Investigating Storm-Driven Thermospheric Density Enhancements with Two-Line Element Sets and Orbital Propagation

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INTRODUCTION

Thermosphere Dynamics

- Neutral densities increase up to 800% during geomagnetic storms[4].
- Satellite two-line element sets (TLEs) show increased orbital decay during geomagnetic storms from increased drag[2].

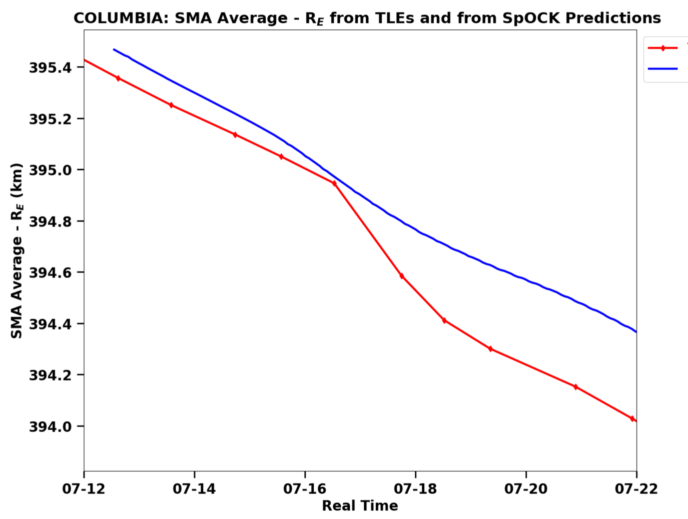

Figure 1: SpOCK inaccurately modeling orbital decay of the Columbia CubeSat.

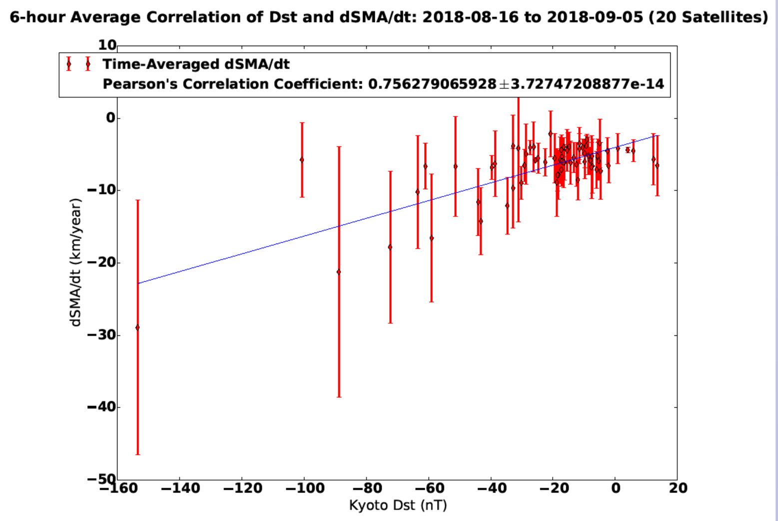

Figure 2: The strongly positive correlation between rate of deorbit and geomagnetic activity indicated by Dst for 20 identical Flock 2K CubeSats.

Weakness of Empirical Atmospheric Models

- Models like NLRMSISE-00 (Picone et al. 2002) poorly reproduce the storm-time density increase.
- Poor model performance reduces accuracy of orbital propagators (Figure 1) like UofM's Spacecraft Orbital Characterization Kit (SpOCK)[1].

Model Correction

- High-Accuracy Satellite Drag Model (HASDM) used by USAF to correct Jacchia-1970[6].
- HASDM Dynamics Calibration Atmosphere (DCA) uses Space Surveillance Network data of >75 orbiting spheres to estimate corrections to F10.7 and a_p[6].
- Doornbos et al. 2008 used TLEs to estimate corrections but assumed TLE-derived densities were sufficient[3].
- We propose a method that estimates corrections by minimizing orbit error between SpOCK orbits and TLEs.

OBJECTIVES

- Develop an algorithm capable of **estimating corrections to empirical model densities** during geomagnetic storms.
- **Validate** the corrected densities returned by the algorithm in comparison to *in-situ* densities measured by the SWARM spacecrafts.
- Demonstrate the algorithm's **self-consistency** across a wide variety of modeled spacecraft orbits during different storms.
- Demonstrate the efficacy of using **orbit error minimization** to back out corrected densities from empirical atmospheric models.

