ETH zürich

Improvement in the estimation of troposphere zenith delays using high-accuracy clocks

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Overview

- Introduction: clock modeling and kinematic height estimation
- Motivation for this study
- Results without and with clock modeling:
  - Influence on kinematic heights
  - Influence on zenith path delays (ZPD)
- Comparison with meteo and WVR data (CEBR and ONSA)
- Conclusions

Highly accurate clocks
Clock model

- Clocks are modelled with offset a_0, drift a_1 and a stochastic parameter p_i

$$clk(t_i) = a_0 + a_1 \cdot (t_i - t_0) + p_i(t_i)$$

- Relative constraints may be imposed on the stochastic parameter

$$p_i(t_i) = p_{i+1}(t_{i+1}) \qquad P_i = \frac{\sigma_0^2}{\sigma_r^2}$$

- Very weak absolute constraints are imposed for regularization

Highly accurate clocks
Clock quality of some selected IGS stations

1) Standard deviation σ after removing a linear polynomial over one day
2) Standard deviation of epoch-to-epoch differences σ_e after removing a linear polynomial.

- Standard deviations σ of the order of 30-120 ps (1 – 4 cm)
- The epoch-to-epoch repeatability σ_e is on the level of 10 - 20 ps (3-6 mm, phase noise)
- Indication of the size of the relative constraints

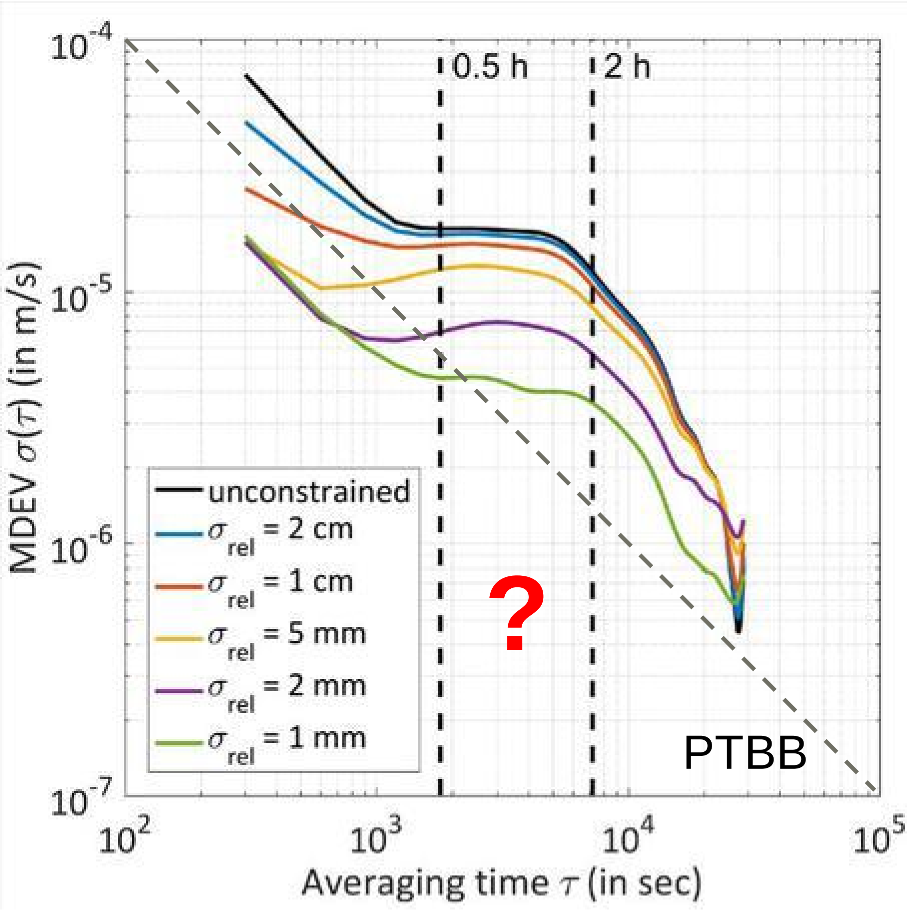
Station	σ (in ps)	σ_e (in ps)
CEBR	86	19
HERS	30	13
HRAO	39	11
MGUE	27	10
PTBB	114	12
ZECK	30	11

August 8, 2015

Motivation
Kinematic station height with clock model

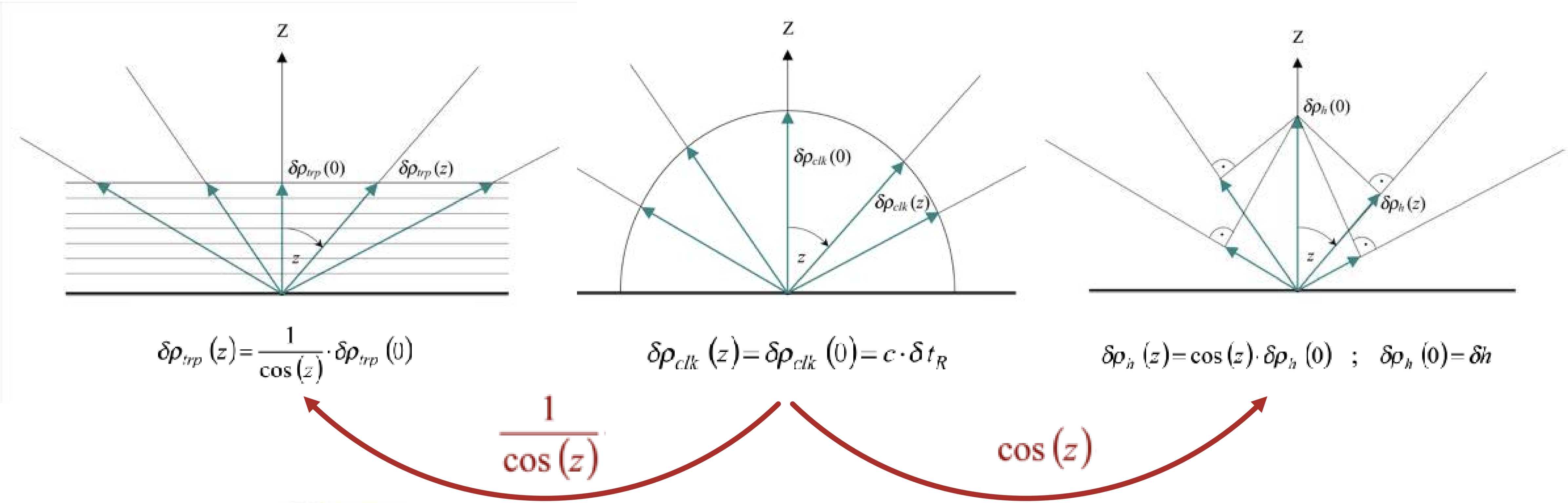
- Standard deviation of kinematic heights without (σ) and with best clock model (σ_c)

