Maximizing Scientific Return and Operations of the GDC Mission

IDS Team NEXUS: **N**eutral **EX**ploration **U**tilizing in-situ **S**ensors

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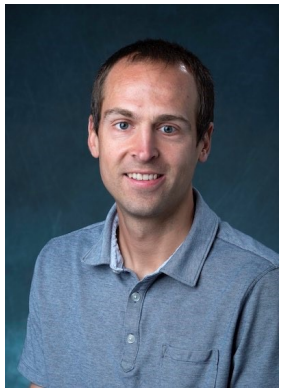

Co-I Marcin Pilinski

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Objectives

Objective 1: To evaluate the constellation configuration and mission requirements in meeting the science goal of determining spatial gradients and temporal variations in I-T properties. [Lead: Jeff Thayer]

Objective 2: To develop a validation scheme involving other satellite data, ground-based data, and the associated communities. [Lead: Katelyn Greer]

Objective 3: To design a real-time data architecture and manage data products and formats. [Lead: Greg Lucas]

Objective 4: To develop a GNSS-accelerometry capability for on-orbit validation of thermosphere properties and enhanced science for the LEO operational community. [Lead: Marcin Pilinski]

Objective 5: To advance a unique data assimilation (DA) scheme to optimize mission development and improve physics-based models leading to the enhancement of GDC science. [Lead: Eric Sutton]

NEXUS Objective 4

To develop a spacecraft GNSS-accelerometry capability for **on-orbit validation** of thermosphere properties and **enhance science** for the LEO operational community.

Using LEO Satellites as Scientific Instruments for Upper Atmosphere and Satellite Drag Research

(GDC will be the most capable spacecraft ever launched to evaluate gas-surface interaction physics fundamental to LEO drag research)

Waldron, Z.C, K. Garcia-Sage, E. K. Sutton, J. P. Thayer, V. Ray, F. Lemoine, D. Rowlands, S. Luthcke, M. Kuznetsova, R. Ringuette, and L. Rastaetter, Validating Thermospheric Neutral Density Models using GEODYN's Precision Orbit Determination, submitted to Space Weather Journal (2023).

V. Ray, E. K. Sutton, J. P. Thayer, and Z. C. Waldron, Error analysis of thermospheric mass density retrieval methods using Precision Orbit Determination, submitted to Space Weather Journal (2023).

GDC Constellation Configuration and Mission Requirements

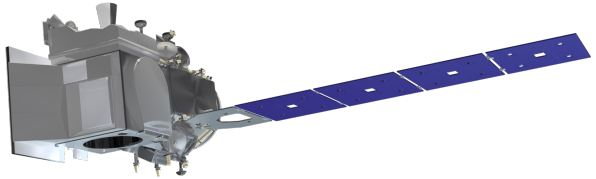
Satellite and GNSS Accelerometry Considerations

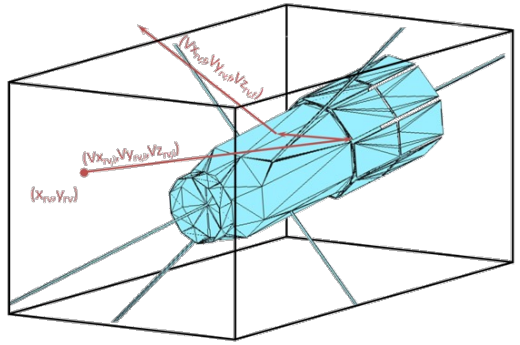
- Review GNSS receiver design specifications for GNSS-accelerometry: work with PROFILE Team
- Review and assess GNSS and housekeeping downlink schedule to ensure the necessary data are available and archived at the required cadence.
- Review precision orbit determination (POD) methods and related orbit ephemeris products
- Review satellite attitude determination plan: likely met by instruments' driving requirements (MOSAIC)
- Review documentation of spacecraft geometry model, surface materials, mass updates, GNSS antenna phase center, solar array drive angles, etc…
- Develop a drag coefficient modeling and validation plan
- Suggest modifications of ConOps to allow for accurate and reliable GNSS-accelerometry
- Consider retroreflectors on nadir side of the satellite for accurate position information from satellite laser ranging sites.

