EXPANDING AND TESTING ORBIT PROPAGATION CAPABILITIES USING CCMC-HOSTED MODELS as Presented at AGU Fall Meeting 2021

Katherine Garcia-Sage[1], Rebecca Ringuette[1], Asher Pembroke[1], Lutz Rastaetter[1], Darren De Zeeuw[1], Jia Yue[1], Tina Tsui[1], Masha Kuznetsova[1], Zachary Waldron[2], Eric Sutton[2], Jeffrey Thayer[2], David Rowlands[3], Frank Lemoine[3], and Scott Luthcke[3]

[1]NASA GSFC/CCMC
[2]CU Boulder SWxTREC
[3]NASA GSFC

February 9, 2023

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Frank Lemoine
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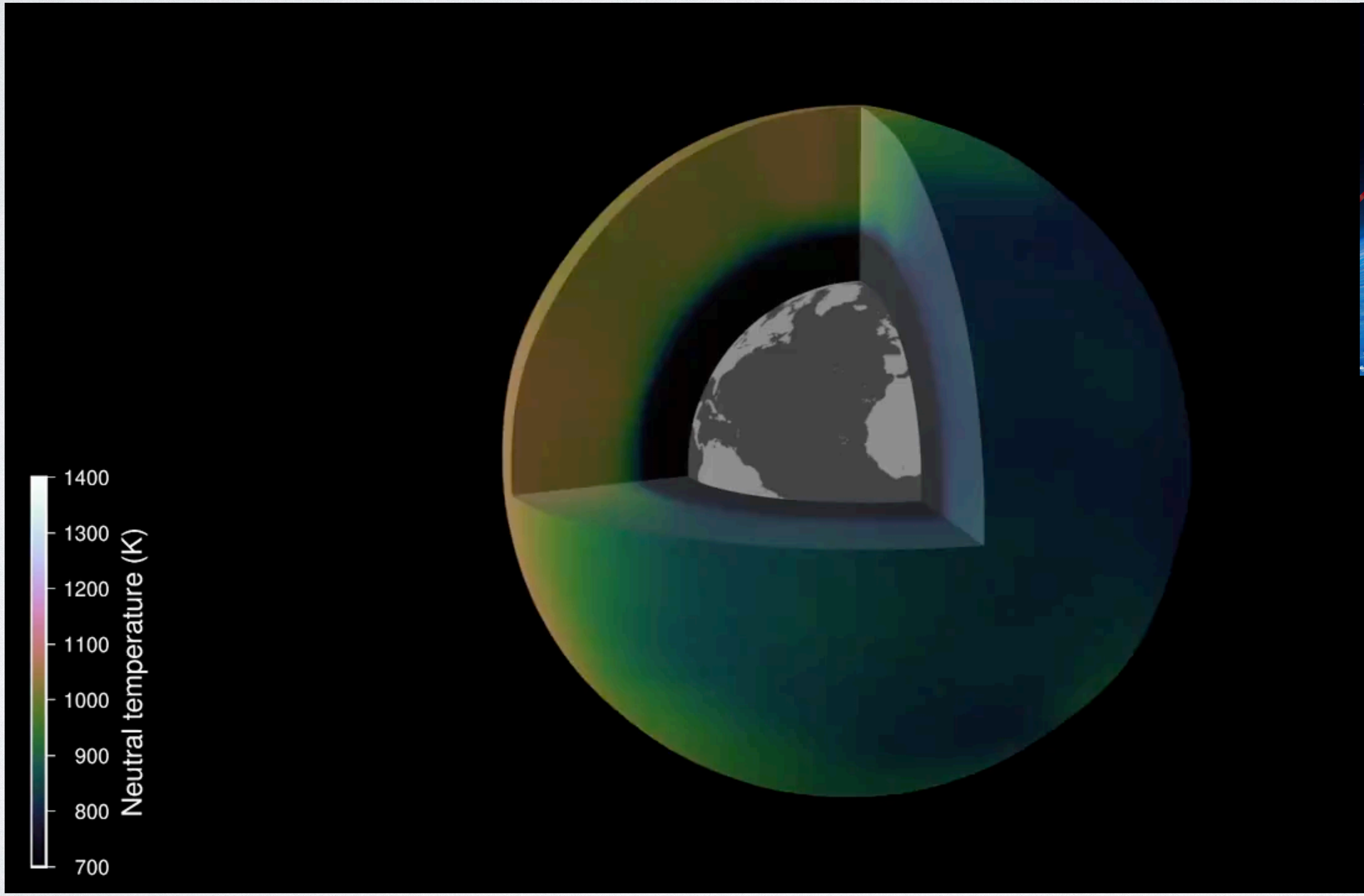
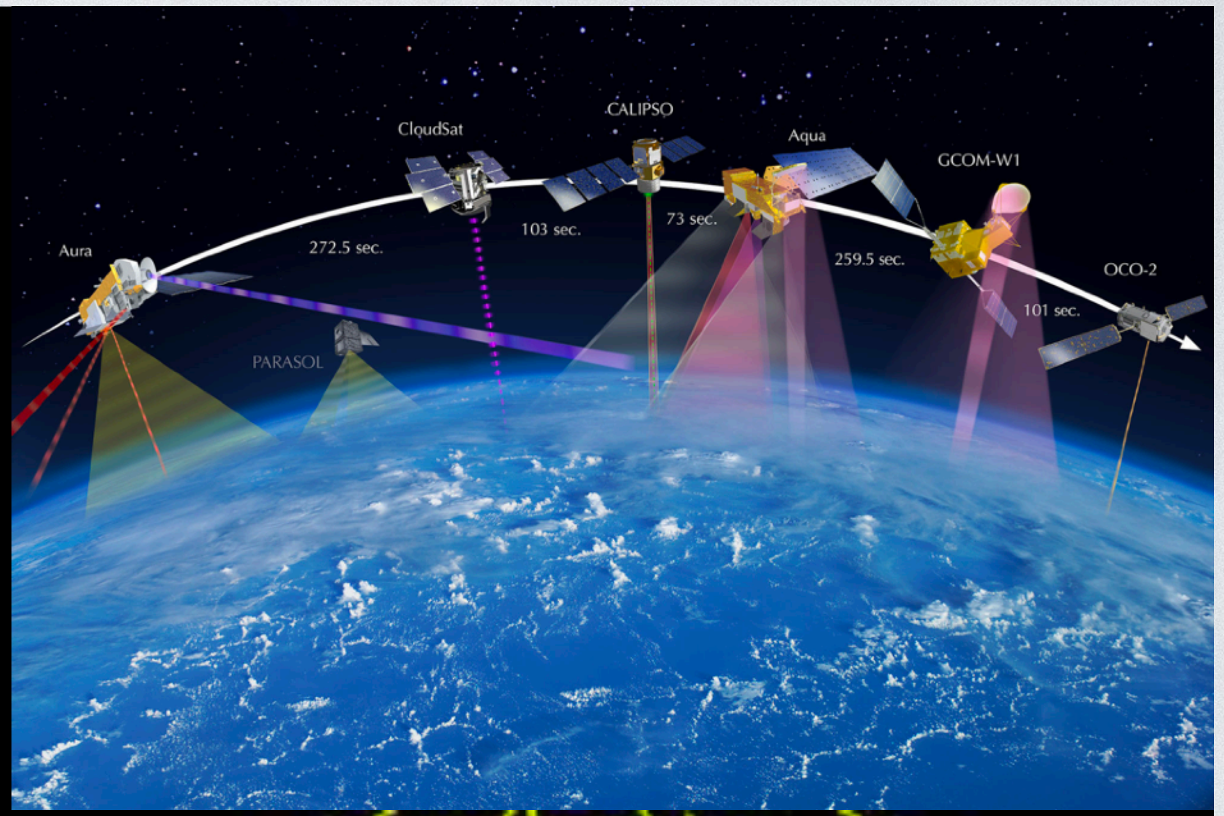
NASA GSFC/GEODYN Code 61A

