Recent Progress on Sensing Thermospheric Density Using COSMIC-2 Satellites

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Outline

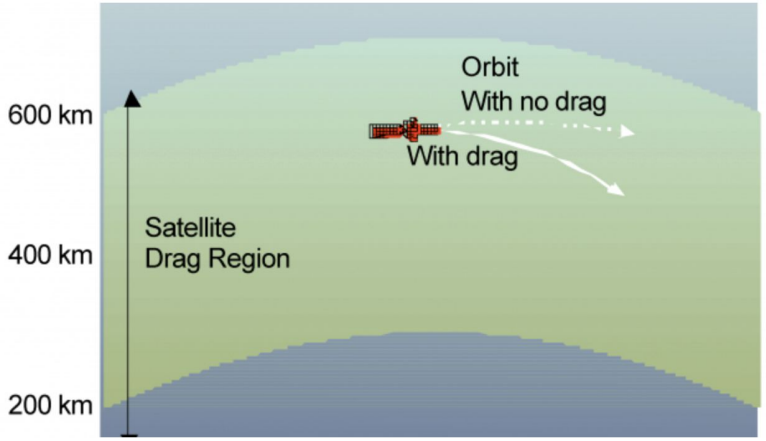
- Why do we study the thermospheric density?
- How to sense the thermospheric density using LEO precise orbit determination?
- Result & validation: daily-averaged observation vs model
- Result & validation: high resolution (5-min) observation vs model
- Products: high-resolution thermospheric-density product
- Future work

Why Sensing Thermospheric Density?

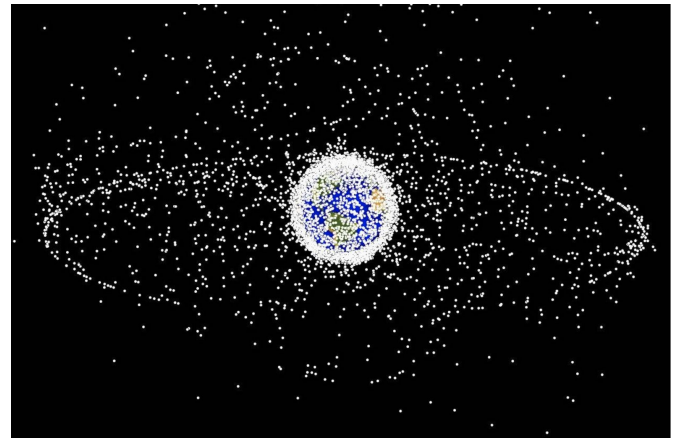
- The atmospheric density is very low at the LEO satellite altitude. However, its forces can still accumulate to impact the satellite orbits significantly.
- With fast growing LEO satellite constellations, we want to monitor and predict thermospheric density at various altitudes and locations, to avoid satellite-to-satellite collisions and satellite-to-debris collisions.
- Thermospheric density has increased dramatically over the past years, due to more intense solar activities.

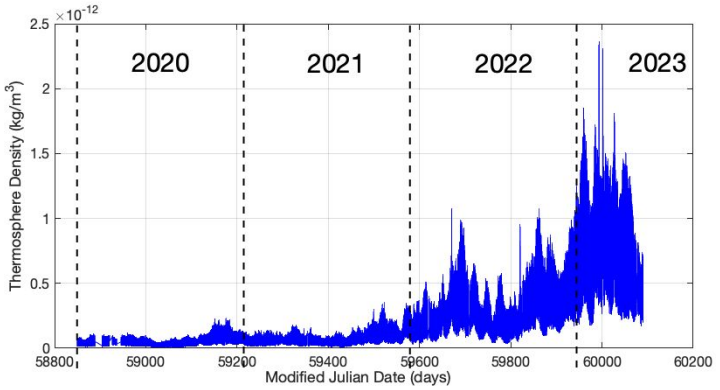
Prior studies have investigated the feasibility of sensing thermospheric density using satellites, e.g. SWARM [3].

[1]



[2]



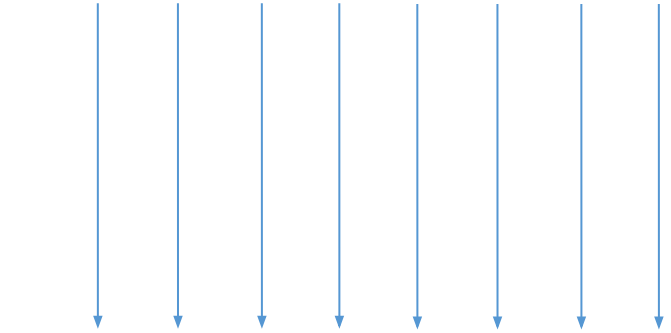


[1] https://www.swpc.noaa.gov/impacts/satellite-drag

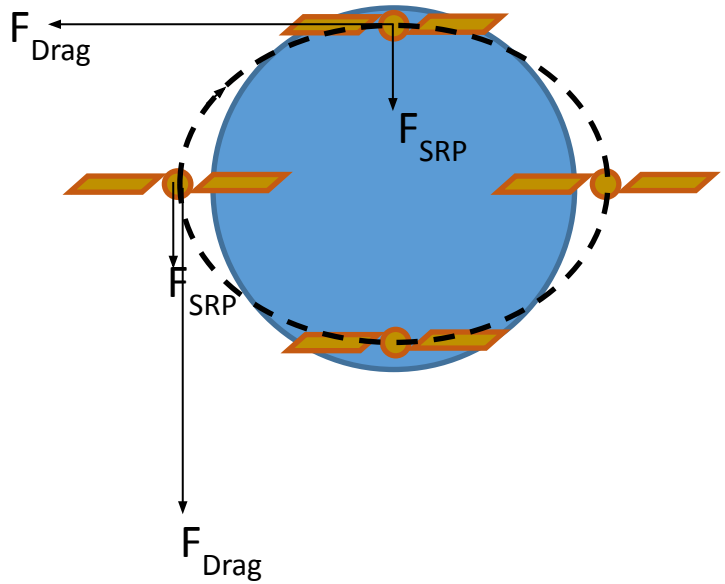
[2] https://spaceref.com/newspace-and-tech/space-debris-a-quantitative-analysis-of-the-in-orbit-collision-risk-and-its-effects-on-the-earth/