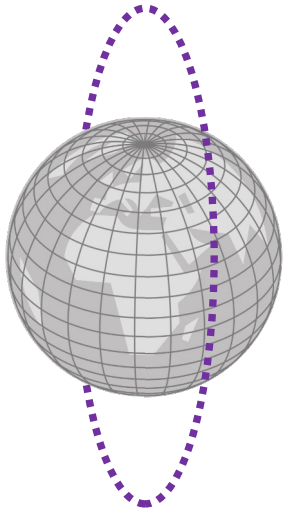
Provide input **by KDP B** detailing the requirements needed by the orbital GNC GNSS receiver and attitude sensor. **IDS-task A** provides more detail about developing the analysis tool needed to extract density information

GNSS "Accelerometry" Demonstration

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







ICESat-2 Satellite: 9/2018 - Present	
Altitude	$z = 496\ km$
Inclination	$i = 92°$
Eccentricity	$e = 0.001398$
Period	$P = 94.22\ mins$

1 **GSFC GEODYN II POD Software**

First Pass: Construct Precise Science Orbits

- Use reduced-dynamics run with empirical accelerations
- Validate outcome using independent satellite laser ranging: < 2-cm accuracy

GNSS "Accelerometry" Demonstration

2

GSFC GEODYN II

Second Pass: Use PSO as tracking data and construct orbit fits for a given density model

