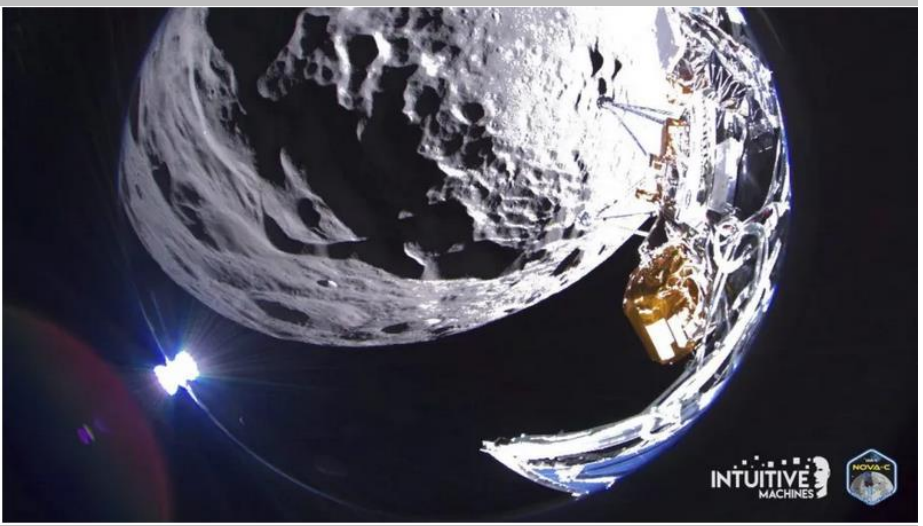
Smart Lander for Investigating the Moon (SLIM)
Jan 2024 (Image: JAXA)

Odysseus Lunar Lander
Feb 2024 (Image: Intuitive Machines)



SCAF 2024: Welcome and NASA Introductory Comments

Joseph I. Minow, PhD
Technical Fellow for Space Environments
NASA Engineering and Safety Center
NASA, Marshall Space Flight Center

Spacecraft Anomalies and Failures 2024
27 March 2024, GSFC, Greenbelt, MD
joseph.minow@nasa.gov

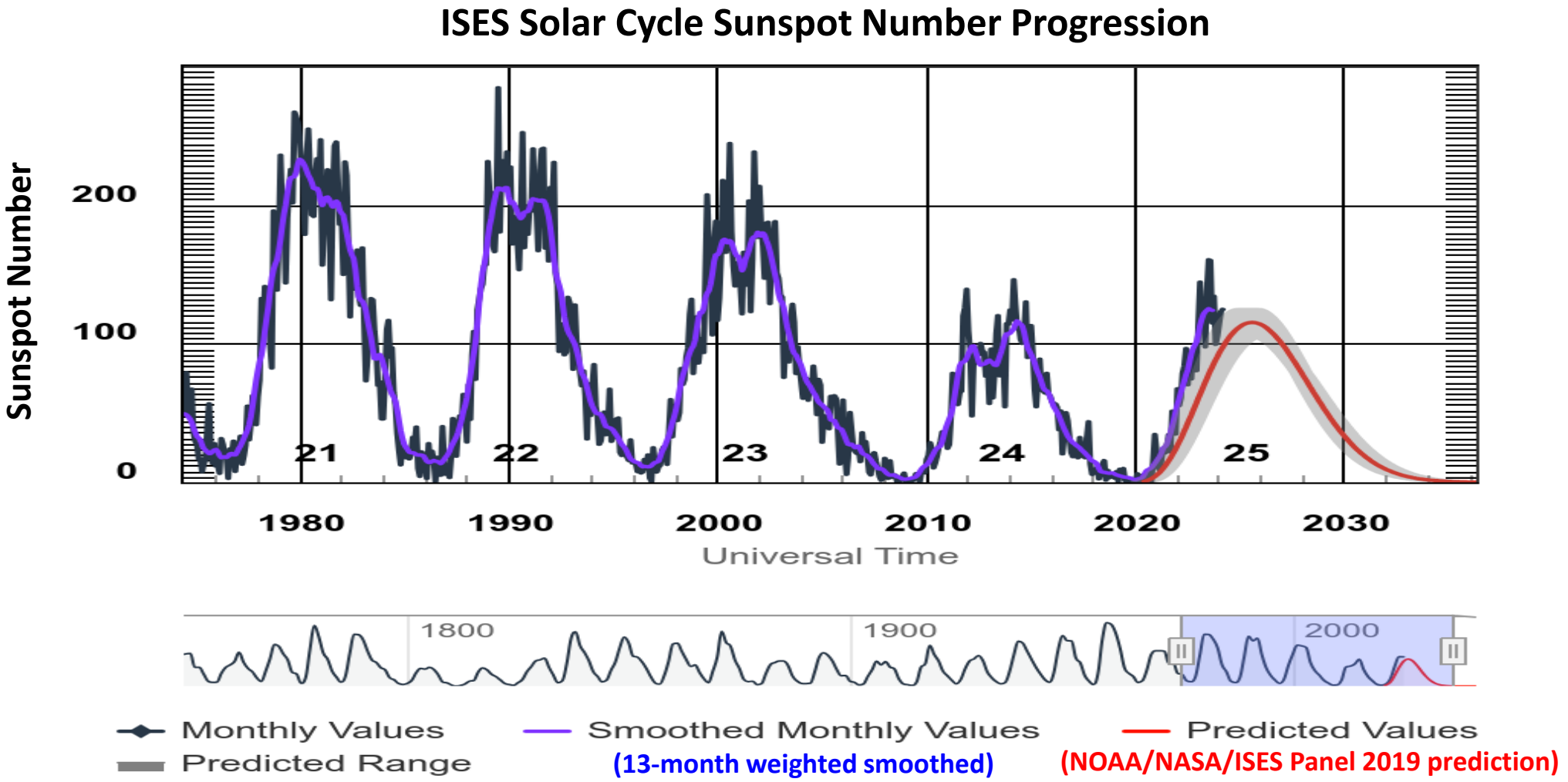
Outline

- Introduction and logistics
- Comments on state of Solar Cycle 25 space environment
- Introduction to Day 1 presentations

Introduction

- Welcome to NASA GSFC and SCAF 2024!
- Logistics
  - Fire, weather, restrooms
  - Maps to on-site cafeteria, food options off-site at check-in desk
- Wi-fi is available in the auditorium:
  - NASA personnel connect to NASA Device network
  - Non-NASA personnel connect to NASA Guest network
- Session chairs
  - Day 1: Joseph Minow NASA/MSFC
  - Day 2: Michael Manning NRO
- Organizing committee
  - Mike Campola NASA/GSFC
  - Martha Obryan GSFC/SSAI
  - Linda Parker MSFC/Space Weather Solutions
  - Mike Squire NASA/LARC
  - Yihua Zheng NASA/GSFC
- Let us know if you have questions or need help today!

