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Do the GPS Repositioning Events Degrade the Stability of GNSS Scale Contribution?

Presented by:

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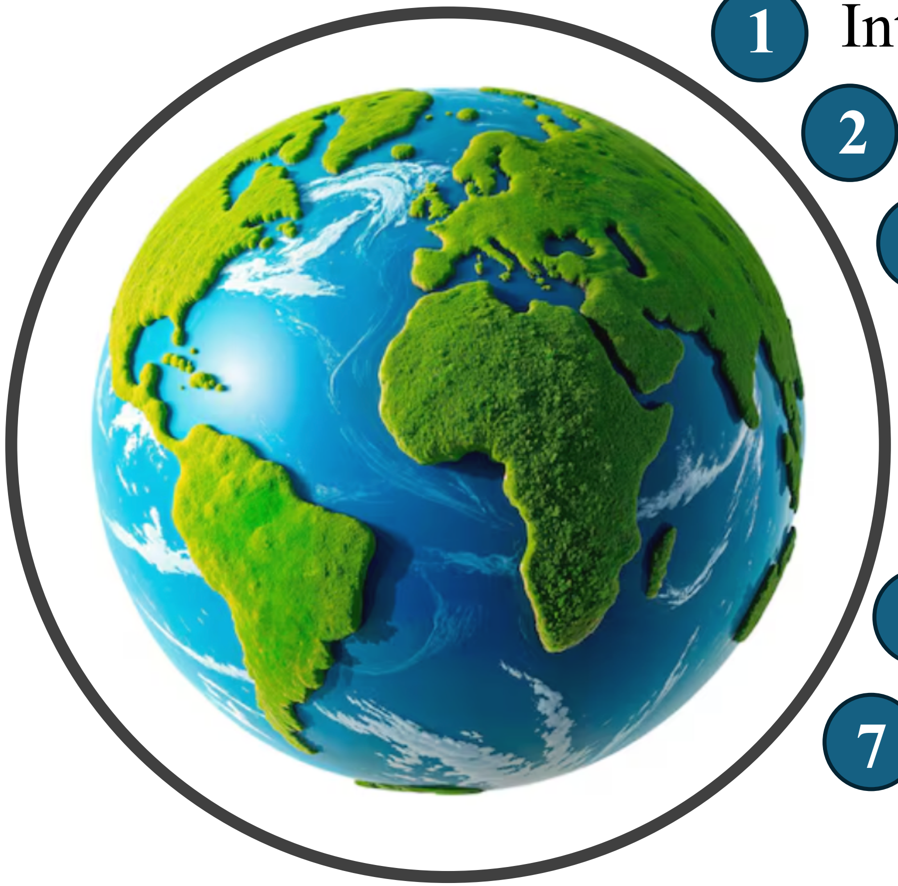
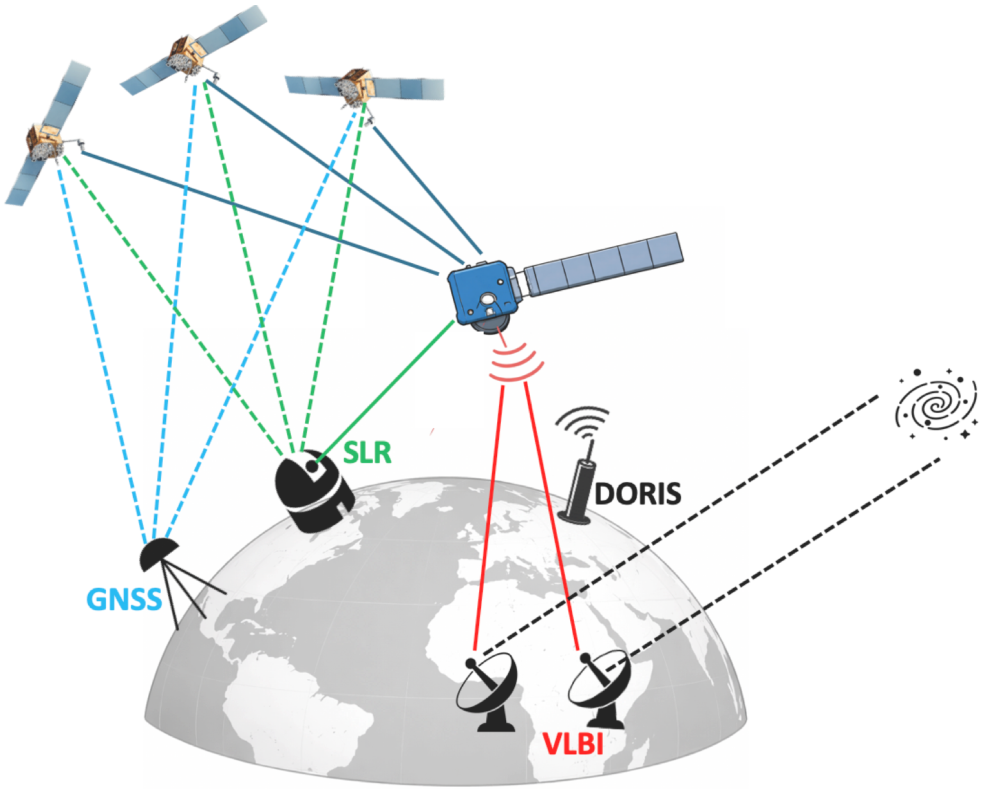


INTRODUCTION

Introduction



Adapted from Böhm & Wolf (2024)

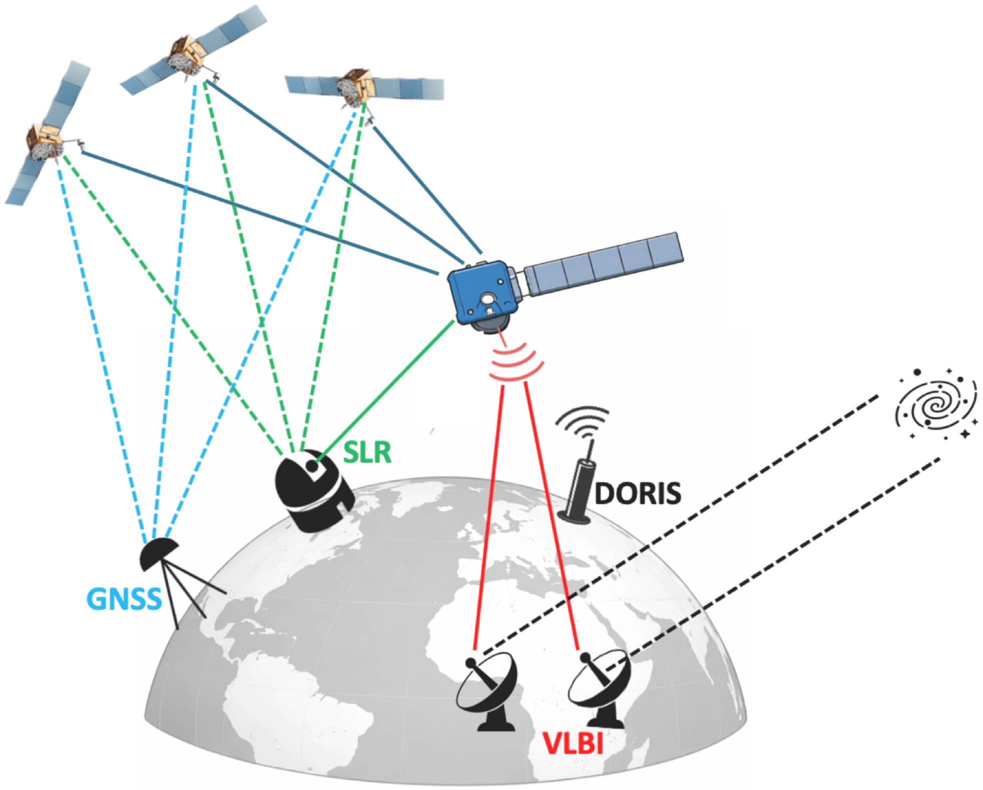
Fig :Four geodetic techniques that define ITRF

ITRF (International Terrestrial Reference Frame)

- It is a global reference for precise positioning, navigation and Earth science.
- Scale traditionally defined by VLBI and SLR.

VLBI: Very Long Baseline Inferometry
SLR: Satellite Laser Ranging

Introduction



Adapted from Böhm & Wolf (2024)

Fig :Four geodetic techniques that define ITRF

ITRF (International Terrestrial Reference Frame)

- It is a global reference for precise positioning, navigation and Earth science.
- Scale traditionally defined by VLBI and SLR.

ITRF scale and GNSS contribution

- Modern GNSS satellites (active in recent years) provide calibrated antenna phase centers.
- The scale must be propagated backward through the GNSS solution using satellites' overlapping operational intervals.