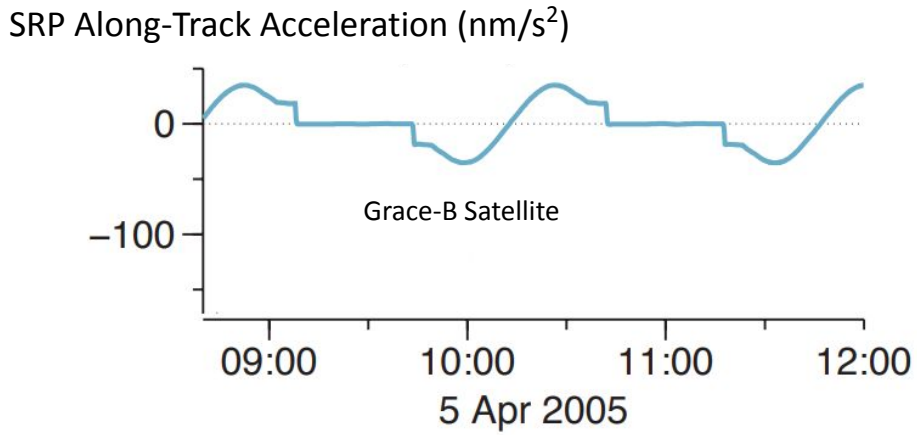
[3] Jose van den Ijssel, et al, "Thermosphere densities derived from Swarm GPS observations," Advances in Space Research, vol. 65, pp. 1758-1771, 2020.

Basic Technique of Sensing Thermospheric Density



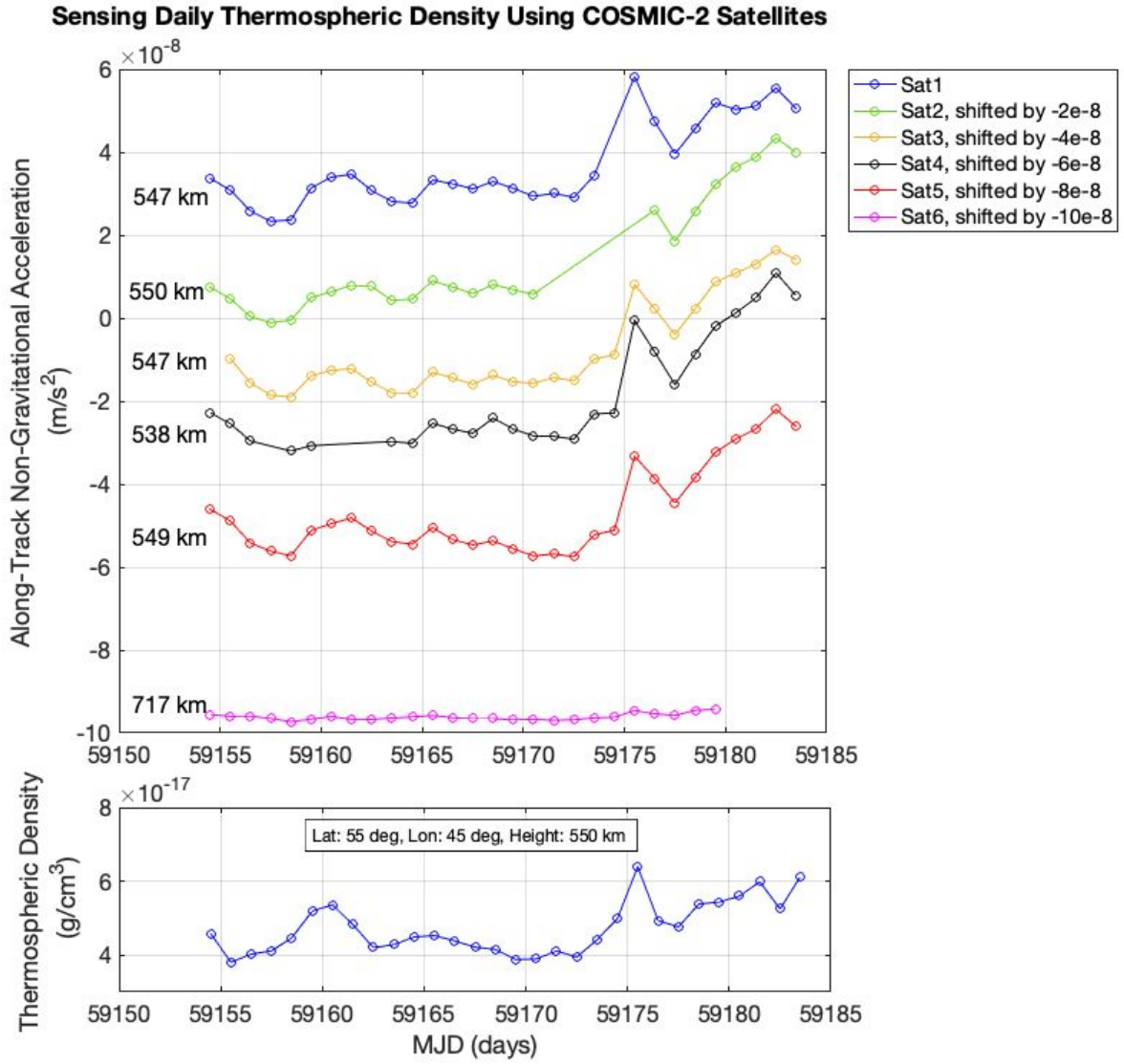
$$\mathbf{a}_{\text{drag}} = C_D \frac{A_{\text{ref}}}{m} \frac{1}{2} \rho v_r^2 \hat{\mathbf{v}}_{\mathbf{r}}$$ [1]





