Improved Precise Orbit Determination by use of highly accurate clocks

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Introduction

- Measurement principle: One-way travel time of the respective signals from satellite to receiver
- High-quality satellite atomic clocks and their predictability are key to achieve highest accuracy for precise real-time applications of GNSS
- State-of-the-art precise GNSS applications:
  - Epoch-wise clock correction estimation
  - High Degree of Freedom
  - Possible weakening of parameter estimation

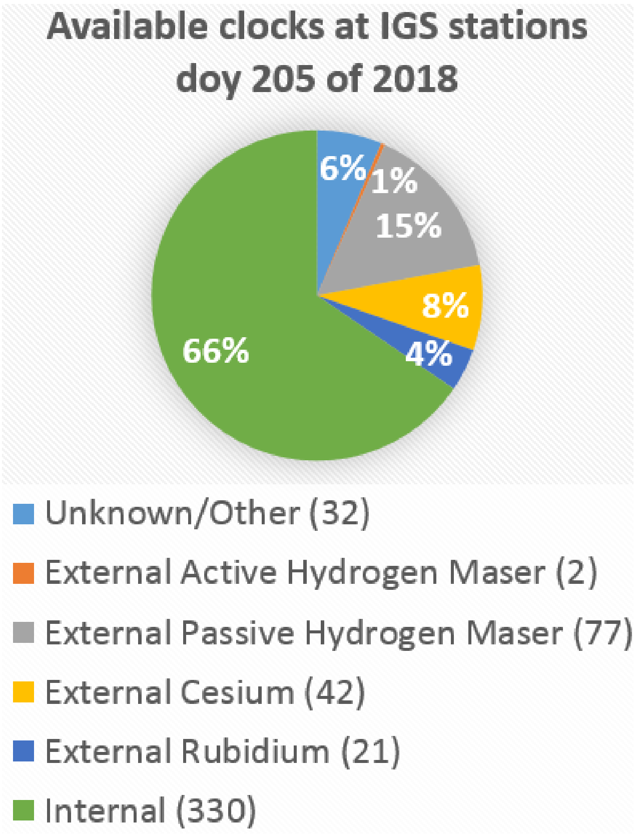
Introduction

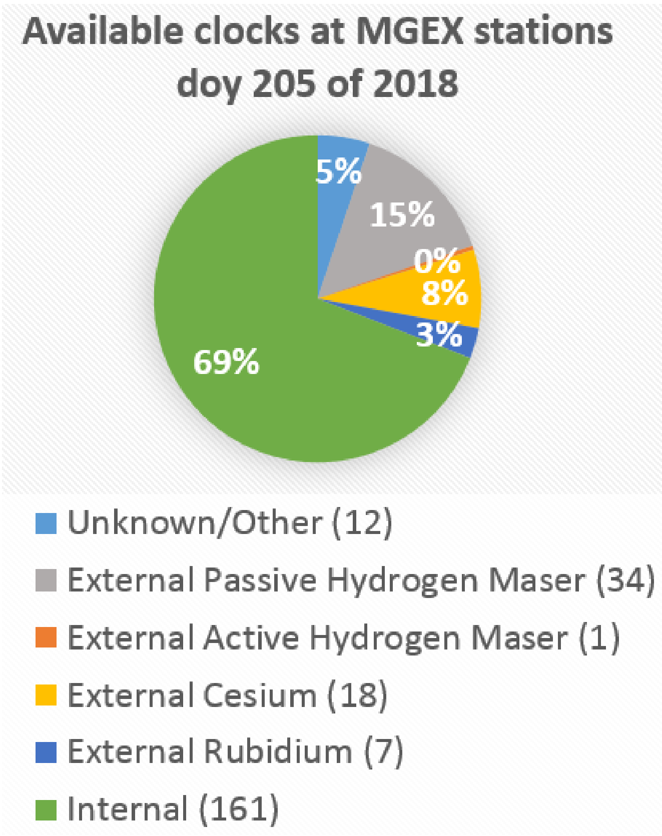
- More and more highly accurate clocks available (eg. Passive Hydrogen Masers on Galileo satellites)

$\Rightarrow$ Model clocks in a physical meaningful way
$\Rightarrow$ Constrain epoch-wise estimated clock parameters to an a priori clock model

  - Better estimates of global parameters (orbits, ERPs)
  - Better decorrelation and estimates of high-sampled parameters
  - Better orbit prediction

Receiver clocks





$\Rightarrow$ Ca 15 % Hydrogen Masers in IGS/IGS-MGEX network

Satellite clocks

GNSS	Block	Rb	Cs	PHM
GPS	I	3	0-1	-
	IIA	2	2	-
	IIR/IIR-M	3	-	-
	IIF	2	1	-
	III	3	-	-
GLONASS	I	v	-	-
	II	(v)	v	-
	M	-	3	-
	K1	v	v	-