VLBI: Very Long Baseline Inferometry
SLR: Satellite Laser Ranging

AIM

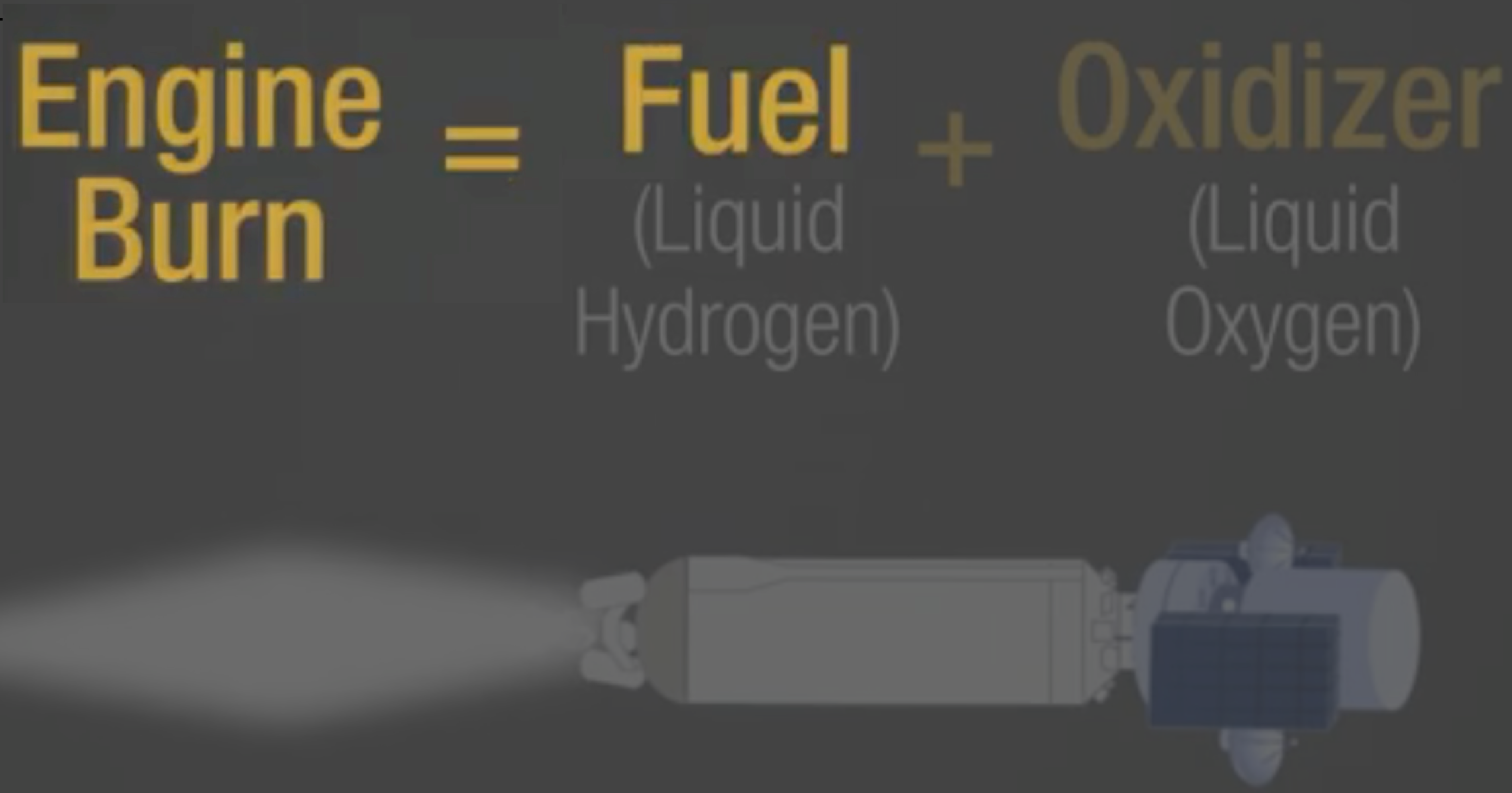
Aim

- The aim of this project is to investigate whether GNSS-derived scale information can be transferred backward in time by analyzing the stability of GPS satellite antenna offsets between repositioning events.

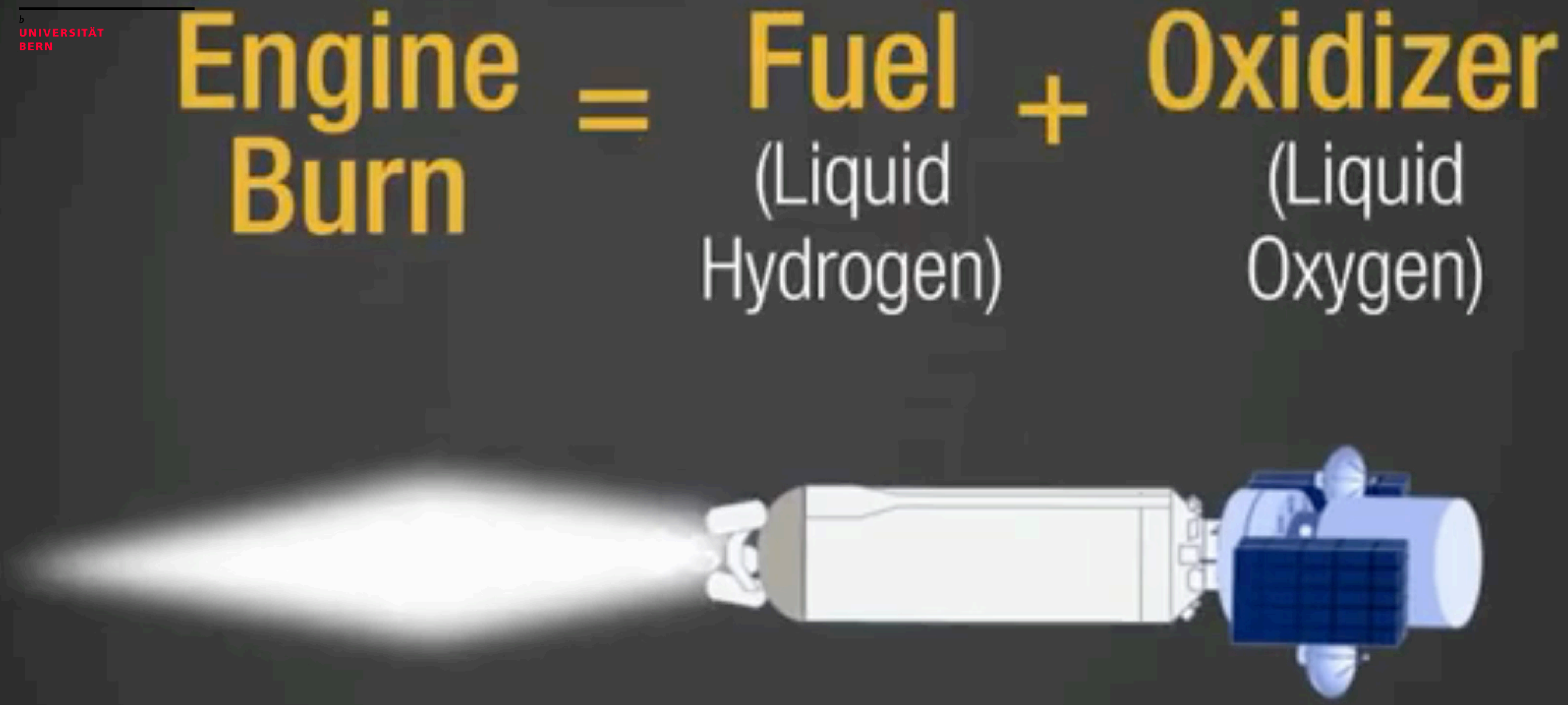
PROBLEM ANALYSIS

Do the repositioning events change the center of mass of GNSS satellites?

Source: https://www.youtube.com/unitedlaunchalliance



Source: https://www.youtube.com/unitedlaunchalliance



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Problem Analysis

Why is this relevant?

Problem Analysis

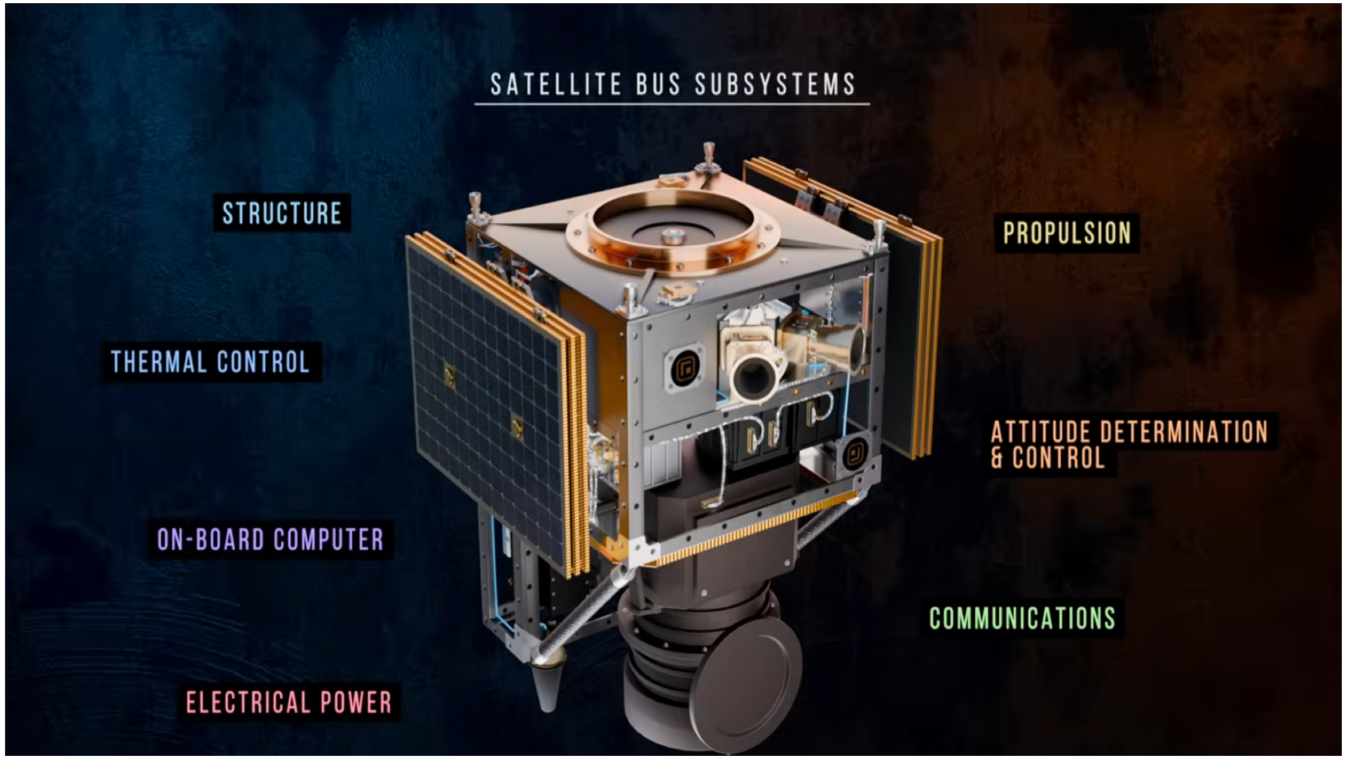

Fig :Satellite bus Architecture

A satellite bus is the main body of the satellite.

