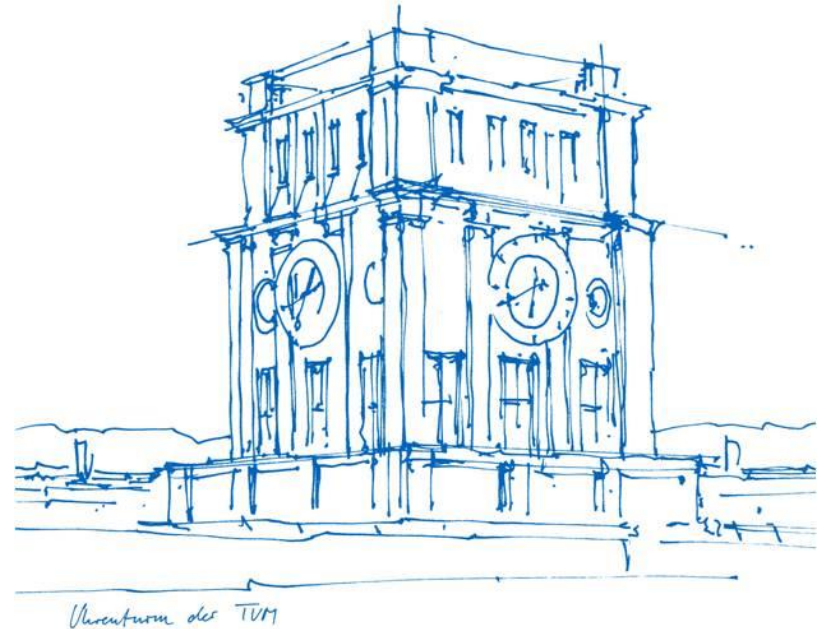


Combination of Microwave and Optical Observations for minimizing Atmospheric induced Variations in Parameter Estimation

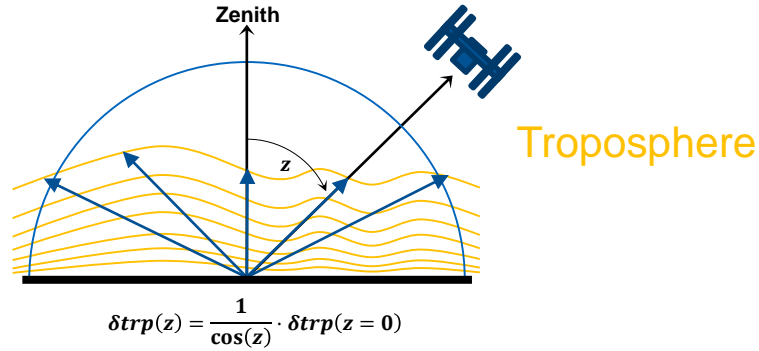
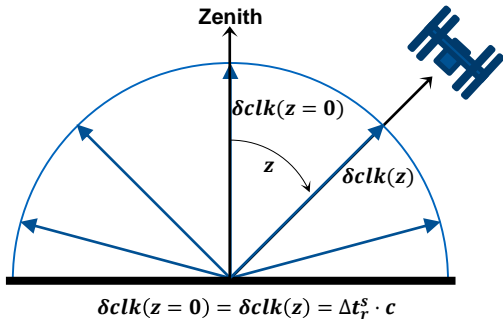
Peter Vollmair, Anja Schlicht, Stefan Marz
Forschungseinrichtung Satellitengeodäsie
TUM School of Engineering and Design
Technical University of Munich

Paris, 20. October 2022



Motivation

Clock

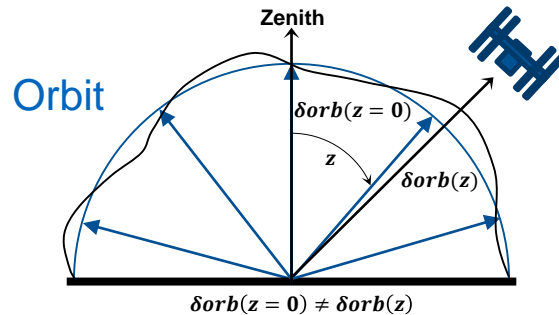
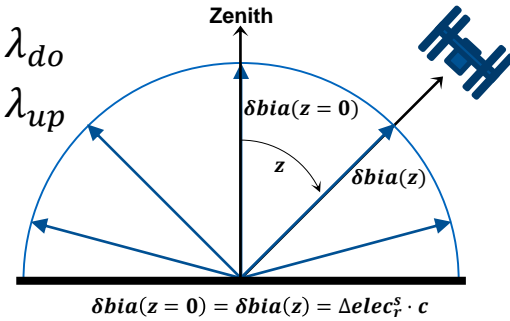


