# Combining the EUREF Local Analysis Centers' Solutions

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**Abstract**

The EUREF combined solution of station coordinates is one of the products of the EUREF Permanent Network (EPN). Subnet solutions of currently 13 Local Analysis Centers (LACs) are introduced into a normal equations stacking procedure to generate the final coordinate solutions of currently more than 110 stations.

Since GPS week 1100 solutions from the Delft Institute of Earth Orientated Space Research (DEO) contribute to the combinations. It is the first LAC within the EPN using the GIBSY/OASIS software. A-priori constraints for station coordinates, introduced by the LACs in the processing, may be visualized, if the correlation coefficients of the corresponding covariance matrix are printed. This approach was used to fix some inconsistencies of the first submitted solutions from the DEO LAC. It is now a helpful tool to check any solution.

Because each station is processed by at least three LACs, the residuals between the combined and the LACs' solutions may indicate outliers, which are subsequently excluded. A seven-week coordinate repeatability check is performed to detect outliers affecting the solutions of all LACs.

For test purposes, alternative processing strategies have been proposed and applied by some LACs. These changes include the introduction of a new mapping function for the site-specific troposphere parameters as well as a new cut-off angle and weighting of the observations. The test solutions have been combined and compared to the routine products. Empirically determined weighting factors are applied to the LACs solutions before the combination. This weighting scheme is under investigation in order to introduce factors with a rational basis.

## 0. Introduction

The observations of the EPN are currently analyzed by 13 LACs. The resulting station coordinates of each of the LACs solutions contribute to the EUREF combined solution that is available to the public. For purpose of outlier detection, the individual solutions are successively compared to the combined solution. Stations or even complete LAC solutions, whose differences to the combined quantity exceed a specified tolerance, are excluded from the final combination. Graphical visualization tools, e.g., the plot of correlation coefficients of the coordinates, are also used for quality control. A report file of the combination, which includes the residuals before any station exclusions, gives the feedback of its contributions to the LACs. The use of various analysis software by the LACs requires a scaling of the covariances of each solution in the combination in order to remove the software-specific differences. The data analysis and combination methods are continuously adjusted to meet the state of the art.

## 1. Combination Scheme

Each of the 13 LACs (see Table 1) processes the observations of a subset of the EPN stations. The EPN Network Coordinator selects the subset of stations of each LAC in order to ensure that each station is processed by at least 3 LACs. The LACs submit weekly solutions of their subnet in the SINEX format (SINEX, 1996) to the EUREF Data Center at the Bundesamt fuer Kartographie und Geodaesie (BKG) in Frankfurt, Germany.

The generation of the combined solution is performed at BKG and shown in Figure 1. The ADDNEQ program of the Bernese Software (Beutler et al., 1996) is used to convert the weekly SINEX files into normal equations, and the a priori constraints of the station coordinates are removed. These normal equations are combined into a free solution of the EPN stations, where 13 stations are selected to define the “minimum constrained conditions” in the ADDNEQ program. The free solution has the purpose of outlier detection, which is detailed in Section 3. If stations are detected to be outliers, these stations are excluded in a second iteration of the combination. After the exclusion of all outliers, a fixed solution is generated, where the coordinates of 13 stations are fixed to the ITRF-97. This fixed solution is converted to the SINEX format and declared the “EUREF combined solution”. In order to check the coordinate time series, a free network combination of the last seven EUREF combined solutions is calculated. This may indicate outliers for more stations and may require an additional iteration of all combination steps.

