Enhancing the Swiss Permanent GPS Network (AGNES) for GLONASS

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1 Abstract

Since 1998 swisstopo has been operating the Automated GPS Network of Switzerland (AGNES) presently consisting of 31 permanent GPS stations and used for different applications such as maintenance of the national reference frame, estimation of zenith total delays for numerical weather prediction, and the commercial real-time positioning service swipos. During 2007, the network will be equipped with GLONASS-capable receivers and antennas. The paper covers the selected approach for the transition, the consequences of the equipment change, as well as tests revealing the benefits and problems to be expected for post-processing and real-time applications.

2 GLONASS data used for EPN solution

At the Analysis Center Workshop held in Padua in March 2006, a number of model changes for the EUREF Permanent Network (EPN) data processing were discussed and introduced for the official solution starting with GPS week 1400 [Bruyninx 2006]. To recall only the most important ones:

- Use of absolute antenna models.
- Estimation of gradient parameters for the troposphere.
- Transition from the ITRF2000 to the ITRF2005/ IGS2005 reference frame.

At the same time, swisstopo started to include GLONASS data into the processing of its EPN subnetwork. Four sites are providing combined GPS and GLONASS observations: Borkum (BORJ), Helgoland (HELG), Wettzell (WTZR), and Hoernum (HOE2) (Figure 1).

Since the IGS (International GNSS Service) was not providing a combined orbit product at that time, the new solutions are based on the combined orbit products of CODE (Center for Orbit Determination in Europe). Ambiguity fixing for the GLONASS observations was not yet implemented in this first phase of the combined processing, but is expected to be realized in near future.

The resulting differences between a GPS-only solution and a combined GPS/GLONASS solution, derived from an average of 7 weeks, are shown in Table 1. The influence of GLONASS on the resulting coordinates is quite small: Below 0.3 mm for the North and East component and below 0.7 mm for the Height component. Also the daily coordinate repeatability values are very similar in both cases.

It is gratifying to see that no big systematic effect is introduced when including GLONASS data into the

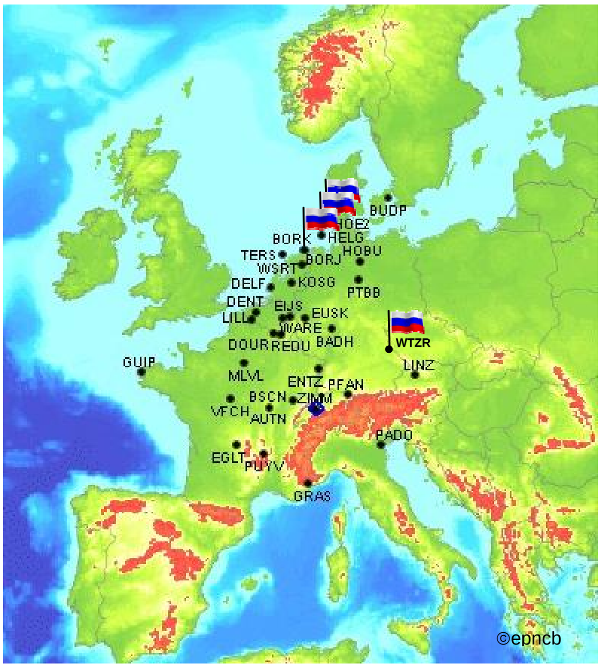

Figure 1: Four sites of the EPN subnetwork processed by swisstopo providing combined GPS/GLONASS data (BORJ, HELG, HOE2, WTZR).

	Δ North [mm]	Δ East [mm]	Δ Up [mm]
BORJ (Borkum)	-0.3	0.1	-0.7
HELG (Helgoland)	0.1	-0.1	0.3
HOE2 (Hoernum)	0.0	0.1	-0.1
WTZR (Wettzell)	0.1	0.0	0.3

Table 1: Coordinate differences comparing a GPS-only and a combined GPS/GLONASS solution (average of 7 weeks).

