# Advancing Zero-Difference GNSS Processing for Operational Use at Center for Orbit Determination in Europe (CODE)

**Authors:** C. Kobel[1], R. Dach[1], D. Arnold[1], E. Brockmann[1], M. Kalarus[1], M. Lasser[1], S. Schaer[2], P. Stebler[1], A. Jäggi[1]
[1] Astronomical Institute, University of Bern, Bern, Switzerland
[2] Federal Office of Topography (swisstopo), Wabern, Switzerland

**ABSTRACT ID 6959**

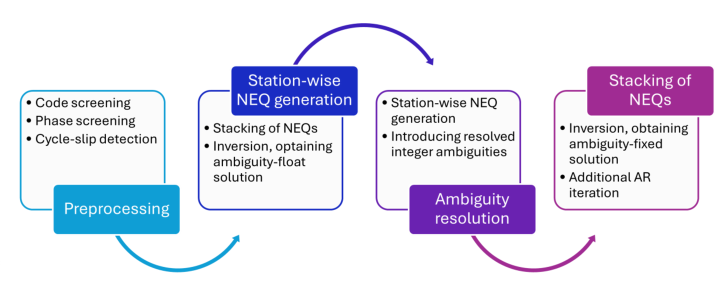
IGS 2026 WORKSHOP
SANTIAGO DE CHILE
33°26' S 70°39' O

## Global GNSS solutions based on the zero-difference approach

Since 1992, the Center for Orbit Determination in Europe (CODE) has continuously produced GNSS products (Dach, Brockmann, et al. 2009). The Bernese GNSS Software has been employed for this purpose (Dach, Lutz, et al. 2015). As an IGS Analysis Center, CODE thereby provides a significant contribution to the International GNSS Service (IGS). Traditionally, global GNSS solutions have been generated using the double-difference (DD) approach, in which observables are formed as differences between measurements from two receivers and two satellites. A principal advantage of this method is the elimination of a large number of parameters. The zero-difference (ZD) approach is mathematically equivalent to the DD method, but offers several advantages, including greater flexibility in modifying the ground station network and the ability to incorporate data from Low Earth Orbiters (LEO). This study evaluates the quality of global GNSS solutions obtained using the ZD approach, in comparison with operational CODE DD products, to assess the potential of ZD-based solutions for operational products.

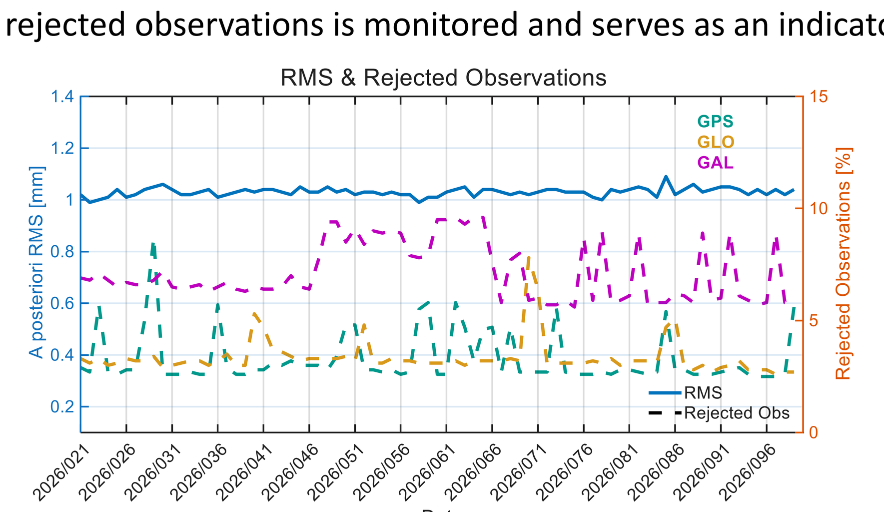
## Processing Scheme of the zero-difference approach

