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Swiss National Report on the

GEODETIC ACTIVITIES

in the years 2003 to 2007

Presented to the XXIV General Assembly
of the International Union of Geodesy and Geophysics
in Perugia, Italy, July 2007

Rapport National Suisse sur les

ACTIVITÉS GÉODÉSIQUES

exécutées de 2003 à 2007

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In addition to the bibliographies at the end of each section we recommend the following webpages:

Astronomical Institute of the University of Bern (AIUB):	http://www.aiub.unibe.ch
Federal Office of Topography (swisstopo):	http://www.swisstopo.ch
Federal Institute of Technology, ETH Zürich:	http://www.igp.ethz.ch
Federal Institute of Technology, EPF Lausanne:	http://topo.epfl.ch

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Preface

The Swiss Geodetic Commission (SGC) is an organisation within the Swiss Academy of Sciences (SCNAT). It is devoted to research into scientific problems of geodesy including the transfer to practical application in national geodetic surveying. Of particular importance is the promotion of international cooperation and national coordination. The SGC has close links to the Swiss Geophysical Commission, in particular in the field of gravimetry where research projects are being pursued jointly on an interdisciplinary basis.

The national report covering the scientific activities of the past 4 years is divided into four sections according to the structure of the International Association of Geodesy (IAG):

1. Reference Frames
2. Gravity Field
3. Earth Rotation and Geodynamics
4. Positioning and Applications

These main chapters were compiled by an editorial staff consisting of A. Wiget (Section 1), Dr. U. Marti (Section 2), Prof. Dr. H.-G. Kahle (Section 3), P.-Y. Gilliéron (Section 4). Our special thanks go to Dr. M. Troller, secretary of SGC, for the careful editing and preparation of the layout. Without his efforts this report could not have been realized in due time.

The SGC expresses its appreciative thanks to all colleagues who have contributed to this report and who are promoting Geodetic Sciences in Switzerland. Financial support was provided by the SCNAT. Its valuable help is gratefully acknowledged.

On behalf of the Swiss Geodetic Commission, April 2007

Prof. Dr. Alain Geiger
President of SGC

Dr. Urs Marti
Vice-President of SGC

Contents

1 Reference Frames

CODE Contributions to the IGS

by S. Schaer, G. Beutler, H. Bock, R. Dach, A. Gäde, U. Hugentobler, M. Meindl, L. Ostini, M. Ploner and C. Urschl

CODE, the Center for Orbit Determination in Europe, is a joint venture of the following three institutions:

- the Federal Office of Topography (swisstopo), Wabern, Switzerland,
- the Federal Agency of Cartography and Geodesy (BKG), Frankfurt, Germany,
- the Astronomical Institute of the University of Bern (AIUB), Bern, Switzerland.

CODE is located at the AIUB. It may be mentioned that the cooperation between swisstopo and AIUB/CODE could be intensified by creation of a new position at swisstopo which is dedicated nominally to 70% of tasks concerning CODE/AIUB. This position is held by S. Schaer since September 1, 2004. (Fig. 1.6 may be seen as a symbol for this closer cooperation.)

A wide variety of GNSS (Global Navigation Satellite System; active systems today are GPS and GLONASS) solutions is computed at CODE. All solutions and results are produced with the latest development version of the Bernese GPS Software (Dach et al., 2007). It is a declared goal of CODE that they have to fulfill highest quality standards (otherwise distribution of an analysis product is stopped). An overview of the analysis products made available through anonymous ftp may be found in Hugentobler et al. (2007), or Dach et al. (2007), or specifically at http://www.aiub.unibe.ch/download/BSWUSER50/TXT/AIUB_AFTP.README.

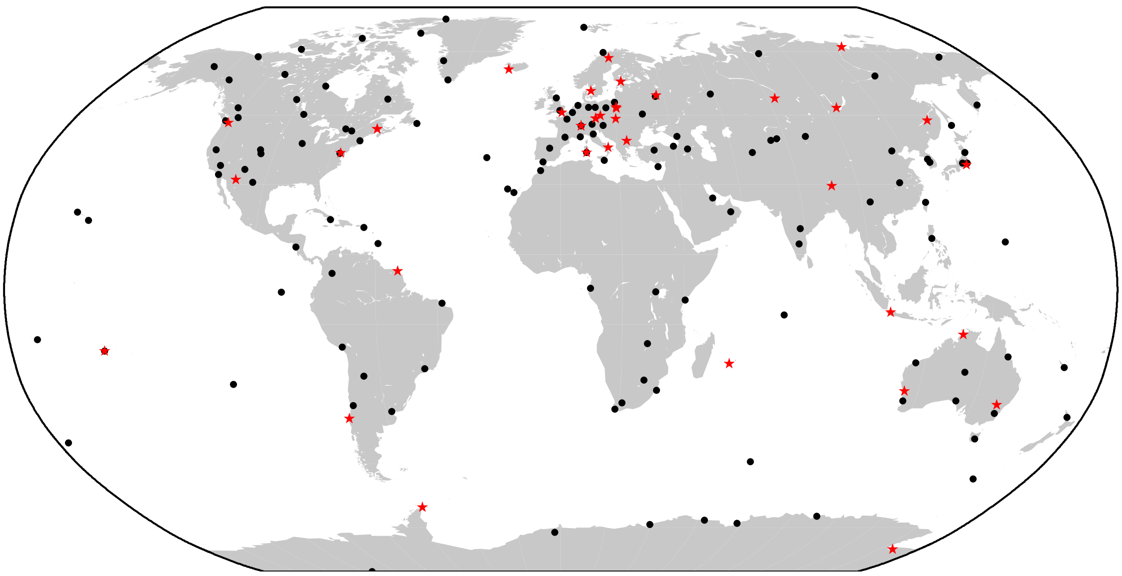


Figure 1.1: GNSS tracking network as considered at CODE for final analysis (GPS-only stations are shown in black, GPS/GLONASS-combined stations in red).

The global GNSS data analysis is performed on the basis of observations from the IGS (International GNSS Service) tracking network (see Fig. 1.1). GNSS orbits, Earth orientation parameters, station coordinates, model parameters describing local tropospheric and ionospheric conditions, global ionosphere maps, phase-consistent satellite and receiver clock corrections, and other parameters of geophysical interest are estimated on a daily basis. Consideration of calibration parameters responding to GNSS antenna phase center variation effects and different pseudorange biases becomes more and more important. CODE plays a leading role in retrieval of corresponding calibration parameters and is highly involved within the IGS in the further development of adequate data correction models (see also the contribution in this section, page 20).

The CODE processing scheme for IGS analyses is constantly subject to updates and improvements. A major step forward was the incorporation of the GLONASS satellite system throughout all analysis steps, with the exception of the determination of precise clock corrections (Schaer, 2003a,b). This lead to strictly integrated GPS/GLONASS-combined products with best possible consistency in terms of geodetic datum definition. Starting on July 30, 2003, CODE's preliminary ultra-rapid orbit product (being pure predictions based on daily rapid orbit solutions) was replaced by a near-real-time product now generated on the basis of hourly observation data (Schaer, 2003c). As a consequence, our ultra-rapid submissions were officially included in the corresponding IGS product combination process. It is worth mentioning that the newly established CODE ultra-rapid orbit product did cover both the GPS and the GLONASS satellite constellation from the beginning. CODE's IGS ultra-rapid GPS orbit submissions belong to the best ones in terms of quality and reliability. With regard to GLONASS, there is no orbit product with comparable quality available worldwide.

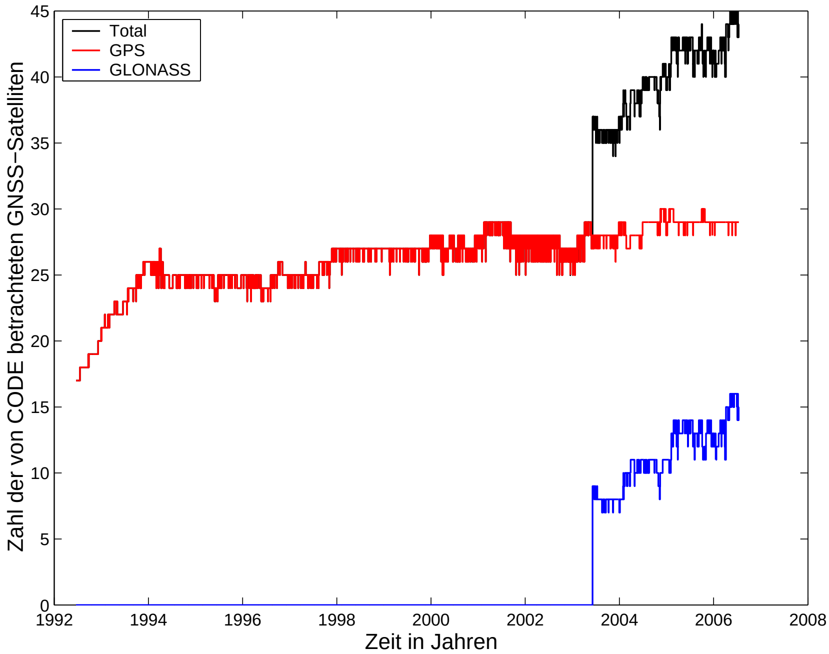


Figure 1.2: Evolution of the number of GNSS satellites included in the CODE final orbit product.

Since the beginning of 2004 (January 5), CODE GNSS orbit products include positions and clock offsets for repositioned (GPS) satellites. The principle is illustrated in Fig. 1.3. The estimated mean epoch of event and velocity change components are reported in the CODE analysis summary files (Schaer, 2004).

CODE is the only IGS analysis center that has been producing GNSS orbit information for all active GNSS satellites, independent of whether a satellites is marked as unhealthy/unusable or is observed sparsely (in the extreme case relying on single receiver baselines). This is also true for brand new satellites and, as initially stated, for GPS satellites being repositioned. Note that a dedicated procedure for orbit initialization is needed in both cases. Fig. 1.3 illustrates the continuous GNSS analysis product generation as carried out at CODE on the basis of the chronology of a GPS satellite launch.

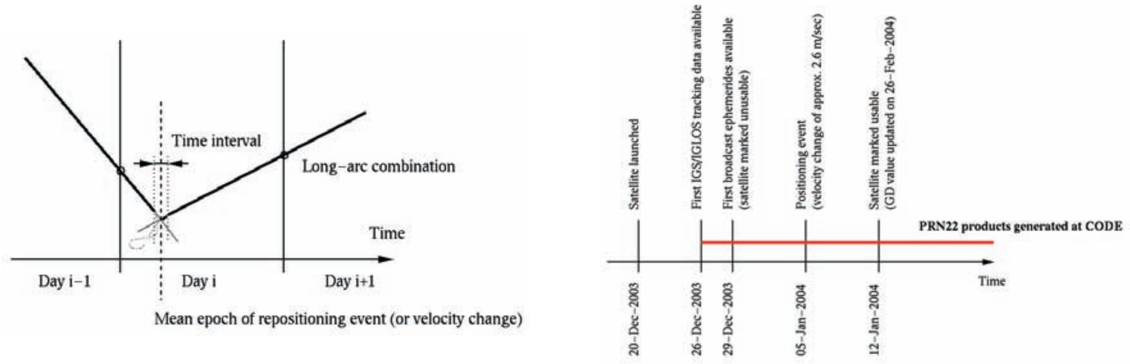


Figure 1.3: Continuous orbit generation for GPS satellites being repositioned: switching from one orbit arc to another arc (left). Chronology of a GPS satellite launch and uninterrupted analysis product generation at CODE (right).

Finally, we have to emphasize the model change related to the generation of high-rate satellite and receiver clock corrections (started on April 5, 2004). Resulting clock-RINEX files containing 30-second clock values for all GPS satellites are provided to the IGS community. Such high-rate clock corrections are not only generated for the final product line but also for the rapid product line. These clock corrections are consistent to phase and pseudorange observations and may be used for precise point positioning (PPP) applications.

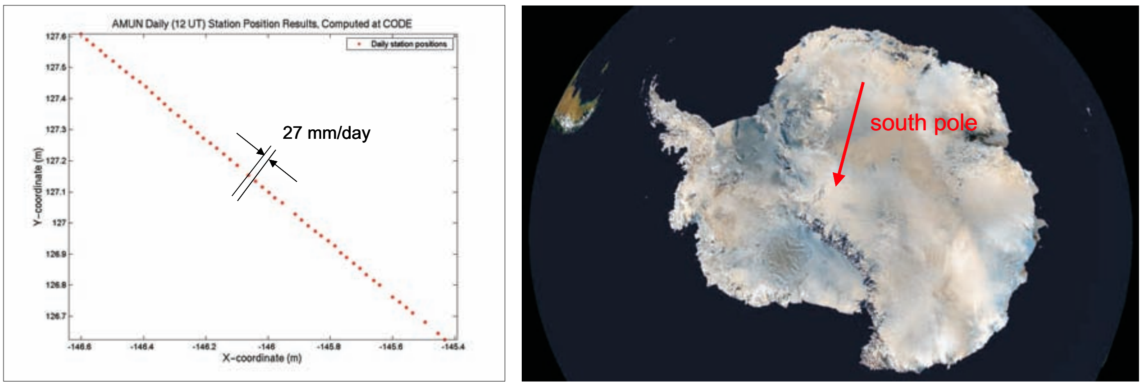


Figure 1.4: Inclusion of a fast moving permanent station in IGS operational analysis at CODE. The Amundson-Scott station (AMUN, meanwhile replaced by AMU2) is located in the Antarctica (very close to the geographic south pole).

The switch from the relative to an absolute GNSS PCV model was prepared over long time and finally performed starting with GPS week 1400 (November 5, 2006). This path-breaking model change was activated in CODE's analysis at the same time with a remarkably big number of other model improvements (Schaer and Hugentobler, 2006a).

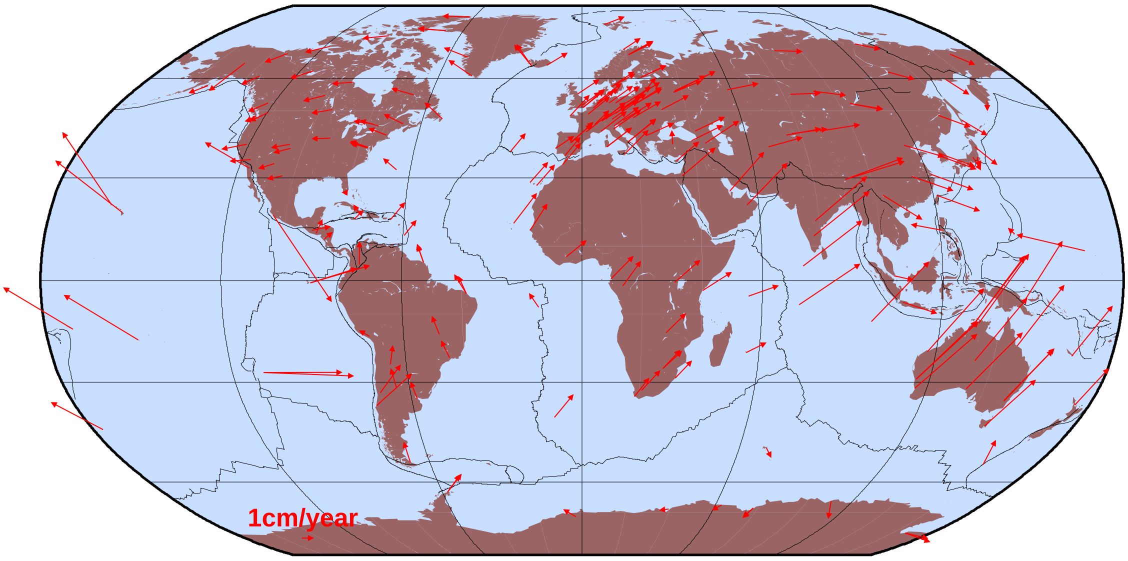


Figure 1.5: Horizontal velocity vectors for the IGS tracking network as derived from daily station coordinate results produced at CODE (and stored in NEQ form for this kind of combination analysis).

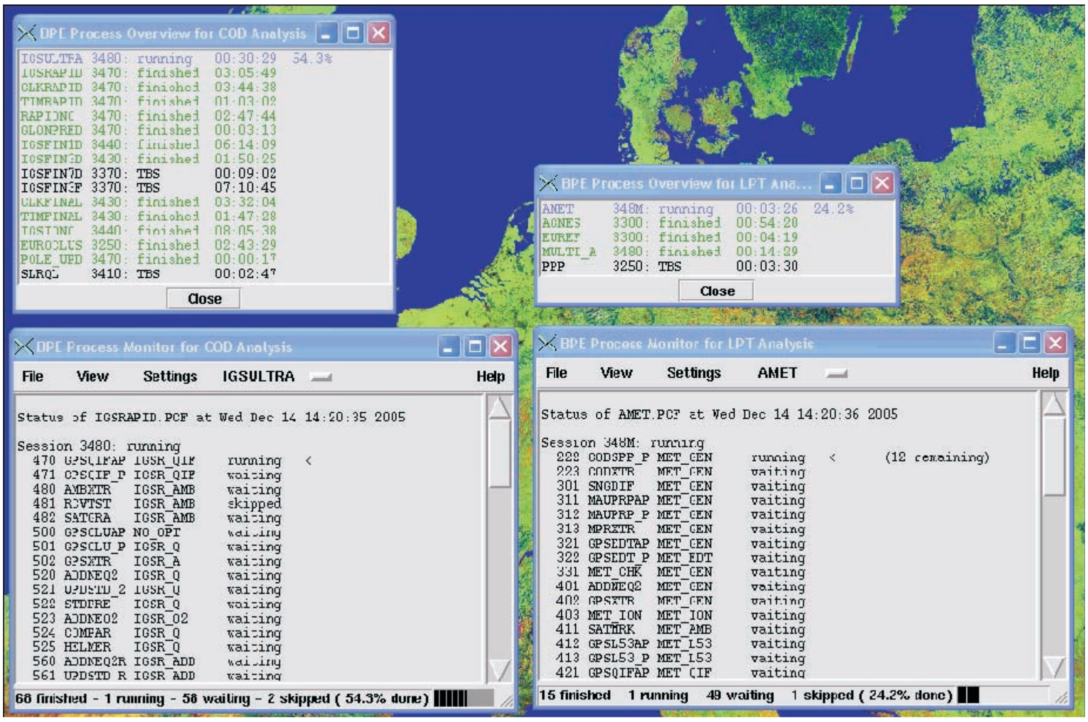


Figure 1.6: Monitoring of BPE routine processing from both CODE and swisstopo, displayed on a computer screen at swisstopo in Wabern.

A highlight to be emphasized was the IGS Workshop and Symposium 2004 that was hosted at Bern University from March 1 to 5, 2004, celebrating a decade of the IGS (Meindl, 2005).

EUREF Activities at CODE

by M. Meindl and S. Schaer

EUREF, the IAG (International Association of Geodesy) Reference Frame Subcommission for Europe, is responsible for the definition, realization, and maintenance of the European Reference System ETRS89 (European Terrestrial Reference System) and its Reference Frames. The European Permanent Network (EPN) plays a key role in these activities. It comprises almost 200 permanent tracking stations, continuously observing the GPS and to some extent the GPS/GLONASS constellation (see Fig. 1.7).

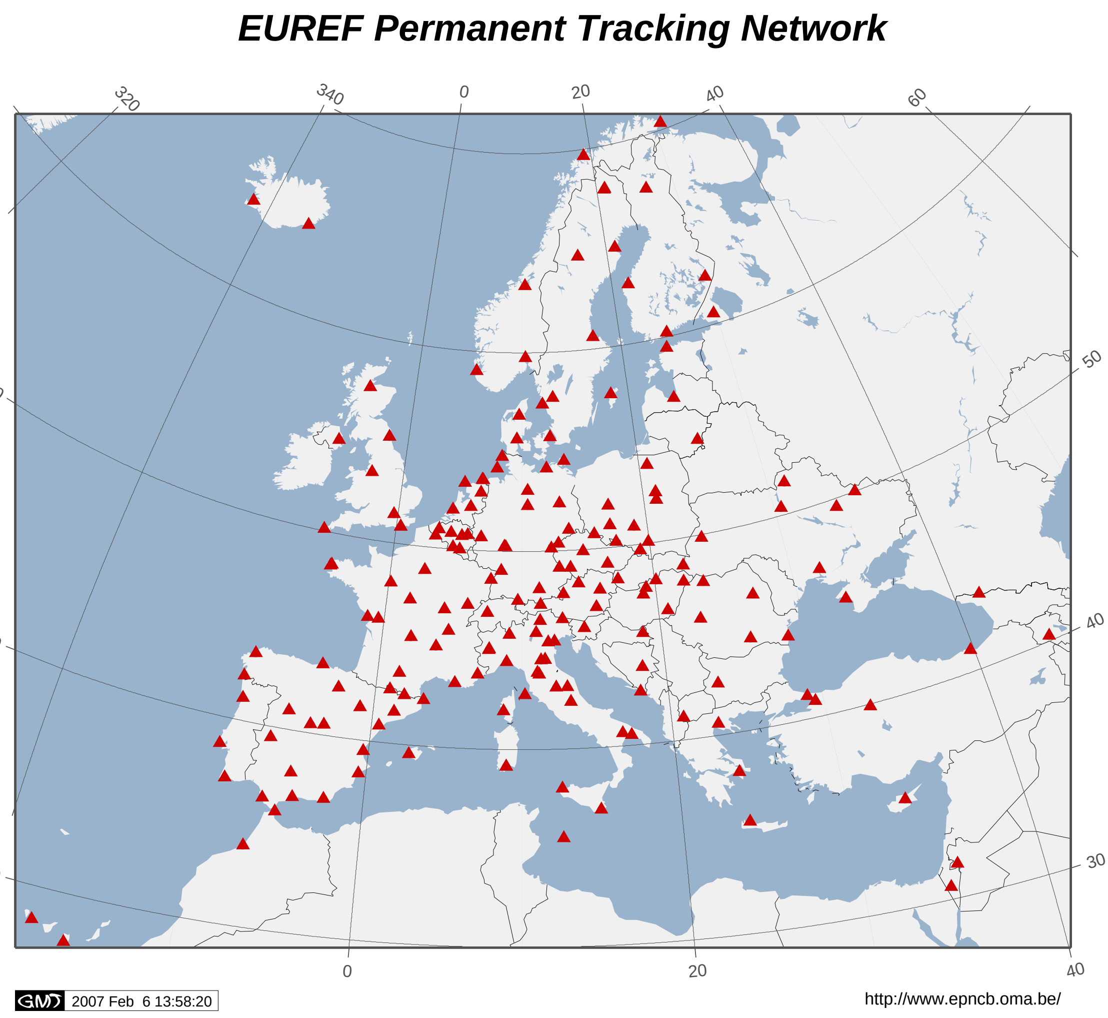


Figure 1.7: The EUREF tracking network consisting of 192 stations (date October 1, 2006).

Data of these tracking stations is processed by 16 local analysis centers (LACs) following a distributed data processing approach. The individual subnetwork results are combined to a final

EUREF SINEX (Solution INdependent EXchange format) solution based on the full variance-covariance information of the single contributions. This task is carried out by the EPN combination center which is located at the Bundesamt für Kartographie und Geodäsie (BKG, Frankfurt a. M., Germany). The combined SINEX solution is sent to the IGS (International GNSS Service) every week for inclusion into the IGS densified network solution. More details can be found in Bruyninx et al. (2002).

The Center for Orbit Determination in Europe (CODE) is a joint venture between the Astronomical Institute of the University of Bern (AIUB, Bern, Switzerland), the Swiss Federal Office of Topography (swisstopo, Wabern, Switzerland), and the German BKG (Frankfurt a. M., Germany). It acts as one of the EUREF LACs. An EPN subnetwork consisting of about 50 stations is processed on a daily basis. The corresponding regional network is, with a maximum extent of approximately 8000 kilometers, the largest EPN subnetwork (not all included stations are actually shown in Fig. 1.8). A weekly station coordinate solution is computed and submitted in SINEX form to the EUREF. In addition, hourly troposphere parameter estimates (zenith path delays) for all stations involved are delivered.

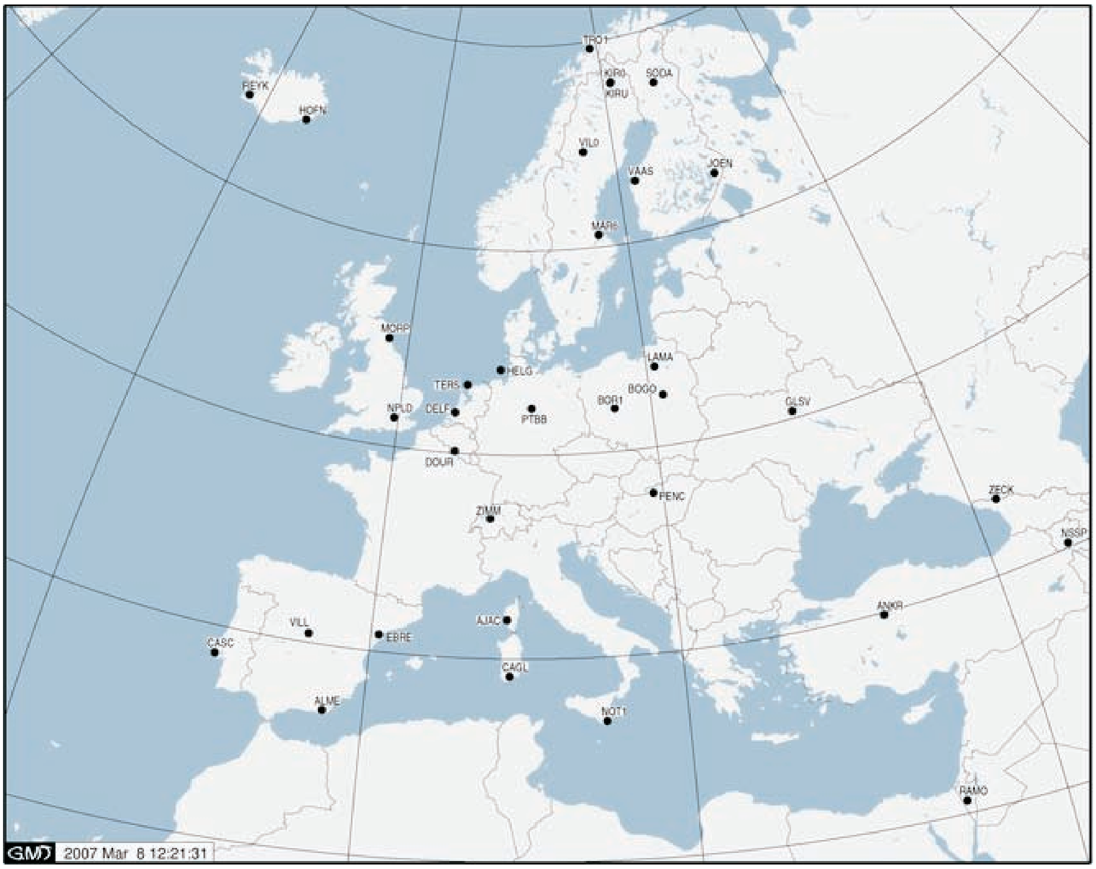


Figure 1.8: Core of the EUREF subnetwork processed at CODE.

Such a regional GNSS network is an ideal test environment for different processing strategies. Always striving to heighten the understanding of GNSS data processing and getting the best out of the available observation data, eight additional solutions are computed (besides the official one). These test solutions are used to validate refined processing options, such as inclusion of low-elevation data and estimation of horizontal tropospheric gradient parameters, but also to compare different orbit products from the IGS (combined products) and CODE. Note that just GPS observation data is used for generation of all regional solutions. Consideration of data originating from the GLONASS system is intended (starting with GPS week 1400).

CODE computes all results with the in-house developed Bernese GPS Software, a high-performance software package for scientific GNSS data processing (Dach et al., 2007). It is worth mentioning that 13 of the other 15 LACs also use the Bernese GPS Software package to compute their individual EUREF contributions.

Analysis of Permanent GPS-Networks at swisstopo

by E. Brockmann, D. Ineichen and S. Schaer

The Automated GPS Network of Switzerland (AGNES) is a multi-purpose reference network for national first order surveying, scientific research such as geodynamics and GPS meteorology and serves as a base for the Swiss positioning service (swipos). AGNES was set up beginning in 1998 and reached its designated configuration of 29 stations by the end of 2001. After moderate modifications, the network consisted of 31 sites at the end of 2006.

The overall performance of the AGNES network over the last 4 years was excellent. The availability of the RINEX data files was in the order of 98% (mean value over all stations).

The permanent GPS networks analyzed at swisstopo are shown in Tab. 1.1. The routine operation of the Permanent Network Analysis Center (PNAC) is divided into 3 sub-networks which are processed on an hourly and daily basis. All analyses are done with the Bernese GPS Software (Hugentobler et al., 2001). In 2005 the processing was completely redesigned and based on the newest version V5.0 of the Bernese GPS software (Ineichen et al., 2006b). 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 Berne (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. This very close collaboration between these two organizations is possible because S. Schaer, employed by swisstopo since September 2004, is also a collaborator at the AIUB.

The number of analyzed sites has also continuously been increased. Fig. 1.9 shows the processed networks in Europe and Switzerland.

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 Table 1.1, swisstopo contributes, as one of several European processing centers of the European Permanent Network EPN, weekly coordinate and troposphere parameters. From solution 2 and 3 of Table 1.1, similar results are obtained for the area of Switzerland which is embedded in the EPN network.

Monitoring the quality of the derived products is essential not only on a short-term but also on a long-term basis. Different tools, such as an SMS/e-mail messaging system and a web interface, were developed for monitoring the computers, the data flow, the stability of the coordinates, and the availability and quality of the other products. The monitoring of coordinates and zenith total delay estimates derived using the Bernese GPS Software (see Figure 1.11) is complementary to the monitoring of the real-time positioning software GPSNet from Trimble. It is satisfactory that both monitoring tools show mostly similar results.

swisstopo plans to equip all AGNES sites with GNSS (Global Navigation Satellite Systems consisting of GPS, GLONASS and future systems such as Galileo) receivers by the end of 2007. The new

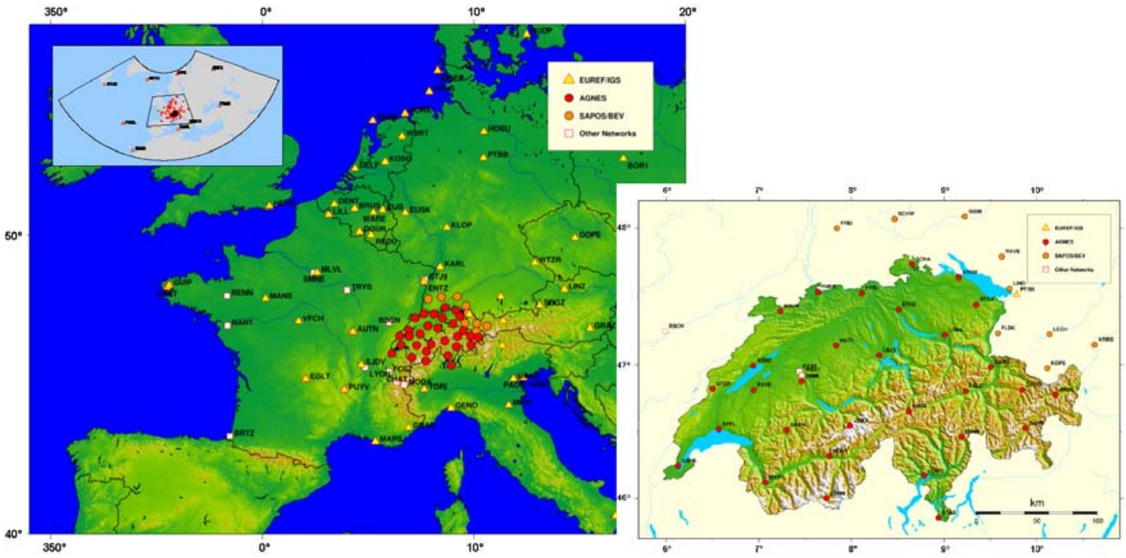


Figure 1.9: Overview of the permanent GPS stations processed at swisstopo.

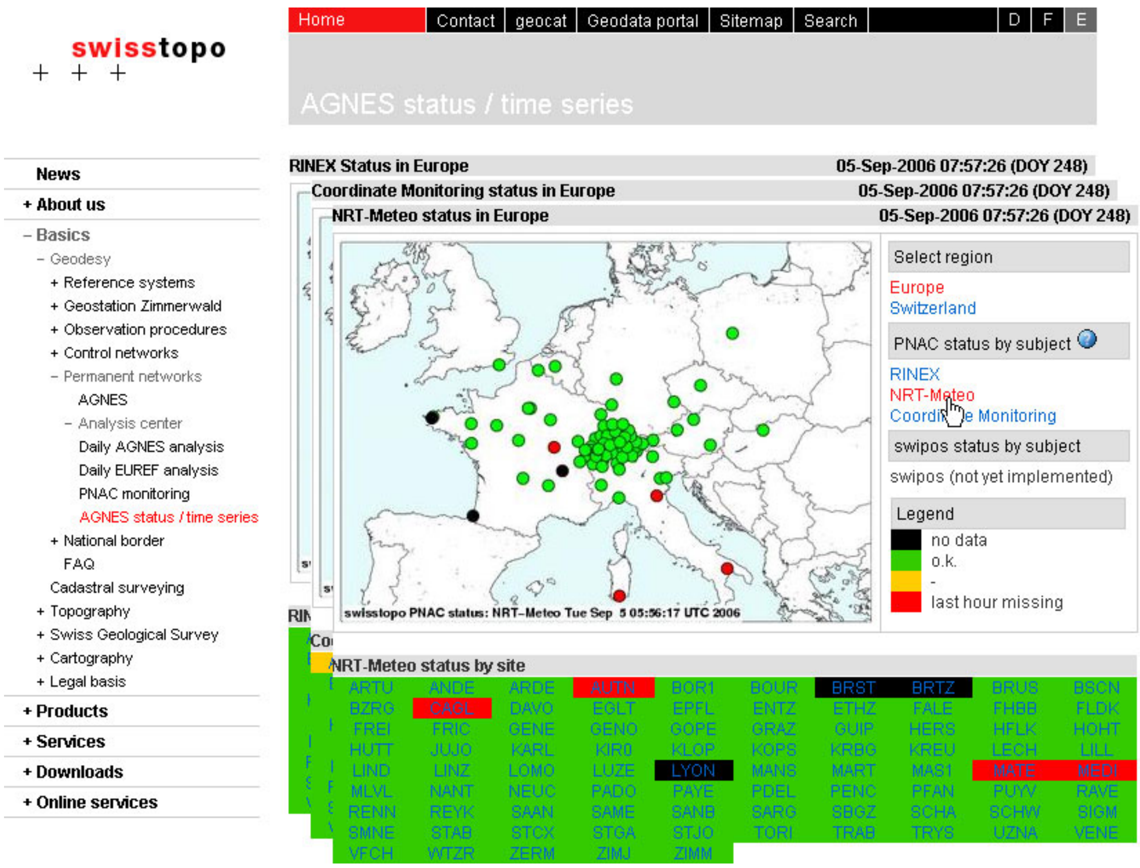


Figure 1.10: Overview of the processing status at swisstopo on www.swisstopo.ch: the available hourly RINEX files, the coordinate monitoring, and the availability of GPS-derived atmospheric parameters in Europe.

Network solution	Stations (2003 -> 2006)	Processing interval	Delay
1: EUREF (EPN) sub-network	20 -> 31	daily observations	21 days
2: AGNES + sub-net EUREF	65 -> 89 (31 AGNES)	daily observations	21 days
3: AGNES + sub-net EUREF	63 -> 80 (31 AGNES)	hourly observations	1 hour

Table 1.1: Network analyses of permanent GPS data at swisstopo.

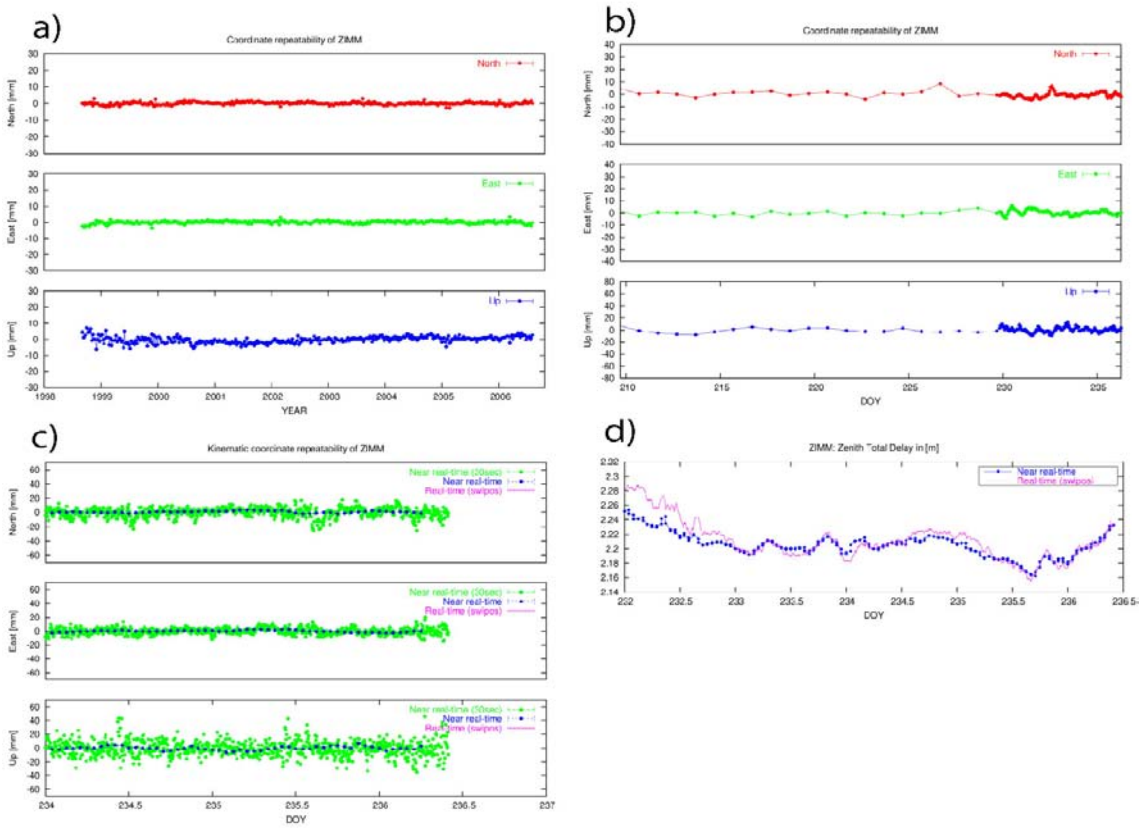


Figure 1.11: Available time series for the AGNES site Zimmerwald (ZIMM) on www.swisstopo.ch: a) long-term coordinate residuals in North, East and Up; b) 1 month with daily and hourly residuals; c) 3 days with hourly and kinematic coordinates (Bernese and GPSNet); d) several days with ZTD estimates (Bernese and GPSNet).

receivers will also be able to collect data from GLONASS satellites. The main improvements are expected for the real-time positioning service and the hourly solutions used for GNSS meteorology / tomography. First GNSS analyses were done at the end of 2006 by using GNSS observations for the EPN contribution as well as by making detailed analyses of the data from the different GNSS receivers at the fundamental station Zimmerwald.

National Terrestrial Reference Frame CHTRF2004, the GPS Reference Network LV95 and Test Network Turtmann

by E. Brockmann, D. Ineichen, A. Schlatter, B. Vogel and A. Wiget

In the year 2004, a third independent coordinate estimation was realized for all points of the Swiss GPS Reference Network LV95 (see Fig. 1.12 and the contribution in section 3, page 65). The assumed coordinate accuracies were excellent and validated the results of the first re-observation campaign in 1998.

It was therefore not necessary to change the published horizontal LV95 coordinates. This set of coordinates, to be used in cadastral surveying, was rounded to the cm level in 1995 and only differences larger than 2 cm need to be changed.

Due to the introduced new height reference frame and the good consistency to the geoid CHGeo2004, the "provisional" ellipsoidal heights of the LV95 points were replaced by "final mm heights" derived from the combined CHTRF2004 computation.

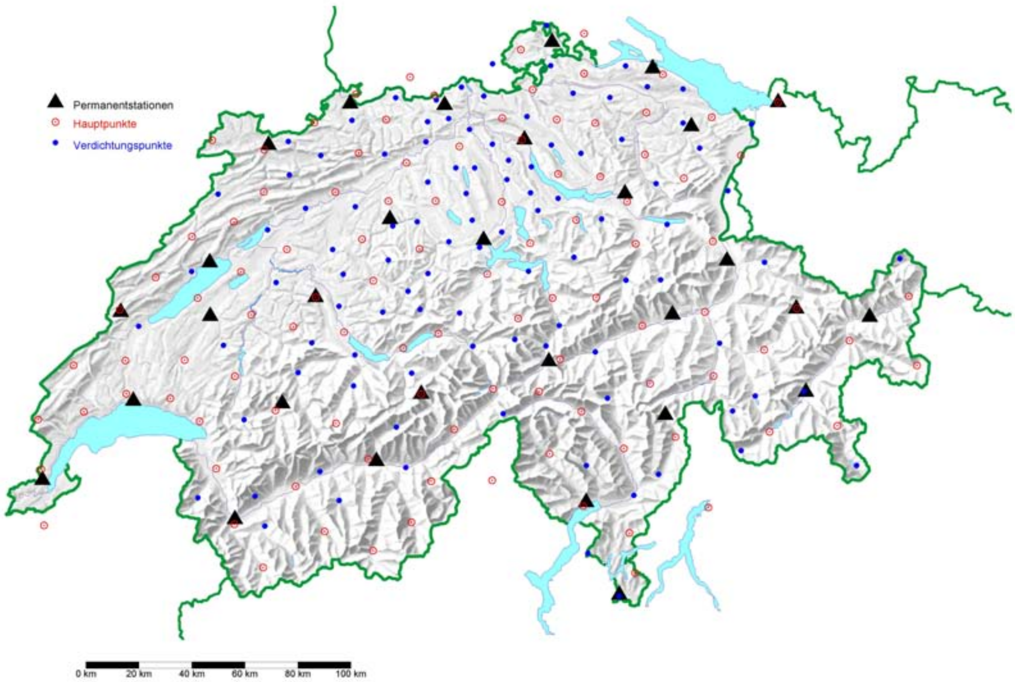


Figure 1.12: The LV95 network consisting of 106 main, 102 densification and 30 AGNES stations.

In October 2005, the test network Turtmann was also re-observed. The Turtmann network was established already in the early days of GPS (1986) in order to justify the use and the accuracies of the GPS technique for national surveying. In combination with the two projects of the ETHZ Zurich (TECVAL for the determination of tectonic movements in the Valais and WATEC for the determination of GPS tomography in dense GPS networks), 2 weeks of data were collected in autumn 2005. Preliminary results using the Bernese software 4.2 show that with the exception of

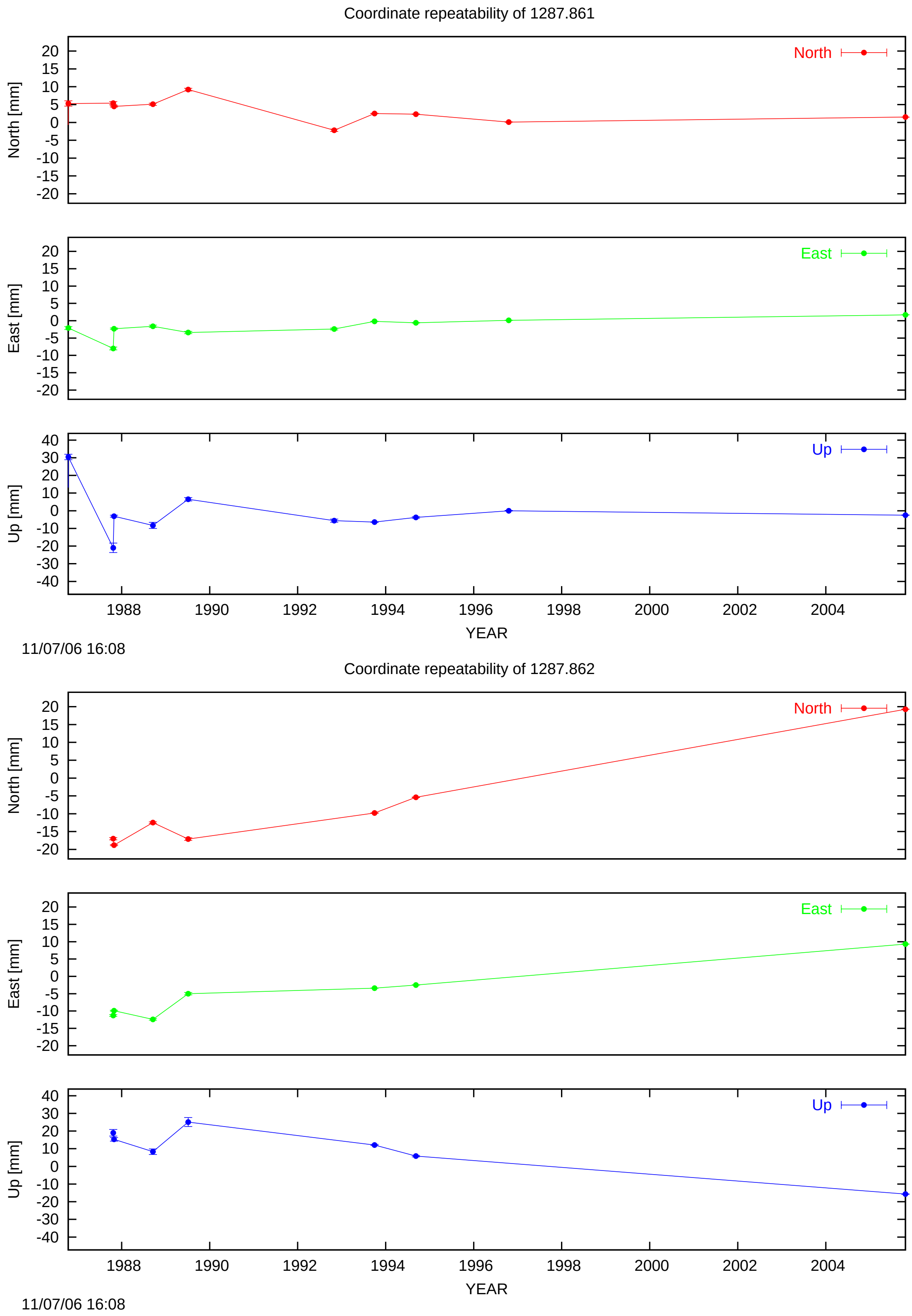


Figure 1.13: Coordinate repeatability of the stable TURTMANN point 1287.861 (Oberems) and the unstable point 1287.862 (Emshorn).

a single site, the 9 Turtmann sites are very stable. It also shows the limited coordinate accuracies in the very early years of the GPS system (1987-1989).

A maintenance concept was developed for all existing reference points. The extent of the maintenance work is defined by a 4-year performance contract with the Department of Defense as our contractor. Besides a legal aspect, the maintenance concept is also based on a quality management system (ISO 9001) which is applicable to all of swisstopo. The regulations governing the maintenance work are an important part of the new "Geoinformation Law" which was developed during the last 2 years and will become effective in the next years.

All categories of surveying points are covered by the maintenance concept. Included are the GNSS permanent stations of the AGNES network, the control points of the LV95 network, the category 1 points of the old triangulation network LV03 (the first and second order triangulation points plus a few third order points), the bench marks of the vertical control network (LHN), the gravity network (LSN), and two test networks (Turtmann and Thun). Tab. 1.2 shows a general summary of the maintenance on the different networks.

Tasks **Networks**	**Establishment**	**Renovation** planned	**Maintenance** what	 where	 when
Permanent network AGNES	as required	yes	visit operation	Switzerland Switzerland	every 5 years as required
National control points LV95	as required	yes	visit	Switzerland	every 5 years
Control points in categories 1 and 2 (LV03)	never	never	***Before LV95:*** visit visit visit revision of pyramids ***After LV95:*** visit revision of pyramids	 Central Plateau pre-Alps/Jura Alps Switzerland Switzerland Switzerland	 every 15 years every 25 years as required as required as required as required
Height network	as required	yes	as required	Switzerland	every 15 years
Gravity network	as required	as required	as required	Switzerland	every 5 years
Test networks	as required	as required	as required	Switzerland	every 5 years

Table 1.2: Overview of the maintenance work on the national survey networks.

Status of the Swiss Combined Geodetic Network CH-CGN

by E. Brockmann, U. Marti, A. Schlatter and D. Ineichen

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 improve the consistency of different reference frames, the height systems and the geoid. The primary goal was the collocation of various geodetic observation types such as SLR, GNSS, gravity, levelling, deflections of the vertical, etc. at the fundamental station Zimmerwald, which thus qualified as

	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, later 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 1.3: Status of the Swiss ECGN contribution.

an ECGN core station. The status of the activities is given in Tab. 1.3 (Brockmann et al., 2005a).

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). The following additional measurements were performed during the last years (Brockmann et al., 2005a):

- Astronomical measurements using two digital zenith camera systems in the years 2001-2003 (automated digital camera systems TZK2-D and DIADEM were used in close cooperation between the University of Hanover and the ETH Zurich resulting in an excellent precision of well below 0.10”)
- GPS levelling (37 new GPS levelling sites in 2003 with 3282 hours of GPS observations)
- GPS campaign in 2004, covering all 106 main and 102 densification points of the LV95 network (see the contribution in section 3, page 65)
- Absolute and relative gravity measurements

A rigorous combination of all GPS campaigns since 1988 (CHTRF2004) generated a new, consistent set of ellipsoidal height estimates for about 190 GPS levelling sites.

LHN95 heights in an orthometric height system were derived using a kinematic adjustment of geopotential numbers.

Figure 1.14: GPS height residuals of the combined adjustment CH-CGN (orthometric heights LHN95, geoid model CHGeo2004, GPS heights CHTRF2004).

The results of the Astro 2003 campaign were used together with the other 690 available vertical deflections for the computation of an improved geoid model. The new national geoid model CHGeo2004 of Switzerland was released in March 2005 (Marti and Schlatter, 2005). It was determined by combining gravity, vertical deflections and GPS/levelling observations. Its accuracy (1 σ) is in the order of 2-3 cm, as could be verified by comparisons with independent data. 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). Besides the standard models (topography and global geopotential model), a simple 3D density model of the Earth's crust was introduced for the reduction of the observations. The computation method was basically a least-squares collocation with a slight modification: the parameters of the covariance function were chosen to minimize the resulting residuals between the astrogeodetic, the gravimetric and the GPS/levelling geoid model. The official geoid model CHGeo2004, which was released to the surveyor community, is primarily based on GPS/levelling, since the geoid model is mainly used for GNSS height determination with the aim of being consistent with levelled heights and the orthometric system LHN95.