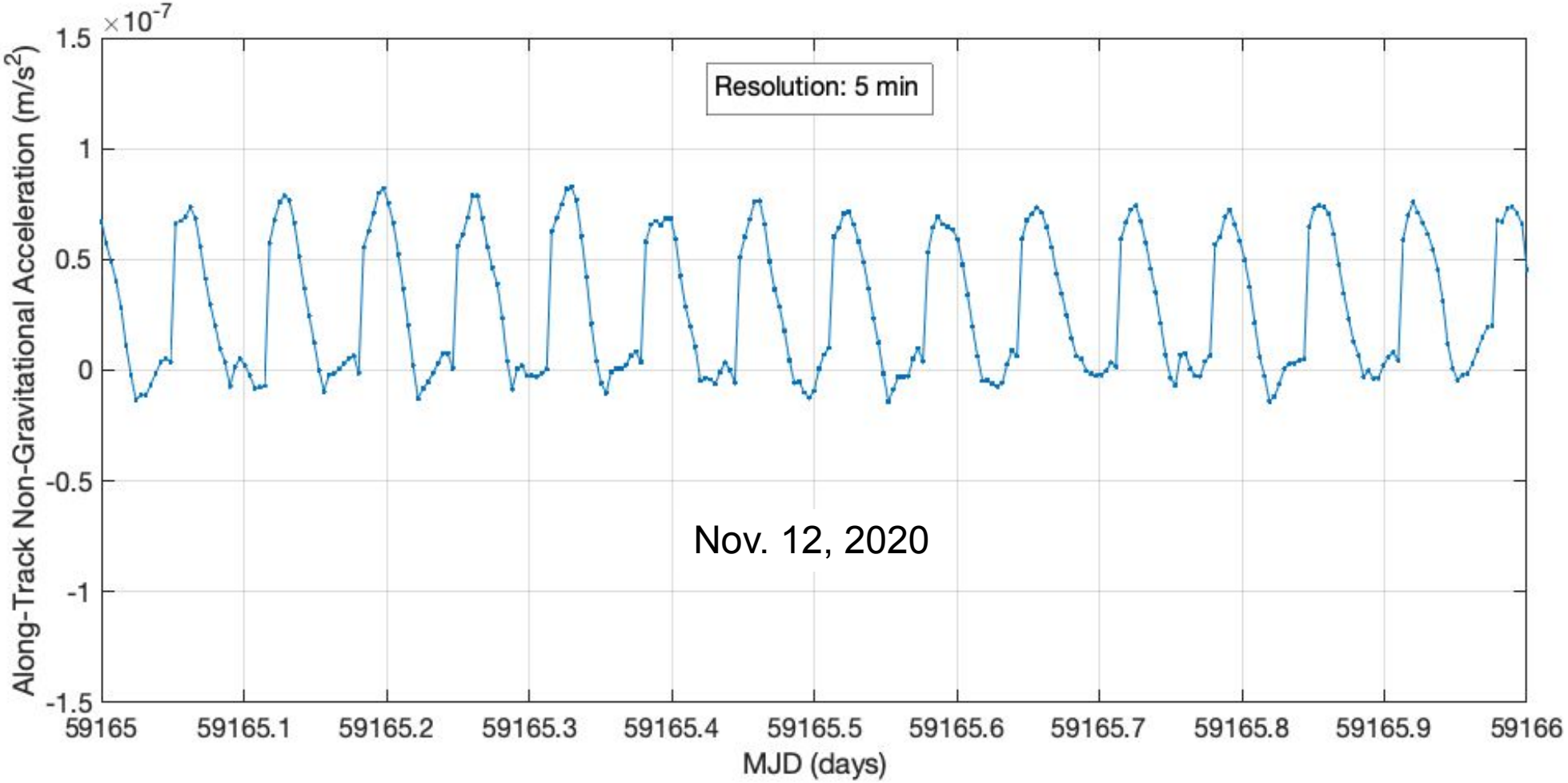
[1] P. Visser, E. Doornbos, et al, "Thermospheric Density and Wind Retrieval from SWARM Observations," Earth, Planets and Space, 65, 1319-1331, 2013.

