Improved GNSS-Based Precise Orbit Determination by using highly accurate clocks

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IGS Workshop 2017

07. July 2017, Paris

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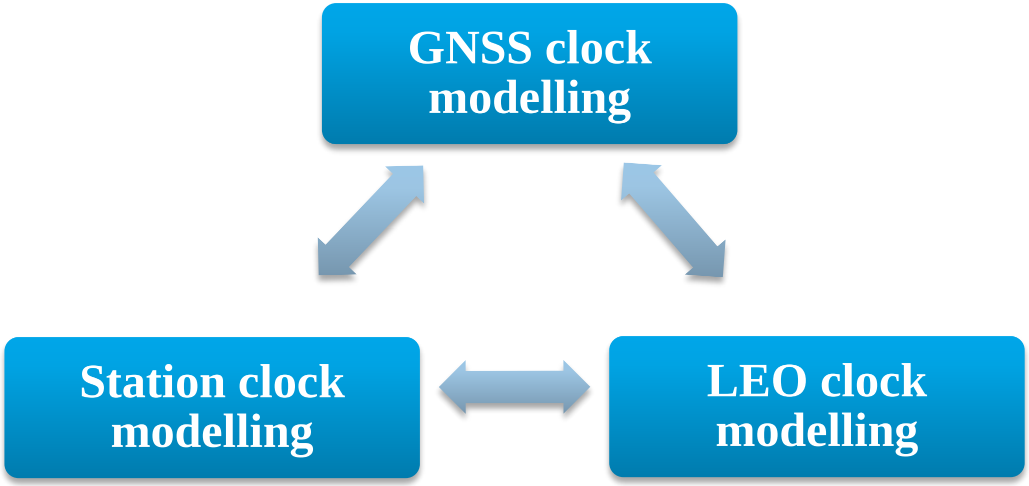
Outline

- Project overview
- Clock modelling for GNSS POD
- Kinematic orbit determination for GNSS with satellite clock modelling
- Clock modelling for kinematic LEO POD
- Sentinel 3-A clock assessment

Project Overview

- To investigate potential of modern satellite clocks for physical clock modelling for improving Precise Orbit Determination (POD) for GNSS and Low Earth Orbiting (LEO) satellites.
- Concepts and algorithms for clock modelling have been developed and their impact on POD for GNSS and LEO analyzed.



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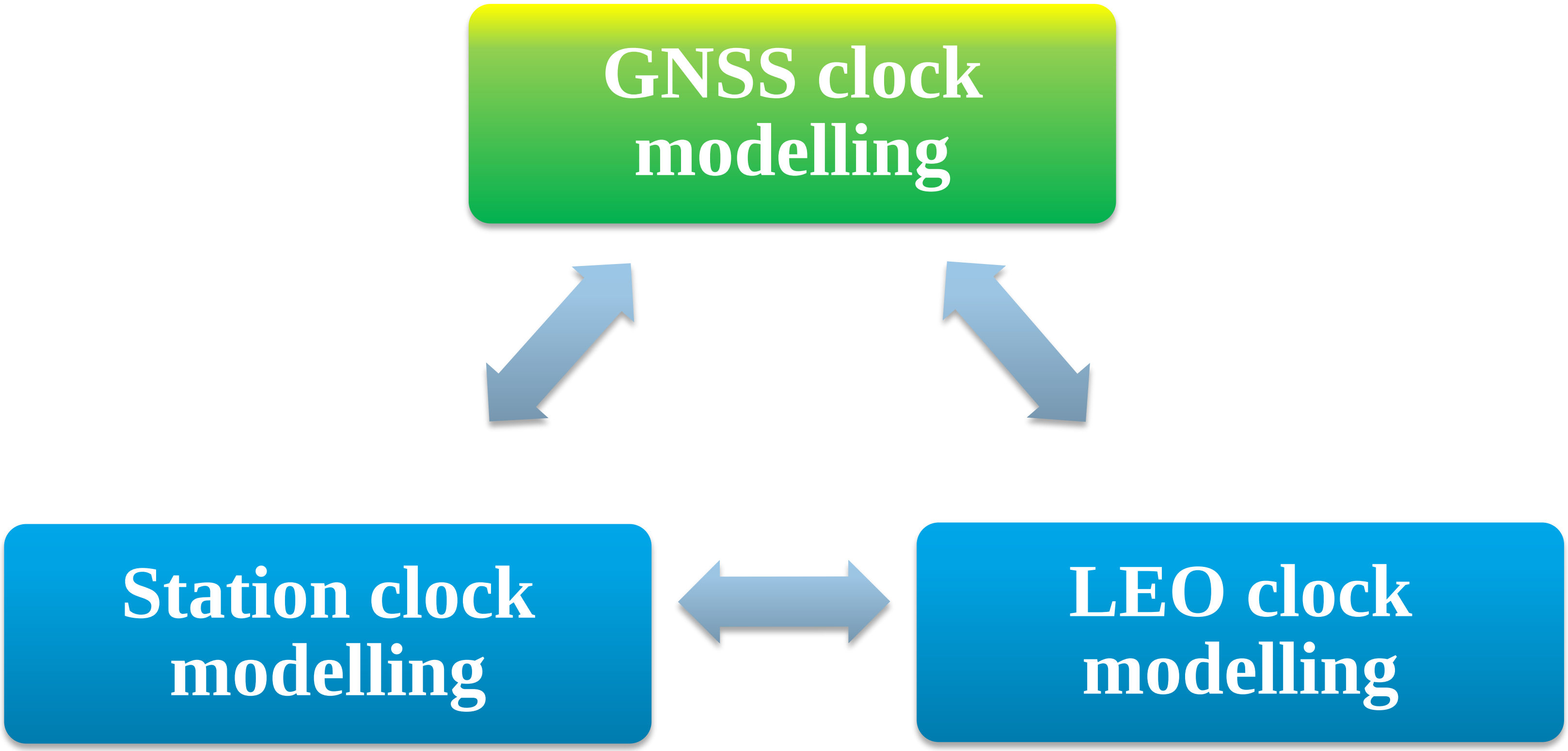
Clock modelling for GNSS POD



Clock modelling for GNSS POD

- Constraining of epoch-wise clock corrections to a clock model for highly accurate Galileo satellite clocks (Passive Hydrogen Masers):

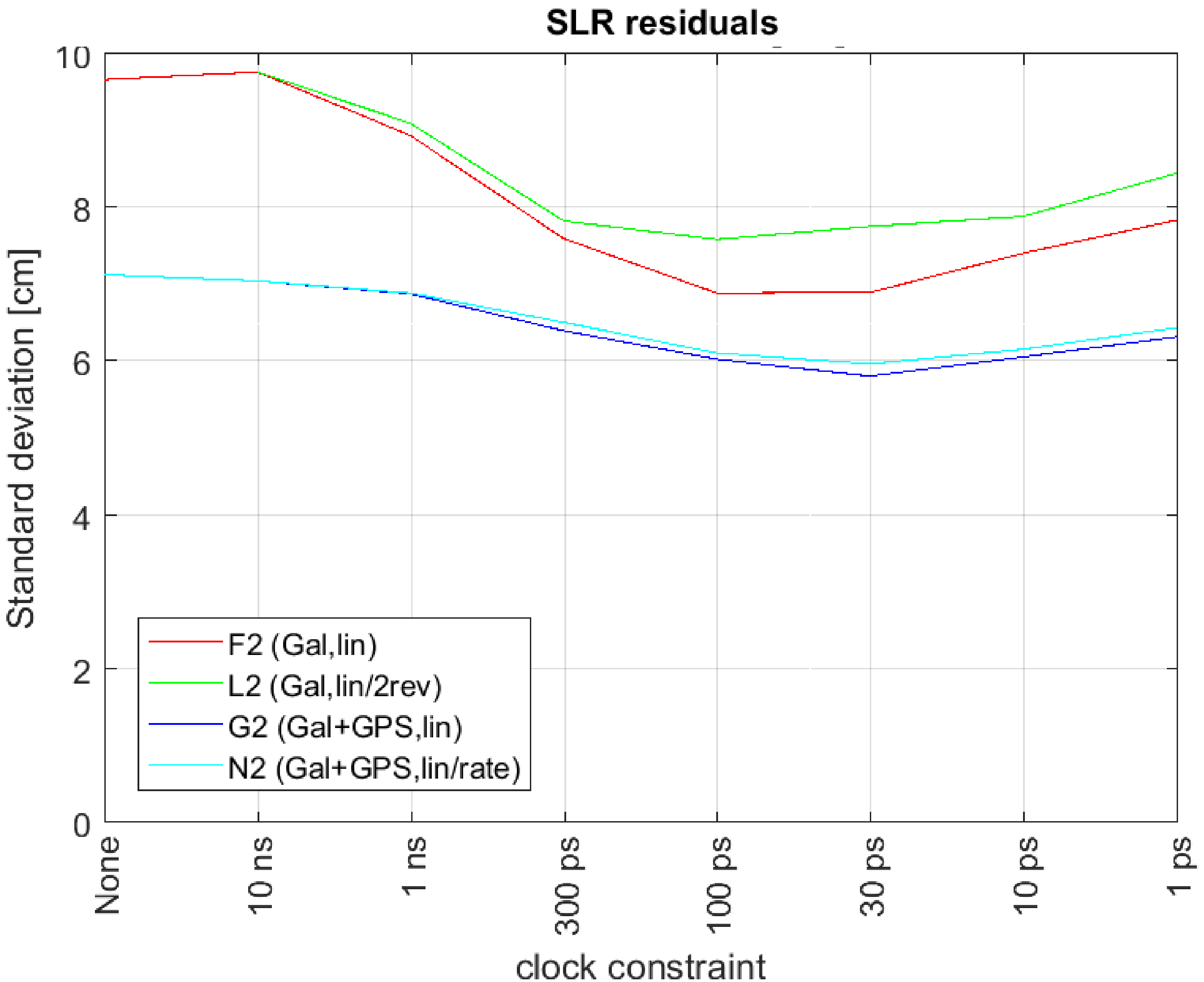
(1) „lin“: $\delta t(t) = a_0 + a_1(t - t_0)$