Problem Analysis

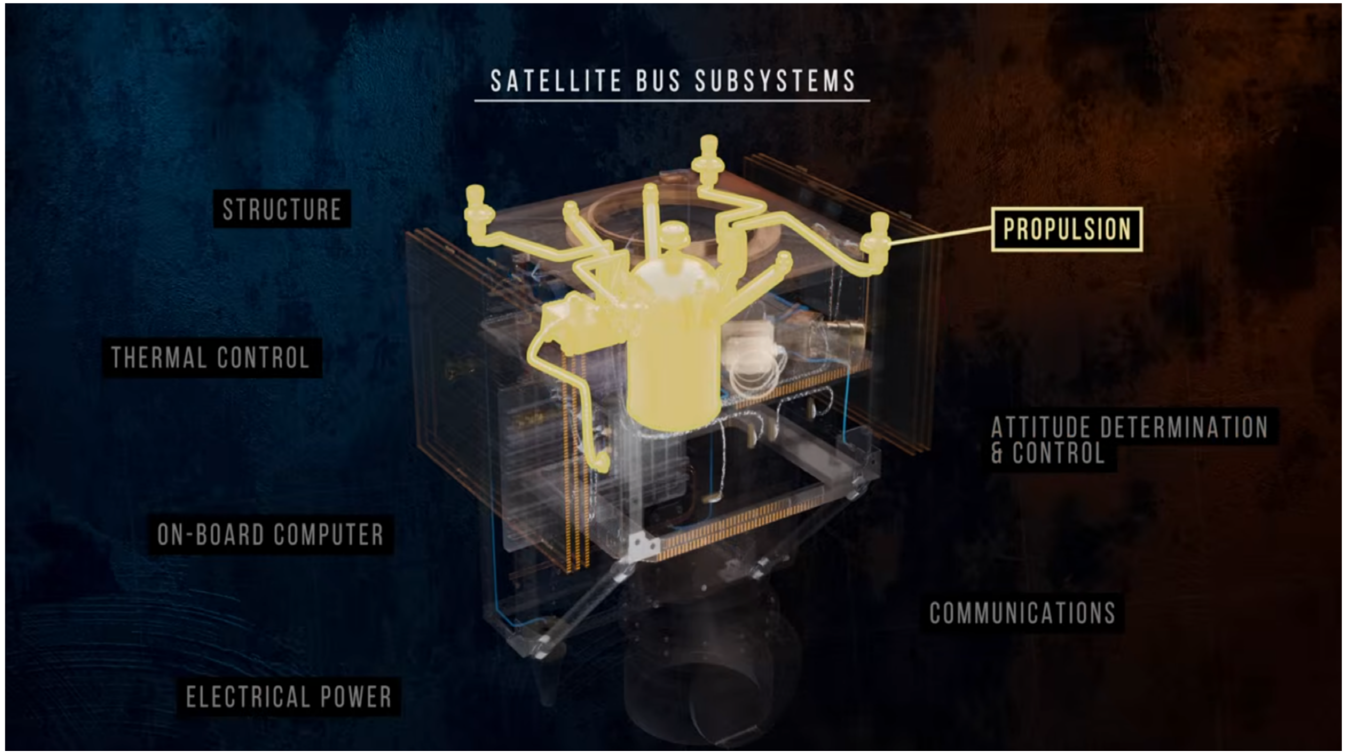

Fig :Satellite bus Architecture

A satellite bus is the main body of the satellite.

The propulsion tank (containing fuel) makes up a major portion of the satellite bus, so any fuel consumption could in principle change the Center of Mass (CoM).

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SATELLITE ANTENNA PARAMETERS AND RELATIONS

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Satellite Antenna Parameters and relations

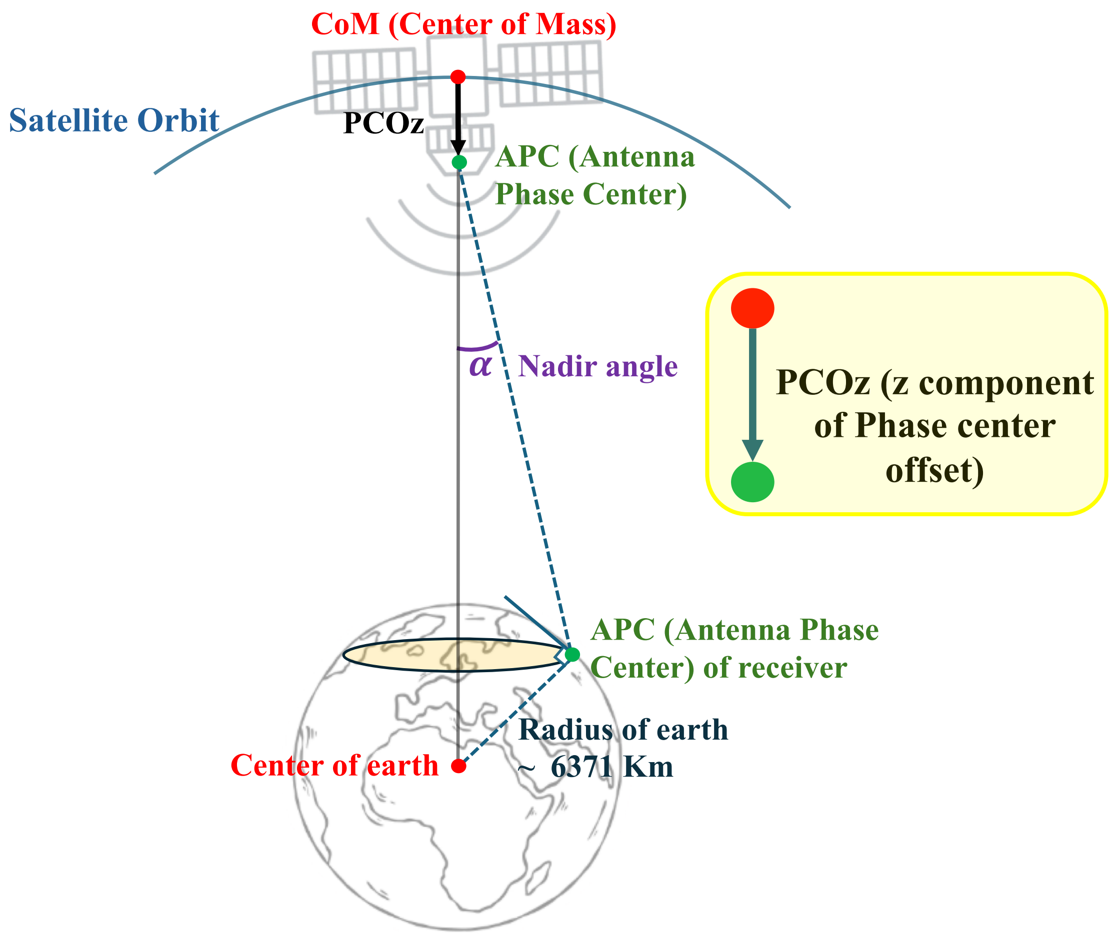

Fig :Satellite Antenna Parameter relations

- Phase Center Offset (PCO) is a vector pointing from the center of mass (COM) to the antenna phase center(APC) in a satellite body-fixed coordinate system.
- The vertical PCO is critical for scale realization, as the **PCOz (Z-offset) is directed to the center of the earth.**
- PCOz and satellite clocks are correlated.

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METHODOLOGY

Methodology

1. **Extracted IGS Daily NEQs (Normal Equations).**

CODE daily NEQs containing **CRD** (station coordinates), **ORB** (satellite orbit parameter), **TRP** (station-wise troposphere corrections), **ERP** (Earth rotation parameters), and **SATA** (SATellite Antenna Parameters). All of these come from the standard CODE processing, which is based on **three-day orbit arcs**.

CODE : Center for Orbit Determination, Europe

Methodology

1. Extracted IGS Daily NEQs (Normal Equations).
2. **Datum verification and NEQ reduction.**

   Datum definition (**minimum constraint solution** with NNR-, NNT-, and NNS-condition w.r.t. IGb20) using a **verified list of reference stations**. All parameters apart from SATA parameters were pre-eliminated resulting a **daily NEQs just containing SATA parameters**.

NNR - No Net Rotation
NNT - No Net Translation
NNS - No Net Scale

Methodology

1. **Extracted IGS Daily NEQs (Normal Equations).**
2. **Datum verification and NEQ reduction.**
3. **Combining multiple years (2004–2020).**

Combine daily NEQs with SATA parameters where **one set of SATA parameters** is **estimated** for the interval **between two repositioning events** of a certain satellite.

Methodology

1. Extracted IGS Daily NEQs (Normal Equations).
2. Datum verification and NEQ reduction.
3. Combining multiple years (2004–2020).
4. **Filtering of SATA-values.**

Excluded all **SATA values** which have **less then 45 days** of duration as they cannot contribute because of the uncertainty (**correlation with satellite clock and orbit parameters**).

Methodology

1. **Extracted IGS Daily NEQs (Normal Equations).**
2. **Datum verification and NEQ reduction.**
3. **Combining multiple years (2004–2020).**
4. **Filtering of SATA-values.**
5. **Final Analysis**

