Comparison of the BERNESE and GIPSY/OASIS II Software Systems Using EUREF Data

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Abstract

The data processing within the EUREF permanent network is presently distributed among 16 analysis centers, 14 of which are using the Bernese GPS software. Thus, the combined result is almost exclusively based on only one software package. This somehow contradicts the geodetic practice to verify and validate results by applying different softwares and processing strategies. Therefore, a comparison of the two totally different software systems BERNESE and GIPSY/OASIS II is performed by analysing single baselines as well as a 20 stations network selected from EUREF. Both softwares are applied in their commonly used mode. The obtained results do not suggest any clear preference of one of the systems upon the other. The BERNESE performed in particular better on longer baselines, whereas GIPSY/OASIS II showed slightly better daily repeatabilities of the horizontal position components in the network mode. On the average, the network adjustments, comprising 40 days of data, agree on the 2 mm level. The only systematic effect appears to be a scale difference of $2 \cdot 10^{-9}$.

1. Introduction

Verification and validation of the achieved results is a main feature of geodesy. As regards the observations, primary goals are to provide sufficient redundancy as well as measurements at various environmental situations. Concerning GPS these aspects are almost perfectly met when operating permanent stations. In case of continental or global networks an important issue also is to base the results on all available space techniques in order to detect systematic errors and minimize their effect on the combined products. Equally important is the application and comparison of different software packages and processing strategies. An example is the generation of the IERS Terrestrial Reference Frame (ITRF) where global and regional network solutions based on various techniques and software systems are combined following state-of-the-art procedures.

The observations collected by the permanent network of the International GPS Service (IGS) are also processed by various analysis centers using different software packages; thus, the combination of these solutions implicitly implies certain software comparisons. The EUREF permanent network is a densification of the global IGS network. The processing of the EUREF data is presently distributed among 16 analysis centers. However, as all of these centers, except two, are using the Bernese software, the EUREF results are almost exclusively based on only one software system. Therefore, considering the high performance of the EUREF network, a comparison of different software packages seems to be worthwhile. As we have the capability and experience in using both, the BERNESE and the GIPSY/OASIS II (hereafter called GIPSY/OASIS) software systems, we perform dedicated analyses of selected EUREF data sets and compare the obtained results.

2. Analysed Data Sets

Part of the EUREF stations and data periods involved in this analysis where originally selected for another study with completely different objectives. This is the reason for the concentration of sites at the Iberian Atlantic coast. Figure 1 displays the location of all stations included in the analysis.

The composition of the network, comprising 20 stations, and of the single baselines is given in table 1. The number of days processed is 40 for the network and ranges from 29 to 37 in case of the single baselines.

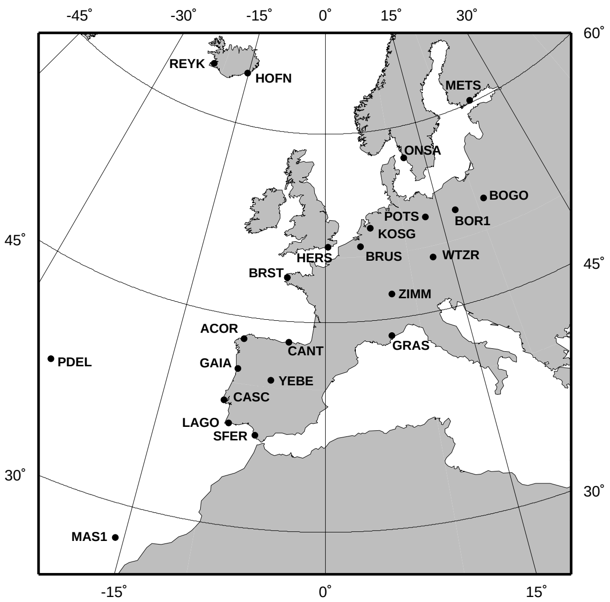

Fig. 1: Stations of the European permanent network included in this analysis

The network analysis included data during the first half of 2001. The data periods selected for the single baselines were

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around April 2000 and October 2001 respectively. In any case, all time periods were short enough as to neglect relative site motions in the analysis. As regards the extension of the network, it should still be representative for EUREF although it does not include sites in the uppermost north. The majority of stations observed during the analysed periods almost without loss of data, the only remarkable exceptions being HERS and MAS1.