METHODOLOGY

<u>**Multifaceted Optimization Algorithm:**</u>

Corrects NRLMSISE-00 model densities:

1. **Area Optimization Algorithm (AROPT):**
   - Loop over preceding quiet time and adjust cross-sectional area until orbit error is minimized.
2. **F10.7 Optimization Algorithm (FOPT):**
   - Obtain the **mean** of the optimized area distribution (<u>assumes NLRMISISE-00 underpredicts effects from storms</u>)
   - Repeat the loop, adjusting F10.7 until orbit error is minimized; retrieve the F10.7 correction for each interval.
3. **Applying Corrections:**
   - Linearly interpolate median corrections across all satellites.
   - Apply corrections to F10.7 inputs to NRLMSISE-00 along-track the orbits of validation spacecraft.
   - Compare the resulting densities to *in-situ* measurements.

<u>**Scenario:**</u>

- Time: 2018-08-21 and 2018-08-31
- Calibration Targets: 10 Flock 2K satellites
- Validation Satellites: SWARM-A, -B, -C

<u>**Note:**</u> Chosen quartile of the optimized area distribution strongly impacts corrections. Best results when correcting NASA OMNIWeb inputs (static daily indices).

Figure 3: An example of a Flock 2K 3U CubeSat launched by Planet Labs, Inc.

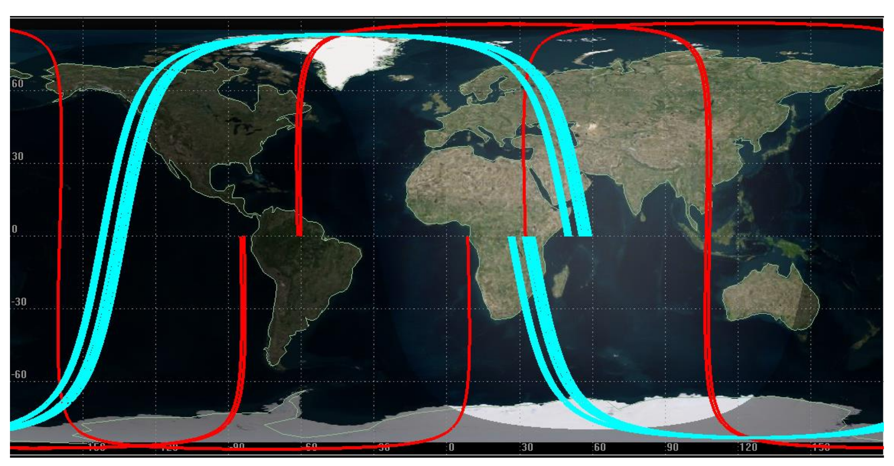

Figure 4: Orbits of the Flock 2K CubeSats (cyan) and of SWARM (red) in the August 2018 storm.

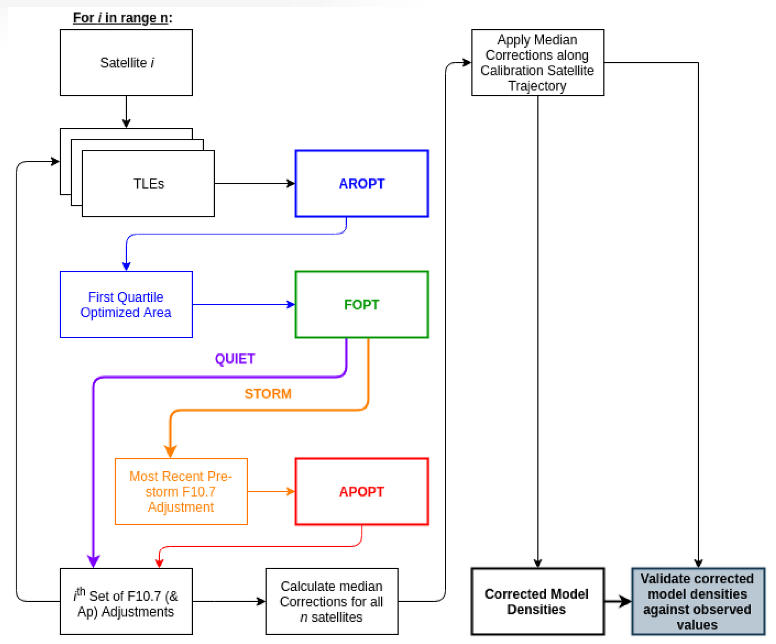

Figure 5: A flowchart of the MOA algorithm. We restricted ourselves to the AROPT and FOPT sub-processes for this initial study.