- Non-drag forces specified in run 1
- Apply selected density model

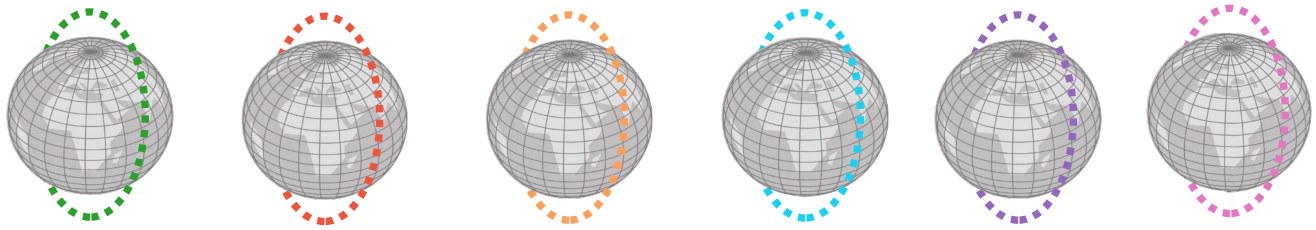
3

Adjust Model Density

Third pass: Adjust density for best orbit fit

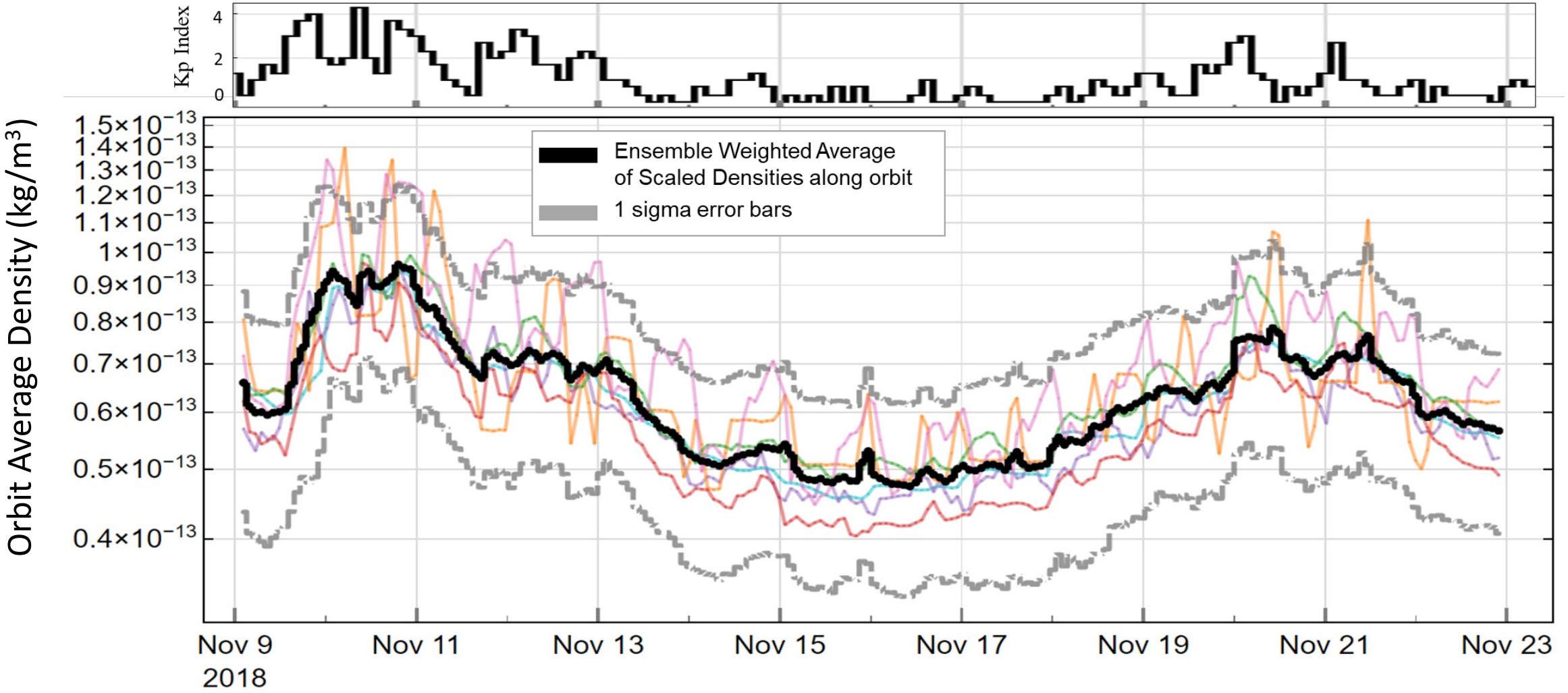
- Employ parameter adjustment scheme
- Output scaled density along orbit

Dynamically constructed PSO-based Orbit Fits
are generated for each selected density model

