# EUREF'03: National Report of Switzerland

## New Developments in Swiss National Geodetic Surveying

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### 1 Introduction

Beginning in 1988 the Federal Office of Topography (swisstopo) has conceived a new national geodetic reference system CHTRS95 which should replace the existing frames LV03 (position) and LN02 (height) with its new reference frames CHTRF95 (global) and LV95 (local). CHTRS95, which is closely related by a geometric transformation to ETRS89, also consists of a new height system, a geoid model on the cm level and a kinematic model.

After 15 years most elements of the new system have been realized and most of the data is available to the user. The fundamental station Zimmerwald together with 5 EUREF stations links the national networks to the European and worldwide reference frames. Various geodetic measuring techniques such as SLR, GPS and gravimetry are already collocated at Zimmerwald. As a contribution to the ECGN initiative, the number of measuring techniques is presently being increased.

The Automated GPS Network (AGNES) with 29 permanently operating GPS stations is used for various applications such as real-time positioning and GPS meteo. It is optimally integrated into the EUREF permanent network. The national GPS network LV95 has been densified and includes 206 well-monumented control points. A large effort has been undertaken to establish a new height reference frame LHN95 which, together with the new geoid, is compatible with the 3D frame of LV95.

Presently geodetic work is focused on the following tasks:
- Connecting geodetic networks (AGNES, LV95, LHN95 etc.) with the objective of making them compatible (GPS–leveling)
- Completing the combined kinematic adjustment of LHN95
- Improving the geoid model
- Developing a local–regional kinematic model describing tectonic motion
- Improving the access to geodetic data by the user (Internet services)
- Making available procedures for the transformation between old and new reference frames (position and height)
- Linking the Swiss Positioning Service *swipos* to those of the neighboring countries (e.g. SAPOS)
- Practical application of GPS humidity measurements to meteorology

### 2 Fundamental Station Zimmerwald

The fundamental station Zimmerwald is jointly operated by the Astronomical Institute of the University of Berne (AIUB) and the Swiss Federal Office of Topography (swisstopo).

#### 2.1 SLR observations

Since 1997, when the first SLR observations were performed with the new SLR system in Zimmerwald, a continuously increasing number of observed passes could be submitted to the International Laser Ranging Service (ILRS).

Although there was an almost two-month shutdown of the station due to maintenance (re-coating of the primary mirror), Zimmerwald ranked # 9 out of about 40 stations regarding the total number of collected passes, and # 5 in the rating with respect to the number of Lageos normal points. From March 16 to 22, 2003, Zimmerwald collected the largest number of passes for that week worldwide.

Thanks to the possibility of automated and unattended operation or remote control during limited times (typically a few hours per day), a nearly 24-hour tracking coverage can be realized with only two shifts per day.

Zimmerwald was the first ILRS station to submit dual-color range observations on a regular basis between mid-August and December 2002.

#### 2.2 GNSS observations

Presently the following GNSS receivers are operating in Zimmerwald:

- Trimble 4000 SSI receiver (main receiver, providing tracking data to the IGS)
- Ashtech Z18 (combined GPS/GLONASS receiver)
- Javad Legacy receiver (combined GPS/GLONASS receiver)

The Trimble receiver runs with the GPS Base Station Software and provides daily files to the IGS data centers. Furthermore, hourly files are generated and distributed with a time delay of a few minutes, and are used for near real-time applications by the IGS and other institutions. The delivery rate of the daily observation files was very high during the last three years: 99% for 2000, and nearly 100% for 2001 and 2002. In addition, the Trimble receiver provides epoch-wise GPS data in real-time to the central AGNES server, which is one of the currently 29 AGNES stations (see chap. 3).

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In addition to the main GPS receiver, two combined GPS/GLONASS receivers are installed at Zimmerwald, both providing data for the IGLOS-PP. This International GPS Service Pilot Project is a follow-up project of the former IGEX-98 campaign and maintains a global station network and provides precise orbits for the GLONASS satellites.

## 2.3 Contribution to ECGN

Switzerland contributes to the ECGN project with various observations in Zimmerwald [Brockmann et al., 2003].

