Satellite altimetry POD using GPS satellite quaternions from IGS CNES/CLS ORBEX files

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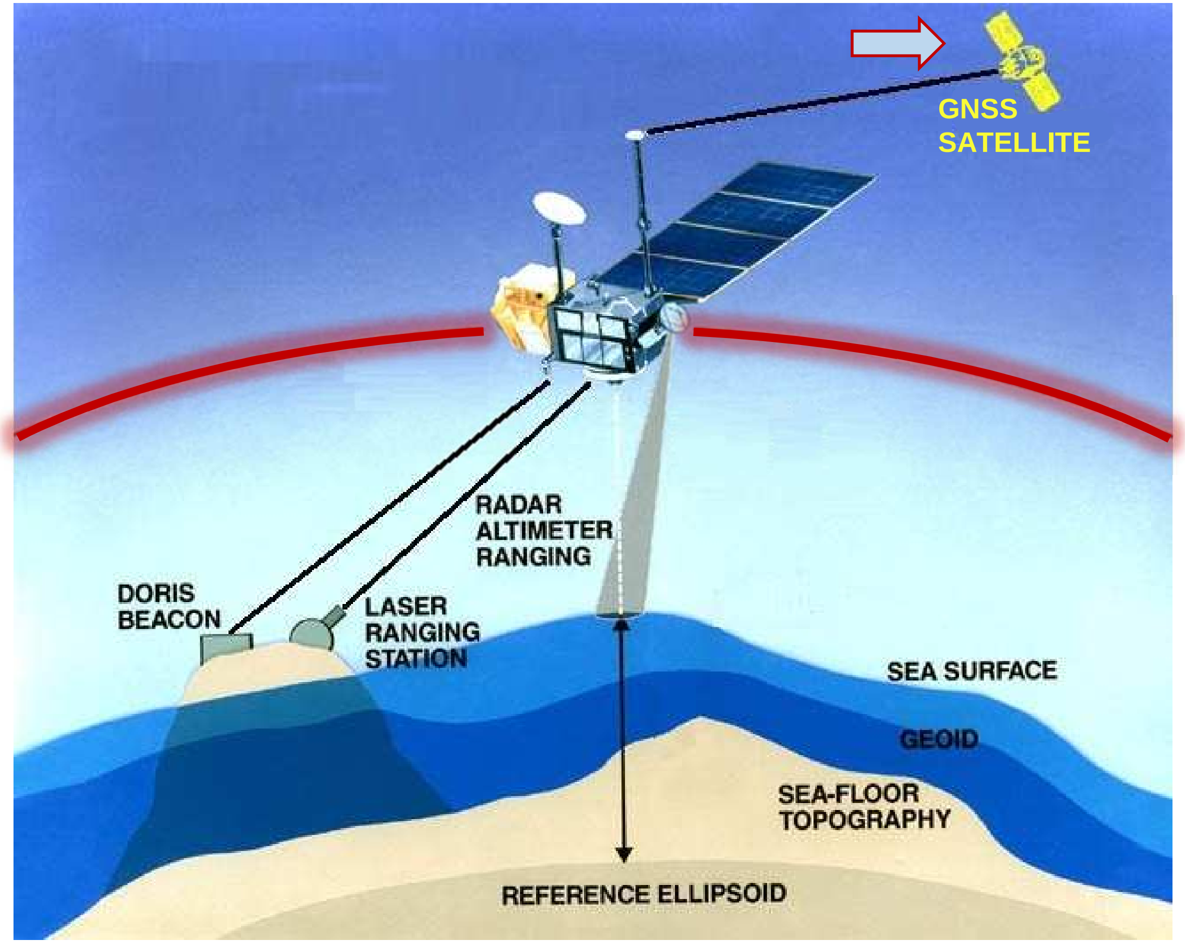
The Importance of GNSS for Precise Orbit Determination

- Current altimetry satellites GNSS onboard:
  Jason-3, Sentinel-3A/B, HY-2B/C/D, Sentinel-6MF
- CNES POE-F standards (Picot et al.,2018)
- CNES POD software ZOOM (Carrou, 1986)
- Example of GNSS POD accuracy
  (DORIS+GPS Red. Dyn. phase fixed ambiguities)

WRMS	Jason-3
Doris	~ 5 mm
GPS code	~ 60 - 70 cm
GPS phase	~ 6 mm
SLR	~ 1 cm

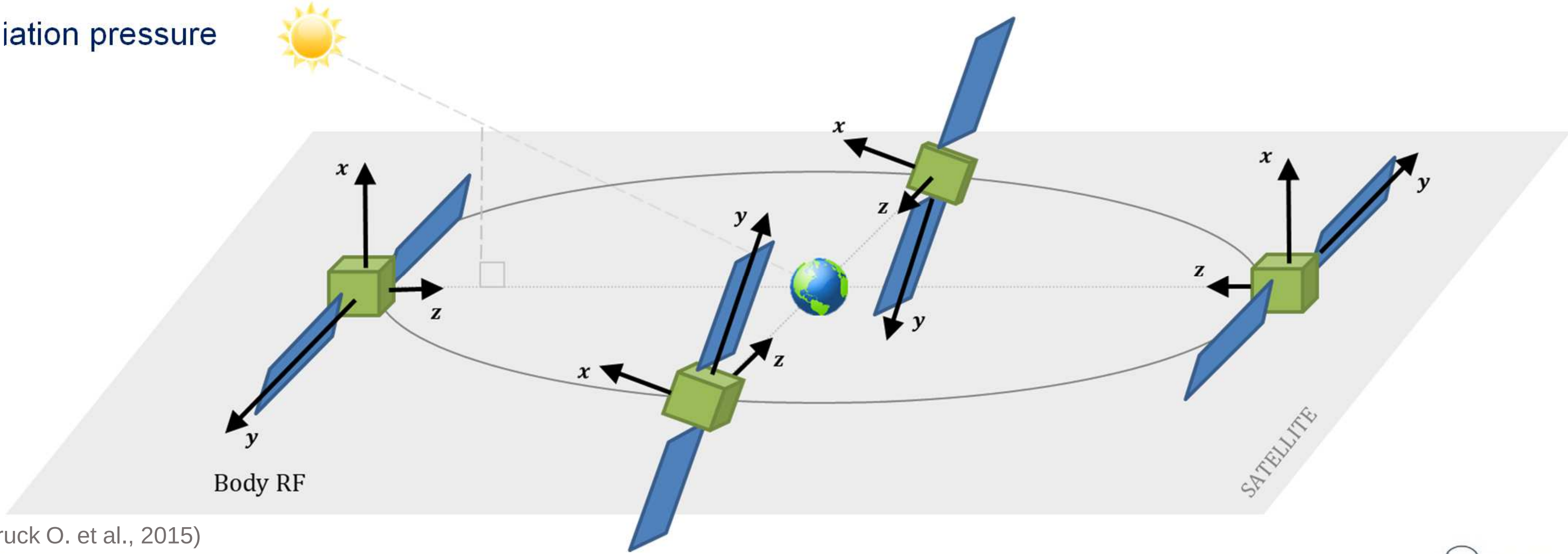
Can better knowledge of the GNSS attitude improve POD of LEO ?



