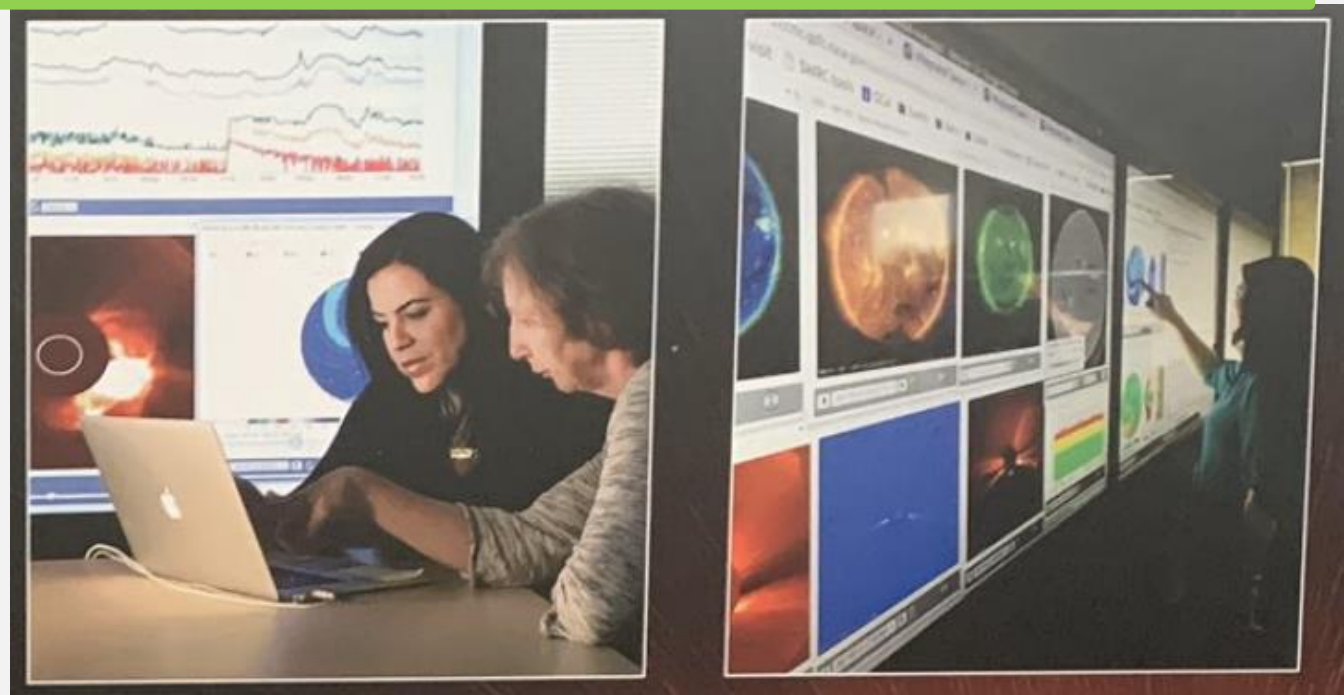



**In close collaboration with the Community Coordinated Modeling Center (CCMC) and the Space Radiation Analysis Group (SRAG) from JSC.**

# M2M SPACE WEATHER ANALYSIS OFFICE

**Mission Statement:** The Moon to Mars (M2M) Space Weather Analysis Office was established to support NASA's Space Radiation Analysis Group (SRAG) 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.

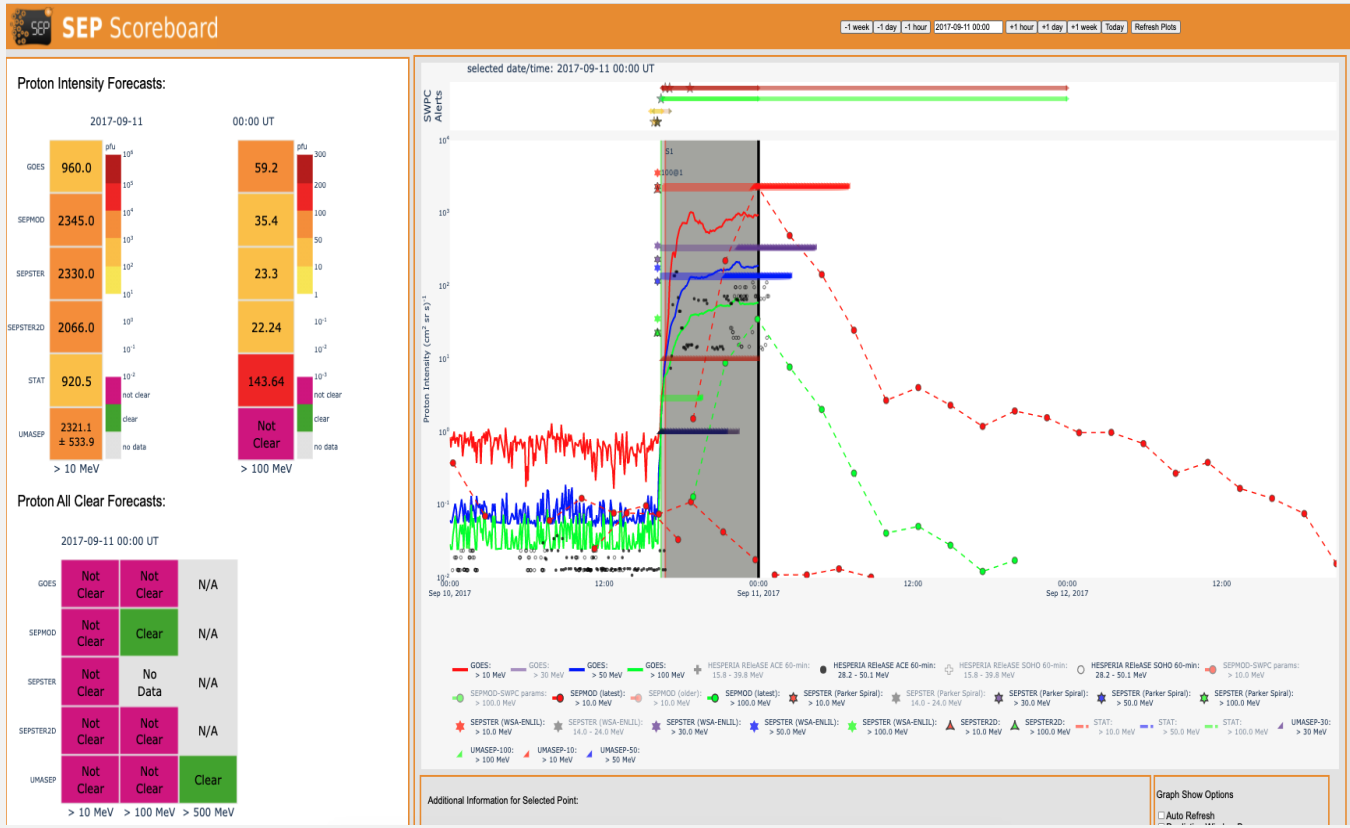
- M2M will work as the proving grounds and testbed for the capabilities that will eventually transition to operational agencies.



# Community Coordinated Modeling Center/ Space Radiation Analysis Group Collaboration

https://ccmc.gsfc.nasa.gov/isep

- The Integrated Solar Energetic Proton Alert/Warning System (ISEP) project is a partnership between CCMC and NASA JSC SRAG that began in 2018 to transition research Solar Energetic Particle models to operations.
- The project aimed to identify, transition, and evaluate new models (R2O), to develop software tailored for SRAG.
- CCMC has transitioned 6+ real-time models and built **the SEP Scoreboard application.**
- The tool was used in a real time setting by SRAG and M2M for the Artemis 1 mission.




https://sep.ccmc.gsfc.nasa.gov/probability/
https://sep.ccmc.gsfc.nasa.gov/intensity/
https://sep.ccmc.gsfc.nasa.gov/allclear/





- Artemis 1-A success for the future of human spaceflight. We are part of a new generation, the Artemis generation!
- A great success for the M2M team. We supported the mission 24/7 during the 25.5 days of flight and worked closely with NASA SRAG and NOAA SWPC.
- A post-Artemis evaluation meeting between NASA SRAG, NASA M2M and NOAA SWPC was held on Jan 5-6 hosted by NOAA SWPC.
- The next steps are many (changes in the scoreboard, discussion with model developers, data outages solutions and ways we communicate) but the collaboration with our agencies is stronger than ever.

