# Atmospheric Models and Space Weather for Accurate Low-Earth Orbit Satellite Predictions

## NOAA SWPC Testbed Experiment

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# Accurate satellite orbit predictions are key for spaceflight safety

In LEO, drag is the main driver for orbit uncertainty, which is influenced by:

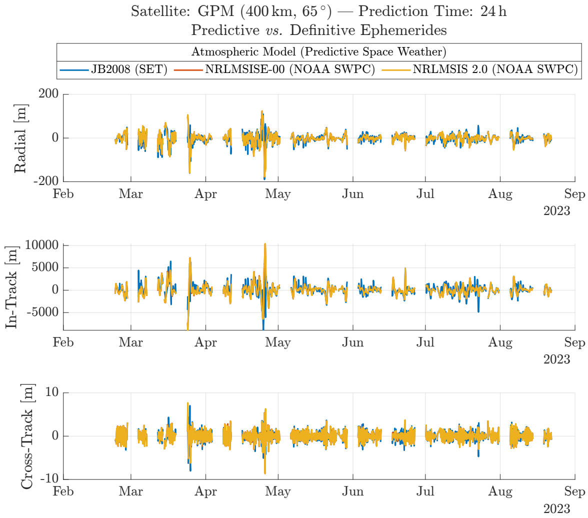
- Unknown physical characteristics of the satellite (effective drag area, $C_D$)
- **Inaccurate and biased atmospheric models**, such as:
  - **NRLMSISE-00** is perhaps the most commonly used. Uses $F_{10.7}$, $\bar{F}_{10.7}$, and $A_p$ as the main space weather inputs.
  - The updated **NRLMSIS 2.0** released in 2020 focused on altitudes below 200 km, but included changes to the thermosphere. Inputs remained the same.
  - **Jacchia–Bowman 2008** is based on Jacchia's diffusion equations, but uses new solar indices $F_{10}$, $S_{10}$ (EUV), $M_{10}$ (MUV), and $Y_{10}$ (X-ray) and the geomagnetic $dT_c$.
- **Errors in space weather predictions** ($F_{10.7}$ and $K_p$ or $A_p$ indices)

# A framework to evaluate the accuracy of atmospheric models

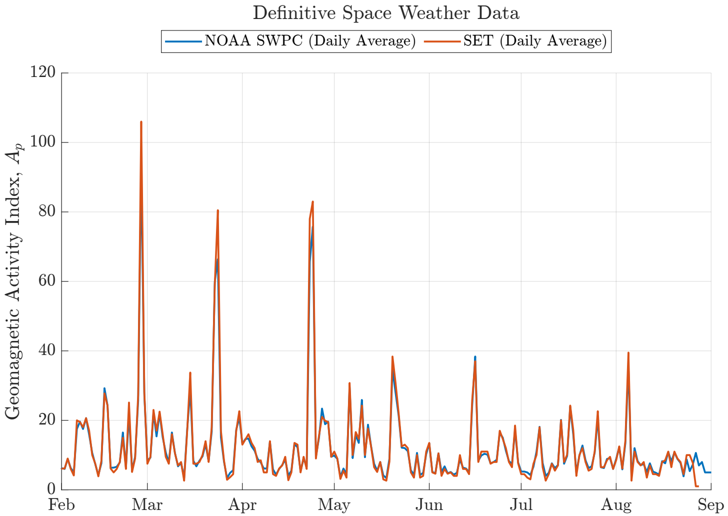
*We cannot simply compare orbits propagated with the same initial conditions and different atmosphere models; parameters such as the drag coefficient must also be estimated with the same model before generating new predictions.*

- Generate definitive states by processing GNSS tracking data over an extensive analysis time interval of 6 months.
- Using the last definitive state at the end of each orbit determination arc, we generate a prediction using the solved-for $C_D$ value and the most up-to-date space weather data at the time.
- We overlap definitive and predictive ephemerides to obtain prediction errors at 24, 48, and 72 hours — use the results to compute an empirical covariance.