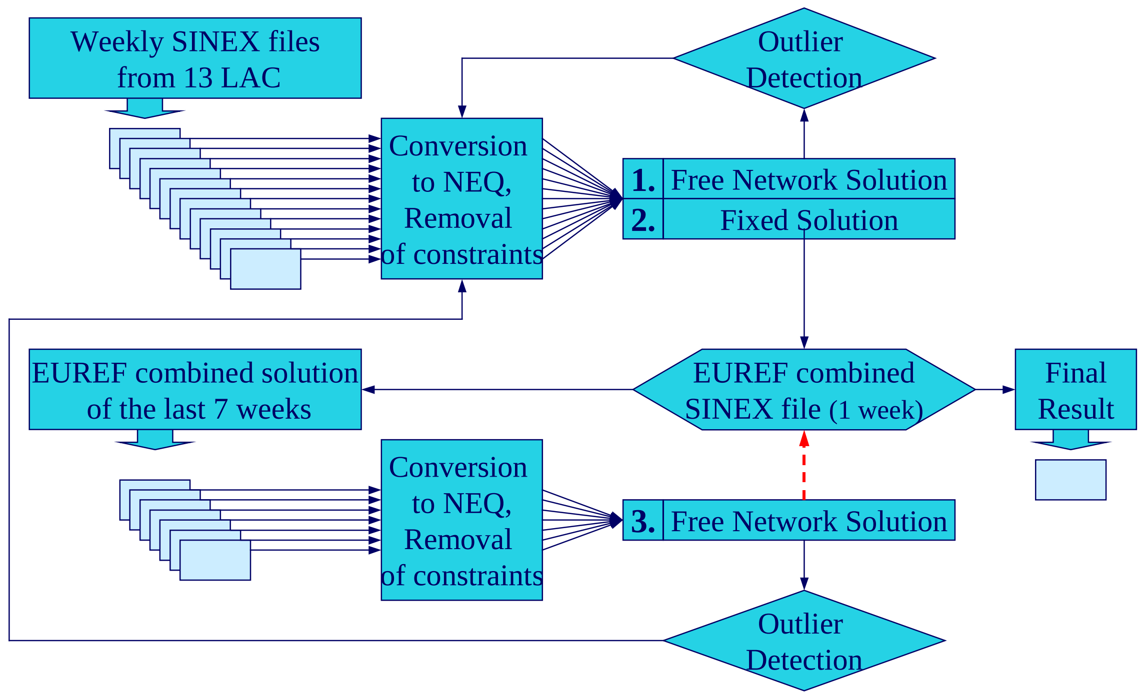


**Figure 1: Combination Scheme**

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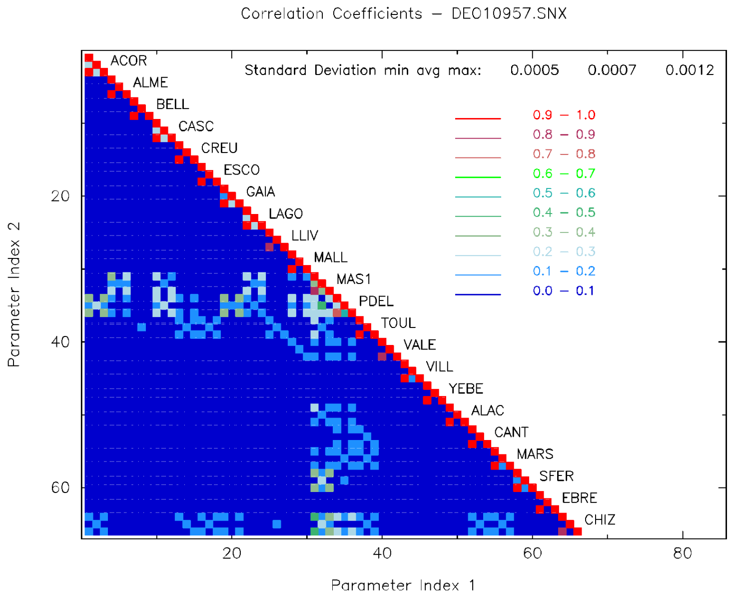
|---|---|---|
| 1 | ASI | Nuova Telespazio S.p.A., Space Geodesy Centre, Italy |
| 2 | BEK | International Commission for Global Geodesy of the Bavarian Academy of Sciences, Germany |
| 3 | BKG | Bundesamt fuer Kartographie und Geodaesie, Germany |
| 4 | COE | Centre for Orbit Determination in Europe, Astronomical Institute University Berne, Switzerland |
| 5 | DEO | Delft Institute for Earth-Orientated Space Research, Delft University of Technology, Netherlands |
| 6 | GOP | Geodetic Observatory Pecny, Czech Republic |
| 7 | IGN | Institut Geographique National, France |
| 8 | LPT | Bundesamt fuer Landestopographie (L+T), Switzerland |
| 9 | NKG | Nordic Geodetic Commision, National Land Survey, Sweden |
| 10 | OLG | Observatory Lustbuehel Graz, Austria |
| 11 | ROB | Royal Observatory of Belgium |
| 12 | UPA | Universita di Padova, Italy |
| 13 | WUT | Warsaw University of Technology, Poland |