UNCERTAINTY IN THERMOSPHERIC DRAG LEADS TO UNCERTAINTY IN SATELLITE TRAJECTORY





movie credit: Eelco Doonbos, KNMI

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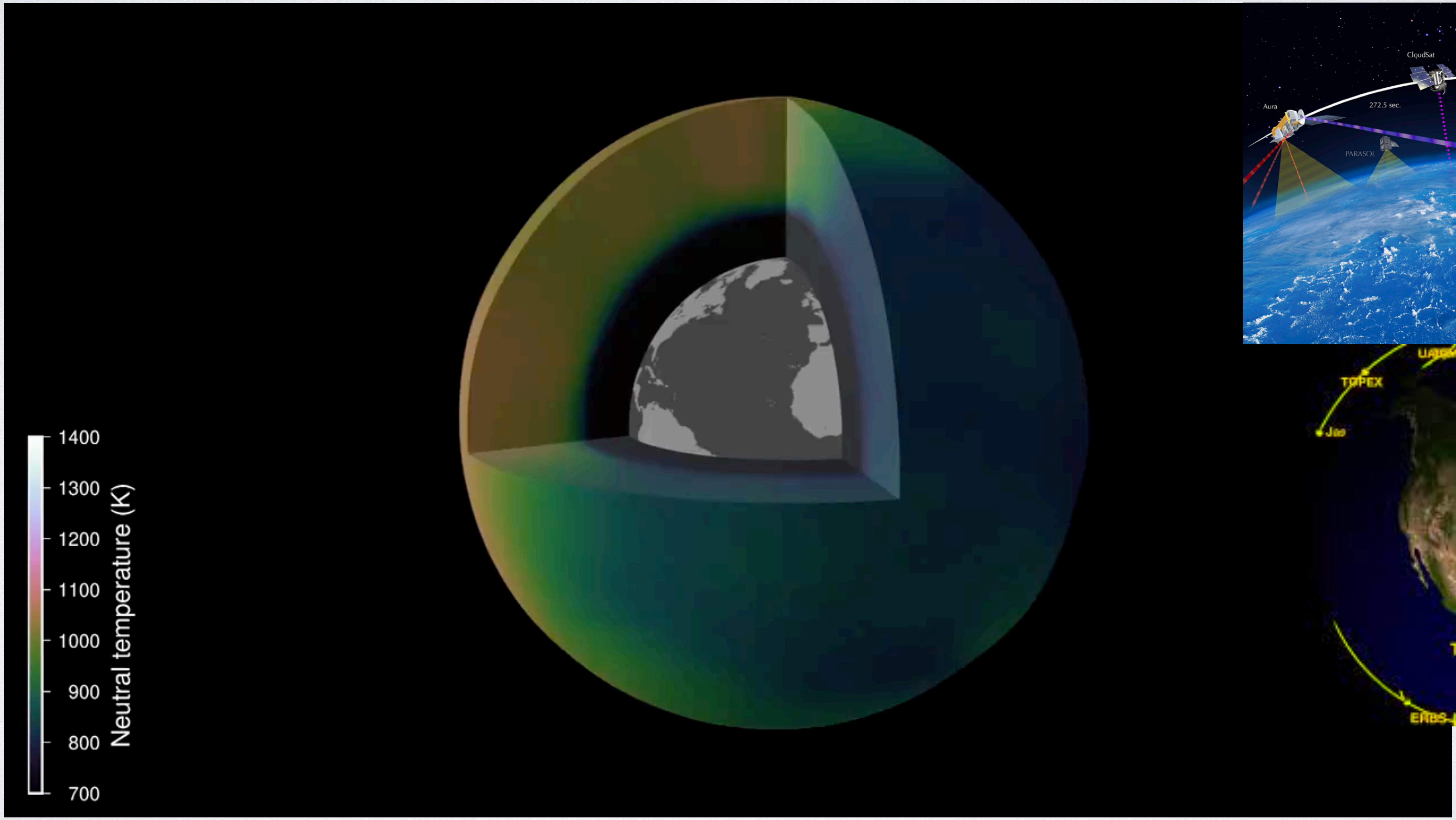

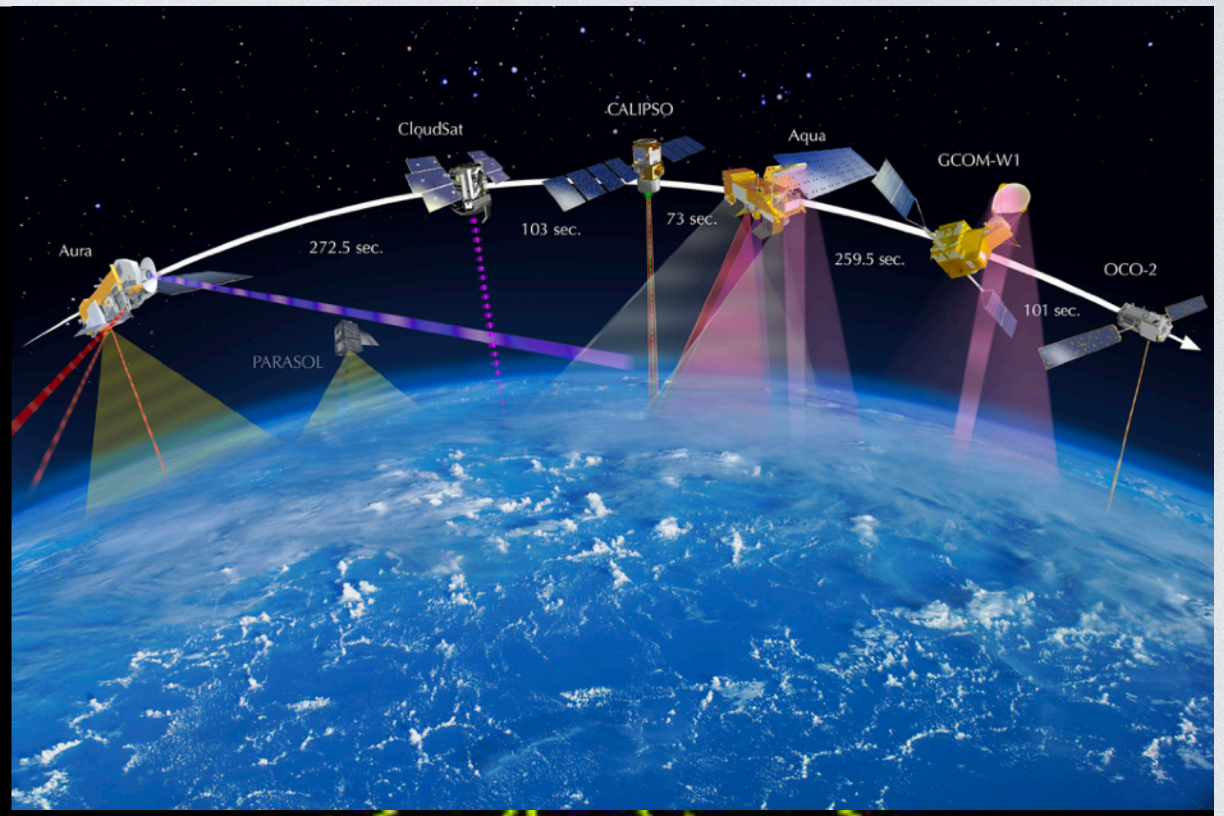

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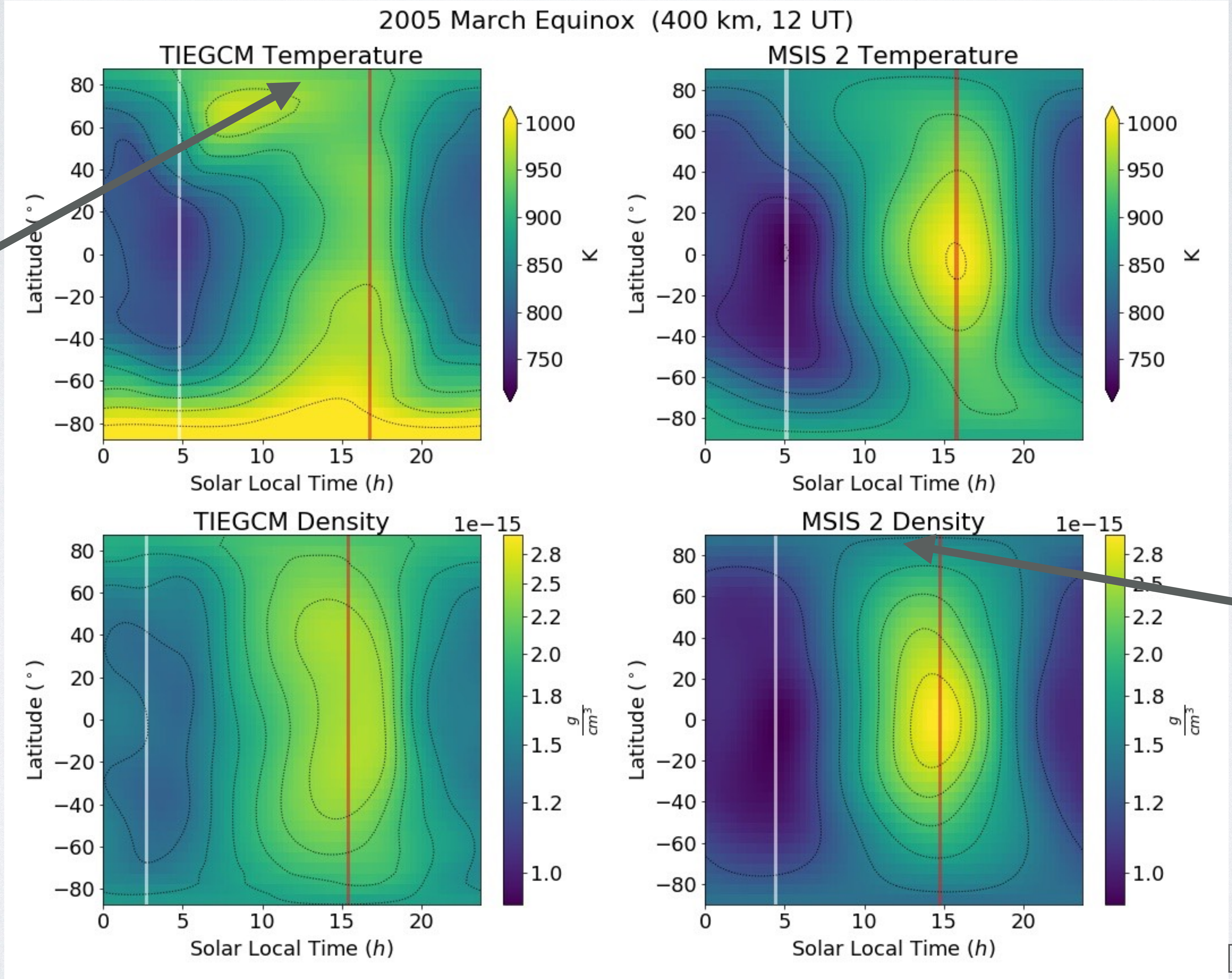
EMPIRICAL AND PHYSICS-BASED MODELS