# 3 Permanent GPS network AGNES and positioning service

The Automated GPS Network of Switzerland (AGNES) reached its final configuration of 29 stations by the end of 2001. During 2002 the last refinements of the station installations were done, including an improved lightning protection unit and a remote-accessible power switch for the station computers. In addition, local ties and the connection to the old national first order network LV03 were measured at 23 stations in order to contribute to the determination of the transformation parameters between the old (LV03) and the new reference frame (LV95).

The overall performance of AGNES was excellent, and the availability of the RINEX data files on the Web server was 99.1% (mean value over all stations). At 20 stations the station outages were below the indicator of 3 days/year, at 9 stations this value could not be attained. These "critical stations" were identified, and organizational and technical actions were taken in order to improve the availability of the data.

For the real-time positioning service swipos-GIS/GEO, a new version of the Virtual Reference Station (VRS) software was installed, which performed better with respect to stability, initialization times and accuracy. In addition, the new software version allows the storage of real-time estimates of the troposphere. Comparisons of these "real-time" tropospheric parameters with those of our geodetic post-processing showed a good agreement of the two methods (see chap.4).

Parallel to the software updates, the server architecture was enhanced. The VRS computation was separated from the data communication and the data storage on the Web server. In addition, a new software tool allowing the VRS computation for post-processing applications was installed on the AGNES Web server. The new configuration provides a maximum flexibility for data communication (e.g. data exchange over the Internet, see below).

The real-time service swipos-GIS/GEO and the corresponding SAPOS service in Baden-Württemberg (Germany) were connected over a direct phone line, which will be replaced by an Internet connection as soon as possible. The data of 9 stations are exchanged on a real-time basis, allowing an improvement of the quality of VRS processing in the region along the border between Germany and Switzerland. Connections to SAPOS in Bavaria (Germany) and to Austria are planned and will be realized within the next year.

The developments of EUREF-IP were followed closely. First tests were performed in August 2002 and showed good results even for RTK applications over Internet. Swisstopo would therefore like to become an "Internet Broadcaster" within EUREF-IP for DGPS correction data. The installation of the corresponding server infrastructure is planned for the end of 2003.

# 4 Analysis of permanent GPS networks

The permanent GPS networks analyzed at swisstopo are shown in Tab. 4-1.

| Network | Stations | Analysis interval; Delay |
|---|---|---|
| EUREF subnet | 20 (1 AGNES) | daily; after 21 days |
| AGNES + EUREF subnet | 65 (29 AGNES) | daily; after 21 days |
| AGNES + EUREF subnet | 63 (29 AGNES) | hourly; after 0.5 hours |

**Tab. 4-1**: Routine GPS data analysis at swisstopo

The data of the AGNES sites have been monitored since the end of 1998 on a daily basis. In addition to the 29 AGNES sites, 40 EUREF permanent sites are processed with 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 possible site movements. An updated multi-year solution, where the site coordinates and velocities are solved for, is automatically generated after having processed an additional week of data. The results are e.g. estimated velocity and repeatability plots. As an example, the horizontal velocities relative to Zimmerwald are shown in Fig. 4-1.

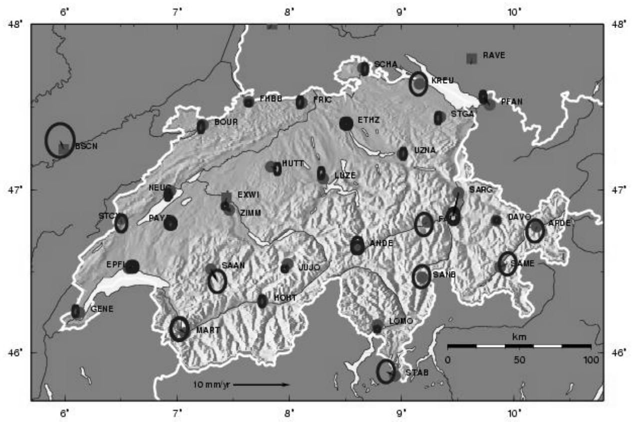


**Fig. 4-1**: Horizontal site velocities in ITRF00 (relative to Zimmerwald. The time span of the sites with the longest "history" is summer 1998 till May 2004).

Since 1999 swisstopo 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 December 2001. 95-98% of the solutions arrive at the data archive of the UK met office within 1 hour and 45 minutes.