Observation vs Model : Daily-Average



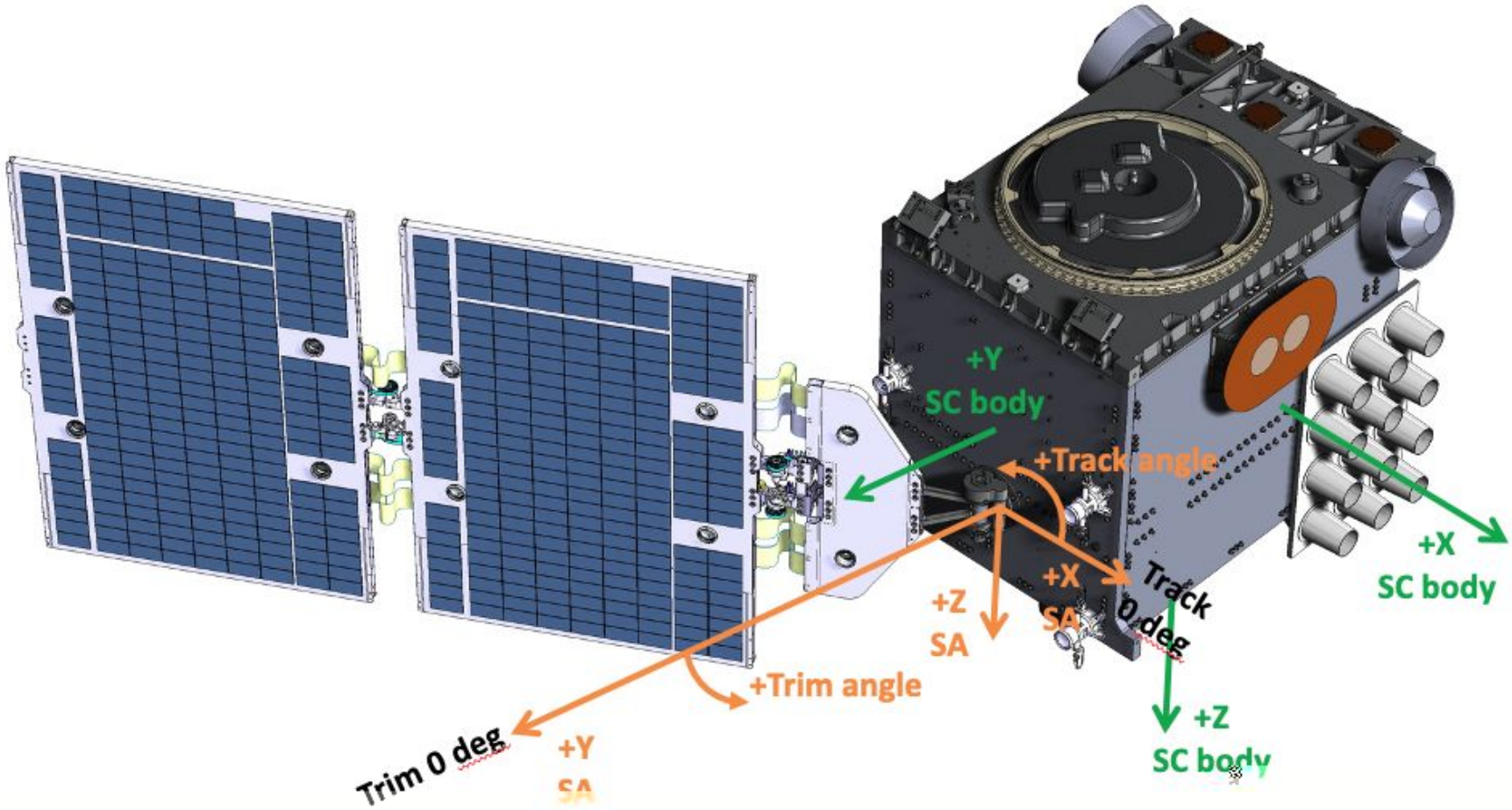
- **We can sense the daily-average thermospheric density using COSMIC-2 orbits.**

Higher Resolution?

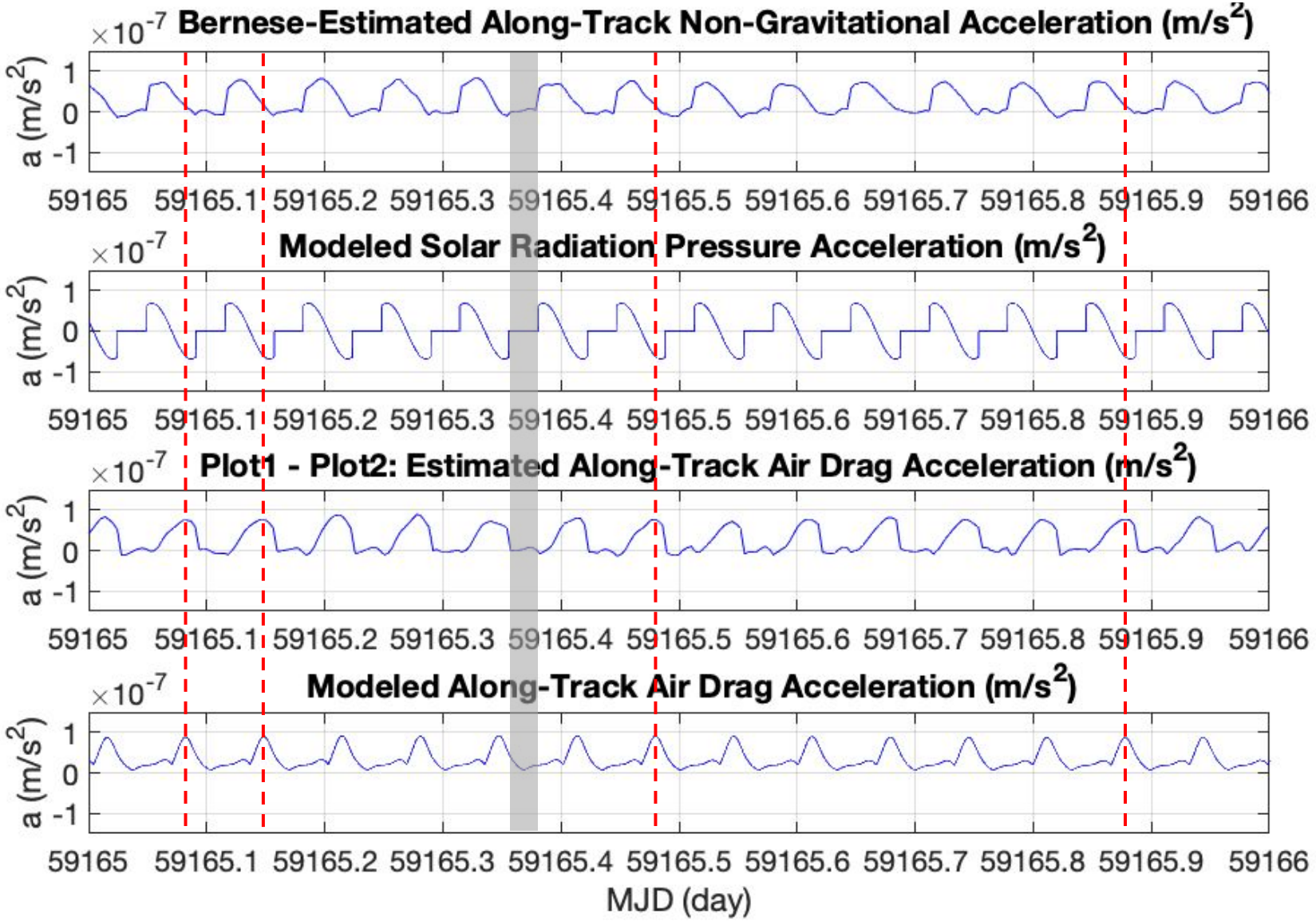


- The Precise-Orbit-Determination (POD) processing using the Bernese GNSS software can generate the along-track non-gravitational acceleration with a resolution of 5 minutes.
- The non-gravitational acceleration is mainly composed of the drag acceleration from the thermosphere and the solar-radiation-pressure (SRP) acceleration.