physics-based

empirical

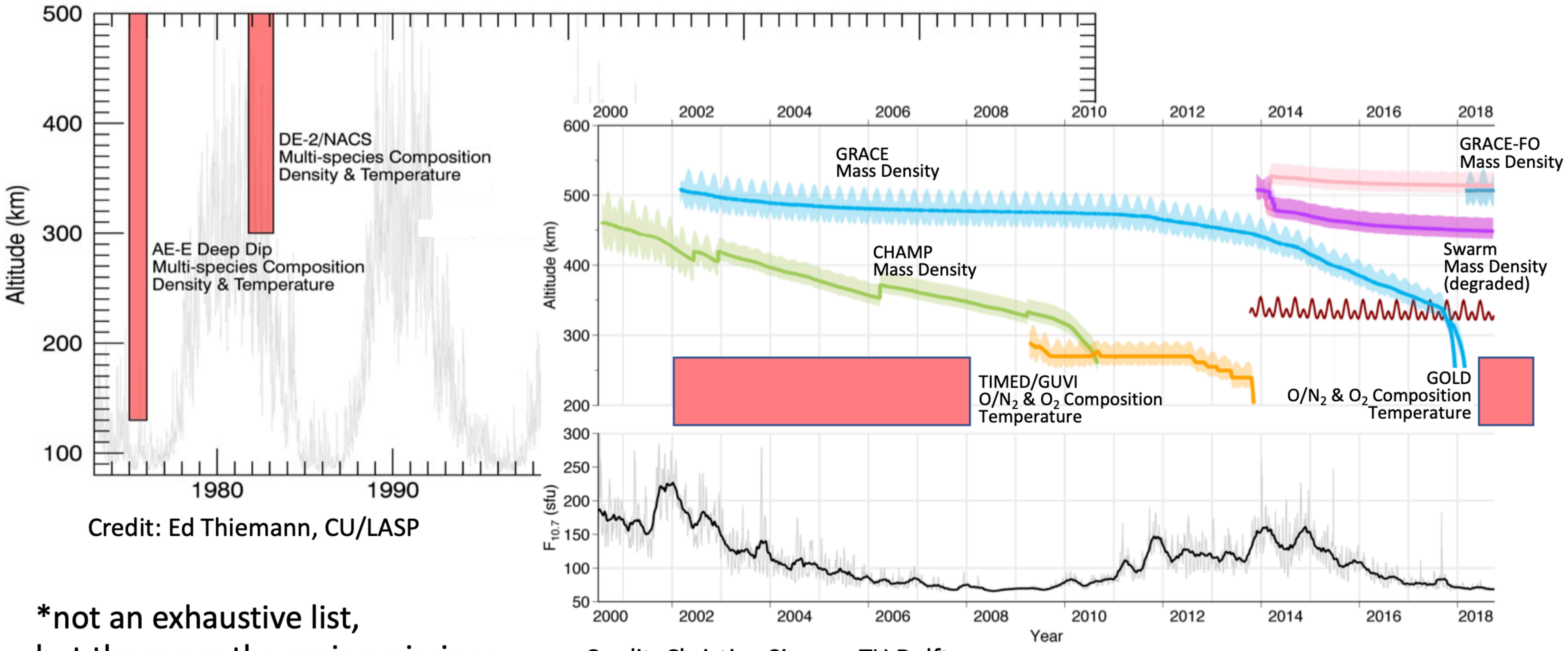
high-latitude heating



lower density

[Waldron, Masters Thesis, 2020]

