Improving a Model of the Thermospheric Density Using CubeSat Ephemeris Data

Center for Orbital Debris Education and Research

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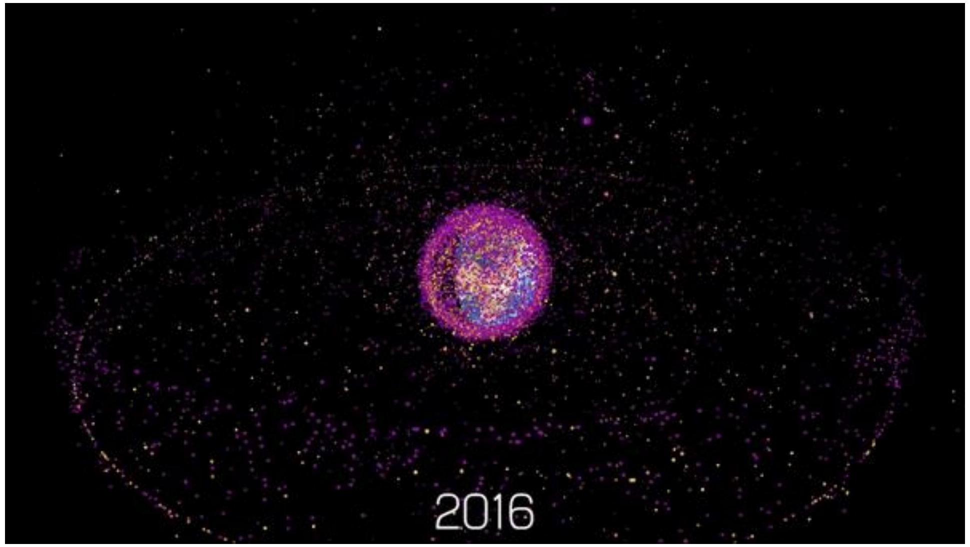
Motivation

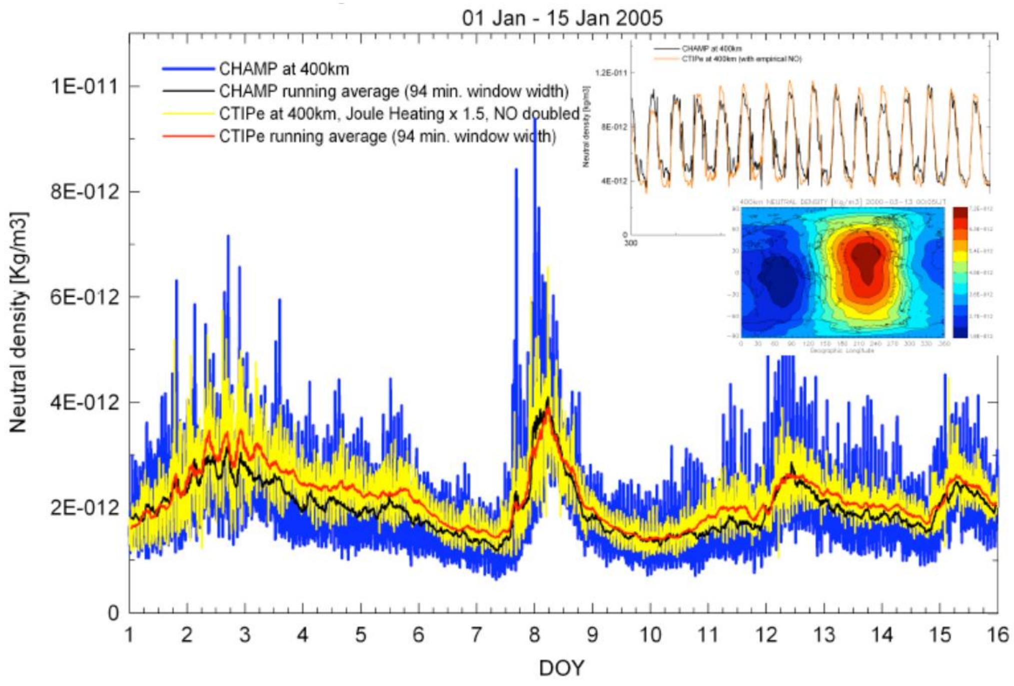
- Prominence of LEO satellites and space debris necessitates accurate thermospheric density modeling.
  - USSPACECROM tracks ~8,000 objects
  - NORAD tracks ~20,0000 objects of softball size or larger
- Public relies on empirical density models (Jacchia, MSISE); we know ephemeris data can be used to calibrate density estimation.
- No near real-time calibration algorithm exists for our most accurate empirical model, NRLMSISE-00.



A simulation of ~17,000 trackable objects supplied by Space-Track, by Dr. Stuart Grey of the University College London (objects not to scale).

Previous Work on Density Measurement and Calibration

- Thermospheric density variation and response to geomagnetic activity characterized by CHAMP, GRACE, and GOCE.
  - Density enhancements between 400%-800% of quiet time values during geomagnetic superstorms (Liu and Lühr 2005).
  - Seasonal variation of annual density amplitude can reach ~40-50% of the annual mean, decreasing northward from high latitudes in the southern hemisphere (Lei et al. 2012).
  - Accelerometer-derived densities suffer errors <15% sourced from solar radiation pressure, unknown lift and drag coefficients, instrument precision and biases, and unaccounted for thermospheric winds (Sutton et al. 2007).



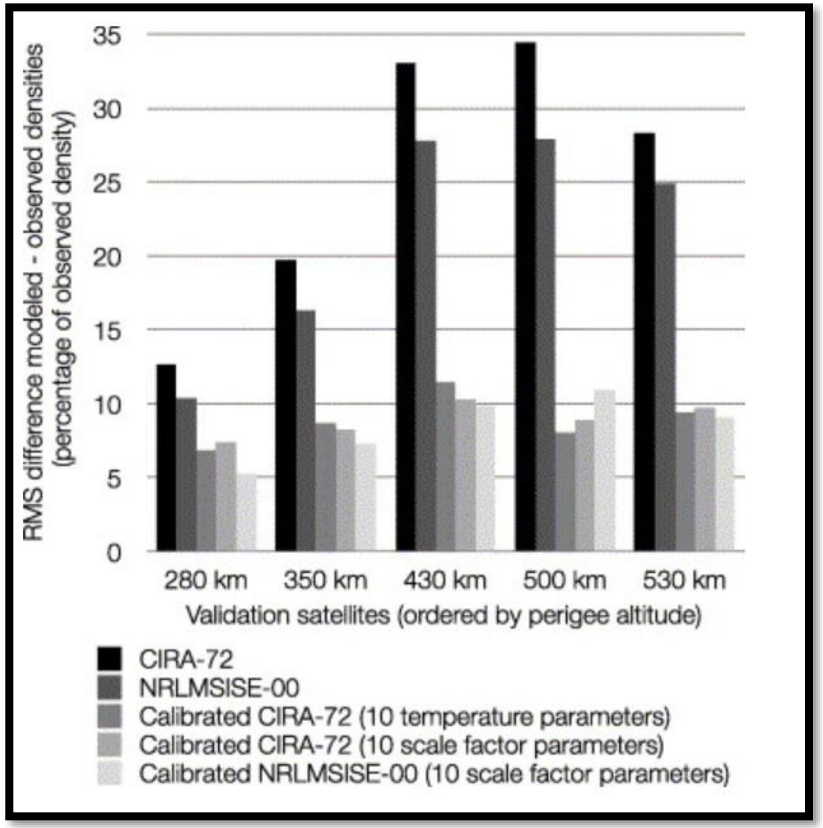
Thermosphere density fluctuations at 400 km measured by CHAMP satellite and modeled by the Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics Model (CTIPe) during a geomagnetic storm (Fedrizzi et al. 2015).

Previous Work on Density Measurement and Calibration (cont.)

- HASDM (USAF Space Battlelab)
  - Validates GOCE densities to within 3% compared 10% for NRLMSISE-00, JB2008 and DTM2012 (Bruinsma et al. 2014)
  - Dynamic Calibration Atmosphere (DCA)
  - Near Real-Time calibration of density prediction
  - Uses direct Space Surveillance Network observations for calibration (75-80 objects)

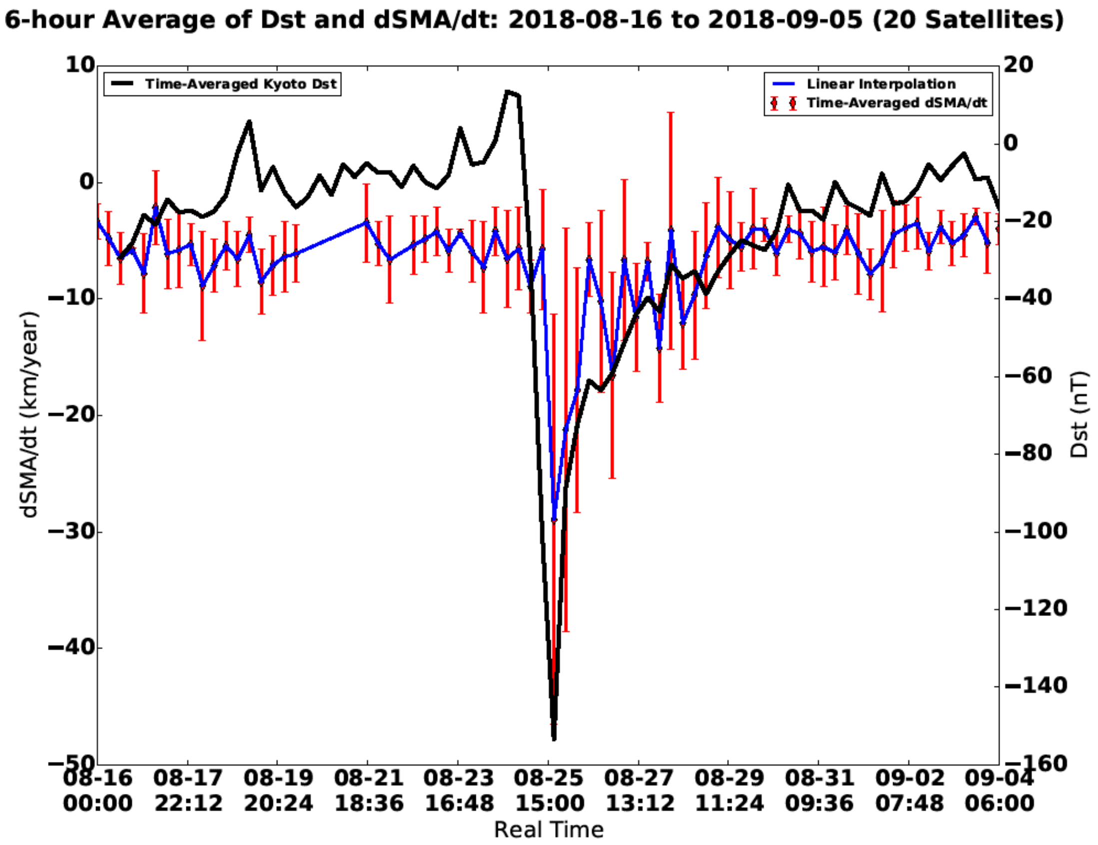
Previous Work on Density Measurement and Calibration (cont.)