$$\phi_{do} = \rho_r^S + \delta clk_r^S + \delta orb + \delta trp + \delta bia + N_{do} \cdot \lambda_{do}$$

$$\phi_{up} = \rho_r^S - \delta clk_r^S + \delta orb + \delta trp + \delta bia + N_{up} \cdot \lambda_{up}$$

$$\tau_{ELT} = (\rho_r^S - \delta clk_r^S + \delta orb + \delta trp) \cdot c^{-1}$$

$$\tau_{SLR} = (\rho_r^S + \delta orb(\delta clk_r^S) + \delta trp) \cdot 2c^{-1}$$



Electronic Delay

Figure 2: Parameter Correlations (Figures adapted from Wang, 2011)

Simulation

Parameter	Model	MWL	OPT
Troposphere	ERA5	X	X
Ionosphere	NeQuickG	X	-
Orbit	TLE	X	X
Clocks	Noise-Modeled	X	X
Height Offset	1 mm	-	X
Time Offset	1 ps	-	X
Electronic Delay	1.0 ns / 0.9 ns delay (stable)	X	-
Noise	White Noise	0.2 ps	37 ps
Sampling (Hz)	12.5 (MWL) / 100/300 (ELT/SLR)	100 %	10 %



Dataset:	<ul style="list-style-type: none"> 100 passes 	<ul style="list-style-type: none"> ~ 7 min. mean duration 	<ul style="list-style-type: none"> ~ 65° mean max elevation
Assumptions:	<ul style="list-style-type: none"> Good weather 	<ul style="list-style-type: none"> Single-Photon-Mode 	<ul style="list-style-type: none"> Stable electronic delay

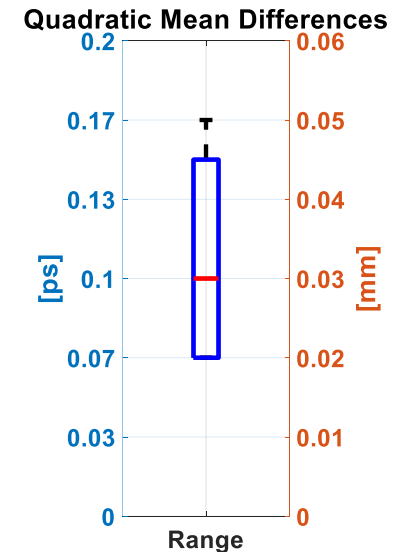
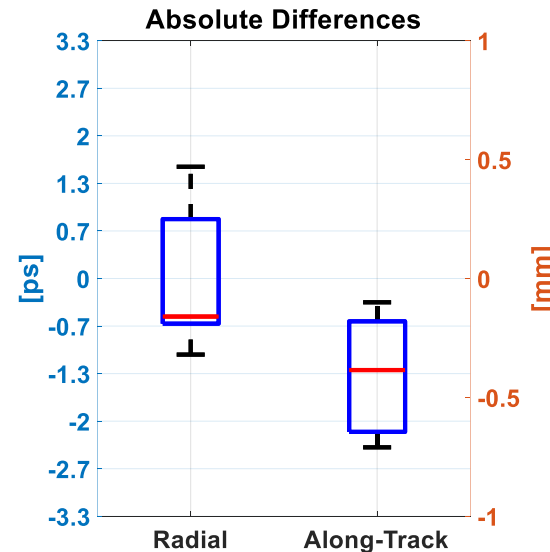
Parameter Estimation – Least Squares Adjustment

Parameter	Description	LSA	Model
Troposphere	<ul style="list-style-type: none"> - A priori values from VMF - Estimate a common troposphere - Gradient estimation 	X	-
Ionosphere	<ul style="list-style-type: none"> - Linear Combination (STEC) 	-	X
Orbit	<ul style="list-style-type: none"> - Stochastic model - 4 parameter 	X	-
Clocks	<ul style="list-style-type: none"> - Clock offset 	X	-
Electronic Delay	<ul style="list-style-type: none"> - MWL Delay in up/down 	X	-
Height Offset	/	-	-
Time Offset	/	-	-
Noise	/	-	-

Assessment of Parameter Estimation - Orbit

- Best possible solution shows the limits of what is feasible
- Simulation with no errors
- Estimation of only orbit parameters by using wrong a priori orbit