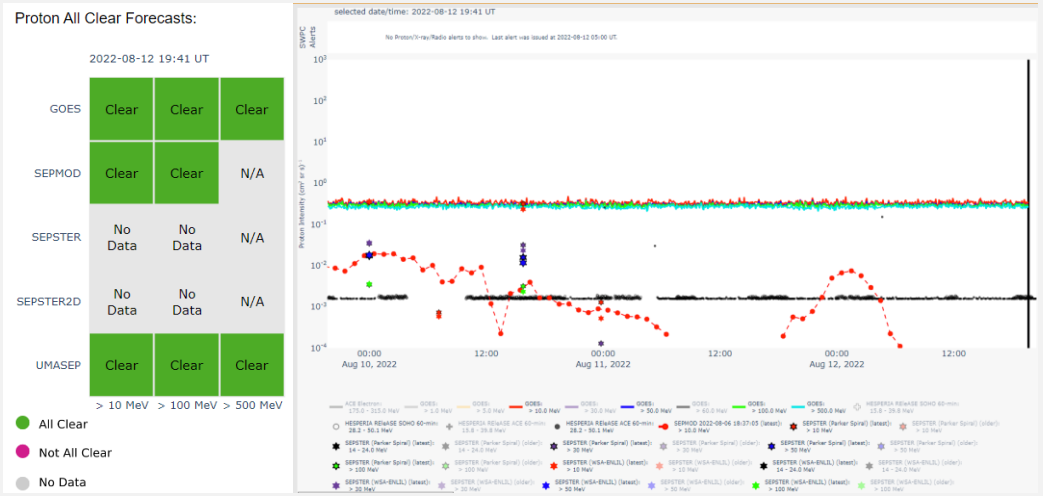
# General Infrastructure for ISEP Models and SEP Scoreboards

*There are three distinct environments running ISEP-related software:*

| CCMC<br>Local Environment | ⟷ | CCMC-SRAG-M2M<br>Shared Environment | ⟷ | M2M<br>Environment |
|---|---|---|---|---|
| ***Models received.*** | | ***Models containerized in AWS.*** | | ***Models deployed in production.*** |

**Each environment hosts versions of the SEP Scoreboards which include:**

- **Probability Scoreboard**
- **Intensity Scoreboard**
- **All Clear Scoreboard**



# ISEP RESEARCH MODELS

| | Inputs | Outputs |
|---|---|---|
| **MAG4** | • LOS or vector magnetogram (from SDO/HMI) | • Probability of SPE occurrence |
| **UMASEP** | • Soft X-ray flux (GOES)<br>• Differential proton flux (GOES)<br>• SOD version only: Type-III Radio Burst Data (from NOAA/SWPC) | • Maximum proton intensity<br>• Time of threshold crossing |
| **HESPERIA REleASE** | • Electron intensity (from ACE/EPAM or SOHO/EPHIN) | • Proton intensity for 30, 60, 90-minute prediction windows and two energy ranges (15.8-39.8 MeV and 28.2-50.1 MeV) |
| **SEPSTER/SEPSTER 2D** | • CME speed + width from DONKI<br>• Connectivity angle (from DSCOVR PlasMag, ACE SWEPAM, or 450 km/s + the Parker spiral equation) | • Peak proton intensity<br>• Time of the peak |
| **SEPMOD** | • CME shock radial distance<br>• Magnetic connectivity to observer | • SEP intensity time profile |

# Overview of current M2M Activities

- **Real-time analysis of SWx activity (7 days a week; 8am-4pm ET; Artemis-24/7)**
  - *SWx notifications and weekly reports issued to support NASA missions (analysis of events in all directions).*
  - *Documented/archived analysis to support research and requests for information.*
    - *Support on anomaly analysis for NASA robotic missions*
    - *Part of the GSFC Mission Resilience Program activities*
    - *Support of information for NASA payloads in launch activities*

***Resources used to support real-time analysis:***

Space Weather Database Of Notifications, Knowledge, Information (DONKI)

integrated Space Weather Analysis (iSWA) system

Stereo CME Analysis Tool (StereoCat)

SWPC CME Analysis Tool Web Version (SWPC_CAT_Web)


- **Integrated Solar Energetic Proton Alert/Warning System (ISEP)**
  - *Host ISEP models and SEP Scoreboards within M2M environment on AWS.*
  - *Offer real-time analysis of ISEP models in support of SRAG console operators as a proving ground of the new capabilities.*
  - *Validate performance of ISEP models tested in a real-time operational setting during the Artemis mission.*

# Framework of M2M's Real-time Validation

**Currently:** M2M conducts an event-based validation in which the real-time model outputs for specific events of interest *(e.g., SPEs/ESPEs or ICME arrivals)* are evaluated. M2M validation studies include the following components:

I. Event Analysis (e.g., event onset, duration, associated activity, etc.)
   - Details of each event analysis are documented in the M2M_Catalog within *The Space Weather Database Of Notifications, Knowledge, Information* (**DONKI**) hosted by CCMC.

II. Review of Human-in-the-loop Activities (e.g., CME analysis and model triggering)
   - Real-time data availability for CME analysis, review of initial/updated CME measurements, and identified model triggers are closely examined.

III. Assessment of Model Performance (e.g., advanced warning time, prediction accuracy, etc.)
   - The configuration and real-time outputs of each model are carefully evaluated by reviewing real-time model input data and relevant observational data.

