Processing Combined GPS/GLONASS Data at swisstopo's Local Analysis Center

D. INEICHEN, E. BROCKMANN, S. SCHAER [1]

1 Introduction

The Local Analysis Center at swisstopo is involved in the processing of combined GPS/GLONASS data. Our analysis solution of a subnetwork of the European Permanent Network is computed on the basis of GPS data and, if provided by the corresponding observation site, additional GLONASS data. Furthermore, the Automated GNSS Network of Switzerland (AGNES) was enhanced to a combined GPS/GLONASS network during the last year. The AGNES permanent network is used for various applications, such as the maintenance of the national reference frame, the estimation of near real-time zenith total delays to be used for numerical weather predictions, and for commercial positioning service purposes. The experiences made with the processing of multi-GNSS data as well as the impact on the resulting (daily to epoch-wise) analysis products are presented in this paper.

2 GLONASS data used for the EPN subnetwork solution

At swisstopo, we started to include GLONASS data into the processing scheme of our subnetwork of the European Permanent Network (EPN) with GPS week 1400 (November 2006). A corresponding decision that the use of GLONASS data is accepted and desirable for the processing of official EPN contributions was taken at the Analysis Center Workshop held in Padua in March 2006 [Bruyninx, 2006]. At that time, we started with four sites providing combined GPS/GLONASS observations: Borkum (BORJ), Helgoland (HELG), Wettzell (WTZR), and Hoernum (HOE2). In the meantime, the number of combined GNSS sites increased to eight sites by adding the data of the sites EIJS (Eijsden), HOBU (Hohenbuenstorf), UNTR (Terni), and ZIM2 (Zimmerwald) to the solution. An overview of the sites delivering combined GPS and GLONASS data is given in Figure 1.

One of the newly included EPN GNSS stations, namely ZIM2, is an additional receiver and antenna setup at the geostation Zimmerwald and is operated by our institute, the Swiss Federal Office of Topography. The new equipment was installed in the framework of the enhancement of the Swiss permanent network AGNES to a combined GNSS network (see Section 3 of this paper). The observation data of this new EUREF site is also provided to the International GNSS Service (IGS). The station is equipped with a Trimble NetR5 receiver and a Trimble Zephyr GNSS antenna (TRM55971.00) and is delivering data since November 2007 (see also [Brockmann et al., 2008]).

Since the IGS (International GNSS Service) is still not providing a combined orbit product, our EPN subnetwork solutions are based on the combined orbit products of CODE (Center for Orbit Determination in Europe). During the last year, a progress in the processing concerning the ambiguity resolution could be realized: Since August 2007, also the ambiguities of the GLONASS observables can be fixed. To achieve this goal, some extensions had to be implemented into the Bernese GNSS Software, which are not yet included in the current official Version 5.0 [Schaer, 2007].

The combination of subnetwork solutions based on GPS-only data and corresponding subnetwork solutions based on combined GNSS data should not cause major problems, since the influence of the additional GLONASS observations on the resulting coordinates is at maximum 0.3 mm for the horizontal components and below 1 mm for the height component (see also Section 4 and [Ineichen et al., 2007]).

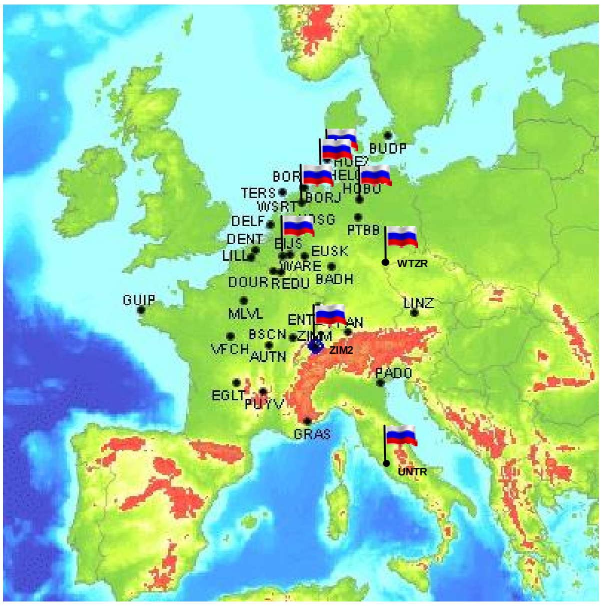

Figure 1: Eight sites of the EPN subnetwork processed by swisstopo providing combined GPS/GLONASS data (BORJ, EIJS, HELG, HOBU, HOE2, UNTR, WTZR, ZIM2).

