Validating Thermospheric Neutral Density Models using GEODYN's Precision Orbit Determination

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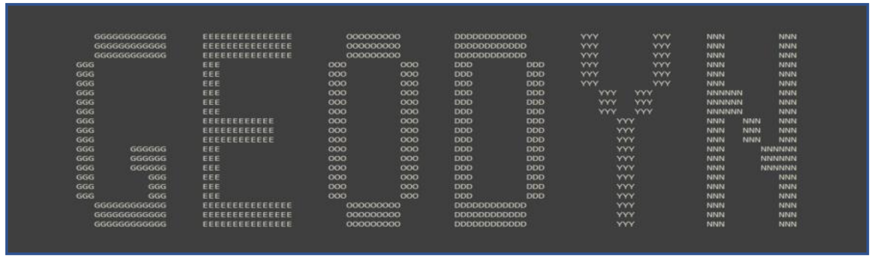
Project Goals

1. Develop a methodology and tool that can use GEODYN's POD to validate upper atmospheric density models
2. Allow POD program to access many density models while remaining user-friendly
3. Perform a case-study validation using ICESat-2



GEODYN ASCII art from an output file

Contributors

- Space Weather Technology, Research, Education Center (SWx TREC) Gas-Vehicles Interaction Team
- CCMC and the Kamodo Team
- GSFC Geodesy and Geophysics Laboratory

ICESat-2
ICE, CLOUD, AND LAND ELEVATION SATELLITE-2

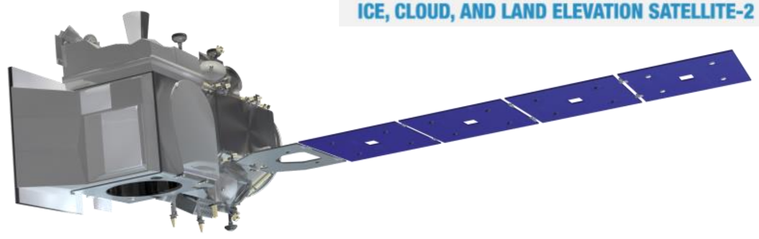


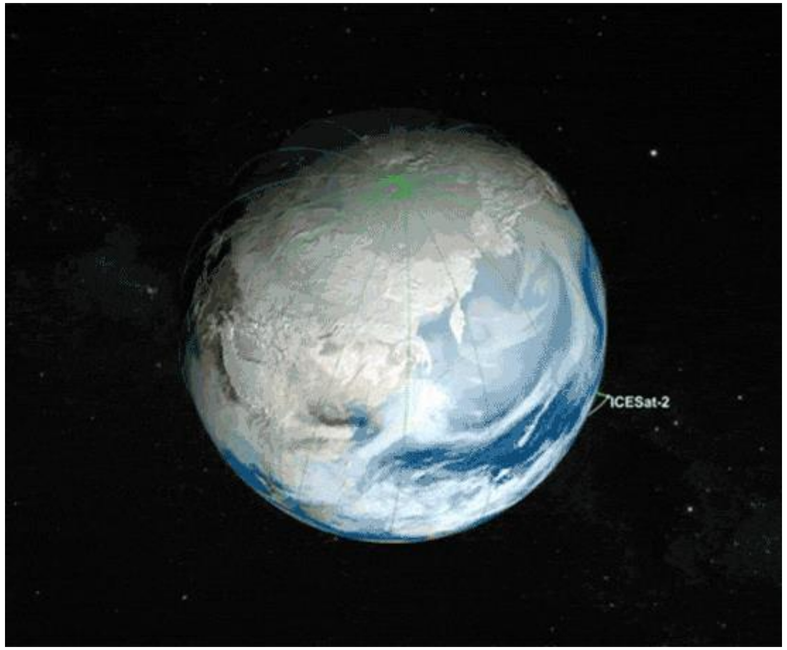
Image and logo from the ICESat-2 Visualization Gallery

Validation as Motivation

1. Leverages the high-precision nature of space geodetic POD, but refashioned to focus on satellite drag and density model validation.

2. Takes advantage of the global coverage becoming available through other GNSS-enabled satellites

3. Almost any high-quality POD solution can theoretically be used for density model validation through this new tool

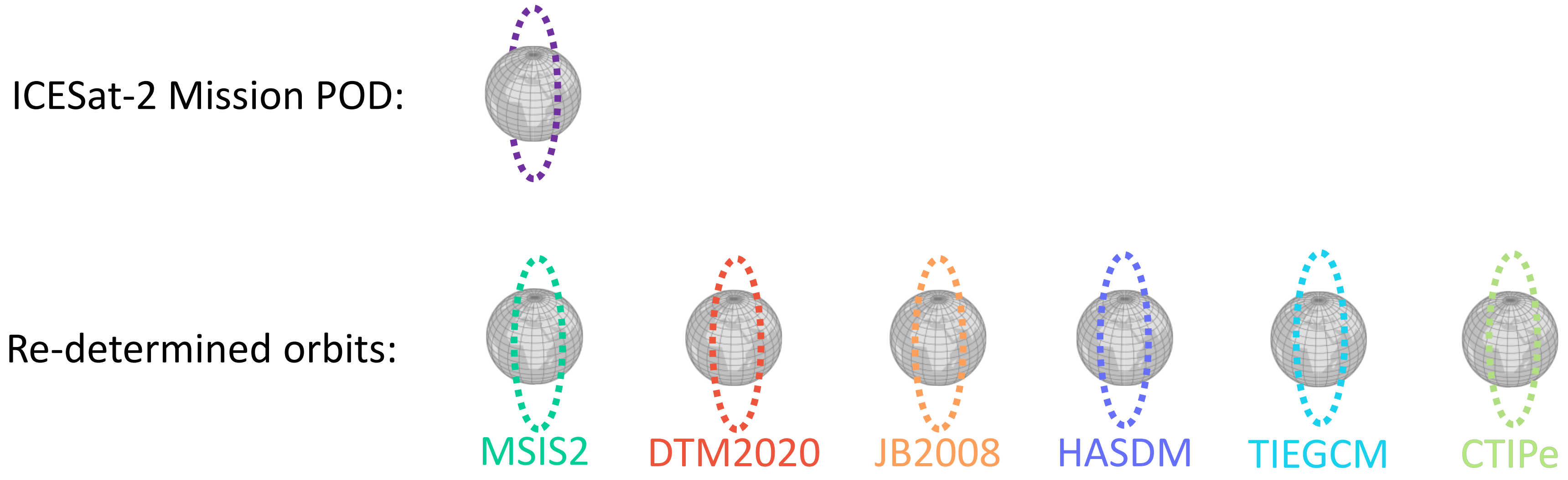


Animated GIF of the ICESat-2's Polar Orbit from the ICESat-2 Visualization Gallery

Step 1: Prepare GEODYN II for drag study using ICESAT-2 input parameters

Step 2: Use different density models to re-determine the ICESat-2 orbit using GEODYN

Step 3: Perform the Validation



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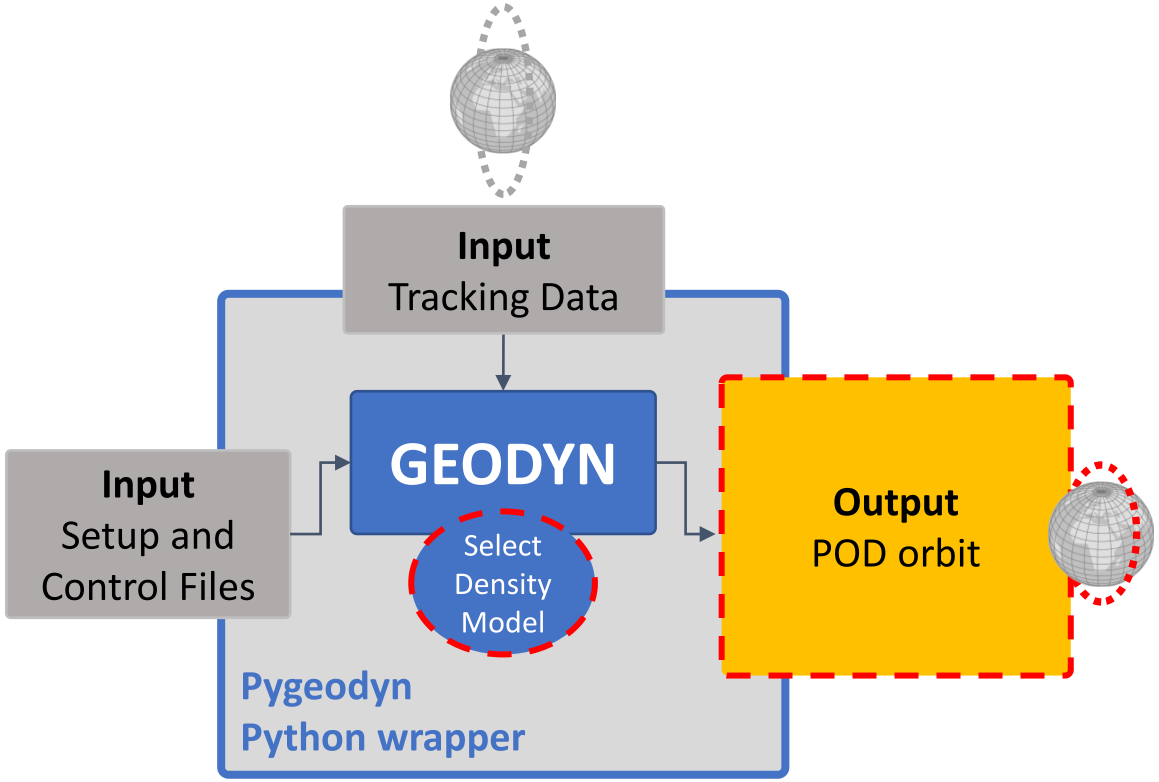