# Overview of M2M's Real-time Validation Efforts

## CME Scoreboard

https://kauai.ccmc.gsfc.nasa.gov/CMEscoreboard/

### Example of CME with Community Predictions

**CME: 2022-01-29T23:36:00-CME-001**

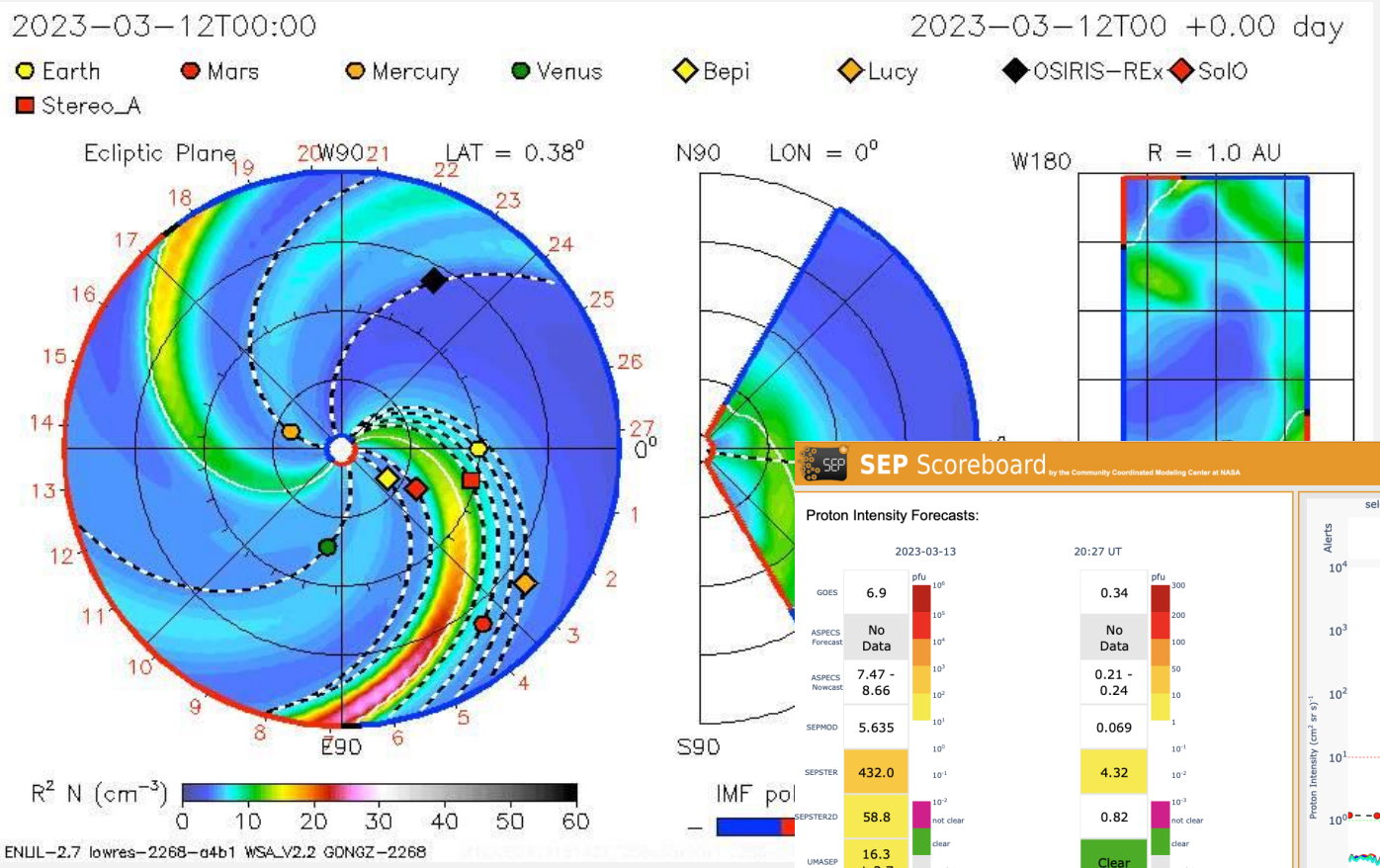
Actual Shock Arrival Time: 2022-02-01T21:37Z

Observed Geomagnetic Storm Parameters:
Max Kp: 4.0
CME Note: Visible as a halo in SOHO LASCO C2/C3 and as a partial halo to the W in STEREO A COR2. Associated with an eruption from AR 12936 (N17E10), visible in SDO AIA 171/193 (eruption/EUV wave) and SDO AIA 304 (post-eruptive arcades) beginning 2022-01-29T21:57Z. Also visible in STEREO A EUVI 195 beginning 2022-01-29T22:05Z. Associated with elevated 0.035-0.065 MeV electron flux at STEREO A beginning 2022-01-30T00:15Z and elevated 2.2-12 MeV proton flux at STEREO A beginning 2022-01-30T00:59Z. 13-100 MeV proton flux at STEREO A remained at background level. UPDATE (2022-02-02T12:35Z): Arrival indicated by sudden jumps in density (exceeding 15 per cc), speed (exceeding 470 km/s), temperature, and field amplitude (exceeding 13 nT). This IPS arrival time is the arrival of the sheath, and the flux rope arrived around 2022-02-02T19:43Z.

| Predicted Shock Arrival Time | Difference (hrs) | Confidence (%) | Submitted On | Lead Time (hrs) | Predicted Geomagnetic Storm Parameter(s) | Method | Submitted By | |
|---|---|---|---|---|---|---|---|---|
| 2022-02-01T23:07Z (-9.0h, +9.0h) | 1.50 | ---- | 2022-01-30T12:00Z | 57.62 | ---- | EAM (Effective Acceleration Model) | Evangelos Paouris (UoA) | Detail |
| 2022-02-01T21:29Z (-9.0h, +9.0h) | -0.13 | ---- | 2022-01-30T12:00Z | 57.62 | ---- | EAM (Effective Acceleration Model) | Evangelos Paouris (UoA) | Detail |
| 2022-02-02T12:00Z (-12.0h, +12.0h) | 14.38 | 80.0 | 2022-01-30T12:47Z | 56.83 | Max Kp Range: 3.0 - 6.0 | Other (SIDC) | Robert Loper (M2M Office) | Detail |
| 2022-02-01T19:36Z (-7.0h, +7.0h) | -2.02 | ---- | 2022-01-30T13:50Z | 55.78 | Max Kp Range: 4.0 - 6.0 | WSA-ENLIL + Cone (NASA M2M) | Robert Loper (M2M Office) | Detail |
| 2022-02-01T17:48Z | -3.82 | ---- | 2022-01-30T16:00Z | 53.62 | Max Kp Range: 3.0 - 4.0 | SARM | Marlon Nunez (UMA) | Detail |
| 2022-02-02T04:00Z | 6.38 | ---- | 2022-01-30T16:43Z | 52.90 | ---- | WSA-ENLIL + Cone (Met Office) | Met Office (Met Office) | Detail |
| 2022-02-01T09:07Z (-12.2h, +17.1h) | -12.50 | 100.0 | 2022-01-30T21:24Z | 48.22 | Max Kp Range: 4.0 - 6.0 | Ensemble WSA-ENLIL + Cone (NASA M2M) | Robert Loper (M2M Office) | Detail |
| 2022-02-02T10:00Z (-12.0h, +12.0h) | 12.38 | 100.0 | 2022-01-31T00:11Z | 45.43 | Max Kp Range: 5.0 - 6.0 | WSA-ENLIL + Cone (BoM) | Duty Forecaster (ASFC) | Detail |
| 2022-02-02T00:00Z (-7.0h, +7.0h) | 2.38 | ---- | 2022-01-31T01:31Z | 44.10 | ---- | WSA-ENLIL + Cone (NOAA/SWPC) | Robert Loper (M2M Office) | Detail |
| 2022-02-02T01:00Z | 3.38 | 70.0 | 2022-01-31T01:37Z | 44.00 | Max Kp Range: 4.0 - 6.0 | Cone+HAF (SEPC, NSSC, CAS) | Jingjing Wang (NSSC SEPC) | Detail |
| 2022-02-01T23:48Z | 2.18 | 87.5 | --- | --- | Max Kp Range: 3.83333 - 5.66667 | Average of all Methods | Auto Generated (CCMC) | Detail |

- M2M assists with populating the CME Scoreboard with events and predictions
- Official arrival times are determined in consultation with ICME experts at NASA GSFC involved with the *Large-Scale Structures Originating from the Sun* (LASSOS) project.

# HUMAN IN THE LOOP ANALYSIS/VALIDATION





| | | | |
|---|---|---|---|
| CME | 2023-03-13 03:36 | M2M_CATALOG | SOHO: LASCO/C2<br>SOHO: LASCO/C3<br>STEREO A:<br>SECCHI/COR2 |

*PSP saw the event!*

# Space Weather Highlights

*January 01 to March 28*

| Activity Type | 01 Jan – 28 Mar | Notes for 01 Jan – 28 Mar |
|---|---|---|
| **Numbered Active Regions** | 92 | Notable Beta-Gamma-Delta Active Regions:<br>3181, 3182, 3184, 3186, 3190, 3194, 3217, 3234<br>8.7% of ARs were Beta-Gamma-Delta<br>Likely cause of significant far-sided halo on March 13 |
| **Flares (M-class or higher)** | 119 | X-class flares or higher: 6<br>(X-class flares made up 5.04% of M-class or higher flares) |
| **CMEs (>500 km/s)** | 159 | CME: 2023-03-13T03:36Z measured with speed 2127 km/s |
| **Coronal Hole High Speed Streams** | 22 | 16 (73%) observed at L1 (Possible cause: STA PLASTIC data has not been reliable) |
| **Interplanetary Shocks** | 34 | 18 observed at L1; most notable signature at: 2023-03-23T09:10Z (Kp=8 storm). |
| **Geomagnetic Storms (Kp > 6)** | 2 | NOAA KP: 8 for the periods 2023-03-24T06:00Z to 09:00Z. |
| **Radiation Belt Enhancement** | 6 | Energetic electrons were elevated above 1000 pfu from Feb 28 to March 10. |
| **Solar Energetic Particle Events** | 3 | 1. 2023-02-25T21:10Z (GOES) (M6.3-flare)<br>2. 2023-03-13T07:45Z (GOES) (Significant far-sided halo CME)<br>3. 2023-03-14T11:55Z (GOES) (Re-enhancement of March 13 event due to CME arrival?) |

# Anomaly Analysis Support for NASA Robotic Missions

- Anomaly Analysis are requested by NASA missions several times a week/month.
- An assessment is prepared and sent to the mission team for their evaluation and decision.
- Sometimes follow up 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, Ingenuity, JWST, etc.