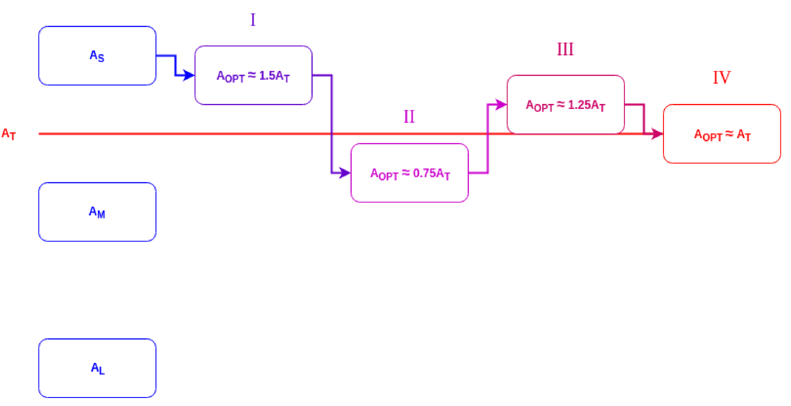

Figure 6: A flowchart of the bracketing processes used by AROPT to find the optimized area.

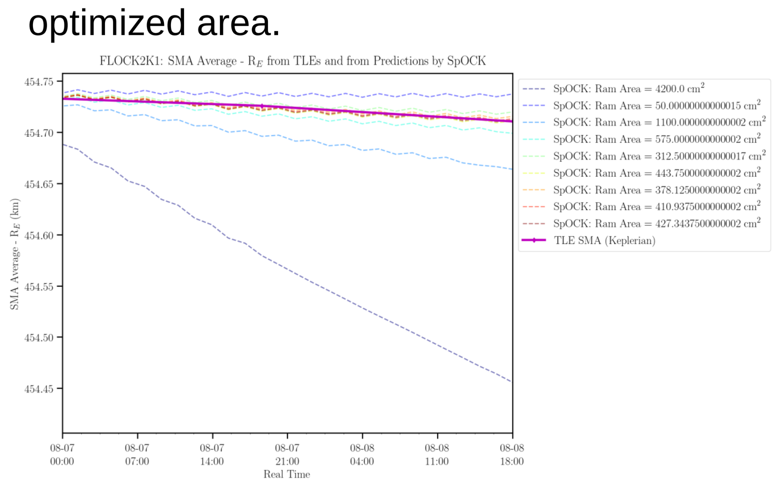

Figure 7: AROPT optimizing the area of the Flock 2K 1 satellite.

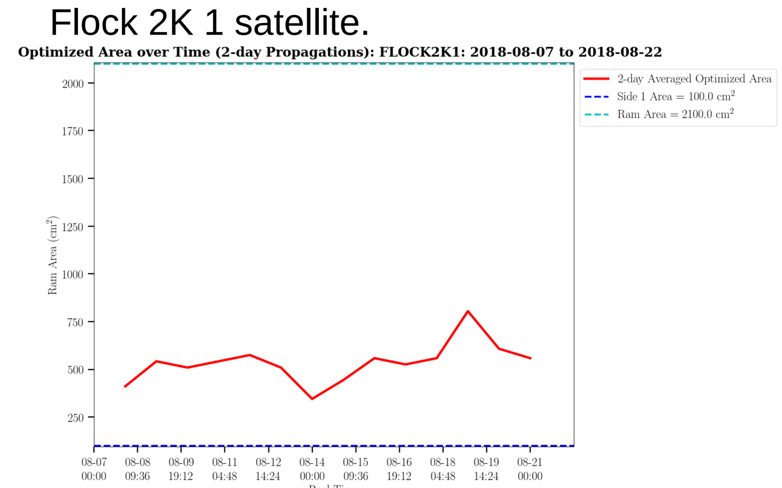

Figure 8: AROPT's resulting optimized areas for Flock 2K 1 during quiet time.