(2) „lin/rate“: $\delta t(t) = a_0 + a_1(t - t_0) + \boxed{a_2(t - t_0)^2}$

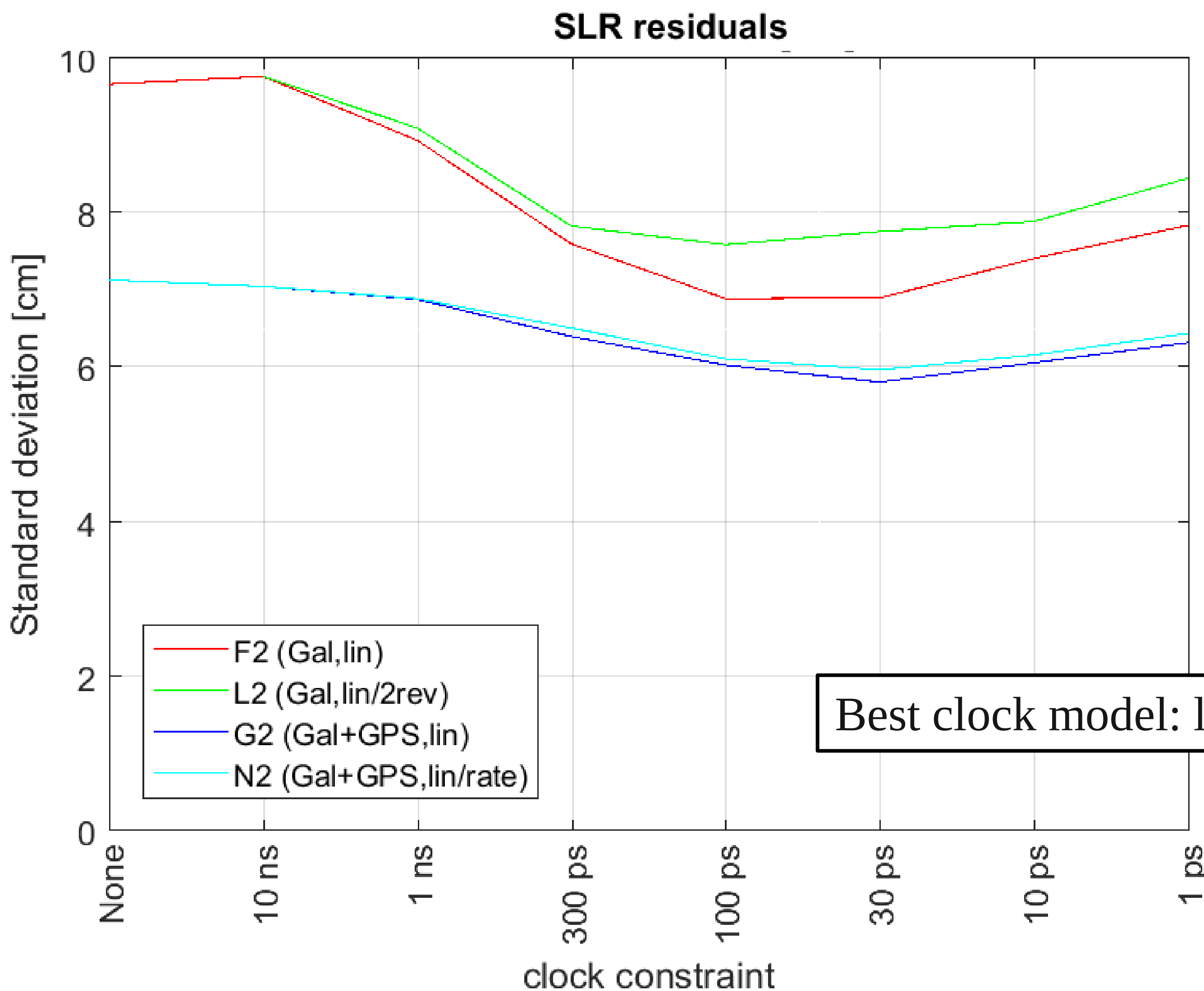
(3) „lin/2rev“: $\delta t(t) = a_0 + a_1(t - t_0) + \boxed{c_2 \cos 2nt + s_2 \sin 2nt}$

- Analysis of POD results for selected test scenarios.
- Time span of one week in 2016 (doy 059-065).

Clock modelling for GNSS POD

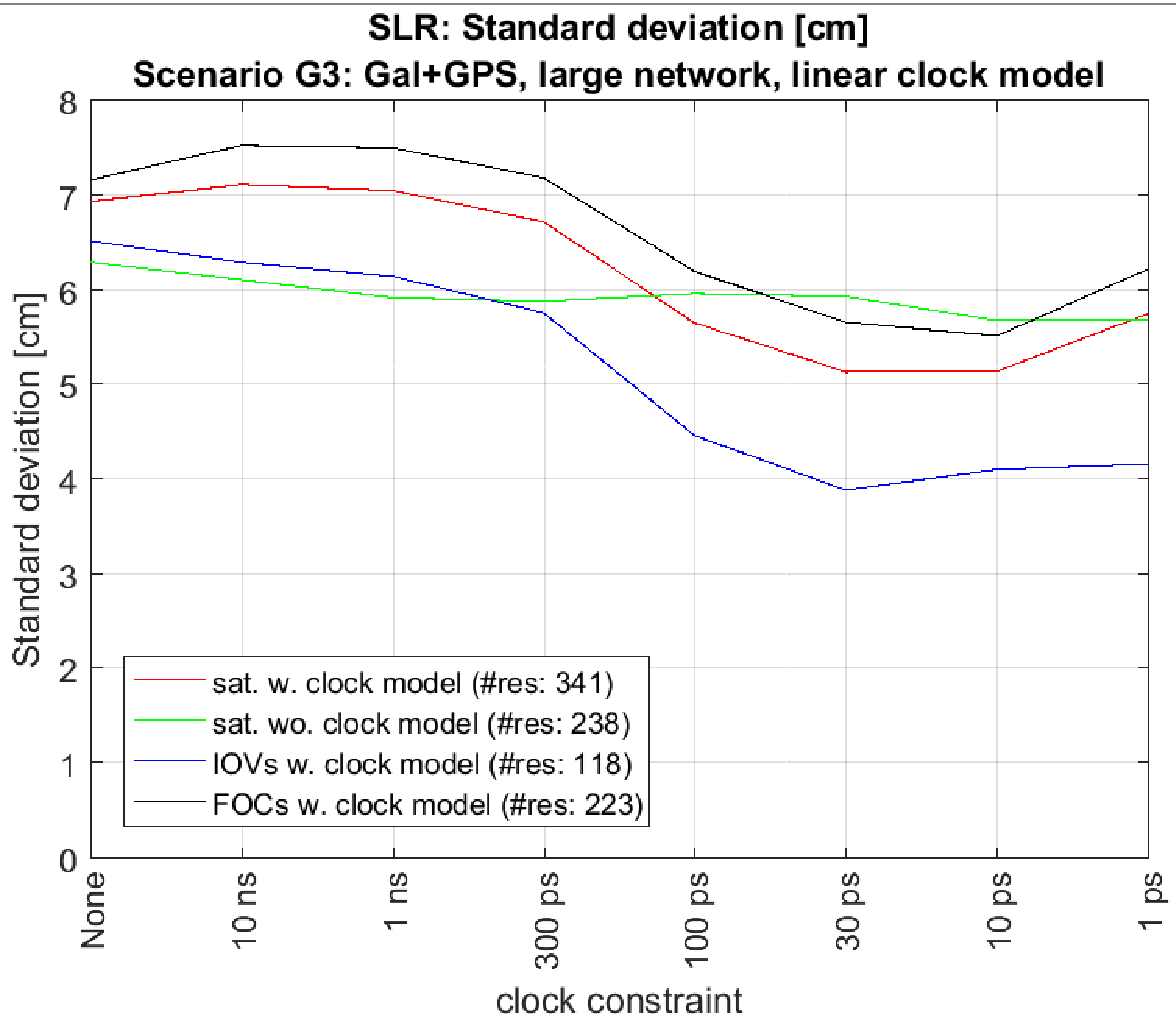


Clock modelling for GNSS POD

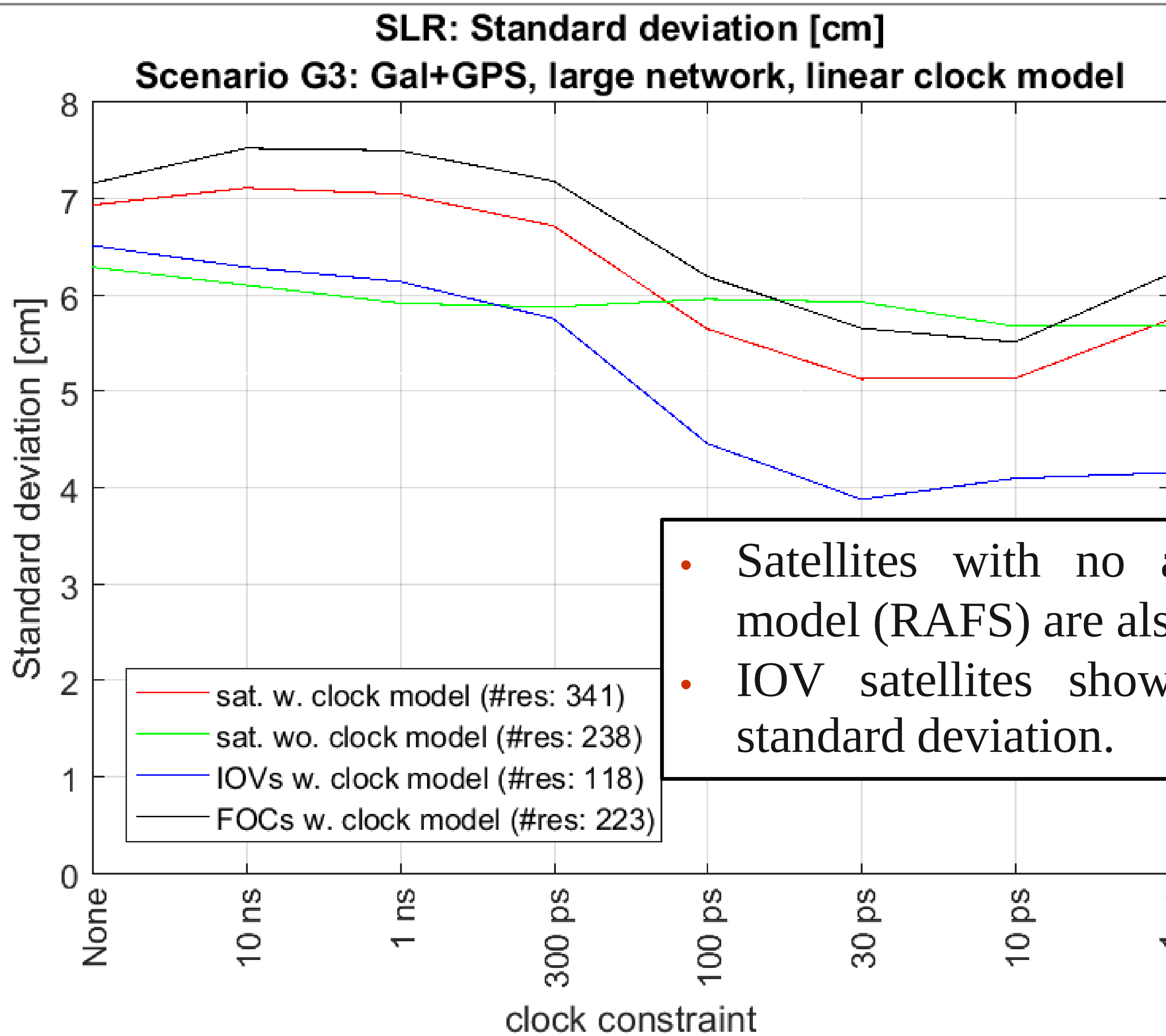


Best clock model: linear

Clock modelling for GNSS POD



Clock modelling for GNSS POD



- Satellites with no applied clock model (RAFS) are also improved.
- IOV satellites show lower SLR standard deviation.