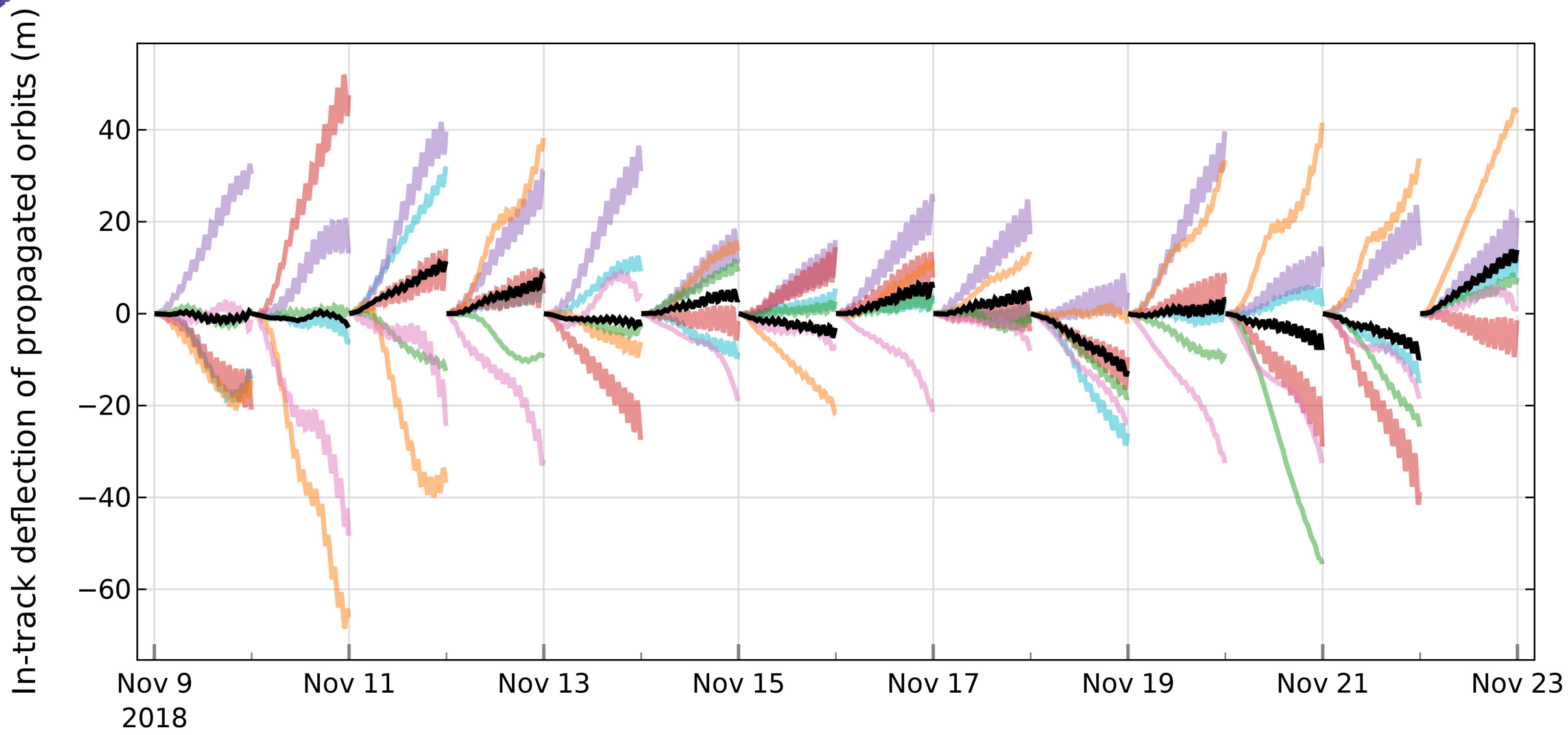


MSIS2 DTM2020 JB2008 TIEGCM CTIPe GITM

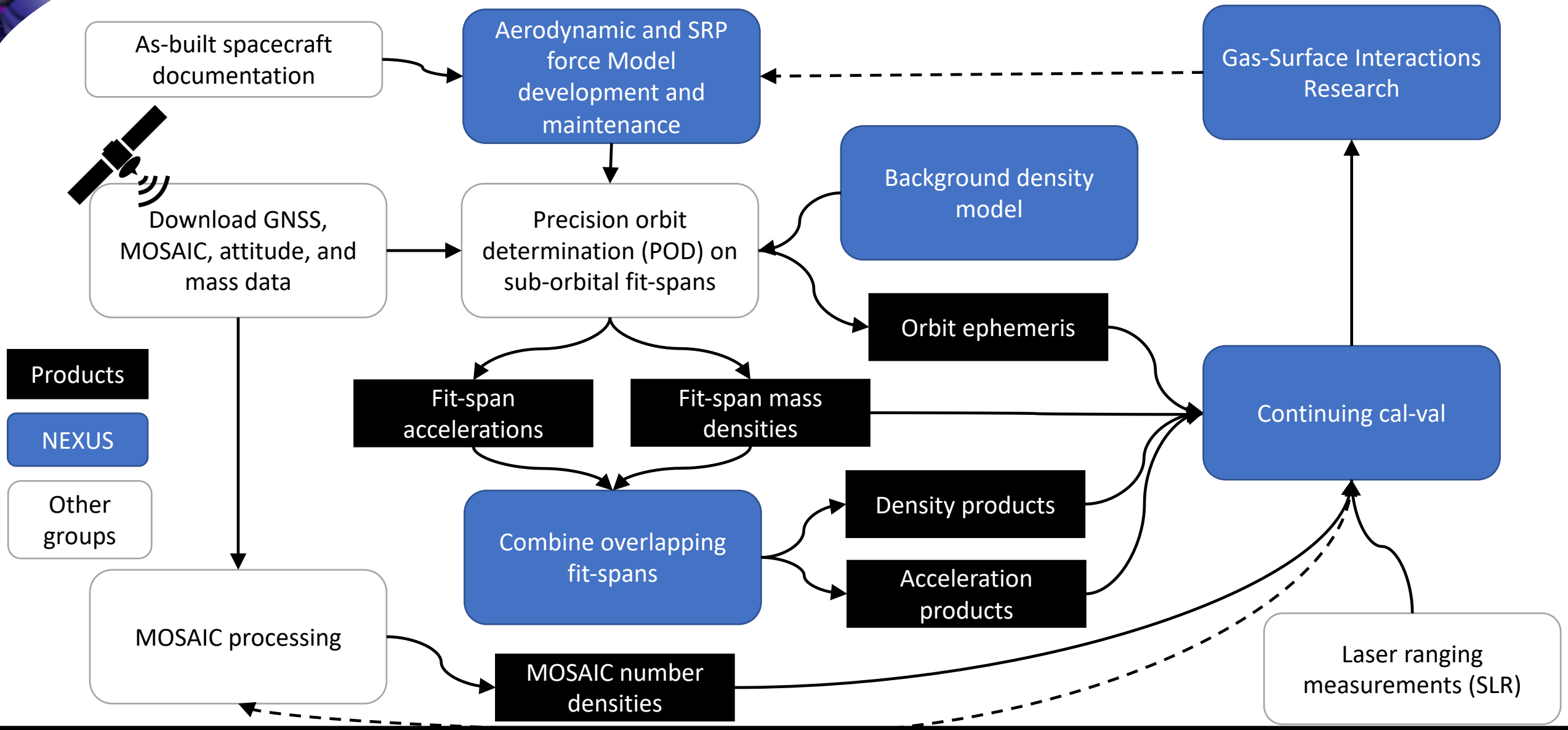
GNSS "Accelerometry" – Mass Density Estimates