*MeteoSwiss* used the NRT-ZTD estimates in a test study for numerical weather prediction. The numerical forecast models were computed for the different test periods (summer, autumn, winter) in two different schemes: 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] for summer and a slightly negative impact for winter. A by-product of the hourly processing is the monitoring of the site coordinates. Cumulative solutions averaging 12-24 hourly solutions allow the detection of coordinate changes of the order of 2 cm.

Swisstopo will also be active in the follow-up European project TOUGH "Targeting Optimal Use of GPS Humidity Measurements in Meteorology" (2003-2005).

Since January 2003, ZTD values can also be extracted from the real-time positioning software GPSNet 2.0 with accumulation intervals of 1 minute with a negligible time delay.

The results of the different analyses are available on http://www.swisstopo.ch/en/geo/pnac.htm.

# 5 National reference frame LV95 and its relation to the old networks

## 5.1 The national reference frame LV95

The densification of the GPS network LV95 has been completed on the national level. There are a total of 206 well-monumented control stations serving as the basis for the reference frame. In order to ensure the transition between the old and the new reference frame, transformation programs were developed, one each for height and position. These control points together with the AGNES stations serve as a reliable basis for the determination of the transformation check points.

## 5.2 Transformation LV03 ⇔ LV95

As in many other countries, the transformation between the old reference frame (LV03), determined mainly by triangulation, and the new GPS reference frame (LV95) still has to be realized. Due to the distortions of the triangulation network in the order of more than 1.5 m (see Fig. 5-1), a simple modeling of the differences by means of a 4-parameter similarity transformation does not give adequate results. A possible solution would be to divide the country into sub-regions and to use individual transformation parameters for each sub-region. But this would result in ambiguous coordinates along the boundaries. Another possibility that was chosen by several countries was to model the differences by polynomials of a certain degree. This method causes the problem of reversibility of the transformation and can lead to unrealistic results in regions without known common points.

Switzerland has chosen another method which is called FINELTRA (finite element transformation), whereby the whole territory is covered with triangles. For each of these triangles an affine transformation with 6 parameters is defined. This method has the following advantages:

- the transformation is continuous - no ambiguous coordinates at the boundaries
- the transformation is reversible and works in both directions
- the common points which are used as transformation check points in both networks transform exactly to the coordinates of the other network

Up to now the mesh of triangles has been defined on the level of the 1st and 2nd order triangulation points (Fig. 5-2) which allows a transformation in the order of about 5 to 20 cm, depending on the region and the quality of the old triangulation. Presently the cantonal surveying authorities are working on further densifying the triangles.

Since FINELTRA is a rather special solution which cannot be implemented easily in GPS receivers, an approximation of this method had to be developed, where the differences between LV03 and LV95 are calculated in a regular grid of 1-km spacing. This grid can be stored directly in the GPS receivers and the surveyors obtain the still official LV03 coordinates in real-time. For a 1-km grid maximal differences are usually better than 1 cm compared to the solution of FINELTRA.