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processing. This is not only an effect of the lower weight of GLONASS due to less operational satellites and the missing ambiguity resolution: Also direct comparisons of independent GPS and GLONASS solutions show a good agreement of the coordinate values derived from the two systems.

3 Post-processing tests at ZIMM

The IGS site Zimmerwald is providing combined GPS and GLONASS data since the beginning of the first International GLONASS Experiment (IGEX) in 1998. Still up and running from these times is the Javad receiver mounted on marker "ZIMJ" (JPS Legacy receiver with JPSREGANT_SD_E antenna). To get experienced with the processing of combined GPS/GLONASS data collected with equipment stemming from various manufacturers, two additional combined receivers were set up.

- A Trimble NetR5 receiver together with a Zephyr GNSS antenna TRM55971.00 ("ZIMT") was permanently installed in July 2006. Its data were analyzed on a daily basis by swisstopo's and CODE's analysis center.
- A Leica 1230 GNSS receiver with a LEIAX1202GG antenna ("ZIML") was temporarily mounted on a tripod for a test period of 7 days (August 16 to 22, 2006).

In addition, data from the official IGS site ZIMM, a Trimble NetRS GPS receiver with a TRM29659.00 chokering antenna, was used for the computations. An overview with pictures of the whole test scenario is given in Figure 2.

For almost all markers, ground truth information determined by means of classical terrestrial surveys is available. The only exception is the temporary antenna setup of ZIML (tripod), where only the height component was linked to the local reference network by means of levelling.

The test should not be viewed as a true receiver performance test: The antenna setups and the covered time periods are too different for this purpose. The tests were intended to collect GNSS data from different equipment in order to gain more experience with the processing of combined GPS/GLONASS observations on short baselines.

