

How best combining GNSS to a multi-GNSS solution?

Rolf Dach, Daniel Arnold, Elmar Brockmann, Maciej Kalarus, Cyril Kobel,
Martin Lasser, Stefan Schaer, Pascal Stebler, Adrian Jäggi

Astronomical Institute, University of Bern, Switzerland

IAG 2025 Scientific Assembly
01–05. September 2025; Rimini, Italy

Assumptions in GNSS data processing

Experimental setup to proof these assumptions

Selected results from the test solutions

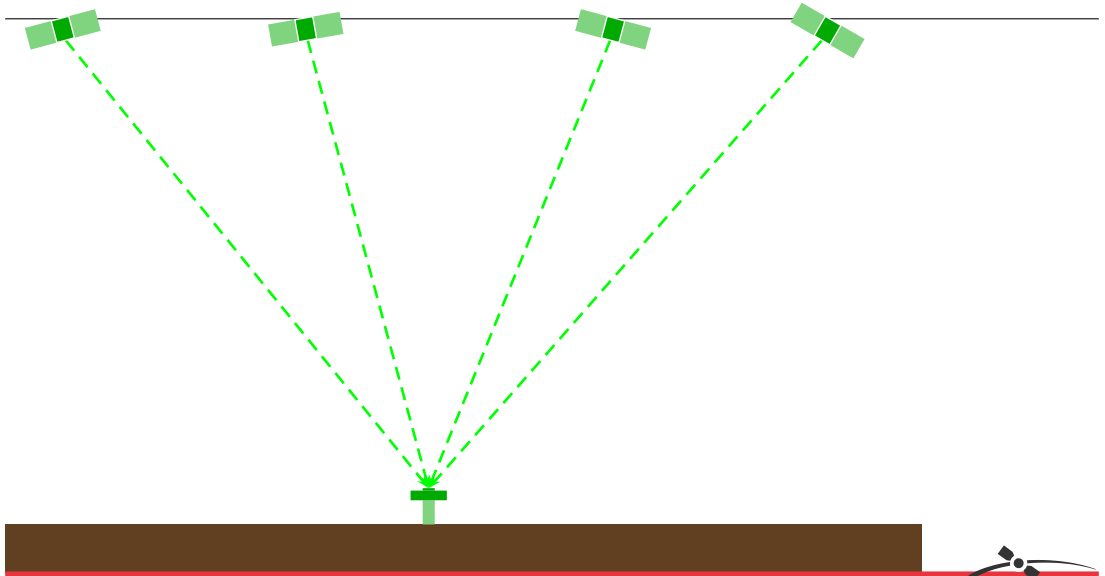
Conclusions

Assumptions in GNSS data processing

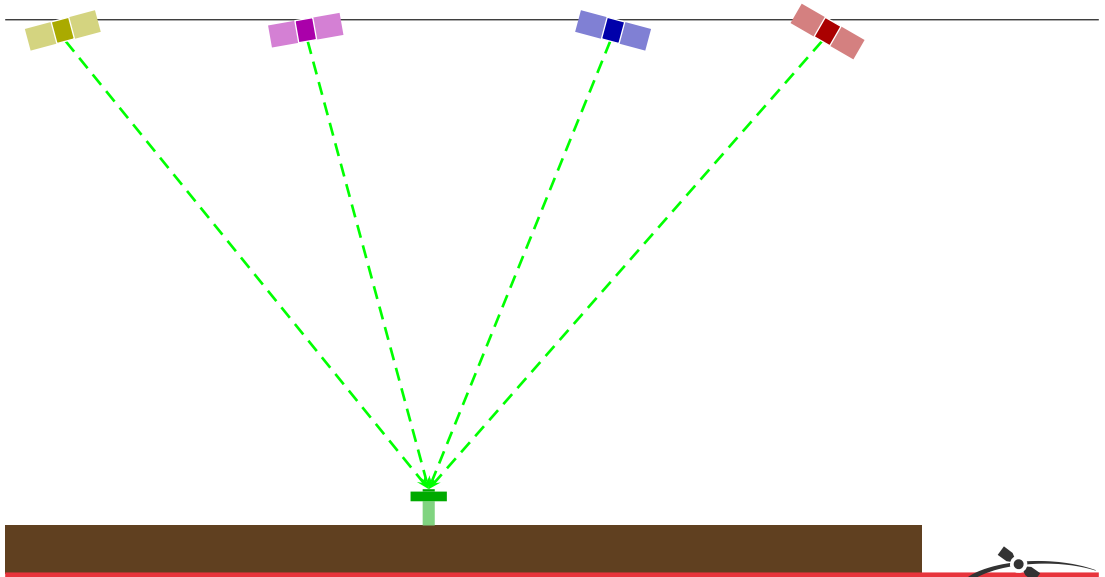
R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly; 01-05, September 2025; Rimini, Italy