Table 1: Processed single baselines and network, number of days included

Baseline	Days	Baseline	Days
BOGO – BOR1	29	POTS – BOR1	29
POTS – WTZR	37	WTZR – ZIMM	37
BOGO – POTS	29	POTS – METS	37
Network			Days
ACOR, BOR1, BRST, BRUS, CANT, CASC, GAIA, GRAS, HERS, HOFN, KOSG, LAGO, MAS1, ONSA, PDEL, POTS, REYK, SFER, WTZR, YEBE			40

3. Analysis Outline

As the aim of this paper is a comparison of the BERNESE and the GIPSY/OASIS software systems for operational applications such as the EUREF network processing, we used both softwares as far as possible in the modes recommended by its authors or commonly applied respectively. Thus, this analysis does not include a comparison of the physical models involved or their realizations in the software. Considering that the use of the BERNESE is well established in EUREF; the following comments refer mainly to the GIPSY/OASIS software (WEBB and ZUMBERGE 1997) which has been developed at the Jet Propulsion Laboratory (JPL). Its principal characteristic is the processing of GPS observations in the undifferenced mode. This requires the estimation of both the satellite and receiver clock biases which are modelled as white noise. In contrast, double differencing software like the BERNESE (HUGENTOBLER et al. 2001) requires the clock offsets to be known only on the microsecond level in order to fix the observation epochs sufficiently accurate, and then these biases are eliminated in the further processing.

GIPSY/OASIS cannot, or at least not easily, use normal equations as standard algorithm, because clock and other biases are treated as stochastic variables. This applies also to the wet component of the tropospheric zenith delay, while the dry part is assumed to be constant as predicted by a model. Thus, the estimates of the wet delay include also variations of the dry component. GIPSY/OASIS uses a Square Root Information Filter (SRIF) to estimate all unknown parameters. This kind of filter solves the para meters in small batches and avoids the inversion of large matrices. The sequential processing is somewhat more time consuming but has the advantage that all types of parameters can be handled as stochastic processes. Even though undifferenced observations are modelled the phase ambiguities cannot be resolved in this mode. The ambiguity fixing process works only in the double difference mode. Therefore, GIPSY/OASIS uses the undifferenced estimates to create real valued double difference phase biases which are then used for resolving the ambiguities. The BERNESE software offers several alternatives for fixing the phase ambiguities. Based on our experience from a number of projects we applied the Quasi Ionosphere Free (QIF) strategy. This method yielded a success rate of better than 80% on all baselines, only slightly depending on the baseline length.

As regards the single baselines specified in table 1, daily adjustments with and without resolving the ambiguities were performed with both software systems. In the case of GIPSY/OASIS the procedure described above was applied. This involves an automatic screening of the postfit residuals for detecting and repairing cycle slips and for identifying and eliminating outliers in an iterative process. However, this procedure is not any more efficient in case of larger networks. Therefore, the network solutions with GIPSY/ OASIS were performed in the precise point positioning mode (ZUMBERGE et al. 1997, MENGE et al. 2000), which leads to position estimates of all stations independently of each other. This strategy reduces the processing time tremendously. Table 2 summarizes briefly the main features of the data processing and reference frame realization of the single baseline and the network adjustments performed with both software packages.

Table 2: Main characteristics of the data processing and reference frame fixing using the two software systems

	BERNESE	GIPSY/OASIS
Observation Modelling	Ionosphere free linear combination; 30 seconds sampling rate; 10° elevation angle cutoff; NIELL (1996) tropospheric mapping function; ocean loading according to GOT99.2; antenna phase center variations according to IGS recommendations; phase ambiguity fixing only in single baseline, but not in network adjustments; residual tropospheric delays estimated in adjustment.	
	Double difference phase observations; least squares estimates; no automatic outlier detection and elimination, no iterative solution.	Undifferenced phase and code data; square root information filter; automatic outlier detection and rejection, iterative solution.
Reference Frame Realization	IGS combined satellite orbit, satellite clock offset and earth orientation parameter series; one station tightly constrained to its ITRF 2000 position	Satellite orbit, satellite clock offset and earth orientation parameter series provided by JPL; transformation to ITRF2000 using parameters available at JPL.