Station	σ (in cm)	σ_c (in cm)	Improvement
CEBR	8	4	2.0
HERS	9	4	2.3
HRAO	49	14	3.5
MGUE	12	5	2.4
PTBB	10	4	2.5
ZECK	9	3	3.0

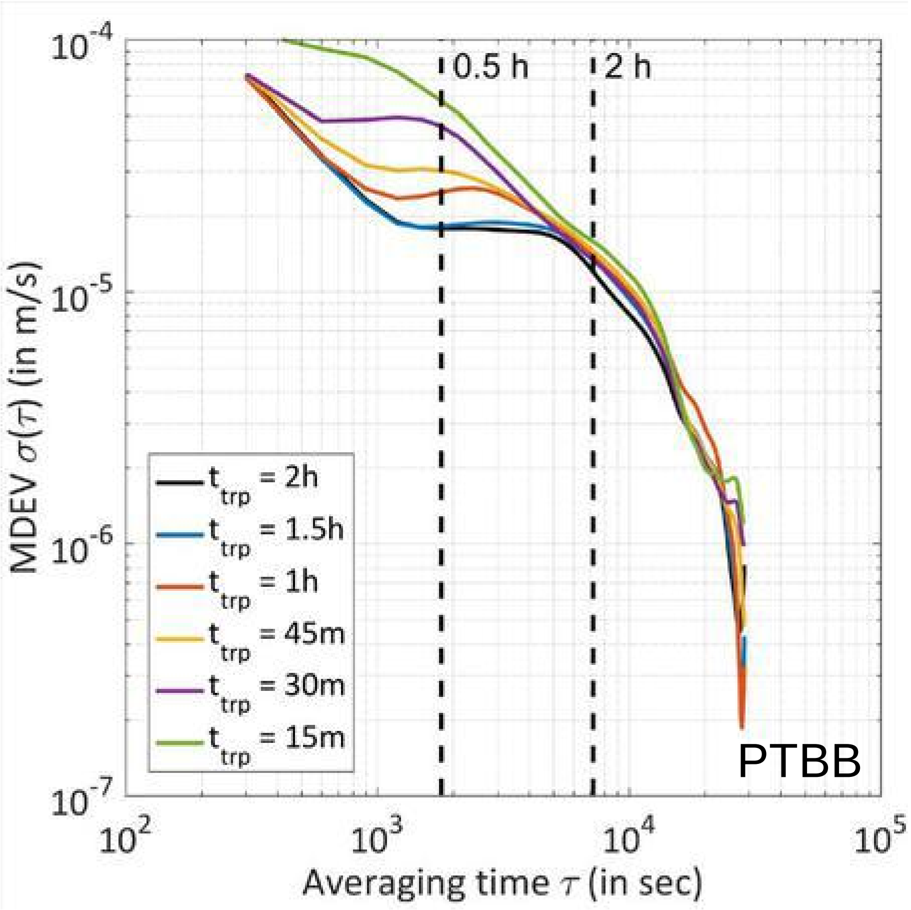


Motivation
Correlation of troposphere, station clock, and height

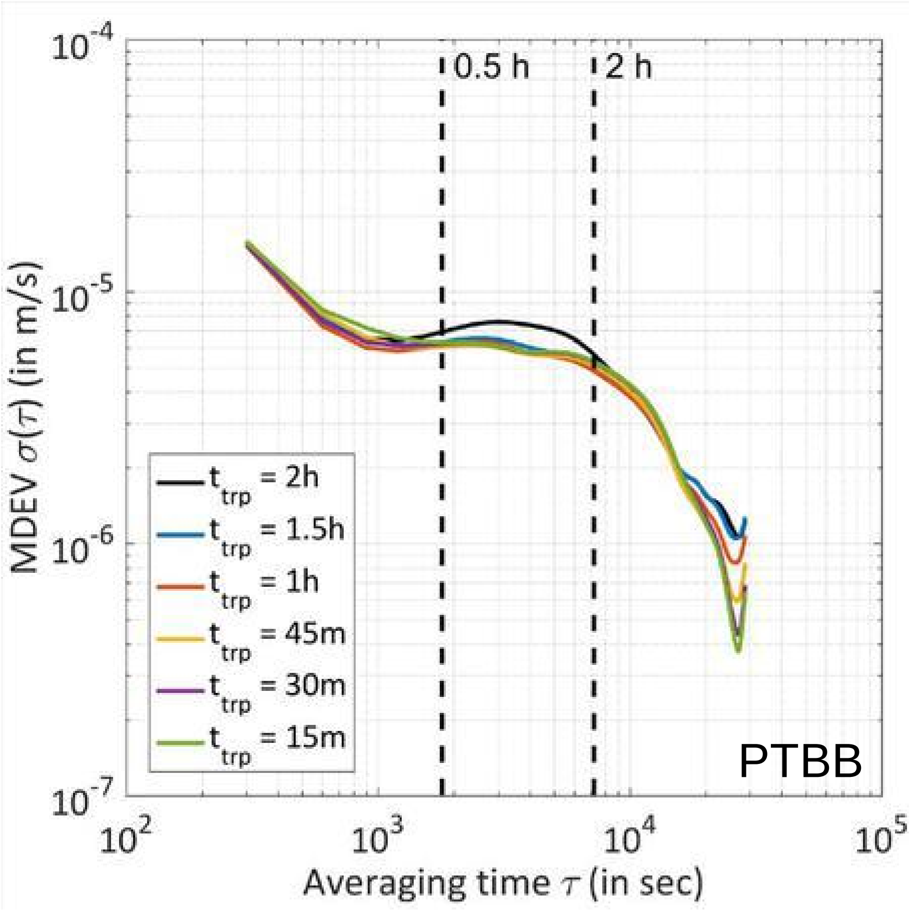
- Troposphere
- Station clock
- Station height