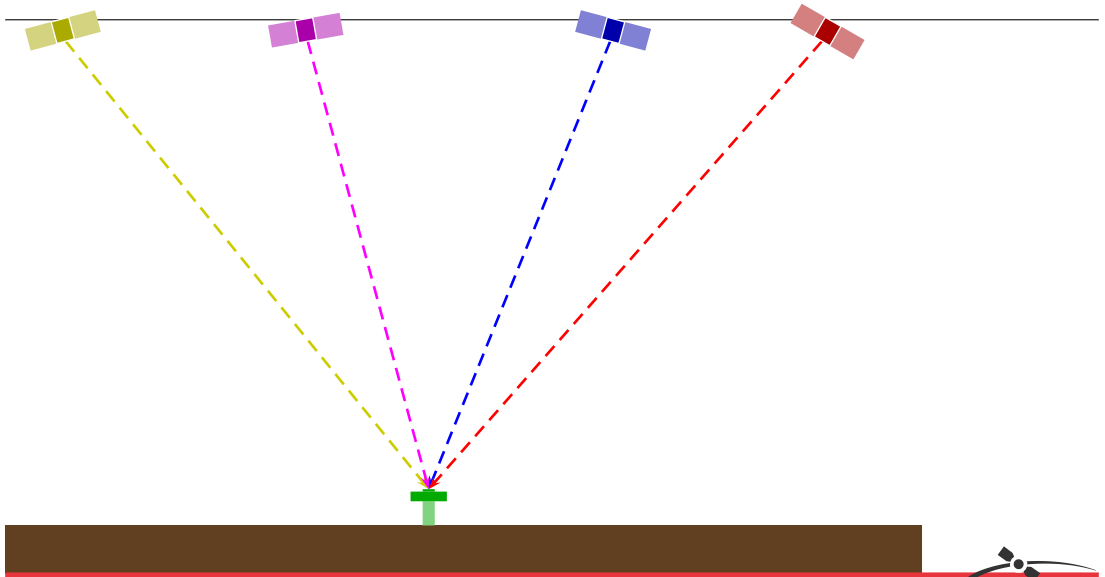
Assumptions in GNSS data processing



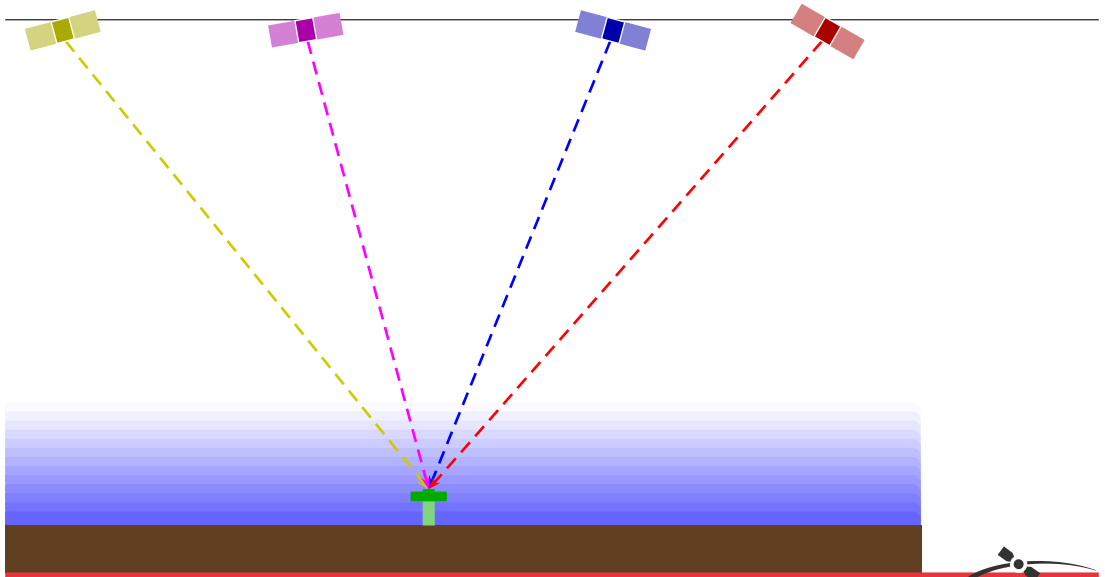
Assumptions in GNSS data processing



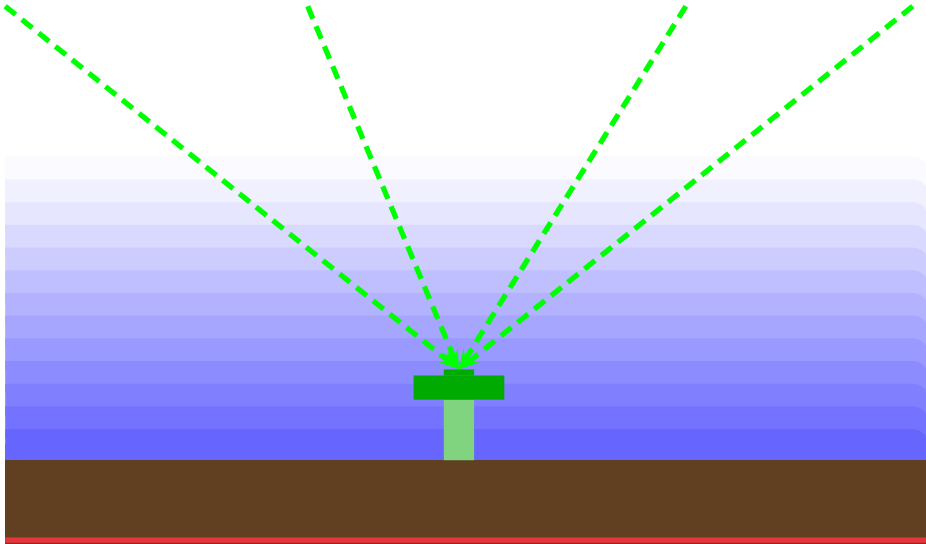
Assumptions in GNSS data processing



Assumptions in GNSS data processing

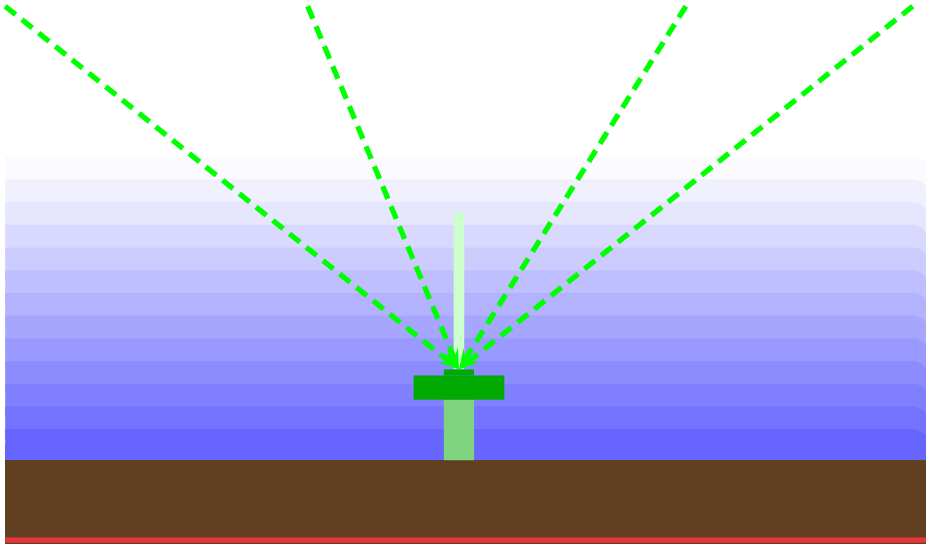


Assumptions in GNSS data processing



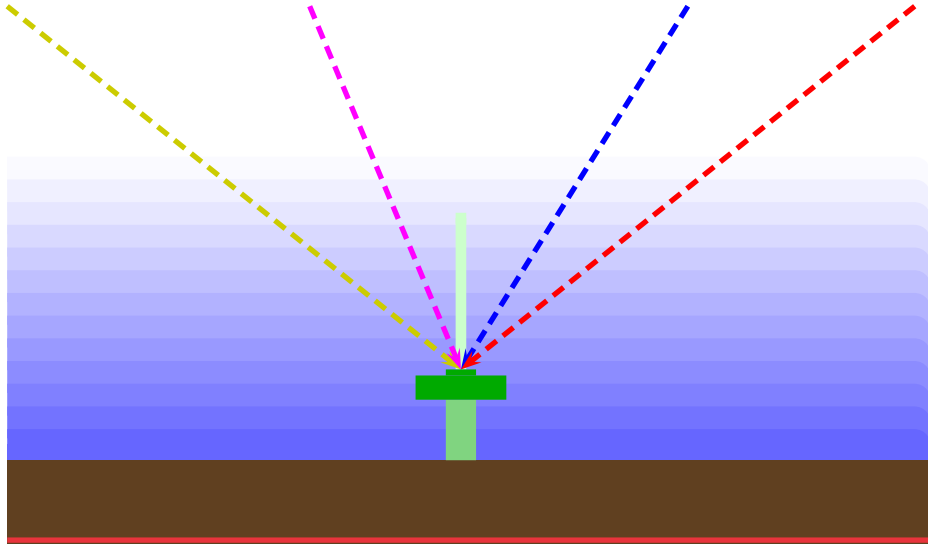
R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly: 01-05, September 2025, Rimini, Italy