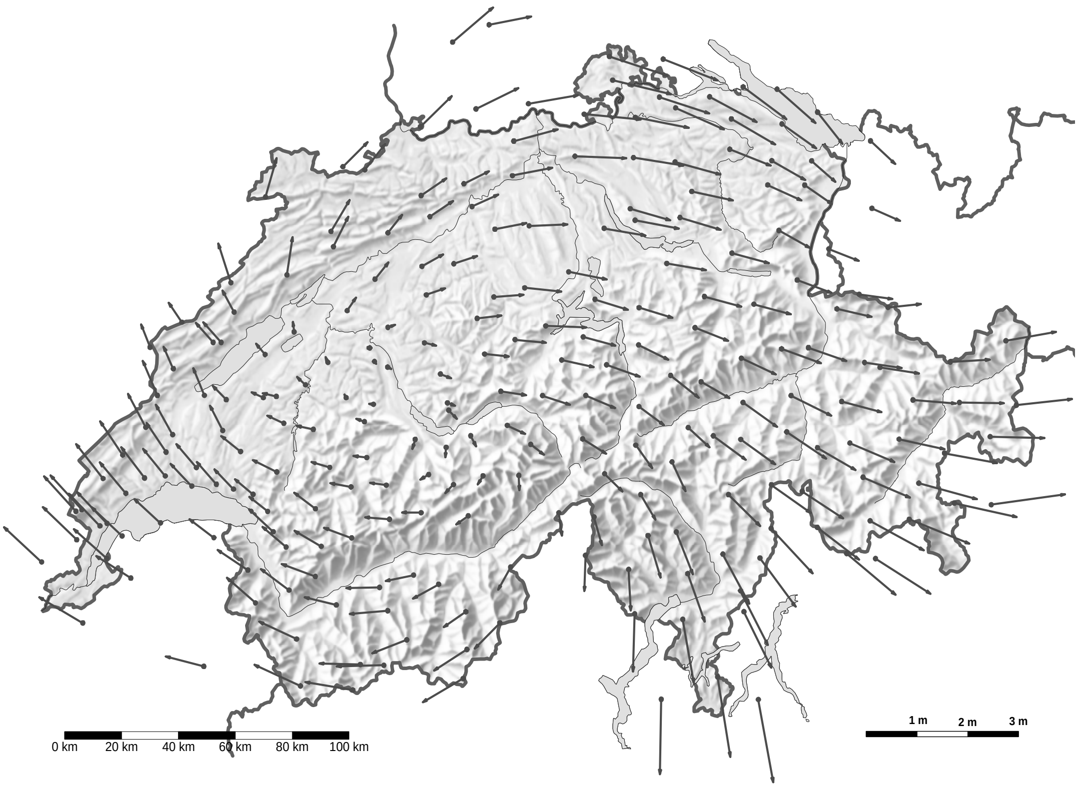


**Fig. 5-1** Differences LV95 minus LV03

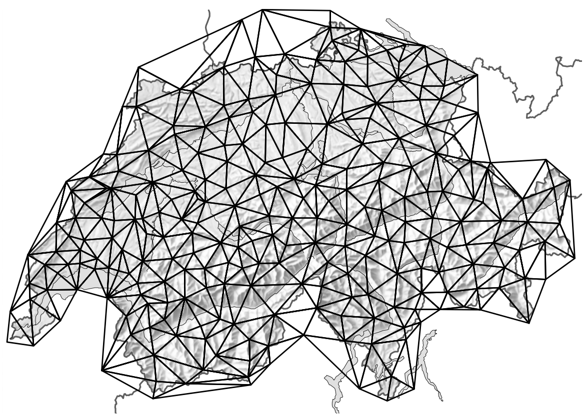

**Fig. 5-2** Triangles defined by 1st and 2nd order triangulation points

## 5.3 Transformation LN02 ⇔ LHN95

A similar problem as the one for the position is the transformation of heights between the old leveling network LN02, which was adjusted without taking into account the influence of the gravity field, and the new orthometric height system LHN95. Due to the special structures of leveling networks, an approach with triangles, as it was used for position, is not recommendable. In addition, the differences between LN02 and LHN95 show a strong correlation with the height. Therefore, an approach was chosen that splits the differences into one part that is a function of only the horizontal position and into a second part that is a function of the elevation as well. The first part (Fig. 5-3) is identical to the differences between LN02 and normal heights, and reaches amounts between -20 and +10 cm. This part includes the distortions of LN02, the influence of vertical movements and a part of the influence of the gravity field. It shows practically no correlation with height.

The second part of the differences, which is identical to the difference between normal heights and orthometric heights, works like a local scale factor. It reaches amounts between -40 and +220 ppm. The Bouguer anomalies are a very good approximation for this scale factor.

Therefore, the total of the differences are modeled by the function

$$H_{LHN95} = H_{LN02} + f(x,y) - \frac{\Delta g_{Boug}(x,y)}{g} \quad H$$

The transformation calls for one grid that represents the differences between LN02 and normal heights f(x,y), and another grid of the Bouguer anomalies. Near the leveling lines and in flatter areas, the accuracy of the transformation is in the order of ±2 mm. In mountainous regions the accuracy is decreased and can reach amounts of up to 2 cm.

Fig. 5-4 shows the total of the differences between LN02 and LHN95, which are between -20 and +60 cm. The correlation with the height is clearly visible.

