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Baseline-dependent clock offsets in VLBI analysis

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Motivation

- Primary goal of VLBI
  - provide highly accurate TRF + CRF + EOP

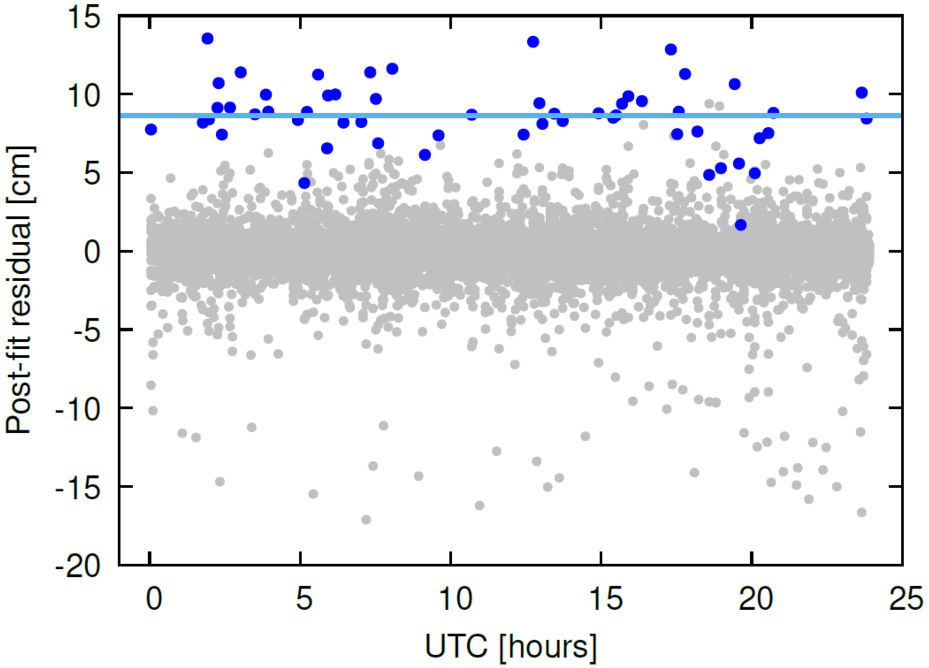
- Additional parameters in compliance with the VLBI concept
  - relative **clock** offsets and their variations (form the link between the time series of observations)
  - zenith wet delay + trop. gradients (effects of **tropospheric refraction**)

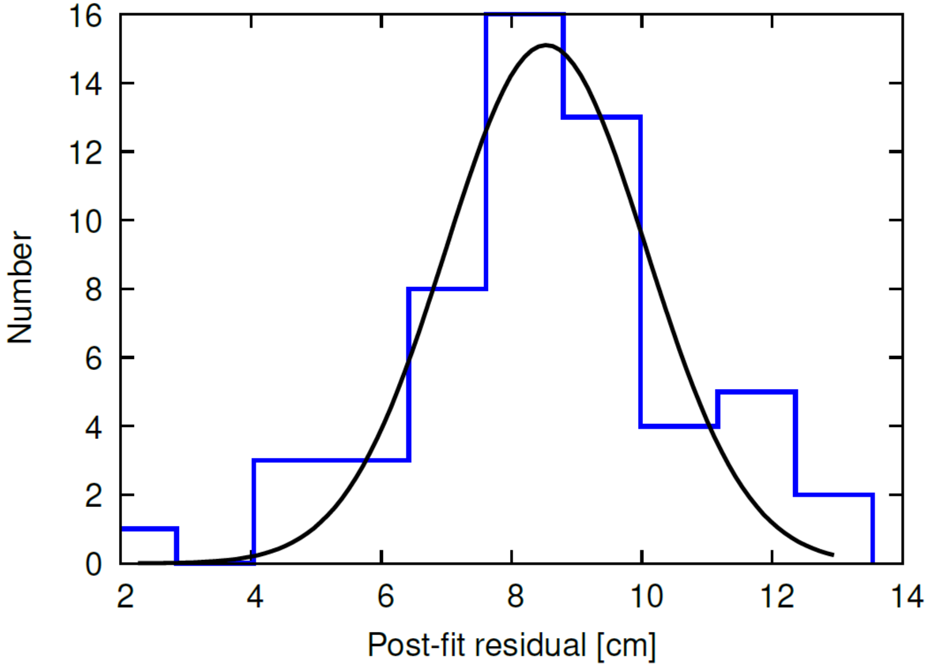
- With perfect technical equipment and exactly same observing frequency these parameters would be **sufficient to fit the theoretical VLBI model**.

Post-fit residuals

CONT17-L1 session on Dec 01, 2017

baseline Kashim11 – NyAles20





The distribution is well fitted by a Gaussian centered at 8.5 +/- 1.5 cm

Reality shows that sometimes significant **offsets** appear **in the observed group delay** for **individual baselines**.

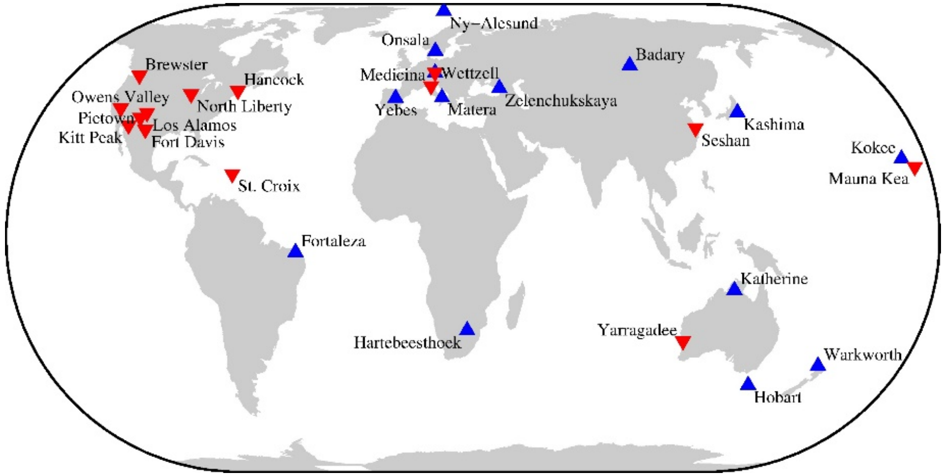
Compensation by estimating so-called **baseline-dependent clock offsets**.

