Satellite Drag Analysis During the May 2024 Geomagnetic Storm*

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*Parker, William E., and Richard Linares. "Satellite Drag Analysis During the May 2024 Geomagnetic Storm." arXiv preprint arXiv:2406.08617 (2024). Accepted AIAA Journal of Spacecraft and Rockets.

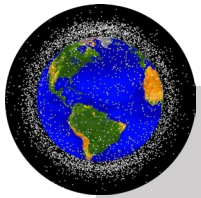
This work was supported by the joint NSF-NASA Space Weather with Quantified Uncertainties program under NSF grant number 2028125

MIT AEROASTRO

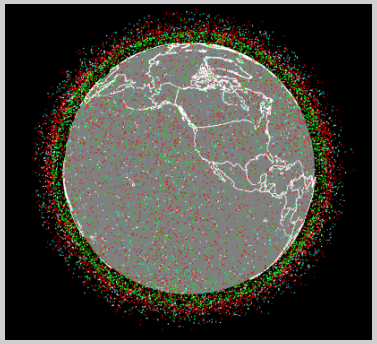
MIT Astrodynamics, Space Robotics, and Controls Laboratory

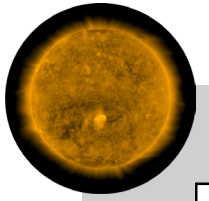
MIT ARCLab

Above: Lab members (Oct. 2023)

