National Report of Switzerland: Geodetic activities at swisstopo presented to the EUREF2011 Symposium

E. Brockmann, D. Ineichen, M. Kistler, U. Marti, S. Schaer, A. Schlatter, B. Vogel, A. Wiget, U. Wild
Swiss Federal Office of Topography swisstopo, Geodesy Division, Seftigenstrasse 264, 3084 Wabern, Switzerland

1 Geostation Zimmerwald

The permanent GNSS receivers ZIMM, ZIM2 and ZIMJ were sending its data to the IGS and EUREF networks without bigger losses. NTRIP data of station ZIM2 are provided in real-time to the three broadcasters of the EUREF-IP activity. Unfortunately, the ZIMJ receiver crashed on October 22, 2010, just one day after the local tie measurements. Discrepancies in the local tie on a level of some millimetres could possibly be explained with thermal expansions of the 9-meter steel masts of the ZIMM and ZIM2 station. A short-baseline analysis of L1 data of ZIM2 and ZIMJ (mounted on the roof) showed especially on the sunny day of the local tie some daily variations of an order of several millimetres. In future, the local tie will be performed under cloudy weather conditions.

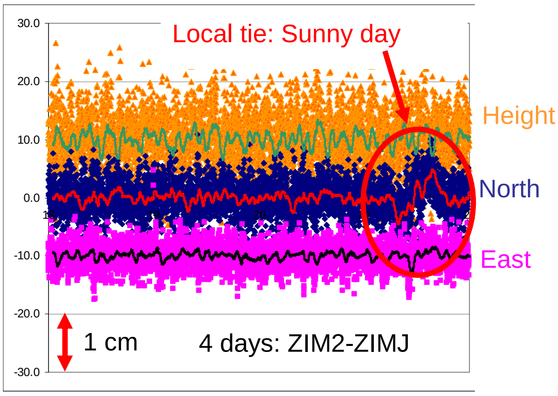

Fig. 1 Results of a L1 GPS analysis of the baseline ZIM2-ZIMJ during 4 days when the local tie was observed.

2 Gravity Field and Geoid

In collaboration with the Federal Office of Metrology (METAS), absolute gravity measurements were carried out in Andermatt (controlling the questionable measurements of 2007) and on the Monte Ceneri (first observations 1994 in collaboration with the Austrian BEV).

Additionally, absolute gravity measurements were collected in Zimmerwald during a longer period of 3 months (instead of 2 observations per year). Fig. 2 shows a good agreement of ±4 µgal (min-max).

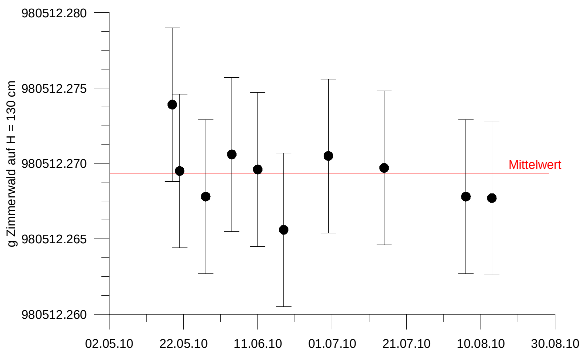

Fig. 2: Results of absolute gravity measurements in Zimmerwald covering 3 months.

3 Permanent GNSS Network AGNES

In 2010, first activities of redesigning the permanent AGNES network were realized. On 9 double stations, where GPS and GPS-GLONASS receivers are simultaneous operating, new robust industry PCs were installed for data collection.

Table 1. Network analyses of permanent GNSS data at swisstopo (status end of 2010).