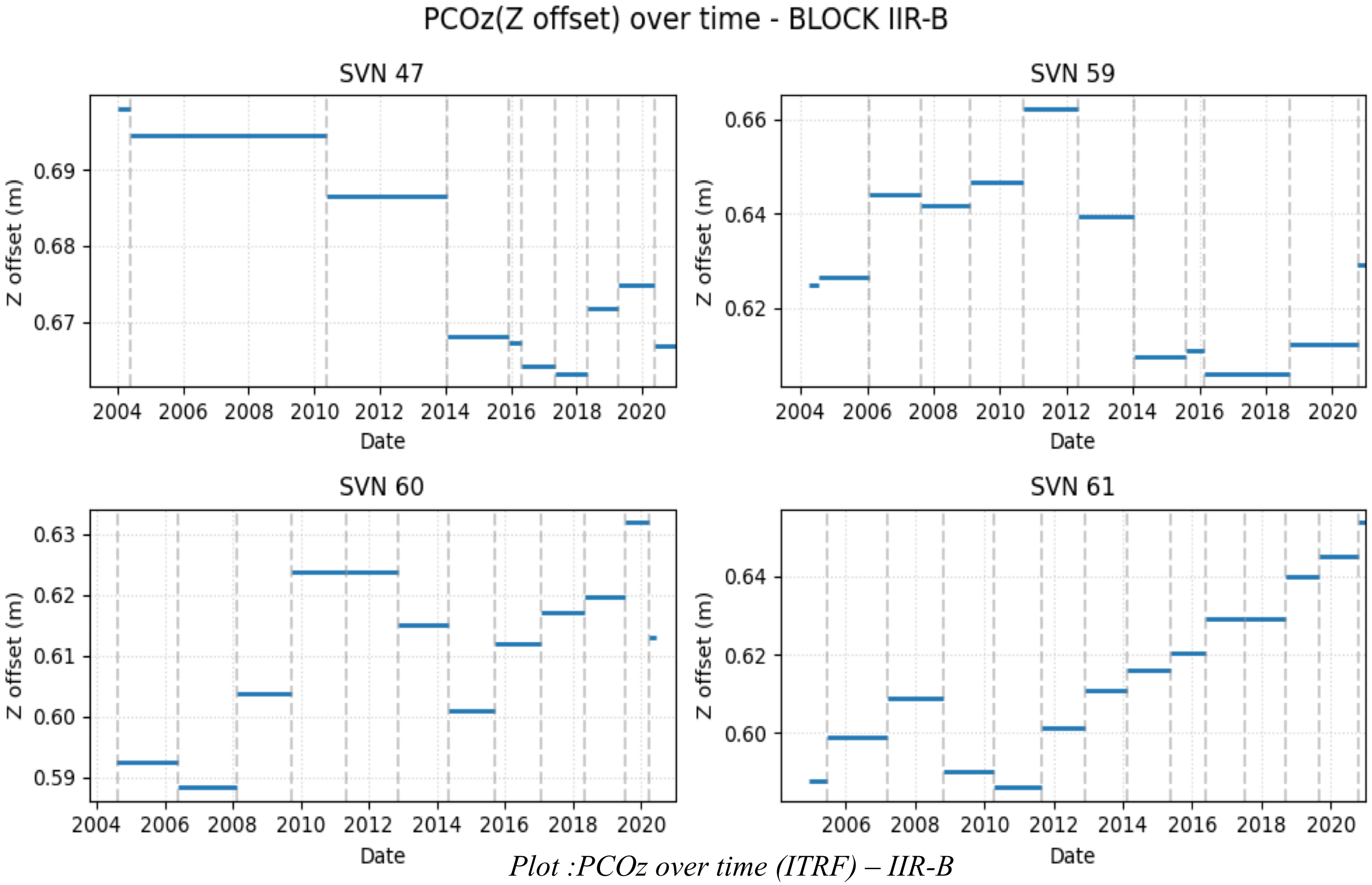
→ Comparing the **changes in the SATA series with the magnitude of the maneuvers** as estimated in the operational CODE processing since 2004.

CODE : Center for Orbit Determination, Europe

RESULTS AND ANALYSIS

1. Time evolution of Z offset (PCOz).

Time evolution of PCOz- GPS Block IIR-B



Plot :PCOz over time (ITRF) – IIR-B

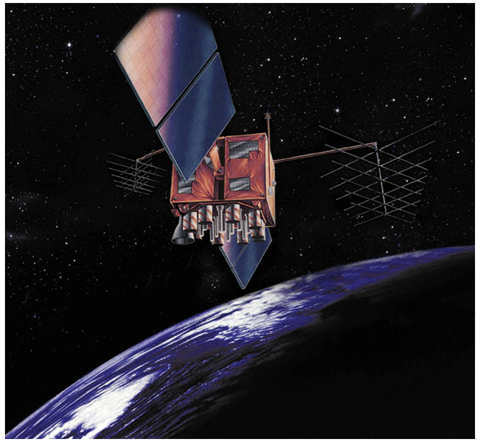


Fig :GPS block IIR series

Here, PCOz estimates between repositioning / maneuver events are plotted.

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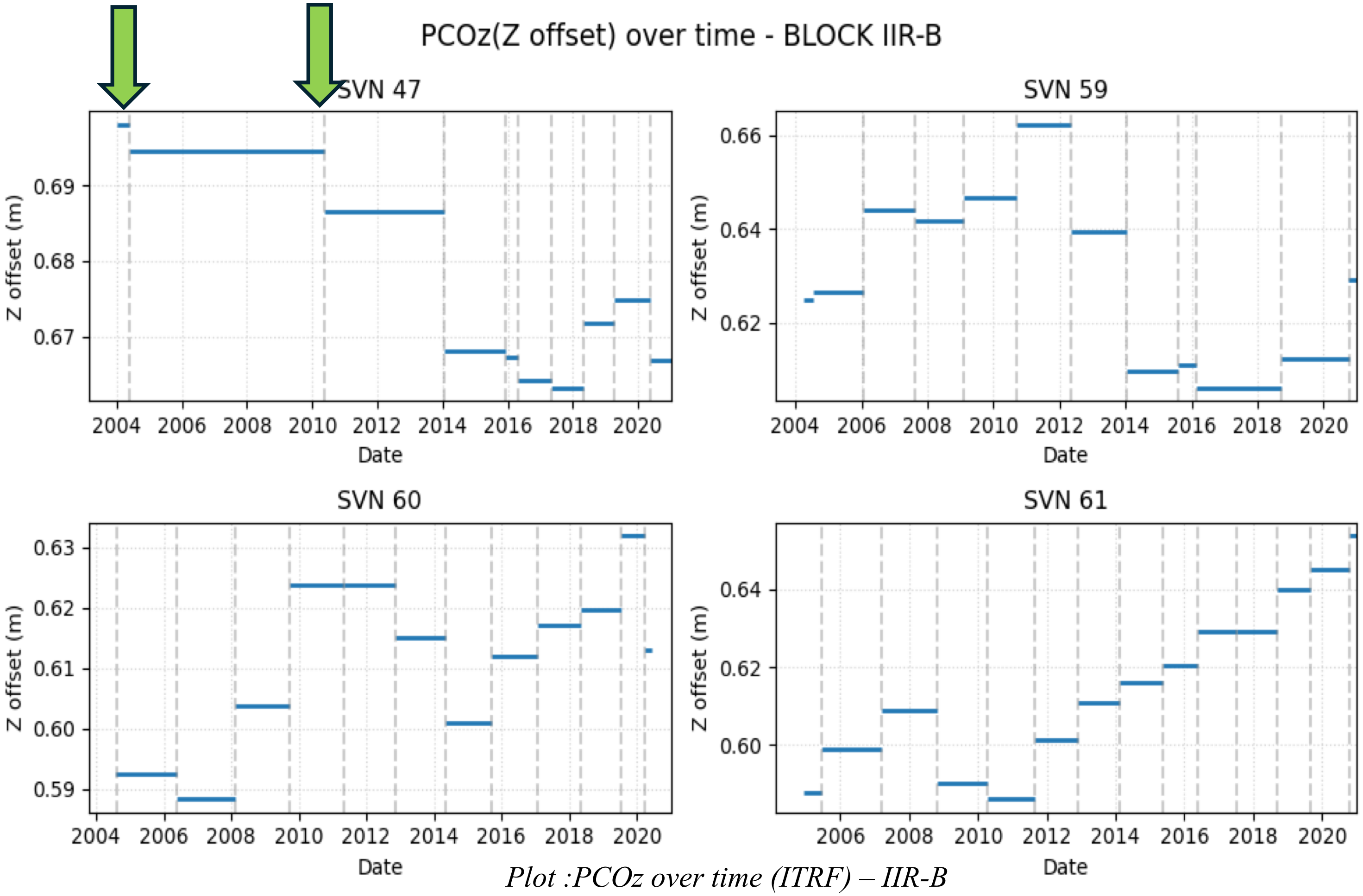
Time evolution of PCOz- GPS Block IIR-B



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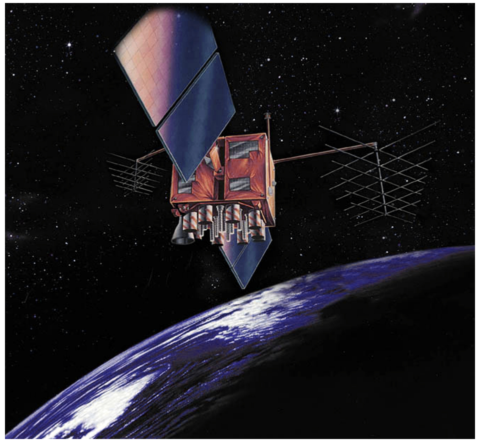
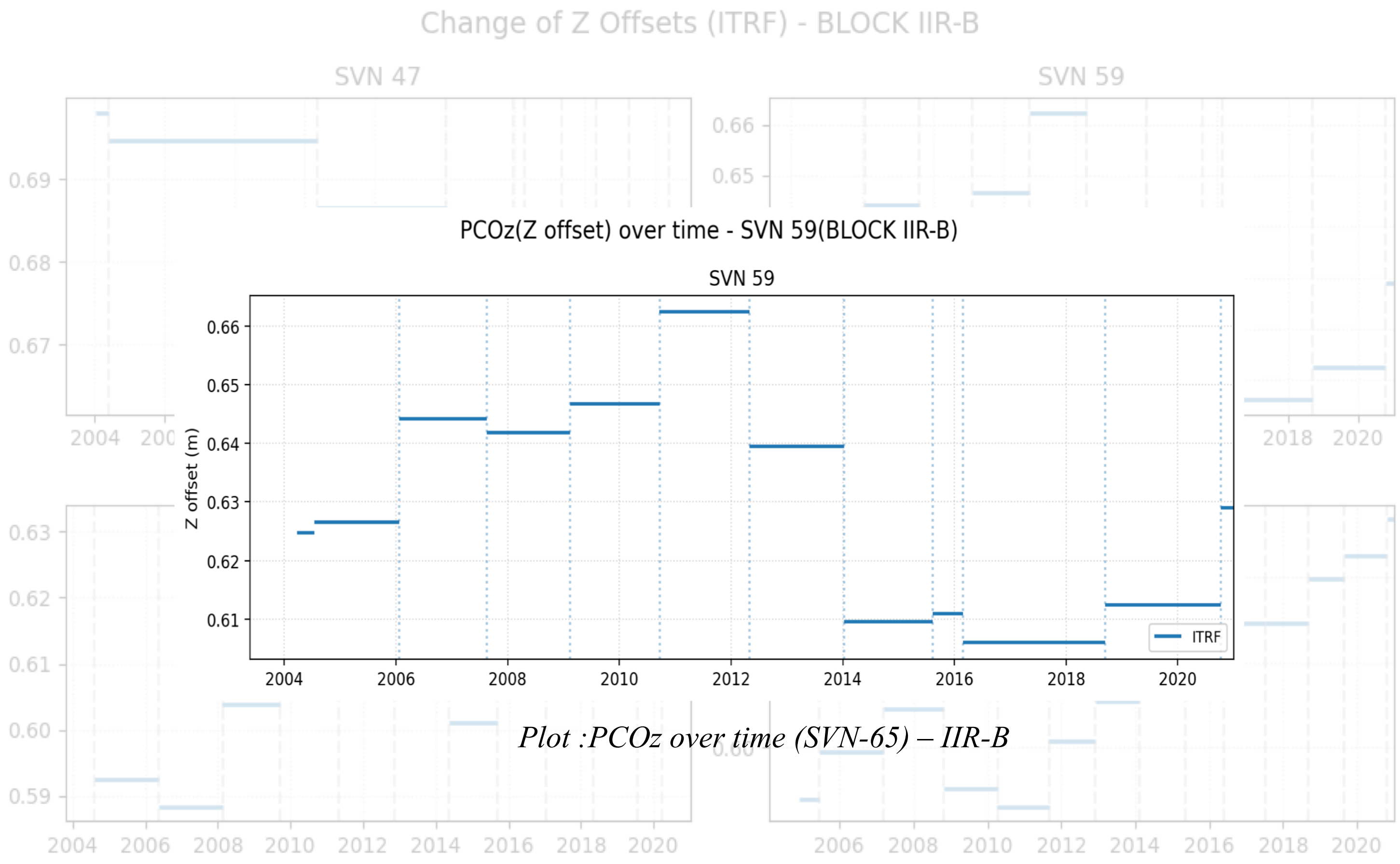


Fig :GPS block IIR series

Here, PCOz estimates between repositioning / maneuver events are plotted.

