EUREF'02: National Report of Switzerland

New Developments in Swiss National Geodetic Surveying

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1. Introduction

The Swiss national GPS reference network, consisting of 104 well monumented main stations was installed in the years 1989 to 1992. A selection of 5 of these points are EUREF stations (including the permanent GPS station in Zimmerwald and station Pfänder in Austria, close to the national border to Germany and Switzerland). It was measured twice between 1988 and 1994, and again in 1998. Within the last decade, the network has been densified mainly in the Central Plateau but also in the Jura and in the Alpine area in order to fulfill various demands for surveying in Switzerland.

At the end of 2001, the Swiss Federal Office of Topography (*swisstopo*) completed the installation of the Automated GPS Network for Switzerland (AGNES), which now consists of 29 permanently operating GPS tracking stations.

AGNES is conceived as a multipurpose network. It is not only the backbone of the Swiss national survey but of all surveying demands in the future. It also serves for various scientific applications such as geodynamic investigations especially in the Alpine area, and for atmospheric research.

Based on AGNES, a high-precision real-time positioning service under the product name *swipos*â (Swiss Positioning Service) is operational on a commercial basis since March of this year.

The official height system of Switzerland, LN02, is still based on levelling measurements only, without taking into account the gravity field. In order to overcome the problems of inconsistencies when heights are determined from GPS measurements and geoid information, a new National Height System LHN95 is presently being established. LHN95 is based on the large amount of levelling data measured between 1903 and today, and the gravity data collected along these lines. A largenumber of links between the levelling network and the national GPS reference network LHN95 as well as AGNES have been measured during the last few years. The orthometric heights for the new national height network LHN95 are now being computed in a common kinematic adjustment of GPS, the repeated levelling data and the precise Swiss geoid.

2. Densification of the National GPS Reference Network "LV95"

2.1 The main network "LV95" established between 1989 and 1992

The GPS reference network (LV95) consisting of 104 main stations was installed and measured in 4 sections beginning in 1989. Due to the tight resources at that time (GPS receivers, personnel, etc.), the work had to be carried out in 4 stages. The network is area-wide and the points were set at an interval of 15-20 km in the Central Plateau and 20-25km in the Alpine area. The post-processing was carried out in 1995 using the "Bernese GPS Software". The resulting coordinates were published in 1996 under the term CHTRF95.

2.2 Densification between 1994 and 2001

The main network was densified with an additional 101 points between 1994 and 2001, and was promoted accordingly in order to meet the growing demands of various users (large engineering projects, cadastral survey, etc.). The densified network features point intervals of 10-15 km in the Central Plateau and 15-20 km in the Alpine area. A further densification in view of the simultaneously developed AGNES permanent network is not planned (see Chap. 3).

