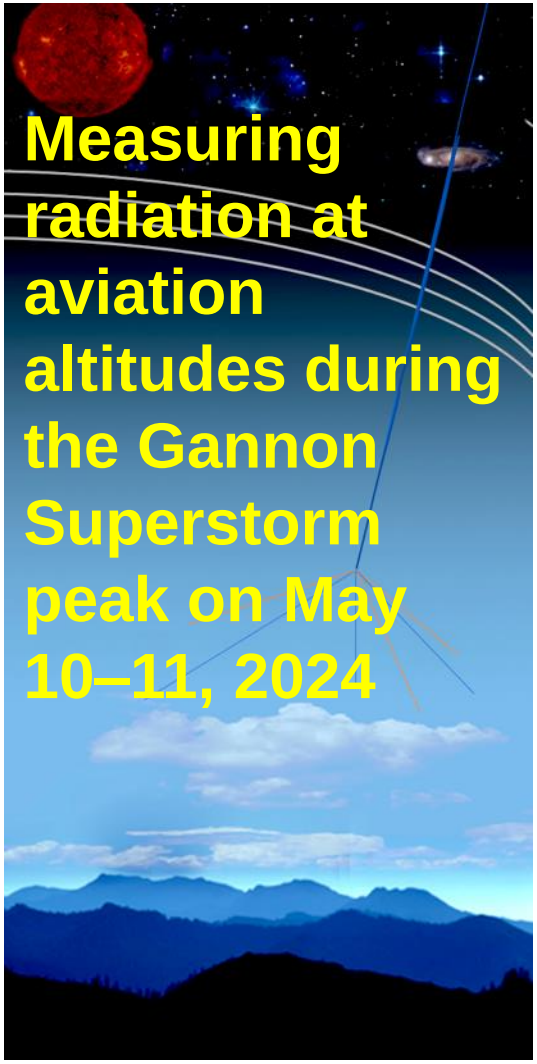
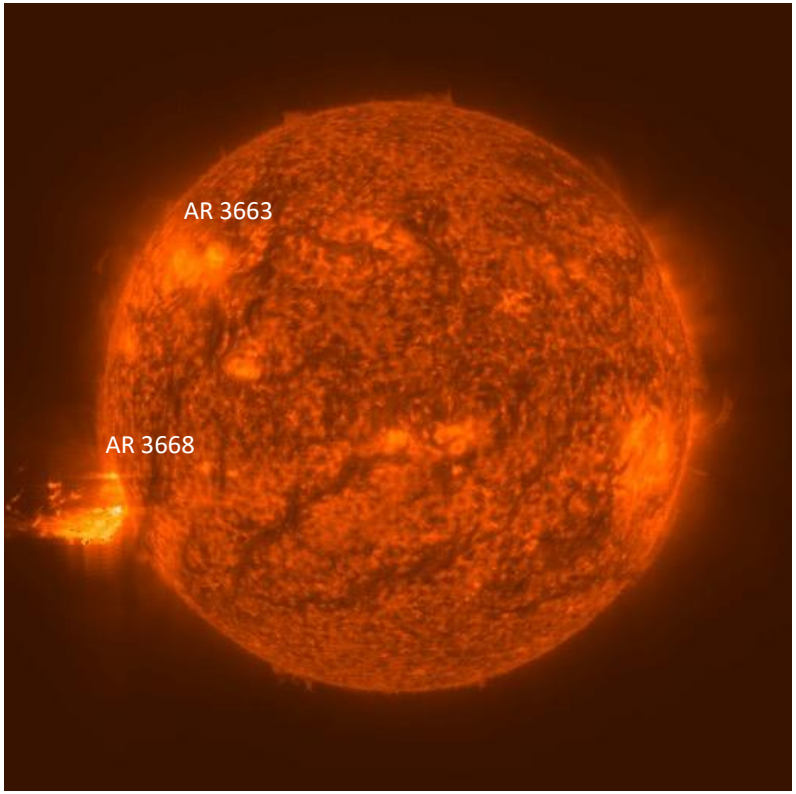


Topics covered

- Flight during the May 10–11, 2024 storm
- Flight during the June 14, 2024 quiet period
- Lessons learned



