Realization of a Swiss Combined Geodetic Network (CH-CGN)

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Abstract

In order to contribute to the European geodetic projects ECGN (European Combined Geodetic Network) and EUVN-DA (European Unified Vertical Network – Densification Action) of EUREF, a joint effort under the auspices of the Swiss Geodetic Commission (SGC) and in close co-operation with national (and international) institutes in the field of geodesy and metrology was launched in 2003. The main objective of this project entitled "Swiss Combined Geodetic Network (CH-CGN)" is the combination of different geodetic networks and observation types in order to attain the consistency of different spatial reference frames, the height systems and the geoid. The primary goal was the collocation of various geodetic observation types such as SLR, GNSS positioning, gravity and levelling, as well as deflections of the vertical, etc. at the fundamental station Zimmerwald, which in this way may qualify as an ECGN core station. A second part of the project deals with the connection of national reference networks such as the Automated GPS Network of Switzerland (AGNES), the GPS reference network (LV95) and the new National Height Network (LHN95). Astronomical measurements using two digital zenith camera systems, GPS-levelling, as well as absolute and relative gravity measurements were performed with the objective to improve the local geoid model. A combined kinematic adjustment of the GPS coordinates, the levelling network and the new geoid model should lead to a consistent national geodetic reference frame.

1 Contribution to ECGN

The proposal by Switzerland to the ECGN project [*Ihde et al., 2002*] and to the EUVN-DA project [*Kenyeres et al., 2002*] was presented at the EUREF03 symposium in Toledo [*Brockmann et al., 2003*].

The combination of the different networks involves many different subjects in the field of geodesy. It covers permanent observations of satellites using Satellite Laser Ranging (SLR) and the Global Positioning System (GPS). These activities are a permanent task and already automated to a large extend [*Schneider et al., 2004*]. Furthermore, specialists in the field of gravity measurements, astronomical observations, classical geodetic techniques and meteorological measurements need to be involved in the project.

A complete list of the activities and the present status is given in Table 1.

In the following sections some of our ECGN activities of the years 2003 and 2004 are presented.

1.1 Deflections of the vertical

With two digital zenith cameras TZK2-D from the University of Hanover and DIADEM from ETH Zurich (see section 2.2) several measurements of the deflection of the vertical were carried out in Zimmerwald. Figure 1 shows the repeatability of 7 measurements of the TZK2-D in October 2003. A standard deviation for each measurement of about 0.10“ could be achieved.

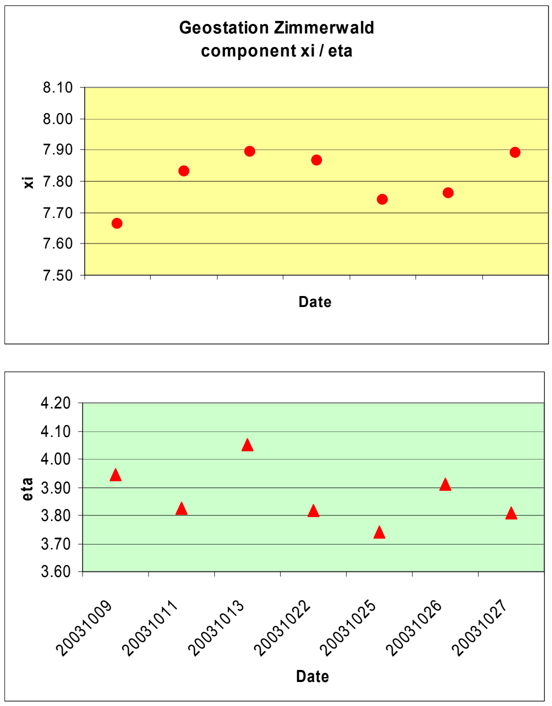

Figure 1: Repeatability of measurements of deflections of the vertical for the components xi and eta using the TZK2-D zenith camera. Standard deviation xi: 0.09“, eta: 0.10”.

