An Update on the EPN Reprocessing Project: Current Achievements and Status

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Abstract. The EPN project *Reprocessing* has been initiated in 2009 to coordinate the reprocessing of the entire EPN by the Local Analysis Centres (LAC). Today almost each LAC is involved in the reprocessing effort. In 2010 a first step has been achieved by the re-analysis of the data from the year 2006 in a so called *Pilot Processing*. The results of this effort are very promising since improvements were clearly achieved. Coordinates and the parameters for the troposphere were much more consistent and the noise level has been improved using the reprocessed orbits and EOPs provided by the reprocessing campaign *Repro1* of the IGS. Since various software packages and strategies are applied by the different LACs it was decided as well to conduct a so called *Benchmark Test* beforehand. Therefore, a network consisting of 30 EPN sites has been analysed by all participating LACs applying their software, strategy and models in order to verify the consistencies between all solutions. The decision to extend the analysis back to 1996 was taken on the last Local Analysis Centre workshop in Warsaw, Poland (2010). This analysis is called EPN Repro1. Recent operational EPN analysis is based since the end of 2006 (GPS-Week 1400) on the IGS05. Together with the now reprocessed data consistent coordinates are provided in the same reference frame for at least 15 years.

Keywords. Reprocessing, EUREF Permanent Network, reference frame

1 Introduction

The EUREF Permanent Network (EPN) has been established in the end of 1995 with the main focus on the realisation of the European Terrestrial Reference System, known as the ETRS89. During the past 15 years better global reference frames emerged, analysis tools improved, modelling the Earth's physics and the better understanding of the interaction between satellite signals, the atmosphere and the GNSS antennas lead to the development of improved correction models to account for these effects. As soon as new models became available and have successfully been tested they were implemented into the analysis. Just to name some examples: the elevation cut-off angle was changed, ocean loading models were included, the ambiguity resolution strategies have improved and last but not least better models for the correction of the antenna phase centre became available.

Different models, strategies and realisations of the ITRS had their own impact on the coordinates. These effects are visible in the time series of the EPN stations and clearly show that they are not consistent. Only a homogeneous reprocessing would allow the generation of a consistent set of coordinates and their corresponding time series. It has been realized by many groups that it is worth making this effort (e.g. Steigenberger et al. (2006)) and culminated in the first reprocessing campaign of the International GNSS Service (IGS Repro1). Similar activities were initiated by different groups on the regional level for parts (Völksen 2008) or the complete EPN (Figurski et. al. 2009).

During the EPN LAC workshop in 2008 it has been decided to put a special focus on the reprocessing of the complete EPN - possibly back to the very start. A charter for the EPN reprocessing was presented to the EUREF Technical Working Group (TWG) in early 2009, has been accepted and lead to the formation of the EPN project *Reprocessing*. Today each of the current LACs of the EPN is participating in this project.

2 Pilot Processing

As a first measure it was decided to start with the so called *Pilot Processing*. This phase was thought

as an initial step in order to set-up the facilities at the different LACs (computer, data and software), re-distribute EPN sites within the group of participating partners, test of different analysis strategies and develop recommendations from the achieved results for the complete EPN reprocessing. The Pilot Processing is also intended to serve as a proof of concept for the analysis centres, data centres, combination centres and other components of the EPN reprocessing. For this special analysis only the data of the year 2006 were selected due to the change in the references frame realisation from the ITRF2000 to the ITRF2005 in the end of that year (GPS-week 1400).

The reprocessing of the GNSS data does not only require the most recent analysis strategy but most of all reprocessed products like the orbits and the clocks that have to be available in the same reference frame realisation for the entire period. In respect to the IGS Repro1 campaign these data were provided. Beside the combined IGS Repro1 products there were also a number of reprocessed orbits and clocks available from the individual analysis centres of the IGS (e. g. CODE, JPL and the PDR products).

GNSS-data for the reprocessing are available at the two Regional Data Centres (RDC) located at BKG (Federal Office of Cartography and Geodesy, Germany) and at OLG (Austrian Academy of Sciences). In addition the EPN Central Bureau located at the Royal Observatory of Belgium has spent significant effort to collect a vast amount of historical EPN data and made those available to the community.

Different software packages were used for the Pilot Processing. The majority of the EPN LACs is using the BERNESE 5.0, while some LACs applied GAMIT 10.35 (or 10.40) and GIPSY 5.0 for the analysis. Some differences between these packages should be mentioned. Modern mapping functions as the Vienna Mapping Function (VMF) by Böhm and Schuh (2004) and the Global Mapping Function (GMF) by Böhm et.al. (2006) are so far only realized in GIPSY and GAMIT as well as the 2nd-order-correction of the ionosphere. On the other hand only the BERNESE software was and is already capable of analysing also the data of the GLONASS satellites. But of course the impact of the Russian GNSS on the analysis is not significant for the historical data.

