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Ambiguity Resolution with Multiband-Singleband Delay Differences

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Session Processing

- Scheduling
- Observation
- Correlation
- Ambiguity Resolution
- Ionospheric Calibration
- VLBI Data Analysis

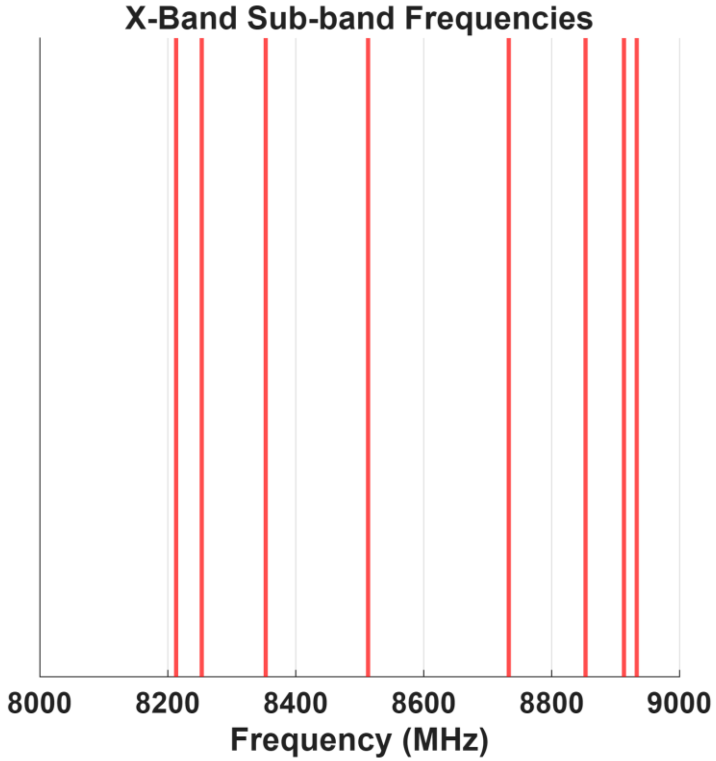
} **VieVS** (developed by TU Wien Research Unit Higher Geodesy)

Singleband Delays (without Ambiguities)

- Group delay is determined for each individual channel

- Final group delay is obtained by averaging the individual delays

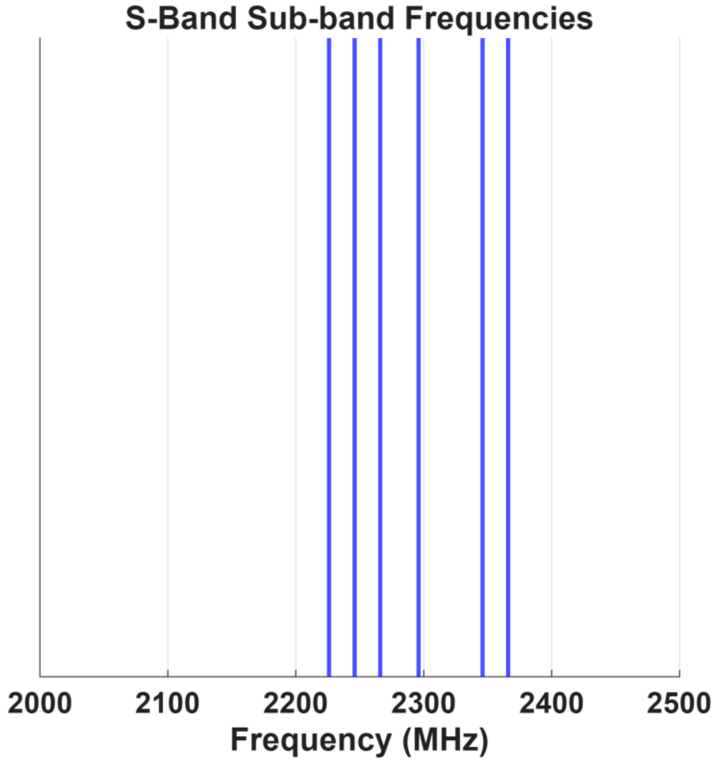
- No ambiguities occur



Multiband Delays (included Ambiguities)

- Entire bandwidth is used to determine the group delay

- However, since the spectrum is only sparsely occupied by channels at certain frequencies, ambiguities occur



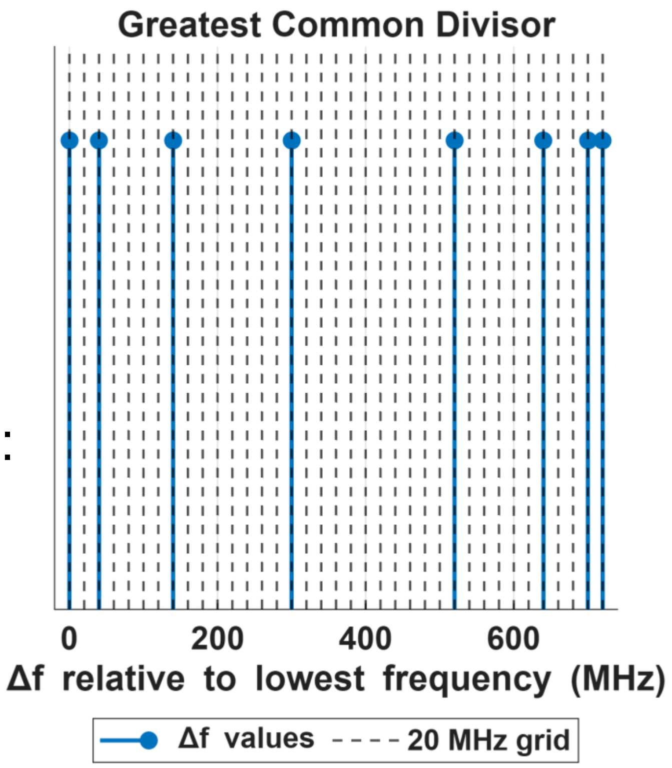
Ambiguity Spacing

- The inverse of the largest common devisor of all sub-band frequency differences

