# Phase centre variation of the GNSS antenna onboard the CubeSats and its impact on precise orbit determination

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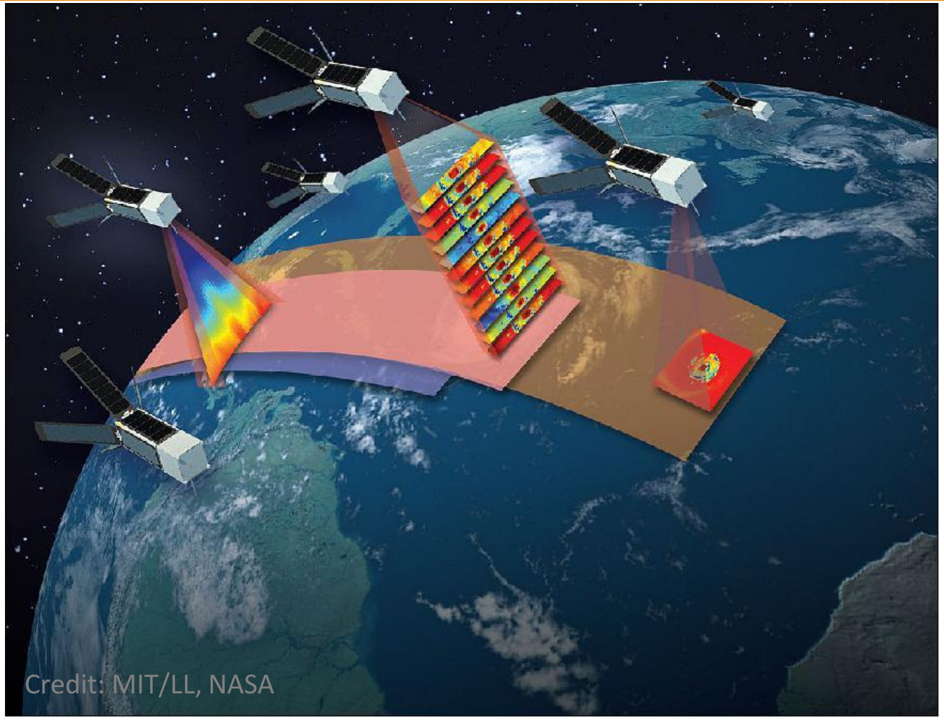
# Outline

- Background
- Problem statement
- Proposed solution
- Validation of Results
- Conclusion

# CubeSats

- CubeSats are cheap, small and low-power satellites,
- 1U CubeSat: 10 × 10 × 10 cm

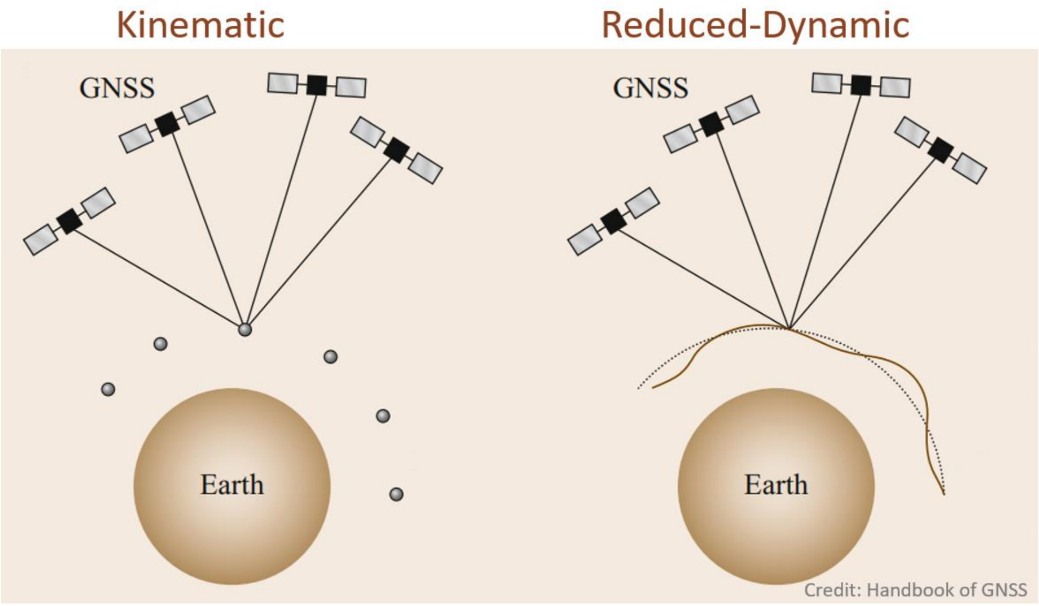




**CubeSats' applications in Earth Science:**

- Monitoring the movement of the Earth's surface and oceans
- Weather forecasting
- Satellite Altimetry,
- Gravimetry, etc.