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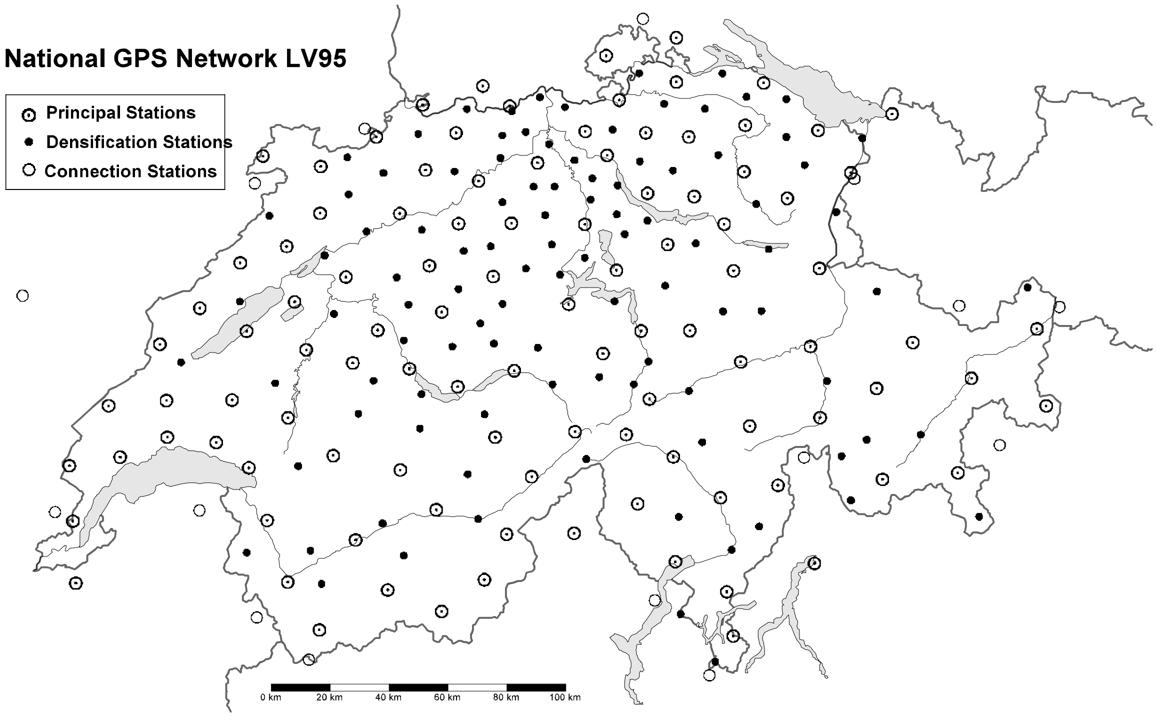

Fig. 1 GPS reference network LV95 (main points, densification and connections to neighbouring countries) in 2001

Table 1: National GPS reference networks (AGNES, LV95): Number of points, density and accuracy

Reference Network	Reference Frames	Number of points	Mean distance [km]	RMS N [mm] E [mm] U [mm]
EUREF EUREF (perm.)	ETRFxx ITRFxx	5 [1] 2 [1]	150	2 2 5
AGNES	ITRFxx CHTRF98 LV95	29 [1]	50	2 2 5
LV95 Main Points	ETRF93 CHTRF95 CHTRF98 LV95	104 [1]	15 - 25	10 10 30
LV95 Densification	ETRF93 CHTRF98 [2] LV95	101	10 - 20	10 10 30
Transformation LV03 <-> LV95 Fiducial points	LV95 LV03	250	5 - 20	20 20 -

[1]) including Austrian station Pfänder
[2]) partly also in CHTRF95

2.3 Maintenance, re-measurements and kinematic investigations

The GPS network LV95 is maintained on a regular basis. The sites are visited every five years, and a re-measurement is planned every five to ten years. The first re-measurement took place in 1998 (CHTRF98) [GUBLER et al., 1998] and showed excellent agreement with the first determination (CHTRF95) (see Table 2). The selection of stations also allows kinematic studies of the earth's upper crust. First investigations of the coordinates, however, have not shown any significant coordinate changes due to horizontal crustal movements. Further investigations based on re-measurements are planned.

Table 2: Repeatability of GPS network LV95: comparison of reference frames CHTRF95 and CHTRF98

Number of points	RMS [mm] horizontal position	RMS [mm] height	scale [ppm]
138	3.3	12.7	-0.05

3. Completion of the Automated GPS Network "AGNES"

3.1 Concept and installation

The permanent Swiss reference network AGNES was already presented in earlier national reports. [GUBLER et al., 1998; SCHNEIDER et al., 1999; 2000; BROCKMANN et al., 2001].

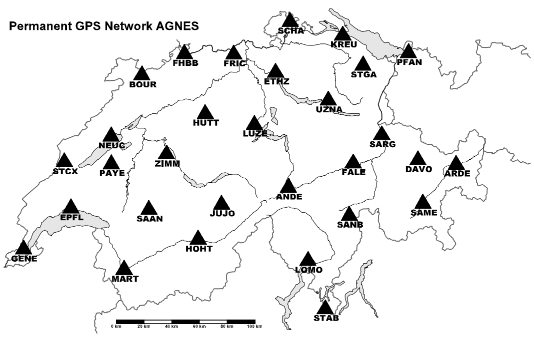

Fig. 2: Permanent GPS Network AGNES 2002

When the AGNES project was started in 1996, a small test configuration of 7 stations was established [WILD et al., 1996]. In this stage, the data transfer to the processing center was done once a day using standard telephone lines.