Source : gssc.esa.int

GNSS Attitude – Why is it important ?

- Attitude = Geometry + Orientation
- CoM (orbit) ≠ Position of antenna (signal)
- Body Reference Frame (RF), Terrestrial RF
- Phase wind-up effect
- Solar Radiation pressure



Source : (Montenbruck O. et al., 2015)

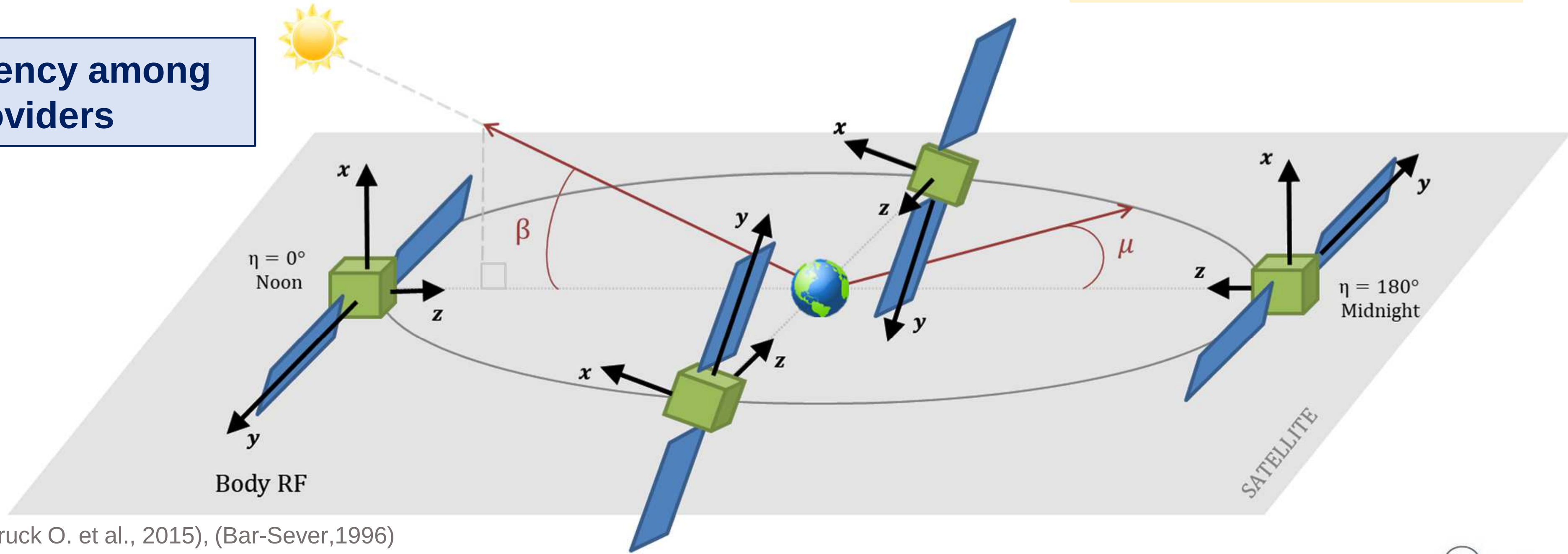
GNSS Orientation and Attitude Laws

- Mathematical models “laws”:
- Nominal law (Yaw steering)
- Auxiliary laws during satellite eclipses ($\beta \cong 0^{o}$)

Yaw-angle:

$$\psi = atan2(-tan\beta, sin\mu)$$

Inconsistency among GNSS providers



Source : (Montenbruck O. et al., 2015), (Bar-Sever,1996)