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

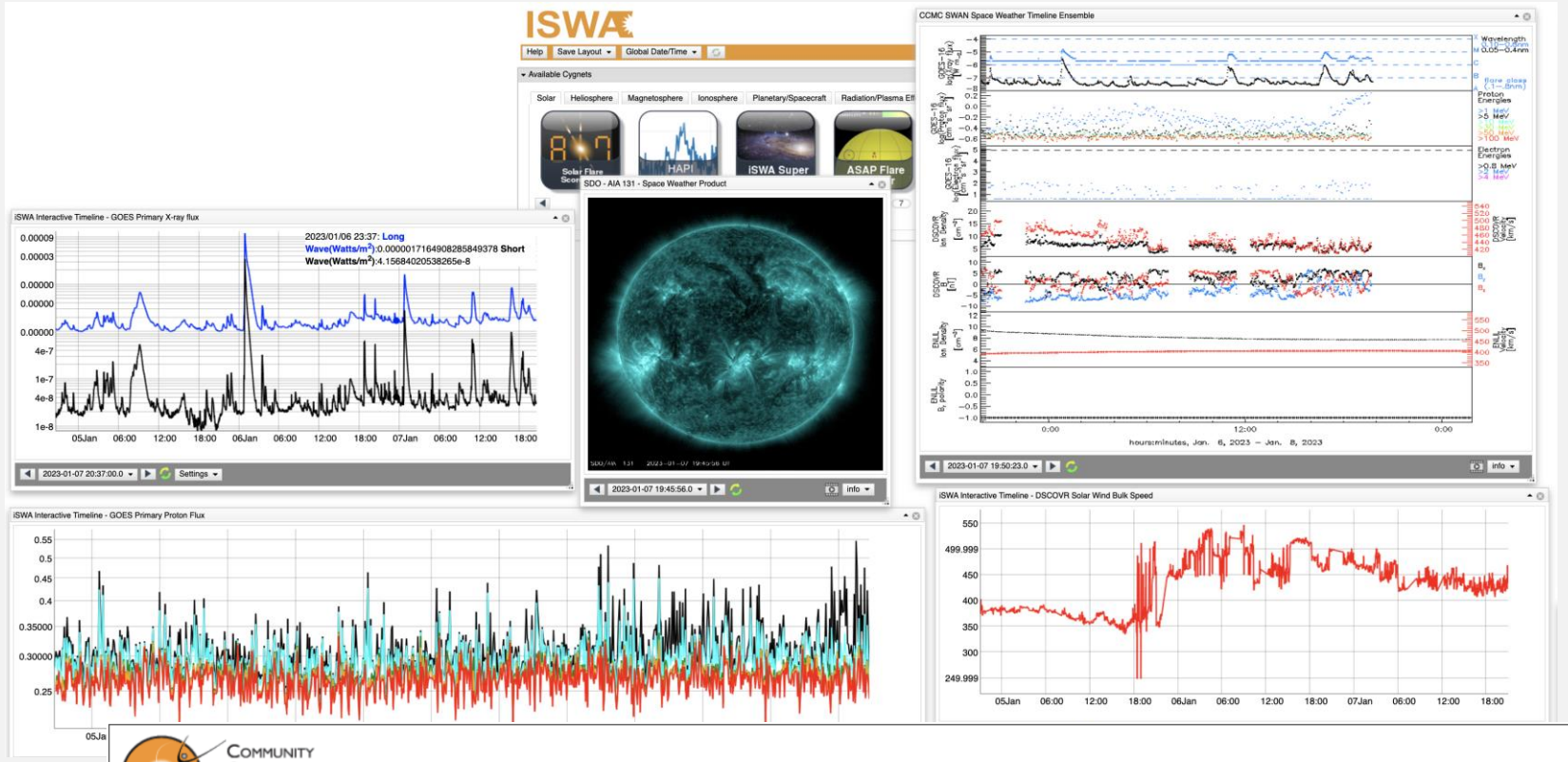
The support has been very important for the development of new missions.

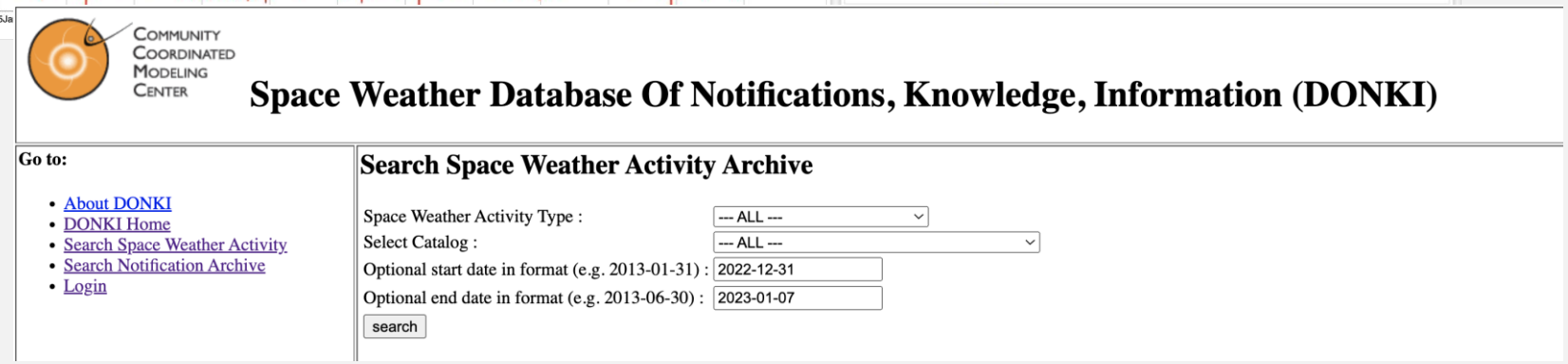
# SWx Assessment Steps Taken

https://iswa.ccmc.gsfc.nasa.gov/

- We need the location of mission and the time of the event. It also helps to have an idea of what happened.
- We then look at the overall conditions:
  - Flares and coronal mass ejections (CMEs)
  - Particle environment
  - Geomagnetic Conditions
  - Localized environment (if possible, TEC, auroral oval location, etc.)

**Real time anomaly assessment is very challenging. We try to look for every model and dataset available with the understanding there is much more validation needed.**



COMMUNITY COORDINATED MODELING CENTER

# Space Weather Database Of Notifications, Knowledge, Information (DONKI)

**Go to:**

- About DONKI
- DONKI Home
- Search Space Weather Activity
- Search Notification Archive
- Login