4. Results

4.1 Single Baselines

In order to assess the performance of both software systems on single baselines, examples of the differences between daily estimates and the means from all processed days in baseline north, east and height components are displayed in figures 2-5.

The results for the two baselines POTS-BOR1 and BOGO-POTS of 271 km and 540 km length respectively are given for both the ambiguities float and fix adjustments. A summary of the daily repeatabilities achieved on all baselines listed in table 1 are given in table 3, again for the float and fix solutions. Table 3 documents also the mean absolute differences between the BERNESE and the GIPSY/OASIS adjustments in north, east and height components.

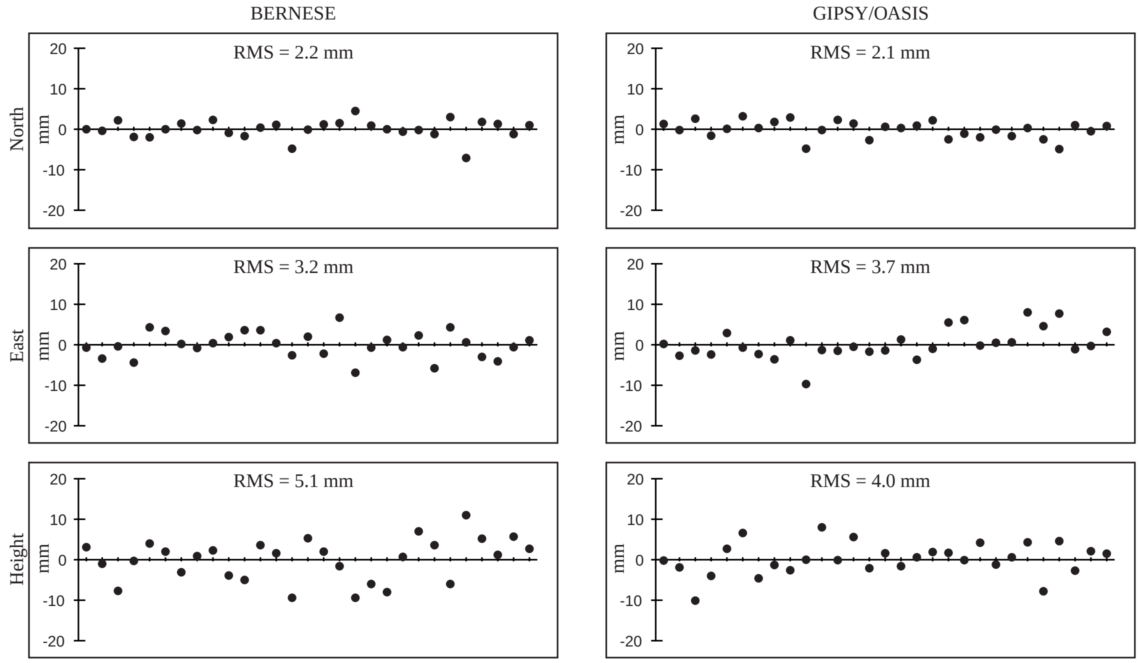

Fig. 2: Baseline POTS-BOR1 float solution; daily repeatabilities in north, east and height with respect to mean [mm]