$$\tau_{amb} = \frac{1}{\Delta \nu_{max}}$$

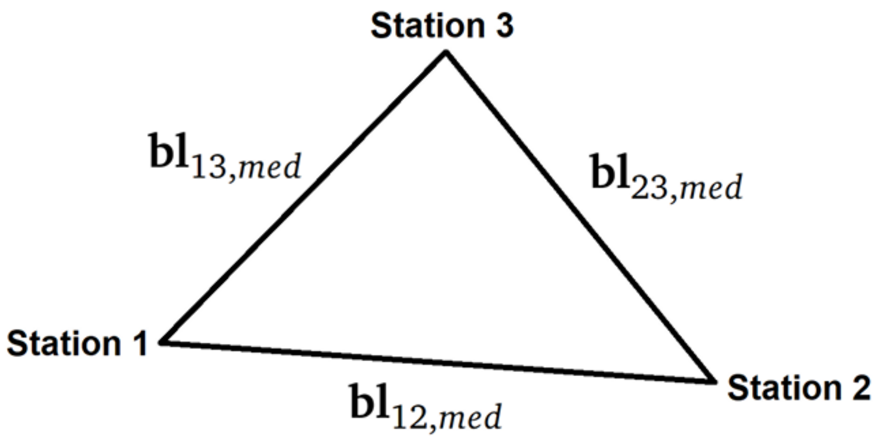
Ambiguity Spacing Example: X-band

- 8 sub-bands, ~720 MHz bandwidth
  - Given sub-band frequencies (MHz):
    8212.99, 8252.99, 8352.99, 8512.99,
    8732.99, 8852.99, 8912.99, 8932.99
  - Frequency differences (relative to the lowest frequency):
    40, 140, 300, 520, 640, 700, 720 MHz
    → Greatest common divisor (GCD): 20 MHz
  - Ambiguity spacing:
    1 / GCD = 1 / (20 MHz) = 50 ns



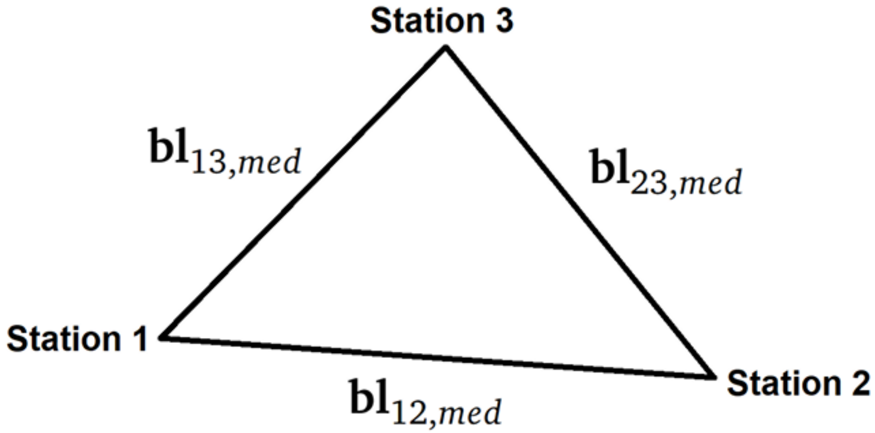
Ambiguity Resolution with Triangle Closures

- Ambiguities arise in multiband delay observations in the X/S-band
- Use triangle delay closures to resolve them
- Based on difference between:
  - Multiband delays (with ambiguities)
  - Singleband delays (without ambiguities)
- The calculated closure should be within the limit of half the ambiguity spacing



Ambiguity Processing per Baseline

- Consider all observations per baseline
- Use observations with quality code 9
  - or best available quality code
- Compute the median value
- Median reduces influence of outliers



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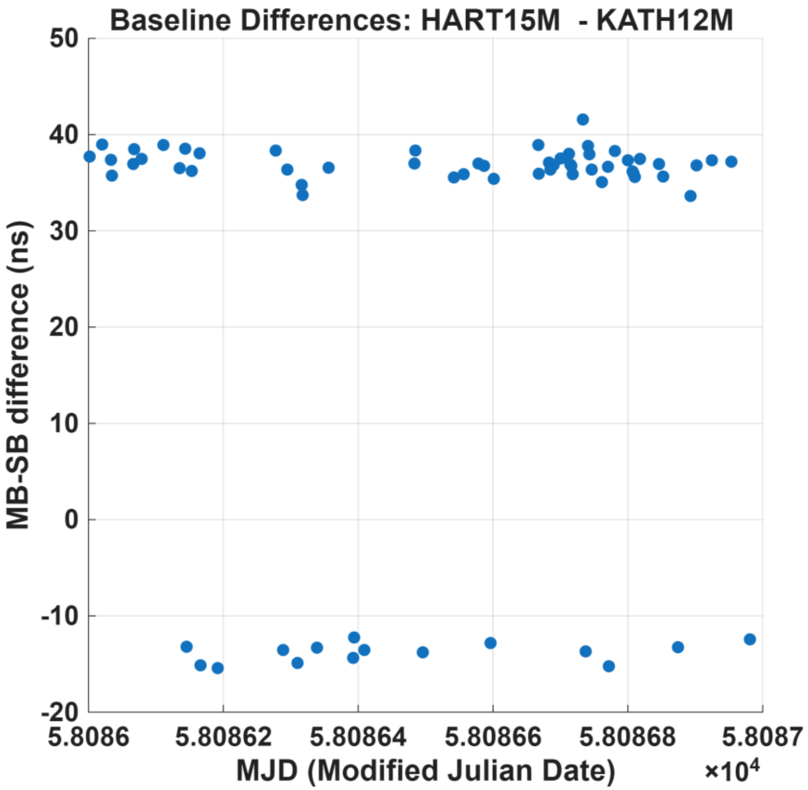
Ambiguities within a Baseline

- Example: baseline HART15M – KATH12M
- Session: 17NOV29XB (X-band)
- Median value of baseline: +40 ns
- Multiband–singleband delay differences: –10 ns
  - Apply ambiguity correction: +50 ns



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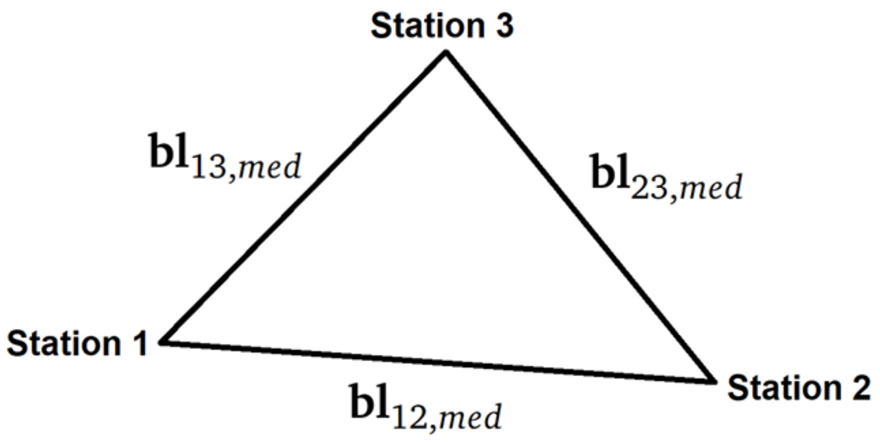
Ambiguity Network Solution

- Solve ambiguities for the entire network
  - Includes all stations and baselines
- Max. 2 × ambiguity spacing per baseline

$$\tau_{close} = (\mathbf{bl}_{12,med} + \mathbf{bl}_{23,med} - \mathbf{bl}_{13,med}) \cdot s_i$$