## Search Space Weather Activity Archive

Space Weather Activity Type : --- ALL ---
Select Catalog : --- ALL ---
Optional start date in format (e.g. 2013-01-31) : 2023-03-01
Optional end date in format (e.g. 2013-06-30) : 2023-03-03
search

| Event Type | Start Time (UT) | Associated Instrument | Peak Time | End Time | Class | Source Location | Active Region Number | Directly Linked Event(s) |
|---|---|---|---|---|---|---|---|---|
| Solar Flare | 2023-03-01 00:56 | GOES-P: EXIS 1.0-8.0 | 2023-03-01T01:07Z | 2023-03-01T01:18Z | M1.0 | N26W33 | 13234 | |
| Solar Flare | 2023-03-02 04:39 | GOES-S: EXIS 1.0-8.0 | 2023-03-02T04:50Z | 2023-03-02T04:57Z | C9.2 | N20W55 | 13234 | 2023-03-02T06:12:00-CME-001 |
| Solar Flare | 2023-03-02 21:05 | GOES-P: EXIS 1.0-8.0 | 2023-03-02T21:16Z | 2023-03-02T21:25Z | M3.8 | N20W65 | 13234 | 2023-03-02T21:36:00-CME-001<br>2023-03-03T02:00:00-CME-001 |
| Solar Flare | 2023-03-03 10:10 | GOES-P: EXIS 1.0-8.0 | 2023-03-03T10:32Z | 2023-03-03T10:48Z | M3.2 | N20W70 | 13234 | 2023-03-03T11:36:00-CME-001 |
| Solar Flare | 2023-03-03 17:42 | GOES-P: EXIS 1.0-8.0 | 2023-03-03T17:52Z | 2023-03-03T17:59Z | X2.0 | N20W75 | 13234 | 2023-03-03T18:12:00-CME-001<br>2023-03-03T19:19:00-SEP-001<br>MODEL: REleASE:ACE/EPAM 28.2-50.1 MeV<br>2023-03-03T22:11:00-SEP-001<br>MODEL: REleASE:SOHO/EPHIN 28.2-50.1 MeV<br>2023-03-03T22:11:00-SEP-002<br>MODEL: REleASE:SOHO/EPHIN 15.8-39.8 MeV |

| Event Type | Event Time (UT) | Associated Model or Instrument | Directly Linked Event(s) |
|---|---|---|---|
| Solar Energetic Particle | 2023-03-03 19:19 | MODEL: REleASE:ACE/EPAM 28.2-50.1 MeV | 2023-03-03T17:42:00-FLR-001<br>FLR Type: X2.0<br>2023-03-03T18:12:00-CME-001 |
| Solar Energetic Particle | 2023-03-03 22:11 | MODEL: REleASE:SOHO/EPHIN 28.2-50.1 MeV | 2023-03-03T17:42:00-FLR-001<br>FLR Type: X2.0<br>2023-03-03T18:12:00-CME-001 |
| Solar Energetic Particle | 2023-03-03 22:11 | MODEL: REleASE:SOHO/EPHIN 15.8-39.8 MeV | 2023-03-03T17:42:00-FLR-001<br>FLR Type: X2.0<br>2023-03-03T18:12:00-CME-001 |

Generate report for all CME parameters (PDF or TEXT)

Generate report for the most accurate and complete CME parameters only (PDF or TEXT)

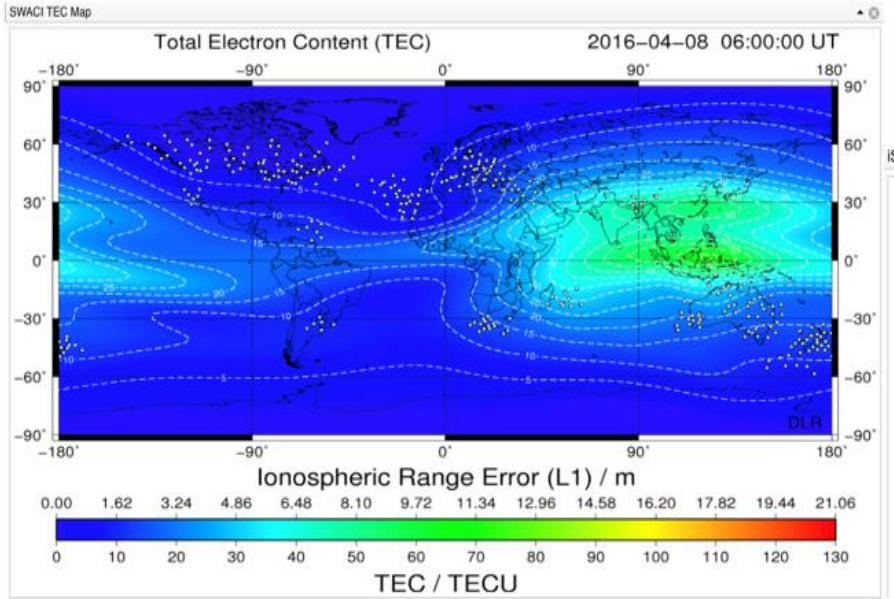
| Event Type | Start Time (UT) | Catalog | All Detecting Instruments | Source Location | CME Analysis |
|---|---|---|---|---|---|
| CME | 2023-03-01 02:24 | M2M_CATALOG | SOHO: LASCO/C2 | | Event Type: CME Analysis; Catalog: M2M_CATALOG; Measurement Type: LE; Prime?: true; Technique: Plane-of-sky; Long: NONE; Lat: -16.0; Speed: 264.0; Type: S; Half Width: 35.0; Time 21.5: 2023-03-01T16:05Z; WSA-ENLIL+Cone Result(s: Not modeled |
| CME | 2023-03-01 04:48 | M2M_CATALOG | SOHO: LASCO/C2 | | Event Type: CME Analysis; Catalog: M2M_CATALOG; Measurement Type: LE; Prime?: true; Technique: Plane-of-sky; Long: NONE; Lat: -16.0; Speed: 310.0; Type: S; Half Width: 35.0; Time 21.5: 2023-03-01T16:28Z; WSA-ENLIL+Cone Result(s: Not modeled |

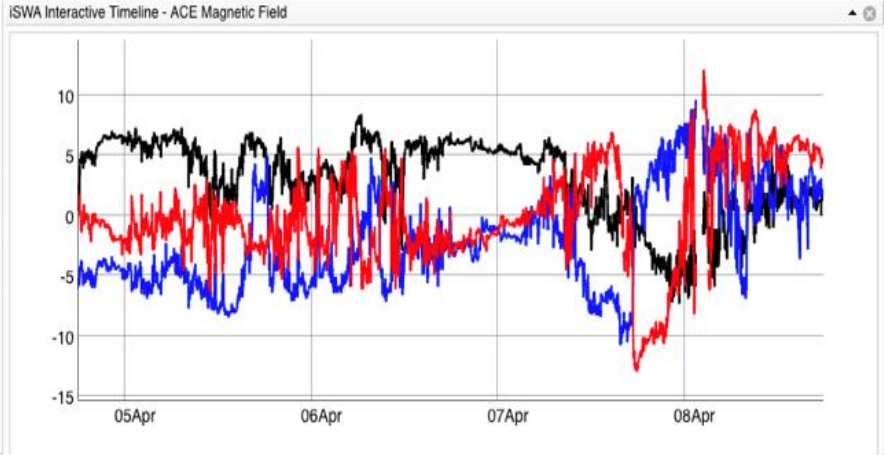
# Anomaly Support Example

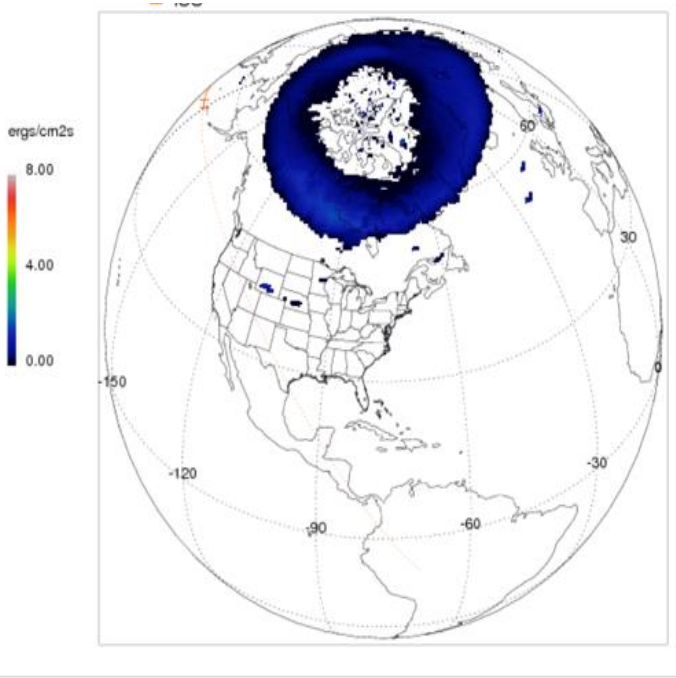
Please find below our assessment for the events on 2016-04-08:

Based on our preliminary analysis, space weather activity was low to moderate on 2016-04-08. There were no major solar flares or coronal mass ejections. The solar energetic particle environment at Earth was benign as GOES and SOHO proton fluxes were at background levels. However, the electron belt fluxes (>0.8 MeV channel) measured by GOES decreased below normal levels at the end of the day before (2016-04-07) due to a compression in the magnetosphere caused by an interplanetary shock that arrived at ACE around 2016-04-07T09:00Z. The interplanetary shock was believed to be associated with an arrival of a CME that originated in a filament eruption around 2016-04-04T14:40 UT close to solar disk center. This eruption was not visible in the coronagraphs and therefore was not measured, but it was noted in our logs. Geomagnetic activity was elevated to minor levels with Kp<=5 (ranges from 0-9, 9 being the strongest) due to this activity during the synoptic periods 2016-04-07T18:00Z to 2016-04-08T03:00Z.