Solar Activity



NOAA Space Weather Prediction Center
https://www.swpc.noaa.gov/products/solar-cycle-progression

New SWPC Solar Cycle Progression Predictions (Experimental)

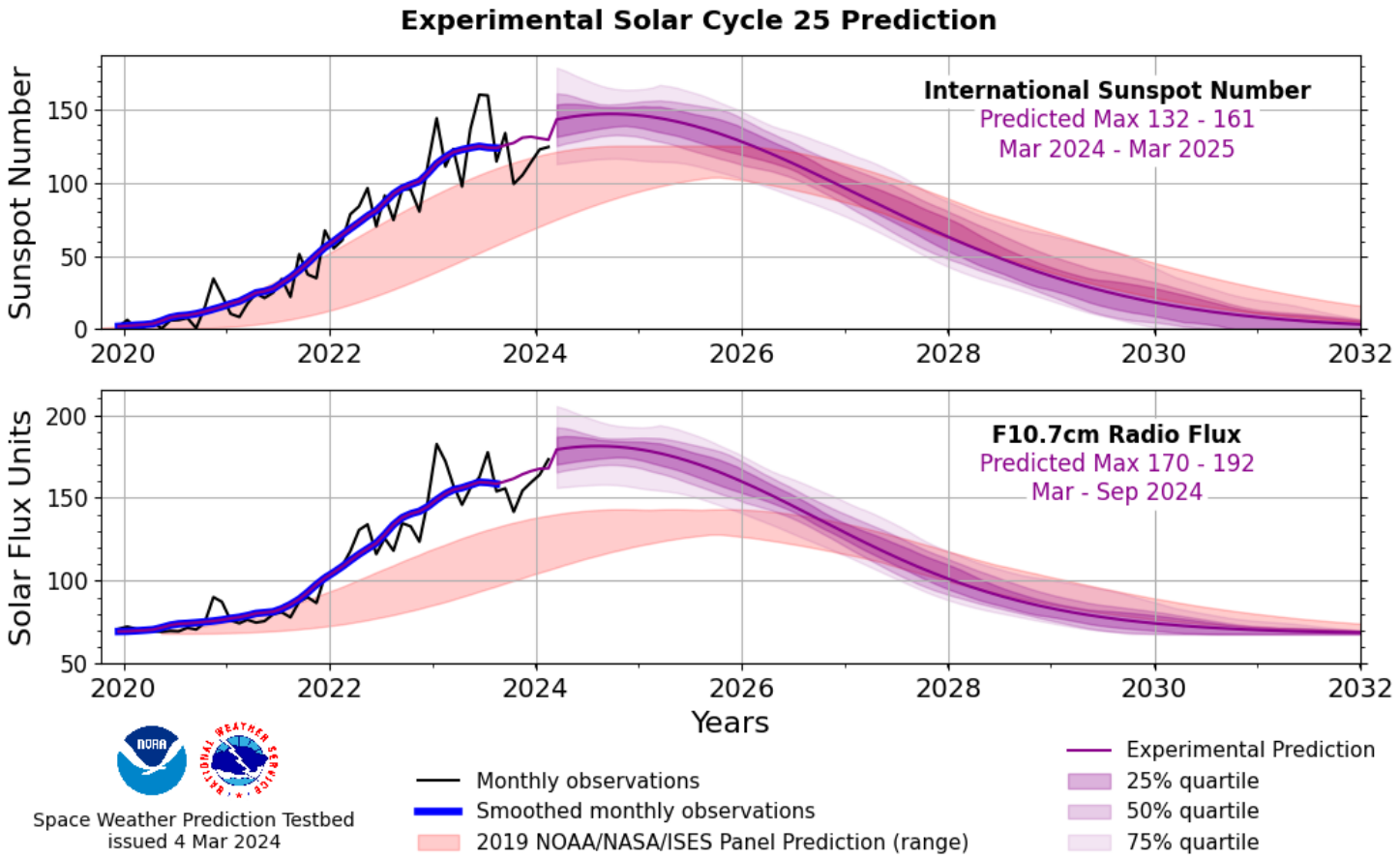
- NOAA's Space Weather Prediction Center released an updated solar cycle progression prediction in December 2023

https://testbed.swpc.noaa.gov/products/solar-cycle-progression-updated-prediction-experimental

- NOAA/NASA/ISES Panel 2019 prediction
  - Cycle 25 peak in July 2025
  - SSN of 115 (range 105 – 125)

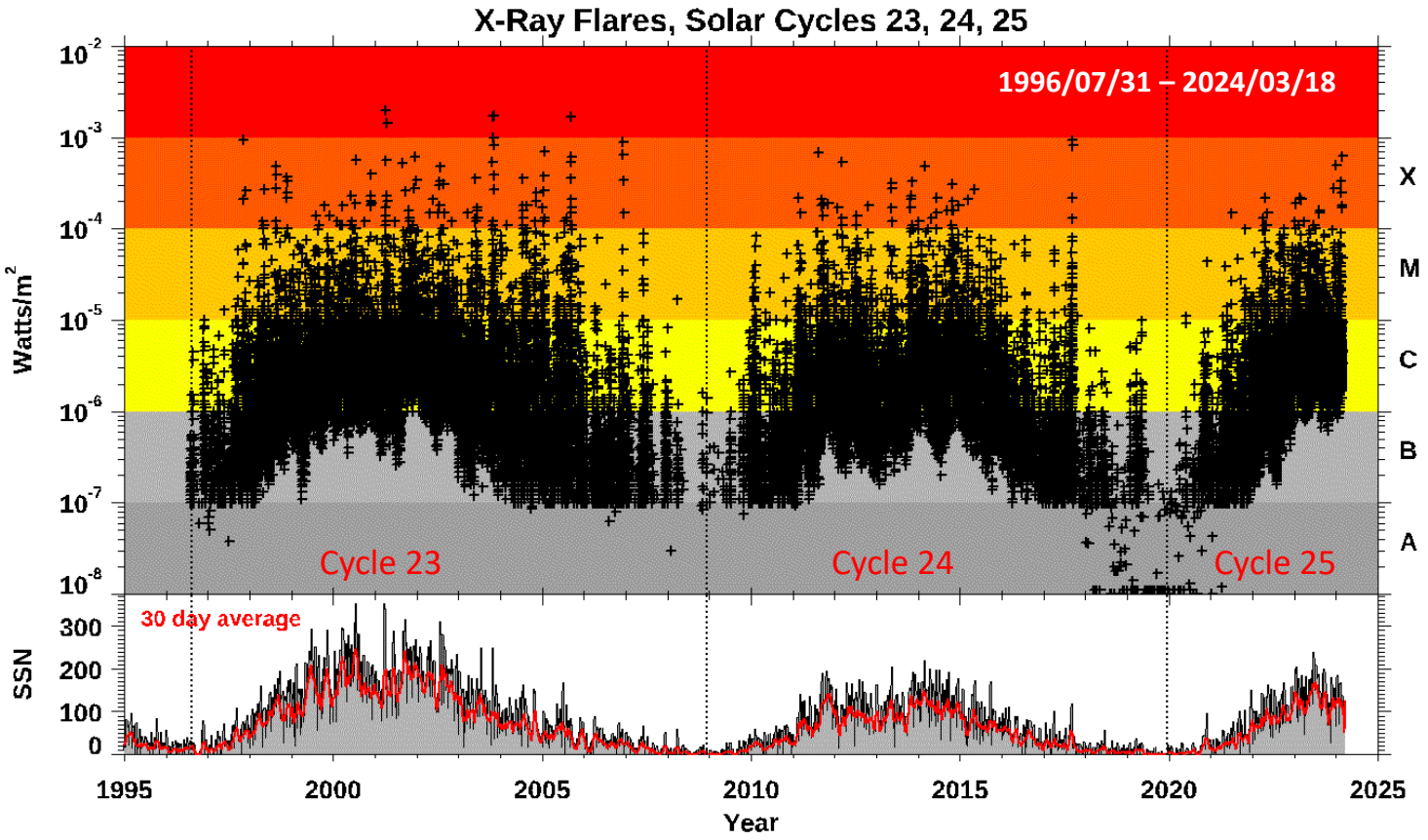
- NOAA SWPC Updated Prediction (experimental)
  - Cycle 25 peak in September 2024
  - SSN of 147 (range 133 – 154)

- Suggests Cycle 25 (current) will ultimately come in between Cycle 23 and Cycle 24 in activity



Solar X-Ray Flares

- Major SWx impact of x-ray flares is increased ionization in the D-region ionosphere which interferes with terrestrial HF radio systems
- Large M and X class flares are correlated with coronal mass ejections and solar particle events (SPE) which can potentially impact satellite operations
- X-ray flares can provide advanced warning for geomagnetic storms, SPEs



