Validation & Qualification of Space Debris Laser Systems at the Expert Centre for Space Safety

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Yebes, Spain

Agenda

- Problem Statement
- Observation Equation
- Example
- Road Map V & Q

Problem Statement

How can we determine the quality, performance and stability of a given space debris laser ranging system to ensure an optimal exploitation of the observable?

Rationale: Let's try to split the problem analyzing the error sources of the observable assessing their contribution considering only single passes from a unique station.

Observation Equation:

$$\rho_{obs}^{1-way}(t) = ||X^S(t) - X_R(t)|| + T(*)_{del} + S(*)_{del} + CoM(*) + Rel(*) + Rb(*) + \xi.$$

$(*) \rightarrow$ dependencies due to system, target, etc.

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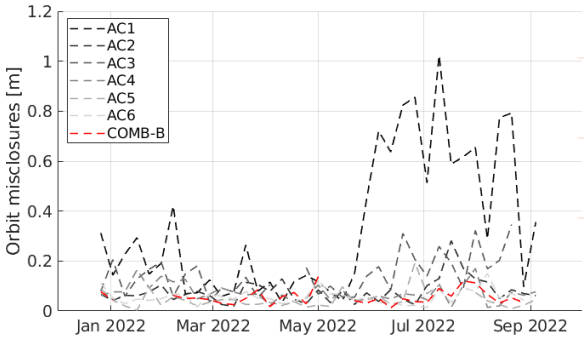
Satellite Position



- How good are the orbits? On average $\approx$ 10 cm $\rightarrow$ orbit misclosures
- When no overlap $\rightarrow$ extrapolated overlap if error <= 5 cm
- Could we use precise predictions instead?

Error between CPFs and COMB-B of about 10 cm at same epoch and $\approx$ 30 cm after 3 days

Orbit overlaps LAGEOS-1 7-arc solution $\neq$ AC

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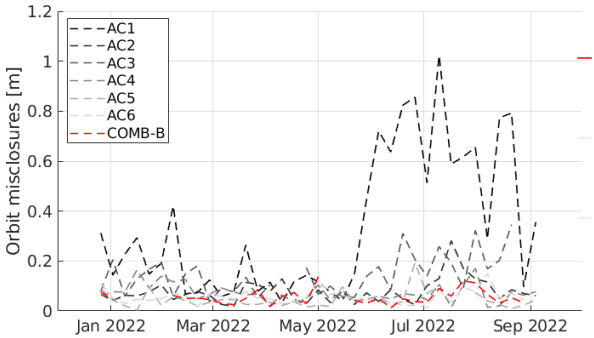

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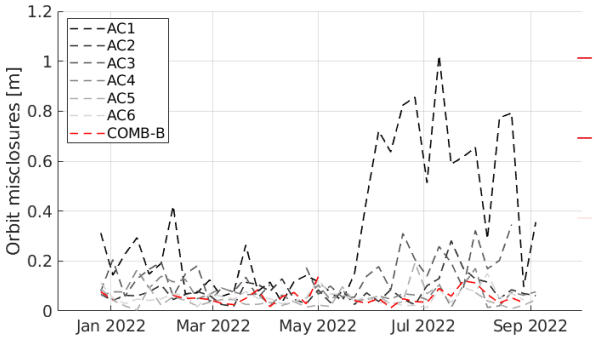

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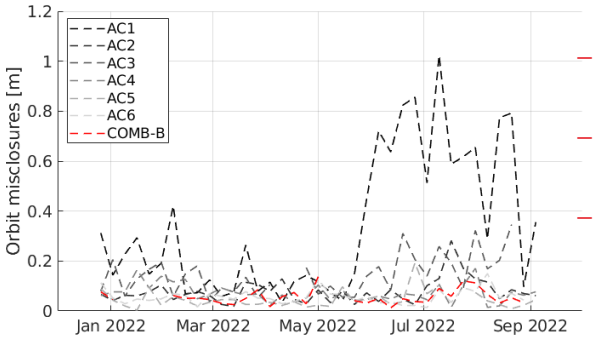