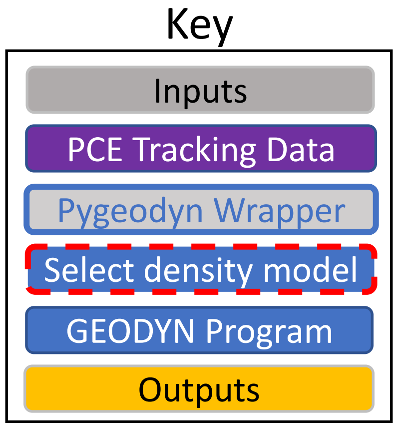

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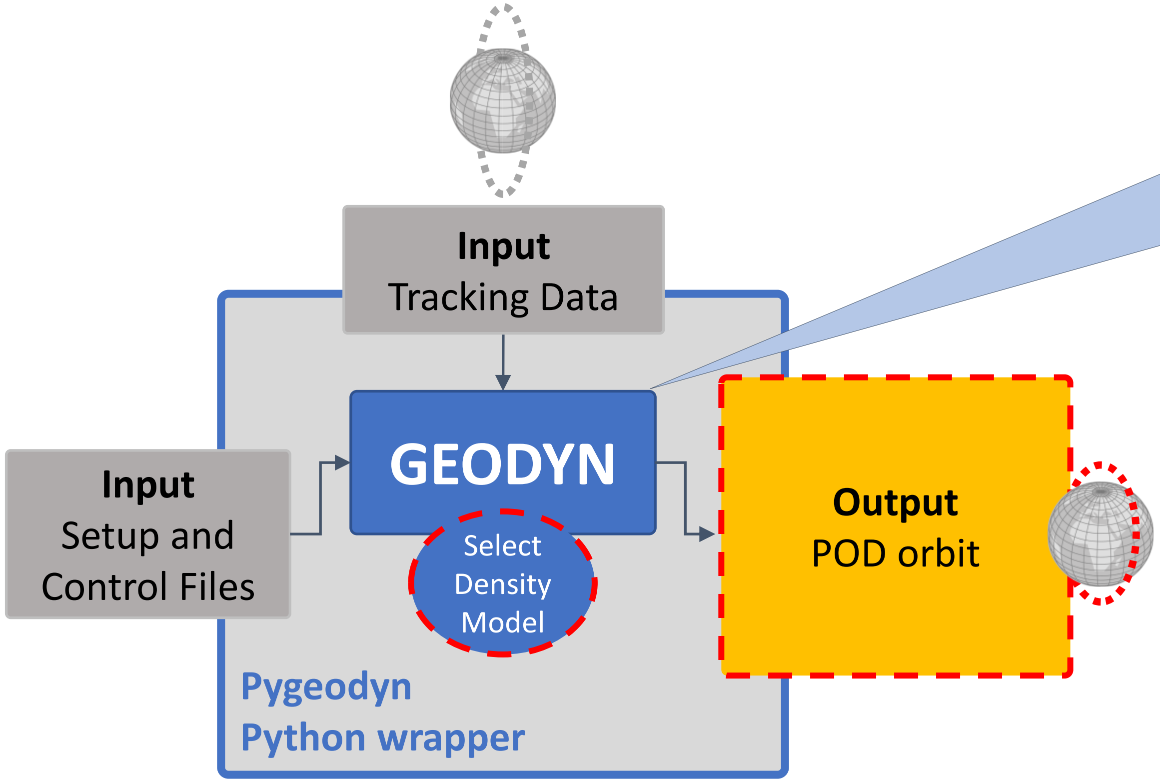

The GEODYN II Software

- Precision orbit determination and geodetic parameter estimation tool
- Made by the GSFC Geodesy and Geophysics Laboratory
- Used on every NASA geodetic Earth and planetary altimeter mission since 1985.
- Provides very high-fidelity conservative and non-conservative force modelling

Key

- Inputs
- PCE Tracking Data
- Pygeodyn Wrapper
- Select density model
- GEODYN Program
- Outputs

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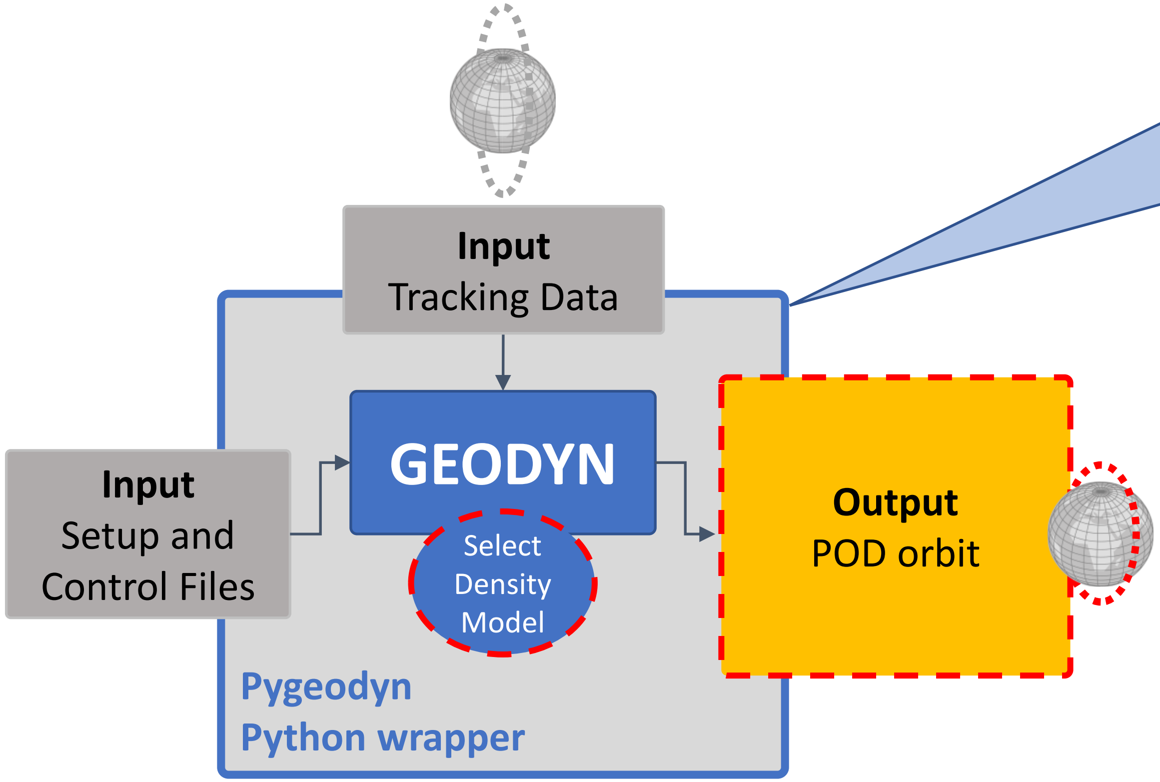
The Pygeodyn Wrapper

- Makes it easier to use GEODYN for satellite drag studies
- Makes it easier to add and run multiple density models



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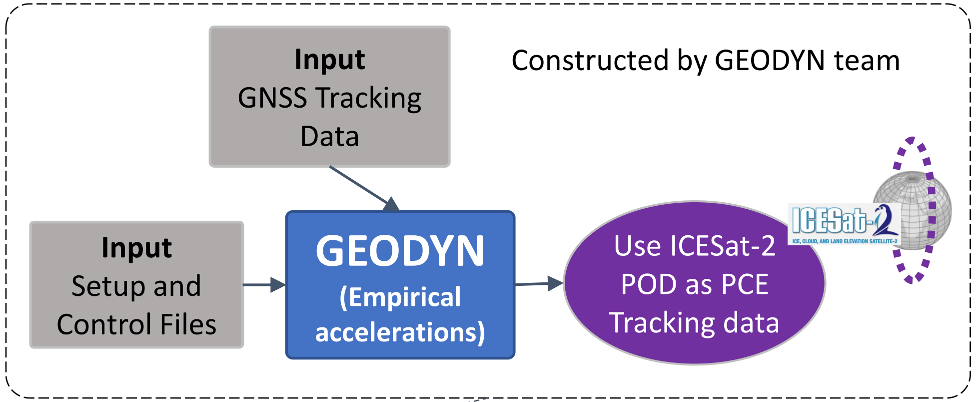