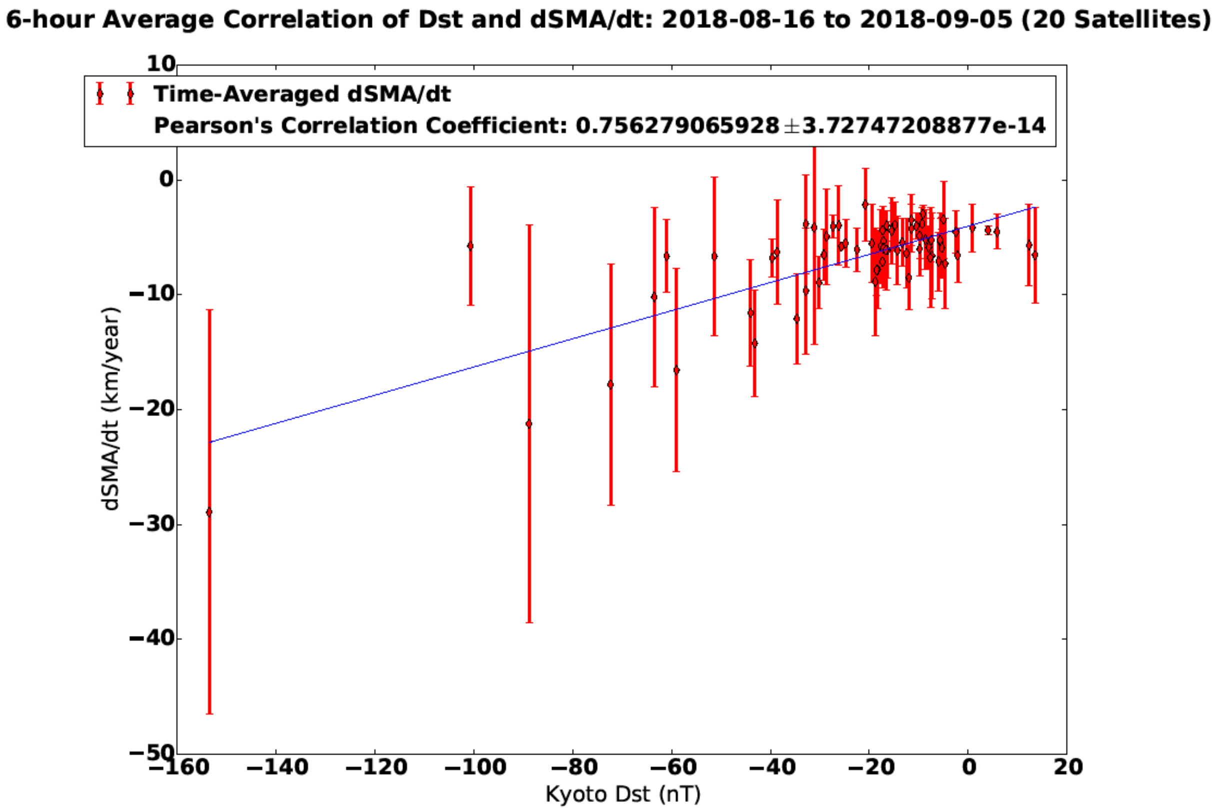
- Doornbos et al. 2008 demonstrated that density errors in empirical thermospheric density models can be reduced by using TLE data for calibration:
  - Modifying height-dependent scale factors to the density
  - Implementing temperature corrections to the CIRA-72 (Jacchia 1972) model, *based on DCA in HASDM*
- The most recent version of MSISE (NRLMSISE-00) <u>outperforms</u> CIRA-72 (see right).



The resulting increase in density prediction accuracy due to calibration (Doornbos et al. 2008).

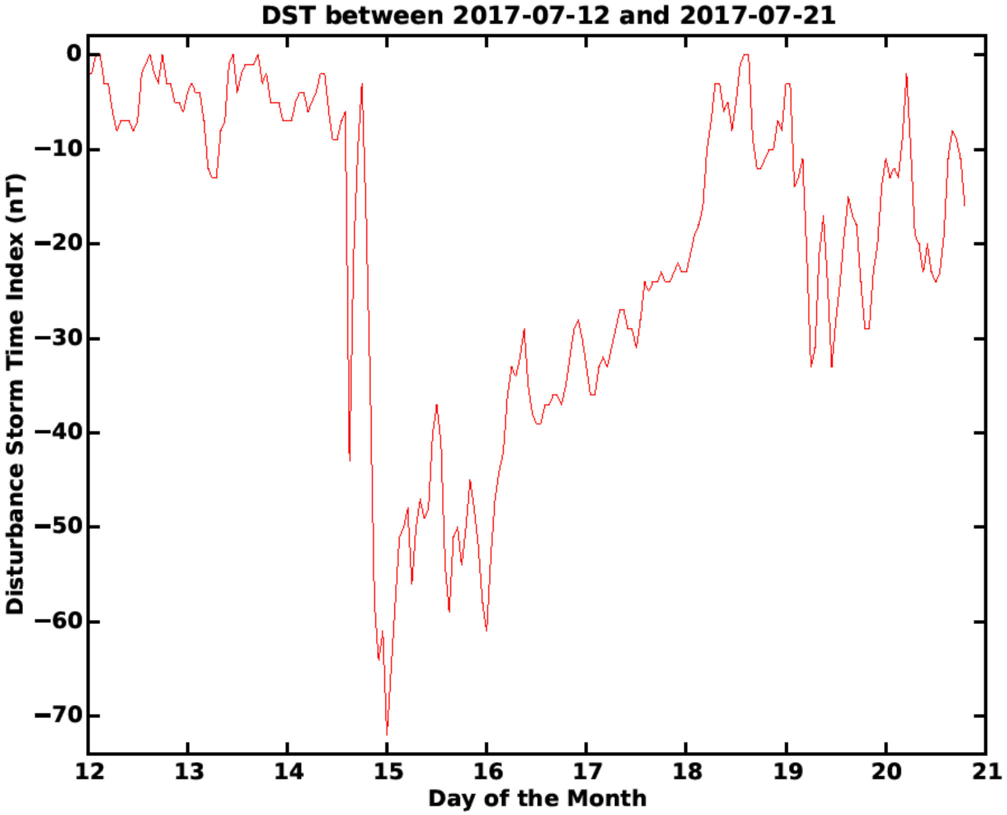
Visualizing Geomagnetic Activity and Change in Satellite Altitude

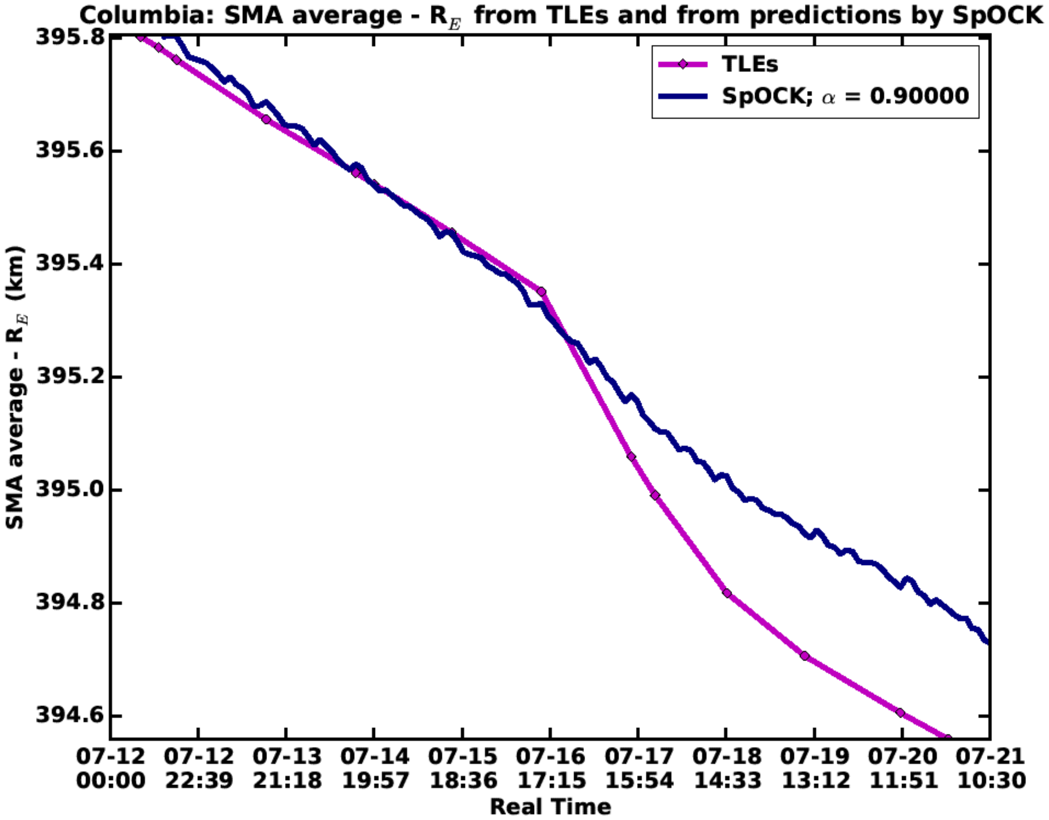




The rate of orbital decay (here in change in semi-major axis per year) correlates quite strongly with disturbance storm time (Dst).

SpOCK and the Limitations of NRLMSISE-00



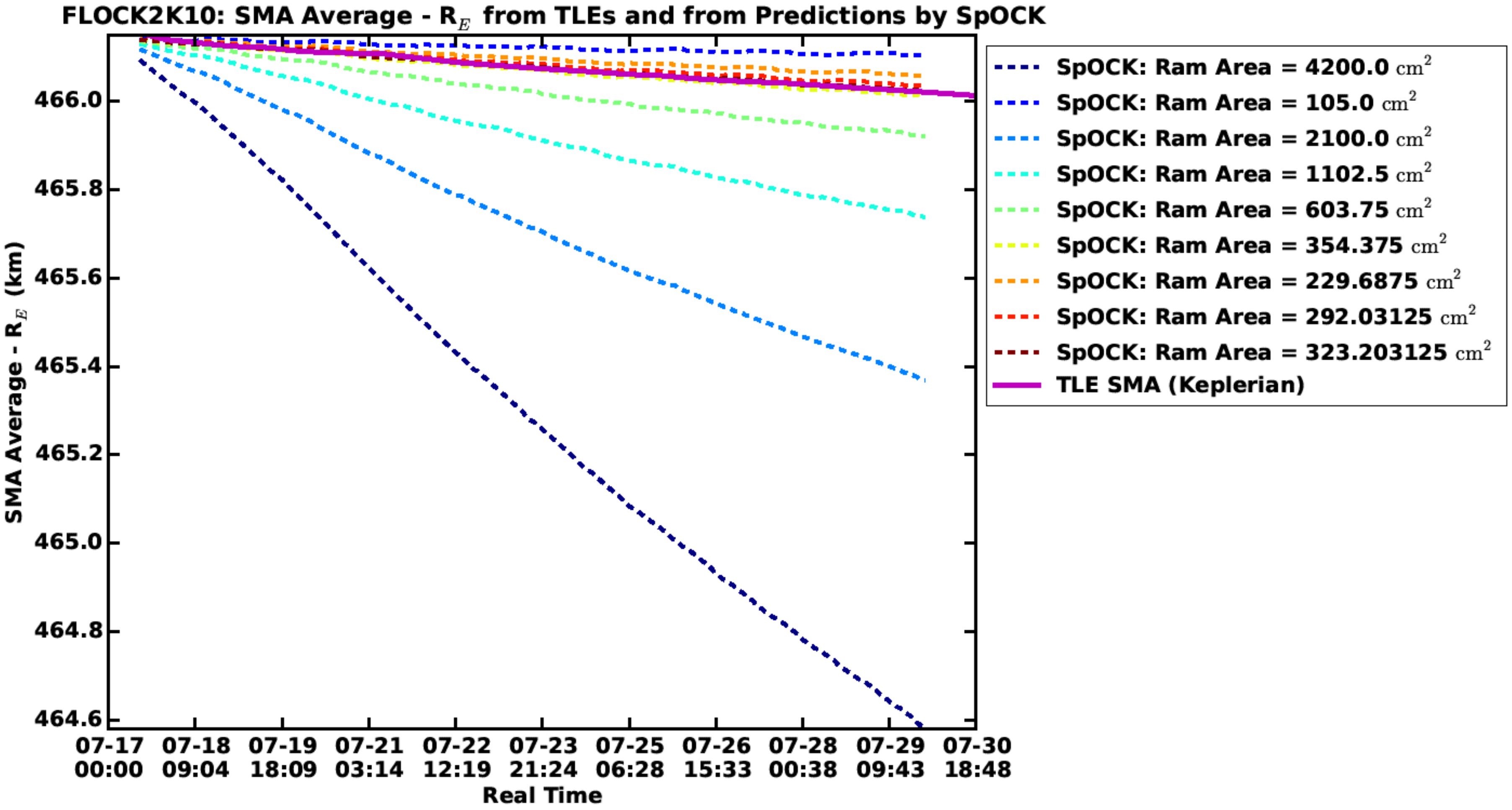


SpOCK draws density predictions from MSISE, yet when trying to reproduce spacecraft orbits during enhanced geomagnetic activity, the altitudes are too high → MSISE is underpredicting the density