Possible causes of the BCO

- Loss of one or more frequency channels during recording at a radio telescope
- Poor phase calibration

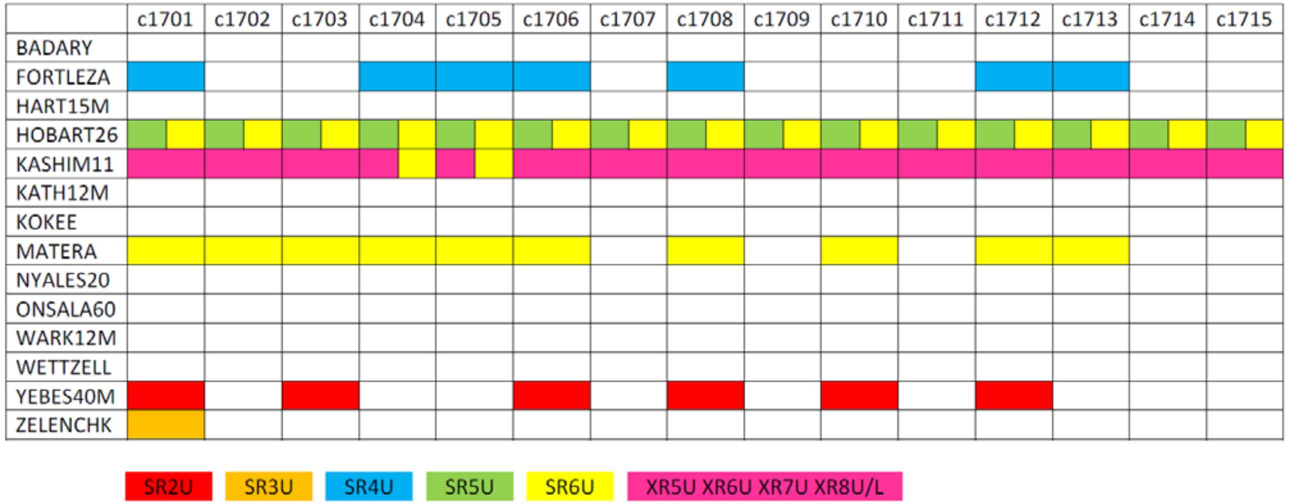
(pers. comm. John Gipson, Dan McMillan, Leonid Petrov)

Case study: CONT17-L1 and CONT17-L2

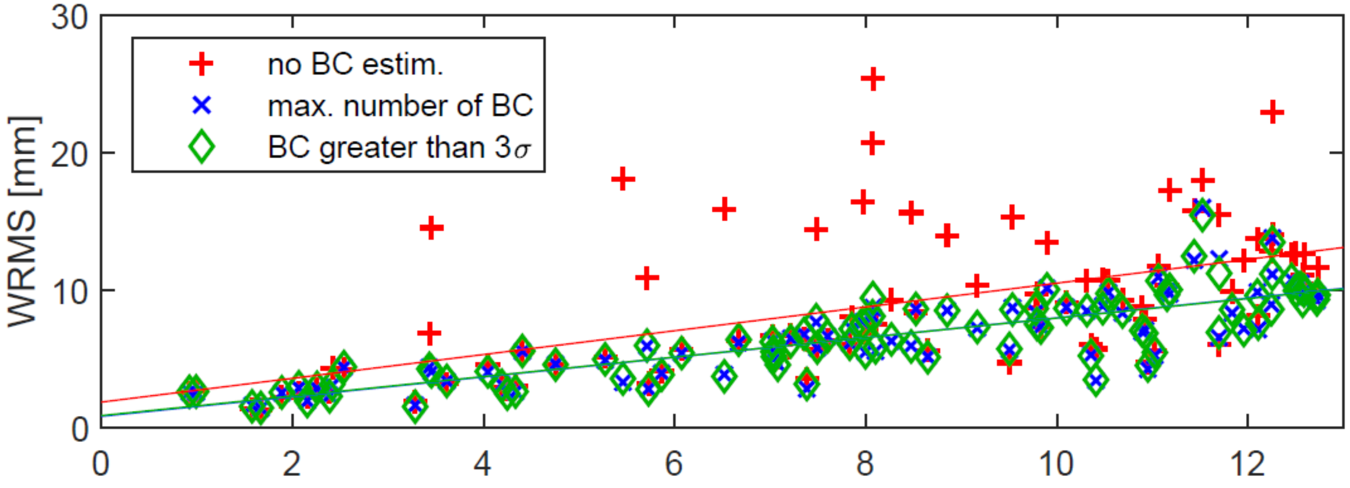


Behrend et al. (2020)

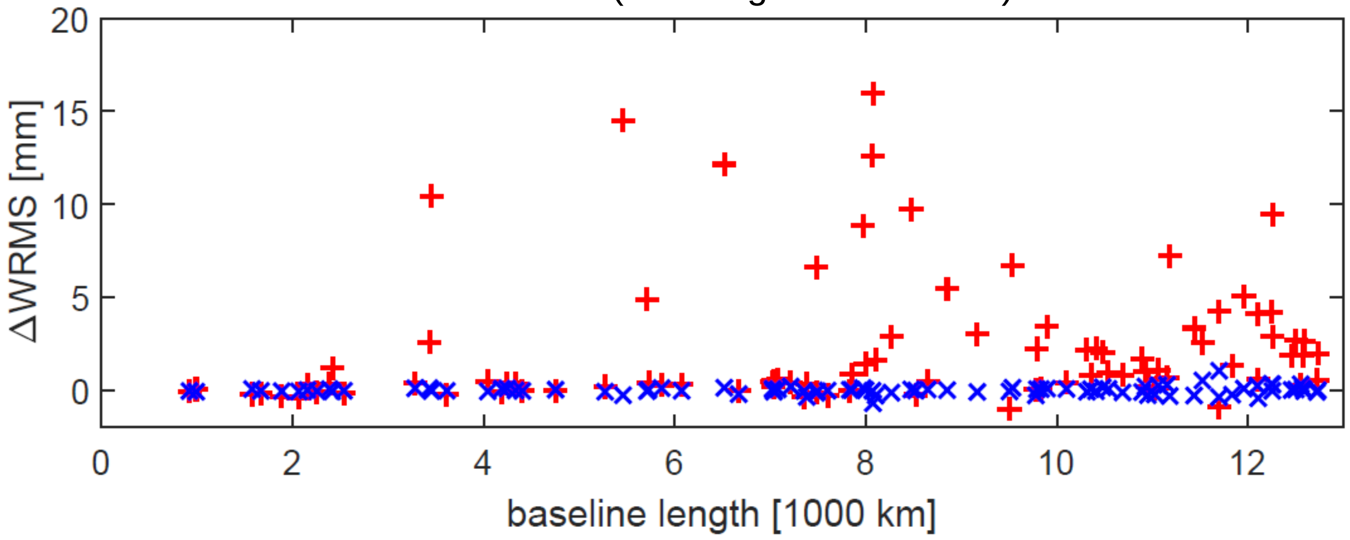
Flagged channels for fringe fitting in CONT17-L1 according to level-1 processing reports