GNSS "Accelerometry" – 24-hr Orbit Propagation



On-Orbit Validation of MOSAIC Using POD-Accelerometry

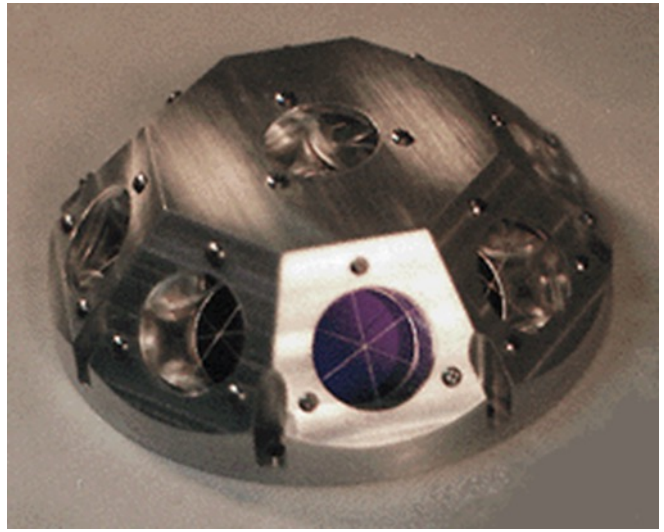


Conclusions

- GDC MOSAIC and Accelerometry Validation enhances data-product value
- Unique opportunity to study fundamental problems in satellite drag
  - Free-stream conditions fully defined
  - Ability to characterize relative drag via precision orbit determination
  - Best-ever bounding of gas-surface interactions parameters
- Space-Weather Product: demonstrate and refine techniques for future POD monitoring of the Thermosphere
- Useful for tracking and assessing other resident space objects (i.e., debris)