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	Geodetic observation	Type	Interval	Quality	Organization	Status
1	SLR observations (dual color)	permanent	24 h	< 10 mm (RMS)	- AIUB - *swisstopo*	☑
2	Positioning using GNSS (GPS, GLONASS, GALILEO)	permanent	24 h	3 mm (pos.) 10 mm (hgt.)	- AIUB - *swisstopo*	☑
3	Astro geodesy (digital zenith camera)	repeated (epochs)	10 years	0.2" (arcsec)	- IGP ETHZ - *swisstopo*	☑
4	Optical astronomy with CCD arrays (link to astronomical reference system; proj. CQSSP)	epochs	sub-yearly	< 0.1 " (arcsec)	- AIUB - *SGC*	(☑)
5	Absolute gravity measurements (FG5)	repeated (epochs)	yearly	~10-8 ms-2 ~(1µGal)	- metas - *swisstopo*	☑
6	High-frequency gravity variations (tidal gravimeter)	permanent	1 min	10-8 ms-2 (1µGal)	- IGP ETHZ - *swisstopo* - *AIUB, - SGC*	(☑)
7	Gravity field related heights and relative vertical velocity (links to EVRS	repeated epochs	10 years	1 mm / km 0.1 mm / y	- swisstopo	(☑)
8	Meteorology (air temp., pressure, humidity) WV radiometry	permanent epochs	24 h repeated	IGS/ILRS requirements	- AIUB - IGP ETHZ - *SGC*	☑
9	Eccentricities through local network and through links to the national reference networks	repeated	yearly	< 1.0 mm (3D)	- swisstopo	(☑)

Table 1: Status of the Swiss ECGN contribution

1.2 Absolute and relative gravimetry

With respect to the concept provided to ECGN, absolute gravity is measured once a year in Zimmerwald.

On March 16-17, 2004, the Swiss Federal Office of Metrology and Accreditation (metas) measured 24 sets of 100 drops each during 24 hours using their FG5 instrument. A gravity value at 130 cm above the ground of 9.805122772 (3) m/s^2 was determined which is in a good agreement with the measurements by the Italian group from Istituto di Metrologia "Gustavo Colonnetti" IMGC in 1997 after an offset correction (estimated by metas) and considering the newly measured vertical gradient.

Relative measurements between the continuously operating tide gravimeter LCR ET 25 in Zimmerwald and the regularly operating FG5 at in the laboratory of metas are performed semi-annually by swisstopo and EPF Lausanne using a Scintrex CG-5. The distance between these first mentioned instruments is only some kilometers.

Figure 2: Absolute gravity measurements in Zimmerwald using an FG5

1.3 Water vapour measurements

In September 2003, water vapour measurements were carried out by the University of Armed Forces Munich [*Becker et al., 2003*]. Water vapour was observed at the three permanent GPS stations Berne (EXWI), Jungfraujoch (JUJO) and Zimmerwald (ZIMM) of the Swiss GPS network AGNES with two Radiometrics WVRs. At station EXWI on the roof of the University of Berne, the two radiometers were measuring simultaneously for the first three days to evaluate a possible bias between each other and between GPS and the radiometer. In addition, the radiometer of the Institute of Applied Physics of the University of Berne, ASMUWARA, served as a reference for the ongoing measurements at ZIMM and JUJO. As shown in Table 2, the results of the 2-week campaign were very promising. In Zimmerwald the detected offsets were on the average below 1 mm ZTD.

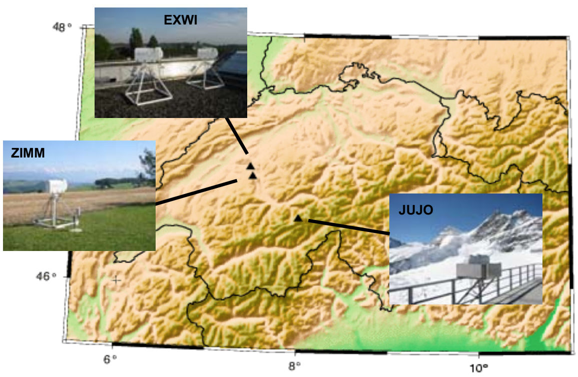

Figure 3 Sites selected to perform WVR measurements in September 2003

ZTD Offset [mm]	GPS-AGNES
ZIMM (WVR43)	-0.4 ± 3.5
JUJO (WVR42)	5.9 ± 5.3
EXWI (ASMUWARA)	-15.7 ± 5.2

Table 2: Offset and rms of a comparison of GPS-derived zenith total delay estimates and estimates derived from water vapour radiometers (average of 2 weeks of observations)

1.4 Local ties

For the determination and monitoring of the local ties between GPS and SLR, a local control network has been observed regularly since 1987 (1989, 1992, 1995 (before and after the mounting of the new telescope), 1998 and 2003). A measurement of the complete network is scheduled approximately every 5 years, control measurements with a reduced program are planned annually according to the ECGN concept.