PROMISE AND PITFALLS OF THERMOSPHERIC VALIDATION

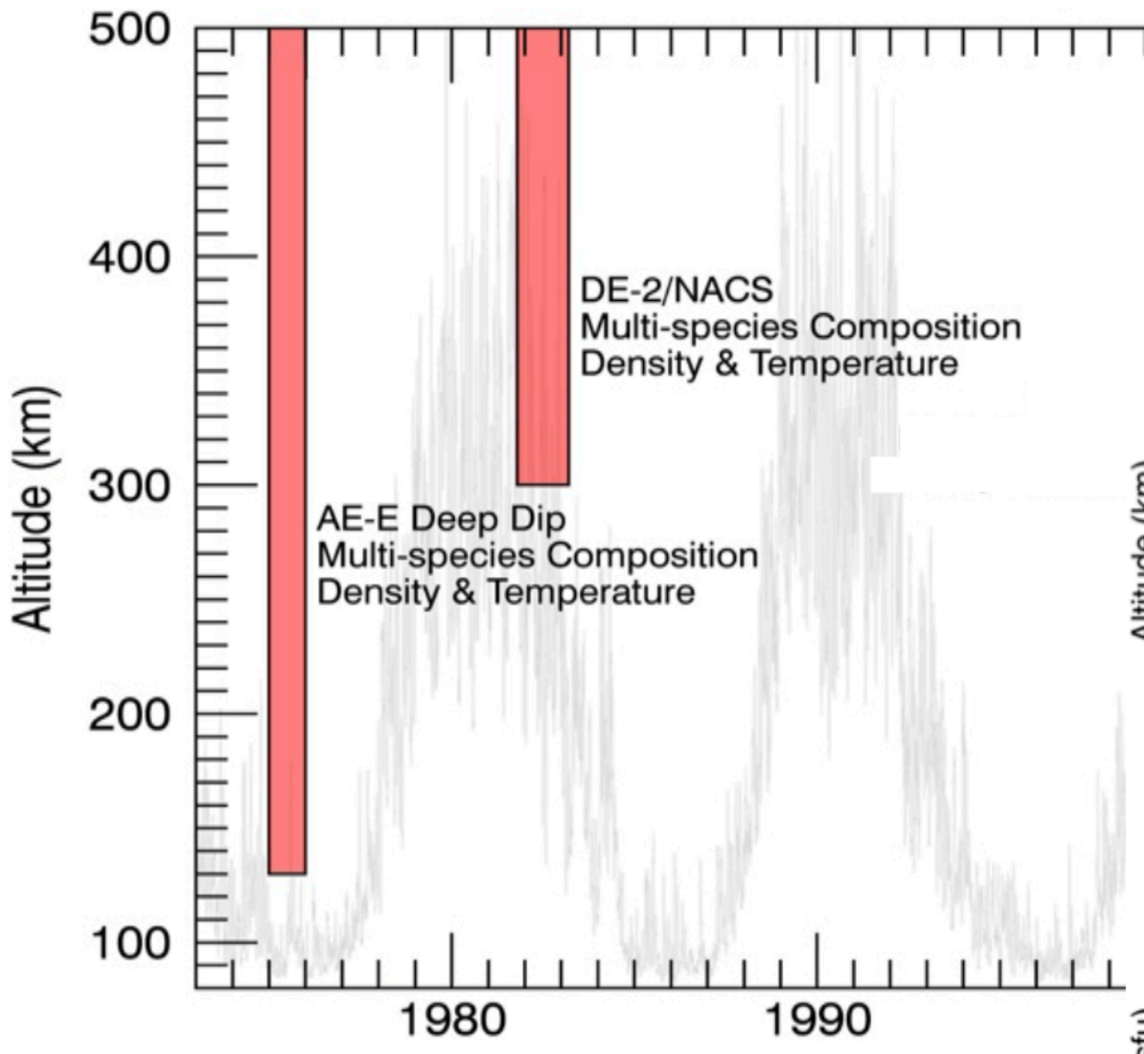


Credit: Ed Thiemann, CU/LASP

Credit: Christian Siemes, TU Delft

*not an exhaustive list,
but these are the major missions

PROMISE AND PITFALLS OF THERMOSPHERIC VALIDATION



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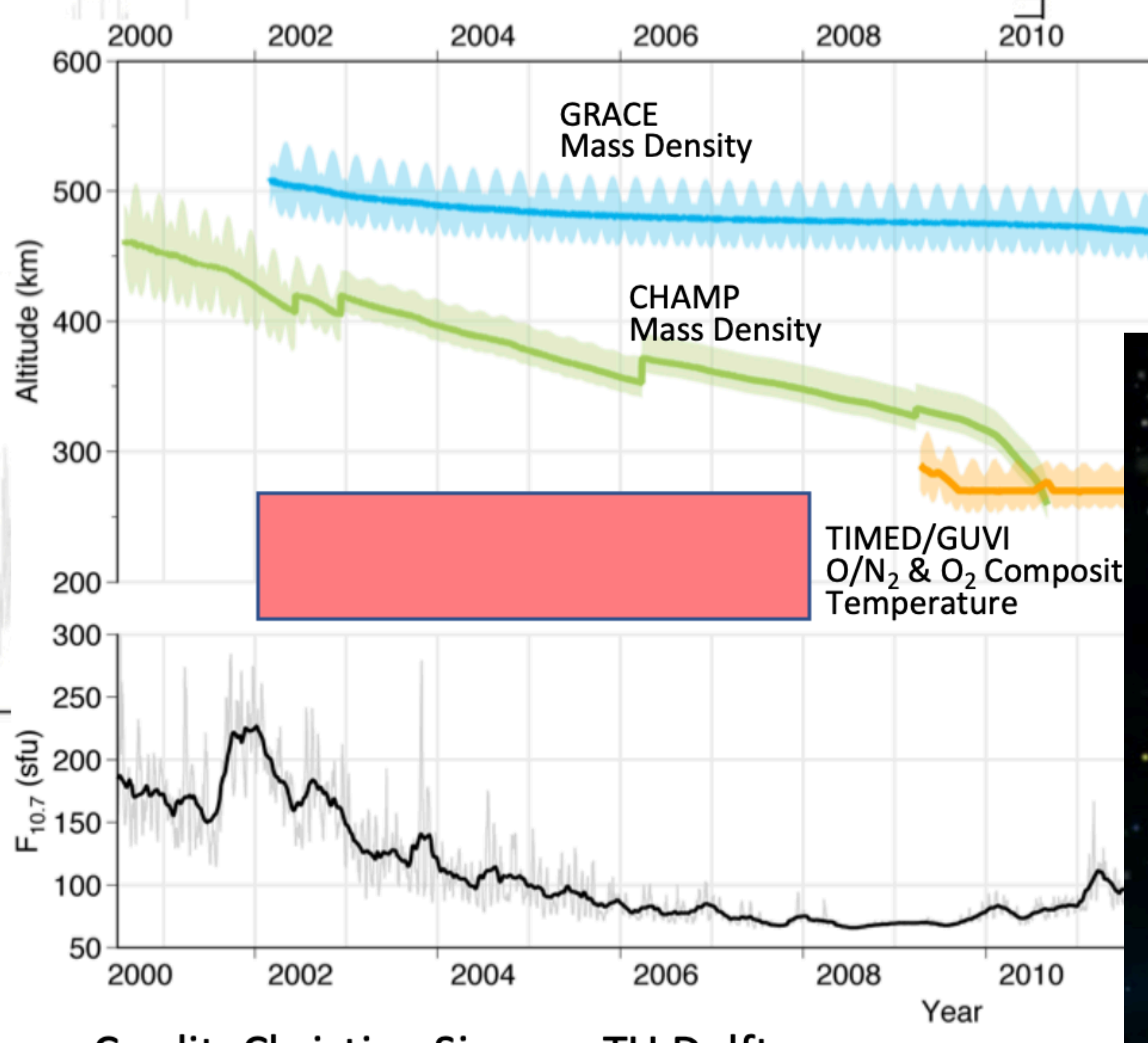

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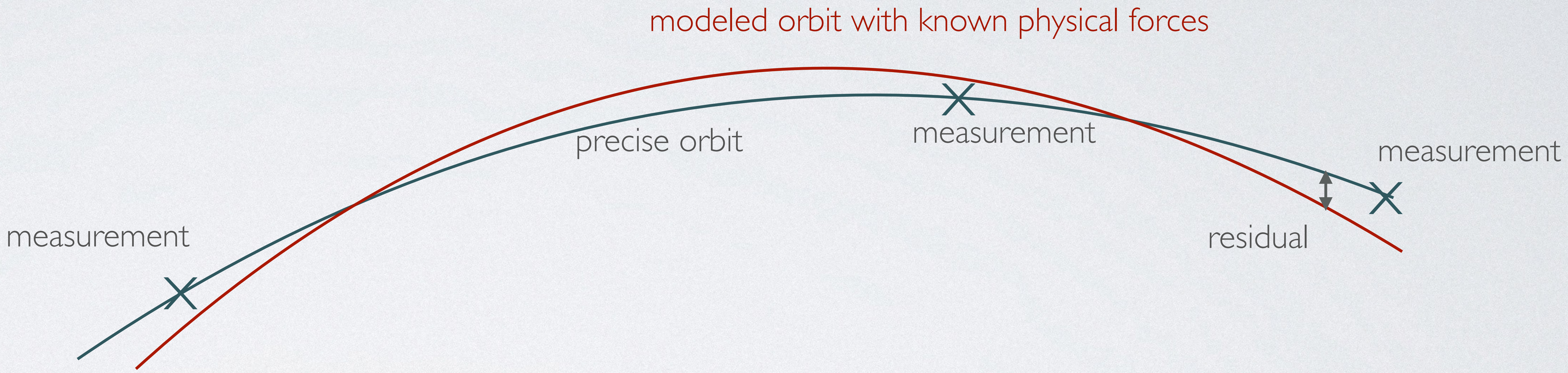


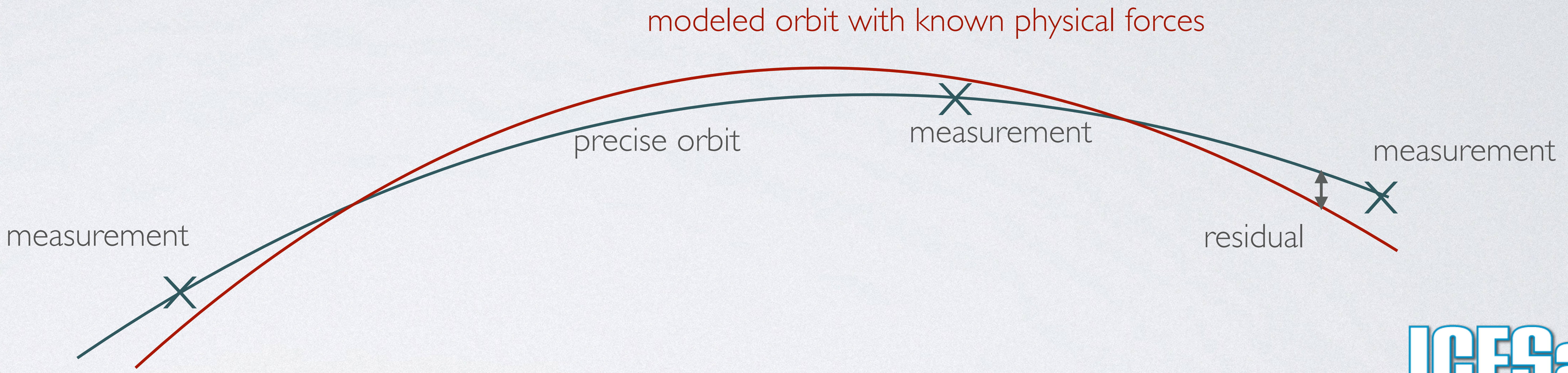
- Adjustment of acceleration
- Adjustment of drag coefficient