CONT17-L1, baseline length repeatabilities

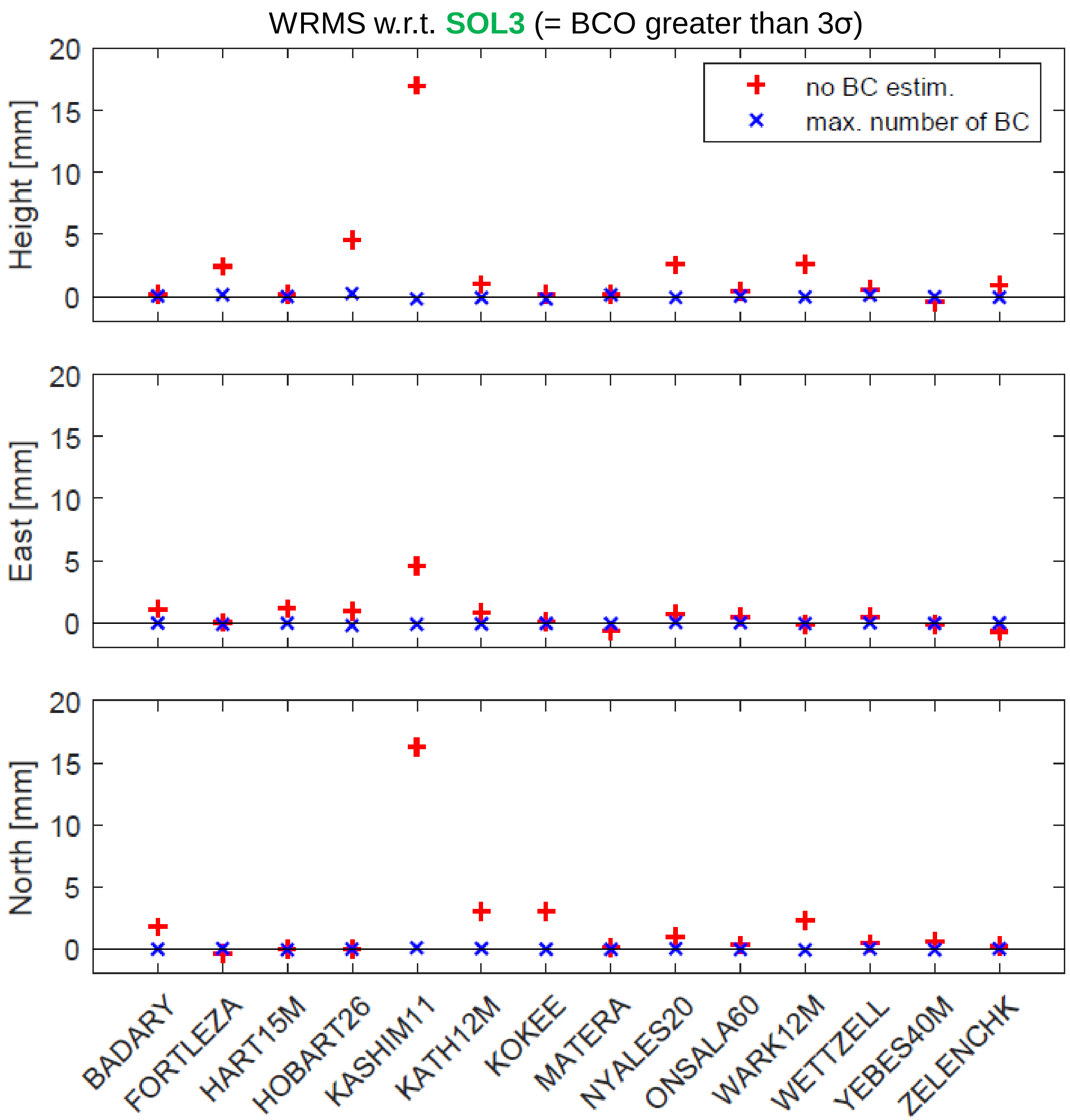


w.r.t. **SOL3** (= BCO greater than 3σ)



- mean improvement in terms of WRMS
  - 2.2 mm in **SOL3** compared to **SOL1**
  - 79% improved baselines
  - 0.0 mm in **SOL3** compared to **SOL2**
  - 48% improved baselines

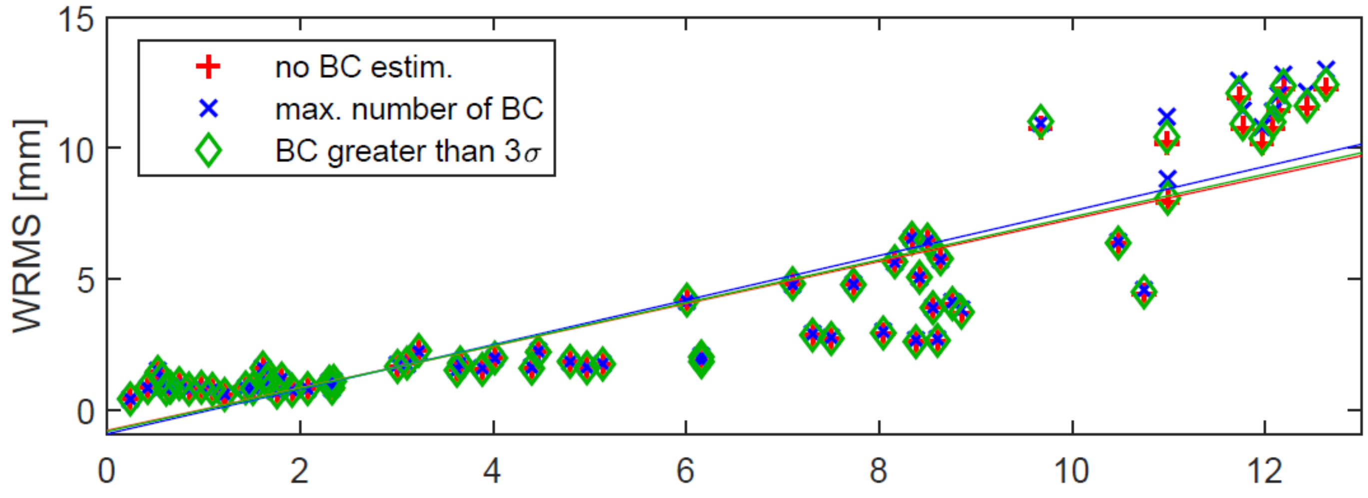
CONT17-L1, ΔWRMS of station position components