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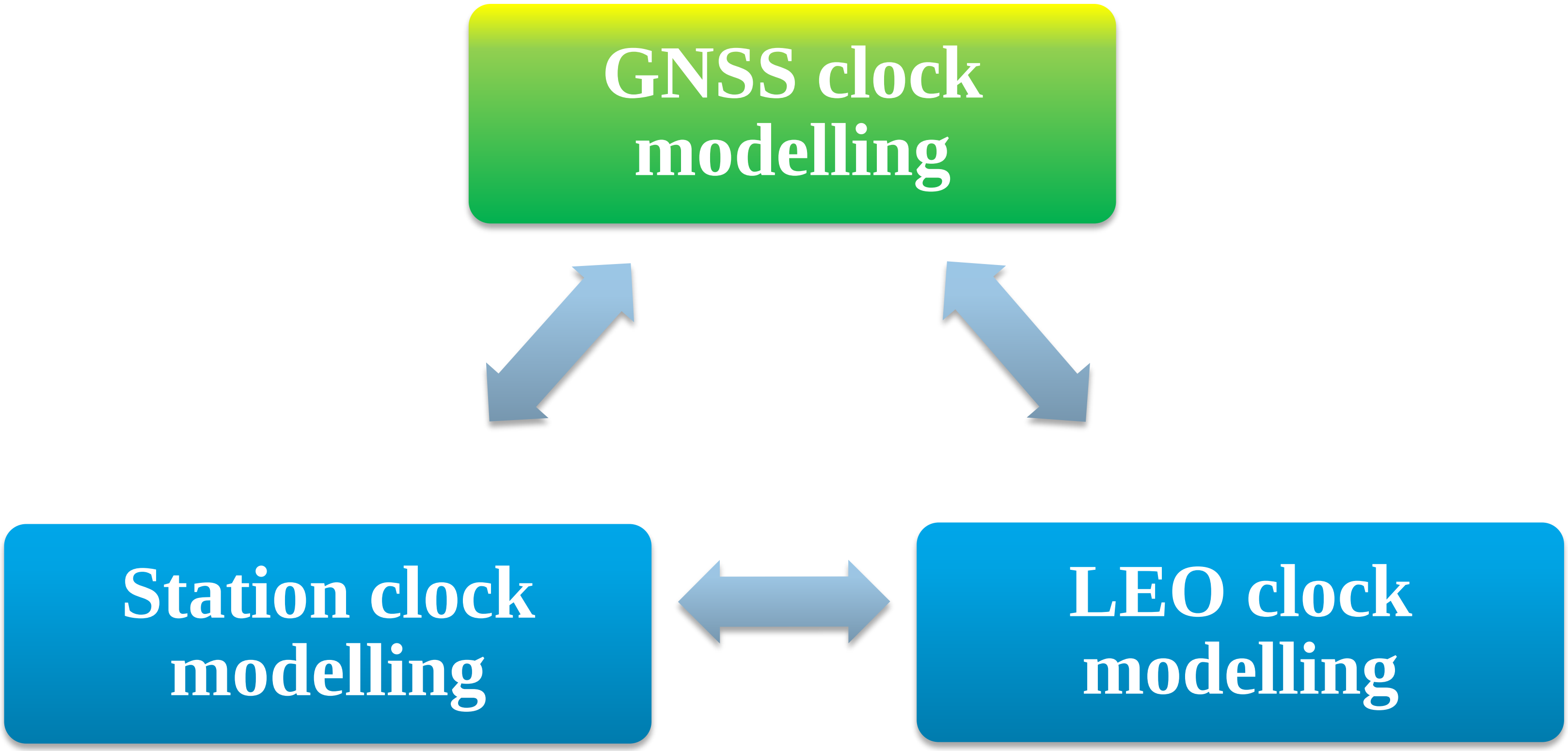
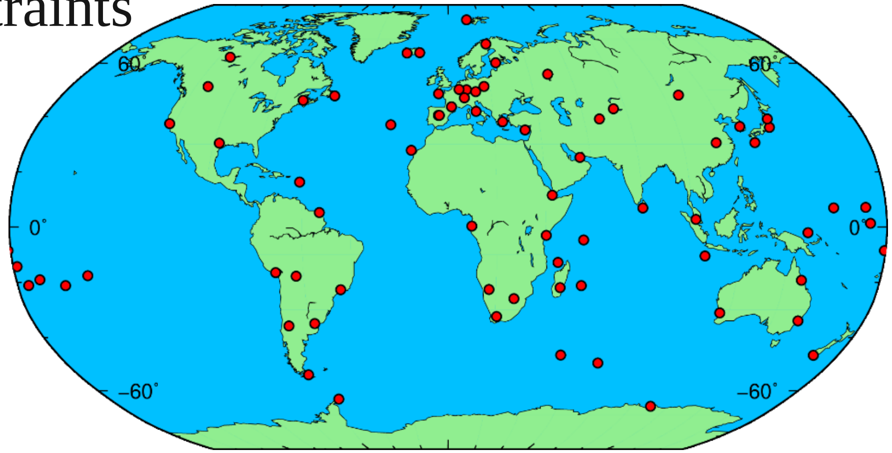
Kinematic orbit determination with satellite clock modelling



Kinematic orbit determination with satellite clock modelling

- **Goals:**
  - Determine optimum clock constraining for different clock types
  - Investigate dynamical orbit model deficiencies through clock modeling
- **Modelling the satellite clock with relative constraints:**
  - Deterministic 1st degree polynomial fit estimated
  - Stochastic epoch-to-epoch constraints
- **Satellites considered:**
  - Galileo: H-masers
  - GPS: Block IIF with RAFS

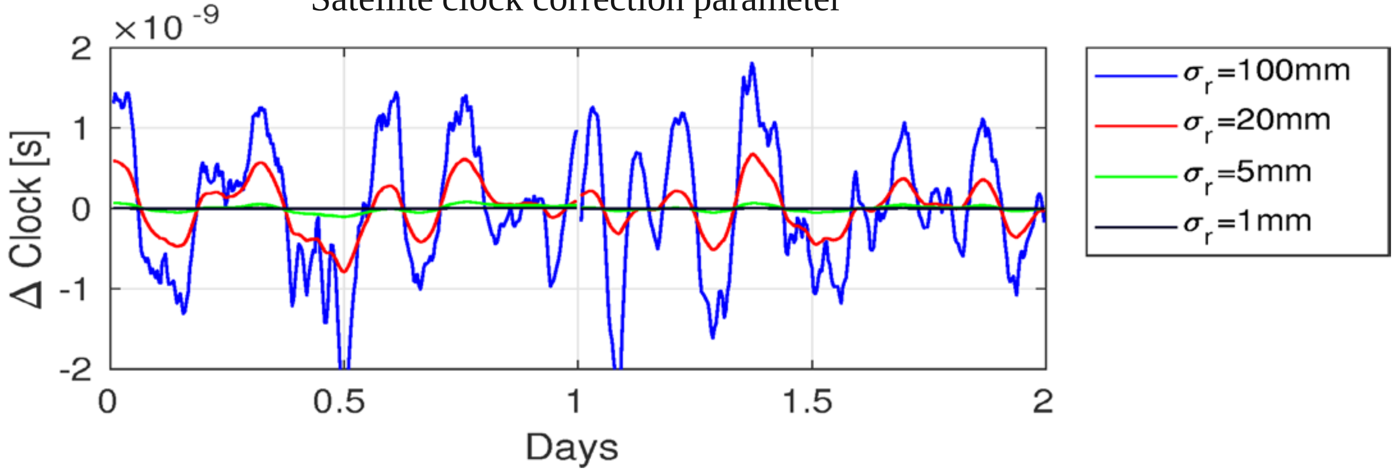


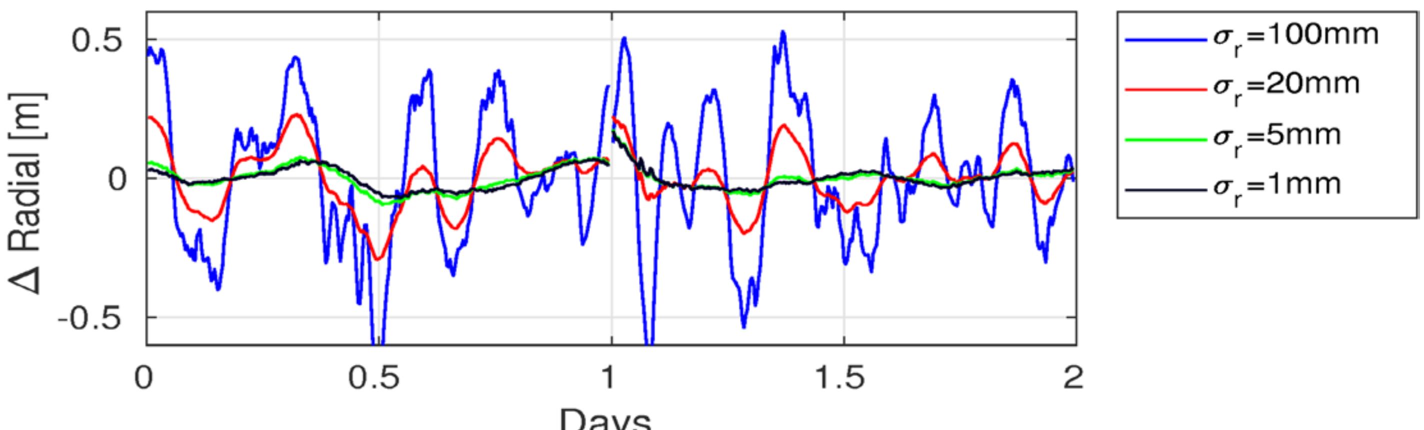
Data: 1 week, 5 min sampling, 74 stations

Effects of the clock constraints on the radial orbit component

- Compared with ESOC dynamic orbits; example for E19

Satellite clock correction parameter





Difference of the radial component between the kinematic estimated orbits and the dynamic reference orbit.

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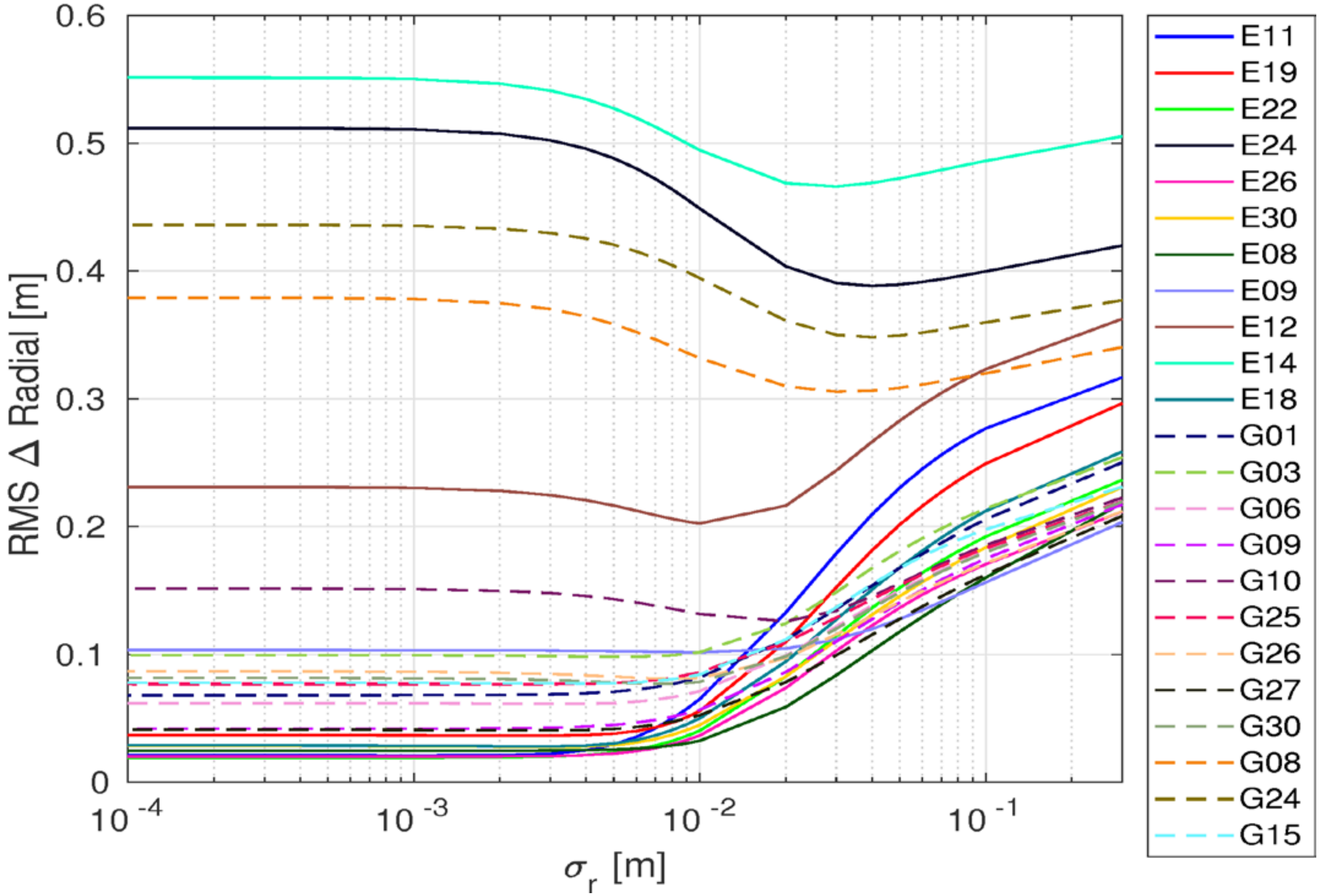