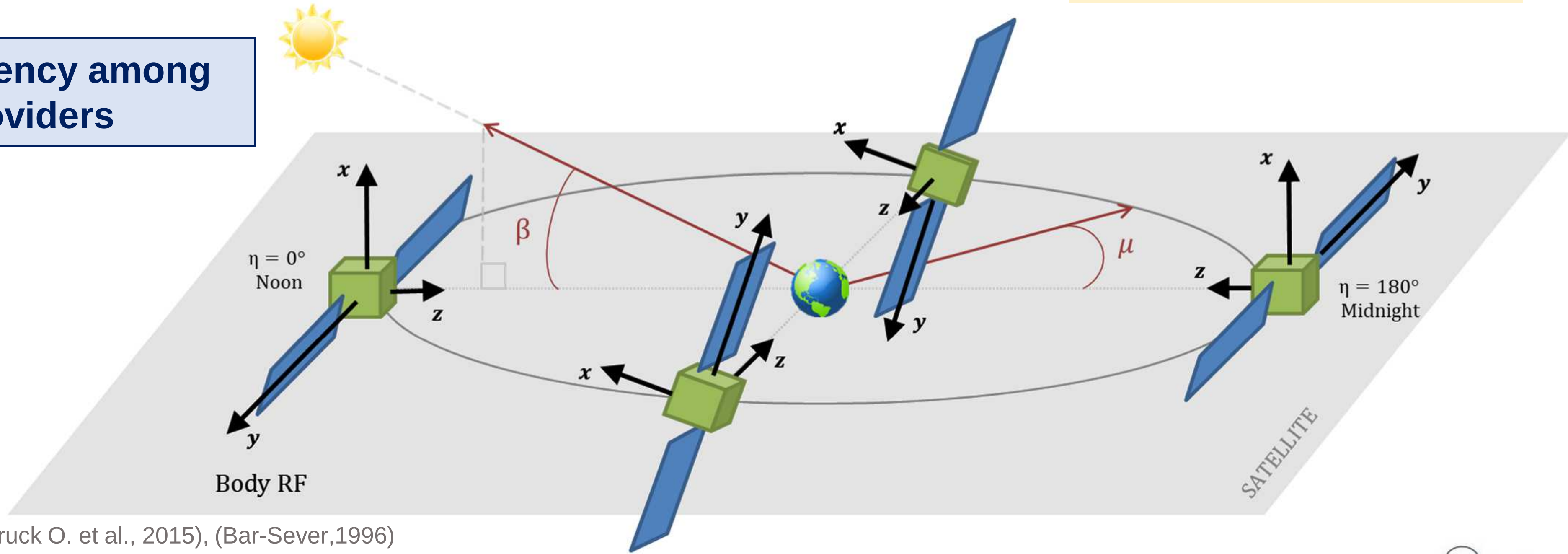
GNSS Orientation and Attitude Laws

- Difficulties:
- Attitude not available as measurement
- True attitude vs. Attitude Laws vs. Attitude adopted by GNSS providers
- Laws published for some GNSS systems (e.g. Galileo) but not all (e.g. GPS)

Yaw-angle:

$$\psi = atan2(-tan\beta, sin\mu)$$

Inconsistency among GNSS providers

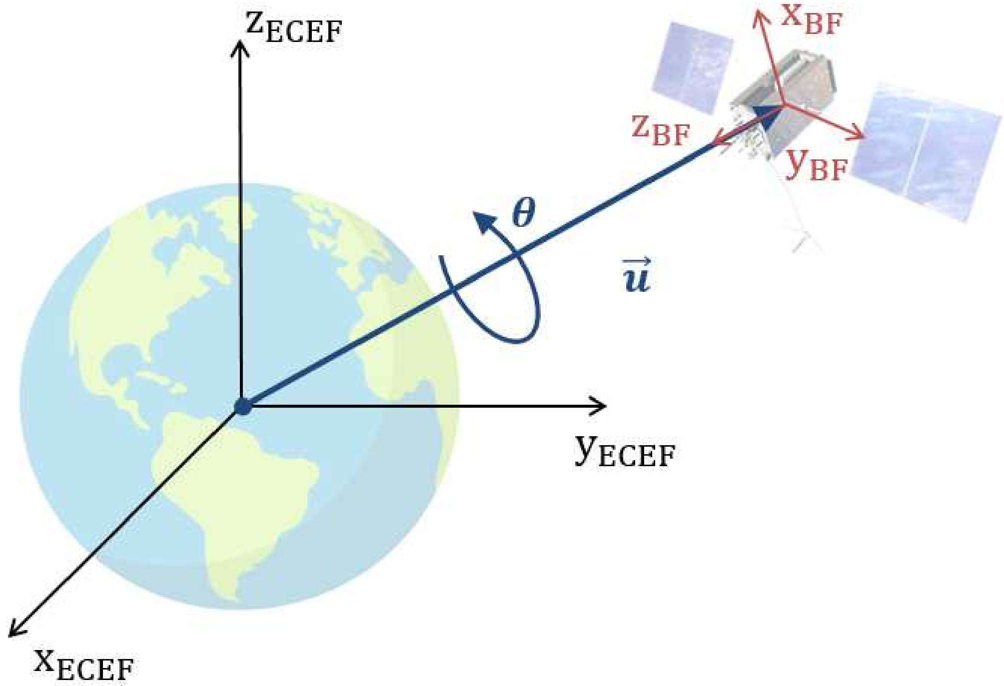


Source : (Montenbruck O. et al., 2015), (Bar-Sever,1996)

GNSS ORBEX files

- IGS decision (04/2019)
- Adopted by several IGS Analysis Centers (AC)
- Transformation: Terrestrial RF → Satellite BF
- Benefits: - kinematic PPP

  - smoother code / carrier-phase residuals



Quaternions:

$$q = (q0, q1, q2, q3) = (s, \vec{V})$$

$$q_{\theta,\vec{u}} = (\cos\frac{\theta}{2}, \vec{u} \cdot \sin\frac{\theta}{2})$$

Related Sources:

- Loyer S. et al. (2019), *GNSS Attitude quaternions exchange using ORBEX (Version 30/04/2019)*
- Loyer S. et al. (2021), *Exchanging satellite attitude quaternions for improved GNSS data processing consistency*, Adv. Space Res.
- Liu, T., et al. (2022), *Assessing the exchanging satellite attitude quaternions from CNES/CLS and their application in the deep eclipse season.* GPS Sol.

A Case of Study in LEO

- Mathematical models

POD: Orbits, Clocks, *Attitude* = inconsistencies ?