Kinematic station height: varying the ZPD resolution

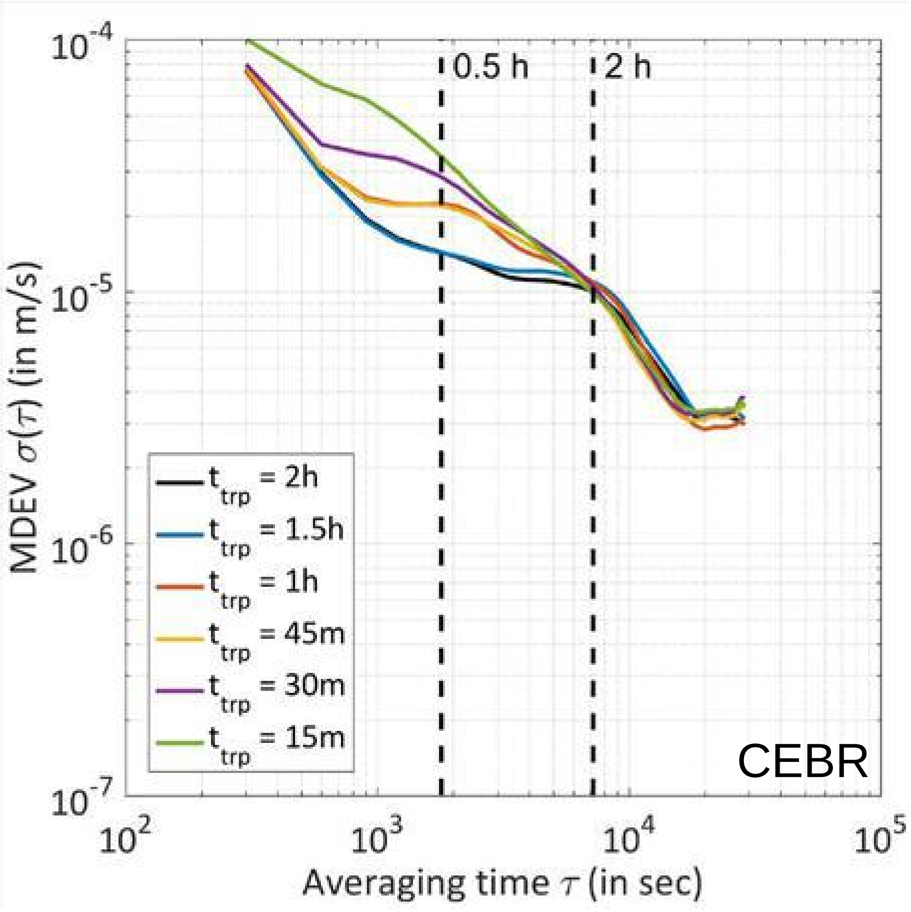


No clock model

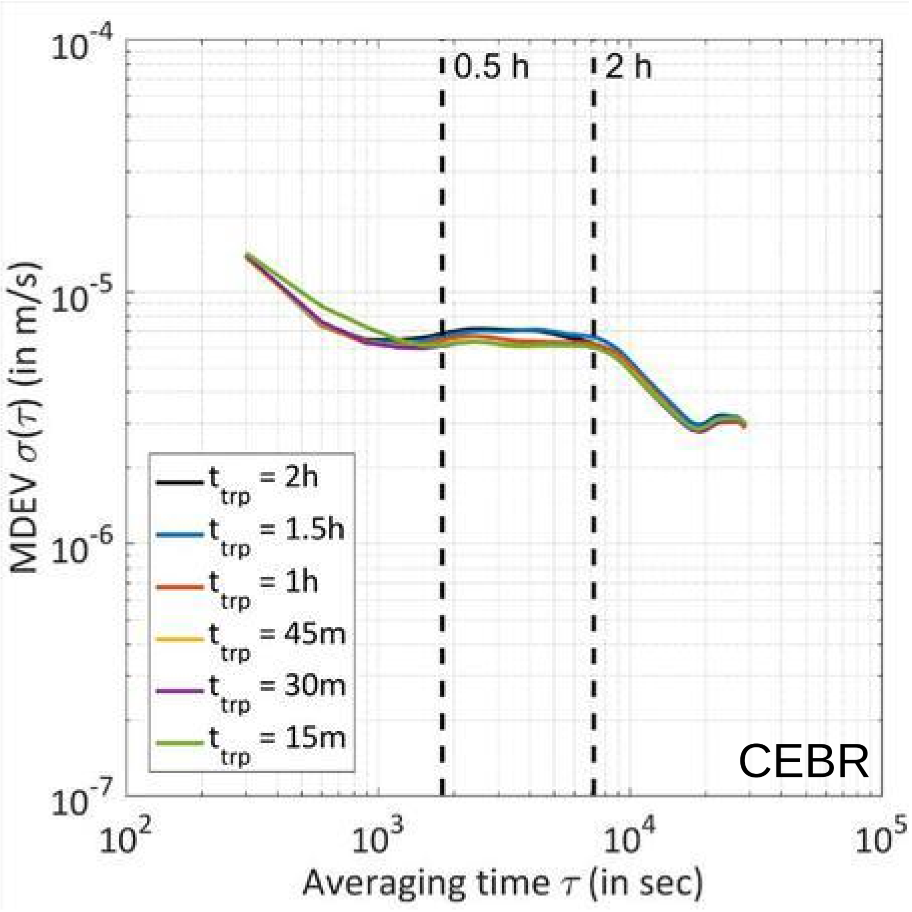


Clock model with 1 mm constraint

Kinematic station height: varying the ZPD resolution