X-ray flare data source:
https://www.swpc.noaa.gov/products/solar-and-geophysical-event-reports

100 Largest X-Ray Flares in Cycles 23, 24, and 25

Rank	YYYY DOY HH:MM	Class	Cycle
1	2001 092 21:51	X20	23
2	2003 308 19:53	X17.4	23
3	2003 301 11:10	X17.2	23
4	2005 250 17:40	X17.0	23
5	2001 105 13:50	X14.4	23
6	2003 302 20:49	X10.0	23
7	1997 310 11:55	X9.4	23
8	2017 249 12:02	X9.3	24
9	2006 339 10:35	X9.0	23
10	2003 306 17:25	X8.3	23
11	2017 253 16:06	X8.2	24
12	2005 020 07:01	X7.1	23
13	2011 221 08:05	X6.9	24
14	2006 340 18:47	X6.5	23
15	2024 053 22:34	X6.3	25
16	2001 347 14:30	X6.2	23
17	2005 252 20:04	X6.2	23
18	2000 196 10:24	X5.7	23
19	2001 096 19:21	X5.6	23
20	2012 067 00:24	X5.4	24
21	2003 296 08:35	X5.4	23
22	2005 251 21:06	X5.4	23
23	2001 237 16:45	X5.3	23
24	2023 365 21:55	X5.0	25
25	2014 056 00:49	X4.9	24
26	1998 230 22:19	X4.9	23
27	2002 204 00:35	X4.8	23
28	2000 331 16:48	X4.0	23
29	2003 307 09:55	X3.9	23
30	1998 231 21:45	X3.9	23
31	2005 017 09:52	X3.8	23
32	1998 326 06:42	X3.7	23
33	2003 148 00:27	X3.6	23
34	2004 198 13:55	X3.6	23
35	2005 252 09:59	X3.6	23
36	2006 347 02:40	X3.4	23
37	2001 362 20:45	X3.4	23
38	2002 201 21:30	X3.3	23
39	2024 040 13:14	X3.3	25
40	2013 309 22:12	X3.3	24
41	1998 332 05:52	X3.3	23
42	2013 134 01:11	X3.2	24
43	2014 297 21:41	X3.1	24
44	2002 236 01:12	X3.1	23
45	2002 196 20:08	X3.0	23
46	2001 345 08:08	X2.8	23
47	1998 230 08:24	X2.8	23
48	2013 133 16:05	X2.8	24
49	2023 348 17:02	X2.8	25
50	2015 125 22:11	X2.7	24
51	1998 126 08:09	X2.7	23
52	2003 307 01:30	X2.7	23
53	2005 015 23:02	X2.6	23
54	2001 267 10:38	X2.6	23
55	1997 331 13:17	X2.6	23
56	2024 047 06:53	X2.5	25
57	2004 315 02:13	X2.5	23
58	1998 326 16:23	X2.5	23
59	2001 100 05:26	X2.3	23
60	2000 329 15:13	X2.3	23
61	2000 158 15:25	X2.3	23
62	2013 302 21:54	X2.3	24
63	2014 161 11:42	X2.2	24
64	1998 327 06:44	X2.2	23
65	2023 048 20:16	X2.2	25
66	2011 046 01:56	X2.2	24
67	2017 249 09:10	X2.2	24
68	2022 110 03:57	X2.2	25
69	2005 253 22:11	X2.1	23
70	2023 062 17:52	X2.1	25
71	2013 298 15:03	X2.1	24
72	2015 070 16:22	X2.1	24
73	1997 308 05:58	X2.1	23
74	2002 140 15:27	X2.1	23
75	2011 249 22:20	X2.1	24
76	2014 300 14:47	X2.0	24
77	2000 329 05:02	X2.0	23
78	2014 299 10:56	X2.0	24
79	2001 102 10:28	X2.0	23
80	2004 312 16:06	X2.0	23
81	2023 009 18:50	X1.9	25
82	2011 267 09:40	X1.9	24
83	2000 194 10:37	X1.9	23
84	2000 330 18:44	X1.9	23
85	2011 307 20:27	X1.9	24
86	2004 197 01:41	X1.8	23
87	2002 199 07:44	X1.8	23
88	2014 354 00:28	X1.8	24
89	2024 052 23:07	X1.8	25
90	2012 297 03:17	X1.8	24
91	2000 084 07:52	X1.8	23
92	2004 231 17:40	X1.8	23
93	1999 287 09:00	X1.8	23
94	2000 329 21:59	X1.8	23
95	2011 250 22:38	X1.8	24
96	2003 160 21:39	X1.7	23
97	2001 088 10:15	X1.7	23
98	2024 053 06:32	X1.7	25
99	2013 298 08:01	X1.7	24
100	2005 256 23:22	X1.7	23

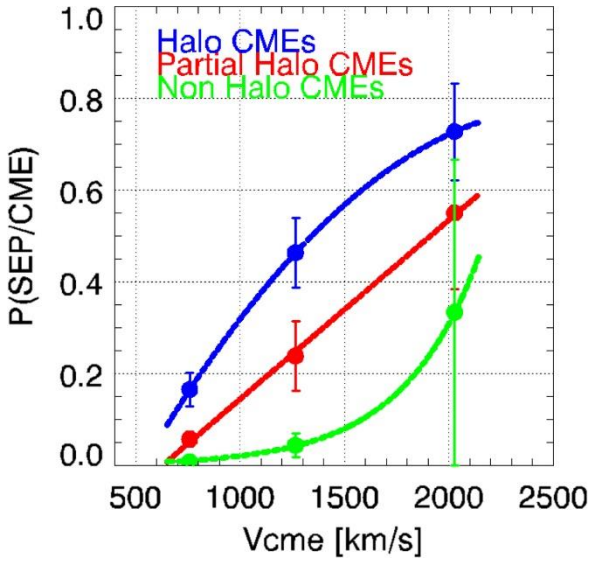
Largest Cycle 25 x-ray flares to date are ≤ X3.3 in intensity with two reaching X5.0 and X6.3