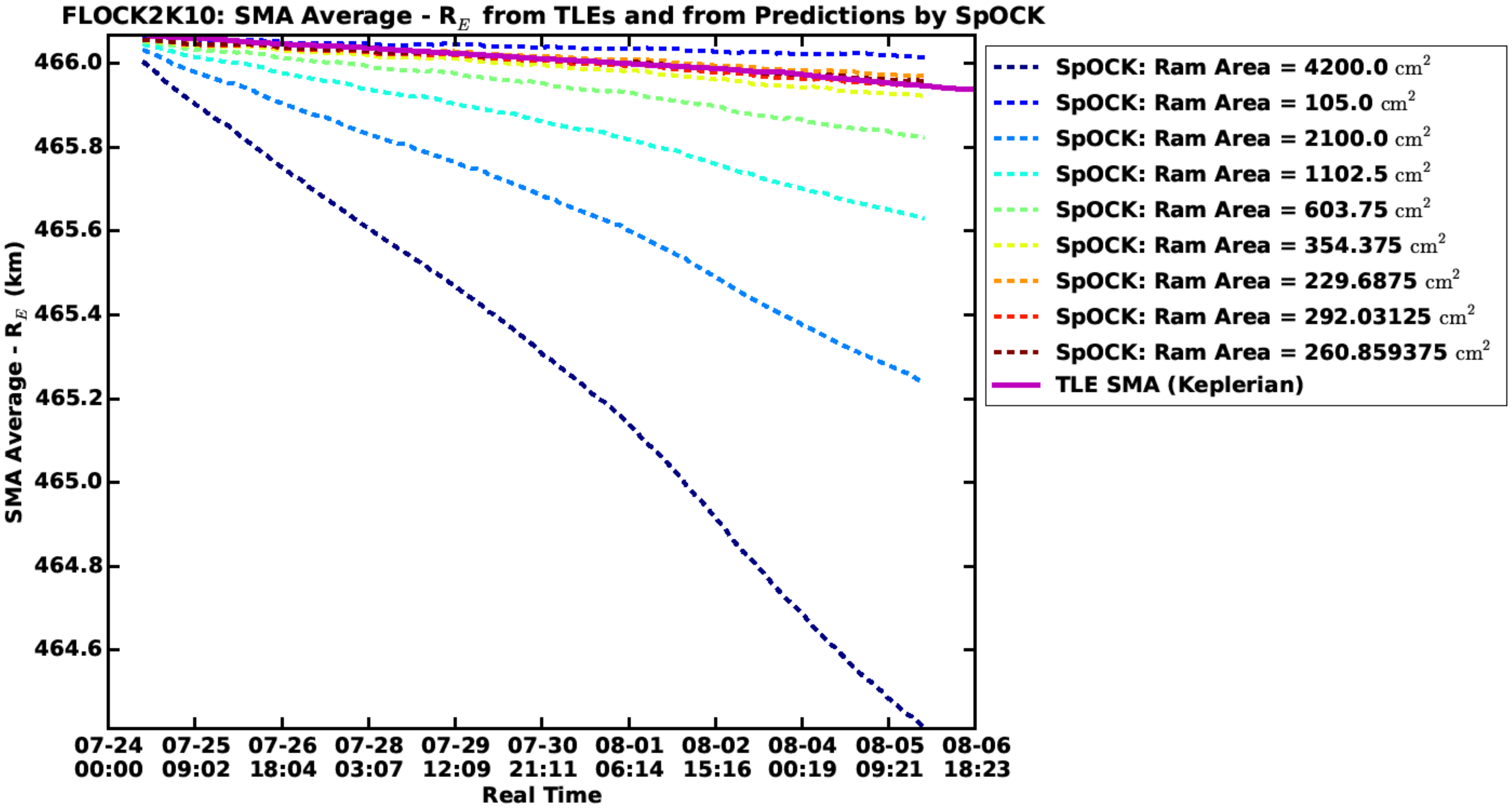
Methodological Approach to Density Estimation Calibration

- Characterization of satellite geometry through bracketed optimization algorithm employing SpOCK (geomagnetic quiet time).
- Determination of seasonal optimized geometry dependency (in progress).
- Adjustment of 3-hour Ap/F10.7/neutral density during active geomagnetic times, employing SpOCK with optimized geometry.

Area Optimization



Area Optimization (cont.)



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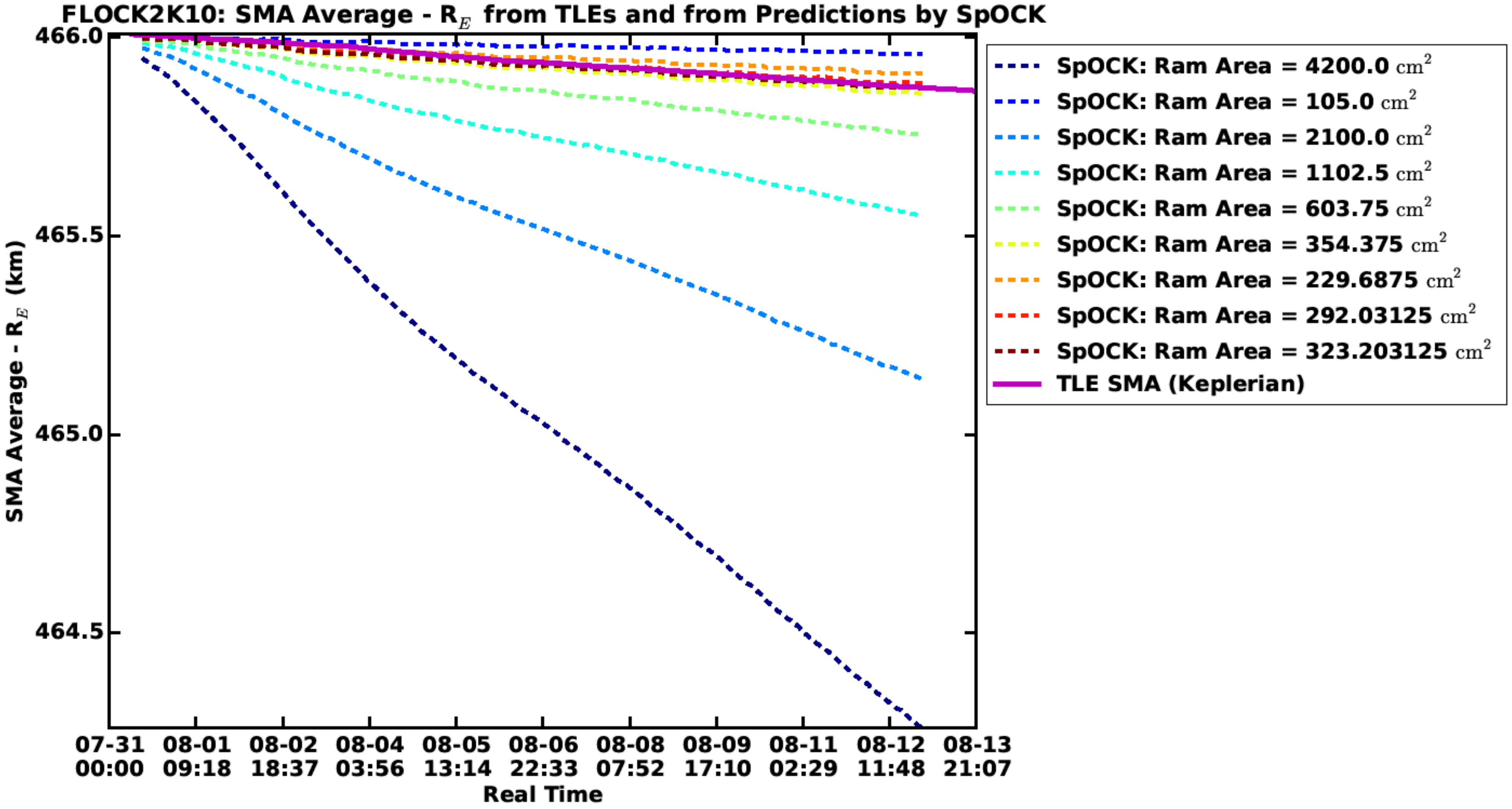

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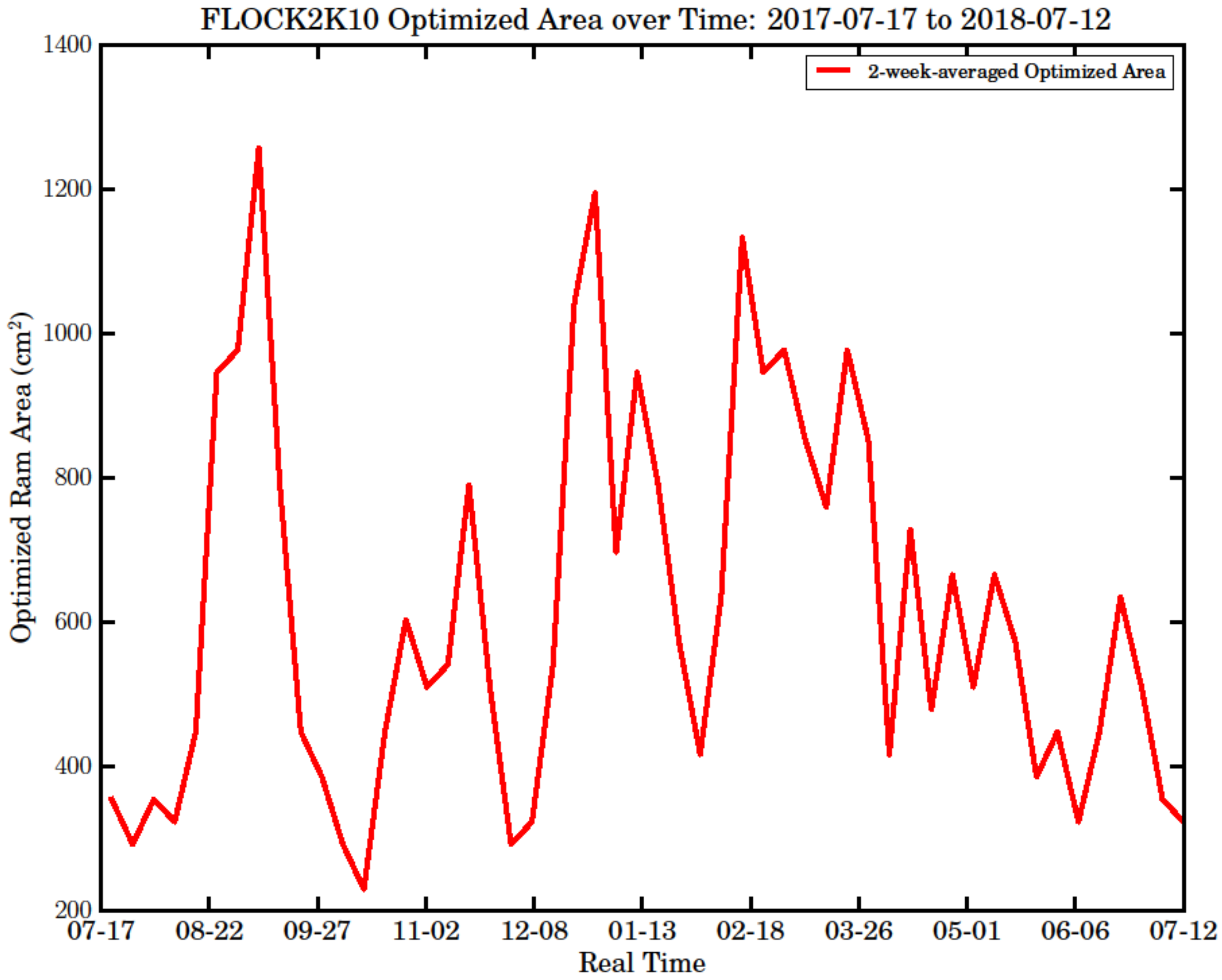