The total electron content plot at 2016-04-08T06:00Z show slightly elevated levels at the anomaly location (see attached plot). I attached also the plot that describes the solar wind magnetic field at ACE (Bx (black), By (blue), Bz (red)) at the beginning of the day on 2016-04-08. Looking also at the Ovation Prime model, a precipitation model that separates different types of auroras, the auroral activity was very nominal during the 06UT time of the day. Auroral activity could be associated with scintillation and GPS error.



# New Tool at CCMC

## Develop by P. O'Brien et al.

UNCLASSIFIED - For Demonstration Purposes Only

# SEAESFC - NASA/CCMC

*Energetic Charged Particle Hazard Assessment System Flow Charts*

## Data Entry

UNCLASSIFIED DATA ENTRY ONLY!!!

Anomaly Description:

Date and Time of Anomaly (yyyy-mm-dd HH:MM:SS, UTC): 2023-02-27 18:19:00

History of GCR SEE on vehicle or in constellation: NO

Internal charging anomaly on vehicle or in constellation during 5 days (120 hours) prior to anomaly: NO

Automatically store anomalies in browser database

| Orbit | | |
|---|---|---|
| **Specify Type & Location** | **Catalog Lookup** | **Enter TLEs** |
| • Type GEO<br>• Inclination, deg<br>• Altitude of perigee, km<br>• Altitude of apogee, km<br><br>Anomaly Location:<br>• Latitude, deg<br>• East Longitude, deg<br>• Altitude, km<br><br>Run For This Orbit/Location | On-Line Ephemeris Source: NASA SSCWeb<br><br>ACE<br>1997-08-25T17:48 to 2023-05-22T23:48<br>SSC-Web<br>Run for selected vehicle | TLE Line 1<br>TLE Line 2<br>Space-Track.org provides ELSET/TLEs for registered users<br>Set Type and Location from TLE |

# Space Weather Overview

## 2021-359 (2021-12-25) to 2022-196 (2022-07-15)

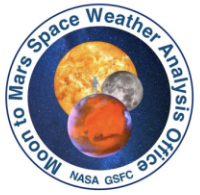
# JWST Continuous Support

- Overall highlights
  - 5 Solar Energetic Particle (SEP) events
    - 2022-01-20T07:20Z, associated with CME: 2022-01-20T06:12Z and M5.5 flare (2022-01-20T05:41Z)
    - 2022-03-28T12:45Z, associated with CME: 2022-03-28T12:09Z and M4.0 flare (2022-03-28T10:58Z)
    - 2022-03-31T06:20Z (>10 MeV only), associated with CME: 2022-03-31T06:20Z, X1.3 flare (2022-03-30T17:21Z), and arrival of CME: 2022-03-28T12:09Z at L1
    - 2022-04-02T14:30Z (>10 MeV only), associated with CME: 2022-04-02T13:38Z and M3.9 flare (2022-04-02T12:56Z)
    - 2022-07-09T15:232Z (SOHO COSTEP 15.8-39.8 MeV and 28.2-50.1 MeV), associated with CME: 2022-07-09T14:00Z and C8.5 fl
    - 9 other periods of slight enhancement in >10 MeV proton flux level (>50 MeV, >100 MeV fluxes near background levels during t
    - 1 additional period of slight enhancement in >10 MeV, >50 MeV, >100 MeV proton fluxes (below threshold)
  - 76 M-class and 6 X-class flares, some flaring may be associated with anomalies.
  - ICME arrivals at L1 on 2021-361, 2022-018, 2022-024, 2022-032, 2022-034, 2022-040, 2022-069, 2022-072, 2022-0
    2022-096, 2022-098, 2022-099, 2022-103, 2022-104, (2) 2022-119, 2022-128, 2022-131, 2022-134, 2022-157, 2022
    2022-184, 2022-188, 2022-192.
  - High Speed Stream arrivals at L1 on 2021-364, 2022-001, 2022-008, 2022-014, 2022-028, 2022-036, 2022-042, 202
    064, 2022-082, 2022-086, 2022-092, 2022-099, 2022-105, 2022-110, 2022-117, 2022-139, 2022-147, 2022-163, 20
- Anomalies

Space Weather Events for JWST
Processed: Mon Jan 16 18:25:00 2023 UTC
Source: # M. Anastopulos, 16 Jan 2023, 1:25 PM EST