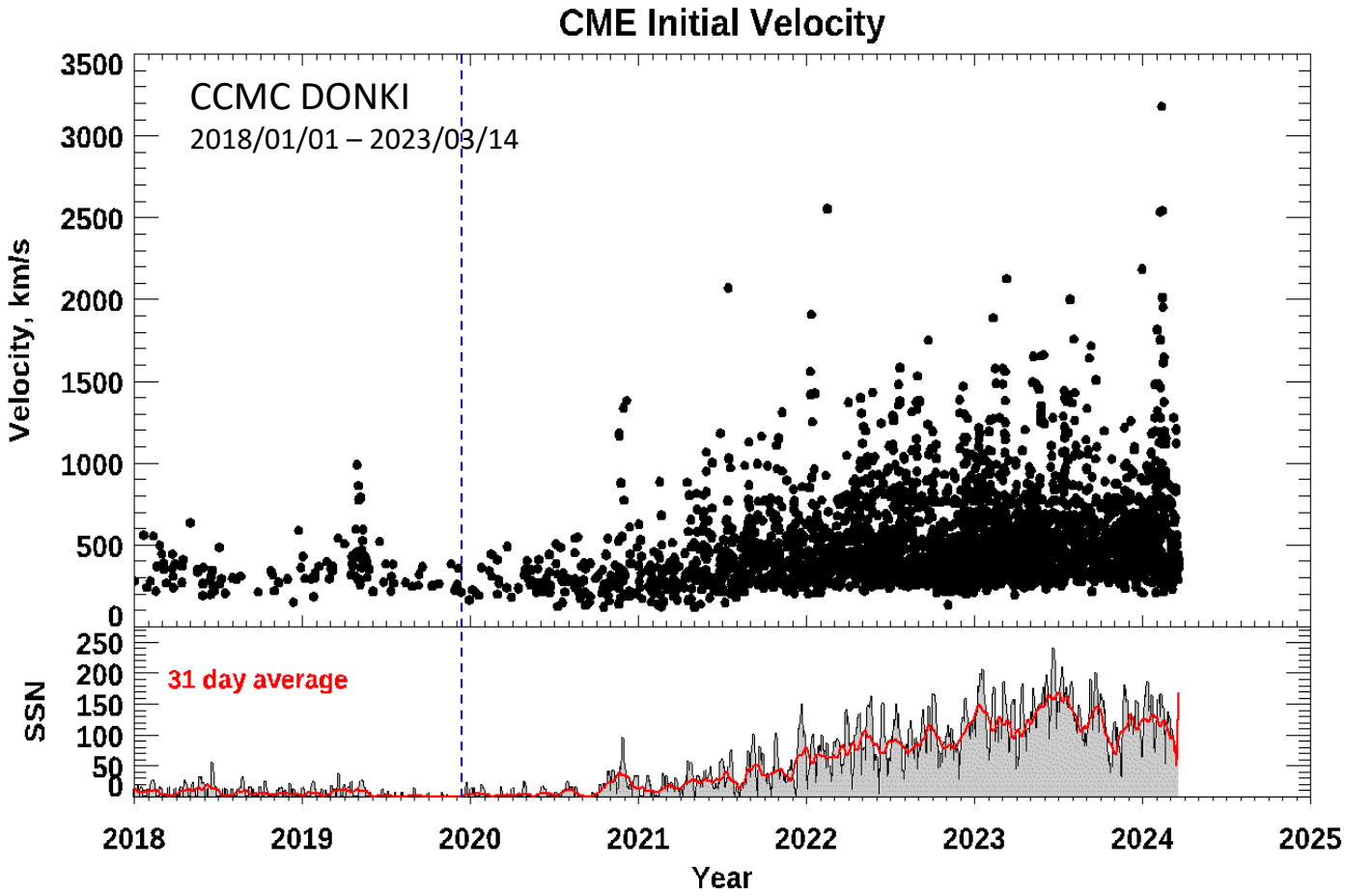
Coronal Mass Ejections (CME)

- CME formation rates and the number of high speed CMEs is correlated with solar activity

- Fast CMEs are particularly geoeffective when headed towards Earth:
  - Relativistic electron enhancements in the outer radiation belt (internal charging)
  - Magnetospheric hot plasma (surface charging)
  - Solar protons and heavy ions (single event effects)
  - Geomagnetically induced currents

Papaioannou et al., 2018

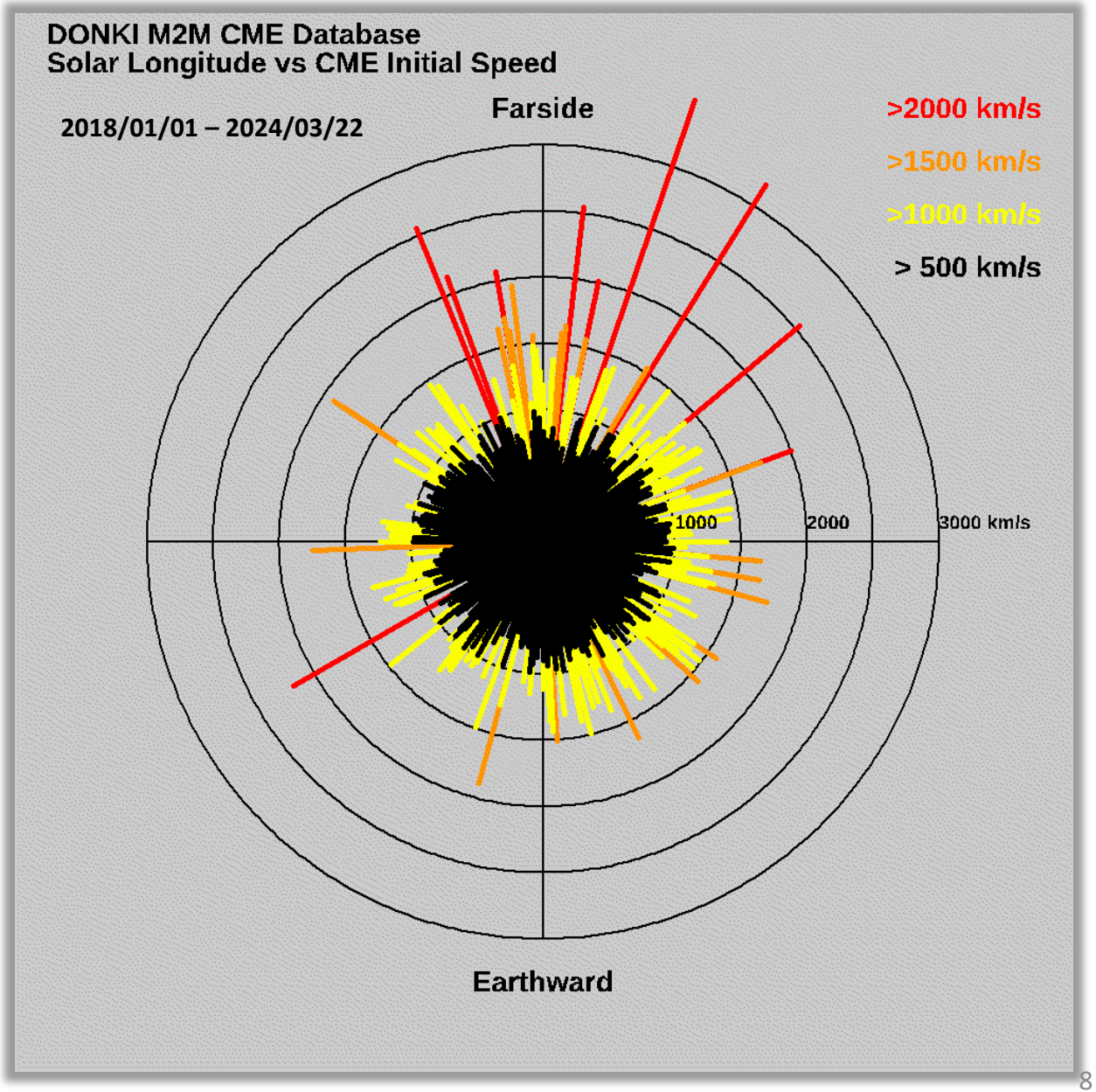




- CME is data from GSFC's Moon to Mars (M2M) Space Weather Office Catalog (most accurate only) available from the GSFC CCMC *Space Weather Database of Notifications, Knowledge, Information* (DONKI) database
- URL: https://ccmc.gsfc.nasa.gov/tools/DONKI/

CME Initial Velocity: 2018 to present

- GSFC's Moon to Mars Space Weather Analysis Office estimates the 3-D kinematic properties of CMEs including velocity, half angle, and source location on the Sun using the StereoCaT tool and archives the results on DONKI
- Earth has been relatively lucky so far in Solar Cycle 25 with the fastest CMEs (>2000 km/s) observed to forming primarily on the farside of the Sun with little or no direct impact on near Earth space
- Geomagnetic storm and solar particle event activity has therefore been relatively moderate for the current cycle
- Good for satellite operators!