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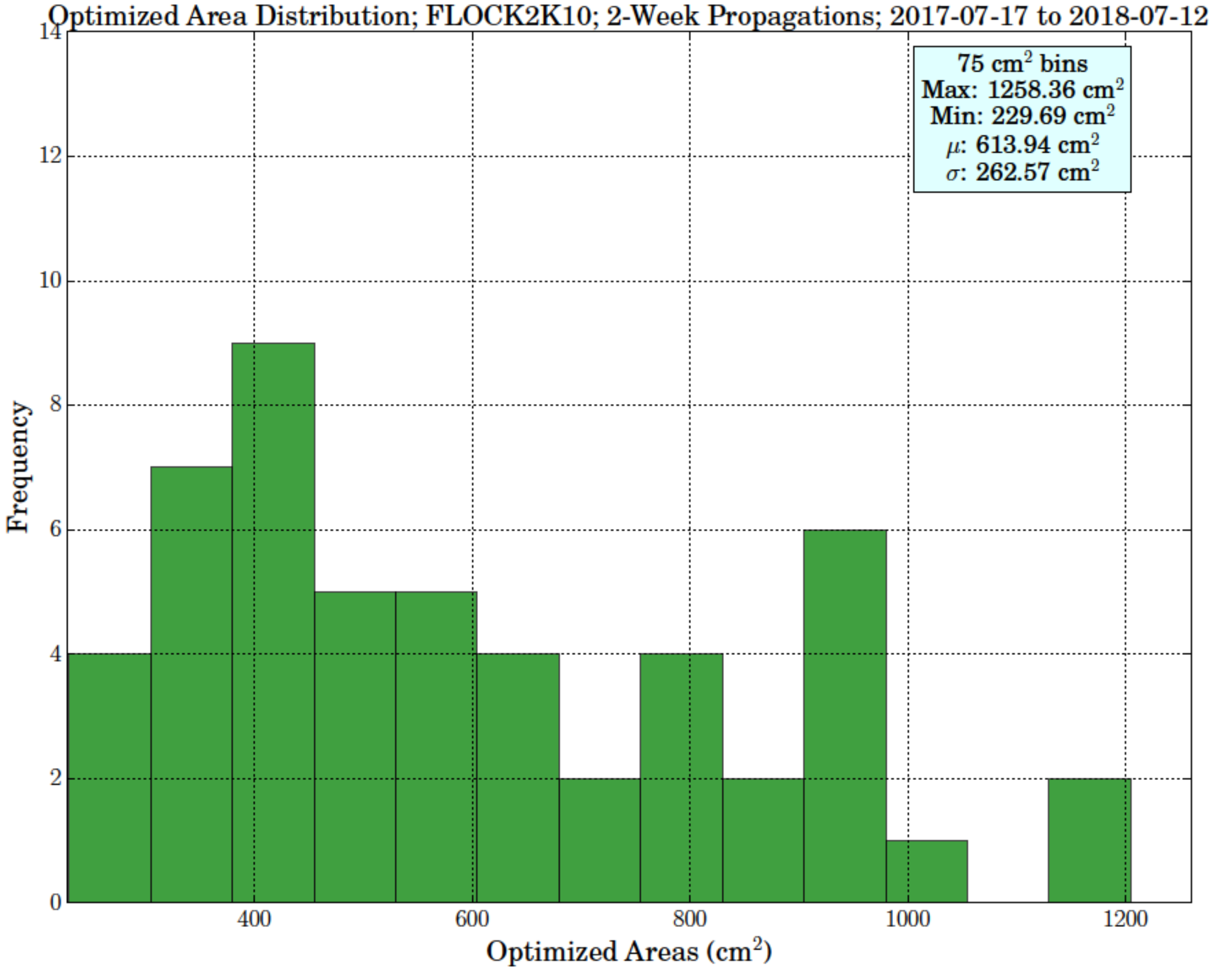

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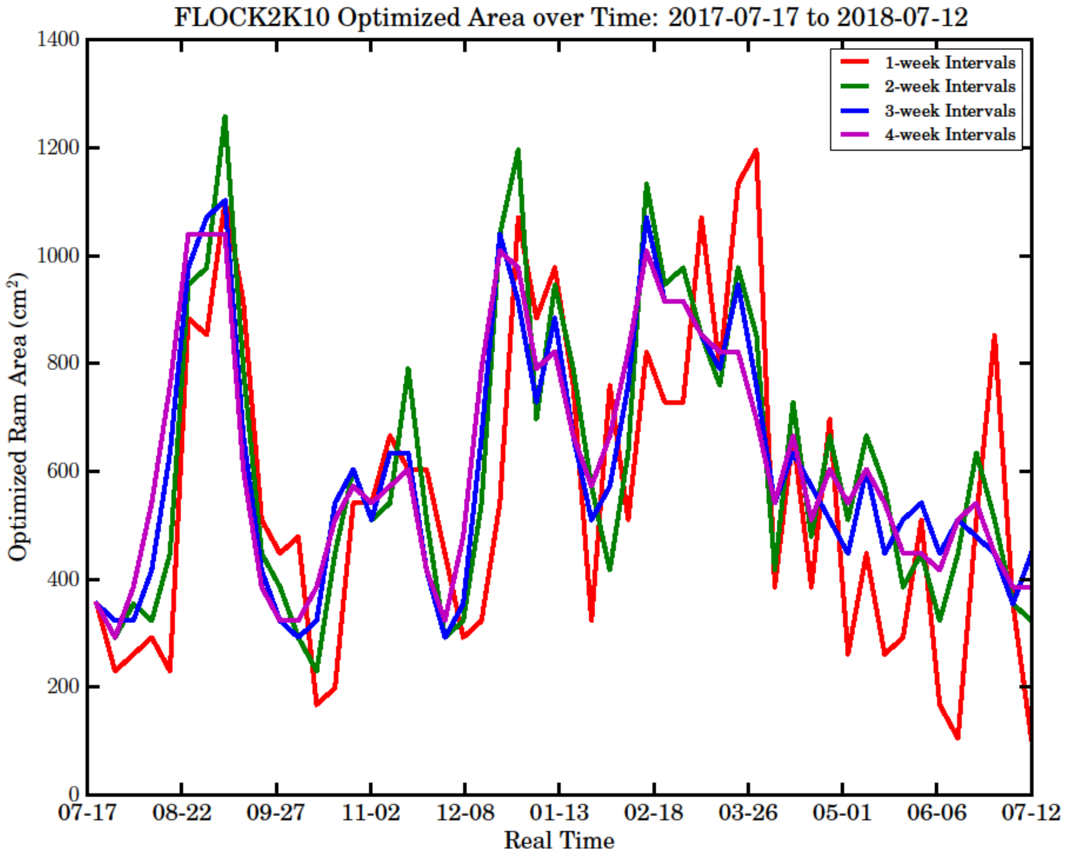
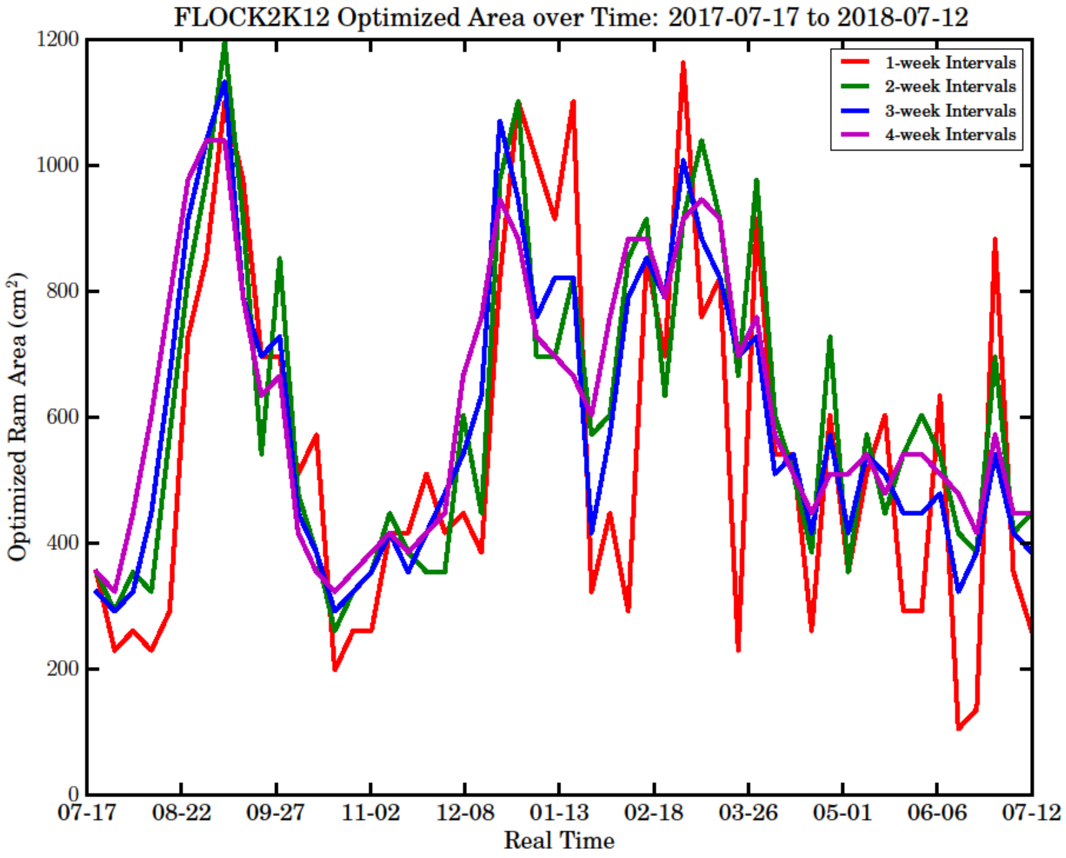
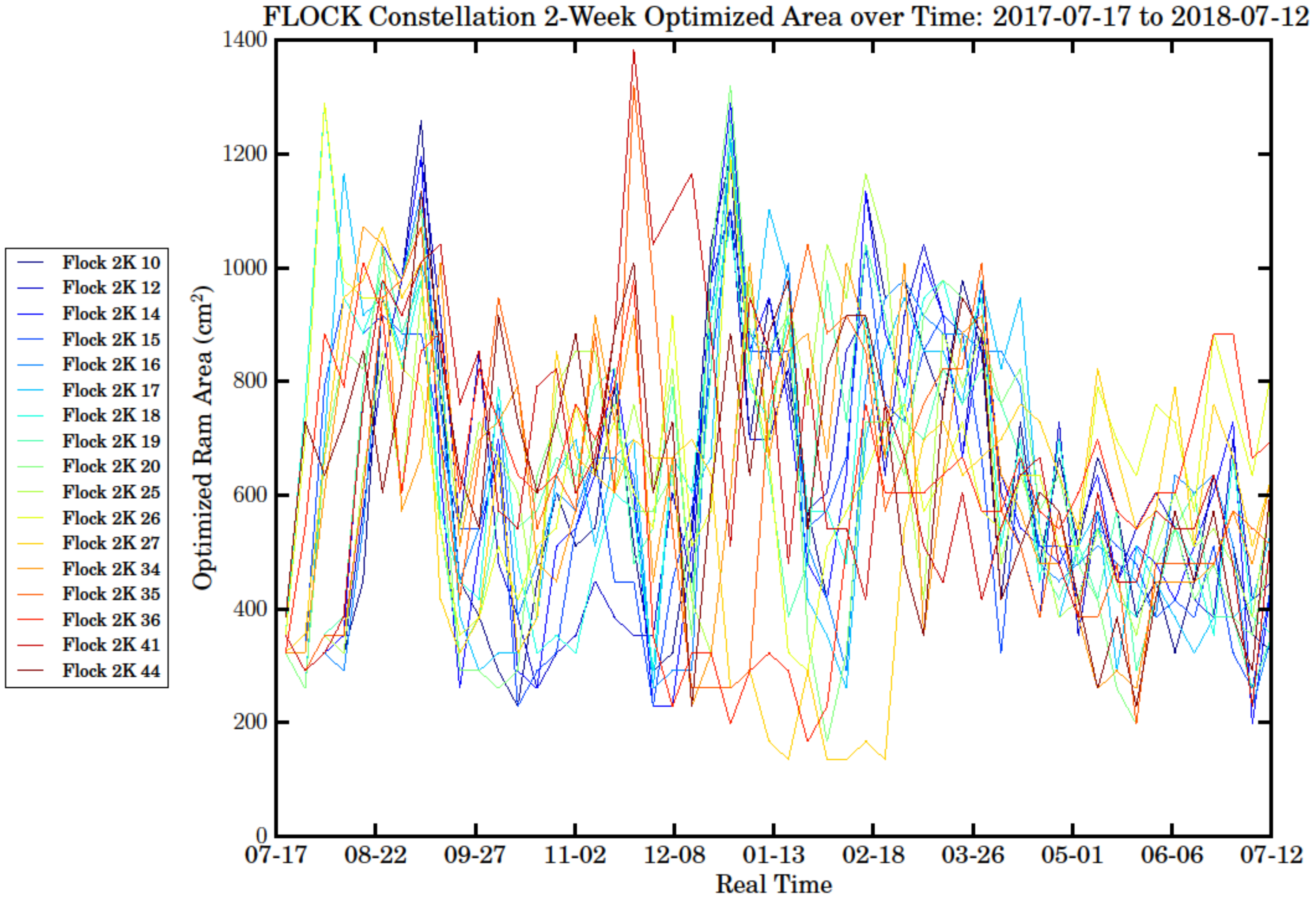




Area Optimization (cont.)