Network solution	Stations	Processing interval	Delay
1: EUREF (EPN) sub-network	50	daily observations	14-21 days
2: AGNES + sub-net EUREF + third-party sites	118 (41 AGNES)	daily observations	14-21 days
3: AGNES + sub-net EUREF+ third-party sites	115 (41 AGNES)	hourly observations	1:45 hour

For the other 21 stations it is planned to arrange the data flow without any local PC on the station. Furthermore, the connection lines to the federal communication network KOMBV were changed from telephone lines (64 kbit/s) to S2S+ connections which use ADSL lines (5000/500 kbit/s) and as a fall back GSM/GPRS connections. Availability is specified with 97.7 % and test measurements gave delays of 30 msec (ADSL) and 150 msec (GSM/GPRS). This year, more changes are planned, such as the replacement of the software and the provider handling the real-time data. A complete redesign of the RINEX data flow finishes the list of planned activities.

4 Permanent Network Analysis Center (PNAC)

The characteristics of the permanent GNSS networks analyzed at swisstopo are shown in Table 1. The routine operation of the Permanent Network Analysis Center (PNAC) is divided into 3 sub-network solutions, which are generated on an hourly and daily basis. All analyses are done with the Bernese Software BSW5.0. The use of synergies with the global analyses of the permanent network of the International GNSS Service (IGS) performed at the Astronomical Institute of the University of Bern (AIUB), which operates the Center for Orbit Determination in Europe (CODE), could be realized by several software modules which are absolutely identical at AIUB and swisstopo. Furthermore, improvements of the BSW5.0 were developed (e.g. GLONASS ambiguity resolution) which will be included in future updates of the BSW.

The number of analyzed sites has continuously been increased including foreign stations close to the Swiss national border (partly delivering also data in real-time for the positioning service), third-party stations, and new EPN stations.

The main processing products are continuously derived coordinates for reference frame maintenance and zenith total delay estimates for numerical weather prediction. From solution 1 of Tab. 1, swisstopo contributes, as one of several European processing centers of the European Permanent Network EPN, weekly coordinate and troposphere parameters. Solution 2 and 3 of Tab. 1 are used for monitoring the Swiss reference frame in near real-time and generating products used in federal surveying and for scientific applications (GNSS meteorology).

A new linux computer with 24 CPUs and modifications in the hourly processing scheme (3 clusters instead of 2 clusters) speeded up the hourly solutions by 40% end of 2010.

5 Positioning Service swipos®

Very positive is the increasing number of users and licenses sold (see Fig.3). Despite reductions of the fees for using swipos by 30% as a consequence of the strategy pursued by the Federal Act on Geoinformation (see section 7), the total sales volume of the year before was reached.

The availability of the swipos® services can be specified with 99%.

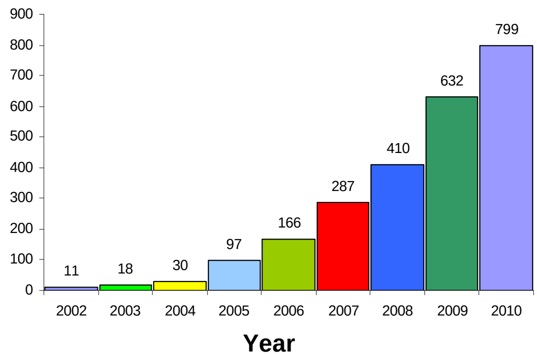

Fig. 3. Development of swipos licences.

6 National Reference Frames

6.1 CHTRF2010 campaign

Between 1988 and 1995, the Federal Office of Topography (swisstopo) installed the Swiss

Reference Network LV95 as the first national network completely determined with GPS observations. Together with the permanent stations of AGNES, this network represents the backbone of the Swiss terrestrial reference frame CHTRF95. As a quality check and for studying the stability of the reference frame, a fourth independent coordinate estimation was realized for all reference points in 2010. During each of the 15 observation weeks (April – October), 2 operators occupied about 16 points using totally 8 GPS receivers and measuring about 43 hours (double as much as in the previous validation campaigns) on each of the 221 LV95 points. The campaign and its analysis are given in detail in (Brockmann et al. 2011).

The results proved the stability of the reference frame on the cm level. The Swiss concept of maintaining the reference frame (Wiget et al. 2010a) suggests to change coordinates exceeding 2 cm in the horizontal plane and 3 cm in height. It was therefore not necessary to change any of the published horizontal LV95 coordinates (which are rounded to the centimeter).