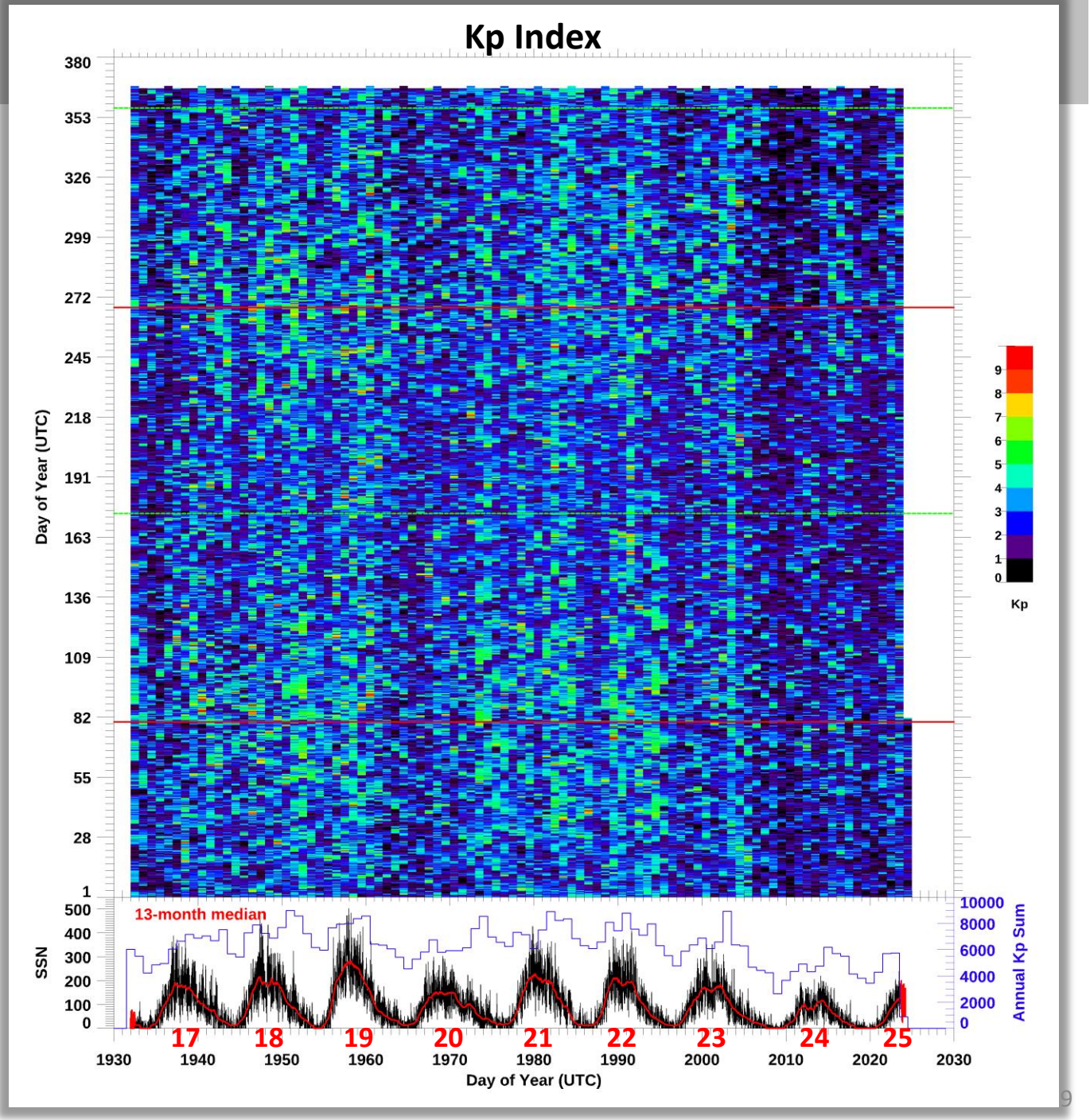


Geomagnetic Activity

- The geomagnetic Kp index is a convenient proxy used for monitoring geomagnetic storm activity
  - Greatest magnetic disturbance in a chain of midlatitude stations over a 3-hour period

- Geomagnetic storm impacts:
  - Outer belt surface and internal charging
  - LEO satellite drag
  - HF radio propagation interference
  - Radio scintillation
  - Geomagnetic induced currents, power grid fluctuations

- Geomagnetic activity during Solar Cycle 24 and current Cycle 25 have been relatively low compared to geomagnetic storm history from earlier cycles over the past 100 years