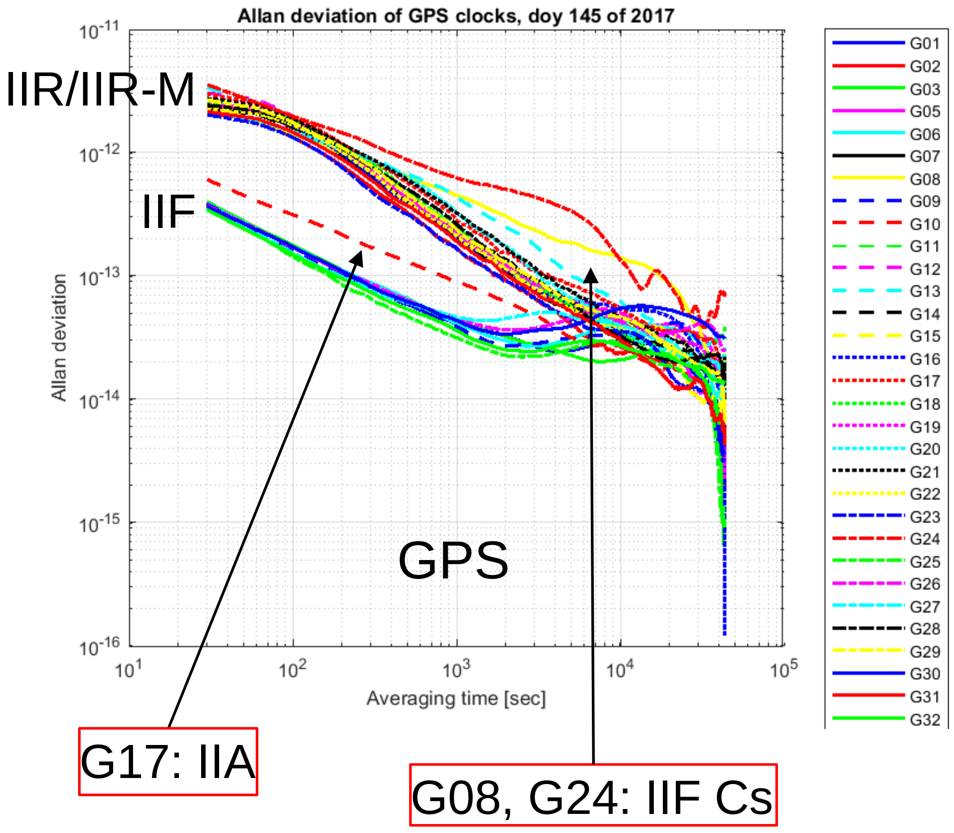
GNSS	Block	Rb	Cs	PHM
Galileo	GIOVE-A	2	-	-
	GIOVE-B	2	-	1
	IOV/FOC	2	-	2
	III	v	-	v
BeiDou	C104/C105	v	-	v
	other	v	-	-
QZSS		2	-	-
IRNSS		v	-	-