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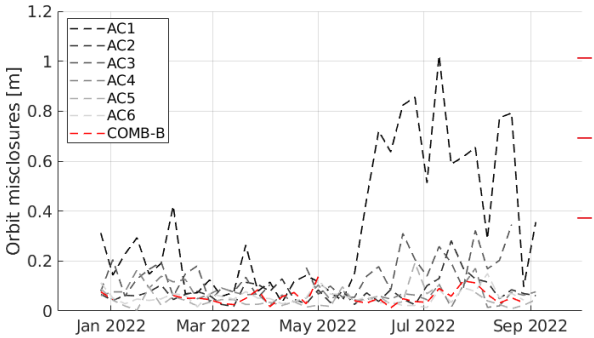

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Observation Equation

Station Coordinates & Eccentricities

Coordinates estimated according to ILRS framework:

- Estimate station position, velocities & formal errors associated to a specific reference frame (ideally SLRF2020)
- Include corrections to the station coordinates (post-seismic deformations, tidal effects, etc.) when > 30 cm (predictions)

If sensor prefers to be agnostic to any existing network:

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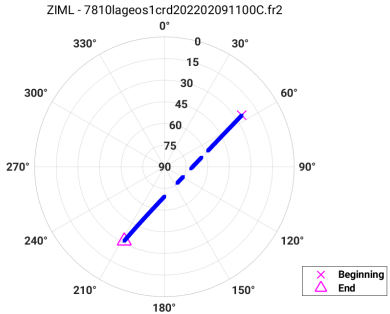
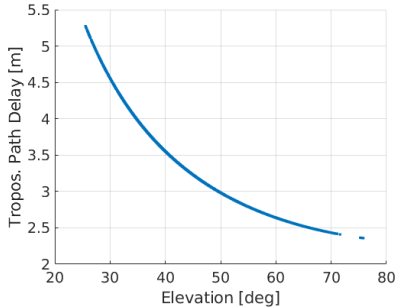
Observation Equation

Tropospheric Path Delay





- Yes, it is a must (models available Marini-Murray & Mendes-Pavlis)
- Dependent on the relative geometry of the observed pass, wavelength & meteorological information of the station

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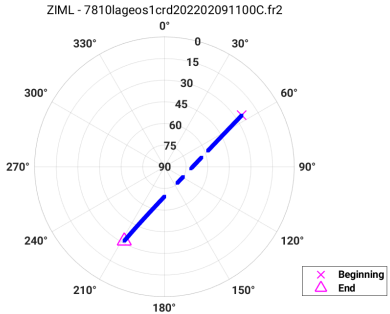

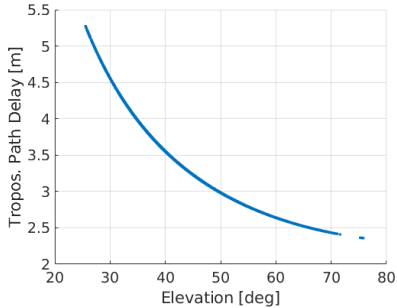

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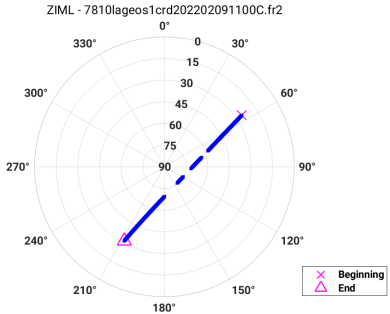