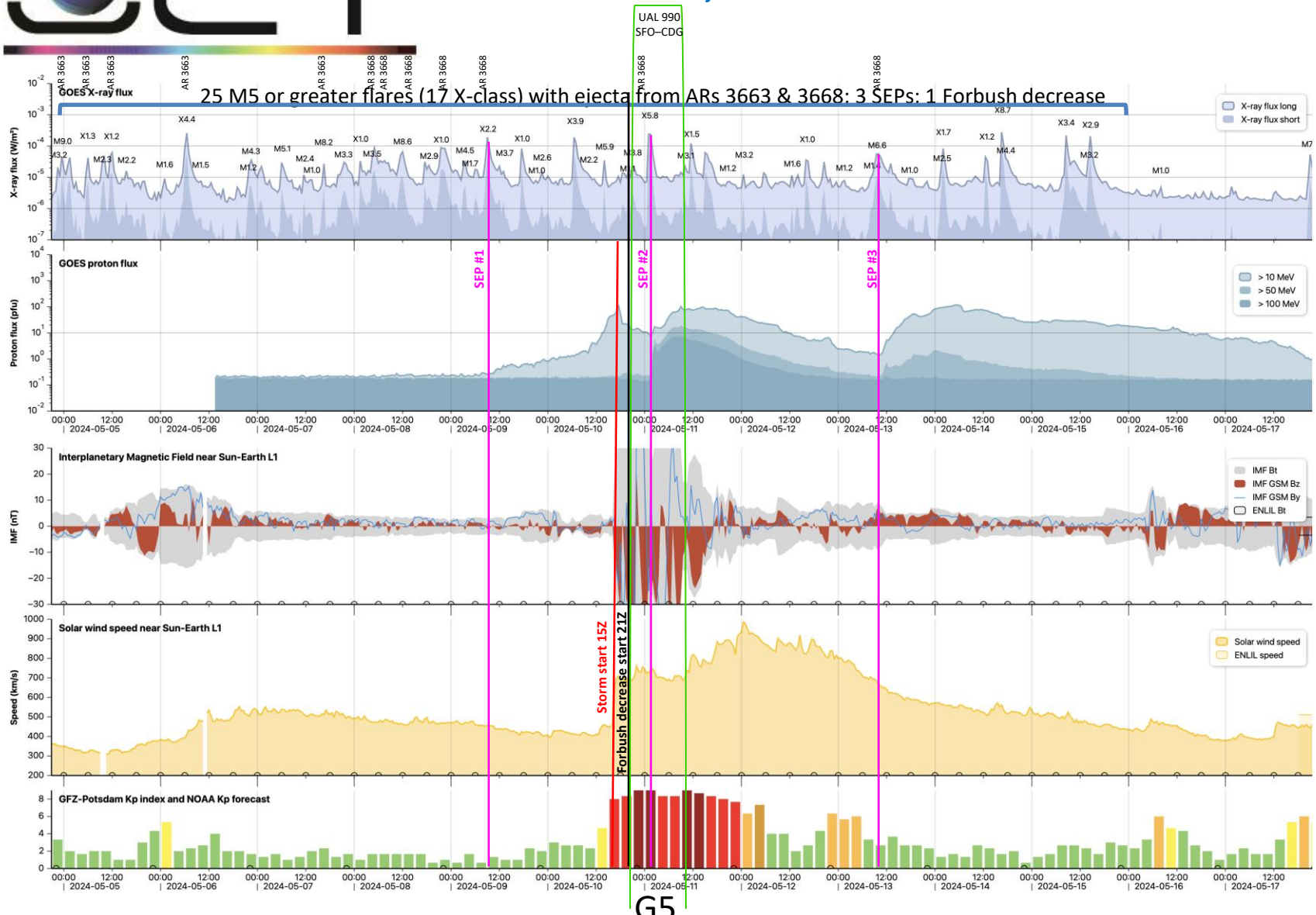
W. Kent Tobiska

Space Environment Technologies' ARMAS Team

Justin Bailey, Leonid Didkovsky, Seth Wieman, Kevin Judge, Ben Hogan, Zane Perry, Brad Gersey, James Hall-Prior, Benjamin Sullivan-Douglass, Dave Bouwer, Kaiya Wahl, Kai Drumm

July 8, 2024

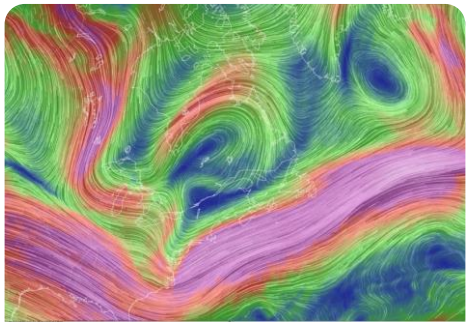
Gannon superstorm trifecta of space weather – CMEs, SEPs and Forbush decrease