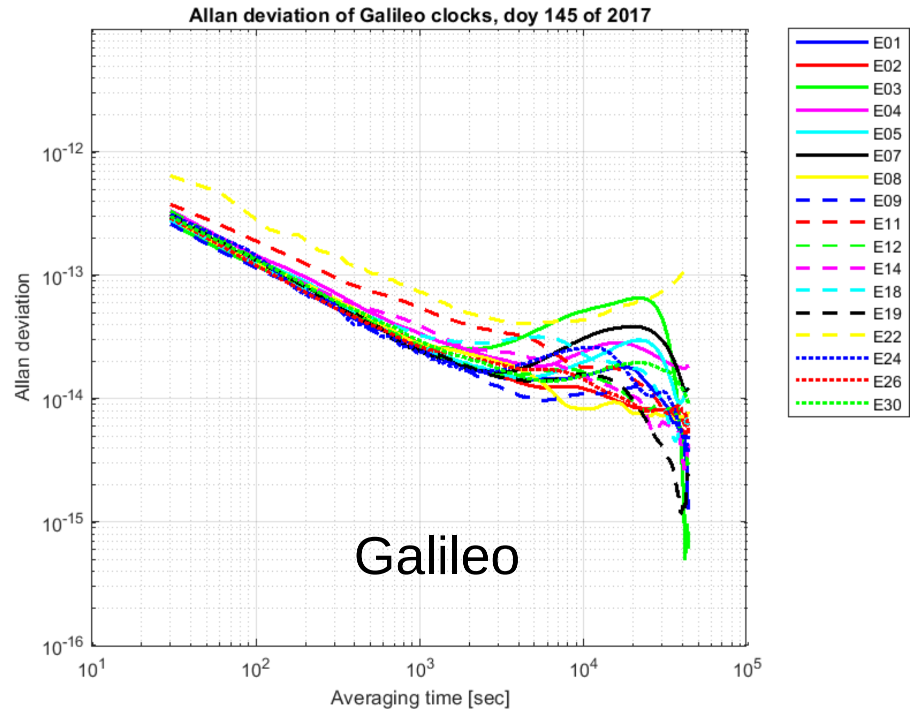
Decommissioned

Operational/launched

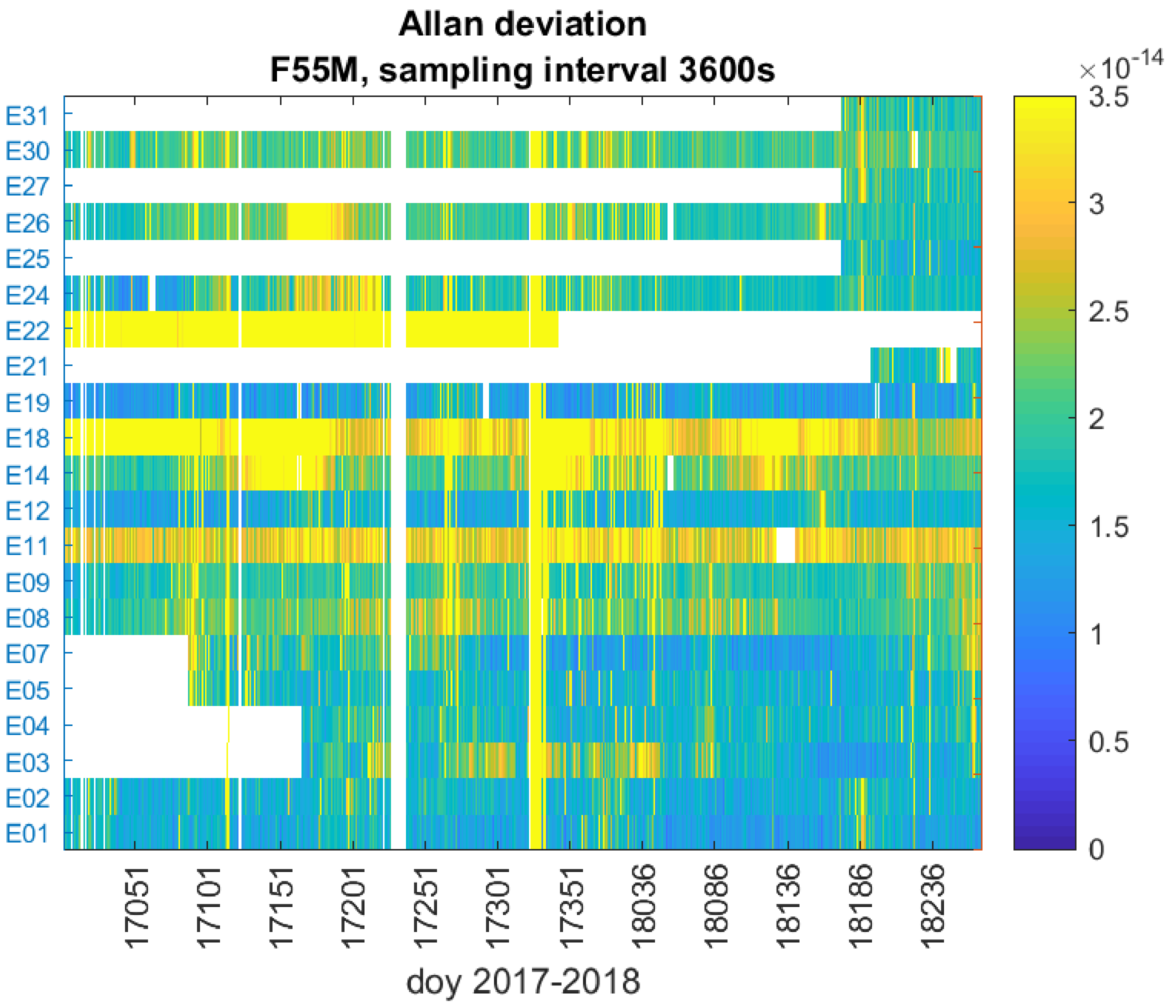
Planned

Allan deviation





Allan deviation



- ADEV sampling interval 3600 sec
- From TUM Galileo clocks
- Selection criteria for Galileo clock modelling

Clock modelling

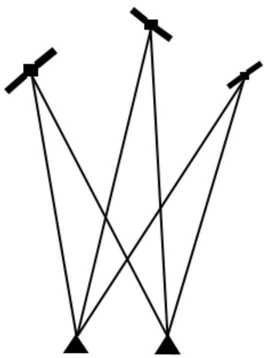
- **Deterministic clock model**:
  - „lin“: $\delta t(t) = a_0 + a_1(t - t_0)$
  - „lin/quad“: $\delta t(t) = a_0 + a_1(t - t_0) + a_2(t - t_0)^2$
  - „lin/2rev“: $\delta t(t) = a_0 + a_1(t - t_0) + c_2 \cos 2nt + s_2 \sin 2nt$

- **Stochastic clock model**:
  - **Absolute constraining** of the epoch-wise estimated clock corrections to the selected deterministic a priori clock model