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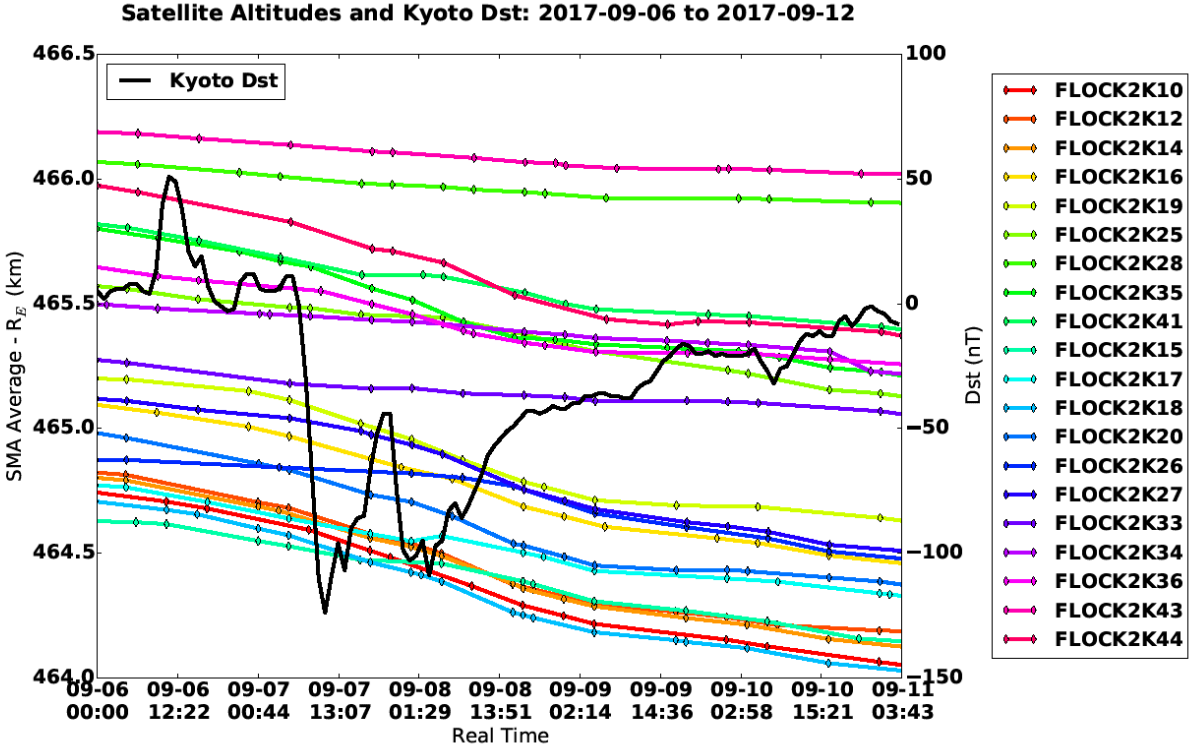
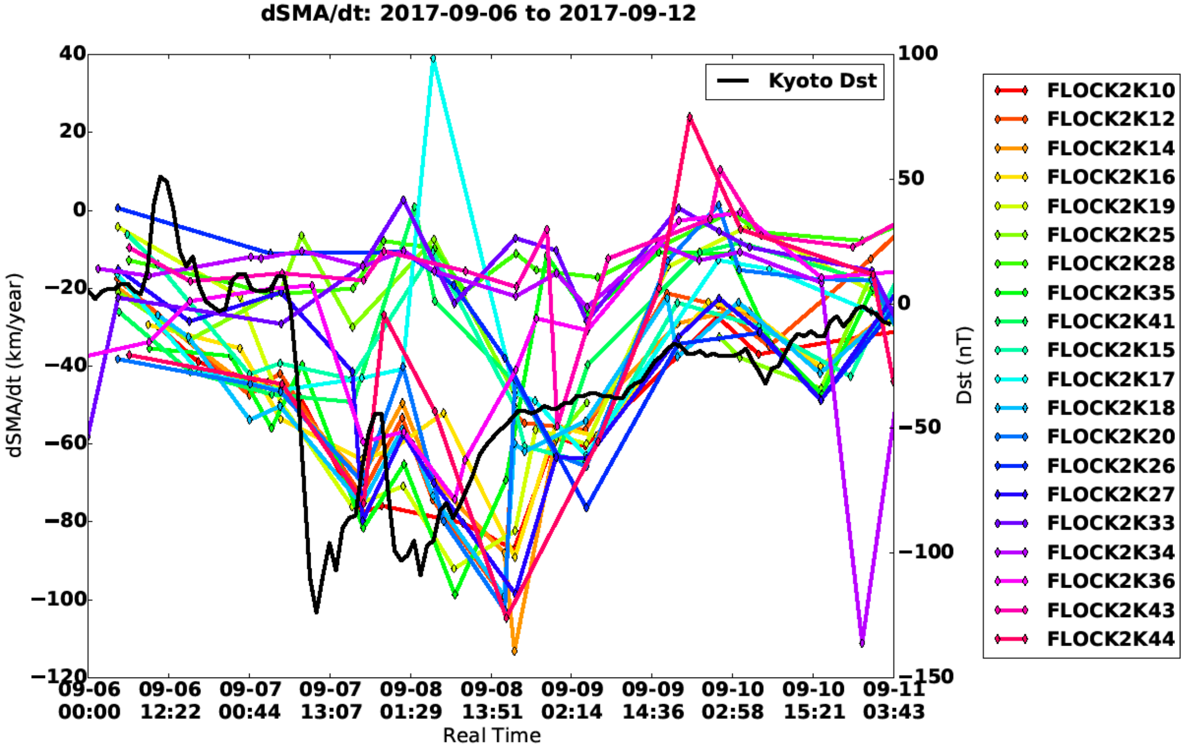
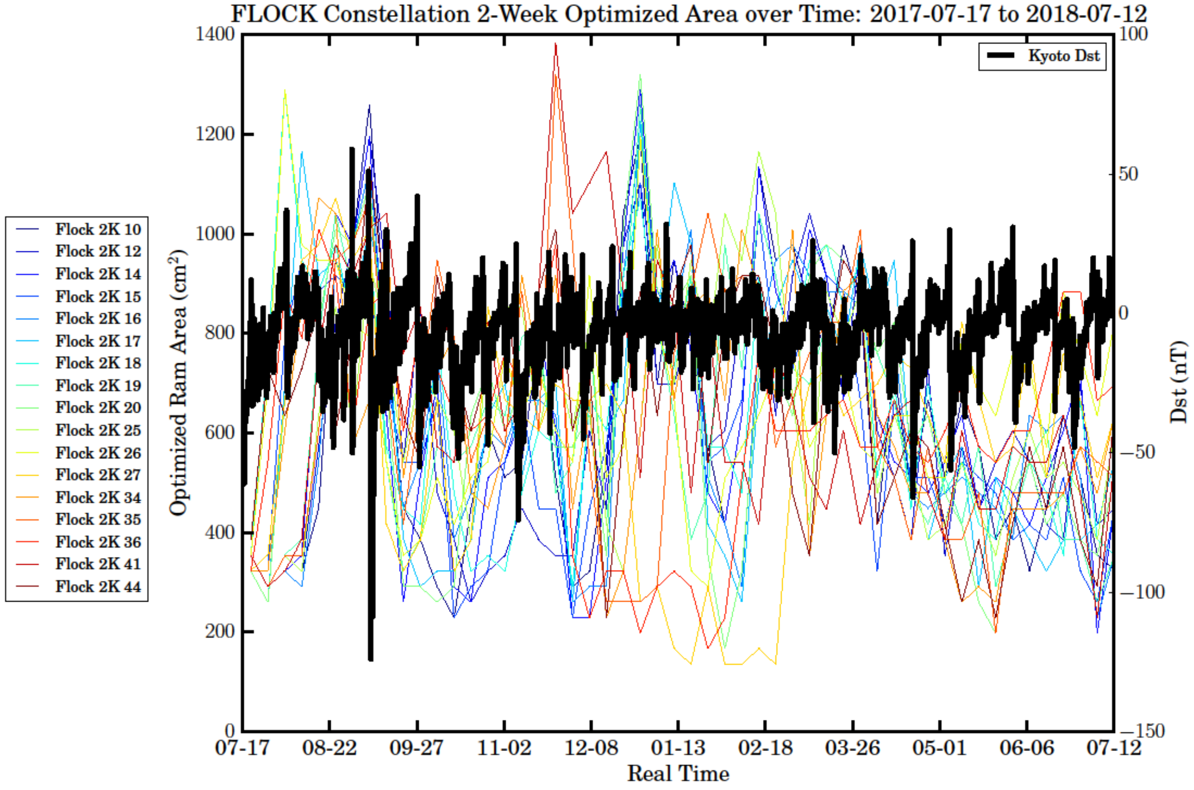
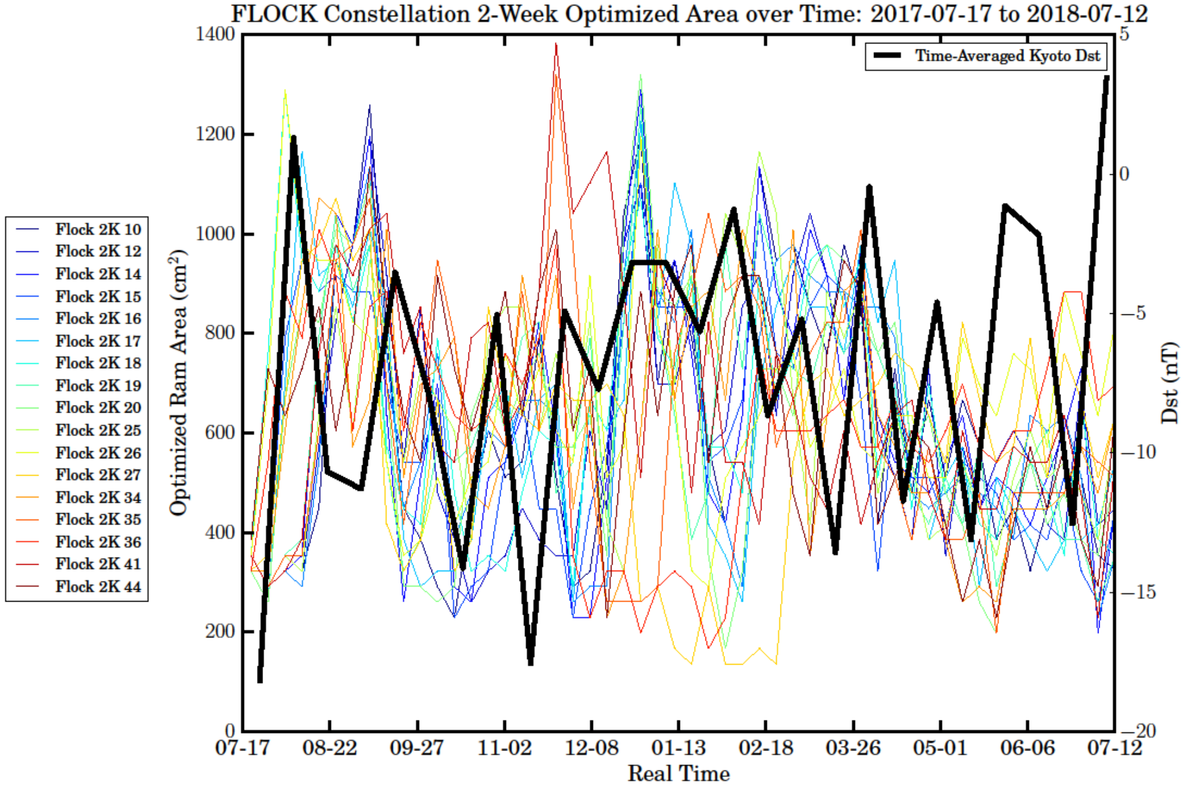