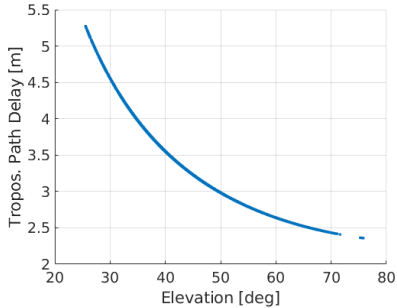

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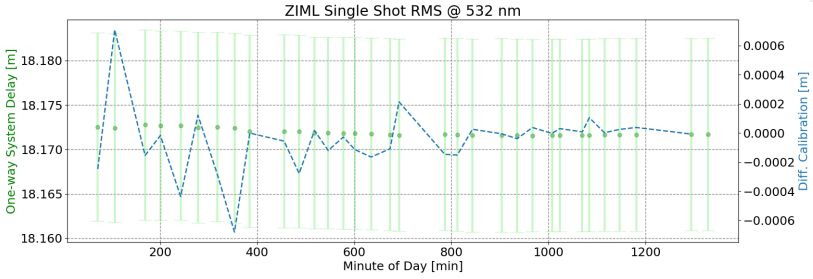
Observation Equation

System Delays $\longleftrightarrow$ Range Bias



- Agreement between the pulse width (60 psec @ 7810) and dispersion (error bars)
- Stability of the system delays over time
- Consider a longer time span analysis to have a more representative figure

Observation Equation

Center of Mass Correction

- Corrections dependent on target object & system specifications
- For fiducial targets CoM offsets are estimated for stations with technical specifications (see ILRS recommendations)

How to proceed with completely new sensors?

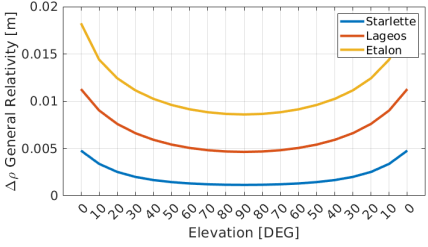
- Only relevant for validation
- For space debris laser systems, the *standard* CoM for LAGEOS-1 is 25.1 cm (!)

Observation Equation

Other Corrections: General Relativity (Light Path Bending)

$$|\text{certain corrections}| < |\epsilon_{X^s}|$$

Example:

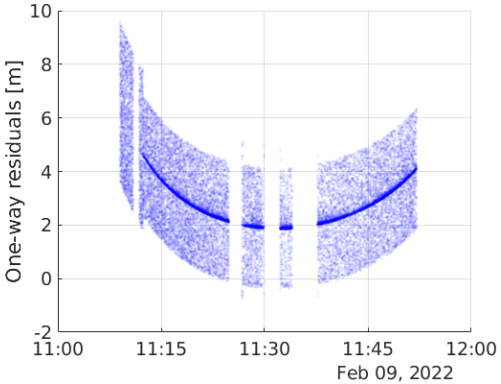


Other corrections applied for round trip travel time in ECEF:

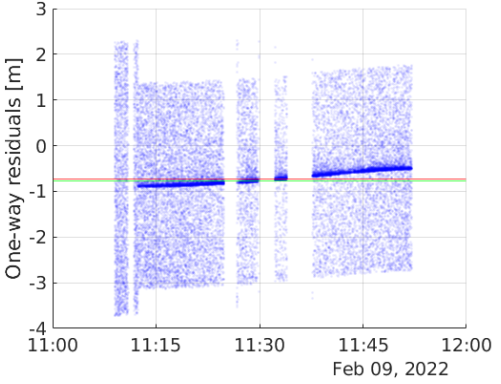
- Sagnac
- Light travel time

Example

Only from system delays



Other error sources



Visible trend of the residuals?

Example

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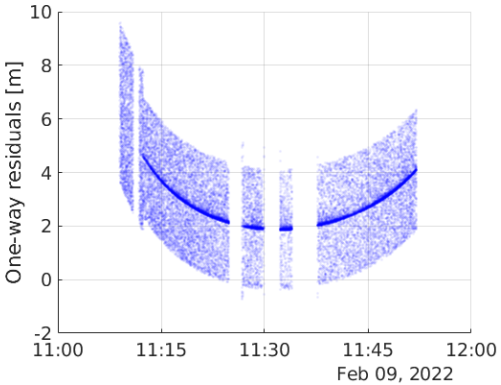