Figure 4 shows the measured differences of the "new" SLR telescope, built in 1995, relative to the GPS reference point (on top of a 9-m steel mast). It seems obvious that the laser has moved significantly by 5-6 mm horizontally and -3 mm vertically since 1995. The subsidence can also be proved when checking the results of levelling benchmarks located near the telescope. The sinking effect seems to have settled now. Nevertheless, the detected differences exceed an order of magnitude which should not be neglected when comparing the different techniques of GPS and SLR.

In order to monitor the differences more precisely and with a higher time resolution, the control network and the measurement program need to be improved.

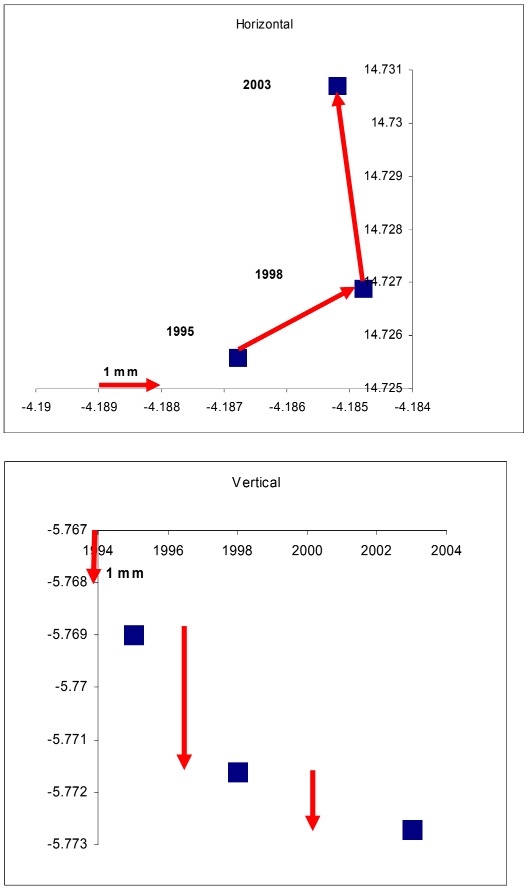

Figure 4: Differences of the SLR telescope relative to the GPS reference point since 1995. Horizontal movements are shown in the upper diagram, vertical movements in the lower diagram. The formal accuracies are of the order of 2 mm (95%). Possible thermal expansions are not yet corrected.

2 CH-CGN activities

2.1 Concept

Combining the different observation techniques is also of increasing importance on the national level. The combination of the classical measurements levelling, gravity, deflections of the vertical and GPS for deriving the consistency between the mentioned techniques is an ongoing task in national geodetic surveying.

Figure 5 gives an overview of the concept for combining various reference frames on a national level and shows the relation to the corresponding frames on the European level.

By the end of 2004 it is planned to compute a combined solution in the national reference system CHTRS95 which should result in a consistency between spatial data (CHTRF2003-C), the geoid (CHGeo2003-C) and the heights (CHVRF2003-C).

This proposed solution will contain all precise geodetic data including all observations collected up to the year 2003. The GPS measurements planned for 2004 (third re-observation of the GPS control network LV95 consisting of more than 200 sites) will probably serve only as a comparison.

Important input is coming from the GPS densification campaigns and the astrogeodetic campaign CHGeoid2003, which is described in detail in sections 2.2 and 2.3.

In addition, there is also the static local reference system CH1903+, in which a zero-velocity field is assumed, and the older local system CH1903, which is presently still the official reference system for cadastral work in Switzerland. Its relation to the planned consistent combined product is given in the lower part of the diagram.

2.2 Astro campaign 2003

In the years 2001 to 2003, the automated digital camera systems TZK2-D and DIADEM were developed in close cooperation between the University of Hanover and the ETH Zurich respectively (see Figure 6). Both systems are now ready for operational use. From October 7 to 29, 2003, measurements were carried out on 65 different sites (see Figure 7) with the goal of

- improving the geoid by replacing some older astrogeodetic observations,
- further densification of the network of measured deflections of the vertical,
- and determining the accuracy of the deflection of the vertical by comparing measurements of the two camera systems and by producing time series at the same site (e.g. Zimmerwald).