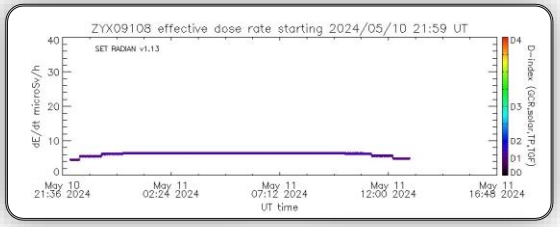


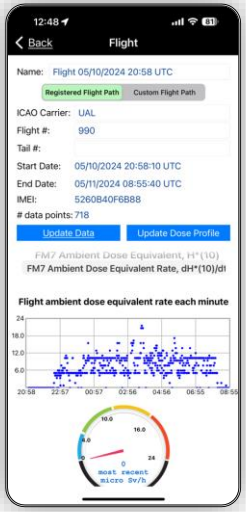
https://spaceweather.knmi.nl

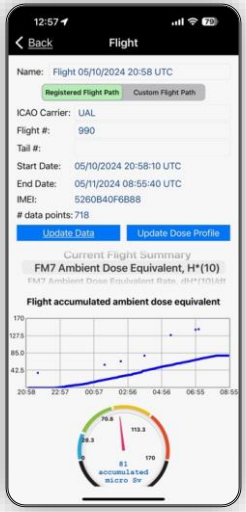
Gannon superstorm – flight conditions

- UAL 990 (Boeing 777-200) flight from San Francisco to Paris May 10–11, 2024
- This flight normally flies high latitude over Canada's Hudson Bay, across Greenland, and down to Paris flying at 37,000 - 40,000 ft while reaching latitudes to >70N geographic; however, a flight diversion was in effect for this route to a non great circle route across CONUS (~43N) and then trans-Atlantic (<45N)
- The pre-flight GCR background, using ISO 20785-3:2023 with NAIRAS climatology (no SEPs or trapped particles), predicted 6 μSv/hr effective dose rate
- SET flew its ARMAS radiation detector and, for the first time ever, made historic dose measurements for 11.2 hours at a maximum cruise altitude of 36,000 ft (10.792 km) on a high latitude route (51N maximum latitude) during a NOAA G5 extreme event, during a SEP event, and during a major Forbush decrease of the GCRs
- The flight exposure totaled 78.8 μSv, which is far less than 200-300 μSv that might be expected if the flight followed the usual higher altitude and high latitude route, which would have occurred during storm conditions
- An interesting flight fact was that the selected route took advantage of a very fast jet stream, allowing 1111 km/hr ground speed at one point; the flight arrived at CDG with essentially no delay despite the lower altitudes and longer distances