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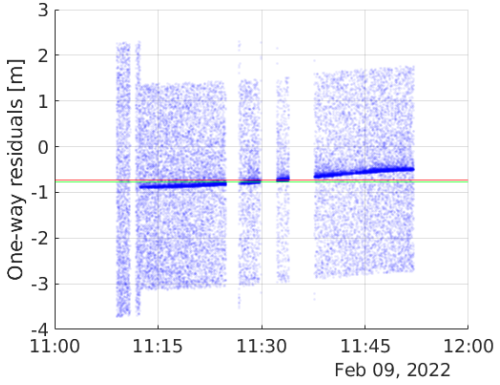

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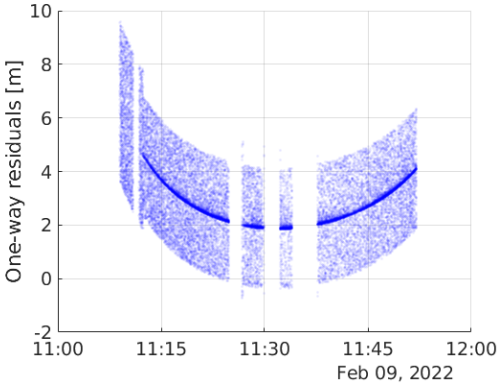

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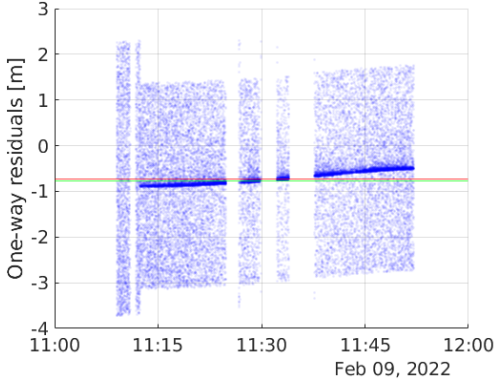

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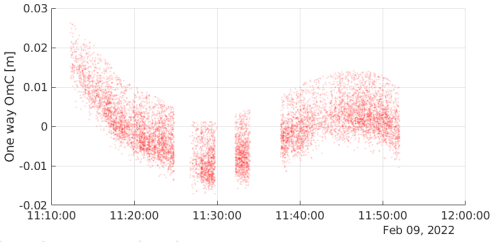

First order approximation:

- 1^{st} order Taylor series expansion ($O(Tb^2)$) of ρ_{obs}^{1-way} yields:
  Rb = -0.70 m ± 0.02 m,
  Tb = -0.10 msec ± 0.01 msec.
- Remaining trend may be modeled by variations in $X^S(t)$ or $X_R(t)$

Consistency check:

Pass Num.	Tb [msec]	Rb [m]
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Feb-09-22 15:00	-0.2	-0.60
Feb-09-22 23:00	-0.1	-0.50

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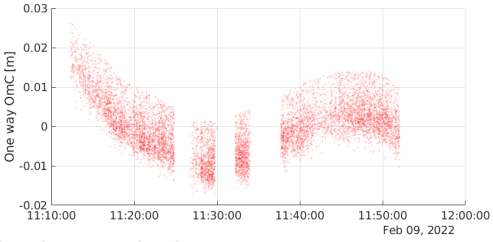

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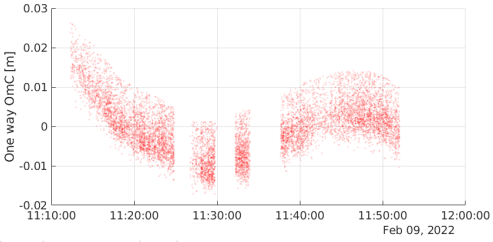

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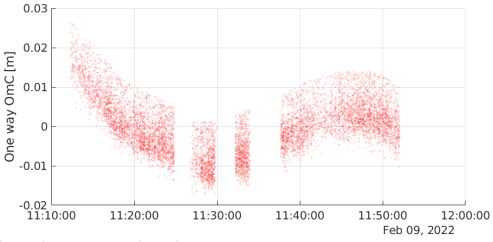