Ambiguity Triangle Solution: Example

- Closure = 50 ns
- Ambiguity spacing = 50 ns
- → Apply 50 ns to one baseline

$$\tau_{close} = (\mathbf{bl}_{12,med} + \mathbf{bl}_{23,med} - \mathbf{bl}_{13,med}) \cdot s_i$$

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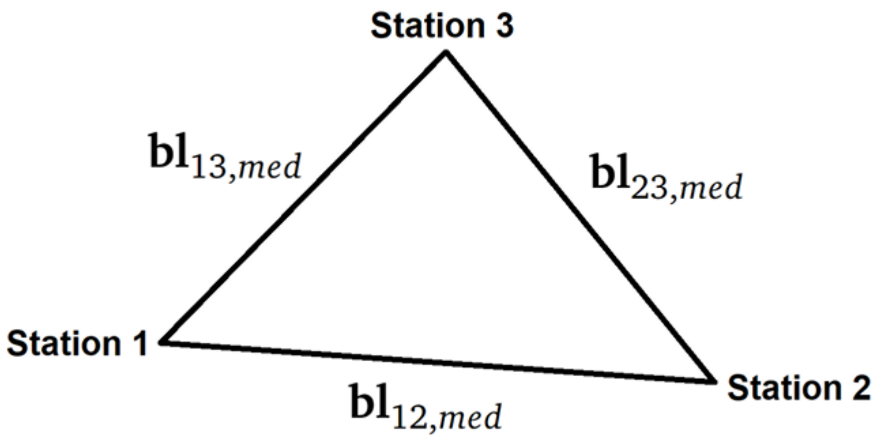

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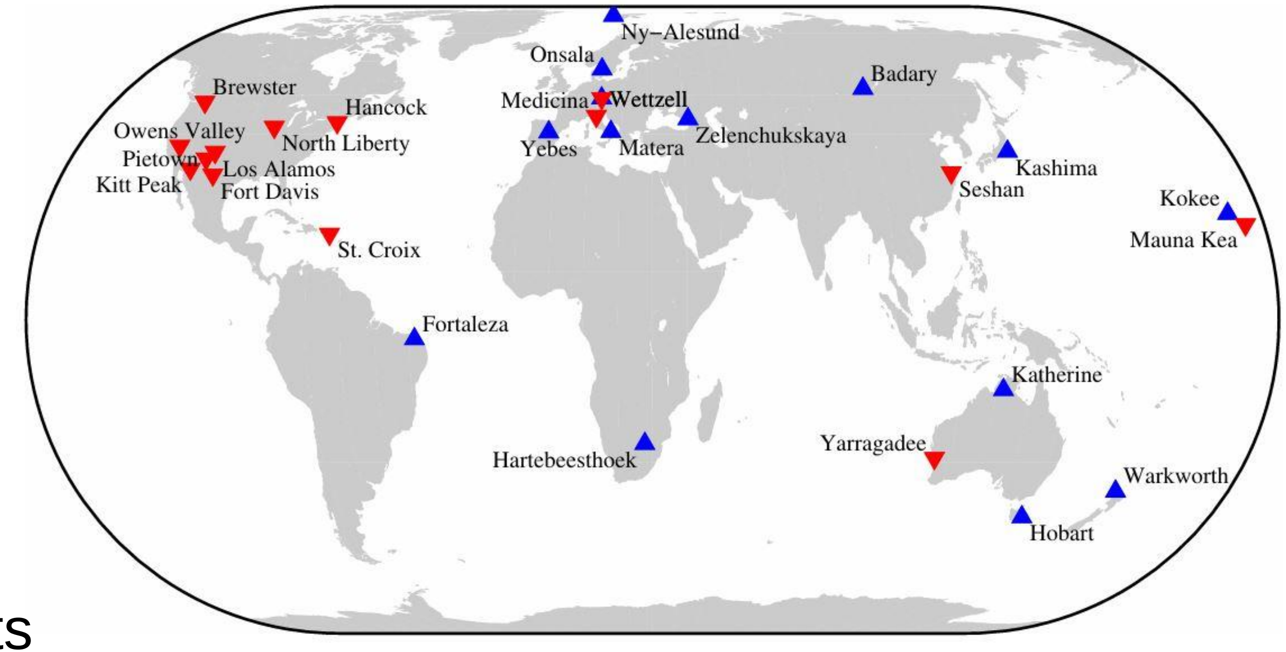
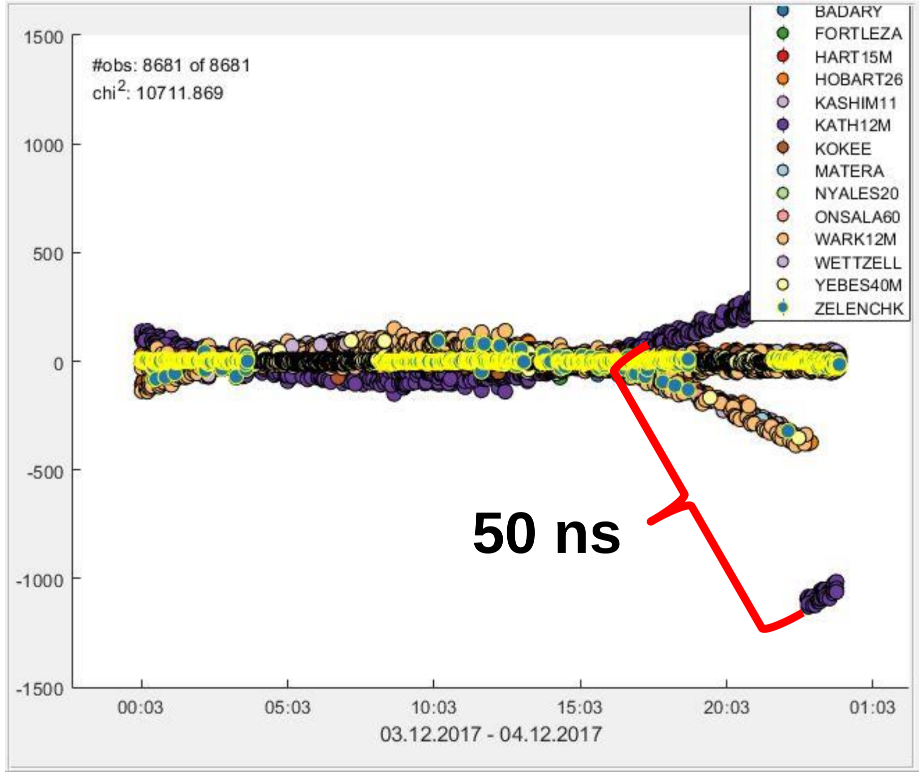
CONT17

- Two legacy X/S-band networks
- 14 stations
- Operating for 15 consecutive days from November 28 to December 12, 2017
- CONT17-L1 (blue) for first results



Automatic Ambiguity Solution

- Ambiguities might remain unresolved
- Manual ambiguity resolution (new feature in VieVS) for a small amount of observations if necessary
- → Automation is possible to some extent