# We need to precisely know where is the CubeSat in space!


**Precise Orbit Determination (POD) and its applications on the earth and space sciences**





**Using Signals from Global Navigation Satellite System (GNSS)**
**+**
**applying complicated dynamic models**

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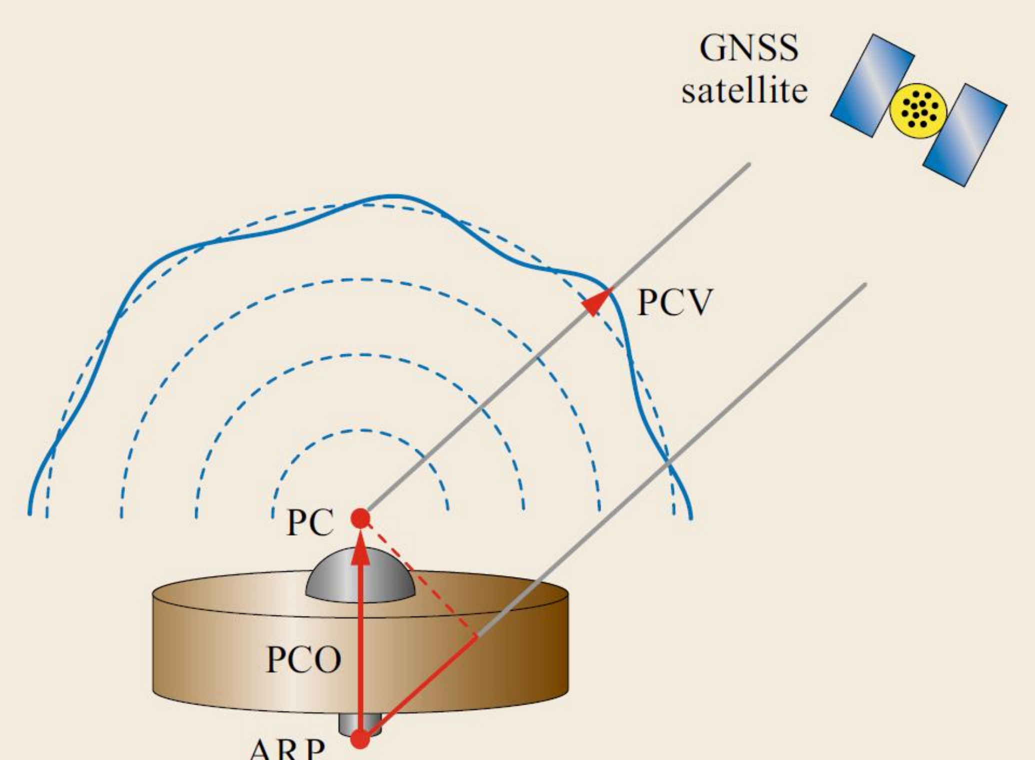
# Background

- In POD procedure we use GPS signals,
- These signals are received by GPS antenna onboard the CubeSat,
- Phase center offset (PCO) and its variations (PCV) are important to get high accurate observations from GNSS satellites:


Credit: ISIS



Credit: Handbook of GNSS

**Antenna Reference Point (ARP)**: A physical reference point

**Phase Center Offset (PCO)**: The offset between the actual reception point of signal (PC) and the physical reference point (given by the manufacturer)✓

**Phase Center Variation (PCV)**: Deviation of the antenna phase center beyond the antenna offset → depends on the direction (elevation angle and azimuth) of the GNSS satellite **(derived by calibration) !**

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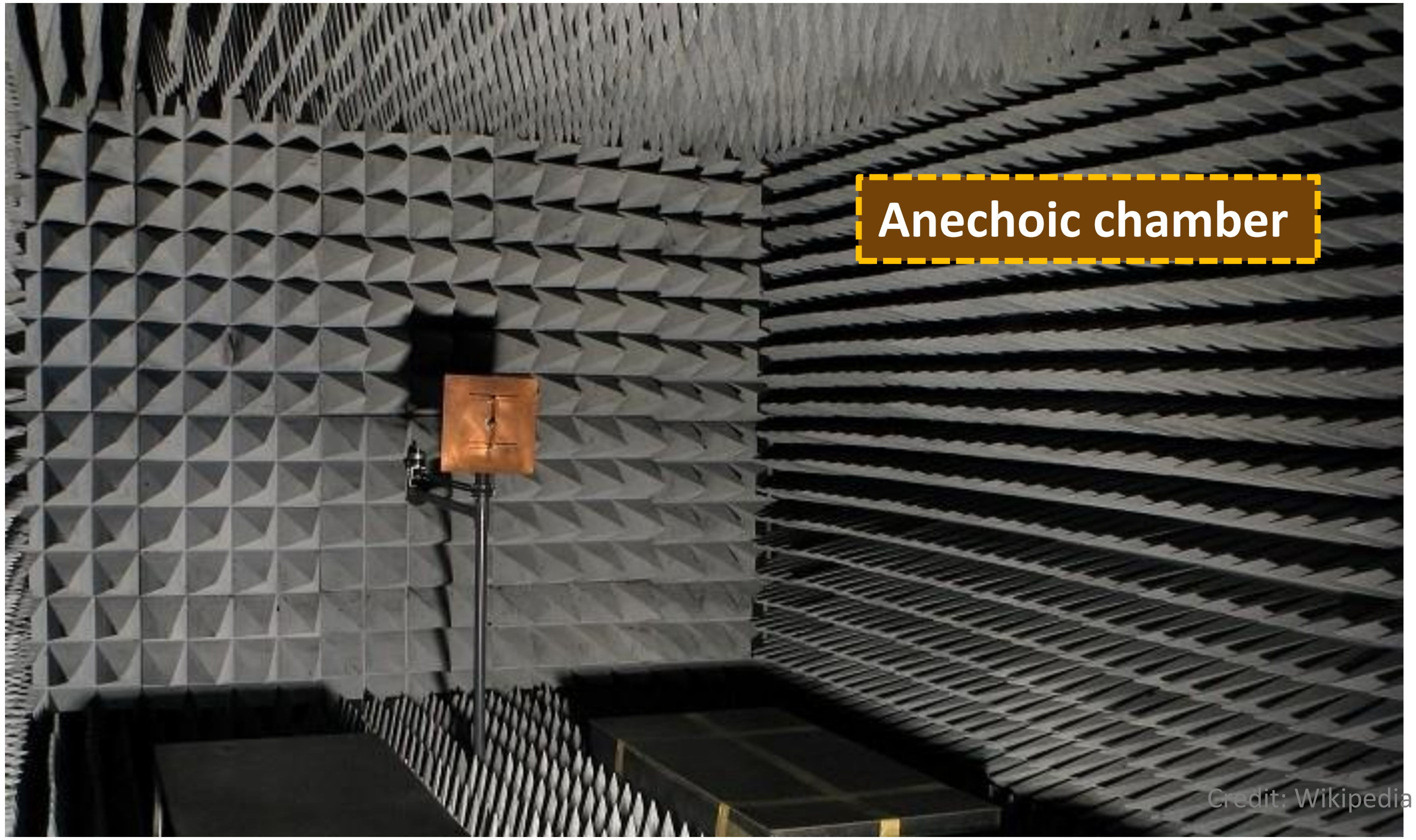
# Problem Statement