New National Height System LHN95, Height Transformations (HTRANS) to the Old Height System and Differences to the Height Systems of Neighbouring Countries

by A. Schlatter and U. Marti

With the introduction of the new geoid model of Switzerland (CHGeo2004), the consistency between the ellipsoidal heights based on GPS observations and the orthometric heights resulting from precise levelling (and gravity) has now been achieved. Furthermore, the gravity-field-related vertical reference frame completes the new national survey in Switzerland, LV95. On March 18, 2005, the results of the new National Height Network LHN95 (Landeshöhennetz 1995) were presented to the geodetic community for the first time (Marti and Schlatter, 2005). They will now be available to all surveyors interested in applying GNSS-based height determination, even though LHN95 is not officially in use for cadastral surveying.

The kinematic adjustment of the potential differences between 1,600 selected stations along approx. 10,000 km of repeatedly observed precision levelling lines forms the backbone of the LHN95. The adjustment is based on the fundamental reference point Zimmerwald, where the discrepancy of the geopotential numbers to the UELN-73 solution amounts to 0.102 gpu. This difference stems from the definition of the datum for LHN95, which was chosen in such a way that the value of the old Swiss vertical datum LN02 (Repère Pierre du Niton: H = 373.6 m) remains the same.

The result of the adjustment of the 3380 observations, including a total of 2,750 unknowns (potential numbers and their temporal changes), was a standard deviation of 1.4 mgpu for the unit of weight. This corresponds to a standard deviation of 1.4 mm for the length of 1 km with a height difference of 100 m. The vertical velocities are set to zero at the arbitrarily chosen reference benchmark in Aarburg. The resulting vertical velocities show significant amounts of up to 1.5 mm/a, especially in the Alpine areas (see also the contribution in section 3, page 70).

At the same time, swisstopo introduced the software HTRANS which made possible the transformation from LHN95 to the old official vertical frame LN02 (Schlatter and Marti, 2005). HTRANS can be purchased as geodetic software, but it is also available as an Internet application free of charge. Furthermore, HTRANS is accessible as an additional mode of the swipos® positioning service via a separate telephone number. Fig. 1.15 shows the differences between the new orthometric heights LHN95 and official heights of the old vertical frame LN02 for about 1'450 reference points.

For the modeling of the differences between LN02 and LHN95, a 1-km grid f(y,x) representing the differences between LN02 and normal heights and a 1-km grid of Bouguer anomalies are provided. The Bouguer anomalies allow the modeling of the height-dependent discrepancies between orthometric and normal heights. The differences between the model and the calculated values of the reference points lead to another 1-km grid (f_{rest}). All grids are easy to interpolate, and one obtains the differences between LHN95 and LN02 (Fig. 1.16) with the formula

$$H_{LHN95} = H_{LN02} + f_{Norm-LN02}(y, x) + f_{rest}(y, x) - \Delta g_{Boug}(y, x) \cdot H$$

Finally, the differences between normal heights (from the geopotential numbers LHN95) to the official heights of the neighbouring countries are shown in Fig. 1.17. A very good agreement can be found especially between France and Switzerland after taking into consideration an offset of -36 cm. The normal-orthometric heights (Status 130) were used for the comparison to Germany.

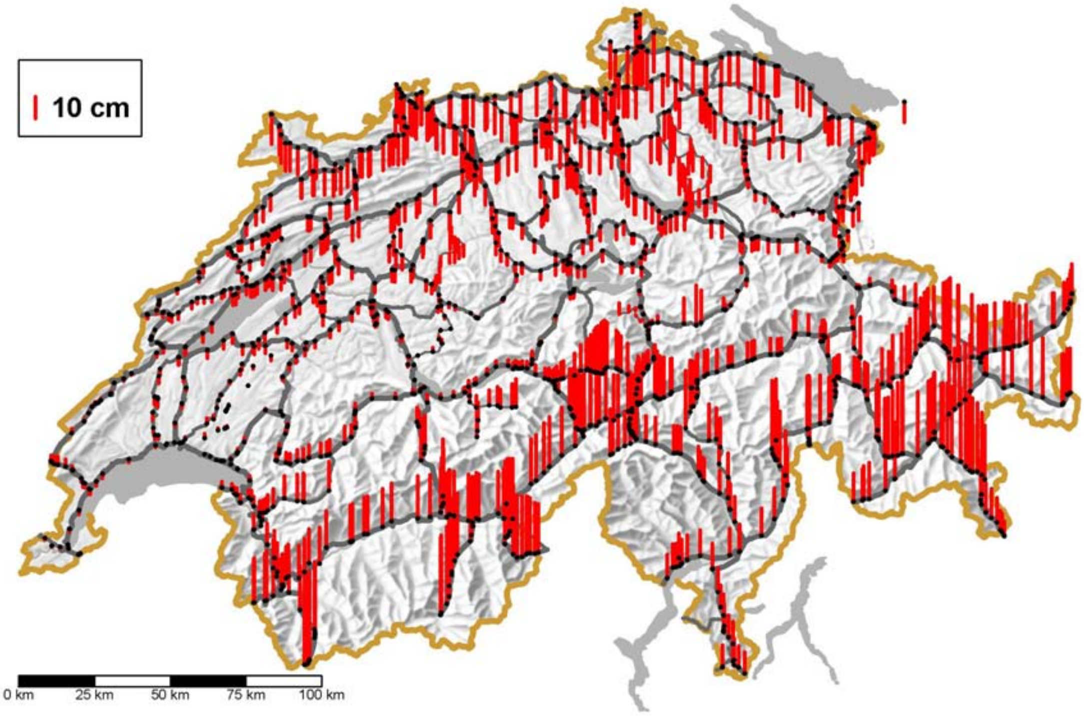


Figure 1.15: Differences between the orthometric heights LHN95 and the official (levelled) heights LN02 for about 1'450 reference points.

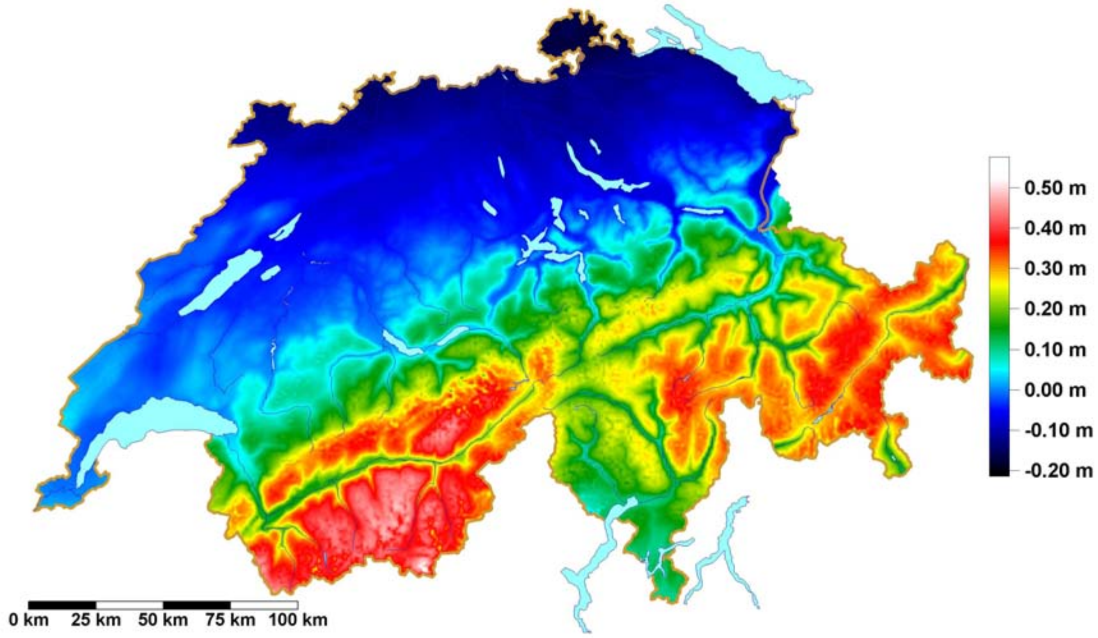


Figure 1.16: Total surface of the differences between the orthometric heights LHN95 and the official (levelled) heights LN02 as a grid from the geodetic software HTRANS.

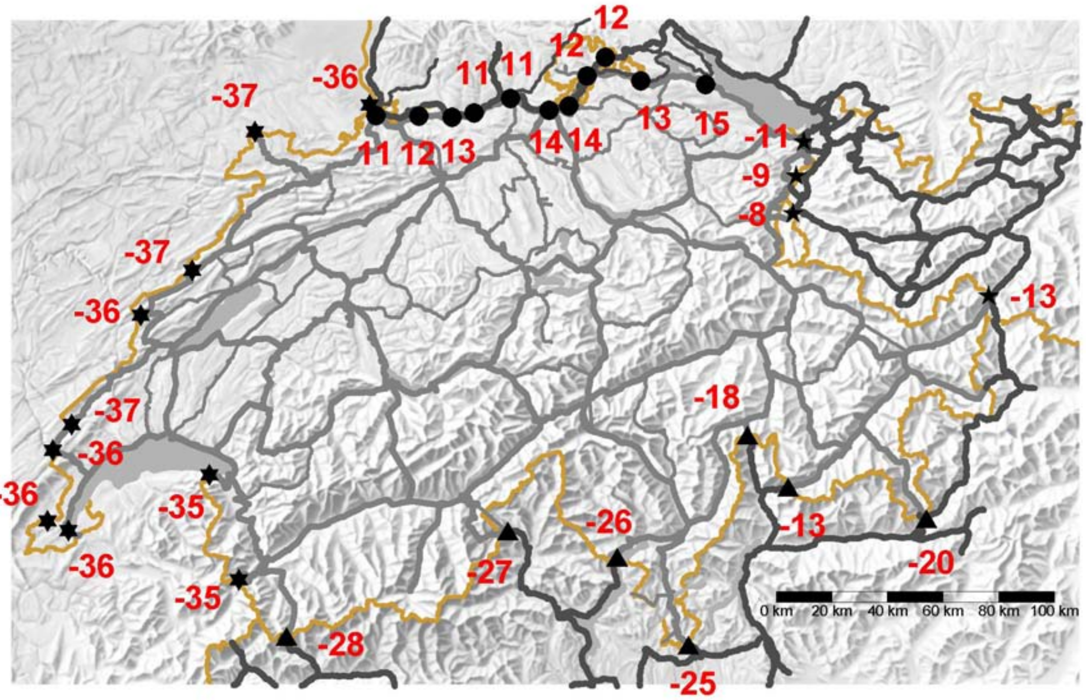


Figure 1.17: Differences between the Swiss normal heights LHN95 and the heights of neighbouring countries [cm].

Completion of the Swiss National Triangular Transformation Network: Precise Transformation between the Old Reference Frame LV03, the New LV95 and Global Frames

by M. Kistler, A. Papafitsorou, U. Marti, J. Ray, B. Vogel, U. Wild and C. Métraux

The end of 2006 saw the completion of a basic geographical data-set of the greatest importance for the establishment of the spatial data infrastructure SDI of Switzerland, the national triangular transformation network. This new data-set permits the elimination of the systematic deformations resulting from the first Federal survey of Switzerland completed in 1903 which reached a maximum of 2 to 3 m as well as the local distortions from the cadastre survey on the cantonal level.

Switzerland was subdivided into almost 12'000 triangles, each having its own affine transformation parameters matched to local conditions. In addition, to prove the accuracy of the transformation, the cantonal authorities have measured almost 47'000 control points. The results were excellent: geographical data in Switzerland can now be transformed into the new LV95 reference frame or in a global one like ETRF with an accuracy of 2 cm on average.

The national triangular transformation network will also be implemented in the Swiss GNSS Positioning Service swipos as a new real-time option with GPS correction as well as "old reference frame adaptation": GPS users, who have to work in the old, for many applications still valid LV03 datum, can so position or measure with an accuracy of a few centimetres without establishing a local fit. Furthermore a new software REFRAME including all relevant transformations Switzerland was released as client version as well as web service.

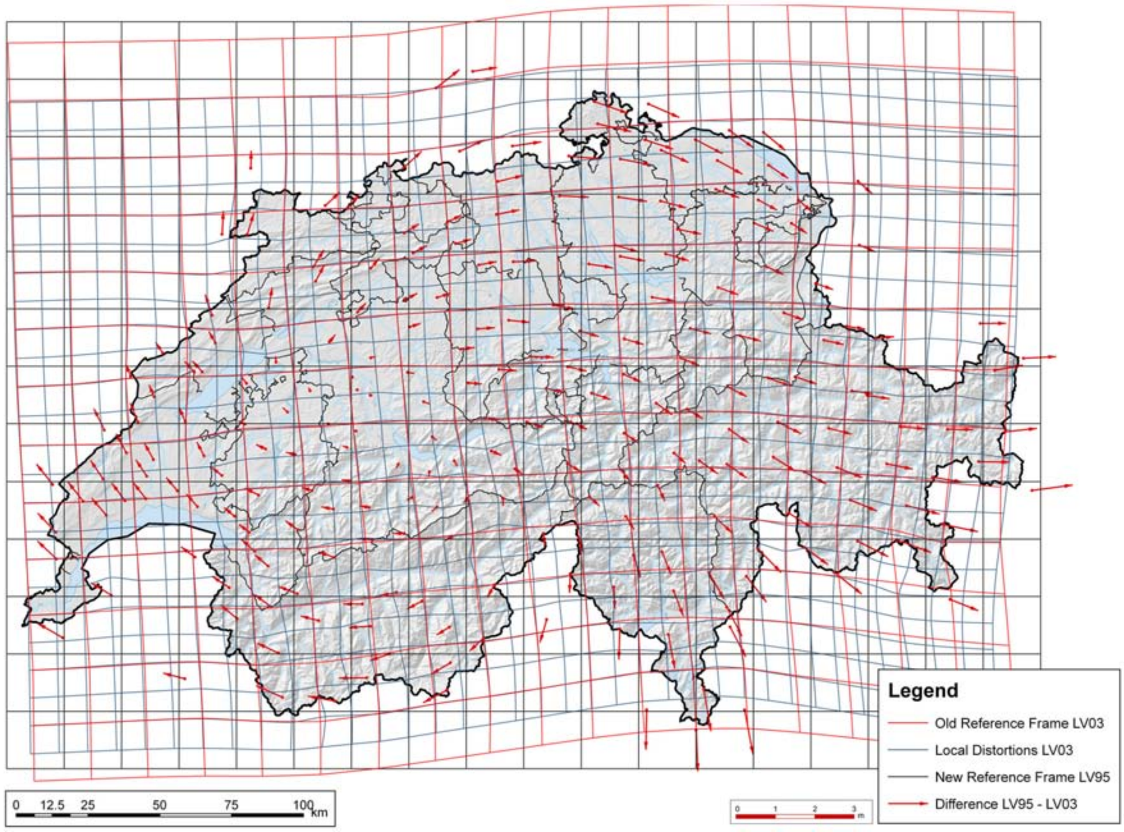


Figure 1.18: Deformations of the reference frame of 1903 still in use today (LV03 = red grid with the deformations from the national survey and the blue grid including also the local distortions from the cadastre level) compared with the new Swiss reference frame of 1995 (LV95 = black grid).

In 2007, swisstopo switches to a designated Internet portal for datum transformation. This will give detailed information about the transformation process and will provide access to the official national transformation data-set. In addition, a service will be provided free of charge which allows to transform geographical data in common formats such as DXF, SHP or the national GIS standard INTERLIS 1, or even formatted as text (separated by tabs or hyphens), from the old LV03 system to the new LV95 reference frame and vice versa, and also into the European ETRS89 reference system. Last but not least, the accuracy of the transformation can be accessed through a web GIS application for everywhere in Switzerland and the transformed data sets can be exported in the KML format in order to visualise the results in Google Earth or Maps.

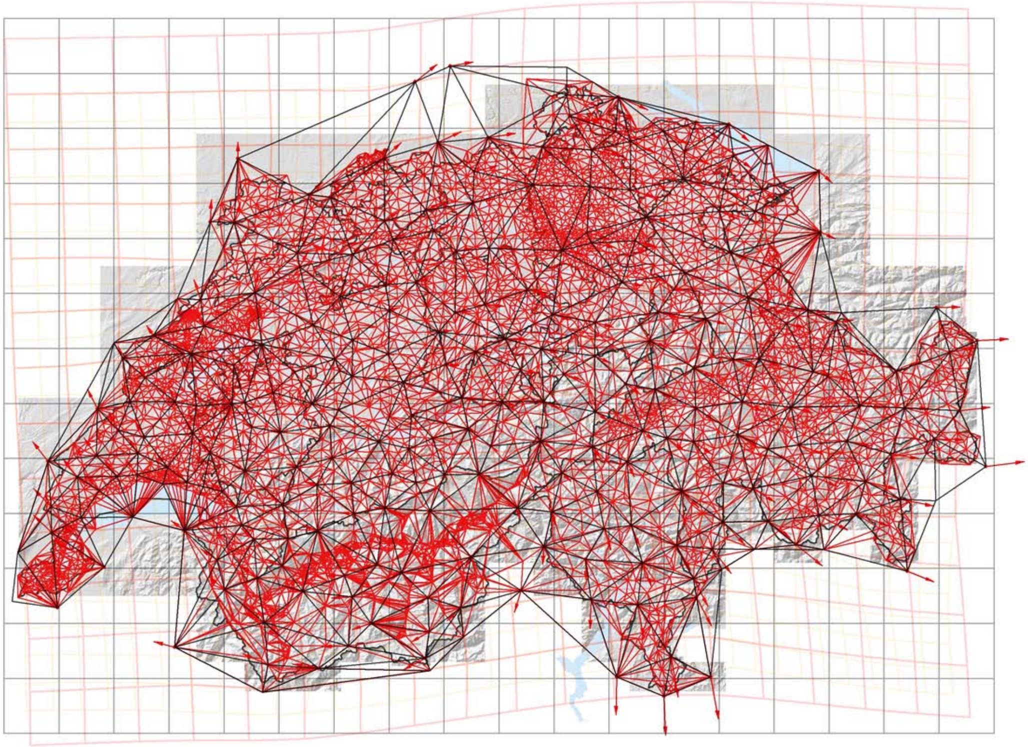


Figure 1.19: National triangular transformation network.

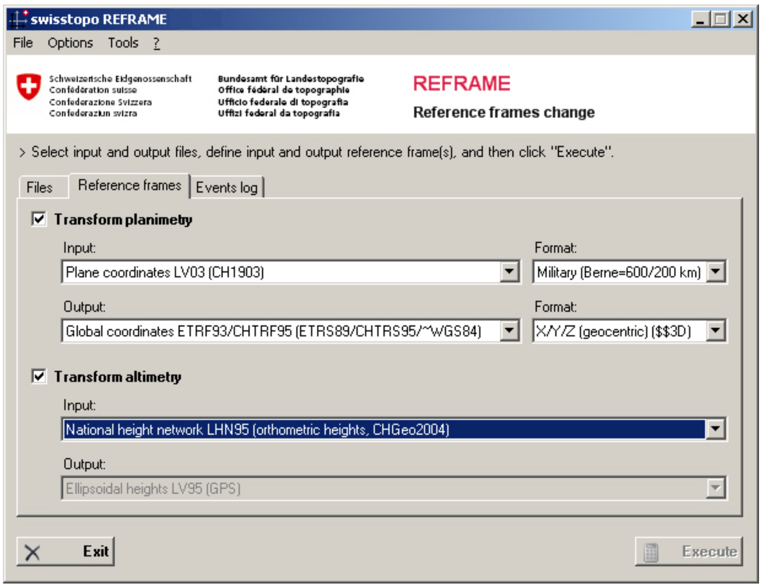


Figure 1.20: The user interface of the new "REFRAME" transformation software. Besides the transformation LV03 ⇆ LV95 in either direction, geoid undulations from the reference ellipsoid (geoid heights) and differences between the LN02 and LHN95 height systems can also be computed (discrepancies between the "official heights" of the LN02 datum and other height systems). In addition, Swiss national coordinates can be converted into global reference systems such as ETRS89.

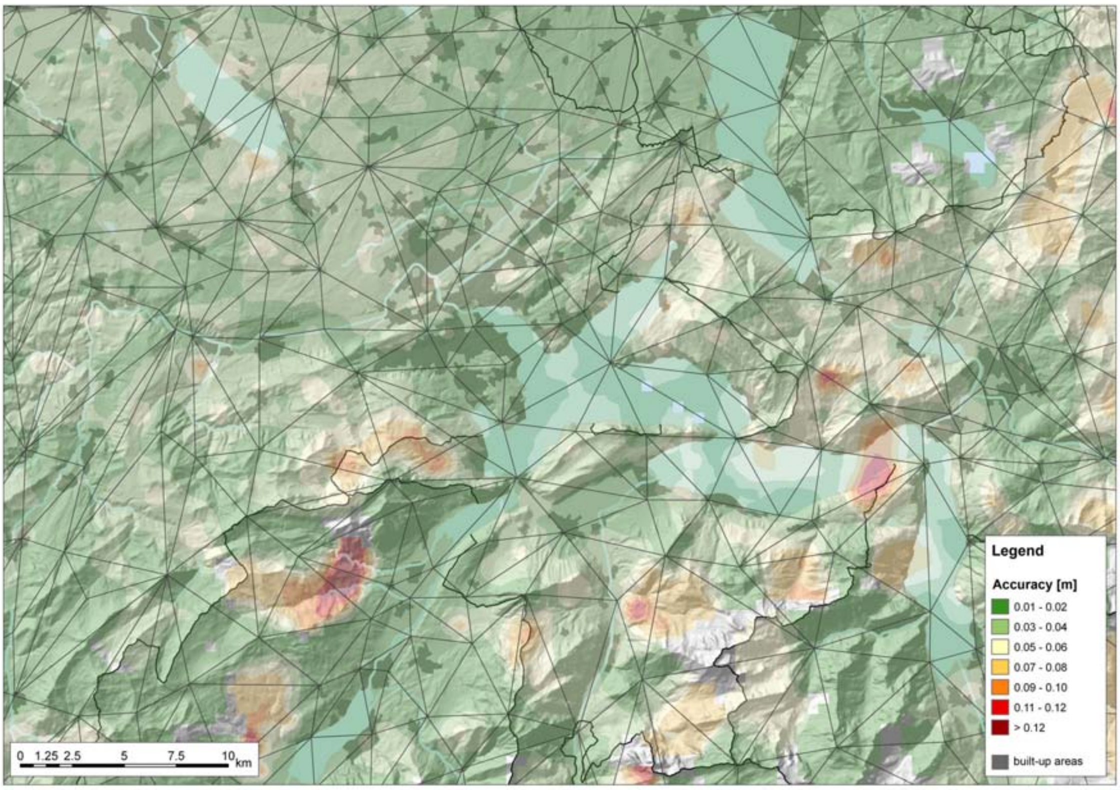


Figure 1.21: Expected empirical accuracy of the transformation in the region around Lucerne.

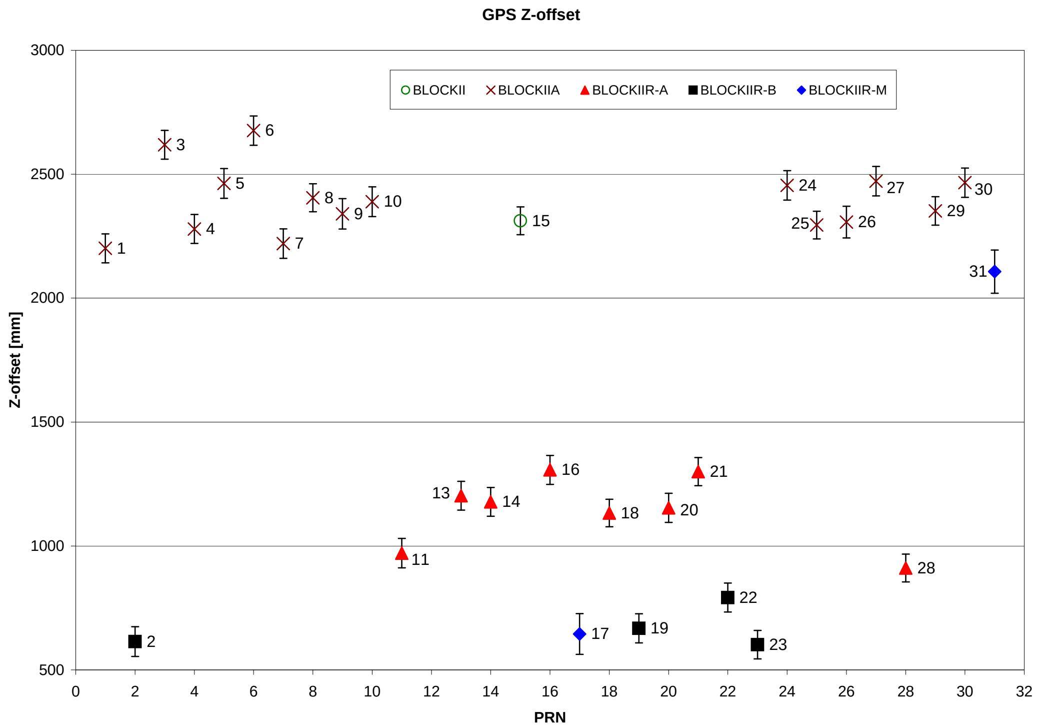
GNSS Data Calibration Parameters

by S. Schaer, A. Gäde, R. Dach, U. Hugentobler and M. Meindl

Antenna phase center variations (PCV) and the differential code biases (DCB) have to be considered for GNSS data analysis, to achieve highest accuracy of GNSS derived analysis products.

When relying on an absolute antenna model, it is a must to apply receiver antenna PCV in conjunction with satellite antenna PCV values. Receiver antenna PCV values are obtained from robot, anechoic chamber, or field relative calibrations. Satellite antenna PCV values are estimated in the data analysis of a global GNSS tracking network on top of a (preferably absolute) receiver antenna PCV model (Görres et al., 2006), or (Schmid and Rothacher, 2003).

The Center for Orbit Determination in Europe (CODE) has been contributing to the estimation of GNSS antenna PCV models. An antenna PCV correction model consists of a constant part (offset) and a variable part (pattern, dependent on the direction of the line of sight). The satellite antenna offsets are estimated in a satellite-fixed coordinate system, where the Z-direction points to the Earth. Estimated Z-offsets reach values between 0.50 m and 2.65 m for GPS satellites and values between 1.80 m and 2.40 m for GLONASS satellites (see Fig. 1.22). It is interesting that GLONASS satellite antenna patterns show a much lower variation in comparison to GPS satellite antenna patterns, which deviate significantly from the zero model. Values of up to 10 mm for GPS satellites very clearly indicate that (satellite) PCV values are not negligible for highest precision applications. The complete set of receiver and satellite antenna PCV values is compiled in an ANTEX-formatted file (igs05.atx) and made available on the IGS ftp server. The corresponding file is updated when



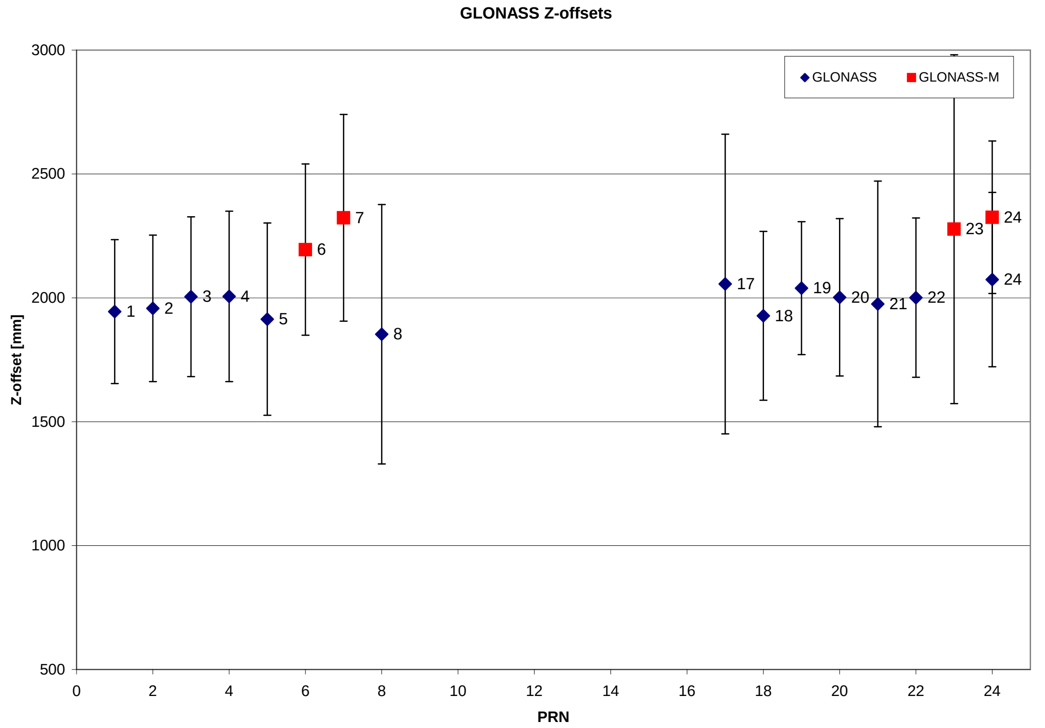


Figure 1.22: Satellite antenna Z-offsets for the GPS and the GLONASS satellite constellation, estimated at CODE from 10 months of data in 2005 and 2006 (error bars rescaled by a factor of five for plotting).

new receiver or satellite antenna model values become available. It should be mentioned that any IGS antenna model information concerning the GLONASS satellite constellation is exclusively produced at CODE.

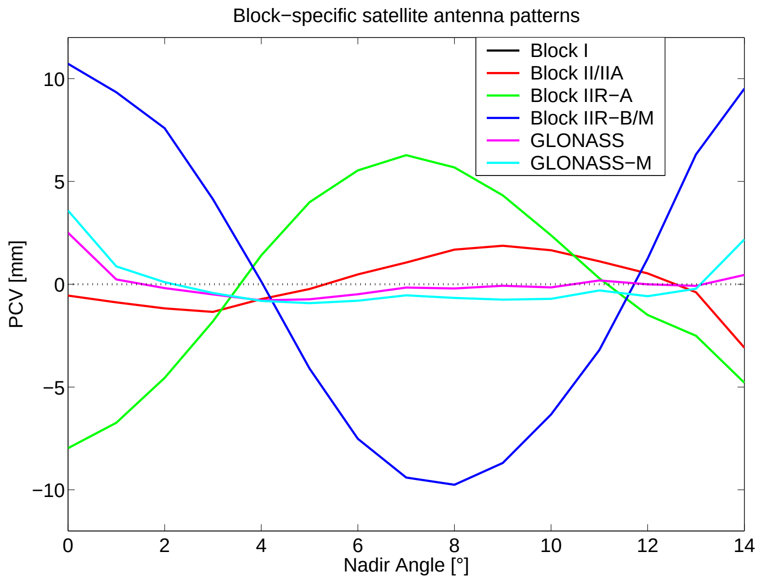


Figure 1.23: Satellite antenna patterns for the various groups of GNSS satellites, estimated at CODE from 10 months of data in 2005 and 2006.

Daily sets of P1-P2 DCB values for all GPS/GLONASS satellites and IGS stations involved are obtained as a by-product of the ionosphere analysis at CODE. The satellite-related P1-P2 bias values multiplied by -1.55 yield, when allowing for a common offset, a quantity corresponding to the GPS broadcast group delay (GD). A corresponding figure comparing GD values derived by CODE and broadcast by GPS is posted daily to the Internet.

As of GPS week 1056, CODE regularly extracts satellite-specific P1-C1 DCB values from the global satellite and receiver clock estimation process. Although the size of P1-C1 bias values is approximately three times smaller than that of P1-P2 values, these biases may, however, still be detected (see Fig. 1.24). Based on ambiguity-fixed double differences using the Melbourne-Wübbena linear combination, it is also possible to retrieve P1-C1 bias values. The day-to-day bias reproducibility concerning this double-difference product (generated since May 2002) is of the order of only 30 picoseconds (Hugentobler et al., 2007). Let us point out that the P1-C1 bias values produced by CODE are recommended for use with the IGS official products. Monthly sets of DCB values are archived and made available to the IGS community and to the users of the Bernese GPS Software. Note that P1-P2 bias values are not only computed for GPS but also for GLONASS (since April 2003).

When dealing with P1-C1 biases, one has to distinguish between three receiver classes: classical P1/P2 receivers (usually also providing C1), older cross-correlating C1/X2 receivers, as well as modern C1/P2 receivers (not providing P1). A smart method to assign a particular receiver to one of these three tracking technology classes has been developed: multipliers for the P1-C1 bias are estimate and interpreted. The reliability of this method could be demonstrated several times in the past.

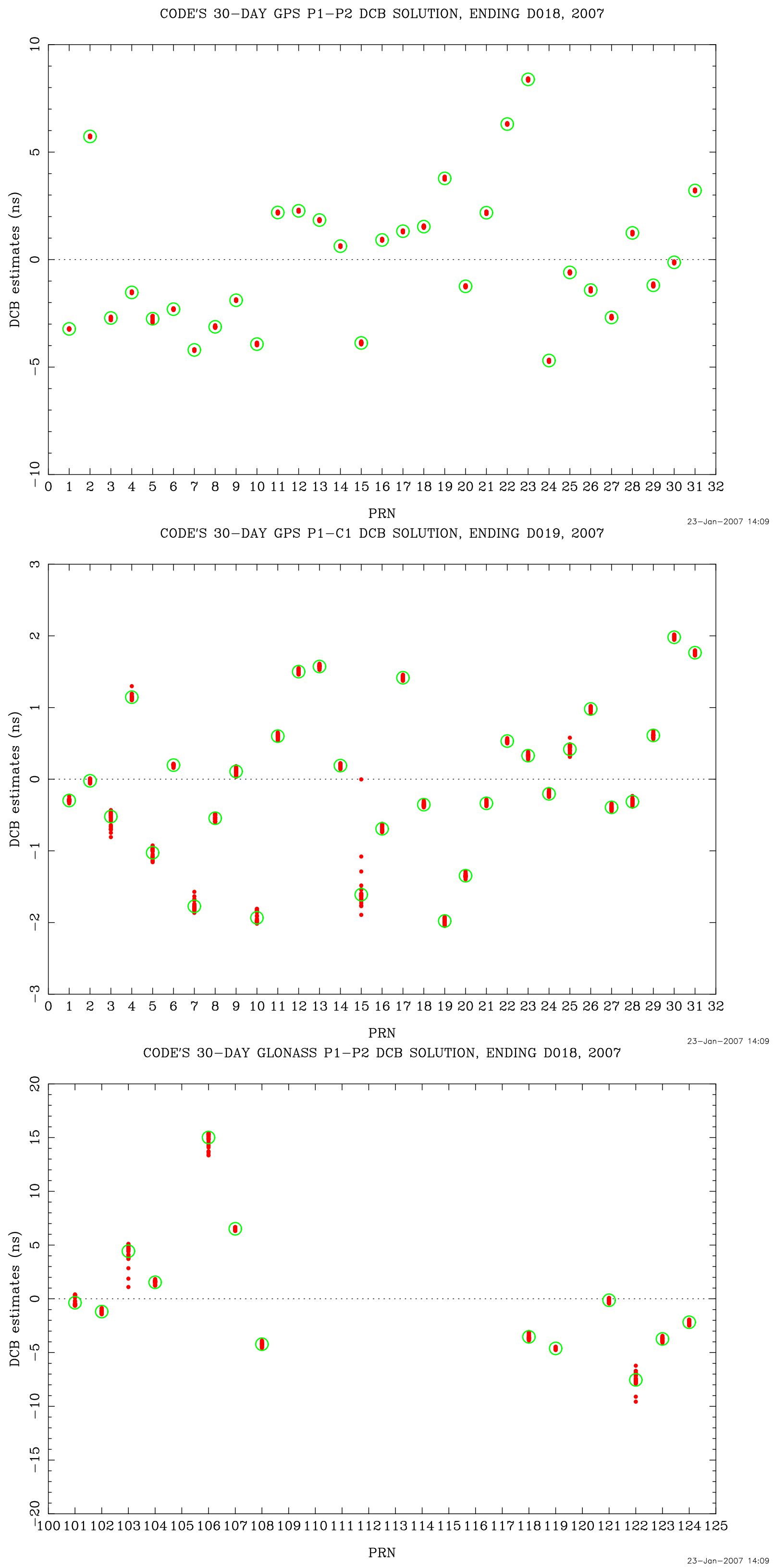


Figure 1.24: 30-day averages of P1-P2 and P1-C1 code bias values for the GPS (and GLONASS) satellite constellation, computed at CODE.

Galileo Geodesy Service Provider Prototype (GGSP)

by A. Gäde, U. Hugentobler and R. Dach

The realization of a highly precise and stable Galileo Terrestrial Reference Frame (GTRF), the basis for all Galileo products and services, is the main function of the GGSP serving both, the Galileo Core System (GCS) and the Galileo User Segment. GGSP should allow it toe all users of the Galileo System, including the most demanding ones, to rapidly access the GTRF with the precision required for their specific application. Furthermore, the GGSP must ensure the proper interfaces to all users of the GTRF, especially the application and scientific user groups. In addition, the GGSP must establish the adherence to the defined standards of all its products. Last but not least the GGSP will play a key role to create awareness of the GTRF and educate users in the usage and realization of the GTRF.

The primary task of the GGSP is to provide GTRF station positions and velocities for the Galileo Sensor Stations (GSS, see Fig. 1.25). The GGSP responsibilities will also include the generation of other precise products that are needed by the Galileo advanced geodetic user community to get full and unlimited access to the GTRF. These products, which are generated simultaneously with the GTRF activities performed within the GGSP, will at least comprise Earth Rotation Parameters as well as Galileo orbits and clocks. Only with such a complete and consistent set of high precision products the GGSP can truly meet its primary objective of providing a reference frame to all relevant user communities, including the most demanding ones.

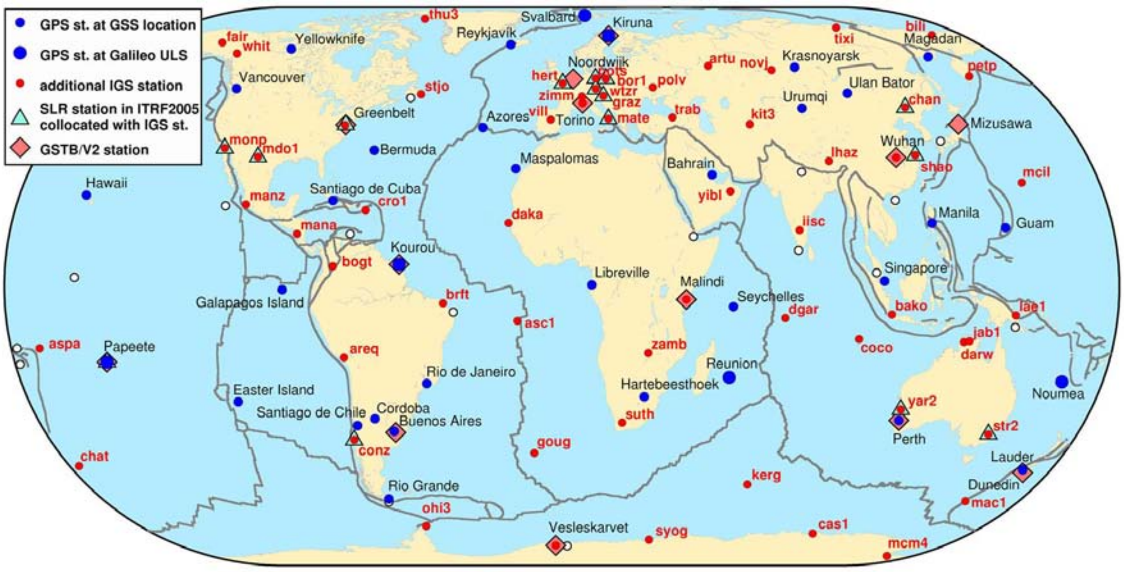


Figure 1.25: Tracking network for initial GTRF realization.

The main task of GGSP includes the generation, the maintenance, and also the validation of the provided GTRF. A consortium of the following seven institutions has been formed to meet the objectives: GeoForschungsZentrum Potsdam (Germany), Astronomical Institute of the University of Bern (Switzerland), Bundesamt für Kartographie und Geodäsie Frankfurt (Germany), European Space Operation Centre Darmstadt (Germany), Institut Géographique National Paris (France), Natural Resources Canada Ottawa (Canada), and Wuhan University (China). In the initialization phase only GPS data are used for the data analysis. The global tracking network consists of all GSS stations (ca. 45) and additional IGS stations for densification. These IGS stations are also necessary to align the GTRF to the ITRF within an accuracy of 3 centimeters.

The task of the AIUB within the consortium is to define the used parameters and models, to process the GPS data as analysis center (AC), to validate the GGSP system itself and to validate the main product, the GTRF. Fig. 1.26 gives an overview of the GGSP architecture.

GGSP homepage: http://www.ggsp.eu

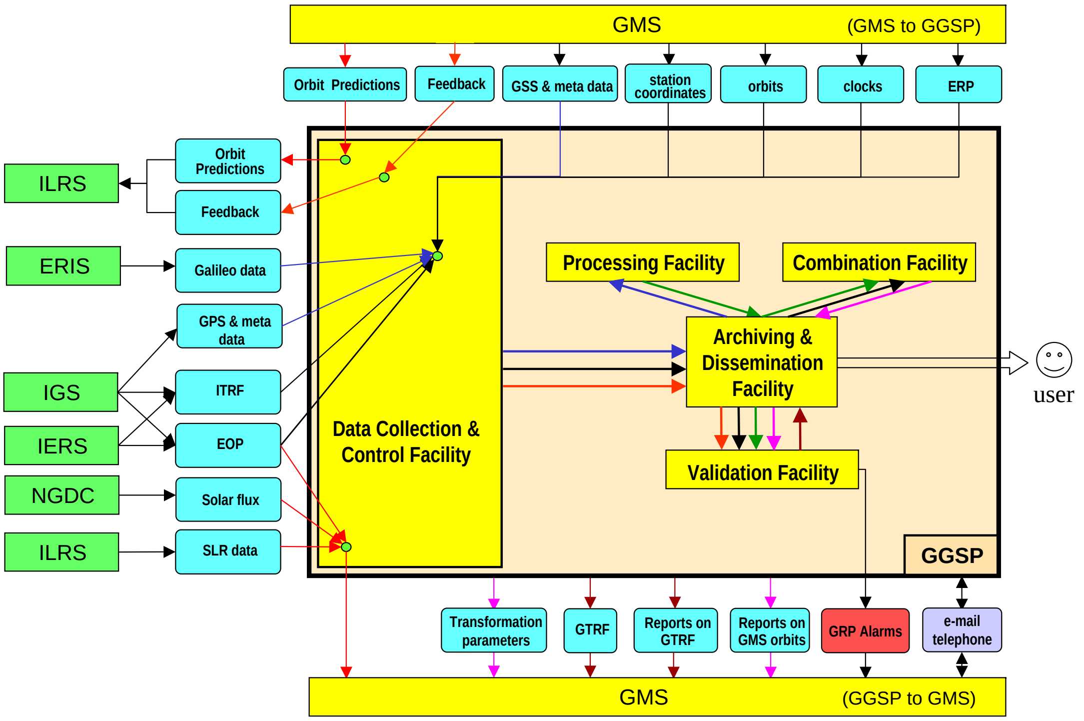


Figure 1.26: GGSP Architecture - Overview.

The Zimmerwald Observatory

by W. Gurtner, E. Pop, J. Utzinger and M. Ploner

The main activities at the Zimmerwald Observatory are:

- Satellite laser ranging (SLR) as a station of the global tracking network of the International Laser Ranging Service ILRS (Astronomical Institute AIUB, swisstopo)
- Astrometric observations of satellite, space debris, and near-Earth asteroids with CCD cameras (AIUB)
- Operation of permanent GPS and GLONASS receivers (swisstopo, AIUB)
- Operation of a permanent Earth tide gravimeter (swisstopo, ETH Zürich)
- Since end of 2006: Atmospheric observations (mainly water vapor contents and distribution, Institute for Applied Physics IAP)

In October 2006 the observatory celebrated its 50-years anniversary and the inauguration of the new building for the atmospheric research of the Institute of Applied Physics.

Figure 1.27: The Zimmerwald Observatory.

SLR Observations

by W. Gurtner, E. Pop and J. Utzinger

From 1995 till 1997 we replaced the first observing system in Zimmerwald mainly dedicated to SLR (50-cm telescope, Neodyme:YAG laser) by a new Titanium:Sapphire laser and a larger 1-m telescope (ZIMLAT: Zimmerwald Laser and Astrometric Telescope) equipped with powerful CCD cameras. This dual-mode system can be used for laser ranging as well as for astrometric observations of space objects by means of CCD cameras.

One of the original system design goals was complete computer control, leading to the possibility to control the system from remote locations and to gradually automate all functions of the system.

The improvement of the system performance (accuracy, data volume, ease of operation), reliability, and degree of automation was and still is a major concern of the group responsible for the station. In parallel with these improvements the Zimmerwald laser station slowly became one of the most productive stations of the ILRS tracking network. In 2006 it observed more satellite passes and (with the exception of the new 2 kHz-station Graz) more normal points (normalized range observations) than any other station on the northern hemisphere (Fig. 1.28 and 1.29). The system usually runs a few hours per day in fully automated mode, mainly to cover gaps between the two daily shifts (day/night).

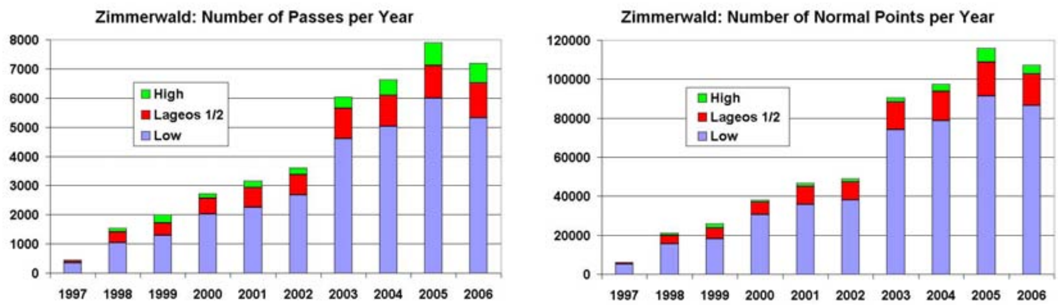


Figure 1.28: Zimmerwald: Number of passes and normal points per year.

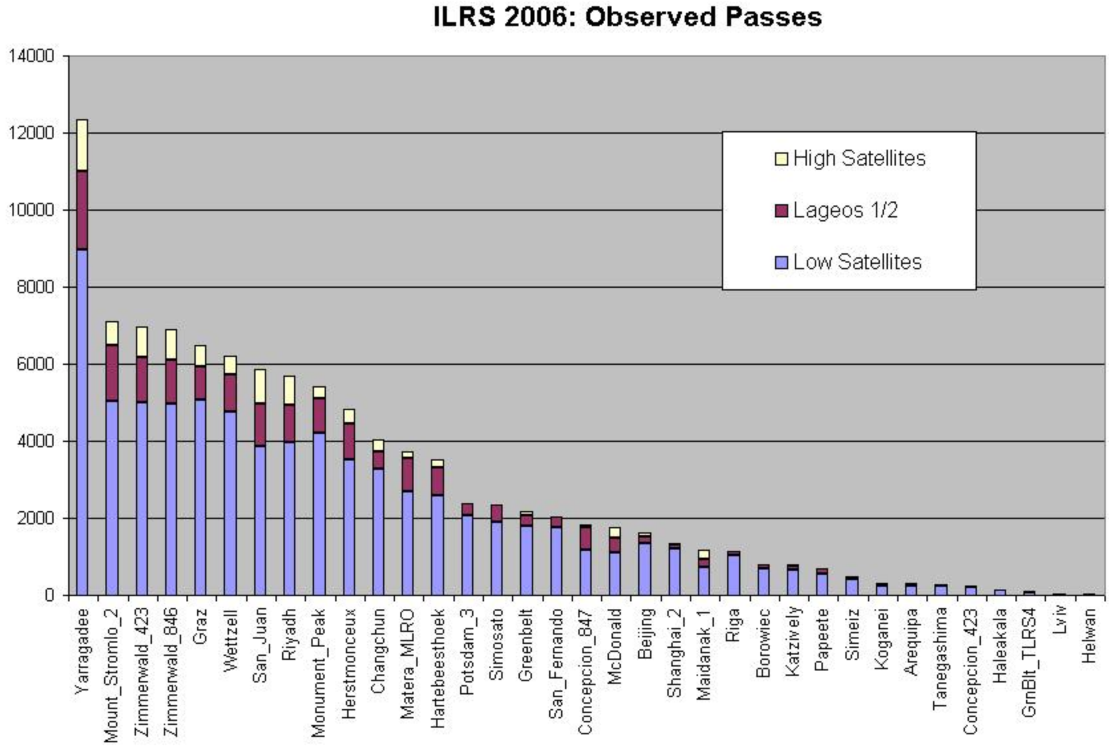


Figure 1.29: Number of passes observed by the ILRS stations in 2006.

During the last four years Zimmerwald significantly contributed to new and advanced concepts and procedures, such as

- tracking of vulnerable satellites (satellites equipped with sensors that could be damaged by the tracking laser pulses)
- development, test, and integration of a new orbit prediction scheme
- real-time distribution of system status and satellite orbit information

Zimmerwald is the only ILRS station routinely observing ranges to satellites in two wavelengths. Unfortunately the accuracy of the observations is not sufficient to reach the original goal: to use the two-color observations to improve the atmospheric range corrections. However, the second color (infrared wavelength) is still very useful to detect systematic errors and to extend the range of operation especially under difficult atmospheric conditions.

Maintenance and operation of the SLR system are supported by the Federal Office of Topography, the Swiss National Science Foundation and the Swiss Academy of Sciences.

SLR Validation of GNSS Orbits

by C. Urschl, G. Beutler, W. Gurtner, U. Hugentobler and S. Schaer

Satellite Laser Ranging (SLR) observations of GNSS (Global Navigation Satellite System) satellites allow for a completely independent validation of GNSS orbits, which are derived from microwave data. For validation purposes, the SLR ranges are compared with the distances computed from the microwave-based orbits. The resulting range residuals are an indicator for the orbit accuracy. Validations can be done for those GNSS satellites which are routinely tracked by the SLR community, i.e., the two GPS satellites (PRN G05 and G06) equipped with retro-reflector arrays (LRAs), and a set of three GLONASS satellites (all GLONASS satellites carry LRAs).

We validated microwave-based GNSS orbits generated at CODE - the Center for Orbit Determination in Europe. CODE is a joint venture of the Astronomical Institute of the University of Bern (AIUB), Bern, Switzerland, the Federal Office of Topography (swisstopo), Wabern, Switzerland, and the Federal Agency of Cartography and Geodesy (BKG), Frankfurt, Germany. As one of the Analysis Centers of the International GNSS Service (IGS), CODE routinely provides orbit products derived from a global GNSS analysis (Hugentobler et al., 2007). For orbit validation the Bernese GPS Software, Version 5.0 was used (Dach et al., 2007).

Recent validation results of the CODE final orbit products show a standard deviation of the range residuals of about 2 cm for the GPS, and of about 5 cm for the GLONASS satellites. The GPS orbits have a better accuracy compared to GLONASS, due to the much denser GPS microwave tracking network. In addition, we found a mean bias of 3-4 cm as well as significant seasonal variations of up to 10 cm amplitude for the two GPS satellites (see Fig. 1.30). The mean bias is known from previous studies and its origin is still unexplained. An erroneous value for the retro-reflector offset, giving the vector from the center of the LRA's to the satellite's center of mass, would be a simple explanation.