Assumptions in GNSS data processing



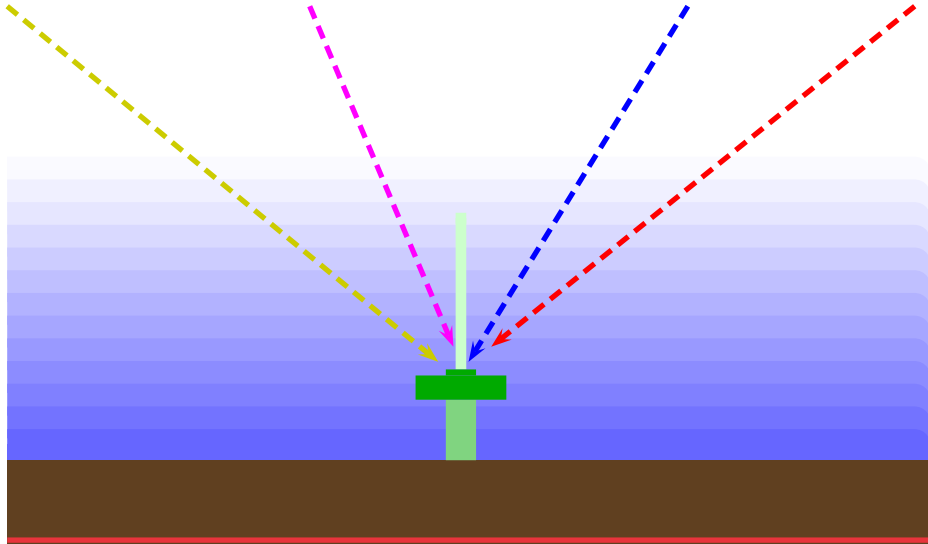
R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly: 01-05, September 2025, Rimini, Italy

Assumptions in GNSS data processing

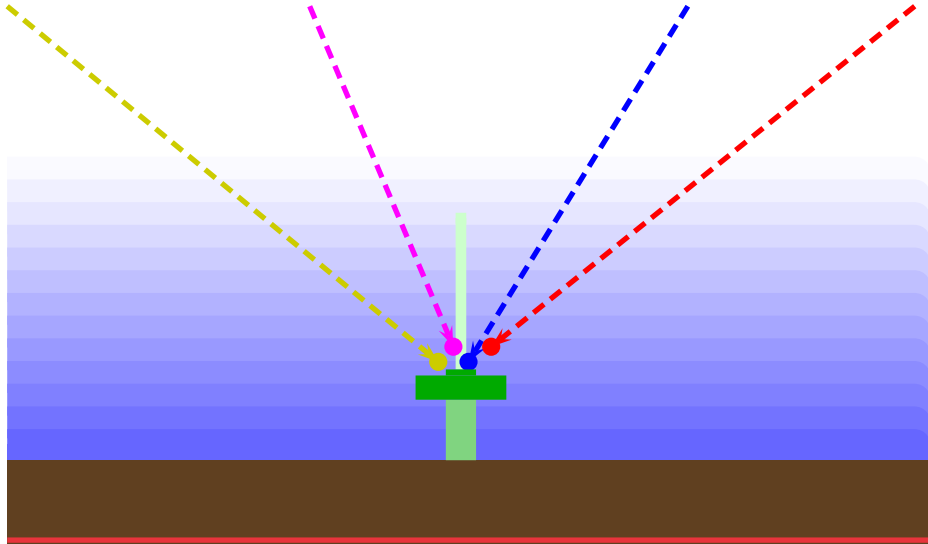


R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly: 01-05, September 2025, Rimini, Italy

Assumptions in GNSS data processing

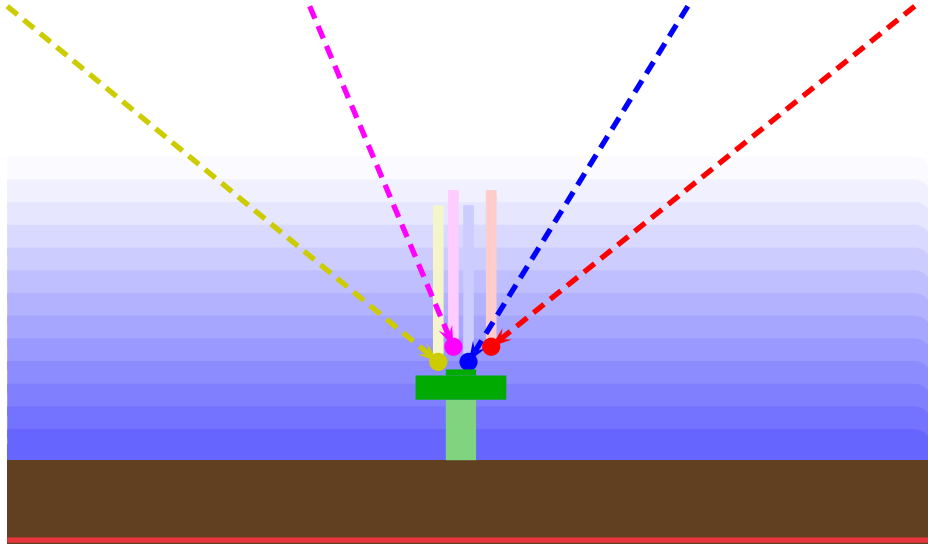


Assumptions in GNSS data processing

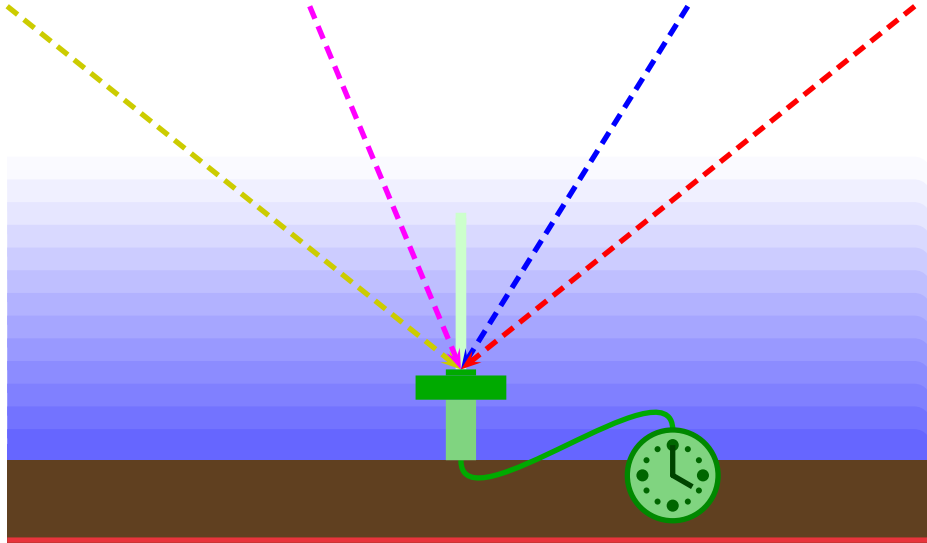


R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly; 01-05, September 2025; Rimini, Italy