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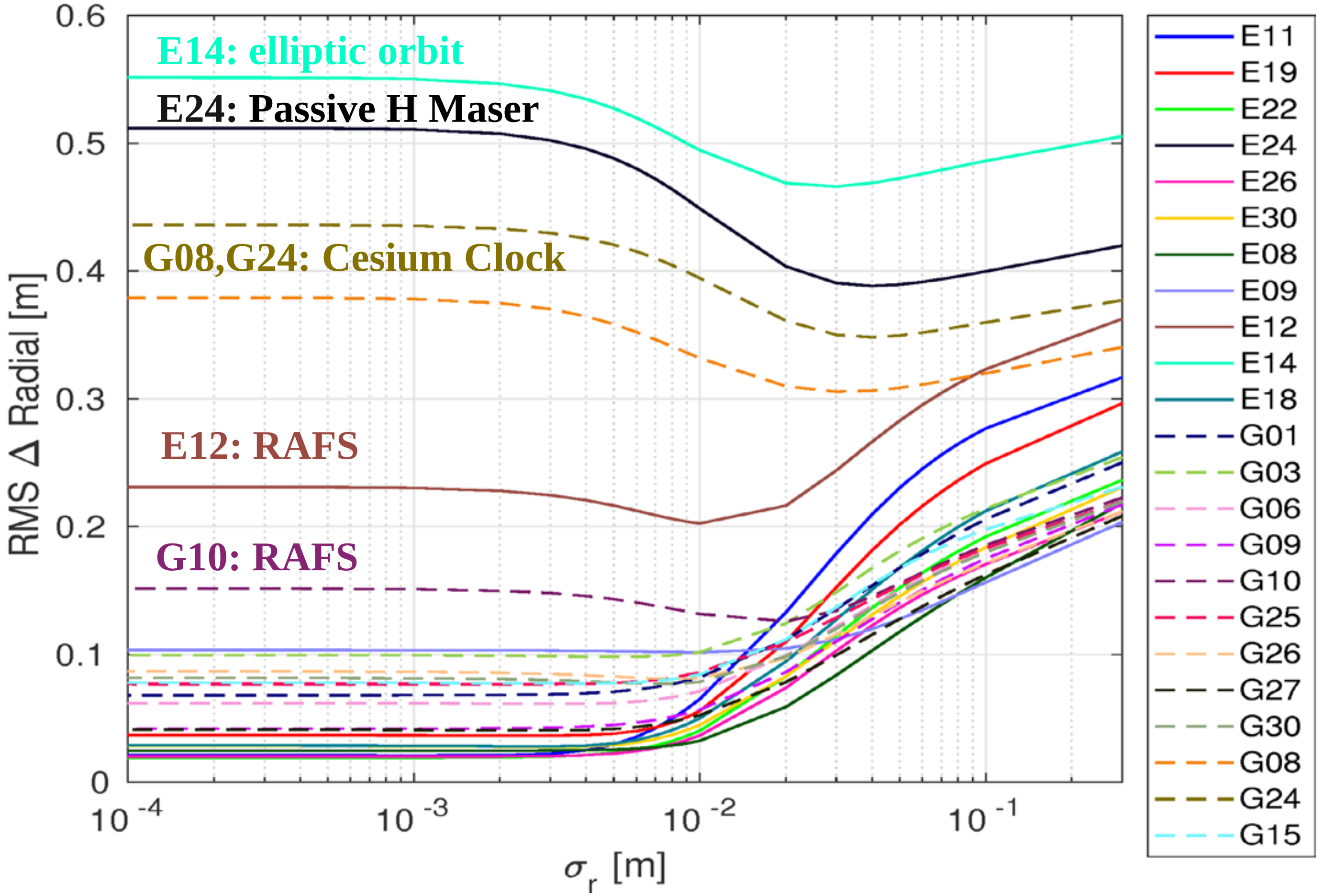

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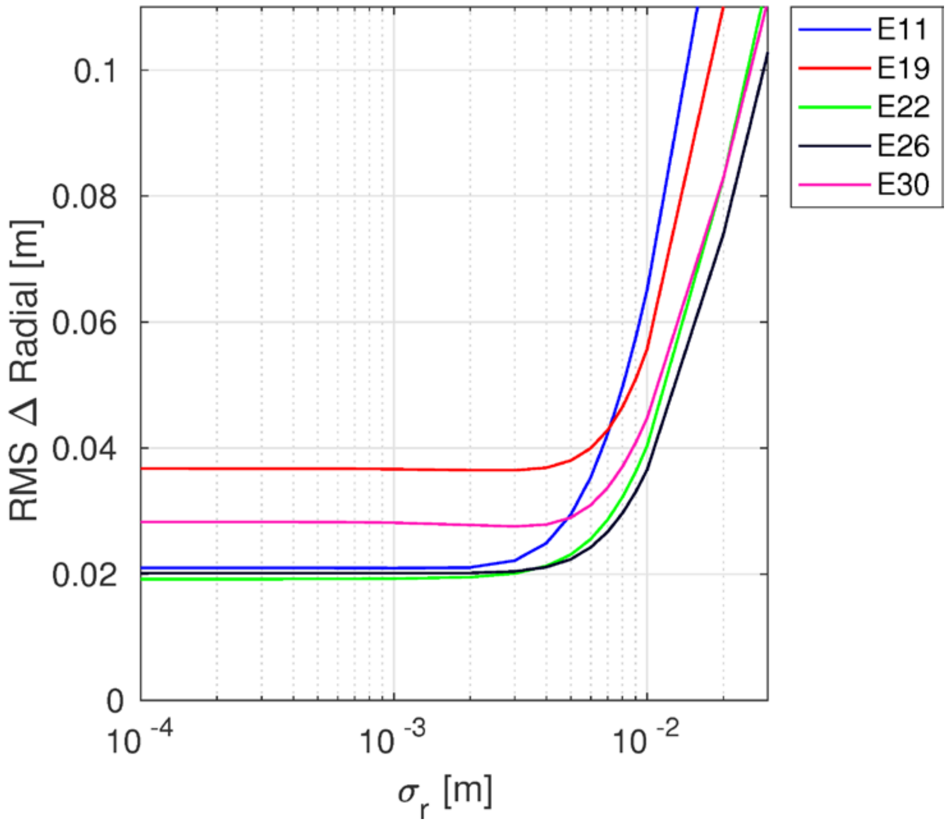
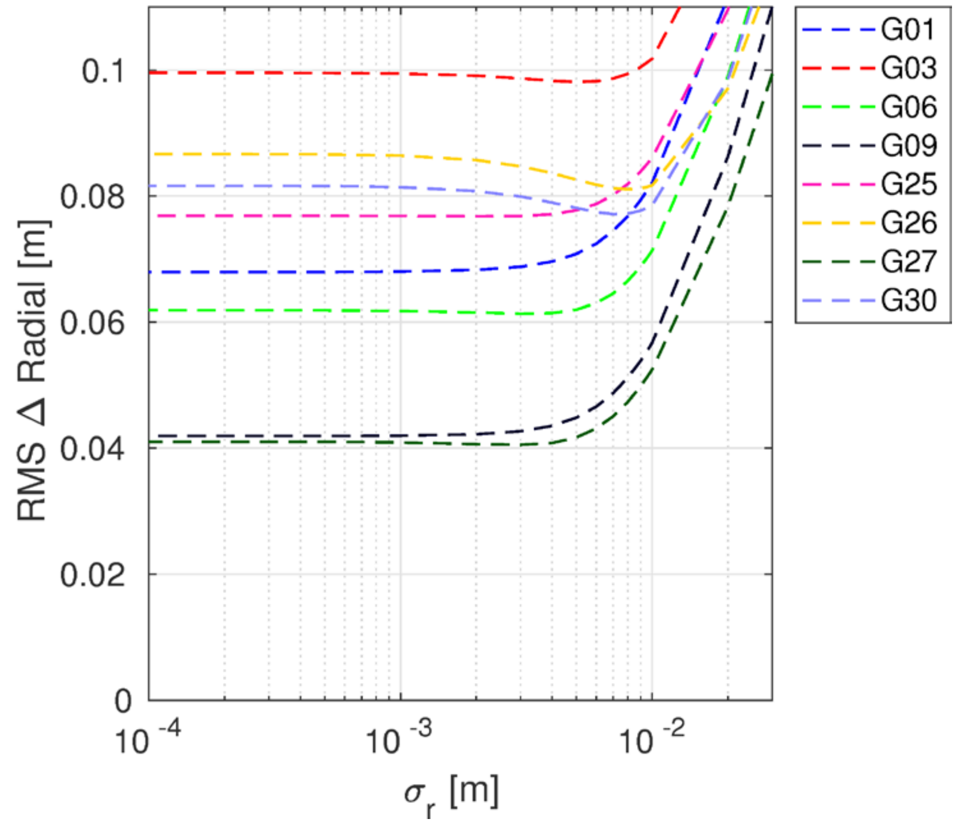
Effects of constraining the clock on the radial component