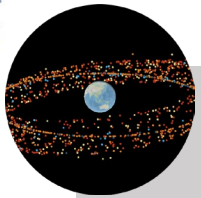


Space Sustainability

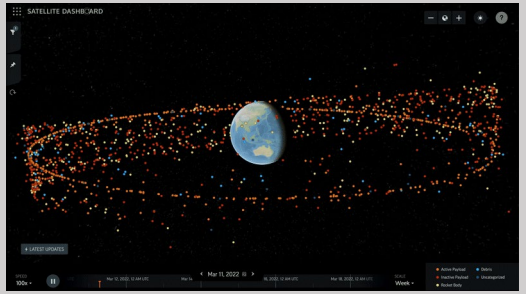


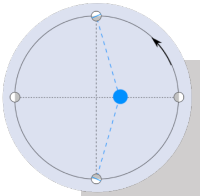


Space Weather

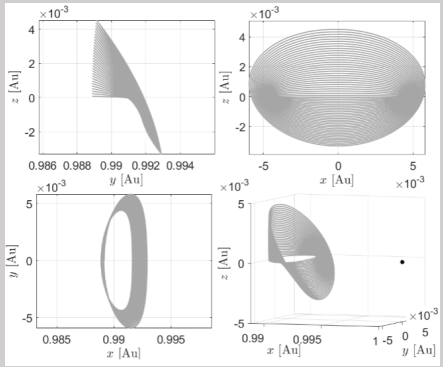


AI for Space



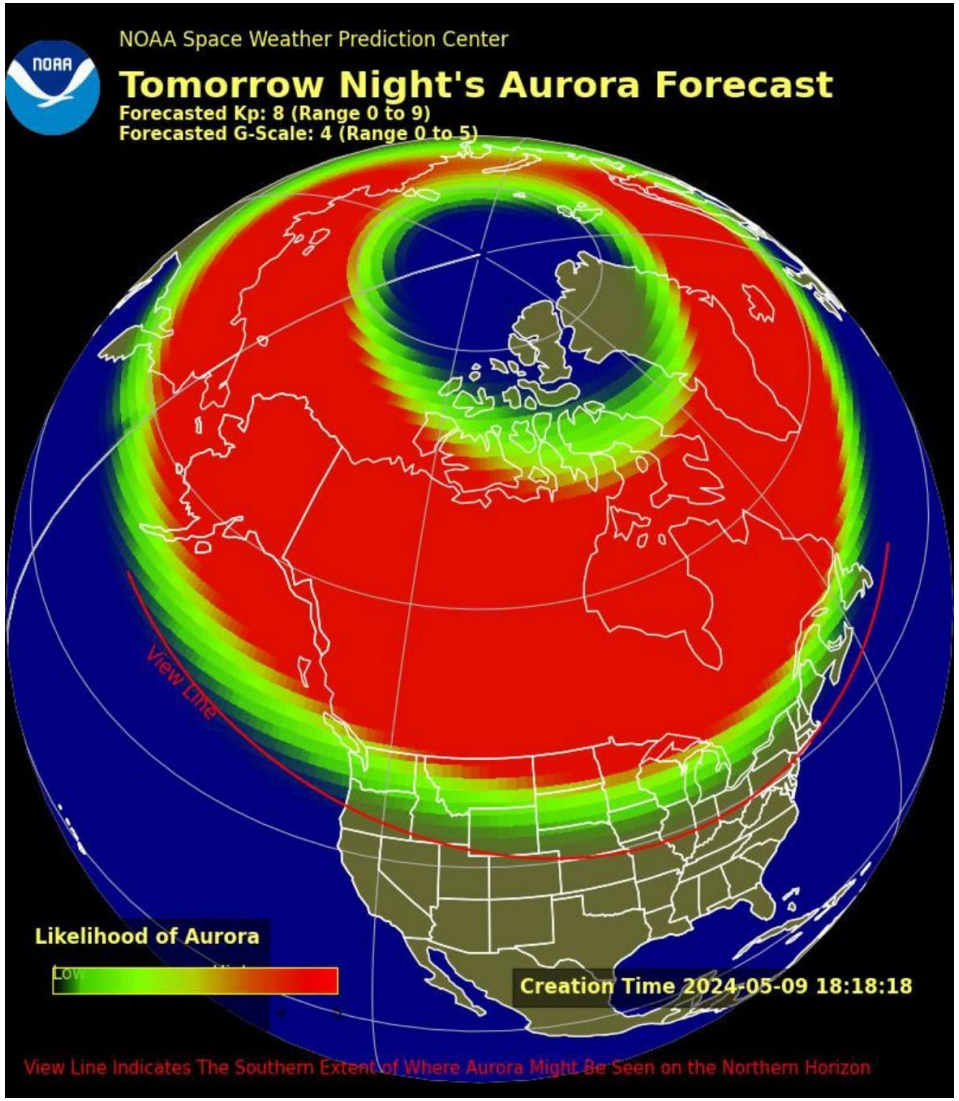


Analytical Astrodynamics



The Gannon Storm, May 2024

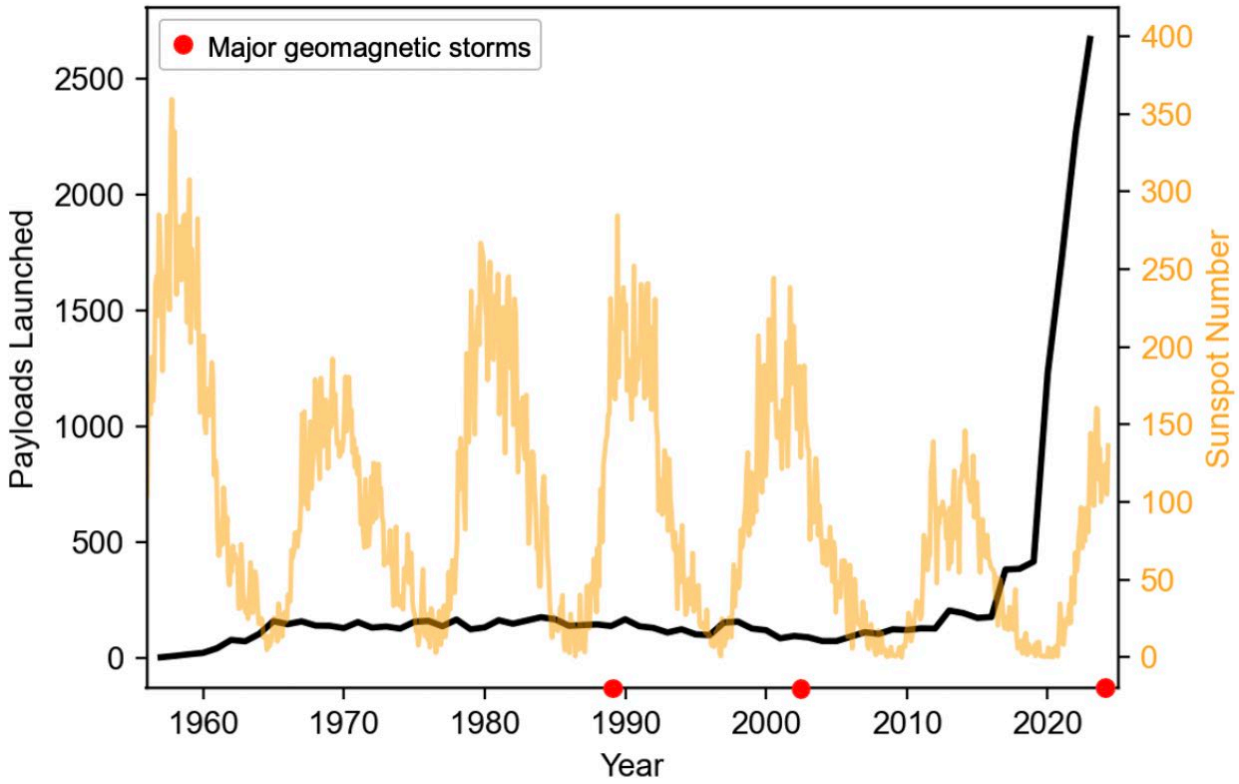
- Large disturbances in Earth's magnetosphere caused by Gannon Storm
  - Triggered by X-class solar flares and coronal mass ejections (CMEs)
  - May 7-11, 2024: Several X-class flares and at least five Earth-bound CMEs detected
- Active region AR3664, characterized by a large cluster of sunspots
  - Peak enhancement: May 10, 12:30 PM UTC
  - Auroral activity visible as far south as 21° N latitude



