Observing GNSS L-band signals:

ionospheric corrections by co-located GNSS measurements

B. Männel and M. Rothacher

based on:

Männel, B. and Rothacher, M.: Ionospheric corrections for single-frequency VLBI observations by co-located GNSS measurements, submitted to Journal of Geodesy

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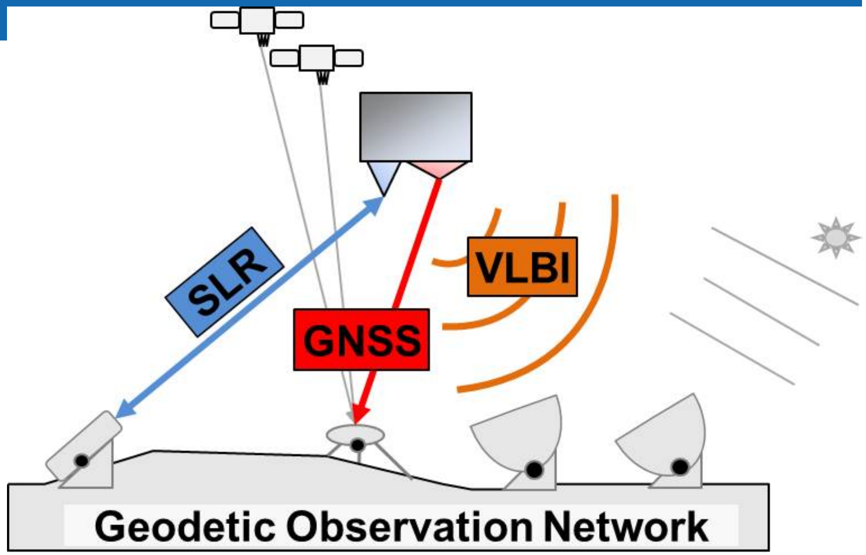
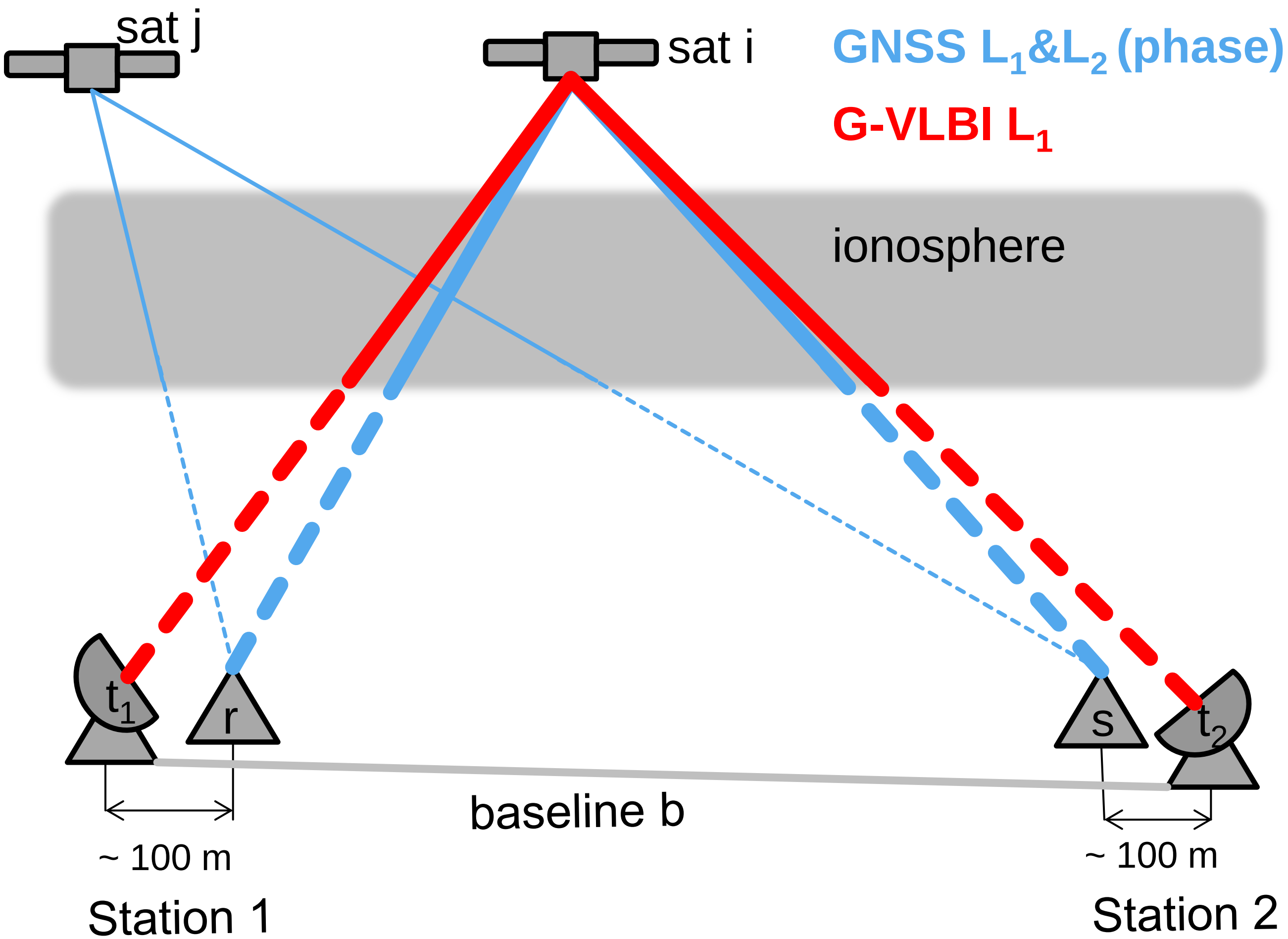
Motivation