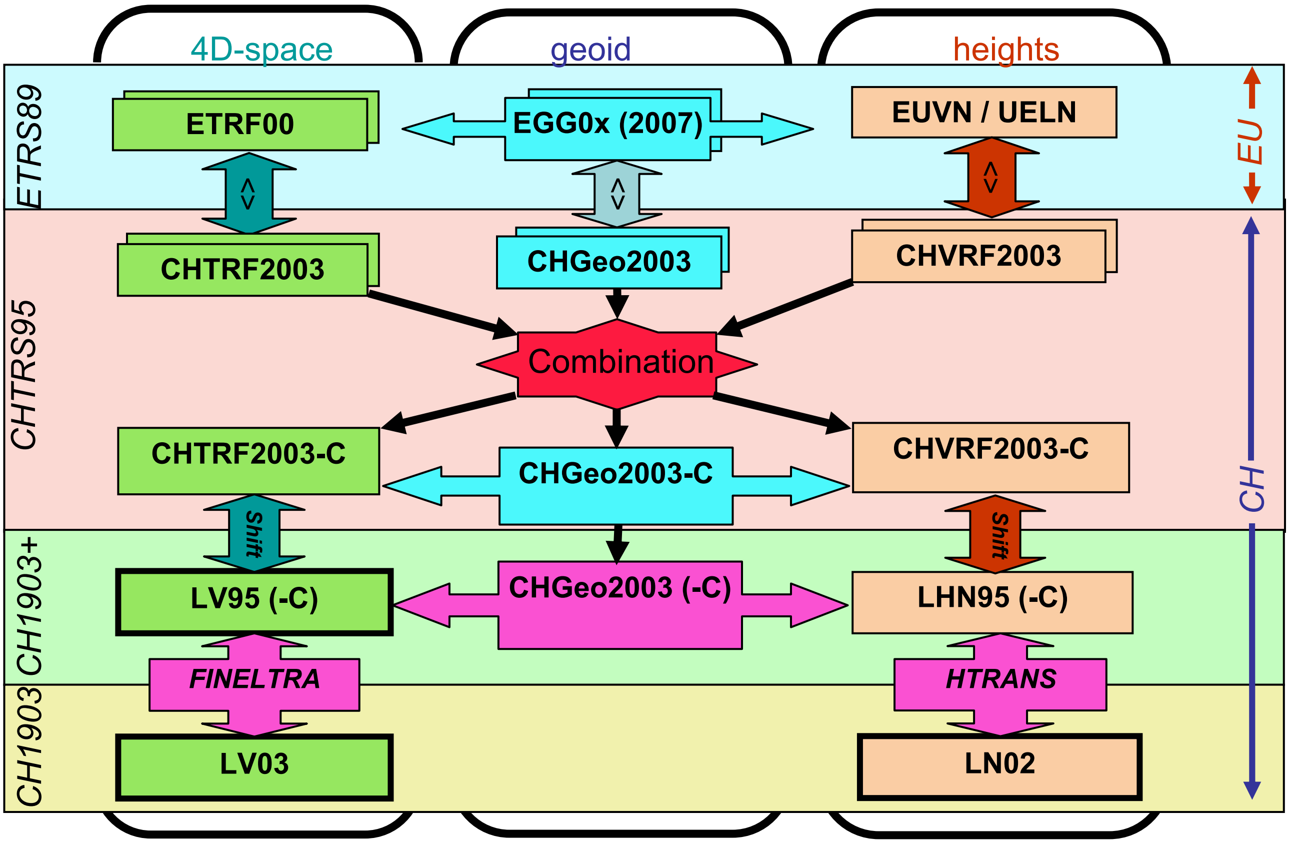

Figure 5: CH-CGN concept of achieving consistency between GPS, levelling and the geoid on the different levels from national to global scale

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Figure 6: The two digital camera systems DIADEM (left: Zurich) and TZK2-D (right: Hanover)

Approximately 4-5 sites could be observed per night, depending mainly on the weather conditions and the distances between the sites. The position of the camera was determined using the swipos-GIS/GEO positioning service with an accuracy of well below 10 cm. The duration of the 80-160 repeated measurements in 2 to 4 different azimuthal orientations is approximately 1 hour. A total of more than 20,000 pictures (120 Gbytes) were analyzed. On the average, about 18 stars were used from the Tycho-2 catalogue. The achieved accuracy for most of the points is in the order of better than 0.10”. That is approximately a factor of 3-4 better than the quality of the old data collected by analogue zenith cameras.