Assumptions in GNSS data processing

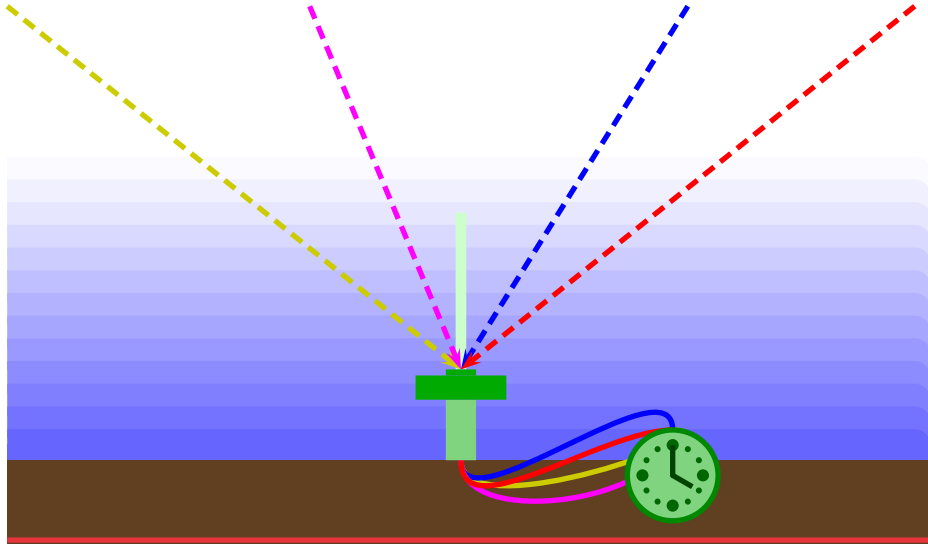


Assumptions in GNSS data processing



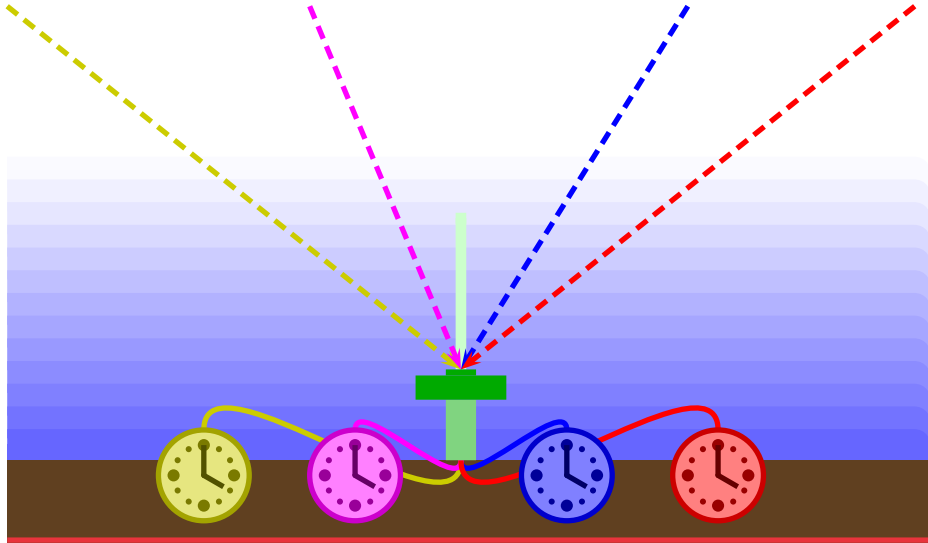
R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly: 01-05, September 2025, Rimini, Italy

Assumptions in GNSS data processing

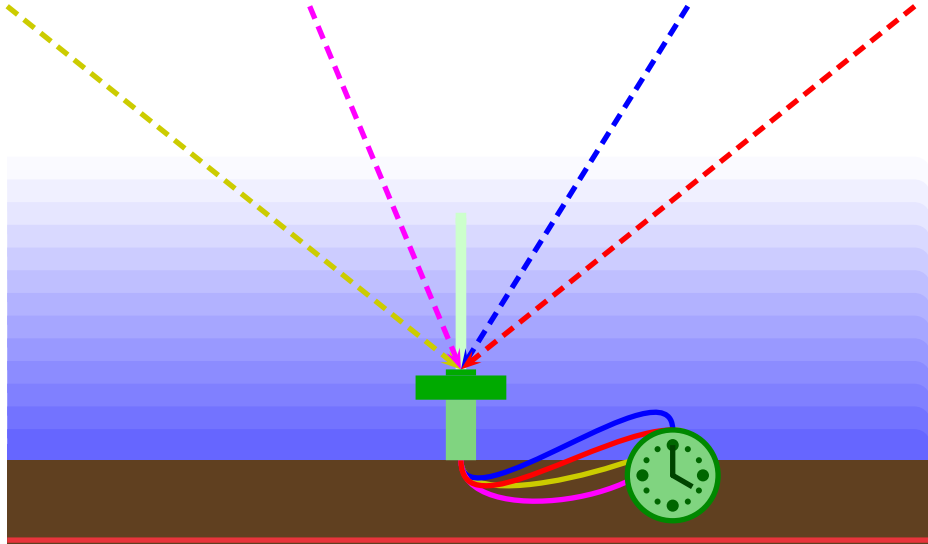


R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly; 01-05, September 2025; Rimini, Italy

Assumptions in GNSS data processing

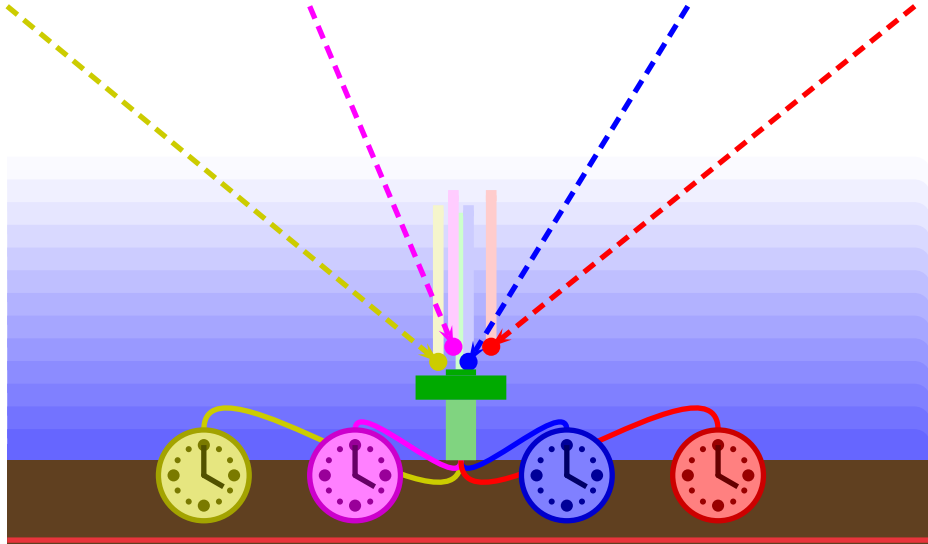


Assumptions in GNSS data processing



R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly; 01-05, September 2025; Rimini, Italy

Assumptions in GNSS data processing



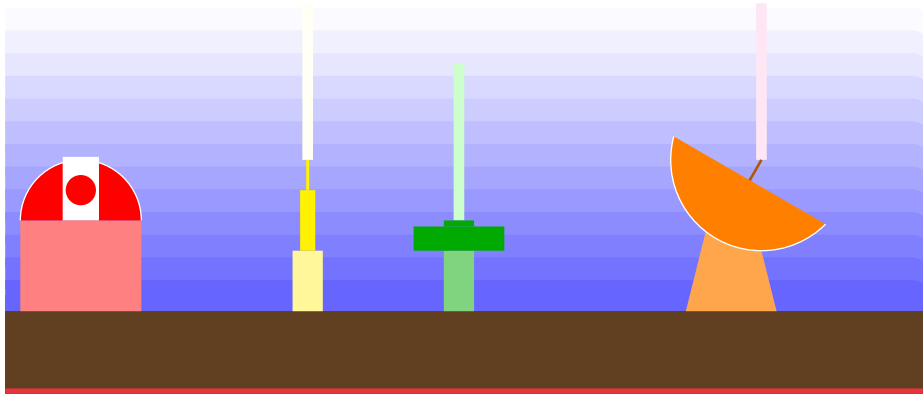
R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly: 01-05, September 2025, Rimini, Italy