- **G-VLBI:** independent observation of GNSS satellites using radio telescopes
- Advantages of G-VLBI observations:
  - Co-location in space for **GNSS, SLR and VLBI**
  - Improved investigations on ties and technique-specific error sources
  - Common parameters (e.g. atmospheric delays, orbits)
- G-VLBI might be limited to single-frequency → **ionospheric corrections**
  - GNSS-based model or GNSS-based local VTEC estimations
  - **Usage of the GNSS signal measured by a co-located GNSS antenna?**

The L4R approach – Idea



The L4R approach – Implementation

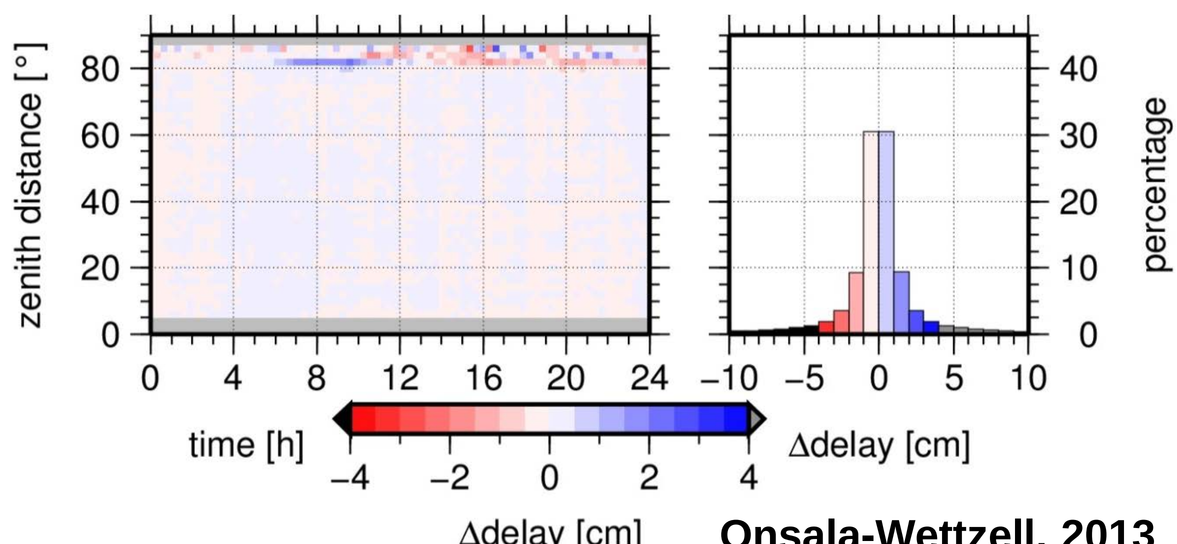
geometry-free L_4 double difference residuals (ambiguities resolved)