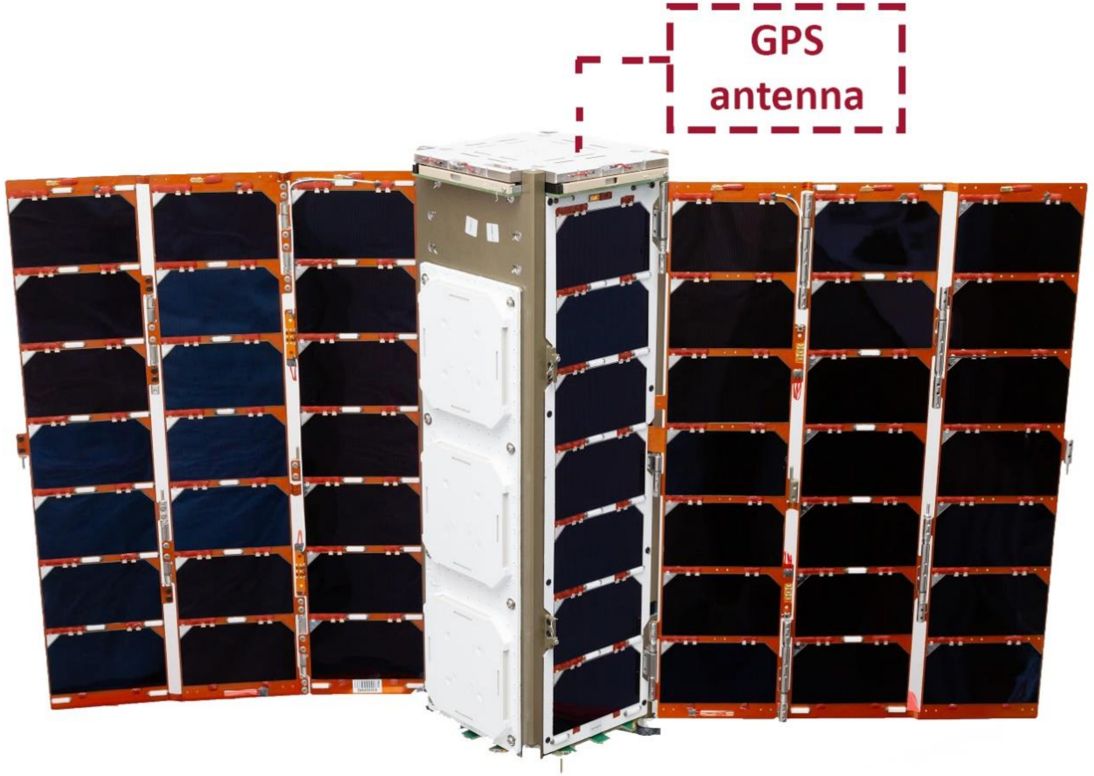
- The calibration methods are **suitable for ground antenna**, but **cannot consider the actual space environment**.



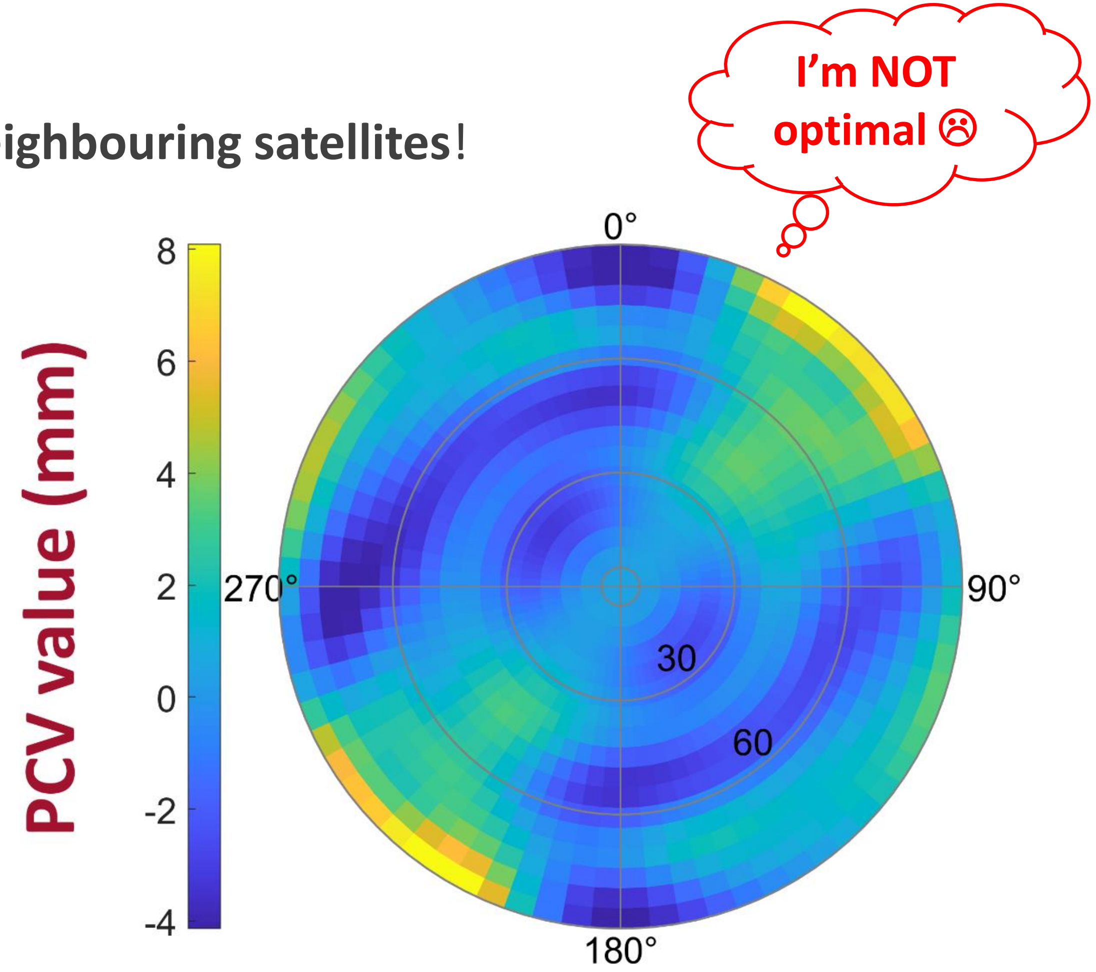

# Objective

Estimate the PCV pattern suitable for space.