Partially compensate for inaccuracies in thermospheric model

- Knowledge of future measurements
- Knowledge of future thermospheric state

Validation of past vs predictive modeling

PROMISE AND PITFALLS OF THERMOSPHERIC VALIDATION



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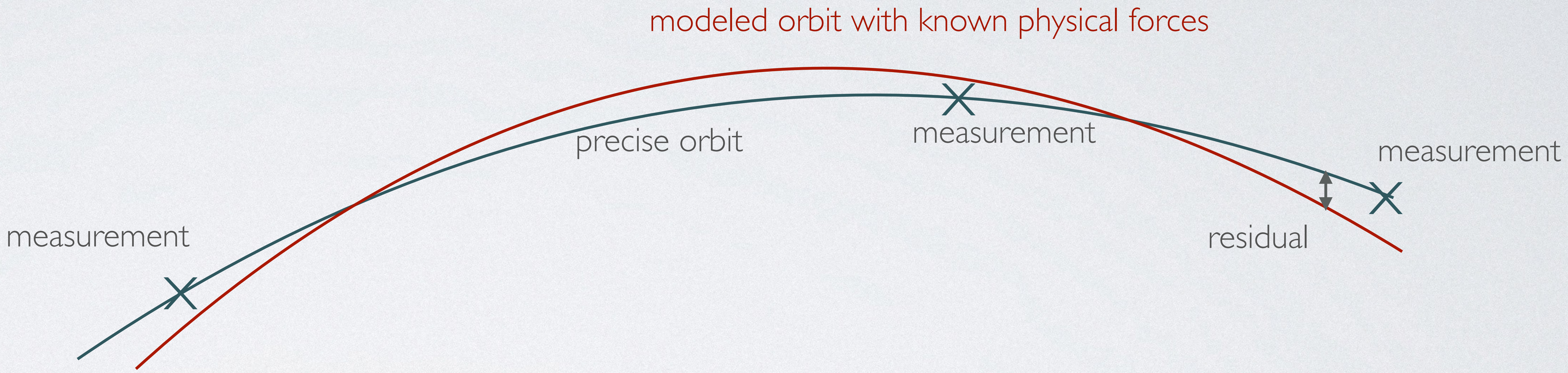

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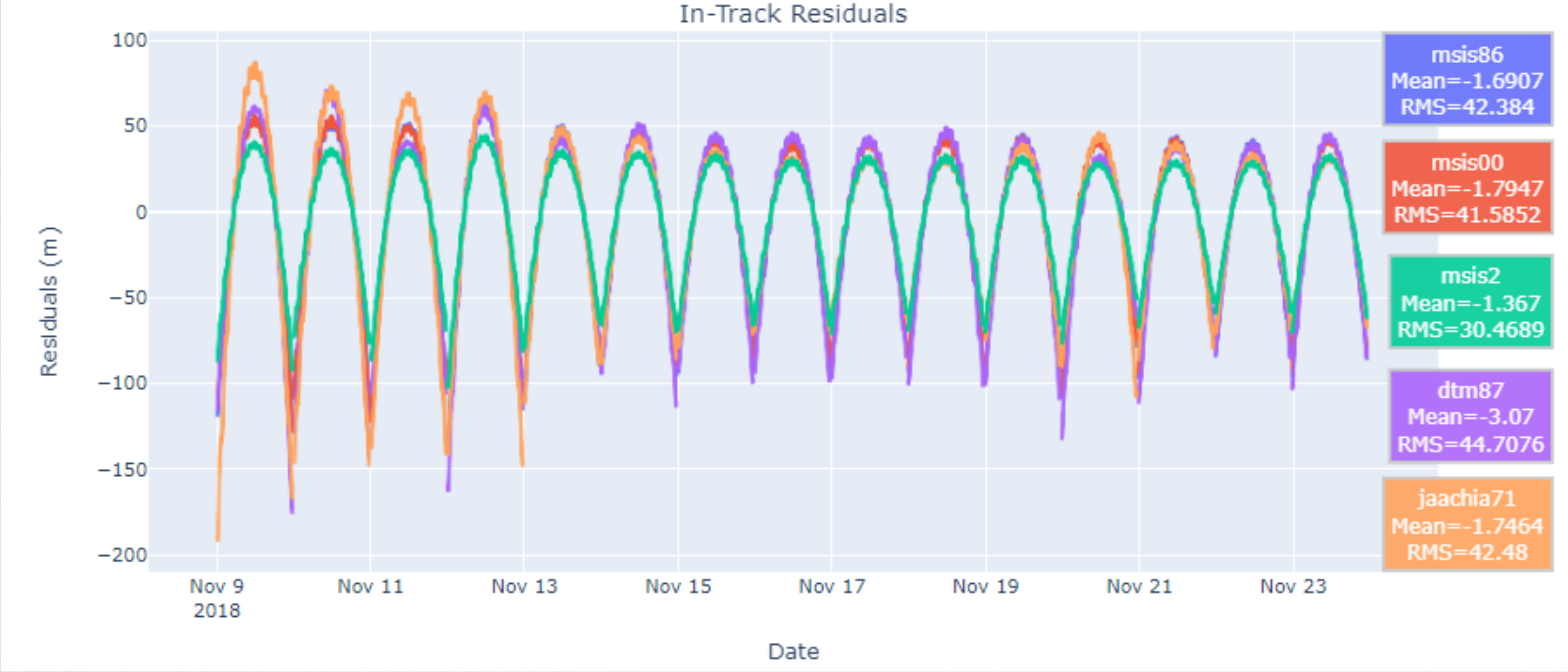
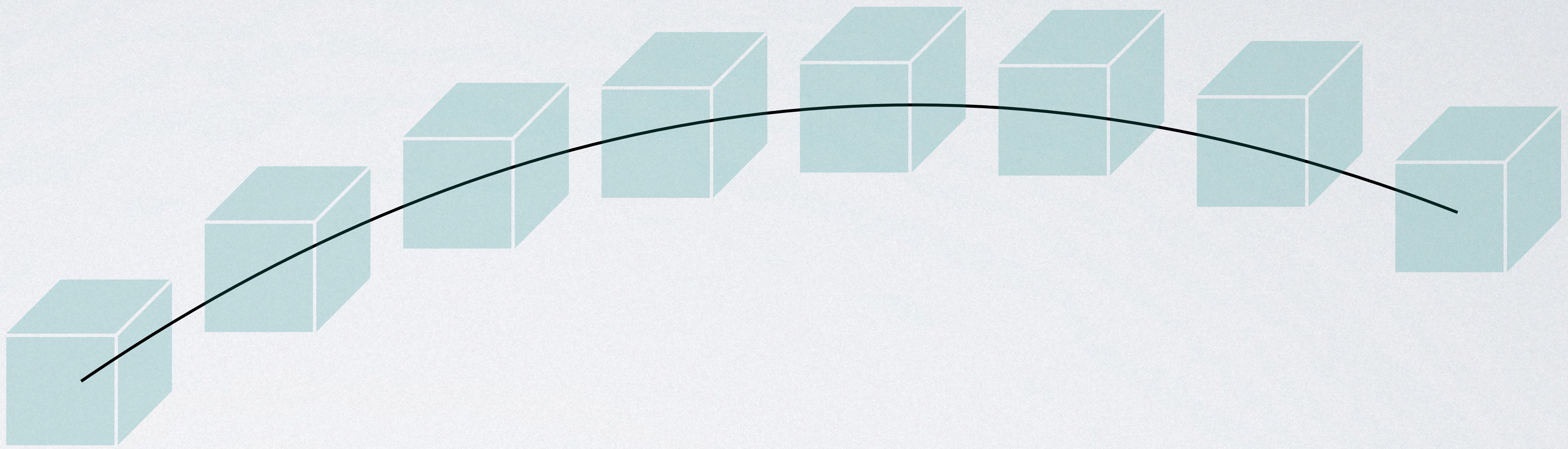
ADDING CUTTING-EDGE EMPIRICAL THERMOSPHERE MODELS



- NRL-MSISE00 and MSIS2.0 added to GEODYN
- Modern empirical models show improved performance

ADDING PHYSICS-BASED MODELS

- Repeated 4D interpolation of simulation output is computationally expensive



- Solution:
    - estimate orbit based on MSIS2.0 orbit determination
    - use Kamodo's vectorized satellite flythrough to extract cubes along the orbit
    - interpolate to exact satellite location within cubes
    - re-run flythrough based on most recent complete orbit if the trajectory ends up outside of initial estimates
- Speed is crucial for operational users!
- Expect even more speed up with continued Kamodo work

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See Rebecca Ringuette's poster SA45D-2243

