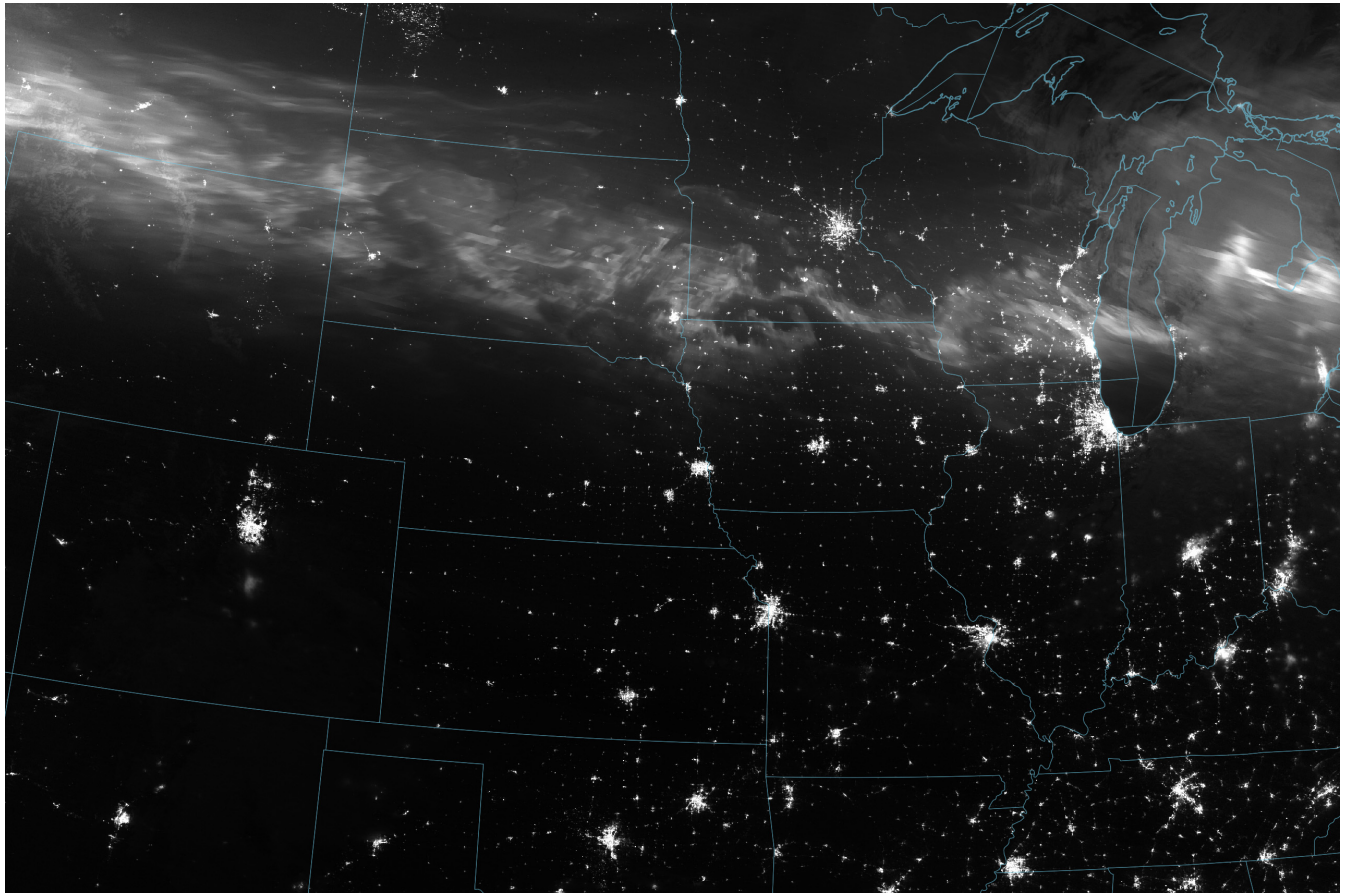
May 2024 Gannon Storm: Impacts on Low Earth Orbit (LEO) Spacecraft and Operations*



Auroral image at 8:20 UT, 11 May 2024
from the VIIRS imager on the Suomi NPP
NASA Earth Observatory image by Wanmei Liang,

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STM/C Aggregated reports from the internet, science meetings, and publications