Historical Context and Current Space Environment

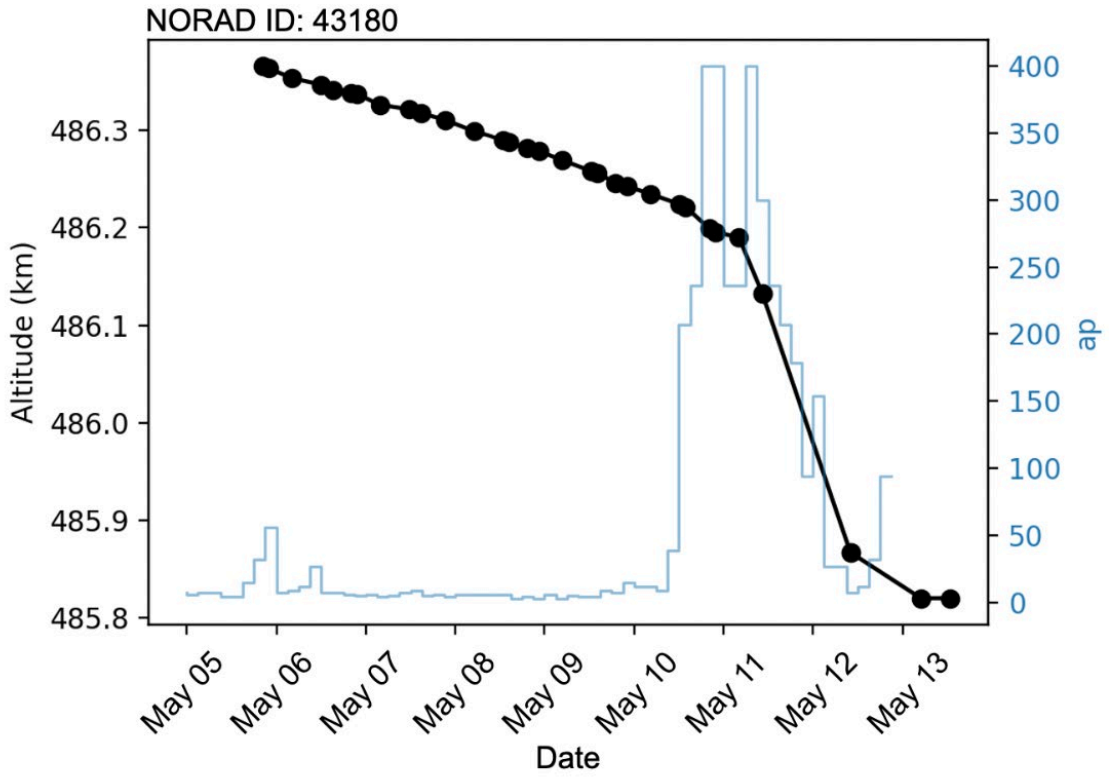
- Figure on the left, number of payloads launched to Earth orbit per year
  - This Highlights the dramatic increase in satellite launches since the last major geomagnetic storm
  - There is a growth of proliferated LEO constellations (e.g., Starlink, OneWeb)
  - There has been a transition towards small, inexpensive satellites

- As a result there is an increased importance of conjunction assessment and collision avoidance