The main difficulty, which has up to now not yet been fully resolved for the DIADEM instrument, is the problem of the synchronization of the shutter. Such problems cause biases in the eta component.

The results of the Astro 2003 campaign were introduced together with the other 690 available vertical deflections for the computation of an improved geoid (see section 2.4). An outcome of this campaign was also a detection of observations with a degraded quality. In fact, almost all observations measured before 1980 had to be excluded from the geoid computation.

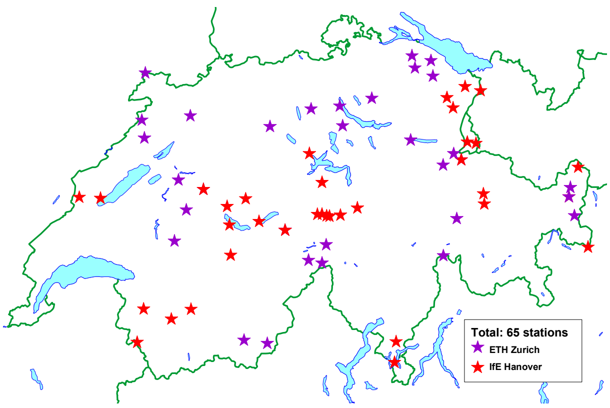

Figure 7: Sites measured in the Astro campaign 2003 from the teams of Zurich and Hanover

2.3 GPS-levelling campaign 2003

Between April and October 2003, a GPS densification campaign was carried out. The main focus was to densify the network in areas near the border and in areas where unreasonably large discrepancies between GPS, levelling and the geoid are observed. 37 new GPS sites were selected with a connection to near-by levelling points. Due to the fact that the sites are close to the levelling points, it is not always possible to guarantee perfect GPS visibility for all sites in the Alpine area. Therefore, observations of about 4 x 24-hour were collected to guarantee a reliable GPS height estimation. In order to avoid errors in the antenna height recording, different observers performed the site set-up and site shut-down.

The GPS data were analyzed together with the data of the 29 permanent GPS sites using the Bernese software 4.2 [*Hugentobler et al., 2001*]. At swisstopo these GPS analyses are performed in a very efficient way based on a semi-automated procedure which also generates a protocol file of the processing (html format).

The GPS-levelling sites as well as the rms estimates (ratio of horizontal and vertical errors) are given in Figure 9. It is clearly visible that certain sites in mountainous regions show a poor estimation of the station height due to a weak geometry (e.g. station VSD_423, Gondo; see also the visibility plot in Figure 8).

A rigorous combination of all GPS campaigns since 1988 [*Brockmann et al., 2003*] generated a new consistent set of height estimates from about 190 GPS-levelling sites.

It is worth mentioning that the new observations also fit very smoothly in the already existing set of GPS-levelling data. Therefore, the impact on the geoid determination is not expected to be large, except an improved redundancy.