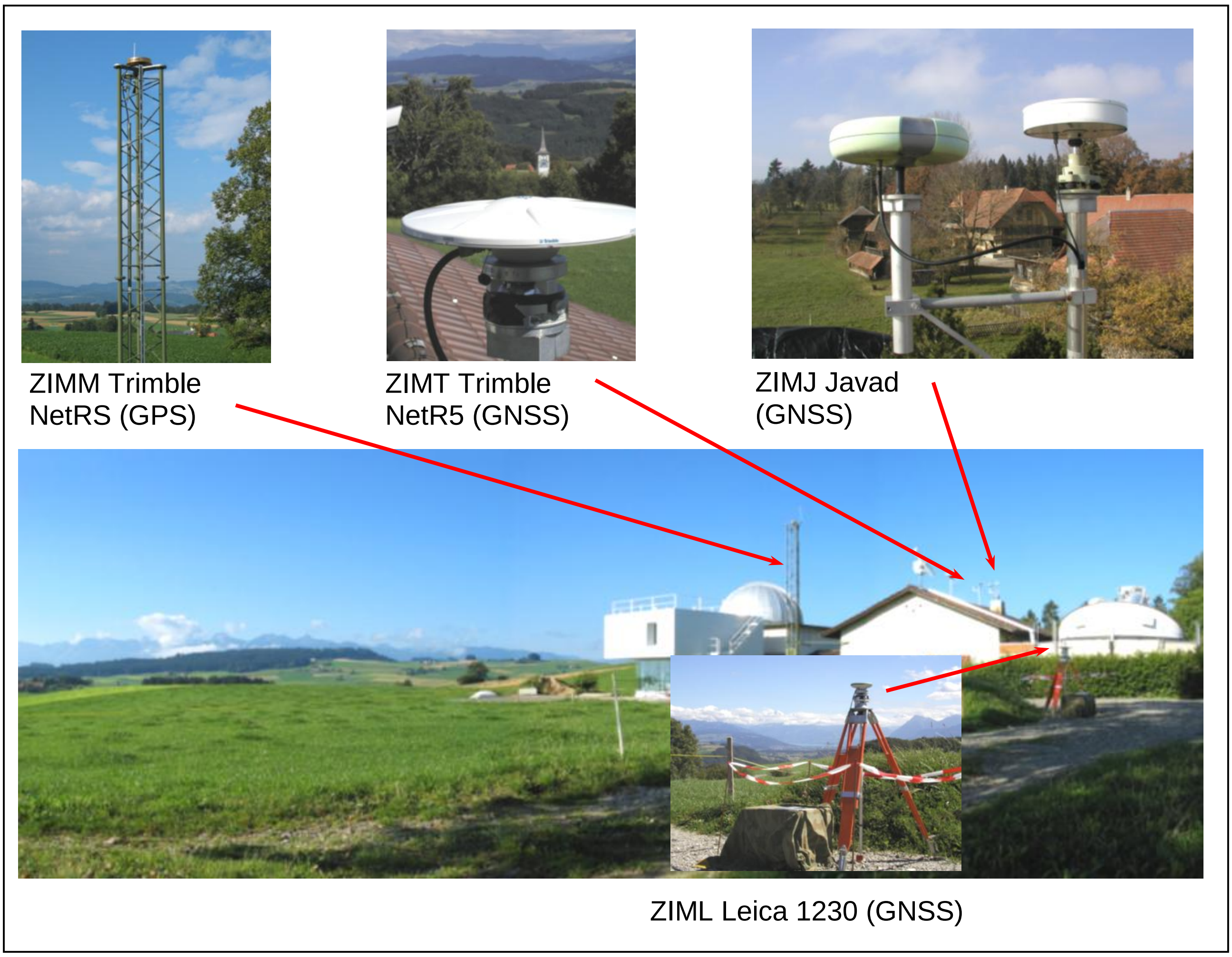


Figure 2: Antenna and receiver setup at the IGS site Zimmerwald (Switzerland) for the GNSS post-processing tests of short baselines with the Bernese GPS Software.

Data were analysed with the Bernese GPS Software 5.0 and Leica's Software LGO. Results presented in this paper are stemming from the Bernese Processing.

The Zimmerwald GNSS data set was analyzed together with data from the GNSS cluster in Wettzell, with the focus on testing GNSS ambiguity fixing. After several software modifications (from BSW5.0 to BSW5.0+), GLONASS ambiguity fixing was possible.

The daily repeatabilities shown in Figure 3 are derived from 7 sessions. Compared are the repeatabilities stemming from a GPS-only processing with the repeatabilities stemming from a combined GPS/GLONASS solution. The coordinate repeatabilities were determined with respect to site ZIMJ, which was selected as reference site. From more than ten different test scenarios, the results of the L1 linear combination and the L3 linear combination are presented. For both solution types, the troposphere parameters are not solved for and absolute antenna phase center variations are used.

The investigations were done for the L1-only solution (top) and the L3 linear combination (bottom).

For the L1 solution, the coordinate repeatability values remain almost unchanged for both solution types. Only the site ZIMM shows slightly increased values. This is all the more astonishing, since the site provides only GPS data. However, it's complaining on a high level, since even in the case of the combined solution, the repeatability values are still clearly below the 1 mm-level.

For the L3 solution, a raise of the repeatability values is clearly visible. With respect to the ZIMJ reference site, they increased by about a factor of two (from 0.5 mm to 1 mm for the horizontal components, and from 1 mm to 2 mm for the height component). Possible explanations for the degraded performance of the L3 solution when fixing GLONASS ambiguities are complications in the ambiguity fixing process due to insufficient single difference initializations and neglected inter-system phase biases.

These remaining inconsistencies in the combined processing of GPS and GLONASS data were the starting point for further investigations and developments of the AIUB (Astronomical Institute of the University of Berne). For further information please refer to the paper presented in this volume [Schaer, 2007].