[1] Swiss Federal Office of Topography swisstopo, Geodesy Division, Seftigenstrasse 264, CH-3084 Wabern, Switzerland, Phone: ++41 31 963 21 11, Fax: ++41 31 963 21 51, E-mail: daniel.ineichen@swisstopo.ch, Web-site: http://www.swisstopo.ch

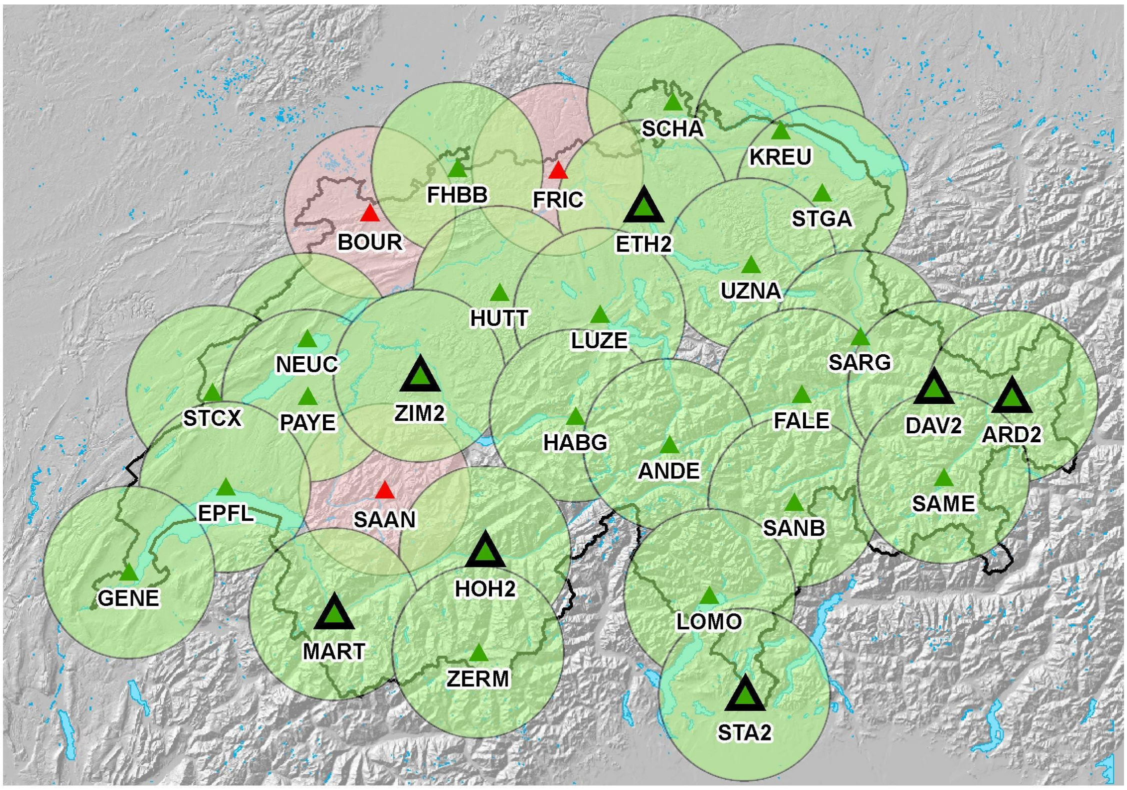

Figure 2: The status of the AGNES network after the transition to a combined GPS/GLONASS network (June, 2008): 21 sites with exchanged equipment, 7 sites running old and new equipment in parallel ("double stations" ARD2, DAV2, ETH2, HOH2, MART, STA2, ZIM2), and 3 sites which will be enhanced to "double stations" in the near future (BOUR, FRIC, SAAN).

3 Enhancement of the AGNES network with GNSS capable equipment

Important manufacturers bringing combined GNSS receivers on the market, the operators of the GLONASS system replenishing the system to full constellation, and the Galileo system being delayed till at least 2012 were the main reasons for swisstopo to decide in 2006 to upgrade the AGNES network with GPS and GLONASS capable tracking equipment. This means that mainly considerations concerning the real-time positioning service (swipos) led to the decision of swisstopo to equip the AGNES network with GLONASS capable Trimble NetR5 receivers and Zephyr GNSS antennas. The new antennas were individually calibrated by the company Geo++ by means of robot calibration. For the GLONASS part, only individual offsets together with group values for the phase center variations could be determined.