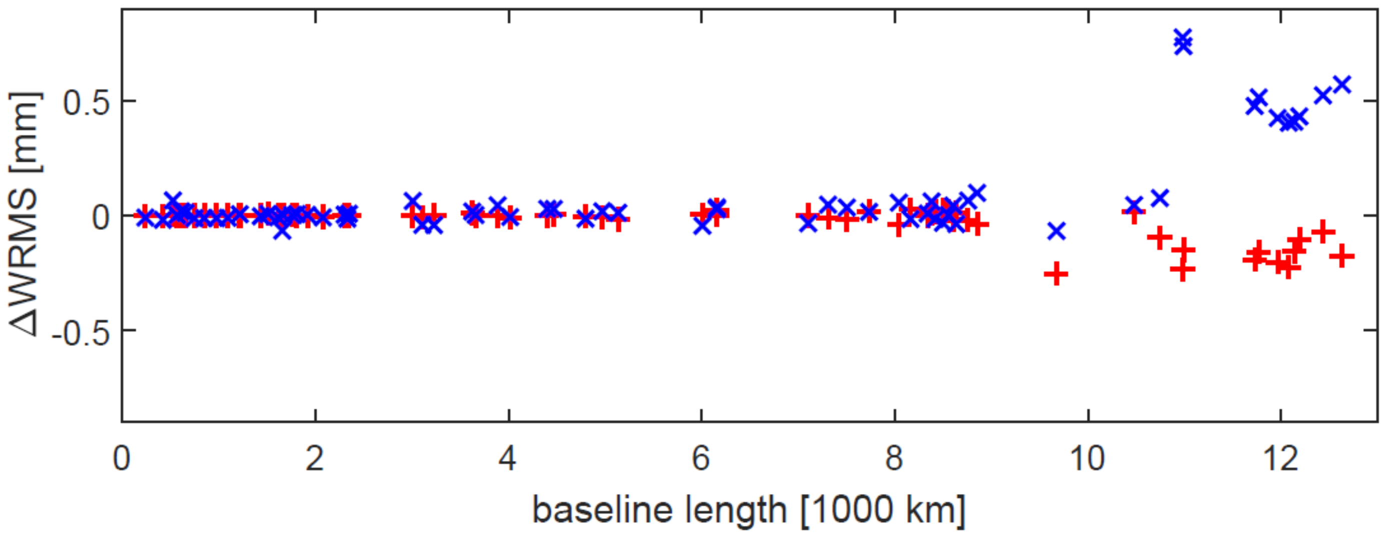
- mean improvement in terms of WRMS
  - SOL3 compared to SOL1
  - H: 2.3 mm (93% improved baselines)
  - E: 0.6 mm (72% improved baselines)
  - N: 2.1 mm (79% improved baselines)

  - SOL3 compared to SOL2
  - H: 0.0 mm (50% improved baselines)
  - E:-0.1 mm (14% improved baselines)
  - N: 0.0 mm (57% improved baselines)

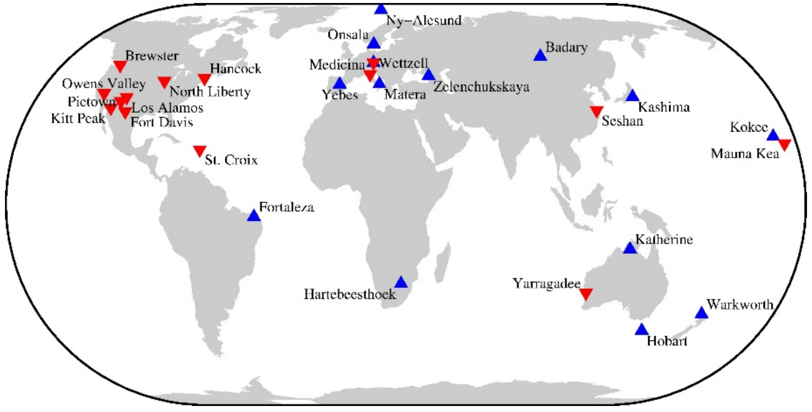
CONT17-L2, baseline length repeatabilities



w.r.t. **SOL3** (= BCO greater than 3σ)