The analysis of the Zimmerwald GNSS data set and the comparison with corresponding ground truth information revealed other interesting results:

- The GNSS tracking performance depends strongly on the used receiver type and the installed firmware version (untracked satellites or unusable data of satellites which are not operational).
- The influence of near-field effects on the Trimble Zephyr GNSS antenna was tested by adding a concentric, 6 cm high adapter to the antenna setup. The observed change of the height component was very close to the expected value of 6 cm (less than 1 mm difference).
- Compared to the analysis results and the available terrestrial local ties, the ITRF2005 coordinates for the antenna markers 14001M004 (ZIMM) and 14001M005 (ZIMT) differ by 9 mm in the East component.
- The absolute antenna calibration values (igs05.atx) are invalid for the JPSREGANT_SD_E antenna mounted on 14001M006 (ZIMJ): Not all antennas of this type are identical in construction. Therefore, we suggested IGS to include different calibration values for this antenna type, depending on the corresponding serial number. The effect may be up to 19 mm for the height component.

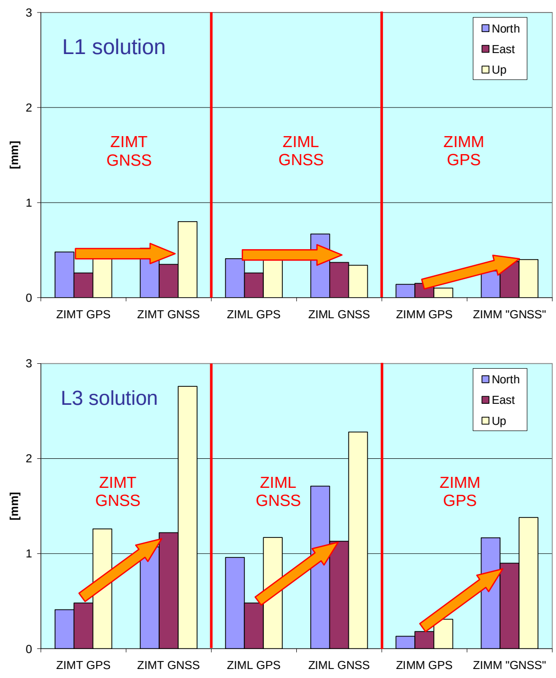


Figure 3: Repeatability values of a L1 solution (top) and a L3 solution (bottom) with fixed ambiguities for GPS-only and combined GPS/GLONASS observations.

4 Real-time kinematic (RTK) tests using GNSS data

Besides the post-processing activities using GLONASS data for ambiguity fixing, also tests concerning the influence of GLONASS data on real-time positioning were performed.

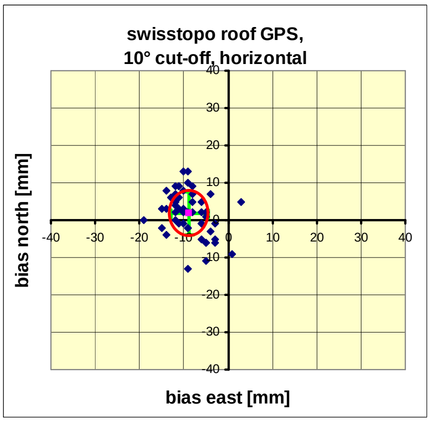
Presented in this paper is the example of a 5 km baseline from the AGNES site Zimmerwald to the roof of the swisstopo building (Wabern). A Trimble NetR5 receiver served as base station, whereas a Leica 1230GG was used as rover system.

New initialisations were done every 30 minutes during 4 days (September 19 to 22, 2006) with the "VRS monitor box", a self-developed monitoring system for real-time positioning [Grünig, 2005].

The tests were done with two different cut-off angles: 10 degrees (in order to simulate optimal measuring conditions) and 30 degrees (in order to simulate measuring activities under difficult conditions like densily built-up or mountainous areas).

The tests were performed from the point of view of a user of the swipos positioning service, and therefore not designed as true scientific investigations. The observations for the GPS and GNSS comparison are, for example, not performed exactly at the same time using an antenna cable splitter and two parallel running receivers. The results are rather representing first experiences with GPS and GNSS real-time positioning.