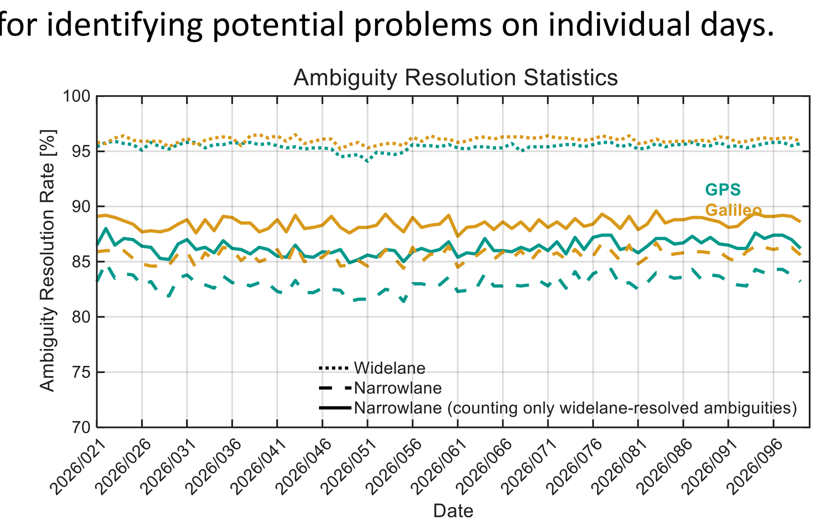
The prototype for the computation of the ZD solution follows the structure of the established DD strategy at CODE. To ensure computational efficiency, parallelization is implemented throughout the processing chain. The ambiguity resolution method introduces ambiguity clusters and satellite-wise Consistency corrections (Calero-Rodriguez et al. 2023). Details of the full processing chain are provided in Calero-Rodriguez (2024).




## Processing Quality

Processing quality is assessed using several indicators, including the a posteriori RMS of unit weight. The number of rejected observations is monitored and serves as an indicator for identifying potential problems on individual days.