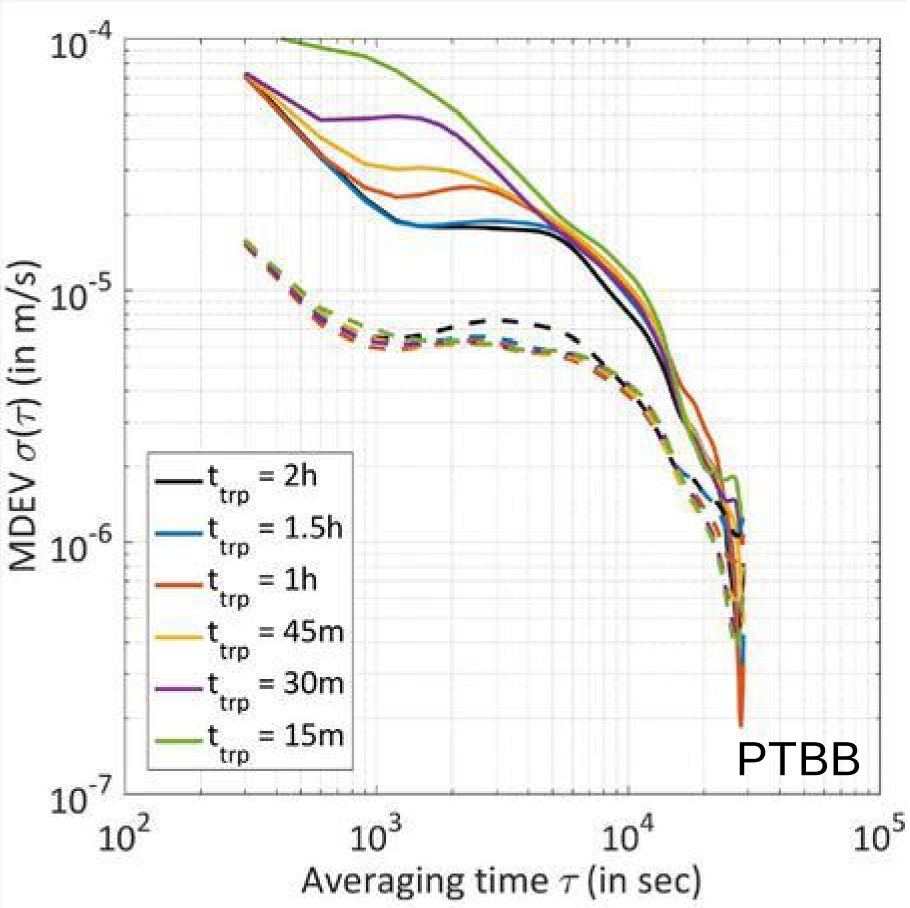


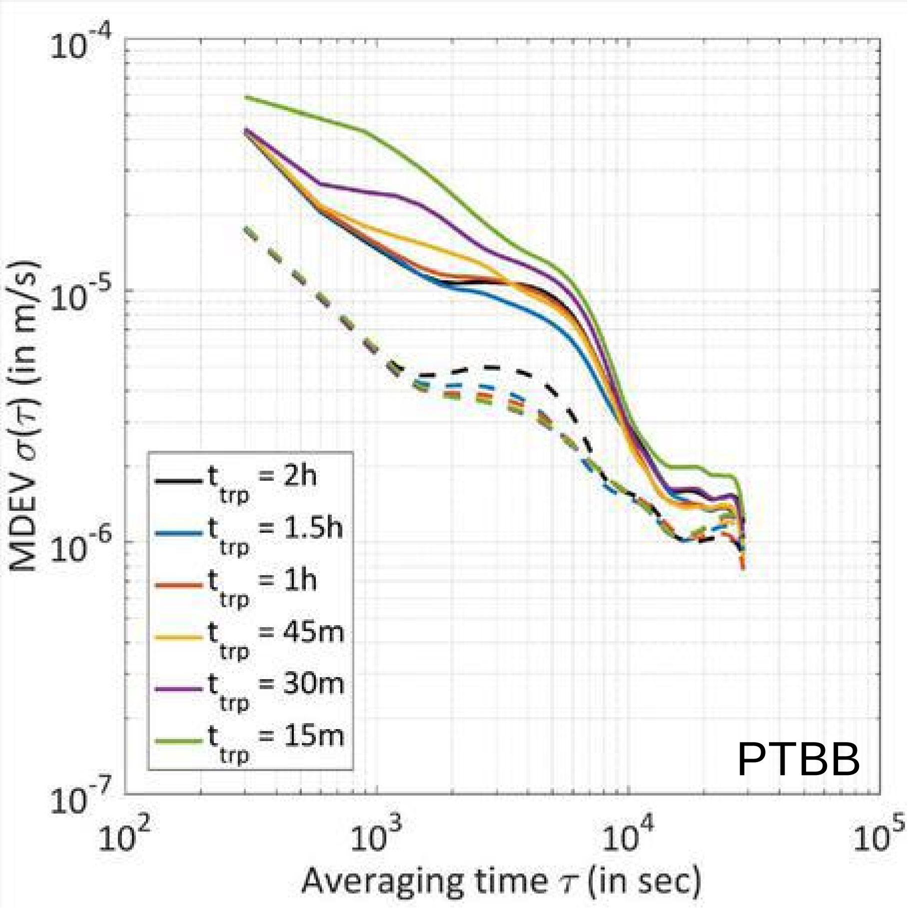
No clock model



Clock model with 1 mm constraint

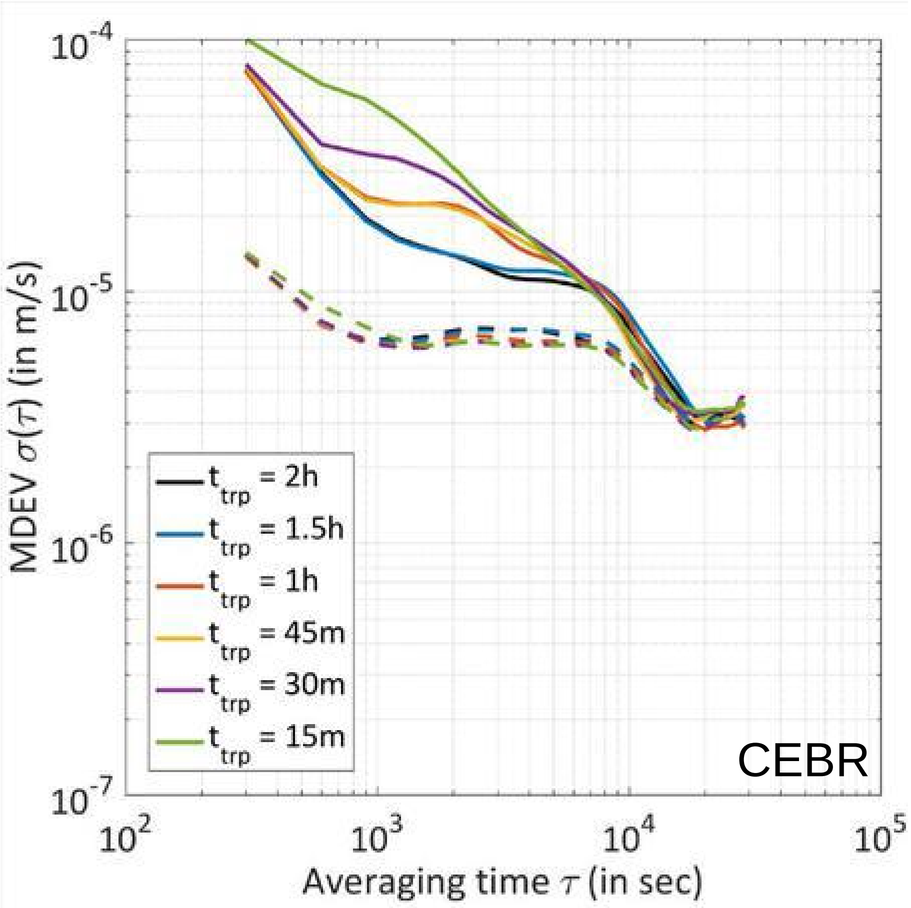
Kinematic station height: varying the ZPD resolution