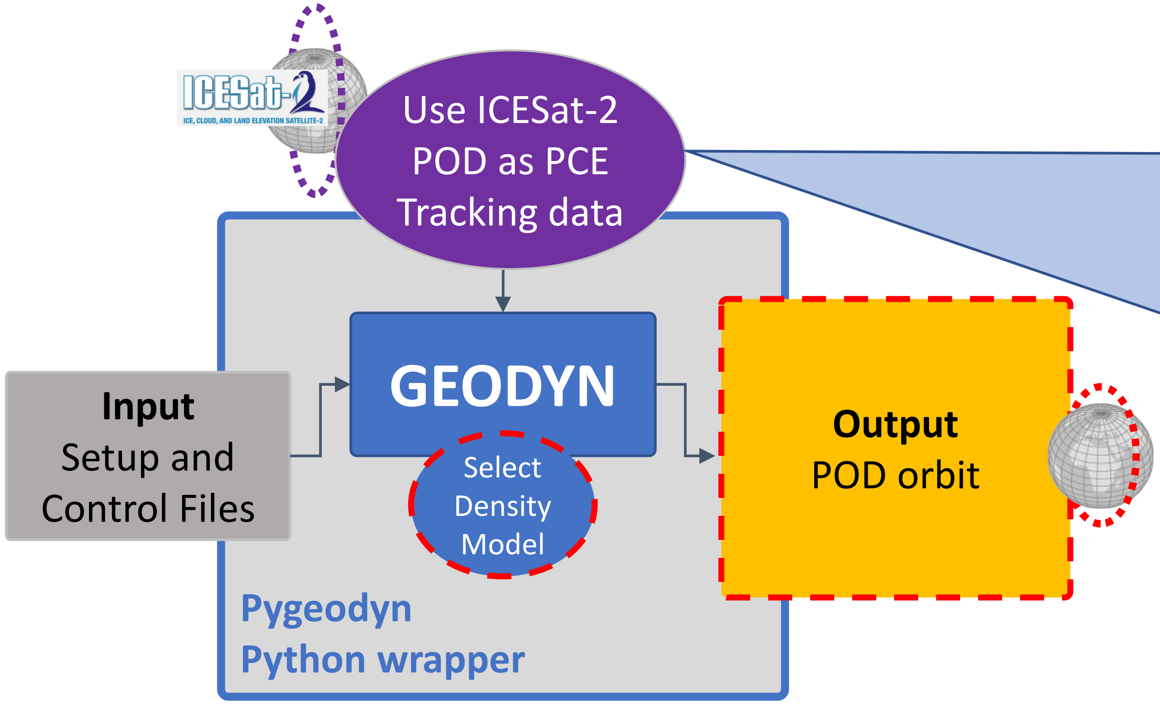

ICESat-2 POD Solutions as PCE tracking data

- Constructed by GEODYN team
- Empirical accelerations are used to fit GNSS tracking data
  - *Very low orbit error at ~1.5cm radial precision*
- "PCE" = precisely converted elements
  - orbit trajectory is used as tracking data

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Construct an ICESat-2 POD-based orbit fit using each density model

- Semi-empirical models are written directly into the GEODYN source code.
- More complex physics-based model outputs are interfaced via Kamodo

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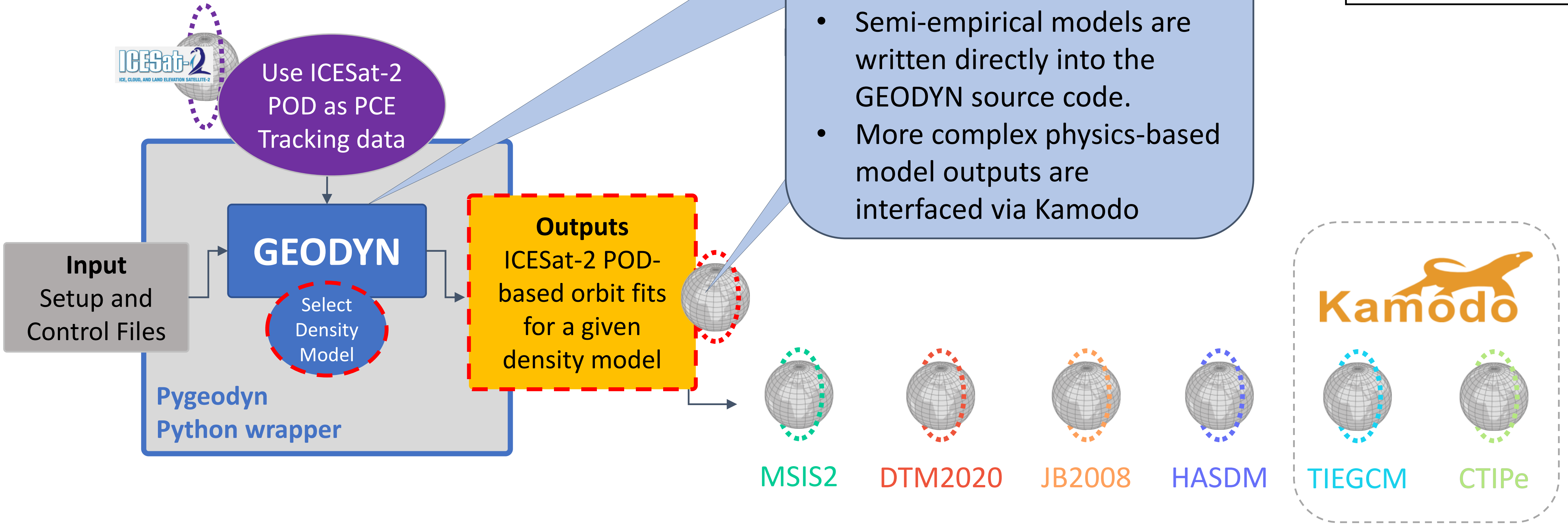


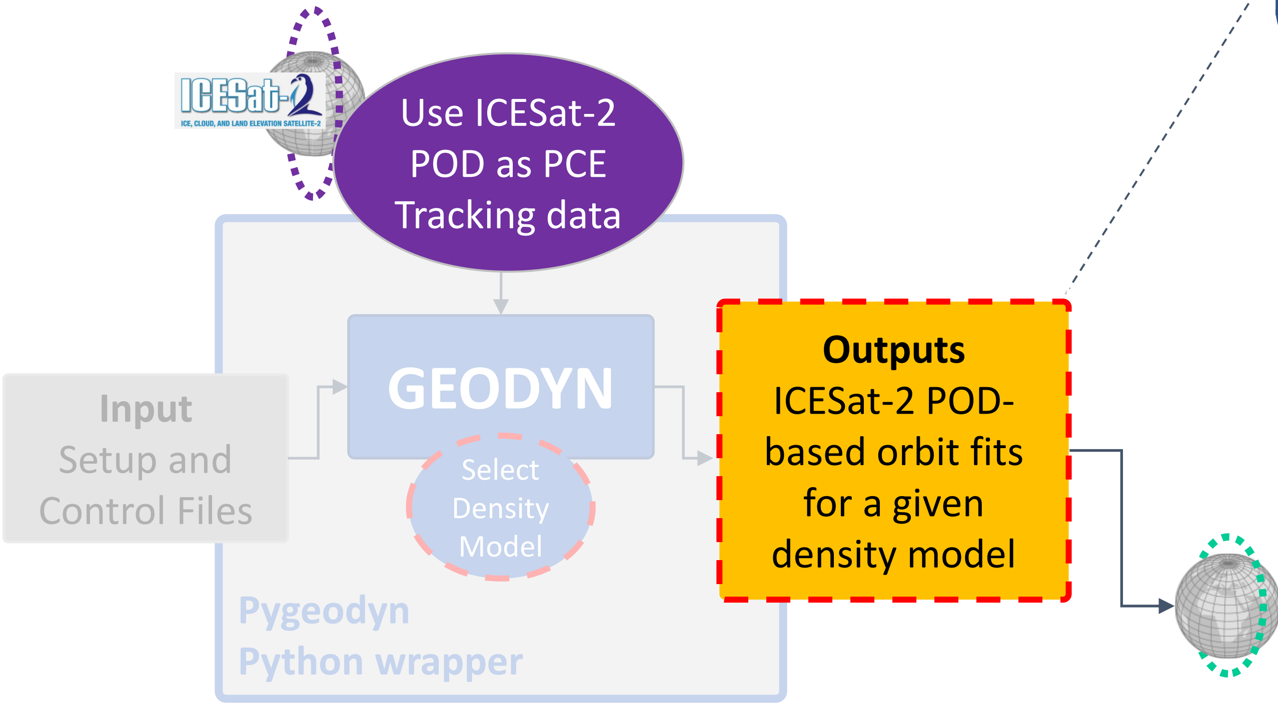
Step 1: Prepare GEODYN II for drag study using ICESAT-2 input parameters

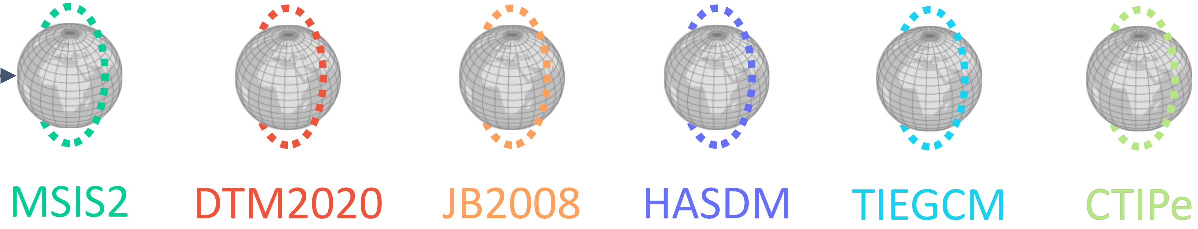
Step 2: Use different density models to re-determine the ICESat-2 orbit using GEODYN

Step 3: Perform the Validation

Key Assumptions

- All parameters other than atmospheric density are held constant
- Drag coefficient is fixed at $C_D = 2.2$
- Empirical Accelerations are turned off