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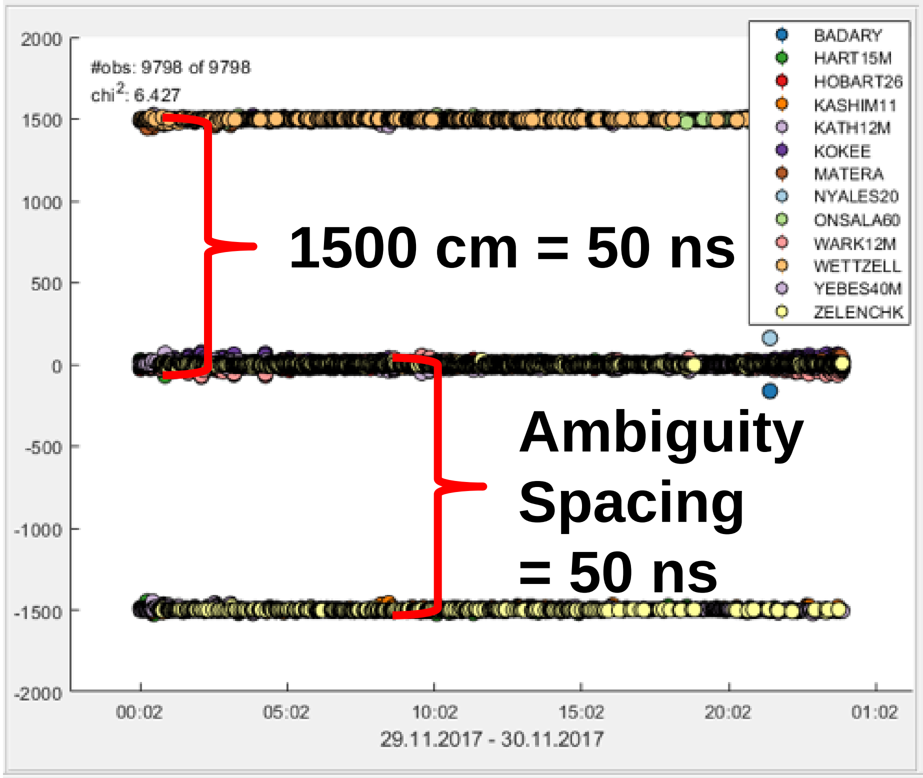
Manual Ambiguity Solution for the Entire Session

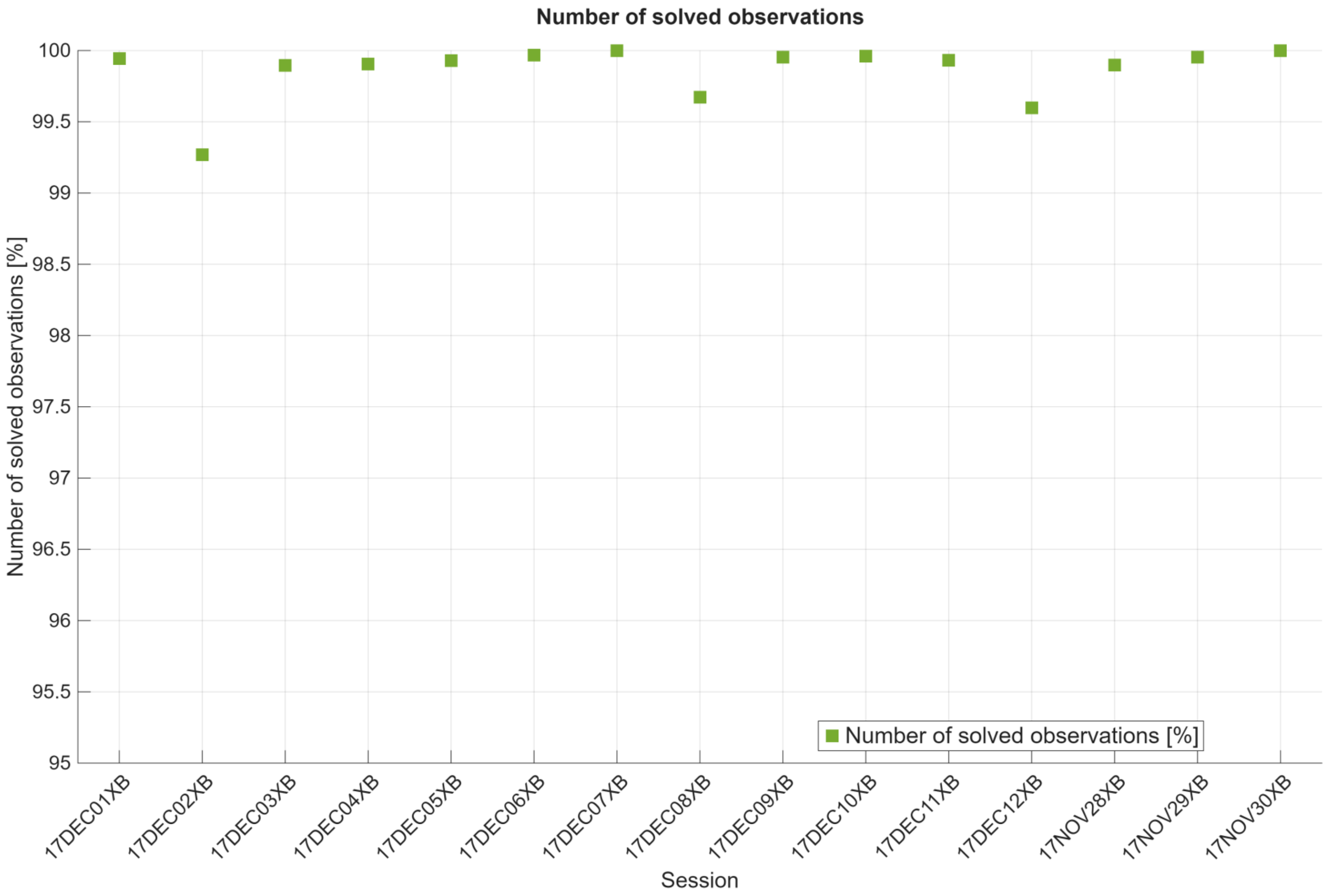
- More steps need to be applied:
  - Some stations or baselines have to be turned temporarily off
  - Choose the option of a down-weighting of non-independent baselines in VieVS
- → Very time consuming
- → Requires practice