Impact on Individual Satellite Orbits

- There is an increased decay rate: from 38 m/day to 180 m/day during the storm
- This Figure also highlights the reduced cadence of TLE publishing during rapid decay
- There are implications for satellite operators: orbit maintenance, constellation management



Figure, Time-averaged orbit altitude for SATCAT 43180 (KANOPUS-V 3)

Mass Satellite Maneuvering

- This compares Gannon storm to October 2003 Halloween storm
- There was a significant increase in maneuver activity: ~1000 to thousands of satellites
- This highlights the role of the Starlink constellation in the mass maneuver event
- The motivation for these maneuvers: maintaining constellation integrity

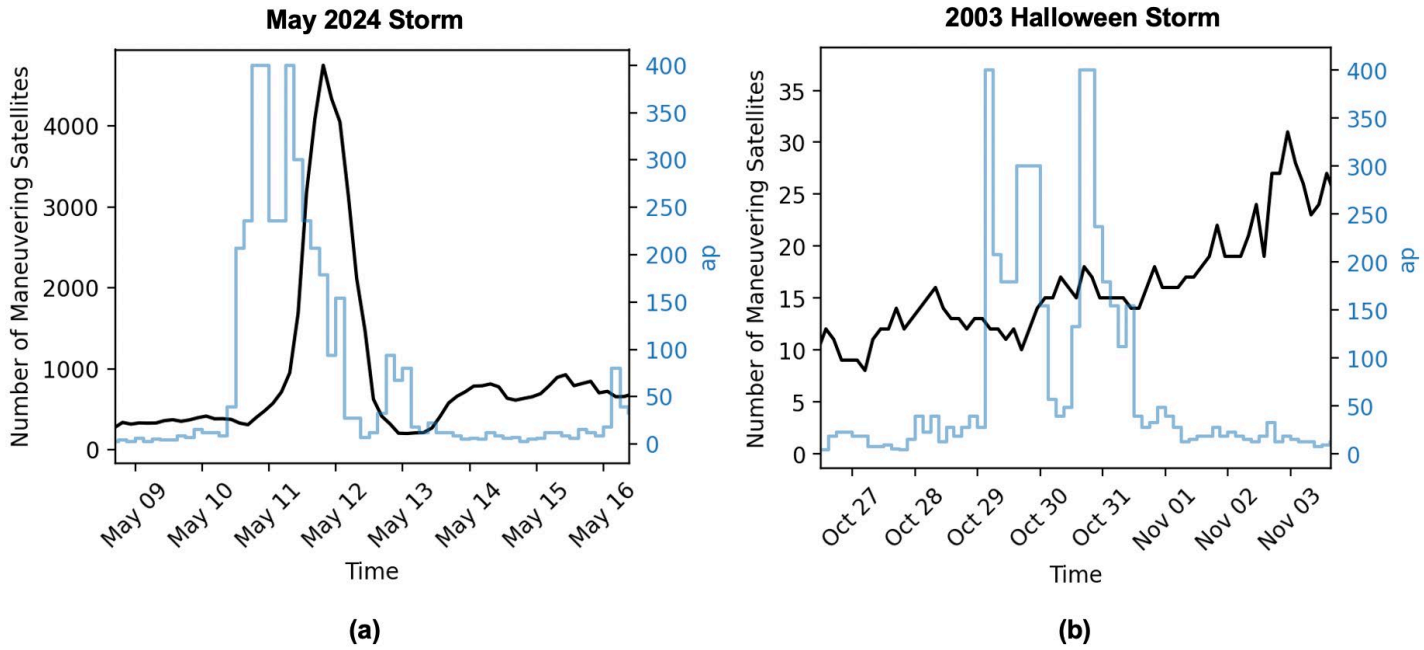
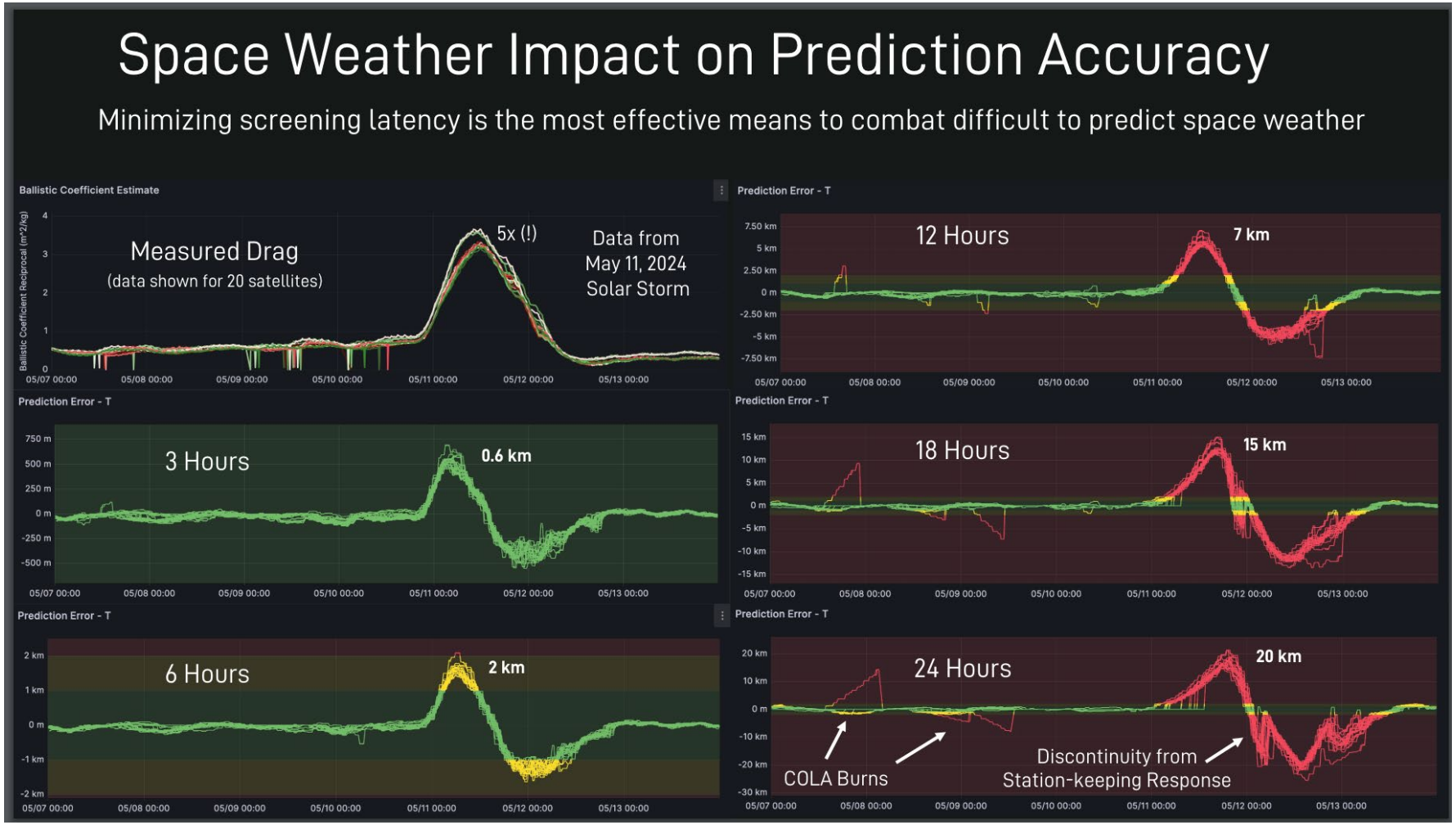