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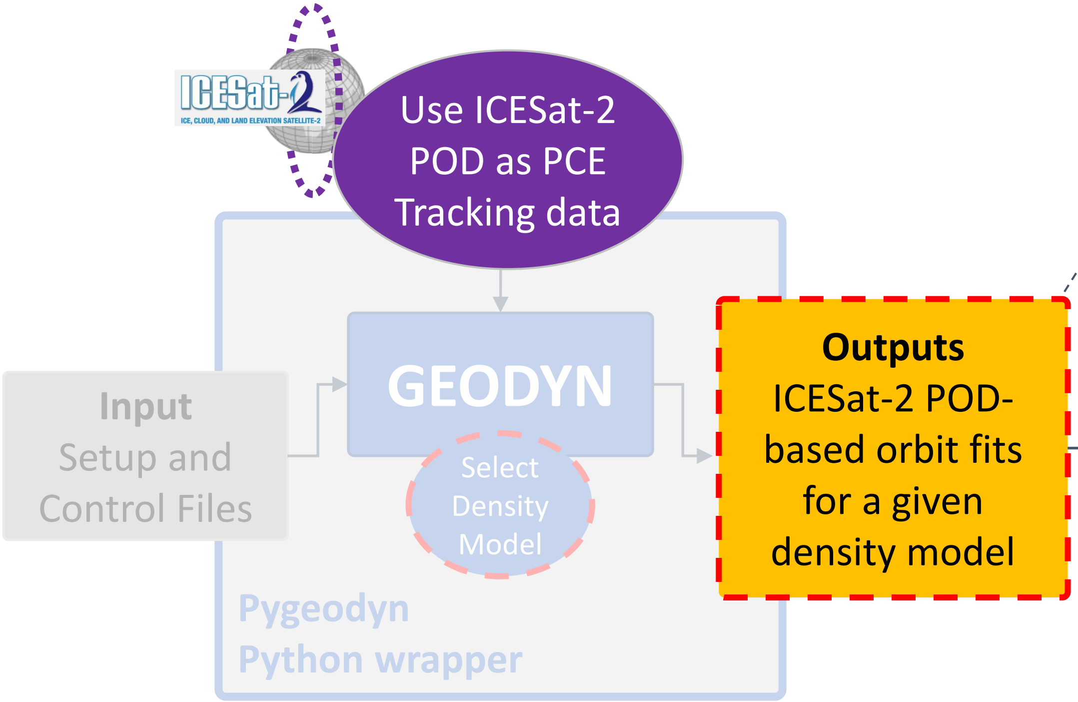

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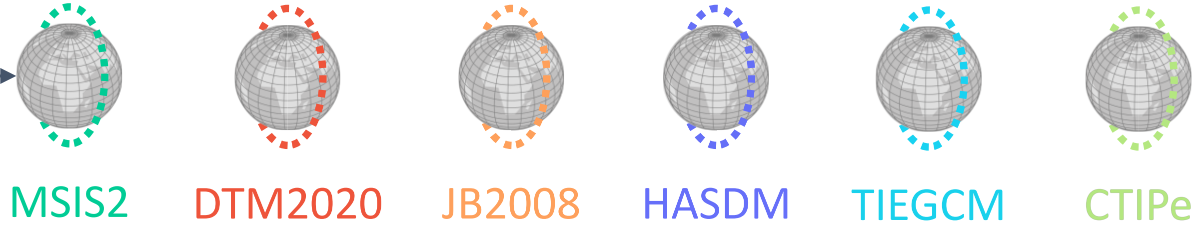
For each density model:

PCE "True" Orbit Trajectory − Model's Orbit Trajectory = **Orbital Residuals**



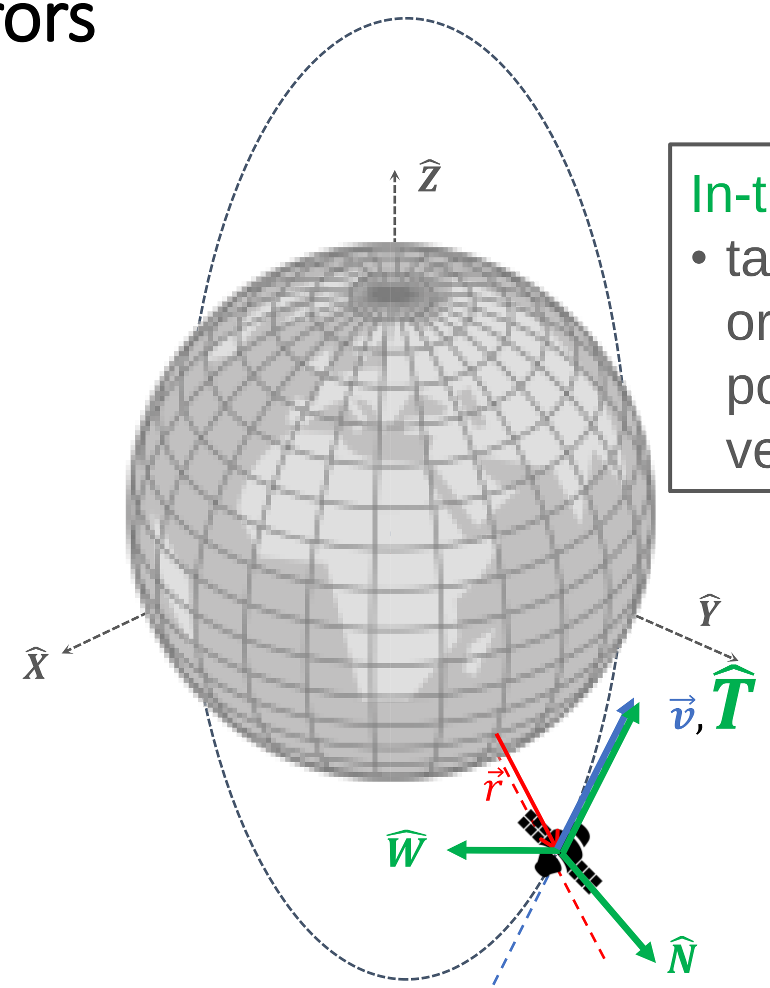
Validation Metrics for Model Densities are the **In-track Residuals** and the **In-Track RMS errors**

In-track Residuals

- Drag effects are seen most clearly in the in-track direction
- Relative deviations from PCE orbit are treated as a proxy for model densities differing from a true density (unknown)

In-track RMSe

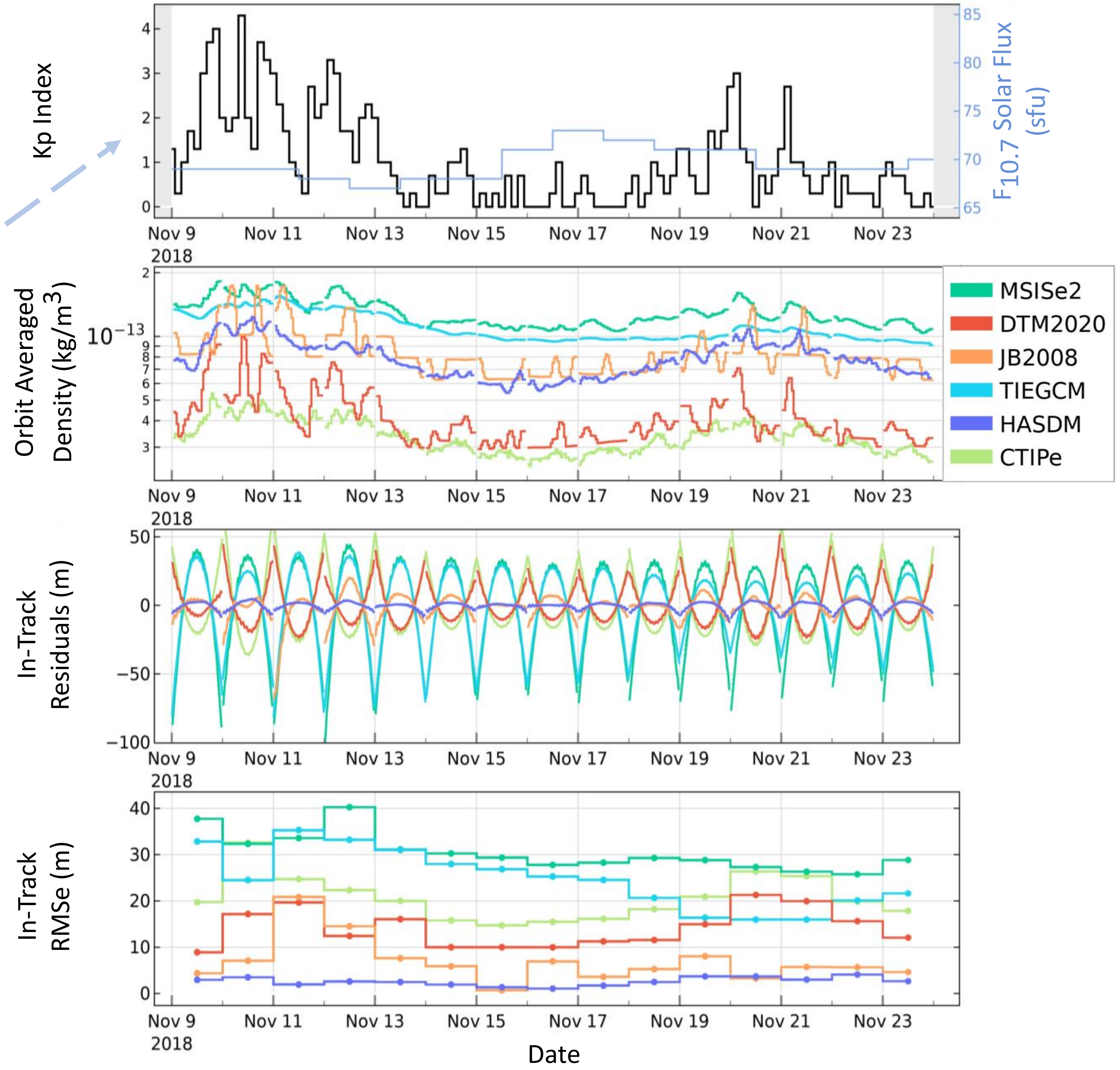
- Indicates how well the output orbit matches the PCE orbit over a given arc. The RMSe is the square root of the variance of the residuals.