Table 1: AGNES permanent GPS network. Classification of stations

Class	Stability / ground	Number of stations
A	stable / on stable bedrock	9
B	stable / installed on concrete underground pillar or on stable building	3
C	uncertain / temporary installation on buildings	17
all	total	29

The final design of the network was developed in 1999 and the project was completed at the end of 2001. The network now consists of 29 stations (Fig. 2). One third of them are installed on masts, well founded on bedrock (Tab. 1; Fig. 3). The objective of a national permanent network covering the surface of Switzerland has now been reached. The distance from any site to the nearest station is under 25 to 30 km. All stations (except Pfänder) are connected to the real-time data network of the Swiss federal administration, which makes surface-covering RTK applications available [WILD et al., 2000].

Fig. 3 Example of AGNES permanent GPS station (antenna installed on mast founded in bedrock; computer rack)

3.2 AGNES monitoring

The data of the AGNES sites are being monitored since the end of 1998 on a daily basis and since Dec. 2001 on an hourly basis (see Chap. 5). In addition to the 29 AGNES sites, 40 EUREF sites are processed using the Bernese GPS Software Version 4.2 [*Hugentobler et al., 2001*] using the final IGS orbit products with a time delay of 3 weeks. This monitoring allows the detection of a possible site movement. An updated multi-year solution is automatically generated if an additional week is processed. The results (estimated velocity, repeatability plots, etc.) are available under http://www.swisstopo.ch/ (survey section). An example of an "unstable" site (we assume that ground water is responsible for the movement in the station height of SAME) is given in Fig. 4.

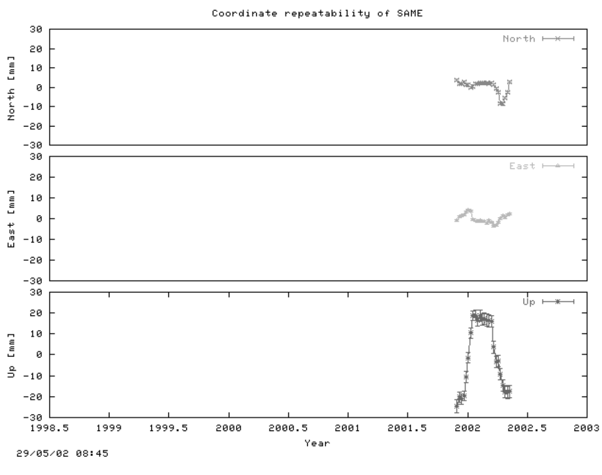

Fig. 4: Time series (north, east, up) of the AGNES station SAME (Samedan)

Fig. 5 shows an example of a stable station. The weekly repeatability is below 1 mm horizontal and 3 mm vertical. It is also clearly visible that the quality of the solutions has improved since mid-2000 (denser network, more reliable ambiguity resolution).

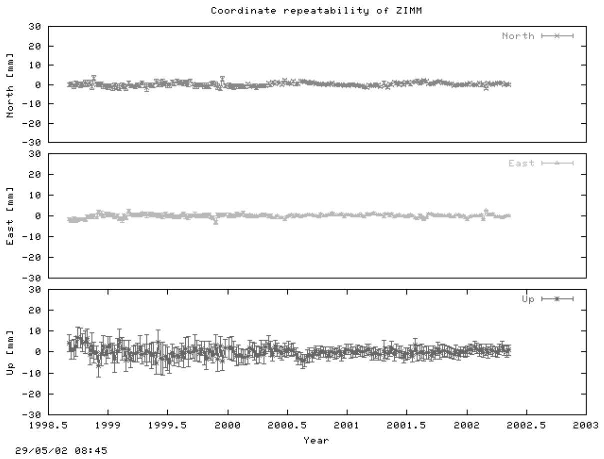

Fig. 5: Time series (north, east, up) of the AGNES station ZIMM (Zimmerwald)