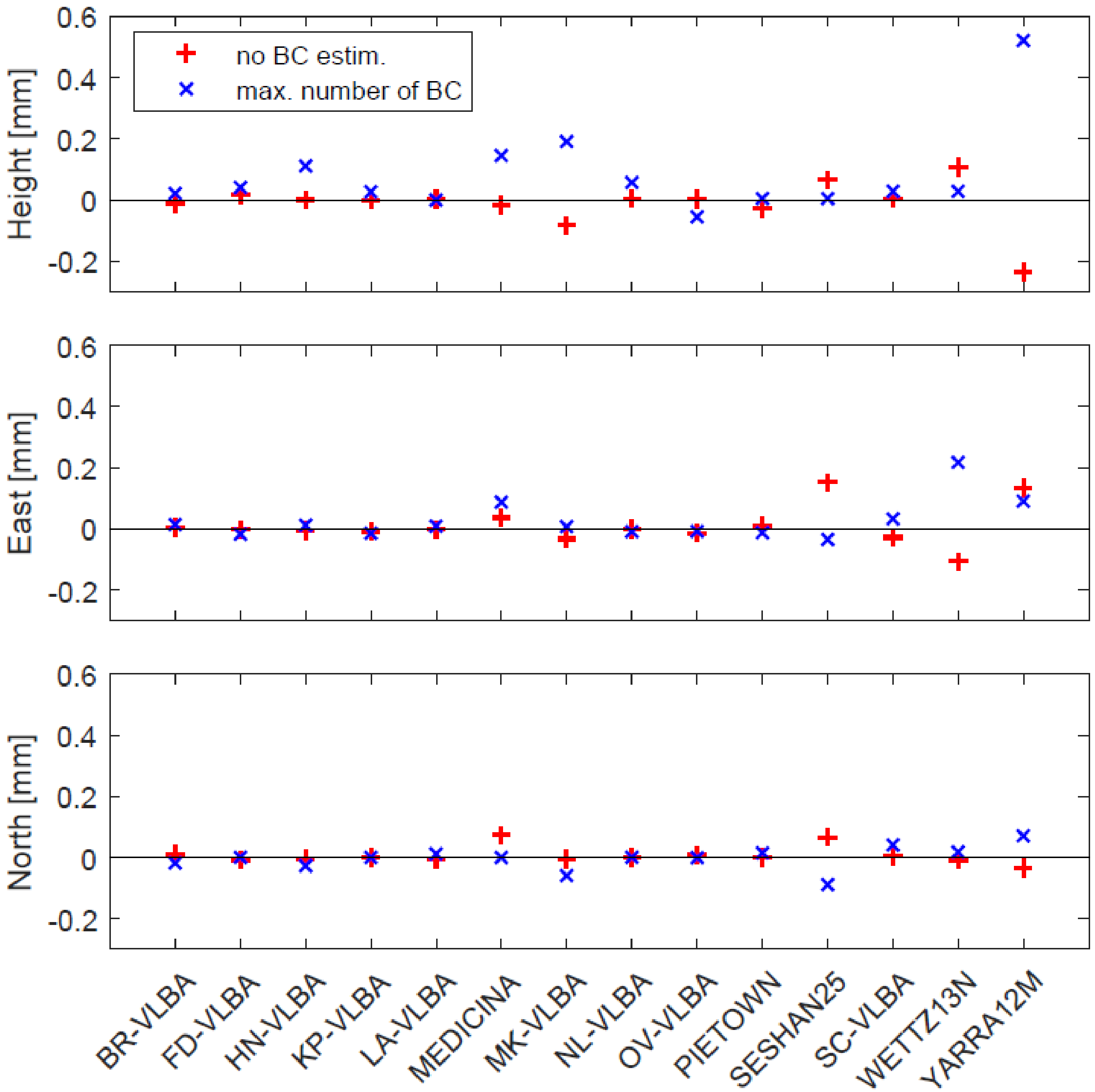
- mean improvement in terms of WRMS
  - 0.0 mm in **SOL3** compared to **SOL1**
  - 29% improved baselines
  - 0.1 mm in **SOL3** compared to **SOL2**
  - 67% improved baselines



Behrend et al. (2020). CONT17-L2 network

CONT17-L2, ΔWRMS of station position components

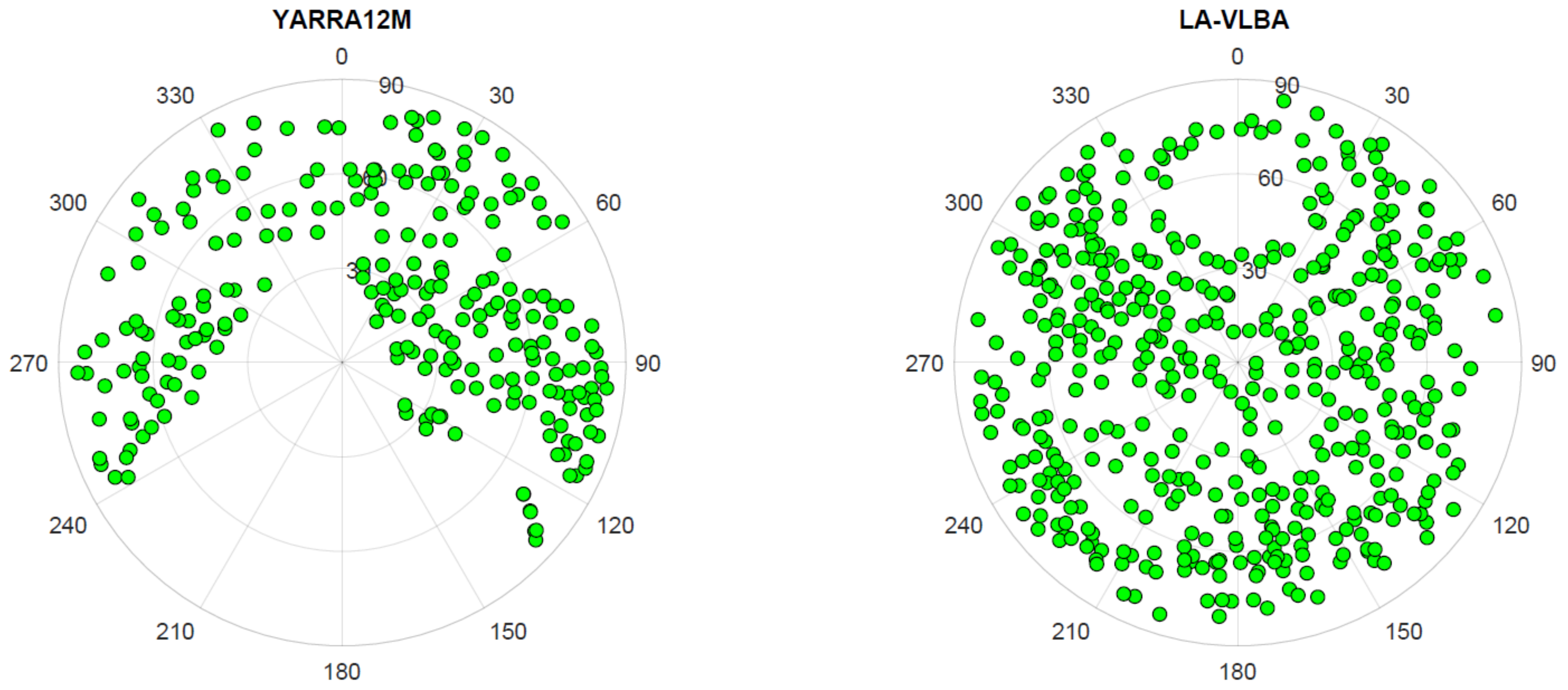
WRMS w.r.t. **SOL3** (= BCO greater than 3σ)



- mean improvement in terms of WRMS
  - **SOL3** compared to **SOL1**
  - H: 0.0 mm (64% improved baselines)
  - E: 0.0 mm (36% improved baselines)
  - N: 0.0 mm (57% improved baselines)

  - **SOL3** compared to **SOL2**
  - H: 0.1 mm (93% improved baselines)
  - E: 0.0 mm (57% improved baselines)
  - N: 0.0 mm (74% improved baselines)