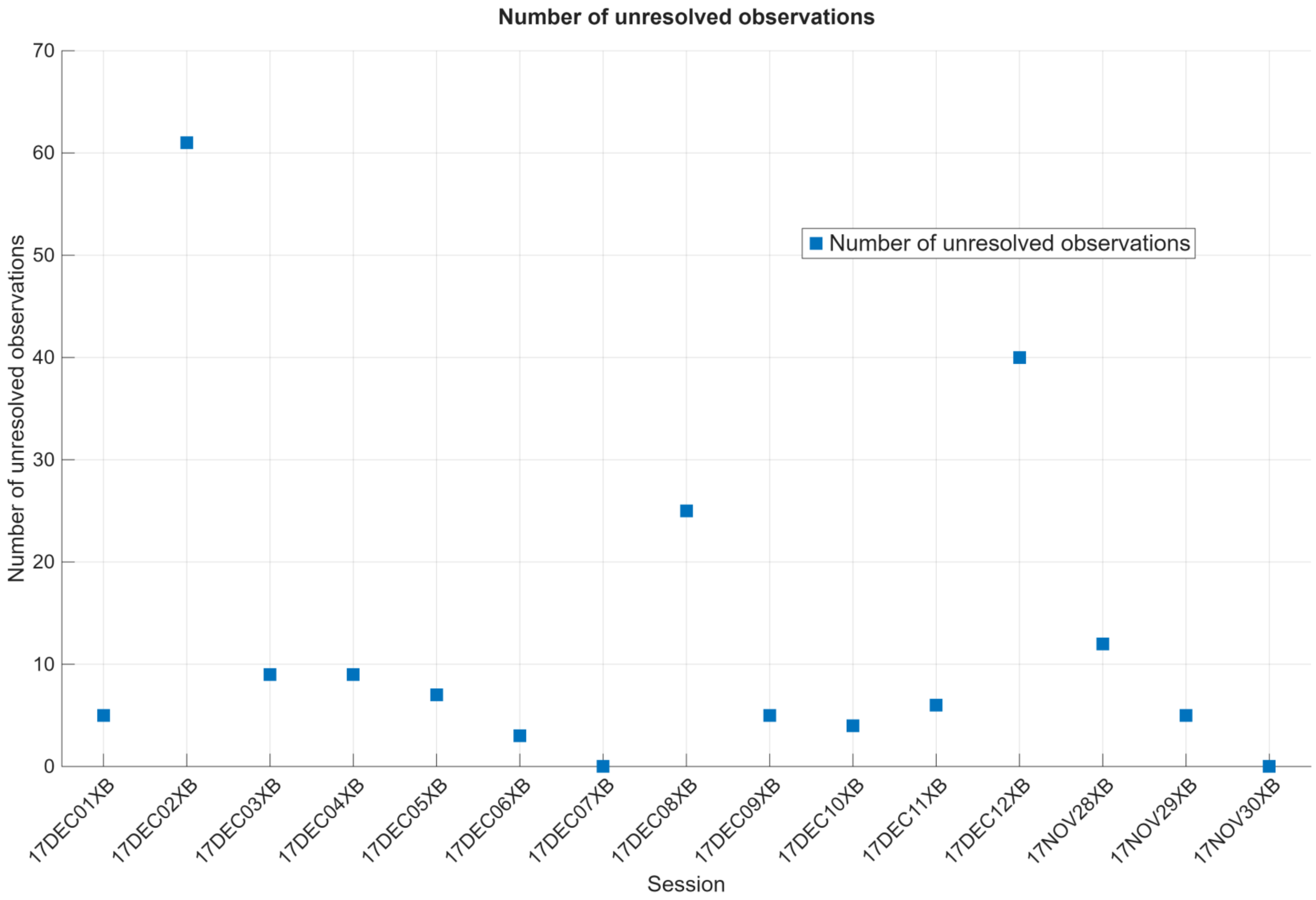
CONT17-L1 X-band

- The main objective was to test and develop the new approach
- All Sessions could be automatically solved
- Sessions with clock breaks can be solved without previous knowledge of these clock breaks
  - → Ambiguity resolution works independently from clock breaks
- → Ambiguities for every observation could be solved

Number of Solved Observations for CONT17-L1 S-band



Number of Unresolved Observations for CONT17-L1 S-band



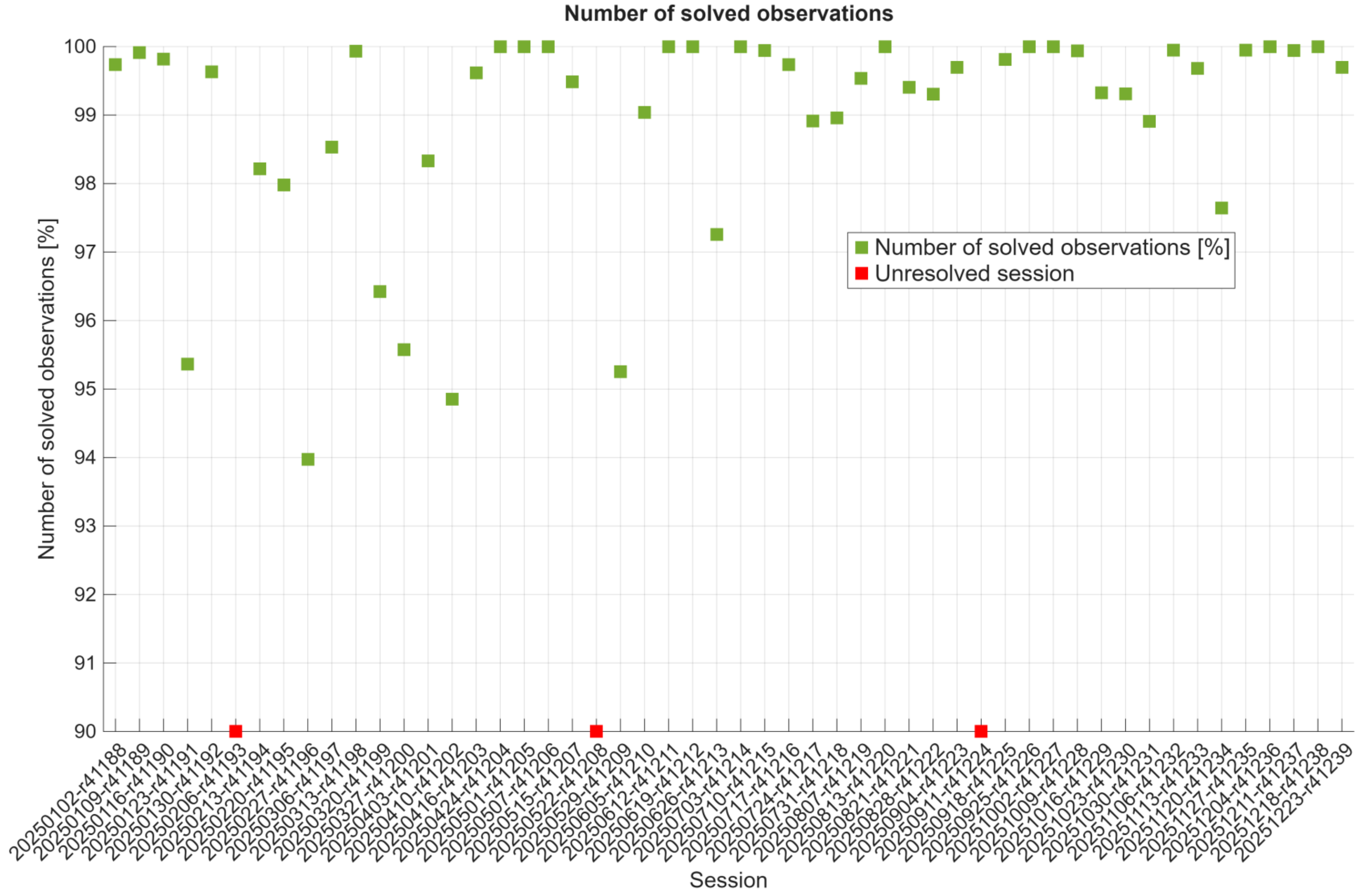
Understanding Issues in Automated Solutions