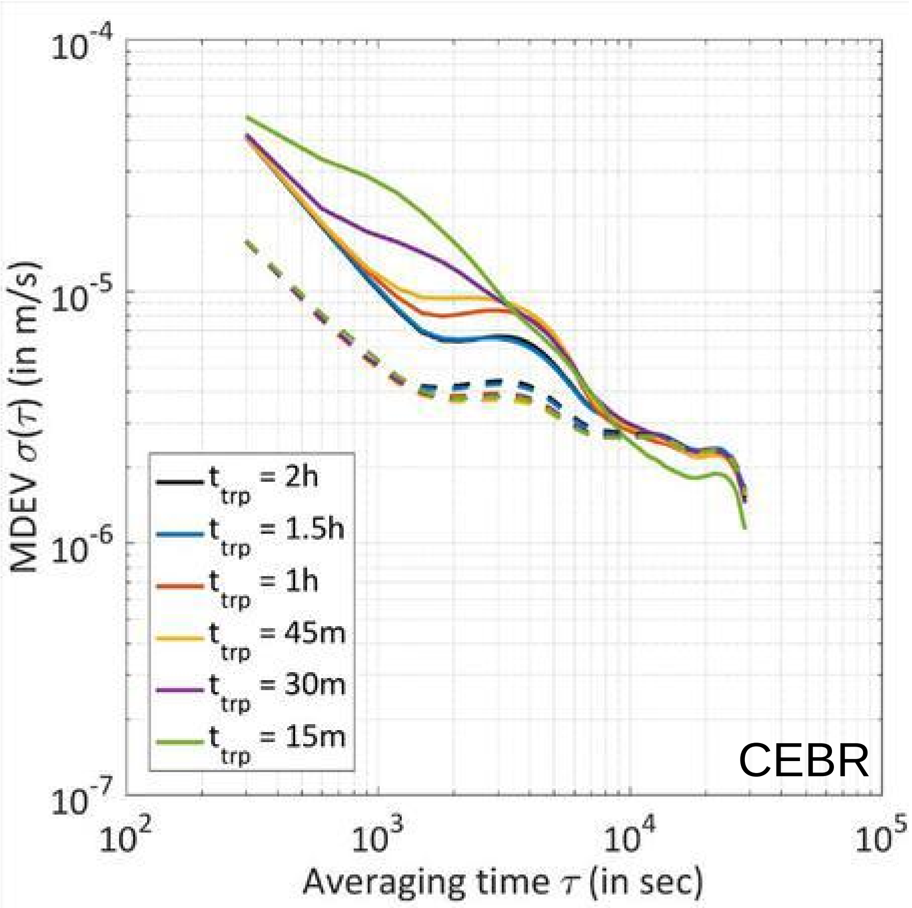




Aug 2015 without (solid) and with (dashed) clock model Nov 2015

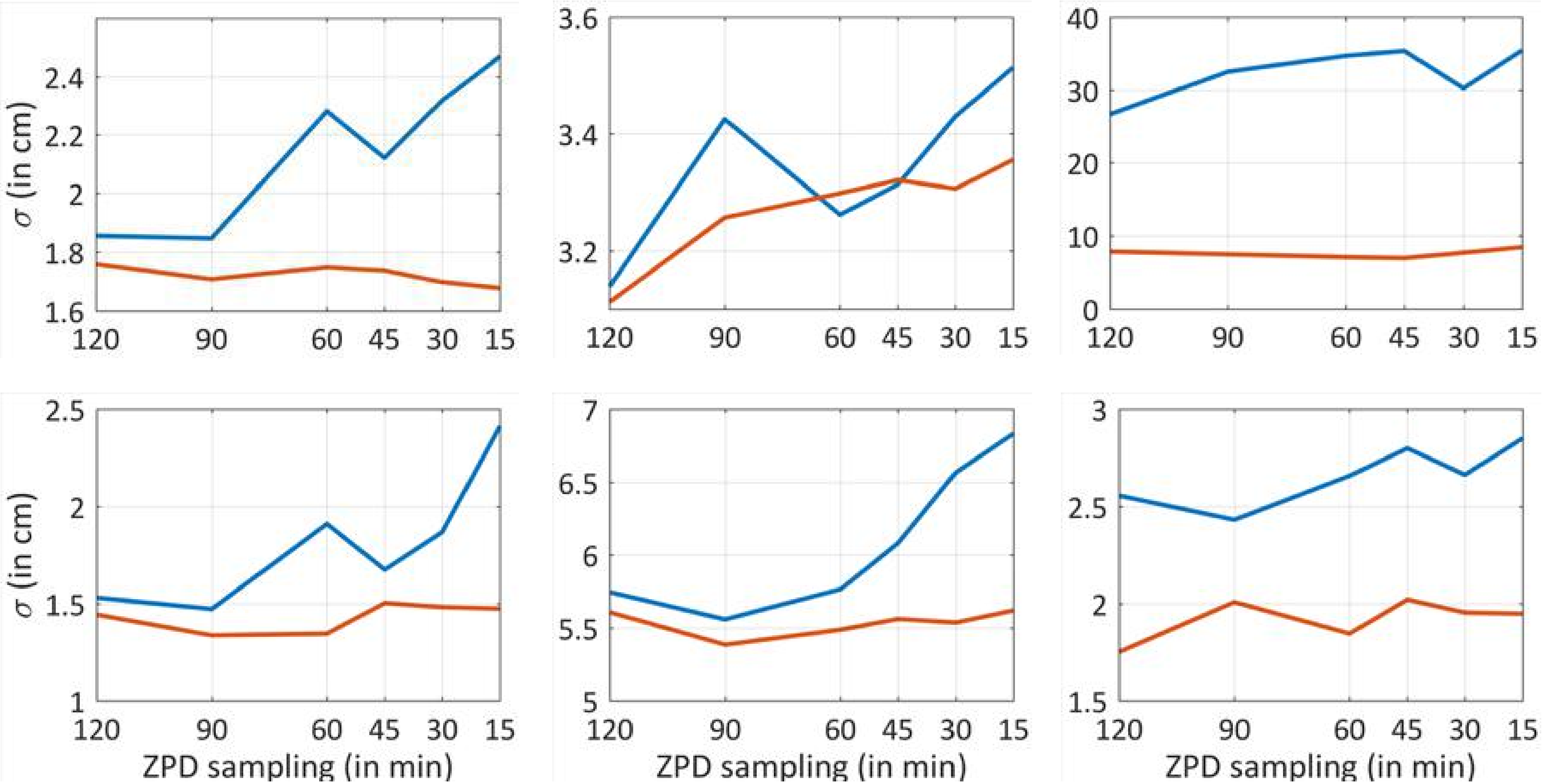
Kinematic station height: varying the ZPD resolution





Aug 2015 without (solid) and with (dashed) clock model Nov 2015

ZPD comparison with meteo data



- STDs of the differences ZPD(GPS) – ZPD (meteo)