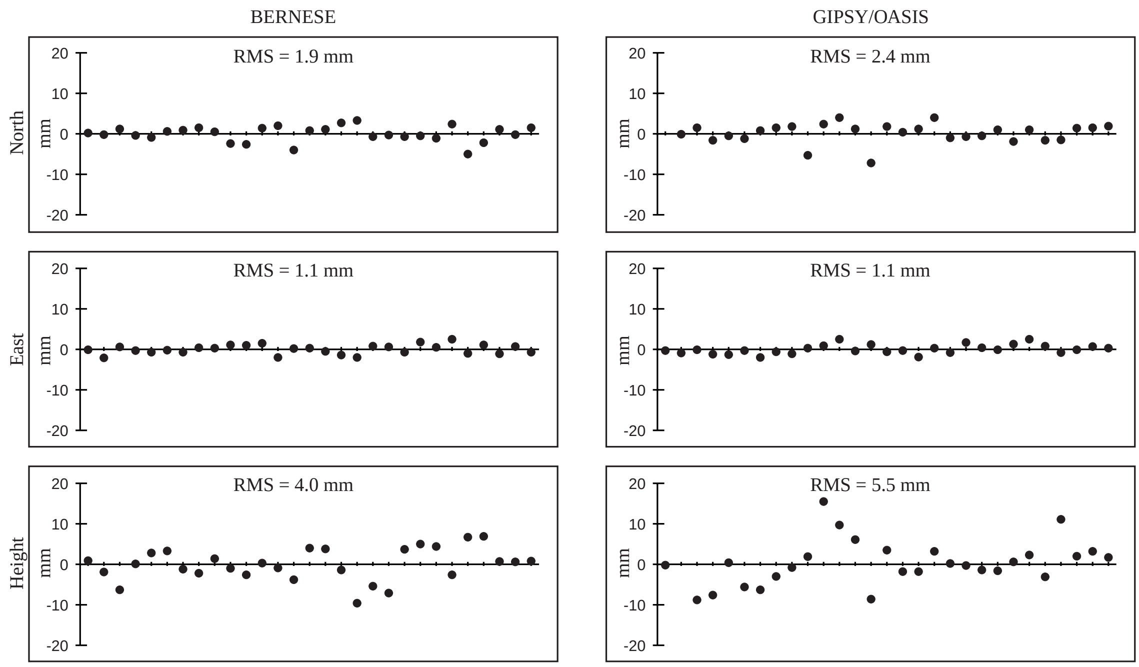

Fig. 3: Baseline POTS-BOR1 fix solution; daily repeatabilities in north, east and height with respect to mean [mm]

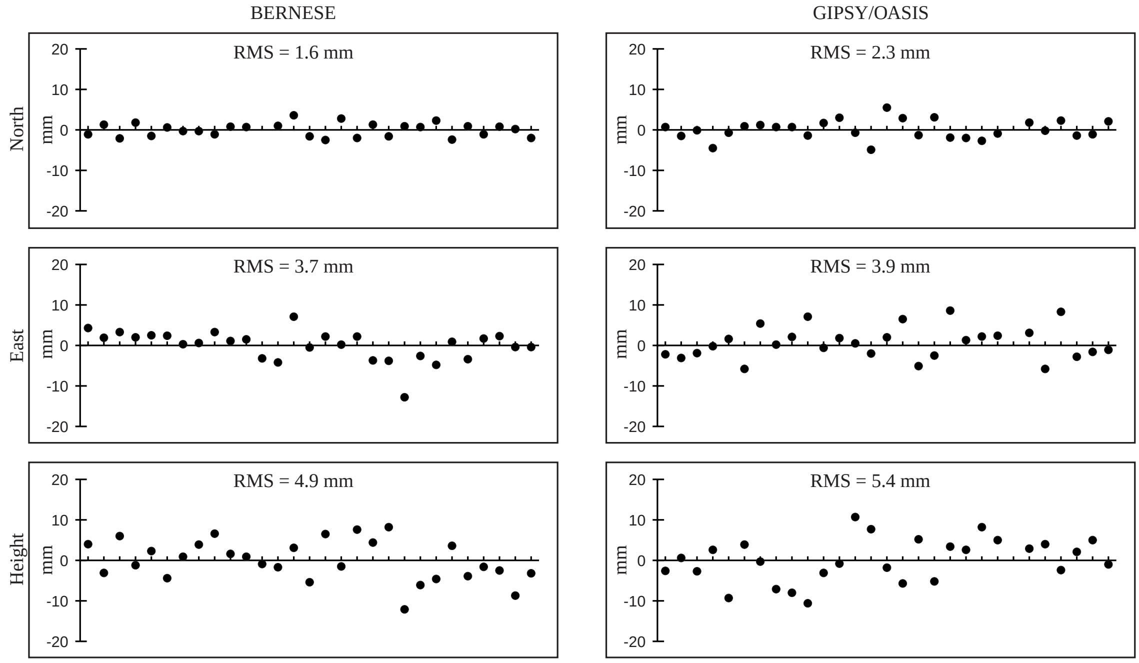

Fig. 4: Baseline BOGO-POTS float solution; daily repeatabilities in north, east and height with respect to mean [mm]