Backup Material

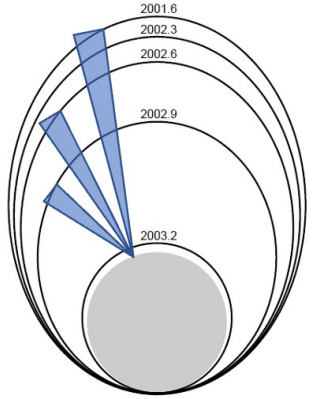
Retro-Reflector Array



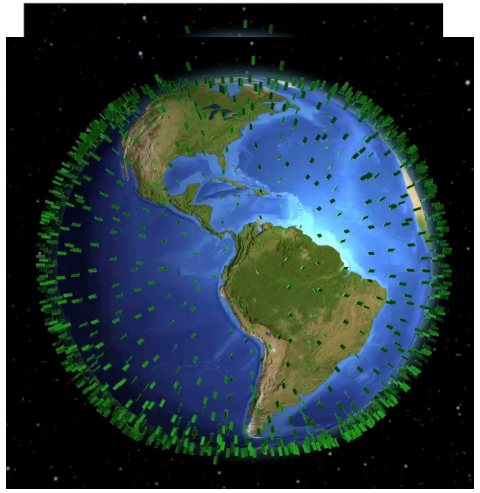
- SLR Retro-Reflector Array flown on: ICESat-1, JASON 1&2, GFO, ADEOS-II:
- 9 solid cubes – each 32 mm
- Research grade radiation resistant suprasil quartz
- Silver coated
- Array shape: hemispherical, 16cm diameter
- Array mass: 731 gm
- Array response from ICESat-1 was strong and SLR tracking was very successful

Diverse, High-Cadence Measurement Sources

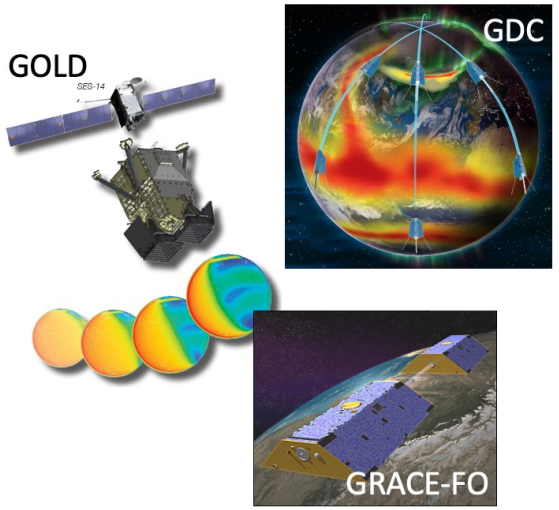
Traditional:
e.g., Ground-Based Satellite/Object Tracking



GNSS-Equipped Constellations:
e.g., Spire, SpaceX, Planet Labs

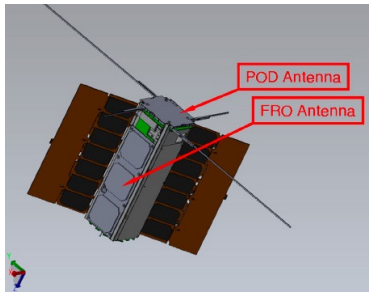


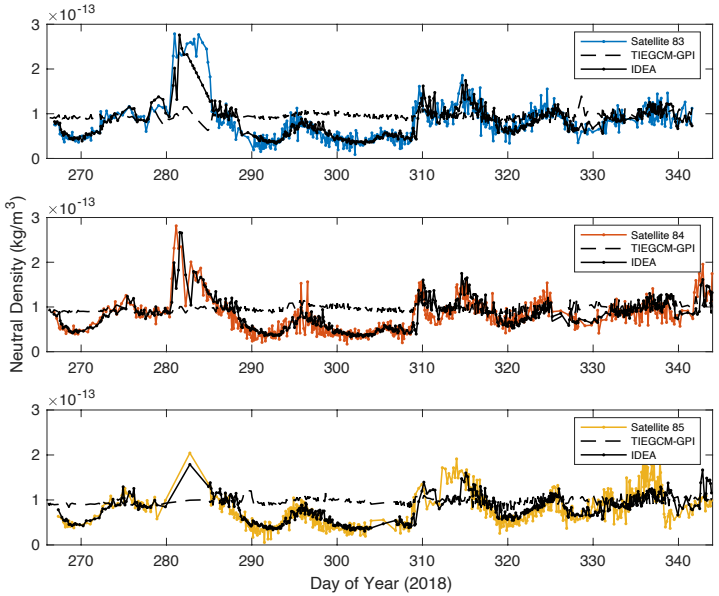
Dedicated Science Missions:



Traditional	GNSS-Equipped Constellations	Dedicated Science Missions
Availability / Redundancy		
High	High	Medium
Coverage		
Medium	High	Medium
Resolution		
Low	Medium	High
Information Content		
Low	Medium	High

Assimilation of Spire GNSS-Based Ephemeris into Physics-based Model



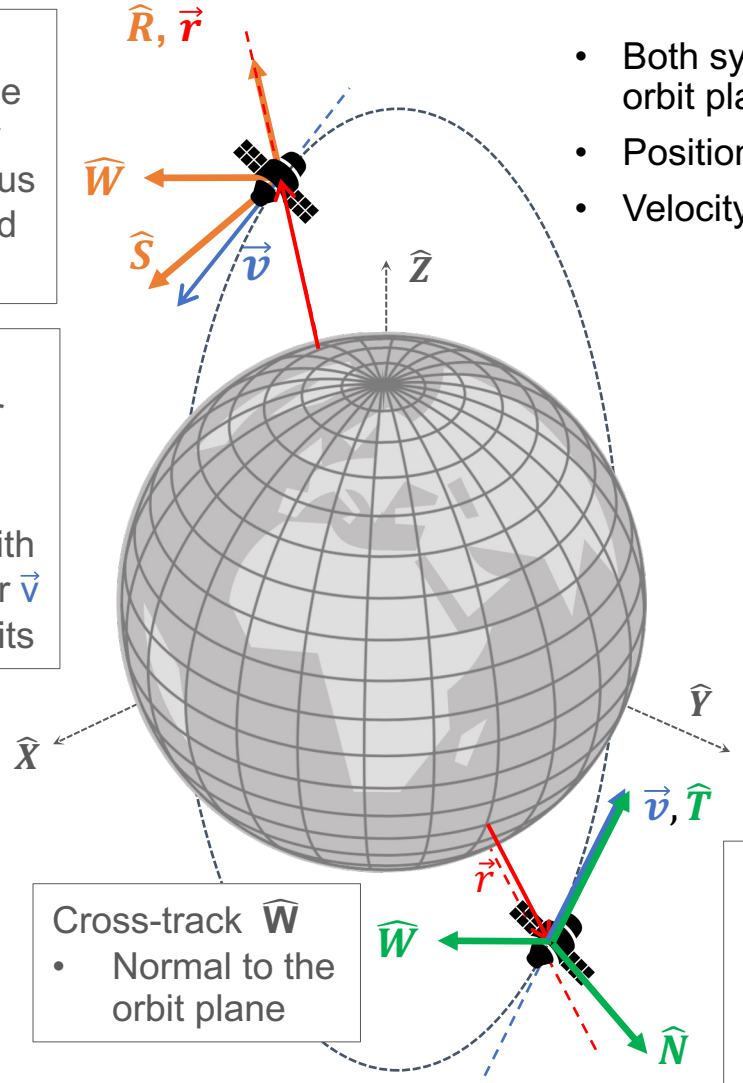


Sutton et al. [2021, Space Weather]

Satellite Coordinate Systems: NTW and RSW

Radial $\hat{R}$
- Points from the Earth's center along the radius vector $\vec{r}$ toward the satellite

Along-track $\hat{S}$
- Perpendicular to the radius vector $\vec{r}$
- Only aligns with velocity vector $\vec{v}$ in circular orbits



- Both systems lie in the orbit plane
- Position vector is $\vec{r}$
- Velocity vector is $\vec{v}$

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

Cross-track $\hat{W}$
- Normal to the orbit plane

Normal $\hat{N}$
- Perpendicular to the velocity vector $\vec{v}$
- Aligns with radius vector $\vec{r}$ in circular orbits

NOTE:
- In-track errors in the NTW system are not the same as along-track variations in the RSW system. In-track errors are in the exact direction of the velocity $\vec{v}$, whereas along-track variations are simply along the general direction of the velocity vector $\vec{v}$.
- We **use NTW to analyze satellite drag effects** because drag always affects the relative velocity vector.