- ZPD(meteo) are free from correlations with the heights and the clocks

→ **Significant improvement** in the ZPD stability, especially for high sampling rates

August 9, 2015

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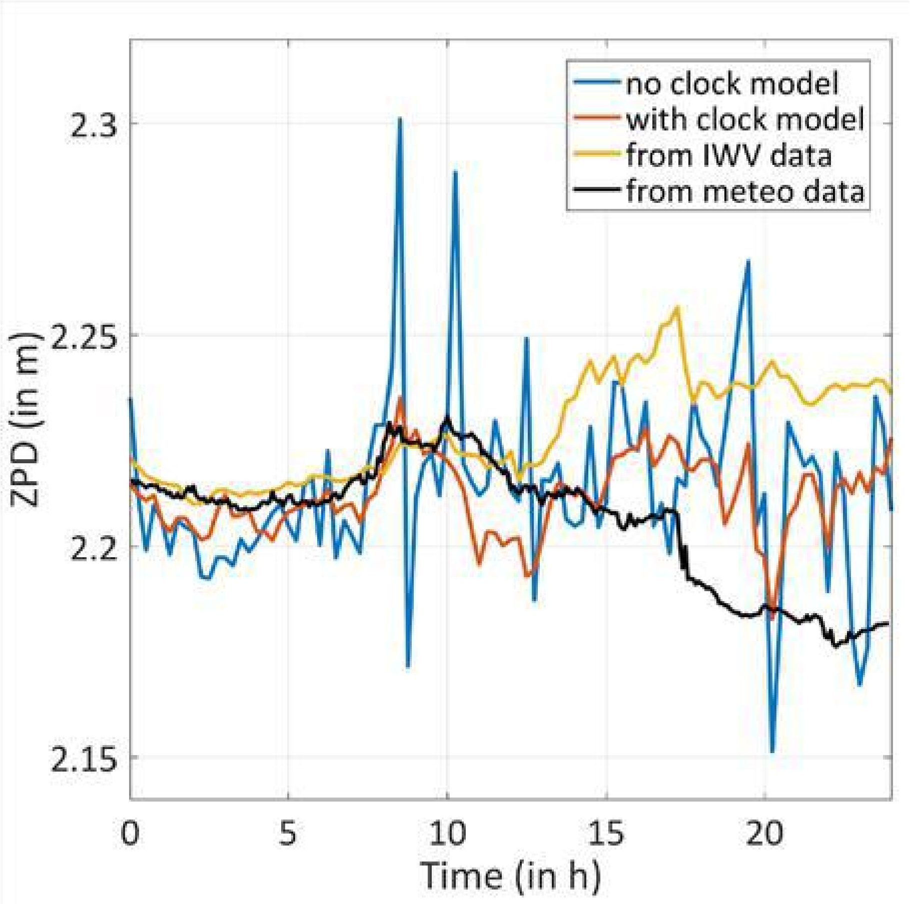
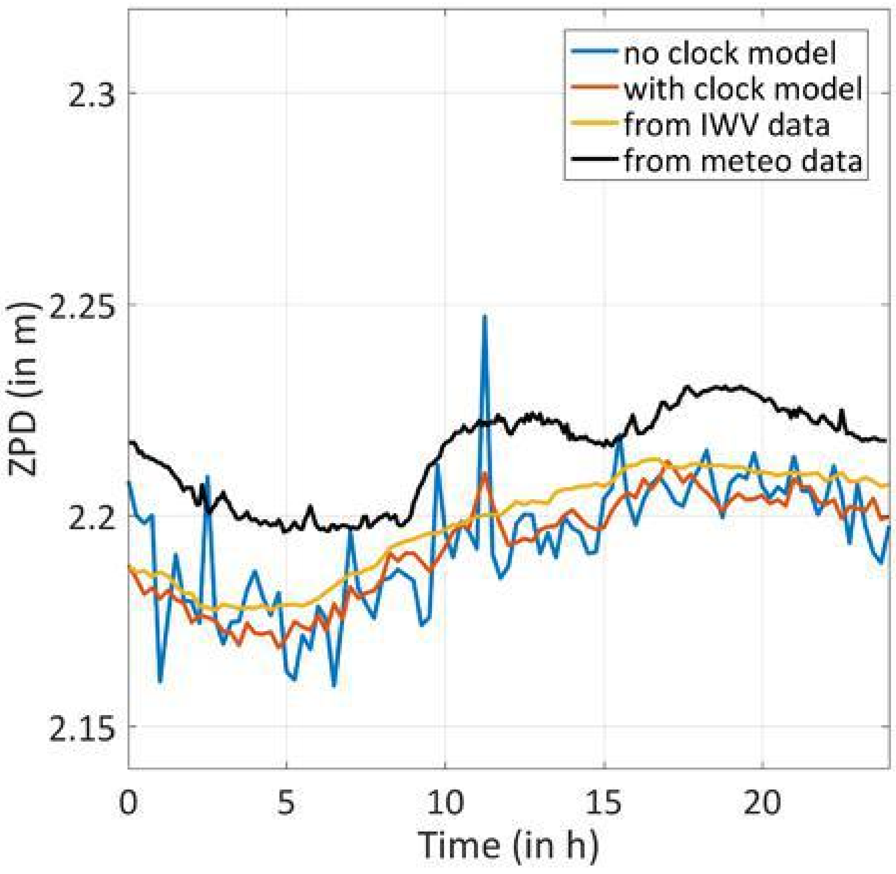
ZPD comparison with WVR, station CEBR