Figure: Number of LEO tracked objects maneuvering over time

Slide from SpaceX: Derived Drag Measurements



Credit: Alex Petrov, Mike Hoot, SpaceX, 2024 SSA Operators' Workshop, Boulder Colorado, May 14th –May 17th

Atmospheric Density Modeling

- There is high importance of accurate atmospheric density models for satellite operations
  - In-situ measurements: CHAMP, GRACE, and Swarm satellites
  - NRLMSISE-00 model: Empirical model using F10.7 and ap as inputs
- NRLMSISE predicted density enhancements: up to 6x baseline value
- Note the concentration of density enhancement in the northern hemisphere

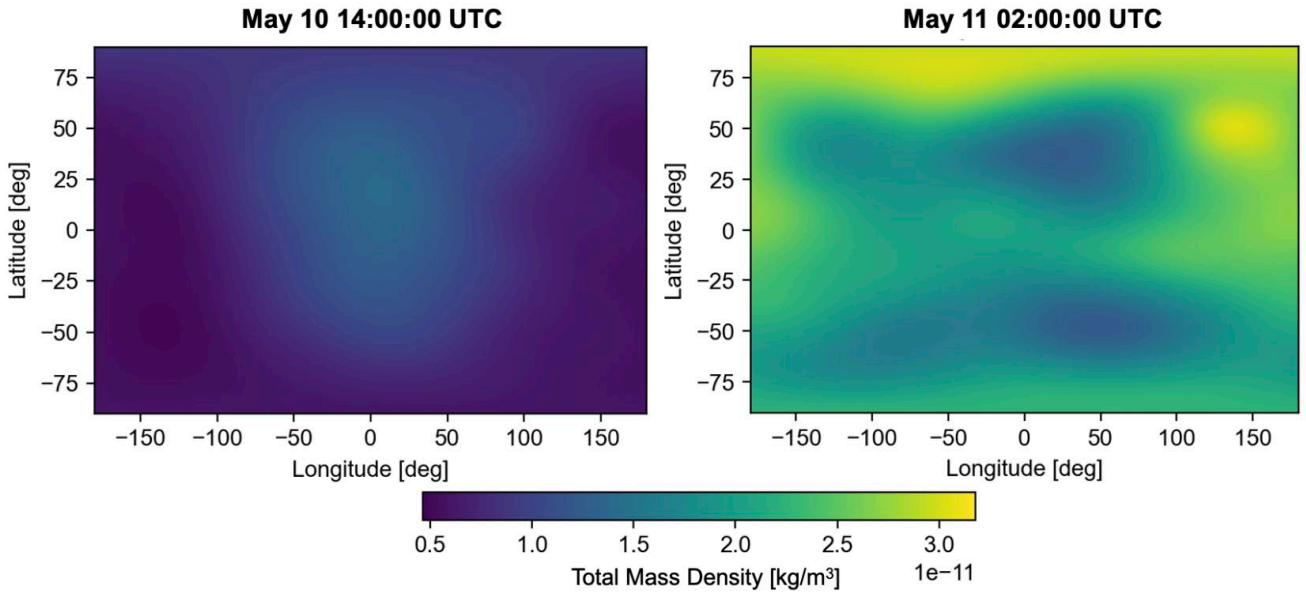
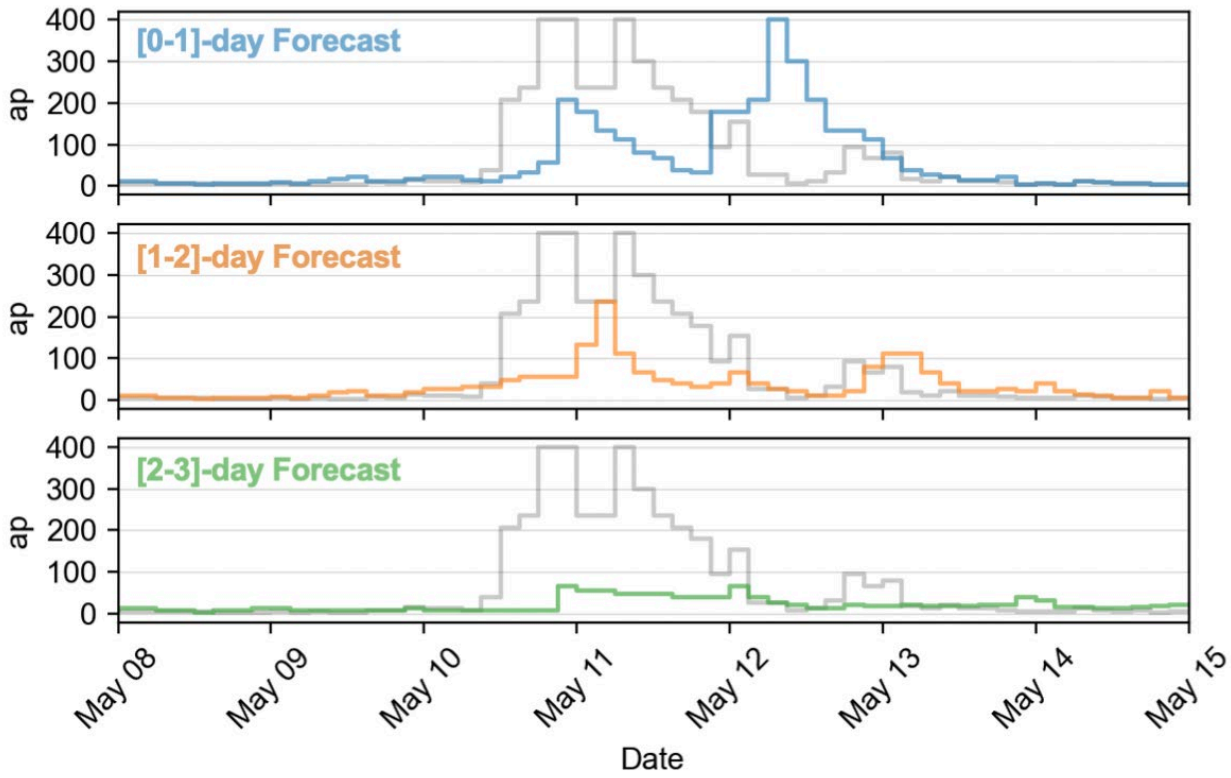