Galileo: mean RMS = 2.5 cm



Mean optimum σ_r = 1.6 mm

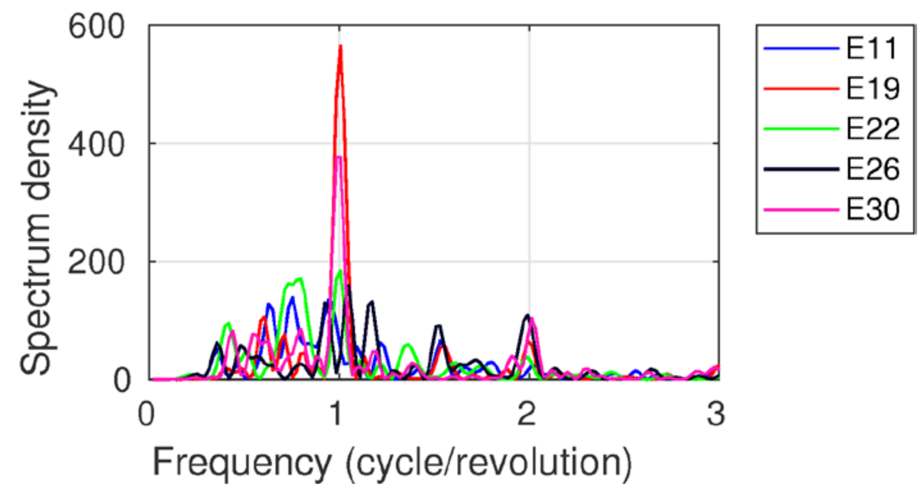
GPS: mean RMS = 6.8 cm

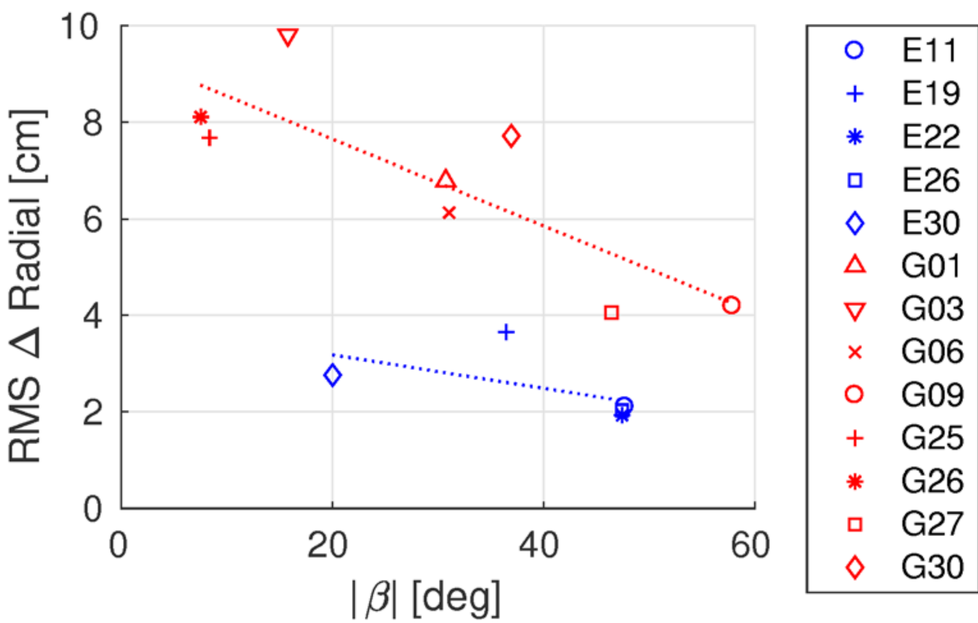


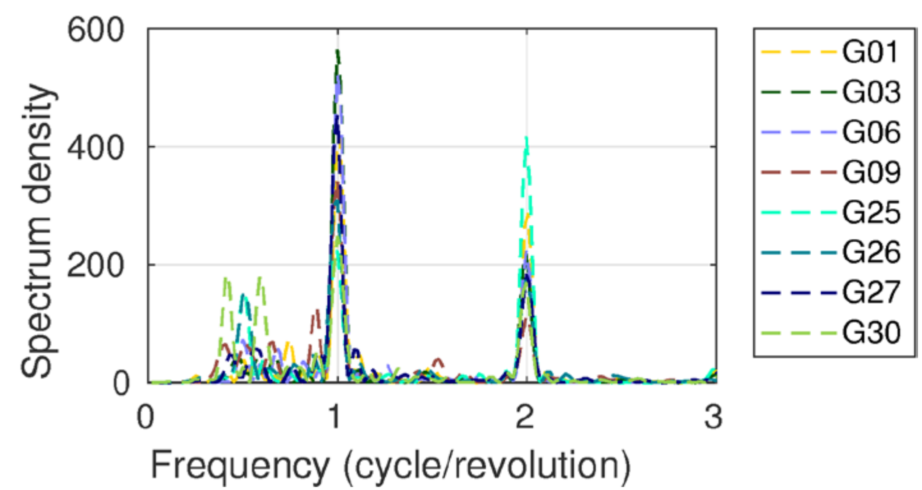
Mean optimum σ_r = 3.5 mm

What remains in the difference to the dynamic orbit and where does it come from ?

- Apparent β angle dependency indicates SRP model deficiencies.
- Strong 1/rev oscillation for Galileo satellites with lower β angles.
- Both 1/rev and 2/rev oscillations visible in GPS.







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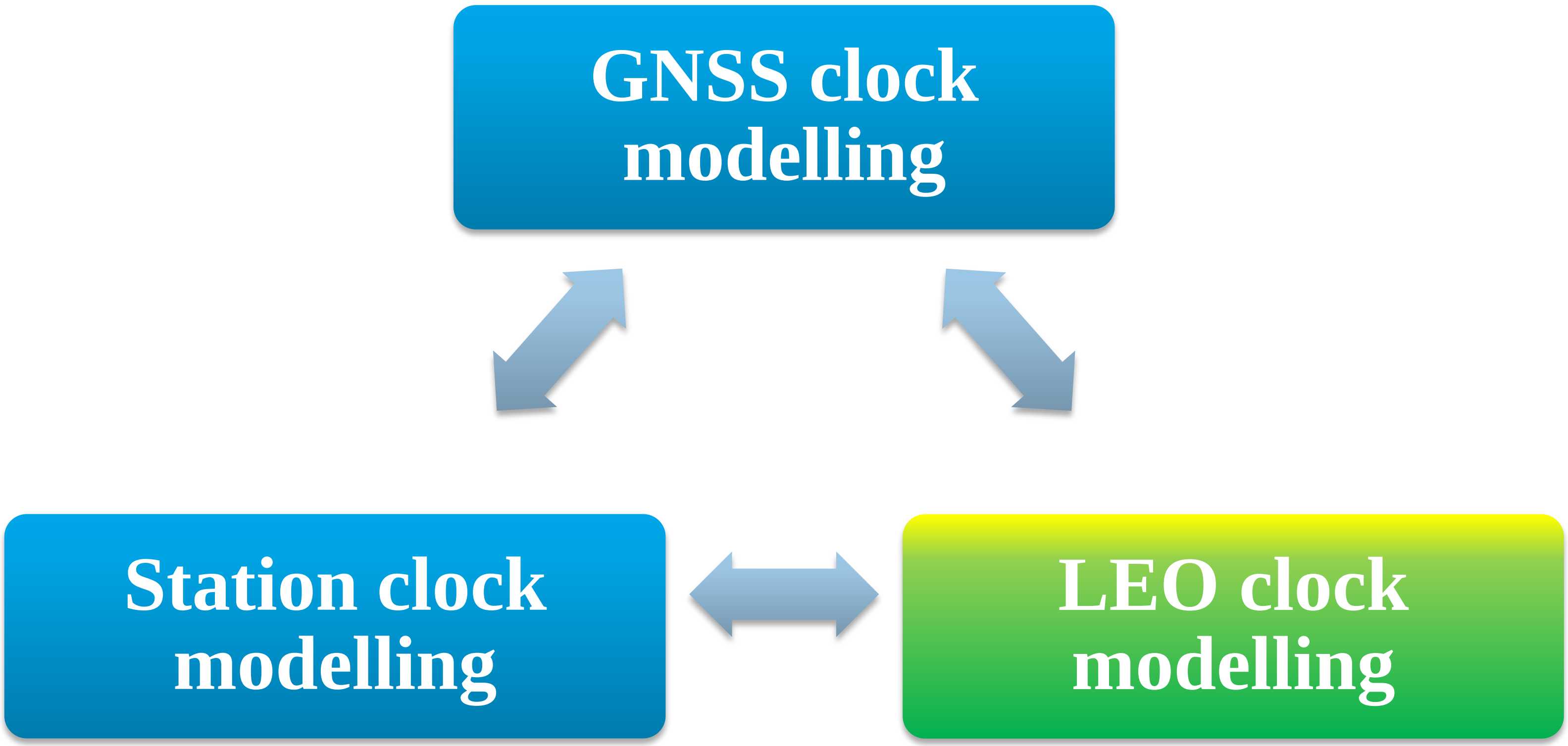
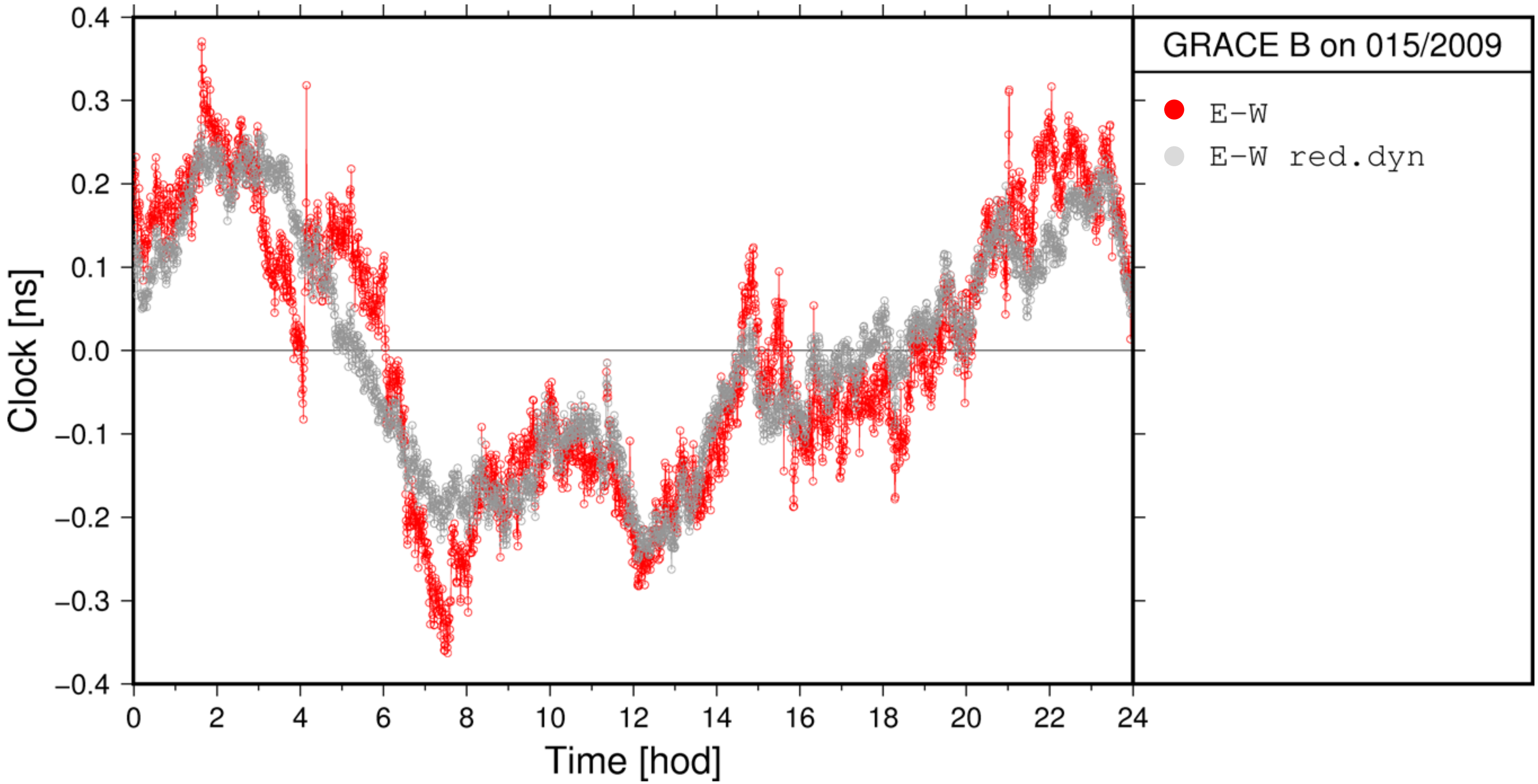
LEO clock modelling



Clock modelling for kinematic LEO POD

- Deterministic clock modelling:
  → clock behavior is modelled as unconstrained piece-wise linear function with a certain number of knot points over 24 hours (1 min, 2 min, 3 min and 5 min).
- Applied on GRACE A and GRACE B POD, using data from January 2009.
- Sentinel 3-A receiver clock assessment.