3.3 Contribution to EUREF-IP

Since April 2002 ***swisstopo*** contributes to the EUREF-IP project. RTCM corrections of Zimmerwald are made available via TCP-IP (port 2101). Preliminary tests showed that the corrections arrive via the Internet with usually 2-4 seconds latency. The accuracy of the code-differential solutions is mainly dependent on the quality of the GPS equipment used at the rover side. In a test study, a Trimble 4000SSI rover in Frankfurt was able to determine its position using the Zimmerwald RTCM corrections via Internet with an accuracy of below 2 m.

3.4 The precise positioning service *swipos*-GIS/GEO

After a pilot phase in 2001, the precise real-time positioning service has been available on a commercial basis since March 2002 under the brand name *swipos*-GIS/GEO. Details of the concept can be found in the previous EUREF national report [BROCKMANN et al., 2001].

4. Combining levelling, the geoid and GPS height determination for the Swiss National Height Network "LHN95"

4.1 Concept of "LHN95"

The concept of the new national height network "LHN95" is based on the combined kinematic adjustment of repeated levelling (measured since 1903) and gravity data with orthometric heights from GPS and the geoid. The height reference system was described in a previous national report [SCHNEIDER et al., 1997]. A detailed presentation of the project LHN95 is given in [MARTI et al., 2001].

4.2 Preparation of levelling and gravity data

The project began in 1995 with the collection of 1st and 2nd order levelling data measured since 1903 taken from the archive. The necessary mean gravity values along the plumb-line are calculated from surface gravity, a 25 m DTM and associated density models. The project will be completed in 2003 with the combined kinematic adjustment of the new vertical reference frame [SCHLATTER et al., 2001].

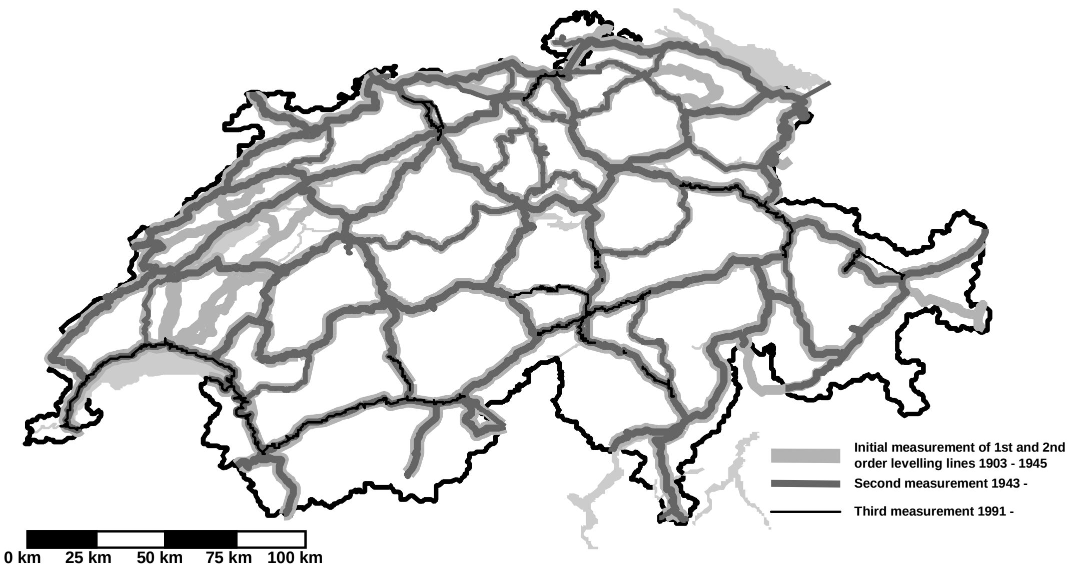

Fig. 6: Different levelling epochs contained in the National Height Network (LHN95)