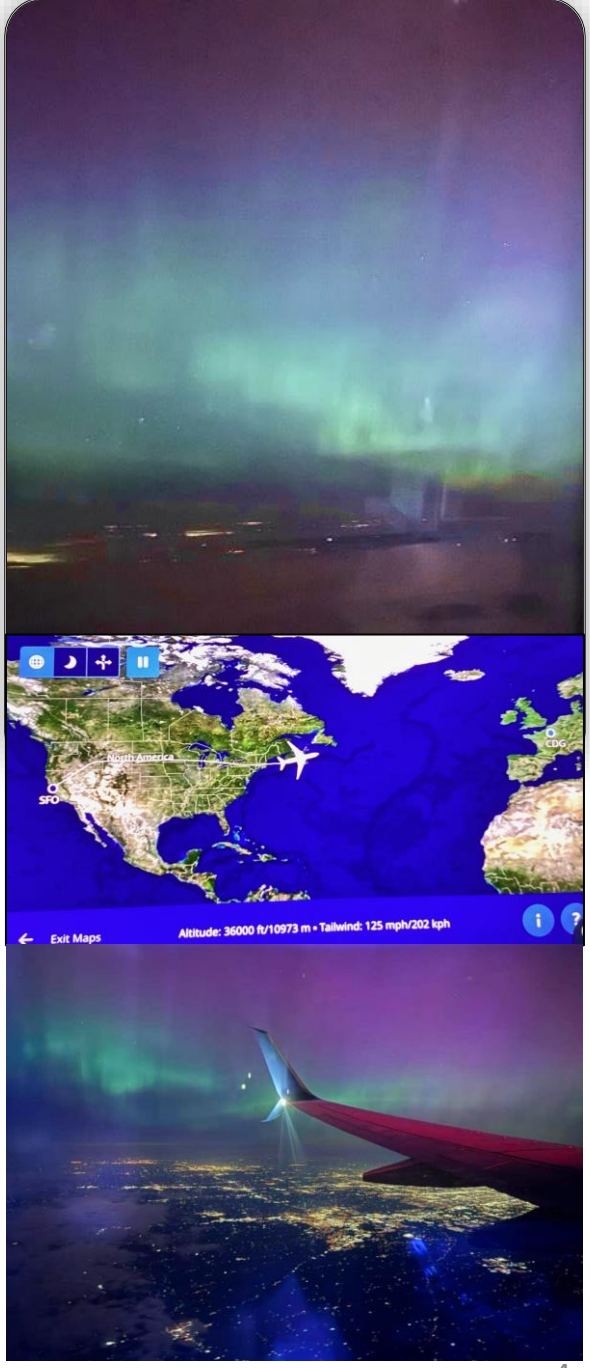




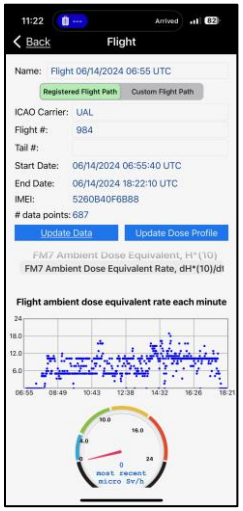


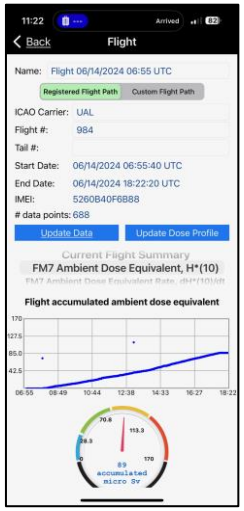
Gannon superstorm – images

- A poor-quality photo was taken from the exit door window (with 6 inches wide with curved optical plastic) when UAL 990 was just south of Nova Scotia (lights visible) at 36,000 ft. on May 11, 2024, at 03:36 UT.
- The seasoned pilots, one of whom lives in Alaska, said after the flight that it was the most intense auroral display he had ever seen. He showed his personal pictures of brilliant streaming “starburst” aurora directly over the plane and taken through the cockpit overhead window. Another view is shown Minneapolis to Baltimore near the same time (Ken Trombatore, credit).

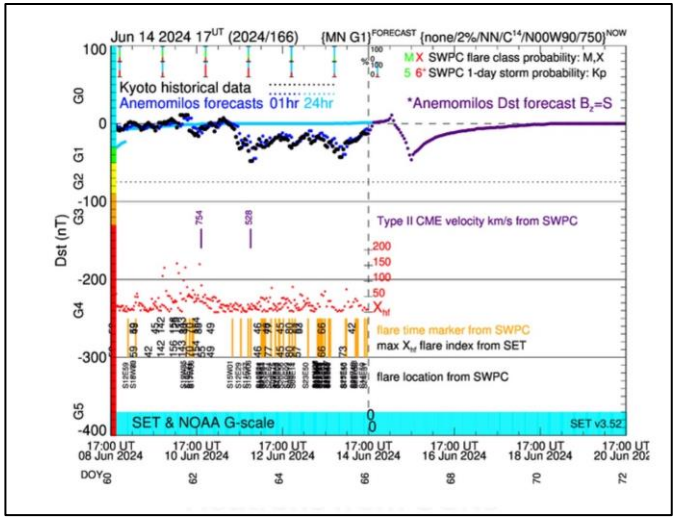


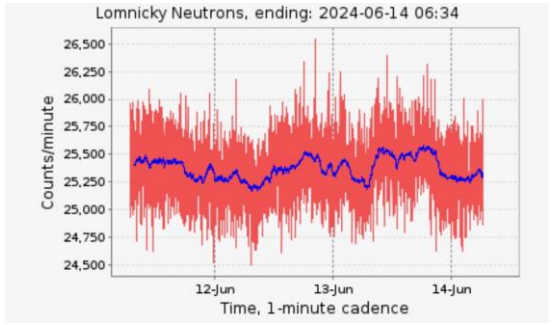
Non-storm great circle route – flight conditions





- UAL 984 (Boeing 777-200) flight from Paris to San Francisco June 14, 2024
- This flight normally flies high latitude across Greenland, over Canada's Hudson Bay, and down to San Francisco flying at 36,000 - 38,000 ft while reaching latitudes to ~70N geographic and it flew that route
- SET used its ARMAS radiation detector and made dose measurements for 11.5 hours at a maximum cruise altitude of 38,000 ft (11.582 km) on a high latitude (68N maximum latitude) route during NOAA G0 quiet conditions
- The flight exposure totaled 87.3 μSv
- The Dst index showed very low values indicative of quiet, non-storm conditions and the neutron flux indicative of the GCR environment was nominal for the solar maximum period during the solar cycle





Lessons learned on aviation radiation exposure mitigation

2. Commercial aviation CAN mitigate the exposure hazard and operate safely during extreme events – the key is to fly **lower latitudes** and **lower altitudes** than a Great Circle route during storm periods. NOTE: greater distance/time may be offset by taking advantage of jet stream tailwinds on W-E routes.