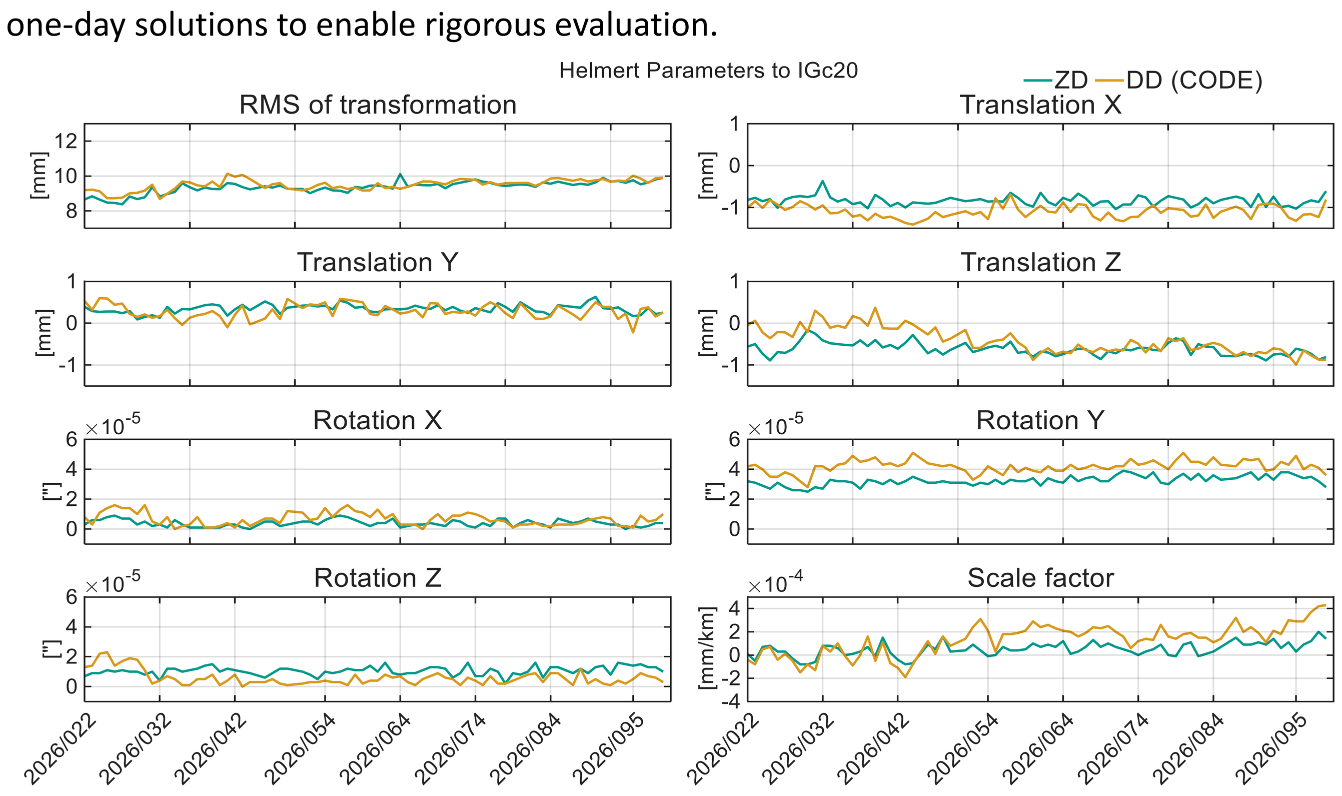


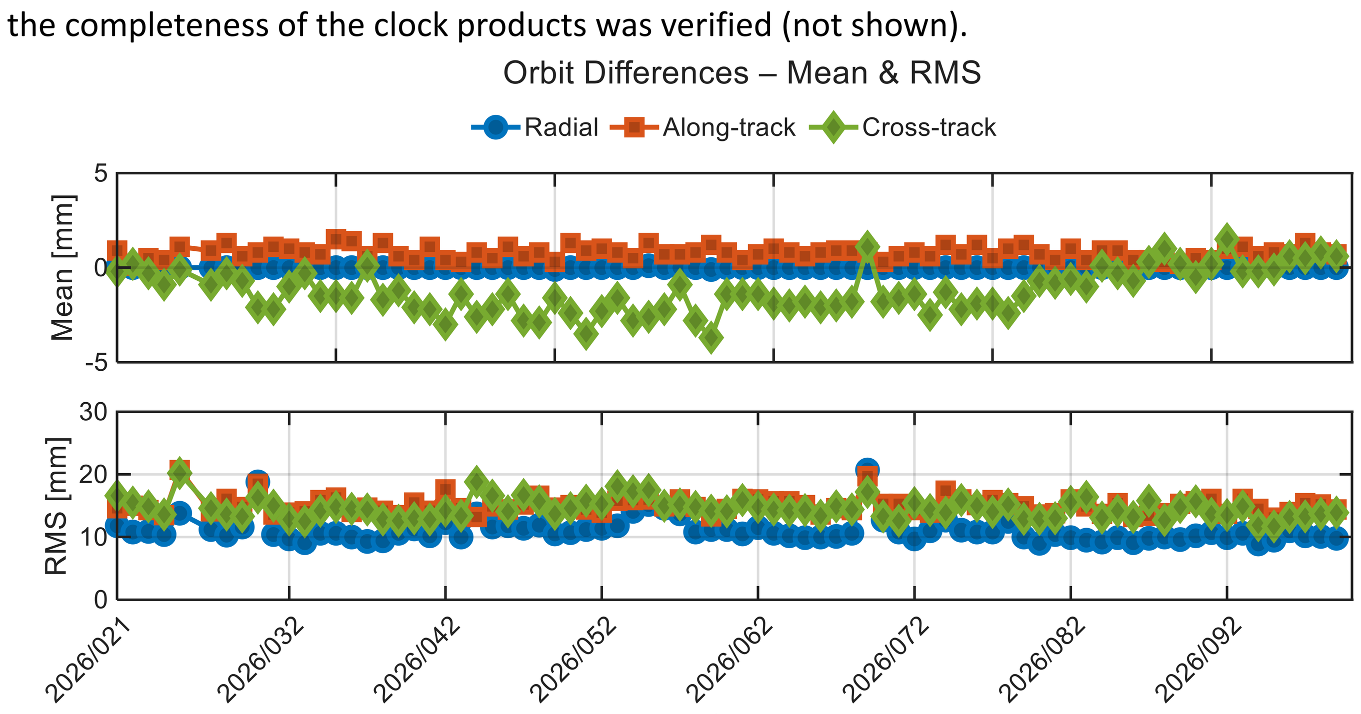

To validate the ambiguity resolution strategy, ambiguity fixing rates are analyzed, distinguishing between widelane and narrowlane ambiguities.

## Validation of Results

Validation procedures include a Helmert transformation to a reference frame (IGc20). One-day ZD solutions are compared with CODE DD one-day solutions to enable rigorous evaluation.




A direct validation is carried out by computing orbit differences between the ZD solution and the CODE DD solution. Mean values and RMS values are determined in all three spatial directions across all satellites included in both solutions. Furthermore, the completeness of the clock products was verified (not shown).




## Conclusion of the zero-difference processing

The results shown clearly demonstrate that the prototype of the ZD processing chain achieves acceptable stability. This conclusion is based on the analysis of the presented time series. To obtain further confidence, a longer time series is required. The comparison with the established CODE DD products shows that the solutions derived from the ZD processing are of adequate quality. It can therefore be concluded that ZD-based GNSS processing can be used to compute stable global products on a daily basis and represents a promising foundation for next-generation GNSS solutions at CODE.