**Table 1: EPN Local Analysis Centers**

## 2. Introduction of a new Local Analysis Center

A new LAC located at the Delft University of Earth-Orientated Space Research, Delft University of Technology, Netherlands (DEO) submitted its first solution for GPS week 1095. It is the first LAC within the EPN using the GIBSY/OASIS II software from the Jet Propulsion Laboratory, Pasadena, USA. The first solution from DEO could not be combined with the other 12 contributions using the ADDNEQ program. For test purposes, a different approach for the combination was applied. It calculates a seven-parameter Helmert transformation between the station coordinates of the individual solutions and a “reference solution”, e.g. the first solution in the list. In a second step, these transformed coordinates are combined. This approach had successfully been used to introduce the DEO solution of week 1095 into the combination. This result was in discrepancy with the failure of the ADDNEQ program. After that test, some inconsistency in the DEO SINEX files had been identified in the plot of the correlation coefficients as shown in Figure 2. The plot on the top of Figure 2 shows the correlation coefficients of week 1095. The dark color indicates the poor correlation of 0 to 0.1 between the station coordinates. Due to that fact, the combination using the ADDNEQ program failed. The long distances between them may explain the significantly high correlation between the stations MAS1, i.e., PDEL and the other stations. After some small changes in the processing scheme of DEO, the correlations showed up as given in the plot at the bottom of Figure 2. Significant correlations of 0.5 to 1.0 between the station coordinates are now given in the SINEX files. With the beginning of week 1100, the ADDNEQ program has successfully been used to introduce the DEO solution into the EUREF combined solution.



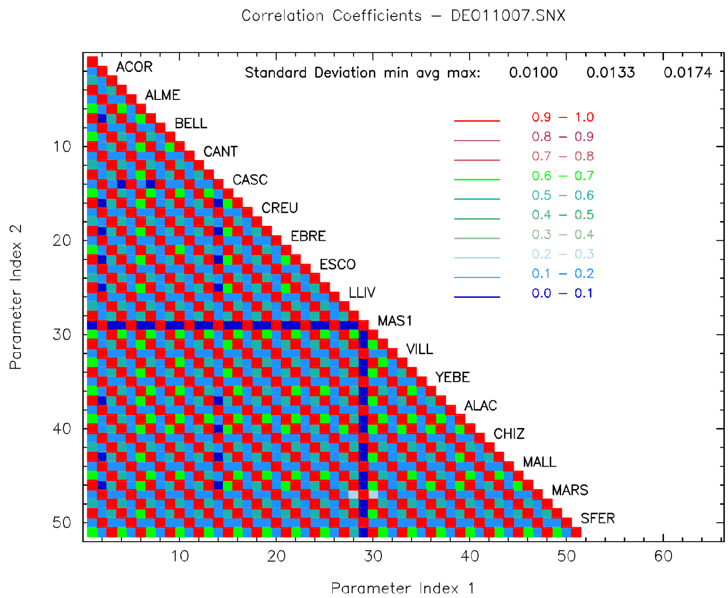




**Figure 2: Correlations in Solutions from DEO for Weeks 1095 and 1100**

## 3. Exclusion of Stations

The fact that each station of the EPN is analyzed by at least 3 LACs leads to a redundancy that is used for quality control. If the residual between an individual LAC solution and the combined solution of a specified station exceeds 5 mm for the position or 10 mm for the height, this station of the LAC solution is excluded from the combination.

All exclusions of stations are documented in a file named STACRUX.EUR that is publicly available. The number of exclusions is used to monitor the success of the LACs. Figure 3 shows, for example, the exclusions of stations of the ASI LAC for a period of 20 weeks. The stations of the EPN subnet processed by ASI have been excluded in 0 to 10 % of the weekly