Keeping the prevailing conditions for the different software packages in mind it was decided that any IGS Repro1 product could be used for the Pilot Processing (e.g. the combined IGS Repro1 products or the reprocessed CODE, JPL, MIT or PDR products). Especially the GIPSY software harmonizes much better with the original JPL products than with any other product.

Daily and weekly solutions for the year 2006 were analysed by the different local analysis centres and submitted to the EPN Combination Centre at the BKG. The submitted solutions by the different LACs, the analysis software and the used products are shown in table 1.

Table 1: Contributions by the individual LACs for in the Pilot Processing, used software and products (rep.: reprocessed products of the IGS Repro1 campaign).

LAC	BERNESE	GAMIT	GIPSY	Products
ASI	-	-	X	JPL rep.
BEK	X	-	-	PDR05
DEO	-	-	X	JPL
GOP	X	-	-	IGS rep.
IGE	X	-	-	IGS rep.
IGN	X	-	-	IGS rep.
LPT	X	-	-	CODE
MUT	X	X	-	IGS rep.
NKG	X	-	-	IGS rep.
OLG	X	-	-	IGS rep.
ROB	X	-	-	COD rep.
SGO	X	-	-	IGS
SUT	X	-	-	IGS rep.
UPA	X	-	-	PDR05
WUT	X	-	-	IGS rep.

The combination of the weekly and daily solutions conducted by the BKG has shown a significant improvement for the coordinate repeatability by a factor of two. In addition it could be shown that the derived coordinates for this year have been of course consistent and therefore the inconsistency in the coordinate time series between GPS week 1399 and 1400 - visible in the operational analysis – disappeared completely as expected.

The combination of the troposphere parameters derived at the BKG during the Pilot Processing verified the improvements achieved due to the reprocessing. Based on the consistent orbit and clock products and of course using a consistent set of absolute antenna PCV correction models the weekly mean biases of the individual LAC troposphere solutions converged close to zero [mm] and the standard deviations are almost below the 1mm-level.

3 Benchmark Test

The Pilot Processing has shown that there were still small discrepancies between the different submitted solutions. Each LAC was and is using different software, strategies or correction models. As an example one should mention that most GIPSY users prefer a Precise Point Positioning (PPP) approach, while BERNESE and GAMIT users apply a network approach for the computation. At the same time the different software packages offer different corrections models (e.g. troposphere). Since each LAC is processing a different network the solutions are not directly comparable.

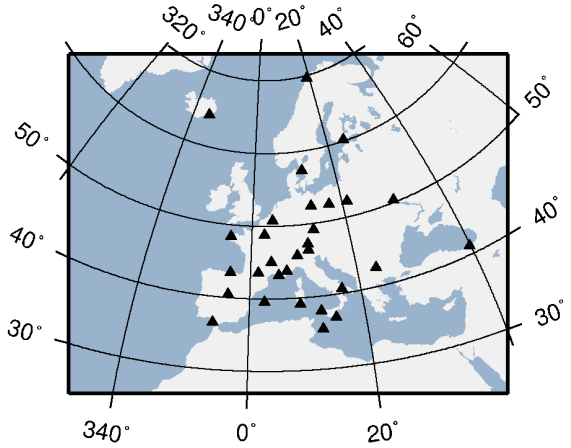

Fig. 1: The network of the benchmark test. About 30 sites were distributed evenly over the Europe.

Therefore the idea of a benchmark test was born on the LAC workshop in Warsaw. Each LAC was asked to perform an analysis of one week of data (GPS week 1381) on a set of 30 selected sites distributed over Europe (see Figure 1). The same reprocessed orbits had to be used (IGS Repro1 realized in the IGS05) and identical absolute antenna correction had to be applied. Here, the file containing type mean and individual calibrations for the antennas *epn_05_1604.atx* - as it is supplied by the EPN Central Bureau - had to be used.

The individual results of this benchmark test were uploaded to the EPN Combination Centre. In total 13 solutions have been provided in time. Of these 13 solutions eleven had been analysed with BERNESE and one solution each for the GAMIT and GIPSY software. Table 2 shows the RMS and 7 parameters of a Helmert transformation between the combined solution and the individual solutions of each LAC.

Table 2: RMS and Transformation parameters between the combined weekly combination of the Benchmark Test with the individual LAC solutions (SW: Software, B: Bernese 5.0, GP: GIPSY, GA: GAMIT).