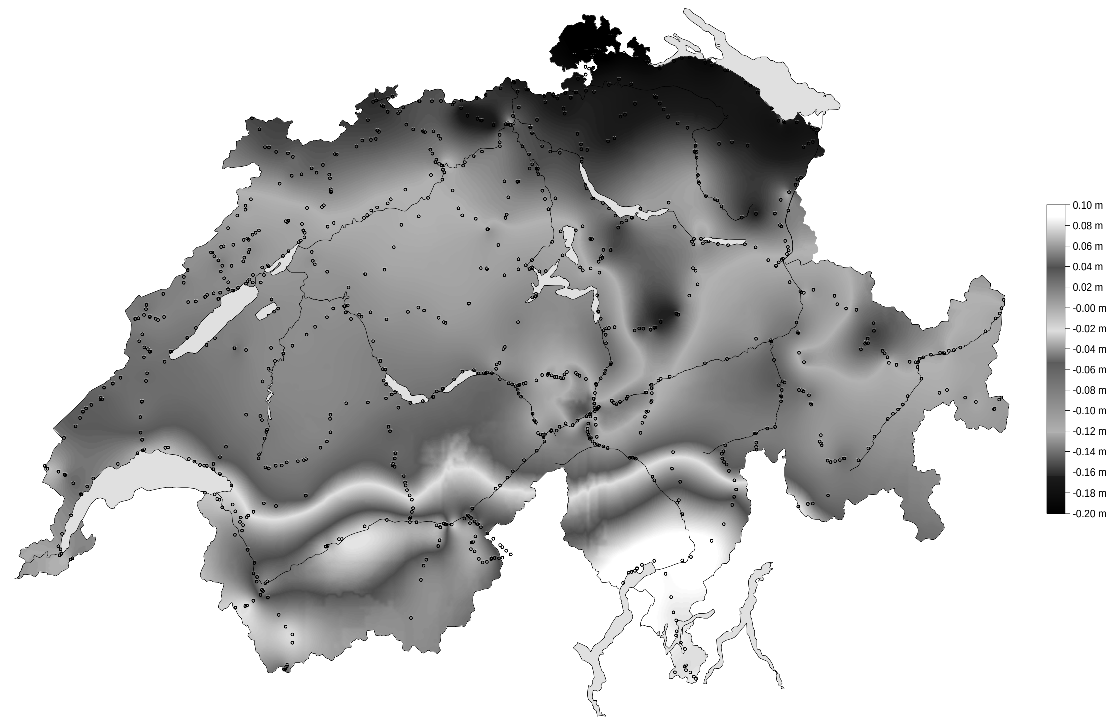


**Fig. 5-3** Differences between LN02 and normal heights

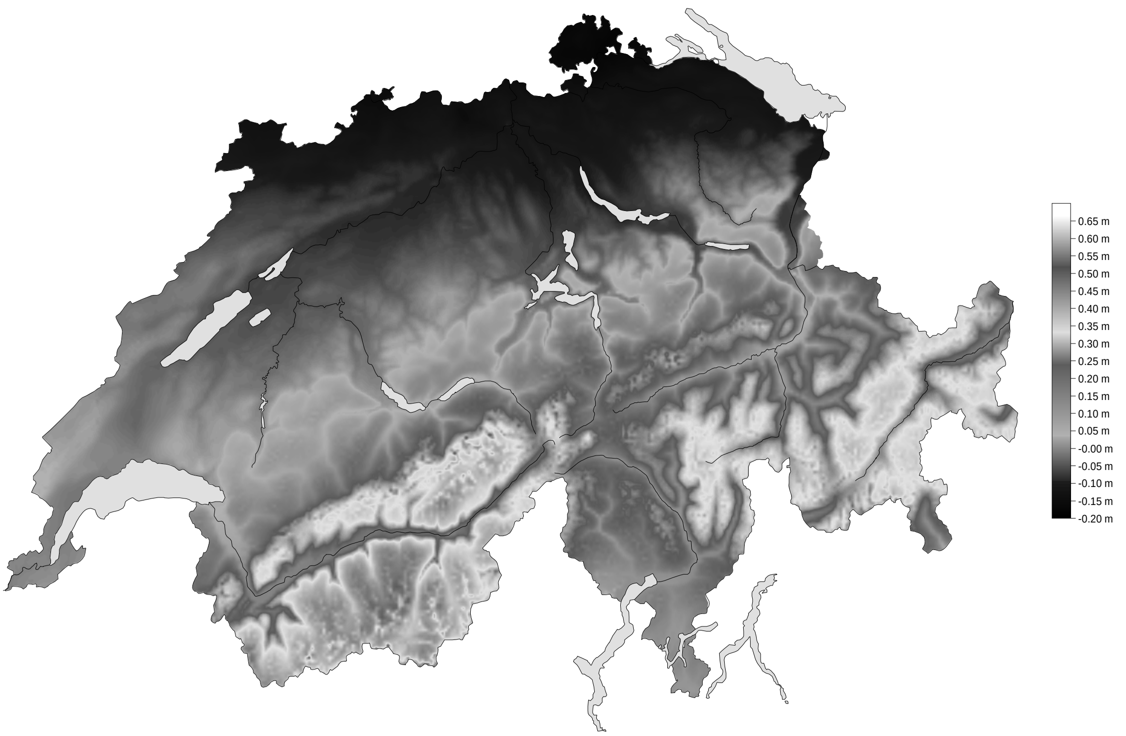


**Fig. 5-4:** Differences between LHN95 and LN02

# 6 Maintenance of networks in Switzerland

The organization and the revision cycle of the various networks are defined in the internal report 02-01 "Landesvermessung der Schweiz, Unterhaltskonzept der geodätischen Netze" [Santschi et al., 2002]. The revision work, quality standards, data management, documentation and archiving are defined for the various categories. All stations of the European networks are integrated in these categories and thus their maintenance is ensured.

## 6.1 EUREF stations

This maintenance concept includes the following networks:

- non-permanent EUREF stations
- fundamental station Zimmerwald

## 6.2 National control points

This maintenance concept includes the following networks:

- the permanent stations of the Automated GPS Network of Switzerland, AGNES (including the fundamental station Zimmerwald)
- stations of the GPS network LV95
- transformation fiducial points for the conversion of the national triangulation network LV03 ⇔ national GPS control network LV95 (first order points)
- control points of the old LV03 (first order points)
- height control points (benchmarks) of the national height network LHN95 (first order points)
- test networks of the national survey

The organization and revision cycles are shown in Tab. 6-1.

| Tasks | number of sites | distance | establishment | maintenance | | |
|---|---|---|---|---|---|---|
| | | km | when | what | where | when |
| **Zimmerwald** | 1 | 250 | -- | operation/measurement | CH | perm./yearly |
| **EUREF stations** | 3 | 150 | if required | inspection | CH | every 5 years |
| **AGNES stations** | 29 | 50 | if required | operation/inspection | CH | perm./every 5 years |
| **LV95 stations** | 206 | 15 | if required | inspection | CH | every 5 years |