- It should consider the **CubeSat's structure** and possible **neighbouring satellites**!




Test case: Spire CubeSat for GNSS Remote Sensing




PCV pattern provided by ground calibration methods

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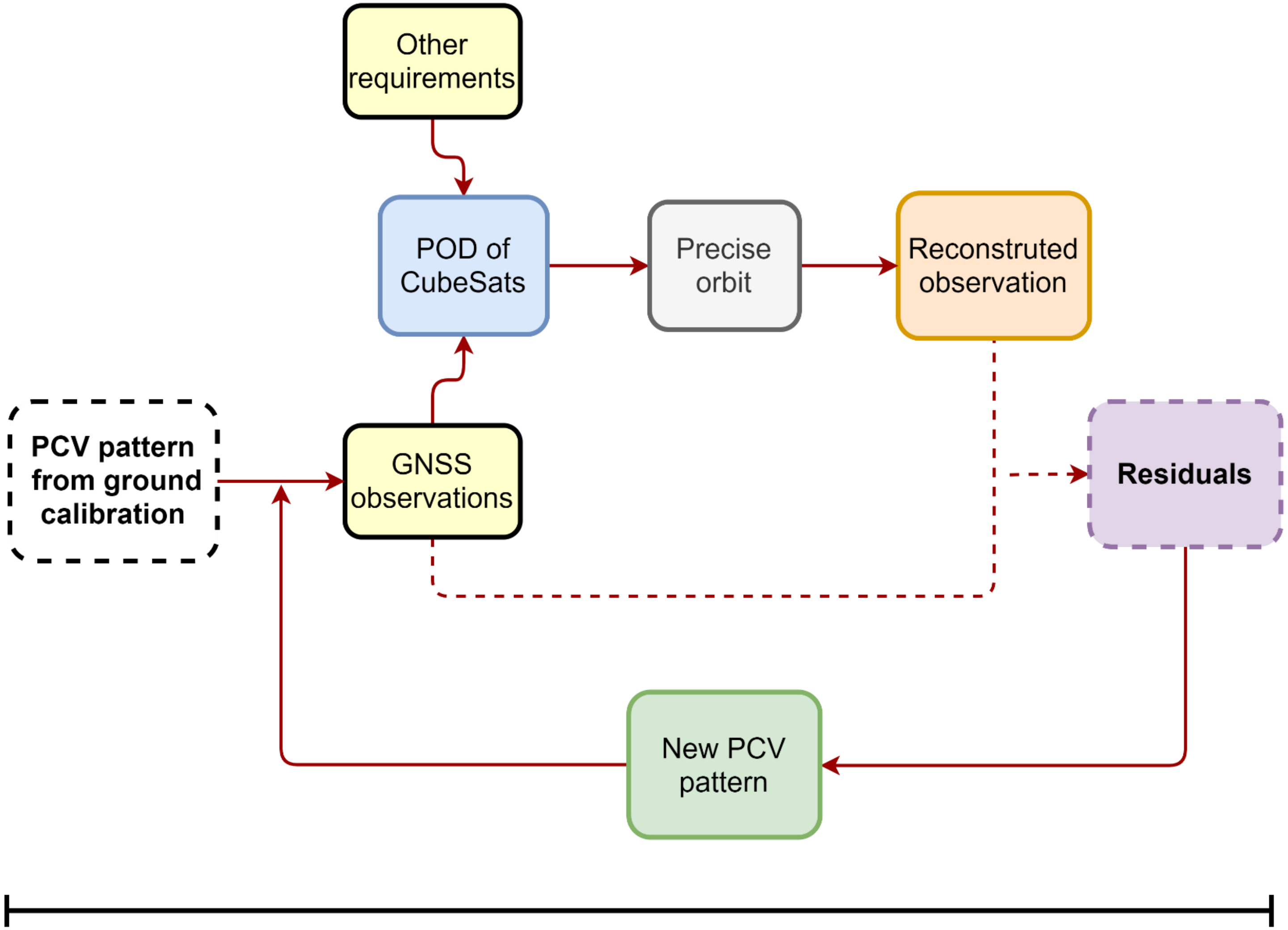
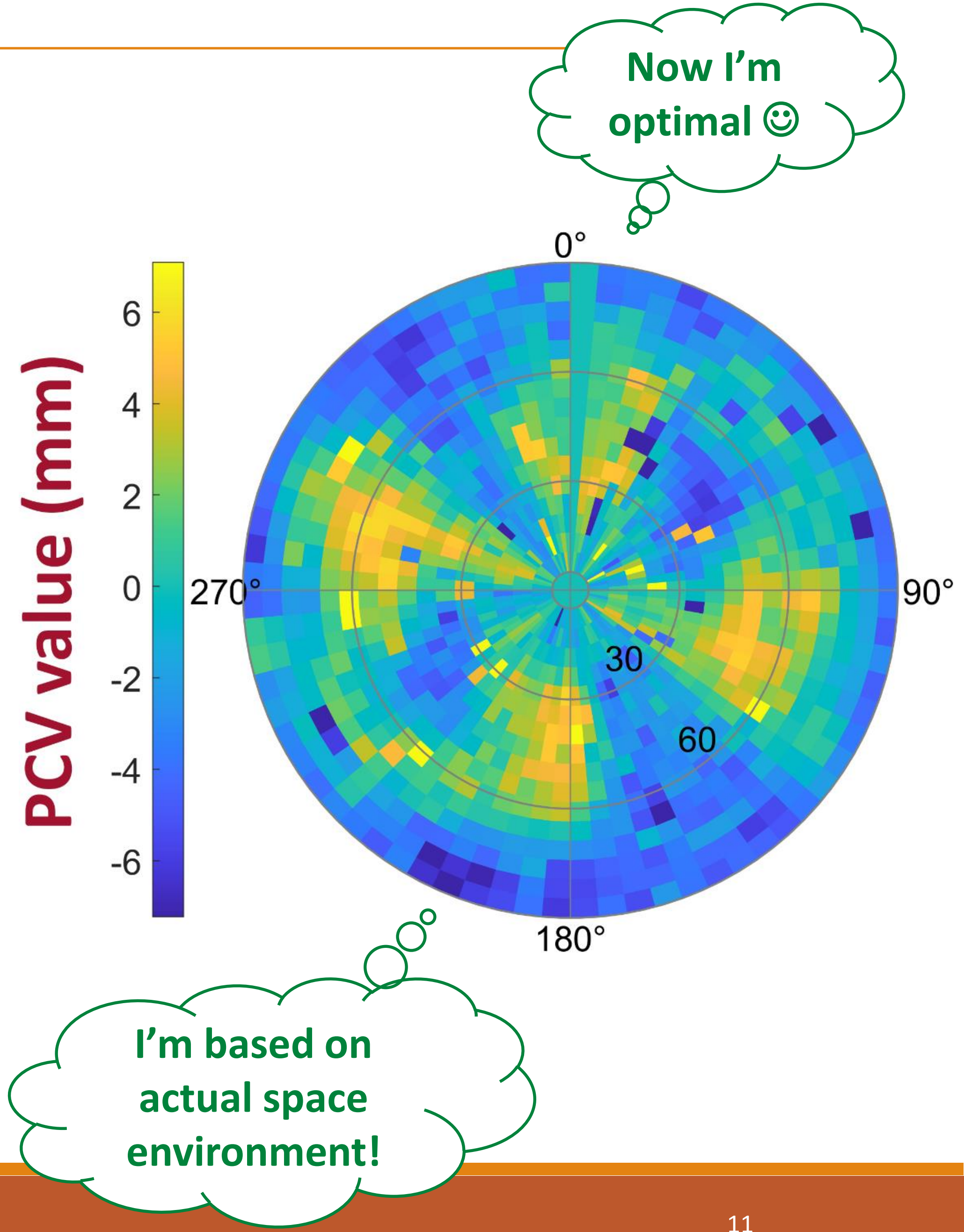
# Solution