4.3 Connection to the GPS reference network LV95 and to AGNES

Since surveyors are increasingly using GPS (and the geoid) for height determination, it was a primary goal of the project to reach consistency between both reference frames LHN95 (orthometric heights) and LV95 (ellipsoidal heights from GPS) and the geoid model CHGEO98. Because of random and systematic errors in all three data sets, this condition is usually not fulfilled. In order to make the data as compatible as possible, the GPS reference network LV95 was linked as closely as possible to the levelling network. Today there are 140 GPS levelling stations available which connect the two reference frames and the geoid. Additional points will be measured during 2002 and 2003 (see Fig. 6). Most of these points (82) are AGNES and LV95 (main and densification) points which were directly connected to the levelling network (collocated stations). In order to reach a more homogeneous density all over Switzerland, an additional 51 levelling benchmarks have been linked by short GPS vectors (see Tab. 3).

The quality of the GPS height data depends on the number of independent sessions and the length of the sessions (see Tab. 4). The best quality (RMS < 3 cm) is available at the AGNES stations which are directly connected to the levelling network. The LV95 stations have been measured twice or more with session lengths of at least 12 h (RMS < 5 cm). The auxiliary links by GPS vectors have been measured 1 to 2 times with session lengths of at least 4 h (RMS < 7 cm).

Table 3: Total number of GPS levelling stations at the end of 2001 (planned in 2002)

Links from LN (levelling) to:	Collocated points	Links by GPS	Total # of points
AGNES	4 (11)	7 (12)	11 (23)
LV95 main points	47 (49)	41 (42)	88 (91)
LV95 densification	31 (31)	3 (4)	34 (35)
Other GPS lev. stations			7
Total number (planned)	82 (91)	51 (58)	140 (156)