COSMIC2 Satellite Geometry



Observation vs Model: High Resolution



- The observed drag acceleration (Plot3) has peaks that exactly match the modeled drag acceleration (Plot4). This indicates that **we can achieve a high-resolution observation of thermospheric density.**

Products: High-Resolution Thermospheric Density

ThermosphereDensity_Estimated - Notepad

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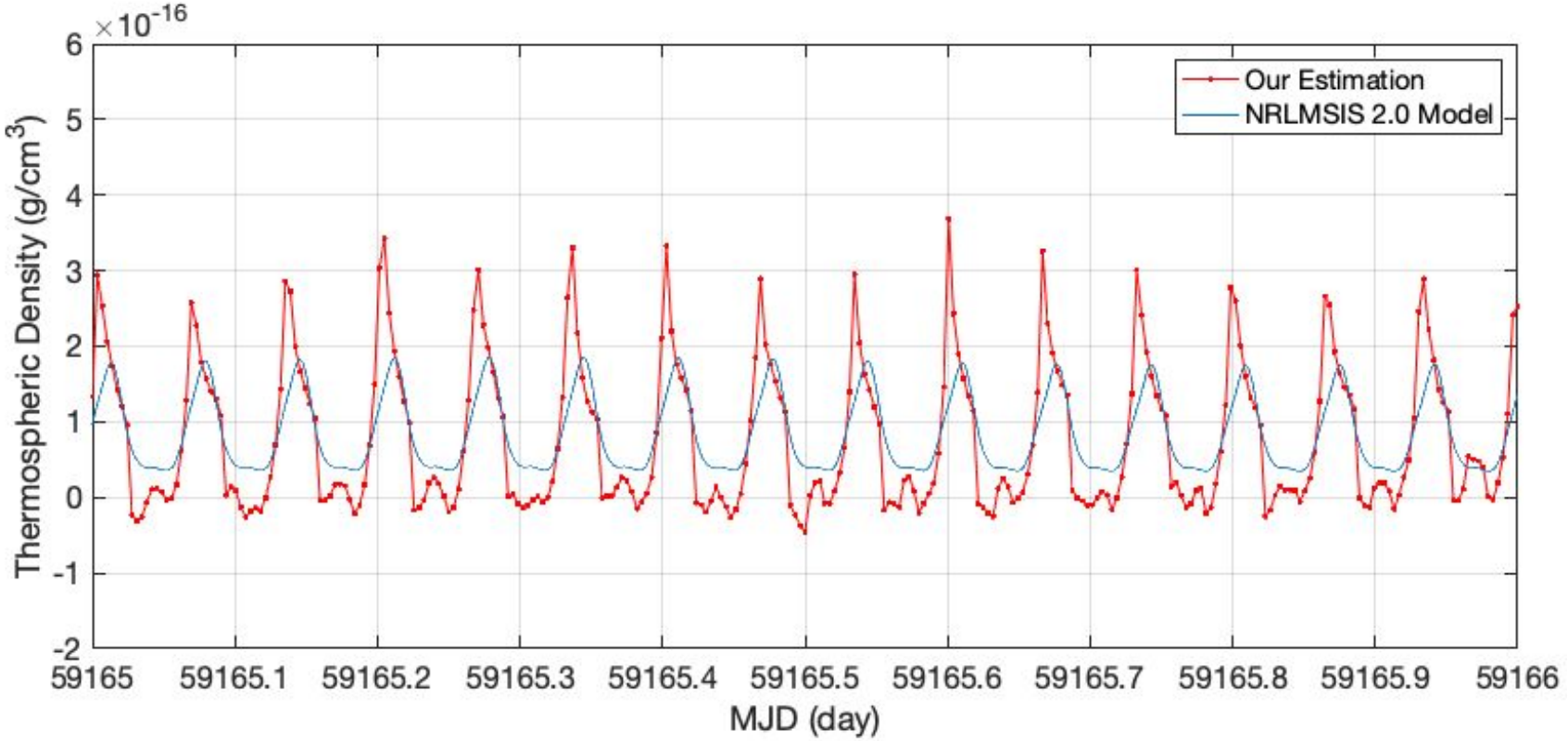
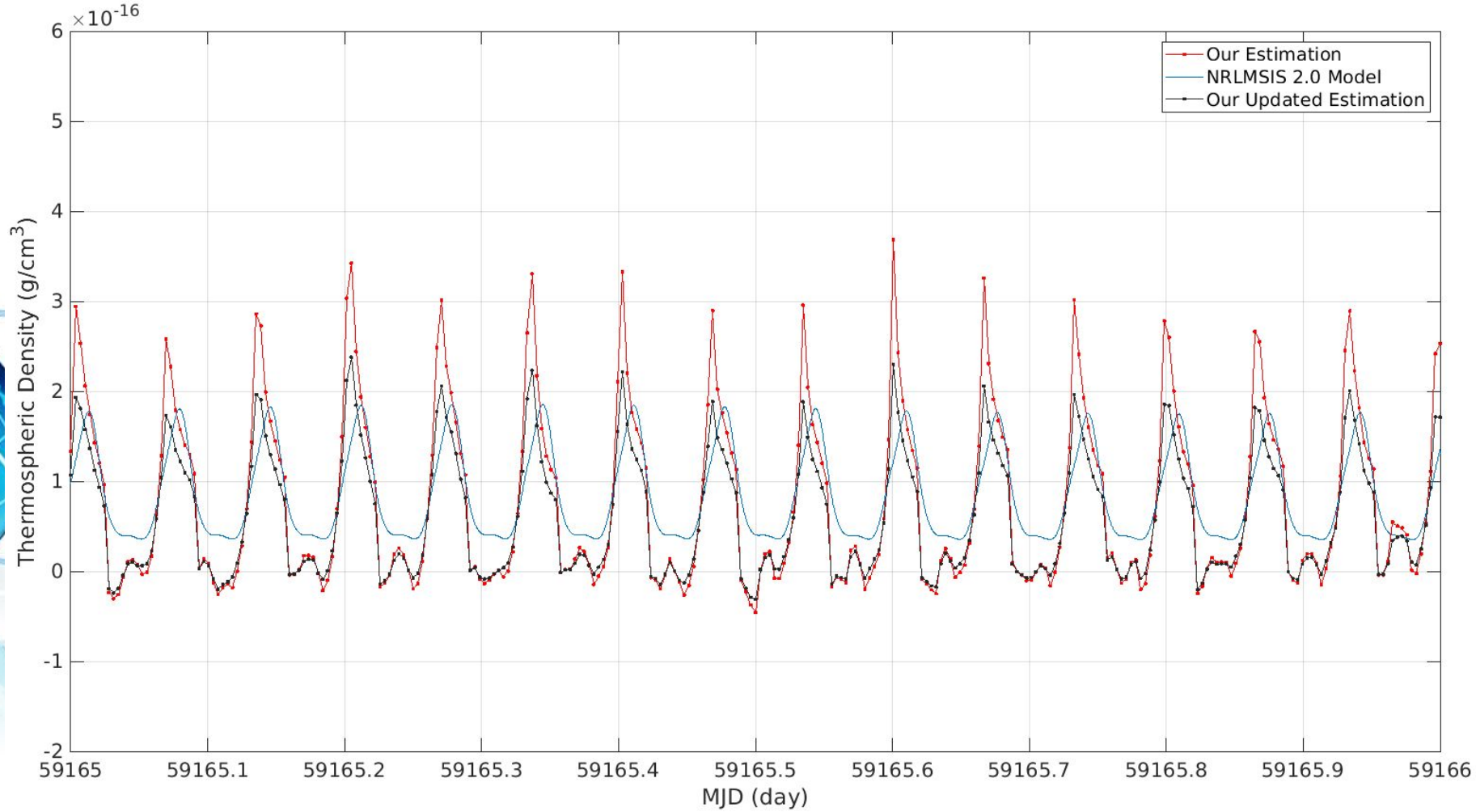
MJD	Density(kg/m^3)	Lat(deg)	Lon(deg)	H(m)
59154.000000	3.077800e-13	1.4274e+01	1.7970e+02	5.3305e+05
59154.003470	3.573359e-13	7.6153e+00	-1.6427e+02	5.3270e+05
59154.006940	2.813735e-13	-3.2073e-01	-1.4751e+02	5.3391e+05
59154.010420	2.327566e-13	-8.2205e+00	-1.3073e+02	5.3671e+05
59154.013890	2.018847e-13	-1.4783e+01	-1.1466e+02	5.4034e+05
59154.017360	1.755752e-13	-1.9988e+01	-9.7671e+01	5.4435e+05