Horizontal velocities derived from AGNES for stations with a time series of more than 3 years and from the campaign data for stations covering at least 3 occupations in more than 4 years resulted in a velocity field with very small horizontal velocities. The hypothesis that there are no movements on the Swiss territory holds true on a 1-σ level of 0.35 mm/year. Vertical velocities cannot be estimated from the campaign data covering almost 20 years.

6.2 Height network

110 km levelling lines (Pfäffikon - Weesen; Rapperswil - Wattwil; Wattwil - St. Gallen) were observed in 2010 and 100 km levelling lines were prepared for 2011. Again, due to a malfunctioning gravimeter, no gravity measurements were performed.

6.3 Transformation from old to new reference frame

The transformation data set CHENyx06, which defines the transition from the old to the new data set (Vogel et al. 2009), was not modified in 2010. To assist the cantons and local authorities in their work to straighten their local networks and to detect network distortions in the old reference frame, swisstopo develops a graphical tool allowing to find best possible interpolations and to find suited reference points.

6.4 Control Point Data Service (FPDS)

The Control Point Data Service (Fixpunkt-Datenservice FPDS) makes available all geodetic control points in a central database. A part of the information may also be obtained over the Internet. A graphical user interface for revisions and for the administration of the database by the cantonal surveying authorities operates stable since the end of 2006. The central database contains 700 points for category LFP1 (responsibility of swisstopo) and almost 100% or 24'600 points for category LFP2 (on average 0.5 points per km^2, responsibility of the 26 cantons and the principality of Liechtenstein, status February 2011, not all data are approved). The database of the height control points contains 8'600 points of category 1 (HFP1) and 6'900 points of category 2 (HFP2). Every day the content of the data base is exported to an INTERLIS format including a checking service to detect inconsistencies.

7 Legal aspects

Since July 2008 the Federal Act on Geoinformation (Geoinformation Act, GeoIA) is in force (http://www.admin.ch/ch/e/rs/c510_62.html).
Its purpose is to assure the rapid, smooth and sustainable availability of up-to-date geographical data over the entire territory of the Swiss Confederation. Furthermore, the GeoIA sets the legal basis for Cadastral Surveying and the Swiss Geological Survey. Geodata and geoinformation shall be made easily accessible to the federal, cantonal and municipal authorities, as well as to the private sector, to the scientific circles and to the general population in the required quality and at reasonable costs, so that the data can be used in a broad variety of applications. To support this goal, a new platform (www.geo.admin.ch) was established where users are able to directly access federal geoinformation, geodata, geo-services and metadata.

Further details such as qualitative and technical requirements for official geodata are issued in successive ordinances to the GeoIA. The 'Geoinformation Ordinance' (GeoIO, SR 510.620) specifies regulations valid for all official geodata under federal legislation. A catalogue of these geodata is an appendix to the GeoIO. The official geodetic reference system and reference frame are stated and the Federal Office of Topography swisstopo is entitled to specify the definitions and technical details. Furthermore the GeoIO issues regulations on the relevant geodata models and presentation models; data collection, updating, management and archiving; data quality, availability, access, use and exchange; geospatial metadata; geodata services (geoservices) as well as fees for the access to and use of geodata and geoservices of the Confederation.

The 'National Survey Ordinance' (NSO, SR 510.626) regulates the National Survey in more detail. The National Survey shall make the geospatial reference data of the Confederation available for civil and military purposes. This task includes in particular the definition of the geodetic reference system and the establishment, updating and management of the reference framework as well as the monumentation and survey of national borders. The NSO governs the responsibilities and entitles the Federal Office of Topography swisstopo to specify further details (e.g. regarding fundamental stations, permanent GNSS stations and analysis center, national gravity network and geoid model).

Based on these legal regulations swisstopo published in 2010 the concepts for data collection, updating and management of the geodetic survey in Switzerland (Wiget et al. 2010a) as well as the quality standards to be observed (Wiget et al. 2010b).