- Issues with multiband-singleband delay differences:
  - Stations or baselines with a small number of observations (e.g. only 10 observations) → may lead to an unreliable median difference used as input for the closure network
  - Low-quality singleband delay observations → directly affect the delay differences
  - Possible systematic offsets (e.g., clock resynchronization between sessions) → can introduce biases (e.g. ~30 ns shift in CONT 20171201-v1704)

Testing of R1/R4 Sessions (2025)

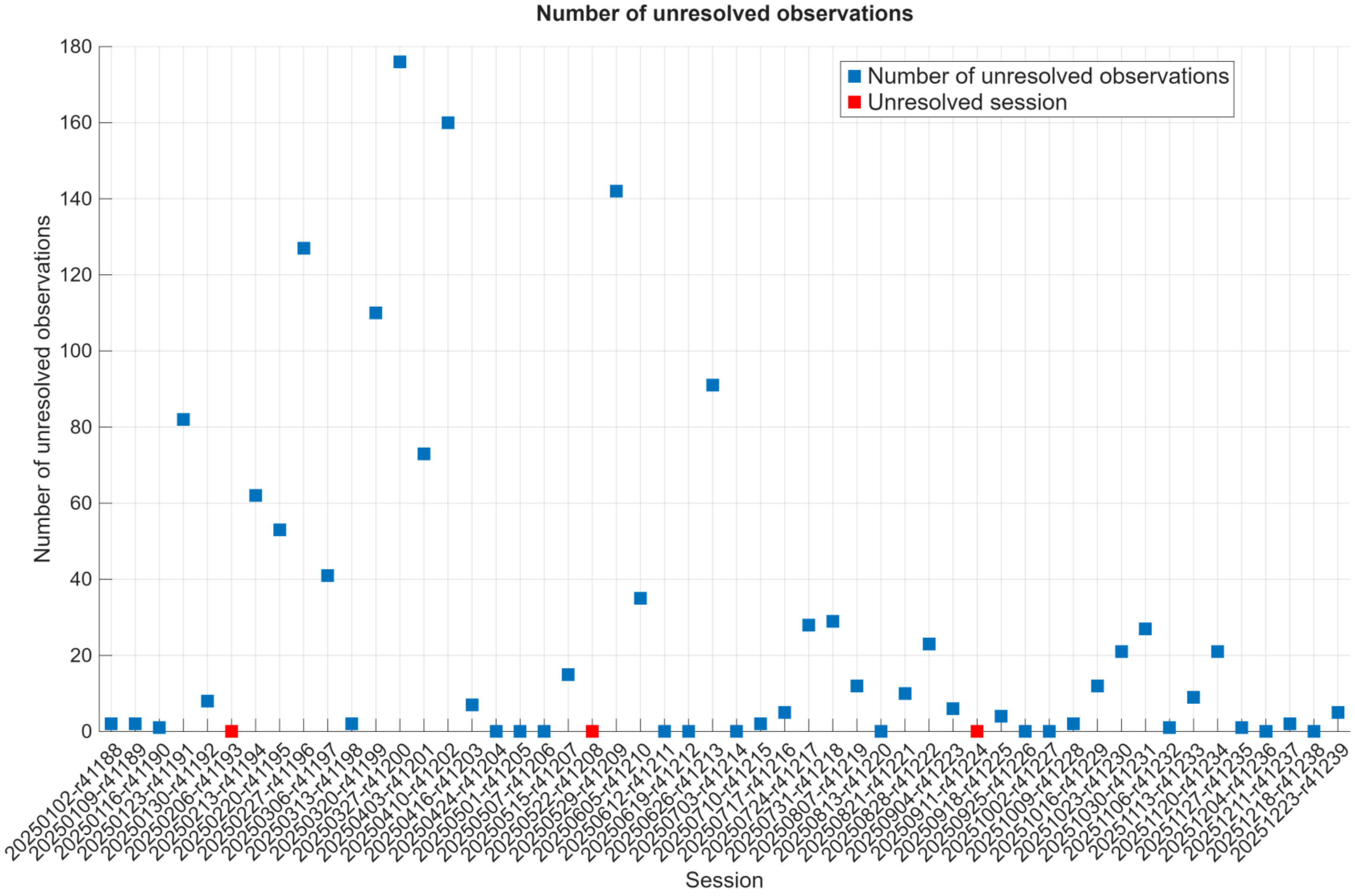
- 1) Ambiguity resolution for the S-band
- 2) Ambiguity resolution for the X-band
- → Multiband delay solution in the X-band with ionospheric calibration calculated on the fly in VieVS based on the two ambiguity solutions

Number of Solved Observations for R4-Sessions (2025)