Note : Dotted lines in the plot are maneuver dates.

Time evolution of PCOz- GPS Block IIR-B



Plot :PCOz over time (SVN-65) – IIR-B

SVN 59, shows irregular jumps that appear stochastic rather than trend-driven.

The step sizes vary, but **there is no systematic long-term increase or decrease.**

Note : Dotted lines in the plot are maneuver dates.

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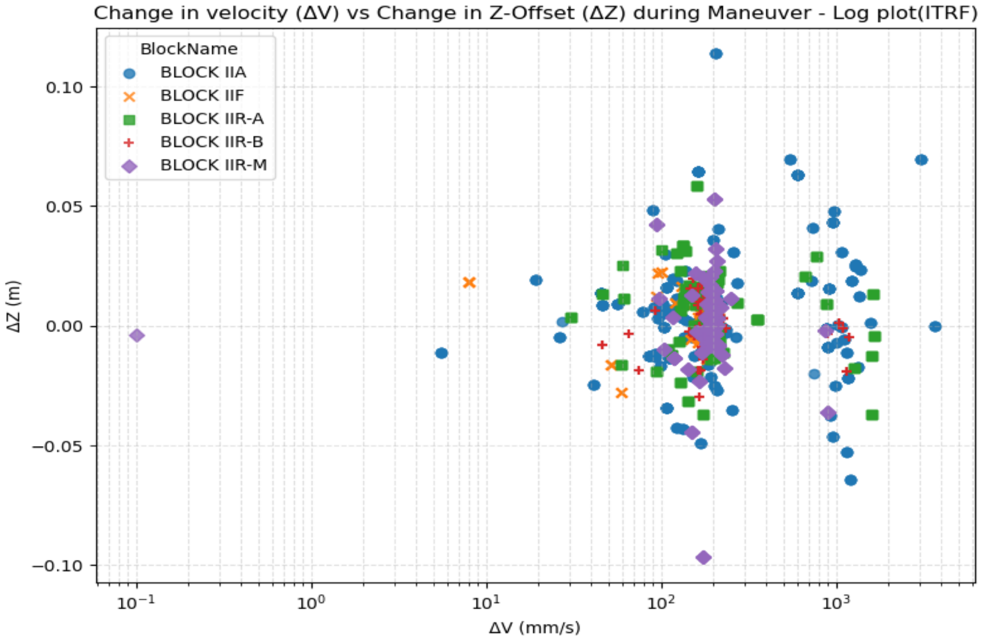
RESULTS AND ANALYSIS

1. Time evolution of Z offset PCOz.
2. Maneuver Characteristics vs Change in Z offset (PCOz).

Characteristics - Change in Z offset (PCOz) vs Maneuver Magnitude



Plot :ΔZ (Change in PCOz) vs ΔV (Change in velocity)

- **ΔV** (**Maneuver Magnitude**) values are plotted in **logarithmic scale.**
- **Maneuver Magnitude** shows no clear relationship with ΔZ during maneuver events.

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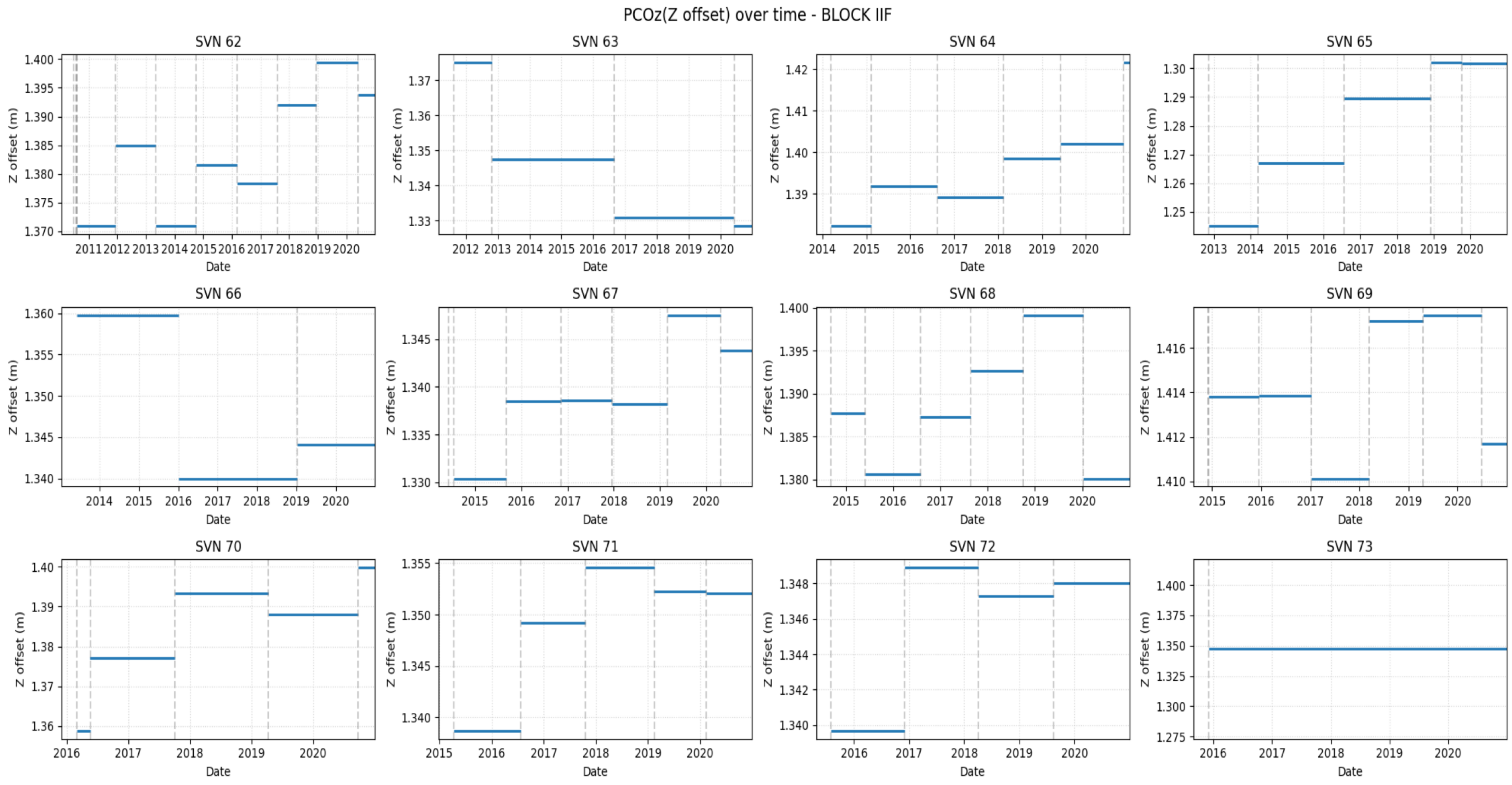
RESULTS AND ANALYSIS

1. Time evolution of Z offset PCOz.
2. Maneuver Characteristics vs Change in Z offset (PCOz).
3. Time evolution of Z offset (PCOz) – IIF.

Time evolution of PCOz- GPS Block IIF



Plot :PCOz over time (ITRF) – IIF

Fig :GPS block IIF

Here, PCOz estimates between repositioning / maneuver events are plotted.

Note : Dotted lines in the plot are maneuver dates.