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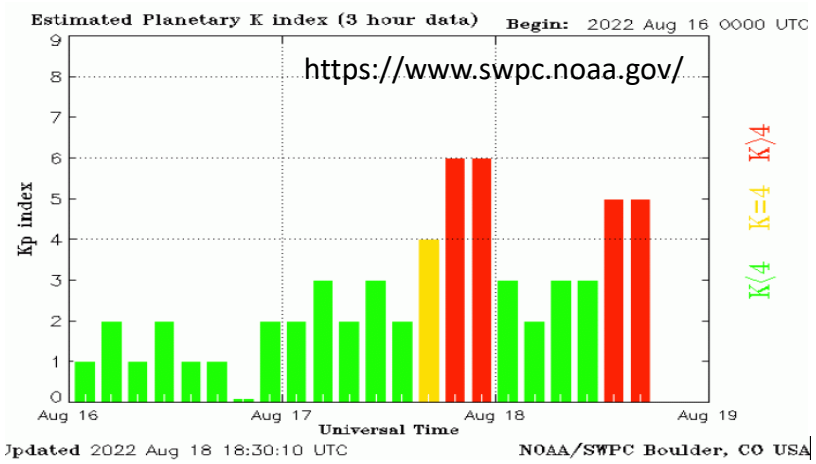
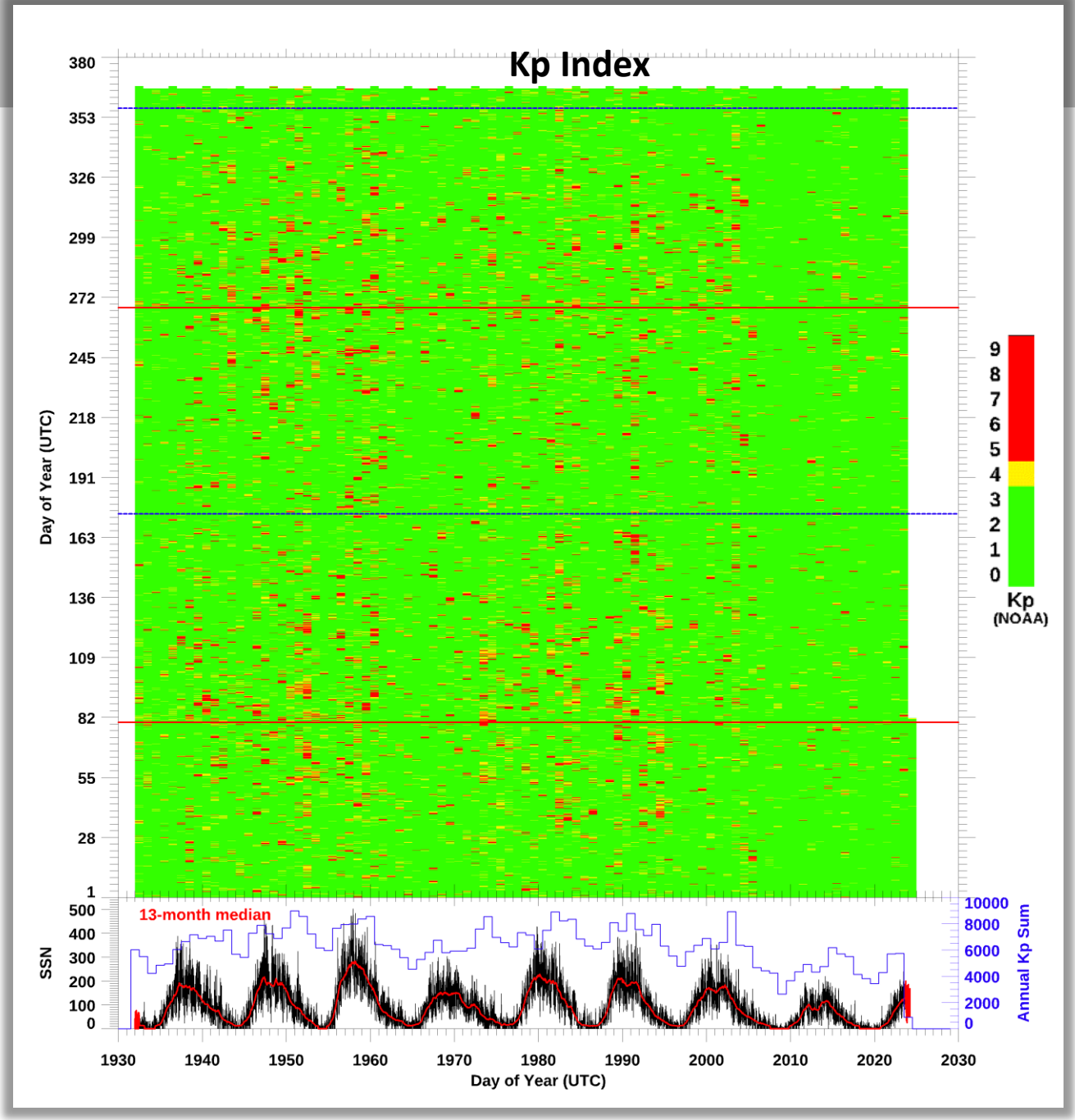
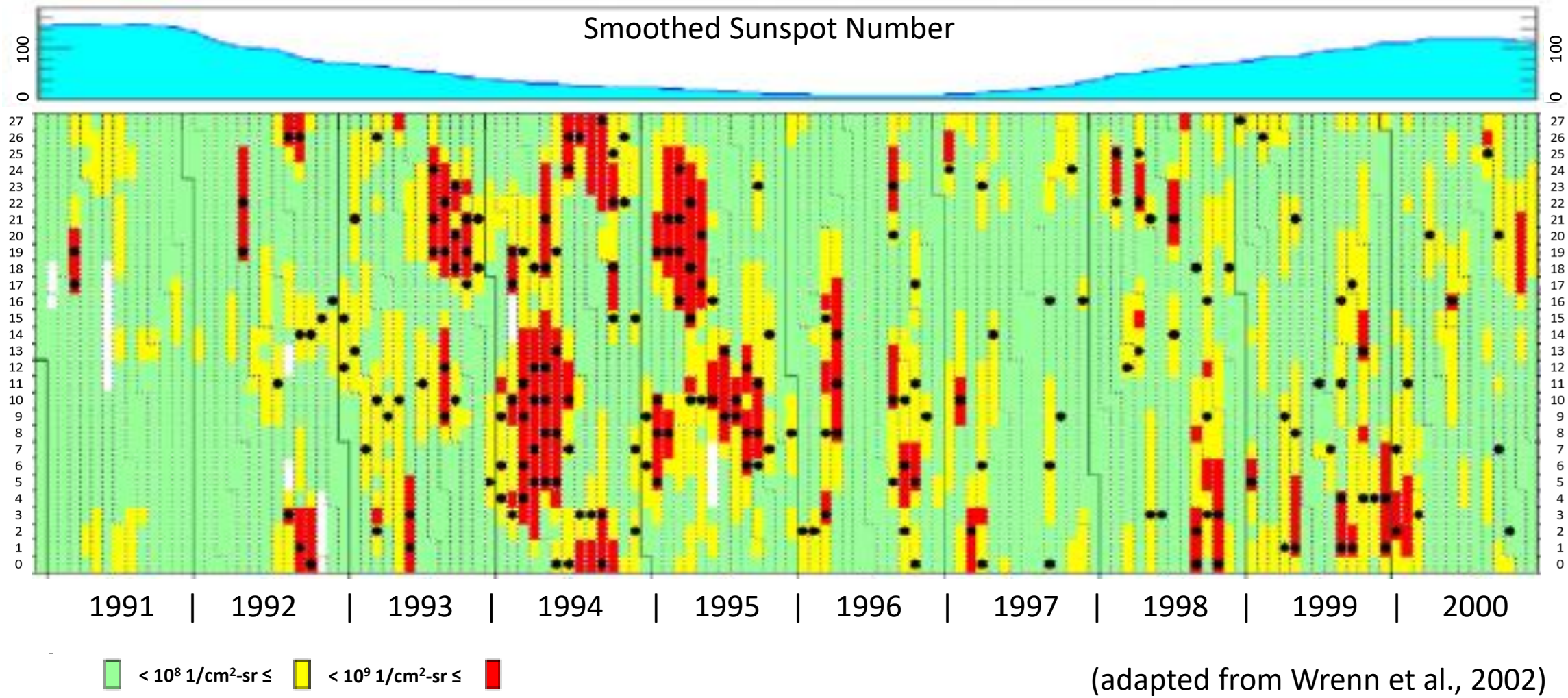




GOES Internal Charging Anomalies (Phantom Commands) in GEO

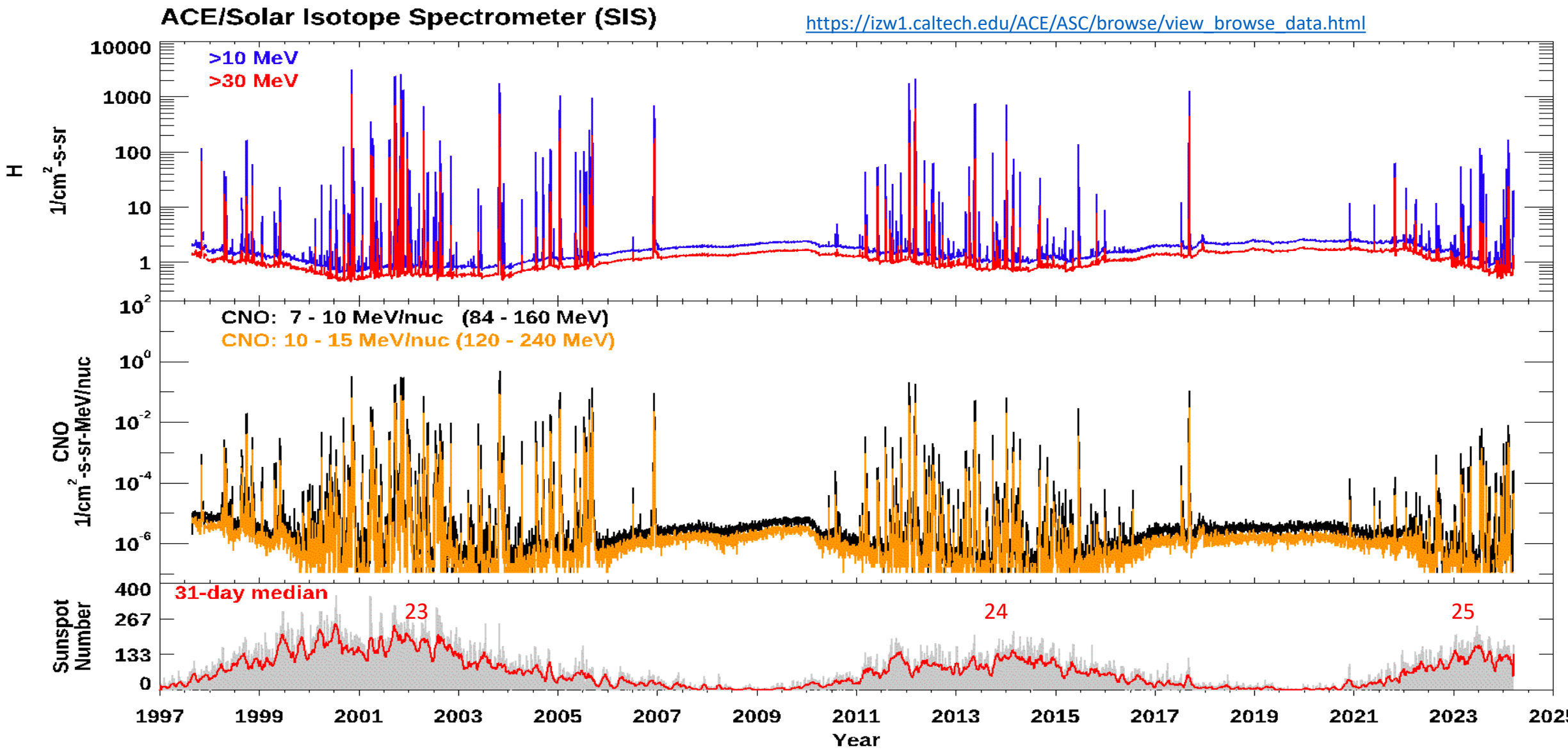


(adapted from Wrenn et al., 2002)

Fig. 1. (a) 2-day fluence of >2 MeV electrons at GEO showing 214 correlated phantom commands. (b) smoothed sunspot number from January 1991 to December 2000.