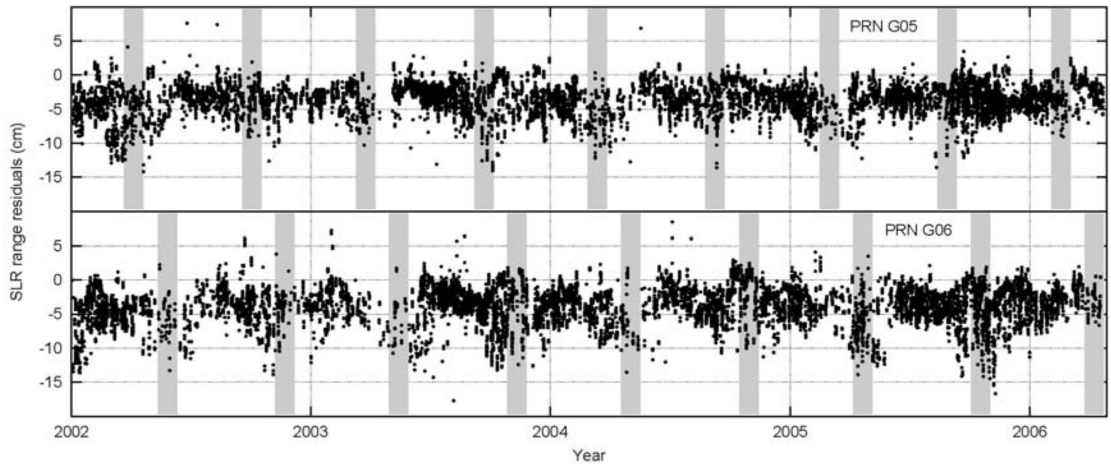


Figure 1.30: SLR range residuals in cm for GPS satellites PRN G05 and G06, derived from CODE final orbits. The shaded areas indicate eclipse seasons.

These clearly visible seasonal variations were studied in detail. The largest residuals occur when the satellite is observed within the Earth's shadow during the eclipsing seasons (indicated with shaded areas in Fig. 1.30). As the observation geometry as well as the Sun-orbit geometry reproduced at the same period, it was not possible to identify the source of the periodic pattern - either due to the SLR or to the microwave technique.

No significant dependencies on SLR-specific parameters, as the tropospheric zenith path delay, satellite- or station-dependent biases, and SLR site coordinates, were found. We could, however, attribute the periodic signature of the range residuals to orbit modeling problems, by displaying the color-coded residuals in the (β,u)-coordinate system, where β is the elevation of the Sun above the orbital plane and u is the argument of latitude of the satellite with respect to the argument of latitude of the Sun. Fig. 1.31 shows the range residuals in the (β,u)-system. The dependency of the residuals on the satellite's position within the orbital plane is clearly visible, which rules out SLR tracking biases. The pattern must therefore be a finding caused by the microwave analysis, indicating attitude or orbit modeling problems (Urschl et al., 2007). Deficiencies in the solar radiation pressure modeling might be one possible explanation. Further investigations will hopeful lead to an improvement of the orbit models.

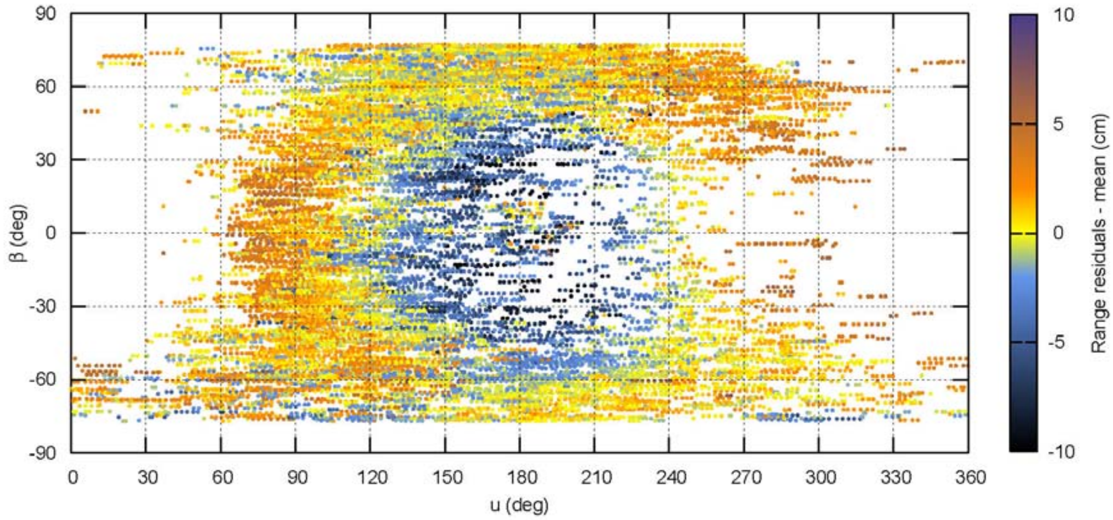


Figure 1.31: Color-coded SLR range residuals in cm minus mean value for the GPS satellites PRN05 and PRN06, derived from CODE final orbits.

We also made the attempt to calibrate the SLR measurements. CODE, as an Associate Analysis Center (AAC) of the International Laser Ranging Service (ILRS), provides daily comparisons of SLR tracking data with ranges derived from CODE orbits for GPS and GLONASS satellites in form of quick-look reports. These reports are distributed via e-mail to the SLR-report mail server every day, giving rapid feedback to the ILRS community concerning the SLR data quality.

The first European navigation satellite GIOVE-A (Galileo In Orbit Validation Element) was launched on December, 28, 2005. As no microwave tracking data are available until now, the orbit determination based on SLR data is of vital interest. We succeeded to determine SLR-based orbits of GIOVE-A, analyzing about eight weeks of SLR data. Orbital arcs with a length of nine days were determined with an accuracy of about 0.1 m, 0.5 m, and 1 m in radial, along-track and cross-track direction, respectively. In addition, a satellite maneuver could be identified that was not announced. The microwave-based GIOVE-A orbits as well as the first Galileo orbits in the IOV (In Orbit Validation) phase will rely on microwave tracking data of a very limited number of stations. Therefore, SLR has the potential to give an important contribution to the orbit determination in a combined analysis of microwave and SLR data. The potential improvement of the orbit accuracy could be qualified on the basis of an a priori variance-covariance analysis, using SLR range measurements and simulated microwave data.

CCD Observations

by M. Ploner, W. Gurtner and T. Schildknecht

CCD cameras mounted on a special derotator platform on the telescope allow the observation of space objects using the 1-meter mirror of the telescope. Thanks to the special telescope design the switch from SLR to CCD and vice versa can be done within a few seconds time.

Objects routinely observed are

- GEO (geostationary objects): Active satellites and space debris
- GTO (geostationary transfer orbit): Space debris
- Minor planets: Confirmation exposures for near-Earth asteroids
- GPS to check system status (e.g., timing system)

The control software for optical observations by means of CCD cameras was improved to a degree that CCD operations can run fully automatically, embedded into the SLR tracking by fast-switching between SLR and CCD mode.

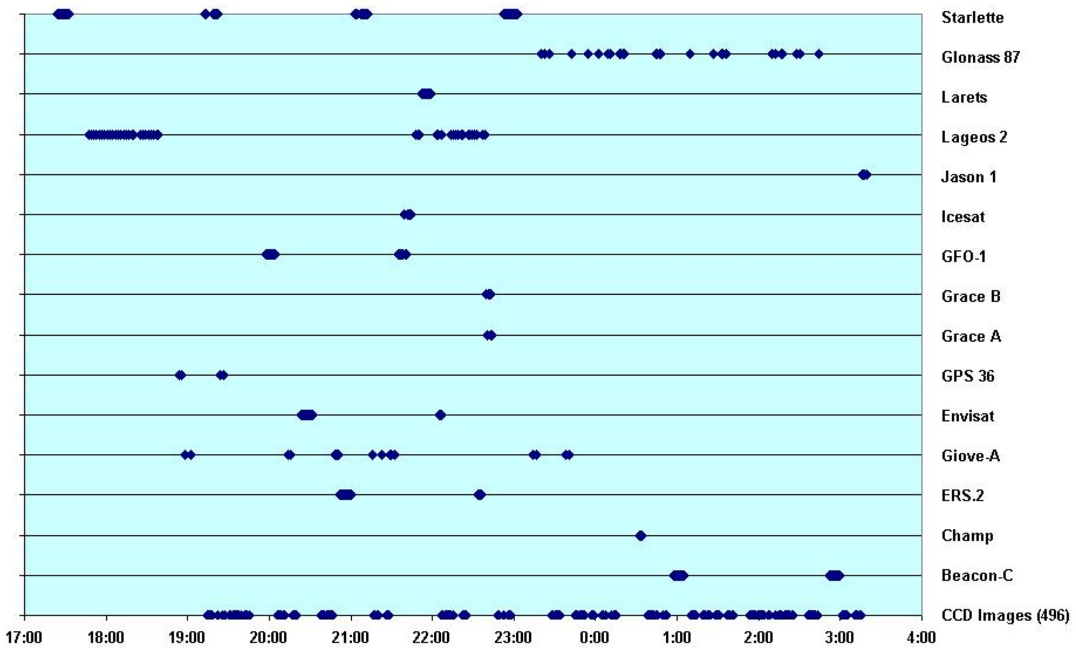


Figure 1.32: SLR/CCD interleaving.

Fig. 1.32 shows a typical example of the distribution of SLR and CCD (bottom line) tracking during a night between 17:00 and 04:00 UT. On the average more than 2000 CCD observations are taken each month (Fig. 1.33). It is remarkable that the performance of the SLR station competes with the top stations of ILRS although the system is devoted to CCD for a significant amount of the night time.

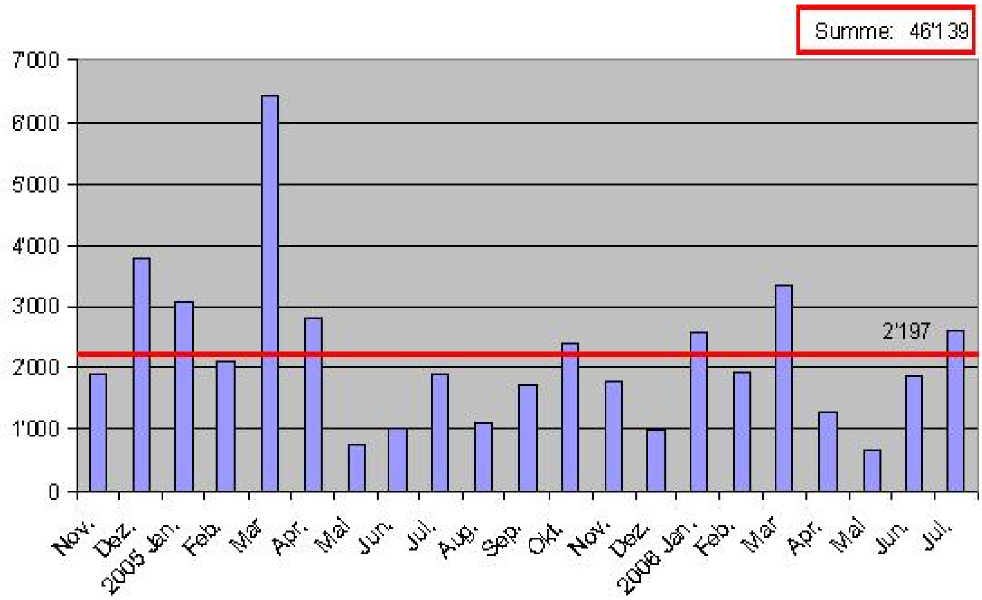


Figure 1.33: Monthly number of CCD images Nov 2004 - Jul 2006.

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2 Gravity Field

The National Gravity Network LSN2004

by U. Marti, Ph. Richard and R. Olivier

a) Introduction

The existing national gravity network (SG95) was established between 1992 and 1995 by the Geodesy and Geodynamics Lab (GGL) of the ETH Zurich on behalf of the Swiss Geodetic Commission (SGC) and the Swiss Geophysical Commission (SGPC). It is based on absolute measurements on five stations (Zurich, Pratteln, Chur, Lausanne, Monte Ceneri), which have been observed with the JILA-G 6 of the BEV (Vienna) in 1994. This zero-order network was densified by relative measurements on about 110 stations, which form the first and second order network. Mostly, these relative stations are identical with the principal stations of the national GPS network (LV95). SG95 is connected to the gravity networks of neighbouring countries by a few relative measurements to their nearest absolute stations. The relative observations have been performed with three Lacoste&Romberg G instruments in parallel. The accuracy of the adjusted gravity values of SG95 is in the order of 0.02 mgal. The measurements of SG95 are currently the contribution of Switzerland to the Unified European Gravity Network (UEGN).

In 2003, the project LSN2004 was started to modernize the national gravity. In this project, it is foreseen to establish some new absolute stations and to re-measure the existing ones with an FG5. Additional relative measurements are planned with a SCINTREX-CG5 in order to improve the accuracy and stability of the network. By repeated observations, the accuracy of LSN2004 should also allow the determination of vertical movements.

b) Absolute measurements for LSN2004

Since 1999, the Federal Office of Metrology (METAS) owns the only absolute gravimeter in Switzerland. This FG-5 free fall instrument was acquired for their Watt balance experiment (redefinition of the SI-unit 'kilogram') and is principally used in the laboratories of METAS, where about once per month absolute measurements are performed. This instrument participates regularly at the international comparison campaigns in Paris and in Luxemburg.

An agreement between METAS and swisstopo allows since 2003 the re-occupation of the older absolute stations and the establishment of several new stations. Until now, the three destroyed stations at Jungfraujoch, Brig and Pratteln have been replaced by new stations nearby and have been observed with the FG-5. In the next years it is foreseen to establish two new sites in the Alps (Andermatt and Engadin) and to re-occupy the stations of 1994.

Usually, an absolute measurement lasts 24 hours with 100 drops every hour. The obtained accuracy is in the order of 1-2 μgal. Each absolute observation includes the determination of the gravity gradient. This is done by relative measurements on 3 different levels with a SCINTREX CG-3M or CG-5. The accuracy of the gradient is in the order of 1 μgal/m.

A special agreement was made for the absolute measurements in Zimmerwald, which is a core station of the European Combined Geodetic Network (ECGN). This station is observed once per year since 2004. The monitoring of gravity changes is supported by regular relative measurements between Zimmerwald and Wabern (2-4 times per year) and by the observations of the permanent Earth tide gravity meter (LCR ET25).

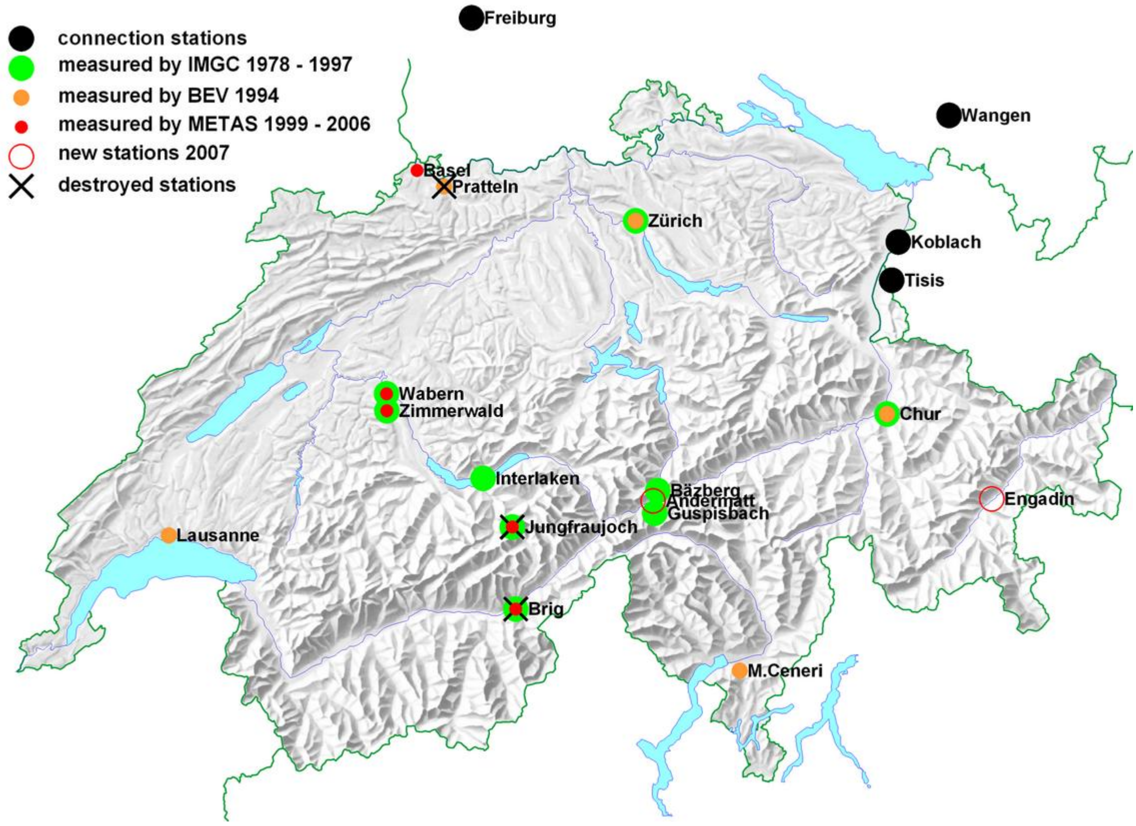

Figure 2.1: Absolute gravity measurements in Switzerland.

c) Relative measurements

The absolute network is densified by relative measurements on the stations of SG95. These relative measurements are performed with 2-3 instruments in parallel (SCINTREX CG-5, CG 3, LCR-Aliod, LCR-D, LCR-G) in collaboration with the institute of geophysics of the university of Lausanne. Until now, two larger campaigns have been measured in 2005 and 2006. The first results showed that the accuracy of the measurements is in the order of only a few μgal. The results are mainly given by the measurements of the Scintrex CG5. The other instruments have a reduced accuracy and their results finally are only used to detect gross errors of the CG5.

It is not foreseen to re-observe all the 2nd order points of SG95. For these stations, without new observations for LSN2004, the original measurements of 1992-1995 are re-processed and treated in a common adjustment with the new measurements. Of course, the accuracy of these points will not be increased in comparison with the results of SG95 and remain in the order of 0.02 mgal.

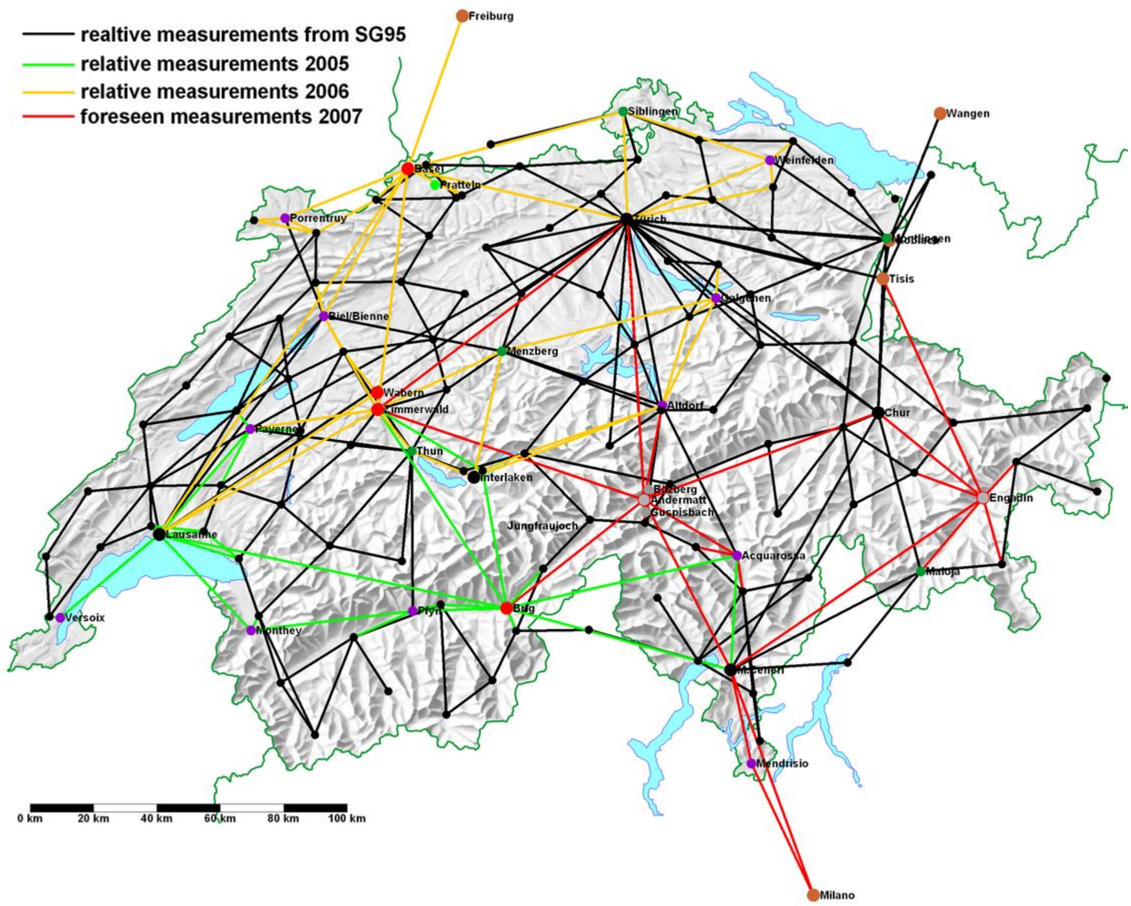

Figure 2.2: Relative measurements for LSN2004.

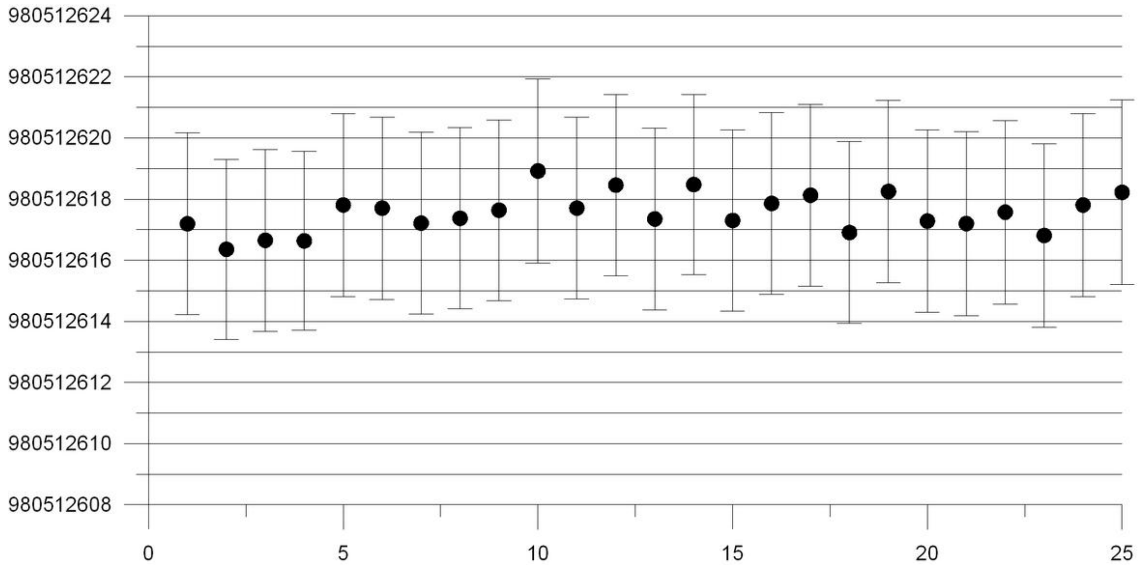

Figure 2.3: Hourly solutions of the absolute measurements in Zimmerwald 2005.

Gravity Measurements for the Vertical Network

by U. Marti and A. Schlatter

The gravity measurements for the Vertical network along the first and second order levelling lines are performed with a Lacoste&Romberg type G gravimeter in the same year as the levelling measurements. These measurements are used for the calculation of geopotential numbers and orthometric heights. The gravity measurements are only performed on a representative selection of all levelling points. For stations without measured gravity, the values are interpolated from the neighbouring data on levelling lines or from the gravity data set of the Swiss Geophysical Commission and mass models.

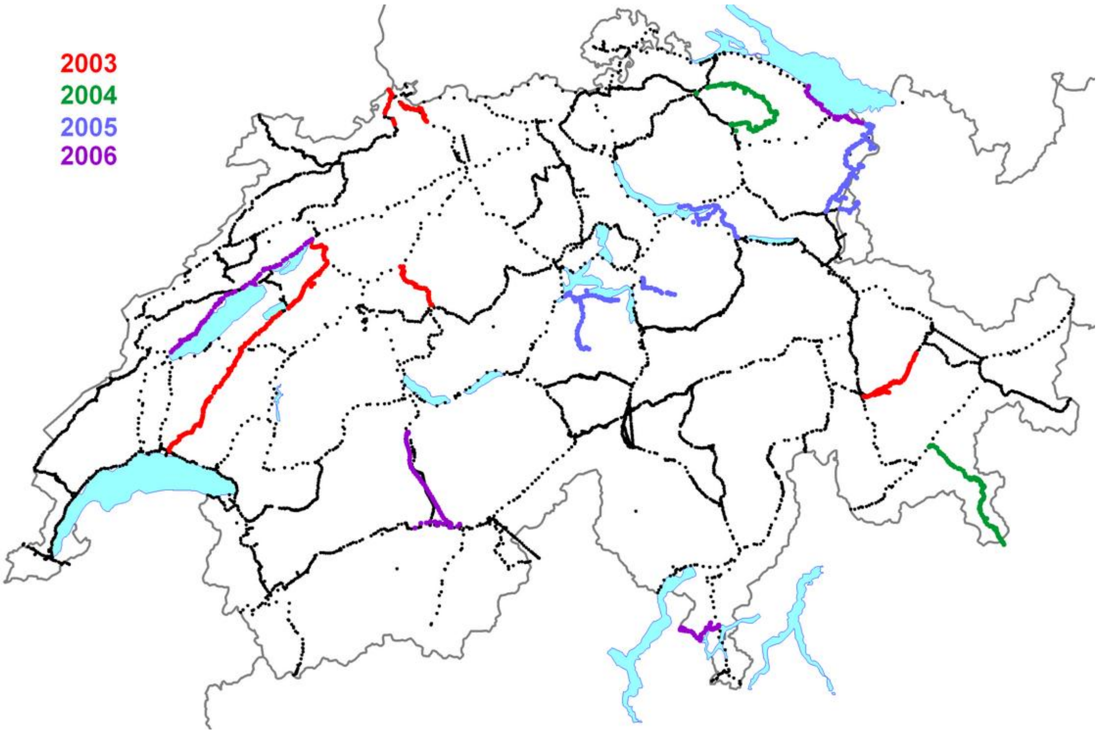

Figure 2.4: Gravity measurements along the Swiss levelling lines. The dots in different colours indicate the gravity measurements during the last four years.

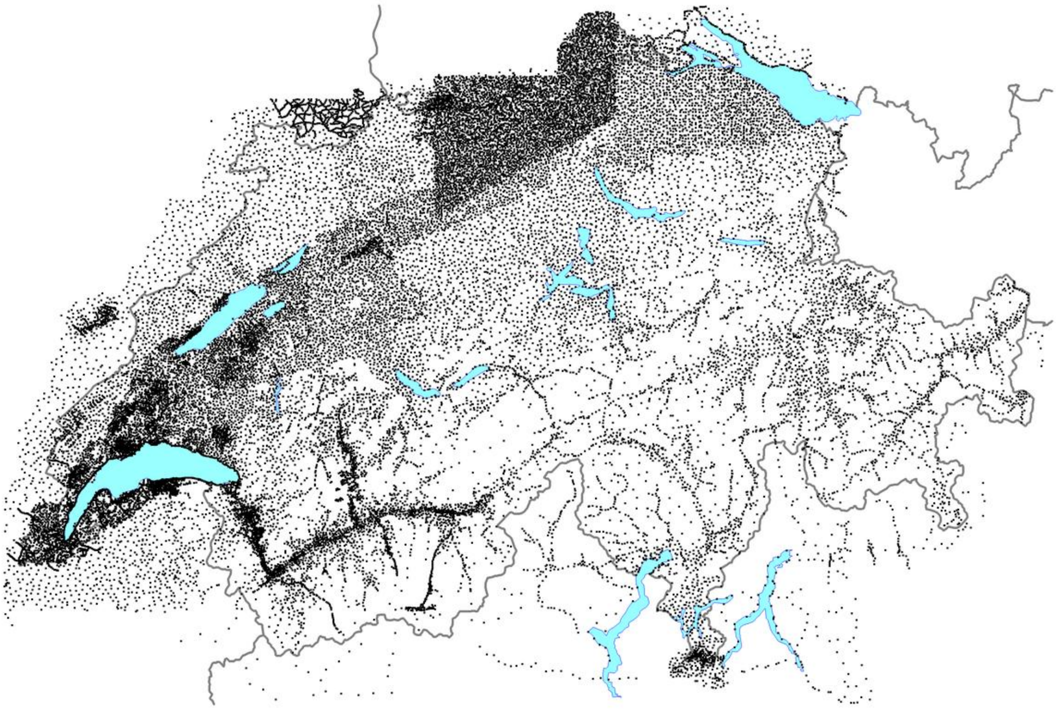

Figure 2.5: Gravity data set of the Swiss Geophysical Commission; used for gravity interpolation.

Airborne Gravimetry

by H. Baumann, E. Klingelé and H.-G. Kahle

The project "Airborne Gravimetry" has been conducted in collaboration with *micro-g solutions, Inc.* It deals with the development of an Absolute Airborne Gravimeter (AAG) measuring system. The challenging problem in absolute airborne gravimetry is the compensation of perturbing vertical accelerations. To solve this problem it is absolutely necessary to have a system able to measure both the accelerations induced by the movements of the aircraft and by those generated by the engines and the propellers.

In order to compensate these accelerations two different methods were studied. The first one consisted of decoupling the gravimeter from its support by means of a mechanical filter while the second one used a mathematical model for subtracting numerically the perturbing accelerations. Three mechanical filters were studied: A commercial optical table from Alcyonics, a multilyers table and a hanging table. The application of the transfer functions of these filters to the amplitude spectrum of the vibrations of the aircraft has shown that the hanging table presented the best characteristics in flight conditions.

The numerical compensation and the general behaviour ot the modified gravimeter FG5-L of *micro-g, Inc.* were studied in detail. It was clearly seen that the principal components of the FG5-L allow to measure g with a resolution of 2.5 mGal for each single fall. It was also confirmed that with the numerical compensation of the movements of the reference mirror the residuals are reduced by a factor of 8. In order to test the methods of compensation a dynamic experiment was carried out in a small truck. It was shown that the whole system and especially the FG5-L work correctly also in an extremely noisy environment.

A first test in strapped-down configuration (without mechanical filter) has shown that the numerical compensation is a fully satisfactory method. The strategy developed consists of decomposing the perturbing accelerations in two distinct groups. The first group consists in the perturbations produced by the engines of the aircraft and lying in the frequency band between 10 Hz and 200 Hz. The lower limit of this group corresponds to the falling time of the prism, and the higher limit is given by the sampling rate of the external sensors (Episensor and INS). The second group contains the low frequency accelerations due to the movements of the platform.

The compensation was done in two stages. In the first stage the accelerations of the first group were integrated twice in order to determine the movement of the reference mirror during the fall. This movement was then introduced as variable in the system of equations allowing the determination of the apparent acceleration. After this procedure has been applied to each fall a function $a(t)$ was obtained from which it was necessary to remove the accelerations of the second group in order to obtain $g(t)$. This method applied to the truck experiment has shown its efficiency and allowed the determination of g with a resolution of 16 mGal. Even if this resolution was higher than the expected resolution we found it sufficiently promising for applying it to a real airborne experiment.

We were able to demonstrate that the positioning by GPS allows a reasonable determination of the kinematic accelerations and consequently to correct the raw values of g to obtain the true gravity. A combination of GPS and INS measurements produced complete information on the position of the aircraft in space with a high sampling rate. Using the experience gained during the small-truck experiment it was possible to develop a method of compensation for the airborne measurements taking into account the attitude of the platform during the flight.

The Earth Tide Observatory in Zimmerwald

by U. Marti, Ch. Hollenstein, E. Klingelé and H.-G. Kahle

Continuous recording of the Earth tides is necessary for providing accurate corrections for field gravity measurements. The use of the recorded data in conjunction with satellite laser ranging information allows the determination of the elasticity parameters of the Earth's crust (Love's numbers). The measurement system of the observatory of Zimmerwald is composed of a special high-sensitive gravimeter (LaCoste&Romberg ET25) driven by a PC and working at 1 min. sampling interval. Since 1995 this permanent station has recorded more than 4'500'000 Earth's tide data which are now being analysed.

During 2006 a new additional building was constructed directly above the gravity recording station. In order to prevent the instrument from any impact during the construction works, the instrument was moved to the basement of swisstopo at Wabern some few kilometers apart. Meanwhile the observation software has been upgraded. After the completion of the construction work the instrument was deployed again at the old place. Due to the changed environment by the additional building the gravity value re-measured was found to be 10 microgals smaller than before the construction.

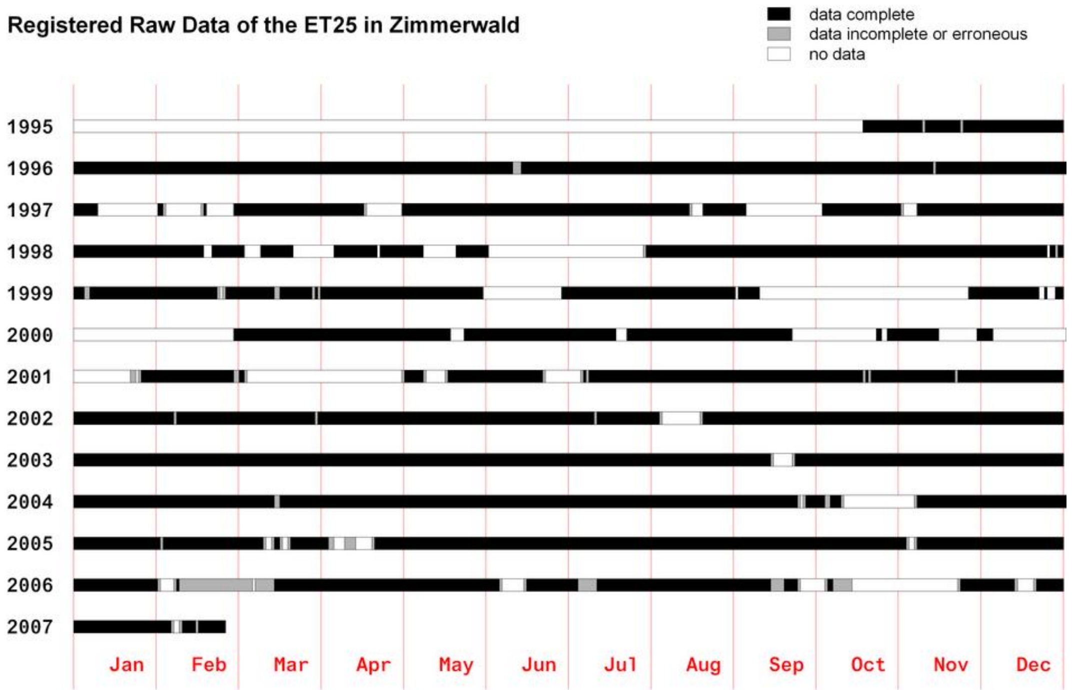

Figure 2.6: Available Earthtide Data registered in Zimmerwald.

Figure 2.7: Permanent gravimeter ET25 in Zimmerwald.

Inversion of Potential Data

by E. Klingelé

A new inversion technique based on artificial intelligence has been devised. An advanced algorithm for continuation of potential fields between general surfaces was also developed. Both techniques were successfully tested with synthetic and real examples.

The first technique aims at the recognition of disturbing bodies and quantitative gravity interpretation in two dimensions by using algorithms of artificial intelligence. This technique has demonstrated its clear superiority over the classical techniques. It allows to recognize the disturbing body with more than 99.9% of confidence. It also yields very good results by determining the parameters of the shape of the body.

The second technique involves gravity and magnetic data acquired in rugged topography and their transformation form an irregular surface to a horizontal one. The aim is to process the anomalies with methods involving Fourier transforms. To this end the GGL has developed different techniques allowing to process the data on a routine basis. In the frame of the application of gravimetry to glaciology GGL performed gravimetric studies on a rock glacier in the Upper Engadine and on a large Alpine glacier in the Bernese Alps in collaboration with the Laboratory of Hydraulics, Hydrology and Glaciology of ETH Zürich. The aim of these studies was the determination of the structure and thickness of these ice masses. The results obtained from three-dimensional interpretations correspond well with data obtained using other geophysical methods, eg. reflection and refraction seismics, well logging and electrical sounding.

LEO Precise Orbit Modelling and Global Gravity Field Determination

by A. Jaeggi, G. Beutler, H. Bock, U. Hugentobler and L. Prange

Precise modeling of low Earth orbits (LEOs) is a necessity for many scientific Earth satellites, e.g., for satellite missions dedicated to radar and laser altimetry or gravity field recovery. Current gravity field recovery missions like CHAMP, GRACE, and GOCE (expected launch in Dec. 2007) are equipped with dual-frequency on-board receivers for the Global Positioning System (GPS) to enable a most precise restitution of the satellites' trajectories in post-processing analyses from the uninterrupted GPS tracking data.

Starting with data from the CHAMP GPS receiver, a more refined reduced-dynamic orbit representation was developed to reconstruct the trajectory of the CHAMP center of mass with unprecedented accuracy from undifferenced GPS data (Jäggi et al., 2006a). The so-called pseudo-stochastic orbit representation is based on piecewise constant accelerations to compensate for deficiencies in the force models in an effective way. Quality assessments with independent Satellite Laser Ranging (SLR) data indicate an accuracy of about 3 cm for the reconstructed CHAMP trajectories. A slightly better accuracy of about 2.5 cm could be demonstrated for the two GRACE satellites (see Fig. 2.8). The validation of the inter-satellite distance with the ultra-precise observations from the microwave K-band link even indicate a precision of the relative positions of about 1.2 cm.

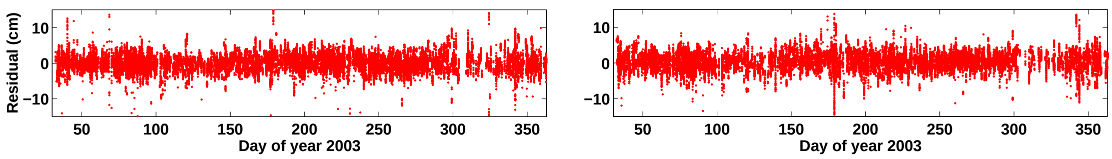

Figure 2.8: SLR range residuals for GRACE A (left) and GRACE B (right) for reduced-dynamic orbits based on piecewise constant accelerations.

In order to fully exploit the potential of double-difference GPS data between the two GRACE satellites, it is necessary to resolve the double-difference ambiguities of the GPS carrier phase measurements. The validation of the reconstructed ambiguity-fixed space-baseline with the ultra-precise observations from the K-band microwave link confirmed that sub-millimeter precision is achievable in conjunction with pseudo-stochastic orbit modeling (see Fig. 2.9) (Jäggi et al., 2007).

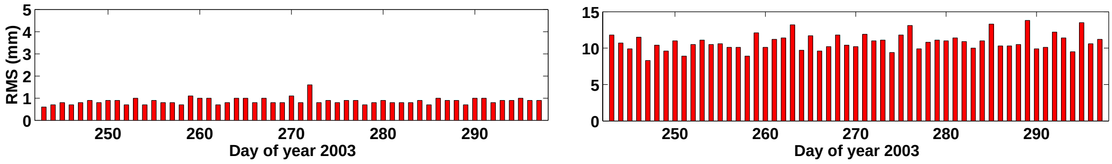

Figure 2.9: K-band range RMS errors for reduced-dynamic orbits based on piecewise constant accelerations with ambiguities resolved to integers (left) or not (right). Note the difference in the scale.

Due to the very low altitudes below 500 km of gravity field recovery missions, it may be necessary to adjust not hundreds but thousands of pseudo-stochastic orbit parameters to compensate for uncertainties in the dynamic models. In order to still ensure an efficient processing, algorithms based on the full exploitation of the structure of the underlying normal equations of the least-squares adjustment were developed (Beutler et al., 2006). Consequently, it is feasible to relax the strength of the dynamic models to any user-specified level by setting up large numbers of pseudo-stochastic orbit parameters, even to the kinematic limit, if the frequency of the estimated pseudo-stochastic orbit parameters is equal to the frequency of the GPS observations (Jäggi et al., 2006b).

Starting with simulation studies, experience was gained at the AIUB to recover the spherical harmonic coefficients of the Earth's gravity field from kinematic or, alternatively, from highly reduced-dynamic LEO orbit positions based on piecewise constant accelerations estimated at a frequency close to that defined by the GPS observation epochs. It could be shown that it is possible to achieve a slightly better recovery from highly reduced-dynamic orbits than from kinematic orbits, provided the intervals of the piecewise constant accelerations are short (Jäggi et al., 2006c). The recovery of the gravity field coefficients from real data either from kinematic or highly reduced-dynamic CHAMP and GRACE orbit positions, was also initiated. A first gravity field model based on our algorithms and on a one year observation period of the CHAMP satellite may be expected by mid 2007. Additional studies will deal with the exploitation of the GRACE baseline for gravity field recovery.

Processing Facility for ESA's GOCE Gravity Field Explorer Mission

by H. Bock, A. Jäggi, U. Hugentobler and R. Dach

The GOCE (Gravity field and Ocean and Climate Explorer) satellite is the first core mission of ESA's Earth Explorer programme (Drinkwater et al., 2003) and is scheduled for launch in December 2007.

The Astronomical Institute of the University of Bern (AIUB) is member of the European GOCE Gravity Consortium (EGG-C) formed by ten European institutions (in alphabetical order of acronyms):

- AIUB, Switzerland,
- Groupe de Recherche de Géodésie Spatiale, Centre National d'Etudes Spatiales (CNES), Toulouse, France,
- Department of Earth Observation and Space System (DEOS), Delft University of Technology, The Netherlands,
- Department 1 "Geodesy and Remote Sensing", GeoForschungsZentrum Potsdam (GFZ), Germany,

- Institute for Astronomical and Physical Geodesy (IAPG), Technical University of Munich, Germany,
- Institute for Theoretical Geodesy (ITG), University of Bonn, Germany,
- Sezione Rilevamento, Politechnico Milano (POLIMI), Italy,
- National Institute for Space Research (SRON), Utrecht, The Netherlands,
- Institute of Navigation and Satellite Geodesy, University of Technology (TUG), Graz, Austria, and
- Department of Geophysics, University of Copenhagen (UCPH), Denmark.

EGG-C is responsible for the GOCE Level 1b data processing and Level 2 product generation, which is integrated in the GOCE High-level Processing Facility (HPF).

AIUB carries out precise orbit determination (POD) based on GPS measurements provided by an on-board 12-channel Lagrange receiver. The resulting Precise Science Orbit (PSO) consists actually of two different orbit solutions, a reduced-dynamic and a kinematic solution. The orbit determination for both orbit types is performed in a single processing scheme (Bock et al., 2007; Visser et al., 2007). The orbit determination process is based on undifferenced GPS measurements and has been tested and validated sucessfully with GRACE microwave data.

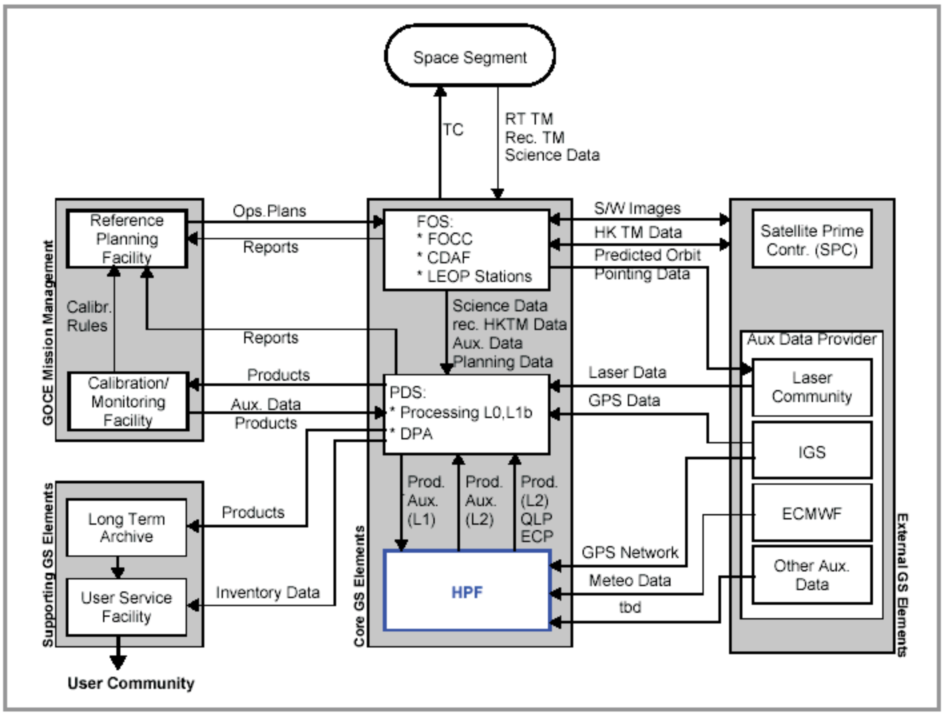

Figure 2.10: GOCE ground segment - overview.

The GPS satellite clock corrections generated by CODE (Center for Orbit Determination in Europe) for the International GNSS Service (IGS) are densified from 30 seconds to high-rate 5-seconds sampling for the HPF. Additionally, external data like ocean loading tables and IGS data and products are prepared for distribution within the HPF consortium. The estimated and prepared data support both, the GOCE POD and the gravity field model estimation performed by other groups within the HPF.

Fig. 2.10 shows the ground segment overview for the GOCE mission.

Determination of Highly-Precise Deflections of the Vertical: Switzerland 2003/2005, Portugal 2004 and Greece 2005

by A. E. Somieski, B. Bürki, H.-G. Kahle, U. Marti, C. Hirt und I. N. Tziavos

During the last five years a digital Zenith Camera, called DIADEM (Digital Astronomical Deflection Measuring System) has been developed at the Geodesy and Geodynamics Laboratory of ETH Zurich. The instrument aims at the determination of the direction of the vertical in terms of the astronomical latitude Φ and longitude Λ. The difference of these parameters to the geodetic coordinates (φ,λ) corresponding to the reference ellipsoid allows the calculation of deflections of the vertical in North-South (ξ) and East-West direction (η). DIADEM provides deflections of the vertical with an accuracy of better than 0.15" thus contributing to a highly-precise geoid determination.

1) CHGeo2003 in Switzerland (2003)

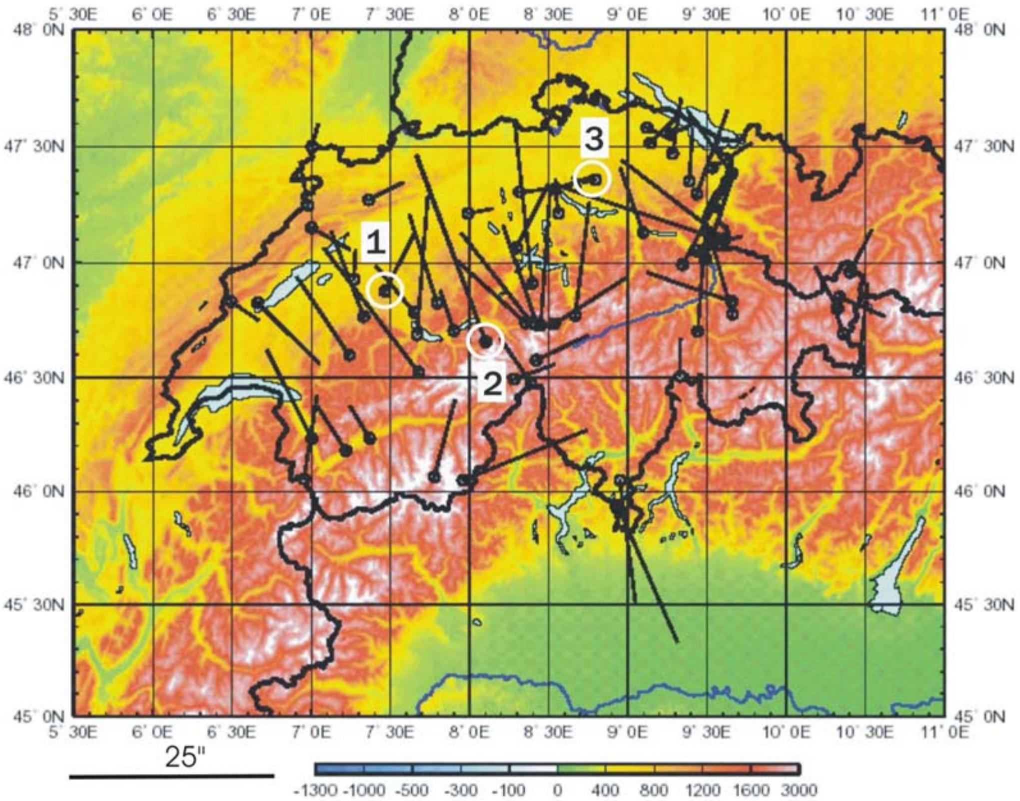

Figure 2.11: Measured deflections of the vertical in Switzerland at 68 stations throughout Switzerland. 1: Zimmerwald, 2: Grosse Scheidegg, 3: Pfäffikon. The vectors indicate the deflections of the vertical projected into the horziontal plane (components are equal to ξ and η).

The CHGeo2003 project has been initiated by the Swiss Federal Office of Topography (swisstopo) aiming at the improvement of the Swiss geoid model CHGeo98. The project included observations with two digital Zenith Cameras, DIADEM (ETH Zurich) and TZK2-D (University Hannover), in order to provide highly precise deflections of the vertical. Other dedicated goals were to prove the field capability of the enhanced instruments and the comparison of both systems regarding their accuracy. The Zenith Camera observations have been carried out in regions where the geoid model presently used showed larger discrepancies between GPS/leveling and geoid undulations based on the model. The project contributed to the European Combined Geodetic Network (ECGN) and the European Unified Vertical Network - Densification Action (EUVN-DA) of EUREF (Brockmann et al., 2003, 2005).

The campaign took place during four weeks in October 2003 in Switzerland. A total number of 68 stations have been measured in 16 observation nights. This averages to 2-5 stations per night and team depending on the weather, location (mountains, valley) and distance between the stations. Four stations have been observed simultaneously, among them the geodetic reference station in Zimmerwald. In addition, this station has been measured repeatedly during different nights. The data gathered at station Zimmerwald confirmed the high accuracy of both Zenith Cameras (<0.15").