This procedure should be perfomed 2-3 Iterations [2]



# Reduced-Dynamic POD

State vector: $y = \begin{pmatrix} r \\ v \end{pmatrix}$

Equation of motion:

$$\frac{d^2r}{dt} = a(t,r,v,p) \rightarrow \frac{dy}{dt} = \begin{pmatrix} v \\ a \end{pmatrix}$$

**Initial condition** $y_0$

**accelerations** $a$

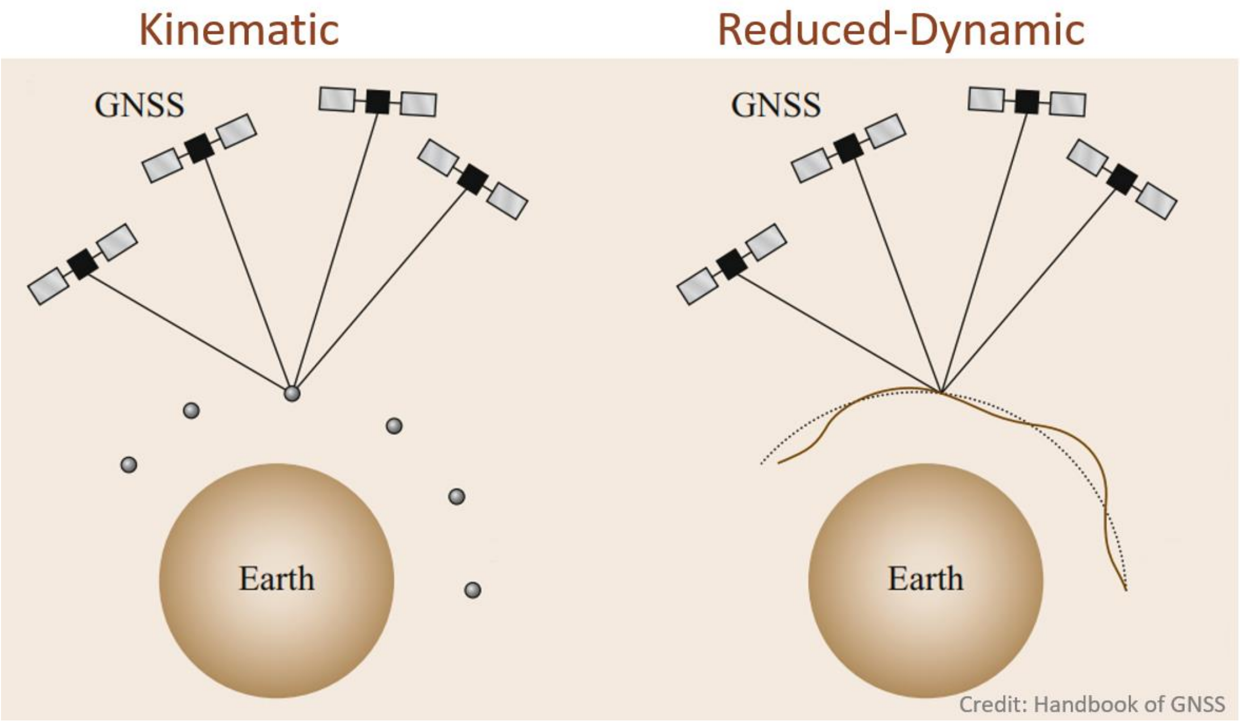
**Numerical integration**

**State vector** $y_t$

$a = a_{\text{known}} + a_{dynamic}$

Calculated from the available models

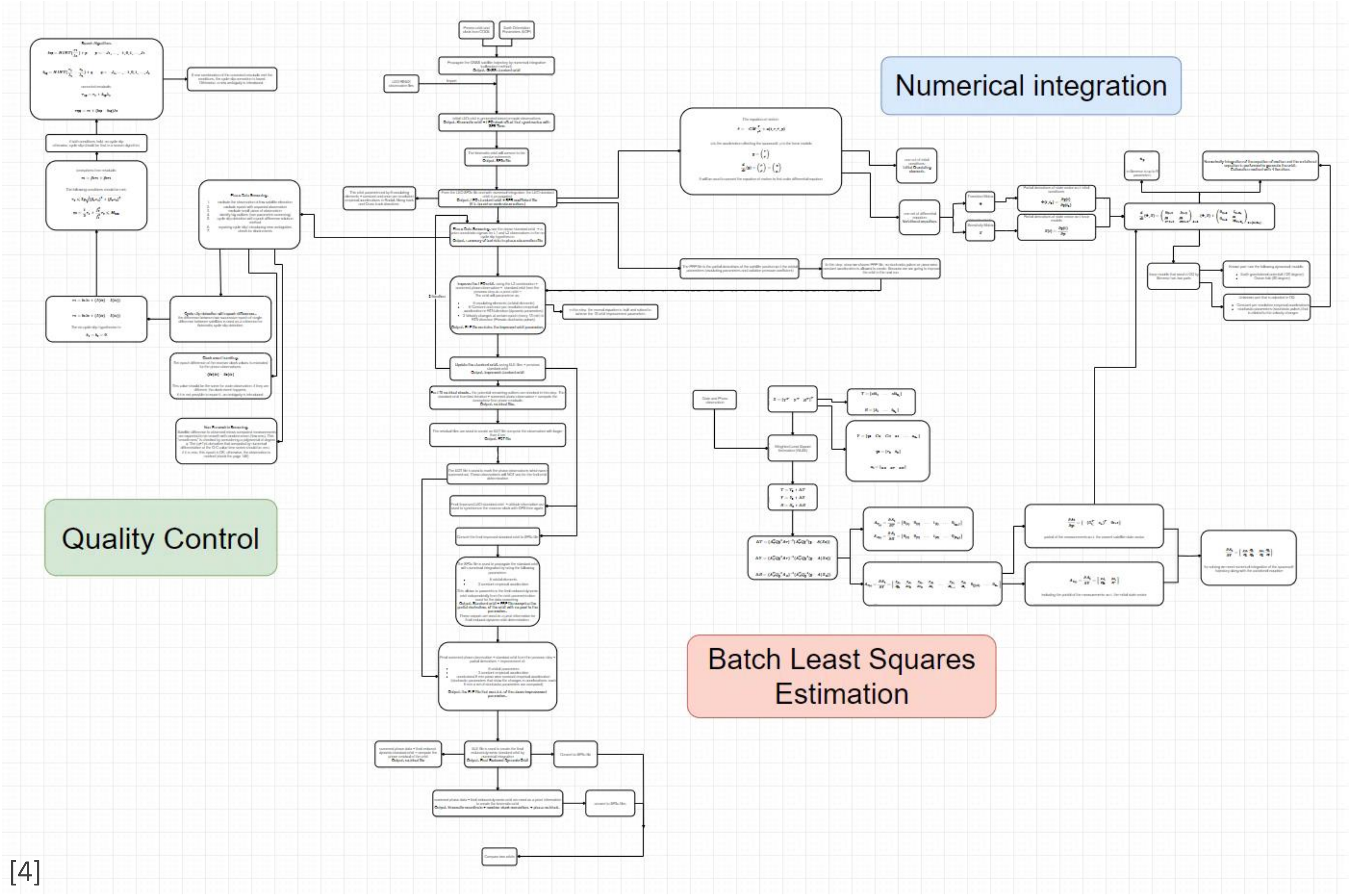