8 Cut-through of the AlpTransit Gotthard Base Tunnel

On October 15, 2010, the main cut-through of the Gotthard Base Tunnel in the Swiss Alps was achieved, with 57 km the longest, and with a depth of up to 2500 m under the surface also the deepest railroad tunnel in the world. Together with the high accuracy requirements for the cut-through of large tunnel networks, there are – especially in the alpine areas – other geodetic characteristics to be taken into consideration such as spatial variations of the gravity field, the kinematics of the upper crust of the Earth as well as the influences of refraction on GPS observations.

The Swiss Railway Company SBB contracted the survey of the tunnel to the consortium "Vermessung Gotthard-Basistunnel (VI-GBT)" consisting of four private companies: Grünenfelder und Partner AG, BSF Swissphoto AG, Studio Meier SA and Studio Gisi SA. The basic geodetic networks above ground (horizontal, vertical and gravity) upon which all survey work for more than 152 km of tunnels in a period of more than 15 years have been based were established in close cooperation with the Federal Office of Topography swisstopo.

With the national geodetic control network LV95 (Landesvermessung 1995) surveyed until the mid-1990s, swisstopo had provided a modern geodetic reference frame with a country-wide homogenous horizontal accuracy (1 sigma) better than one centimeter. There were a total of eight LV95 control points available for the AlpTransit network (see Fig. 3). In addition, further local survey markers were included at each main portal (Erstfeld and Bodio/Biasca) and for each intermediate access tunnel (Amsteg, Sedrun and Faido), thus making the reference to the (old but still official) national survey LV03 and to cadastral surveying possible. The GPS observations for the Gotthard Base Tunnel were carried out by the survey-consortium VI-GBT during only two days in November 1995. The LV95 control points were occupied permanently during the entire measuring campaign of the basis network GBT in order to position the network optimally. The accuracy of the 31 basic geodetic points covering all five portals (an extension of approx. 60 km) was estimated to $1\sigma_{\text{horiz., vert.}} < 10$ mm, the differential accuracy within the network is $< 10^{-6}$. A comparison of the coordinates to those of the network LV95 showed maximum differences (discrepancies from a Helmert transformation) of 5 mm (Haag et al. 1996). In the course of a repeat measurement in 2005, the differences were also within 2-6 mm. The LV95 control points contributed not only to the increase in the accuracy of the network but also to higher reliability, an important component of a tunnel survey.

The geoid model CHGeo98, which is essentially based on deflections of the vertical and also on GPS levelling data, was used for staking out the GBT.

This model, however, is not only a simple reference surface for height determinations but an actual 3D model with which gravity data and deflections of the vertical may be interpolated at any given point beneath and above the earth's surface.

A special investigation (Marti 2002) determined that the mass models from the CHGeo98 would be sufficient for the rigorous tolerances demanded for the construction and cut-through of the GBT and further mass model studies would not be required. In order to determine whether gravity observations would be necessary inside the tunnel or if the extrapolated values for height corrections from the surface to the tunnel section would be sufficient, gravity observations were carried out on a few points around the portals and in the already accessible part of the tunnel in 2005 together with the Institute for Geophysics at the University of Lausanne and compared to the values interpolated from CHGeo98. The resulting maximal discrepancies of less than 3 mgal are negligible for the calculation of orthometric corrections. It was thus established that no systematic gravimetric observations of the GBT would be required and that CHGeo98 provided sufficiently accurate interpolated gravity values.