- ORBEX files

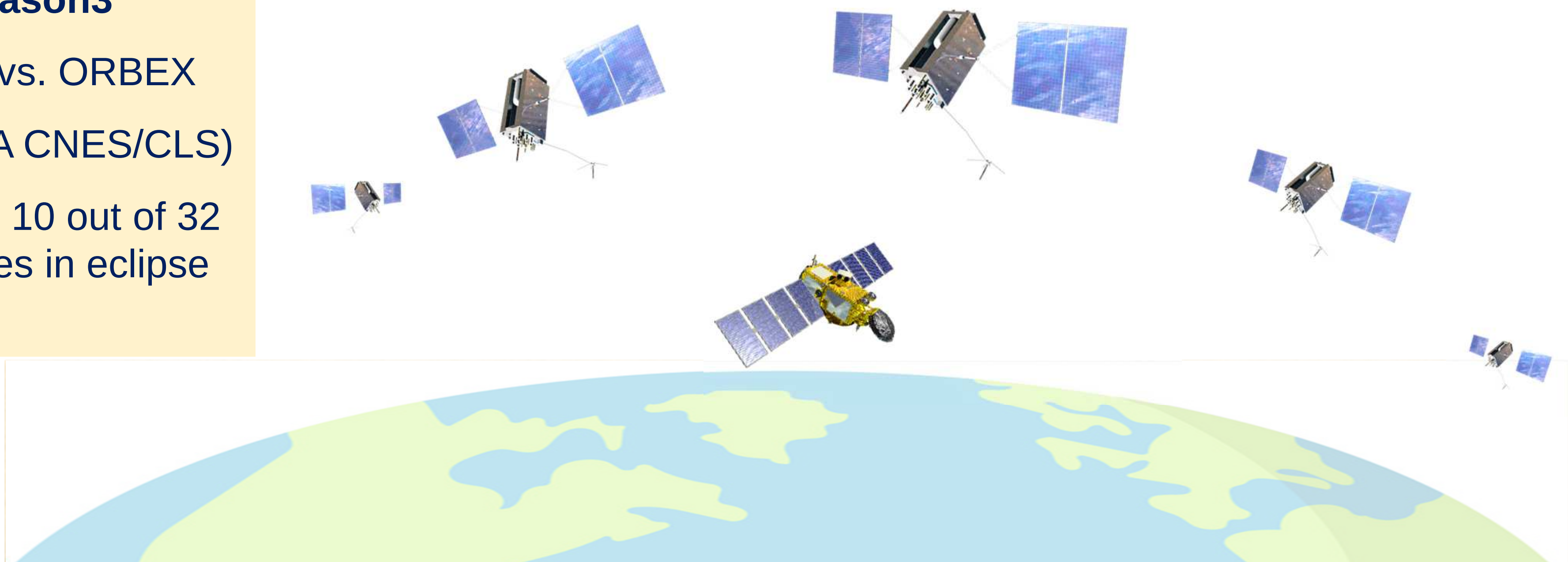
POD: Orbits, Clocks, Attitude

Jason3

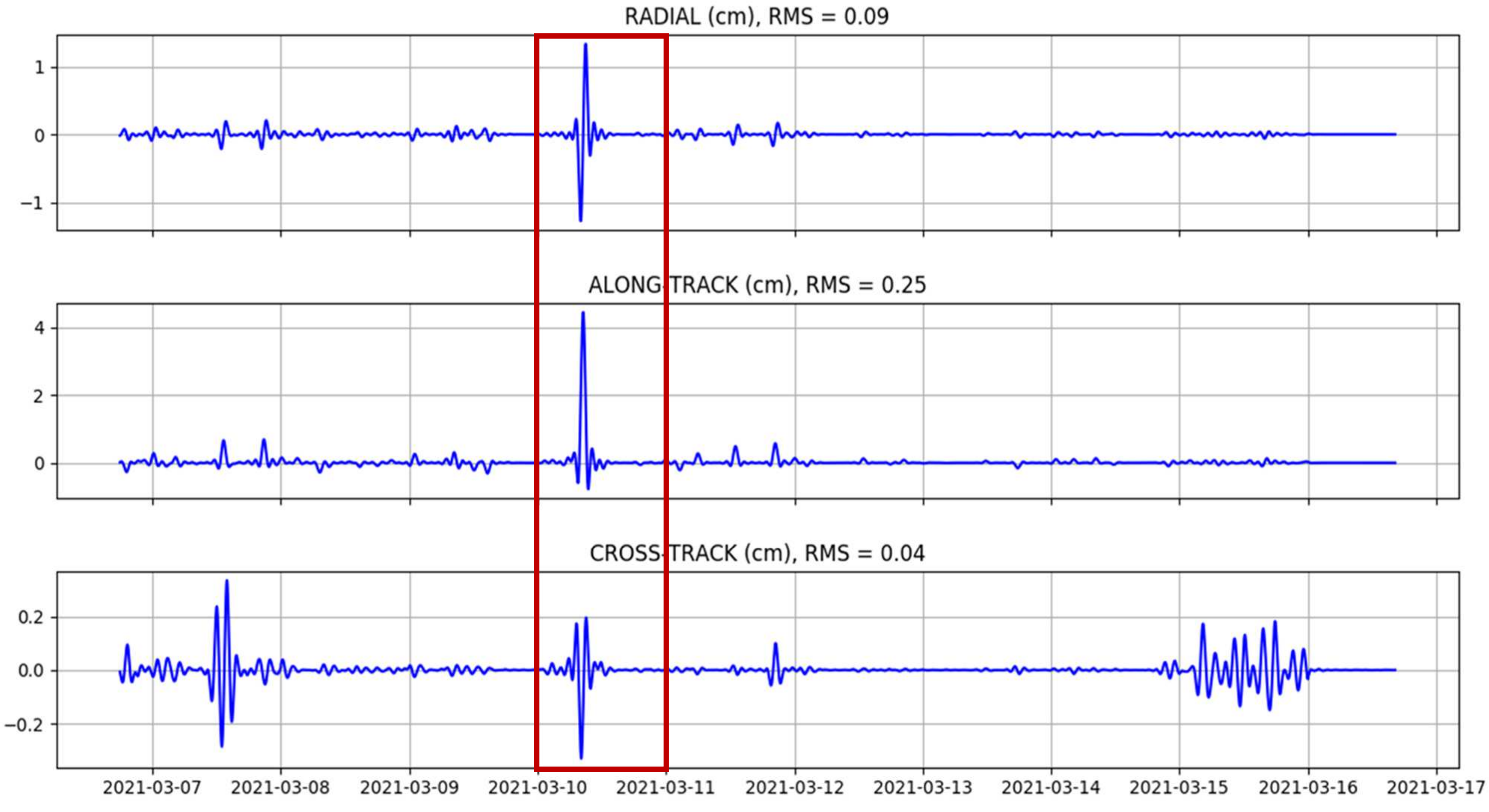
Laws vs. ORBEX

(from CA CNES/CLS)