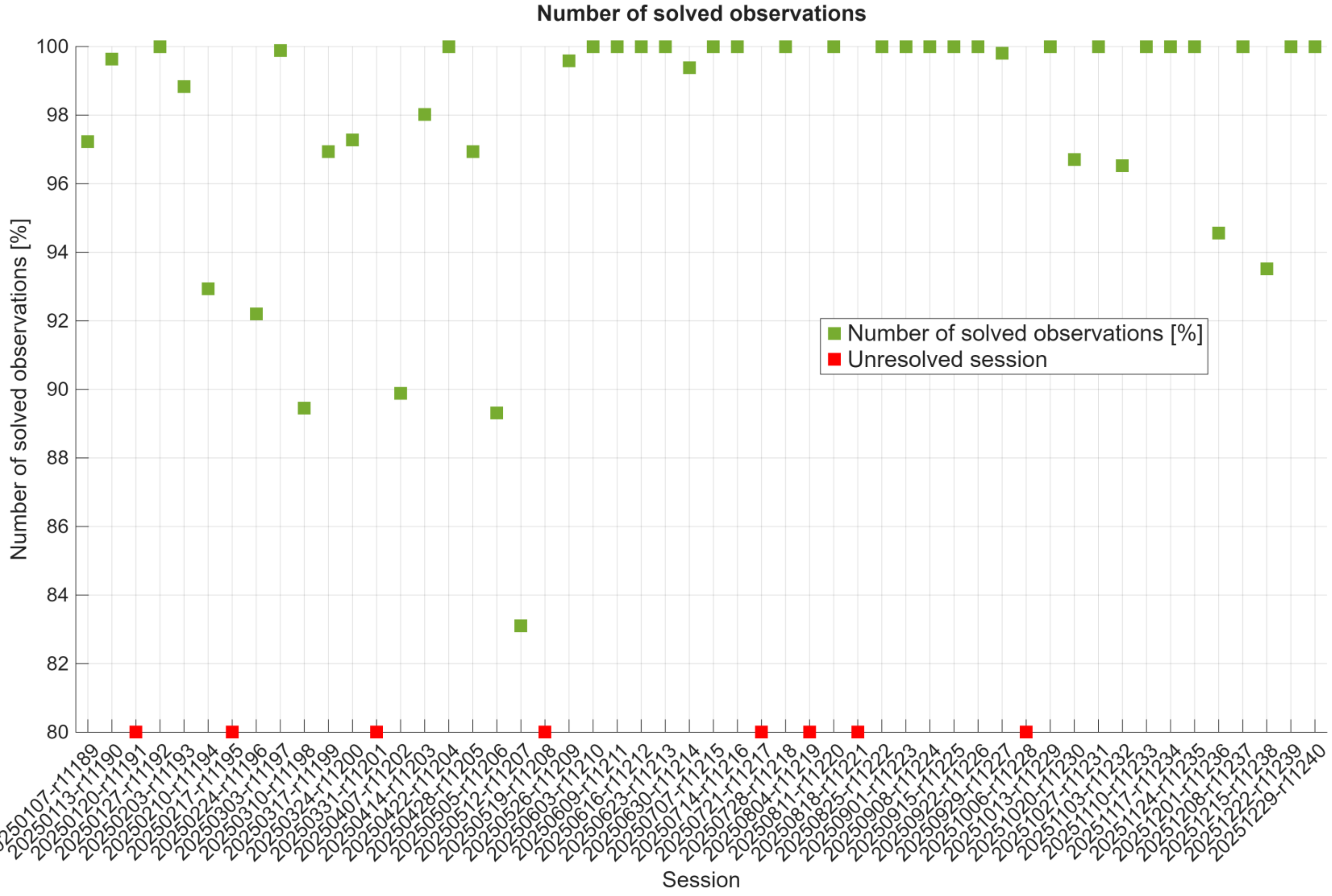
49 / 52
sessions solved

Number of Unresolved Observations for R4-Sessions (2025)



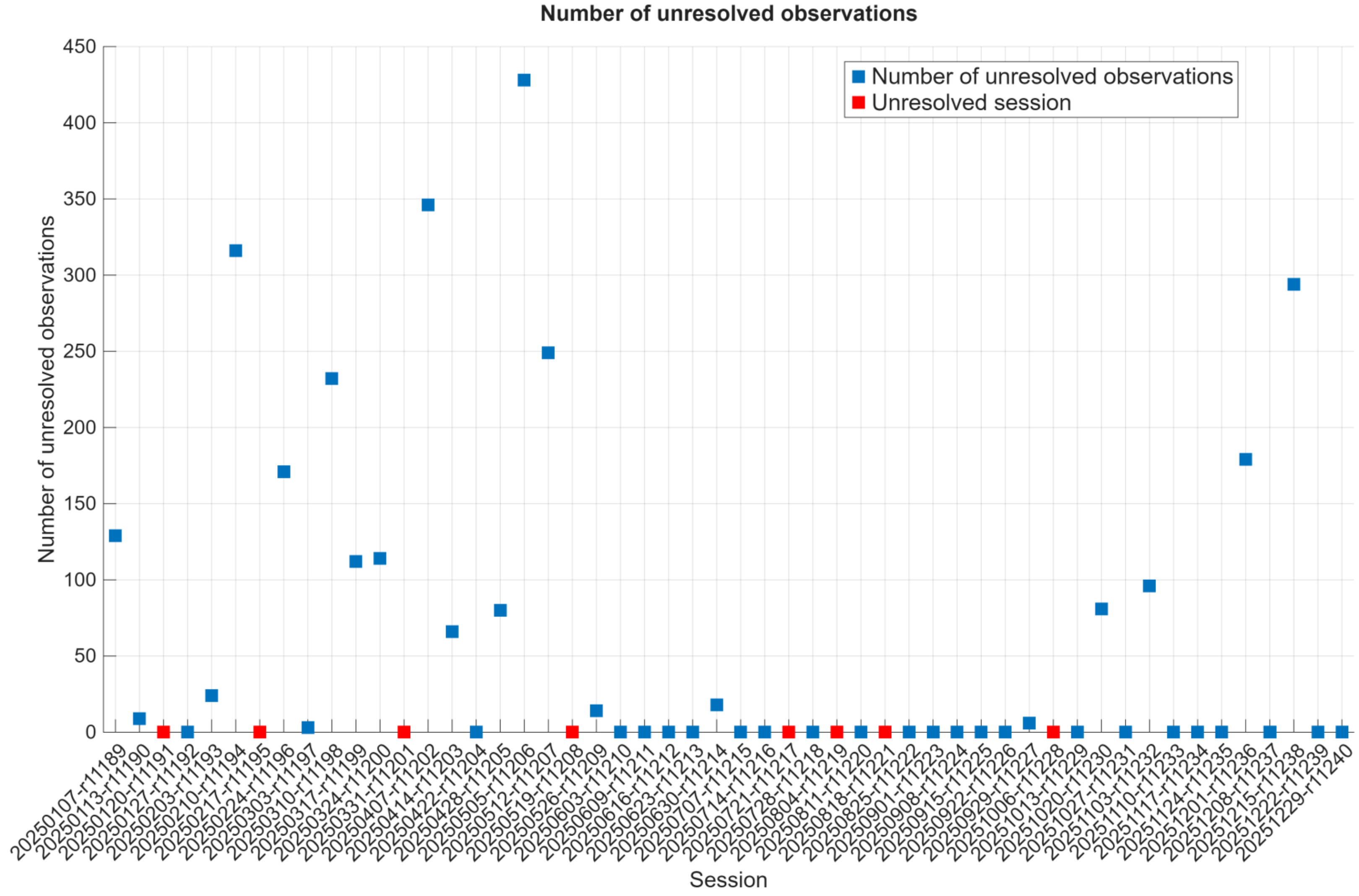
49 / 52
sessions solved

Number of Solved Observations for R1-Sessions (2025)



44 / 52
sessions solved

Number of Unresolved Observations for R1-Sessions (2025)



44 / 52
sessions solved

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Summary

- Automatic Ambiguity Resolution
  - All observations for the CONT17-L1 network in the X-band could be automatically solved and for the S-band at least 99% per session.
  - R1/R4 sessions from 2025 show a high rate of automatically solved observations for the X/S-band, with at least 80% being resolvable and at least more than 98% in most sessions.