Sky coverage in CONT17-L2



experiment on December 12, 2017

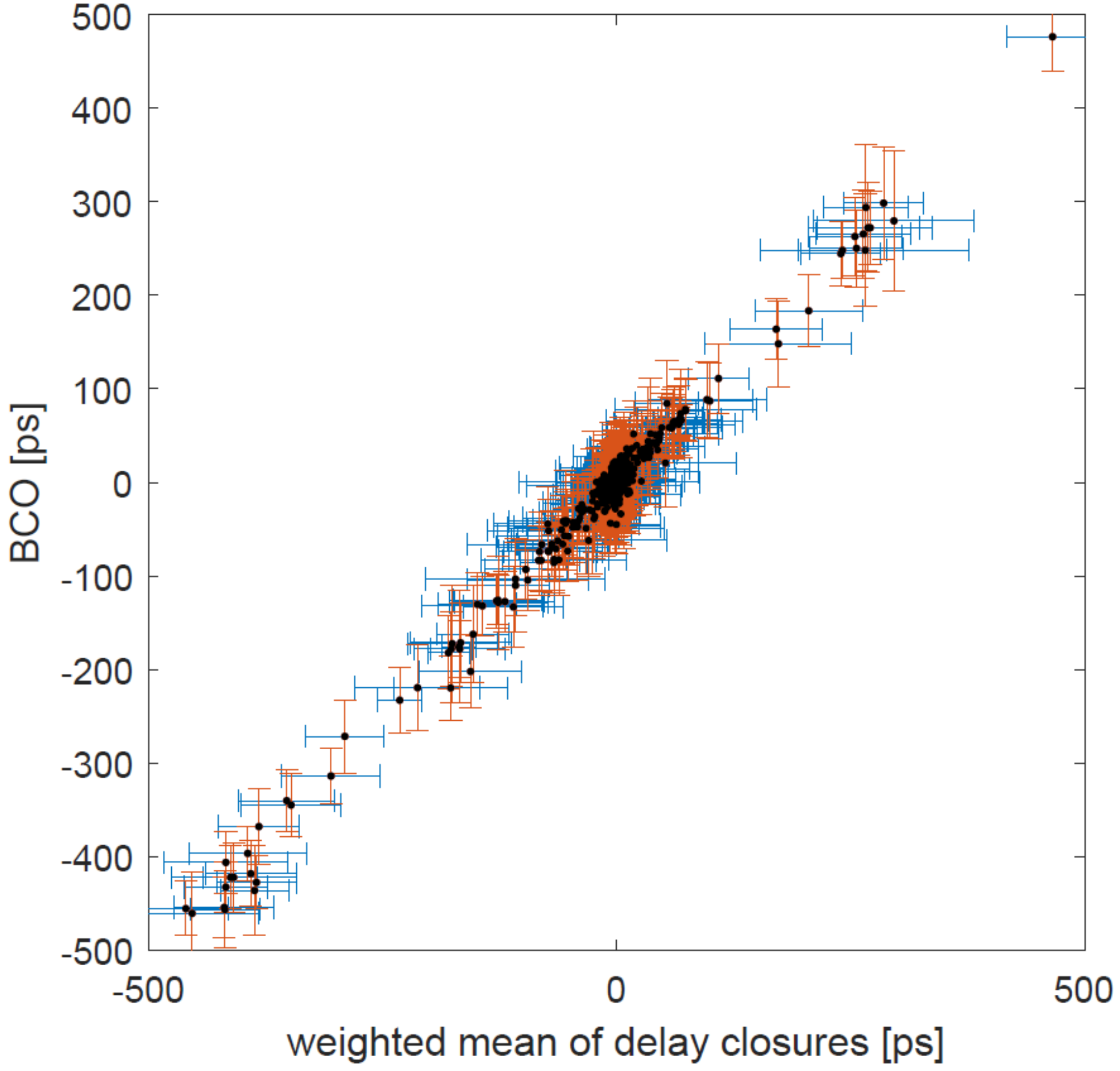
Conclusion: Estimation of the BCOs at baselines without any significant offset does not harm the geodetic solution under the condition that there are enough observations at the telescopes which allows for de-correlation of station-dependent parameters.

BCO versus delay closures

Solutions from three station networks

- Badary chosen as reference in all triangles
- All combinations for the two remaining stations in CONT17-L1 sessions
  yield 78 resp. 66 triangles per session (for 14 resp. 13 stations in the original sessions)
- Simple parametrization applied
  - one clock bias, one rate and one quadratic term at two stations with respect to the reference telescope (Badary)
  - one baseline clock offset (at baseline opposite to Badary)
  - zenith wet delay as pwlo every 60 minutes at all three stations
  - all five EOP as an offset