Solar Particle Events (SPE) and Galactic Cosmic Rays (GCR)

ACE Browse Data (Daily Averages) from 1997/08/25 to 2023/03/18



6 -12 Feb 2024
Series of X-ray Flares and SPEs

- **X-ray flares associated with SPEs***

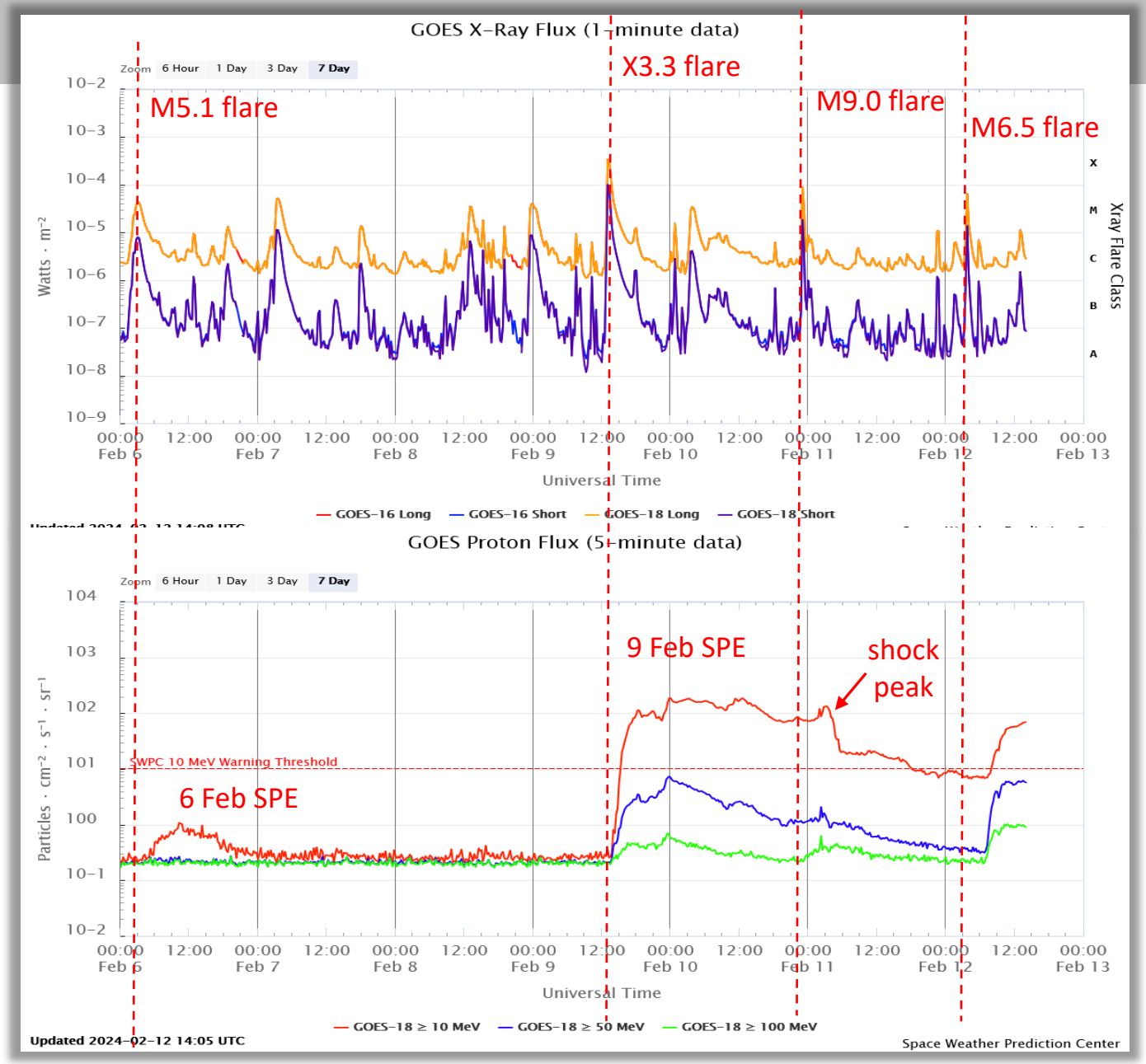
X-ray Flare (W/m^2)	Peak Flux (UTC)	Source Region	Solar Location (deg)	CME Speed (km/s)	Direction (deg)
M5.1	2024-02-06 03:31	13575	S36 W80		
X3.3	2024-02-09 13:14	13575	S37 W100	2226	110/-33
M9.0	2024-02-10 23:07	13576	S12 W13	912	13/16
M6.5	2024-02-12 03:48	13576	S16 W25		

- **Solar Particle Events (SPE)****

X-ray Flare (W/m^2)	Peak Proton Flux (pfu)			
	≥10 MeV	≥50 MeV	≥60 MeV	≥100 MeV
M5.1	1.076	0.272	0.269	0.266
X3.3	187.1	7.344	4.094	0.698
shock peak	134.5	2.076	1.476	0.625
M6.5	69.5^	6.168^	3.955^	1.019^

^Flux still increasing, values are the most recent but peak flux could be higher

Sources:
*GSFC Moon to Mars Space Weather Analysis Office
**NOAA Space Weather Prediction Center