As described in earlier papers [Ineichen et al., 2007], a double station concept was selected for the transition of the AGNES network to a GNSS capable system: For seven sites of the existing network – so called "double stations" – an additional antenna mount was installed for the new GNSS antenna and a new tracking equipment was established. The old and the new equipment will be run simultaneously as long as the old equipment is working. For three of a total of ten planned "double stations" the construction of the second antenna mount is currently under way.

At the remaining 21 "standard stations", the old receiver and antenna equipment was replaced with the new one during last year. An overview of the current network status (June 2008) is shown in Figure 2.

There were mainly two reasons for selecting the double station concept:

Firstly, to guarantee without interruption a stable realization of the national reference frame. Whenever a GNSS antenna is replaced at a site, the determined coordinates of the corresponding site will suffer a jump in the time series. In case of the AGNES network, the old and new official coordinates differ up to 10 mm for the horizontal components and up to 30 mm for the height component. These differences are not only due to the antenna changes themselves, but also caused by the rounding of the old coordinates to cm-values and small station movements between the two different determination epochs. A figure showing the differences for each site may be found in [Brockmann et al., 2008].

Secondly, one of the tasks of the AGNES network is the estimation of velocities for geodynamic studies. Due to the law of error propagation, uninterrupted time series are even more important for this application as they are for the estimation of the coordinate values itself.

4 GNSS results from post-processed daily solutions

With the enhanced AGNES network we have the opportunity to apply GNSS analysis strategies to observables stemming from a dense and homogeneously equipped network. The goal of the investigations was to evaluate the performance of different solution types on a daily level. Therefore, various test solutions were set up in our routinely data analysis scheme, amongst others:

- a GPS-only solution,
- a GLONASS-only solution,
- a GNSS solution (combined on normal equation level, no double differences considered between the GPS and the GLONASS observables).

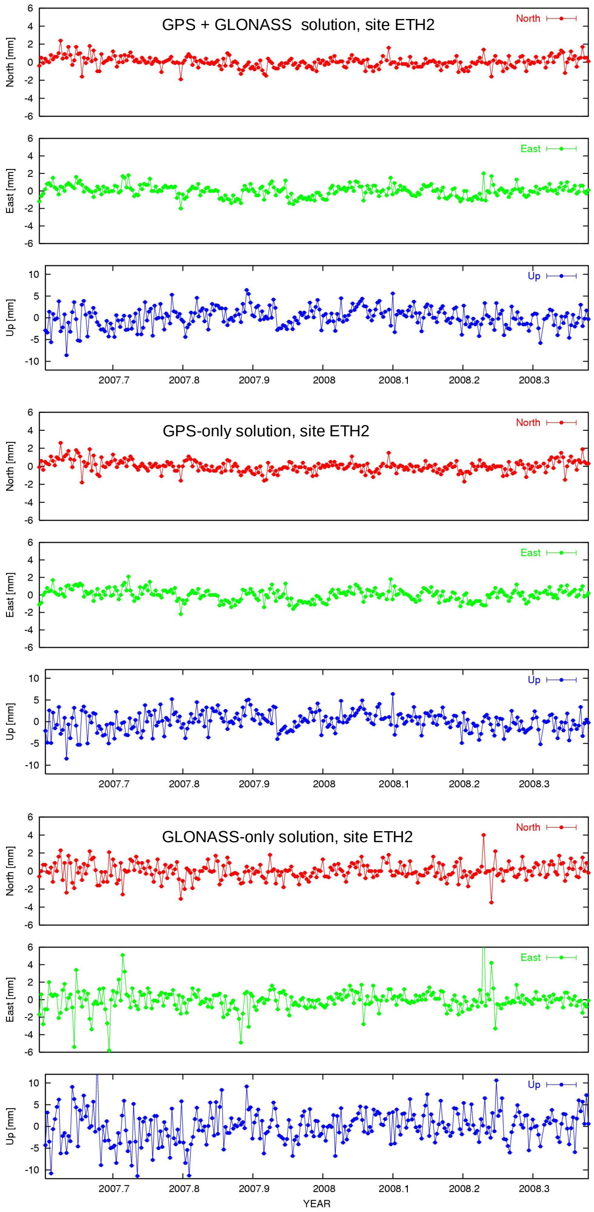

Figure 3: Daily coordinate repeatability of AGNES site ETH2 for the time period of 315 days: GPS+GLONASS solution (top), GPS-only solution (middle), and GLONASS-only solution (bottom).