## Analysis of different network sizes

Optimising processing time is one critical component of an automated processing chain. The impact of different station network sizes on the resulting global GNSS network solution was investigated with the aim of obtaining a reliable network solution as resource-efficiently as possible, since the network size is one of the key parameters affecting computation time. The investigations were conducted for a single day (26/024), varying only the number of stations. The homogeneous distribution of stations was of particular importance, and a corresponding algorithm was applied. In this analysis, the goal was to find the optimal balance between number of ground stations included in the processing and solution quality, using the ZD approach.

## Station Selection Algorithm

To achieve the most homogeneous station distribution possible, weighted farthest point sampling (WFPS) was applied: $N$ is the total number of available GNSS stations and $K_{select}$ the desired number of selected stations. The unit vectors pointing from Earth's center to each station are described by $u_i \in \mathbb{R}^3$ for $i = 1, \ldots, N$. A weight $\omega_i$ is defined for each station based on the number of GNSS systems observed (only GPS, GLONASS, and Galileo):

$$\omega_i = 1 + 0.5 \cdot (n_{sys} - 1), \quad n_{sys}(i) \in \{1,2,3\}$$

The first step is to randomly select the first station $s_1$ from the set of available stations:

$$s_1 \sim Uniform(available\ indices)$$

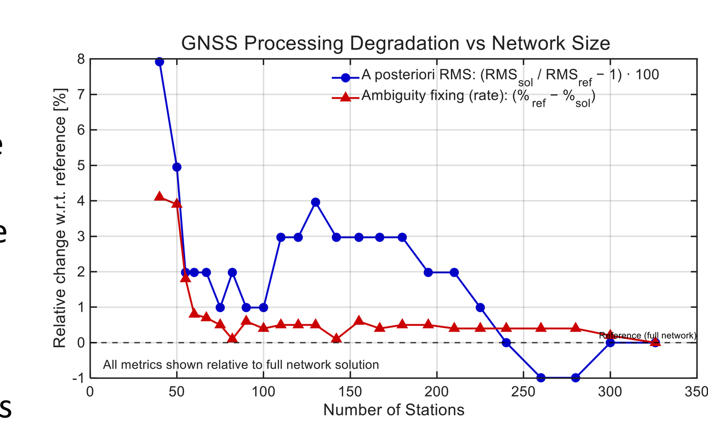
For $k = 2, \ldots, K_{select}$, the next station $s_k$ is selected that maximizes the weighted minimum angular distance to already selected stations:

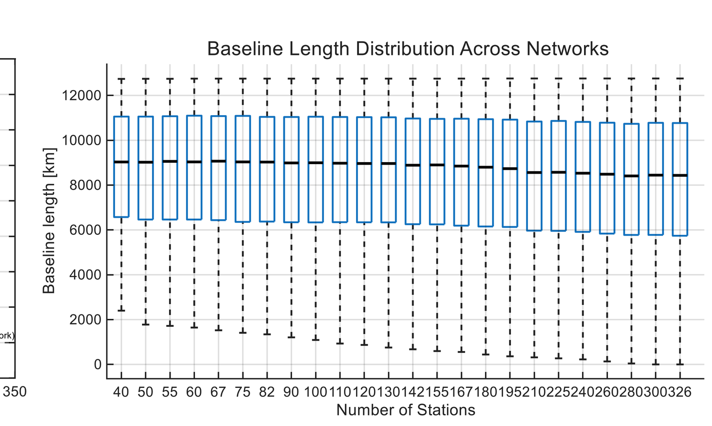
$$s_k = \arg max_{i \in available \setminus \{s_i,\ldots,s_{k-1}\}} \left(\omega_i \cdot min_{j=1,\ldots,k-1} \arccos\left(u_i \cdot u_{s_j}\right)\right)$$

The selected station set $S = \{s_1, s_2, \ldots, s_{K_{select}}\}$ ensures a maximal angular separation between stations and preference for multi-GNSS stations via the weights.

## Statistics of the processing

The variation in the a posteriori RMS and the ambiguity-fixing rate were evaluated as a function of the number of ground stations used.