CY187: 10 out of 32 satellites in eclipse

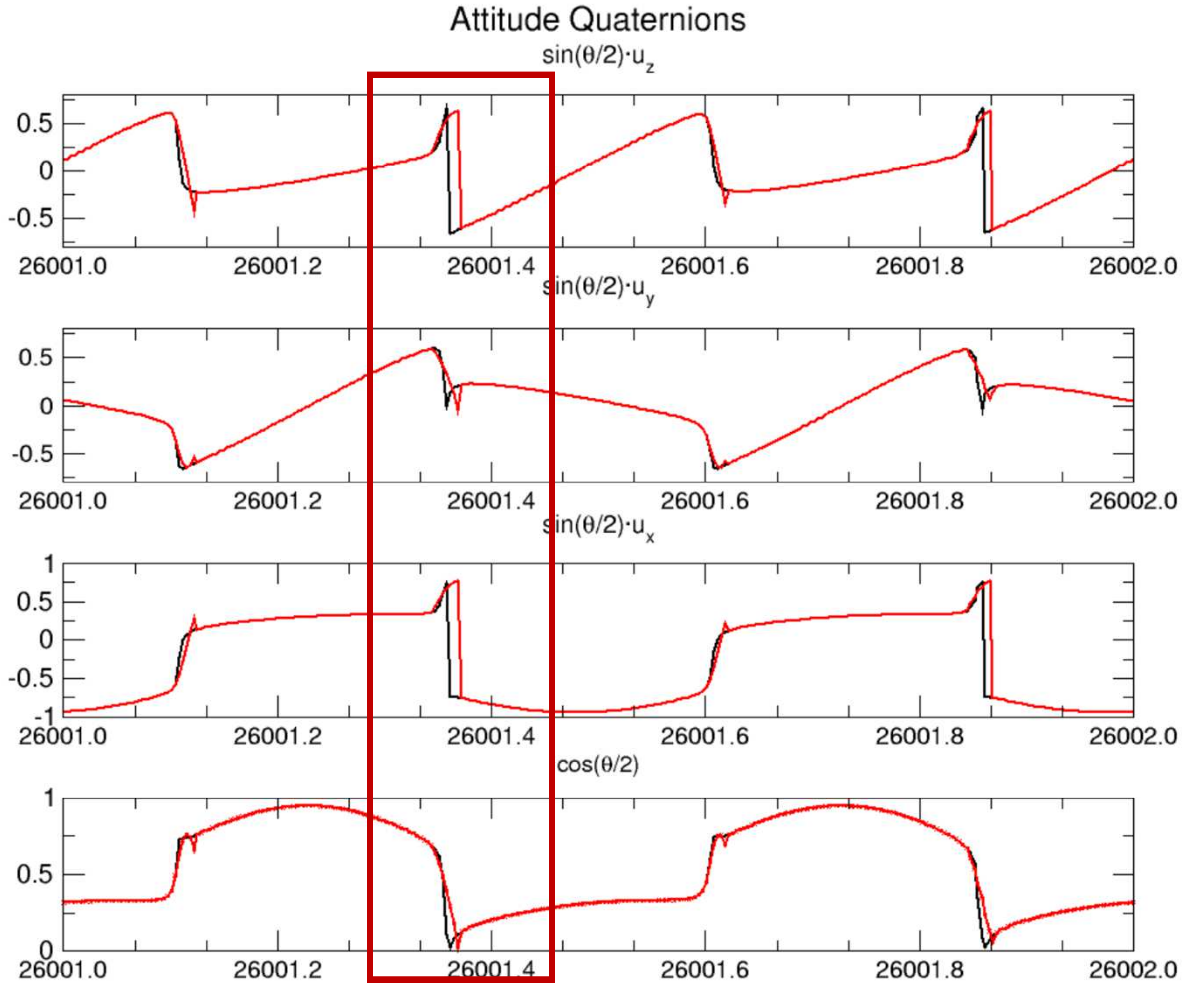


Jason-3 Orbit Difference (Laws Vs. ORBEX)



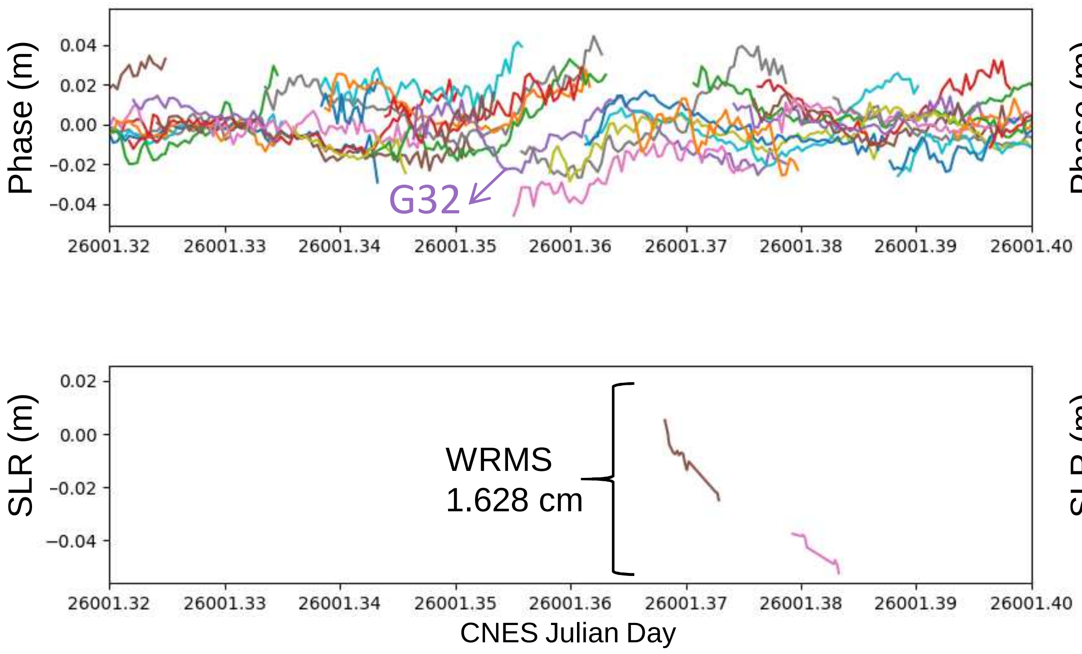
POD with Att. Laws
POD with ORBEX

G32
(in ‘midnight’)