  - The clock constraints are tested between 10ns and 1ps

Scenarios

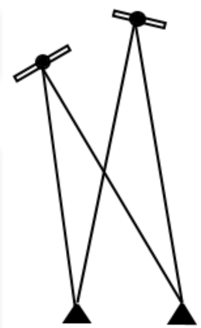
1): GPS-only PPP



CODE orbits, clocks, DCBs

Troposphere parameters
Receiver clocks
Coordinates

2): Network solution



Galileo satellite orbits & clocks
Receiver clocks
Troposphere parameters

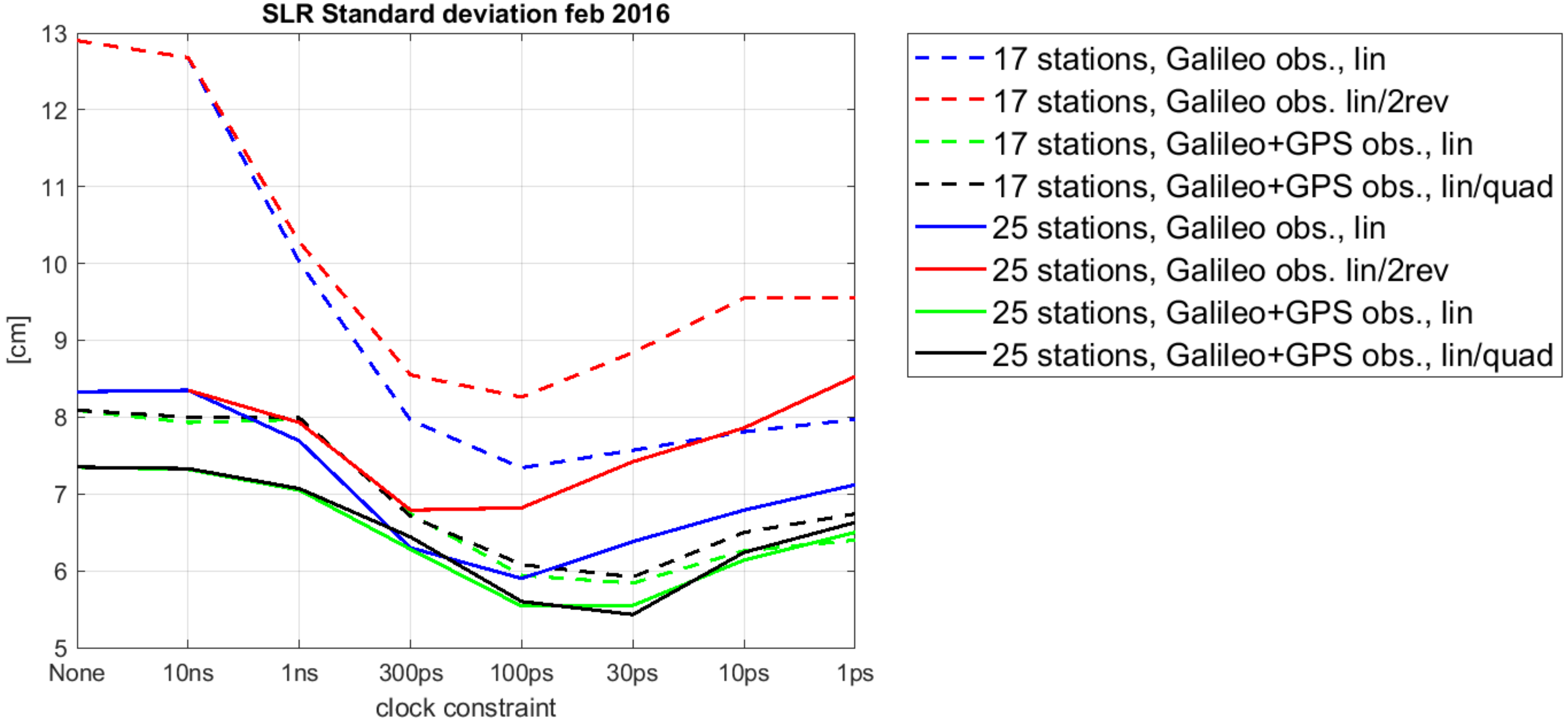
Coordinates, Reference clock

Test Scenarios covering different

- Clock models and clock constraints
- Radiation pressure models
- Network sizes
- GNSS observations

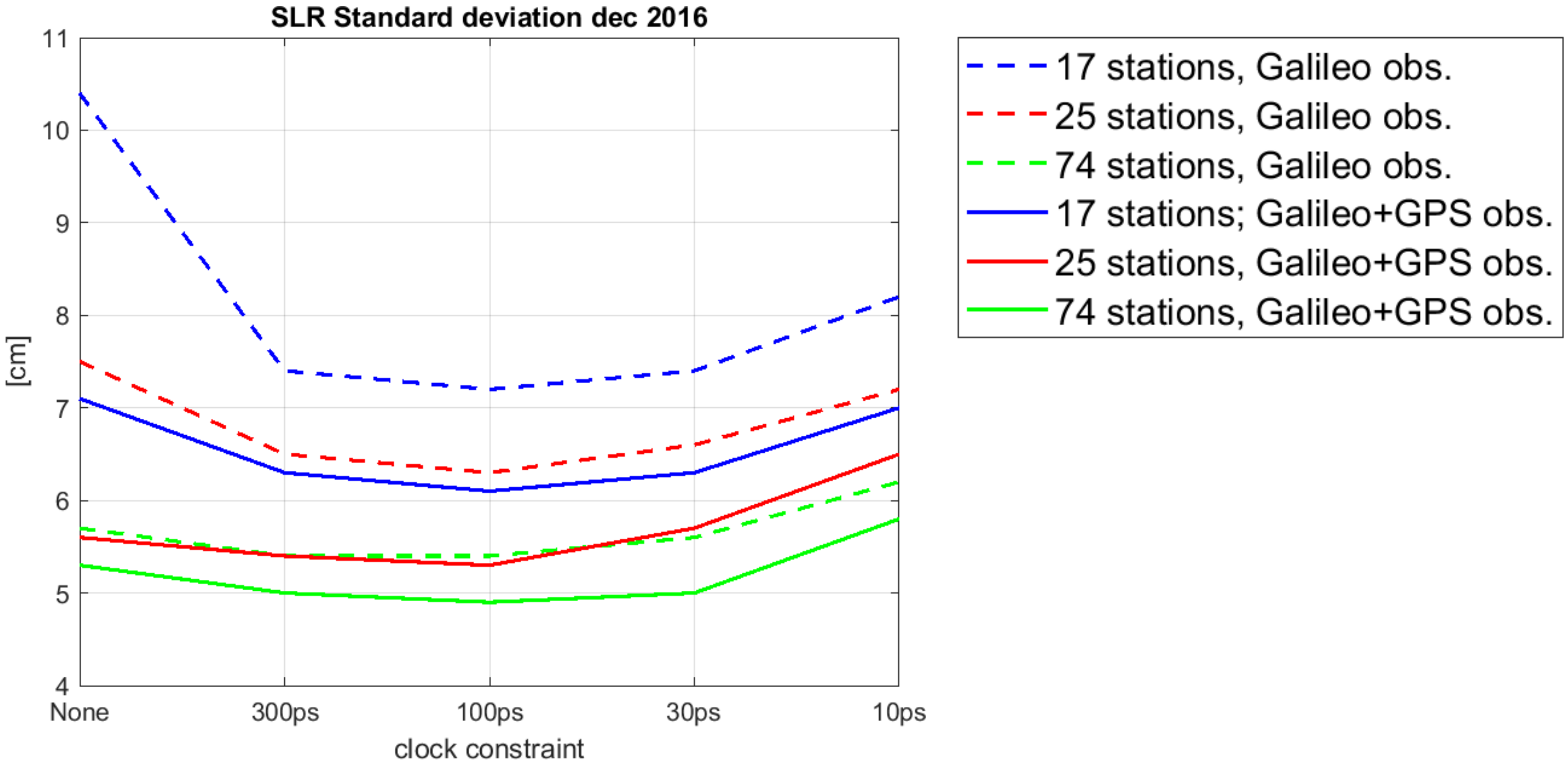
SLR: Clock model

Standard deviation for different clock models:



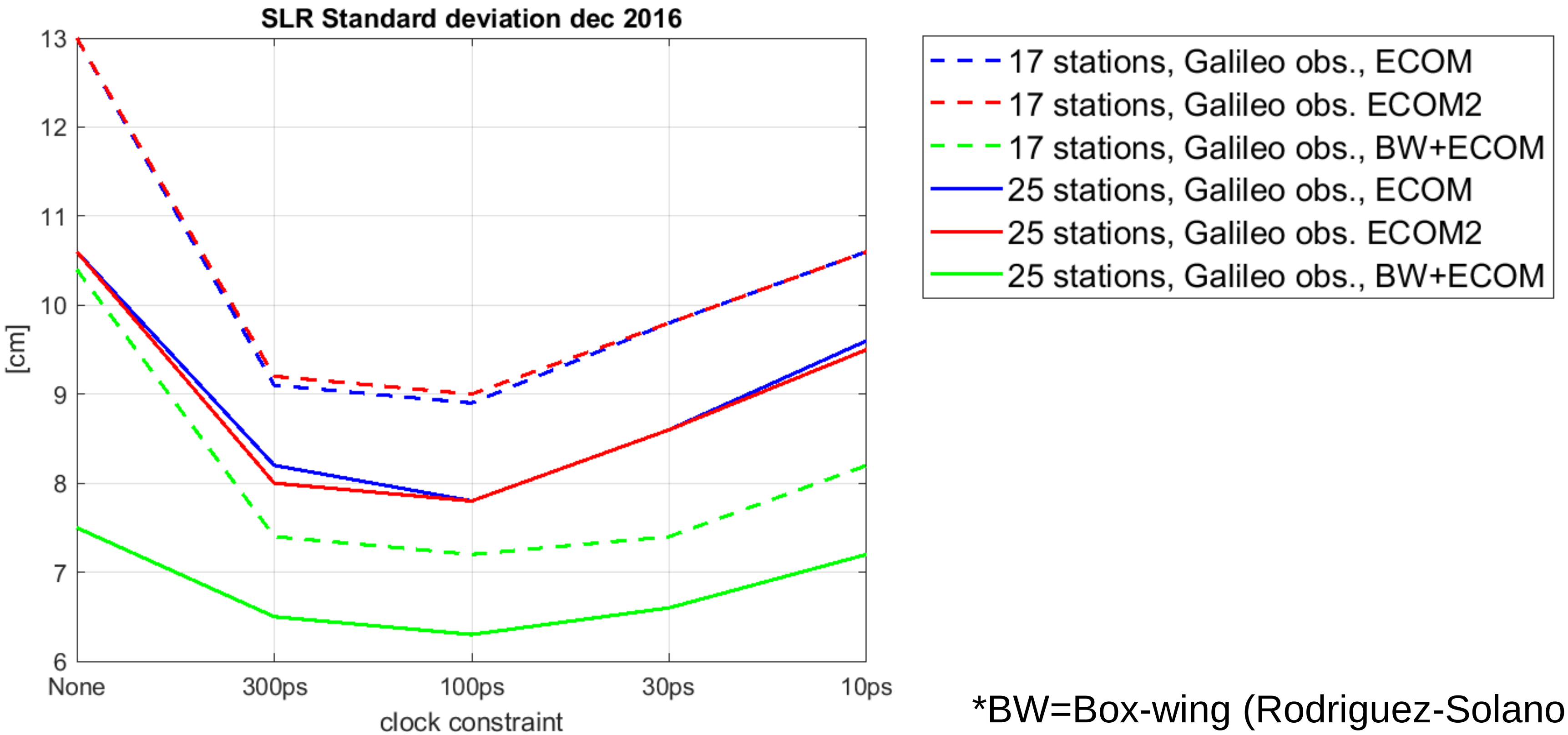
SLR: Network size

Standard deviation for different network sizes



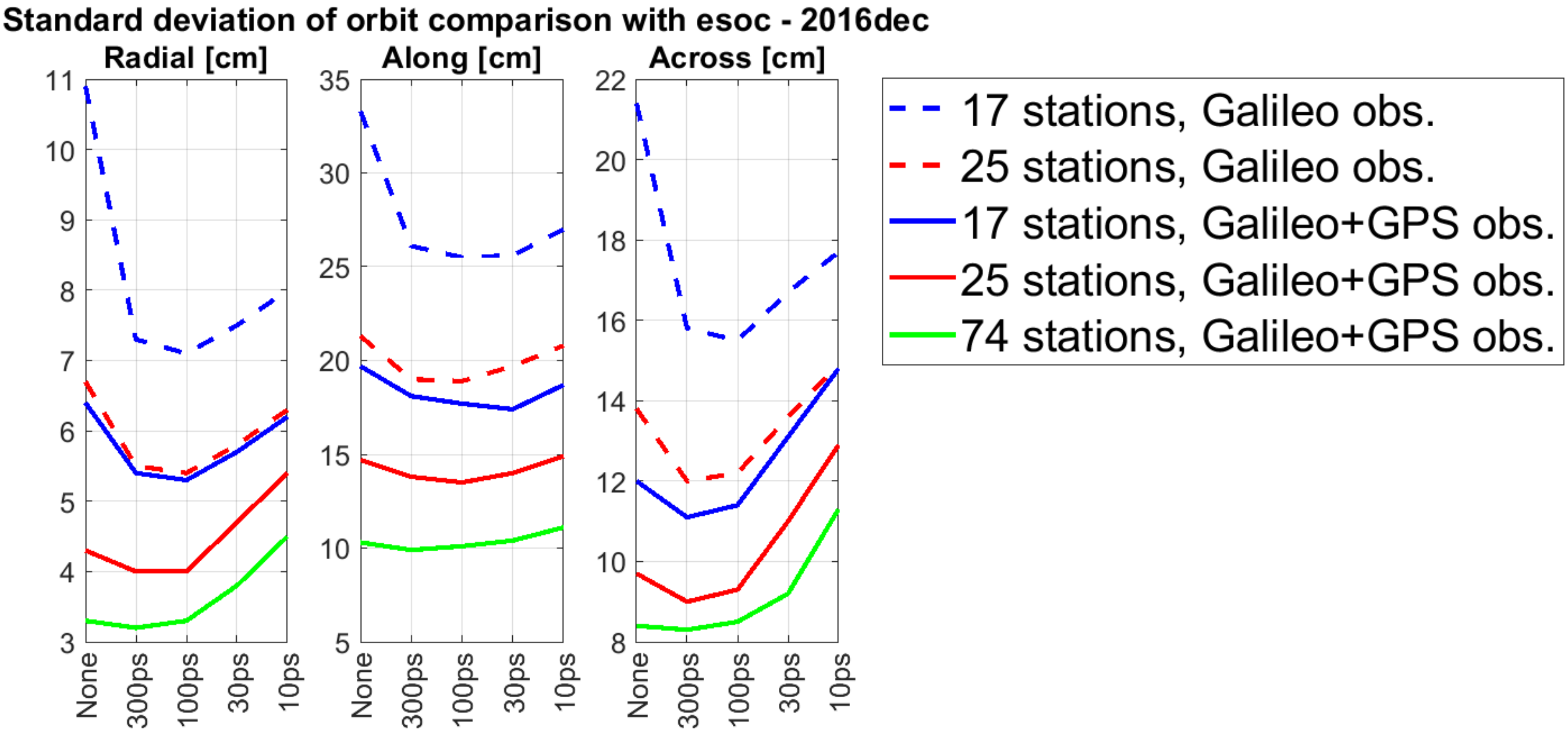
SLR: Radiation pressure models

Standard deviation for different radiation pressure models



*BW=Box-wing (Rodriguez-Solano et al., 2012)