| **First order points (LV03)** [1)] | 3000 | 5 | no new sites | inspection<br>inspection | Centr.Plateau<br>Prealps/Jura<br>Alps | every 15 years<br>every 25 years<br>if required |
| **First order leveling points (LHN95)** | 9000 | 3 | if required | inspection | CH | every 15 years |
| **Test nets** | 2 | 0-5 | if required | inspection | CH | every 5 years |

[1)] Maintenance will be discontinued when LV95 is introduced as the reference frame for all surveying applications in Switzerland

**Tab. 6-1** Maintenance concept of the Swiss control points

# 7 Current projects

## 7.1 Control point data service

The schedule of the initial project "Datashop Geodesy" was revised and renamed "Control point data service" in June 2001. The focus of this project is no longer in just preparing the data of the control points for use on the Internet, but in establishing and updating a central database of the control points together with the surveying authorities of the cantons, whereby the data will be made available to customers via the so-called "Central Point of Delivery".

In the scope of the transition from the old triangulation network LV03 to the new GPS control network LV95, it is very important to maintain and keep up the data of the control points. In order to achieve this goal, close collaboration is required between the Geodesy Division, the Federal Directorate for Cadastral Surveying and the cantons. Currently a Java user interface is being programmed and the data from swisstopo and the cantons are being imported.

## 7.2 GIS for the national border

The responsibility of the technical administration and the maintenance of the national border network lie with the Geodesy Division. For some time already, the main focus has been on drafting a new maintenance and documentation concept on the one hand, and on coordinating this information with the official cadastral surveying data on the other hand. Therefore, in addition to the daily business, the efforts were concentrated on this concept, which resulted in the new project "National Border".