3. Measurements CAN be improved for understanding the radiation exposure hazard – **24/7/365 observations at altitude** are needed.

4. Forecasts with lead times beyond 12 hours ARE possible for the global radiation environment – NAIRAS **climatology gives an estimate of the GCR background**, which is the baseline exposure.

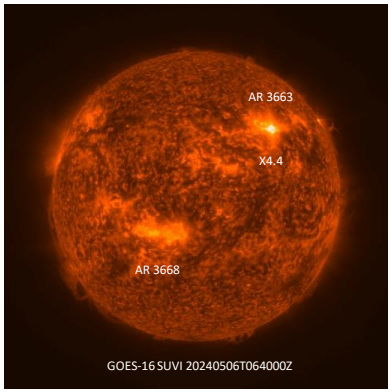
5. Decision-aid planning tools for aviation space weather risk management are in early stage – **apps** associated with detectors or used as standalone flight planning tools are available and **client-focused commercial forecasting services** have been developed.

Backup slides

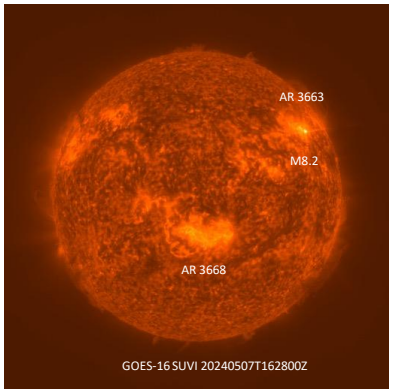
Big questions for aviation radiation

1. What are space weather effects upon commercial aviation, especially from radiation exposure related to extreme events such as geomagnetic storms and SEPs?
2. Can commercial aviation mitigate their exposure hazard and operate safely during extreme events?
3. How can measurements be improved for understanding the radiation exposure hazard?
4. Are forecasts with lead times beyond 12 hours possible for the global radiation environment?
5. Are aviation decision-aid planning tools available for space weather risk management?

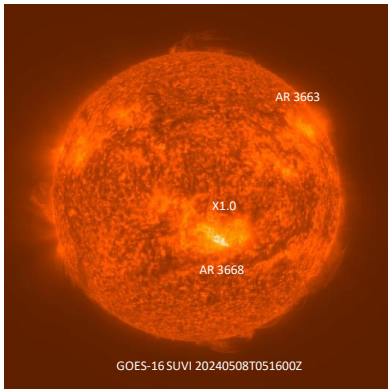
Gannon superstorm – solar events



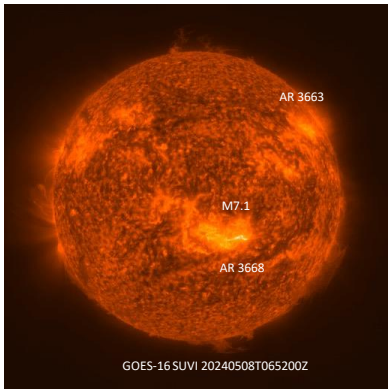
May 06, 2024 06:40
1st CME



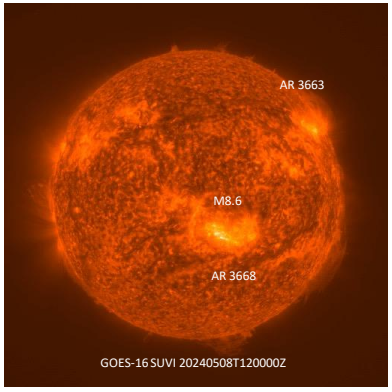
May 07, 2024 16:28
2nd CME



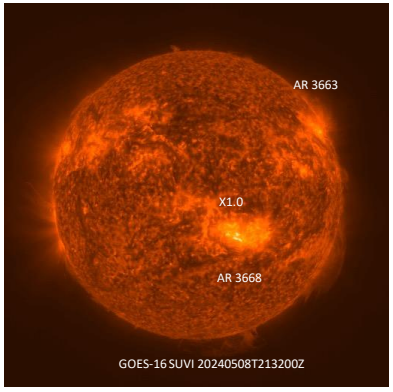
May 08, 2024 05:16
3rd CME (1152 km/s)