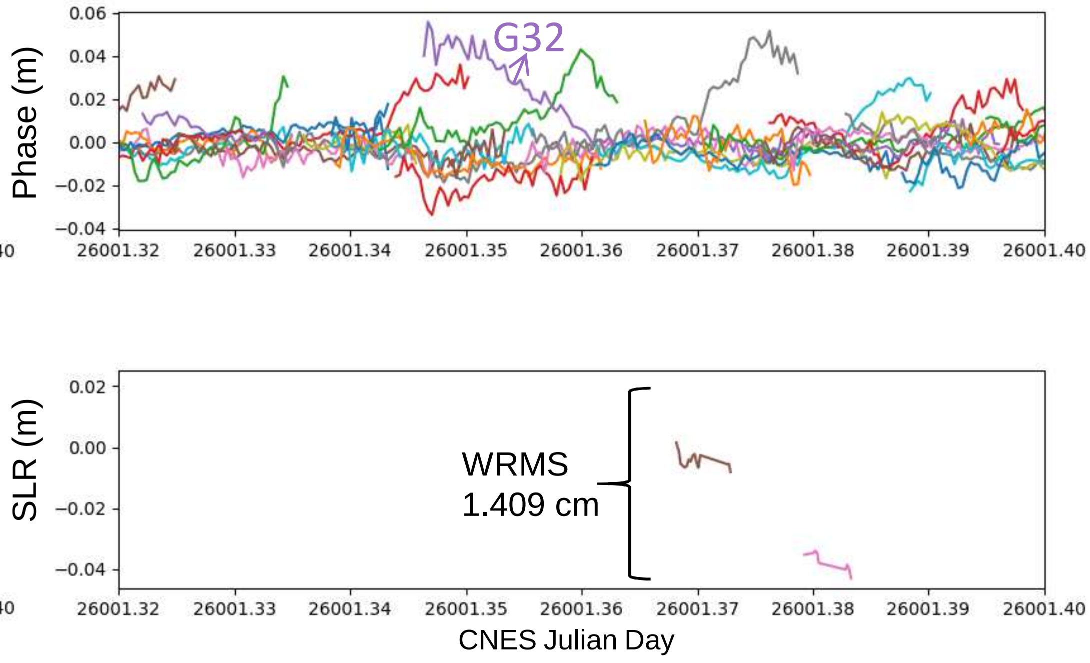


CNES Julian Day

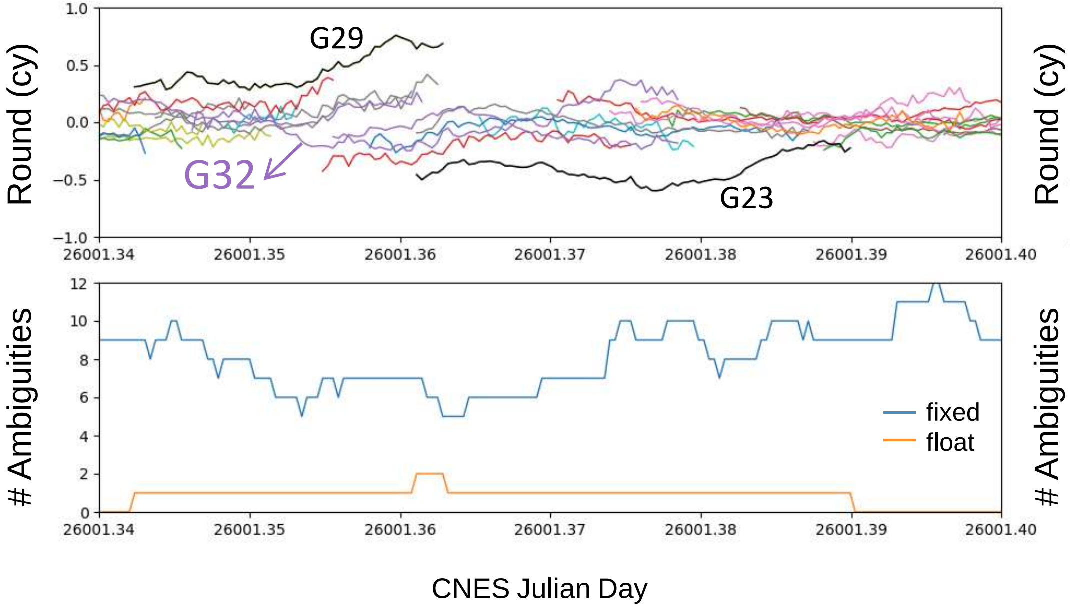
POD with Att. Laws



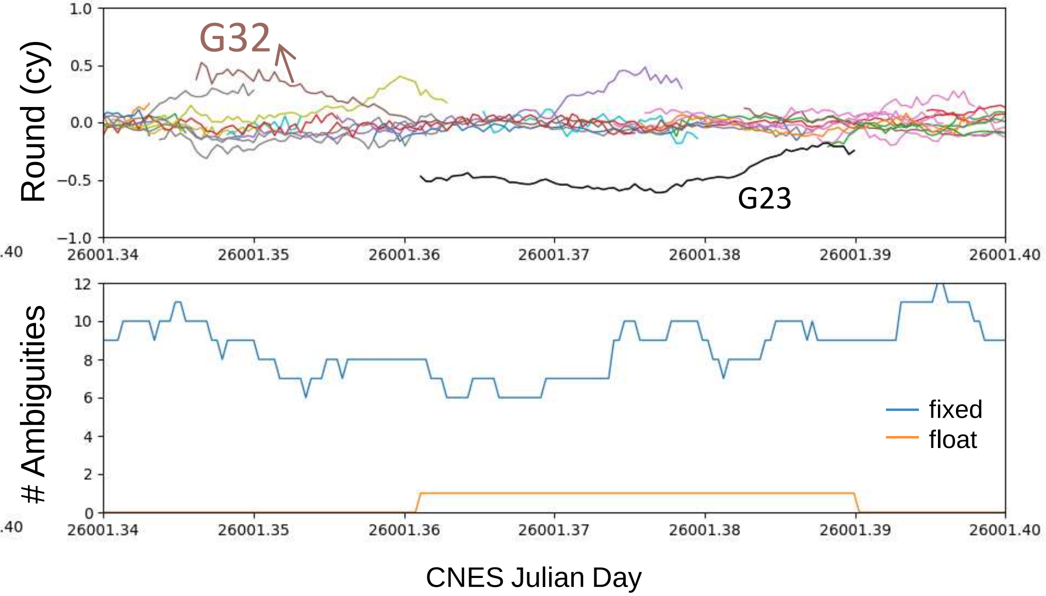
POD with ORBEX



POD with Att. Laws



POD with ORBEX



- In both solutions the pass of G32 was fixed
- … but to different values: N=11 (Laws) vs. N=10 (ORBEX)
- More passes blocked with ORBEX

Conclusions / Recommendations

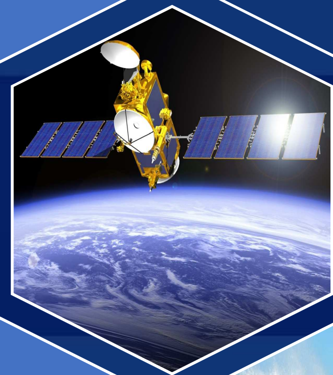
- Negligible differences outside eclipses vs. Significant differences in eclipses
- More stable carrier phase residuals
- Consistency of GNSS products (orbit, clock, attitude)
- Yaw attitude errors can be mitigated

- Future Work:
- Study of Sentinel-6 (GPS and Galileo) / Sentinel 3A & 3B
- Study longer period (for long term effects)
- Adoption of POD with ORBEX from CNES POD team (2023)

Can better knowledge of the GNSS attitude improve POD of LEO ?

Indication of benefits by using ORBEX files

THANK YOU !



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Sources

Bar-Sever Y.E. (1996), A new model for GPS yaw attitude. J Geod. doi: 10,1007/BF00867149
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Loyer S. et al. (2019), GNSS Attitude quaternions exchange using ORBEX, http://acc.igs.org/misc/proposal_orbex_april2019.pdf
Loyer S. et al. (2021), Exchanging satellite attitude quaternions for improved GNSS data processing consistency, Adv. Space Res. doi: 10.1016/j.asr.2021.04.049
Montenbruck O. et al. (2015), GNSS satellite geometry and attitude models, Adv. Space Res. doi: 10.1016/j.asr.2015.06.019
Picot N. et al. (2018), Jason-3 products handbook. SALP-MU-M-OP-16118-CN 1(5):28–31

Images

[1] https://ostst-altimetry-2022.com/
[2] gssc.esa.int/navipedia/index.php/Precise_Orbit_Determination
[6]https://science.nasa.gov/get-involved/toolkits/spacecraft-icons
[11]https://create.vista.com/fr/unlimited/stock-photos/167236754/stock-photo-red-puzzle-piece/
[12] https://cnes.fr/sites/default/files/migration/automne/standard/2011_08/p8334_a2fa690331f41617f30924ebd93bc436P32369_MD.jpg