https://www.swpc.noaa.gov/

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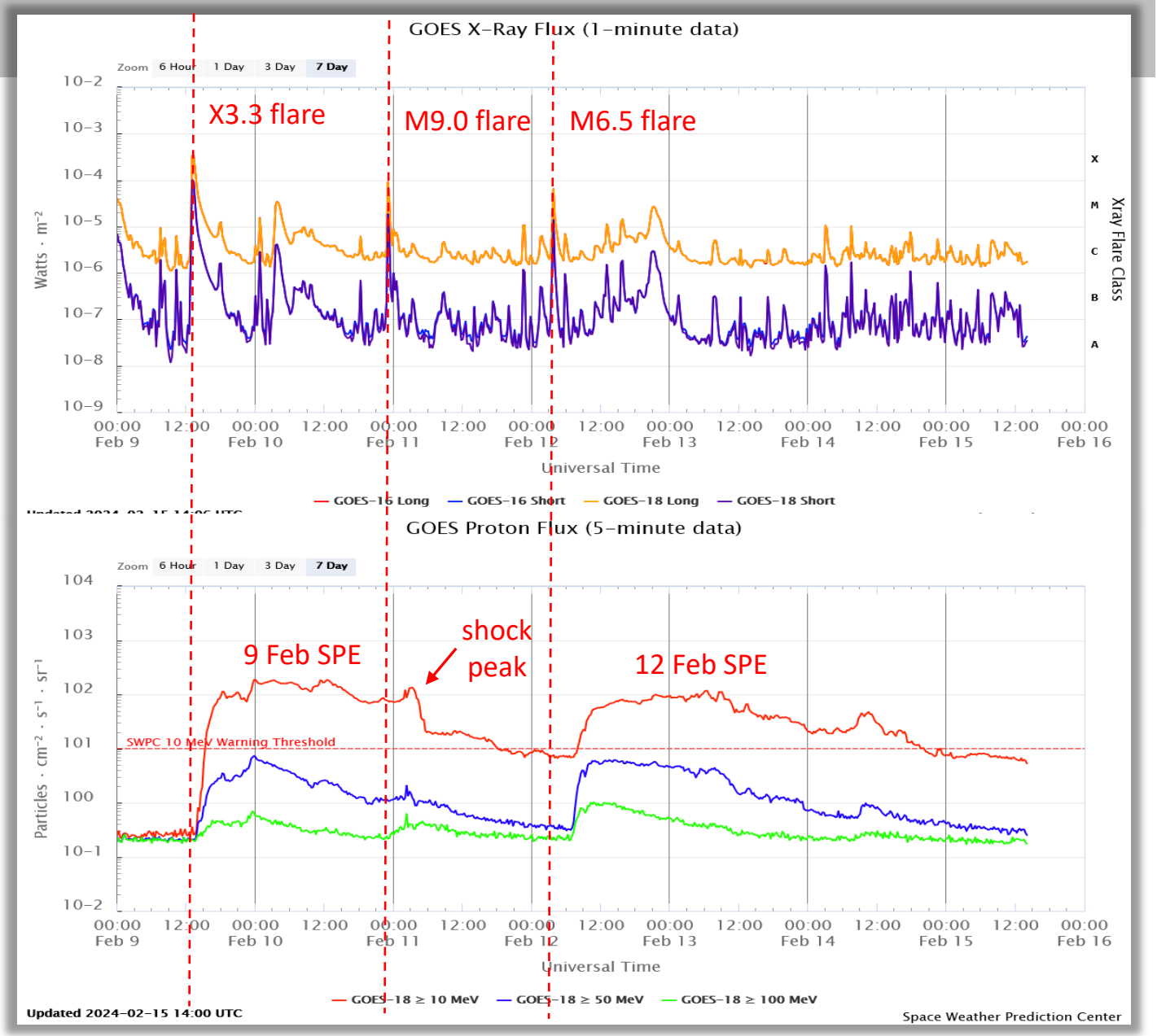
M6.5	117.6^	6.168^	3.955^	1.019^

^Update: peak proton flux for period 12 – 16 Feb

Sources:
*GSFC Moon to Mars Space Weather Analysis Office
**NOAA Space Weather Prediction Center



https://www.swpc.noaa.gov/

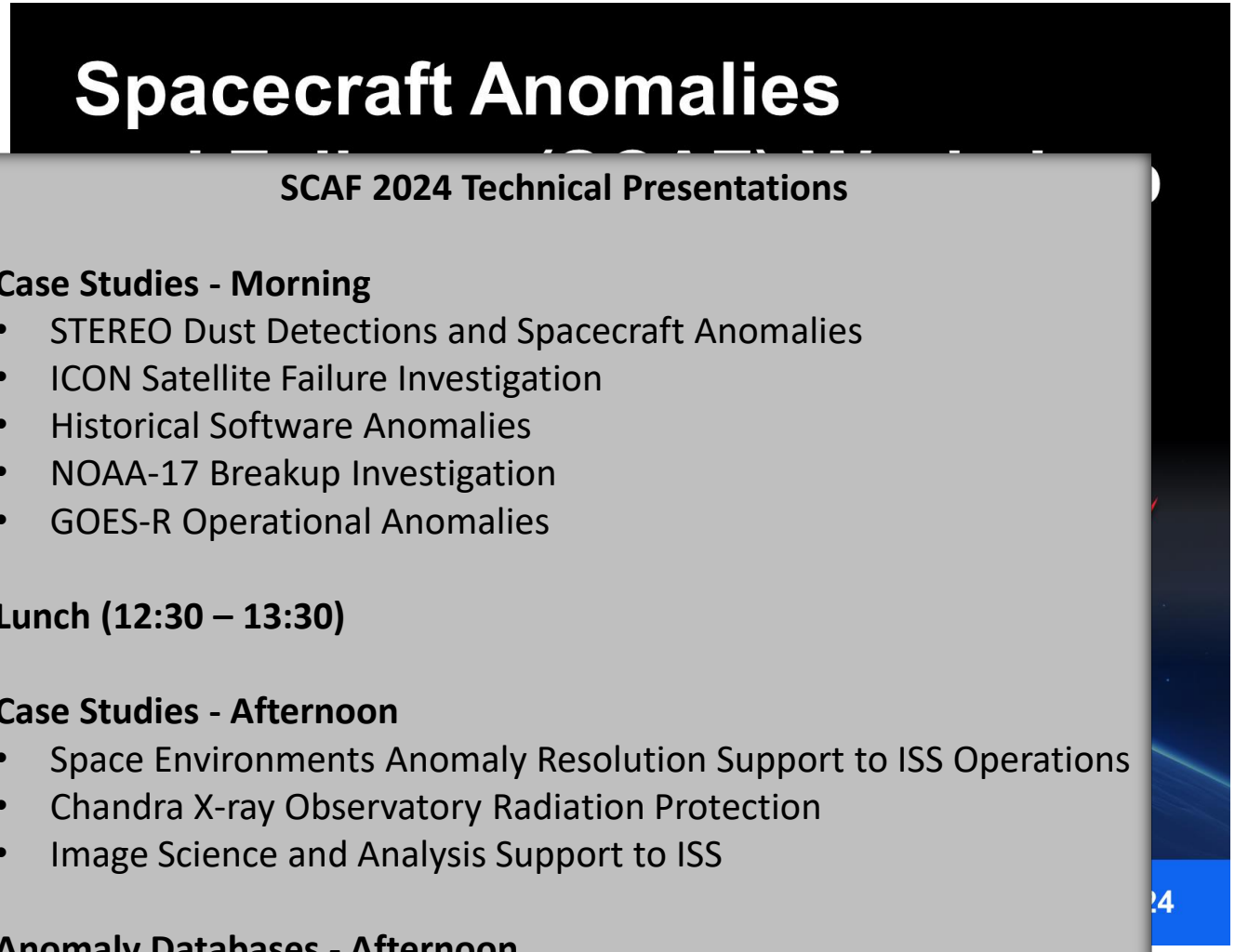
SCAF 2024 Presentations

- The SCAF 2024 organizing committee selected today's Day 1 presentations because they represent a variety of issues encountered on both active and decommissioned satellites that range from anomalies to a mission ending failure

- The morning presentations are case studies of anomalies and failures in NASA and NOAA spacecraft and an investigation into software errors in spacecraft, aircraft, planetary landers, and terrestrial power systems

- The first three presentations following lunch will focus on techniques used by the International Space Station and Chandra X-ray Observatory programs to identify and mitigate on-orbit anomalies

- The final two afternoon presentations discuss the GSFC SOARS anomaly database and tools that are being developed to couple space environments information with anomaly reports contained in the database



SCAF 2024 Technical Presentations

Case Studies - Morning
- STEREO Dust Detections and Spacecraft Anomalies
- ICON Satellite Failure Investigation
- Historical Software Anomalies
- NOAA-17 Breakup Investigation
- GOES-R Operational Anomalies

Lunch (12:30 – 13:30)

Case Studies - Afternoon
- Space Environments Anomaly Resolution Support to ISS Operations
- Chandra X-ray Observatory Radiation Protection
- Image Science and Analysis Support to ISS

Anomaly Databases - Afternoon
- Radiation Events in GSFC SOARS Database
- SPARK Anomaly Tool Applied to SOARS Radiation Anomalies