Clock modelling for kinematic LEO POD



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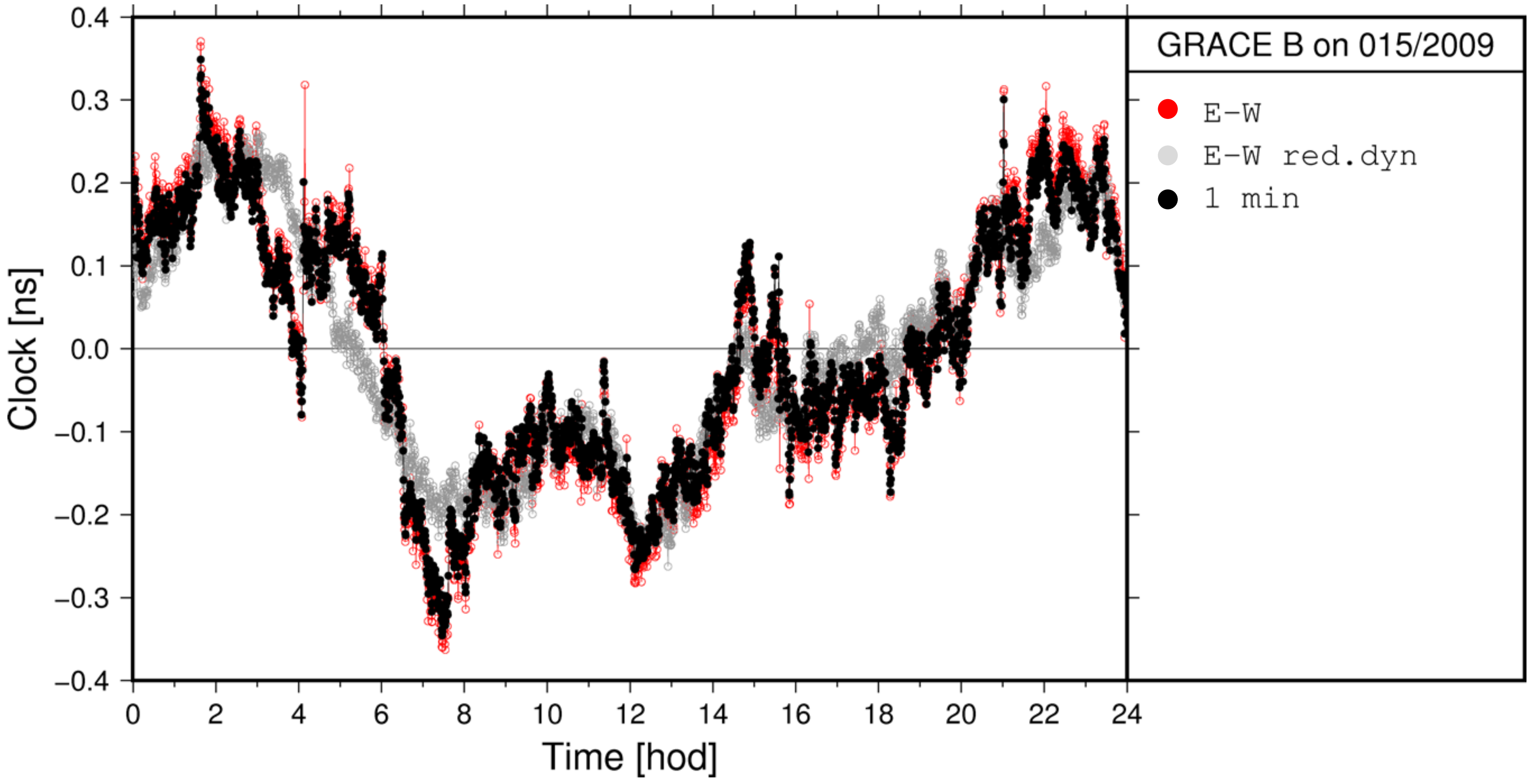
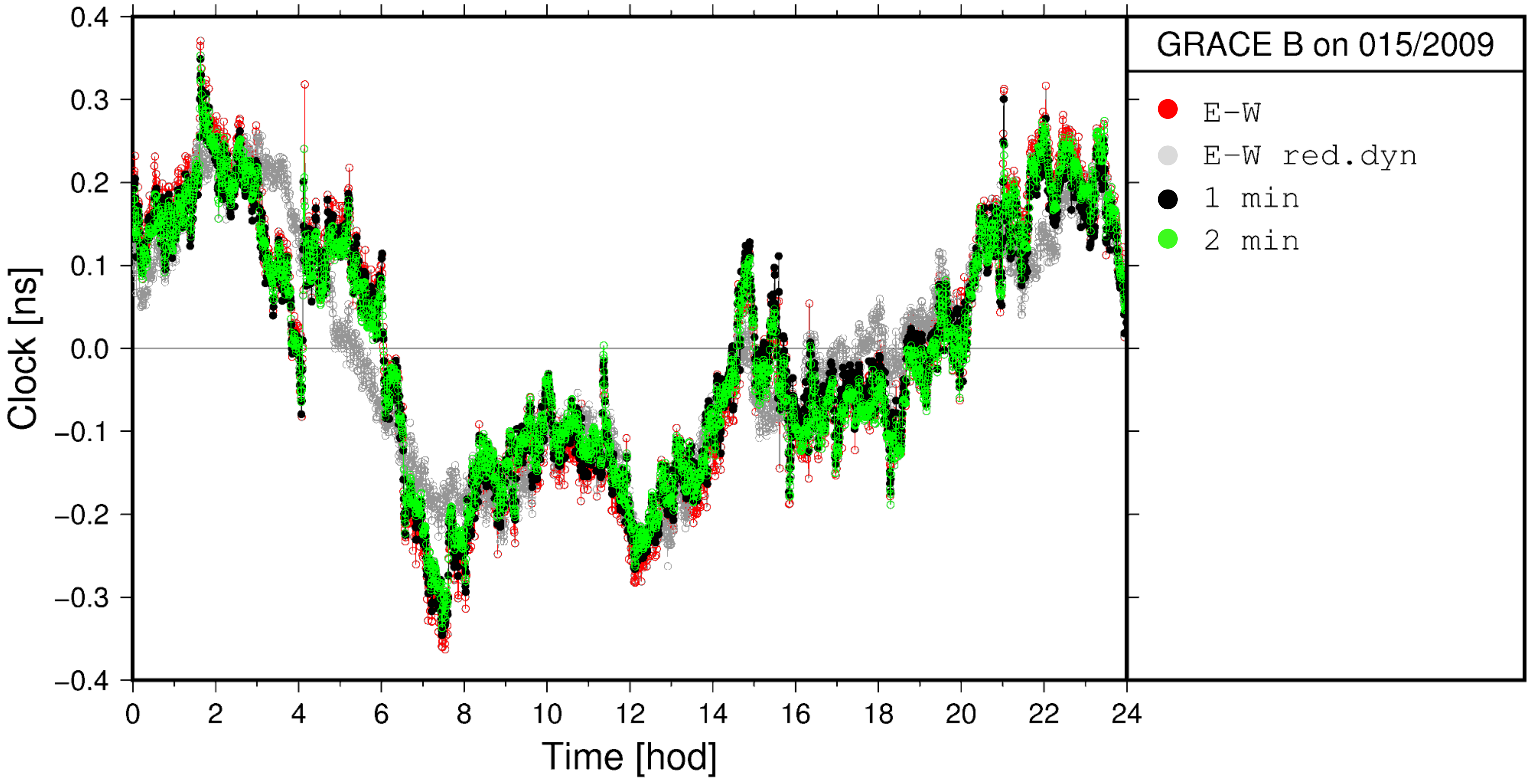


Clock modelling for kinematic LEO POD



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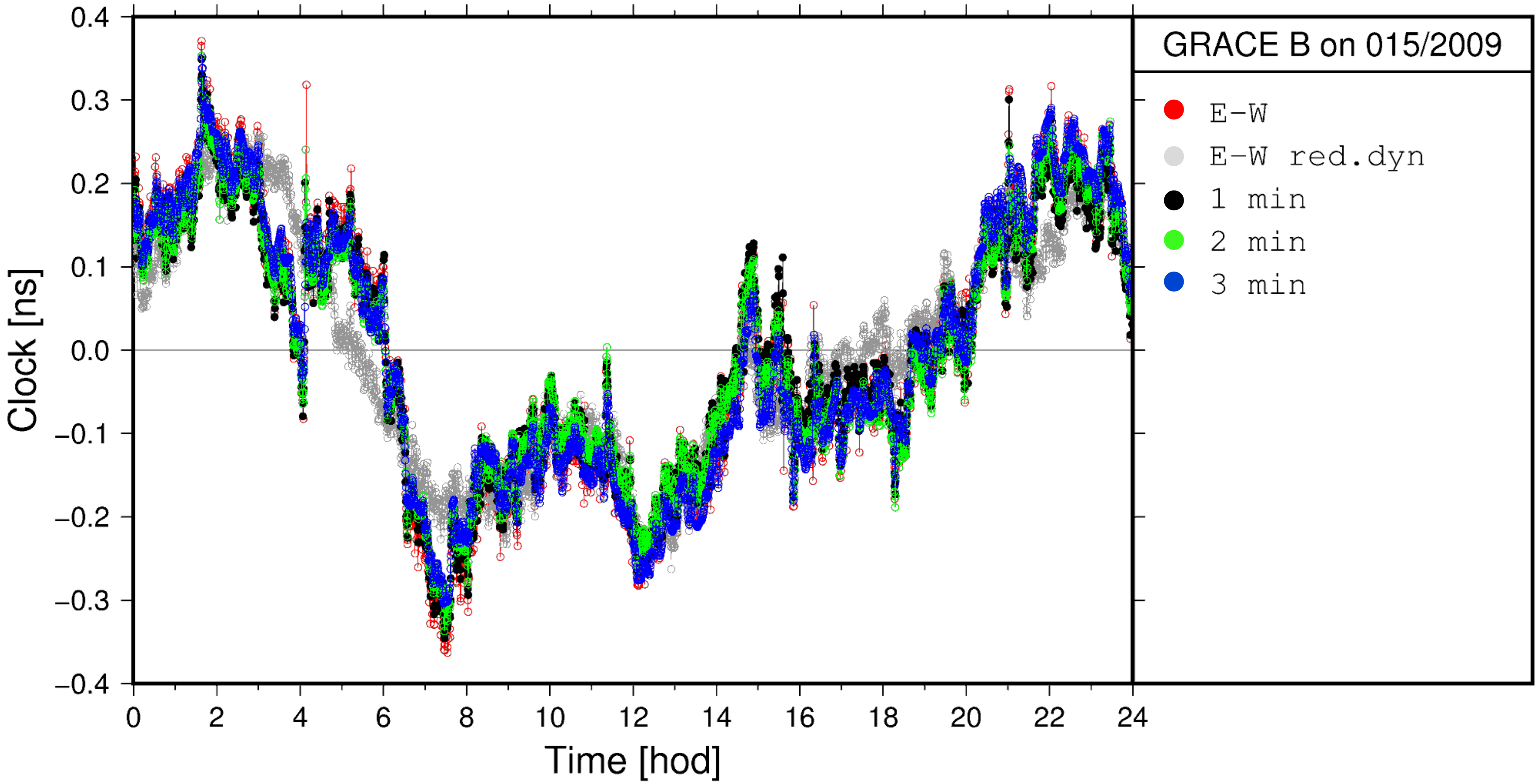