BCO versus delay closures



session-wise BCOs
versus
weighted mean of triangle delay closures

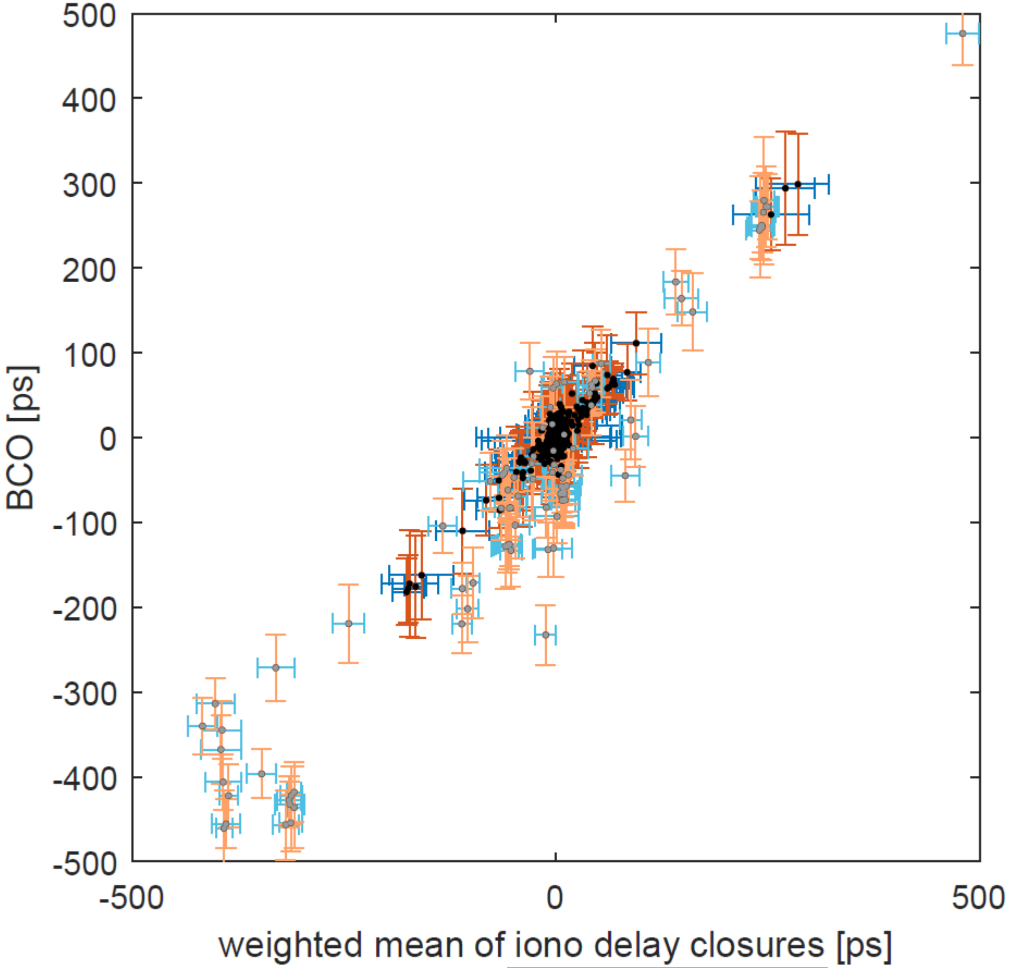
triangles from all CONT17-L1 sessions

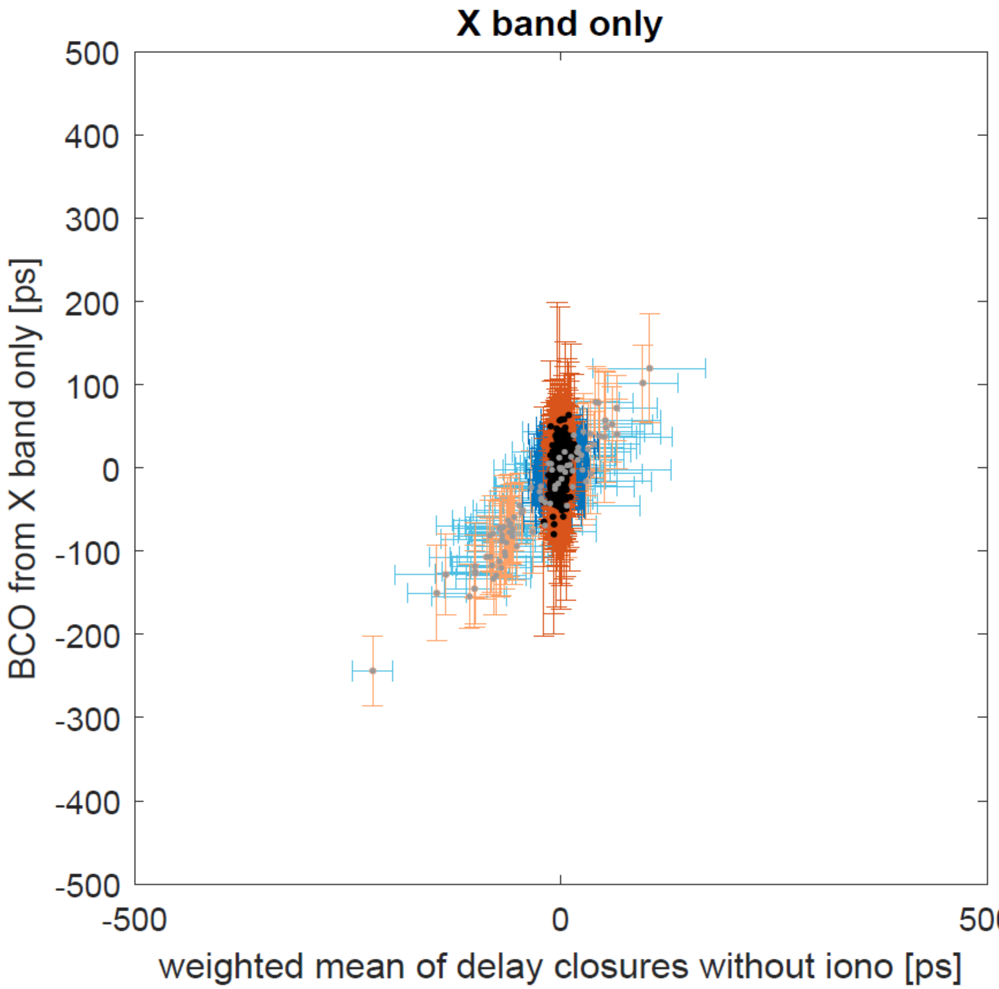
BCO in a triangle is identical
to the mean of the triangle delay closures

- if significant BCOs appear in the data analysis
- within the analysis uncertainty