In-track $\hat{T}$
- tangential to the orbit and always points to the velocity vector $\vec{v}$

Results and Discussion

- Represents a validation of atmospheric models under the following conditions/assumptions:
  - Low-to-minor geomagnetic activity, deep solar minimum
  - ICESat-2 orbit altitude of ~496 km
  - $C_D = 2.2$
  - Method captures large/global scale density variations, of which, drag is most sensitive



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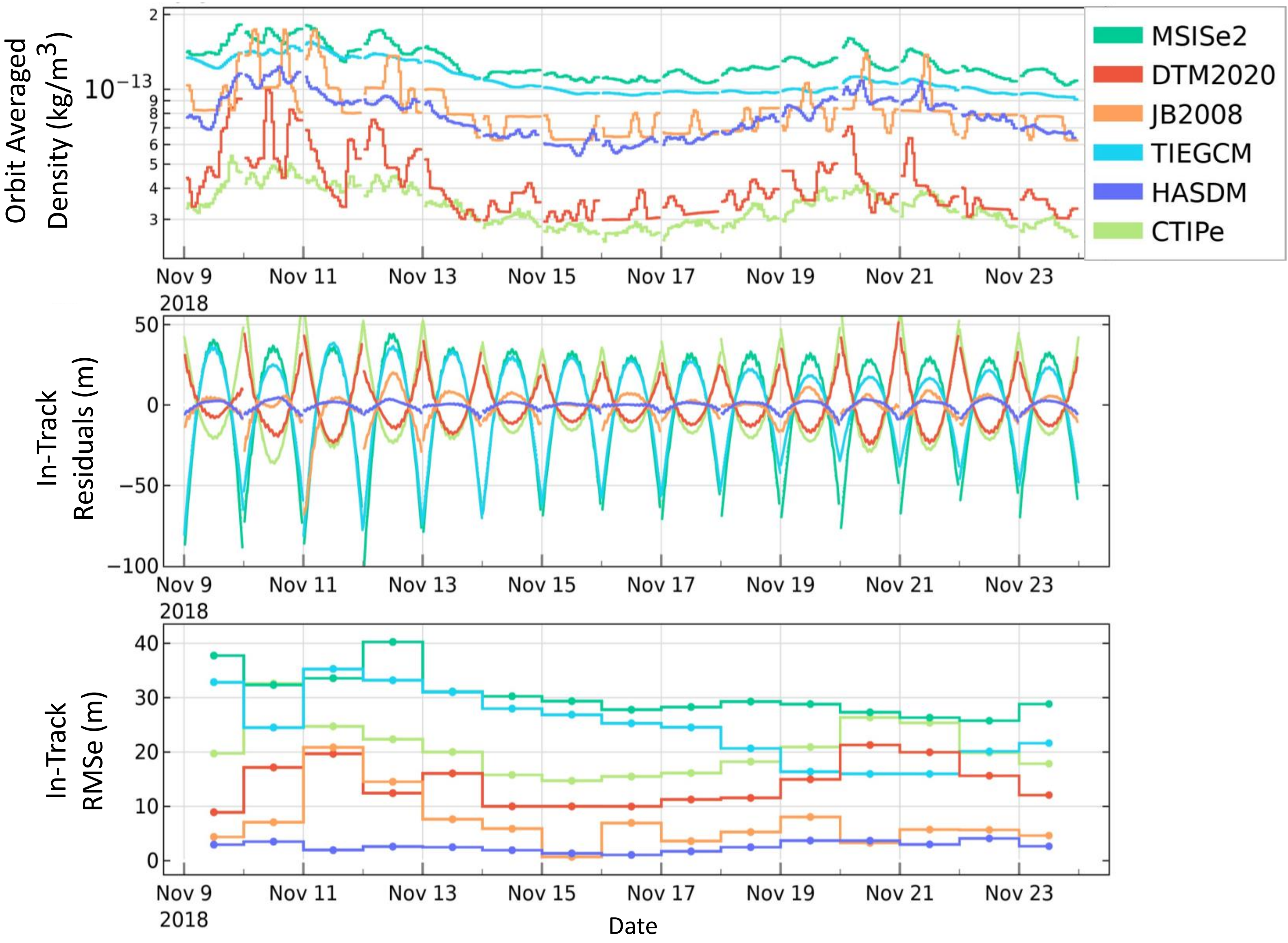

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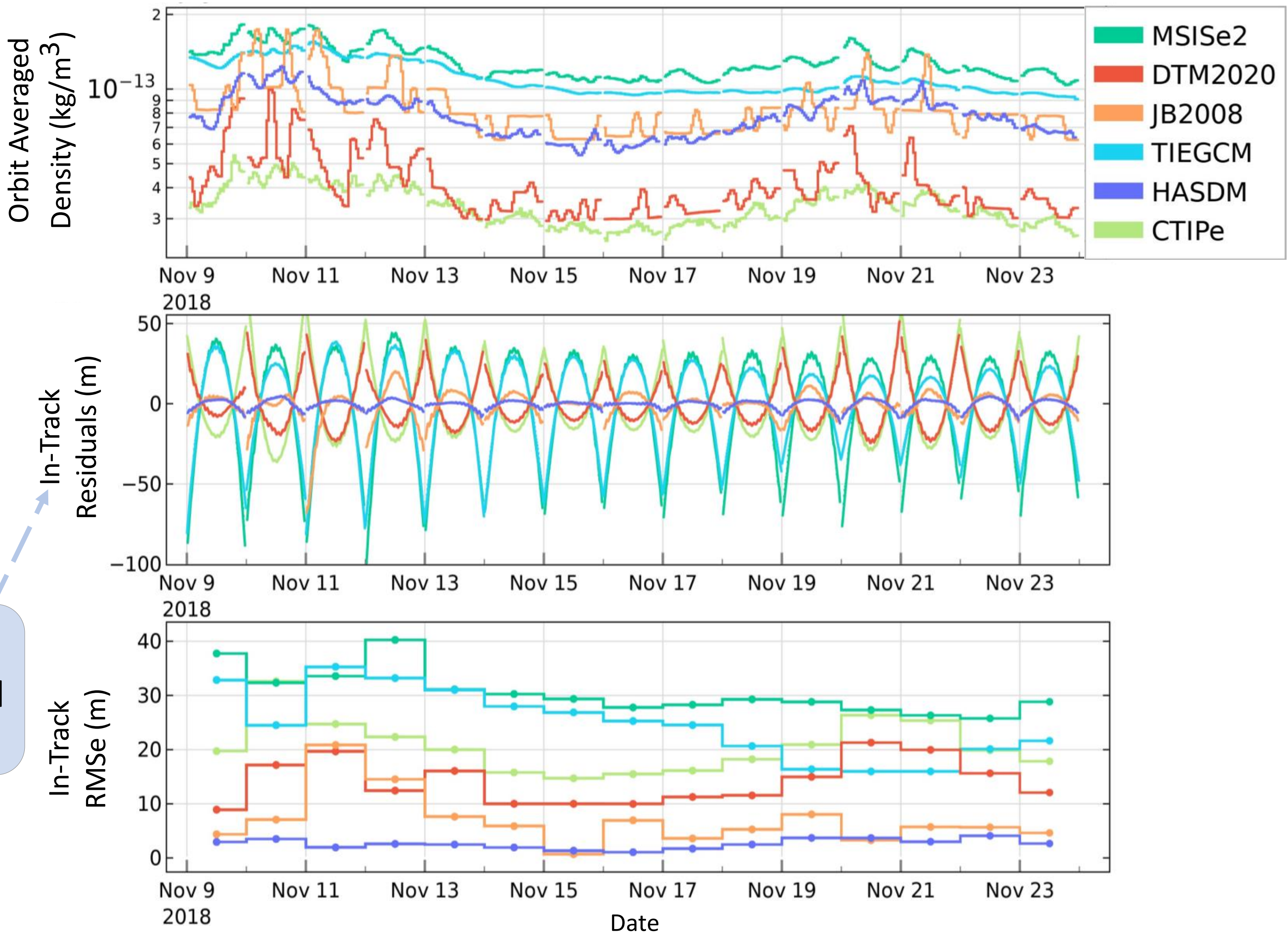
$$PCE - Model\ Orbit$$