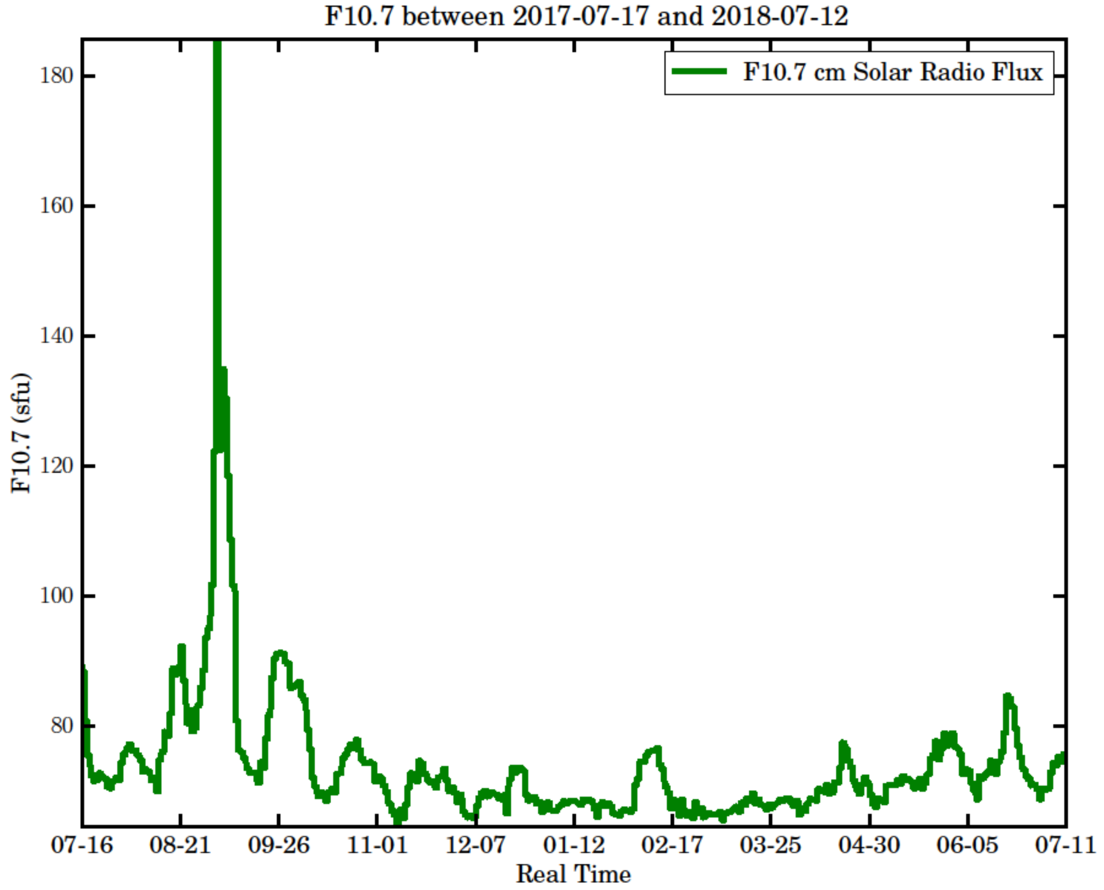
Satellites Flock 2K 28 and Flock 2K 43 were removed from our analysis due to their altitude profiles demonstrating little to discernable Dst-related trend in comparison to the rest of the 2K constellation.

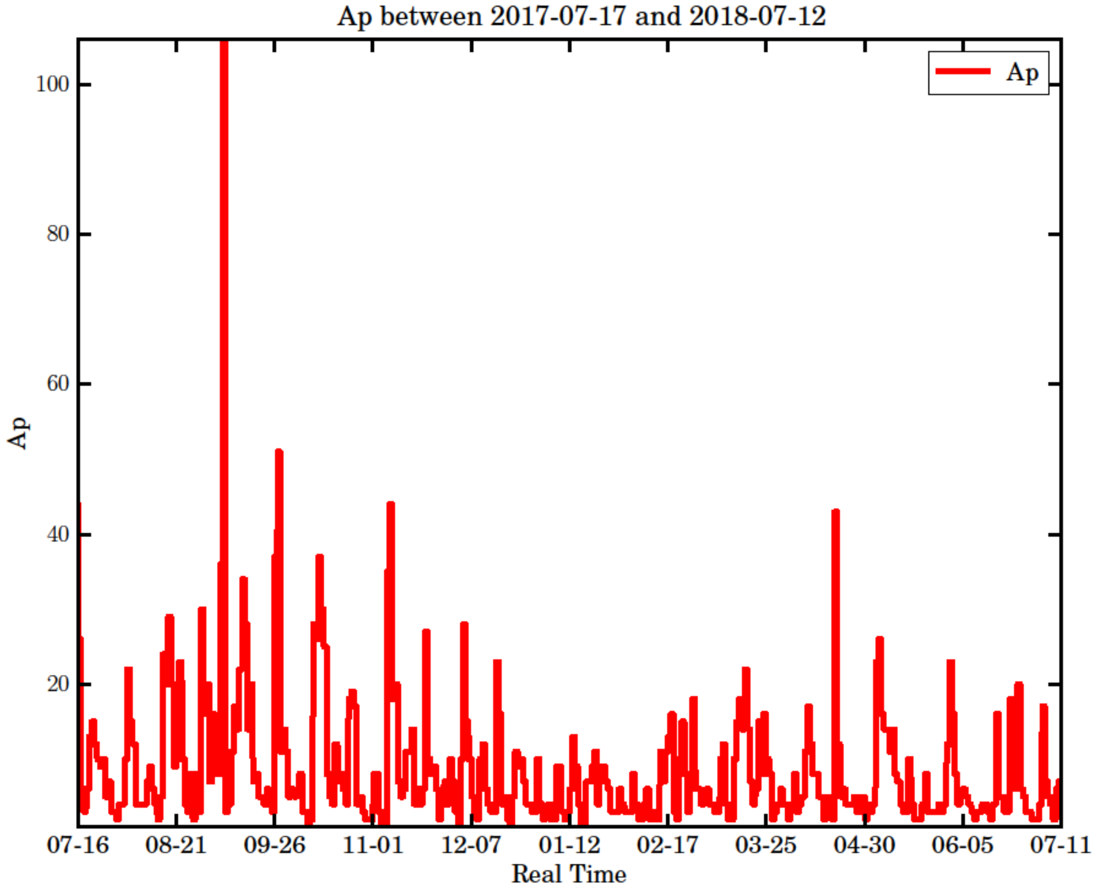
Evaluating Nuances of NLRMSISE-00 Performance



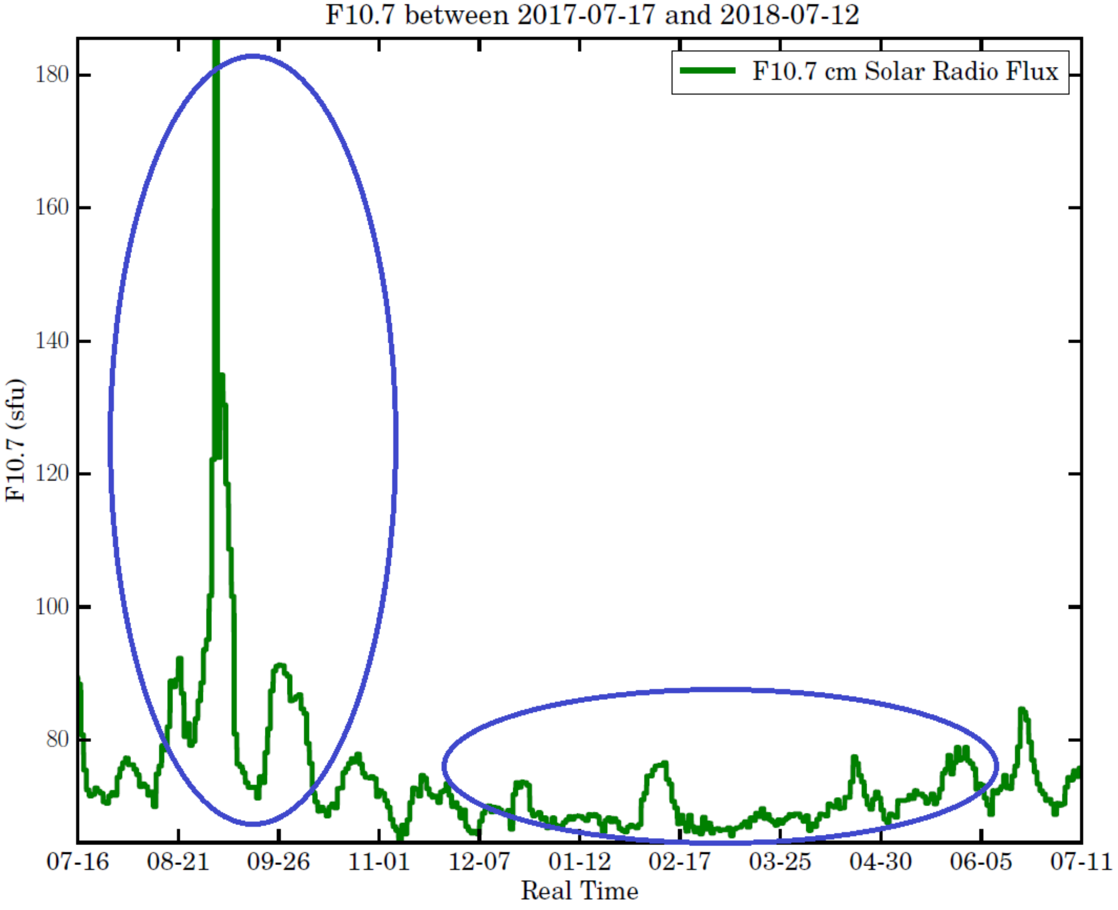


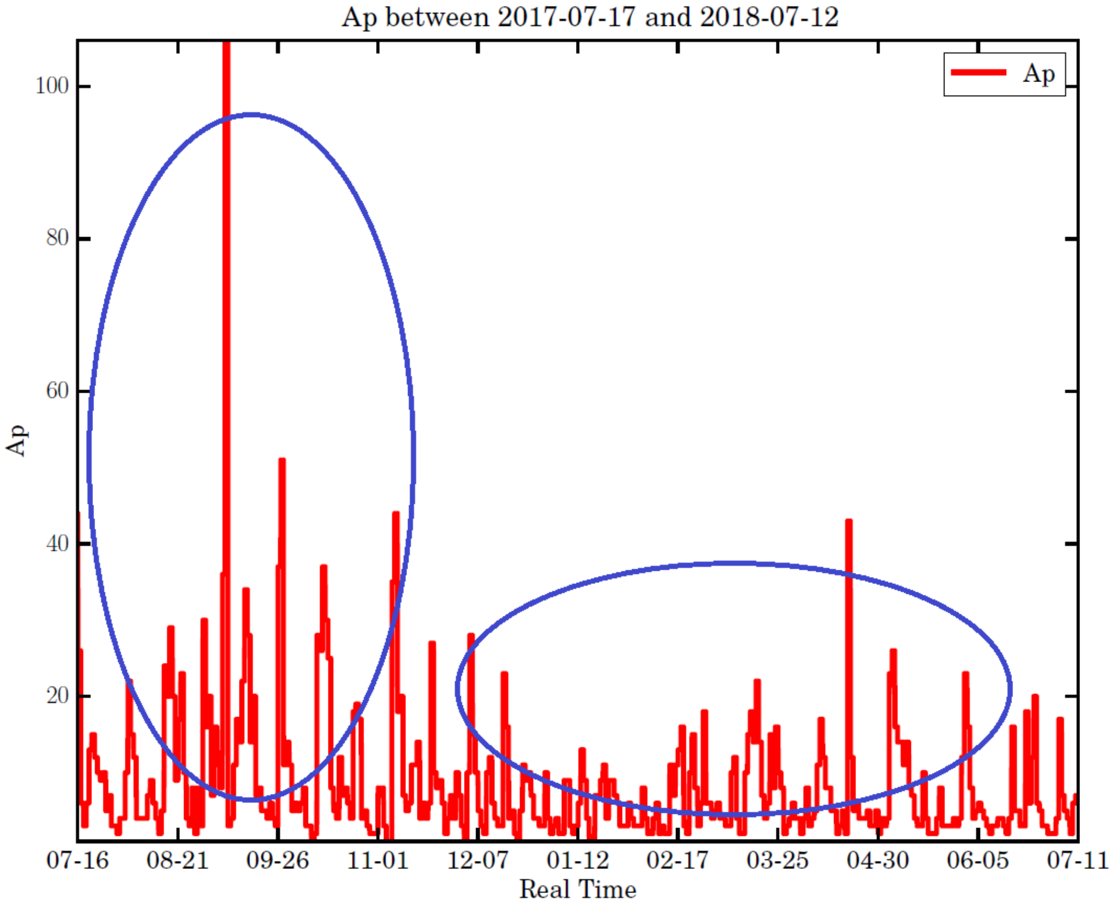
Evaluating Nuances of NLRMSISE-00 Performance (cont.)