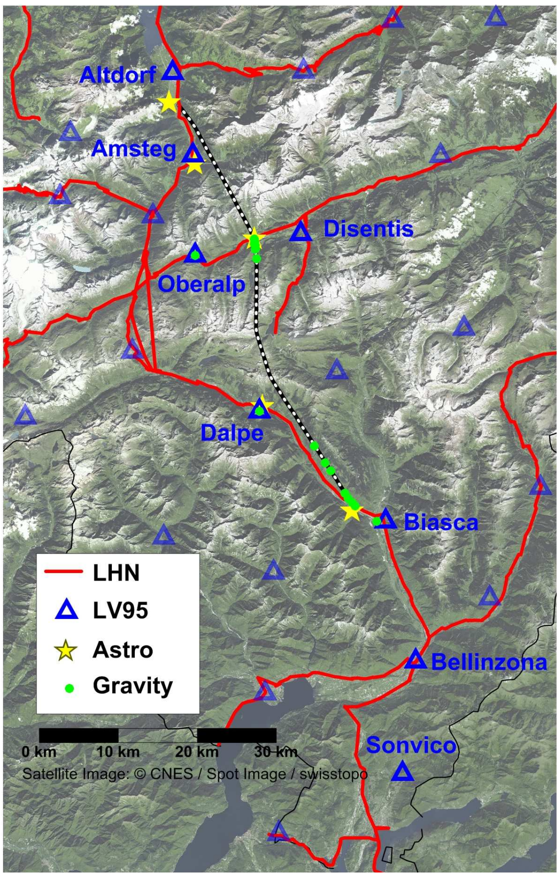

Fig. 3: Part of LV95 network and vertical network (LHN), gravity and astro points of the base network Gotthard Base Tunnel GBT.

Similar to the procedure for the gravity observations, it was also verified that the values computed from CHGeo98 for the deflections of the vertical and astronomic azimuths were sufficient. This was achieved in summer 2005 through astro-geodetic observations carried out by the Federal Institute of Technology in Zurich and by the Technical University of Hannover around the portals and the intermediate access tunnels (Bürki und Guillaume 2010). In this investigation the main result again showed that the interpolated values from CHGeo98 were sufficient for the construction of the GBT and that no further observations would be necessary.

The vertical network of the GBT is based on observations of the national levelling network as well as on calculations from the new vertical network LHN95 (Landeshöhennetz 1995; Schlatter 2007). This network is in turn based on an orthometric height system and was realized through a kinematic readjustment of all observations made since 1903. In addition to the reduction of influences of the gravity field, vertical tectonic movements (Alpine uplift of up to 1.5 mm/year) were predicted and taken into consideration. For the cut-through of the 57 km long tunnel, only 30 km additional precise levelling observations on the surface were required. They served to connect the portals Erstfeld, Amsteg, Sedrun, Faido and Bodio/Biasca to stable markers of the national vertical network LHN. However, further observations extending over several hundred km were carried out for subsidence monitoring, extending the portal networks and for tectonic investigations.

The levelling loop 'mountain pass – vertical shaft Sedrun – railway tunnel' deserves particular attention. Along the mountain pass one obtains usual levelling heights, which are – without gravity reductions – not consistent with a rigorously defined height system, in the vertical shaft orthometric heights, and in tunnels with only a slight grade, almost exact dynamic heights. Without accounting for the gravity field, the loop closures of even error-free observations are only within decimeters. Together with the unavoidable random observation errors, this leaves a small margin for achieving the demanded cut-through tolerance of 12.5 cm (2.5σ).

The project management and the VI-GBT nevertheless decided to stay with the official height system for Switzerland (LN02) since the project planning as well as the connecting constructions had already been carried out in this vertical framework. The most important reasons why the official Swiss heights (LN02) differ from orthometric heights by decimeters are:

– neither the influence of the gravity field nor the different kinds of heights are taken into account;
– precise levelling observations are still constrained into nodal points whose heights are based on the 'Nivellement de Précision' dating from 1864-91;
– therefore, known recent height changes are also not taken into consideration.

Table 2: The accuracy of LHN95, comparison between LHN95, pure levelling heights (LNIV) and LN02 relative to portal Erstfeld as well as vertical uplift with respect to the reference point Aarburg.