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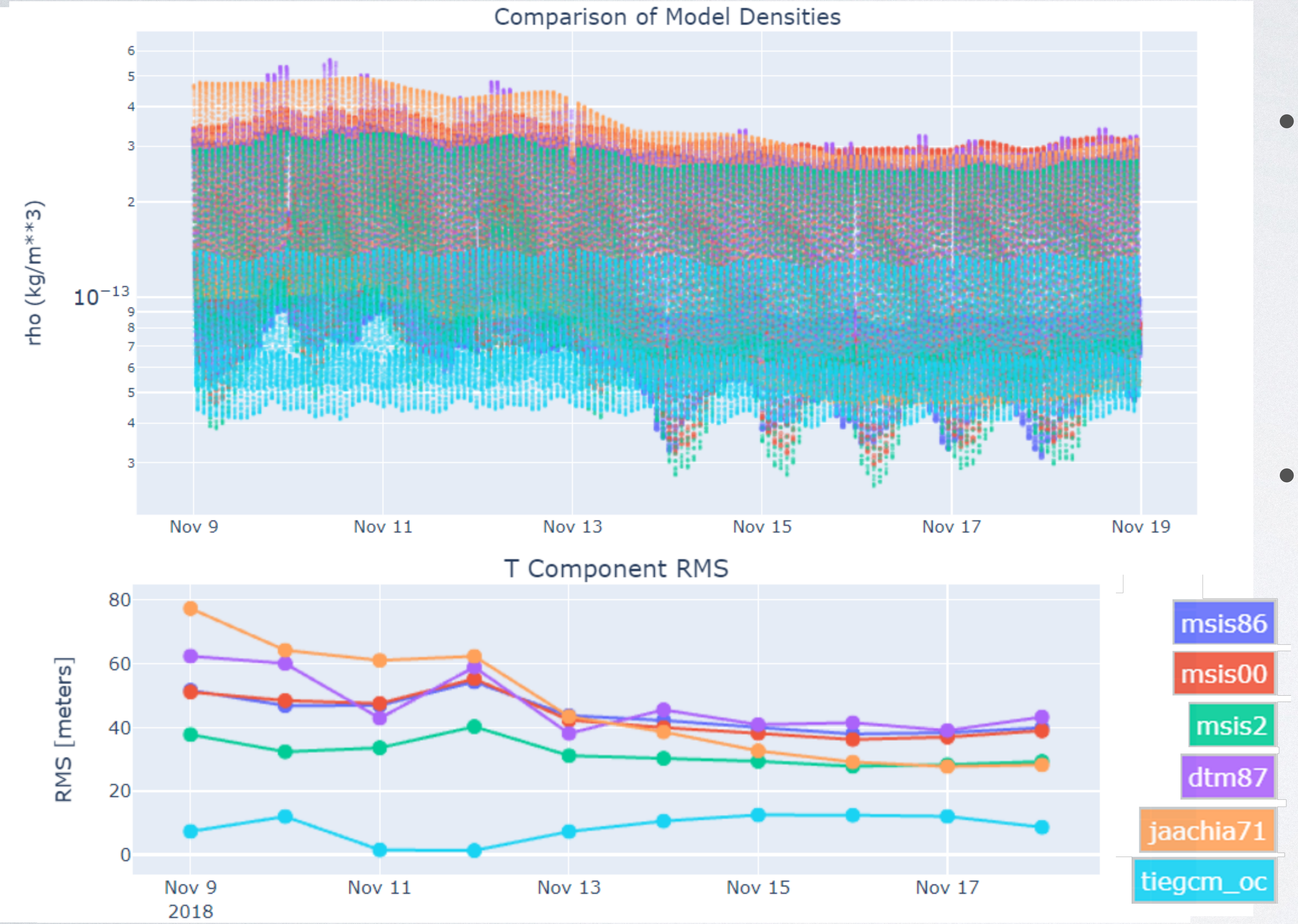
COMPARING MODELS



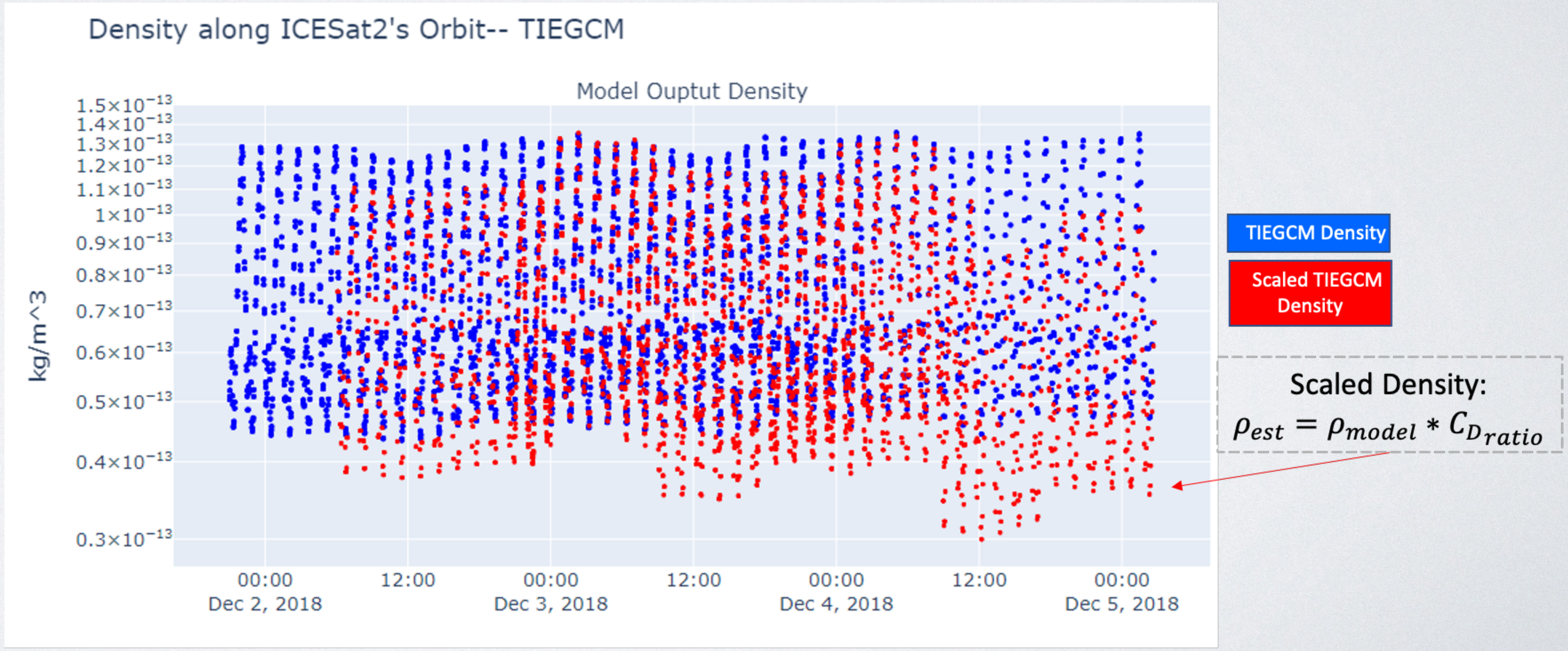
- TIEGCM is an outlier when it comes to modeled density
- RMS error is smallest for MSIS2.0 among the empirical models, much smaller for TIEGCM

DRAG COEFFICIENT EFFECTS

- Drag coefficient adjustments are correcting for modeled thermosphere discrepancies