Majority of the error and variations should be due to drag



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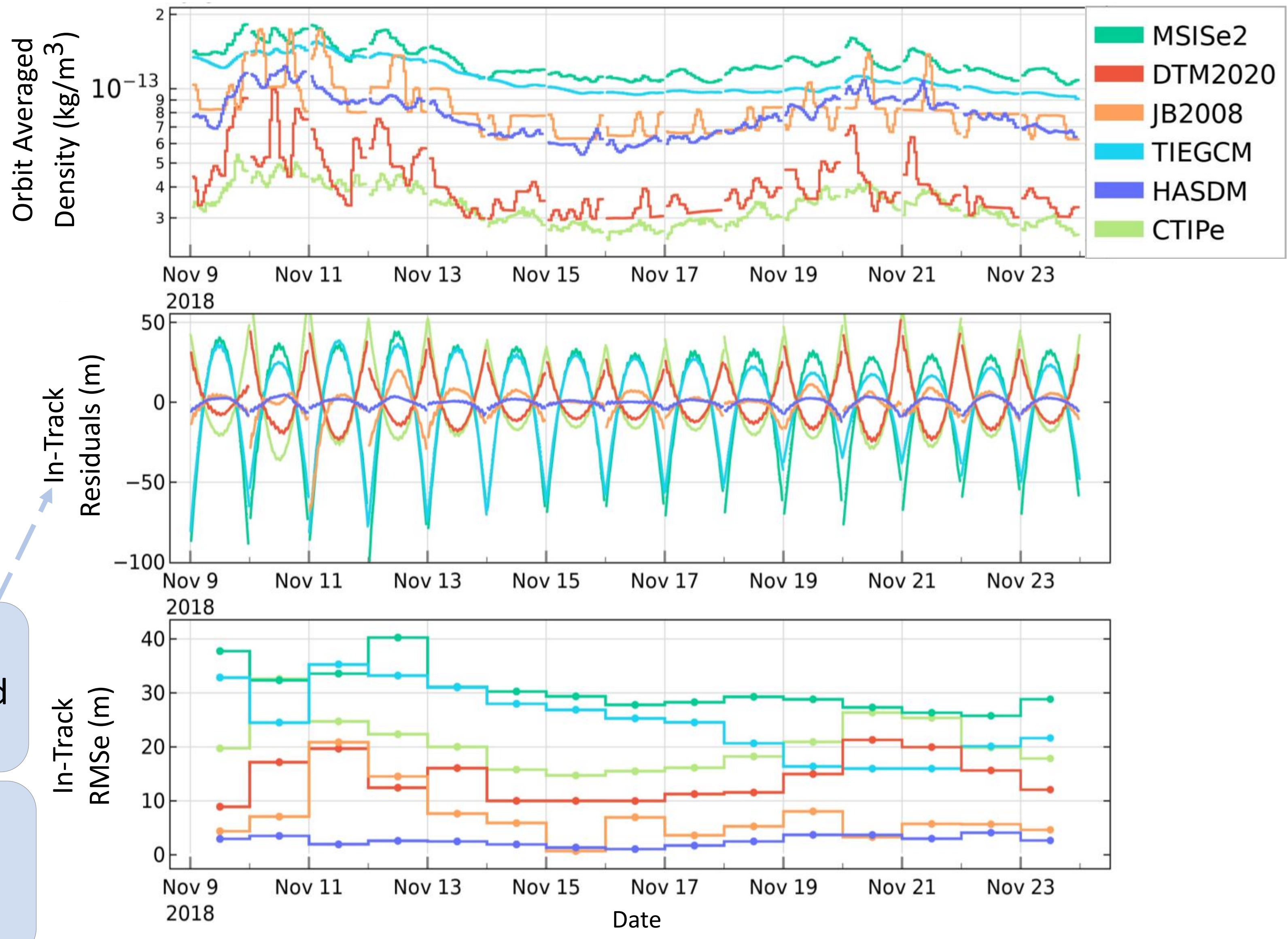

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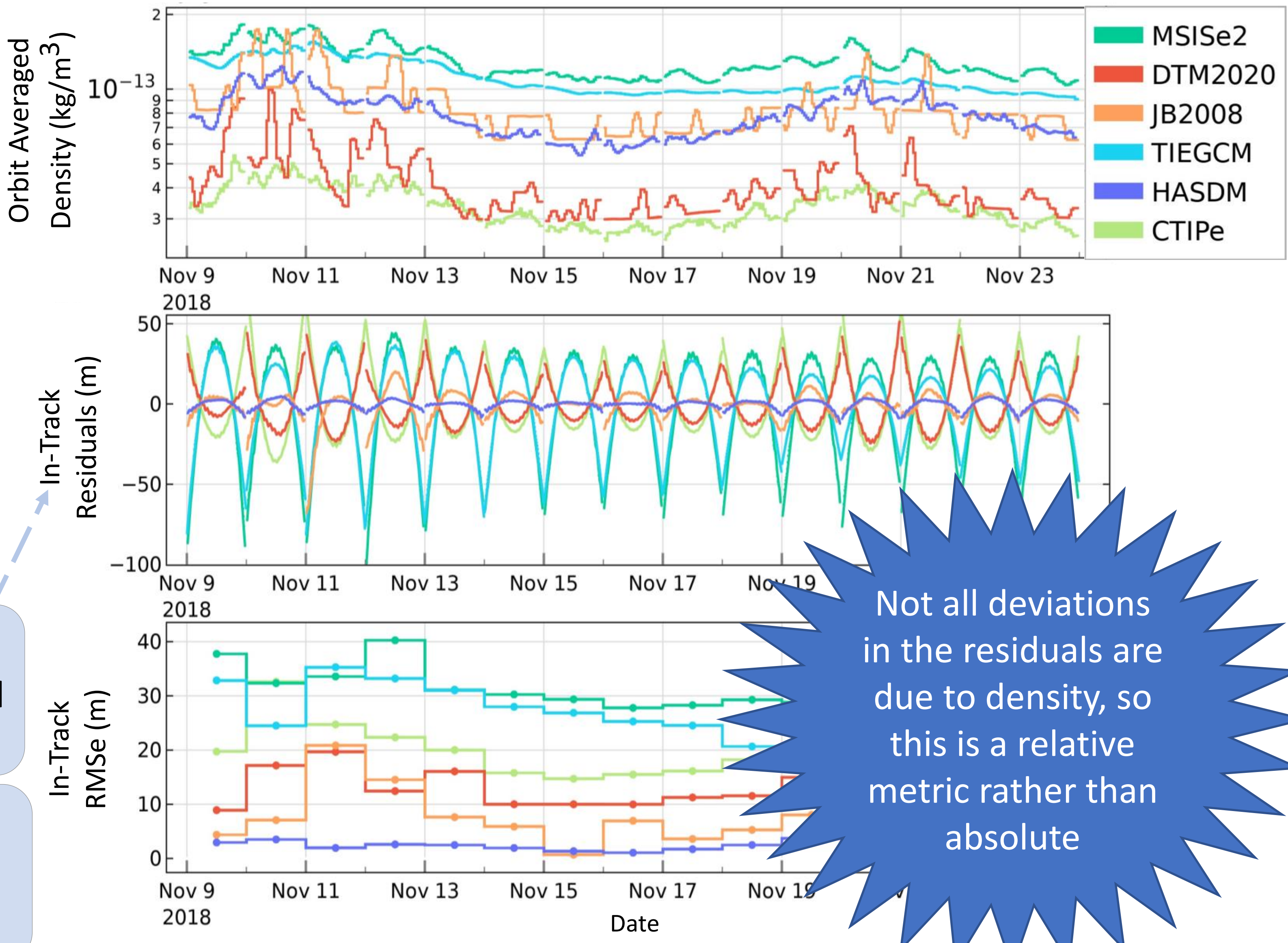

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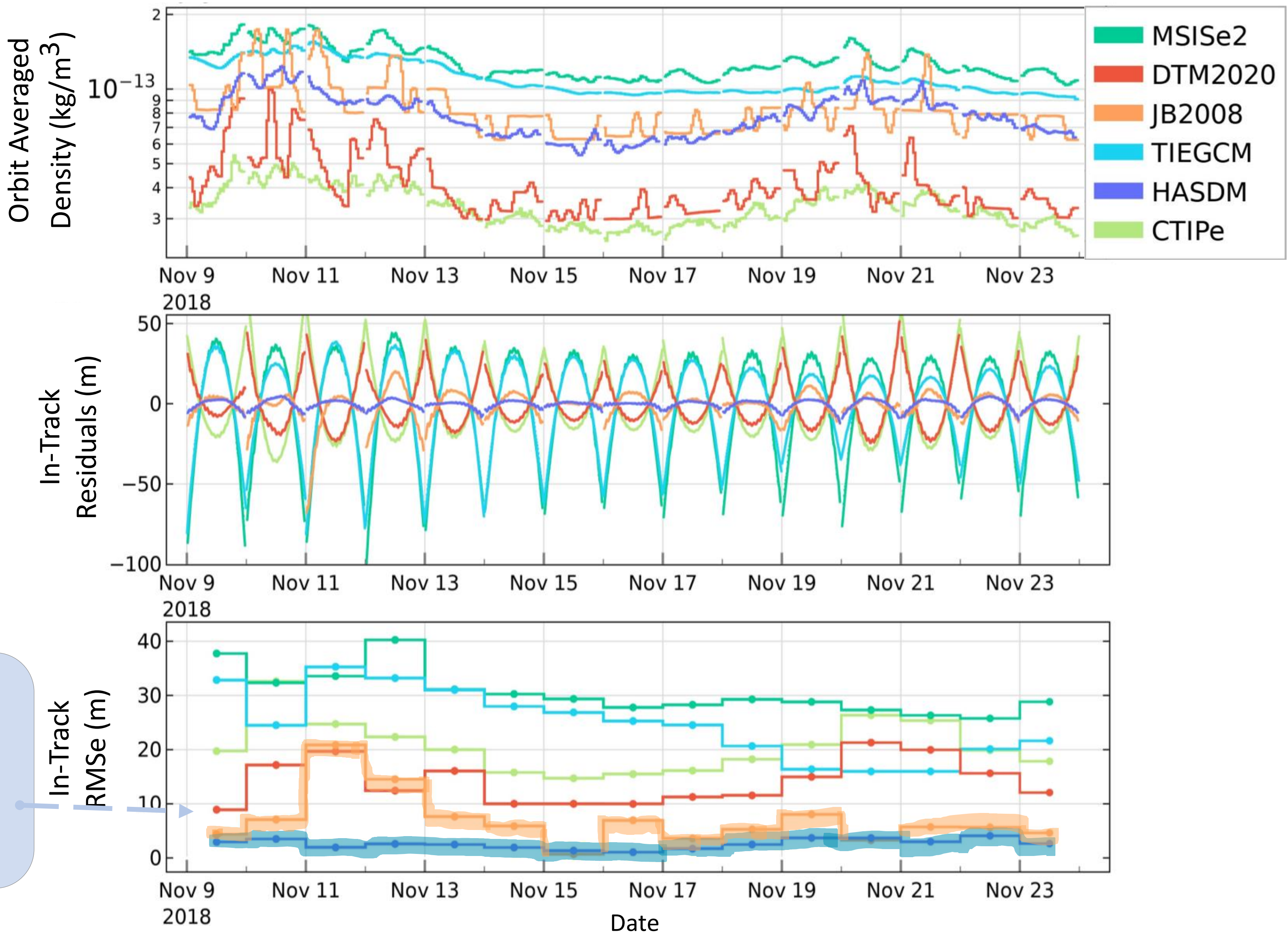