↓

split residuals to single differences

$$L^{ij}_{rs,4} = L^{ij}_{rs,1} - L^{ij}_{rs,2} = \lambda_1 N_1 - \lambda_2 N_2 + \frac{f_2^2 - f_1^2}{f_1^2 f_2^2} I^{ij}_{rs}$$

zero-mean condition per epoch: split *n* double diff. residuals into *n+1* single diff. residuals



Onsala-Wettzell, 2013

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The L4R approach – Implementation

geometry-free L_4 double difference residuals (ambiguities resolved)

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↓

split residuals to single differences

zero-mean condition per epoch: split *n* double diff. residuals into *n+1* single diff. residuals

↓

(optional) split residuals to zero differences

zero-mean condition per epoch: split *n* single diff. residuals into *n+1* zero diff. residuals

↓

add absolute ionospheric value from model

$$I^i_{rs} = absolute + relative = \bar{I}_{rs} + \hat{I}^i_{rs}$$

Absolute part $\bar{I}_{rs}$ is derived from CODE Global Ionosphere Models (GIMs)

↓

ionospheric correction

The L4R approach – Error sources

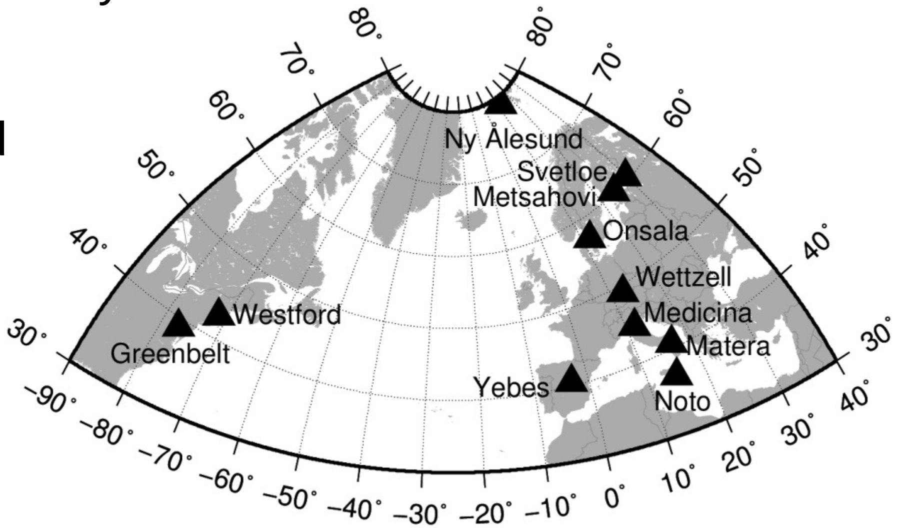
Effect	Impact on ionospheric delay corrections	Possibilities for improvements
GNSS multipath effects	• negligible for typical VLBI baselines (> 100 km)	---
Unresolved phase ambiguities	• Estimated ambiguities partially absorb ionospheric delays • residuals 50cm smaller than in reality for a 5000 km baseline	• improved ambiguity resolution strategy (esp. for GLONASS)
Quality of CODE GIM's	• Smoothing effect has a direct impact on ionospheric delay correction	• usage of models with a higher resolution (temporal, spatial)

The L4R approach – Validation

- Currently implemented in Bernese GNSS Software 5.2 (project version)
  - Estimation of corrections on single and zero difference level
  - Introduction of corrections to further processing steps