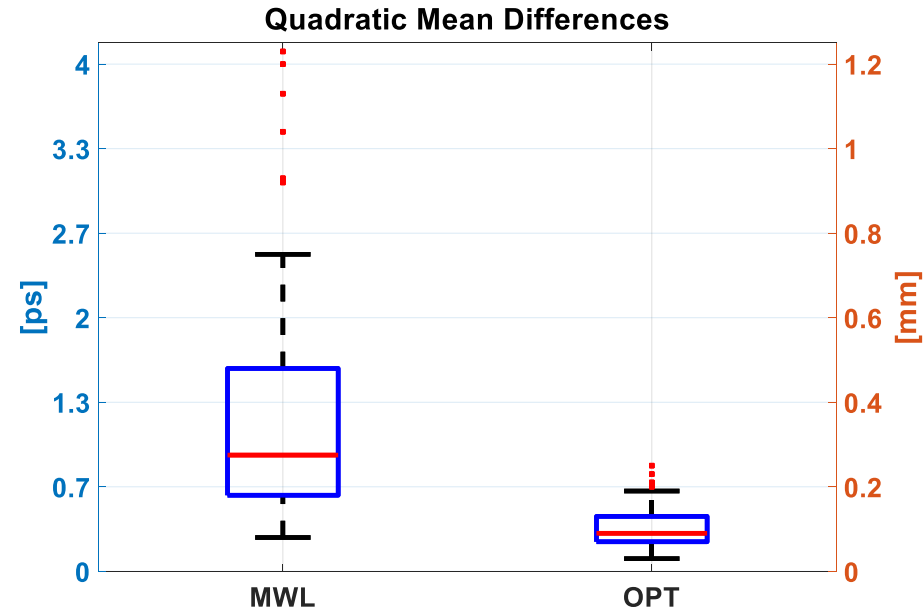
Type	[ps]	Median		Factor
		a priori	a posteriori	
Radial	8	-0.5	~14	
Along-Track	48	-1.3	~38	
Range	7	0.1	~67	



Assessment of Parameter Estimation - Troposphere

- Best possible solution shows the limits of what is feasible
- Simulation with troposphere errors only
- Estimation of a common isotrop troposphere and seperate gradients for both, MWL and OPT

Type [ps]	Median		Factor
	a priori	a posteriori	
MWL	139	0.9	~150
OPT	3	0.3	~10



Strategies

- Several estimation strategies were tested
- Differs only on troposphere gradient estimation
- Gradient corrections are applied to **all** observations

Name	WVPR		Press.		Wet Gradient		Dry Gradient	
	MWL	OPT	MWL	OPT	MWL	OPT	MWL	OPT
wet-both	X		X		X	X	-	-
wet/dry-both	X		X		X	-	X	X

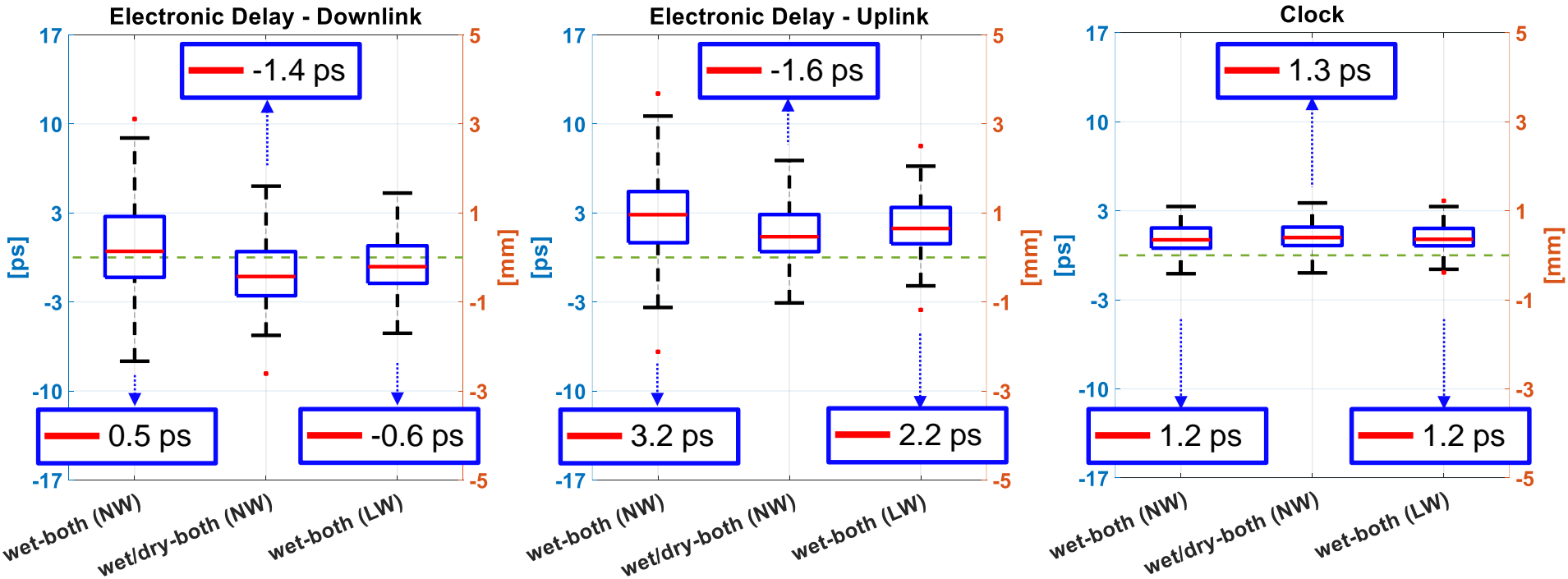
Two different weighting strategies:

- **noise**-dependent (**NW**)
- **laser**-dependent (**LW**)

Weighting Type	MWL	OPT
Noise Weighting (NW)	200	1
Laser Weighting (LW)	1	10

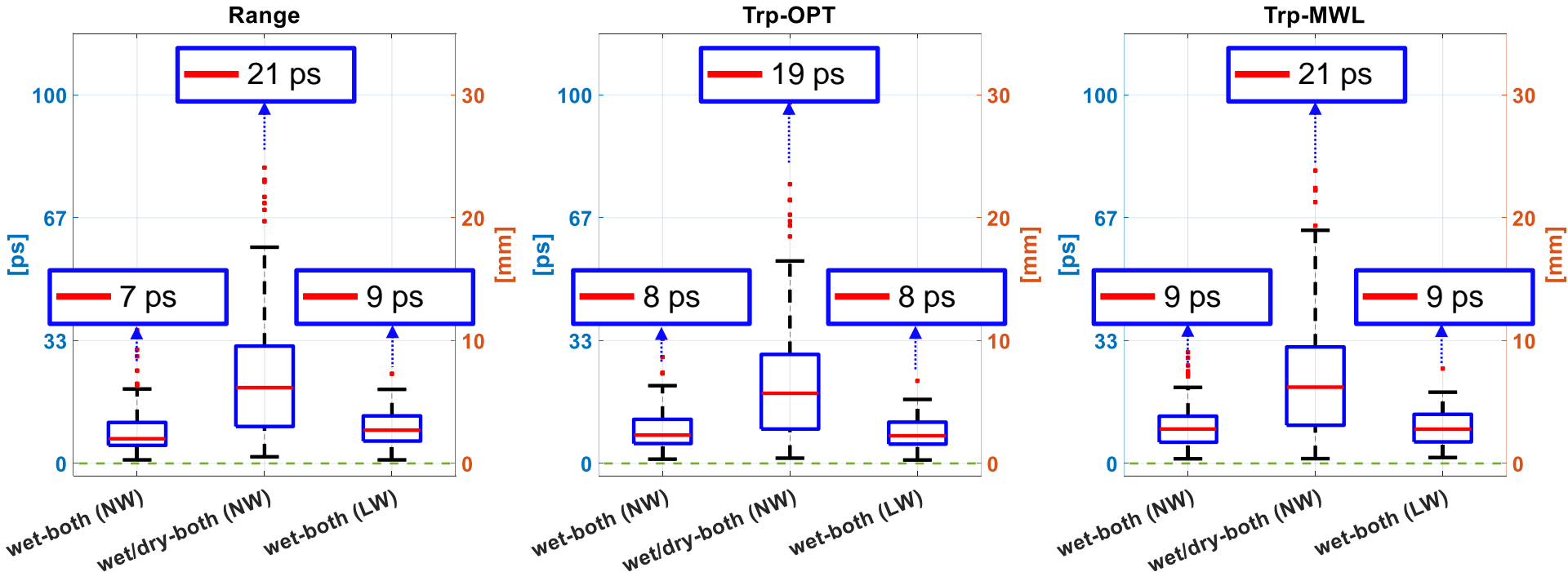
Results (1)