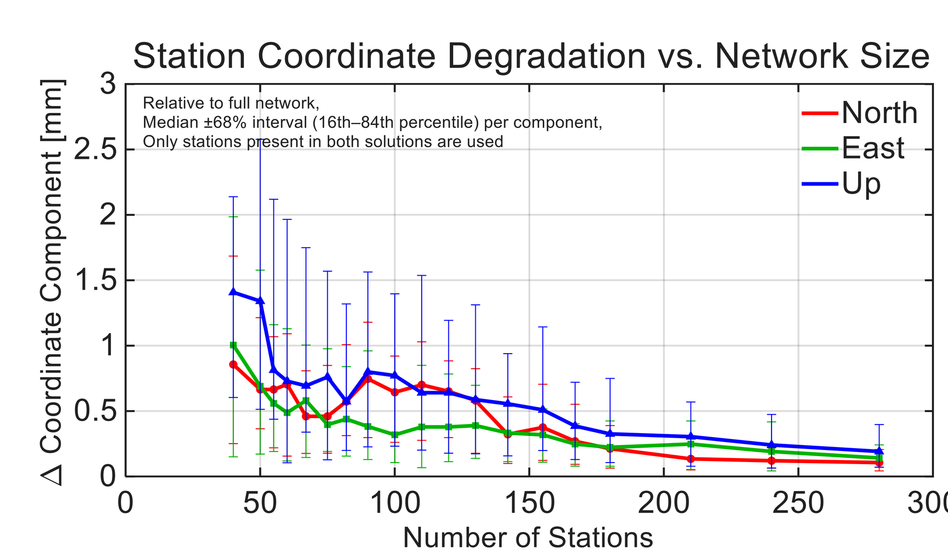


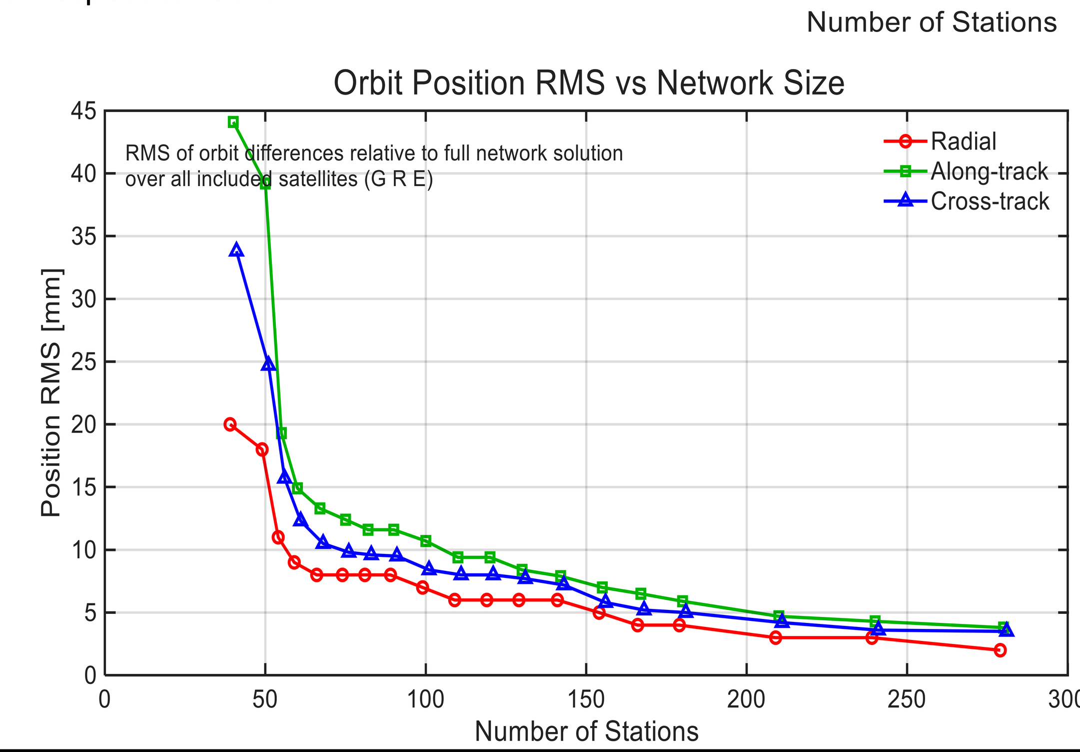




The homogeneity of the selected stations was verified by analyzing the baselines between stations. The median baseline length must remain consistent across the different networks of stations, whereby higher station density naturally results in shorter minimum baseline lengths.

## Comparison of solutions

To assess the degradation resulting from a reduced station network, differences in the computed station coordinates were analyzed. The change in satellite orbits with decreasing station number is considered a quality indicator.
For each selected subset of stations, a verification of the fiducial stations is performed to ensure a consistent datum definition with respect to IGc20.




## Conclusions of analysis of different network sizes

It is clearly evident that when fewer than approximately 60 ground stations are used, the processing quality deteriorates significantly, despite that the stations are homogeneously distributed. The same conclusion is evident when comparing station coordinates and satellite orbits to the reference solution using the full station set. The computational times are currently heavily dependent on resource availability. These are expected to stabilize once the ZD GNSS processing is implemented operationally.

## References

Calero-Rodriguez, Emilio Jose (2024). "Methods and algorithms for undifferenced multi-GNSS global network processing and applications to satellite geodesy". PhD thesis. Universitat Bern.
Calero-Rodriguez, Emilio J et al. (2023). "Between-satellite ambiguity resolution based on preliminary GNSS orbit and clock information using a globally applied ambiguity clustering strategy". GPS Solutions 27.3, p. 125.
Dach, Rolf, Elmar Brockmann, et al. (2009). "GNSS processing at CODE: status report". Journal of Geodesy 83.3, pp. 353–365.
Dach, Rolf, Simon Lutz, et al. (2015). "Bernese GNSS Software Version 5.2". User manual.

POSTER COMPILED BY: C. KOBEL, 13.05.2026
CYRIL.KOBEL@UNIBE.CH