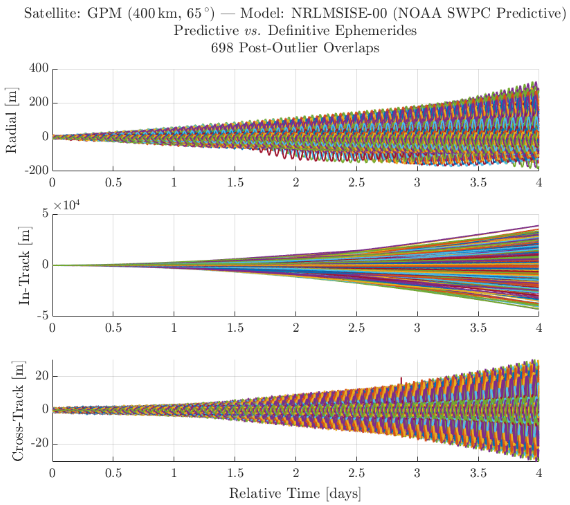
# The RIC differences time history shows all models behave similarly...



# … and prediction error spikes correspond to geomagnetic storm peaks



# Next, we remove all outliers from the overlaps...

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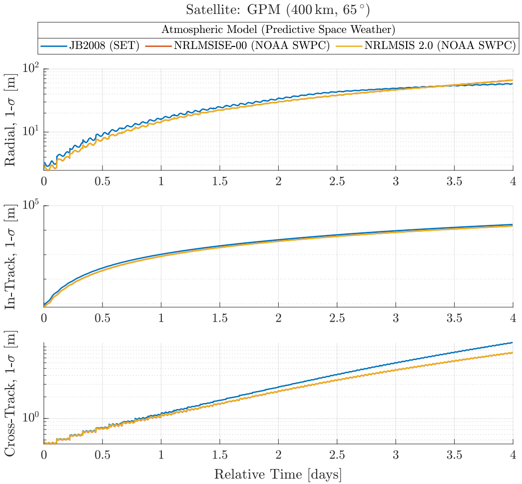
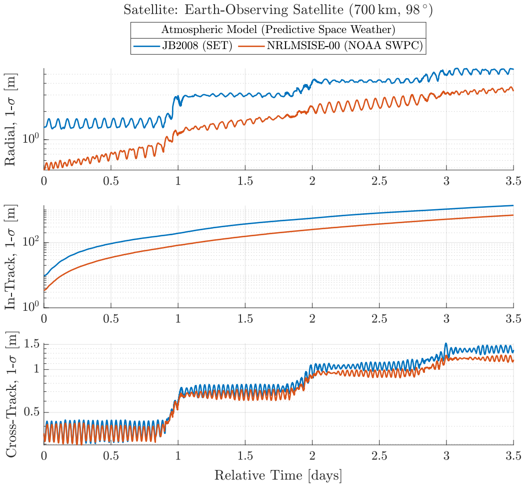
# ... and compute the empirical covariance for each model (400 km)




| Model | Std. Dev. at 48 h [m] | |
|---|---|---|
| | Radial | In-Track |
| NRLMSISE-00 | 30.44 | 3542.65 |
| NRLMSIS 2.0 | 30.44 | 3513.67 |
| JB2008 | 34.48 | 4060.35 |

# … and compute the empirical covariance for each model (700 km)




| Model | Std. Dev. at 48 h [m] | |
|---|---|---|
| | Radial | In-Track |
| NRLMSISE-00 | 2.26 | 251.96 |
| JB2008 | 4.07 | 560.05 |