Figure 4 shows the estimated coordinates and the corresponding standard deviations of the RTK tests using a cut-off angle of 10 degrees. The GPS-only solution (top) is compared with a combined GPS/GLONASS solution (bottom).



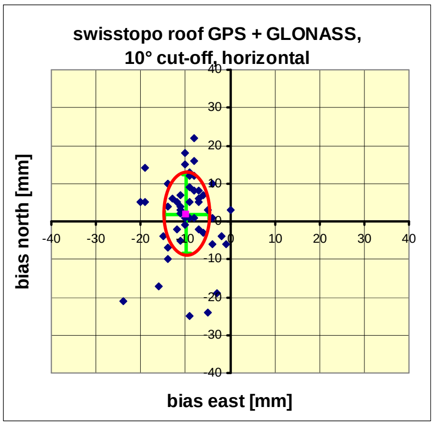
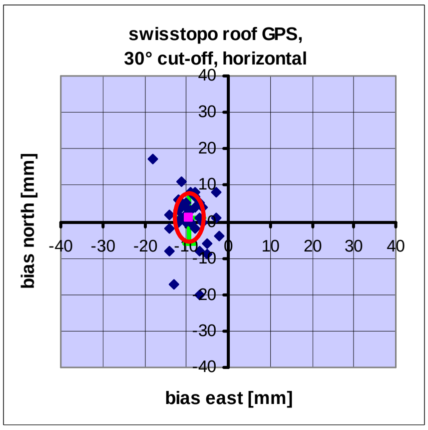


Figure 4: Coordinates and standard deviations (North and East) of RTK tests performed with a 10 degrees cut-off elevation angle. GPS-only results (top) and combined GPS/GLONASS results (bottom).

The horizontal coordinate values are plotted with respect to reference coordinates derived from a post-processing procedure. Whereas the averaged offsets are almost the same for both solution types, the standard deviation increases for the North component from 6 mm to 10 mm in case of the GPS/GLONASS solution.The same tests were performed applying a cut-off angle of 30 degrees (see Figure 5). Here, the standard deviations for the horizontal coordinate components remain almost the same for both solution types.



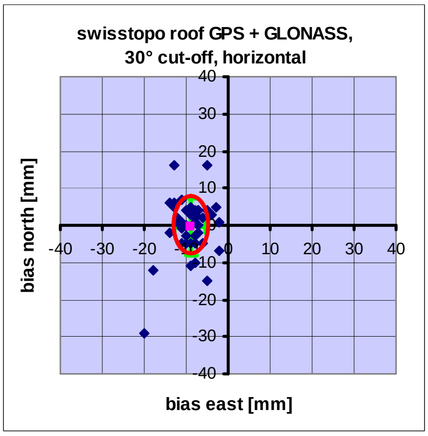


Figure 5: Coordinates and standard deviations (North and East) of RTK tests performed with a 30 degrees cut-off elevation angle. GPS-only results (top) and combined GPS/GLONASS results (bottom).

The results are summarized in Table 2: Besides the results of the coordinate determination, also the needed initialization times and the availability of the solutions are listed. For these properties, the benefit of the additional GLONASS satellites is evident. The used time to fix the ambiguities decreases in the case of the 30 degrees cut-off angle from 68 seconds to 46 seconds and the availability of ambiguity fixed solutions increases from 62.5% to 79.2%.

When judging the results, it is important to keep in mind that the tests were done at a time with quite an unfavourable GLONASS satellite constellation: Three GLONASS satellites were set unhealthy and only ten GLONASS satellites were usable for positioning purposes. A further difficulty might be the use of two different receiver types for reference station and rover, since GLONASS ambiguity fixing is easier for baselines with identical receiver types. The mixture of different equipment represents, however, a standard case for positioning services.