- Validation steps:
  - Tests using real G-VLBI observations not yet done
  - V1: impact on GNSS L_1 processing
  - V2: comparison against VLBI-derived ionospheric delays

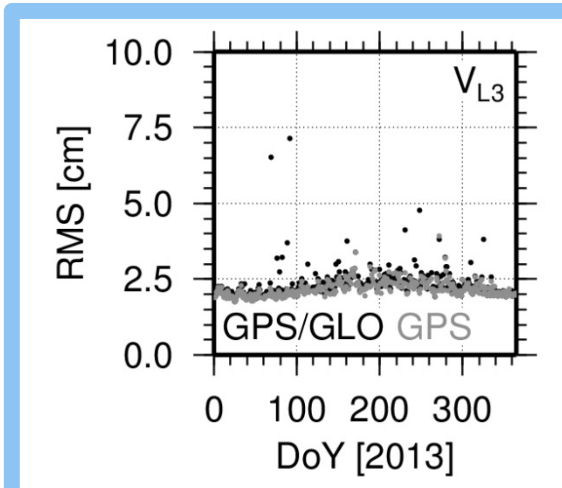
- GNSS and VLBI data from 2013 used



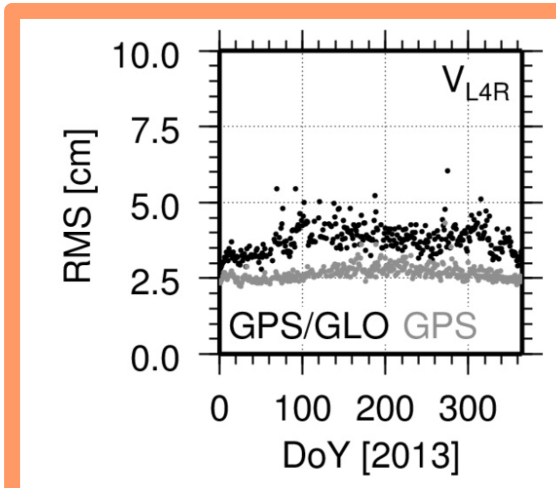
Validation 1: GNSS L_1 processing

- Matera – Wettzell (~1000 km): Baseline MTWR and 0A0M (co-located baseline)
- RMS of residuals

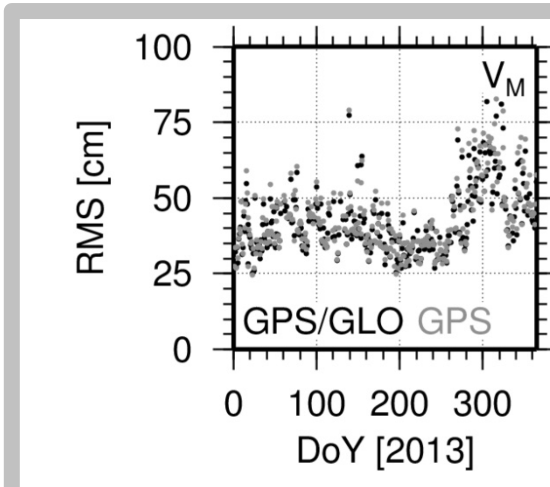
L_3 (two freq.)



L_1 + L4R (same basel.)