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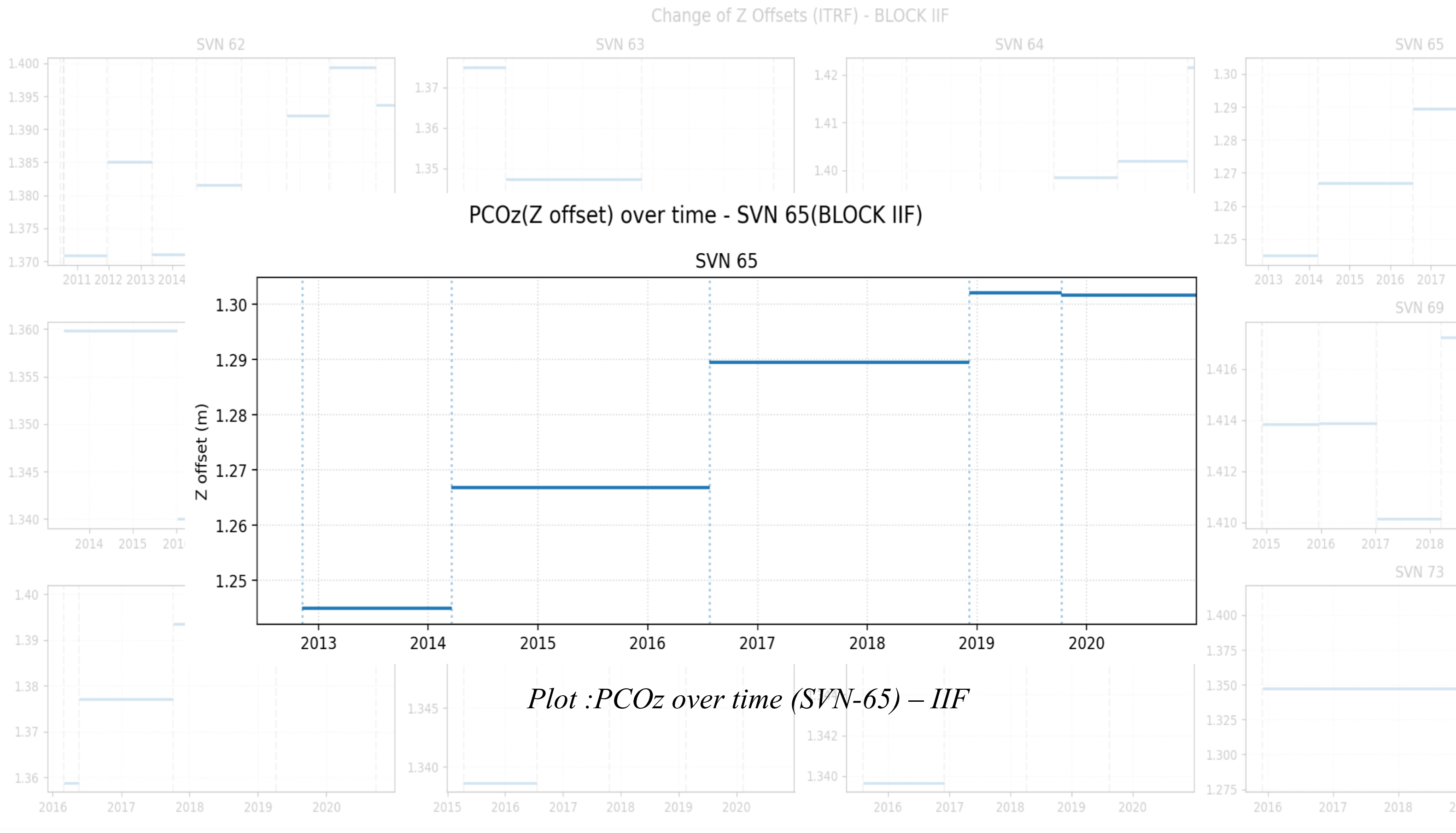
Time evolution of PCOz- GPS Block IIF



Plot :PCOz over time (SVN-65) – IIF

- Estimated PCOz of SVN 65, exhibits an almost upward trend, with step increases after most of the maneuvers.
- The step sizes vary, it has almost **systematic long-term increase**, over the time span.

Note : Dotted lines in the plot are maneuver dates.

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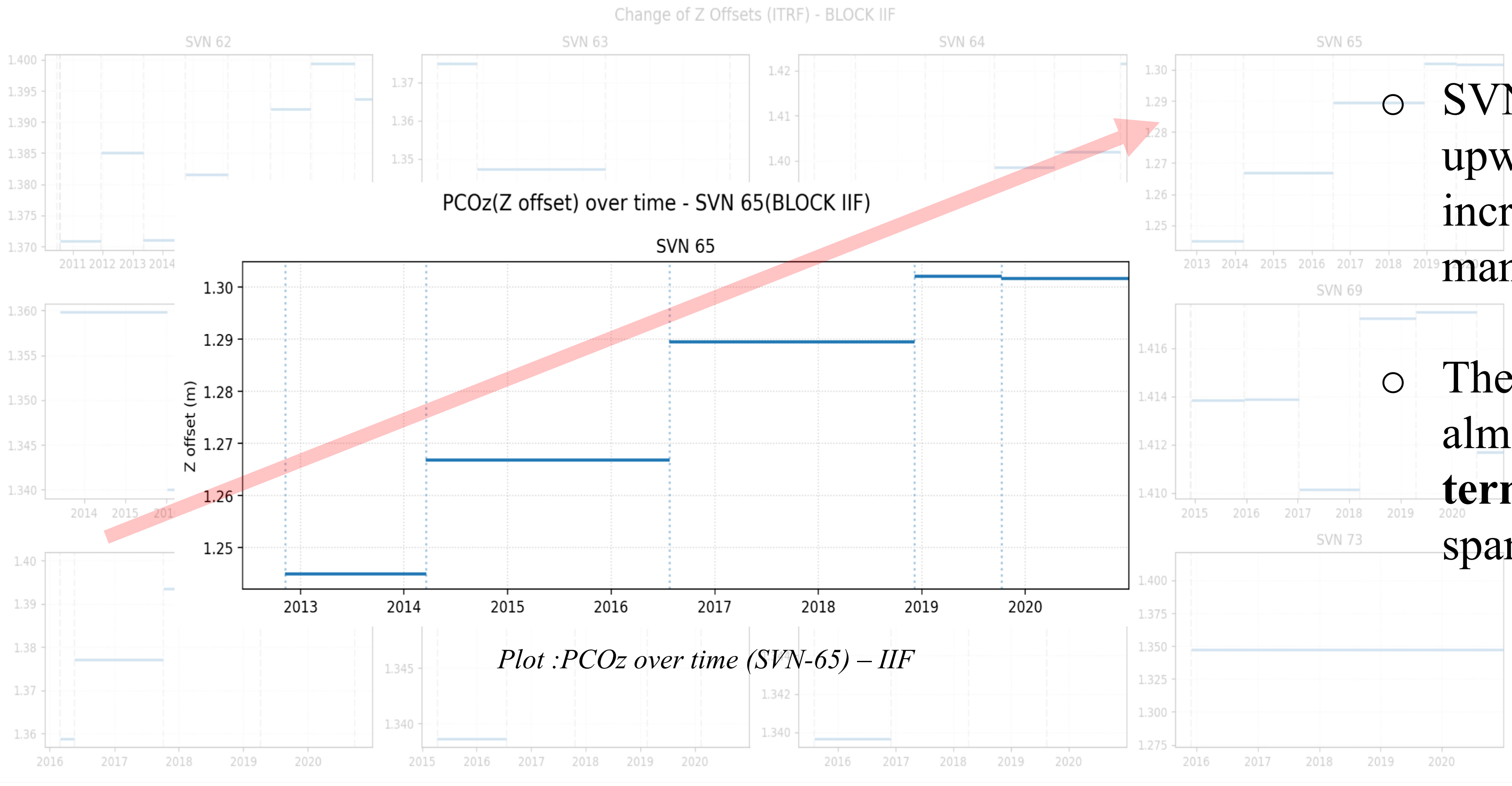
Time evolution of PCOz- GPS Block IIF



Plot :PCOz over time (SVN-65) – IIF

- SVN 65, exhibits an almost upward trend, with step increases after most of the maneuvers.
- The step sizes vary, it has almost **systematic long-term increase**, over the time span.

Note : Dotted lines in the plot are maneuver dates.

RESULTS AND ANALYSIS

1. Time evolution of Z offset PCOz.
2. Maneuver Characteristics vs Change in Z offset (PCOz).
3. Time evolution of Z offset (PCOz) – IIF.
4. Evaluating estimated PCOz values in DTRF-aligned solution.

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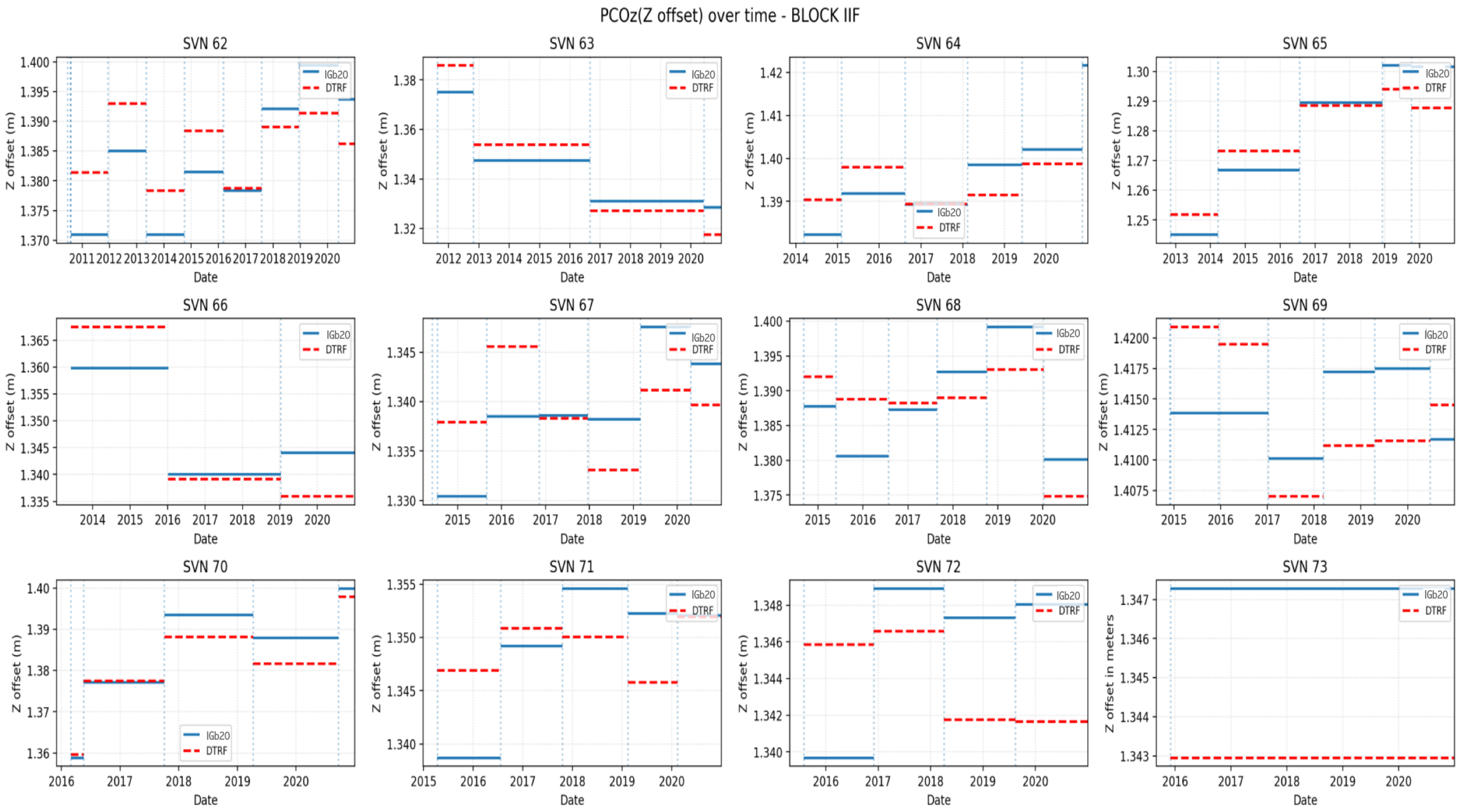
Time evolution of PCOz- IIF (IGb20 vs DTRF)