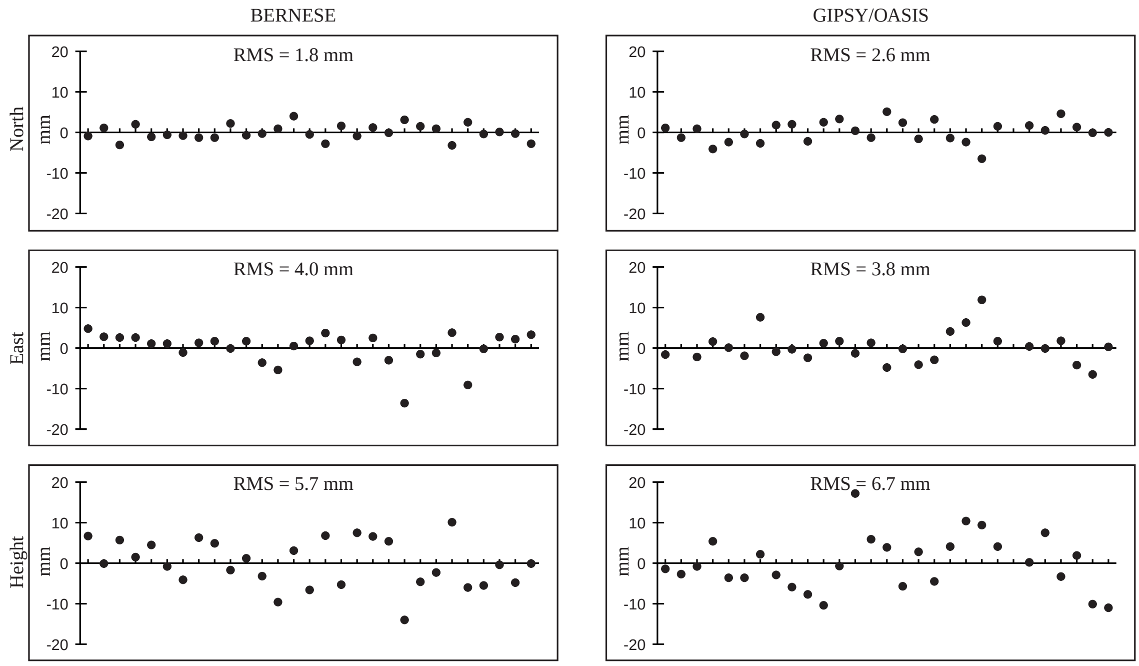

Fig. 5: Baseline BOGO-POTS fix solution dail; y repeatabilities in north, east and height with respect to mean [mm]

The results obtained from these single baseline adjustments can be summarized as follows:

- On short baselines both software systems perform similar in terms of daily repeatabilities; this holds for the ambiguities float as well as the fixed solutions. As expected ambiguity fixing improves mainly the baseline east component.
- On longer baselines the performance of both softwares degrades slightly. In particular, there is no more an improvement with GIPSY/OASIS when applying the ambiguity fixing strategy, and on the longest baseline POTS-METS no ambiguities could be resolved at all. This result is in agreement with findings in (ENGELHARDT and MIKOLAISKI 1996).
- As regards the absolute baseline component differences between the BERNESE and GIPSY/OASIS adjustments, these are on the few millimeters level, but they increase mainly in the east component of the POTS-METS baseline.