Assumptions in GNSS data processing



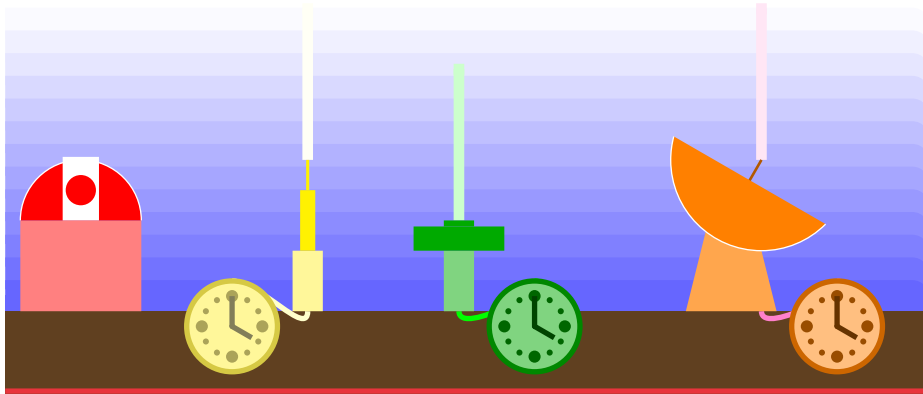
R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly: 01-05, September 2025, Rimini, Italy

Assumptions in GNSS data processing



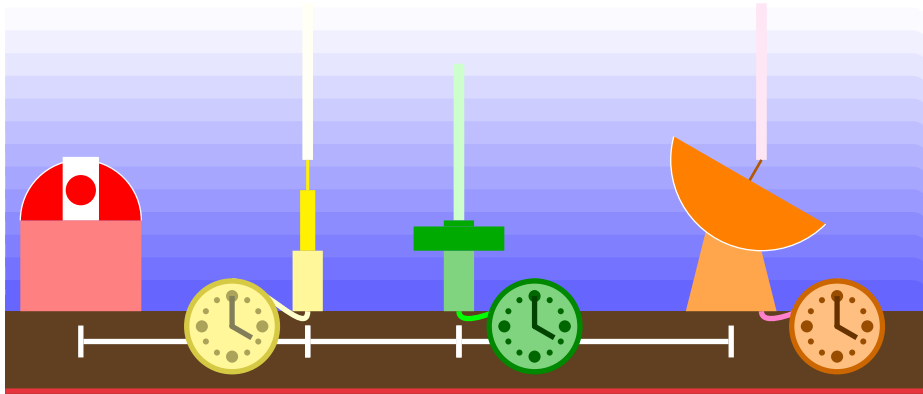
R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly: 01-05, September 2025, Rimini, Italy

Assumptions in GNSS data processing



R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly: 01-05, September 2025, Rimini, Italy

Assumptions in GNSS data processing



R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly: 01-05, September 2025, Rimini, Italy

Assumptions in GNSS data processing

- Receiver antenna is sufficiently calibrated that all measurements do **meet in one point**, that is accessible in one well defined point at the antenna.

Assumptions in GNSS data processing

- Receiver antenna is sufficiently calibrated that all measurements do **meet in one point**, that is accessible in one well defined point at the antenna.
- This applies even, if the signals come from different GNSS.
 - The **scale of each GNSS** is fully consistent.
 - **Antenna phase center** offsets are perfectly calibrated across the systems.
 - No deficiency in antenna phase center variations does map into troposphere model.

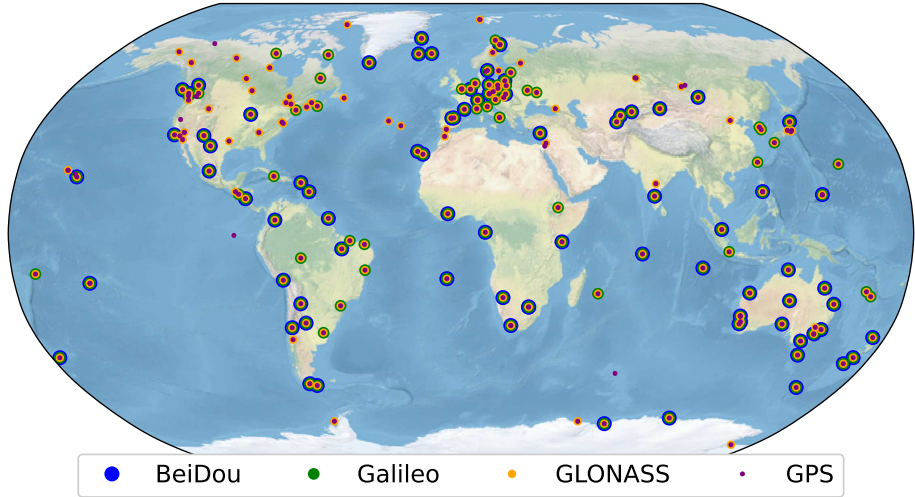
Assumptions in GNSS data processing

- Receiver antenna is sufficiently calibrated that all measurements do **meet in one point**, that is accessible in one well defined point at the antenna.
- This applies even, if the signals come from different GNSS.
 - The **scale of each GNSS** is fully consistent.
 - **Antenna phase center** offsets are perfectly calibrated across the systems.
 - No deficiency in antenna phase center variations does map into troposphere model.
- There is only a **constant hardware delays** in the receiver
 - across various frequencies (in particular GLONASS) and
 - independent from the different signals from the various GNSS.

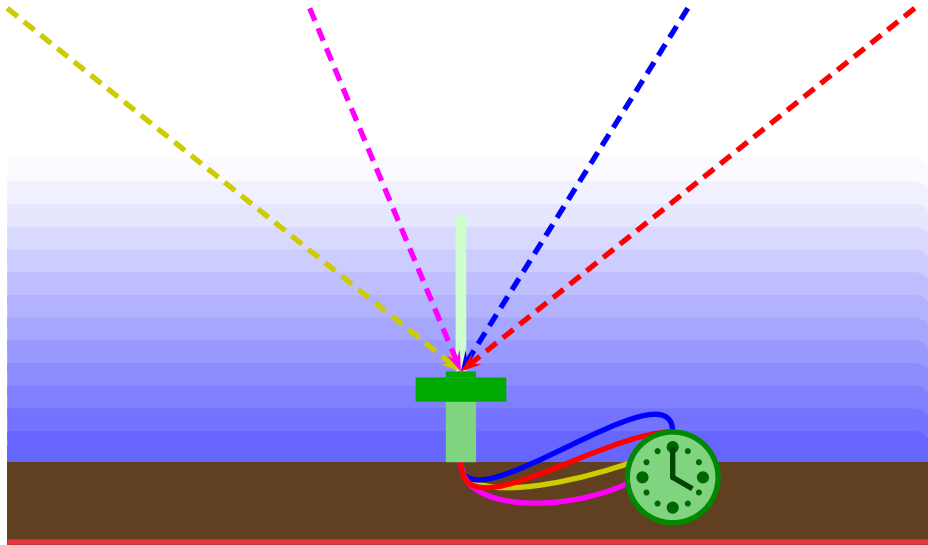
Assumptions in GNSS data processing

- Receiver antenna is sufficiently calibrated that all measurements do meet in one point, that is accessible in one well defined point at the antenna.
- This applies even, if the signals come from different GNSS.
 - The scale of each GNSS is fully consistent.
 - Antenna phase center offsets are perfectly calibrated across the systems.
 - No deficiency in antenna phase center variations does map into troposphere model.
- There is only a constant hardware delays in the receiver
 - across various frequencies (in particular GLONASS) and
 - independent from the different signals from the various GNSS.