HASDM outputs densities that are close to the unknown truth, and **JB2008** performs the best of the semi-empirical and physics-models

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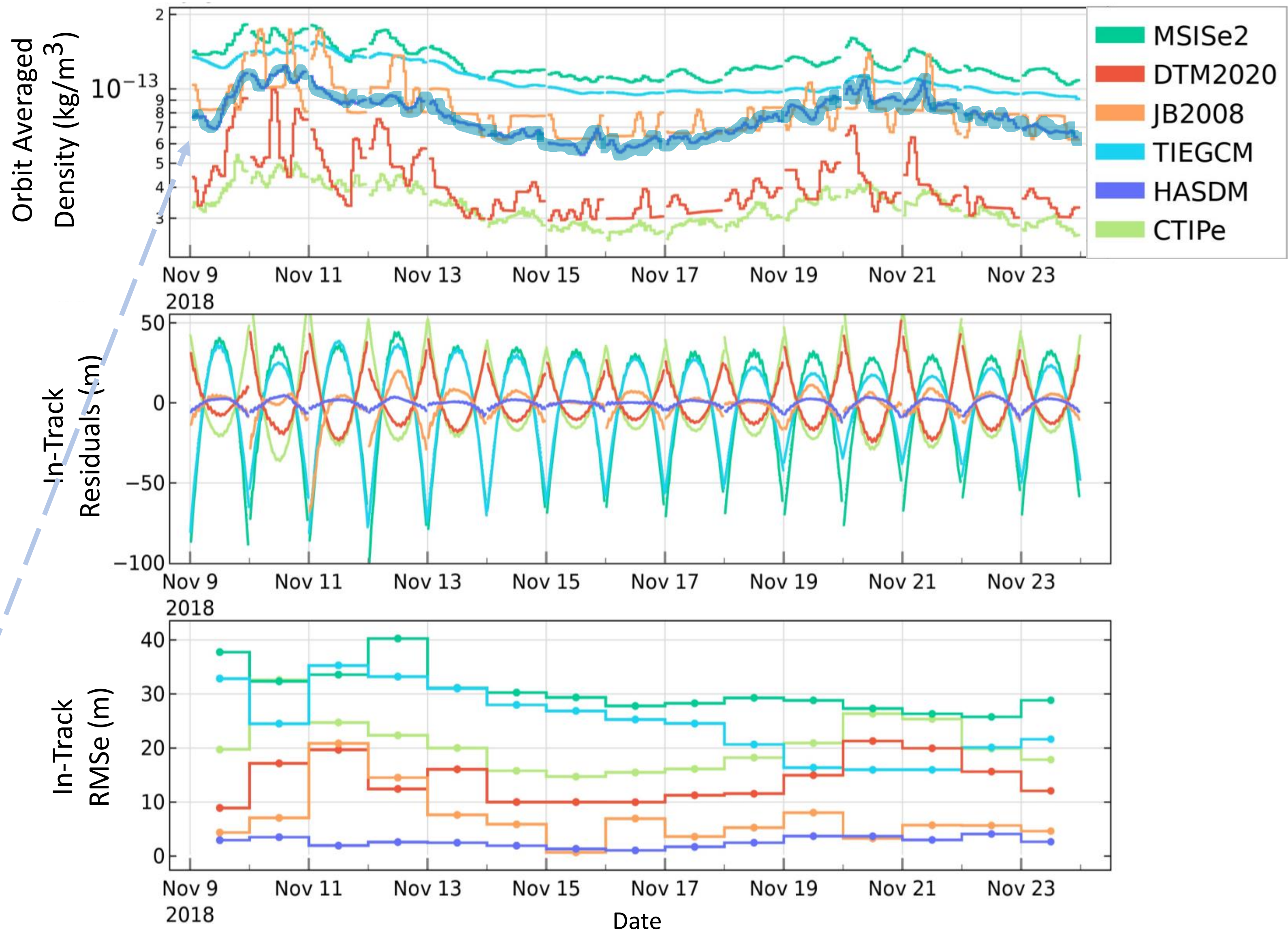
The **HASDM** densities are closest to the true density (unknown)



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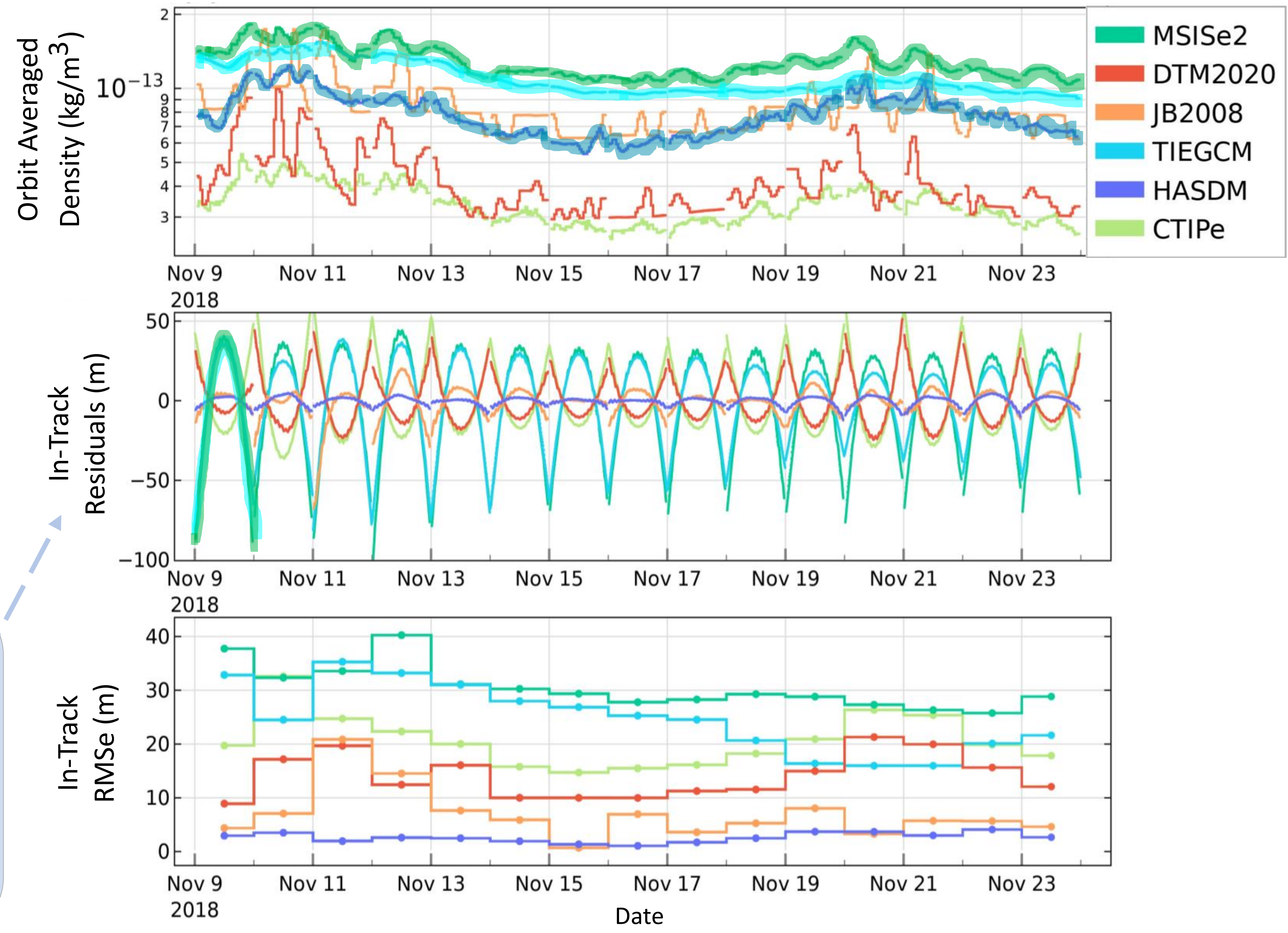
The strongly negative in-track residuals of **MSIS2** and **TIEGCM**

- Modeled density to be too high
  - Causes more drag acceleration
    - Density model orbit is behind the PCE orbit.