- Comparison of ZPD from GPS and ZPD computed from IWV data (15 min samp.)

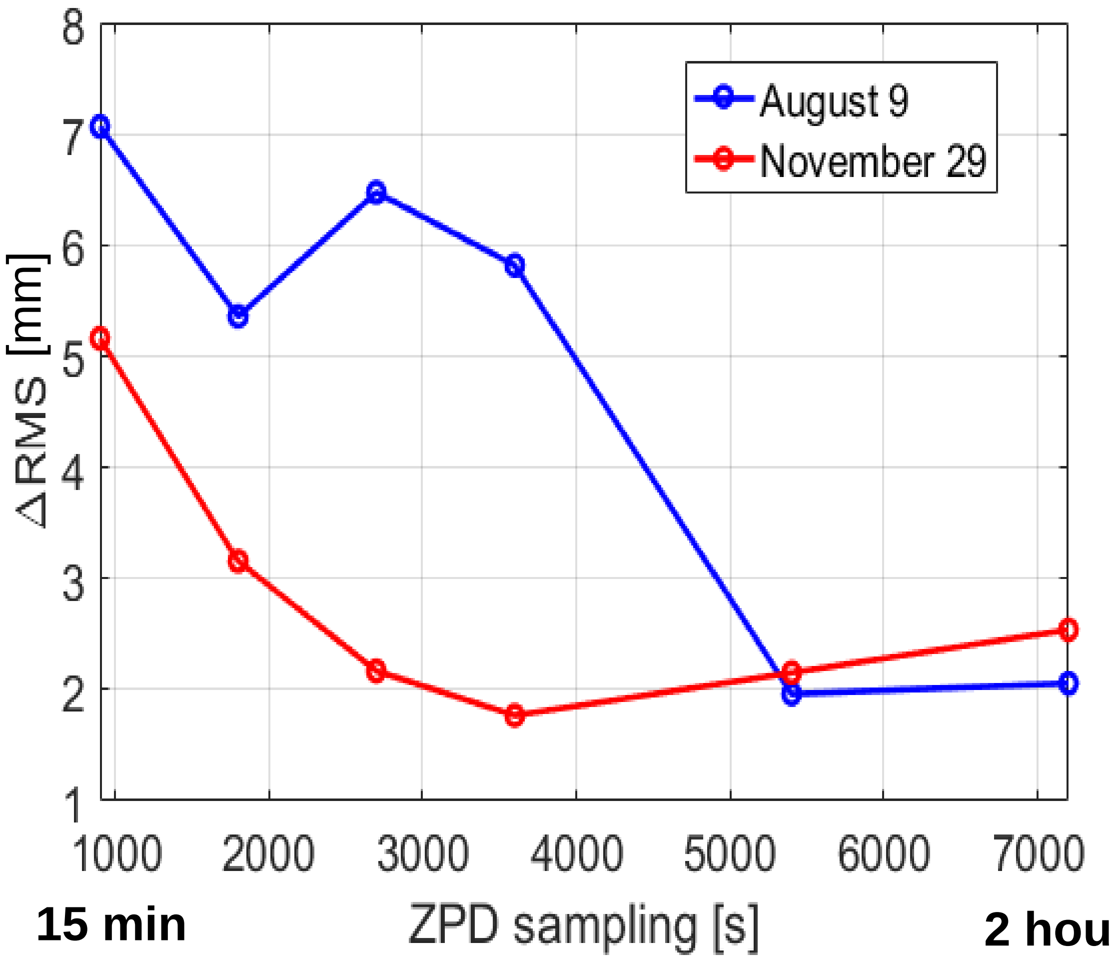


Aug 2015



Nov 2015

ZPD comparison with WVR, station CEBR, 2 days



15 min **2 hours**

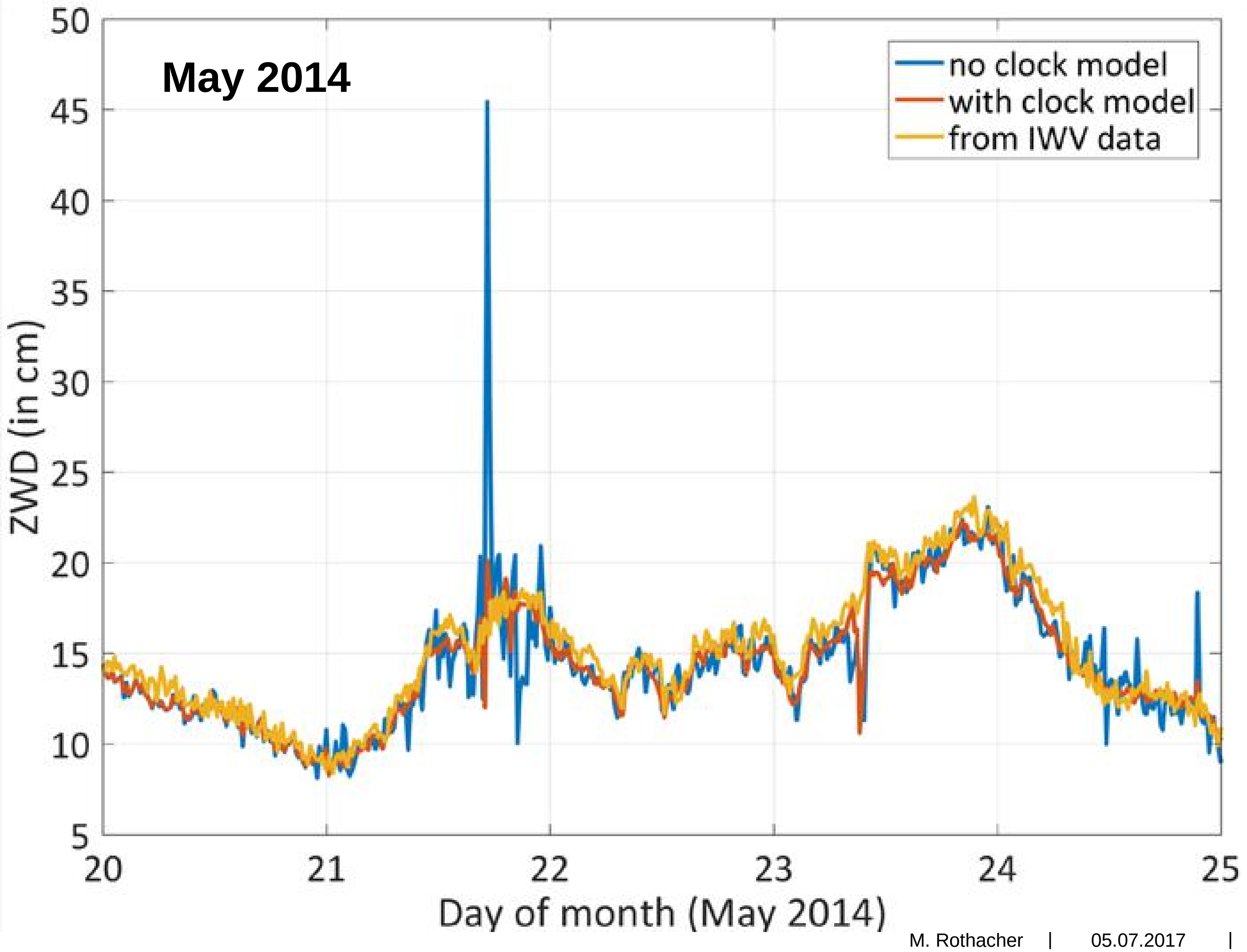
- **Accuracy:** comparison of ZPD from GPS with/without clock model
- **Reduction of the ZPD RMS** when applying the clock modeling
- Higher reduction at **high sampling rate** for the ZPD estimates

→ **Significant improvement of ZPD with clock modeling**

ZWD comparison with WVR, station ONSA, 5 days

- Comparison of ZWD (zenith wet delay) from GPS with/without clock model and ZWD from WVR data (15 min sampling of ZWD, May 20-24, 2014)

→ Much increased stability



ZWD comparison with WVR, station ONSA, 5 days

- RMS of difference between ZWD from WVR data and from GPS

Date	RMS of ΔZWD [m]					
	2 h	1 h 30 min	1 h	45 min	30 min	15 min
		Without clock model				
August 20, 2014	0.0068	0.0060	0.0065	0.0070	0.0066	0.0084
August 21, 2014	0.0223	0.0227	0.0344	0.0405	0.0327	0.0383
August 22, 2014	0.0093	0.0075	0.0092	0.0091	0.0106	0.0107
August 23, 2014	0.0155	0.0137	0.0155	0.0166	0.0169	0.0167
August 24, 2014	0.0125	0.0125	0.0138	0.0134	0.0153	0.0150
		With clock model				
August 20, 2014	0.0060	0.0057	0.0061	0.0064	0.0064	0.0071
August 21, 2014	0.0062	0.0089	0.0074	0.0093	0.0096	0.0105
Augsut 22, 2014	0.0086	0.0075	0.0087	0.0084	0.0085	0.0083
August 23, 2014	0.0126	0.0129	0.0136	0.0136	0.0145	0.0152
August 24, 2014	0.0101	0.0092	0.0113	0.0097	0.0111	0.0100

→ All solutions imptrove with clock modeling

Conclusions

- Clock modeling not only improves kinematic heights but also ZPDs
- With clock modeling there is no degradation in ZPDs, even for time resolution for ZPDs of 15 minutes
- Comparison with meteo and WVR data (CEBR and ONSA) → improved ZWD for all solutions, when modeling the station clock
- Next step: verification with a much larger data sets