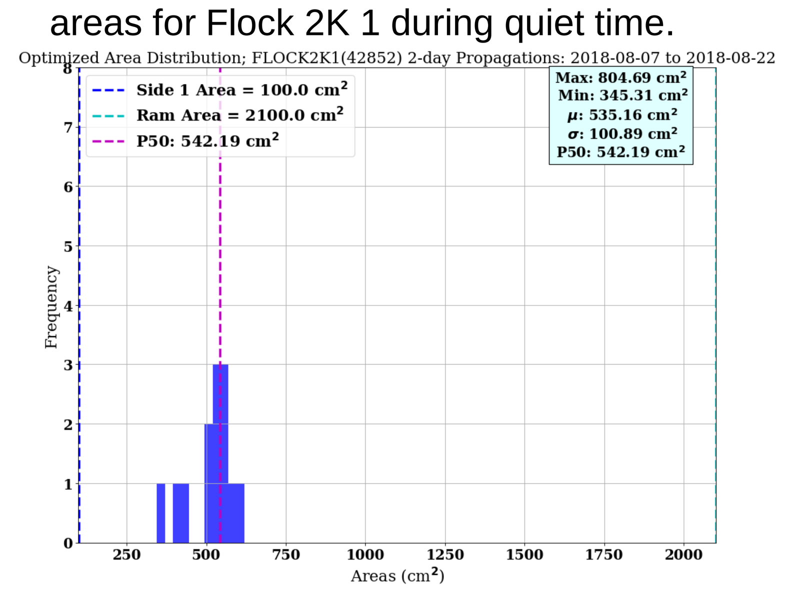

Figure 9: Flock 2K 1 optimized areas during quiet time assembled into a histogram.

RESULTS

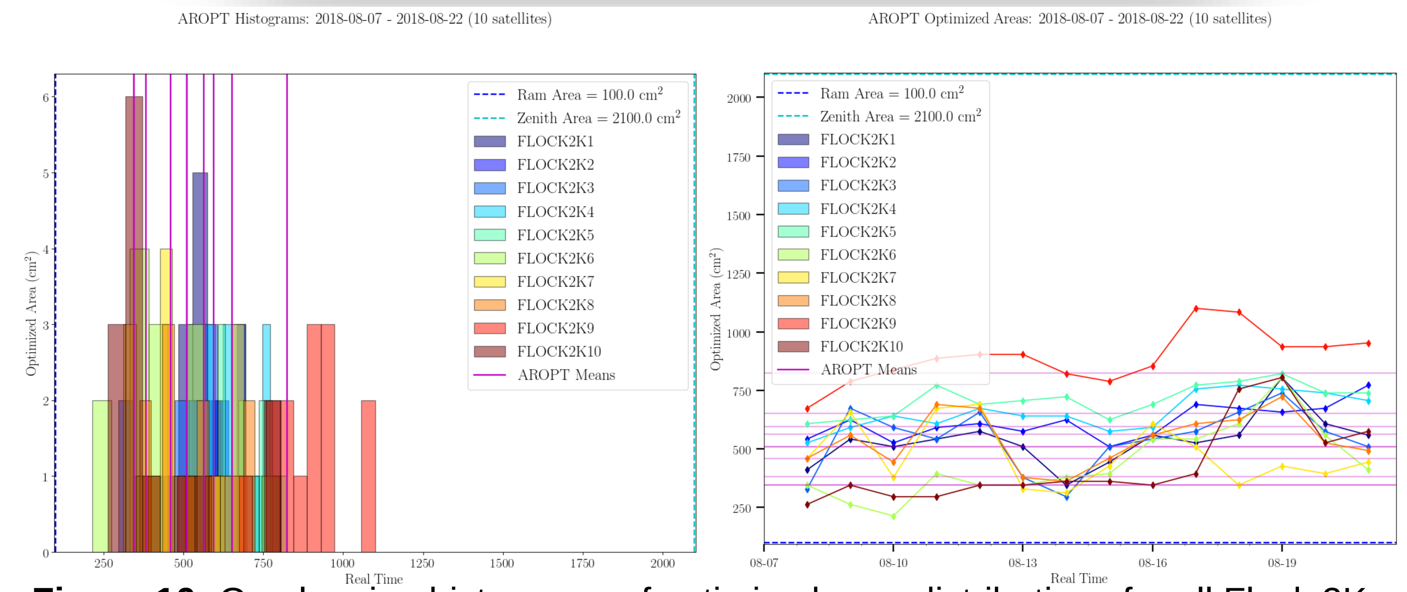

Figure 10: Overlapping histograms of optimized area distributions for all Flock 2K satellites (left) and their corresponding optimized areas over time (right)..

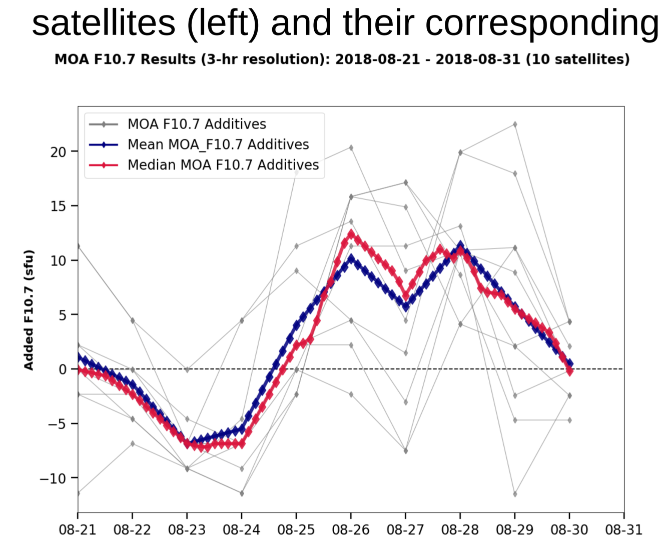

Figure 11: Linearly-interpolated F10.7 corrections across all 10 satellites.