Currently, the time series of 23 sites of the AGNES network providing GNSS observation are available for a time interval of up to 315 days (July 2007 to May 2008). The data processing was done with the Bernese GNSS Software 5.0+ containing new software enhancements concerning the analysis of GNSS data (among others ambiguity fixing for GLONASS).

Figure 3 shows an example of a comparison of the time series of a GPS+GLONASS solution, of a GPS-only solution, and of a GLONASS-only solution. The residuals of the North, East, and Up component are plotted for site ETH2 (ETH Zurich) for a time period of ten months. For the datum definition, a minimum constraint condition with 3 translation parameters was selected. The corresponding residuals were computed without applying a Helmert transformation between the daily and the combined solutions.

The difference of the performance between the combined GPS/GLONASS solution and the GPS-only solution is very small and hardly visible. Interesting to see is that the performance of the GLONASS-only solution is not far from the other solution types. This is only possible due to successful ambiguity resolution and is in fact remarkable, taking into consideration that the GLONASS system is not (yet) a complete system. At the beginning of 2008, the number of operational GLONASS satellites was 13, compared to 32 active GPS satellites.

An overview of the results of 23 stations is given in Figure 4. The graph confirms the findings of the example of station ETH2. The performance of the GNSS solution is almost identical with the GPS-only solution (a little bit better for the North and Up component an a little bit worse for the East component). Surprisingly well performs the GLONASS-only solution, which is only worse by about a factor of 2 or less.

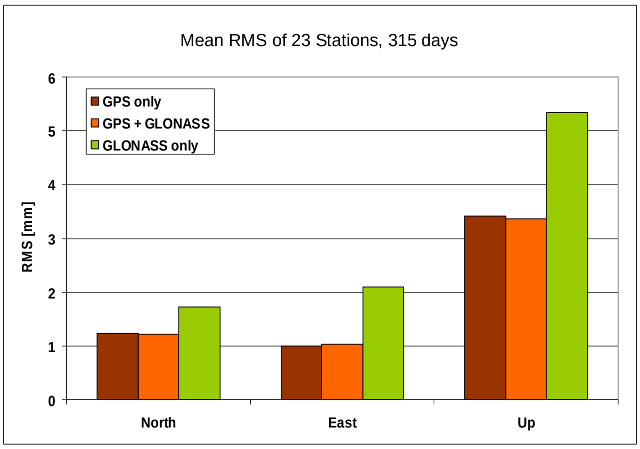

Figure 4: Mean RMS values of the daily coordinate repeatability of 23 AGNES sites providing GNSS data. Compared are a GPS-only solution, a GPS+GLONASS solution, and a GLONASS-only solution.

	North [mm]	East [mm]	Up [mm]
GPS vs. GNSS	0.3	0.2	0.8
GLONASS vs. GNSS	0.7	1.0	2.7
GPS vs. GLONASS	1.0	1.2	3.4

Table 1: Coordinate consistency between GPS, GLONASS, and GNSS solutions: RMS of Helmert transformations (3 translation parameters).

We investigated not only the influence of GLONASS on the coordinate repeatability, but also on the estimated coordinate values themselves. Table 1 shows the coordinate consistency between the three solution types, determined by means of Helmert transformations with 3 translation parameters. The RMS values are derived from the comparison of 315-day solutions of 23 GNSS stations. It is gratifying to see that no big systematic effect is introduced when including GLONASS data into the data analysis.

When we compare the GPS-only solution with the GNSS solution, the RMS of the Helmert transformation is not larger than 0.3 mm for the horizontal components and 0.8 mm for the Up component. But also the GLONASS-only solution shows a nice agreement with the GNSS and the GPS-only solution: The RMS of the North and East component is not larger than 1.2 mm and the RMS of the height component is 2.7 mm for the comparison with GNSS and 3.4 mm for the comparison with GPS-only. When judging these results, it is important to keep in mind that no individual absolute antenna phase center variations could be determined for the GLONASS part by means of robot calibration at that time.