Elevation cut-off	Satellite system	East [mm]	North [mm]	Horizontal [mm]	Height [mm]	Initialization time [s]	Availability [%]
10º	GPS	-8.7 ± 4.2	1.8 ± 5.9	11.1 ± 7.2	15.0 ± 11.3	3	100.0
	GPS+GLONASS	-9.6 ± 4.9	1.8 ± 10.4	9.8 ± 11.5	16.3 ± 10.3	3	97.9
30º	GPS	-9.2 ± 3.4	1.1 ± 7.1	11.7 ± 7.9	17.7 ± 12.0	68	62.5
	GPS+GLONASS	-9.0 ± 3.7	-0.3 ± 7.7	11.7 ± 8.5	15.5 ± 14.2	46	79.2

Table 2: GPS and GNSS RTK tests with elevation cut-off angles of 10 and 30 degrees: Offset and standard deviation values of the resulting coordinates, initialization times, and availability of ambiguity fixed solutions.

Similar test measurements, using instead of the Zimmerwald reference site the swiss@t positioning service, were performed by [Imhasly and Zaugg, 2006]. Results presented in that paper are comparable with our findings. It's worth noting that the swiss@t positioning service, which has competed with the swipos positioning service for several years, will stop operations by the end of 2007 and the corresponding users will be migrated to the swipos service of swisstopo.

5 AGNES enhancement and double station concept

For the following reasons, swisstopo decided in 2006 to upgrade the AGNES network with GPS and GLONASS capable tracking equipment:

- Manufacturers dominating the Swiss positioning market, namely Leica and Trimble, brought combined GNSS receivers on the market.
- The operators of GLONASS expressed their willingness to replenish the GLONASS system to full constellation.
- The operational status of the Galileo system is delayed at least until 2012. Therefore, an equipment change is anyway necessary for the AGNES network before upgrading the network for Galileo.
- As national data provider of GNSS data, it is desirable to offer the complete set of available data.

Therefore, mainly considering the improved availability of RTK solutions led to the decision of swisstopo to enhance the AGNES network for GLONASS. Trimble NetR5 receivers and Zephyr GNSS antennas were selected as appropriate new equipment for replacing the existing Trimble GPS-only infrastructure without performing a new receiver/-antenna evaluation. The new antennas were individually calibrated by the company Geo++ by means of robot calibration.

A double station concept is foreseen for the transition of the AGNES network to a GNSS capable system: For ten sites of the existing network – so called "double stations" – an additional antenna mount will be installed for the new GNSS antenna. It is planned to run the old and the new equipment simultaneously as long as the old equipment is functioning. At the "standard stations", the old receiver and antenna equipment is replaced with the new one. An overview of the network configuration after the upgrade is shown in Figure 6.

There are mainly two reasons for selecting the double station concept.

Firstly, to continuously guarantee a stable and reliable realization of the national reference frame. Whenever a GNSS antenna is replaced at a site, the coordinates of the corresponding site will change. Such coordinate changes may amount to a couple of millimetres for the horizontal components and even centimetres for the height component. A continued operation of some of the old GPS equipment enables to adapt the new equipment in an optimal way into the existing AGNES network.

Secondly, one of the tasks of the AGNES network is the estimation of velocities for geodynamic applications. The formal error of the estimated velocities decreases proportional to $1/\sqrt{t^3}$, where t represents the observation interval of the corresponding site [Brockmann, 1996]. Uninterrupted timeseries are therefore even more important for velocity estimation as they are for the estimation of coordinate values, whose formal errors decrease proportional to $1/\sqrt{t}$. As a result of a simulation of timeseries analyses it can be stated that an extension of a five-year observation period by three additional years, for example, improves the quality of the velocity results more than ten additional years with two equipment changes.

The equipment change for the 21 standard stations will take place in June and July, 2007, whereas the double stations will be installed during the second half of the year 2007.