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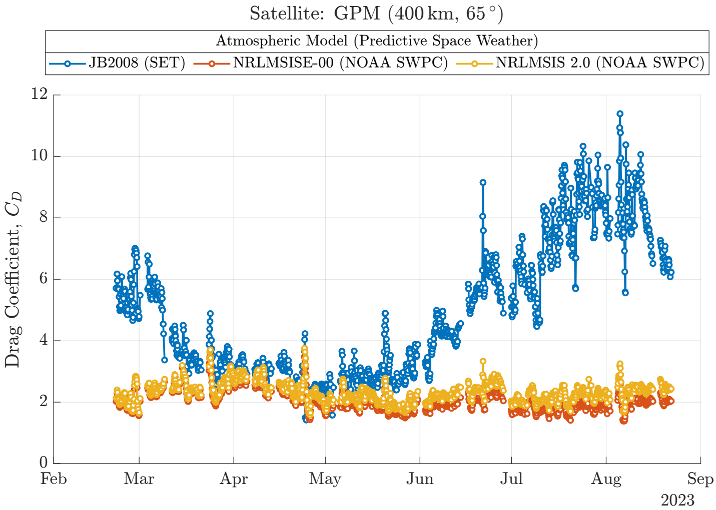
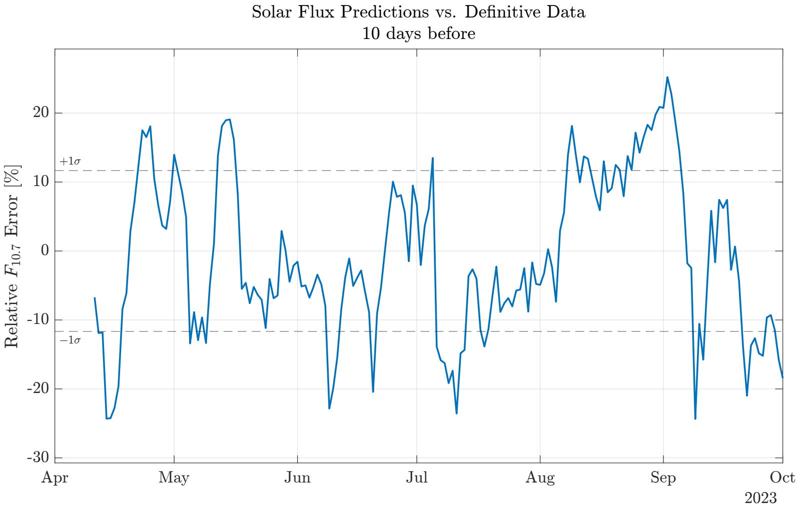
# Solved-for $C_D$ time history indicates JB2008 neutral densities are much lower



# How accurate are space weather predictions? (2023)



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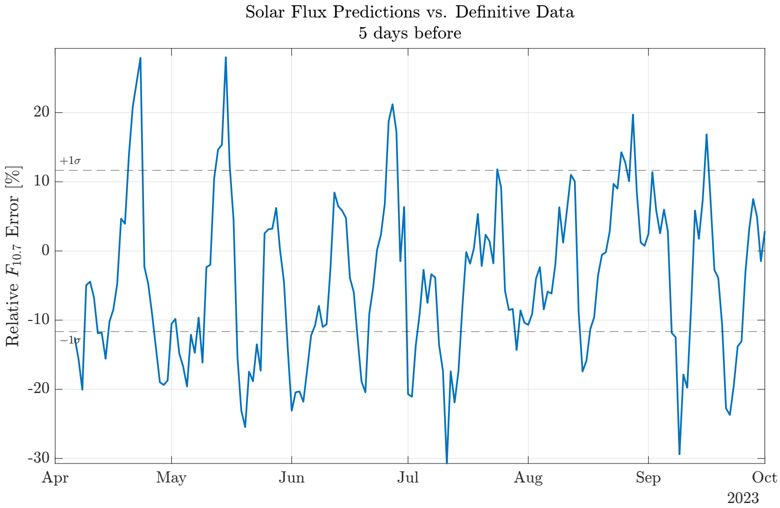