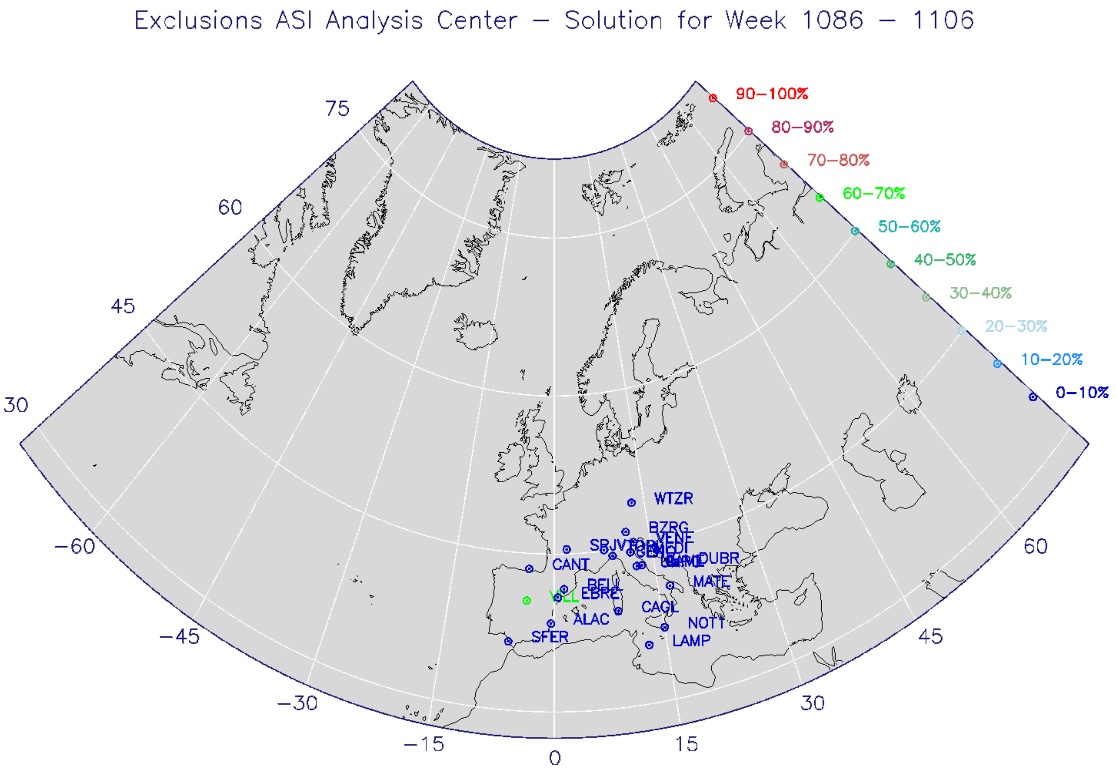



**Figure 3: Exclusions in the EUREF Combined Solution**

combinations, with exception of the station VILL (Villa Franca, Spain). This station has been excluded in 60 to 70 % of the combinations given in Figure 3. This could be explained by the bad receiver performance during that period. ASI is the only LAC using the Microcosm analysis software (MicroCosm Software Vs. 9800.0) and suffered from the receiver problems much more than the other LACs did.

The residuals of the station coordinates of VILL calculated by ASI versus the combined solution are given in Figure 4 for the period of the weeks 1050 to 1100. It shows in more detail ASI's processing problems until the receiver in VILL had been stopped in the week 1111.

## 4. Weighting of Solutions

The use of different analysis software by the LACs requires a correct weighting of the individual solutions in the combination. The weighting scheme as realized in the Bernese Software is shown in Figure 5. The SINEX files resulting from processing with Bernese Software include the RMS of unit weight (δ), which is used as weighting factor. All elements of the covariance matrix are multiplied with the factor $1/\delta^2$ when the SINEX files are converted to normal equations. But the RMS of unit weight is not available from GIBSY and Microcosm solutions.

In addition to the weighting with $1/\delta^2$, an external weight file is introduced to scale each normal equation file in the combination. The factors given in this weight file are currently empirically determined to those numbers that result in an equal contribution of all LACs