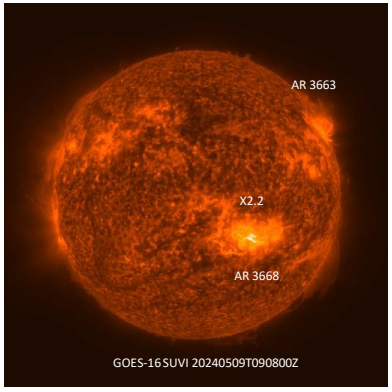
May 08, 2024 06:52
4th CME



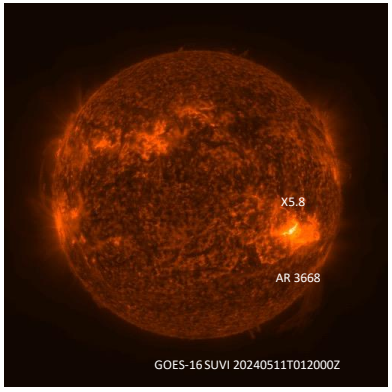
May 08, 2024 12:00
5th CME



May 08, 2024 21:32
6th CME

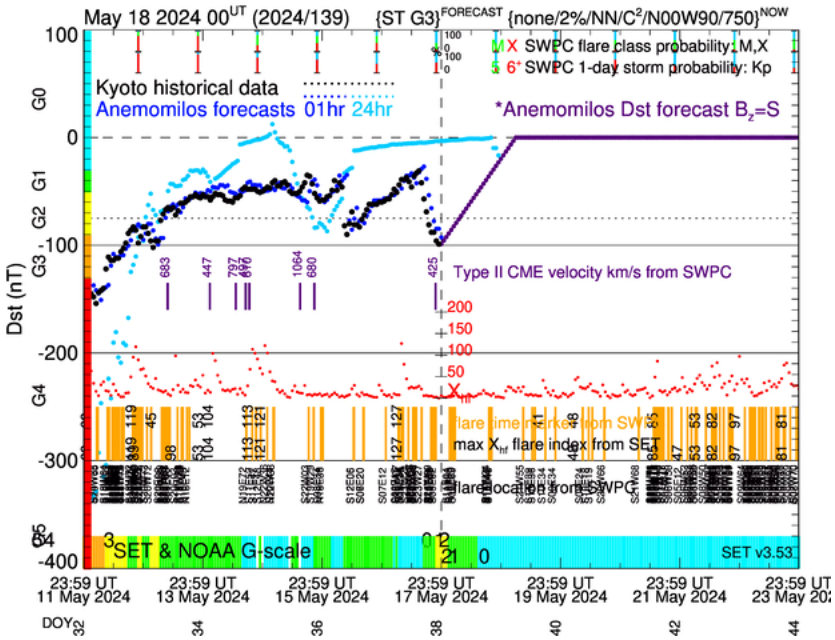


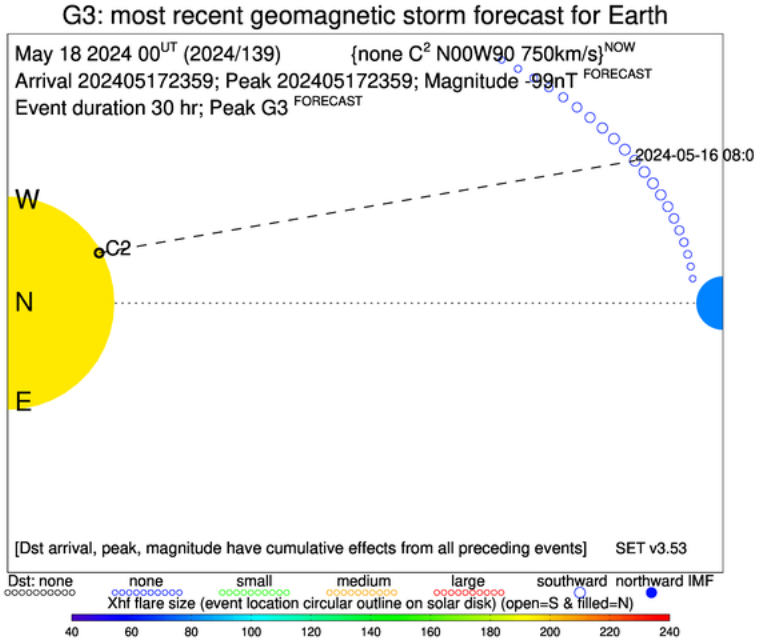
May 09, 2024 09:08
7th CME

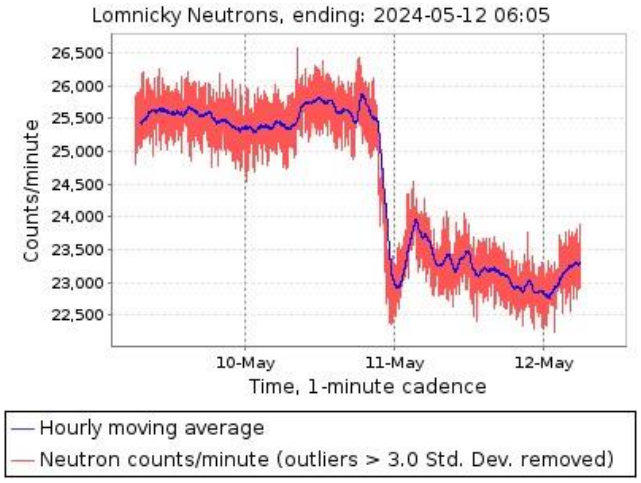


May 11, 2024 01:20
SEP (start 01:45, peak 02:45)