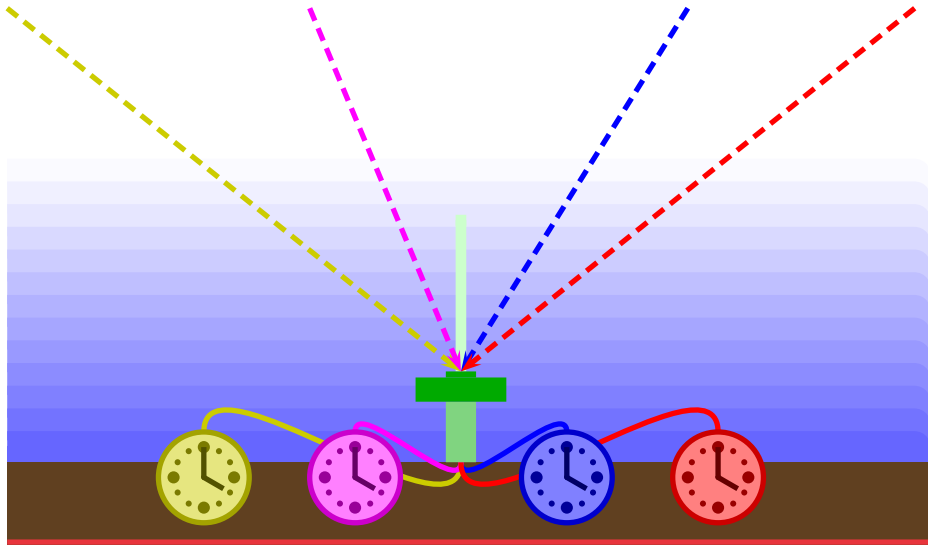
Network from CODE final solution



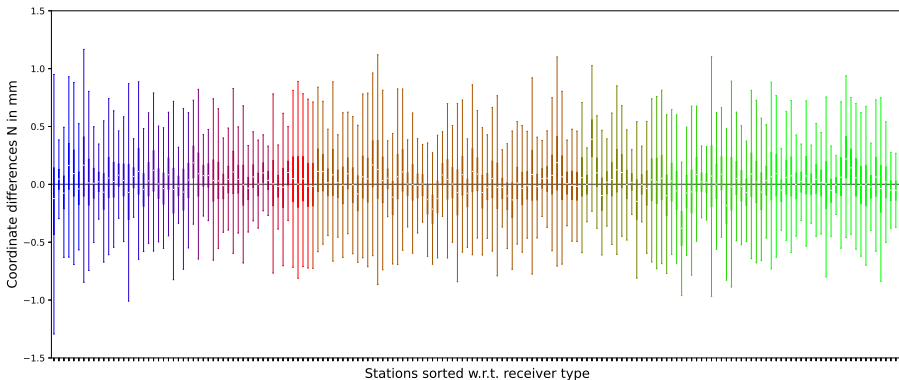
Selected results from the test solutions



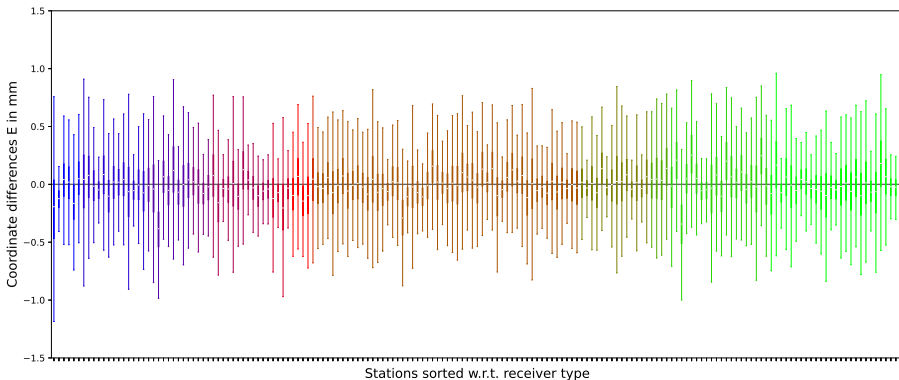
Selected results from the test solutions



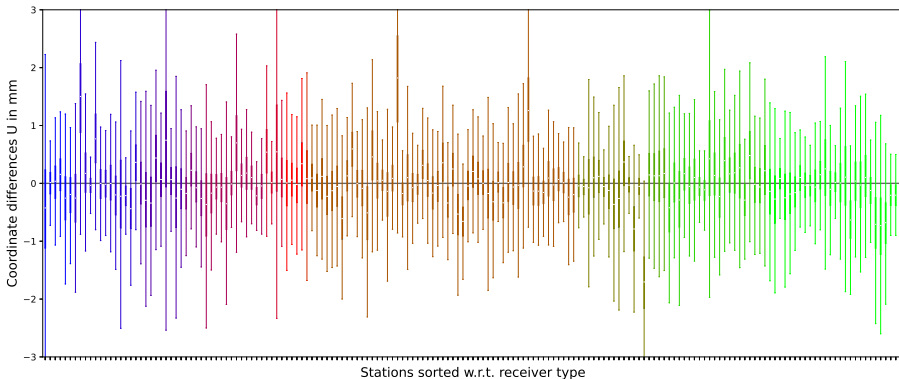
Station coordinate differences (one or four clocks)



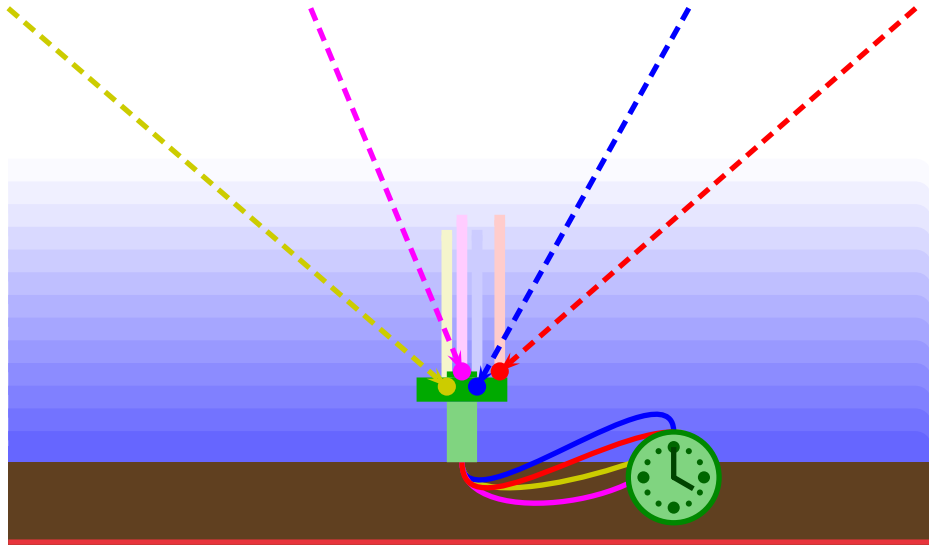
Station coordinate differences (one or four clocks)