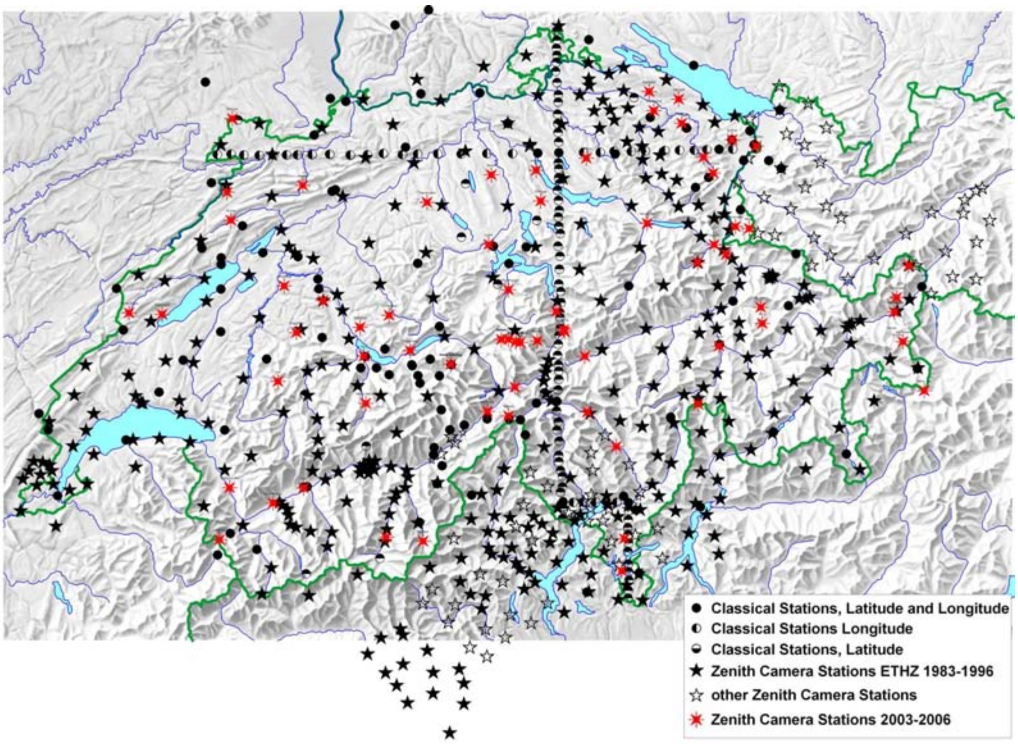

Figure 2.12: Observed deflections of the vertical in Switzerland and vicinity.

The CHGeo2003 campaign offered the possibility to deploy two modernized digital Zenith Cameras for the first time. It was concluded that both systems worked reliably and efficiently, also under very harsh conditions like in high mountains with temperatures at -15°C. Fig. 2.11 shows the deflections of the vertical observed at 68 stations in Switzerland. They clearly indicate the influence of the Alpine chain since the deflections of the vertical measured to the north of the Alps point in direction to the mountains. The maximum value was observed at the station "Grosse Scheidegg" (no. 2 in Fig. 2.11), north-east of Grindelwald, Bernese Oberland, with 27". The smallest vertical deflection was measured in Pfäffikon (no. 3 in Fig. 2.11) near Zurich with 2". The observed deflections of the vertical were introduced together with 690 vertical deflections from older measurements for the computation of an improved geoid. Besides the deflections of the vertical, also GPS-leveling data as well as gravity measurements were used for the recalculation of the geoid (Marti, 2004a; Brockmann et al., 2005). Fig. 2.12 shows the deflections of the vertical observed in Switzerland.

2) Portugal (2004)

The Portugal campaign took place during two weeks in the beginning of September 2004. The stations to be observed were suggested by the Instituto Português de Cartografia e Cadastro (IPCC), based in Lisbon, Portugal. The measuring plan comprised 19 new and repeated observations throughout Portugal on principal and secondary points of the national geodetic network.

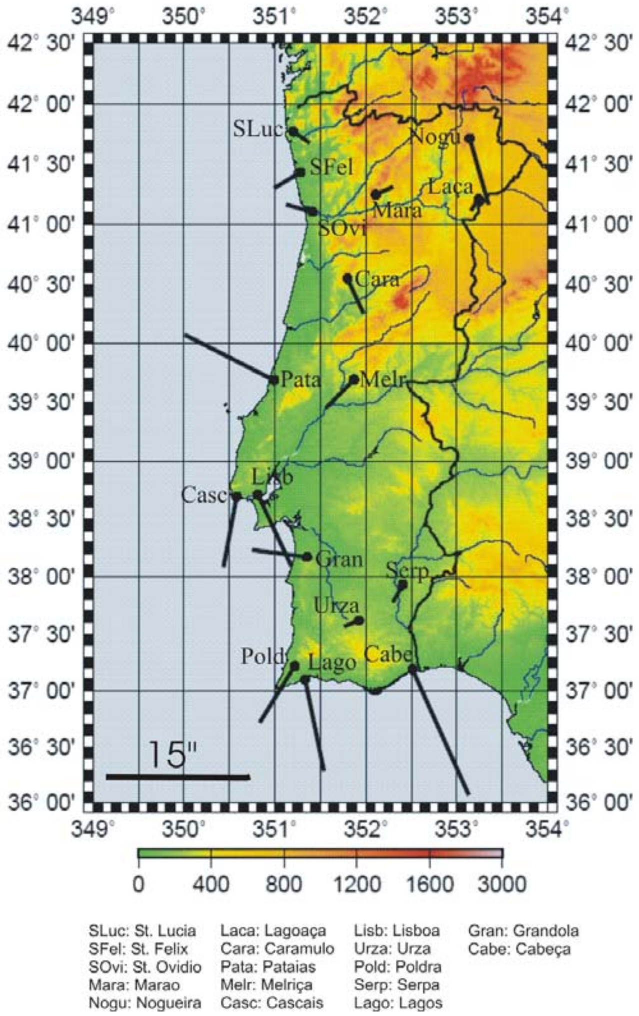

Figure 2.13: Measured Deflections of the vertical at 17 stations throughout Portugal. The maximum deflection of the vertical has been observed in Cabeça (Cabe) with 14".

Within two weeks, 17 of 19 suggested stations have been successfully observed starting at station Lagoaça (Laça) in the north and finishing at station Cabeça (Cabe) in the south. The distances between the stations averaged to about 150 km. Therefore, it was not possible to observe more than two stations per night. In general, the time needed per station was about 45 minutes including assembly and disassembly of the system. Fig. 2.13 shows the measured deflections of the vertical outlined on a map of Portugal. The maximum value has been observed at Cabeça, south of Portugal, with 14", while the smallest vertical deflection (1") has been measured at Lagoaça, a station in the north near the border to Spain. The deflections of the vertical observed at stations near the coastline show clearly the increase of the geoid towards the mainland. The data gathered during the campaign were used by the IPCC for an improved national geoid calculation.

3) Greece (2005)

In May 2005, a four-week campaign has been performed in the North Aegean Sea, including astro-geodetic observations with DIADEM as well as shipborne GPS measurements. The campaign was realised in the frame of a joint project between the Geodesy and Geodynamics Laboratory (GGL) of ETH Zurich, and the Department of Geodesy and Surveying of the Aristotle University of Thessaloniki (AUTH).

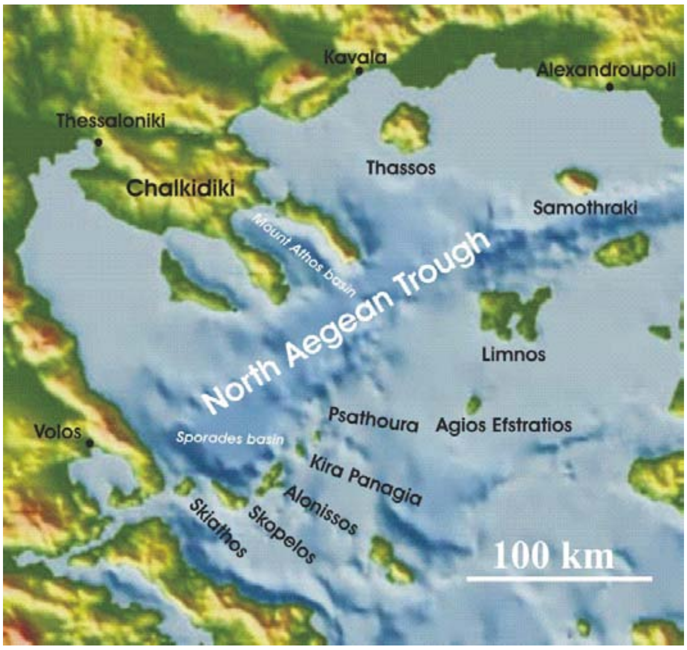

Figure 2.14: Measuring area in the North Aegean Sea, Greece.

The measuring area (Fig. 2.14) is part of the North Aegean Trough (NAT), which is a zone of deep water with maximum depths of up to 1500 m. The NAT is considered to be a continuation of the seismically active North Anatolian Fault Zone. An important goal of the campaign was the recalculation of the Hellenic geoid by combining new data from DIADEM and GPS with gravimetric and altimetric data available in this region.

The distribution of Astro-stations was mainly motivated by the intention to cover the area around the North Aegean Trough (NAT). The observations were carried out along the shoreline of the North Aegean Sea including the Sporades islands (Skiathos, Skopelos, Alonissos, Kira Panagia, Psathoura) and the islands of Thassos, Samothraki, Limnos and Agios Efstratios. Totally, 30 stations have been observed in 20 nights. The accuracy of the deflections of the vertical observed is better than 0.15". The vectors (Fig. 2.15) on the three peninsulas of Chalkidiki, on the Sporades islands and on the islands of Thassos, Samothraki and Limnos clearly indicate the influence of the NAT representing a mass deficit with respect to the surrounding area.

The data gathered during the campaign (Deflections of the vertical, Sea Surface Heights based on GPS measurements) were compared to local gravimetric and altimetric geoid models provided by the AUTH. Fig. 2.16 presents the geoid height differences obtained from deflections of the vertical, GPS as well as from altimetric and gravimetric geoid models along a profile between Skiathos,

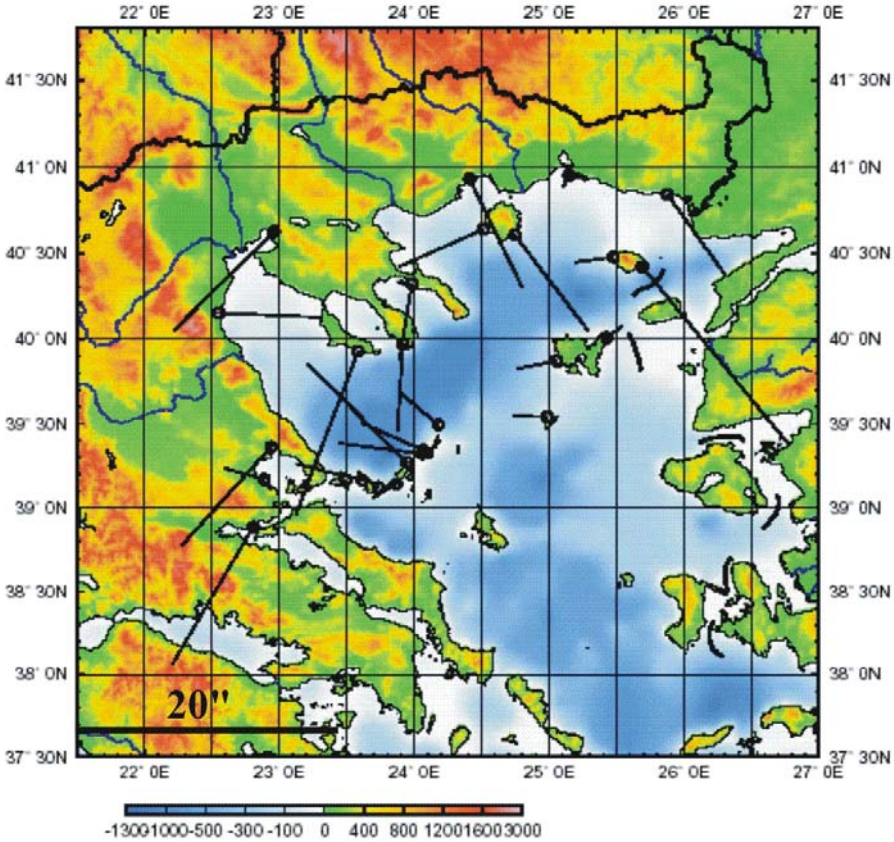

Figure 2.15: Measured deflections of the vertical at 30 stations around the North Aegean Trough. The influence of the NAT as a local mass deficit is well recognizable.

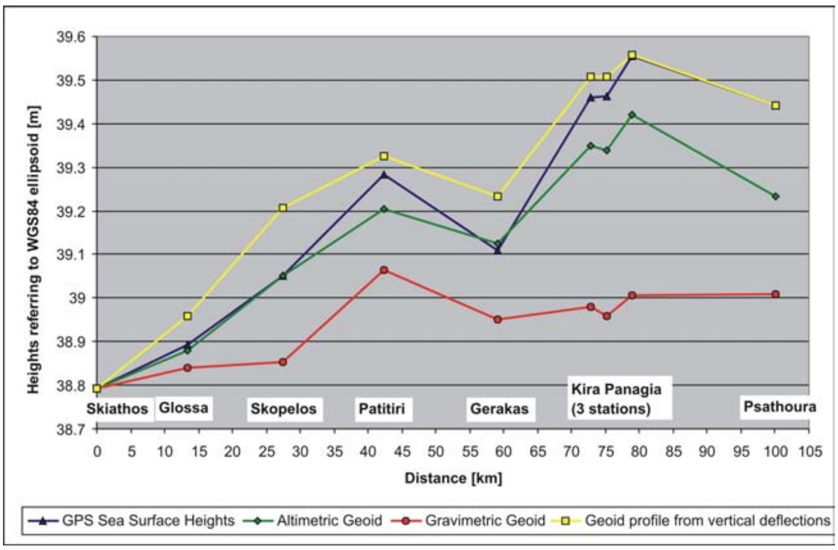

Figure 2.16: Comparison between geoid height differences calculated from Deflections of the vertical, GPS based Sea Surface Heights, altimetric geoid and gravimetric geoid.

Glossa, Skopelos, Patitiri, Gerakas, Kira Panagia South, Kira Panagia North and Psathoura. For a local comparison, all heights have been referenced to the same level based on the gravimetric solution at the station Skiathos. As regards the relative geoid undulations, the GPS, DIADEM and altimetric data show a very good agreement. In contrast, the gravimetric geoid model reveals a significant discrepancy at the end of the profile (Patitiri-Gerakas-Kira Panagia-Psathoura) as evidenced by the relatively small slope between 60 and 80 km distance of the profile. All profiles analysed revealed similar results. The discrepancies can be explained by a lack of gravimetric data in the marine area. These results emphasise the necessity of an improved recalculation of the Hellenic geoid by combining all data available in this region.

Further observations by DIADEM have been carried out in the frame of the project Alptransit in July 2005. For details, please refer to the contribution in section 4, page 4.

The National Geoid Model CHGeo2004

by U. Marti

a) Introduction

The official geoid of Switzerland until 2004 was the model CHGeo98. It was mainly based on astrogeodetic observations with some additional GPS/levelling data. Gravity measurements were only used for the downward continuation of the other observation types. The GPS/levelling residuals were in the order of a few cm with a maximal value of about 20 cm. The accuracy of CHGeo98 was in the order of 3 - 5 cm.

The main goal of a new geoid calculation (CHGeo2004) was to set up a consistent height system where the orthometric heights out of levelling (and gravity) are compatible with the heights out of GPS and the geoid model.

b) Data used for CHGeo2004

Since the consistency of the height system was the principal task for CHGeo2004, new accurate GPS/levelling points had to be observed. Many GPS stations have been connected to the first order levelling network and many levelling benchmarks have been observed by GPS in sessions of at least 24 hours. This gave us for most of the stations an accuracy of better than 1 cm. At present, we can use about 200 GPS/levelling measurements for the geoid computation.

Another improvement of the data set for the new geoid computation was the densification of the already rather dense network of astrogeodetic stations. In regions with known problems in the existing geoid model CHGeo98, additional deflections of the vertical have been determined in 2003 with the digital zenith cameras of the ETH Zurich and of the TU Hanover. In just 1 month about 60 stations could be observed with accuracy in the order of 0.1". For older astrogeodetic observations with analogue zenith cameras or by classical methods, the accuracy was in the order of 0.3 to 1.0".

On the contrary to the geoid calculation of CHGeo98, where gravity was only used to model the difference between geoid and quasigeoid, gravity data has been introduced directly as observations in the determination of CHGeo2004. All the available gravity data was reprocessed to bring them to a common datum and to eliminate gross errors. These more than 30000 gravity values have been gridded with a resolution of 5 km.

This gives us the data set shown in Fig. 2.17 with about 2200 gridded gravity values, about 700 deflections of the vertical and about 200 GPS/levelling observations. Another set of 270 'artificial' GPS/levelling observations has been introduced in the regions in neighbouring countries where we had no or only few data. There, we introduced the height anomalies of the European quasigeoid model EGG97 directly as observations just to avoid the drifting away of our solution in these areas. Inside of Switzerland, these artificial observations have no influence on the geoid solution.

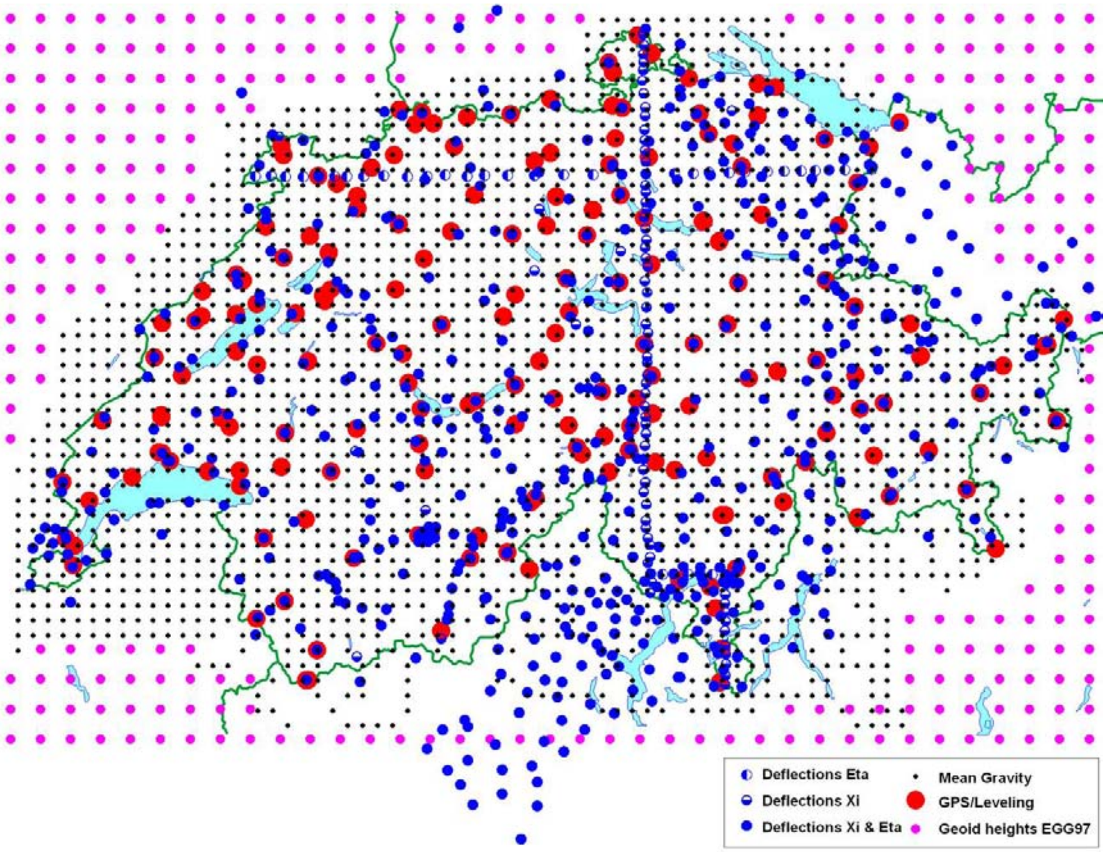

Figure 2.17: Data set used for the geoid calculation CHGeo2004.

c) Mass models and reduction of the data

The reduction of the observations has been performed in a first approach with the standard method by using a global geopotential model (EGM96) and a digital terrain model (DTM). As digital terrain model we used our national 25 meter DTM (DHM25) and outside of its area we used SRTM3. The full resolution of the DTM is only used in an area of about 150 meters around each data point. Further away we use re-sampled models with a resolution of 50, 500 and 10000 meters.

As further models we introduced a rather rough density model of the Earth's crust into the calculation. This model mainly includes a Moho model, a model of the Ivrea body, sediments of rivers, water masses of lakes and the ice thickness of large glaciers. Since a part of the effect of most of these models is already included in the global model, only the remaining part may be used for the reduction. In our calculations, we used the difference between the influence at station height and the influence at sea level for the reduction. This reproduces exactly the differences between normal heights and orthometric heights as we use them in our national levelling network LHN95.

d) Calculation of the geoid

The residual field of all observations has been interpolated by least squares collocation with the 3rd order Markov model as the covariance function. Several tests by varying the parameters of the model and by changing the weights of the individual data sets have been performed, which mainly showed that the most sensitive data set with respect to the variation of the model parameters are the deflections of the vertical, whereas gravity and GPS/levelling are not so much affected by changing the model. The definitive parameters have been chosen in a way that the residuals on GPS/levelling become minimal for a pure astro-gravimetric solution.

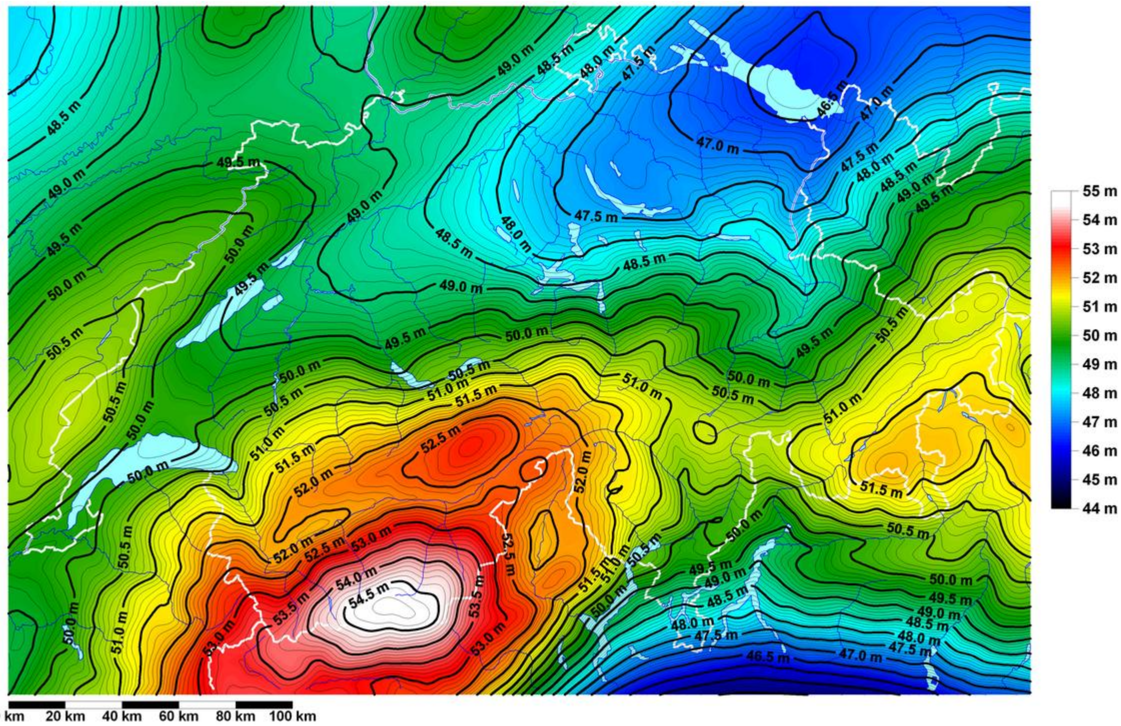

Figure 2.18: Geoid model CHGeo2004 (in ETRS89).

For the official solution of CHGeo2004, a combination of all three data sets (GPS/levelling, gravity and deflections of the vertical) has been used, but GPS/levelling data got a very high weighting, so that these observations got practically no residuals. This is the solution that guarantees the consistency in the height system and therefore, is preferred by the surveyor community but certainly it hides some problems of the GPS/levelling data set.

The restore from the co-geoid to the geoid and to the quasigeoid is simply done by adding the formerly removed effects of the mass models and the global model. Fig. 2.18 shows the calculated geoid model CHGeo2004. Mainly for compatibility reasons with European projects such as UELN, EVRS or the European Gravity and Geoid Project EGGP, the quasigeoid has been calculated as well. The differences between geoid and quasigeoid are in general smaller than 10 cm but they can reach amounts of up to 60 cm in mountainous regions.

The differences to the former geoid model CHGeo98 (Fig. 2.19) are smaller than 5 cm in most of the flatter areas, but reach up to 20 cm in Alpine regions. These larger differences are mainly caused by the strong weighting of GPS/levelling in CHGeo2004 and - outside of Switzerland - by the use of data in areas which were not covered in the calculation of CHGeo98. The recently measured deflections of the vertical have only a minor influence and the introduction of gravity

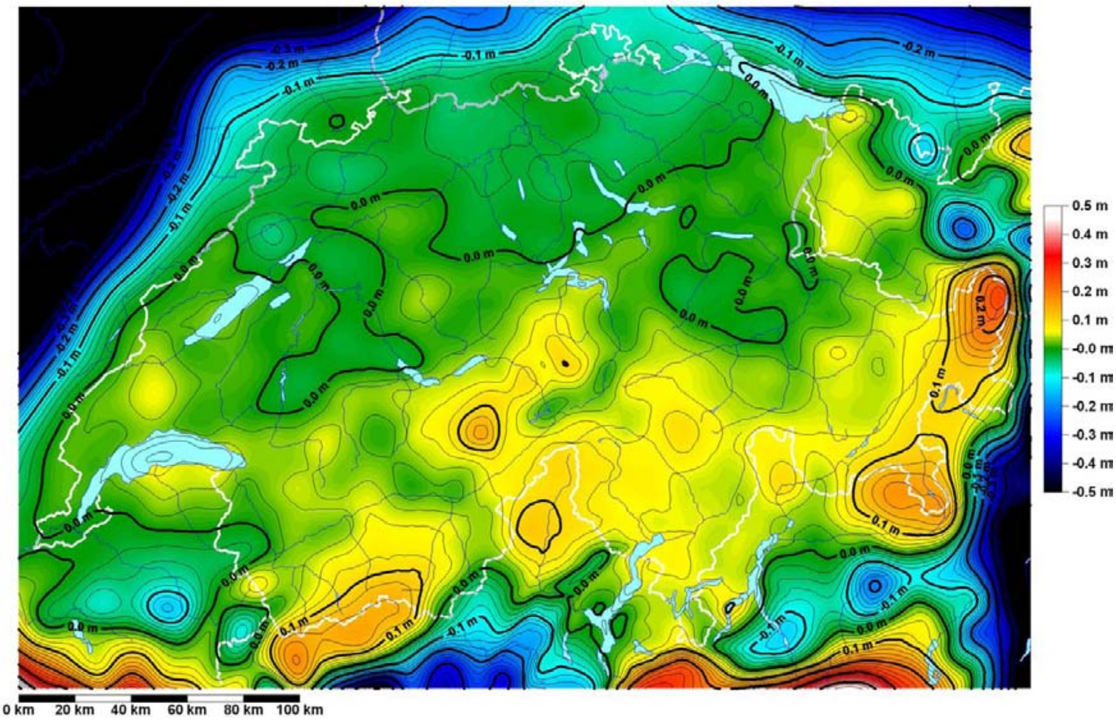

Figure 2.19: Differences CHGeo2004 minus CHGeo98.

data had only an important effect in remote alpine areas which are not covered by astrogeodetic measurements or GPS/levelling.

Geoid Determination on Lakes by Precise Positioning

by B. Bürki, A. Geiger, H. Eugster and S. Reinke

The advent of modern satellite surveying brought the 'old' geoid to a revival. This alleged paradox is rapidly resolved when it comes to the determination of precise heights. To get 'levelled' heights from GPS measurements it is mandatory to know the geoid (geoidal undulation). The geoid in Switzerland is known at the 'cm-level' precision in most locations. On lakes the geoid knowledge is slightly degraded due to the lack of measurements. To mitigate this deficiency a pilot campaign was carried out on Lake of Constance and Lake of Zurich. Measurements were acquired by GPS equipped buoys and surf boards. Additionally, 300 km of laser altimetric profiles were flown over the Lake of Constance. Simultaneously, about twenty temporary gauge marks were related to the precise levelling lines along the lake's shore line. The surface of the lake corresponds to the local equipotential surface which has to be related to the geoid by considering orthometric corrections. The precision of the thus determined surface is at the order of a few centimetres. Previous geoid solutions show departures from the lake measurements of up to 8 cm, whereas the most recent and official geoid of the Federal Office of Topography agrees within about 2 cm.

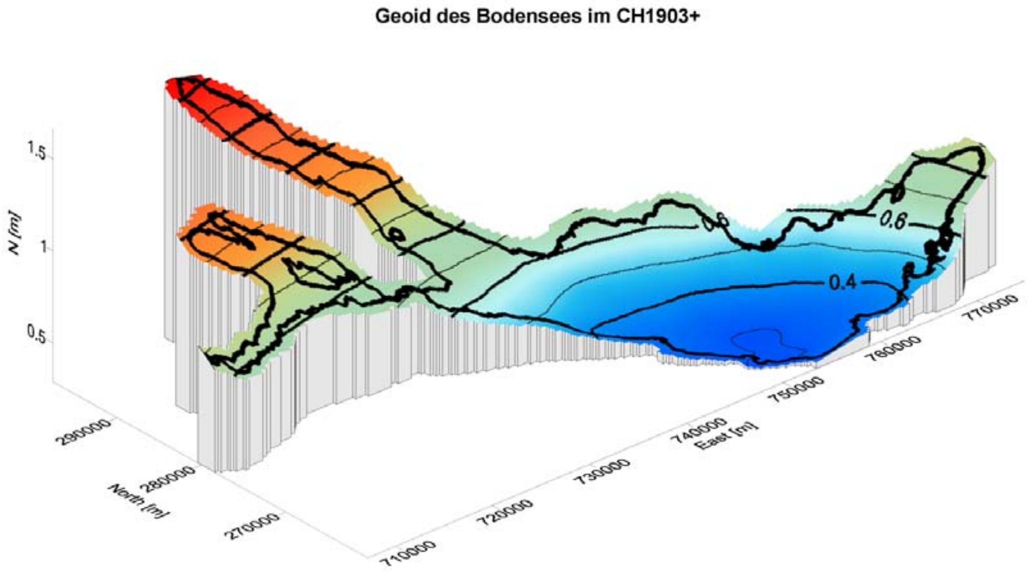

Figure 2.20: Lake of Constance: Sea surface as measured, corresponding to the local equipotential surface (Eugster, 2005).

Ocean Surface Topography Mission (OSTM): Cal/Val Spaceborne Radiometers (JMR)

by H.-G. Kahle, A. Somieski and B. Bürki

Satellite Radar Altimeter missions are of vital importance for the determination of the ocean's sea level and its variability in space and time. In order to extract data of highest quality it is essential to validate and calibrate spaceborne Altimeter Microwave Radiometers (AMR), which are used to correct altimetric heights for significant errors caused by the tropospheric water vapor. The project "Validation and Calibration of Altimeter Microwave Radiometers with Solar Spectrometers (SSM)" contributes to a new high-precision ground-based validation and calibration system for sensing tropospheric water vapor. It is based on high-resolution absorption measurements of solar radiation. Extensive investigations have been carried out including theoretical analysis and practical field observations. The Geodesy and Geodynamics Laboratory (GGL) of ETH Zürich has been engaged in this field of research for several years, participating in various EU and other international projects, which were related to the best possible determination of the sea level and its temporal changes.

SSM is based on the measurement of single vibrational-rotational absorption lines of the water molecules. The number of absorbing water molecules is derived from the amount of absorption of the incident solar radiation by applying the method of Differential Optical Absorption Spectroscopy (DOAS). The advantage of DOAS is its insensitivity to broadband extinction processes like Rayleigh and Mie scattering. Furthermore, the retrieval algorithm used is independent from the measurement site and the season, and the total water vapor content along the line of sight can be determined from the measured absorption lines with high accuracy. A prototype instrument, the GEodetic MObile Solar Spectrometer (GEMOSS) has been developed by GGL in collaboration with the Institute for Analytical Sciences (ISAS) in Berlin, Germany. GEMOSS was successfully deployed during three campaigns in order to measure the zenithal wet path delay (ZWD) simultaneously on subtracks of JASON. Fig. 2.21 and 2.22 show the time series of ZWD measured by the on-board microwave radiometer of Jason (JMR), the water vapor radiometer (WVR) of ETH, the

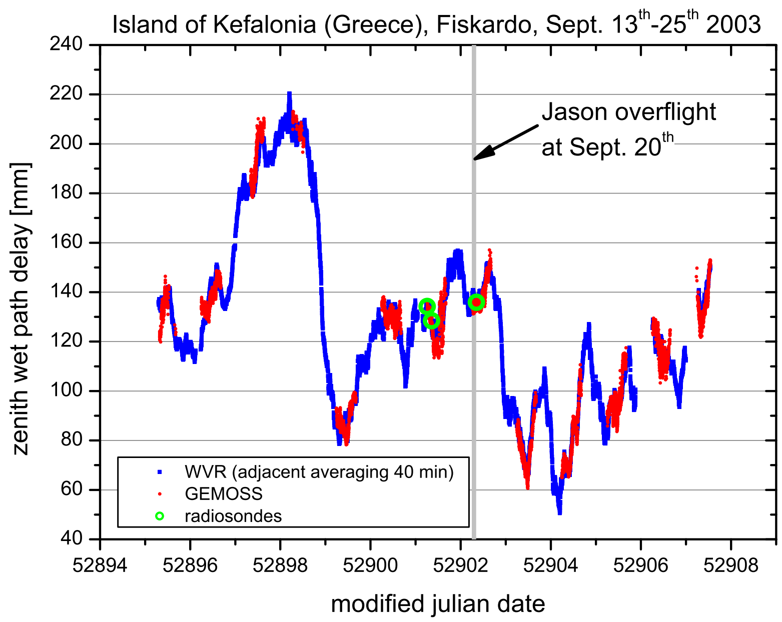

Figure 2.21: Time series of zenithal wet path delay (ZWD) acquired by water vapor radiometer (WVR), solar spectrometer (GEMOSS) and radiosondes. All three techniques agree very well within 1 cm ZWD. The time of the Jason overflight is indicated by the vertical gray bar.

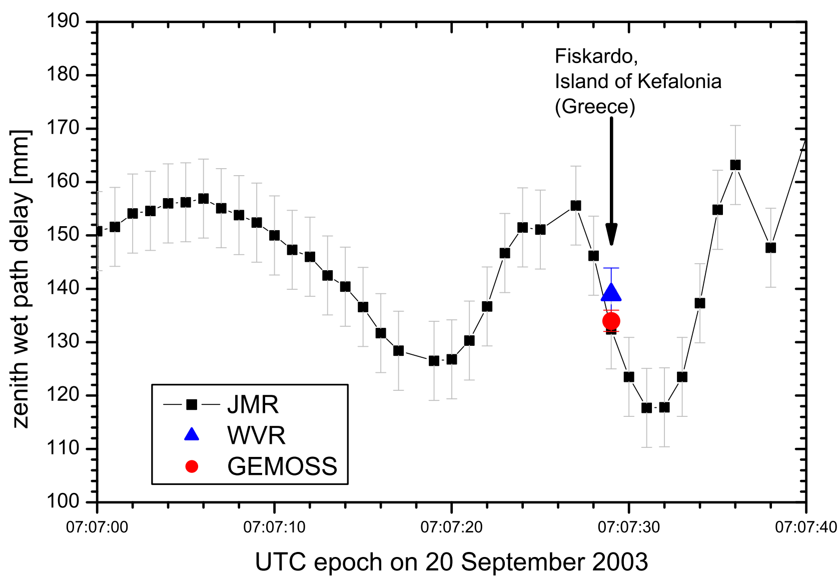

Figure 2.22: Time series of zenithal wet path delay (ZWD) measured by the on-board microwave radiometer of Jason (JMR). When Jason flew over Fiskardo at 07:07:29 AM (UTC) JMR determined the ZWD to about 132.4 ± 7.4 mm. GEMOSS and WVR verify the JMR measurement with 134.0 ± 2 mm and 138.9 ± 5 mm ZWD, respectively.

solar spectrometer (GEMOSS) and radiosondes during the campaign at Fiskardo on the island of Kefalonia, Greece.

The results indicate the ability of solar spectrometry to retrieve the ZWD with an accuracy of a few millimeters (see Fig. 2.22). Of particular interest will be the long-term comparison and validation with other sensors, such as TOPEX/Poseidon, Jason, ENVISAT and ERS-2. The spectrometer system will ultimately contribute significantly to a better understanding of the long-term performance of spaceborne radiometers and will, therefore, provide vital information for the improvement of ongoing and future satellite altimetry missions, such as the Ocean Surface Topography Mission (OSTM).

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3 Earth Rotation and Geodynamics

CODE Contributions to Earth Rotation Monitoring

by R. Dach, S. Schaer, U. Hugentobler, M. Rothacher and R. Weber

Because GNSS (Global Navigation Satellite System) satellite orbits realize a quasi-inertial system, the analysis of tracking data from the global IGS (International GNSS Service) network allows it to estimate Earth rotation parameters (ERPs). As a result x and y positions of the Earth's rotation axis in an Earth-fixed frame (polar motion) and rates thereof as well as excess length of day (LOD) values are obtained.

CODE stands for Center of Orbit Determination in Europe - a joint venture of Astronomical Institute, University of Bern, Switzerland, swisstopo, Wabern, Switzerland, and Bundesamt für Kartographie und Geodäsie, Frankfurt a. Main, Germany, (Hugentobler et al., 2007). CODE is one of the Analysis Centers (AC) of the IGS and computes in this capacity ERPs with a 1-day resolution, represented as piece-wise linear parametrization. To deliver them in SINEX format to the IGS for combination the representation of the parameters is transformed to offset and drift by applying some continuity conditions. Separate time series are provided directly to the IERS (International Earth Rotation and Reference Systems Service) for analysis. Today a time series of more than 13.5 years, covering more than 11.5 Chandler periods, is available from CODE. Fig. 3.1 shows the Chandler wobble of the Earth's rotation axis starting in June 1993. The accuracy of the daily values is of the order at 0.1 mas.

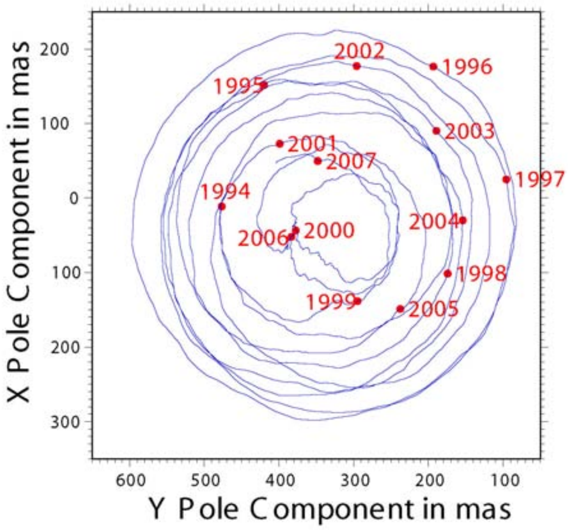

Figure 3.1: Polar motion covering a time period of more than 14 years (1993 to 2007).

Since in June 2003 CODE is processing global GPS and GLONASS tracking data in a fully combined analysis. Due to the different orbital characteristics of GLONASS with respect to GPS - the orbital period is 11:16 instead of 11:58 hours - a slight improvement of estimated pole parameters may be expected. Due to the small number of GLONASS satellites and, in particular, the sparse global GLONASS-tracking network, it was not possible to see a clear improvement of the ERP series.

Fig. 3.2 shows the motion of the pole around New Year 2006 when the destructive interference of the Chandler, the annual, and semi-annual signal allowed it to observe small polar motion loops.

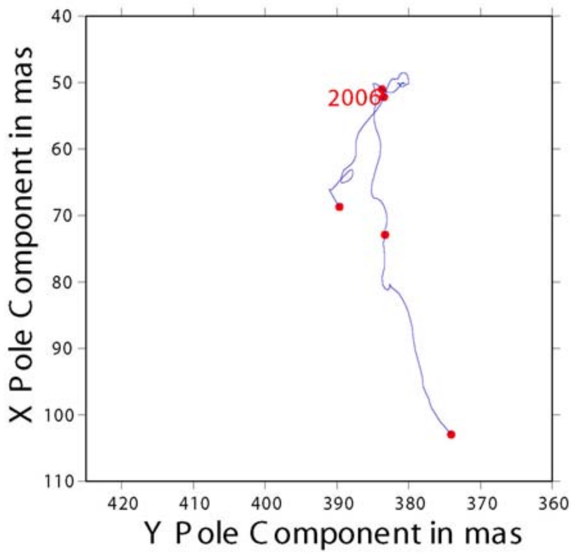

Figure 3.2: Polar motion loops around New Year 2006 (the red dots indicate the position of the pole on the first day of a month).

Fig. 3.3 shows the variations of excess length of day for the time period of more than 13.5 years. As opposed to the first 10 years the started increasing in the most recent three years an average secular trend of 2 ms per century has to be expected. As a consequence a leap second had to be added on December 31, 2006 after seven years without leap seconds.

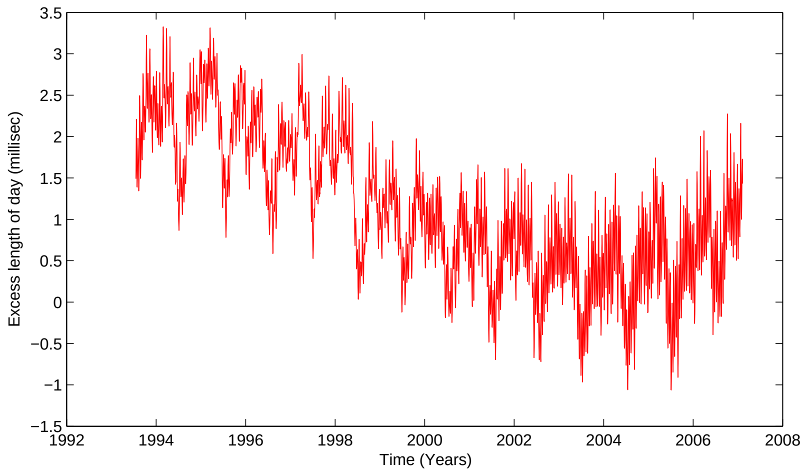

Figure 3.3: Development of excess length of day covering a time period of more than 14 years (1993 to 2007).

Since January 1995 CODE is internally using a 2-hours resolution for polar motion and LOD parameters, extending the unique high resolution time series to more than 12 years. Since April 1994 also daily values for drifts in nutation in longitude and obliquity are estimated at CODE. These particular time series covers more than 13 years by now.

Results of the 3rd Observation of the Swiss GPS Reference Network LV95

by E. Brockmann and D. Ineichen

With the re-observation of the Swiss GPS Reference Network LV95 in 2004, a third independent coordinate estimation was realized. During 13 weeks (from May to September, 2004) a total of 245 stations were observed for about 18 hours each by a team of three simultaneous GPS operators. A distance of 31,000 accident-free km was covered during this campaign. Since the AGNES network is a perfect network for connecting all of the observations, the stations were occupied only once. The reliability was guaranteed by comparing the results with earlier determinations. Only the points of the NEOTEKTONIC network were occupied twice.

Based on the normal equation of all GPS analyses carried out by swisstopo since 1988, a combined adjustment was computed which took into consideration the correlation between all coordinates. Various subsets which merged the results of longer time intervals of 3-5 years were introduced into the adjustment. In addition, a subset of all AGNES stations together with about 30 European GPS sites from the EUREF Permanent Network (EPN) since 1998 were included.

It could be proven that the horizontal accuracy, derived by comparing the coordinates of the approximately 200 points, is about 1 cm (see Fig. 3.4).

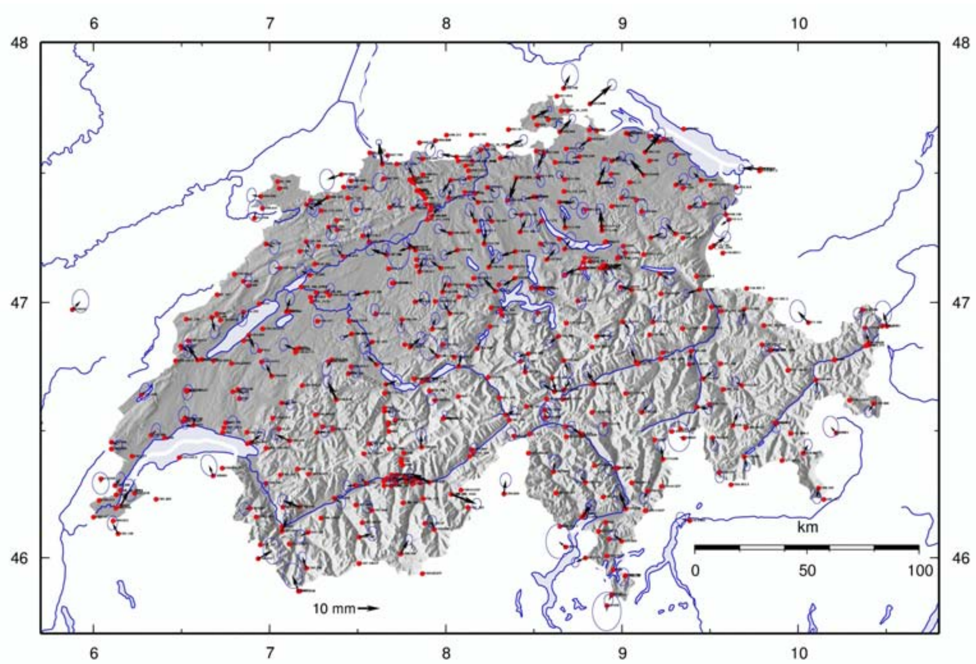

Figure 3.4: Horizontal differences of the new combined adjustment to the coordinates rounded to the cm used for cadastral surveying. The standard deviation (1σ) of the coordinate differences is 3.7 mm.

Because of the relatively long time period of 16 years, it was possible to obtain velocities which are in the order of less than 1 to 2 mm per year for specific Swiss regions, which is slightly above the significance level (Fig. 3.5). This agrees quite well with velocity estimates derived from the permanent GPS network AGNES. Further studies were done within the project Swiss-4D, where, in addition, kinematic estimates from the levelling network were used (see the contribution page 66).

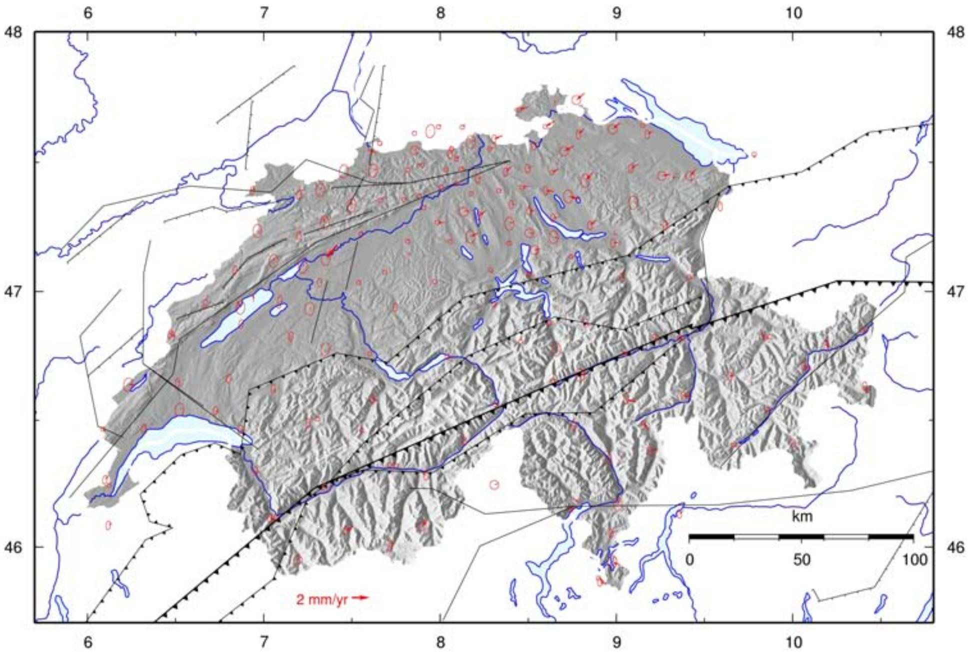

Figure 3.5: Velocities of 176 LV95 points in mm/year and the corresponding error ellipses relative to station Zimmerwald.

Modelling the Kinematics of the Deformation of the Swiss Geodetic Reference Network: Project Swiss4D

by A. Wiget, U. Marti, D. Schneider, R. Egli, A. Geiger, O. Heller and H.-G. Kahle

The study of recent crustal movements in Switzerland and the development of a kinematic 3D model for the Swiss Terrestrial Reference System CHTRS were the main goals of the swisstopo project Swiss4D. The model should be suitable for monitoring the geodetic reference frames as well as for scientific studies. It shall be acknowledged that these studies have partly been initialized and financed by a contract with NAGRA, the National Cooperative for the Disposal of Radioactive Waste.

Between 1988 and 1995, the Federal Office of Topography (swisstopo) installed the Swiss GPS Reference Network LV95 (Landesvermessung 95) as the national first order GPS network and made the first GPS observations on its geodetic control points. As a quality check and for the study of tectonic movements, swisstopo reobserved the whole network in 1998 and 2004 (see the contributions in section 1, page 10 and section 3, page 65). The direct comparison of the new horizontal coordinates with their earlier determinations proved the stability of the reference frame on the cm level. Together with the 30 permanent GPS stations of the automatic GPS network Switzerland (AGNES) (see the contribution in section 1, page 7), the 200 LV95 stations represent the backbone of the Swiss Terrestrial Reference Frame (CHTRF). The vertical velocities were taken from the kinematic adjustment of all national levelling data from 1903 to 2004 used for the definition of the new national height system LHN95 (Landeshöhennetz 95) (see the contribution in section 1, page 15).

The horizontal velocity vectors (∼1 mm/year) derived from the combined adjustment of the high-precision GPS measurements in AGNES and LV95, introduced as SINEX files, were combined with the vertical velocities from LHN95. These values define a set of constraints for a kinematic model of crustal deformation in Switzerland and were used to calculate a three-dimensional discrete velocity field on the surface of the Earth's crust. The strain rate field and the main components of the deformation tensor were then obtained from the interpolated velocity field using the software ALSCStrain, developed by R. Egli at the Geodesy and Geodynamics Lab at ETH Zürich (Prof. H.-G. Kahle and Prof. A. Geiger) (Wiget et al., 2005a,b, 2006b). A detailed description of the "adaptive least-squares collocation" method is given in (Egli et al., 2007).