Estimated in Least-Squares by numerical integration of variational equation




$$\frac{d}{dt}(\tilde{\Phi}, \tilde{S}) = \begin{pmatrix} 0 & I \\ \partial_r a & \partial_v a \end{pmatrix} (\tilde{\Phi}, \tilde{S}) + \begin{pmatrix} 0 & 0 \\ 0 & \partial_p a \end{pmatrix}$$

$\tilde{\Phi} = \partial_{y_0} y \quad \tilde{S} = \partial_p y$ [3]

# Flowchart of Reduced-Dynamic POD




[4]

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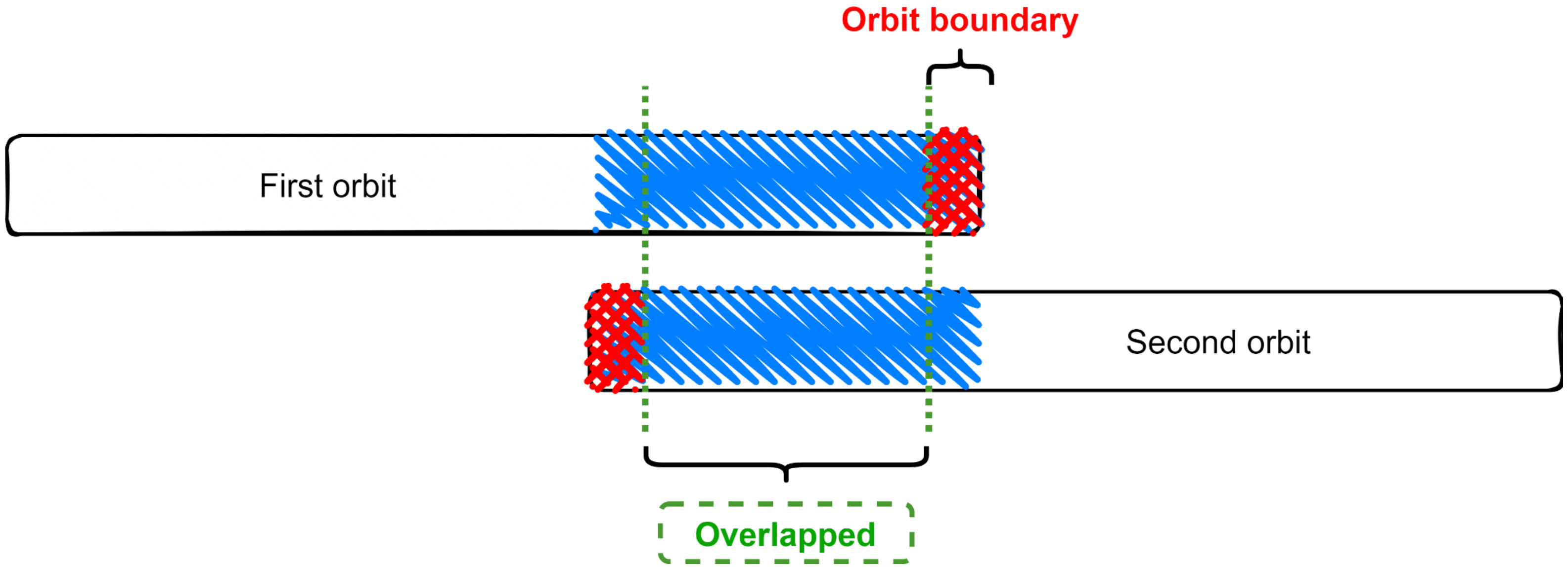
# Validation (1)