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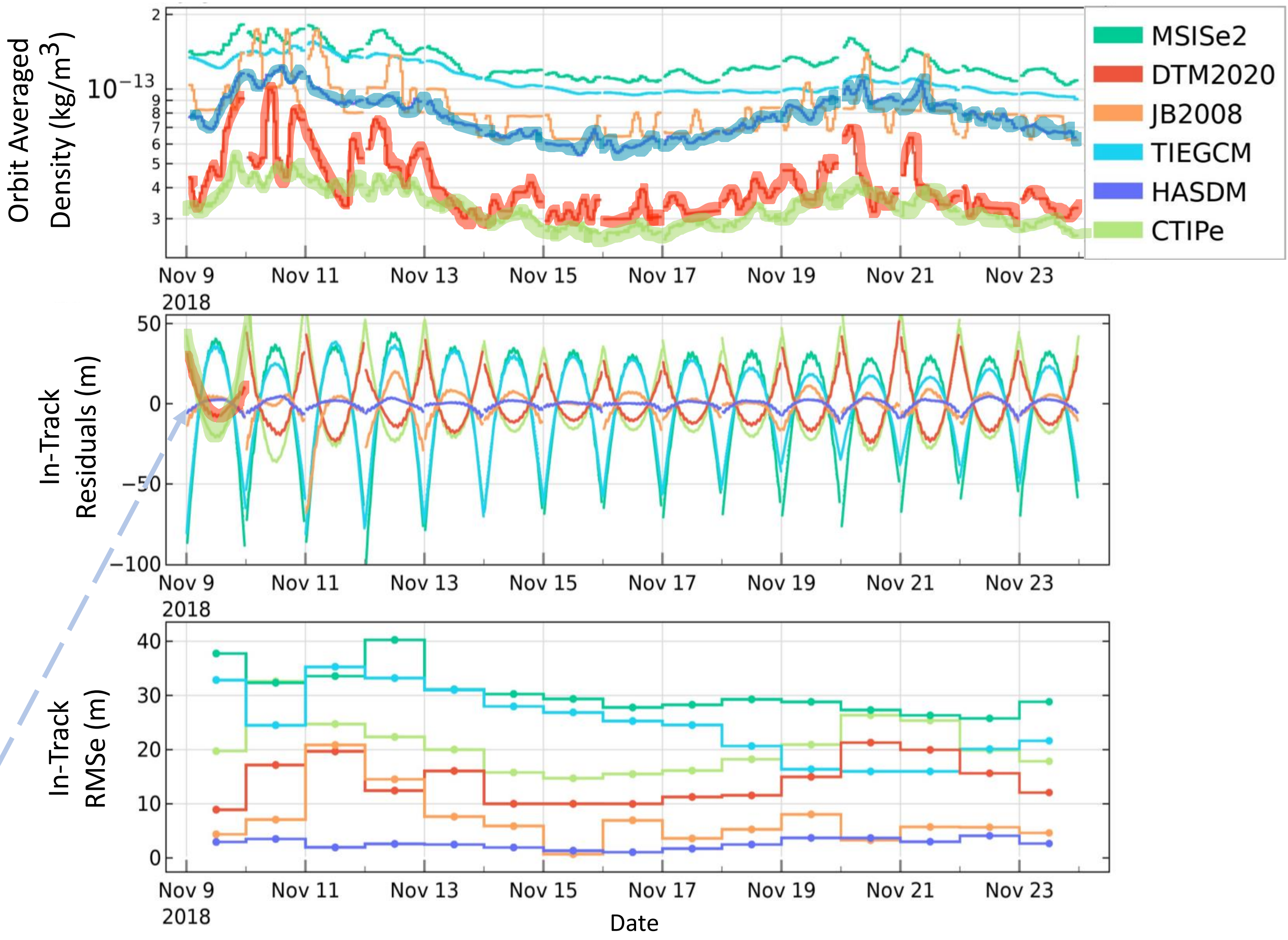
The strongly positive in-track residuals of **DTM2020** and **CTIPe**
- Modeled density to be too low
  - Causes less drag acceleration
    - Density model orbit is ahead of the PCE orbit



Ongoing Efforts and Future Work

- Implementing a physical CD model into GEODYN such that a density scaling factor can be extracted
- Add more models: GITM and WAM-IPE
- Expand ICESat-2 time period
- Expanding to new satellites and their POD solutions

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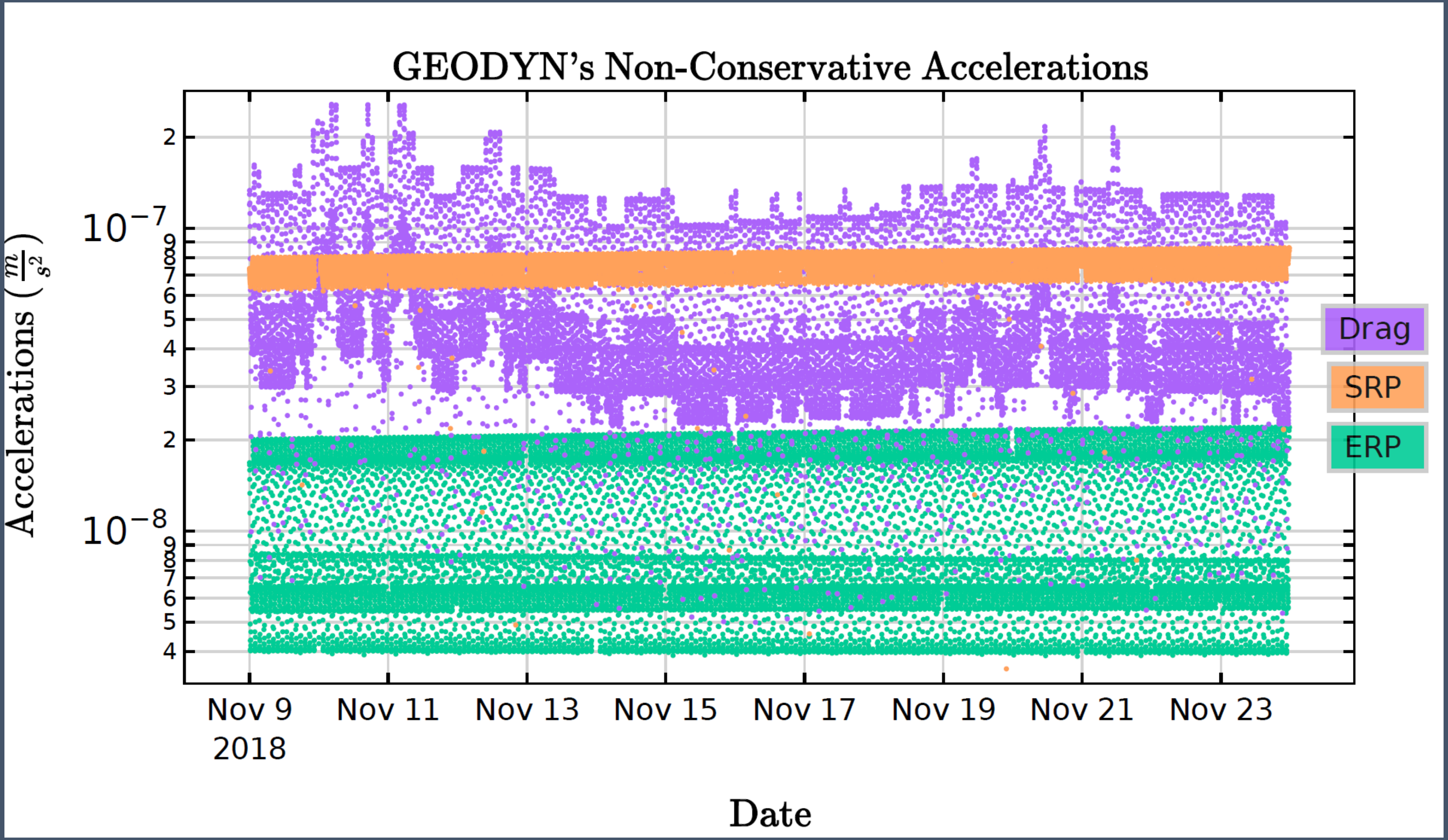
Concluding Remarks and Questions

1. We show our tool can use GEODYN's POD to validate upper atmospheric density models
2. Allow POD program to access many density models while remaining user-friendly
3. Perform a case-study validation using ICESat-2
   - HASDM performs best under these conditions, JB2008 performed 2nd best



GEODYN's Non-Conservative Accelerations
Accelerations $\left(\frac{m}{s^2}\right)$
10^{-7}
10^{-8}
2
9
8
7
6
5
4
3
2
9
8
7
6
5
4
Nov 9 2018
Nov 11
Nov 13
Nov 15
Nov 17
Nov 19
Nov 21
Nov 23
Date
Drag
SRP
ERP

3-month result