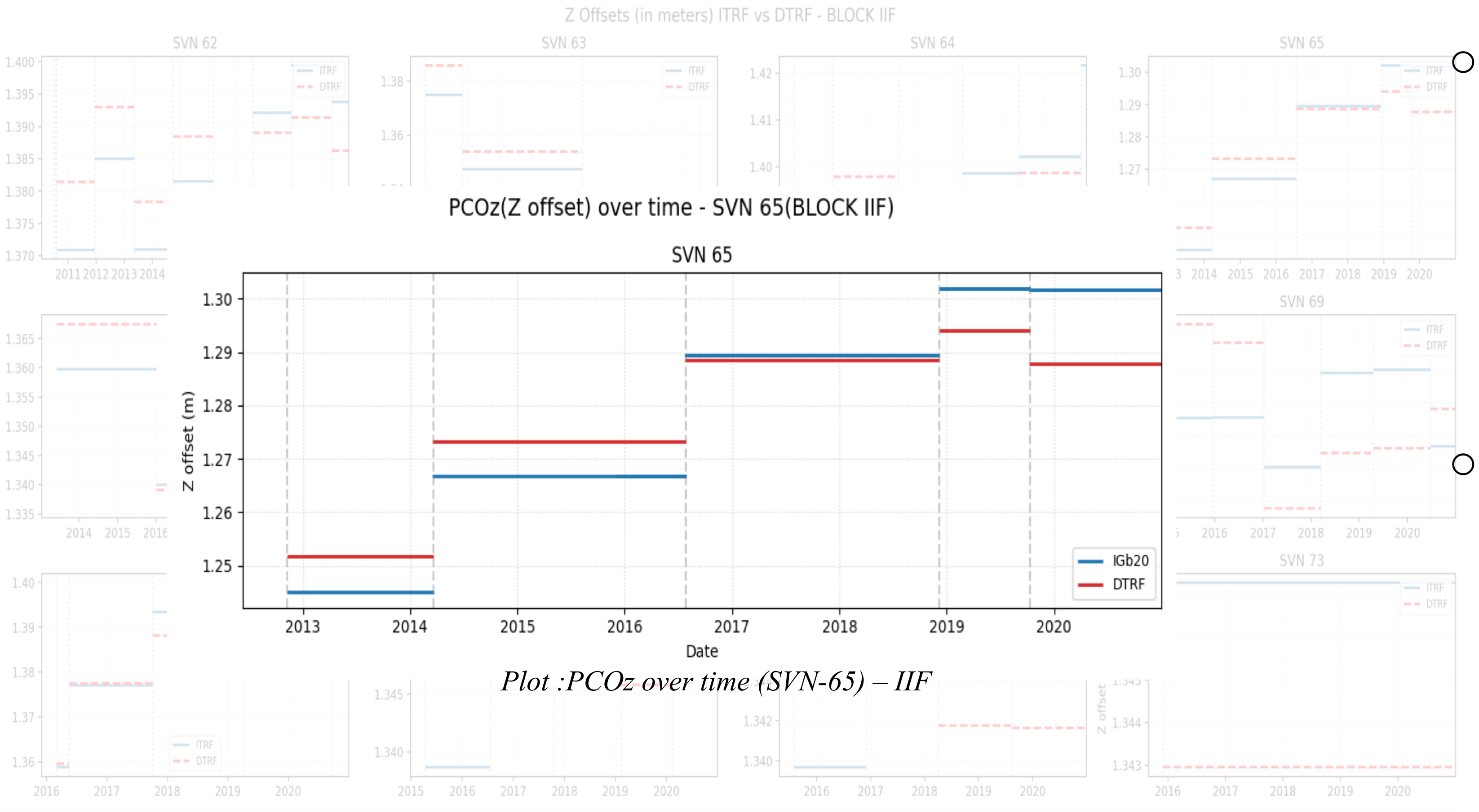


Plot :PCOz over time (IGb20 & DTRF) – IIF

- **ITRF** and **DTRF** are realizations of the ITRS developed by IGN and DGFI-TUM. **IGb20** is the IGS realization of ITRF2020.
- Both realizations have similar estimated PCOz values but they differ in the trend of change in PCOz values between maneuver/ repositioning intervals.

Note : Dotted lines in the plot are maneuver dates.

Time evolution of PCOz- IIF (IGb20 vs DTRF)



Plot :PCOz over time (SVN-65) – IIF

- **Estimated PCOz of SVN 65** shows an almost upward trend in both realizations and, with step changes occurring after most maneuver events.
- The overall evolution is similar in both realizations, while **small offsets between estimated PCOz of IGb20 and DTRF** remain visible throughout the time span.

Note : Dotted lines in the plot are maneuver dates.

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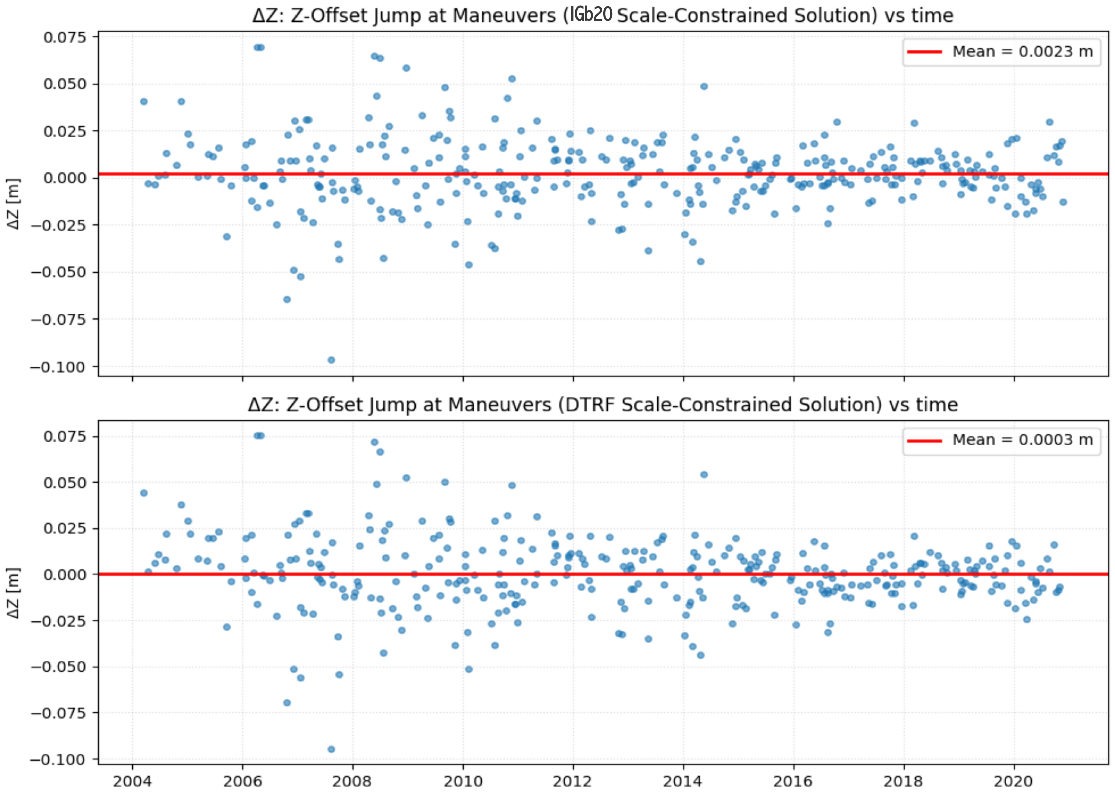
RESULTS AND ANALYSIS

1. Time evolution of Z offset PCOz.
2. Maneuver Characteristics vs Change in Z offset (PCOz).
3. Time evolution of Z offset (PCOz) – IIF.
4. Evaluating PCOz values estimated in DTRF-aligned solution.
5. Trends in estimated PCOZ at Maneuver Intervals.

PCOz Jumps at Manuever intervals (IGb20 vs DTRF)



Plot :PCOz jumps over time

- Mean of ΔZ jumps is small: **2.3 mm (IGb20)** and **0.3 mm (DTRF)**.
- Increased scatter in ΔZ between 2006–2008 (not a trend).
- ΔZ values scatter around zero with **no systematic trend over time**.