Portal	Height	Length GBT	ME LHN95	LHN95 - LN02	LNIV - LN02	Uplift
	[m AMSL]	[km]	[mm; 1σ]	[m]	[m]	[mm/a]
Erstfeld	460	0	± 0 (R)	0 (Ref.)	0 (Ref.)	0.67
Amsteg	510	8	± 3	0.02	0.01	0.78
Sedrun	1410	21	± 9	0.13	0.01	0.80
Faido	760	40	± 7	0.11	0.05	1.25
Biasca	300	57	± 8	0.11	0.09	1.22

In order to counteract the disadvantages and shortcomings of LN02, corrections had to be applied to the heights during the tunnelling stages, namely:

- influence of the gravity field in the tunnel (orthometric corrections and theoretic loop misclosures);
- influence of the differences between LHN95 and LN02 (see Table 2);
- influence of the different uplift rates (see Table 2), which theoretically slightly exceeds 1 cm during a construction period of 10-20 years.

Based on the available height and density models which were also used for the geoid determination, swisstopo calculated a priori orthometric corrections from the project coordinates for VI-GBT. Fig. 4 shows the distribution for the cut-through Amsteg ⇔ Sedrun Nord. It is striking that the vertical shaft has no direct influence; the vertical distance corresponds to an orthometric height difference. If no corrections were applied, the cut-through error would after all still be approx. 3.8 cm. The overall-network-adjustment with observations > 10 years gave a posteriori accuracies (1 σ) for the most important observations as follows: 0.27 mgon for horizontal angles, 1.08mgon for gyro-azimuths, 1.6 mm/km for distance-measurements, 0.9 mm/km for precise levelling.

Orthometric corrections in the range of > 10 cm had been applied underground.

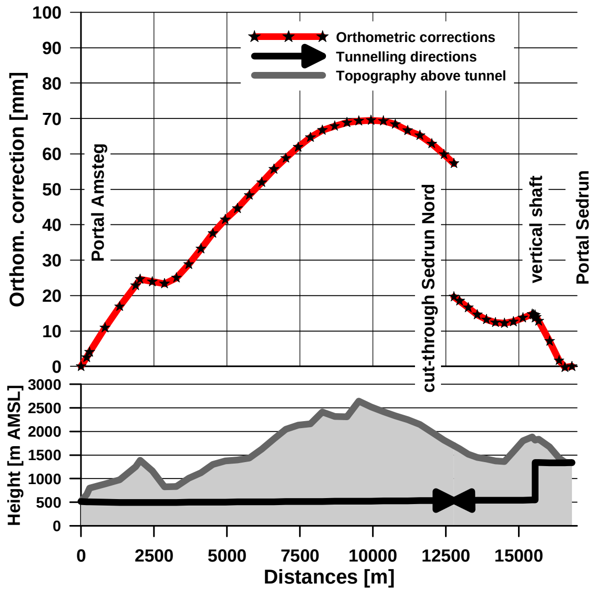

Fig. 4: A priori orthometric corrections in the tunnel derived from orthometric heights in the portals.

Table 3: Cut-through-results (courtesy and copyright VI-GBT).

Date	Section	Length [km]		cut-through [mm]		
				cross	long	vertical
22.08. 2006	Faido Bodio	4.1 15.7	19.8	92	12	17
14.1. 2007	Amsteg Sedrun	13.3 4.0	17.3	137	21	3
16.06. 2009	Erstfeld Amsteg	7.8 2.3	10.1	14	33	5
15.10. 2010	Sedrun Faido	15.0 8.4	23.4	81	136	11

The cut-through-results in five sections of the 57 km long Gotthard Base Tunnel are summarized in Table 3.

From a geodetic point of view, two aspects are special highlights:

1) The 4 km long section of Sedrun towards Amsteg has to be drilled starting from the bottom of the 800 m vertical shaft in Sedrun. For this purpose, a vertical plumbline to transfer coordinates, height-

difference and azimuth has to be measured with maximum accuracy. Different concepts (mechanic plumbline, optical plumbline and inertial sensors) have been used and integrated to a combined solution.

2) The break-through-results in vertical component are exciting "good". Considering

- very long levelling distances with height-differences > 1000 m in the Swiss Alps,
- height-measurements in the 800 m vertical shaft Sedrun
- and extensive model-based height-corrections (orthometric corrections, kinematic modelling of vertical movements)

these results are a perfect "proof of concept" for all involved geodesists and surveyors.

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