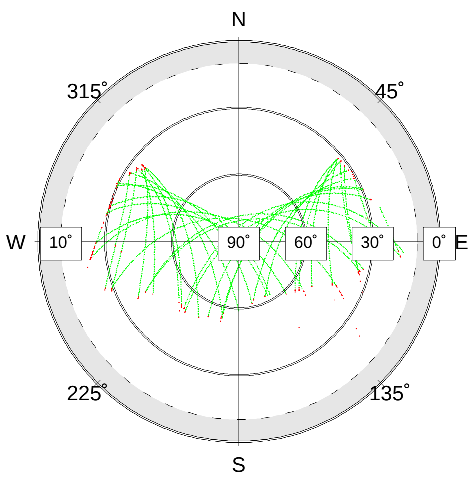

Figure 8: Visibility plot for station Gondo (VSD_423) located in a narrow valley

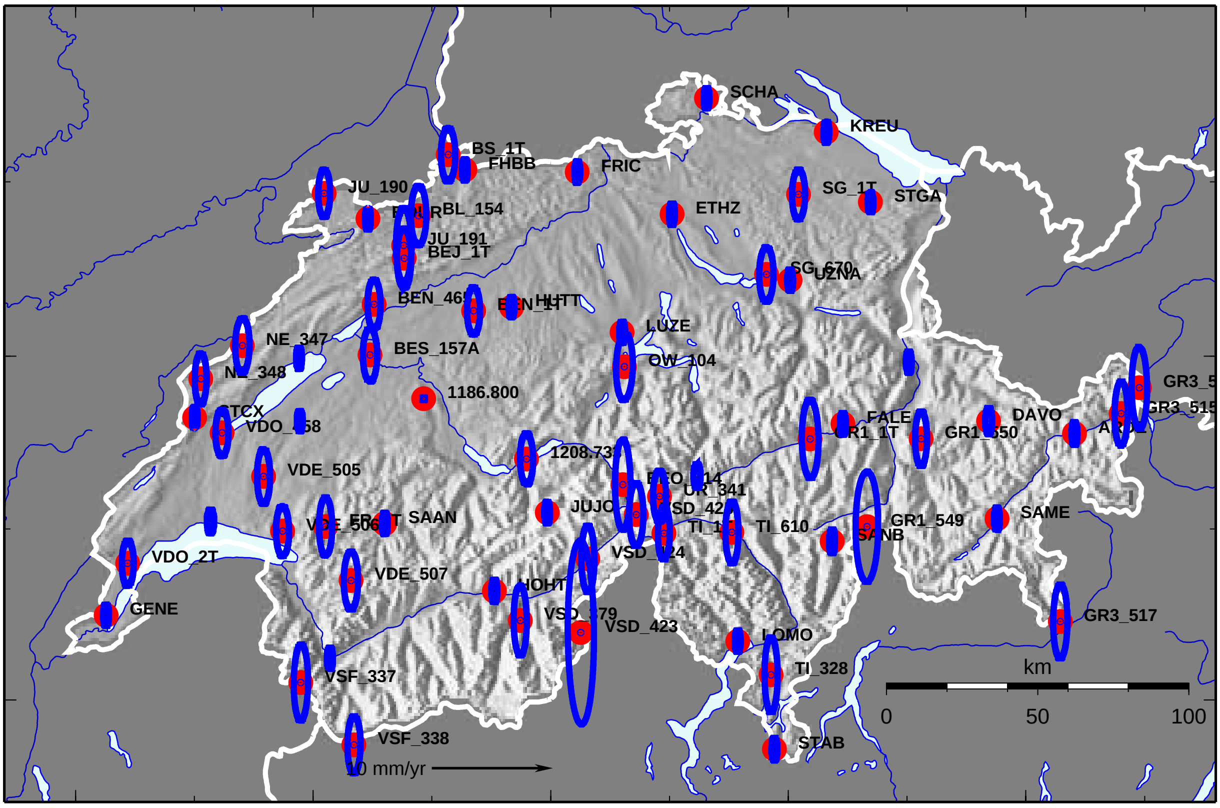

Figure 9: Location of the 37 GPS sites of the GPS-levelling campaign 2003. The error ellipses indicate the amount of the ratio between the error estimates horizontally (east-west) and vertically (north-south).

2.4 Geoid improvements

The differences of the GPS-levelling points with respect to the geoid model CHGeo98, status 2003, [*Brockmann et al., 2003*] are shown in Figure 10. The systematic trend of +5 cm (north-west) and -8 cm (south-east) is obvious. Furthermore, there are also some irregularities in certain areas (e.g. in the central Alps or near the eastern border to Austria).

The main reasons for these larger GPS-levelling residuals have to be sought in some long wavelength errors of the geoid model CHGeo98, which was calculated as a combined solution of deflections of the vertical and GPS-levelling. Gravity was used for the downward continuation.

The elimination of these long wavelength errors and some other more local problems of CHGeo98 have been the main reasons for starting the project of a new national geoid determination CHGeo2003. The calculation methods will be basically the same as for CHGeo98. The principal steps are: the reduction of all observations (deflections of the vertical, gravity, GPS-levelling) for the influence of the topography and models of known density anomalies, the reduction for a global geopotential model, least squares collocation of the residual field and restoring the effects of the models in order to obtain the geoid and the quasigeoid.

The main sources for the improvement of the geoid model are the newly available observations presented in sections 2.2 and 2.3.

Besides the deflections of the vertical and the GPS-levelling stations mentioned above, also a new set of gravity measurements could be used. In a project of the Swiss Geophysical Commission SGC all available gravity measurements have been collected and re-processed. Still existing data gaps have been filled with new additional measurements. This valuable consistent dataset with a mean density of almost 1 point per km^2 is basically used to produce a geoid solution, which is independent from the astrogeodetic and GPS-levelling geoid. The final model CHGeo2003 should be available to the public at the end of the year 2004 and will be a combination of all types of data.