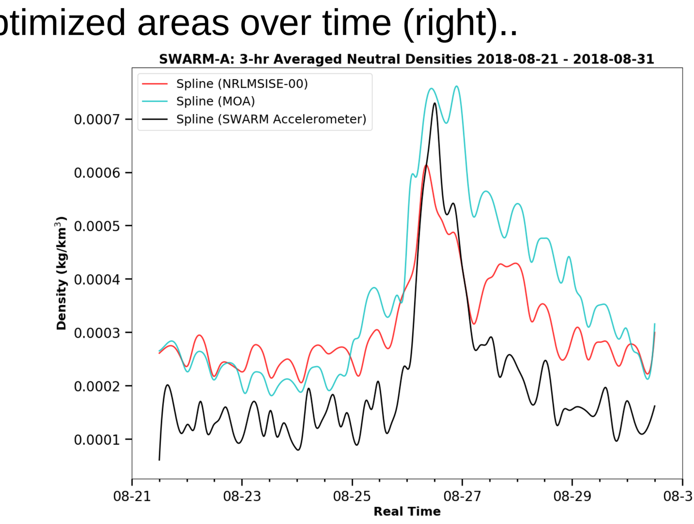

Figure 12: Corrected densities along-track SWARM-A.

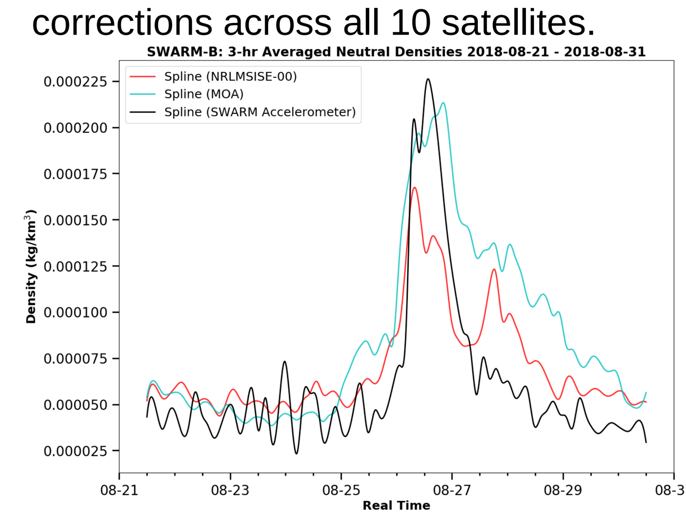

Figure 13: Corrected densities along-track SWARM-B.

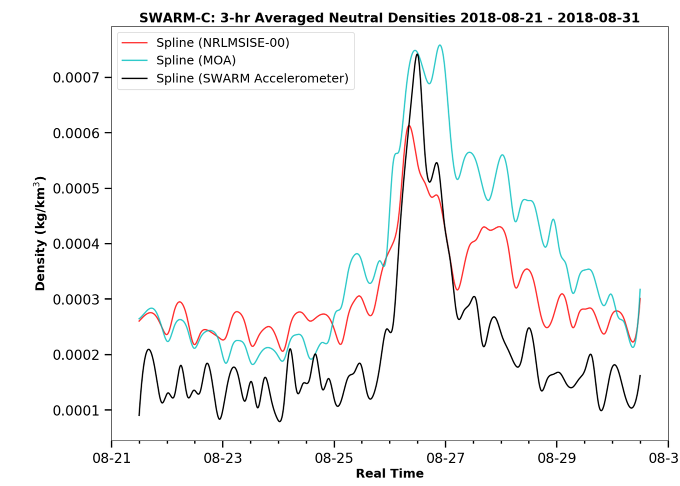

Figure 14: Corrected densities along-track SWARM-C.

DISCUSSION AND FUTURE WORK

- Density correction allowing for reductions up to 10% error in magnitude, on par with results obtained by Doornbos et al. 2008.
- Post-main phase corrected densities are consistently too large.
- Densities more accurate than NLRMSISE-00 during initial onset.
- Raw corrected densities exhibit much greater amplitude variation compared to SWARM.
- Must validate the algorithm in other storms of varying intensities and using a variety of other calibration targets.
- Incorporate the third sub-process of correcting 3-hr a_p during storm main phase.

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