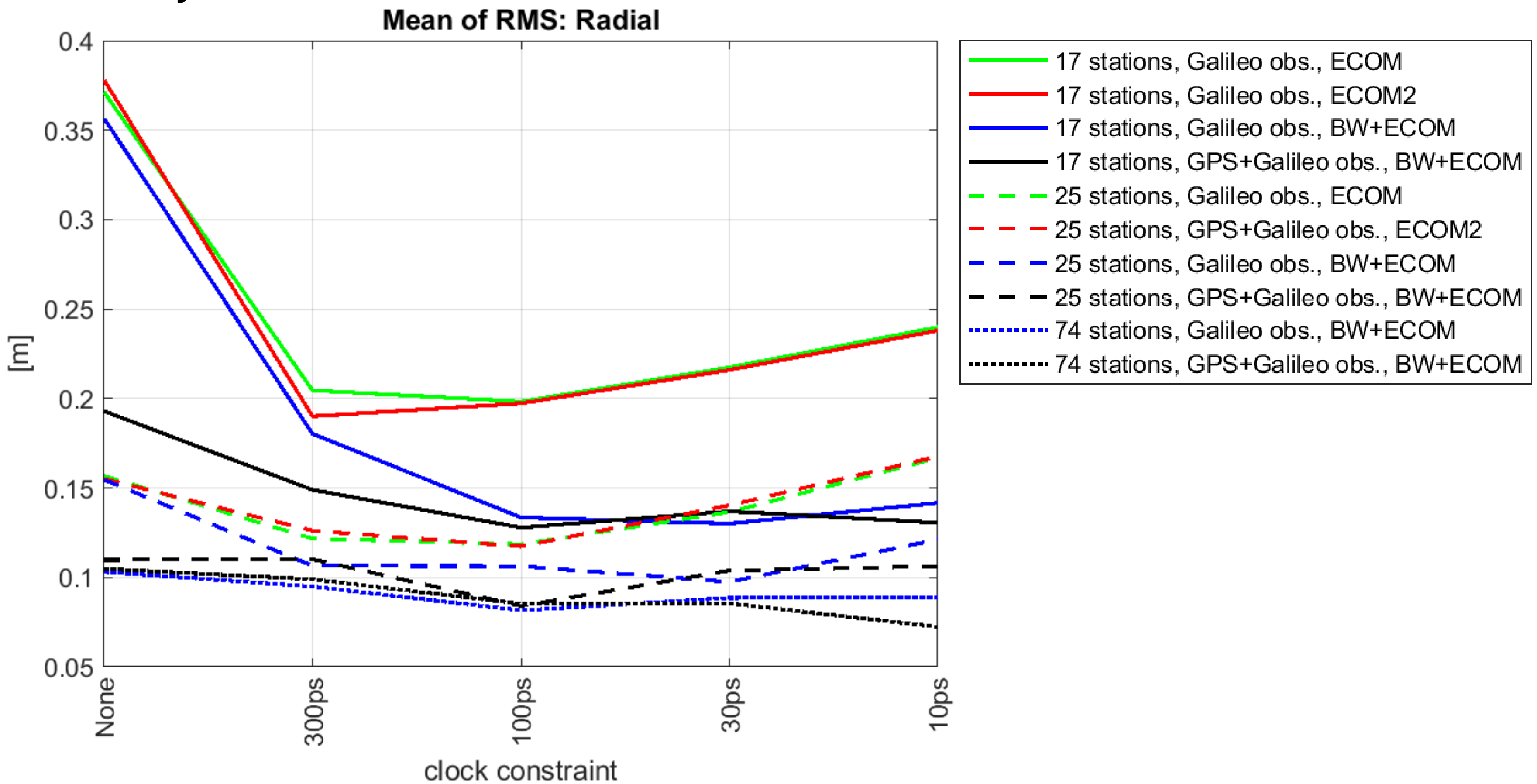
Orbit comparison



clock constraint

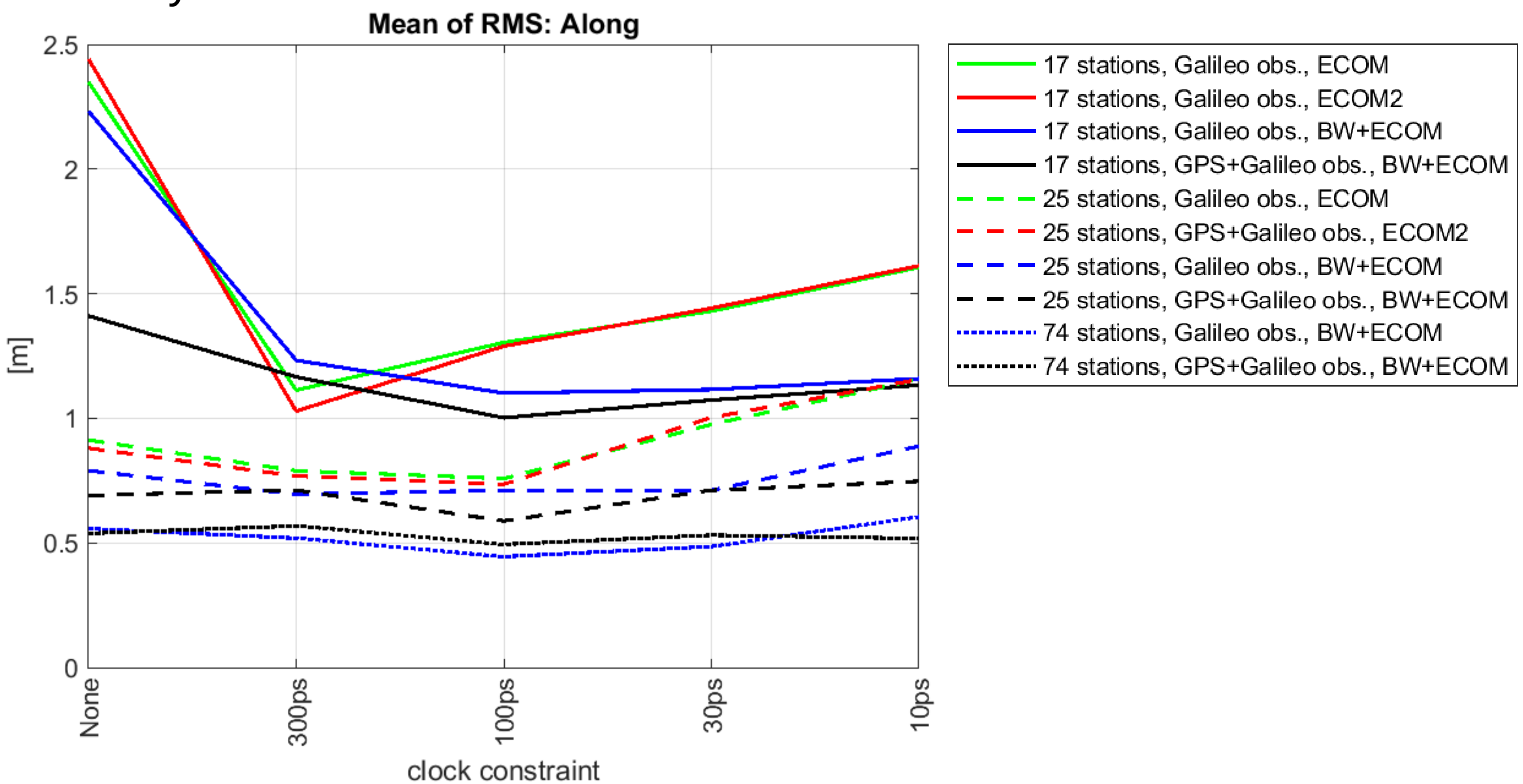
Orbit prediction: Radial

Mean of all satellites of RMS of orbit prediction vs. fitted orbit of next day over one month:



Orbit prediction: Along-Track

Mean of all satellites of RMS of orbit prediction vs. fitted orbit of next day over one month:



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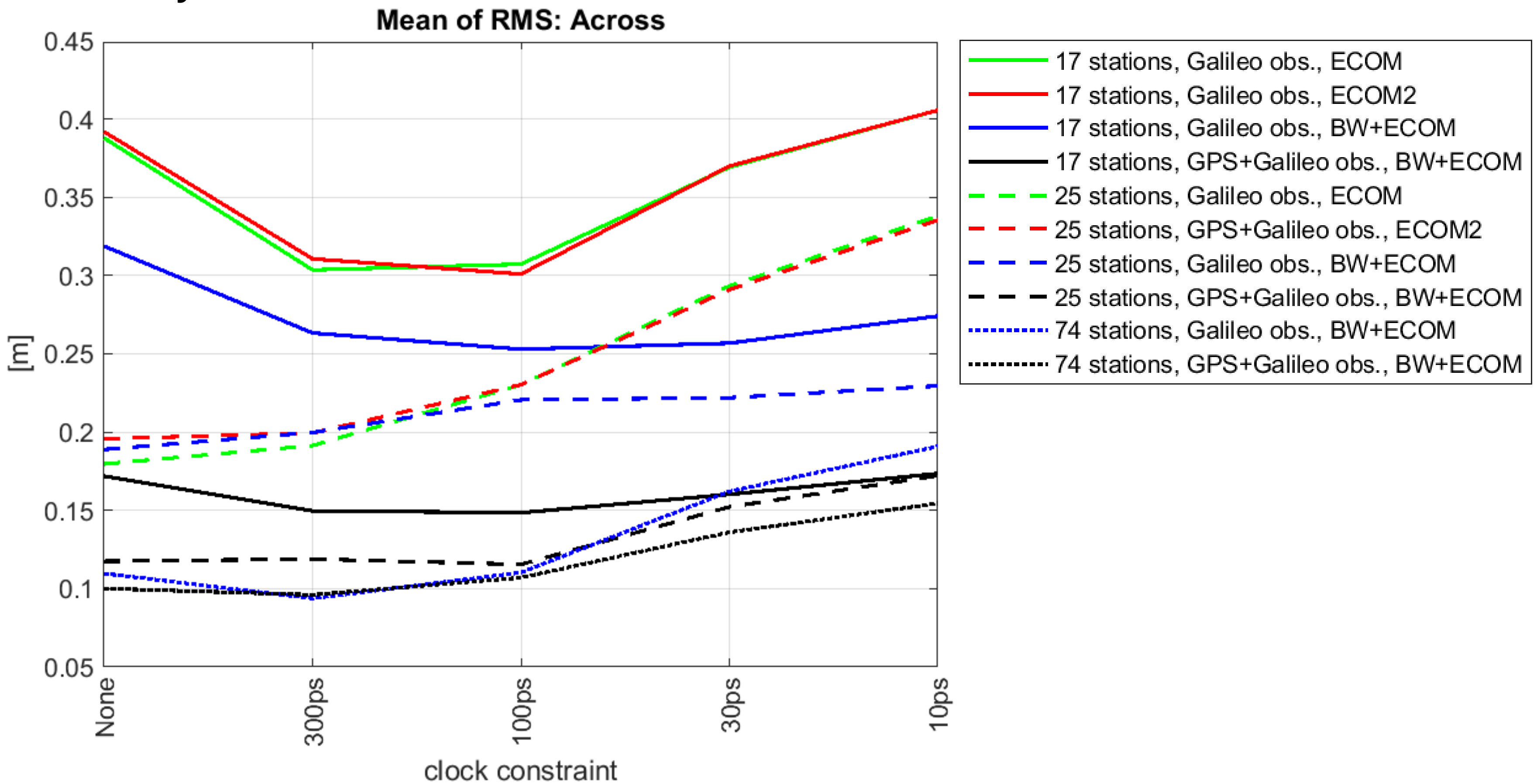
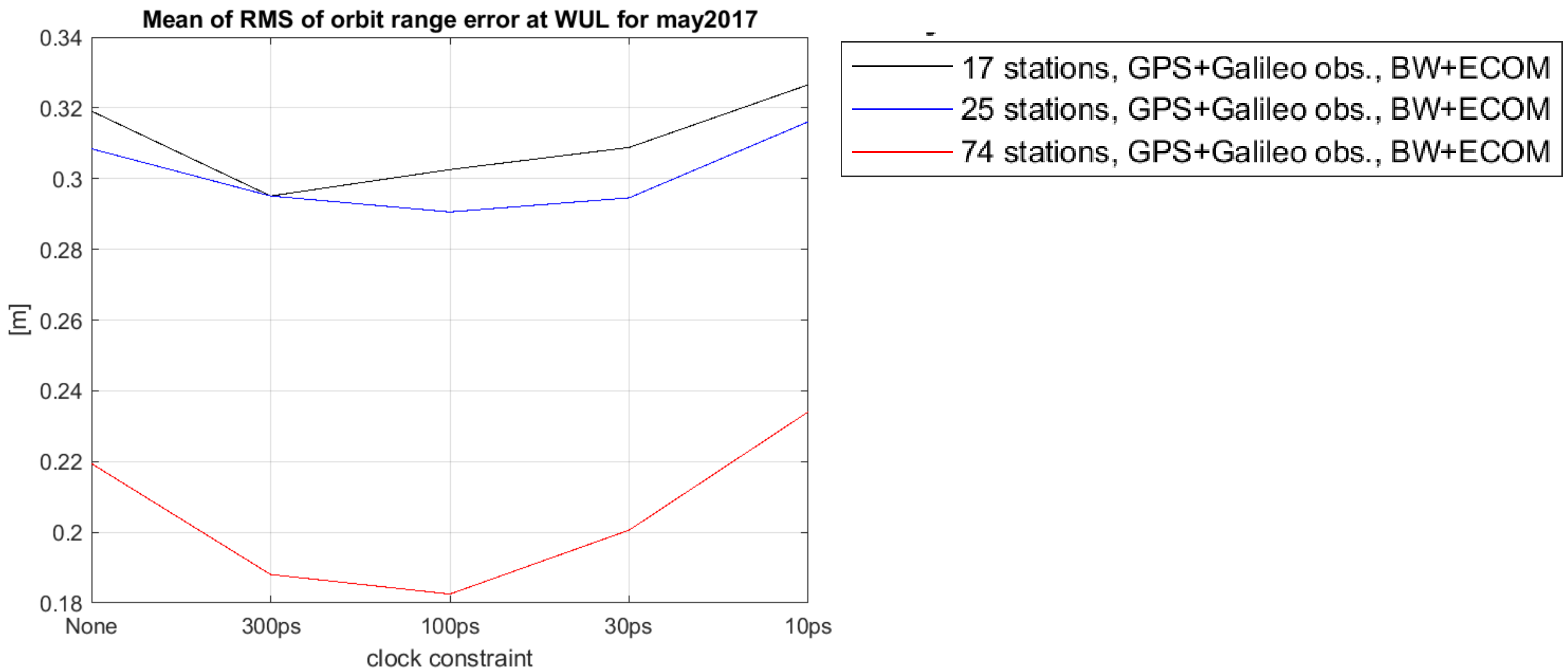


Orbit prediction: WUL

Mean of RMS of orbit range error at **Worst User Location** for different networks sizes and clock constraints



Summary

- All conducted test scenarios show improvements with absolute clock modelling constraints for Galileo PHMs applied

- Simple linear clock model already sufficient
- Optimal constraints between 30-300 ps depending on the solution
- Clock modelling especially beneficial for small networks
- Orbit prediction improves similarly

Thank you for your attention!