The interpolated 3D vector field is presented in Fig. 3.6. The vertical velocities varying from -0.4 mm/year to +1.4 mm/year relative to an arbitrarily chosen reference point have been well known before. New was the conclusion that the horizontal velocities are also on the millimeter level. But since the uncertainty in GPS measurements is of the same order of magnitude, the horizontal results are not yet significant. The threedimensional strain rates vary from 5 to 50 nstrain/year. Fig. 3.7 shows the horizontal strain rates in Switzerland in a 10km x 10km grid.

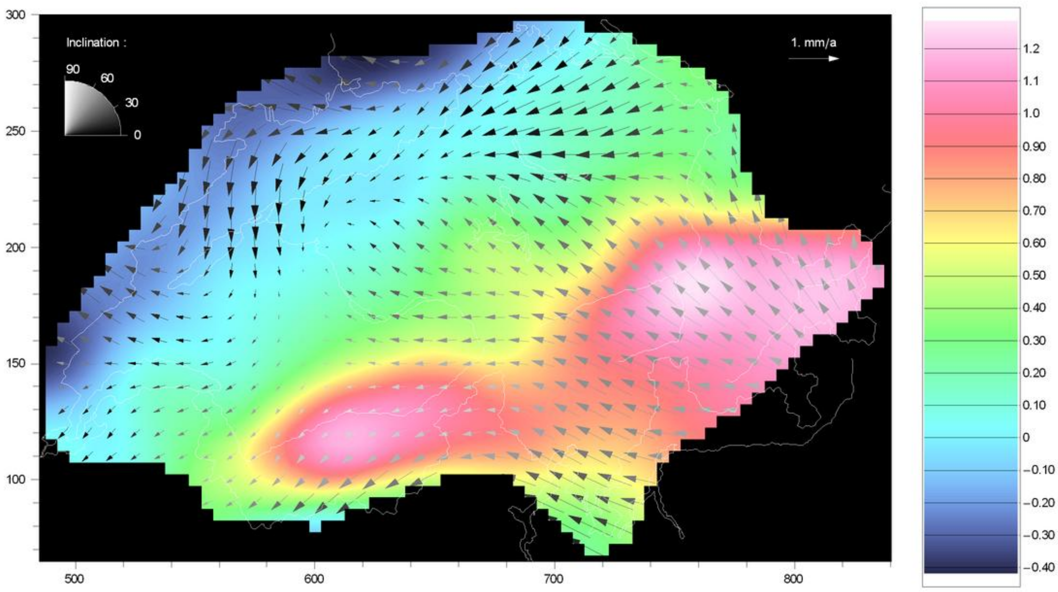

Figure 3.6: Interpolated 3D velocity field for Switzerland represented as spatial vectors. The color scale indicates the magnitude in [mm/year], the gray scale (upper left) indicates the inclination of the velocity vectors.

The project Swiss4D was formally terminated at the end of 2005. However, there are still many problems and unanswered questions regarding the selection and monumentation of the stations as well as the processing and interpretation of the existing measuring methods and the data. Interferences on the stations during observations must be recognized and eliminated in due time if the aim is to obtain a long time series of observation data suitable for kinematic investigations. In addition, the processing and interpretation methods must be further refined. Therefore, a follow-up project Swiss4D-II is being planned for a more profound analysis of the stations, the models and the data.

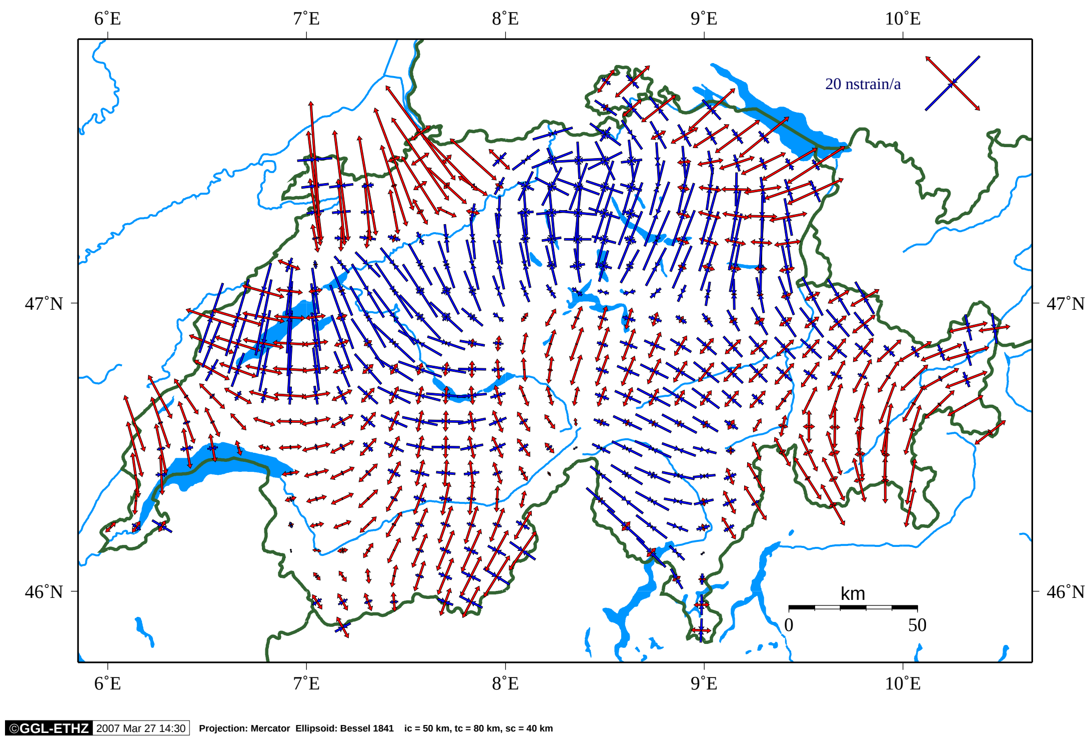

Figure 3.7: Horizontal strain rates in Switzerland in a 10km x 10km grid. They were estimated from a continuous horizontal velocity field calculated by means of a modified least-squares collocation method (Egli et al., 2007) with a correlation length of 80 km for the trend function and of 40 km for the signal.

SAR Interferometry for Land Subsidence Monitoring

by A. Wiget and U. Wegmüller

Within the above-described swisstopo project Swiss4D, a feasibility study for surface deformation mapping with repeat-pass spaceborne SAR interferometry and its comparison and validation with geodetic reference data was done by the Swiss company Gamma Remote Sensing in close cooperation with swisstopo. The SAR processing was done using the GAMMA MSP software, the interferometric processing by using the GAMMA ISP software. ERS SAR data of the time period 1992 to 2000 were selected according to acquisition time interval and perpendicular baseline for an area in central Switzerland. The DTM extracted for this area from the swisstopo DHM25 is shown in Fig. 3.8.

Overall, very small deformation rates - below a few mm/year - were detected, which are at the threshold of 1 mm/year for the interferometric technique. The results of the 1992 to 1996 and 1996 to 2000 intervals are consistent within the expected accuracies. An example of the deformation maps between 1992 and 2000 is shown in Fig. 3.9.

More detailed analyses and comparisons with geodetic data were then done for the region of Lucerne-Zug-Zürich as well as for a local application in Zug, where an interferometric point target analysis on the 10 ERS SAR images was conducted using the GAMMA IPTA software. For the validation approach, swisstopo selected 19 points of the national levelling network which are

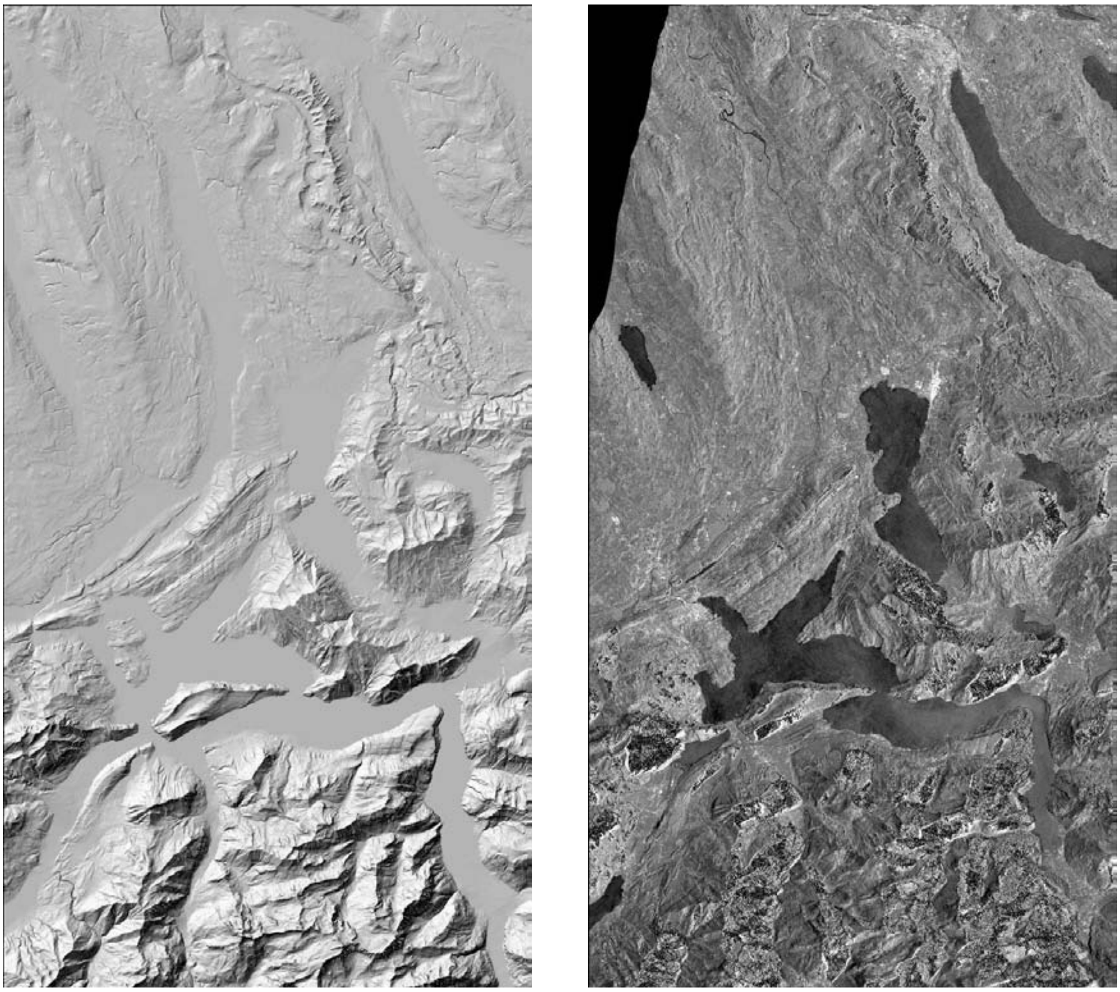

Figure 3.8: Left panel: DTM of the selected test area, right panel: Geocoded SAR backscattering coefficient.

known to be stable and representative. For these points, the vertical velocities were compared with the values extracted from the interferometric result. Differences between the levelling and interferometry-based velocities were calculated. Without further modification, the velocities differ on the average by 0.29mm/year with a standard deviation of 0.25 mm/year. As the velocities from levelling are relative to a reference point, it is adequate to shift the values to a common reference.

In general, the interferometric method gives a relatively good two-dimensional overview of the surface deformation in the area surveyed. The vertical deformation rates for 1992 - 2000 are in the order of ± 2mm/year (estimated precision ± 1mm/year) for various larger and smaller urban areas. The method is primarily suited for urban areas. In areas covered by vegetation (fields, forests) and for water surfaces, the low coherence of the signals doesn't yield reliable interpretations. The interferometric method yields two-dimensional information on surface deformations, limited by the available SAR data, whereas the levelling method allows only point-wise (or approximately linear) interpretations of the deformations. An advantage of the interferometric method is the fact that the analysis can be done without prior installation of markers in the field.

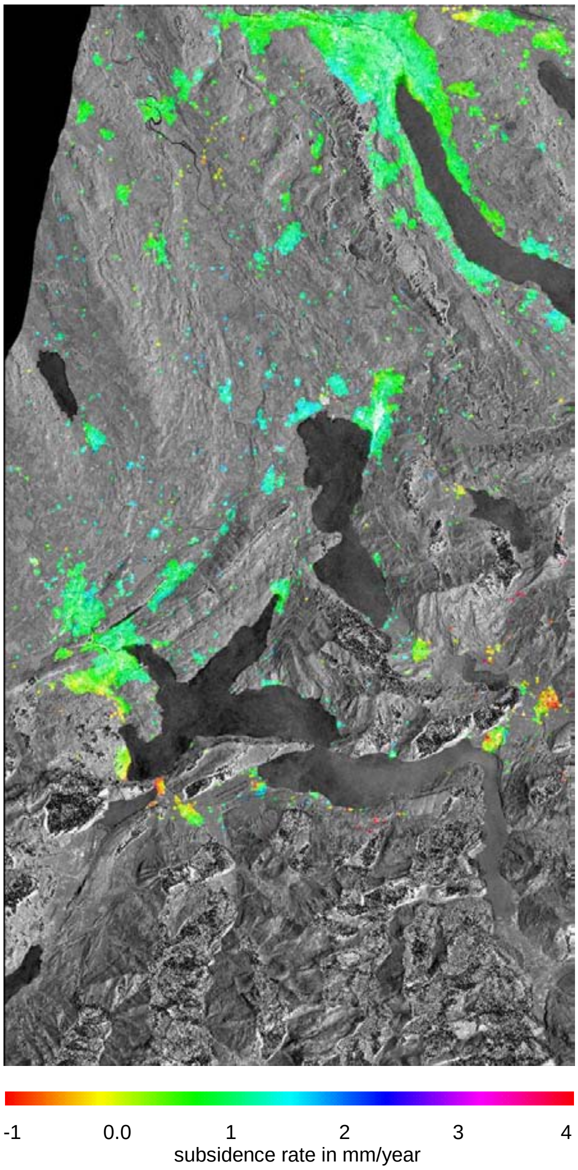

Figure 3.9: Deformation rate between 1992 and 2000.

Recent Crustal Vertical Movements in Switzerland: Activities for the New National Height System 'LHN95'

by A. Schlatter, A. Geiger and H.-G. Kahle

The analyses of recent crustal movements from repeated precise levelling has been investigated in Switzerland for several decades. The Swiss Federal Office of Topography (swisstopo) is responsible for providing the geodetic bases. In this function, swisstopo also maintains the height control networks, mainly in the form of precise levelling. With the project *New National Height System of Switzerland 'LHN95'* (see also the contribution in section 1, page 15), all measurements from 1903 until now were systematically captured in digital form.

Up to now, about 10'000 km of precise levelling are available for the investigation of vertical movements in Switzerland. These data are periodically completed and extended by repeated measurements in the order of about 150 km/yr. Fig. 3.10 shows the lines measured from 2003 to 2006.

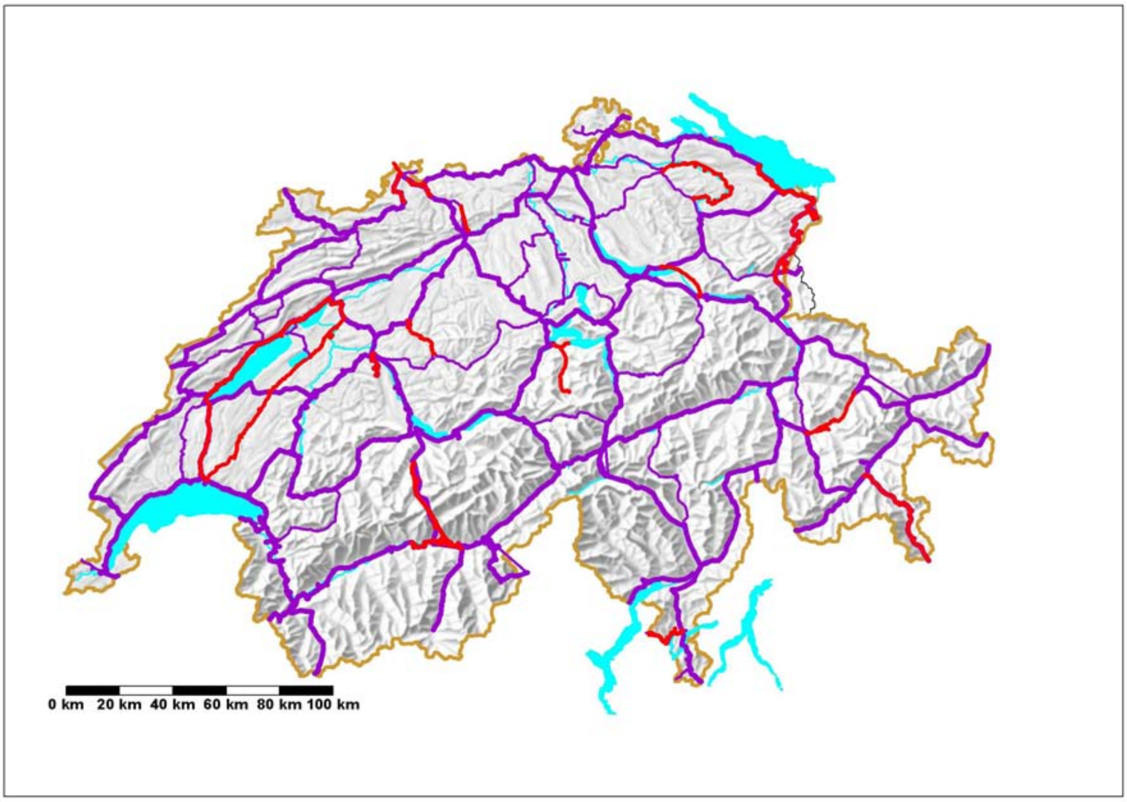

Figure 3.10: New measurements (red lines) in the national height network from 2003 to 2006.

With the so-called kinematic adjustments of precise levellings, it is possible to calculate vertical movements for bench marks which have been observed at least twice. Only nodal points and selected bench marks fixed in bed rock or in stable buildings are integrated in these adjustments. The reference bench mark for vertical movements is located in Aarburg (southern Jura Mountains). Fig. 3.11 shows a selection of suitable bench marks with their annual height changes and the corresponding double standard deviations. The recent crustal movements depicted in Fig. 3.11 clearly show two regions of distinct uplift: the cantons of Valais and Grisons. These are correlated with negative isostatic anomalies. It is, therefore, surmised that isostatic rebound might contribute to the driving mechanism. Investigations on this relationship and corresponding modelling are foreseen in the frame of Swiss 4D (compare the contribution in section 3, page 66).

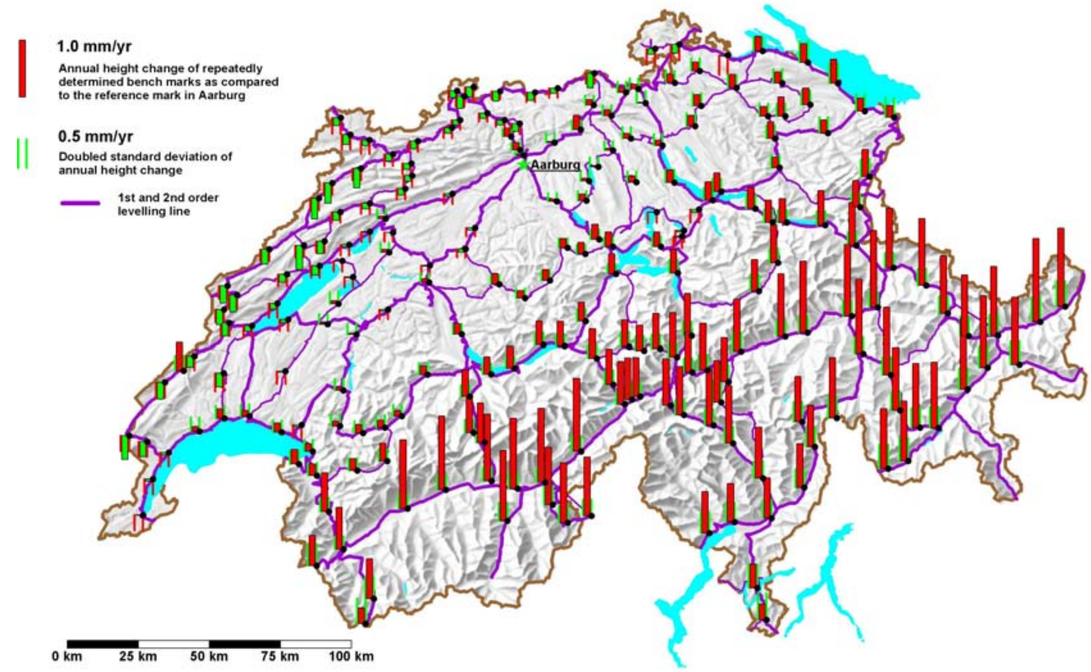

Figure 3.11: Recent vertical movements of selected bench marks of the National Height System LHN95 (relative to Aarburg, southern Jura Mountains).

Environmental Tectonics/Upper Rhinegraben (EUCOR/URGENT)

by A. Schlatter, D. Schneider, M. Tesauro, A. Geiger and H.-G. Kahle

The ENTEC project integrated geological, geophysical, geomorphologic, seismological and geodetic data to quantify the societal impact of neotectonics in areas of major urban development and industrial activity (Cloetingh et al., 2006). The Swiss contribution was based on geodetic data: one topic focused on the strain rate field and the other on the analysis of levelling data in the vicinity of the city of Basle. The local crustal velocity and strain rate field was reconstructed from GPS array solutions. The velocities of permanent GPS stations belonging to various networks (EUREF, AGNES, REGAL and RGP) in central Europe were compiled and studied. Moreover, the strain rate field was displayed in terms of principal axes and values as well as projections of the tensor components perpendicular and parallel to the strike of major faults. The results were compared with the fault plane solutions of earthquakes which had occurred in this area.

A broad - scale kinematic deformation model across the Rhine Graben was provided on the basis of tectonics and velocity results of the GPS permanent stations. The area of study was divided into four blocks. The velocity and strain rate fields were reconstructed along their borders, by estimating a uniform rotation for each block. The tectonic behaviour is well represented by the 4-block model in the Rhine Graben area, while a more detailed model will be needed for a better reconstruction of the strain field in the Alpine region.

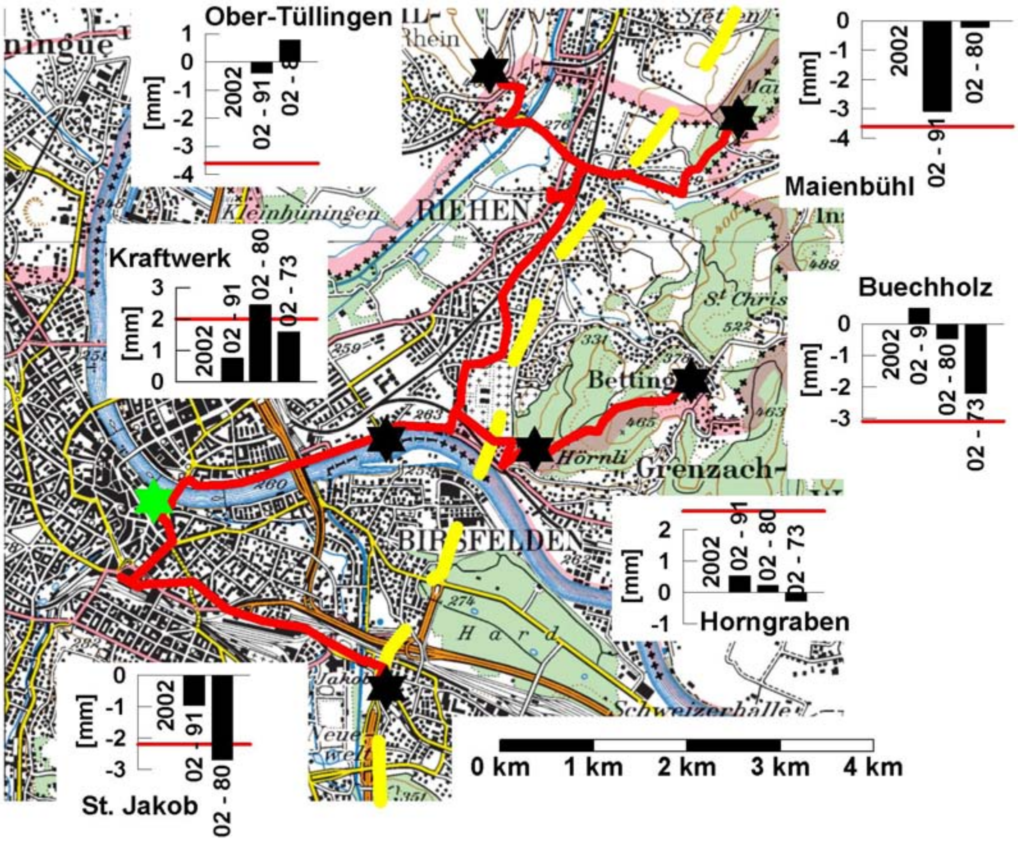

Figure 3.12: Height changes and level of significance (1σ) of selected points of the RCM profile Basel relative to the control points "Münster" and the campaign 2002/03.

The southern end of the Upper Rhine Graben is one of the zones in Switzerland where recent crustal movements can be expected because of ongoing seismotectonic processes as witnessed by seismicity clusters occurring in this region. Therefore, in 1973 a control network with levelling profiles across the eastern Rhine Graben fault was initially installed and measured in the vicinity of the city of Basel in order to measure relative vertical movements and investigate their relationship with seismic events. The profiles were observed a third time in the years 2002 and 2003 and connected to the Swiss national levelling network. The results of these local measurements were discussed in terms of accuracy and significance. Furthermore, they were combined and interpreted together with the extensive data set of recent vertical movements in Switzerland (Jura Mountains, Central Plateau and the Alps). In order to be able to prove height changes with precise levelling, their values should amount to at least 3-4 mm (1σ). The present investigations, however, have not shown any significant vertical movements over the past 30 years.

Analysis of Recent Crustal Movements (RCM) in the Central-Western European Region

by M. Tesauro, Ch. Hollenstein, R. Egli, A. Geiger and H.-G. Kahle

The kinematic field of central western Europe is characterized by relatively small movements (around 1-2 mm/year) and diffuse seismicity with earthquakes occurring mostly in the shallow crust (within 15 km), prevalently concentrated along the Alps and the European Cenozoic Rift System (ECRIS). In order to study and constrain the current crustal kinematic field the velocity and the strain field was reconstructed using permanent GPS stations, belonging to different networks (AGNES, EUREF, REGAL, RGP). The 2D strain rate tensor has been calculated using the method of least-squares collocation. The results show that the area of maximum compression is located along the Alpine chain, where maximum values of 7 ± 2 nstrain/year are found, while maximum extension is measured between the Armorican Massif and the Massif Central, where values of 4 ± 2 nstrain/year are reached.

The earthquakes with $M > 3.0$, have been used to estimate the seismic strain rates, while the style of the seismic deformation was reconstructed from the fault plane solutions available from the literature. Relatively high values of seismic strain rates (around 10 nstrain/year) are measured along the Alpine Chain and the ECRIS. Results obtained by geodetic and seismic data are quite in agreement and reflect the different tectonic evolution of the geological features characterizing the area of study. The orientation of the compressional geodetic and seismic strain axes are NW-SE in most of the area of study, on account of the action of plate boundary forces. A rotation of the same axes to N-S direction along the eastern Alps, possibly related to the Adria convergence, is found.

The GPS velocity field in southern Italy

by Ch. Hollenstein, H.-G. Kahle, A. Geiger, S. Jenny, S. Goes and D. Giardini

Southern Italy is a key area for understanding the tectonic processes in the Africa-Eurasia collision zone. Repeated GPS measurements carried out between 1994 and 2001 were analyzed in combination with data from a large continuous network consisting of 54 mainly European IGS and EUREF sites as well as Greek sites. The velocity results for southern Italy (Fig. 3.13) clearly show several different kinematic blocks. While central Italy (UNPG), Corsica (AJAC), Sardinia (CAGL) and the Tyrrhenian Sea (TS) move like the Eurasian plate, the overall motion of the Sicily Rift Zone (SRZ) region matches African plate motion (within 1.8 mm/yr). There is no indication that the opening of the Tyrrhenian Sea is still active. Unexpected are the large (up to 9 mm/yr) north-northwest directed motions of northeastern Sicily and the Eolian islands. When referenced to the African plate, the velocity field for northeastern Sicily resembles a clockwise rotation (compare Fig. 3.13 b). Apulia (sites MATE, SPEC) shows a north-northeast directed motion of up to 4.4 mm/yr. The strain rate field (Fig. 3.14) calculated from the GPS velocities visualizes the crustal deformation in the region of southern Italy. Most striking is the north–south oriented compression along the northern Sicilian coast. The compression between the African and Eurasian plates seems to be concentrated in a ~ 50 km wide band to the northwest and north of Sicily, which is consistent with compressional focal mechanisms of earthquakes along this belt. The large north components of the velocities in northeastern Sicily enhance compression to the north of it and cause extension in the interior of Sicily. Further significant features in the strain rate field are compression between Apulia and northwestern Greece as well as extension in the Sicily Rift Zone.

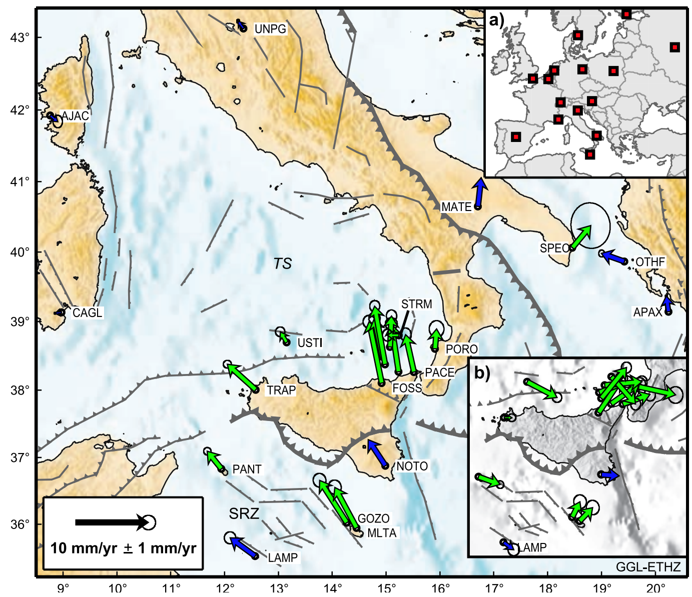

Figure 3.13: GPS velocities relative to Eurasia. Green arrows: based on repeated GPS measurements between 1994 and 2001. Blue arrows: based on continuous GPS measurements. Insets: a) IGS sites used as reference stations. b) GPS velocities relative to the African plate (Hollenstein et al., 2003a).

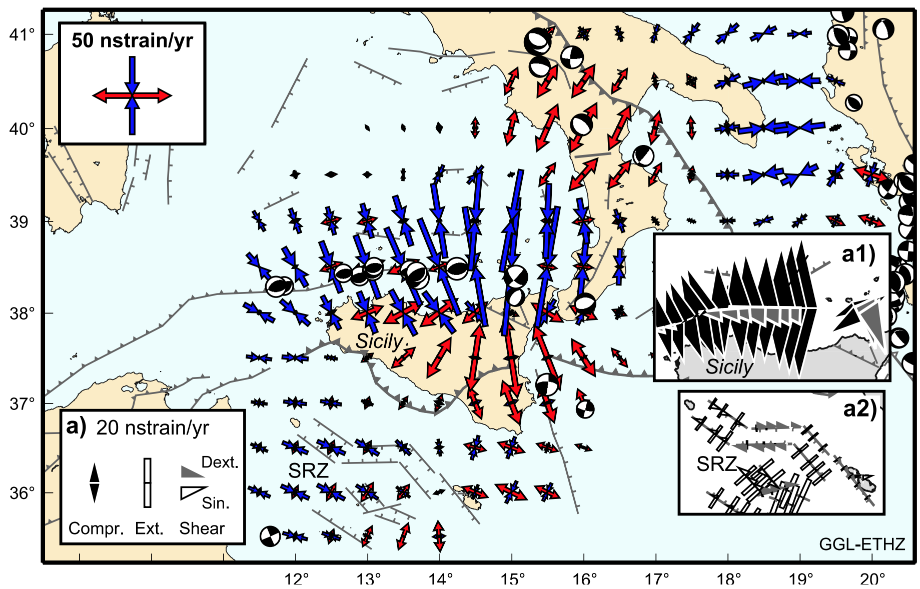

Figure 3.14: Principal axes and eigenvalues of the strain rate tensor calculated from the velocity field shown in Fig. 3.13. Red arrows indicate extension, blue arrows compression. 10 nstrain/yr correspond to a relative motion of 1 mm/yr over a distance of 100 km. Focal mechanisms of larger earthquakes (depth $<$ 40 km) between 1976 and 2002 [Global CMT catalog, http://www.globalcmt.org; (Pondrelli et al., 2002), http://www.ingv.it/seismoglo/RCMT/]. Insets: Normal and shear strain rates projected perpendicular and parallel to selected faults, respectively. a1) Area north of Sicily. a2) Sicily Rift Zone (SRZ) (Hollenstein et al., 2003a).

Continuous GPS time series along the West Hellenic Arc

by Ch. Hollenstein, A. Geiger, H.-G. Kahle and G. Veis

Western Greece is one of the seismo-tectonically most active regions in Europe. The main tectonic structures are the West Hellenic Arc (WHA) and the Kephalonia Fault Zone (KFZ). In order to monitor and understand the crustal movements in space and time, a continuous GPS network was installed in 1995. To ensure a consistent reference frame, 54 mainly European IGS and EUREF sites were included in the data analysis, and the whole processing was done in one single ITRF reference frame. The network finally was constrained to the reference frame by 3D Helmert transformation, which allowed to maintain the good inner precision of the network and eliminated large parts of systematic errors. A selected subset was used to estimate an Euler pole for the rotation of Eurasia. In order to obtain coordinate time series of high precision which are representative for crustal deformation, special emphasis was given to the elimination of non-tectonic effects. Four steps of improvement were pursued, including a reprocessing after exclusion of poor data, the removal of remaining outliers, the correction of unknown phase center offsets after antenna changes, and weighted common-mode filtering. With this procedure, non-tectonic irregularities were reduced significantly, and the precision was improved by an average of 55 %. The final time series (examples see Fig. 3.15) are used as a base for depicting trajectories of crustal motion (Fig. 3.16), interpreting the temporal behavior of the sites and for estimating velocities (Figs. 3.16a and 3.16b). Many previous findings could be confirmed and refined, such as increasing horizontal rates from north to south and dextral shear strain in the Kephalonia Fault Zone. While the seismic activity in the West Hellenic Arc area is relatively high, the motion of most of the sites is surprisingly linear during the 6 years analysed. The most striking deviations from linearity are the co-seismic slips caused by the Strofades earthquake. It is clearly seen that the island of Strofades was uplifted by about 9 cm. The horizontal co-seismic displacements of Strofades and Keri amount to 12 cm and 2 cm, respectively. The time series of KERI show that there is no significant difference between the velocities before and after the earthquake. The trajectory of the site DION near Athens shows a slight variation in the months prior to the Mw6.0 Athens 1999 earthquake. For the first time, height changes in the West Hellenic Arc area were detected and quantified by GPS. The Ionian islands are characterized by interseismic subsidence. The important role of the KFZ as a kinematic boundary is reflected by the significantly different vertical velocities to both sides of this fault: around -2 to -2.5 mm/yr at sites to the northwest of the KFZ and around -3.5 to -4.5 mm/yr at sites to the southest of the KFZ.

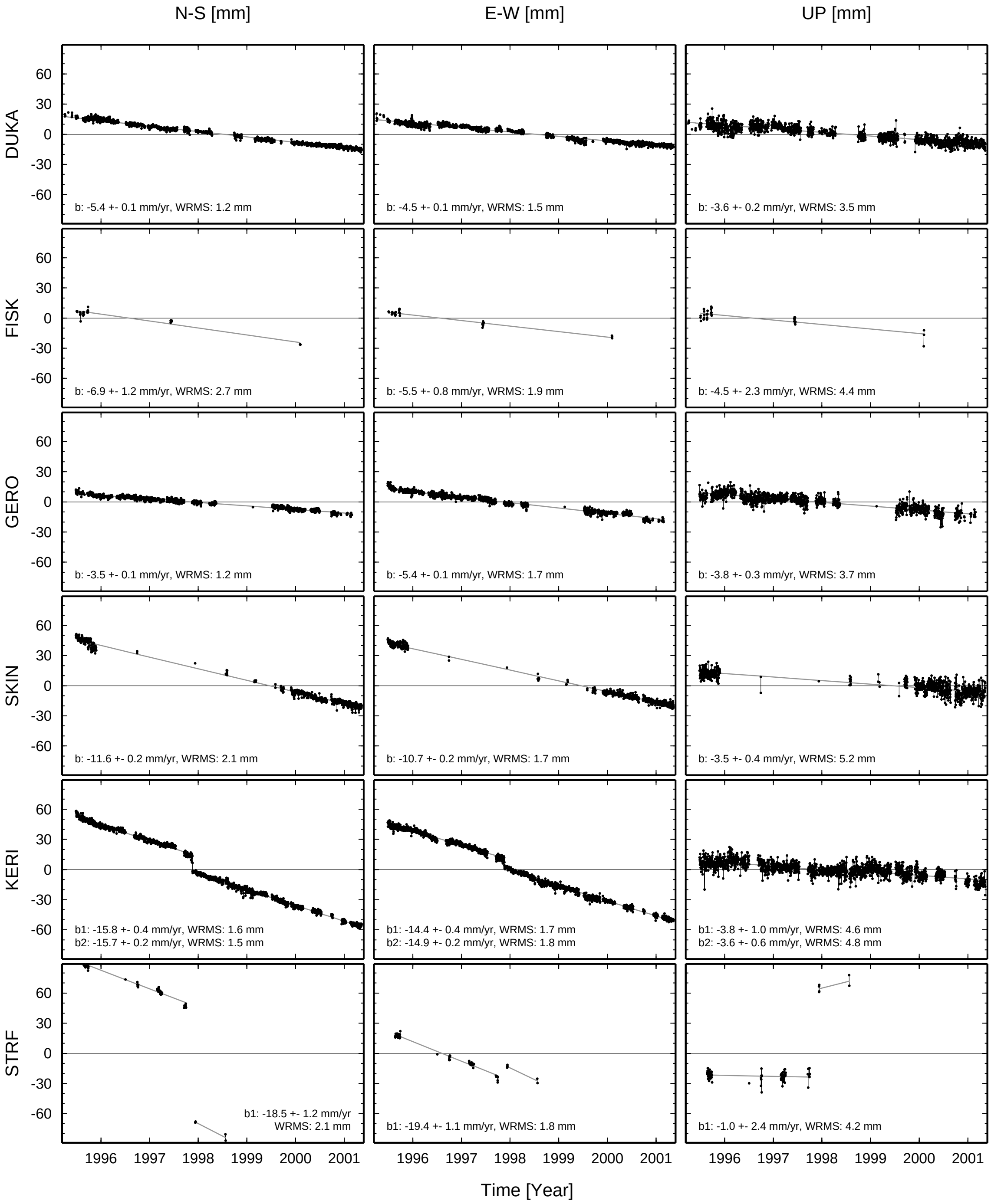

Figure 3.15: Common-mode filtered time series of daily coordinates relative to Eurasia. “b”: velocity, calculated by weighted linear regression; b1: before, b2 after the Strofades 1997 earthquake. WRMS: weighted RMS of daily coordinates. The grey lines represent the weighted linear fit. Site locations see Fig. 3.16. (Hollenstein et al., 2006b)

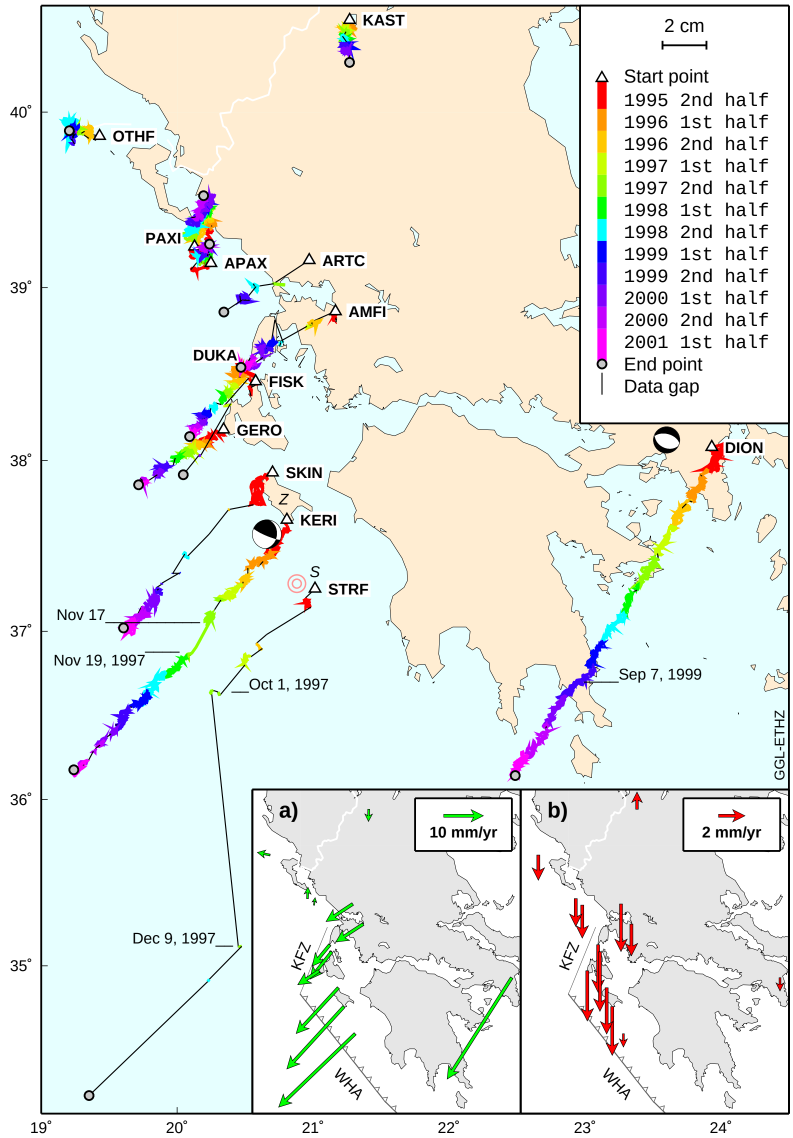

Figure 3.16: GPS-trajectories of horizontal crustal motion 1995–2001 relative to Eurasia, produced from common-mode filtered daily coordinate time series, smoothed with a Gaussian filter (window: 7 days). The start points of the trajectories are at the same time the locations of the sites. The fault plane solutions (fps) represent the large earthquakes which occurred on November 18, 1997 near STRF and on September 7, 1999 near DION, while the red circles mark the strong aftershocks 6 min after the Strofades earthquake (fps: Global CMT catalog, http://www.globalcmt.org; locations: USGS-NEIC, http://gldss7.cr.usgs.gov/neis/epic/epic.html). Insets: Horizontal (a) and vertical (b) GPS-velocities calculated by weighted linear regression of common-mode filtered coordinate time series. For KERI and STRF, velocity 1 (before the Strofades earthquake) is plotted. KFZ: Kephalonia Fault Zone, WHA: West Hellenic Arc, S: Strofades, Z: Zakinthos. (Hollenstein et al., 2006b)

Geodynamics of the Eastern Mediterranean: Plate coupling along West Hellenic Arc and North Aegean Trough?

by Ch. Hollenstein

The seismically very active Hellenic plate boundary region, located in the collision zone between the African/Arabian and Eurasian lithospheric plates, is characterized by a complex field of crustal motion and deformation. During the last 15 years, GPS measurements have been successfully used to determine the crustal motion in the area of Greece aiming at understanding the geodynamical processes of this region. An extended reoccupation network covering whole Greece has been measured periodically in numerous GPS campaigns since the late eighties, and a continuous GPS network has been operated in the region of the Ionian Sea since 1995. A new detailed high-quality solution of continuous and campaign measurements acquired between 1993 and 2003 was produced.

New important results include the existence of deformation zones to the north and to the south of the North Aegean Trough (NAT) and in the West Hellenic Arc (WHA) region, due to plate coupling: The velocity vectors along the WHA show a slight but significant deviation from the overall counterclockwise trend (Fig. 3.17). They are turned away in a clockwise direction. A probable explanation is that friction and a partly locked fault (Hellenic trench) cause the northwestward moving African plate to pull the Aegean near the trench with it. The fact that the magnitudes of corresponding velocity vectors (especially in the northwestern parts of the WHA) are smaller than those found farther northeast would also fit such a model of plate coupling. A further corroboration of this model is given by the southward and southwestward directions of co-seismic displacements during the Strofades 1997 earthquake, possibly representing a sudden rebound of the pulled regions.

The same phenomenon is observed in the northern Aegean Sea (Fig. 3.17). The motions on both sides of the NAT seem to influence each other. The velocity vectors to the north of the NAT turn southwestward the nearer to the fault they are located, while the fault-parallel velocities to the south of the NAT decay towards the fault. This is typical for the interseismic stage of (partly) locked faults. This means that the Anatolian-Aegean plate pulls the sites of the neighboring area with it, while the motion of its border is slowed down at the same time. Such a model of friction and locked faults is confirmed by the co-seismic rebound motions induced by the Izmit earthquake in 1999 and the generally high seismic coupling of the area (e.g. Jenny et al., 2004).

In contrast, numerous studies attributed low seismic coupling to the Hellenic trench, stating that a large part of the convergence and subduction occurs aseismically. However, the above-described motions of the area near the northwestern part of the trench rather argue for a high seismic coupling, which has been shown to be possible for the Ionian islands region (Laigle et al., 2002).

It is concluded that the new GPS results provide clear evidence for plate coupling along the NAT and the WHA, associated with the existence of deformation zones in the adjacent areas.

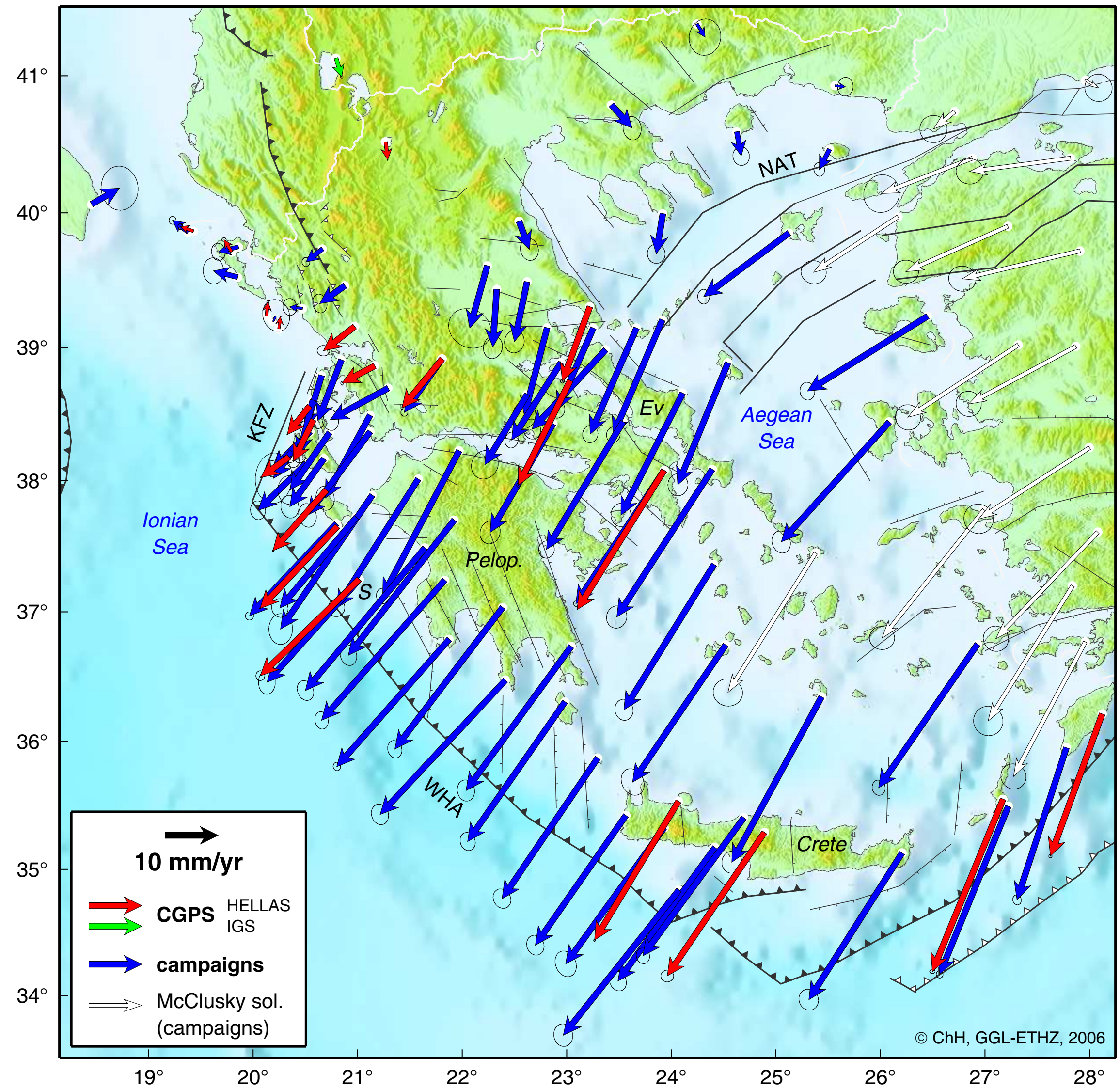

Figure 3.17: GPS-velocities relative to Eurasia, for the period 1993–2003. The error ellipses represent the 1-sigma confidence region. McClusky sol.: solution of McClusky et al. (2000). Ev: Evia, KFZ: Kefalonia Fault Zone, NAT: North Aegean Trough, Pelop.: Peloponnesos, S: island of Strofades, WHA: West Hellenic Arc.

GPS derived Strain Accumulation in the Ionian Sea Region

by Ch. Hollenstein, A. Geiger and H.-G. Kahle

The Ionian Sea region, Greece, is characterized by high seismo-tectonic activity. This is reflected in the occurrence of more than 4500 intermediate-size earthquakes during the last 30 years, with several large and destructive events among them. Extended GPS reoccupation and continuous networks have been measured in order to study the crustal motion and deformation in this region, with particular interest in earthquake-related effects. While strain rates are based on velocities and show the mean deformation per time unit (nstrain/yr), cumulated strain is based on displacements and shows how much strain has been accumulated since a specific starting time. On the basis of continuous coordinate time series, cumulated strain with respect to the starting time can be calculated for each time of observations, which makes it possible to study the temporal evolution of strain accumulation and its regional differences. In connection with the occurrence of earthquakes, important information about accumulated strain before an earthquake can be obtained. Furthermore, the influence of co-seismic displacements on the strain field can be studied by comparing the cumulated strain before and after an earthquake.