To validate the new PCV pattern, one month of the GNSS observations collected in space by a CubeSat from Spire Constellation are processed in Kinematic POD.

☑ The **overlapping orbits** are used to check the internal consistency in POD. [5]




| Orbital parameter | RMS (m) |
|---|---|
| Along-Track | 0.059 |
| Cross-Track | 0.053 |
| Radial | 0.054 |

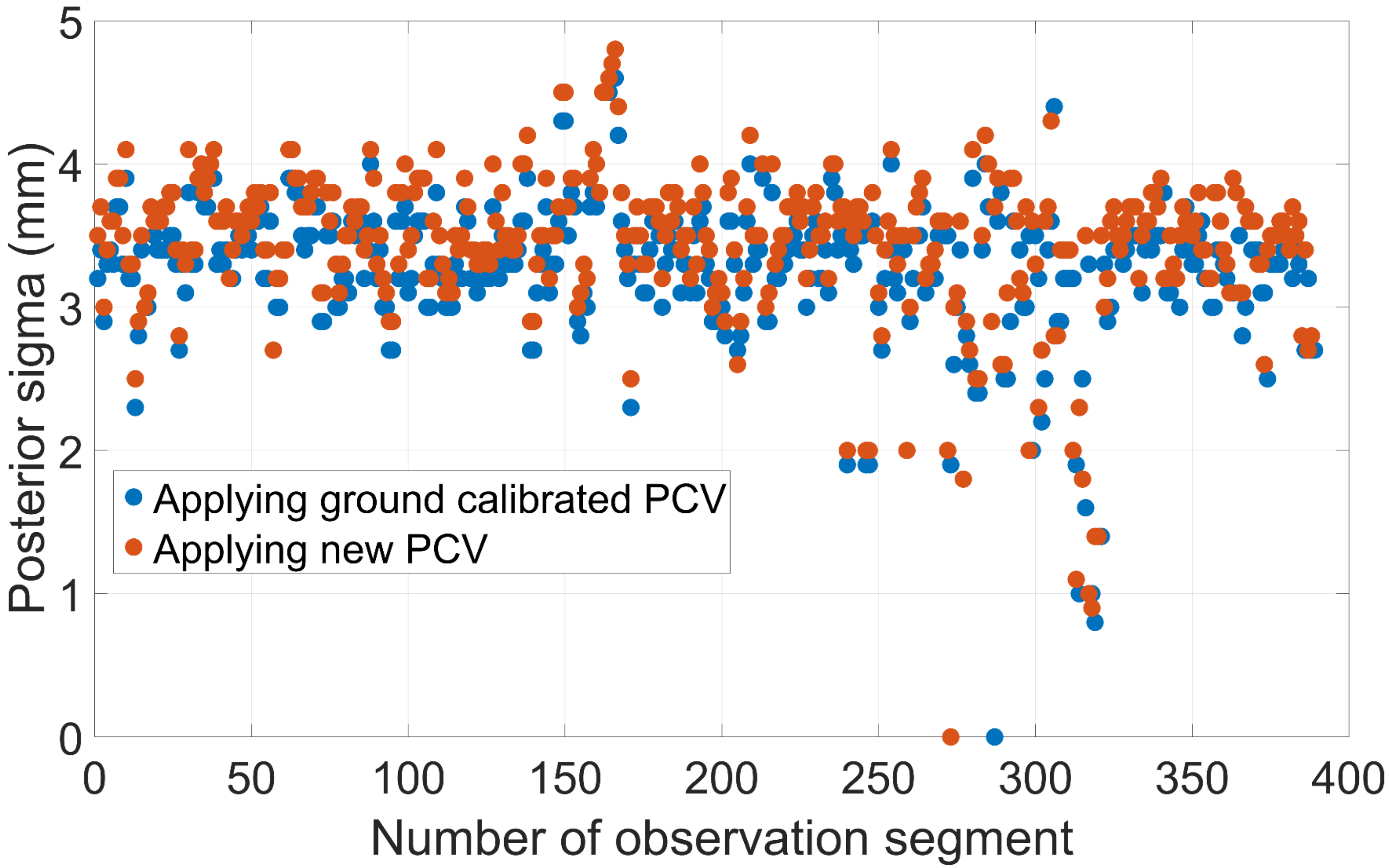
- The Root Mean Square (RMS) of the orbital parameters confirms the orbit consistency after applying new PCV pattern

# Validation (2)

☑ The **posterior variance/sigma factor** is a self-consistency check for the goodness of fit, i.e., to what extent the model fits the problem.

| Scenario | RMS of all posterior sigma (mm) |
|---|---|
| Ground Calibrated PCV | 3.4 |
| New PCV | 3.3 |