L_1 + CODE GIM's



Validation 1: G ing

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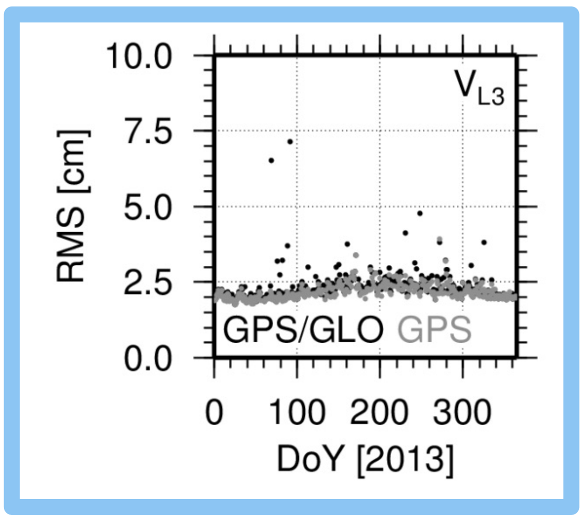
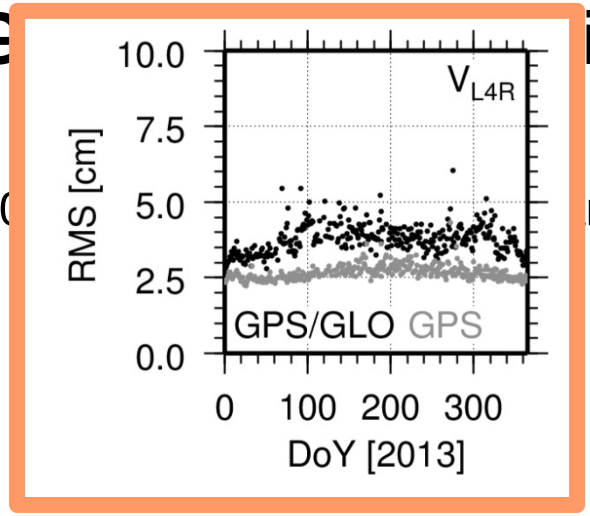
- RMS of residuals

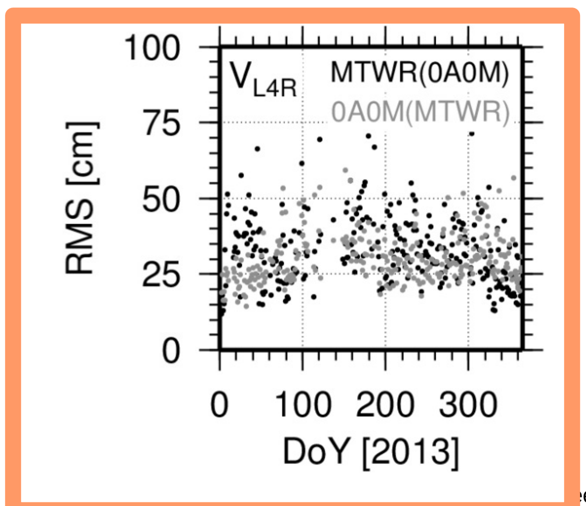
L_3 (two freq.)



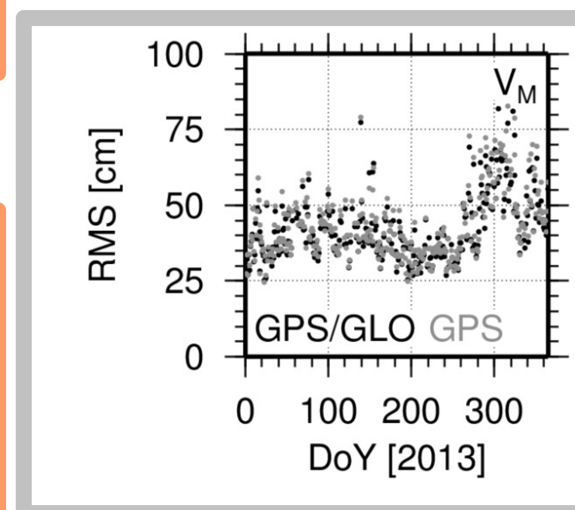
L_1 + L4R (same basel.)



L_1 + L4R (co-loc. basel.)