Table 3: Repeatabilities of daily BERNESE and GIPSY/OASIS adjustments and baseline component differences BERNESE - GIPSY in north (N), east (E) and height (H) [mm]

Baseline	Length [km]	Amb. Res.	BERNESE N	BERNESE E [mm]	BERNESE H	GIPSY N	GIPSY E [mm]	GIPSY H	BERNESE – GIPSY N	BERNESE – GIPSY E [mm]	BERNESE – GIPSY H
BOGO – BOR1	271	Float	1.5	3.2	5.4	1.6	2.5	6.1	0.4	1.1	–3.7
		Fix	1.4	1.1	4.7	1.7	2.0	5.1	0.6	1.8	1.0
POTS – BOR1	273	Float	2.2	3.2	5.1	2.1	3.7	4.0	–1.3	–1.1	–3.5
		Fix	1.9	1.1	4.0	2.4	1.1	5.5	–0.2	–1.7	–0.9
POTS – WTZR	360	Float	2.1	4.4	5.8	3.4	4.3	6.4	1.0	–5.0	–2.3
		Fix	1.5	2.4	4.3	5.0	6.5	6.9	2.4	–2.0	–4.2
WTZR – ZIMM	476	Float	2.9	2.4	6.1	4.0	4.3	8.6	–2.5	2.1	–3.6
		Fix	2.7	2.1	6.0	7.4	9.2	7.4	–2.3	5.0	–3.3
BOGO – POTS	542	Float	1.6	3.7	4.9	2.3	3.9	5.4	1.2	0.6	3.6
		Fix	1.8	4.0	5.7	2.6	3.8	6.7	0.4	2.8	3.4
POTS – METS	1115	Float	4.1	7.7	9.7	6.2	13.7	6.6	3.1	–6.5	–4.3
		Fix	4.4	4.3	9.4	6.2	13.7	6.6	2.3	–8.5	–2.8

4.2 Network

The network selected for this comparison was composed of the 20 stations listed in table 1 and displayed in figure 1. As already mentioned, except HERS and MAS1 all stations operated almost without loss of data. The network adjustments with GIPSY/OASIS followed the precise point positioning concept. JPL satellite orbits, Earth orientation parameters and satellite clock offsets were used. Finally a transformation to ITRF2000 was performed applying parameters available from JPL. The adjustments with the BERNESE software were performed without resolving ambiguities. They refer to IGS combined orbits, satellite clock offsets and Earth orientation parameters. One central station was loosely constrained to its ITRF2000 position. This holds also for the combined solutions including all 40 days of data processed. Thus, all results are approximately in the ITRF2000 reference frame, but further comparisons require Helmert transformations to account for small datum realization differences.

Table 4 summarizes the performance of both software systems achieved in the network adjustments. The table documents the average root mean square agreements of daily network adjustments with respect to the combined 40 days solutions.

Table 4: Average RMS agreement of single day network adjustments with the combined solution in north (N), east (E) and height (H) components [mm]

Software System	N	E [mm]	H
BERNESE	2.5	3.1	4.2
GIPSY/OASIS	1.4	2.3	4.3

Figure 6 displays for all 20 stations involved the coordinate differences between the BERNESE and the GIPSY/OASIS network adjustments including all 40 days of observations. The rms agreement over all stations in north, east and height components are also given. Excluding the two sparsely available stations HERS and MAS1, the agreement in each component is 2 mm or better. The two main conclusions from the network adjustments are:

- In terms of daily repeatabilities GIPSY/OASIS performed slightly better; however, in the BERNESE adjustments no ambiguities were resolved which would presumably improve the repeatability in the east component.
- The only systematic effect showing up significantly in all network comparisons is a scale difference between the GIPSY/OASIS and the BERNESE results of $2 \cdot 10^{-9}$.