Gannon superstorm – magnetic events



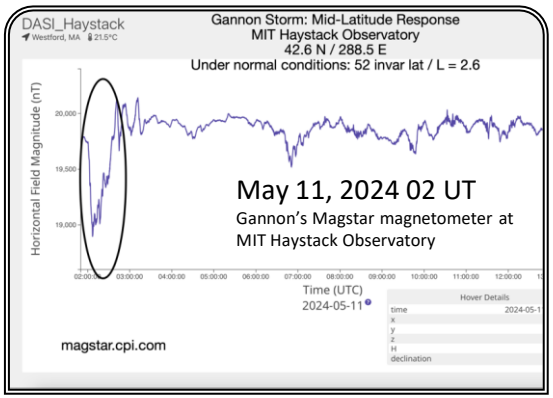




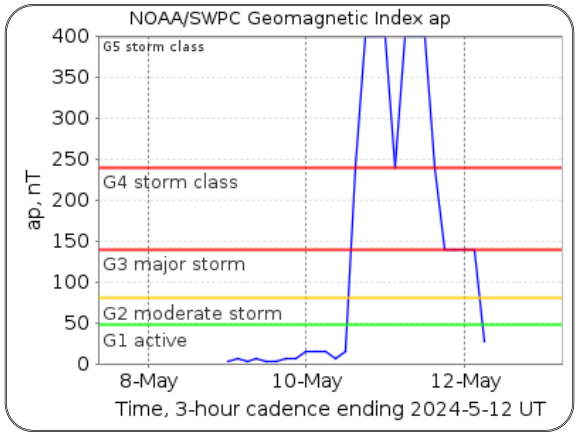
May 07, 2024 00 UT Pre-storm conditioning
May 10, 2024 16 UT Main storm start
May 11, 2024 03 UT MainMain storm peak
May 11, 2024 11 UT storm recovery
May 15, 2024 16 UT Post-event continued storms

May 10, 2024 21:21 UT

Forbush decrease start associated with flux rope magnetic cloud's pressure against the incoming GCRs leading to a 13% decrease in GCRs

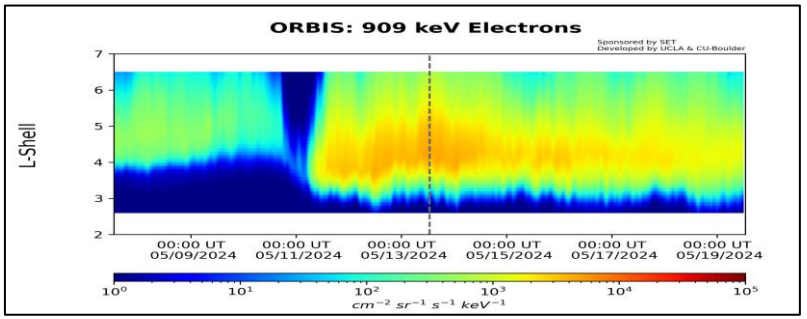


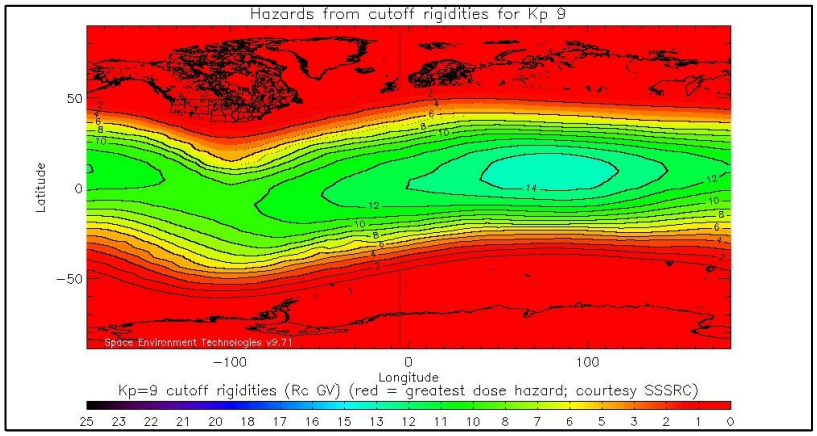
Gannon superstorm – radiation belt events