L_1 + CODE GIM's

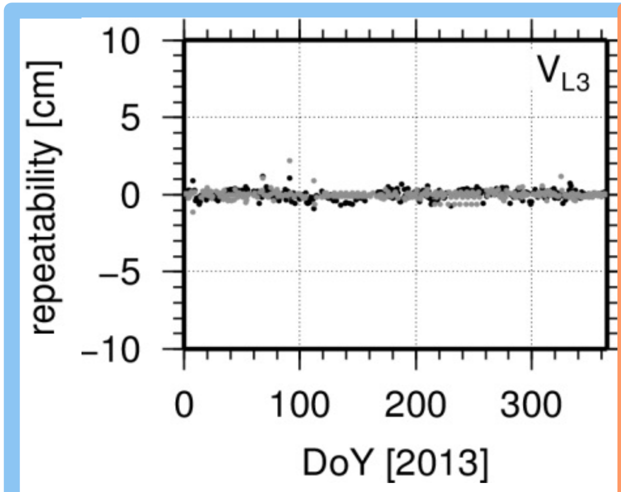


Validation 1: GNSS L_1 processing

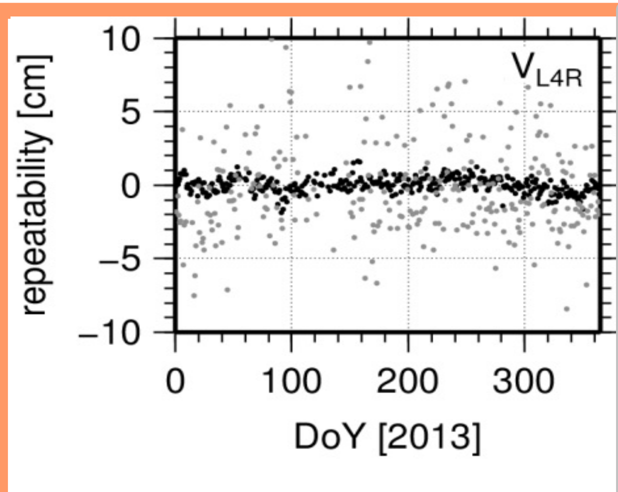
MTWR
0A0M (MTWR)

- RMS of station height repeatability

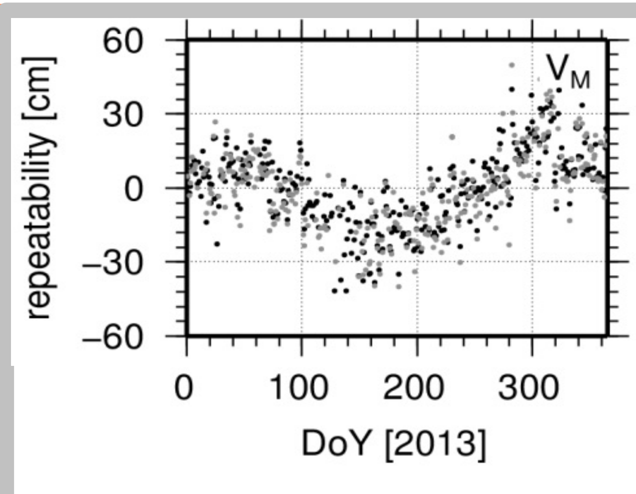
L_3 (two freq.)



L_1 + L4R from MTWR



L_1 + CODE GIM's



Validation 2: VLBI-derived ionosphere delay

- GNSS and quasar observation same epoch, same direction (2°, Δt=15min)
- Difference L4R – VLBI ionospheric delay

- Ionospheric delay correction: $$\tau'_{ion}(t) = \frac{f_S^2}{f_X^2 - f_S^2}(\tau_X - \tau_S) + \Delta\tau_{inst}$$

- $\Delta\tau_{inst}$ assumed to be constant over one session

Analysis of differences after subtracting session-wise mean values	Analysis of session-wise standard deviations