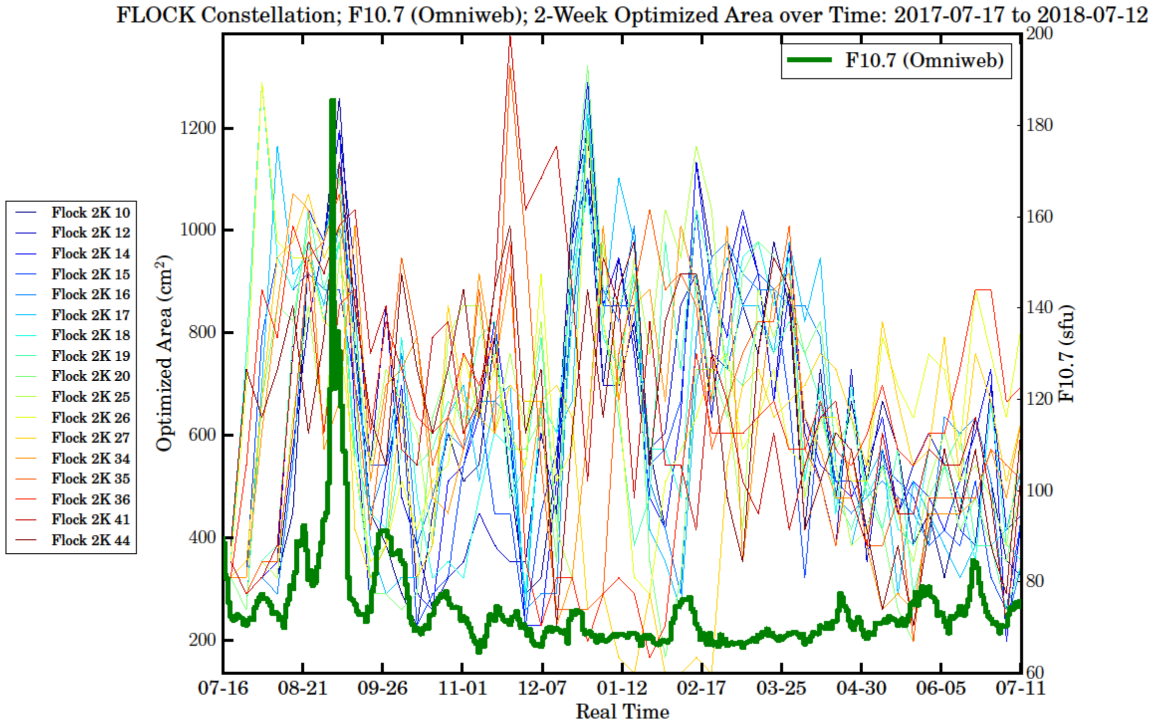


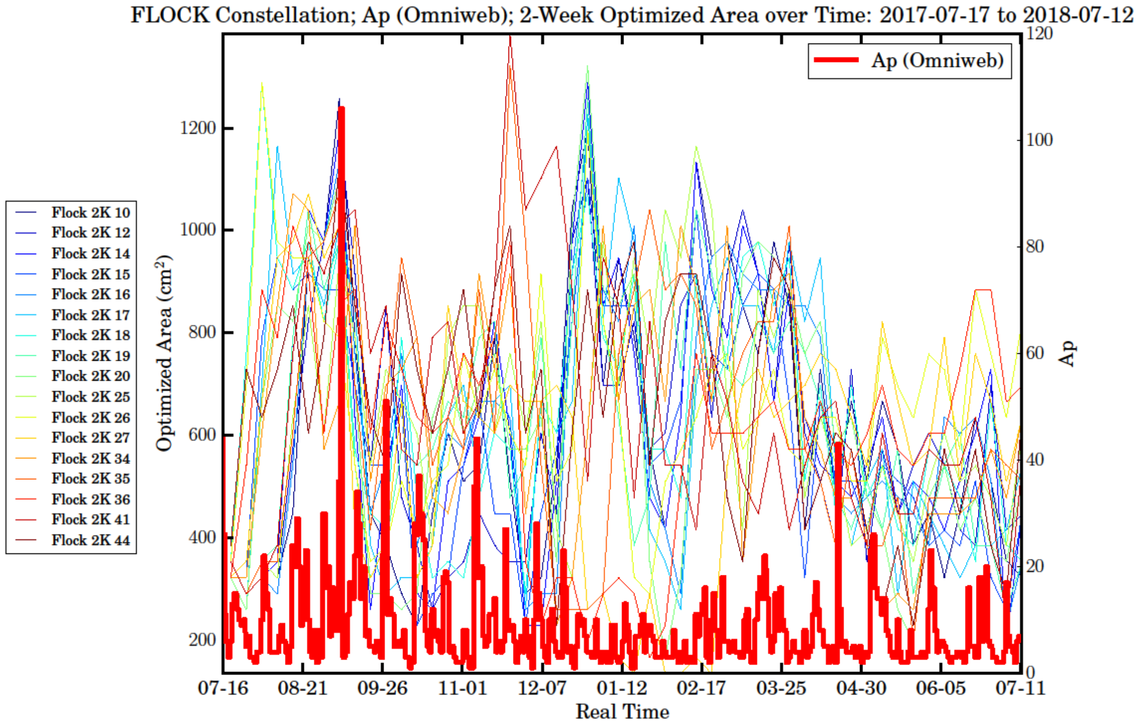
Evaluating Nuances of NLRMSISE-00 Performance (cont.)



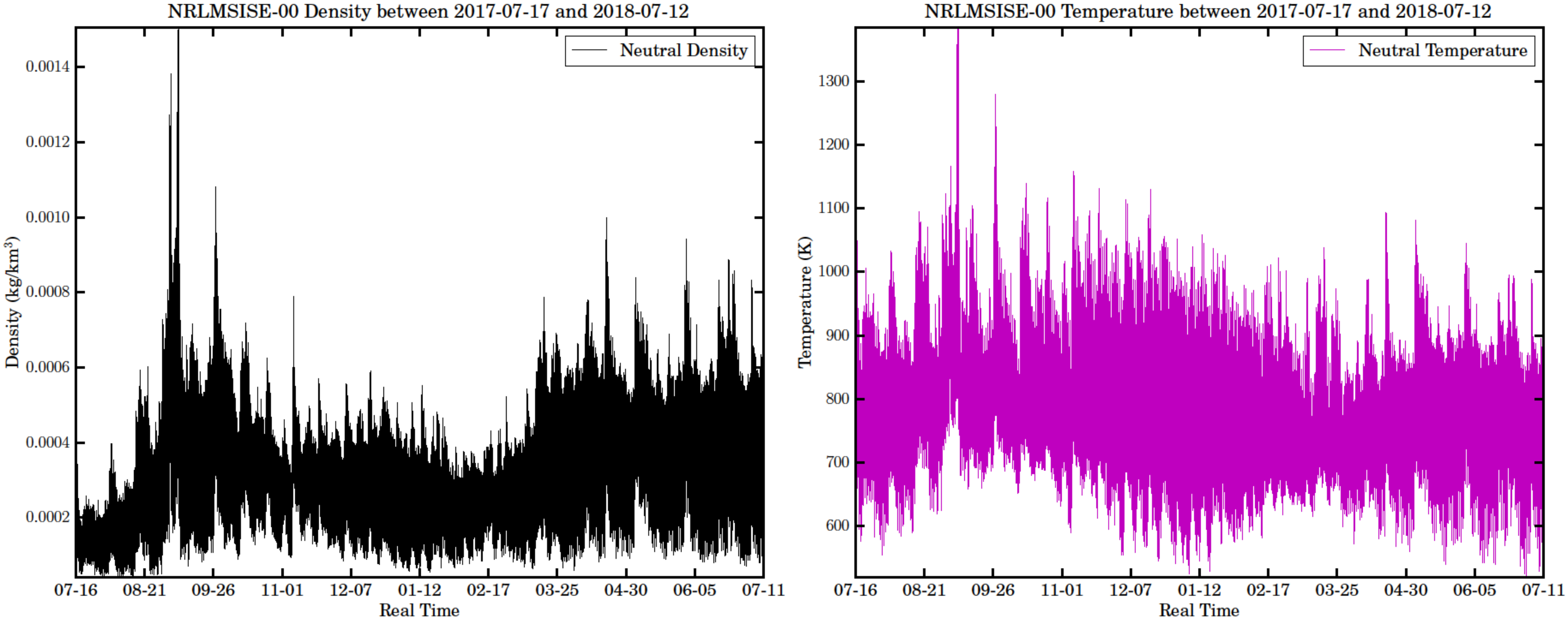


Evaluating Nuances of NLRMSISE-00 Performance (cont.)