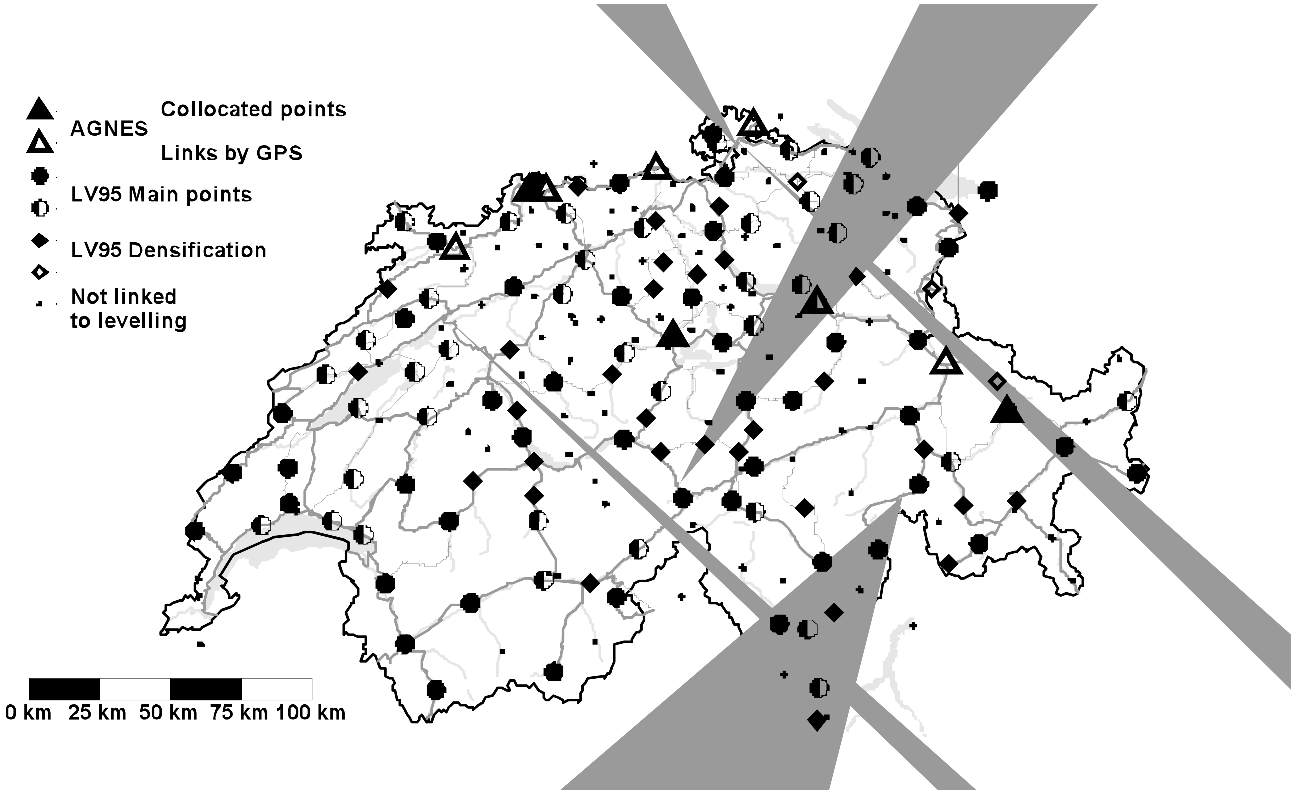

Fig. 7: Connections between the national height network (LHN95) and the GPS reference networks (LV95, AGNES)

Table 4: Connections GPS-LHN95: quality of GPS height data

Type of link from LN (levelling)	Network	# of sess.	Sess. length [h]	RMS of height [mm]
Collocated	AGNES	perm.	24	< 30
Collocated	LV95	$ 2	> 12	< 50
Auxiliary links by GPS	LV95	$ 1	> 4	< 70

4.4 A common adjustment of GPS, levelling and the geoid

The comparison of orthometric heights from GPS and the geoid with orthometric heights from levelling usually shows discrepancies in the order of several cm due to random and systematic errors in the measurements. In Switzerland, these discrepancies are in the order of ±5 cm (except of some outliers) and show a rather systematic behavior (see Fig. 7). In order to correct these discrepancies and to get a consistent height system, it is necessary to perform a common adjustment of all data sets. This is possible if the full variance-covariance information of the three data sets (geoid, levelling, GPS) is available. The approach and first results of this common adjustment are described in [MARTI et al., 2001] and indicate that most of the differences are caused by systematic errors of the geoid. Levelling and GPS received only rather small corrections (see Fig. 7).

In order to improve the geoid model, additional efforts are planned within the next two years. Astrogeodetic observations using a new digital zenith camera *(digital astronomical deflection measuring system; DIADEM)* [HIRT and BÜRKI, 2002] and new gravity data on one side and improvements of the GPS height determination with semi-permanent GPS measurements (automatic processing with AGNES) on the other side will contribute to an optimal consistency of the data sets in the final kinematic adjustment of LHN95.