The project consists of the following tasks:

- securing and maintaining the points of the national border together with the neighboring countries
- modernizing the data management and documentation
- making the coordinates available in the European reference frame ETRF89 as well as in the reference frames of the neighboring countries
- preparing the data and their integration in the GIS of the official cadastral survey and in the topographic database

The data management is to be part of a GIS. The same instrument should also be used for the administration of the boundaries between cantons, districts and municipalities. In addition, the data model should be revised and made available in the geographic data standard INTERLIS in order to guarantee a uniform data transfer. This conversion should be realized by the end of 2007.

## 7.3 New national height system LHN95

The activities in 2002 were mainly focused on the following subjects:

- integrating the new observations 2001/02 of the 1st order leveling network and the connections to the AGNES and LV95 stations
- documenting the network concept LHN95; observation schedule 2004-2008

- collaboration in the CHGeo2003 campaign [Brockmann et al., 2003]
- coordination with the users of the official cadastral survey and GIS
- developing the software module for the transition LHN95 ⇔ LN02 (see chap. 5.3)
- finishing the scans for the site documentation
- developing the new database in the scope of the project "Control point data service" (see chap. 7.1)

The introduction of LHN95 as the official vertical reference frame for cadastral surveying was rejected by the surveying authorities of the cantons. Therefore, the valid height reference frame for official cadastral surveying is still the "old" LN02. However, LHN95 will remain indispensable for applications in national surveying, scientific research, for the integration of European height systems, and for large engineering projects such as the new Alpine railway tunnels (AlpTransit). As a consequence, increased significance will be placed on the software for the transformation between LN02 and LHN95.

## 7.4 Swiss 4D: Establishing a kinematic model for Switzerland

Based on the data of the Swiss permanent GPS network AGNES and repeated measurements, swisstopo is developing a kinematic model in collaboration with the Geodesy and Geodynamics Lab of the Swiss Federal Institute of Technology in Zürich, which will take into account recent tectonic movements (see Fig. 7-1).

The determination of a local–regional kinematic model for Switzerland (CHKM95) is an essential component of the new definition of the Swiss geodetic reference system CHTRS95. CHKM95 describes regional movements in Switzerland relative to the European reference system ETRS89 as well as local movements in the geodetic networks LV95 and LHN95 in all three dimensions.

Last but not least, the deformation of space and time will be analysed so that tectonic interpretations are possible. Continuous spatial velocity or strain rate fields are suited for the description of the deformation processes. Also, seismic and geological information is of interest.

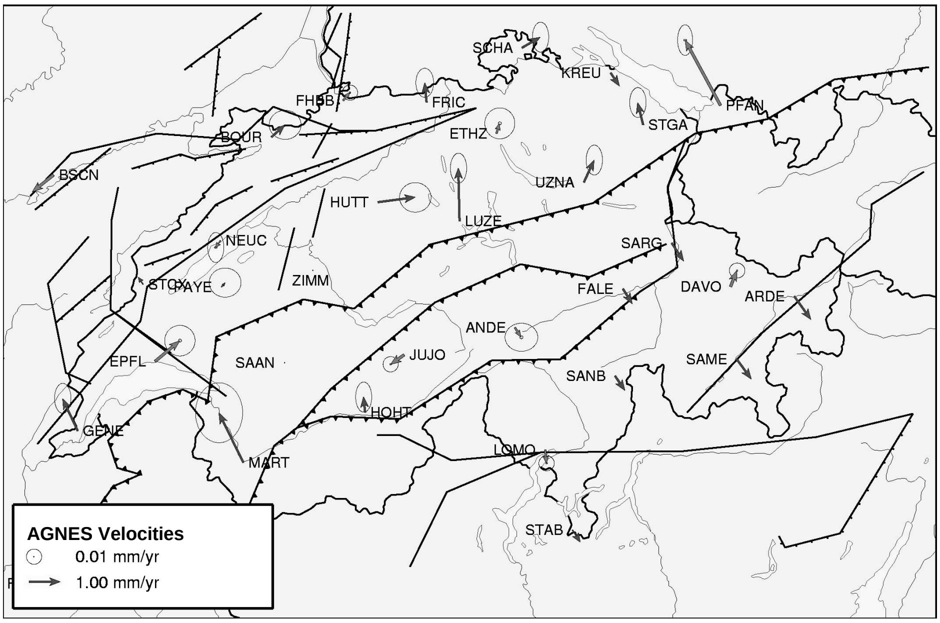


**Fig. 7-1**: Swiss permanent GPS network (blue: station has been operating more than 4 years)

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