5 Kinematic solutions

Besides the studies of the influence of GLONASS data on daily repeatabilites, we also investigated kinematic (or epoch-wise) solutions. The data processing was done in hourly batches for a time period of 7 days (May 31 till June 6, 2008). The troposphere parameters and the fixed ambiguities were introduced from a previously computed, post-processed sliding 8-hour solution. The epoch-wise coordinates were estimated every 30 seconds for all sites of the Swiss permanent network AGNES, while the surrounding European sites were used for realization of the datum definition.

In this way, two types of kinematic solutions were generated: A GPS-only solution and a combined GPS/GLONASS solution. The computation of an epoch-wise GLONASS-only solution was not meaningful: There were too many epochs where the solutions got singular due to the limited constellation of the GLONASS system.

The computation of epoch-wise solutions can be seen as a way of simulating the situation of a user doing real-time positioning in the field and should provide an indication, whether the accuracy of kinematic solutions can be improved by using additional GLONASS observables.

Figure 5 shows the example of a site located in the Swiss Alps (SANB, San Bernardino), where obstructions of the GPS signals through surrounding mountains occur.

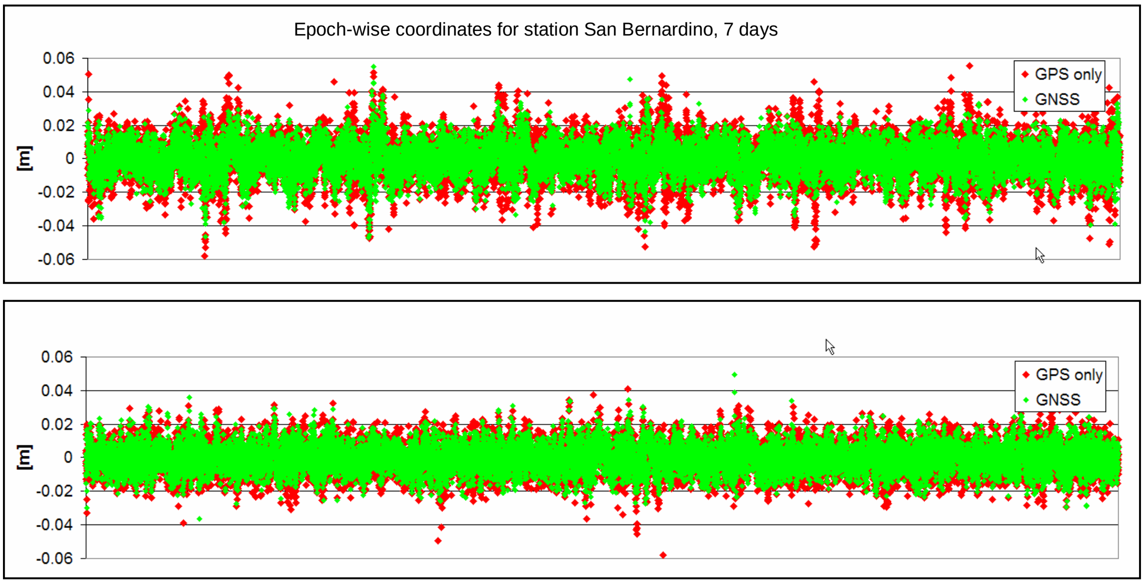

Figure 5: Residuals of an epoch-wise kinematic solution of AGNES site SANB (San Bernardino) over a time period of 7 days (about 20'000 position estimates). Comparison of a GPS-only solution with a GNSS solution for the North component (top) and the East component (bottom).

The plot shows the comparison of a GPS-only solution with a GNSS solution for about 20'000 epoch-wise coordinate estimates (7 days) for the North and East component. It is clearly visible that the scatter of the time series is reduced when we consider additional GLONASS data for the processing. Furthermore, a distinct daily signal is visible in the GPS estimates (see North component). This signal is caused by the characteristic of the GPS satellite constellation with its repetition period of one sidereal day and the corresponding correlated effects like, e.g., multipath. This daily signal is smoothed in the combined GPS/GLONASS solution. A detailed analysis of the influence of the satellite system geometry on the coordinate repeatabilities may be found in [Dach et al., 2008].

Considering the results of all the 23 AGNES sites providing GNSS data, we can state that for all sites and components an improvement is visible when using additional GLONASS data. The average gain is reported in Table 2. The RMS drops from 7.3 mm to 6.0 mm for the North component, from 5.4 mm to 4.8 mm for the East component, and from 12.4 mm to 10.8 mm for the Up component. These values correspond to an improvement between 11 and 17 percent. This behaviour conforms quite well to the "square-root-of-n law", taking into account the number of available satellites (15 GLONASS satellites compared to 31 GPS satellites for the investigated time interval). For stations in mountainous regions the gain may rise up to 30% for the North, 13% for the East, and 16% for the Height component.