Until now, a preliminary solution of a purely astrogeodetic geoid was calculated. This solution showed clearly that it was possible to eliminate the long wavelength error of CHGeo98 by including the new observations of the astro campaign 2003 and by not considering older classical astro observations, which seem to have a systematic error in the order of some 0.1". These systematic errors are most probably caused by problems in the older star catalogues.

A first combined solution of deflections of the vertical and GPS-levelling improves the GPS-levelling residuals significantly to the order of a few mm in flatter areas, and to about 3 cm in Alpine areas. These differences, shown in Figure 11, are larger non-systematic residuals which most likely point to problems in the determination of the GPS heights.

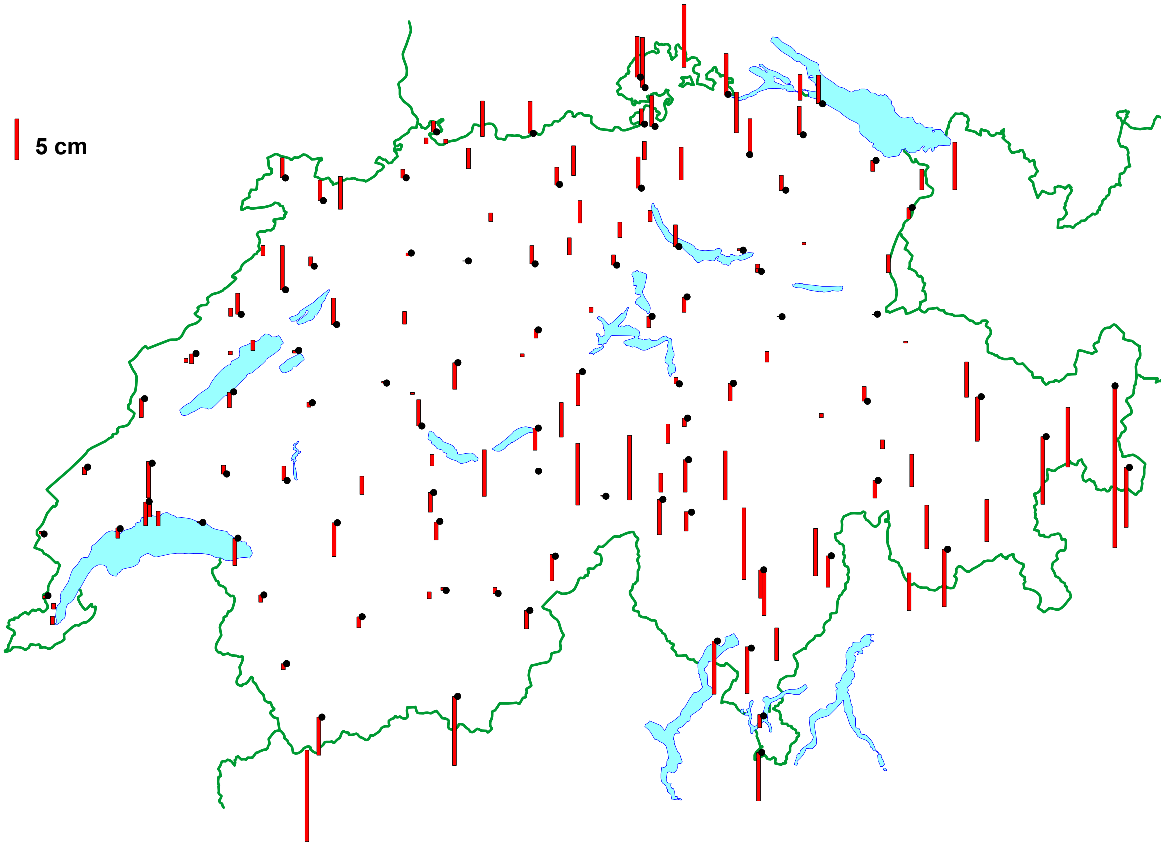

Figure 10: Differences of the GPS-levelling points to the geoid model 1998 (status 2003)