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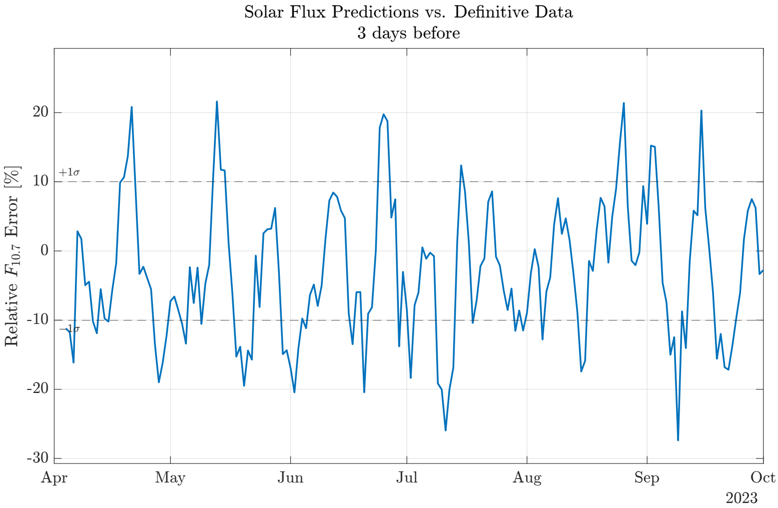

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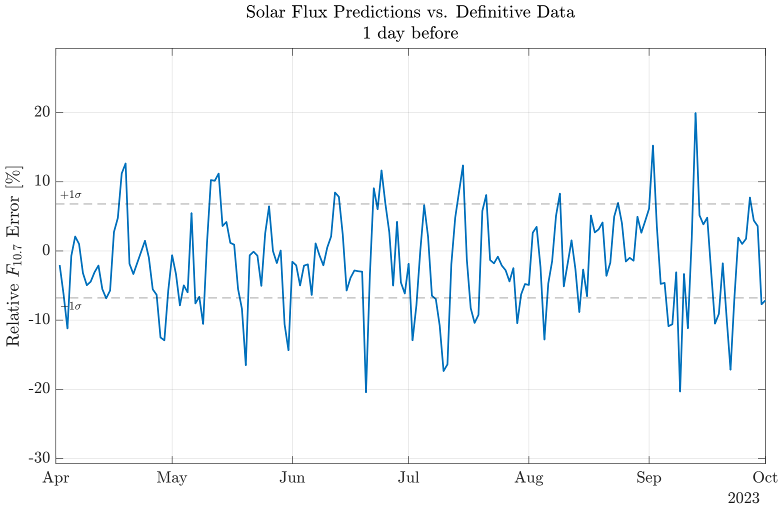
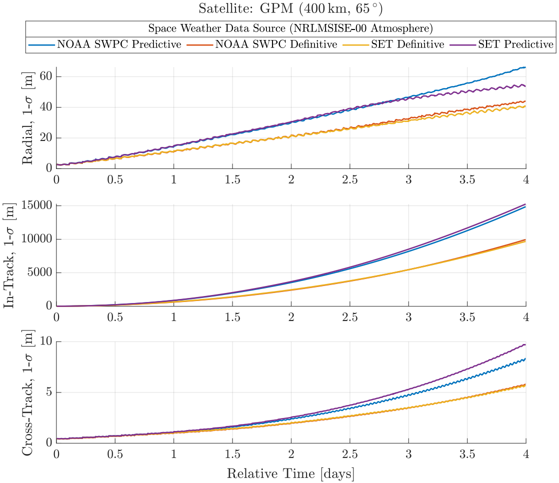


# Using NRLMSISE-00, we compare predictive and definitive space weather sources




| Source | Std. Dev. at 48 h [m] Radial | In-Track |
|---|---|---|
| *Predictive Space Weather* | | |
| NOAA SWPC | 30.44 | 3542.65 |
| SET | 30.77 | 3682.71 |
| *Definitive Space Weather* | | |
| NOAA SWPC | 21.95 | 2418.26 |
| SET | 21.81 | 2468.13 |

*30 % of orbit prediction errors are caused by space weather!*

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*It’s always space weather.*

## Questions?

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