Cumulated strain was calculated in connection with the Mw6.2 Lefkada 2003 earthquake, which caused co-seismic displacements of several centimeters. The earthquake occurred in an area where extensional dilatation of up to 700 nstrain and maximum shear strain of up to 2500 nstrain had been accumulated since 1995 (Fig. 3.18). The comparison of the strain fields of one day before and one day after the seismic event, respectively, reveals some interesting features:

The shear strain to the east of the island of Lefkada was reduced from about 2500 nstrain to about 1500 nstrain by the co-seismic displacements, leaving this region under a predominantly extensional regime. There is a higher maximum of compression in southern Kefalonia and the shear highly increased (from about 1500 nstrain to about 2500 nstrain) in northwestern and central Kefalonia after the event, which probably cannot be fully explained as fault slips. Therefore, it indicates that stress and seismic hazard for the island of Kefalonia has increased as a consequence of the Lefkada 2003 earthquake.

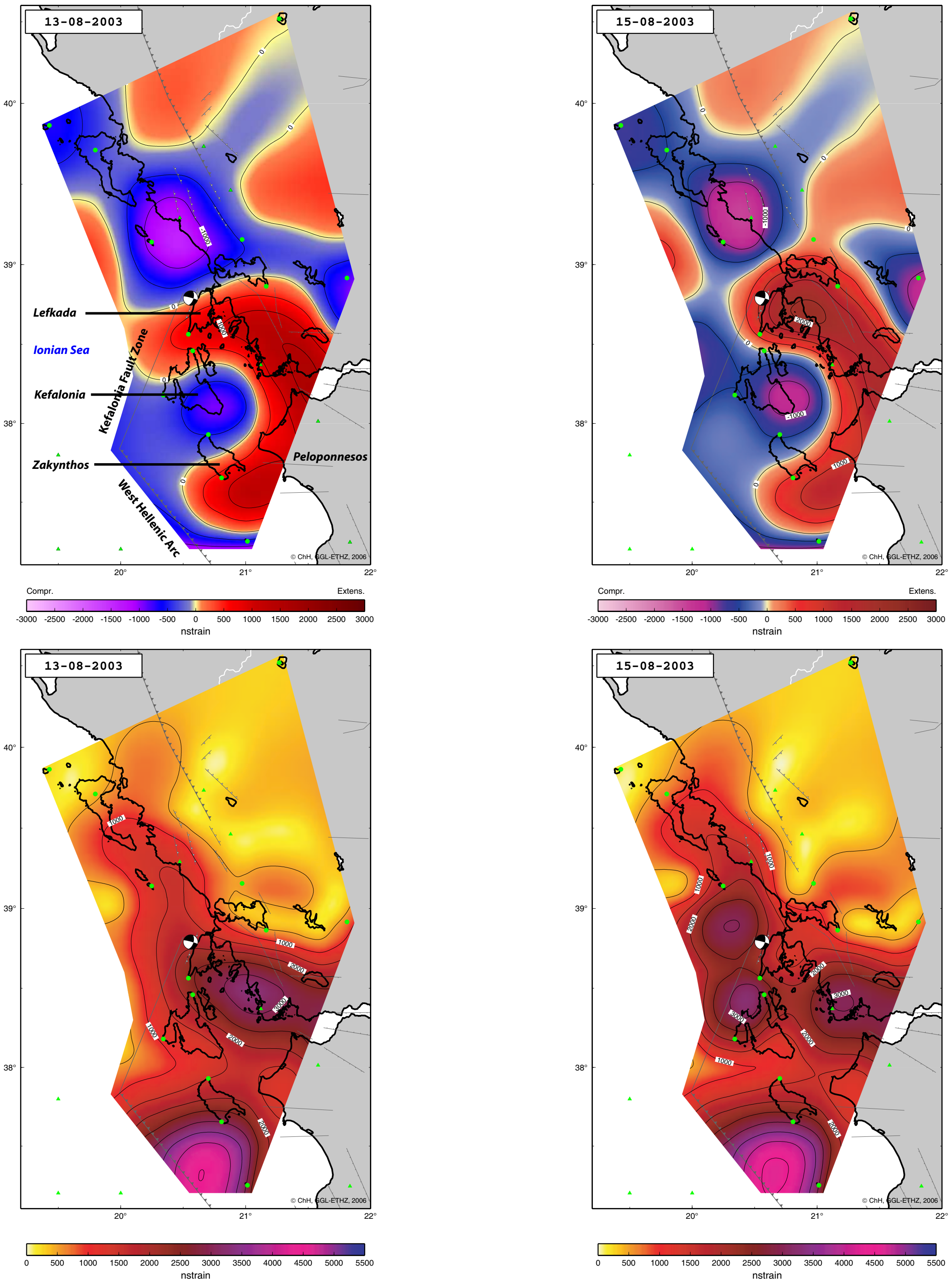

Figure 3.18: Cumulated strain before (left) and after (right) the Lefkada 14 August, 2003 earthquake, since July 1995: top: 2D dilatation; bottom: maximum shear strain. Fault plane solution: Global CMT catalog; earthquake location: GI-NOA, Greece. The locations of the continuous GPS sites used for the collocation of the strain fields are marked by green circles. Additionally included campaign sites and virtual African points are marked by green triangles.

TECVAL: GPS based Determination of Crustal Deformation, and Seismicity in the Canton Valais, Switzerland

by O. Heller, A. Geiger, H.-G. Kahle, S. Jonsson and D. Giardini

The canton Valais is the seismically most active region in Switzerland. This can be seen by both macroseismic records and instrumental observations. Both data sets suggest that the canton Valais exhibits the highest seismic hazard in Switzerland. Geodetic measurements, notably levelling campaigns carried out across entire Switzerland, revealed an ongoing Alpine uplift reaching its maximum of 1.5 mm/a in the Rhone Valley, the western part of the canton Grisons including the Engadin (Schlatter, 2006).

Project TECVAL aims at detecting horizontal crustal deformations deduced from GPS and at combining them with vertical uplift rates to form a 3D deformation field. The comparison of these geodetic strain rates with seismic strain rates, estimated from fault plane solutions by means of Kostrov's summation, gives a measure of the percentage of seismic and aseismic deformation, respectively, of the entire deformation in the study area.

To date, five continuous GPS stations have been installed on both sides of the central Rhone Valley (see Fig. 3.19) from which three are integrated in swisstopo's standard GPS routines estimating both hourly and daily solutions. The other two stations will be integrated in 2007 as well. In addition, stations from the TECVAL, IGS, EUREF, AGNES and RENAG (REseau NAtional GPS permanent) network are being analysed using a separate routine in order to obtain time series across the Alpine belt.

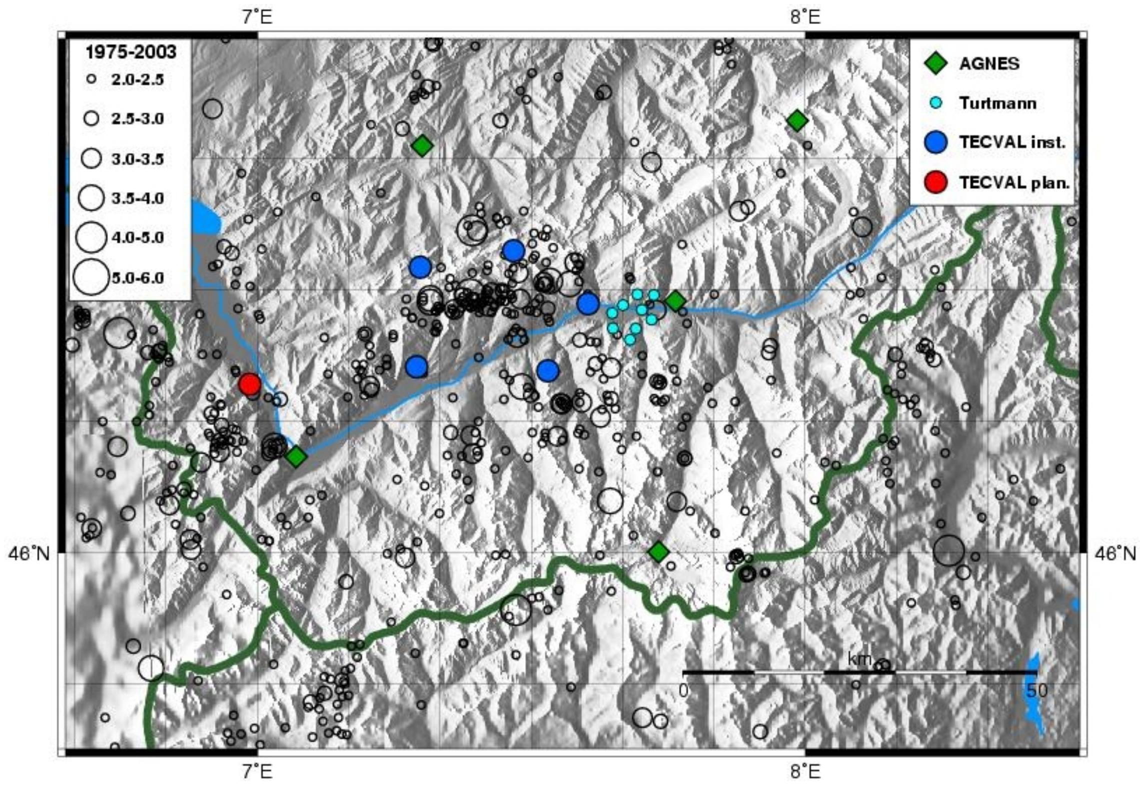

Figure 3.19: Existing and planned continuous GPS stations of the AGNES and TEVAL network respectively. The last major earthquake in Switzerland (Mw 6.1) occurred 1946 a couple of kilometres in the northwest of the most easterly dark blue circle.

Seismic and Geodetic Strain Rate Fields in Southern Italy and Implications for Seismic Hazard

by S. Jenny, S. Goes, D. Giardini, Ch. Hollenstein and H.-G. Kahle

To improve estimates of the long-term average seismic potential of the slowly straining South Central Mediterranean plate boundary zone, constraints on tectonic style and deformation rates were integrated from geodetic and geologic data with the traditional constraints from seismicity catalogs. Seismic potential (long-term average earthquake recurrence rates as a function of magnitude) was expressed in the form of truncated Gutenberg-Richter distributions for seven seismotectonic source zones. Seismic coupling seems to be large to complete in most zones, except along the southern Tyrrhenian thrust zone where a large part of African-European convergence is accommodated. Here aseismic deformation is estimated to range from more than 50% along the western part to almost 100% aseismic slip around the Aeolian Islands. Even so, previous estimates of the seismic potential of this zone based only on the low levels of recorded past seismicity are an underestimate. By contrast, the series of large earth-quakes that hit Calabria in the 18th century released tectonic strain rates accumulated over time spans exceeding the catalog duration, and seismic potential is revised downward. The southern Tyrrhenian thrust zone and Calabria, as well as the northeastern Sicilian transtensional zone between them (which includes the Messina Straits) all have a similar seismic potential with minimum recurrence times of $M \geq 6.5$ of 150-220 years. This potential is lower than that of the Southern Apennines ($M \geq 6.5$ recurring every 60 to 140 years), but higher than that of southeastern Sicily (minimum $M \geq 6.5$ recurrence times of 400 years). The high seismicity levels recorded in southeastern Sicily indicate some clustering and are most compatible with a tectonic scenario where the Ionian deforms internally, and motions at the Calabrian Trench are small. The estimated seismic potential for the Calabrian Trench and Central and Western Sicily are the lowest (minimum $M \geq 6.5$ recurrence times of 550-800 years). Most zones are probably capable of generating earthquakes up to magnitudes 7-7.5, with the exception of Central and Western Sicily where maximum events sizes most likely do not exceed 7.

Sea Surface Topography by GPS Buoys and Airborne Laser Altimetry

by P. Limpach, A. Geiger and H.-G. Kahle

Enhanced ground-based methods for precise sea surface height (SSH) measurements have been developed, in order to contribute to the improvement of sea level monitoring and to provide local-scale information on the short-wave structure of the marine gravity field. These include airborne laser altimetry, shipborne multi-antenna GPS measurements and GPS-equipped buoys. The gathered SSH data can be used to improve local marine geoid solutions. They also contain information on local dynamic ocean topography, tides and waves, and can be used for the validation and calibration of radar altimeter missions. In addition, they provide a link between offshore radar altimeter data and tide-gauge stations. Two local survey areas were chosen in the vicinity of JASON-1 ground-tracks in the Eastern Mediterranean.

A detailed airborne laser altimetry campaign was carried out around the island of Crete in the framework of the EU project GAVDOS in 2003. The aim of the latter was the establishment of a European sea-level monitoring and radar altimeter calibration site for JASON-1, ENVISAT and EURO-GLOSS. The calibration site is located on the isle of Gavdos, at a crossover of two JASON-1 ground-tracks. During the airborne laser altimetry campaign, an area of 200x200 km adjacent to the Hellenic Trench was covered by 24 flight lines (Fig. 3.20). The SSHs obtained reveal very strong gradients, with SSH decreasing from nearly 30 m in the North-East to 5 m towards the Hellenic Trench in the southern part, along a distance of only 200 km.

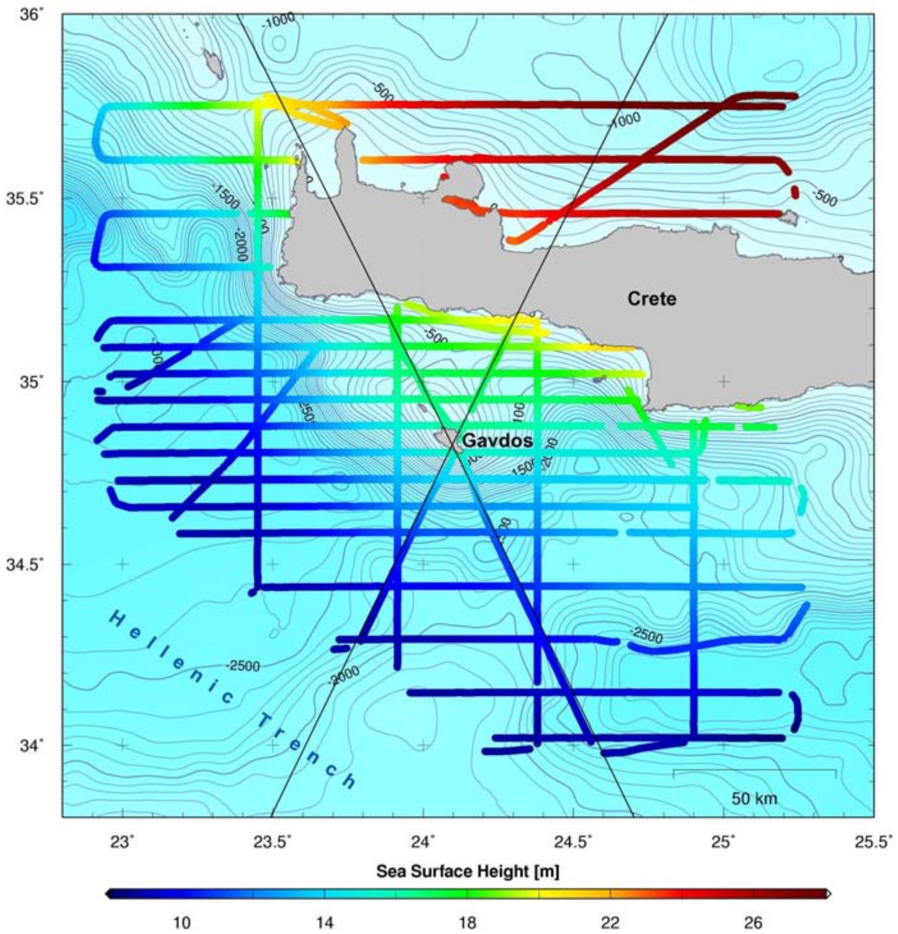

Figure 3.20: Flight-tracks with sea surface height profiles from airborne laser altimetry around Crete. Black lines: JASON-1 ground-tracks. Background: bathymetry.

Two campaigns for shipborne/buoy GPS SSH surveys have been carried out in the North Aegean Sea in 2004/2005, totaling more than 1000 nautical miles of ship tracks (Fig. 3.21). The survey area was chosen in the vicinity of the North Aegean Trough (NAT), which is a tectonic graben-like feature characterized by a zone of deep water reaching 1500 m and trending from north-east to south-west in the North Aegean Sea. The SSH results reveal that the bathymetric low of the NAT is associated with a distinct depression of the SSH which reaches a minimum of 37.5 m above the WGS84 ellipsoid, while the SSH in the surrounding area is more than 39 m and reaches even more than 40.5 m towards the north of the survey area.

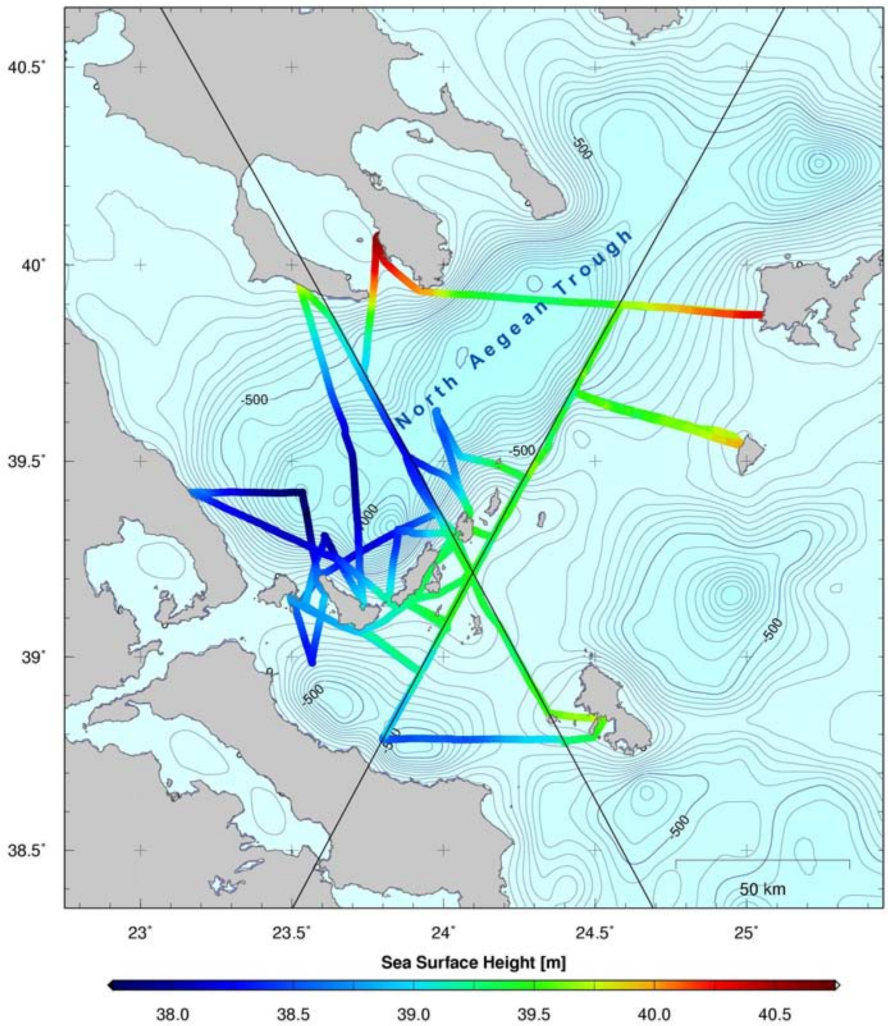

Figure 3.21: GPS survey along two JASON-1 ground-tracks (black lines) in the North Aegean Sea. Boat-track with sea surface heights from combined shipborne/buoy GPS observations. Background: bathymetry.

Earthquake Recurrence Parameters from seismic and Geodetic Strain Rates in the Eastern Mediterranean

by S. Jenny, S. Goes, D. Giardini, Ch. Hollenstein and H.-G. Kahle

In this project, hazard parameters were determined for the eastern Mediterranean consistent with seismicity data, tectonic information and geodetic strain rates. The dense data coverage in this region permits a detailed comparison of the horizontal seismic strain rate field, as recorded in the 500-yr long historical catalogue and the tectonic strain rate field, measured geodetically. We found that the seismic strain rates are very similar in style over all magnitude ranges within each different tectonic regime in the study region. Furthermore, both strain rate fields are similar in style with each other. The high strain rates accommodated in the eastern Mediterranean and historical catalogues spanning at least 100-200 yr, the seismic field should reflect the long-term seismic strain release when averaged over each tectonic zone. To estimate such seismic strain reliably, accurate knowledge about the rates of recurrence of intermediate size events (Mw= 4.5-6.5) is needed. These events can accommodate up to 60 per cent of the strain. The combined analysis provides an estimate of the seismic/total strain. The major strike-slip zones in the region, the Northern Anatolian and Kephalonia Fault Zones, experience little to negligible aseismic deformation. In the remaining eastern Mediterranean up to 10-30 per cent of the total deformation is aseismic. The Hellenic Trench is largely uncoupled, with at least 50 per cent and up to 90 per cent of the compressive strain released aseismically. Only the extensional component of strain at the eastern end of this trench appears significantly seismically active.

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4 Positioning and Applications

SLAM-Simultaneous Localisation and Mapping

by F. A. Bayoud, J. Skaloud and B. Merminod

Integrating visual and inertial sensors has become a common practice in navigation due to the increase in computer power, in algorithms advancement and in sensor improvements. One of the problems yet to be solved is the Simultaneous Localisation And Mapping (SLAM). SLAM is a term used in the robotics community to describe the problem of mapping the environment and at the same time using this map to determine (or to help in determining) the location of the mapping device. The approaches suggested by robotic community employ a single Kalman Filter with a state vector containing the map and the robot coordinates, which introduces non-linearity and complications to the filter, which then needs to run at high rates (20 Hz) with simplified navigation models. Here the SLAM is developed using the Geomatics Engineering approach. Two filters are used in parallel: the Least-Squares Adjustment (LSA) for mapping and the Kalman Filter (KF) for navigation. Conceptually, the outputs of the LSA photogrammetric resection (position and orientation) are used as the KF external measurements. The filtered position and orientation are then employed in the LSA Photogrammetric intersection to map the surrounding features that are used as control features for the resection in the next epoch. In this manner, the KF takes the form of a navigation only filter using complete modeling, with a state vector containing the corrections to the navigation parameters and updated at low rates (1 to 2 Hz). Results show that this method is feasible with limitation induced from the quality of the images used.

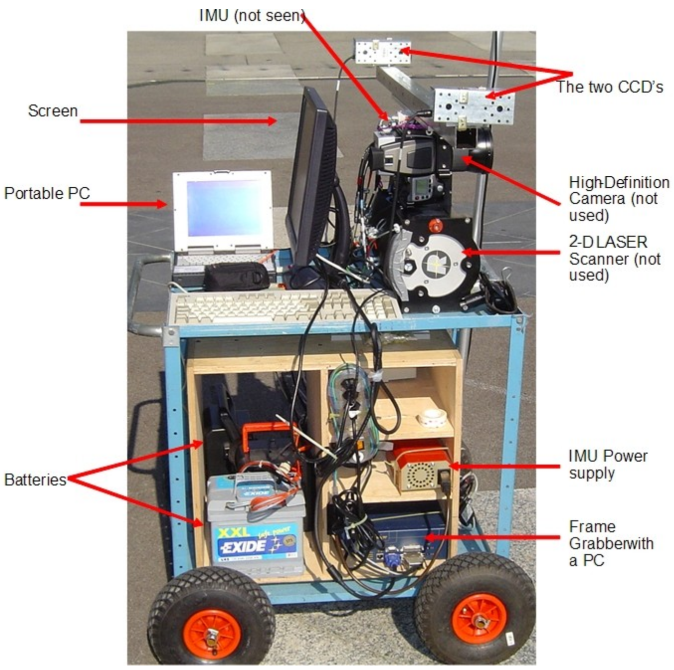

Figure 4.1: View of the SLAM system.

High Resolution Mobile Mapping

by J. Skaloud, H. Gontran and P.-Y. Gilliéron

This development produced two distinct high-resolution mobile mapping systems.

Firstly, the "Scan2Map" is a portable airborne remote-sensing system that facilitates quick helicopter deployment. It integrates high-accuracy navigation sensors (GPS/inertial) with an airborne laser scanner (ALS) and a high resolution digital CCD camera. Operated from the side of a helicopter, it produces high-resolution (less than 1 square meter), high precision (about 0.1 meter), digital surface/terrain model (DSM/DTM) and orthorectified images (less than 0.05 meters/pixel). The system concept incorporates a modular design with off-the-shelf sensors and modern communication to facilitate subsequent upgrades and part replacements. The setup is ideal for large- or small scale airborne surveying of areas such as open pit mines, gravel pits (for periodic determination of extracted volume), forestry (oblique ALS-mapping collects more information about the canopy), and natural hazards or corridor mapping (power lines, railroads, highways, and so on). Installation time is minimal (less than 30 minutes), allowing fast deployment on short notice. Thanks to the sensor-head structure, no recalibration of spatial offsets or boresight is needed after the installation. Oblique and nadir surveying can be performed with the same configuration and the same accuracy.

Secondly, the "Photobus" is a vehicle born mapping solution that combines an accurate positioning by GPS/IMU measurements with a vertically oriented CCD or CMOS camera. This system allows the precise surveying of the road centreline with a quality control of the positioning data in real time. The employment of CMOS imaging device with large dynamic response allows mitigating the illumination problem that otherwise compromise the feature identification. The feature extraction is performed directly on the processor of the imaging device thanks to the open-source-operated architecture.

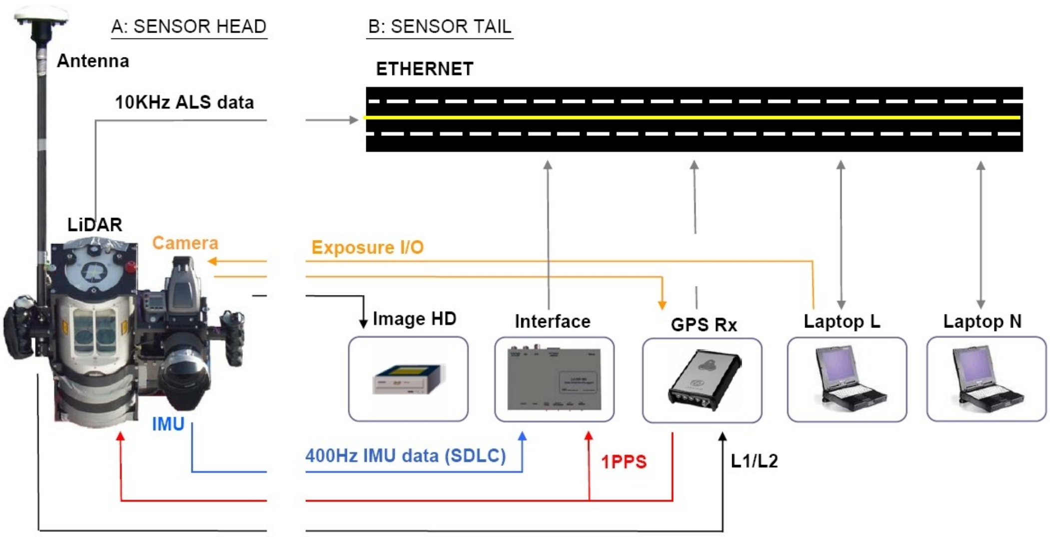

Figure 4.2: Architecture of the Scan2Map system.

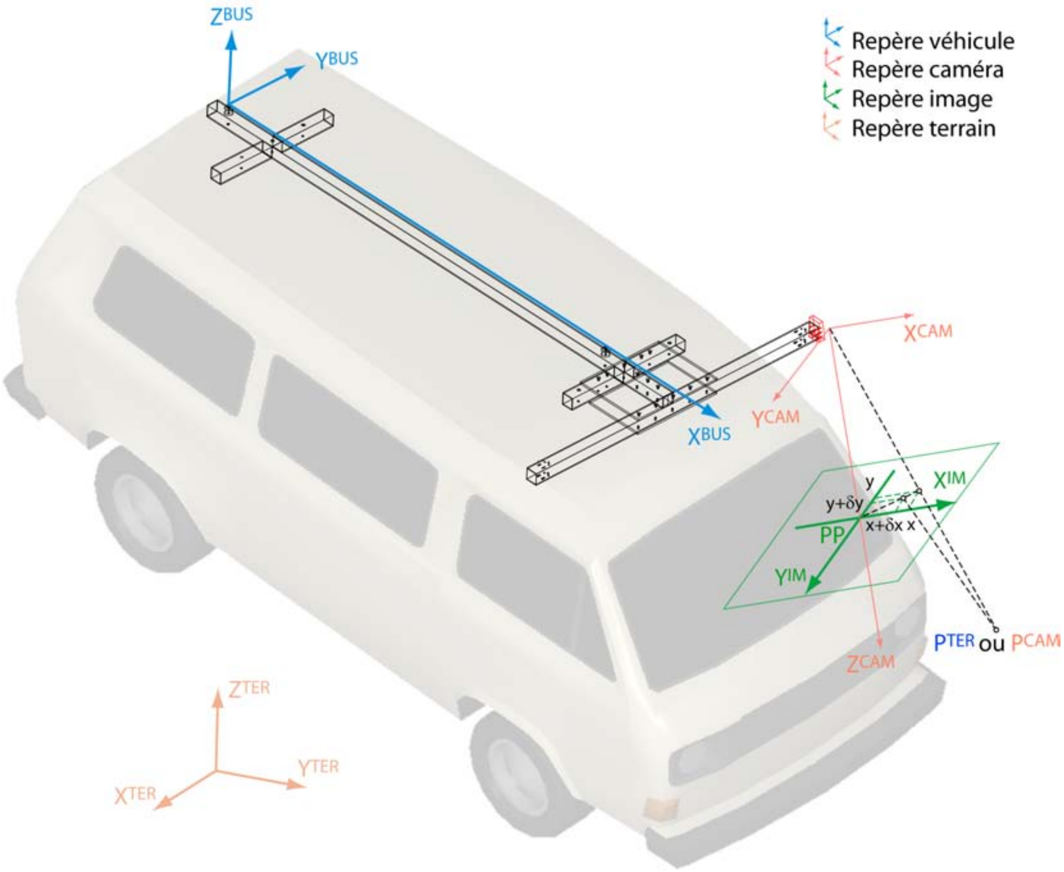

Figure 4.3: Reference frames of the Photobus system.

GPS & MEMS Integration for Positioning and Orientation

by O. Yalak, V. Renaudin, Ph. Tomé, J. Skaloud and B. Merminod

The research activities in the field of pedestrian navigation have focused on a project sponsored by the European Commission entitled LIAISON (Location BAsed ServIceS for the enhancement of wOrking enviroNment).

The main objective of the LIAISON project is to turn emergent technologies, applications and services into actual business cases in order to allow key European actors to fulfil in a competitive manner the needs of workers in their daily life, for seamless and personalised location services across an heterogeneous network. The research activities have focus on the use of inertial sensors based on Micro-Electro-Mechanical Systems (MEMS) technology and their coupling with GPS (and Assisted GPS) for pedestrian navigation.

This research has allowed the introduction of specific enhancements to this particular field of navigation, namely the following:

- A novel architecture based on the distributed placement of the MEMS sensors on a pedestrian (Fig. 4.4) has been adopted to enable the real-time determination of body postures (standing, sitting and lying), from which safety critical situations can be identified.

- An algorithm based on one segment inverse pendulum was introduced to estimate step-length under different walking conditions, such as forward, stairs climbing and descending. In addition, other forms of walking were also addressed, like backwards and sideways.

- A new orientation estimation algorithm that performs online compensation of local magnetic disturbances and inertial sensor errors has also been developed to determine more accurately a pedestrian's direction of walk.

- A simplified, yet flexible, coupling scheme between MEMS and A-GPS was developed to improve the accuracy and availability of location fixes in urban canyons and light indoor environments. The algorithm's flexibility renders possible the coupling with other positioning technologies, namely WiFi or UWB (Ultra-Wide-Band) to improve the system's performance in deep indoor environments.

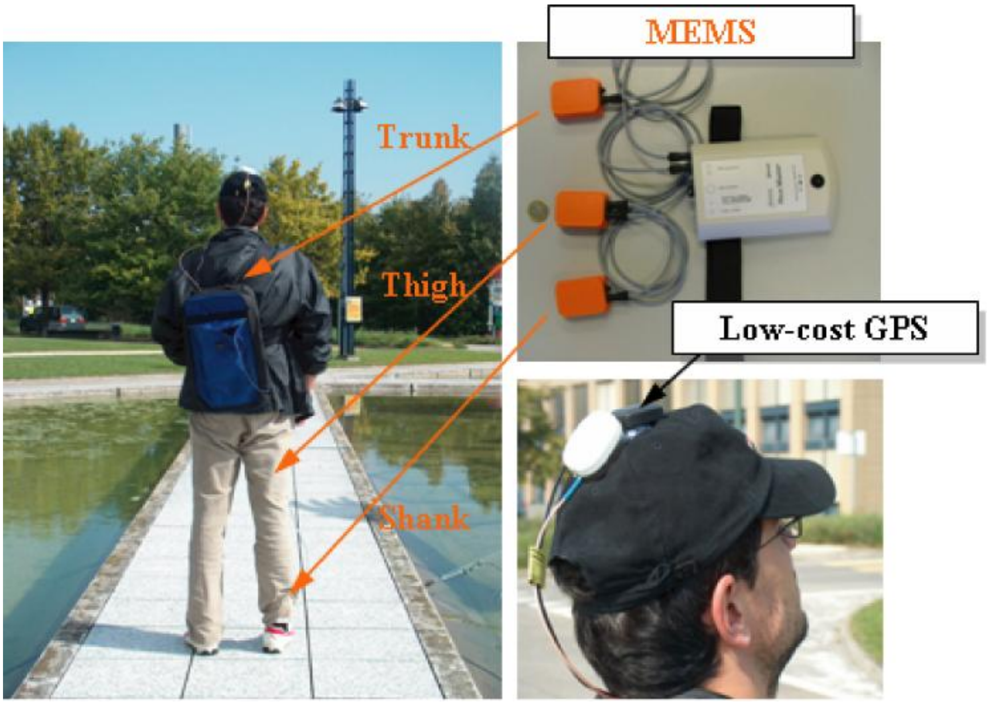

Figure 4.4: MEMS & GPS integrated system for positioning and orientation determination of a pedestrian.

Indoor Positioning and Map Matching

by P.-Y. Gilliéron, I. Spassov, Ph. Tomé and B. Merminod

The development of indoor navigation applications is growing, and one must use existing digital map databases for localization and guidance procedures. Due to the specific design of indoor maps, special algorithms must be developed to combine different sources of data within the navigation process.

The objective of this research is to define and to implement a dedicated data model for indoor applications. Based on this specific model, route guidance, map matching and navigation algorithms can be integrated in order to develop applications with particular requirements. Navigation of physically-challenged people is one example where the database must fit with specific algorithms in order to deliver reliable navigation information to the user.

The final objective of the navigation system is to develop an integrated system which provides support when defining the travel as well as guidance to the selected destination. Such procedures are well implemented in car navigation systems based on road databases. For indoor navigation, the concept of “route” guidance must be reconsidered for several reasons: specific design of map database, style of human displacement and particular needs for users.

Dedicated map matching algorithms have beeb developed in order to take into account movements of pedestrians in different situations. Following the concept of autonomous positioning, map matching algorithms run without relying on external measurements. This challenge imposes some digression from the classical map matching techniques. The developed algorithms are based on modern statistical (particular filter and Bayesian approach) and methods which process data from inertial measurements (azimuth, steps length) and the content of digital map database.

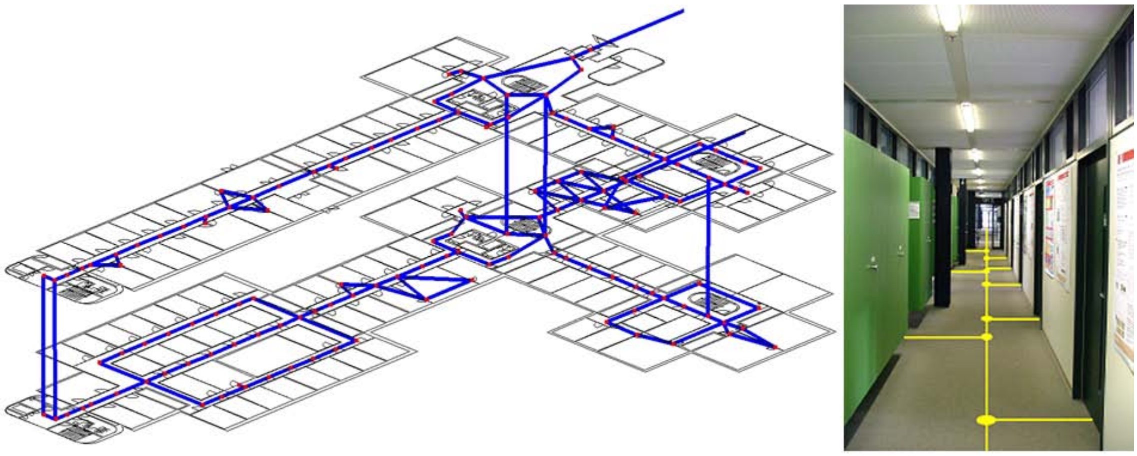

Figure 4.5: 3d map database for indoor navigation.

Positioning in Dynamic Sport Applications

by A. Waegli and J. Skaloud

Nowadays, the performance analysis of athletes is based on simple chronometry and video recordings. GPS measurement methods allow the accurate recording of position, velocity and derived acceleration, which opens new possibilities for continuous comparison of athletes’ performance throughout the racecourse. Unfortunately, the accuracy of GPS is limited by the high dynamics of some sport applications: quick changes of the satellite constellation make the carrier-phase ambiguity resolution difficult or even impossible. To overcome the lack of continuity in the GPS signals and to observe acceleration (and hence forces) directly, Micro-Electro-Mechanical System (MEMS) inertial and magnetic sensors are integrated with GPS. Such sensors are suitable for trajectory analysis in sports because of their small size and low cost. However, their measurements are prone to large systematic effects and, consequently, their suitability for navigation needs has to be evaluated. This was investigated under different integration scenarios for applications ranging from speed skiing to car racings. Trajectory analysis algorithms were developed for comparing trajectories of different shape and any parameter attached/derived to/from them (e.g. hart rate, velocities, a motor's revolution per minute, slip angle). This research resulted in an industrial product.

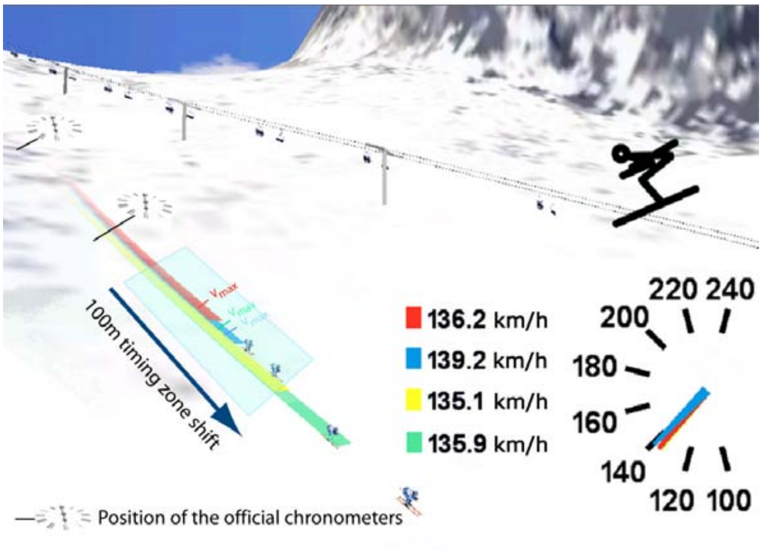

Figure 4.6: User interface for the speed analysis in dynamic sport applications.

Range Imaging Technology

by T. Kahlmann and H. Ingensand

Range Imaging (RIM) is a new suitable choice for measurement and modeling in many different applications. RIM is a fusion of two different technologies. According to the terminology, it integrates distance measurement as well as imaging aspects. The distance measurement principle is dominated by the time-of-flight principle while the imaging array (e.g. CMOS sensor) enables each pixel to store also the distance towards the corresponding object point. Therefore 3D capturing of the environment with up to about 50 Hz and high resolution with several thousand pixels is possible. Due to the technology's relatively new appearance on the market, with a few different realizations, the knowledge of its capabilities is very low.

The calibration of two different RIM cameras has been focused in the last years. Besides calibration of the cameras distortions the investigation if the distance measurement was followed. Some of the results confirmed earlier predictions. Especially the linearity of the distance measurement was investigated with high precision. Beside that, different influencing parameters like temperature, reflectivity, and the integration time on the measured distance were taken into account.

RIM is an outstanding technology for the fast capturing of the environment. In cooperation with the ZHW (Fachhochschule Winterthur) a multisensor module has been developed. This module is equipped with different navigation supporting sensors and can be mounted on a robot, for example. The goal is to capture the closer environment with high resolution in three dimensions.

Because of their high resolution and high speed acquisition, range images, captured by RIM cameras, are suitable to be used for the tracking of objects. Different approaches were followed to verify this.

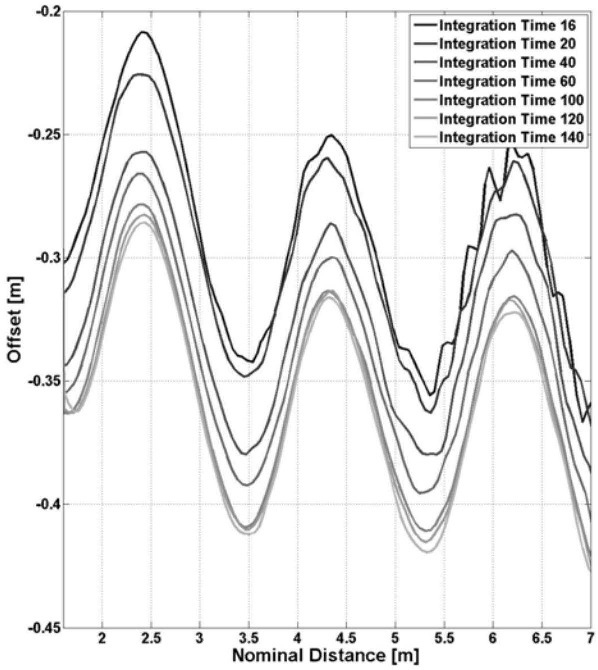

Figure 4.7: Look up table for the calibration of the SR3000. A periodic variation can clearly be seen.

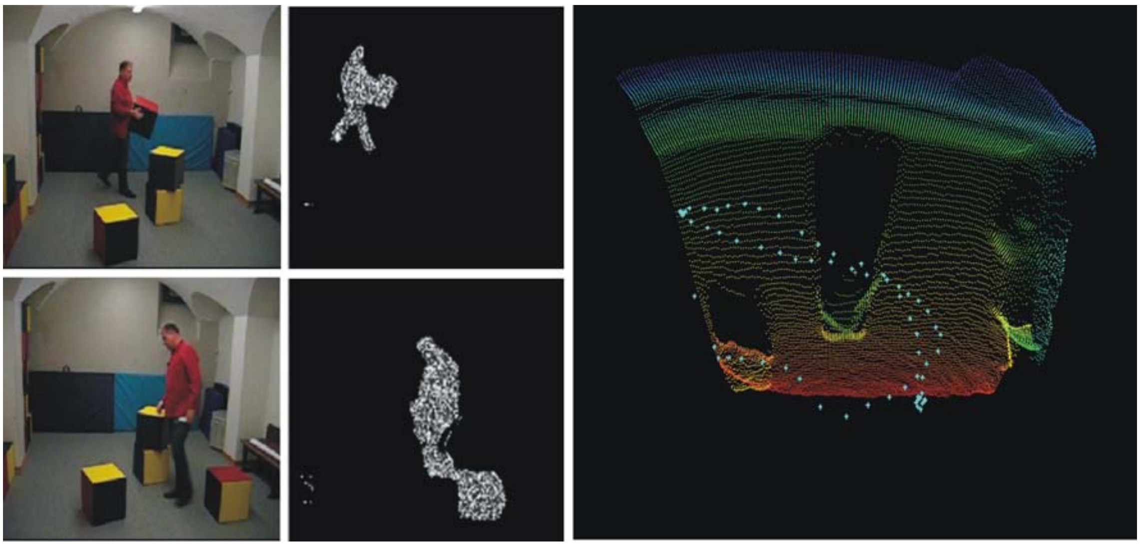

Figure 4.8: Tracking of a person. The movements are recorded with high accuracy and video rate.

Figure 4.9: Preliminary version of a stand alone 3D capturing system "remap". Due to the concept it can be mounted on a robot which works in contaminated environments.

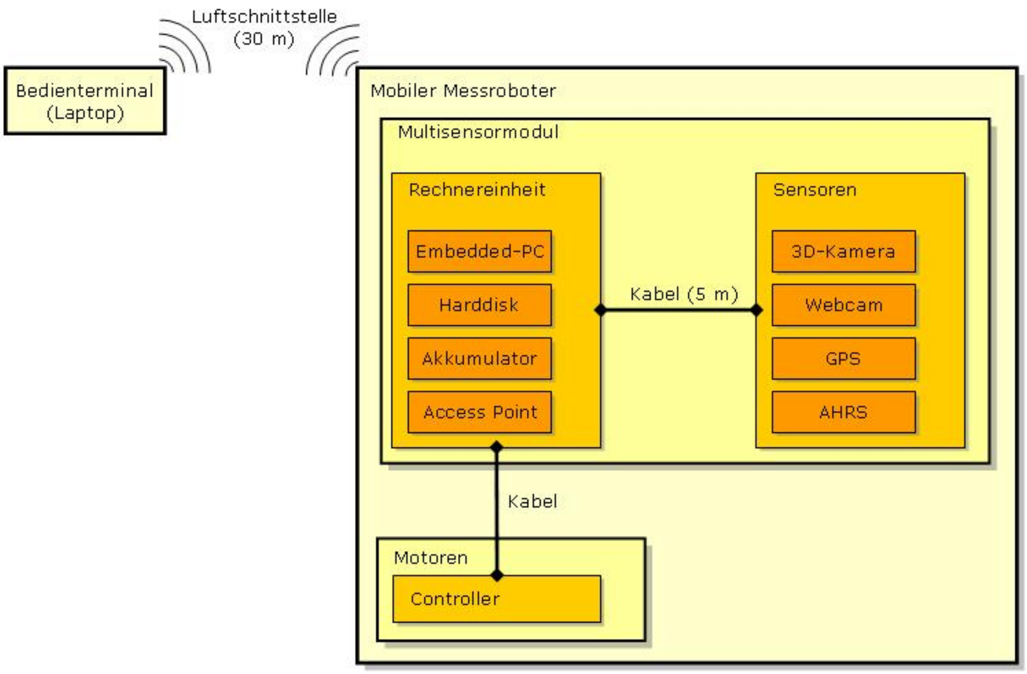

Figure 4.10: Concept of the remap system which has been developed in cooperation with the ZHW. Additional sensors can be introduced at any time.

Terrestrial Laser Scanning for Road Surface Analysis

by T. Schulz

Nowadays, there are ongoing discussions in Switzerland about how to treat polluted road runoff of roads with a high traffic density. One treatment possibility is the infiltration of road runoff in vegetated road shoulders. In order to determine their loading and removal effectiveness for heavy metals such as lead, zinc, cadmium and copper and organic substances, a pilot plant was installed in a road shoulder of a road with a traffic density of more than 17'000 vehicles per day. The purpose of the pilot plant was, among others, to collect the road runoff from a road section in order to calculate the percentage of runoff draining directly into the vegetated swale and not being dispersed diffusely with spray. Based on this information, mass balances can be calculated in order to access the accumulation rates of pollutants in the vegetated road shoulder and to calculate the removal efficiency of the vegetated swale.

The classical approach to estimate the size of a catchment area is to conduct large scale experiments using coloured tracers sprayed over the whole road surface area near the pilot plant. For the present situation, this is hardly possible because due to the heavy traffic density, the road cannot be blocked for hours. As another possibility, a mathematical surface model based on topological data can be used in order to calculate the catchment area. Therefore, the geometrical data (3D coordinates) have to be acquired by surveying.

Figure 4.11: Measurement setup along the road area to be investigated. One can see the laser scanner and some tie points mounted on tripods. Typical vehicles are trucks and cars passing by in high frequency.

In general, 3D coordinates can be derived using different methods, such as tachymetry, levelling, GPS, and (terrestrial) laser scanning. These four methods have to be compared regarding accuracy, point density (sampling interval) and measurement time (sampling rate). Because the road can only be blocked for several minutes, the performance becomes a crucial parameter. In a preliminary trial, the different methods were evaluated. The conclusion is that laser scanning has a significant advantage because of the high sampling rate with several thousand points per second and high sampling interval with a point density from some centimetres up to several millimetres. Further, the desired accuracy for this project of one centimetre (single point) can be met with laser scanning. Based on the gained experiences and results of this preliminary trial as well as former investigations regarding accuracy and performance, the road area along the pilot plant was surveyed by laser scanning.

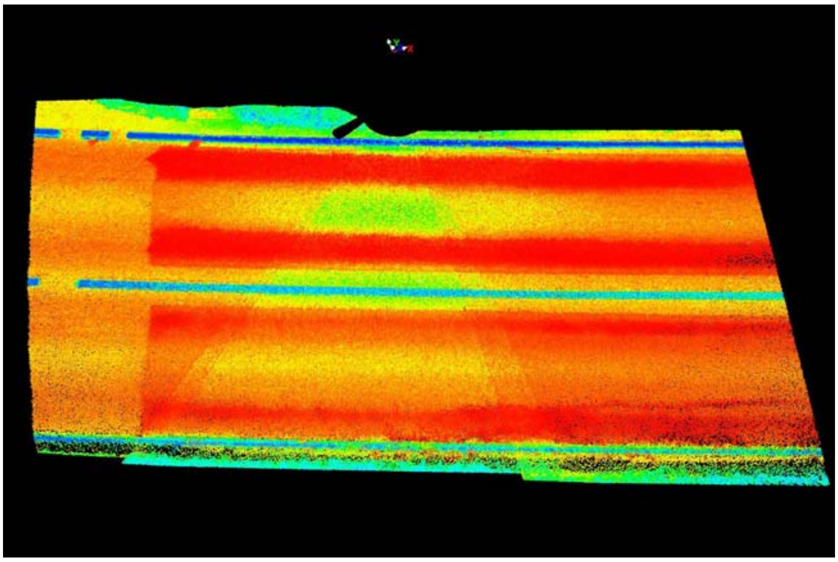

Figure 4.12: 3D-Point cloud including intensity values of the reflected laser beam caused by surface colour. The intensity values allow the interpretation of sign-posting, different tarmacs and skid mark caused by wheel abrasion.