$$\mathbf{a}_{\text{drag}} = C_D \frac{A_{\text{ref}}}{m} \frac{1}{2} \rho v_r^2 \hat{\mathbf{v}}_{\mathbf{r}}$$

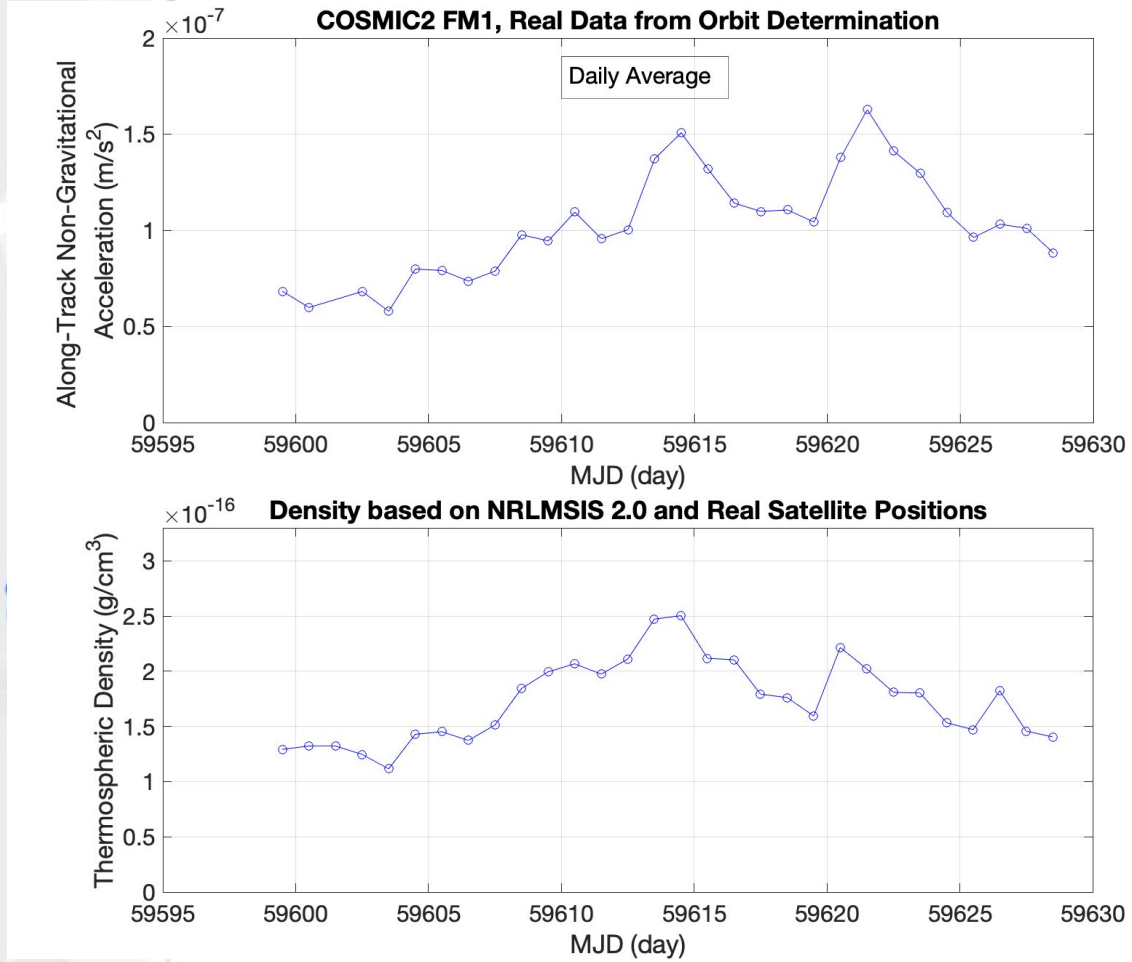


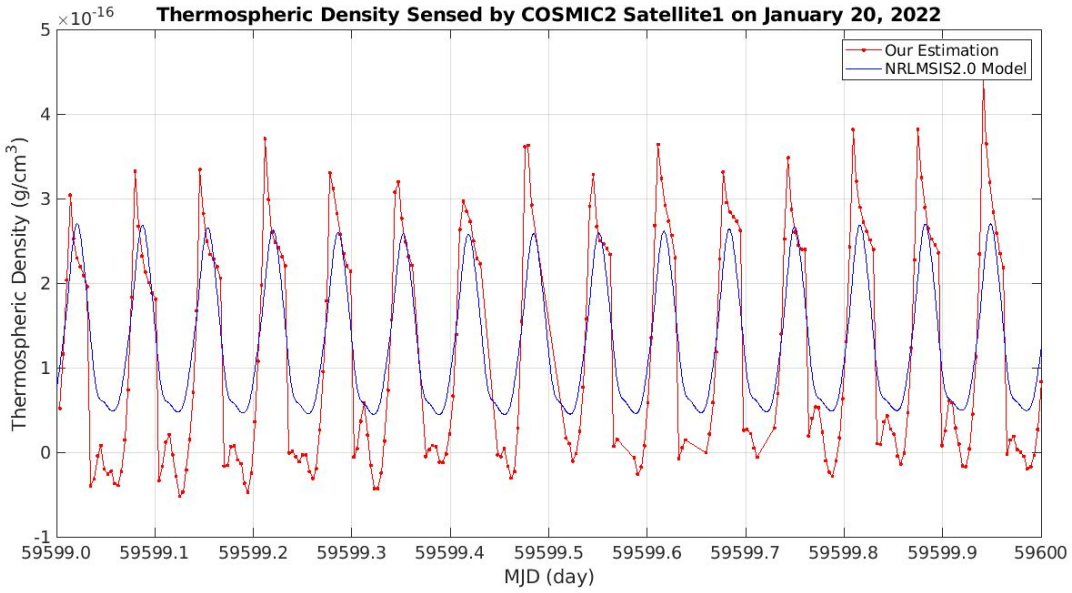