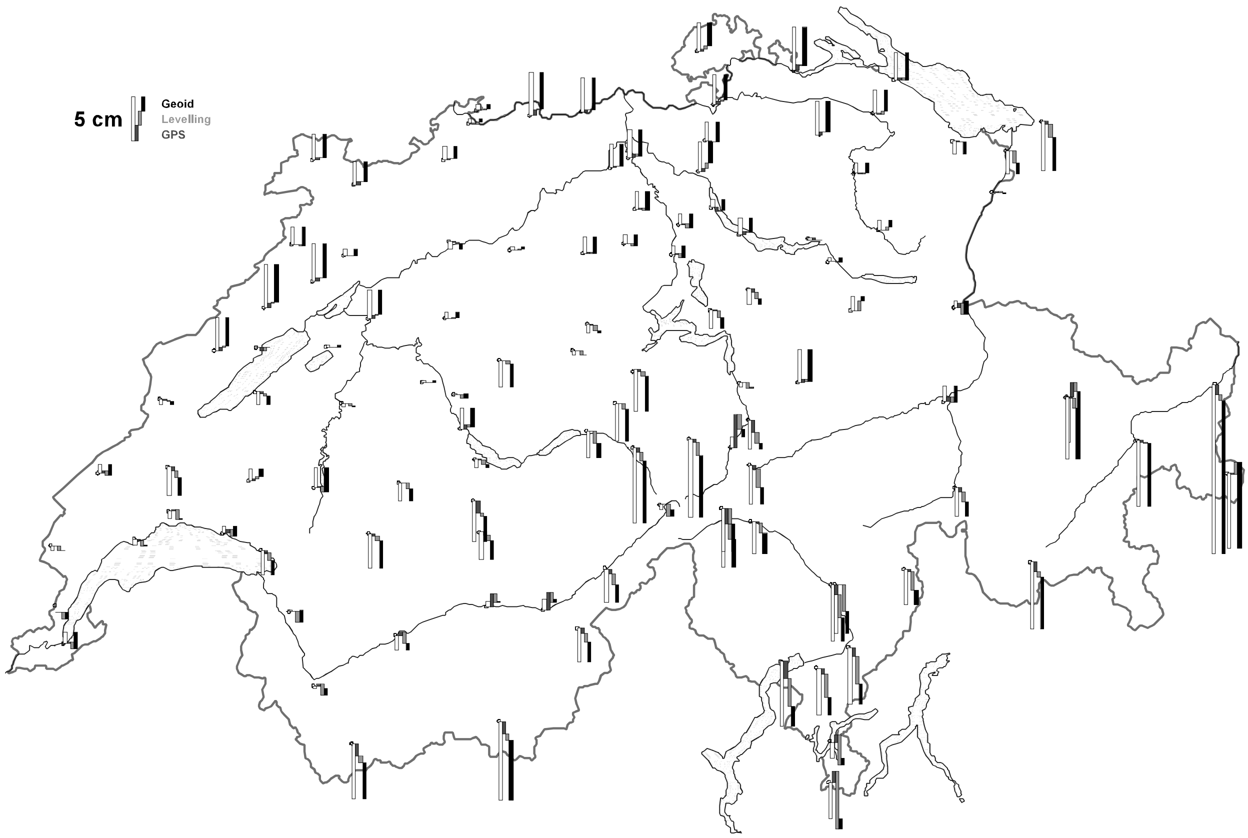

Fig. 8: GPS levelling residuals at stations where the full variance-covariance information of GPS, levelling and the geoid is available and their separation to the individual data sets

5. Collaboration within the GPS meteo project "COST 716"

Since 1999 the Swiss Federal Office of Topography has been active in the European project COST 716 (exploitation of ground-based GPS for climate and numerical weather prediction application). After a successful benchmarking [VAN DER MAREL et al., 2001], ***swisstopo*** has been contributing zenith total delay estimates in near real-time (NRT-ZTD) since Dec. 2001. Fig. 8 shows the stations used. In addition to the 29 AGNES sites, 20 EUREF sites are processed. Furthermore, about 12 sites from other networks, mainly in France, are being used in order to improve the station distribution in the western part of Europe. This area is important because the dominating weather conditions from the Atlantic Ocean usually pass over France before they reach Switzerland. 95% of the solutions arrive at the data archive of the UK met office within 1 hour and 45 minutes (usually within 1:15).

MeteoSwiss used the NRT-ZTD estimates in a test study for numerical weather prediction. The numerical forecast models were computed for the test period of September 2001 in two different ways: A run with assimilated GPS-derived ZTD estimates and a run without assimilated ZTDs. A comparison of the results showed a positive impact of GPS [GUEROVA et al., 2002]. The difference of the integrated water vapor field is given in Fig. 9.

A by-product of the hourly processing is coordinate monitoring. Problems such as the station height change in Samedan (Fig. 4) were detected very early. Cumulative solutions averaging 12-24 hourly solutions already allow the estimation of coordinate changes of the order of below 2 cm.