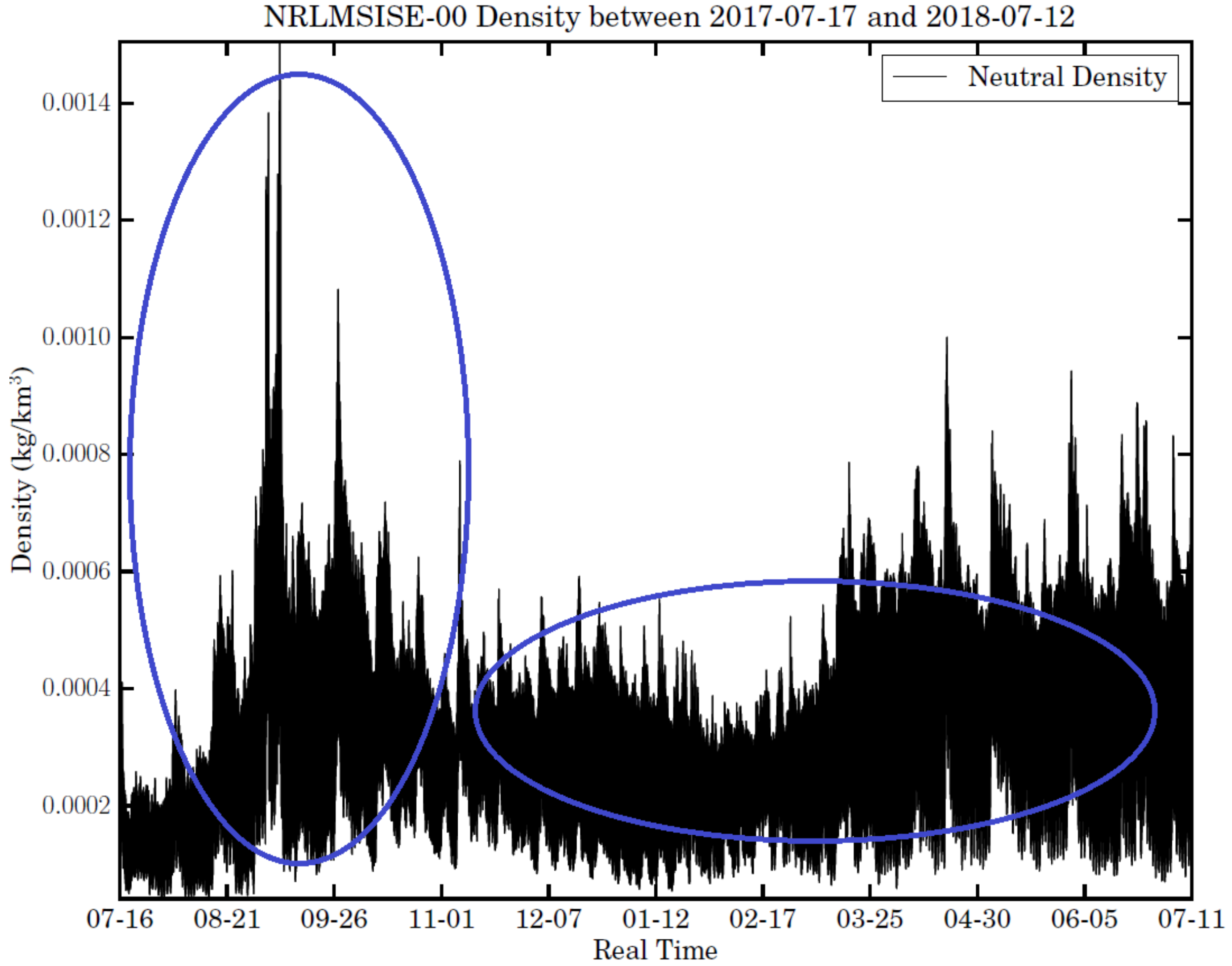


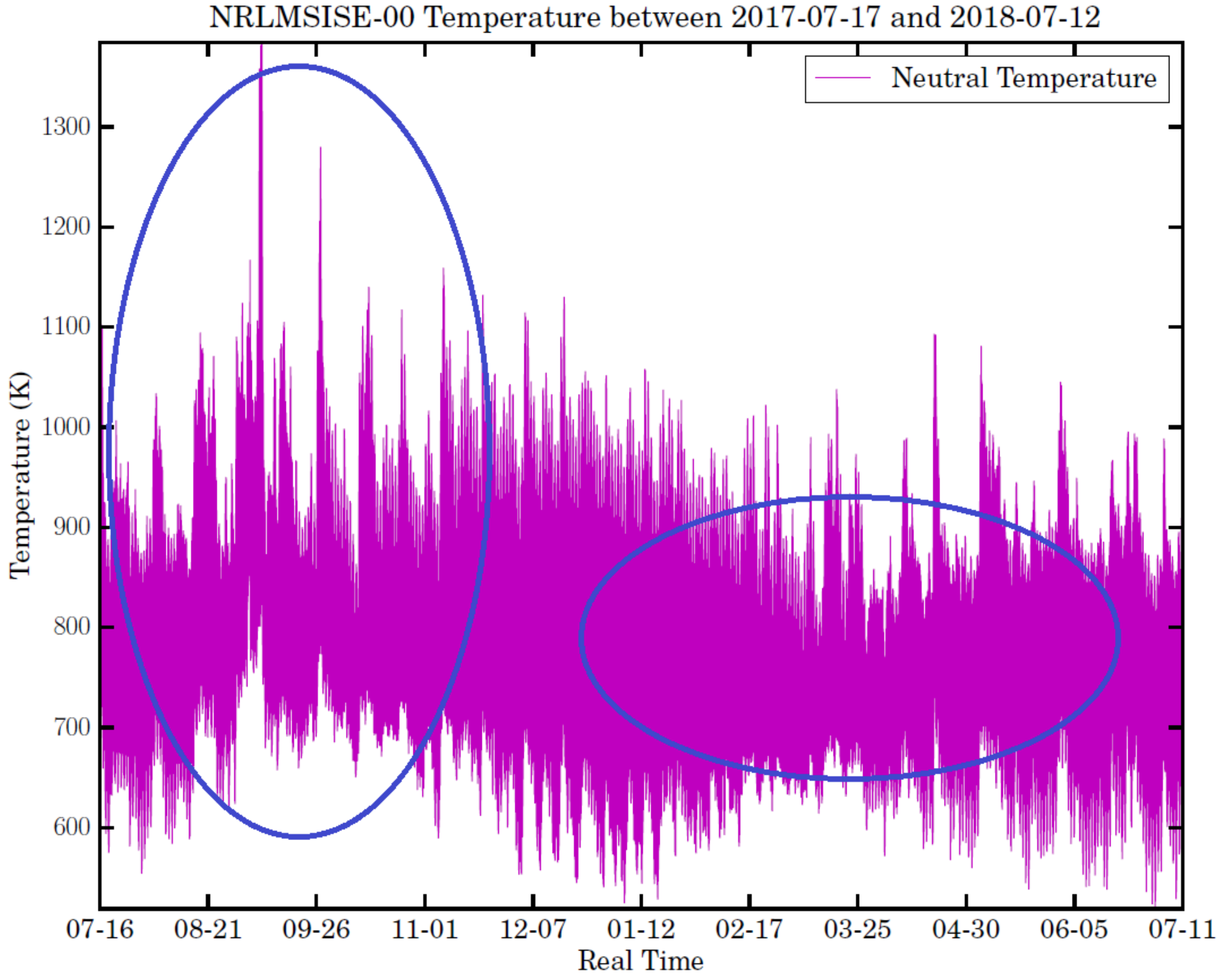


Evaluating Nuances of NLRMSISE-00 Performance (cont.)

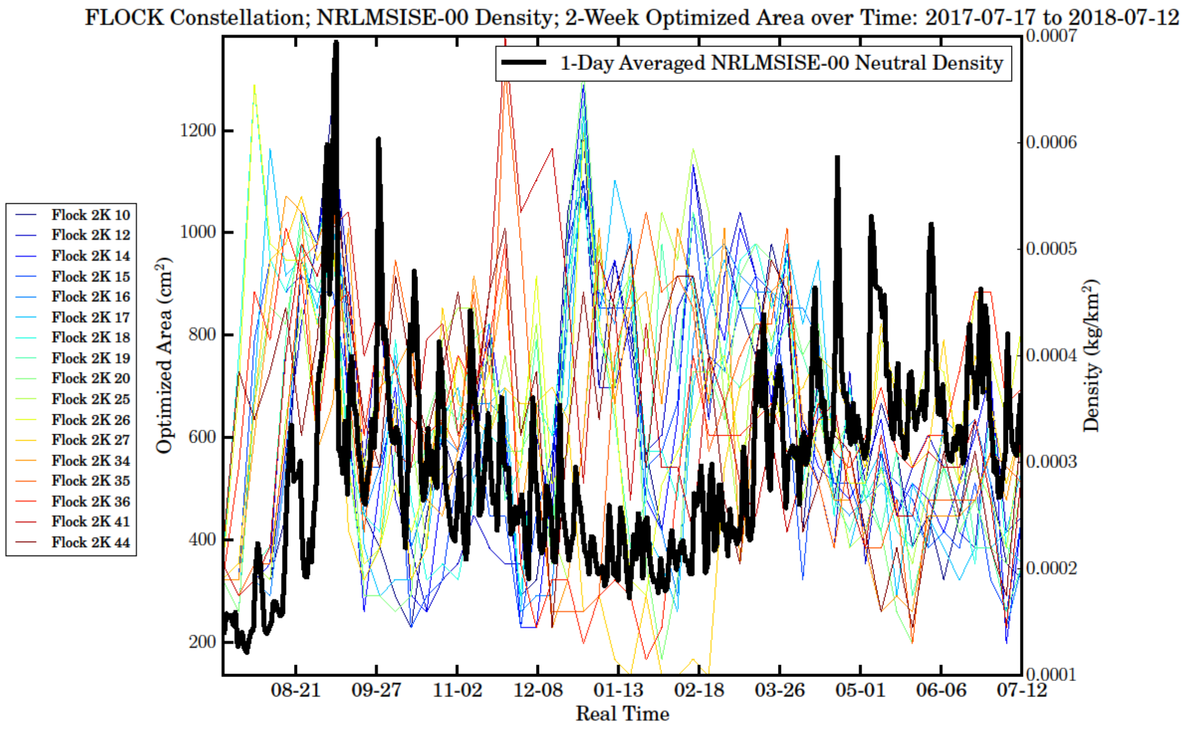


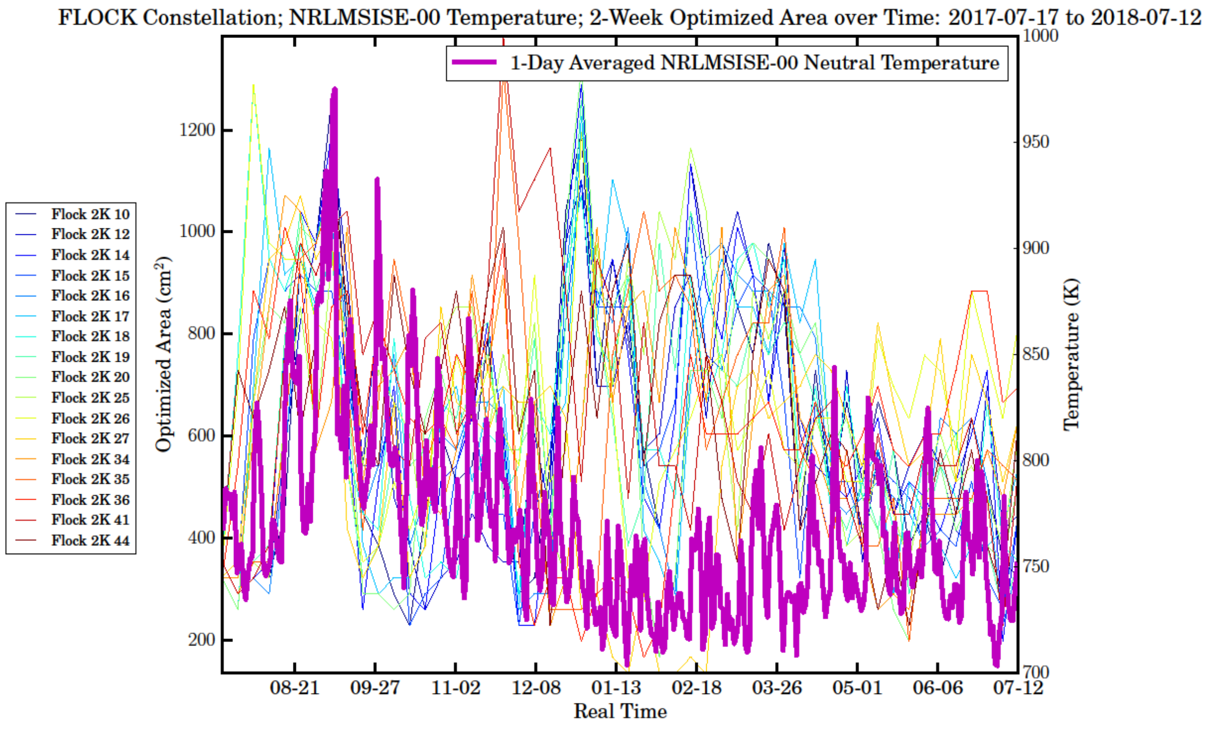
Evaluating Nuances of NLRMSISE-00 Performance (cont.)





Evaluating Nuances of NLRMSISE-00 Performance (cont.)





Conclusion and Future Goals

- MSISE's performance during geomagnetic storms is questionable as noted by high average optimized areas during these times, indicating a bias towards density underestimation; but this is not always the case.
- We must begin multiplicative factor density analysis to isolate the effect of scale factors to the density on minimizing SpOCK orbit RMS error as well as probing the modification of Ap and F10.7.
- These methods must be stress-tested against constellations of non-uniform geometry/configuration satellites at varying altitudes.

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