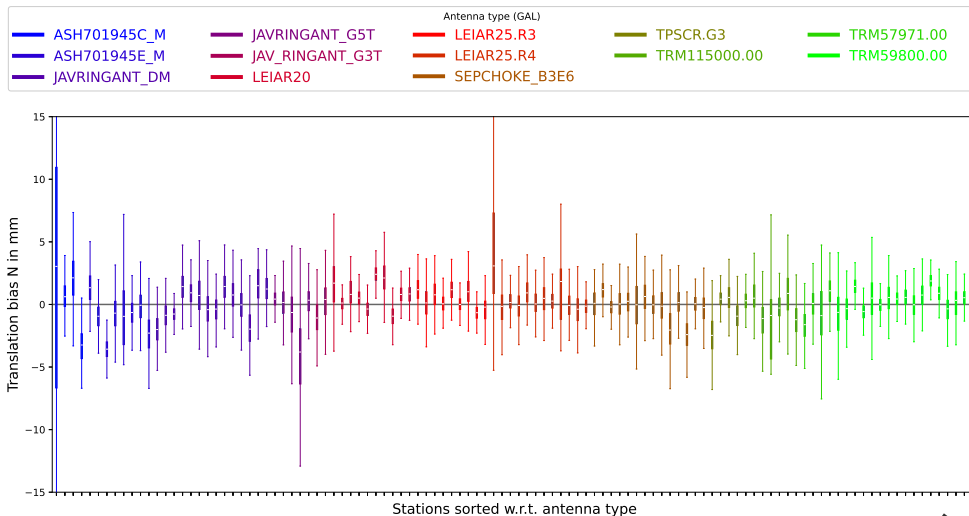
Station coordinate differences (one or four clocks)



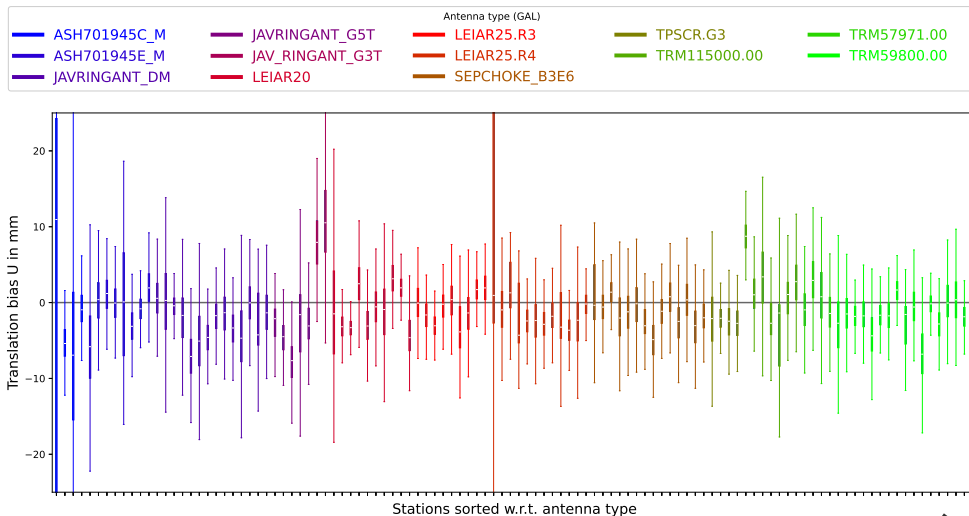
Selected results from the test solutions



Station coordinates: translation biases (one clock)

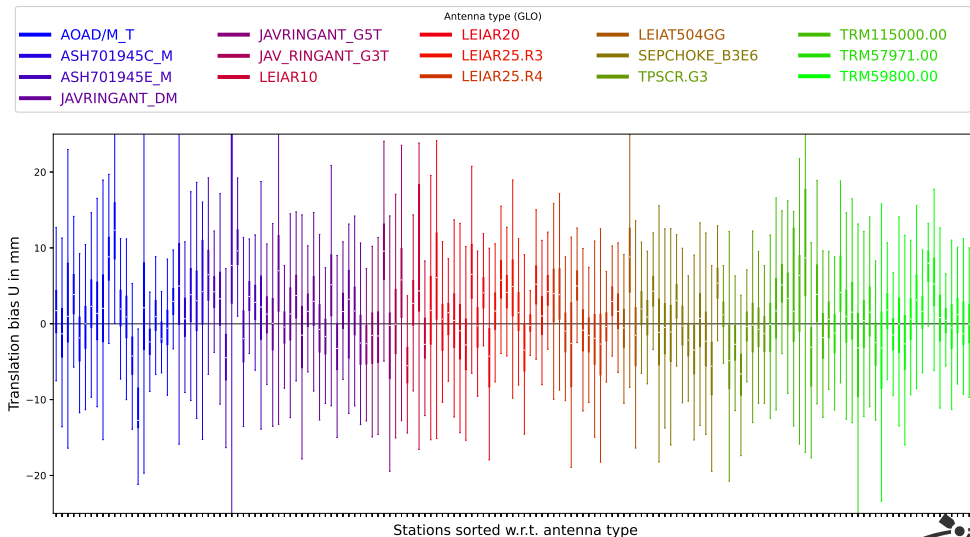


Station coordinates: translation biases (one clock)

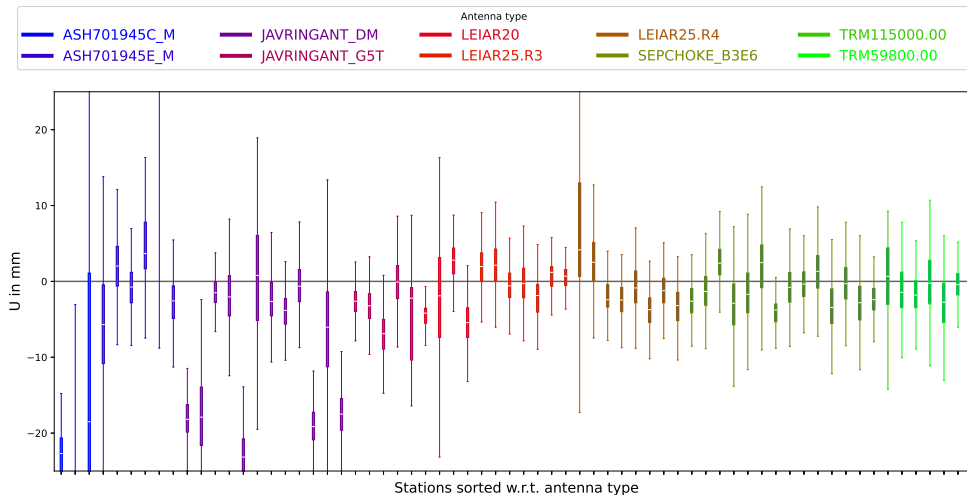


R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly: 01-05, September 2025, Rimini, Italy

Station coordinates: translation biases (one clock)