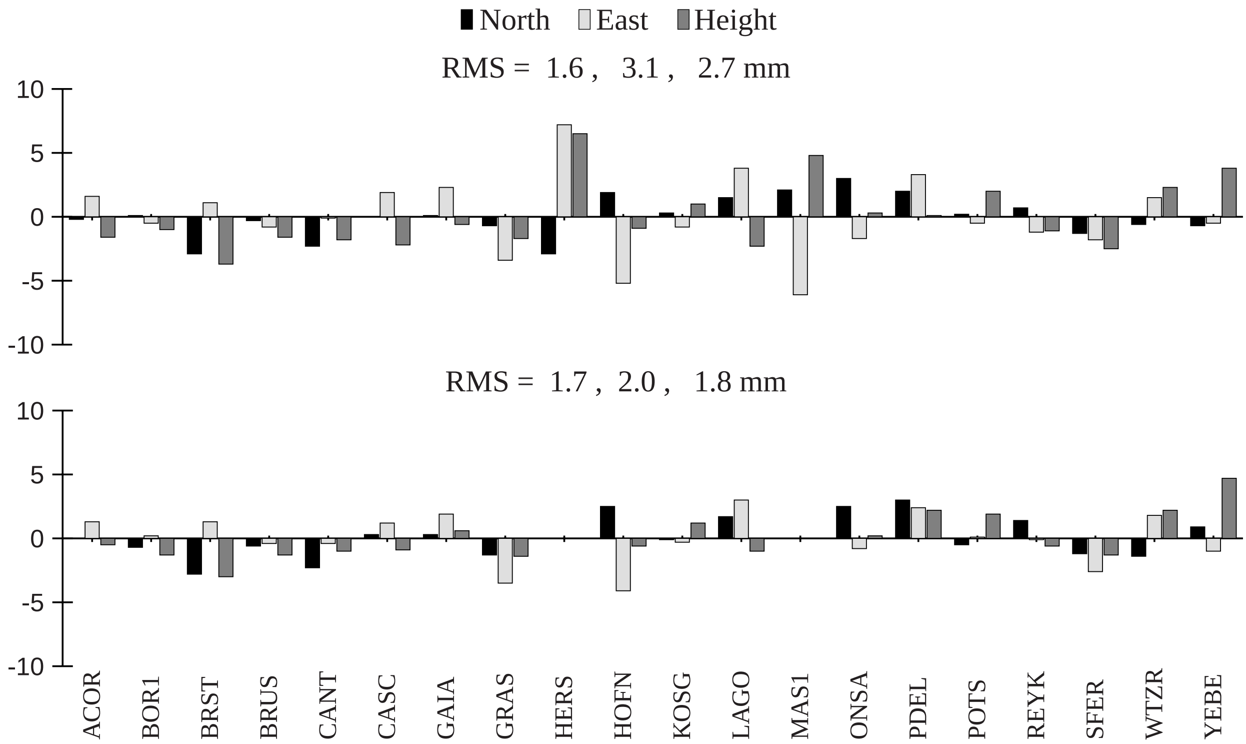

Fig. 6: Differences in north, east and height [mm] between the BERNESE and GIPSY/OASIS network adjustments and RMS values; top part: all stations included, bottom part: sparsely available stations HERS and MAS1 excluded

5. Conclusions

We have processed six single baselines of various lengths and between 29 and 37 days of data with the BERNESE and the GIPSY/OASIS softwares, both with and without fixing phase ambiguities. The obtained results indicate a slightly better performance of the BERNESE. This applies mainly to the longer baselines where GIPSY/OASIS is obviously not any more capable of fixing ambiguities.

In addition, a network comprising 20 stations and 40 days of observations has been analysed, using the BERNESE again in the double differencing, but GIPSY/OASIS in the precise single point positioning mod. In this application the daily repeatabilities of the horizontal position components were better with GIPSY/OASIS than with the BERNESE. This may be due to the automatic outlier rejection applied in GIPSY/OASIS in contrast to the BERNESE, or the fact that in this case we did not fix ambiguities in the BERNESE.

At this stage we are not in the position to claim one of the two software systems to be clearly superior to the other. We could not identify significant systematic differences, except a scale factor of $2 \cdot 10^{-9}$ on the average. This effect could also be associated with the outlier rejection in GIPSY/OASIS if primarily observations at low elevation angles were eliminated. However, the results do not clearly support this hypothesis. In terms of coordinates, the agreement between the network solutions from both softwares was about 2 mm, thus not larger than usually between individual solutions using the same software type.

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