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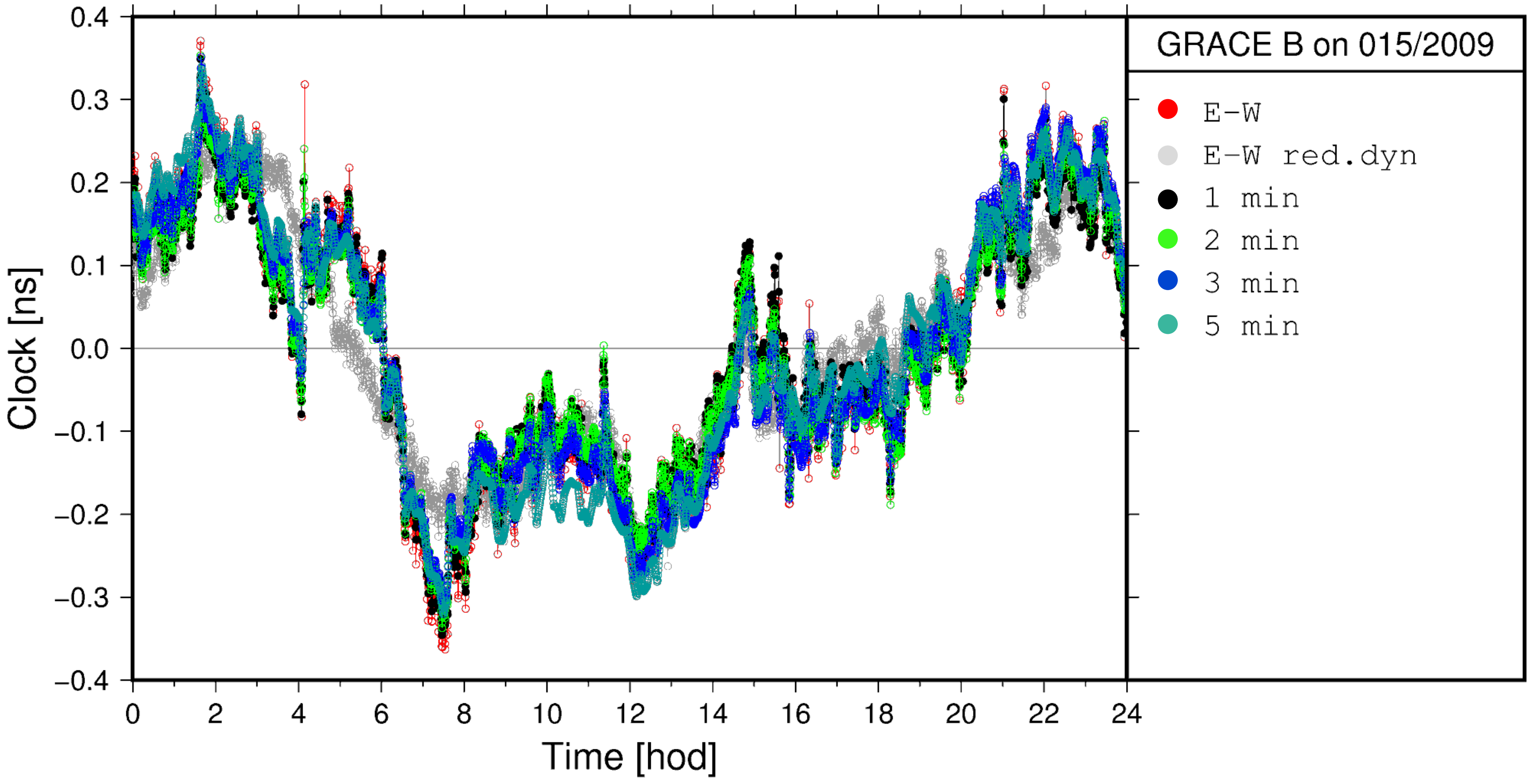

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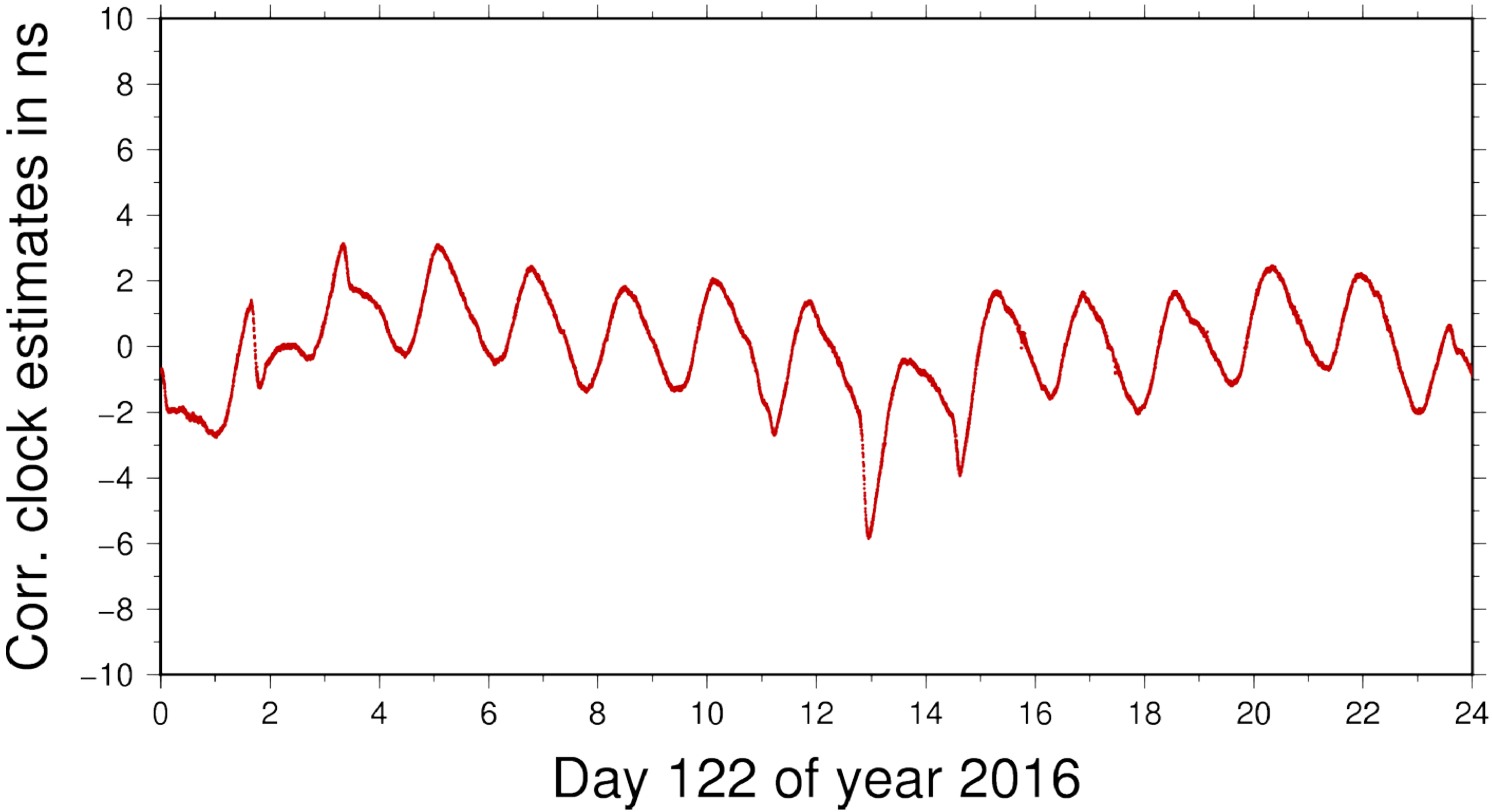
Sentinel 3-A receiver clock assessment

From the corrected (jumps) receiver clock estimates a quadratic model has been subtracted.

Sentinel 3-A receiver clock assessment



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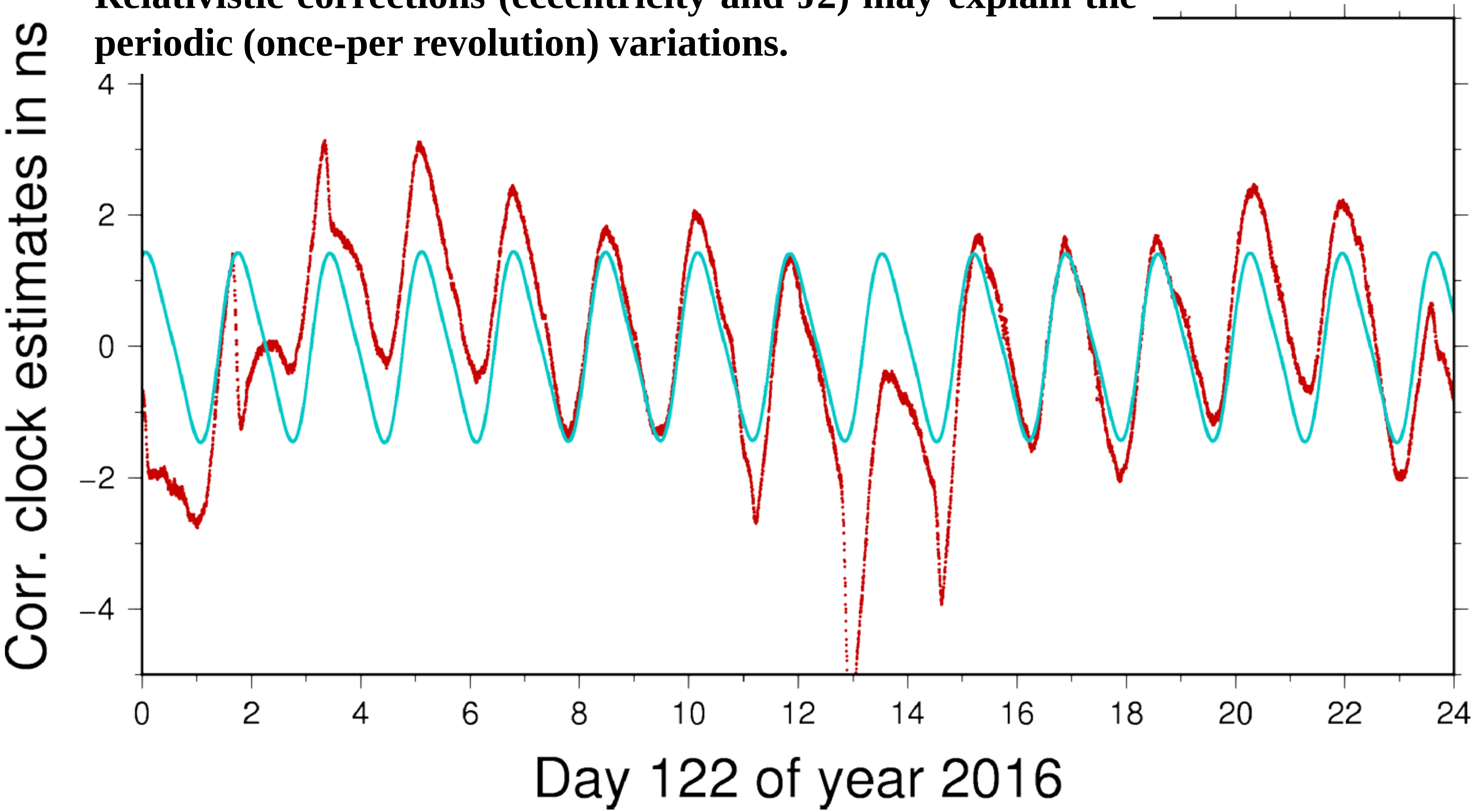
Sentinel 3-A receiver clock assessment

Relativistic corrections (eccentricity and J2) may explain the periodic (once-per revolution) variations.