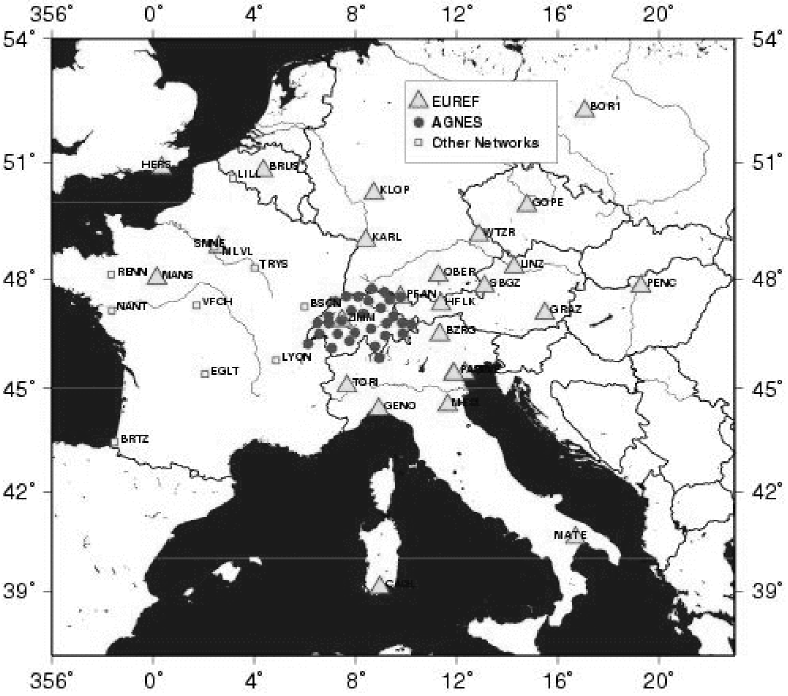

*Fig. 9: European permanent GPS stations processed by **swisstopo** in the COST 716 Project*

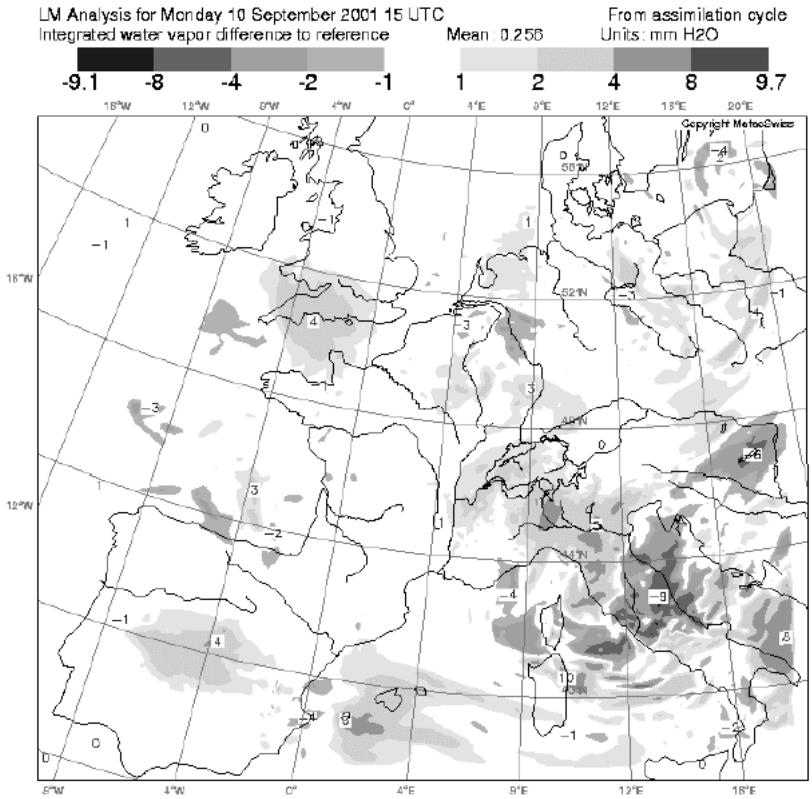

Fig. 10: Difference of the integrated water vapor field (Sep. 10, 2001; 15:00 UTC) with and without assimilated GPS zenith total delay estimates

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