$$\bar{a}_D = -\frac{1}{2} C_D \frac{A_S}{m_S} \rho v_r \bar{v}_r$$

- Adjustments can be inverted to correct mass density



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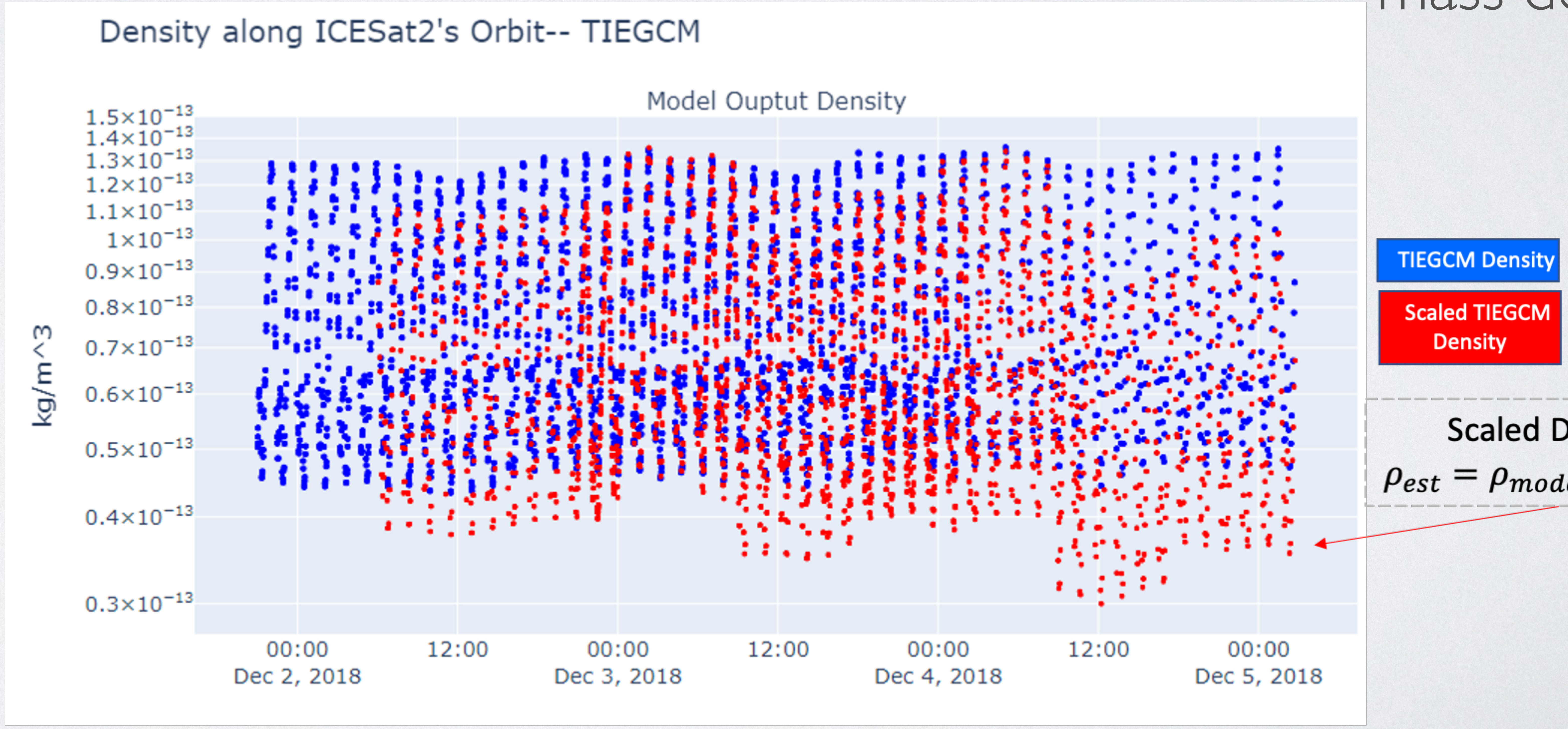
mass density



Scaled Density:

$$\rho_{est} = \rho_{model} * C_{D_{ratio}}$$

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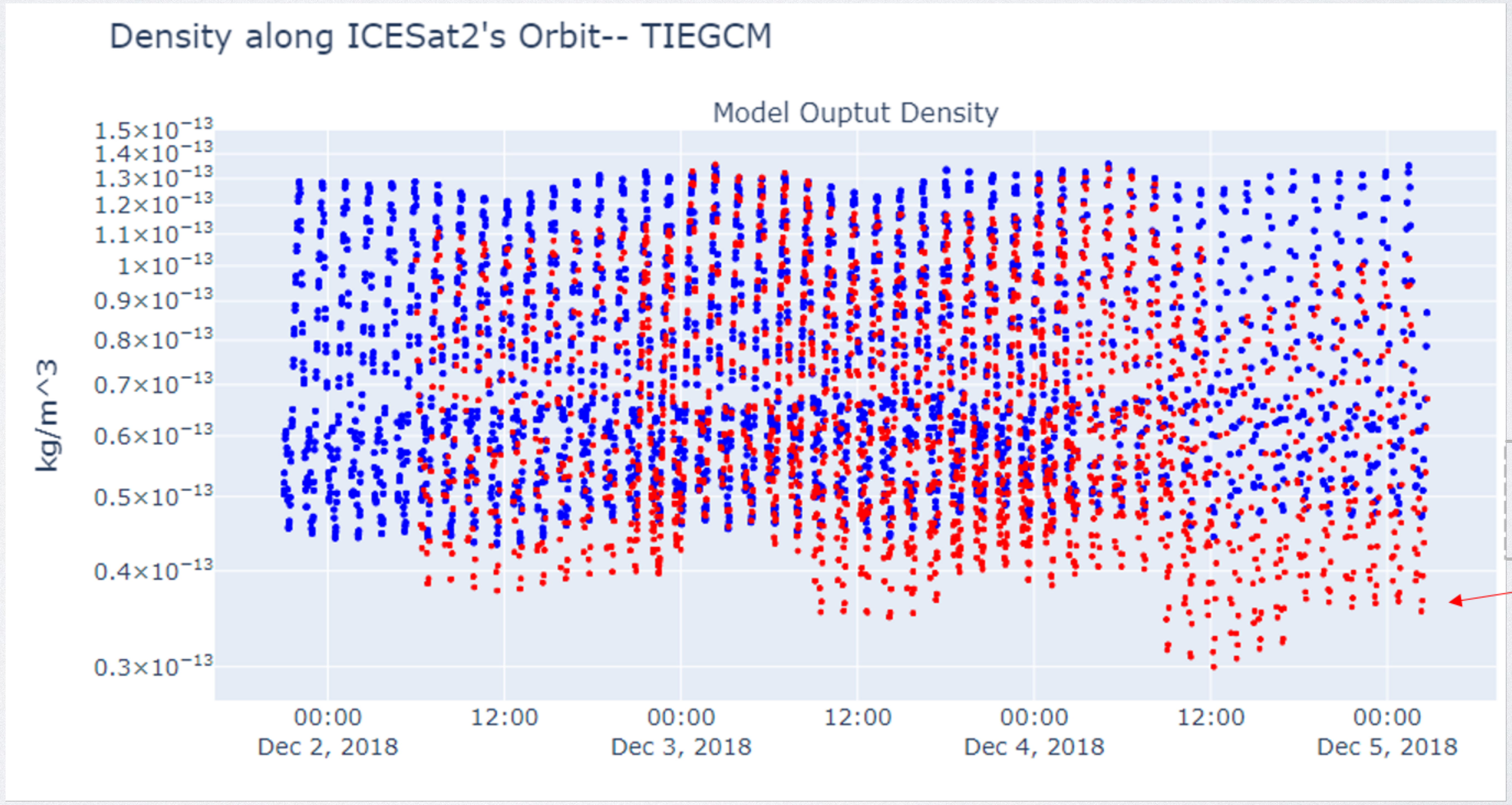
drag acceleration

mass density



TIEGCM Density

Scaled TIEGCM Density

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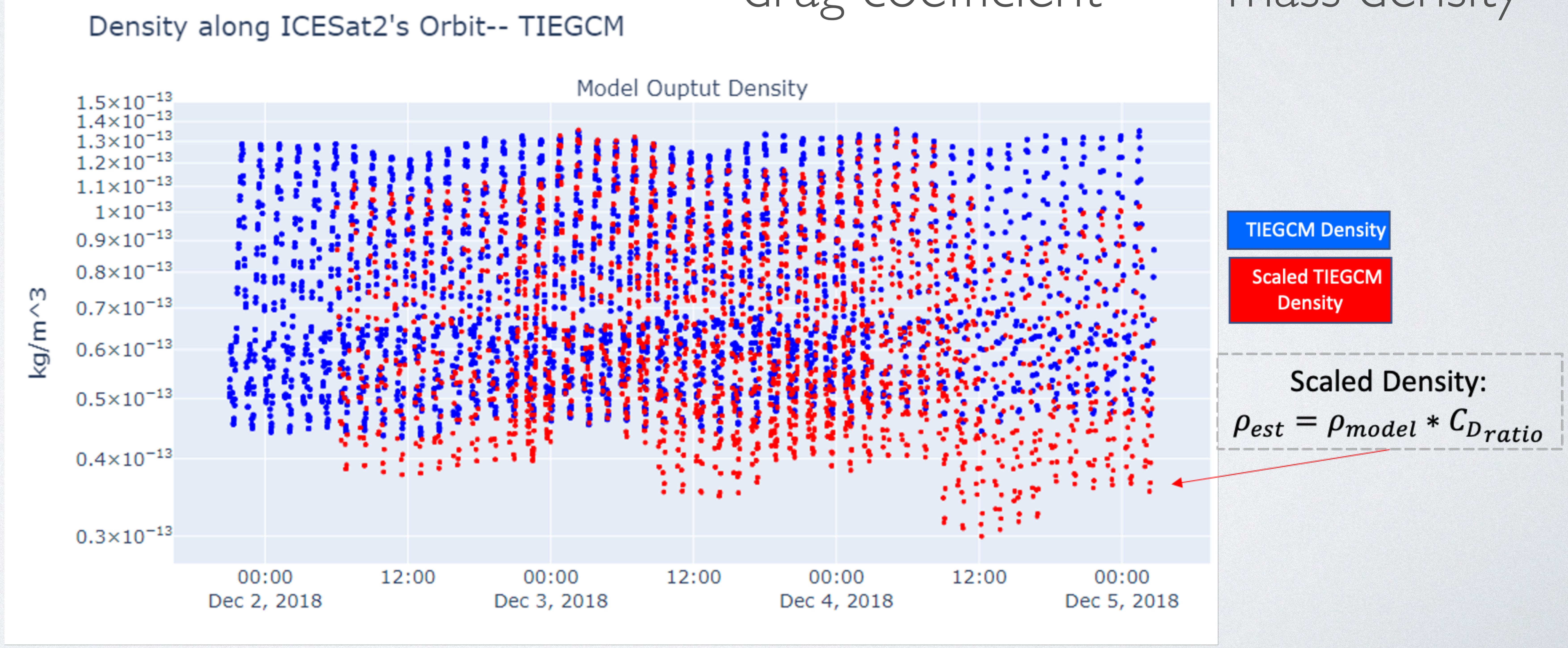
drag acceleration