Figure: Total mass density at 400 km altitude before and during the storm

Forecasting Challenges

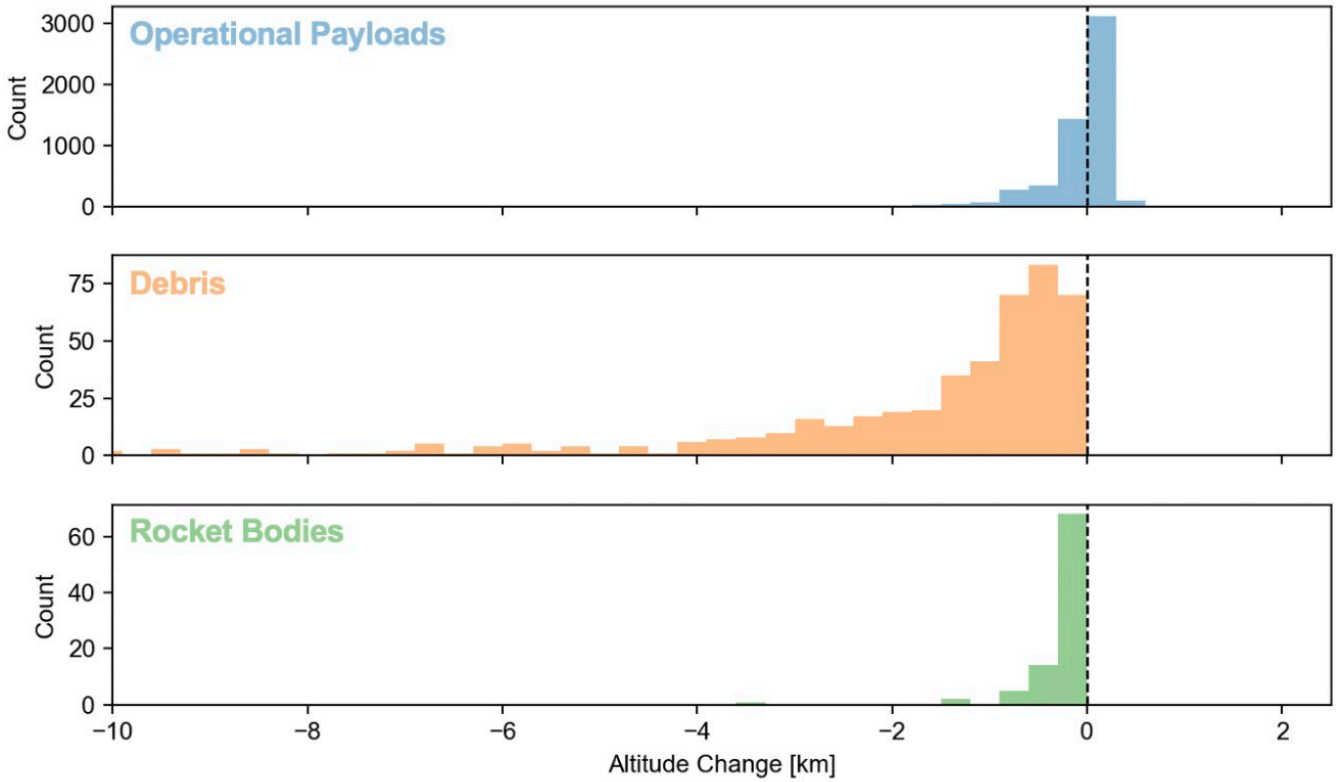
- NOAA SWPC's 3-day forecast of ap
  - This highlight some of the limitations of current forecasting models
  - There is an underprediction of initial ap increase across all time horizons
  - This results in a "persistence" assumption in forecasting models
- It still remains difficulty to predict CMEs and their Earth-arrival times
  - Improving this prediction will be important for space traffic management