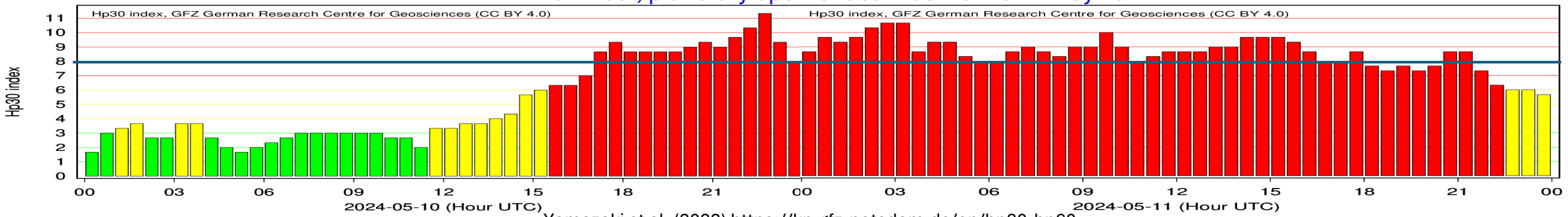
Opinions are my own

User Needs Survey Report

Chap 1: 11-13 May 2024 (Gannon) Storm Example Impacts

- Power Grid: Large-scale mitigation in the US
- Aviation: Large-scale mitigation; WAAS impacted
- Space Traffic Management/Coordination:
  - NASA AURA: Significant orbit decay and high orbit decay rates
  - ESA Sentinels: Power use for attitude control system spiked
  - ‘Mass migration’ of LEO spacecraft (Parker & Linares, 2024)
  - ….And ?
- GNSS: Precision agriculture impacted
  - LEO impacts?

Half-hour, planetary open-ended index for 10-11 May 2024



Yamazaki et al. (2022) https://kp.gfz-potsdam.de/en/hp30-hp60

Reports from High LEO

- **ESA's Sentinel-2** (mean altitude 786 km) power-use for attitude control system spiked during the storm
  - The two Sentinel-2 satellites operate simultaneously, phased at 180° to each other,
- **Iridium Next** satellites experienced significant drag at 780 km
  - S/C in one of Iridium's 6 orbit planes dropped 30 meters during the storm; 5 m/day typical
- **NOAA** reported compromised quality of **Sea Level Anomaly (SLA) product**:
  - Derived from several spacecraft
  - Near-real time orbits for several missions had large errors on May 11, 2024
  - (815 km, 800 km, 717 km and 890 km)
- **NASA's AURA** mission (at ~695 km polar sun synchronous orbit)
  - orbital decay rate: 37.5 m/day (predicted) vs 70 m/day (actual) during 2 days of storming

Maneuvers, Positioning and Tracking

- **Starlink** satellites (~5000 spacecraft) began autonomous orbit maneuvers a few hours into the storm (Parker and Linares, 2024)
- Unexpected drag on NASA's **ICESat-2** at 480 km rotated the satellite, and triggered the satellite to enter safe hold, which turned off ICESat-2's science instrument.
  - Spacecraft unexpectedly remained in safe mode
  - Significant position and track deviations required extra maneuvers
  - Significant fuel expenditures to return spacecraft to before-storm status
- **Commercial Industry** saw 'catalog health statistics' decline during the storm
  - As in previous storms, US Space Force likely had 'custody of catalog' challenges