drag coefficient

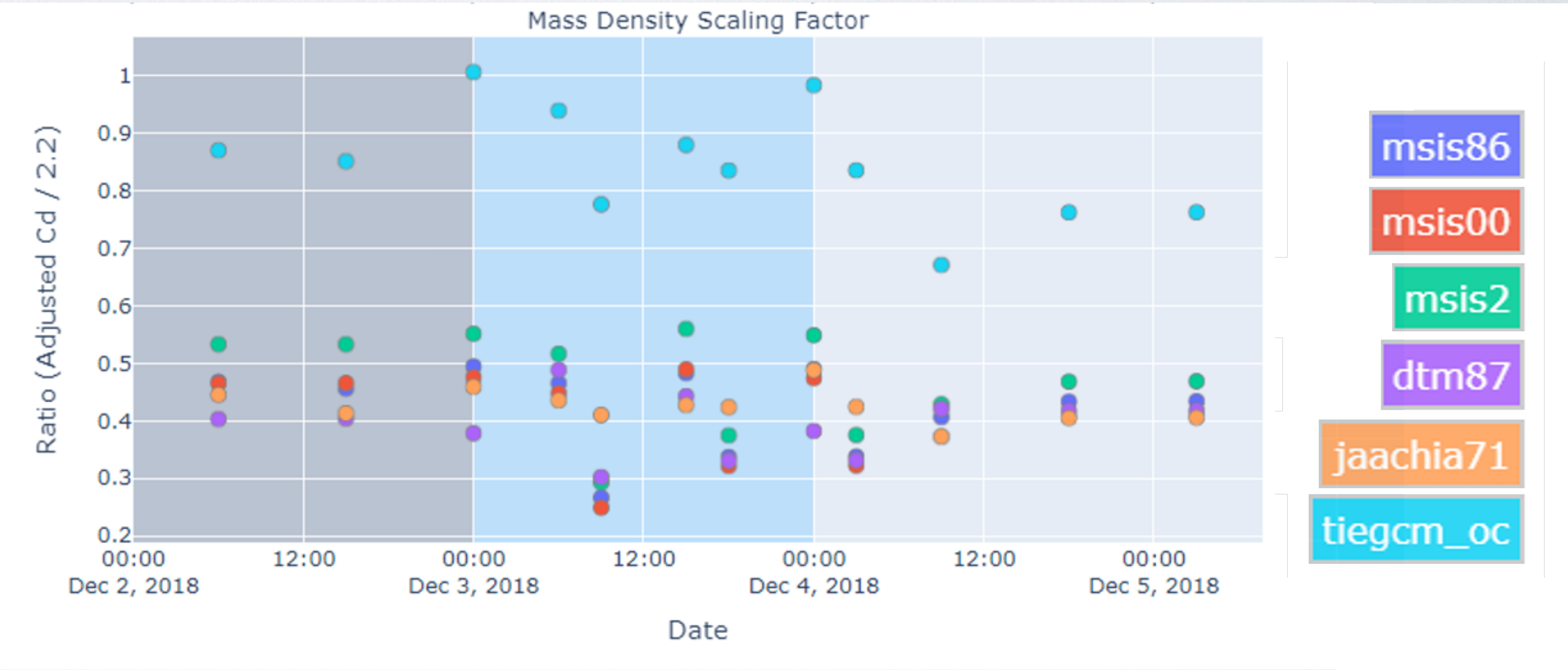
mass density



DRAG COEFFICIENT EFFECTS

- Drag coefficient adjustments are correcting for modeled thermosphere discrepancies
- Adjustments can be inverted to correct mass density
- TIEGCM requires less adjustment in order to reduce residuals

$$\bar{a}_D = -\frac{1}{2} C_D \frac{A_S}{m_S} \rho v_r \bar{v}_r$$



FUTURE VALIDATION

- Extend validation using low-altitude ICESAT-2 satellite
- Use high altitude Starlette and Stella satellites to validate newly-installed high altitude TIEGCM at both low and high latitudes

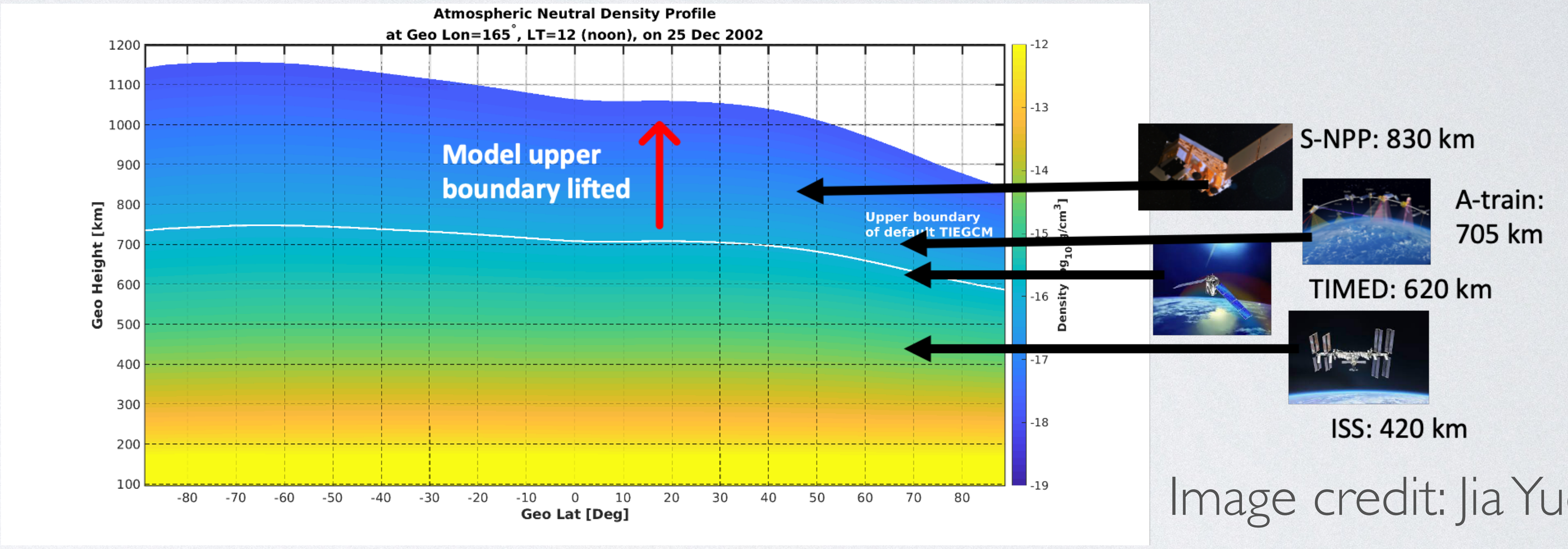


Image credit: Jia Yue

- Include additional CCMC-hosted models: GITM, CTIPe, DTM2020

Space weather-focused model validation

ORBIT PROPAGATION CAPABILITIES AT CCMC

- Collaboration for GMAT orbit propagator for flight dynamics at GSFC

Kamodo ↔ GMAT GENERAL MISSION ANALYSIS TOOL

CCMC-hosted neutral density models

geodynamics science missions

planning heliophysics missions to LEO

space weather operations

COMMUNITY COORDINATED MODELING CENTER