| YYYY | DOY | HH | MM | SS | XDOY (UTC) XYEAR | Altitude (km) | Altitude (Re) | Errors | Unit | X,GSE (Re) | Y,GSE (Re) | Z,GSE (Re) | Regime |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2021 | 361 | 8 | 38 | 00 | -- 2021-12-27T08:38:00-IPS-001 -- Peak Bt=15nT Southmost Bz=-10nT | | | | | | | | |
| 2021 | 361 | 12 | 0 | 00 | -- 2021-12-27T12:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2021 | 362 | 3 | 50 | 00 | -- 2021-12-28T03:50:00-FLR-001 -- M1.8 | | | | | | | | |
| 2021 | 362 | 16 | 0 | 00 | -- 2021-12-28T16:00:00-FLR-001 -- M1.6 | | | | | | | | |
| 2021 | 363 | 19 | 31 | 00 | -- 2021-12-29T19:31:00-IPS-001 -- Peak Bt=21nT Southmost Bz=-10nT | | | | | | | | |
| 2022 | 1 | 6 | 0 | 00 | -- 2022-01-01T06:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 1 | 7 | 7 | 00 | -- 2022-01-01T07:07:00-FLR-001 -- M1.1 | | | | | | | | |
| 2022 | 3 | 3 | 0 | 00 | -- 2022-01-03T03:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 3 | 6 | 0 | 00 | -- 2022-01-03T06:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 8 | 16 | 58 | 00 | -- 2022-01-08T16:58:00-IPS-001 -- Peak Bt=19nT Southmost Bz=-16nT | | | | | | | | |
| 2022 | 8 | 18 | 0 | 00 | -- 2022-01-08T18:00:00-GST-999 -- Kp=5 | | | | | | | | |
| 2022 | 8 | 21 | 0 | 00 | -- 2022-01-08T21:00:00-GST-999 -- Kp=5 | | | | | | | | |
| 2022 | 14 | 1 | 47 | 00 | -- 2022-01-14T01:47:00-FLR-001 -- M1.8 | | | | | | | | |
| 2022 | 14 | 6 | 50 | 00 | -- 2022-01-14T06:50:00-IPS-001 -- Peak Bt=18nT Southmost Bz=-17nT | | | | | | | | |
| 2022 | 14 | 21 | 0 | 00 | -- 2022-01-14T21:00:00-GST-001 -- Kp=6 | | | | | | | | |
| 2022 | 15 | 0 | 0 | 00 | -- 2022-01-15T00:00:00-GST-999 -- Kp=5 | | | | | | | | |
| 2022 | 15 | 18 | 0 | 00 | -- 2022-01-15T18:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 15 | 21 | 0 | 00 | -- 2022-01-15T21:00:00-GST-999 -- Kp=5 | | | | | | | | |
| 2022 | 16 | 0 | 0 | 00 | -- 2022-01-15T00:00:00-GST-999 -- Kp=5 | | | | | | | | |
| 2022 | 16 | 18 | 0 | 00 | -- 2022-01-16T18:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 18 | 0 | 0 | 00 | -- 2022-01-18T00:00:00-GST-999 -- Kp=5 | | | | | | | | |
| 2022 | 18 | 17 | 1 | 00 | -- 2022-01-18T17:01:00-FLR-001 -- M1.5 | | | | | | | | |
| 2022 | 18 | 23 | 4 | 00 | -- 2022-01-18T23:04:00-IPS-001 -- Peak Bt=9nT Southmost Bz=-9nT | | | | | | | | |
| 2022 | 19 | 0 | 0 | 00 | -- 2022-01-19T00:00:00-GST-001 -- Kp=6 | | | | | | | | |
| 2022 | 19 | 3 | 0 | 00 | -- 2022-01-19T03:00:00-GST-999 -- Kp=5 | | | | | | | | |
| 2022 | 19 | 6 | 0 | 00 | -- 2022-01-19T06:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 20 | 5 | 41 | 00 | -- 2022-01-20T05:41:00-FLR-001 -- M5.5 | | | | | | | | |
| 2022 | 20 | 7 | 20 | 00 | -- 2022-01-20T07:20:00-SEP-001 -- GOES>100MeV | | | | | | | | |
| 2022 | 20 | 8 | 0 | 00 | -- 2022-01-20T08:00:00-SEP-001 -- GOES>10MeV | | | | | | | | |
| 2022 | 20 | 8 | 7 | 00 | -- 2022-01-20T08:07:00-SEP-001 -- SOHO15.8-39.8MeV | | | | | | | | |
| 2022 | 20 | 8 | 10 | 00 | -- 2022-01-20T08:10:00-SEP-001 -- SOHO28.2-50.1MeV | | | | | | | | |
| 2022 | 21 | 12 | 55 | 00 | -- 2022-01-21T12:55:00-IPS-001 -- Peak Bt=8nT Southmost Bz=-5nT | | | | | | | | |
| 2022 | 24 | 17 | 9 | 00 | -- 2022-01-24T17:09:00-IPS-001 -- Peak Bt=13nT Southmost Bz=-9nT | | | | | | | | |
| 2022 | 28 | 21 | 0 | 00 | -- 2022-01-28T21:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 29 | 0 | 0 | 00 | -- 2022-01-29T00:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 29 | 3 | 0 | 00 | -- 2022-01-29T03:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 29 | 6 | 0 | 00 | -- 2022-01-29T06:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 29 | 12 | 0 | 00 | -- 2022-01-29T12:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 29 | 22 | 45 | 00 | -- 2022-01-29T22:45:00-FLR-001 -- M1.1 | | | | | | | | |
| 2022 | 32 | 21 | 0 | 00 | -- 2022-02-01T21:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 32 | 21 | 37 | 00 | -- 2022-02-01T21:37:00-IPS-001 -- Peak Bt=13nT Southmost Bz=-12nT | | | | | | | | |
| 2022 | 33 | 0 | 0 | 00 | -- 2022-02-02T00:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 33 | 15 | 0 | 00 | -- 2022-02-02T15:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 34 | 3 | 0 | 00 | -- 2022-02-03T03:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 34 | 6 | 0 | 00 | -- 2022-02-03T06:00:00-GST-999 -- Kp=5 | | | | | | | | |
| 2022 | 34 | 9 | 0 | 00 | -- 2022-02-03T09:00:00-GST-999 -- Kp=5 | | | | | | | | |
| 2022 | 34 | 12 | 0 | 00 | -- 2022-02-03T12:00:00-GST-999 -- Kp=4 | | | | | | | | |
| 2022 | 34 | 23 | 22 | 00 | -- 2022-02-03T23:22:00-IPS-001 -- Peak Bt=19nT Southmost Bz=-18nT | | | | | | | | |

# ANOMALY REQUEST SYSTEM




Moon to Mars Space Weather Analysis Office



## Anomaly Request

For an anomaly assessment, we require the following information:

Your name

Your email

Date of event

03/27/2023

Time of event

Orbit

Altitude

Altitude of perigee

Altitude of apogee

Inclination

Orbit Latitude

Orbit Longitude

Orbit Description

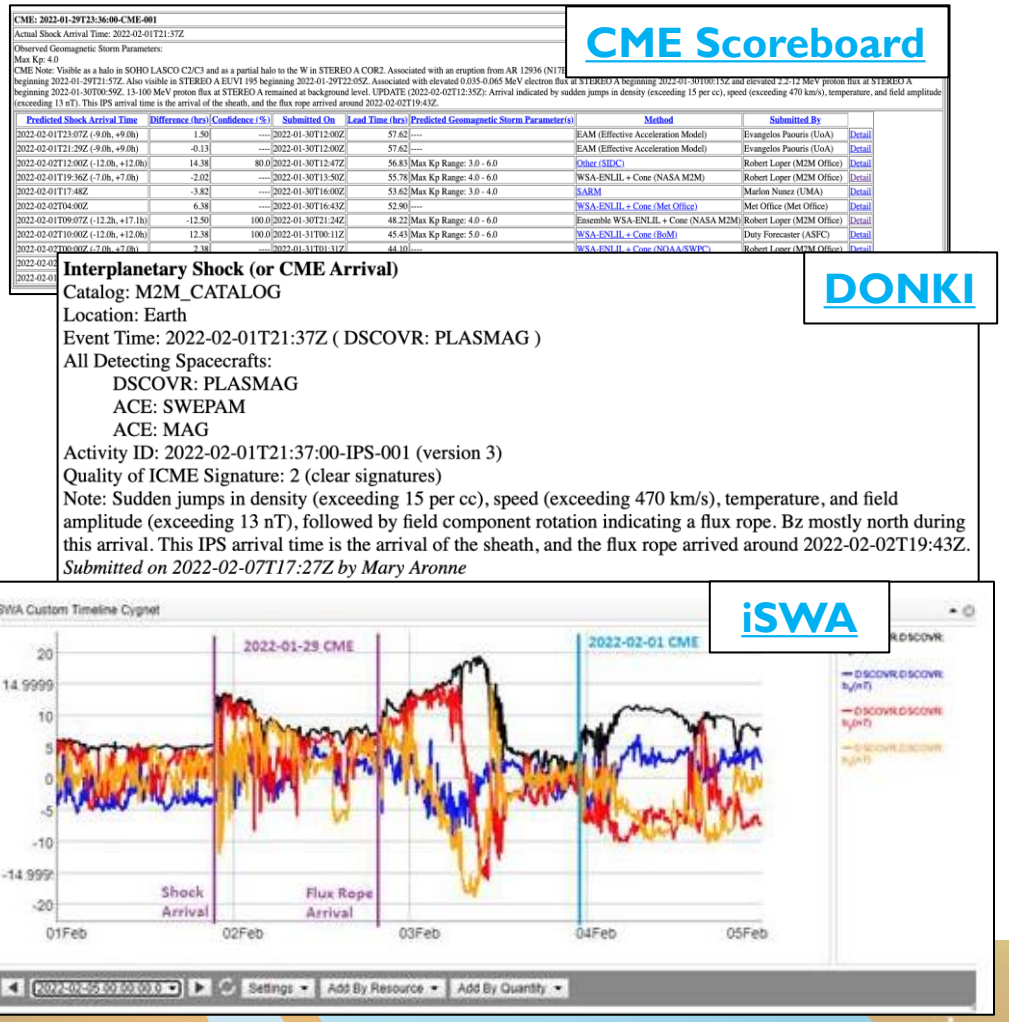
Description of Anomaly

Additional Comments (optional)