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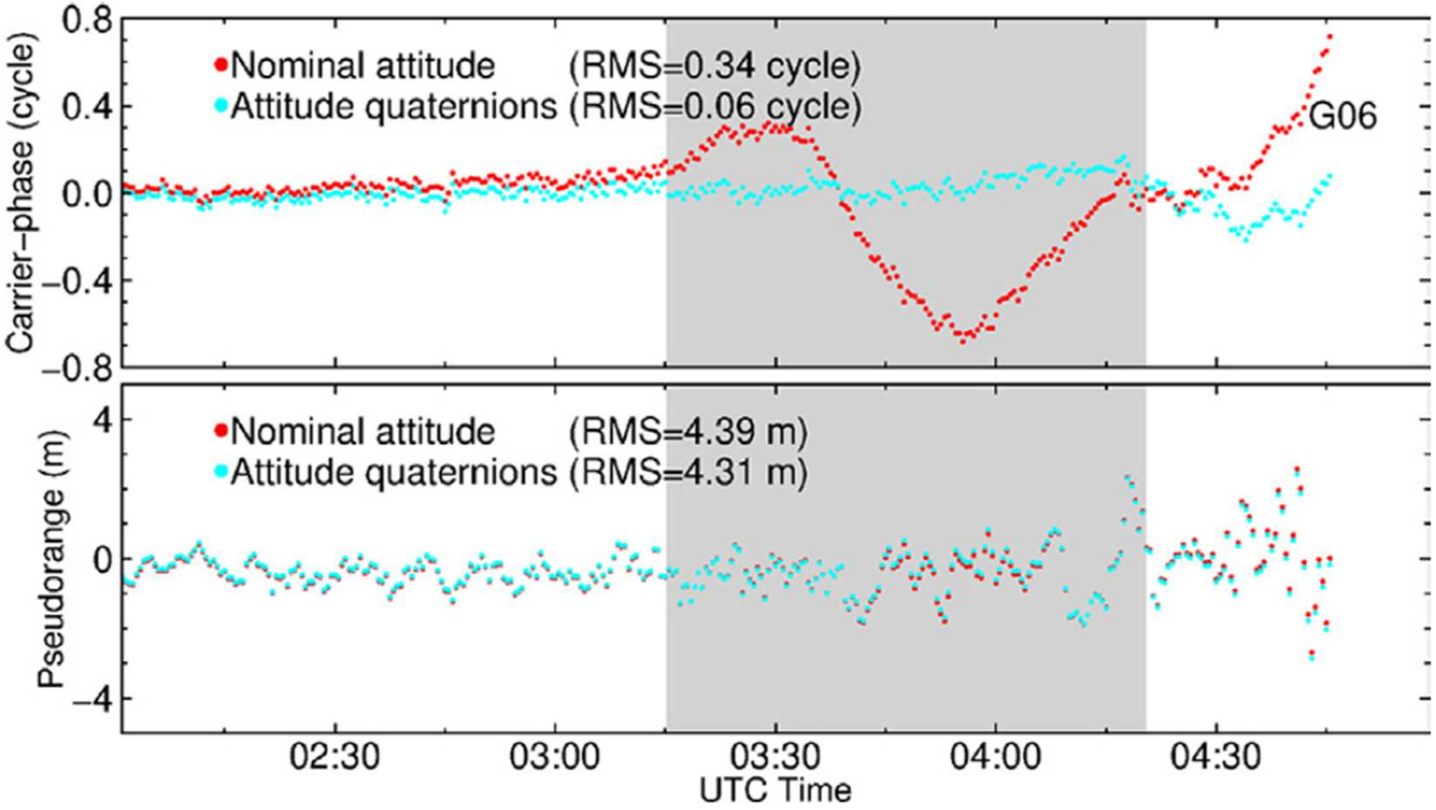
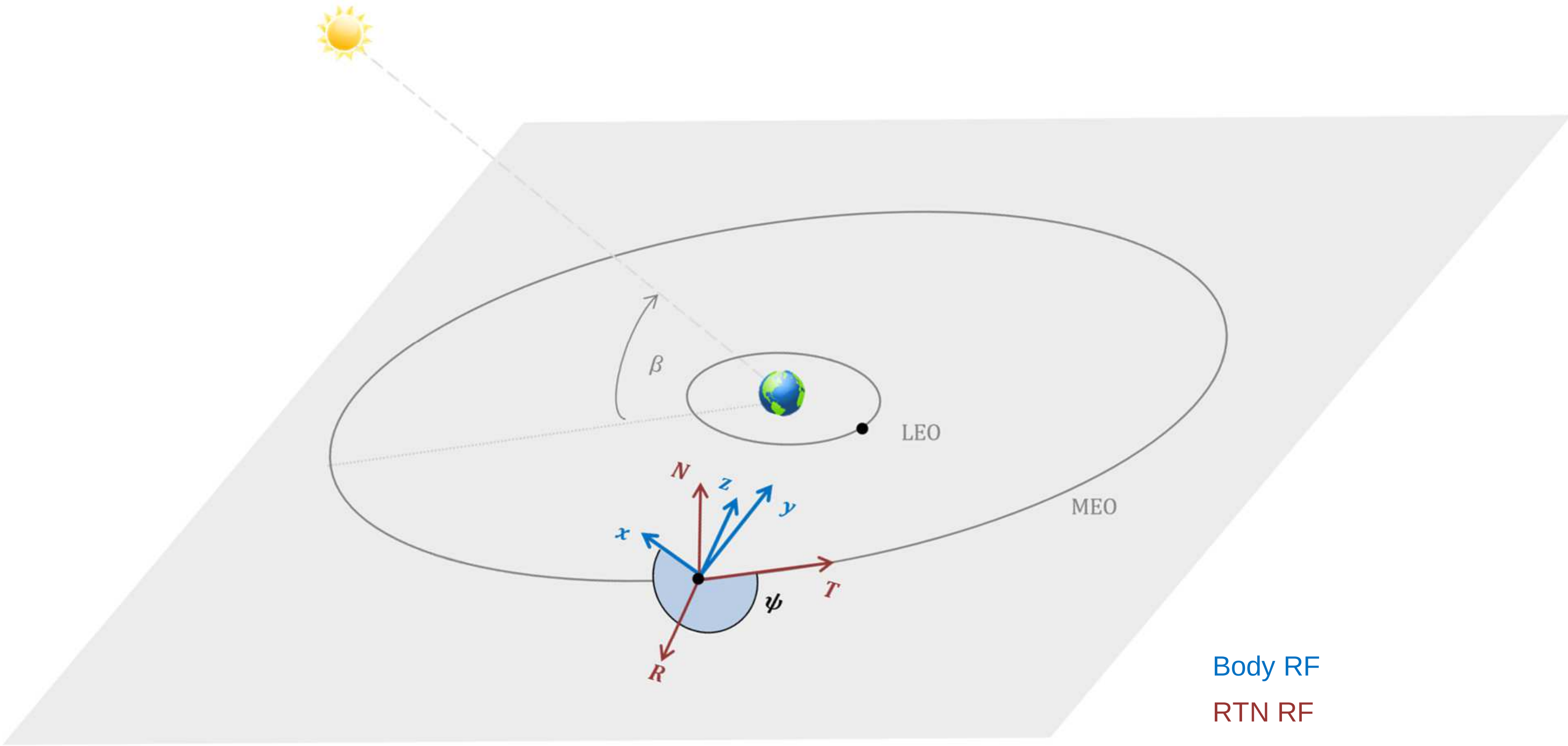
GNSS ORBEX in POD



Example: PPP satellite residuals for URUS station for GPS06 satellite. Comparison of nominal attitude and use of attitude quaternions.

Source: Loyer S. et al. (2021), Exchanging satellite attitude quaternions for improved GNSS data processing consistency, Adv. Space Res. doi: 10,1016/j.asr.2021.04.049

GNSS Orientation and Attitude Laws



Body RF

RTN RF

Source: Montenbruck O. et al. (2015)