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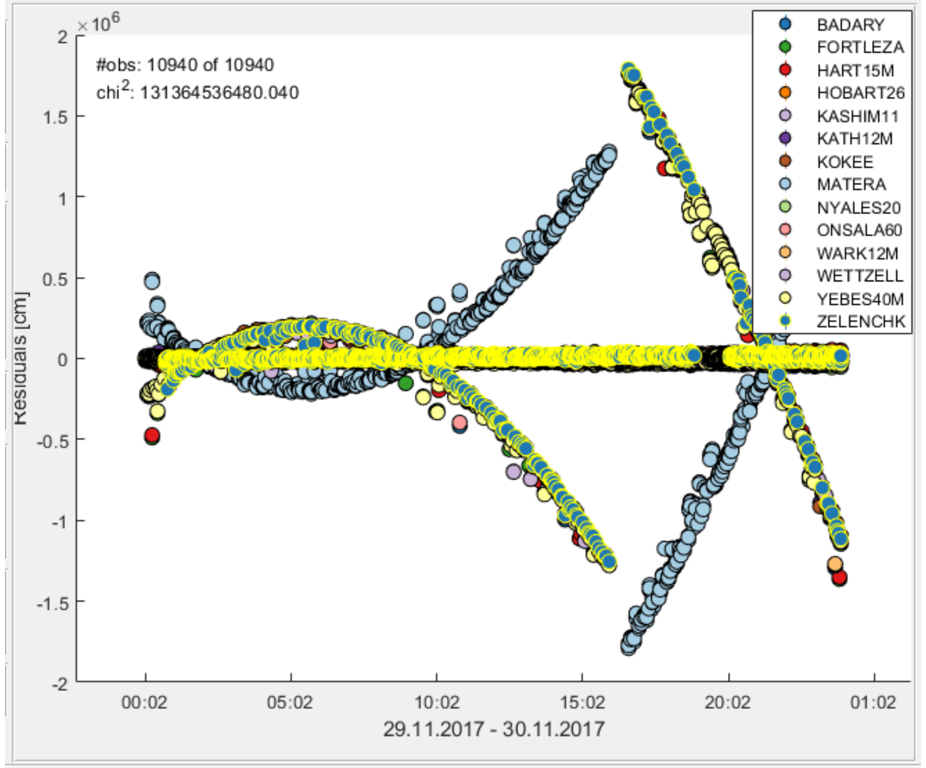
Appendix

Manual Ambiguity Solution for the Entire Session (2)

- First solution of 17NOV29XB without any ambiguity correction
- Clock break at the station Matera
- Clock break is independent solvable from the ambiguity solution



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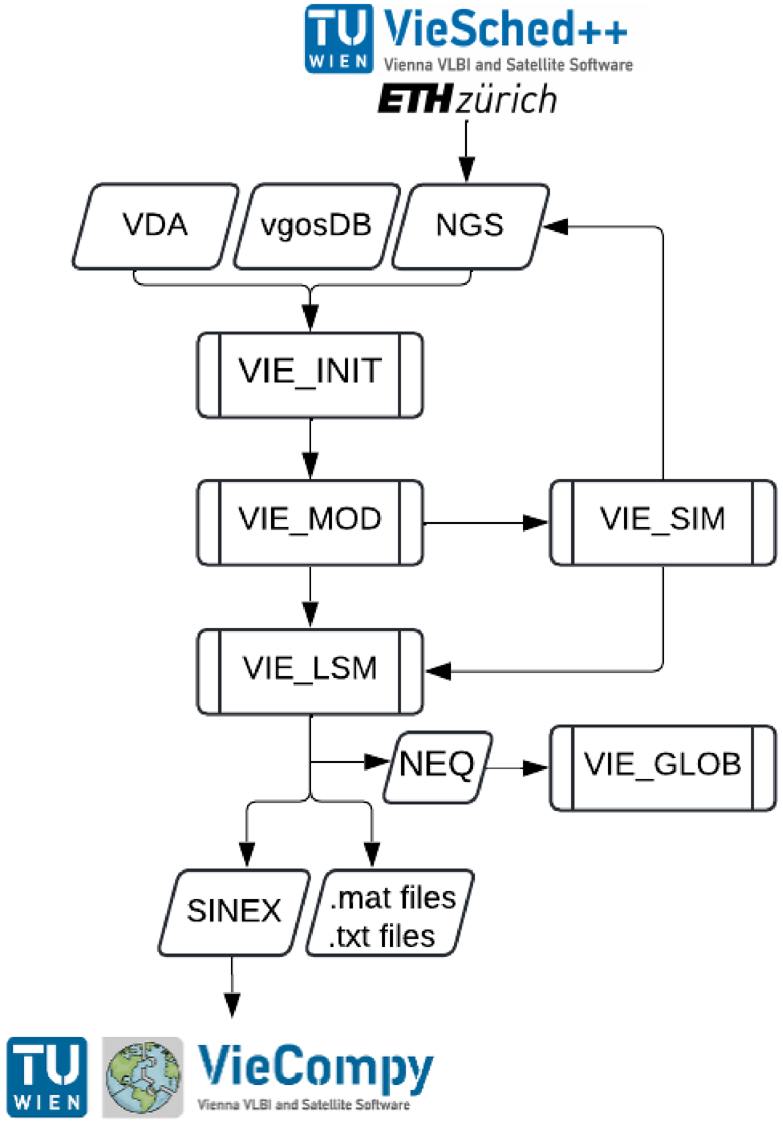
VieVS

- VIE_INIT
  - Reading data
- VIE_MOD
  - Theoretical delays are calculated
- VIE_LSM
  - Optimize the measurement data by adjusting the model to the data
- VIE_GLOB
  - Combine a global solution from several sessions



State-of-the-art Calculation

- L2-norm minimization provides the basis
- Iterative approach
- Functional model based on a second-order polynomial representation of the clock function

Sign

- b_{13}, b_{32}, b_{21} baselines between the stations
- P_1, P_2, P_3 3D-station coordinates
- s_i sign for the closure formula

$$\mathbf{b}_{13} = \mathbf{P}_3 - \mathbf{P}_1, \quad \mathbf{b}_{32} = \mathbf{P}_2 - \mathbf{P}_3, \quad \mathbf{b}_{21} = \mathbf{P}_1 - \mathbf{P}_2$$

$$s_i = \operatorname{sign}\left([\mathbf{b}_{13} \times \mathbf{b}_{32} + \mathbf{b}_{21} \times \mathbf{b}_{13} + \mathbf{b}_{32} \times \mathbf{b}_{21}] \cdot \underbrace{\frac{\mathbf{P}_1 + \mathbf{P}_2 + \mathbf{P}_3}{3}}_{\text{center of gravity}} \right)$$

center of gravity