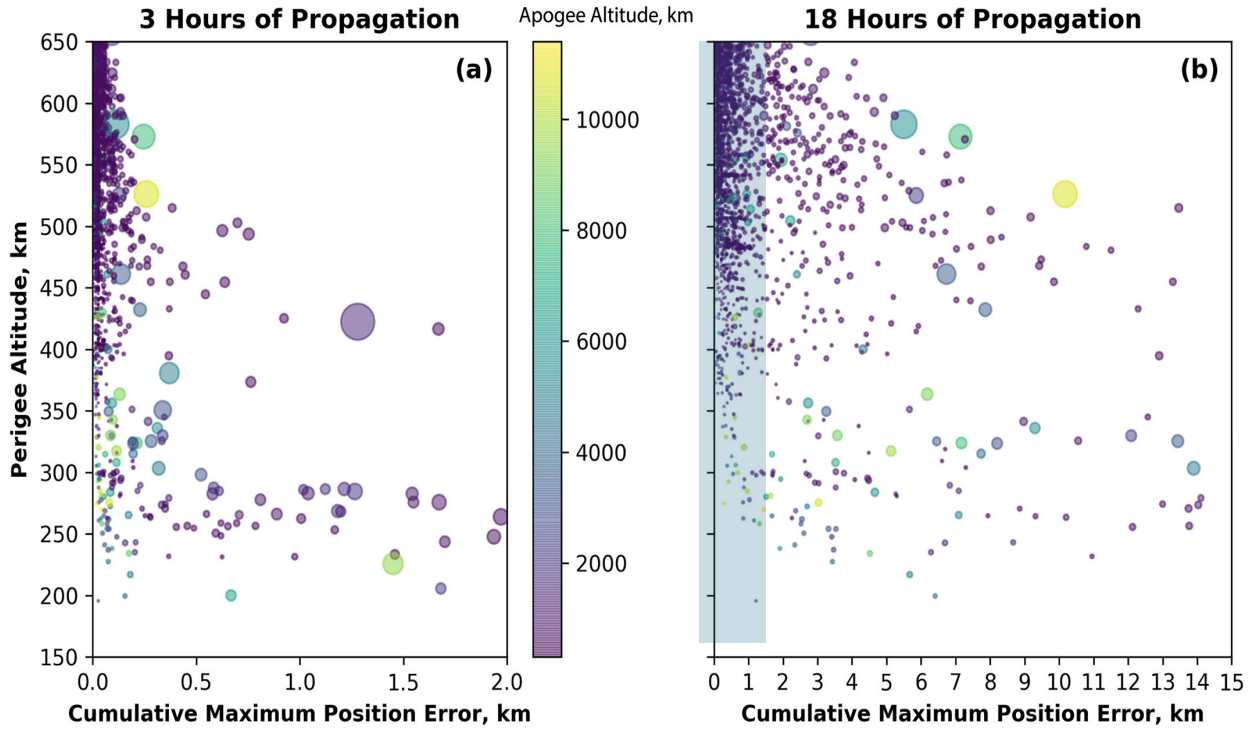
Paused Activities/Loss of Service

- **NOAA** reported that the May 2024 geomagnetic storm affected the quality of the **Sea Level Anomaly (SLA) product**:
  - The SLA product can contain up to 14 days of data inputs in the OI process, thus SLA contained data from anomalous satellite passes that were not removed during QC tests.
- **Iridium Next** halted autonomous maneuvers
- **Planet** paused imaging for its SkySat and SuperDove Earth-observation constellations (over 2 days,~ 24 hr). Various altitudes. (400-500 km)
- **Sen** Imaging (UK) powered down ETV-A1, 16 U- cubesat at 488 km; paused Earth-imaging for 4 days.
- **NASA ICESat-2** several-week-long interruption to data processing
- Collision Avoidance **(COLA)** capabilities compromised for ~3 days
- Numerous LEO cubsats deorbited earlier than expected

Precision Orbit Determination & Forecasts

- Global Navigation System Satellite(GNSS) signals
  - LEO satellite POD (zenith) Total Electron Content Accuracy Compromised
  - Elevated number of cycle slips during storm
- Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)
  - Many satellites contributing to NOAA SLA product outage used DORIS
- Orbit forecast errors for MLEO and VLEO spacecraft
  - On the order of 10's of kilometers
  - 30+ hours of storming

18-hr simulation
Berger et al. (2020)
https://doi.org/10.1029/2019SW002373



Epilogue

- **May 2024 (Gannon) Geomagnetic Storm**
  - Amalgamation of multiple coronal mass ejections
  - Moderate arrival speeds
  - Long duration
  - ‘Wild’ but ‘mild’
- **Several reports of orbit irregularities above 650 km**
  - Paused activities; reduction/loss of service
- **Maintaining health and status of space catalog was challenging**
  - 10,000+ active satellites in LEO; many going into autonomous operations
  - Forecasting challenges
  - POD challenges
  - Space debris also in disturbed motion
- **All contributing to uncertain collision avoidance environment**

Thanks to Contributors & Sources

- E. Sutton, SWxTREC, CU Boulder
- D. Vallado, COMSPOC
- J. Morton, Smead Aerospace Engineering Sciences Dept, CU Boulder
- J. Wilson, Orion Space Solutions, Louisville CO
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