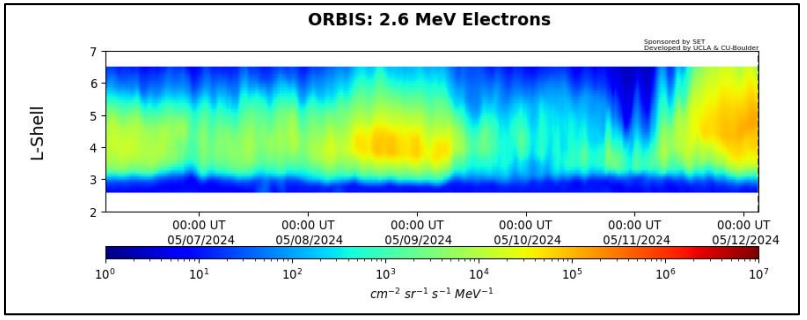


ap planetary index for the Gannon storm

ORBIS outer radiation belt energetic electrons from ML-learned Van Allen Probes REPT instrument dataset







Cutoff rigidities from the Shea & Smart model for Kp 3 and Kp 9

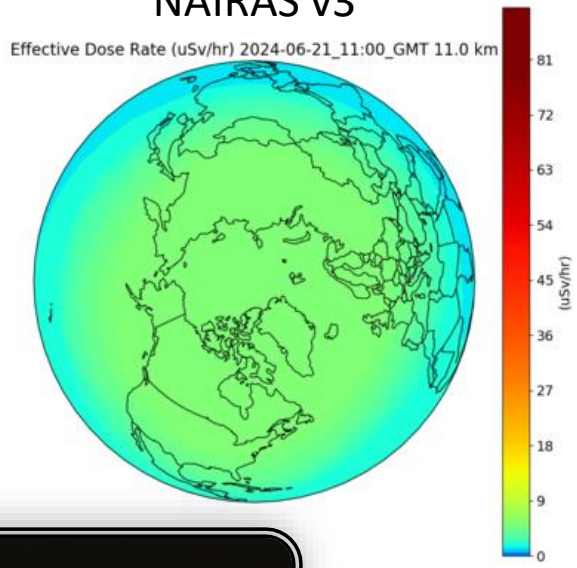
Radiation tools for state-of-the-art monitoring: ARMAS Flight Module 7 (FM7) and NAIRAS v3 combined into the RADIAN system

Features:

- ✓ Measures absorbed dose in silicon from all sources
- ✓ Small size, mass, and power
- ✓ Data retrieval using Bluetooth to pair with Apple Store iOS ARMAS app
  - Current and post-flight dose rate status displayed on app
  - Dose rate can be transmitted to ground using WiFi
  - Can make pre-flight predictions based on NAIRAS v3
- ✓ Displays real-time dose rates of measured absorbed (Si) and derived absorbed (Ti), dose equivalent, ambient dose equivalent, and effective dose

ARMAS FM7

NAIRAS v3



1239 ARMAS flights from 0-550 km 2013–2024

- ✓ **Agency and Commercial Aircraft flying ARMAS instruments**
  - ✓ **AFRC:** DC-8 (a), ER-2 (d), G-III, SOFIA (B747)
  - ✓ **NOAA**: G-IV (b)
  - ✓ **NSF**: G-V (c)
  - ✓ **FAA**: Bombardier Global 5000
  - ✓ **DoE**: B350
  - ✓ **Commercial**:
    - Boeing 737, 747, 757, and 777
    - Airbus 319 and 320
    - Bombardier Q200
    - CRJ 200, 700; Embraer 175
- ✓ **Balloons**
  - ✓ **World View Enterprises:** Stratocraft (f)
  - ✓ **NearSpaceLaunch:** balloons
  - ● **World View Enterprises:** Stratollite
- ✓ **NASA space stations**
  - ✓ **ISS JEM EF** (Low Earth Orbit) (i)
  - ○ **Gateway** (Lunar Orbit)
- ✓ **Proprietary vehicles**
  - ✓ **Perlan** Stratospheric glider (e)
  - ✓ **Raytheon** Corporate Jets
  - ✓ **Virgin Galactic** SS2 and WK2 (g)
  - ✓ **Blue Origin** New Shepard (h)
  - ✓ **SpaceX/NSL** Transporter-2/TAGSAT-2
  - ● **SpaceX/NSL** SWAP-E
  - ● **Intuitive Machines** Mission 2 NOVA-C
  - ● **AXIOM**

✓ Flown
● In progress
○ Potential

3.1 million 10-s data records and counting