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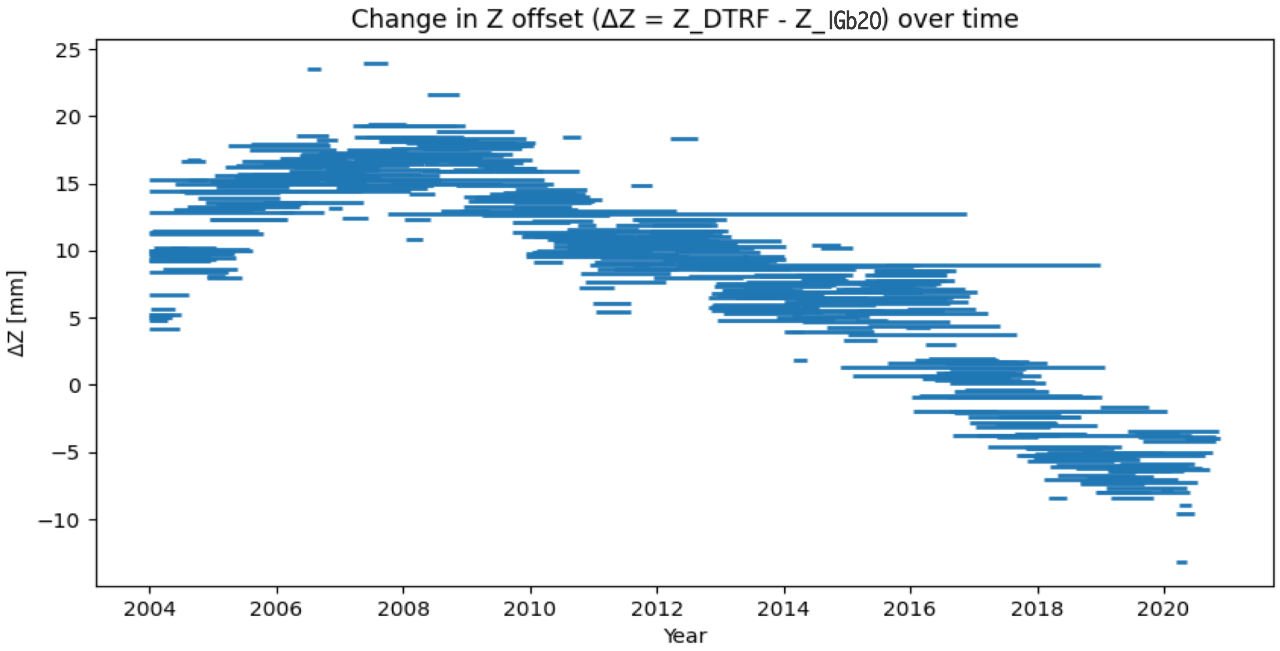
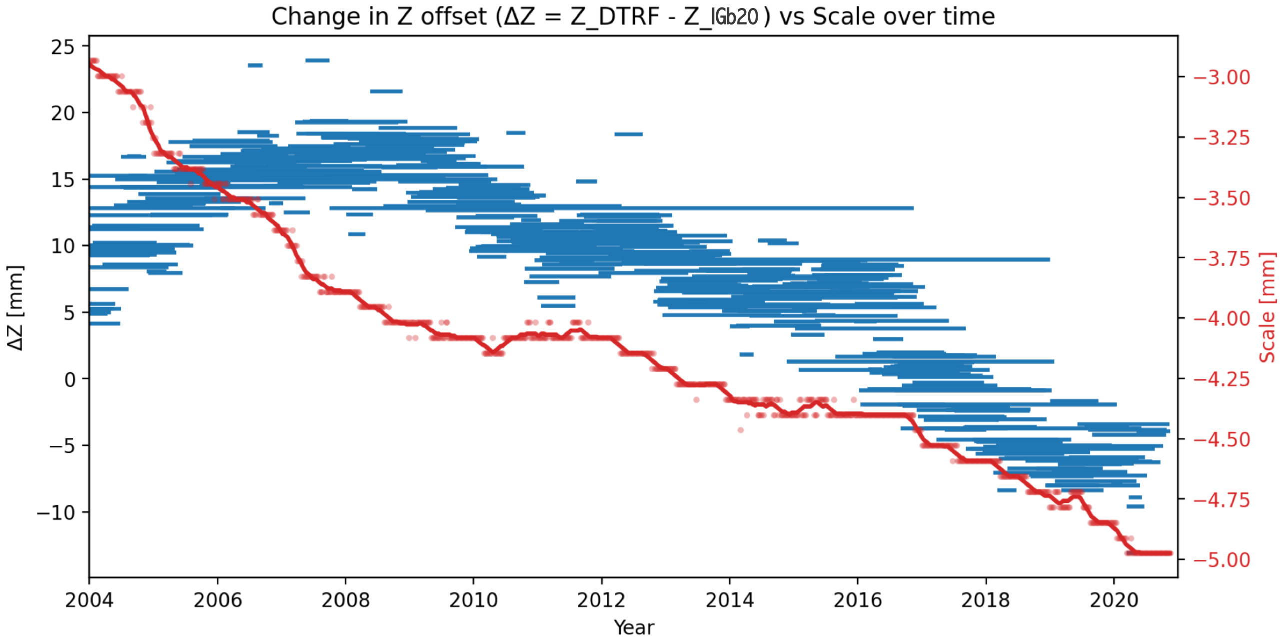
Time evolution of difference in PCOz (DTRF w.r.t iGb20)



Plot :Difference in PCOz vs scale over time (DTRF -ITRF)

The difference between the estimated satellite PCOz of DTRF and IGb20 realizations exhibits a systematic, time-dependent evolution.

Time evolution of difference in PCOz (DTRF w.r.t IGb20)



Plot :Difference in PCOz vs scale over time with scale

- The difference between the estimated satellite PCOz of DTRF and IGb20 realizations exhibits a systematic, time-dependent evolution.
- Trend in time-dependent evolution comes from how the reference frame (DTRF vs ITRF) is realized (scale difference), rather than maneuver-induced satellite changes.

CONCLUSION

Conclusion

1. The focus is on identifying any systematics (trend) over time rather than step magnitude; the plots show no evidence of such a trend.

2. **No correlation** between **ΔZ** and maneuver size (**ΔV**).

3. A clear temporal trend suggests **differences in scale realization between DTRF and IGb20**.

4. **Fuel consumption might not be producing CoM shifts enough (or producing small shifts) to cause sufficient drifts in PCOz.**

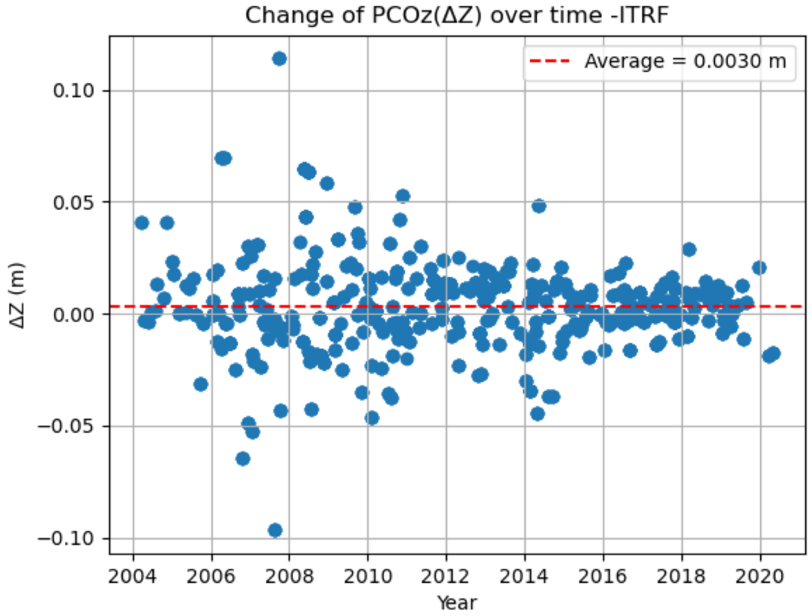
References:

1. Villiger, A., Dach, R., Schaer, S., Prange, L., Zimmermann, F., Kuhlmann, H., ... & Jäggi, A. (2020). GNSS scale determination using calibrated receiver and Galileo satellite antenna patterns. *Journal of geodesy*, *94*(9), 93.
2. Montenbruck, O., Steigenberger, P., Villiger, A., & Rebischung, P. (2022). On the relation of GNSS phase center offsets and the terrestrial reference frame scale: a semi-analytical analysis: O. Montenbruck et al. *Journal of Geodesy*, *96*(11), 90.

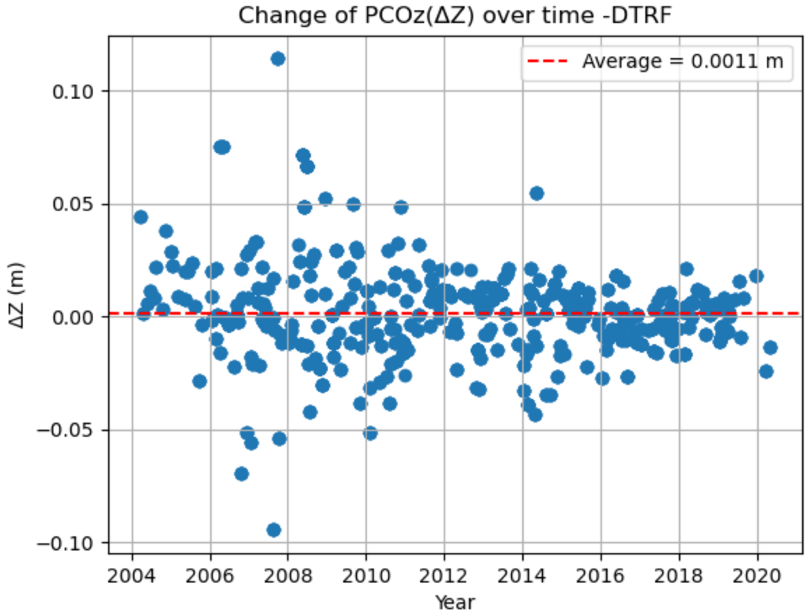
ADDITIONAL SLIDES

Time evolution of change in PCOz

$\Delta Z = Z_{after} - Z_{before}$, at every date of maneuver, for all SVNs.



Plot :PCOz over time –Full data (ITRF)



Plot :PCOz over time –Full data (DTRF)

- The observed difference in mean ΔZ between ITRF and DTRF may reflect differences in reference frame realization, but no causal link could be established from the ΔZ statistics alone.
- Applying the **1/4 Earth scale factor**, yields an **~0.75 mm (ITRF) and ~0.275 mm (DTRF)** on the Earth'ssurface.

Satellite Antenna Parameters and Geometrical relations

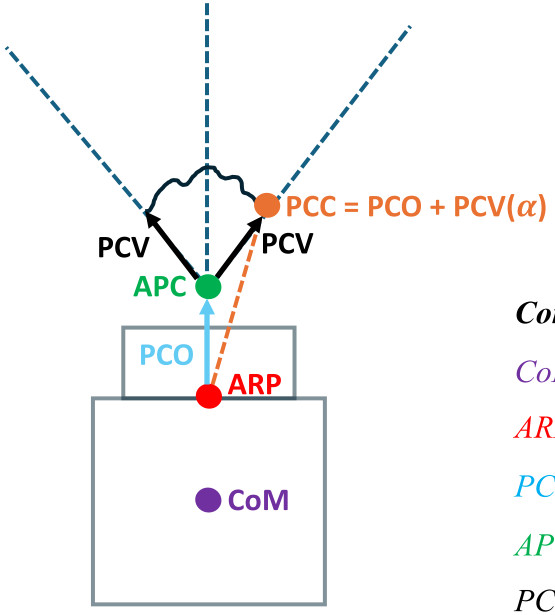


Fig :Satellite antenna parmeters and their relations

Components of diagram are,

CoM (Center of Mass)

ARP (Antenna Reference Point)

PCO (Phase Center Offset)

APC (Antenna Phase Center)

PCV (Phase Center Variation)

PCC (Phase Center Correction)

- PCO: Offset vector from ARP to the antenna's APC.
- PCV: Direction-dependent shift of the APC as a function of nadir angle (α).
- PCC depends on satellite attitude and nadir angle (α).