- Parameter differences: simulated – estimated parameters



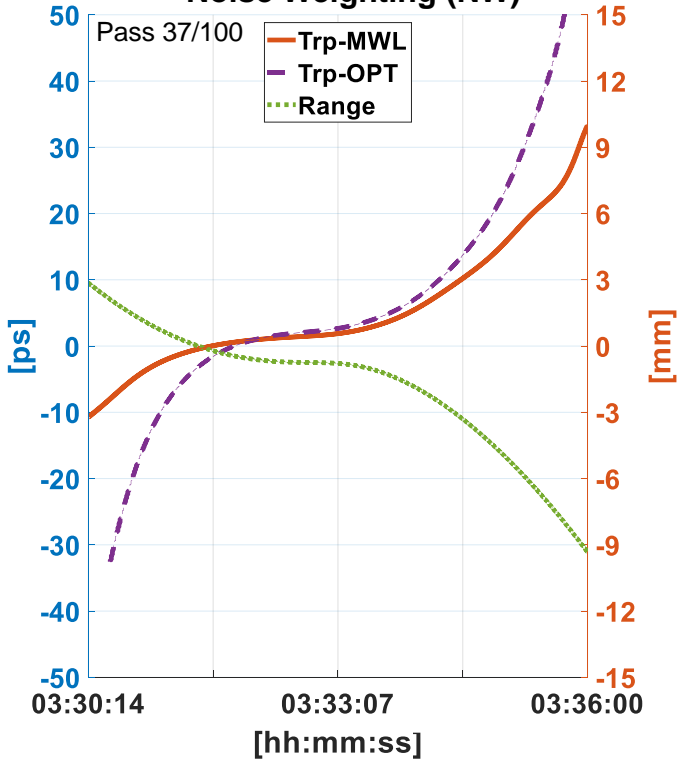
Results (2)

- Quadratic Mean difference of all epochs for all passes



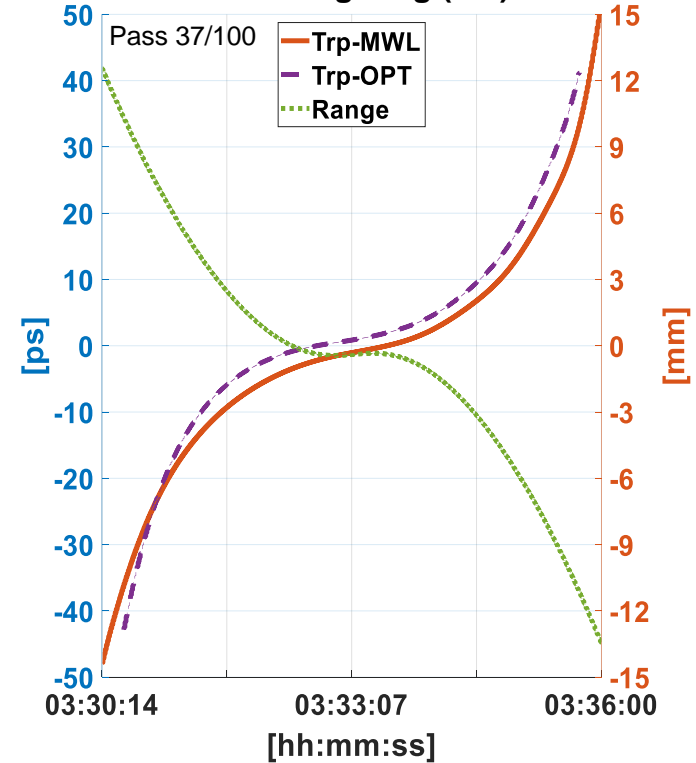
Results (3)

Noise Weighting (NW)



Weighting Type	Electronic Delay Differences [ps]	
	Downlink	Uplink
NW	-13	-7
LW	-0.9	1.1

Laser Weighting (LW)



Conclusions

- promising strategies to calibrate a MWL-Groundterminal
- Electronic Delay Differences < 2 ps (median)

→ Single-wavelength-SLR observations are not enough to stabilize the estimation!

Next:

- Improve simulation/estimation:
 - Tropospheric fluctuations
 - Multi-wavelength-SLR measurements



Figure 3: ISS [ESA, 2011]

Thanks for your attention!



References

Figure 1: L Cacciapuoti and C Salomon, 2011, J. Phys.: Conf. Ser. 327 012049

Figure 2: modified by author after Wang:

K Wang, M Rothacher, M Meindl, E Schoenemann, W Enderle; 2017; „Improvement in the estimation of troposphere zenith delays using high-accuracy clocks “

Figure 3: CC BY-SA 3.0 IGO, ESA, 2011, [Link](#)