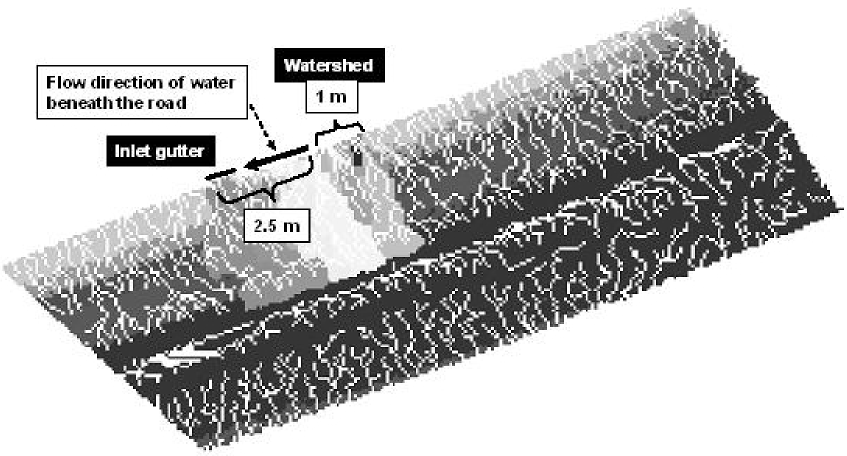

Figure 4.13: Calculated streams based on the topological model. In Addition, flow direction due to preferential flow beneath the road is also indicated. Locations of an inlet gutter as well as a watershed are shown.

Overall, the workflow from surveying to deriving catchment areas includes surveying the road by using terrestrial laser scanning, preparing laser scanning data (for registration and geo-referencing), filtering laser scanning data (reducing noise), deriving catchment areas (3D-model), and calculation of mass balances for road runoff.

Kinematic Scanning by the Swiss Trolley

by R. Glaus

geomETH developed within a joint venture project together with the University of Applied Sciences Burgdorf and private partners the track surveying vehicle swiss trolley. Point clouds are acquired by the forward motion of the swiss trolley. The track surveying vehicle swiss trolley consists of a platform equipped with sensors for positioning and attitude determination. For the geometric determination of the track environment, two laser scanners are used.

Kinematic scanning outmatches static applications regarding the dispensable tripod stationing. Normally, the link to a primary reference frame is not realised by control point procedure as used for static scans. Instead, the sensor platform is positioned and orientated in discrete, very short time intervals. Sensors to be applied are tracking totalstations, GPS and inclinometers. Then, particular scan vectors are attached to the obtained, three-dimensional trajectory.

A further, essential feature of kinematic surveys is the synchronous acquisition of all involved sensors. For surveys with centimetre accuracy at velocities of several metres per second, synchronisation accuracies better than one millisecond are required.

The swiss trolley is successfully used for various tasks. Updates of databases of fixed assets, clearance inspections or contact free geometrical surveys of the overhead line are some typical applications in the field of railway engineering. For a customer, a virtual scenery was created by means of the swiss trolley laser scanners. Autonomous, circulating freight wagons equipped with laser scanners compare the instantaneous environment with this nominal scenery. If differences between both models exceed thresholds, the wagon slows down.

Figure 4.14: The metre gauge version of the *swiss trolley*. For positioning and attitude determination, differential GPS and inclination sensors are used. As an alternative on stretches without GPS reception, tracking totalstations can be applied. Two laser scanners generate fans skewed by 45° with respect to the track axis. By the forward motion of the measuring system, a three-dimensional point cloud is generated. Additionally, an industrial camera provides every second a high resolution image.

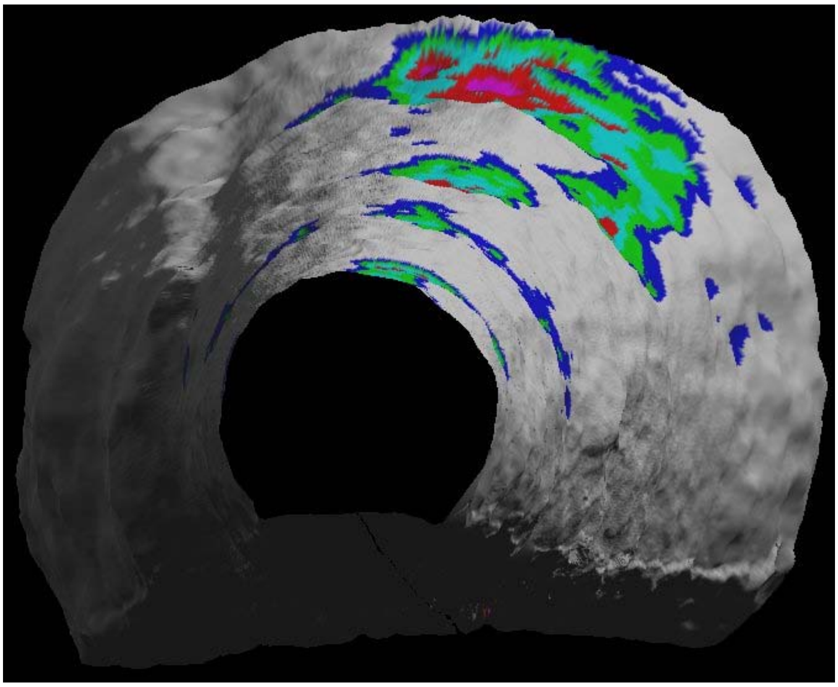

Figure 4.15: Tunnelling application: Clearance violations can be detected by the comparisons of kinematic surveys with nominal data (highlighted zones).

Figure 4.16: Comparison of a *swiss trolley* point cloud and the corresponding synchronised image. The high spatial resolution of the scan data allows for the contact-free, geometrical determination of the overhead line. The colour coding represents distances from the track axis.

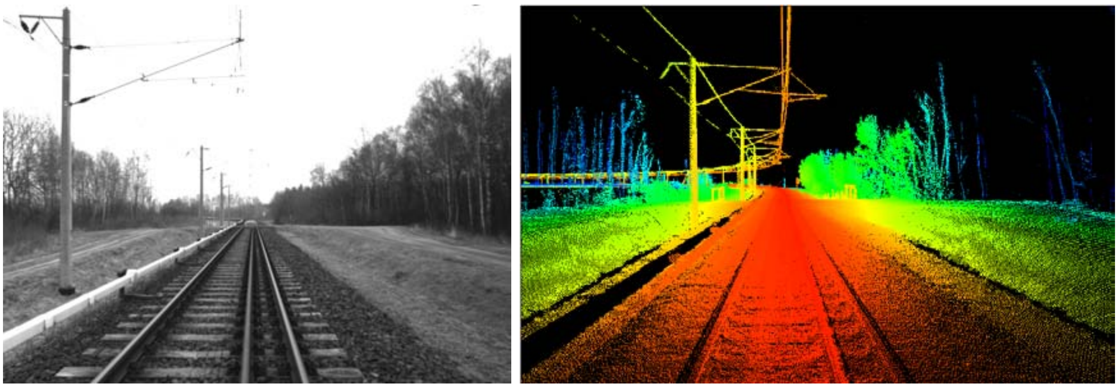

Figure 4.17: Principle of obstacle recognition by means of virtual nominal sceneries. The autonomous navigation system developed by the industry detects alterations from the nominal model in real-time. Thus, the bale of straw in the left image represents such an alteration. The train will slow down. The virtual landscape on the right hand side was generated from *swiss trolley* data. The colour coding represents distances from the track axis.

Quality Model for Airborne Laser Scanning Data

by J. Luethy

Airborne Laser Scanning (ALS) has become the most important technology to acquire high resolution Digital Elevation Models (DEM). Compared to Photogrammetry ALS allows an increased efficiency due to direct georeferencing and direct determination of 3D coordinates. The dense point spacing and the possibility to acquire simultaneous Digital Terrain and Digital Surface Models are additional benefits.

The two main disadvantages compared to Photogrammetry are the number of involved sensors and the unstructured data capturing during the scanning process. The former leads to a delayed discovery of faults in the data acquisition. Not captured features are often detected later on in the feature extraction. Whilst for other survey methods quality measures had been developed over years, standards or guidelines for ALS with appropriate quality indicators and test methods are still missing. The separation between the determination of coordinates in the unstructured data acquisition and the feature extraction during point classification may have a negative impact on the data quality which can not be detected with traditional quality control methods.

In a holistic approach sensors, algorithms and processes were examined to develop up a quality model which eliminates the shortcomings. The core element of the model is the product specification where the representation of the real world in the spatial data set is defined. To the second layer of the quality model belong various components to describe the quantitative quality indicators. By extending the elements from currently used spatial accuracy and point spacing all user requirements can be captured in technical specifications. The entire benefit can only be realised if appropriate test methods and the conformance level are defined. The third layer then defines requirements for process quality. As the outcome of the three inner layers the outermost contains finally the spatial data sets according to product definitions and technical specifications.

The Swiss Positioning Service (swipos)

by U. Wild, S. Grünig and D. Andrey

In 2003 an agreement between the NMA's of the neighboring countries in the region of the Lake of Constance ("Bodenseekonferenz 2003") has been signed for the international exchange of the real-time data for the different positioning services SAPOS (Germany), APOS (Austria) and swipos (Switzerland). Through this initiative a mutual integration of stations along the national borders to a seamless positioning service is now available in this area since 2004 (Wild and Grünig, 2005).

In fall 2004 the AGNES control center at the Federal Office of Informatics and Telecommunication (BIT) was adapted to the newest technological standards. All AGNES and swipos servers were moved in a so-called "demilitarized zone" (DMZ) where they are better protected against any attacks over the Internet. In addition those servers which are indispensable for a secure operation were installed redundantly. At the same time the swipos services were made accessible over the Internet (www3.swisstopo.ch, Port: 8080) (Grünig and Wild, 2005a). The data are transmitted in the new format NTRIP (Networked Transport of RTCM via Internet Protocol), which has also been standardized within RTCM. Using GPRS (General Packet Radio Service) for data transmission instead of GSM, the actual amount of transmitted data is billed instead of the connection time. This means attractive prices for small amounts of data required for DGPS or RTK. In addition the data of the station Zimmerwald are also delivered to the EUREF-IP project.

The development of a monitoring device for assessing the performance of the real-time positioning service swipos-GIS/GEO was completed in 2004 (Wägli and Grünig, 2004). The device is able to automatically log on to the service and to monitor the VRS/RTK coordinate solutions by comparing them to a known reference position. The requested accuracy standard (1 sigma) for swipos-GIS/GEO is 2cm (position) and 4cm (height). The system is permanently mounted on the roof of the swisstopo building in Wabern and serves as the permanent integrity monitoring system for swipos. In order to investigate the VRS performance in other local areas, the system can be temporary displaced to another location (see Fig. 4.18)

Figure 4.18: VRS monitoring device.

A proposal for optimizing the AGNES network constellation has been published in 2005 (Grünig and Wild, 2005b). According to the concept a new AGNES station was set up in Zermatt (Wallis, southern part of Switzerland, see Fig. 4.19) in 2005 and an additional AGNES station in Hasliberg (Bernese Oberland, central part of Switzerland) in 2006. The new station Hasliberg is situated at almost the same altitude as the users of the swipos services and replaces the AGNES station Jungfraujoch (located at 3'500 meters above sea level!) in the VRS processing.

Figure 4.19: Installation of the AGNES station Zermatt.

In order to promote the use of the swipos positioning services in official cadastral surveying, which is still based on the old geodetic reference system CH-1903, the real-time transformations in the swipos positioning service were further improved (Grünig, 2005). For the horizontal transformation (FINELTRA) a new search algorithm for the finite element method of the transformation was integrated, whereas for the height transformation de HTRANS algorithms were integrated. With the availability of the new densified FINELTRA information, swipos allows measurements in the old as well as in the new reference system with a consistency at the cm level.

In 2006 a new project called "AGNES II/GLONASS" has been started, in order to enhance AGNES with combined GPS/GLONASS receivers and antennas. First test measurements for post-processing and real-time applications were performed in 2006, the 'roll-out' of the receivers and the antennas will take place during 2007.

Geodetic Works for AlpTransit Gotthard (Deflections of the Vertical, Azimuths and Gravity Measurements)

by B. Bürki, A. E. Somieski, C. Hirt, U. Marti, P.V. Radogna, A. Schlatter and A. Wiget

AlpTransit Gotthard is a project which establishes the New Rail Link underneath the Alps. It comprises of the worlds longest railway base tunnel with a total length of 57 km. Some of the planned tunnel sections reach length of up to 17 km. In order to fulfil the required accuracy as defined by the project specifications, the impact of the gravity field in terms of deflections of the vertical and orthometric height corrections have to be considered with great care.

Under the auspices of the Swiss Gravity Consortium (Schweizerisches Konsortium Schwerefeld, SKS), which is a cooperation between the Federal Office of Topography (swisstopo) and the Geodesy and Geodynamics Lab (GGL) of ETH Zurich, these two institutions conducted various geodetic works for the AlpTransit Gotthard Base Tunnel. Commissioned by the AlpTransit Gotthard AG already in 2002, swisstopo carried out a priori computations of orthometric corrections in the base tunnel. In order to determine these corrections, gravity values at the tunnel level were measured and applied to the project coordinates along the tunnel axis. Furthermore the mean gravity was derived along the plumb line. The orthometric corrections were then determined for the planned tunnelling. Based on the orthometric heights at the portals, they were used to correct the levelling observations for the tunnel excavation. Thus, a systematic error up to 4 cm in the cut-through of the Gotthard base tunnel can be avoided.

Figure 4.20: The two digital zenith camera systems TZK2-D (University Hannover, Germany) and DIADEM (GGL, ETH Zurich, Switzerland) observing at Amsteg, Canton Uri, near the portal of the 57 km long railway tunnel AlpTransit under the Swiss Alps in Central Switzerland. With these systems, deflections of the vertical can be determined with an accuracy of ≤ 0.1 arcsec. Thanks the digital imaging technique, and the fully automated observation procedures, the results can be processed in near real-time.

In summer 2005, SKS organized gravity measurements around two tunnel portals as well as in already excavated parts of the tunnel. A total of 17 stations were determined by the Geophysical Institute of the University of Lausanne (Prof. Olivier) using relative gravity meters. The measurements were linked to the zero order gravity network of Switzerland. The measured gravity values were then analyzed by swisstopo and compared with the interpolated, model-based gravity values. The small differences to the interpolated values showed that, thanks to the good quality of the interpolated values, no further gravity measurements in the tunnel would be necessary in the future.

In addition to the gravity measurements, the deflection of the vertical was determined at five stations near the main- and the access tunnel portals. These highly precise measurements were carried out by means of two digital zenith camera systems operated by GGL and the Institut für Erdmessung, University of Hannover (see Fig. 4.20). The deflection values were then used to validate the existing geoid solution CHGeo2004 by swisstopo.

Last but not least the underground azimuth transfer azimuths were determined using gyroscopes. In order to validate these instruments, five reference sides have been measured using the astro-geodetic on-line measuring system ICARUS/AZIMUT. For more detail, we refer to the contributions in section 2, page 47 and in this section, page 145 and page 146.

Geodetic Reference Frames for the BLS AlpTransit Lötschberg Base Tunnel and Results after the Cut-Through

by A. Wiget, A. Schlatter and H.-U. Riesen

In April 2005, the constructors of the BLS AlpTransit Lötschberg Base Tunnel celebrated the main cut-through of this 34.6 km-long Alpine tunnel. By providing the above-ground geodetic control framework, the Federal Office of Topography (swisstopo) made an important contribution to this new, north-south railroad connection through the Alps. Valuable synergies resulted from the close cooperation between the specialists of the geodetic and national mapping organisation and the engineering consortium responsible for the project and its underground surveys. The outcome of this cooperation and the resulting cost savings gave direct proof of the benefit to the national economy of a modern national geodetic survey. The successful staking out of the tunnel also provides an example of an efficient and effective division of responsibility between the private sector and the public administration.

The geodetic reference frame of the new national geodetic survey (Landesvermessung LV95) and the new height system (Landeshöhennetz LHN95) were developed with the objective of meeting the survey needs of major engineering projects in Switzerland such as Rail2000 and AlpTransit. In the classic surveys for the large Alpine tunnels Gotthard, Lötschberg and Simplon over the past hundred or more years, special and very costly triangulation and levelling networks were needed in order to achieve the desired accuracy of the cut-throughs. For the Lötschberg Base Tunnel, the above-ground control surveys and the working coordinates for the tunnel drive were directly based on the LV95 and LHN95 reference frameworks of the new national geodetic survey.

For the main tunnel with its five access portals, the above-ground control surveys were carried out by swisstopo in 1997 in close cooperation with the project surveyor (IG BeWa, c/o Riesen+Stettler AG). swisstopo also performed a preliminary analysis of the expected cut-through accuracy. The results were in good agreement with the project surveyors' predictions and thus increased confidence in their reliability.

The principal components of the geodetic control surveys were as follows:

- a high-precision GPS network with at least three GPS points in each of the five portals for the relative positioning and orientation between all of the main and intermediate access portals. A total of 18 GPS points with connections to the national geodetic survey LV95 was specified and measured.

- precise angle and distance measurements in the main and intermediate portal networks with connections to the GPS points for mutual strengthening of their accuracy and reliability and as reference for the gyroscopic azimuth measurements.

- adjustment of all observations in a combined network with output coordinates in the LV95 reference frame of the CH1903+ reference system.

- determination of constraints to the coordinates (LV03) of existing objects in all portal networks.

- for height determination purposes, all portal networks were connected to the national height network by precise levelling. All heights were based on the orthometric height system of the new LHN95 national height network which is based in turn on a kinematic readjustment of the national levelling taking gravitational effects into account.

- the magnitudes of gravitational effects (deviation of the vertical and geoidal undulations) were computed by swisstopo from its geoid model for Switzerland. The deviations of the vertical were especially needed for the correction of the gyro observations required to maintain the correct azimuth within the tunnel.

The accuracy of the horizontal coordinates of the major GPS points of the above-ground control network adjusted in LV95 was 3 mm (confidence level P = 95%). The accuracy of the adjusted LHN95 height difference between Frutigen (north portal) and Raron (south portal) was estimated to be 12 mm (P = 95%). The overall adjustment also confirmed the good agreement between the orthometric height differences from the levelling and the ellipsoidal height differences from GPS as well as with the geoid. Thus, the practical benefits of establishing a consistent national geodetic network have been amply demonstrated.

In April 2005, the northern and southern drives of the 34.6 km-long Lötschberg Base Tunnel met 2000 m beneath the Alps with discrepancies in position and in height which were markedly better than the required tolerances (see Tab. 4.1). This excellent outcome of the cut-through is above all a credit to the performance of the expert survey team involved in the tunnel drive itself. However, it also provides proof of the high quality of the new national geodetic survey.

	Actual discrepancy [cm]	**Prediction 99%** [cm]	**Tolerance 99%** [cm]
Traverse	13.4	20.1	25.0
Longitudinal	10.3	-	-
Height	0.4	1.6	12.5

Table 4.1: Cut-through statistics of the BLS AlpTransit Lötschberg Base Tunnel.

Status of the Control Point Data Service (CPDS / FPDS)

by U. Wild and D. Andrey

The Control Point Data Service (CPDS) will make available all geodetic control points in a central database, and a part of the information may also be obtained over the Internet. The graphic user interface has been accomplished by the end of 2006 and allows for the capture, revision and administration of the control points by swisstopo and the surveying authorities of the cantons.

About 50% of the data of swisstopo and 90% of the data of the cantons have already been imported into the CPDS database. The import of the data should be finalized until the end of 2007.

The public CPDS web site has been operational since January 2006 and allows the display of the control point information on background maps at different scales (see Fig. 4.21). In addition, with different search functions (e.g. by point number, coordinates, city names etc.), information to the corresponding control points may be accessed.

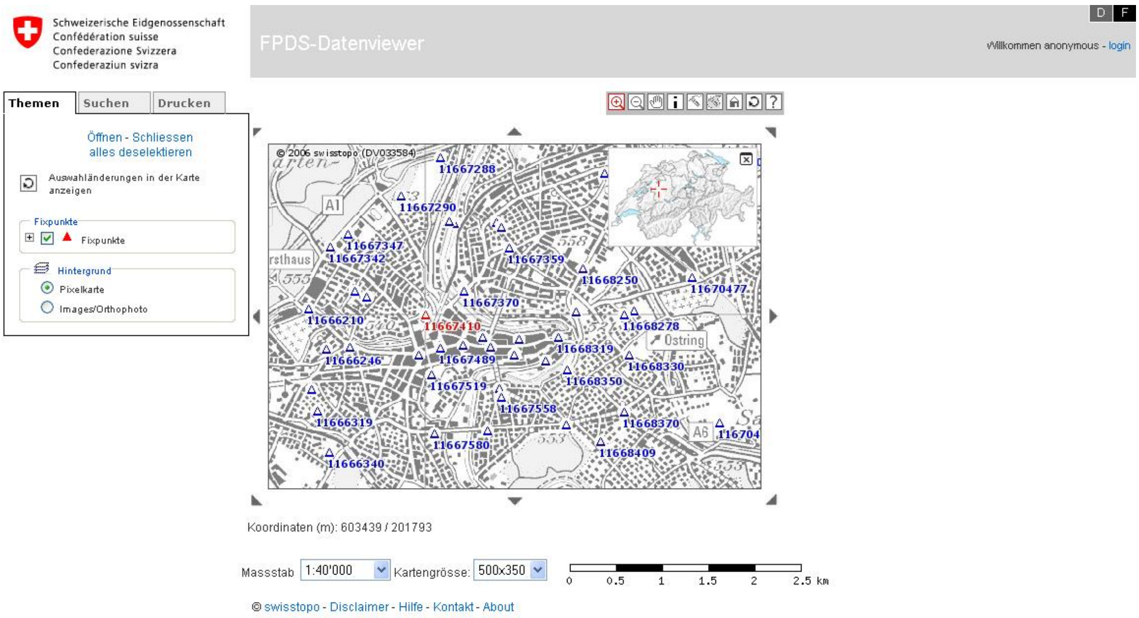

Figure 4.21: CPDS web site.

Future developments will consist in establishing Web Map Services (WMS) for CDPS, which will allow for the seamless integration of the control point data in existing web sites of the cantons.

Build up of a GIS System for the National border of Switzerland

by M. Kistler, D. Gutknecht, R. Rudin, R. Balanche and B. Vogel

swisstopo as the national mapping agency of Switzerland developed an extension for a GIS system in order to process and manage the data sets concerning the national border. So far, the border be-

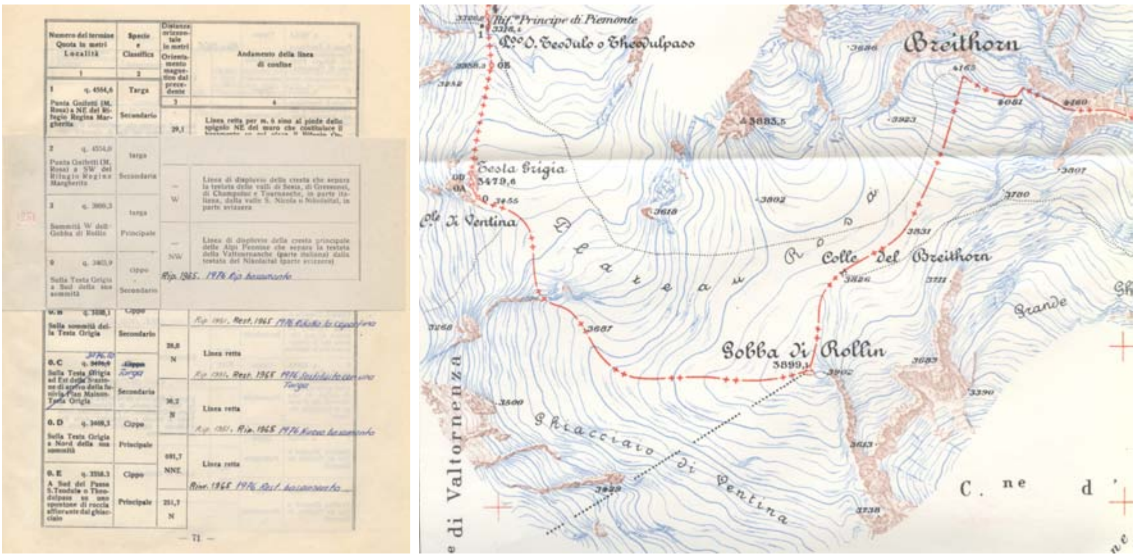

Figure 4.22: Old documents with the description of the course of the national border as a component of the treaty. Until now, no common coordinates exist between the two involved countries.

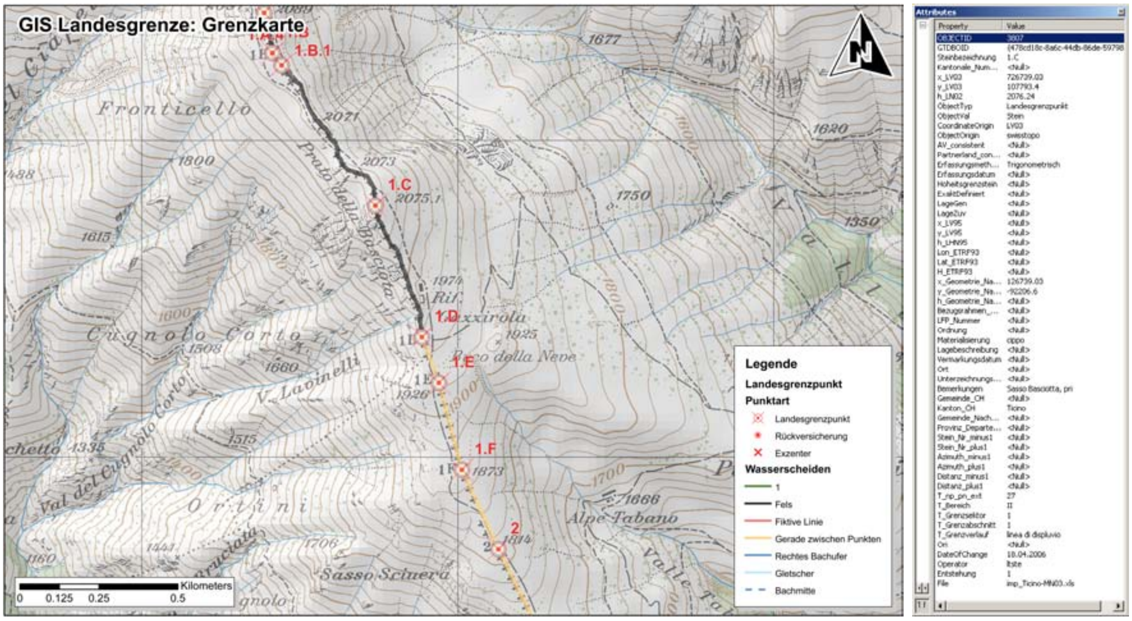

Figure 4.23: Print screen of the GIS system "Nation Border" with an excerpt of the data model for boundary marks on the right.

tween Switzerland and the neighbouring countries have been only defined by addendum documents of the treaty without any coordinates in a global reference frame.

First of all, one consistent border information system for Switzerland shall be produced in consideration of existing cadastre data sets. The support of the old and new national reference frame (LV03 and LV95) as well as the European one (ETRS89) is designated. Afterwards, common coordinates in ETRS89 will be worked out for all the boundary marks together with the neighbours' countries. Finally, probably after a laborious decade, the descriptive definition of the national border will be replaced through a coordinate-based cadastre in the European reference system ETRS89, as the main goal of the project.

On the European level, a project - called Euroboundaries - was launched in order to have a consistent data model as well as to gain precise coordinates about the course of the boundary for all Europe. Switzerland has paid attention that the national data model is consistent with the one from Euroboundaries for an easy data exchange. Furthermore swisstopo will contribute to the build up of an European data base.

Geodetic Assessment of Navaid Constellation in Swiss Air Space

by A. Geiger, P. Herschke and H. Demule

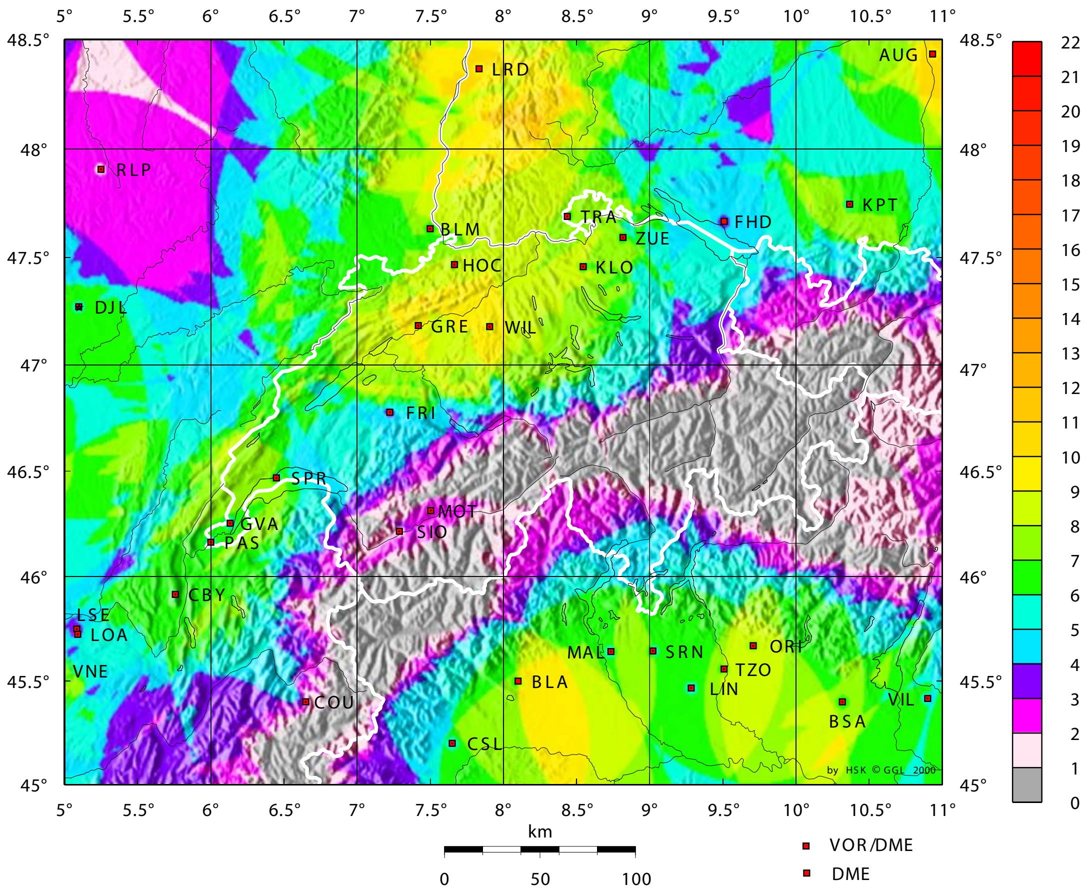

Figure 4.24: Number of DME-transponders visible at a flight altitude of 3000 m.

The performance of the navaids for the Swiss airspace is part of the main interest of skyguide. This study investigates precision, coverage and visibility at different flight levels. Different navaid constellations for en-route area navigation (RNAV) are considered. Special emphasis has been put onto DME/DME positioning, since this may be the predominant classical navigation procedure for RNAV. To assure a realistic simulation the DME stations of the surrounding countries have been taken into account. This study concerns the en-route navigation only and should deliver fundamentals to the planning of the possible re-configuration of the DME stations constellation in Switzerland for the classical en-route area navigation.

In a first work package algorithms have been revised, software development and calculation of horizon for every navaid installation have been carried out. After validation of the software three different scenarios of navaid set-ups were assessed with the aim to detect any deficiencies of the present configuration, to optimise a minimal configuration, and to suggest future constellations. For each of these constellations a number of calculation parameters were taken into account and varied accordingly.

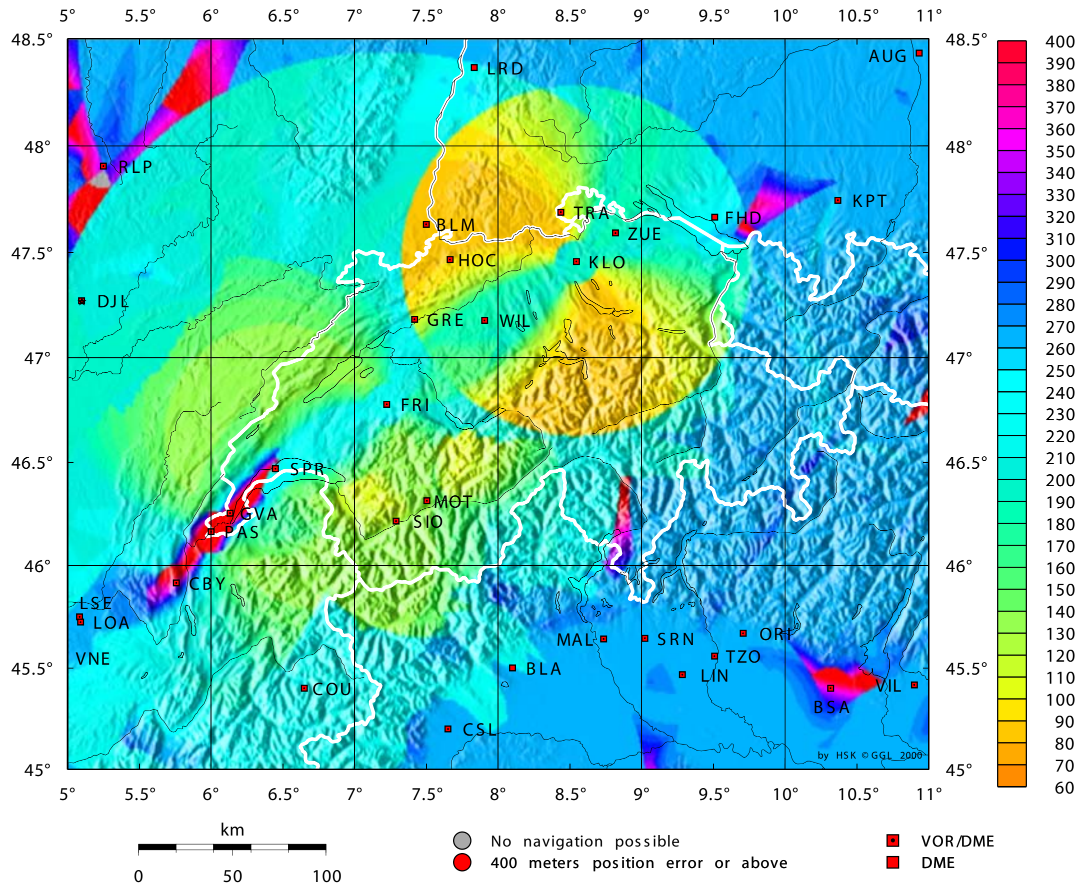

Figure 4.25: Precision (2 sigma) of multi DME-positioning at a flight altitude of 10000 m.

The visibility of each station, considering the 25 m resolution terrain model, the number of the stations visible, and the precision of DME/DME positioning were calculated within the whole air space at four flight altitudes (3000 m, 5000 m, 7500 m, 10000 m). Simultaneously the optimal station combination for best precision was determined. Further emphasis was put onto the analysis of station drop-outs scenarios in order to provide fall-back constellations.

Analysis and Kinematic Modelling of Landslides and surface Deformations

by A. Geiger, T. Reichmuth and C. Baumann

Landslides and terrain movements play a major role in natural hazard assessment. Especially in rugged terrain the percentage of endangered areas might reach a considerable amount. In Switzerland the percentage has been estimated to about six to eight percent, a figure most likely increasing with climate warming.

Geodetic measurements and analyses form a valuable basis for the quantitative hazard assessment of instable slopes. Our investigations and developments aimed at devising methods to adequately detect blocks, to analyse deformation strain, and to estimate parameters of the slip mechanisms. The complete kinematic model of the surface deformation constrains the determination of mechanical parameters such as slip type and contact interfaces. In contrast to continuously deforming slopes, e.g. 'Campo Valle Maggia, Ticino, CH' we also detected very fragmented kinematics. 'Val Brüna, Grison, CH' being of this latter type clearly reveals patterns where acceleration and deceleration sequentially occur in different zoned areas (Reichmuth, 2004). Further statistical analysis answered questions on the correlation of rain and deformation velocity. It could clearly be shown how precipitation causes accelerations on which fragment and in which sequential order. Sometimes the deformation is not controlled in 3D because angle observations are often critical to carry out with sufficient precision due to refraction. A typical set up is to automatically measure distances from one reference station to the points on the slope. In such cases the (1 dimensional) changes in distances will have to be transposed into 3D movements on the slope. To this end we developed different approaches which we tested on an area of instability close to 'Vicosoprano, Grison, CH'.

Detection of Small and Rapid Movements by a single GNSS Phase-Carrier Receiver: G-MoDe

by S.Guillaume and A. Geiger

G-MoDe (GNSS Movement Detection) is a novel method for detecting very small and rapid movements of an antenna. The phenomena investigated are dominated by rapid deformations on the order of a few millimeters. The G-MoDe is based on the filtering of the carrier phase observations. The main advantage over conventional baseline oriented methods is the true real-time capability, the millimetric precision for rapid movements and the applicability to single receivers. The developed algorithm allows to analyse displacements at a high sampling rate. It circumvents complicated processing like ambiguity resolution and additional parameter estimation for error modelling: like precise satellites orbits, tropospheric and ionospheric models, phase centre offset variation, multipath effects, and clock errors. The basic principle is to assume that all effects which affect the carrier phase observations vary continuously; therefore, they are short-time predictable. Movements of the antenna engender signals in phase measurements which are detected and used to reconstruct the real displacements.

The precision and the reliability of the system strongly depend on the constellation of satellites. Nevertheless, in good conditions, quick movements above 5 [mm] in the horizontal and 10 [mm] in height can be significantly (95 %) detected instantaneously. There are multiple advantages of this technique, compared to the conventional differential processing: First, it is based on one stand-alone single receiver. No reference station is needed. It means that, unlike the differential method, the detected movements are determined with respect to WGS84. Furthermore, the processing can be carried out at the measurement site without the need of communication with other stations. In addition, every visible satellite at the station can be used, since no common satellites in view are needed as in standard techniques, and the precision is not dependent on any baseline length.

Secondly, it is not necessary to use complicated models for satellite ephemeris, tropospheric, ionospheric error correction etc. The presented method reduces the noise to an almost white spectrum. This allows an easier analysis of the time series for the detection of movements. Finally, low-cost single-frequency receivers which are able to measure the carrier phase with an acquisition rate equal or higher to 10 [Hz] can be used.

Some concrete applications of this new G-MoDe can be envisaged: As pre-filter for a conventional static measurement. In fact, small and rapid movements, which are not detectable by the standard differential algorithms, can be determined and taken into account, or short term antenna stabilities, can be assessed. However, the real interest of this method resides in the real-time detection of small, rapid and hazardous movements within a controlling network. Such movements can occur during earthquakes, or as precursors of landslides or due to civil engineering activities.

Dynamic Environmental Monitoring

by Ph. Kehl, A. Geiger, H.-G. Kahle and J. Stähelin

Despite the decrease in road traffic emissions air pollutant concentrations of nitrogen dioxide, particulates and ozone often exceed the limiting values at urban sites in Switzerland.

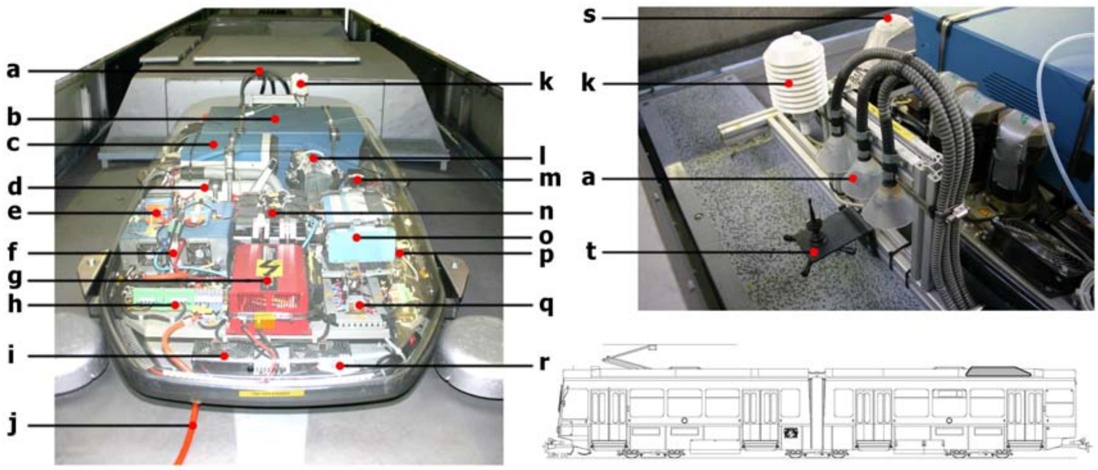

Figure 4.26: The measurement system (box) on the roof of the tram (left), a detailed view of the sample inlets (right) and the position of the box on the tram (bottom right). Legend: a) sample inlets, b) NO_X analyser, c) ozone sensor, d) particle sensor, e) A/D converters, f) power supply, g) 230 VAC inverter, h) power terminals, i) ventilation, j) power input lead, k) meteorological sensors, l) vacuum pump, m) networking equipment, o) data logger and computer, p) GPS receiver (not visible), q) power relays, r) thermostat, s) GPS antenna, t) GSM antenna

The project «Dynamic Environmental Monitoring» (http://www.ggl.ethz.ch/research/wg59, http://www.laborimtram.ethz.ch) aims at providing a dynamic and real-time assessment of ambient air quality and at improving the understanding of the interaction between road traffic emissions and urban air quality. It is designed as a feasibility study for dynamic air-pollution measurements in the local scale.

Three research topics are being pursued in this project: air quality monitoring, satellite based positioning (GPS) of a measurement system in an urban environment and the influence of road traffic emissions on air quality in the city of Zürich.

The data analysed are based on the autonomous operation of a measuring system on a tram in regular service. The tram is equipped with instruments to measure the concentrations of the three most relevant air pollutants in Zürich. These are nitrogen oxides (NO and NO_2), aerosol particles and ozone (O_3). Nitrogen oxides and ozone are measured using the standard techniques involving chemiluminescence of NO and UV absorption of O_3, respectively. Particulates are measured using a diffusion charging particle sensor which suits the requirements for space, a short measurement period and resistance against vibrations. Furthermore meteorological parameters (T, H, p) are measured.

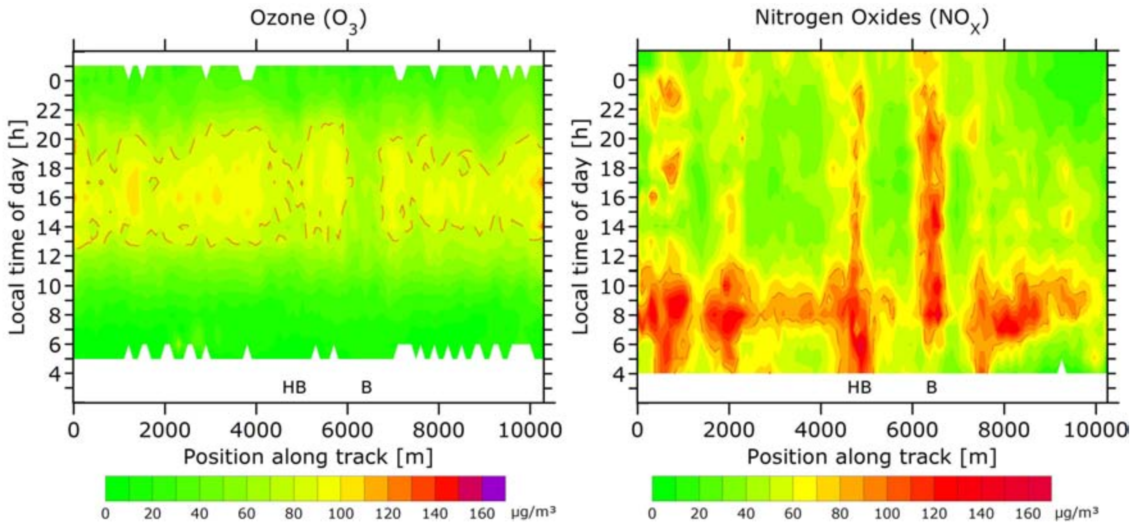

Figure 4.27: The plots show the diurnal change of air pollutant concentrations for days with fair weather (lots of sun). The data is plotted along the track of the line 11 which runs from the north (Oerlikon) to the south of Zürich (Rehalp). The dashed lines represent 80 $\mu g/m^3$. The data has been interpolated to a grid (100m by 60' spacing) using the kriging technique. High concentrations of NO_X are clearly seen near the busy places around Hauptbahnhof (HB) and Bellevue (B) during the whole day. Besides of this traffic-pollution correlation three meteorological and chemical effects can be seen. In the morning hours the NO_X concentrations are rather high all along the track. When the inversion dissolves in the later morning the concentrations generally decrease but at busy places. The ozone concentrations increase with the position of the sun and reach the maximum in the afternoon. The third effect, best visible at the busy places, shows the titration of O_3 by NO below the inversion layer.

The tram travels on tracks that cross the city in north-south or east-west direction. They represent the various characteristics of an urban environment, such as busy places and parts of the city without private road traffic. The measurements are being transferred in real time using mobile communication technologies (GSM, GPRS). A web site is being updated in real time with the position of the tram on a map, the measurements and the operating state of the measurement system and its sensors.

GPS has been used for precise positioning and timing. Urban sites often degrade navigation accuracy and availability. Therefore, a suitable receiver has been evaluated and techniques to provide precise and reliable positioning data have been developed. The latter involves filtering and projective map-matching to exclude faulty positions and determine precise positions. Furthermore, standard position-time relations for the trams have been determined to interpolate GPS outages. These last a few seconds up to a few dozens of seconds.

The feasibility of dynamic and real-time measurements and its limitations have been shown by carrying out two measurement campaigns lasting 18 and 20 weeks in spring 2005 and winter/spring 2005/2006. The analysis of the measurements clearly show varying concentrations of air pollutants along the tram track as well as characteristic hot-spots near busy streets. The data set also allows retrieving diurnal variations for various seasonal conditions.

Dynamic Trajectography of Aircrafts and Vessels

by A. Geiger, S. Häberling, M. Rub and M. Kistler

Satellite geodetic methods are opening up a wide field of research and applications. A main focus of interest is the introduction of GPS in kinematic surveying and the tracking of moving platforms, such as cars, vessels and aircrafts. Special emphasis is put on the combination of GPS and aerogeophysical measurements, such as aeroradiometry and aerogravimetry. Very precise positioning is required in photogrammetric aerotriangulation. For high-precision positioning the resolution of phase ambiguities and cycle slip detection are crucial problems which were being studied. An application of the developed methods has been demonstrated by monitoring the three dimensional movement and oscillations of ropeways by GPS. The determination of the exact position of free hanging cables causes certain difficulties especially in rugged terrain. Even more complicate is the determination of the path of a cabin of a ropeway, because this curve is not visualised by a cable or a rope. The determination of the path by classical methods is very time consuming and often impossible. In many cases the path can satisfactorily be calculated by approved mathematical models. However, in cases where the curve should be known exactly GPS-positioning has to be applied. A very important aspect considers the oscillations of the vehicle. The determination of oscillations is of major interest for the safety assessment of an installation. Passing at the towers, wind loading and emergency stops are operations possibly causing unfavourable oscillations of the cabin. The complete oscillatory movement can be monitored by attaching at least three GPS receivers to the cabin. It has been shown that it is possible to determine relevant physical and geometrical parameters of a ropeway installation as well as the oscillatory or attitude part of its movement. Real measurements confirm the efficiency of the method and reveal the high resolution for the determination of the complete 3-D movement (translations and oscillations) of the ropeway. The frequency and the amplitude of different oscillating modes induced by an emergency stop can clearly be determined. The method has also been applied to determine the dynamics of a vessel in a seaway. The main goal was to correctly orient ultra sonic sounders and to precisely determine position especially height, demanding for precise heave determination. Further investigations are concerned with the determination of the seaway parameters such as the wave spectrum and the directional spectrum using the GPS on the vessel only. In some cases it may be cumbersome and to costly to install multi antenna systems on a platform. To circumvent this problem a single receiver method was developed which yields not only position but attitude as well. The method is very well suited to track gliders where the aerodynamics can well be modelled and, therefore, easily be implemented into the algorithms. The method's suitability was demonstrated on an eight-hour long-distance flight.

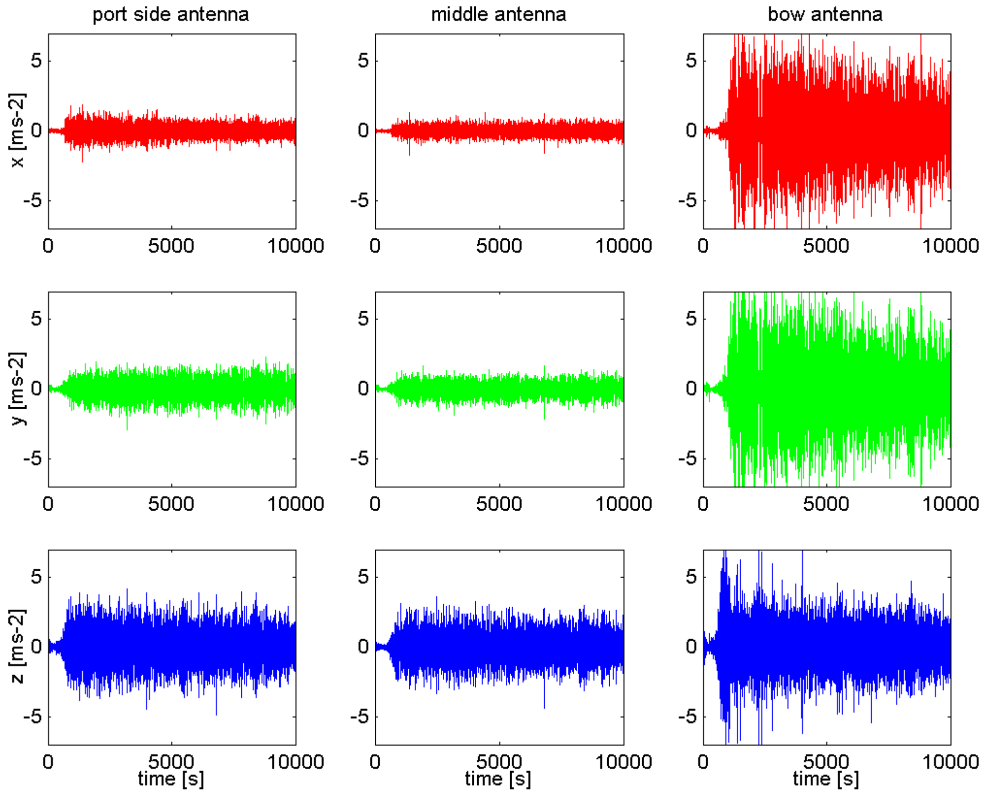

Figure 4.28: Accelerations of a sailing boat determined by GPS. Notice the clearly stronger accelerations on the bow compared to themed-ship antenna (Rub, 2006).