NOAA SWPC's 3-day forecast of ap

Geomagnetic Storms as Debris Sinks

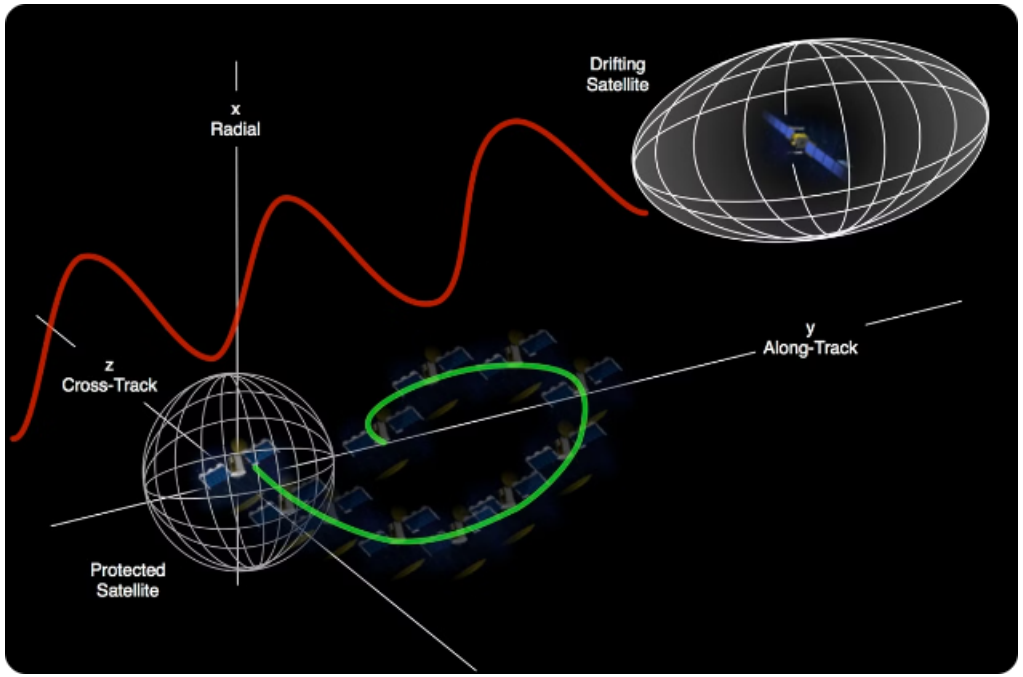
- There is a differential impact on various object types:
  - **Operational payloads:** Mostly maintain altitude through maneuvers
  - **Debris and rocket bodies:** Experience substantial altitude decay
- This highlights the potential benefit of storms in removing debris from orbit
  - Passive debris removal is important for long-term LEO sustainability but unplanned reentries can be a risk on the ground.



Altitude change for cataloged objects by type (400-700 km)

Challenges for Conjunction Assessment

- Conjunction Assessment:
  - Typical conjunction assessment process**: 7-day look-ahead window**
  - Importance of accurate **ephemeris files** for planned maneuvers
  - Issues arising from **unplanned station-keeping maneuvers**
  - Impact on **previously identified** potential conjunctions
  - Need to **restart conjunction assessment** pipeline after mass maneuvers and storm passage
- Space Traffic Management Issues:
  - **Increased complexity** of LEO environment during geomagnetic storms
  - Challenges in **maintaining accurate** space situational awareness
  - Need for **robust conjunction** assessment procedures during storm conditions
  - Potential for regulatory changes to address operation during extreme space weather events



Conclusion

- Recommendations:
  - Enhance **space weather forecasting** capabilities for STM applications
  - Develop **more robust conjunction** assessment procedures for storm conditions
  - Improve **communication and coordination** among satellite operators during storms

- Unique challenges posed by the Gannon geomagnetic storm
  - There is a need for adaptation in the new paradigm of **increased LEO activity**, new level of space traffic
  - We should understand **risk during storms** for conjunctions

- Future considerations:
  - **Approaching solar maximum:** Likelihood of more frequent and intense storms
  - We should do a more detailed study of the neutral density enhancements during Gannon Storm
  - We need more research of the upper atmosphere dynamics during geomagnetic disturbances

Questions

- Thank you!

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