BCO versus delay closures

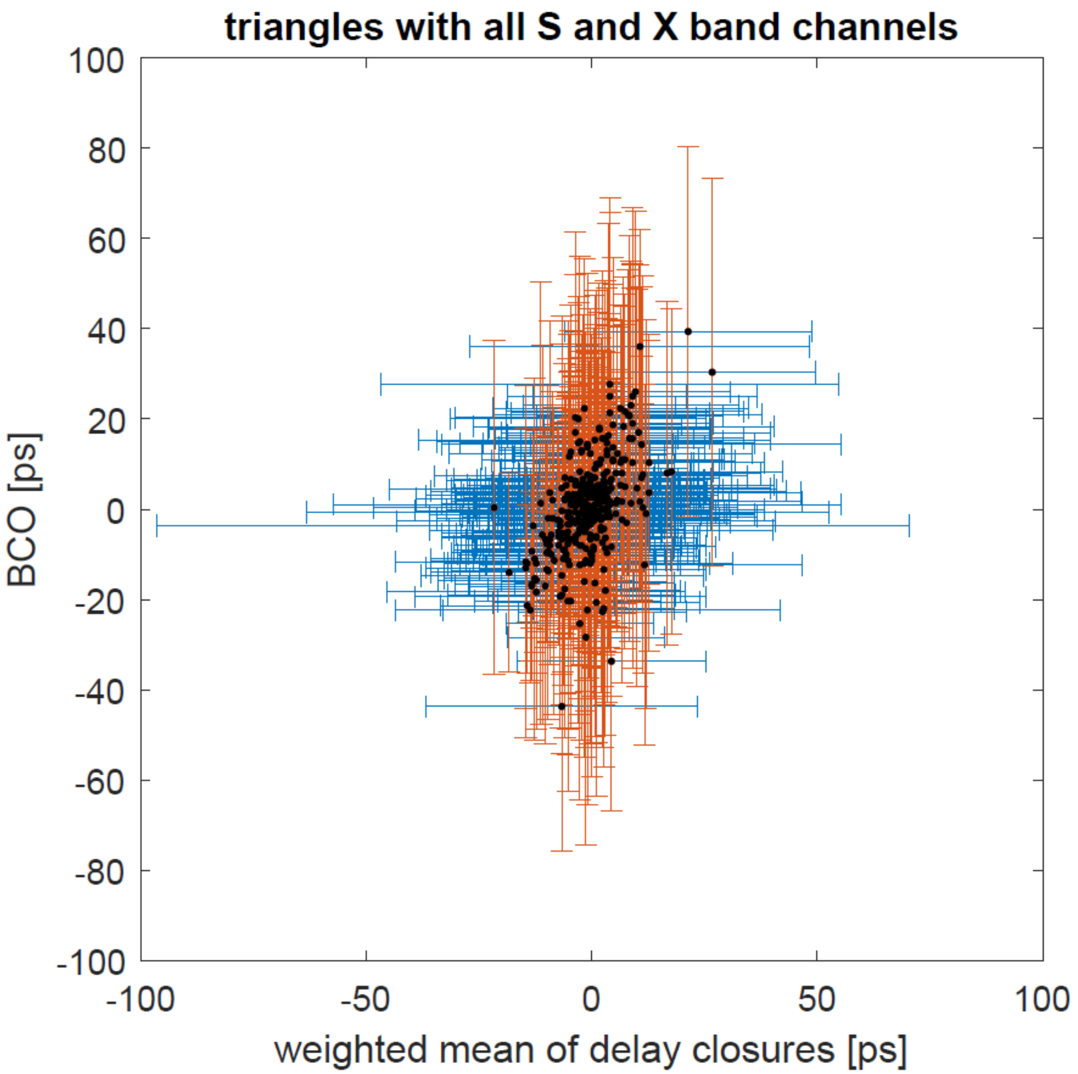
The dominant effect for the occurrence of **significant BCOs** comes from the **ionospheric delay** calibration.





Triangles with Kashim11 (4 X band channels missing) are depicted with reduced color intensity.

BCO versus delay closures



Final uncorrupted set of observations in all CONT17-L1 sessions (i.e., without triangles with dropped channels).

The scatter (in a WRMS sense) is

- < 5.2 ps for the ionosphere calibrated triangle closures
- < 7.8 ps for the respective BCOs

If the delay determination originates from a fringe fitting process of uncorrupted data the relationship between triangle delay closures and BCOs is random.

Conclusions

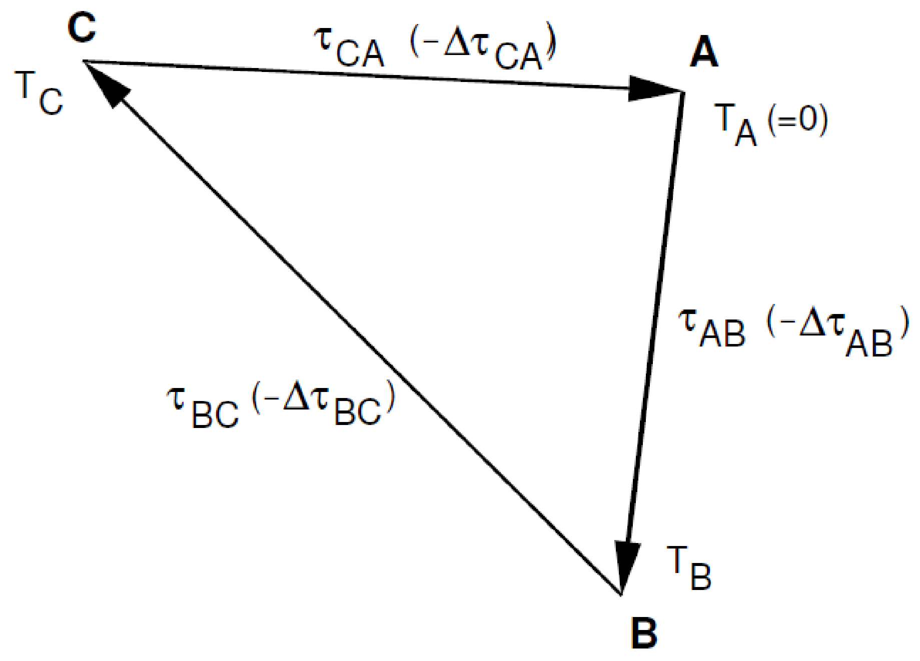
- In the VLBI data analysis **it is essential to estimate BCOs** for baselines where an offset in the observed delay appears.
- **Estimation of the BCOs** at baselines without any significant offset **does not harm the geodetic solution** under the condition that there are **enough observations** at the telescopes which allows for de-correlation of station-dependent parameters.
- We confirmed that a **BCO in a triangle** is **identical** to the mean of the **triangle delay closures** if significant BCOs appear in the data analysis.
- It was recognised that the **dominant effect** for the occurrence of significant BCOs comes from the **ionospheric delay calibration**.

Thank you for your attention!

Backup

Effects of changing the reference clock

clock biases: T_A, T_B, T_C
observed delays: τ_{AB}, τ_{BC}, τ_{CA}
BCOs: $\Delta\tau_{AB}$, $\Delta\tau_{BC,}$ $\Delta\tau_{CA}$
true delays: τ'_{AB}, τ'_{BC}, τ'_{CA}



Case 1: Reference clock A

$T_A = 0$, $T_B = \tau_{AB}$, $T_C = -\tau_{CA}$
for the true delay holds
$\tau'_{BC} = T_C - T_B = \tau_{BC} - \Delta\tau_{BC}$

→ 3 parameters have to be estimated: T_B, T_C, $\Delta\tau_{BC}$

Q: Would estimating of $\Delta\tau_{CA}$ yield a different BCO value than for $\Delta\tau_{BC}$?
Answer: No! The value remains the same!

Case 2: Reference clock B

$T_A = -\tau_{AB}$, $T_B = 0$,
$T_C = \tau_{BC} = \tau'_{BC} + \Delta\tau_{BC}$

for the closing baseline CA holds: $T_C - T_A = \tau'_{BC} + \Delta\tau_{BC} + \tau_{AB}$

→ estimating T_C, T_A, $\Delta\tau_{CA}$ means that you have estimated T'_C, T_A, $\Delta\tau_{BC}$

Conclusion: Estimating BCOs with an arbitrary reference telescope leads to a correct fit but not to true BCOs in the observing network!