	North	East	Up
RMS GPS	7.3 mm	5.4 mm	12.4 mm
RMS GNSS	6.0 mm	4.8 mm	10.8 mm
Improvement	17 %	11 %	13 %

Table 2: Mean RMS of kinematic solutions of 24 stations over a time period of 7 days of a GPS and a GNSS solution and the corresponding improvement.

6 Conclusions

The Swiss permanent GPS network (AGNES) was almost completely re-equipped with GNSS capable receivers and antennas during last year. The availability of such a dense network with modern GNSS equipment provides new possibilities for gaining experience with the simultaneous processing of two independent satellite systems.

Combined GPS and GLONASS observations are routinely processed for the EUREF, the AGNES, and the near real-time solutions (for meteorological and monitoring purposes). We consider the enhancement of the AGNES network with GLONASS as a first step towards the inclusion of other future satellite systems like, e.g., the European Galileo system.

An important improvement of the processing strategy was the implementation of correct ambiguity resolution for the GLONASS observables in the Bernese Software Version 5.0+. This option could be activated in August, 2007. For the daily solutions, the performance of the GPS and the GNSS solutions are almost on the same level and no significant improvement could be verified by adding additional GLONASS data. Astonishing is the quality of the GLONASS-only solution, which performs remarkably well, considering the reduced constellation of the system.

For kinematic (epoch-wise) solutions, the additional GLONASS observations allow to improve the accuracy of the coordinate estimates. The results of all stations benefit from the additional data and the improvement of the repeatability values may reach values up to 30 percent for stations in mountainous regions. It is the first time that we see GLONASS data improving the accuracy of post-processing applications in such a clear way. The results of the kinematic solutions demonstrate furthermore the potential of additional GLONASS data for the amelioration of the accuracy of RTK applications. Earlier tests with the RTK service swipos verified already the increased availability of ambiguity fixed solutions under difficult measuring conditions and the reduction of the needed initialization time due to a higher number of available satellites for each epoch [Ineichen et al., 2007].

The finding that additional GLONASS data improve the accuracy of kinematic solutions, but not (yet) the repeatability values of the daily solutions might be caused in the different revolution periods of the two systems: Whereas the GLONASS satellites have a revolution period of 8/17 of a sidereal day and repeat their ground tracks only after 8 days, the GPS system repeats its constellation every sidereal day. Therefore, the GPS system performs per se better in terms of daily repeatabilities, since many systematic effects, like multipath, influence the daily results in exactly the same manner day after day (see also [Dach et al., 2008]). With the announced replenishing of the GLONASS system and the availability of longer time series, it will be worthwhile to continue studies in this field.

References

Brockmann E., D. Ineichen, M. Kistler, U. Marti, A. Schlatter, B. Vogel, A. Wiget, U. Wild (2008): *National Report of Switzerland: New Developments in Swiss National Geodetic Surveying.* In: Ihde, J. and H. Hornik (Eds): Subcommision for the European Reference Frame (EUREF), Brussels 2008. This volume.

Bruyninx C. (2006): *Minutes of EUREF Analysis Workshop, Padua, March 15-16, 2006.* www.epncb.oma.be.

Dach R., U. Hugentobler, P. Fridez, M. Meindl (Eds.) (2007): *Documentation of the Bernese GPS Software Version 5.0*. Astronomical Institute, University of Berne, Switzerland.

Dach R., E. Brockmann, S. Schaer, G. Beutler, M. Meindl, L. Prange, H. Bock, A. Jaeggi, L. Ostini (2008): *GNSS Processing at CODE: Status Report*. Paper submitted to Jounal of Geodesy.

Ineichen D., E. Brockmann, S. Schaer (2007): *Enhancing the Swiss Permanent GPS Network (AGNES) for GLONASS*. In: Torres, J.A. and H. Hornik (Eds): Subcommision for the European Reference Frame (EUREF), London 2007, in preparation.

Schaer S., (2007): *Inclusion of GLONASS for EPN Analysis at CODE/swisstopo*. In: Torres, J.A. and H. Hornik (Eds): Subcommision for the European Reference Frame (EUREF), London 2007, in preparation.