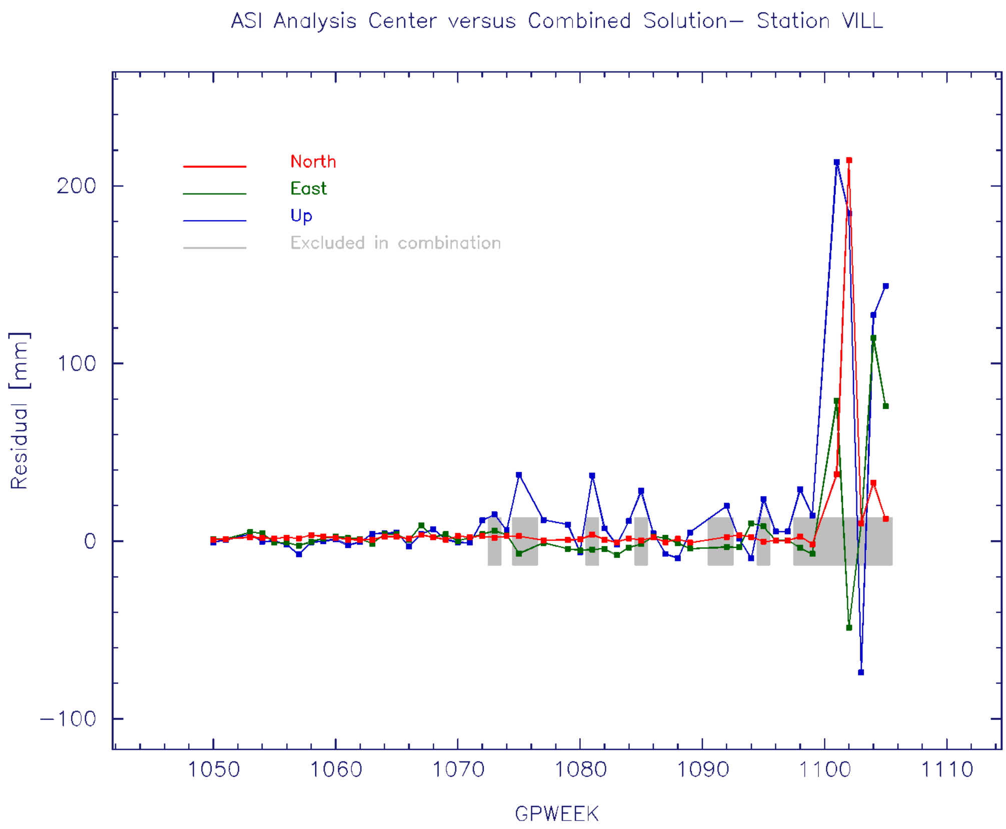



**Figure 4: Residuals of ASI Solution versus Combined Solution**

solutions to the combined solution. For all LACs using the Bernese Software an identical factor has been selected. The weighting scheme is under investigation in order to replace the empirically determined factors with a rational basis.

## 5. Alternative Processing Strategies

The LACs had been asked to process additionally the observations of 3 weeks with changed options. The first new option was the use of the "Dry Niell" mapping function for the estimation of station-specific troposphere parameters. This function is assumed to be more realistic. The elevation-dependent weighting of the observations had been selected as second new option, to account for the increased observation scatter of low-elevation observations. The change of the elevation cut-off angle from 15° to 10° was the third change and should improve the de-correlation of height and tropospheric delay parameters. Five LACs (BKG, GOP, IGN, OLG and ROB) had submitted the requested test solutions for the GPS week 1096, 1097 and 1098 to BKG. The formal errors as well as the residuals of the coordinate repeatability had been decreased after the introduction of the elevation-dependent weighting of the observations. The other two options showed no significant changes in the results of these three weeks.

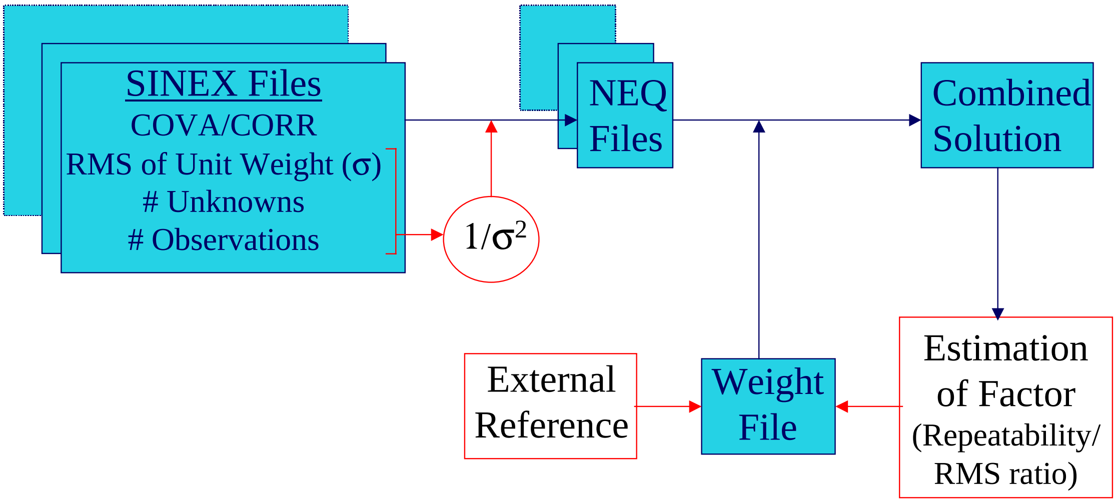



**Figure 5: Weighting of Solutions in Bernese Software**

**6. Conclusion**

There are currently 13 LACs and 3 analysis software packages contributing to the analysis of the EPN and ensuring the reliability of the EUREF combined solution. Graphical visualization tools, such as plotting the correlation coefficients or station specific residuals between individual and combined solutions, are used by the analysis coordinator. Because of the redundancy given by multiple processing of each station, these tools allow to detect and exclude outlying stations or even LACs solutions. The weighting scheme of the combination procedure, as well as the processing strategies used by the LACs, are continuously investigated to achieve improved solutions.

**References**

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