**The posterior sigma values confirms the accuracy of the POD after applying the new PCV pattern**

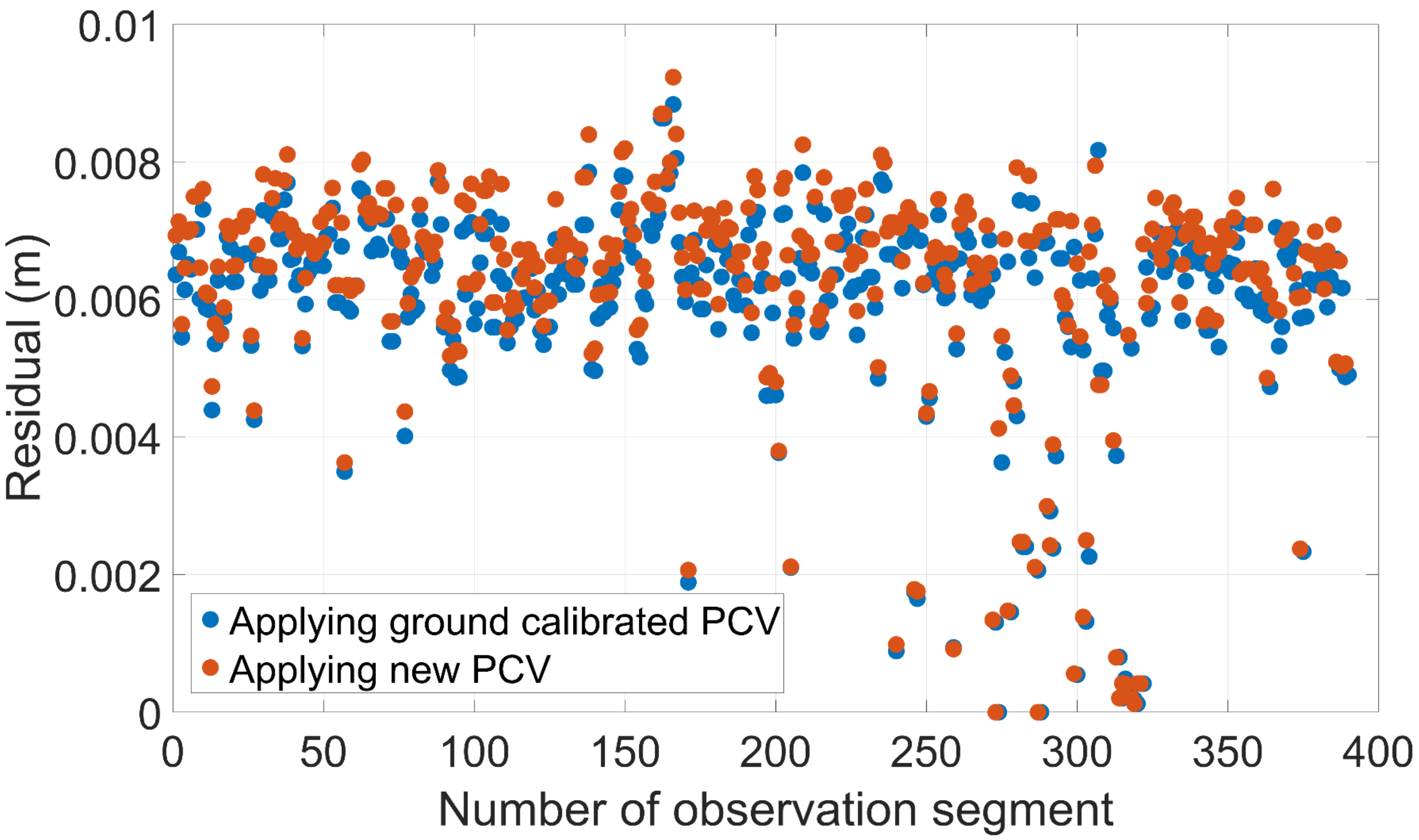


# Validation (3)

☑ The **observation residuals** are used to validate the POD accuracy.

**The observation residuals when we use new pattern is generally smaller after applying the new PCV**

| Scenario | RMS of all residuals (m) |
|---|---|
| Ground Calibrated PCV | 0.007 |
| New PCV | 0.006 |



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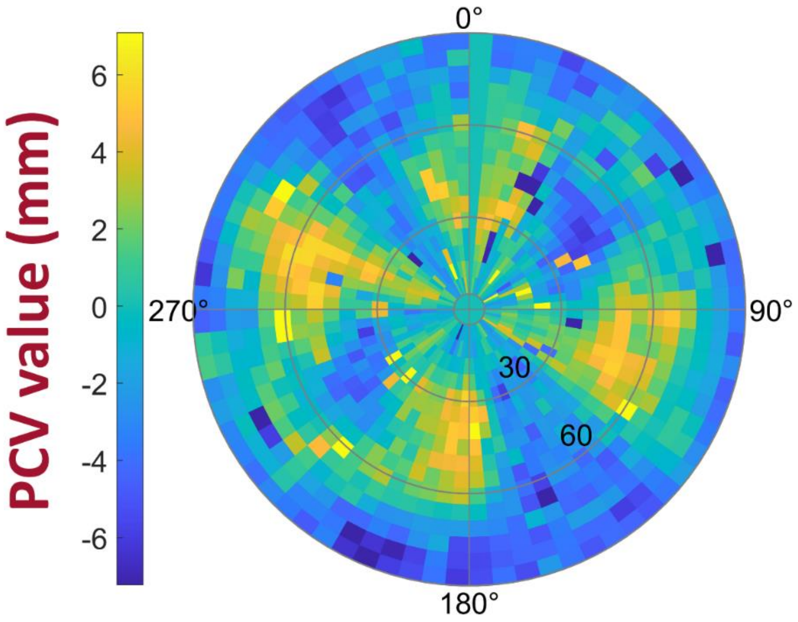
# Summary and Conclusion

- The correct phase center variations (PCV) are required to have a better CubeSat's orbit,
- PCV pattern estimated from ground calibration method do not consider the actual space environment,
- The solution is to use Residual method iteratively to achieve PCV pattern based on actual space environment,
- The validation methods confirm the optimality of new PCV pattern in POD of CubeSats
- New orbits represent higher accuracy, suitable for different applications.



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# References

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