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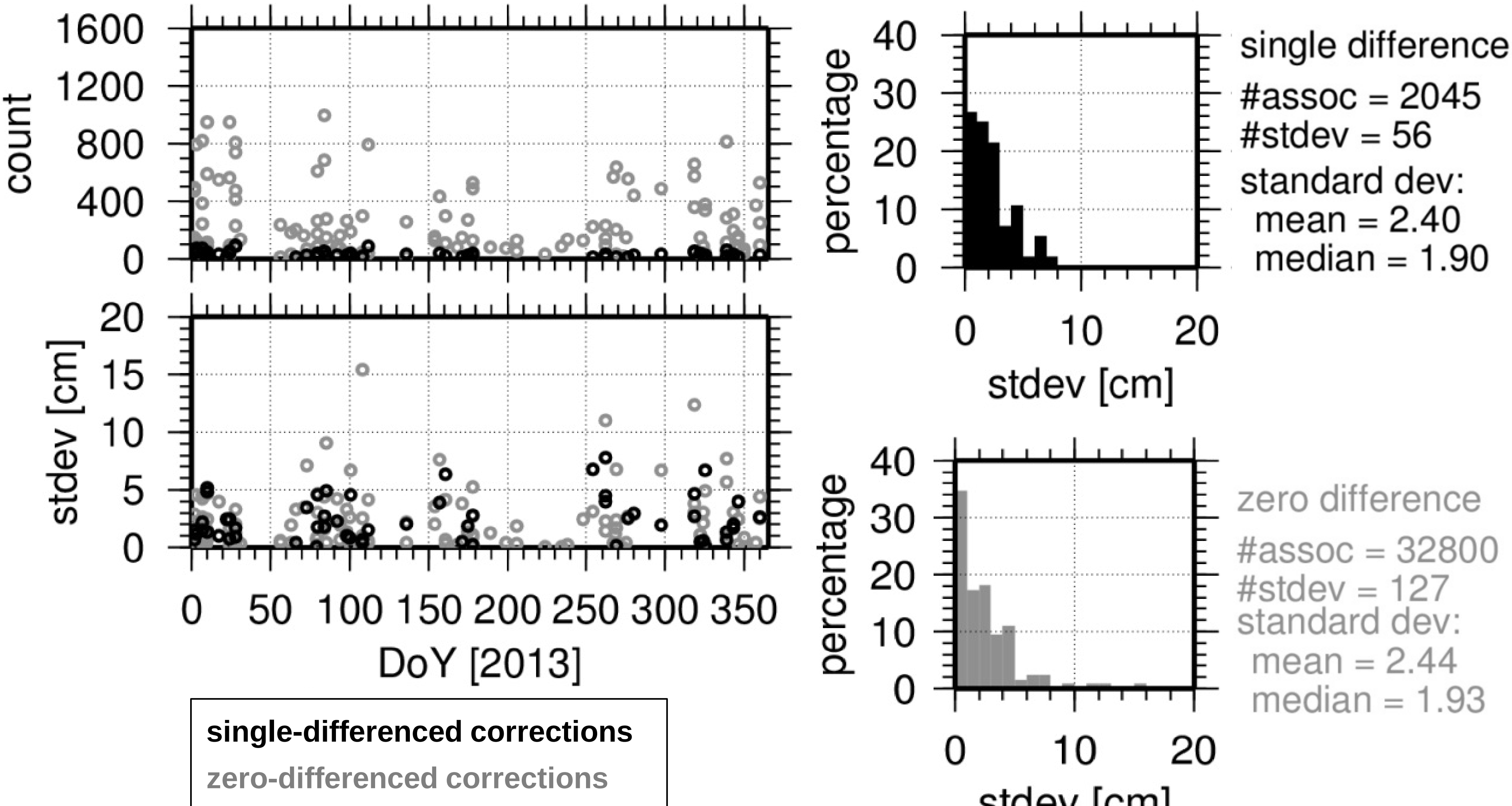
Validation 2: VLBI-derived ionosphere delay



Applications for L4R and conclusions

- GNSS-derived delay corrections are accurate to 2-5 cm
- G-VLBI
  - Usage of same signals to derive ionospheric corrections
  - Only very long baselines problematic (insufficient ambiguity resolution)

  → **High potential for G-VLBI applications**

- Quasar observations
  - GNSS satellite constellation vs. quasar observation schedule
  - Baseline length very critical (single diff. case)

  → **Only possible to a very limited extent**

- **Tests using real G-VLBI have to be done**

Thank You

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