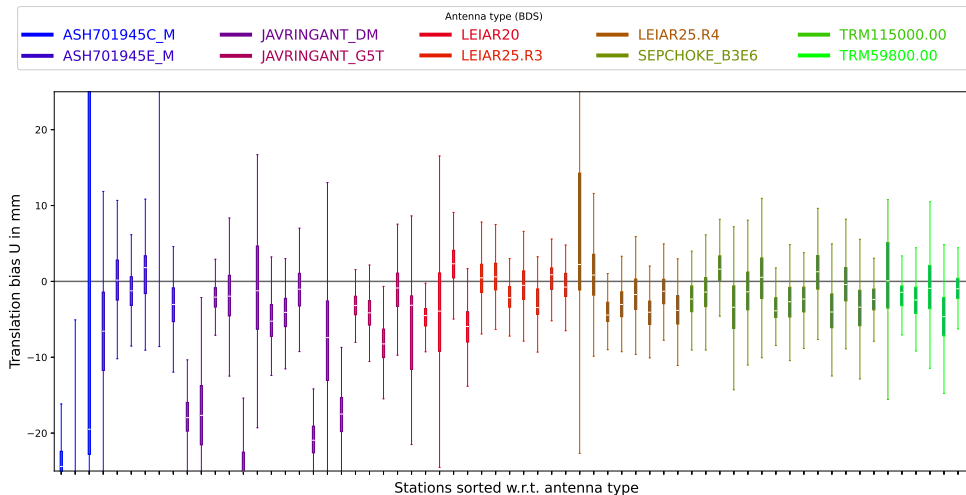


Station coordinates: translation biases (one clock)



R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly: 01-05, September 2025, Rimini, Italy

Station coordinates: translation biases (BDS w/o albedo)



R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly: 01-05, September 2025, Rimini, Italy

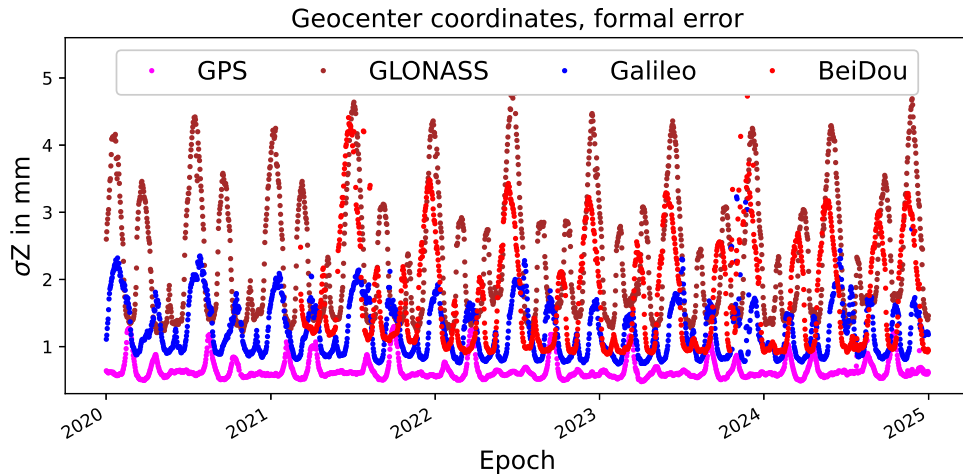
Studying impact of a GNSS on specific parameters

- Since we have demonstrated to get GNSS-specific coordinates and troposphere corrections to investigate consistency of scale and antenna calibrations, **there is no need for epoch-wise receiver clock corrections per system.**

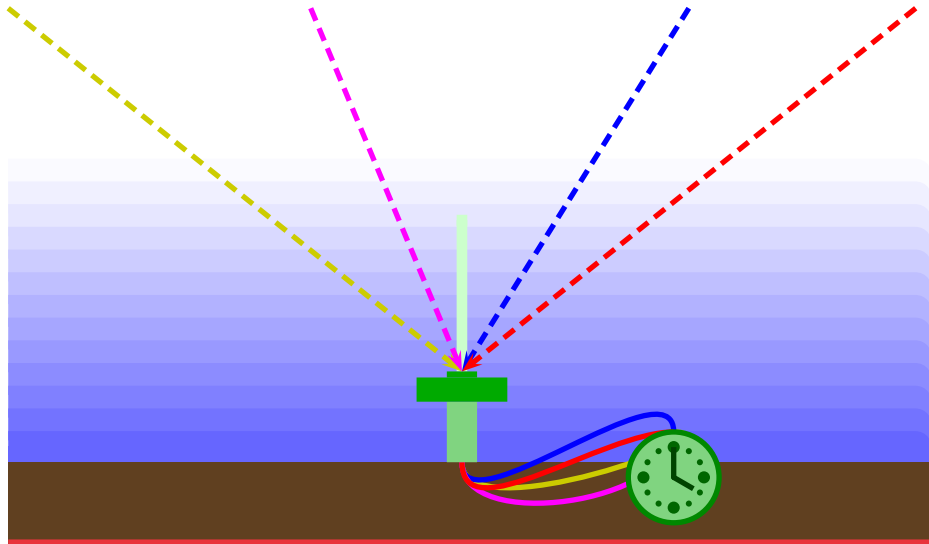
Studying impact of a GNSS on specific parameters

- Since we have demonstrated to get GNSS-specific coordinates and troposphere corrections to investigate consistency of scale and antenna calibrations, **there is no need for epoch-wise receiver clock corrections per system.**
- However, the impact of the various **GNSS on global geodynamic parameters (like, ERP or GCC)** can be assessed by **setting them up per system.**

Studying impact of a GNSS on specific parameters



Studying impact of a GNSS on specific parameters



R. Dach and CODE AC team: How best combining GNSS to a multi-GNSS solution?
IAG 2025 Scientific Assembly: 01-05, September 2025, Rimini, Italy

Conclusions

- With GNSS-specific receiver clock corrections, the power of the multi-GNSS solution is significantly reduced (288+ additional parameters per station).

There is no need for this.

Conclusions

- With GNSS-specific receiver clock corrections, the power of the multi-GNSS solution is significantly reduced (288+ additional parameters per station).

There is no need for this.

- We are proposing instead:
 - GNSS-specific translation biases (antenna calibration deficiencies; scale discrepancies between the systems)
 - GNSS-specific setup of global parameters (e.g., for ERP, GCC)

Conclusions

- With GNSS-specific receiver clock corrections, the power of the multi-GNSS solution is significantly reduced (288+ additional parameters per station).

There is no need for this.

- We are proposing instead:
 - GNSS-specific translation biases (antenna calibration deficiencies; scale discrepancies between the systems)
 - GNSS-specific setup of global parameters (e.g., for ERP, GCC)
- These monitoring parameters can be setup in daily normal equations but can be removed before the standard solution is computed.

Conclusions

- With GNSS-specific receiver clock corrections, the power of the multi-GNSS solution is significantly reduced (288+ additional parameters per station).

There is no need for this.

- We are proposing instead:
 - **GNSS-specific translation biases** (antenna calibration deficiencies; scale discrepancies between the systems)
 - **GNSS-specific setup of global parameters** (e.g., for ERP, GCC)
- These monitoring parameters can be setup in daily normal equations but can be **removed before the standard solution is computed.**
- **This is the approach we are following at CODE AC**
 - no indication has been found that this approach does not cover all needs.
 - the approach contains a number of elements to verify multi-GNSS antenna calibrations.

THANK YOU

for your attention



Publications of the satellite geodesy research group:

<http://www.bernese.unibe.ch/publist>