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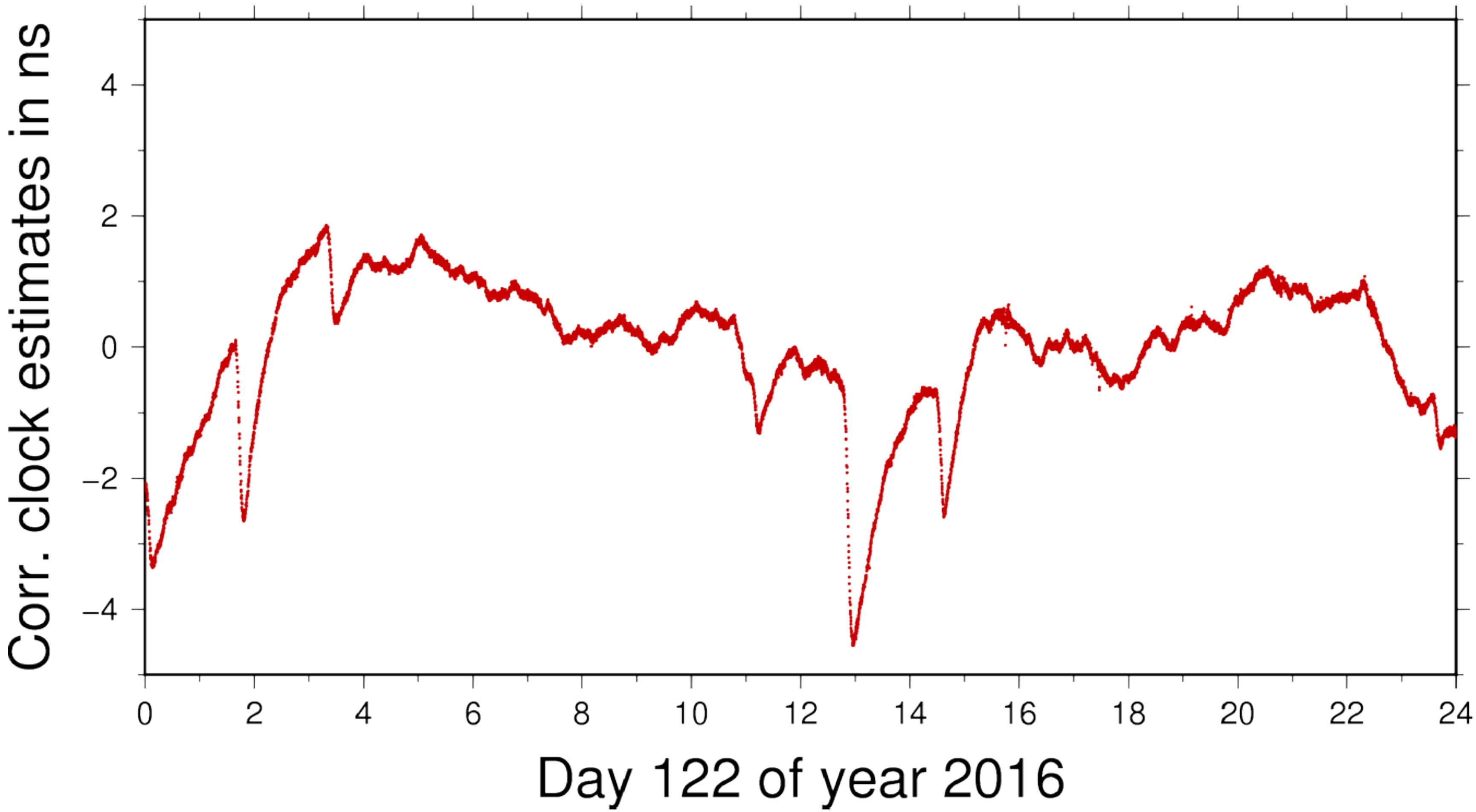
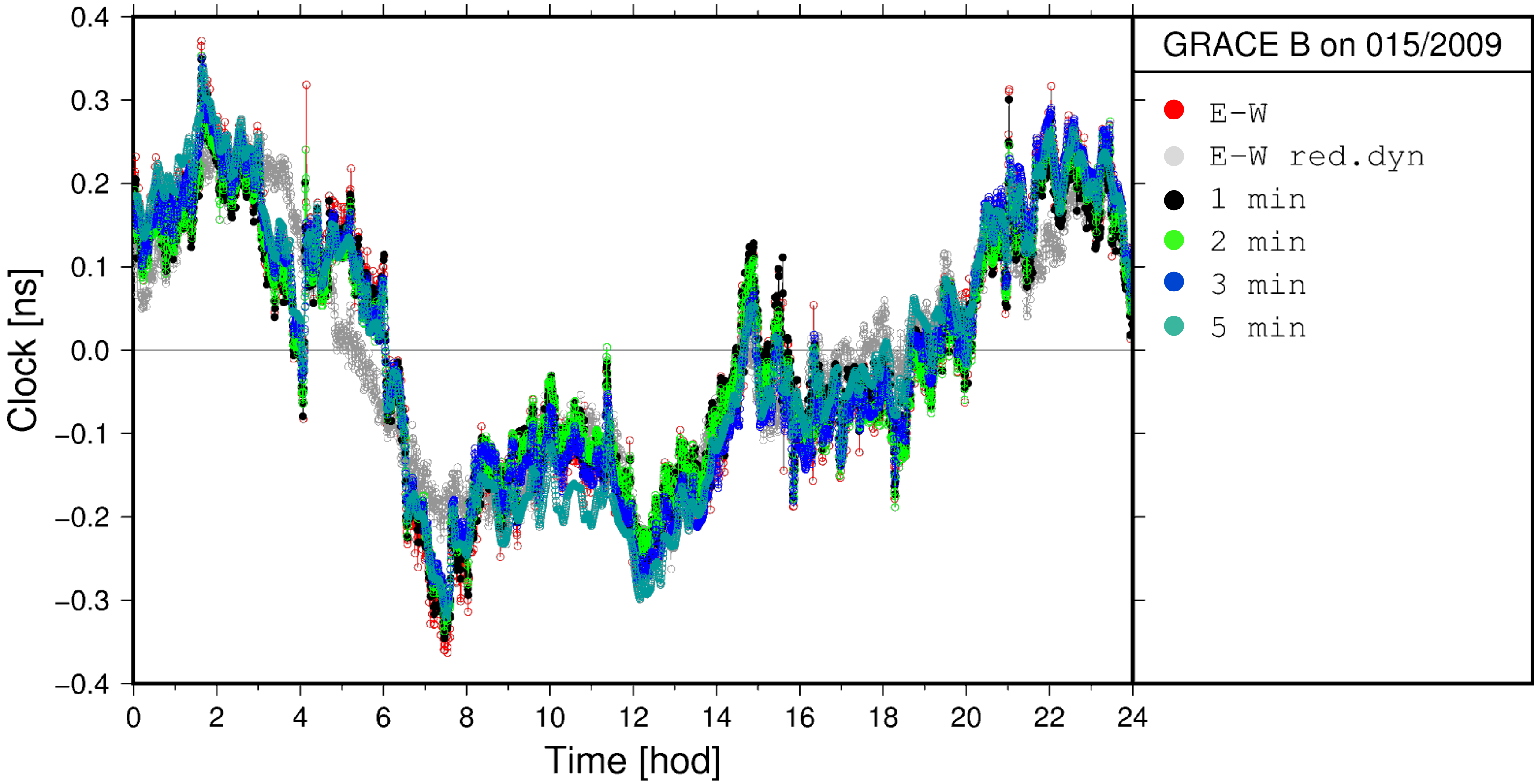


From the corrected (jumps and relativistic effects) receiver clock estimates a quadratic model has been subtracted.

Sentinel 3-A and GRCE B receiver clock comparison



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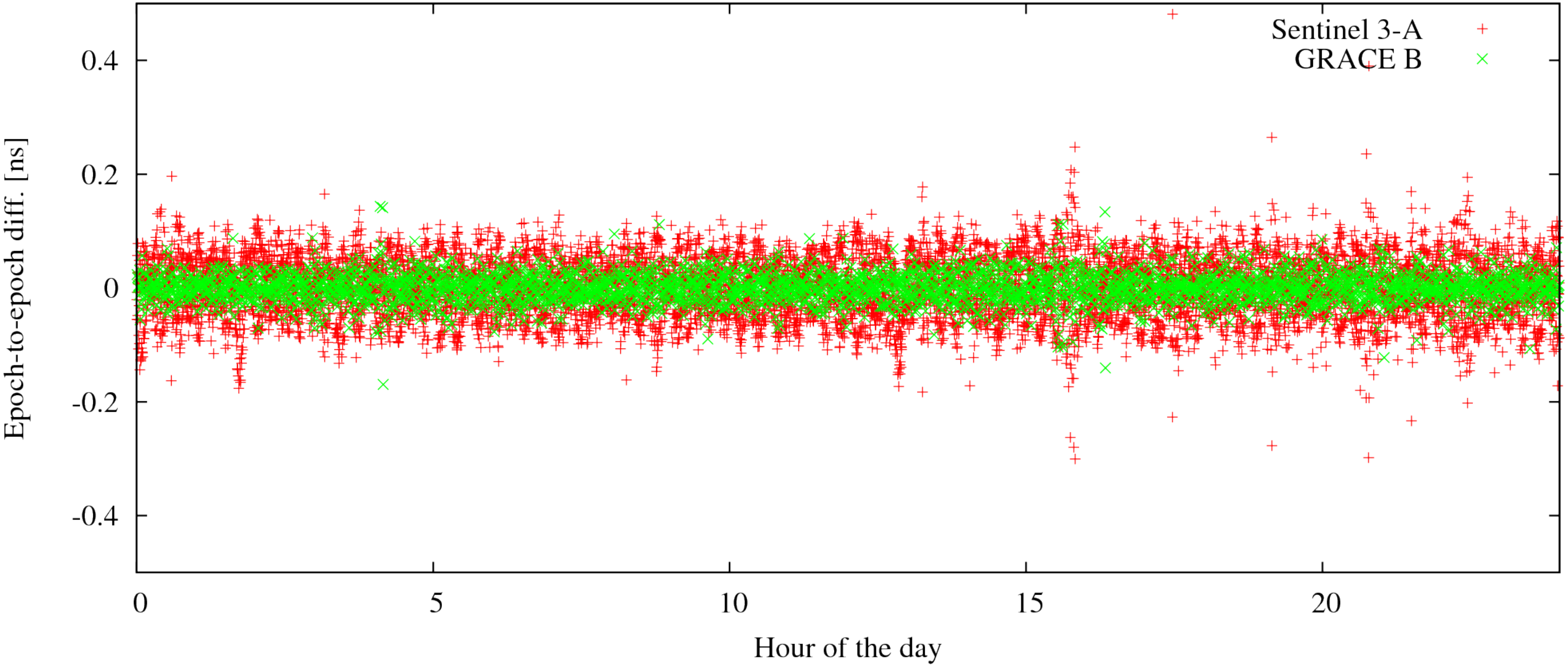

Summary

- Based on different scenarios, model using GPS+Gal observations from big network, with linear clock model applied shows the best results in terms of orbit modelling and SLR analysis.
- The clock quality is reflected in the solutions.
- Analysis showed apparent β angle dependency indicating SRP model deficiencies.
- Comparison between Sentinel 3-A and GRACE receiver clock corrections shows potential for clock modelling.