Product Corrections: Satellite Surface Areas and Sunlight Reflectivity



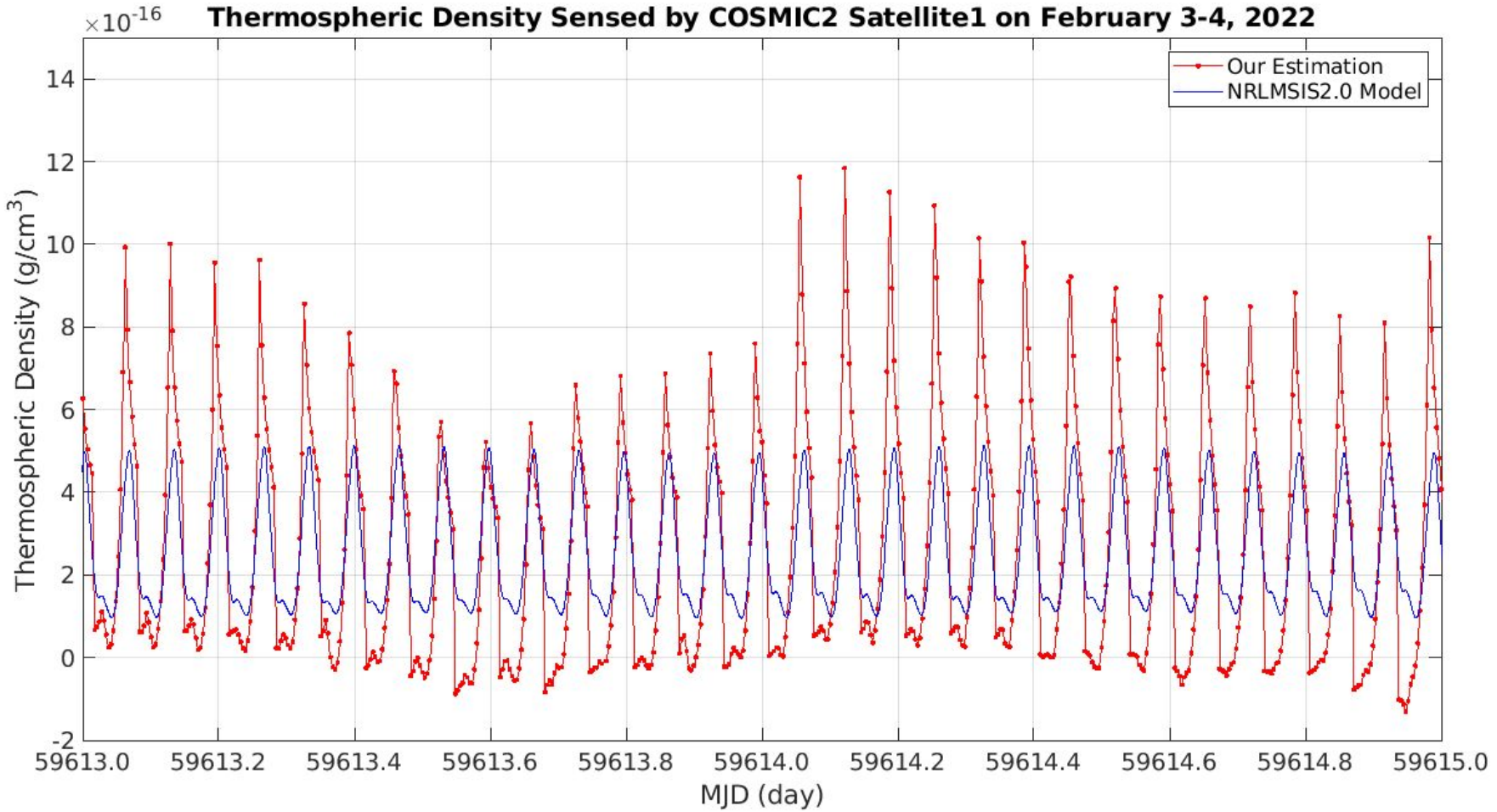
- The problem of artificial spikes has been resolved. However, our estimation (black curve) is still distorted from the model (blue curve).