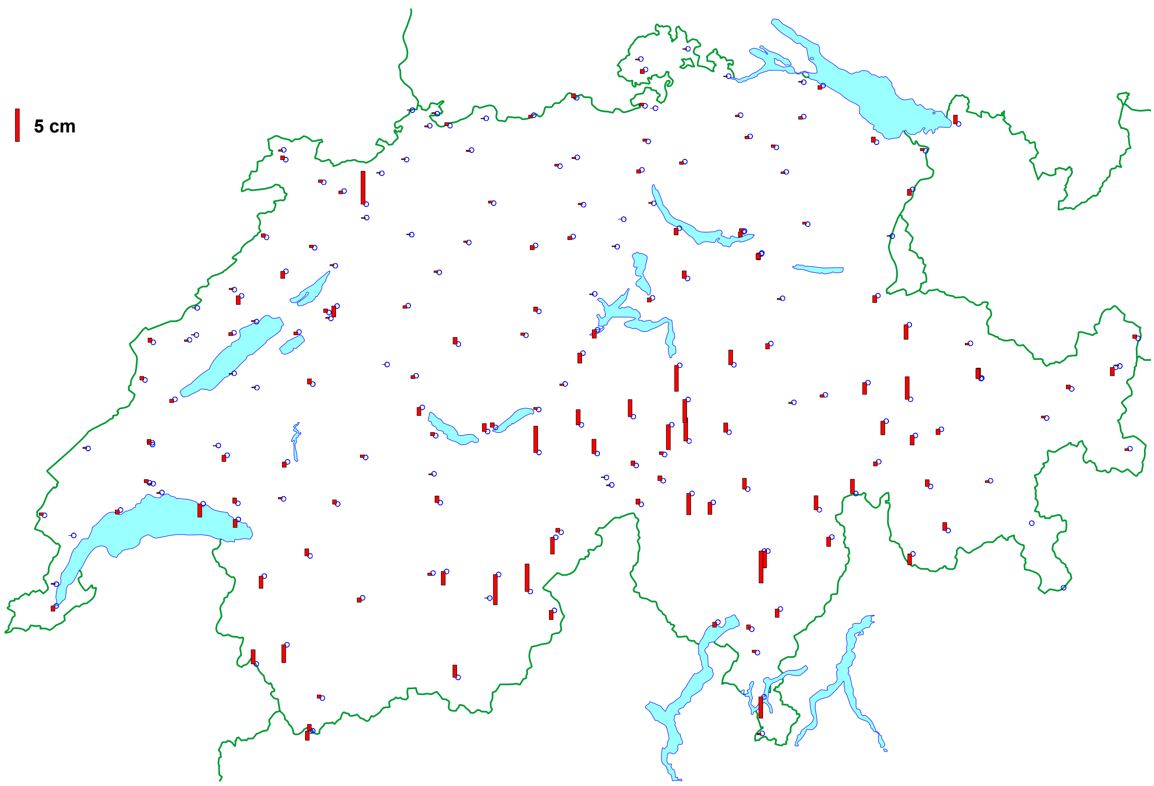

Figure 11: GPS-levelling differences after geoid modelling improvements, and the additional observations of the Astro and GPS densification campaign (status 2004)

3 Conclusions

The main focus in the years 2003 and 2004 was on carrying out additional measurements in order to achieve consistency between different geodetic observation techniques.

For the project ECGN absolute and relative gravity measurements were carried out in Zimmerwald. Besides the operational work in the field of GPS and SLR, also classical measurements were performed in order to monitor the eccentricity between the two mentioned systems. Significant movements in the order of 5-6 mm horizontally were detected during the last 8 years. Astro observations yielded measurements of the deflection of the vertical with an excellent precision of well below 0.10”. Finally, WVR measurements demonstrated that they are consistent with GPS-derived ZTD estimates on a very high level of below 1 mm ZTD (offset during 2 weeks).

On the national level, densification campaigns (Astro and GPS-levelling) brought additional, precise observations which were used for an improved geoid determination. These activities were summarized under the project name CH-CGN. The new observations together with a refined geoid modelling made it possible to further reduce the present systematic differences from some 5 cm to mostly below 3cm. Slightly larger differences in some problematic areas near the Ivrea body (Southern Alps) are still the object of special investigations (modelling problems versus problems of the GPS-levelling data).

The success of this contribution to the projects ECGN and CH-CGN is mainly based on an ideal team work between the specialists of the different areas. It further shows that it is possible to consistently combine the different geodetic observation techniques, from which many users will benefit in the future.

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