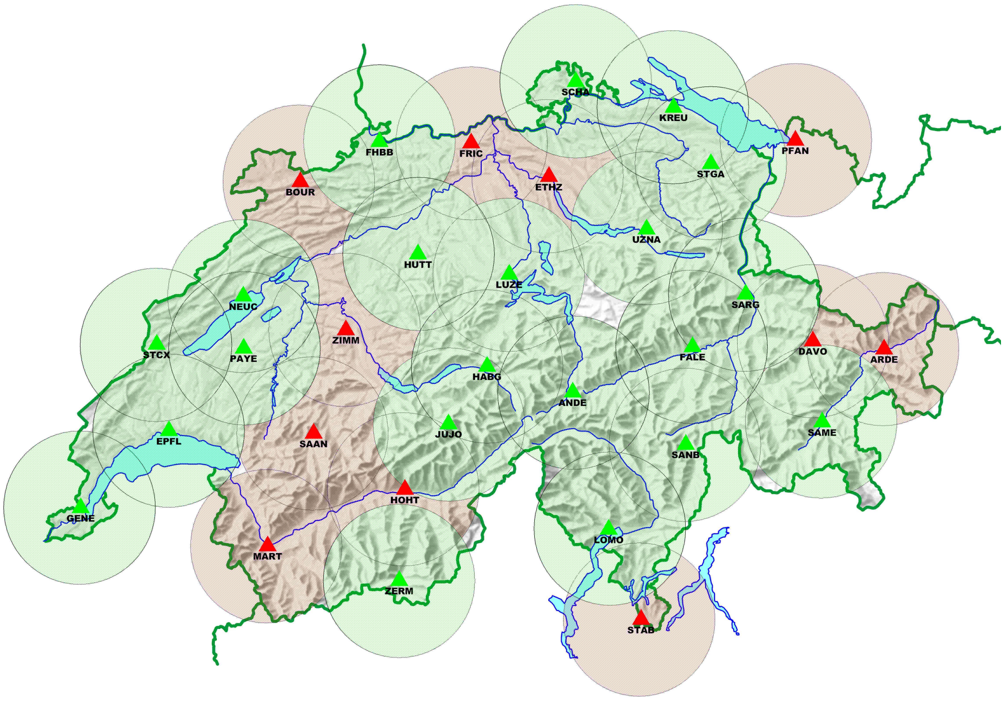


Figure 6: The AGNES network after the transition to combined GPS/GLONASS service: For ten "double sites" (marked in red), the old and new equipment will be run in parallel (PFAN is operated by the Austrian BEV).

6 Conclusions

We consider the enhancement of the AGNES network with GLONASS as a first step towards the inclusion of other new satellite systems like, e.g., the European Galileo or the Chinese COMPASS system. The use of GLONASS data in combination with GPS data is still in the state of a learning process on different levels: The tracking of the GNSS signals itself, the data exchange and data processing for post-processing applications, and the use of the data for near real-time positioning purposes.

GLONASS data are fully included in swisstopo's GNSS post-processed solutions since November 2006. An improved performance in terms of repeatability could not yet be verified. Significant biases between the coordinate estimates derived from GPS and GLONASS are not detectable. The availability of such a dense network of modern GNSS receivers, like it will be the case for AGNES after the equipment change, provides new possibilities for gaining experience with the simultaneous processing of two independent satellite systems. Further improvements and benefits are expected by more active GLONASS satellites and more observation sites providing combined GNSS data. Software developments and refinements of the processing strategies like, e.g., ambiguity fixing for GLONASS observations, will further improve the quality of the results derived from combined GNSS data processing.

The main benefit, however, is expected for real-time applications. Especially, the increased availability of ambiguity fixed solutions under difficult measuring conditions and the reduction of the needed initialization time could be verified. The positioning accuracy, however, does not (yet) improve.

The upgrade of the complete AGNES network with GPS and GLONASS capable equipment, including the installation of ten double stations, is expected to be finished till the end of 2007.

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