Submit

# SWx Assessment Starlink Event

## (Feb 3rd SpaceX Starlink Launch )

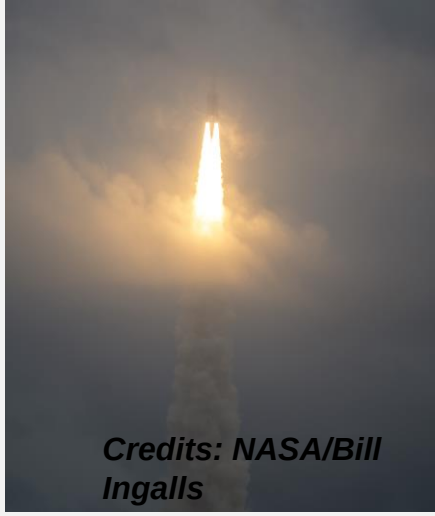



Following a report from SpaceX that up to 40 Starlink satellites were impacted by a geomagnetic storm, NASA requested additional information from M2M to answer the following questions:

- *Was there notable SWx activity in the near-Earth environment around the SpaceX launch window?*
- *What caused the minor geomagnetic storm impacting Starlink satellites?*
- *What SWx predictions were made by M2M and other external forecasting groups around the time of this launch?*

- M2M promptly provided the relevant analysis information to NASA HQ, referencing M2M analysis documentation accessible via DONKI , CME Scoreboard, and iSWA (hosted by CCMC).
- Additionally, we coordinated directly with NOAA SWPC to evaluate the cause of geomagnetic activity and provided a thorough analysis of SWx activity related to the observed enhancement in Kp activity.

# Space Weather Support for NASA Mission Launches


Credits: NASA/Bill Ingalls

M2M analysts provided analysis of the SWx environment tailored to the **James Webb Space Telescope** launch criteria created by the JWST team.

- On the week of the launch the team with daily space weather briefings and written reports. M2M extended its space weather monitoring hours around the launch to alert the JWST team about any significant changes in the SWx environment.
- M2M analyst also collaborated with researchers of the science community to better analyze the SWx environment expected on the launch day.
- On the day (and eve) of the launch, the M2M team participated in the online JWST Space Weather Launch Support Team meeting, contributing to continuous monitoring of potential threshold crossings and ongoing SWx discussion. On this day space weather was monitored around the clock (24 hours).
- M2M analysts monitored the availability of CCMC space weather analysis tools and kept in touch with the CCMC team/other mission data providers to quickly resolve issues and mitigate potential for outages.

**M2M Primary Analyst:** A. Chulaki **M2M Secondary Analyst:** R. Loper **Briefing Date:** 2021-12-25

| ID | Parameter | Threshold(s) | Assessment/Forecast |
|---|---|---|---|
| 201 | Proton Radiation Effects, Solar Flare Activity | **Monitoring begins at L-12 hours with LCC applicable at L-5 hours:**<br>• Active NOAA SWPC **SPACE WEATHER ADVISORY WARNING** or **EXTENDED WARNING** for proton event 100 MeV integral flux above 1pfu<br>• Solar radiation proton flux exceeds 5 pfu for energy thresholds > 50 MeV. | • The proton fluxes observed by GOES for energy channels > 50 MeV and > 100 MeV have remained at background levels.<br>• The MAG4 model continues to show an increased probability for flaring/CMEs, which could possibly result in a proton flux enhancement.<br>• The AR 12907 with the highest magnetic complexity (beta-gamma) has almost reached the SW limb, while ARs 12908, and 12909 are currently still at longitudes favorable for magnetic connectivity with Earth.<br>  ○ These ARs (specifically AR 12909 and 12907) produced a few lower C-class flares today.<br>• More eastern ARs 12916, 12917 and 12918 are not yet magnetically connected to Earth and will not be connected for a couple of days. Observed proton flux enhancement from these regions is less likely to be observed in the near-Earth environment.<br>  ○ These ARs (especially AR 12918) produced multiple low C-class flares today.<br>• There are currently no active SPACE WEATHER ADVISORY WARNINGS or EXTENDED WARNINGS from NOAA SWPC for an SEP event.<br>  ○ NOAA SWPC 3-Day Forecast Product (issued 2021-12-25T12:30Z) indicates the following probabilities for a Solar Radiation Storm (S1 or greater):<br>  ▪ Dec 25: 10%<br>  ▪ Dec 26: 1%<br>  ▪ Dec 27: 1% |
| 202 | Internal Charging, Electron Flux Level | **From L-5 hours to L-10 minutes:**<br>• Electron flux for energies greater than 2 MeV is greater than $4.98 \times 10^4$ e/sec/cm²/ster as measured at the GOES West spacecraft. | • The >2 MeV electron flux observed by GOES West has continued to be elevated above background levels, reaching the peak of ~1800 pfu today.<br>  ○ This radiation belt enhancement is likely associated with the waning influence of the HSS at arriving at L1 on 2021-12-19.<br>• The >2 MeV electron flux levels were below the JWST threshold of $4.98 \times 10^4$ e/sec/cm²/ster during the post-launch period on 2021-12-25. |
| 203 | Surface Charging from Geomagnetic Substorms | **From L-1 hour to L-10 minutes:**<br>• Geomagnetic Kp Index is equal to or greater than 4. | • The Geomagnetic Kp Index varied between 1 and 3 (below minor levels) within 12 hours of the launch today, reaching the maximum of 3 during the synoptic period from 2021-12-25T06:00Z to 2021-12-25T 09:00Z.<br>• For 3-4 hours before the launch there was a possibility that Kp might cross into 4 due to a prolonged period of negative Bz (with the maximum negative value of Bz just below –5nT) from ~2021-12-25T05:00Z to the launch time. This prolonged period of negative Bz was possibly the |

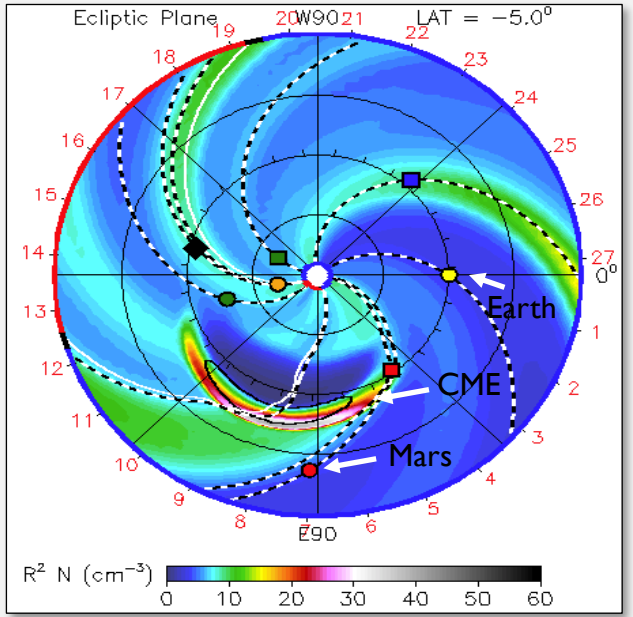
# Space Weather and Ingenuity's Flights

*STEREO A 195 image from 17 April 2021 1645 UTC of Mars-directed flare*

*STEREO A COR2 image from 17 April 2021 1708 UTC of Mars-directed CME*

- 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 challenges with deep space exploration missions, t**he Moon to Mars (M2M)** Space Weather Analysis Office will conduct and provide model-based predictions and analyses as proving grounds of tool development in support of SRAG.
- M2M also supports NASA robotic missions with space weather assessments and anomaly analysis support.
- CCMC and M2M are collaborating to create an effective NASA in-house R2O2R pipeline in support of human spaceflight.
- Currently working closely with missions like JWST, PSP, Solar Orbiter, and MAVEN (teams use our analysis and notifications to create a database specific for their mission).

**We always looking forward to pushing the envelope on the research development and are already working with other missions/groups to validate predictions of the space weather environment at different locations.**

# M2M SPACE WEATHER OFFICE TEAM

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THANK YOU!