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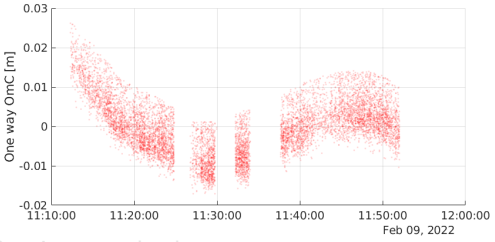

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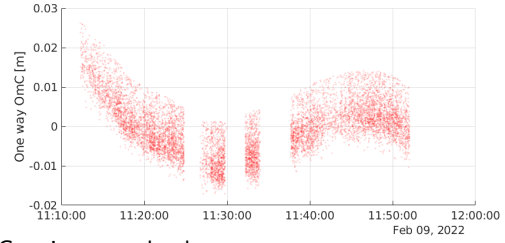

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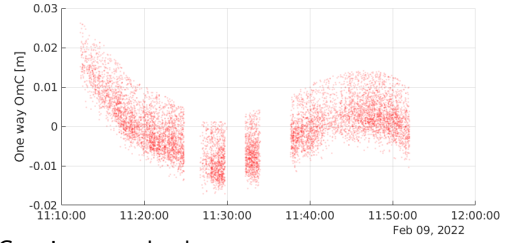

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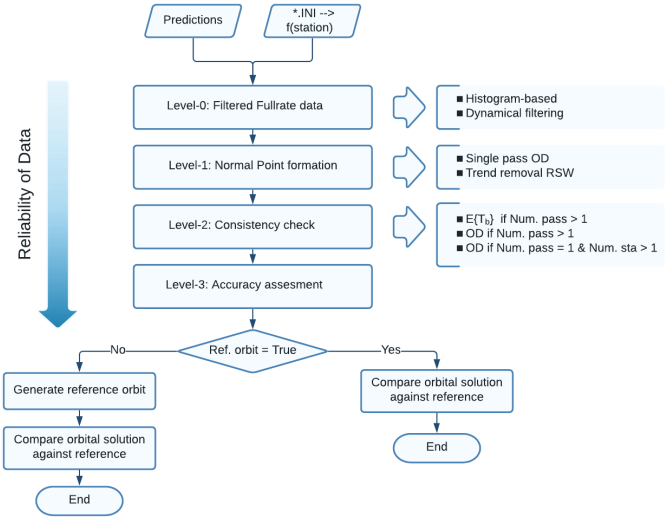
Predictions
*.INI --> f(station)
Level-0: Filtered Fullrate data
Level-1: Normal Point formation
Level-2: Consistency check
Level-3: Accuracy assesment
Reliability of Data
Histogram-based
Dynamical filtering
Single pass OD
Trend removal RSW
E{Tb} if Num. pass > 1
OD if Num. pass > 1
OD if Num. pass = 1 & Num. sta > 1
Ref. orbit = True
No
Yes
Generate reference orbit
Compare orbital solution against reference
End
Compare orbital solution against reference
End

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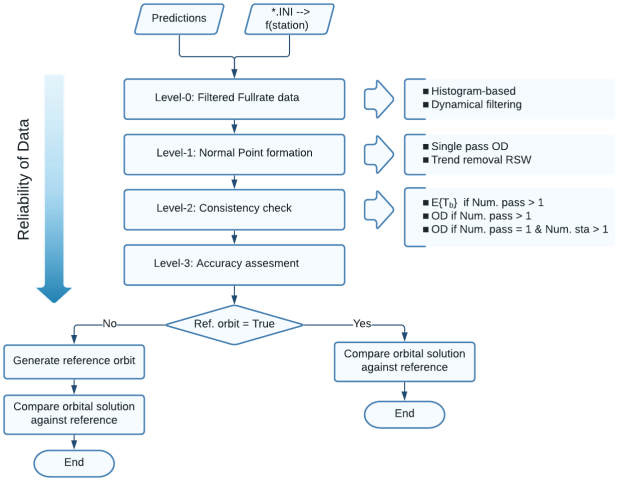

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