LAC	SW	rms	X	Y	Z	x“	y“	z“	Scale
			[mm]				[mas]		ppb
1	B	0.4	-1.5	1.9	1.7	0.0	-0.1	0.0	-0.1
2	B	0.6	2.8	-2.0	-2.3	0.0	0.1	-0.1	0.0
3	B	0.8	1.3	5.4	-2.4	-0.1	0.1	0.1	0.0
4	B	0.4	0.4	3.0	-0.5	-0.1	0.0	0.1	0.0
5	B	0.4	-0.6	3.5	0.7	-0.1	0.0	0.1	-0.1
6	B	0.4	-1.4	2.3	1.0	0.0	-0.1	0.1	0.0
7	B	0.4	0.2	1.5	0.0	0.0	0.0	0.0	-0.1
8	B	0.4	-0.1	4.7	-0.2	-0.1	0.0	0.1	-0.1
9	B	0.8	-2.5	-0.1	1.9	0.0	-0.1	0.0	0.0
10	B	1.0	-1.6	-6.3	2.8	0.2	-0.1	-0.1	0.0
11	B	0.6	2.5	-0.7	-4.4	0.0	0.1	-0.1	0.3
12	GA	1.4	-2.6	1.7	-6.9	0.0	0.1	0.1	1.1
13	GP	2.6	-2.1	-9.8	-8.6	0.2	0.2	-0.1	1.2

The table shows a very good agreement between the BERNESE solutions in comparison to the combined solution as one should expect. The combined solution is dominated by the 11 BERNESE contributions, while the single GAMIT and GIPSY solutions have a minor impact. The RMS for the dominating BERNESE solutions are very small and also the translation parameters are in the range of 0 to 2 mm, only in a few cases up to 4 mm. The RMS is in most of the cases well below 1 mm. A significant difference appears between the combined solution and the two solutions generated with GAMIT and GIPSY. This has of course to be expected, since these are quite different software packages. Beside a significant shift and a larger RMS there is also a significant difference in scale. Possibly this is caused by the different mapping functions (GMF) used in GAMIT and GIPSY while the BERNESE solutions were generated applying the dry-Niell mapping function as a priori model and using the wet-Niell mapping function for the estimation of the zenith path delay corrections.

Apparently there are still differences within the 11 BERNESE contributions that are caused due to

the settings applied by the different operators. Mainly the strategies for the ambiguity resolution and the realisation of the datum within each solution offer a variety of settings.

4 EPN Repro1

The encouraging results of the Pilot Processing initiated the reprocessing of the EPN for the remaining years. The LACs were asked to cover in the analysis the years 1996 until 2005 using the identical analysis methods (IGS05) as they have been used for the Pilot Processing. The methods are very similar to the analysis of the operational data between GPS week 1400 (2006) and today. It was therefore possible that each LAC could provide a set of solutions realized in the IGS05 between 1996 and spring 2011. Again, the solutions for the years 1996 until 2005 were uploaded to the EPN Combination Centre at the BKG and weekly solutions were combined by the EPN Combination Centre.

The preliminary combination of the different solution has shown again that there are significant difference between the three software packages BERNESE, GAMIT and GIPSY as in the Pilot Processing. A better agreement between the three software packages can only be achieved if the applied strategies and model options are comparable and competitive.

The Analysis Coordinator at the BKG will derive based on the submitted solutions weekly combinations that will be then used by the coordinator of EPN Time Series Analysis at FOMI Satellite Geodetic Observatory (Hungary) to compute a multi-year solution with new coordinate and velocities is the IGS05.

In parallel the coordinator of the EPN troposphere product will generate new troposphere products and compare them to the available meteorological data. The completion of the work for the EPN Repro 1 campaign is expected in autumn 2011.

5 Outlook

With the release of the new ITRF2008 and the provision of the IGS08 the operational analysis of the EPN network is now carried out in a new reference frame. Therefore we obviously see a new inconsistency between our recent re-analysis of the EPN (EPN Repro1) in the IGS05 and the current operational work in the IGS08. It is therefore mandatory to reprocess the entire EPN network again as soon as suitable reprocessed products, based on the IGS08, will be released.

Already today reprocessed products in the IGS08 are made available by JPL, but it can also be expected that by the end of this year the Centre for Orbit Determination in Europe (CODE) will have completed a set of reprocessed orbits and clocks in the IGS08 and provide it to the users. But we also have to wait for the release of a new version of the BERNESE software, which is expected by the end of 2011. This version will contain the recently developed mapping functions VMF and GMF that will make the three analysis tools more comparable.

With the experience gained in past years to handle a large amount of data it should not be a problem to reprocess the entire EPN in a new EPN Repro2 campaign.

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