Application toward Geomagnetic Storms



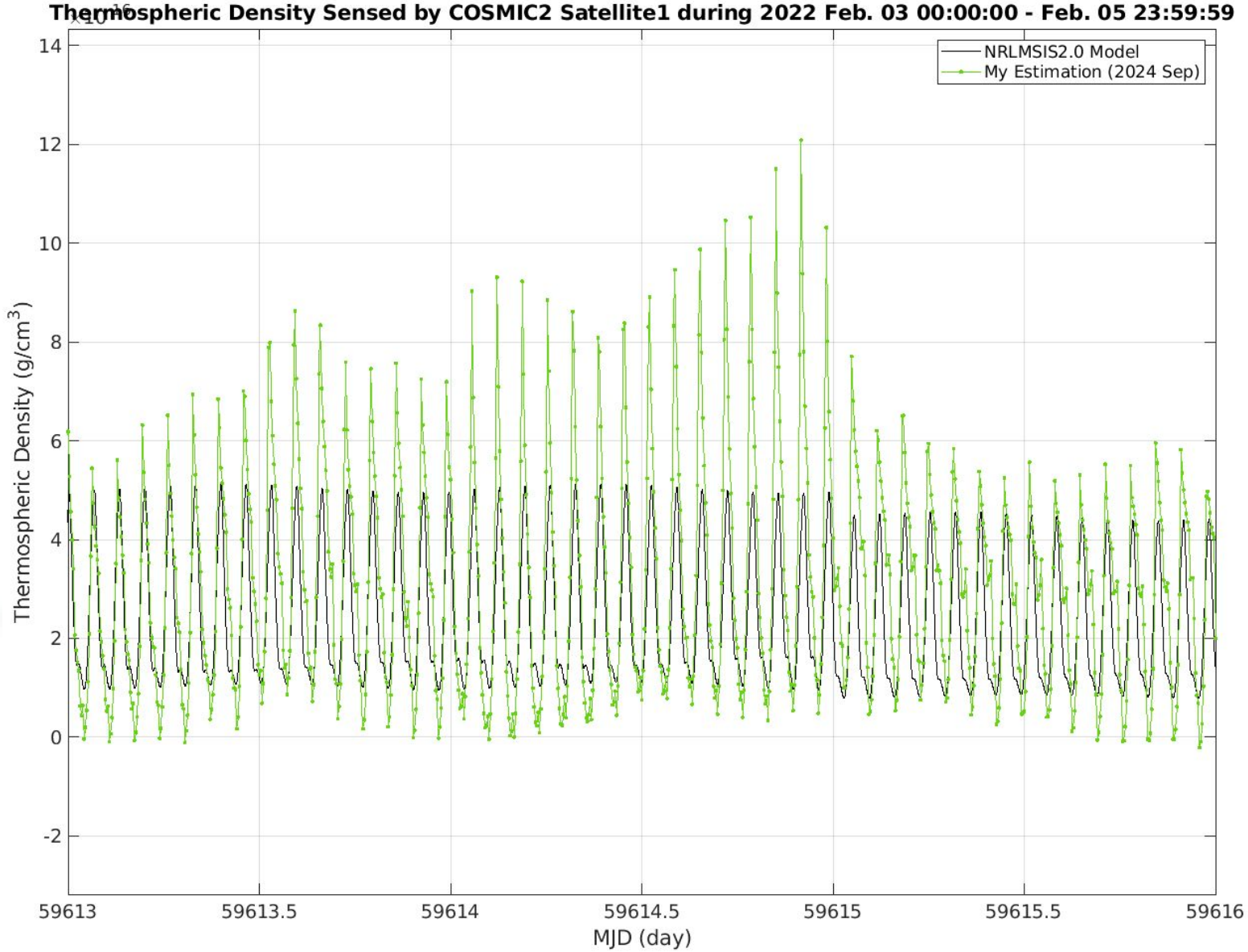


- Our daily-average along-track acceleration has a similar curve pattern to the thermospheric-density model.
- Our high-resolution estimation of thermospheric density matches the NRLMSIS model at some level during the "peaceful" day of Jan. 20, 2022.



- Our estimated thermospheric density seems to be able to capture the short-term thermospheric density behavior. Can our estimation be used for some scientific/technical applications?

Recent Correction



Future Work and Acknowledgment

- Looking forward, I will continue improving the performance of thermospheric-density sensing, by checking all the details of my computation.
- I am also interested in generating the thermospheric-density products for the space-weather community routinely. The more satellite constellations, the better.
- I also look forward to collaborations on applications of these thermospheric-density products, such as satellite trajectory prediction, geomagnetic storm studies, and thermosphere-ionosphere-electrodynamics models, etc.
- Last, I would like to thank UCAR's COSMIC Team, especially Jan-Peter Weiss, for the support of this work.

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Thank you!