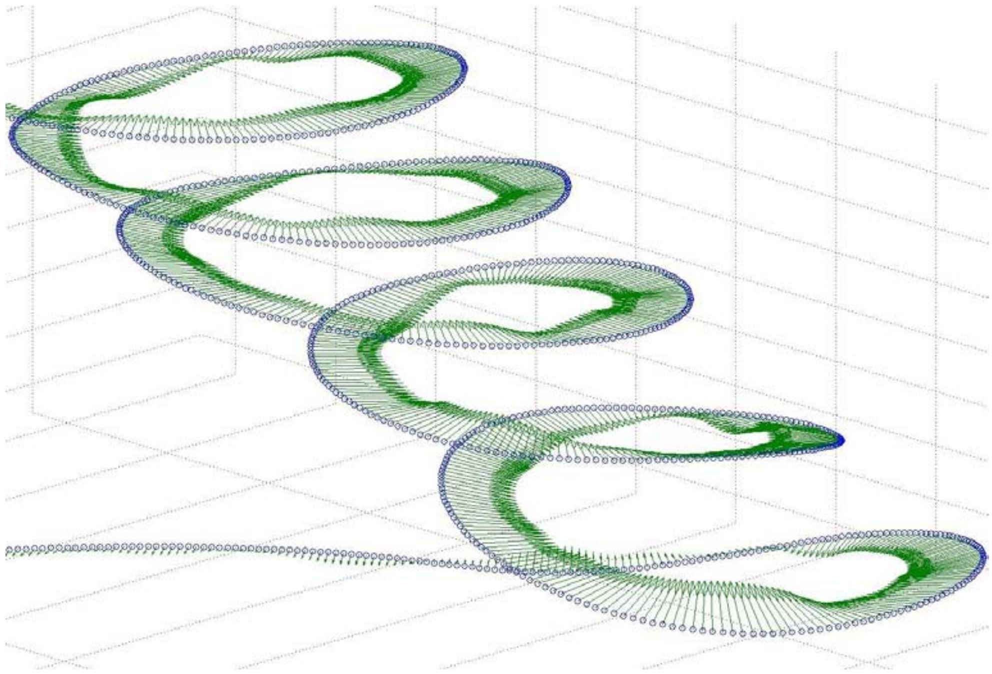

Figure 4.29: Accelerations of a sailplane in a right-hand turn lift determined by one single GPS receiver. Depicted are the additional centripetal accelerations (Häberling, 2006).

Internet Server for High-Rate RTK

by H. Gontran, M. Lehmann and J. Skaloud

Centimeter-level real-time kinematic (RTK) positioning is one of the most widely used surveying techniques. Broadcasting GPS-RTK corrections via Internet-based services has become a new communication procedure to achieve instantaneous positioning with high accuracy. This procedure generally involves a Virtual Reference Station (VRS), the data of which are derived from a network of GPS stations continuously linked to a control center. Its public implementation implies GDGPS (NASA Global Differential GPS) or NTRIP (Networked Transport of RTCM via IP Protocol) to disseminate 1-Hz data streams to stationary users over the Internet. Like their proprietary counterparts implemented by world-class GPS manufacturers, GDGPS and NTRIP are designed as high-quality positioning services that provide their clients RTK corrections whose format and pace are strictly defined. This restricts their use to surveying tasks for pedestrians. GPS-based trajectography in real time is an emerging technique requiring high-cadency data streams that needs a novel approach. We implement an architecture that fully exploits the generous bandwidth of the wireless Internet, so that the RTK users may remotely invoke custom applications on the server side. The emphasis is on designing a multi-client broadcaster of GPS corrections that registers the trajectory of all the connected rovers in real time. Practical experiments assess the tracking quality of fast moving rovers.

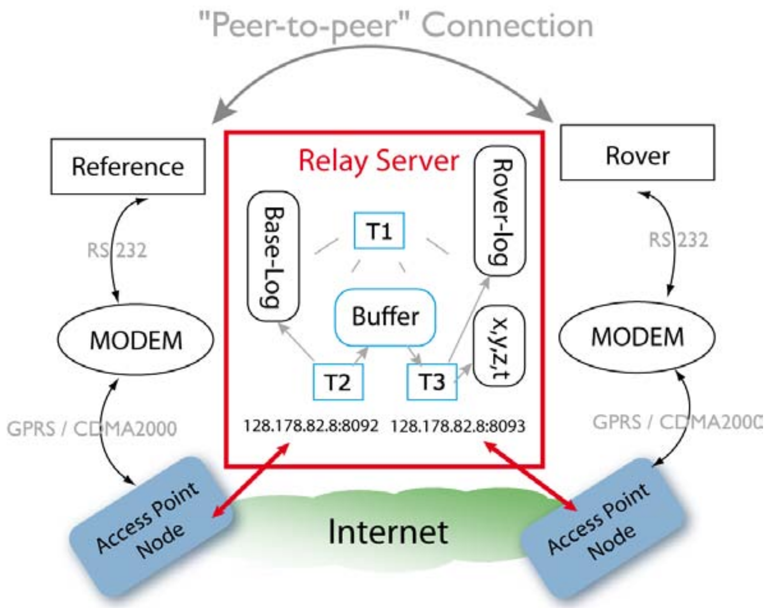

Figure 4.30: Custom relay server for GPS corrections. Thread T1 initializes communication sockets and monitoring functionalities, T2 reads data from the reference and feeds a memory buffer, and T3 moves data from the buffer to one or several references.

Deformation Monitoring based on a Permanent GPS Network

by P.-Y. Gilliéron, C. Honhon, L. Rey and B. Merminod

Monitoring the deformation of the major constructions is enforced by the public authorities. All larger dams and bridges, as well as unstable slopes, are surveyed periodically with triangulation and levelling networks, which provide the relative movement of marks established on and around the structure.

Over the last decades, some events have stressed the need to extend the geodetic networks. Hence the present specifications for the monitoring of deformations include larger areas, especially in regions with landslides or with a potential seismic activity. However, the choice of locations not influenced by geological movements remains a big challenge in the Alps.

For some time now, networks have been extended using satellite techniques. Considering the growing number of GPS stations already installed to provide differential corrections, adding some more stations - operating permanently or not - in the areas to monitor appear as an interesting alternative.

Figure 4.31: GPS permanent station for the monitoring of hydraulic infrastructure.

The positioning service from swisstopo provides continuous GPS raw measurements from 30 stations covering the whole country. The size of the mesh varies between 30 and 50 kilometres. Local control networks for dams and slopes cover areas up to about 10 by 5 kilometres. If an extension is needed, atmospheric modelling becomes the main error source. Connections to the surrounding AGNES stations allow for an interpolation of the biases, and thus for an increase in precision. The basic concept for the extension of a local network to the regional level has to follow various specifications: to include new points in stable areas; to mitigate atmospheric effects; to allow for a fast survey, when required and at a reasonable cost.

The first implementation of such a GPS network will be conducted for monitoring the hydraulic scheme of Grande-Dixence, which includes one of the largest dams in Europe. A test bed GPS network has been implemented in the Rhone Valley with the set-up of a permanent GPS station. Finally, the proposed solution has been evaluated during several GPS campaigns with respect to the long term monitoring of hydraulic infrastructures.

GBAS Activities

by M. Scaramuzza and G. Berz

A Ground Based Augmentation System, GBAS, enabling instrument precision approaches in Cat-I weather conditions for aircraft, is planned to be installed at Zurich International Airport. GBAS is a component of the Global Navigation Satellite System for aviation, consisting of several GNSS reference antennas, receivers, ground processing equipment and a VHF data broadcast. Various studies dealing with the implementation of GBAS were performed, including multipath performance in a vegetation environment, multipath decorellation between reference receivers, suitability of different multipath measurement methods, and VHF signal propagation. Implementation date is not defined yet and depending from GBAS certification achievement.

EGNOS Activities

by M. Scaramuzza and O. Perrin

skyguide is involved in the EGNOS (European Geostationary Navigation Overlay Service) deployment through a bilateral agreement with the European Space Agency (ESA). One of the 34 Ranging and Integrity Monitoring Stations (RIMS) of EGNOS ground segment is hosted and maintained at Zurich Airport. It monitors constantly the GPS, GLONASS and geostationary satellites and send its data to a processing centre. EGNOS activities at skyguide also include the operational approval for civil aviation users in Switzerland, signal in space validation and test flights. These tasks are in coordination with ESA, ESSP, Eurocontrol, other Air Navigation Service Providers (ANSP) and universities.

Figure 4.32: Left panel: RIMS and WAN racks at Zurich Airport; right panel: One of the two RIMS antennas.

Advanced Robust Statistical Procedure in Geodesy - The Forward Search Method: Precision and Robustness on Demand

by A. Carosio, D. Salvini and M. Piras

Typical for most geodetic problems, are low redundancy and precision differences within the observations due to the use of various instrumentations (GPS, theodolite, etc). The low redundancy of the data and the presence of possible outliers, require an intensive use of statistics, to discard the minor number of observations, identifying the effectively wrong ones. This is fundamental in order to avoid singularity in the statistical computation methods of the parameters.

The method of the Forward Search (FS) provides a gradual crossover from the Least Median of Squares (LMS) to the Least Squares method (LS). The concept, on which this technique is based, is to select from the data set with the LMS method an initial subset of size m free of outliers. Usually the algorithm starts with the selection of a subset of u units (number of unknown parameters), leaving $n-u$ observations to be tested. The estimated parameters are applied to all the observations in order to compute the residuals. The values of the squared residuals are then ordered, selecting the $m+1$ observations with the smallest squared residual for the next step. From this subset new parameters are estimated with LS. The loop continues unit by unit, adding one observation at the time until $m=n$, that is when the end of the process is reached delivering a common LS solution.

The innovation of the method consists, beyond its variability given by the gradual crossover from LMS to LS, in providing a continuous monitoring at every step of some diagnostic quantities (residuals, Cook's distance, estimates of the coefficients, t-statistic, etc). Controlling the variation of these indicators during the $n-p$ steps we can identify which of the considered observations causes a relevant alteration of them, allowing distinguishing the presence of classes inside the data. Using this method the data can be classified in "clean", usable for the estimation of the unknown parameters, and "outliers".

The flowchart (Fig. 4.33) shows the application of the FS to geodetic adjustment.

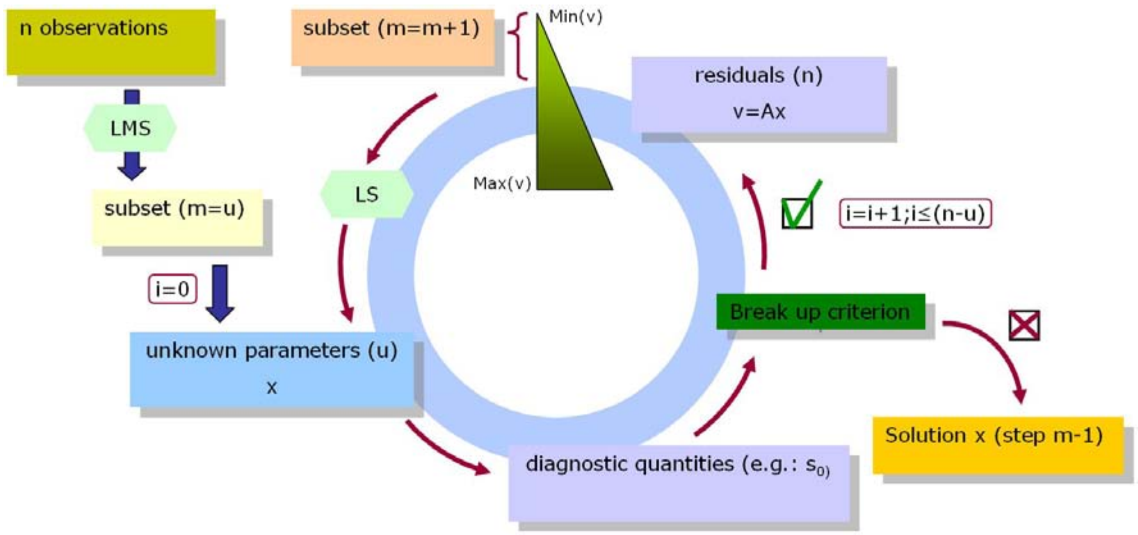

Figure 4.33: Flowchart of the forward search method.

This method has been successfully implemented in the Swiss geodetic software TRANSINT (test version IGP) as robust module for the computation of planar transformation of coordinate systems.

High Accuracy Measurements of Gyroscopic Azimuths - The Essential Technology for Surveying in Extreme Long Tunnels

by A. Carosio, F. Ebneter, D. Salvini and R. Stengele

The realization of the new transalpine rail route requires geodetic surveying techniques, which allow a high accurate positioning and directional reference in extremely long tunnels. When tracing long tunnels, or when the access to them is a vertical shaft, the only way to keep errors (especially the horizontal deviation) in an acceptable range, is to improve the directional reference with high accuracy azimuths measurements. These are measured using a precision-surveying gyroscope (accuracy < 1mgon), which axis oscillates around the geographic north as a result of the interaction of the gyro rotation, the gravitational pull and the Earth's rotation. To reach the high accuracy needed, it is essential to consider all relevant interfering effects during both, the data acquisition and the data processing phases. The most relevant effects on measurements as the deflections of the vertical or the influence of the temperature are widely known and can therefore be corrected using high quality models (e.g. geoid model). Other effects can only be approximated. For this reason the gyroscope must be periodically tested in order to calibrate the correctness of the results. This is done using a laboratory located at the Institute of Geodesy and Photogrammetry (IGP) of the ETH Zurich, where the environmental conditions such as temperature and air humidity are controlled. The calibration consists of a standard temperature variation cycle (range from -10°C to +30°C) or an *ad hoc* cycle which matches the real condition of a data-collection phase (e.g. from -4°C to +27°C).

The employment of gyroscopic measuring instruments requires expert knowledge during the field campaign as well as for the data post-processing. The adjustment of the observed azimuths together with additional surveying data, requires the introduction of an orientation parameter (as done with the sets of directions) in the mathematical model common to all gyroscopic measurements surveyed in the same campaign. Besides the mentioned orientation parameter, the deflection of the vertical, calculated using the geoid model (CHGeo2004), is relevant for the adjustment.

The first results obtained in the Gotthard Base Tunnel can be considered excellent, validating the assumptions as well as the methodologies, already applied during the surveying of the Lötschberg Base Tunnel (main breakthrough on April 2005). At the first breakthrough between Biasca and Faido, after approximately 19km route (incl. access tunnel and multifunction station in Faido), the horizontal deviation was just 92mm. This can be considered as a great success for the surveying.

A Web-Based Solution for Geodetic Computations is Online at ETH Zurich

by D. Salvini and A. Carosio

The adjustment computation is the mathematical fundament of geodetic sciences. The processing of several geodetic data is founded on mathematical and physical principles, which are widely known and constitute the base for further researches. A sample of the developed computation procedures are implemented in software as for example the Swiss geodetic software (geo-software), developed by swisstopo (Swiss federal office of topography) with high contribution of the Institute of Geodesy and Photogrammetry (IGP) of the ETH Zurich.

This software finds wide applications in the academic world as well as in the praxis. The rising complexity of computation modules, which have to be constantly up-to-dated and the weak usability led to develop a new concept for an optimal use of the software. The new concept was developed as web application that offers access to all computation modules, which are kept usable by a central administration. Due to the fact that the IGP owns the source code of the procedures it was possible to draft and realize an efficient interaction concept. The web software application is completed with an informative area, which explains the fundamental statistical principles implemented in the software and supports the planning and execution of the adjustment computations. For selected topics case studies are available, which explain different issues of the geodetic adjustment based on realistic data.

With this project a solution has been developed, which supports the education as well as the praxis in the adjustment computation and benefits from the advantages of the internet. The prototype is in use since some years at the ETH Zurich with considerable success. The education in geodetic adjustment begins with the principles in the third semester and is refined in the following semesters. The lectures include exercises, where professional software are used (usually modules of the geo-software).

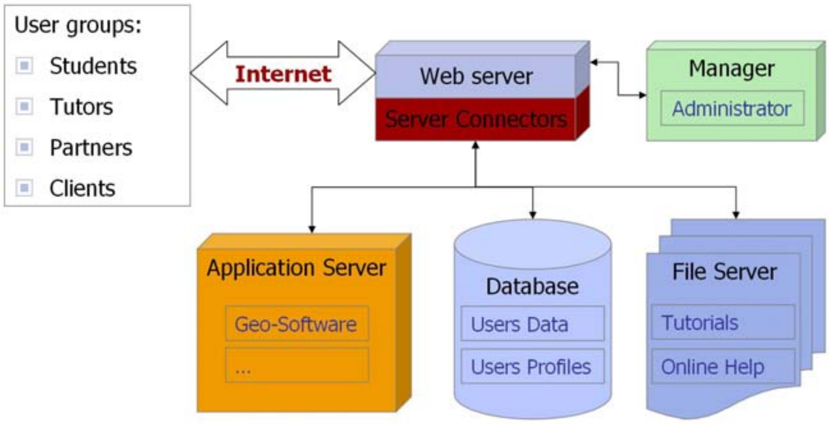

Figure 4.34: Design of the platform.

Hydrostatic Soil Displacement Meter (HSDM) for the Assessment of Long-Term Effects of Soil Compaction

by M. Haberecht, S. Tobias and H. Ingensand

The process of soil compaction can be explained as compression and shearing. Recent research focuses on the assessment of this deformation and its effects. The main objective is now the accurate long-term measurement of soil displacement after wheeling in situ.

In contrast to other deformation measuring methods the hydrostatic systems base on the principle of corresponding liquid tubes. This principle allows deformation measurements without direct sight between the single measuring points. This is the most important advantage of hydrostatic systems for measurements within the soil profile. Further advantages of hydrostatic systems are the high resolution and accuracy in height differences as well as the easy installation of automatic data transmission and remote control. The system HSDM applied in this project of soil compaction is a further development of hydrostatic systems. The HSDM, a hydrostatic multi-line differential-pressure measurement system for long-term monitoring of deformation was developed at the IGP. The height difference between two vessels induces a bending of the membrane in the pressure sensor.

In the winter 2005 was the field experiment with the new HSDM. The experiment was divided in two parts, the wheeling and the long-term measurement. The first aim was to detect the soil subsidence that is an indication for soil compaction. The main objective is the accurate long-term measurement of soil displacement after wheeling in situ in order to monitor possible reversibility of soil subsidence. Fig. 4.35 shows hydrostatic data in a depth of 30 cm and levelling data from the surface. The hydrostatic data shows a soil subsidence and a reversibility of this after the wheeling. This is the plastic and the elastic part of the soil and verified this part of the theory of soil science. The data of long-term monitoring shows in the first 3 months no significant reversibility of the soil subsidence, but reaction of climate events as a strong rain shower.

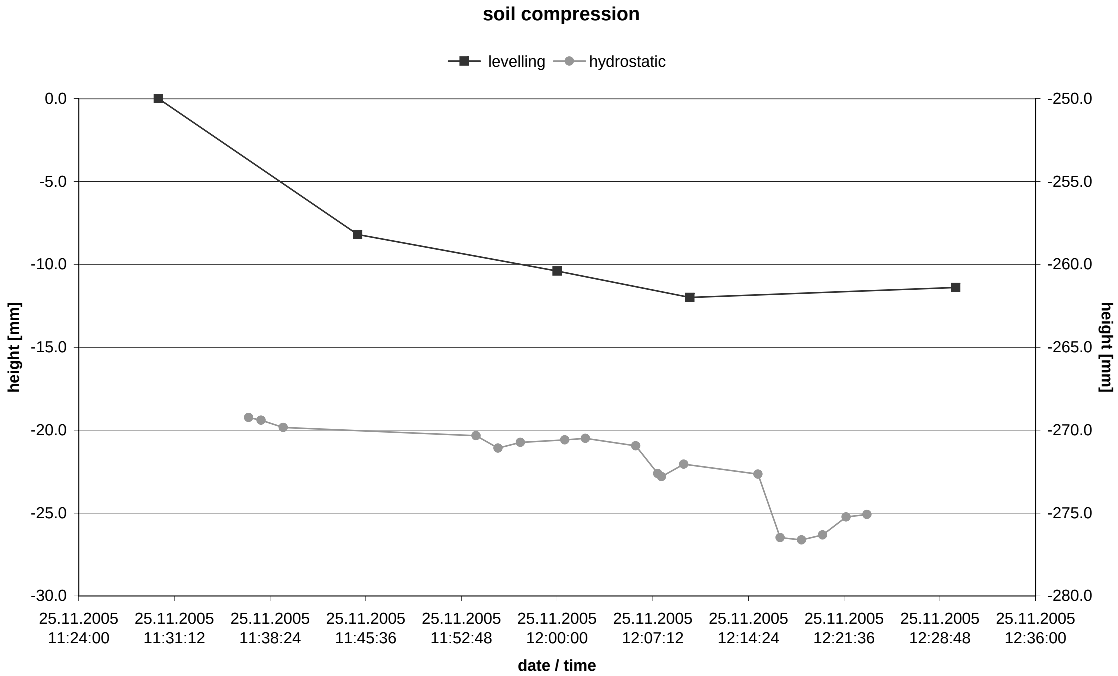

Figure 4.35: Comparison between the measured soil subsidence (HSDM) in a depth of 30 cm and the levelling on the surface.

Direction Transfer in Deep Vertical Shafts - An Inertial Approach

by A. Ryf, T. Neuhierl and H. Ingensand

The orientation of underground networks which have to be accessed by deep vertical shafts is normally determined by high-precision gyroscopes. The independent control with traditional surveying methods can hardly be realised. In Sedrun the underground construction site of the Gotthard Base Tunnel is accessed through an 800 m deep shaft. In a collaboration of ETH Zurich and the Technical University of Munich a new approach of the orientation transfer by combining a high-precision inertial navigation system (INS) with autocollimation has been successfully applied in the Sedrun shaft.

At the top and the bottom of the shaft the orientation of the geodetic network was transferred with the means of autocollimation by a tacheometer stationed in front of the hoisting plant. The autocollimation mirrors together with the INS were fixed in the mine cage and transported to the bottom of the shaft and vice-versa with a velocity of 16 m/s. Three gyros and three accelerators of the INS determined the orientation changes during the transfer in the shaft.

Two measurement campaigns with several ups and downs of the mine cage led to a standard deviation of 1.5 mgon, a value which has the same order of magnitude as the one of the gyroscope. The difference of 2.2 mgon between the gyroscope and the inertial method is not significant. The orientation of the underground network didn't need to be corrected. The reliability of the orientation could be increased significantly.

Figure 4.36: The INS and the autocollimation mirrors fixed in the mine cage.

Position and Height Transfer in Deep Vertical Shafts

by A. Ryf, I. Schätti and H. Ingensand

In Sedrun the underground construction site of the Gotthard Base Tunnel is accessed through two 800 m deep shafts. The accurate and reliable transfer of 3D-coordinates in these shafts was one of the main surveying challenges in the AlpTransit project. The plumbing was realised optically as well as mechanically, in each case with a triple configuration. The optical measurements were carried out in a collaboration of the charged surveyor consortium VI-GBT and the ETH Zurich; the mechanical measurements were done by the DBE Erkundungsbergwerk Gorleben.

The mechanical plumbing with 3 wires and weights between 190 kg and 390 kg lead to a precision of 5 mm. The optical plumbing on 3 tripods with the nadiral plumbing instrument Leica NL resulted in a precision of 6 mm. In both cases the precision was estimated by comparing the triangles at the top and the bottom of the shaft.

As the deviations of the vertical arise up to 2.7 mgon and as the plumbing line in the shaft is curved, the appropriate correction of the deviation values is essential. For the optical plumbing the values at the top of the shaft have to be applied, for the mechanical plumbing those at the bottom of the shaft.

The global network adjustment with either one ore both plumbing methods resulted in coordinate differences of maximal 3 mm. The height differences were measured by electronic tacheometer distances with a Leica TCA2003 at the bottom of the shaft. The reflector at the top of the shaft was mounted under the tripod with an appropriate adapter.

Figure 4.37: Optical plumbing installation in the mine cage at the top of shaft 2.

Contributions of swisstopo to GPS-Meteorology

by E. Brockmann, D. Ineichen and S. Schaer

Since 1999, swisstopo has been active in different projects covering the area of GPS meteorology (see also the contribution in section 1, page 7):

- European project COST-716 (exploitation of ground-based GPS for climate and numerical weather prediction application). After a successful benchmarking, swisstopo has been contributing zenith total delay estimates in near real-time (NRT-ZTD) since December 2001 with a high reliability of 95-98%, arriving at the data archive of the UK Metoffice within 1 hour and 45 minutes. The project was finished in 2003 (Van der Marel et al., 2003; Guerova, 2003; Guerova et al., 2003a,b, 2005a; Brockmann, 2004; Elgered, 2005).

- European project TOUGH (Targeting Optimal Use of GPS Humidity). Very similar to COST-716, the project focused on the operational use of GPS-derived zenith total delay parameters for numerical weather prediction. Refined processing optimizations and model changes were the main focus in the years 2003 - 2005. As a result of a close cooperation with Trimble (Brockmann et al., 2003a; Vollath et al., 2003), it has also been possible to extract ZTD values from the real-time positioning software GPSNet with accumulation intervals of 1 minute with a negligible time delay since January 2003. From 2003 until January 2005, MeteoSwiss generated ZTD parameters from assimilation runs, from numerical weather prediction and from radiosonde measurements which were validated and shown on the swisstopo website (see Fig. 4.38). A service level agreement between swisstopo and MeteoSwiss limited the data flow from MeteoSwiss to swisstopo because of financial restrictions. The analysis of the hourly data was changed considerably on August 3, 2005 (Brockmann and Ineichen, 2005; Ineichen et al., 2006b). Several model changes together with a new processing scheme based on the Bernese Software Version 5.0 were introduced. The project TOUGH was terminated at the end of 2005 (Vedel, 2006) with the status that almost 550 GPS sites were analyzed by several analysis centers (see Fig. 4.39 for the swisstopo contribution).

- Under the auspices of the European Met offices (EUMETNET), the project E-GVAP (GPS water vapor) was started in 2006. With help of a financial contribution by MeteoSwiss, swisstopo was able to continue the hourly ZTD contribution to the project. In the year 2006, several processing improvements were realized (extension of the network from 30° x 15° to 120° x 45°, optimization of the relative constraints, quality monitoring (Ineichen et al., 2006a), absolute antenna phase center models).

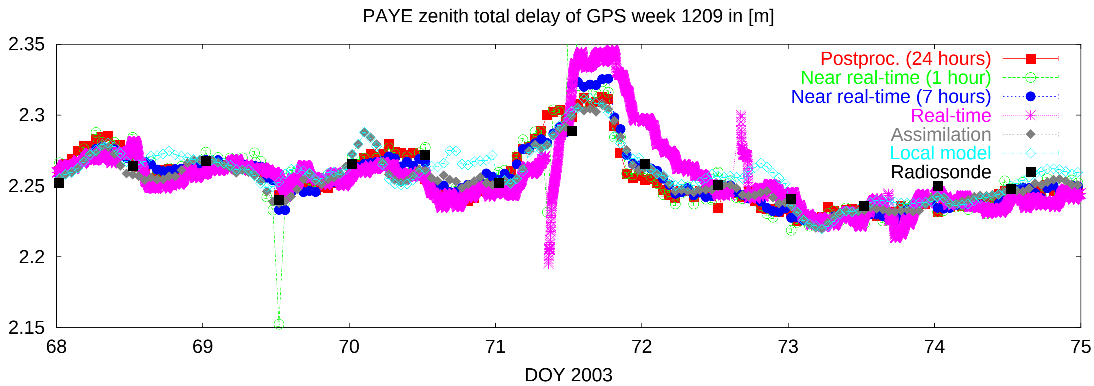

Figure 4.38: Different zenith total delay estimates from GPS for AGNES site Payerne in GPS week 1209 (March 2003): daily, 7-hourly, hourly and real real-time solutions compared to results from meteorological sources (radiosonde, local model from the weather prediction).

During the last 4 years, swisstopo also contributed to several other GPS meteo activities:

- GPS tomography solutions based on data processed during 2 weeks (November, 2002) of the Swiss AGNES network in collaboration with the ETH Zurich (Troller et al., 2003a).

- Validation: Water vapor tests Jungfraujoch-Zimmerwald-Bern in September 2003 (see Haefele et al., 2004a).

- Validation: Sun spectrometer GEMOSS in Zurich (Somieski, 2005).

- GPS tomography solutions based on data processed during 2 weeks (October 10-23, 2004) of the Swiss AGNES network in collaboration with the ETH Zurich (Troller, 2004b).

- WATEC project (begun 2005): Support by measuring and analyzing the data of the 9 Turtmann sites (Lutz et al., 2006).

- GANUWE project (begun 2006): GPS tomography for numerical weather prediction in collaboration with the ETH Zurich and MeteoSwiss (funded by Federal Office for the Environment).

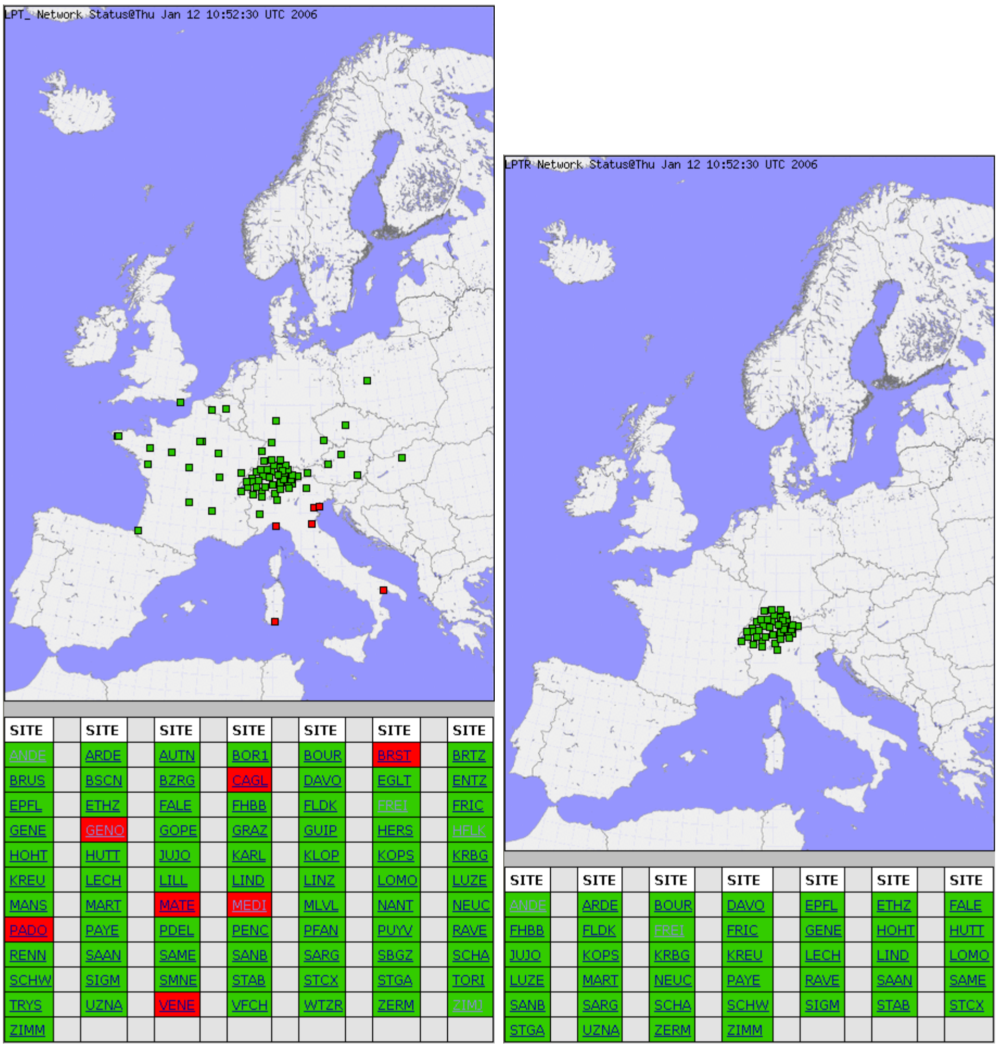

Figure 4.39: GPS permanent networks processed at swisstopo in NRT (left) and RRT (right) on January 12, 2006, 10:00 UTC monitored within the TOUGH/E-GVAP project.

Bernese GPS Software

by R. Dach, H. Bock, P. Fridez, A. Gäde, U. Hugentobler, A. Jäggi, L. Mervart, M. Meindl, S. Schaer, C. Urschl, P. Walser and G. Beutler

The Bernese GPS Software is the basic working tool used at CODE (Center for Orbit Determination in Europe, joint venture of Astronomical Institute, University of Bern, Switzerland, swisstopo, Wabern, Switzerland, and Bundesamt für Kartographie und Geodäsie, Frankfurt am Main, Germany (Hugentobler et al., 2007), to generate the products for the IGS (International GNSS Service) as well as for experiments and tests. With the Bernese Processing Engine (BPE) the routine processing for the IGS and the other test solutions can be generated in a fully automatic mode. The package, consisting of about 100 programs and more than 1000 subroutines is also used by a large number of institutions distributed all over the world. In April 2004 the version 5.0 was released and a revised and updated documentation of about 600 pages is available (Dach et al., 2007).

The new generic graphical user interface (see Fig. 4.40 as an example) is part of the version 5.0 release. A completely redesigned BPE is used for the automated processing. In addition, the new release contains several new features. Three processing examples built up for usage with the BPE are part of the distribution. The sophisticated normal equation combination program ADDNEQ2 replaces the old ADDNEQ and offers the same features and many additional options for manipulating normal equations. The software now contains among other the capability to process kinematic data and to determine precise (kinematic and reduced-dynamic) orbits for Low Earth Orbiters (LEOs) carrying GPS receivers. GNSS satellite antenna phase center patterns can be introduced and estimated. The troposphere modeling was improved. The software is fully compliant with IERS Conventions 2000 and the processing of undifferenced data and the handling of Differential Code Biases (DCB) is refined.

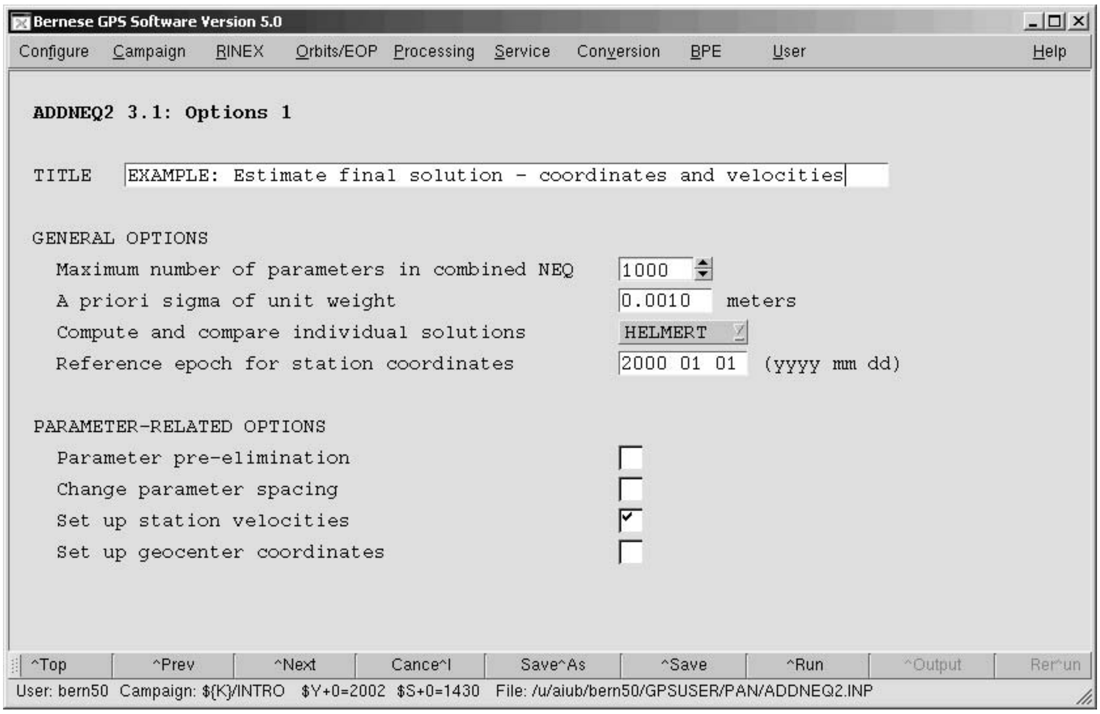

Figure 4.40: Graphical User Interface of the Bernese GPS Software Version 5.0.

The implementation of the upcoming Galileo system into the software is a central issue. Due to the third frequency delivered by the new system the observation files and the handling of linear combinations have to be redesigned. Current developments also include improvements of station displacement modeling, the consideration of Center-of-Mass Corrections (CMC) for orbit modeling, radiation pressure modeling, and troposphere modeling: e.g., GMF: Global Mapping Function (Boehm et al., 2006) and GPT: Global model for Pressure and Temperature (Boehm et al., 2007) are implemented. The upgrade of the software to the IERS Conventions 2003 (McCarthy and Petit, 2004) is in preparation.

The main focus for the next release, however, will be the improvement of the reprocessing capability of the software.

CODE Contributions to Global Ionosphere Monitoring

by S. Schaer

The Center for Orbit Determination in Europe (CODE) is a joint venture between the Astronomical Institute of the University of Bern (AIUB, Bern, Switzerland), the Federal Office of Topography (swisstopo, Wabern, Switzerland), and the Bundesamt für Kartographie und Geodäsie (BKG, Frankfurt a. M., Germany). It is one of the analysis centers of the International GNSS Service (IGS). CODE has been extracting total electron content (TEC) information from IGS tracking data since 1995. Since June 1998, related global ionosphere map (GIM) information is generated in IONEX (IONosphere EXchange) format and provided to the IGS.

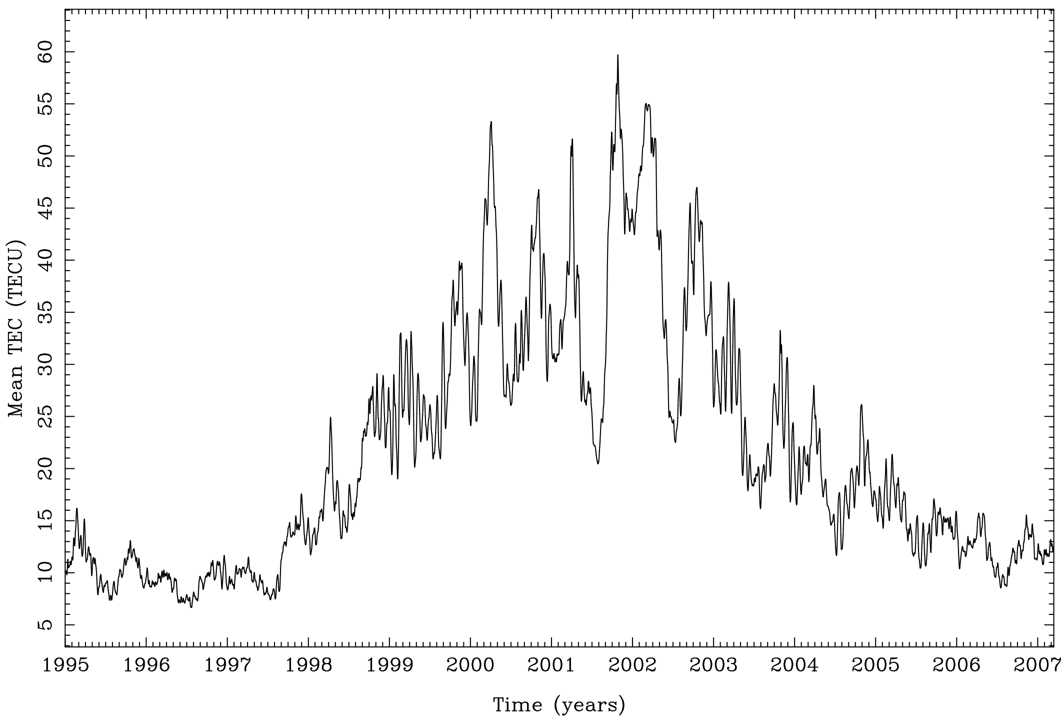

Figure 4.41: Mean Earth's total electron content (TEC) as extracted (and slightly smoothed) from CODE global ionosphere map (GIM) time series, from January 1995 to February 2007.

In addition to this IONEX product, which is a final product, also corresponding rapid as well as predicted GIM products are routinely generated at CODE. All GIM products are made available in form of IONEX or ionosphere files in the internal format of the Bernese GPS Software. Since July 2000, CODE additionally provides RINEX-formatted Klobuchar-style ionospheric coefficients (best fitting CODE's IONEX data). Because of the limited number of coefficients, the latter product type obviously has a much reduced information content compared to the IONEX products. On the other hand, it may serve a large GPS user community as it relies on a widespread ionospheric model.

The list of IGS tracking stations considered for ionosphere monitoring includes about 250 globally distributed stations. GNSS data (GNSS stands for Global Navigation Satellite System) of about 200 stations is regularly available and analyzed. Data from GLONASS is considered in CODE's ionosphere analysis as of the end of April 2003. It is worth mentioning that we started to include the Amundsen-Scott station (AMUN, meanwhile replaced by AMU2), which is located on a moving sheet of ice at the South Pole, in January 2003. The inclusion of GNSS tracking data originating from LEO satellites, like CHAMP and SAC-C, is intended for the future.

Precise Time and Frequency Transfer

by R. Dach, L.-G. Bernier, G. Dudle, U. Hugentobler and T. Schildknecht

Precise time and frequency transfer using carrier phase and pseudo range GNSS measurements in combined analysis have a long tradition in a collaboration between the Swiss Federal Office of Metrology and Accreditation (METAS) and the Astronomical Institute of the University of Bern (AIUB).

GNSS receivers may be connected to external clocks. If this is the case, the differences between the estimated receiver clock parameters may be interpreted as difference of the external clocks (Schildknecht et al., 1990). A calibration of the GNSS receivers is of course necessary (Petit et al., 2001).

Due to the processing scheme used within the International GNSS Service (IGS) a daily independent processing scheme is used, which leads to discontinuities in the time series at the midnight epochs of about 0.1 up to 1 ns (Ray and Senior, 2005).

Since several years we develop methods for a continuous processing using the Bernese GPS Software (Dach et al., 2007). Two methods have been implemented:

- The midnight epochs from two subsequent daily computing batches are estimated as one common epoch. This method is easy to understand. On the other hand, the continuity of the results relies on the data of only one epoch.
- A second algorithm reconnecting the ambiguity parameters of corresponding satellites from consecutive daily solutions to one and the same parameter. This method is more robust but more parameters have to be handled and due to a necessary check for potential cycle slips at the midnight epoch more complicated algorithms are needed.

Both methods are described and compared in (Dach et al., 2006).

The second algorithm - reconnecting the ambiguity parameters - has the advantage that it is possible to generate a phase-only frequency transfer solution over long time intervals of several days or weeks. No inconsistencies between the carrier phase and the pseudo range observations concerning the internal receiver clock affect the solution. The result of such a solution over four weeks was compared to the traditional Two-Way Satellite Time and Frequency Transfer (TWSTFT) method as it is used in the timing community for a long time. The example in Fig. 4.42 is an excerpt from a comparison campaign between four primary frequency standards in Europe and one in America (Bauch et al., 2006). The results for the baseline I.N.RI.M. (Istituto Nazionale di Ricerca Metrologica in Torino, Italy, IGS-ID: IENG) and NPL (National Physical Laboratory in Teddington, United Kingdom, IGS-ID: NPLD) are compared: The results from both independent methods agree very well - at least for the European baselines. In the link to the American station a significant drift between the two time series was detected that is still not completely understood.

The long-term use of the phase-only frequency transfer between several National Metrological Institutes (NMI) contributing to TAI and regularly performing TWSTFT measurements was carried out in collaboration with the BIPM (Bureau International des Poids et Mesures). Some of these NMIs submit GNSS data from receivers related to their UTC realization to the IGS. We have analysed the data of 15 globally distributed sites over an interval of four months and compared them with the results of other time and frequency transfer techniques. The results are published in (Jiang et al., 2006).

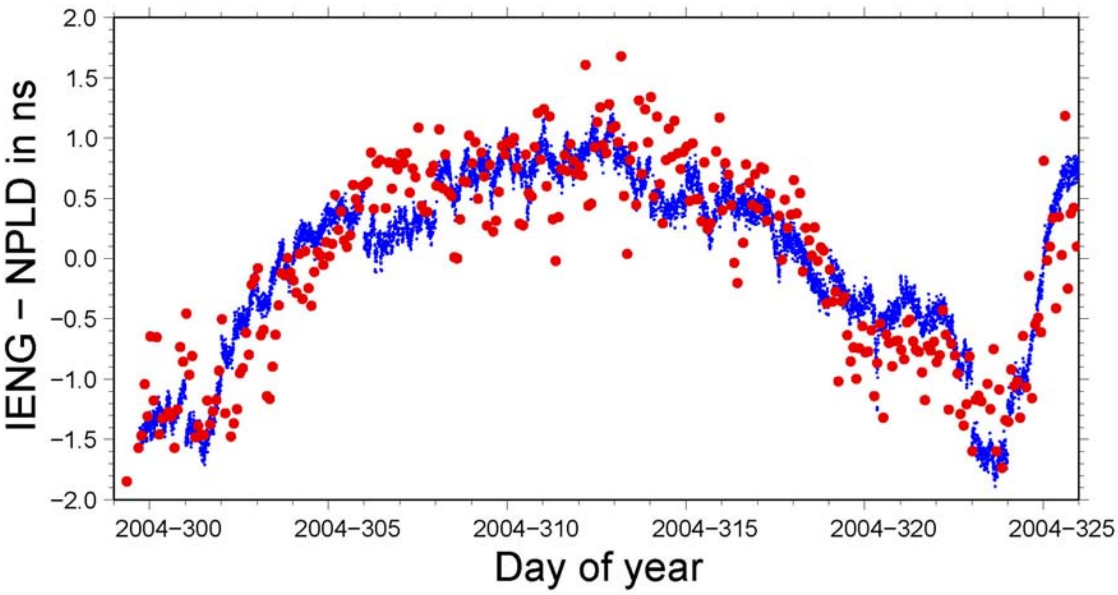

Figure 4.42: Comparison between a GPS derived clock comparison using only the carrier phase data (small red dots) and TWSTFT measurements (blue dots) for the baseline between Torino, Italy and Teddington, U.K., during a four weeks comparison campaign.

GEodetic MObile Solar Spectrometer (GEMOSS)

by B. Bürki, A. Somieski, H.-G. Kahle and P. Sorber

The state-of-the-art in microwave based technologies such as e.g. GPS and satellite radar altimetry reveals that the accuracy depends to a high degree on the possibilities to correct for the impact of water vapour on the propagated signals. The direct measurement of this highly varying greenhouse gas demands for expensive (e.g. regularly launched radiosondes) or laborious measuring systems such as water vapour radiometers. The solar spectrometer technique represents a new technology which is based on the spectrometric analysis of absorption patterns of the solar light at selected frequencies showing absorption lines. Until now two generations (SAMOS and GEMOSS) of observation systems have been designed and built at the Geodesy and Geodynamics Lab (GGL) at ETH Zurich, in collaboration with the Institute of Analytical Sciences (ISAS), Berlin-Adlershof, Germany. The system GEMOSS has been tested in a comparison campaign (COMPA) at the meteostation Payerne operated by MeteoSwiss. Since a variety of different methods sensing water vapor are available there, this station has been chosen for an extended comparative experiment. Payerne represents not only a station of the Swiss Meteorological Network SwissMetNet but also a station of the Automated GPS Network Switzerland (AGNES). Furthermore two radiosondes are launched every day. For this experiment the solar spectrometer GEMOSS as well as the water vapor radiometer have been deployed side by side. The results obtained are shown in Fig. 4.43.

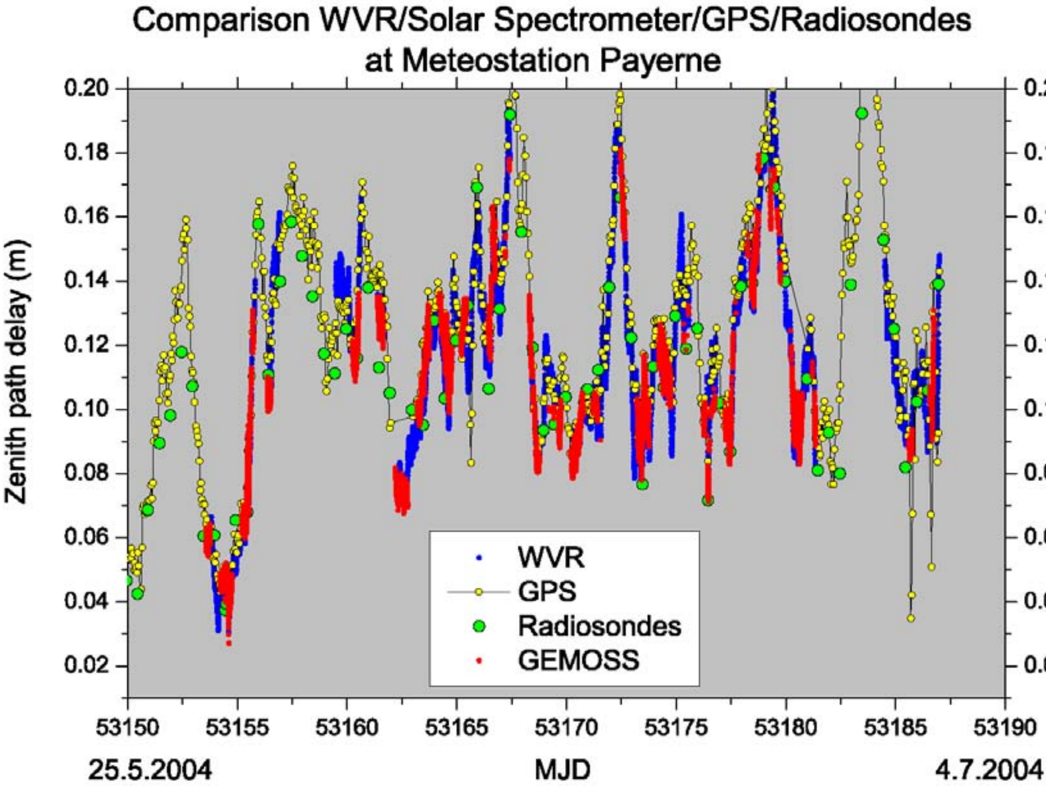

Figure 4.43: Comparison of the zenith path delay as observed by means of GPS, Water Vapor Radiometer (WVR), Solar Spectrometer (GEMOSS), and radiosondes from May 25 until July 4, 2004. These results show the tendency of the GPS solution to overestimate the amount of water vapor.

A first dedicated field campaign was carried out 2004 in Greece in connection with the EU-project Gavdos aiming at the determination of tropospheric water vapor for validation of the measurements of the microwave radiometer (JMR) aboard the satellite Jason-1.

In continuation of the successful experiences gathered within the GAVDOS project, an additional JMR validation campaign took place in the frame of the Ocean Surface Topography Mission (OSTM) in July/August 2005 at the station Patitiri at the Island of Alonnisos (Northern Sporades, Greece). The field measurements were conducted with the solar spectrometer GEMOSS, simultaneously with the Microwave Water Vapor Radiometer (WVR) of GGL. Fig. 4.44 shows the time series obtained.

The most recent validation campaign was carried out at the Naval Base of Ajaccio (Corsica, France) where the system including a meteorological logging unit was deployed between November 2005 and July 2006 on a special tripod. The steering computer, all electronic and communication devices were operated within a trailer.

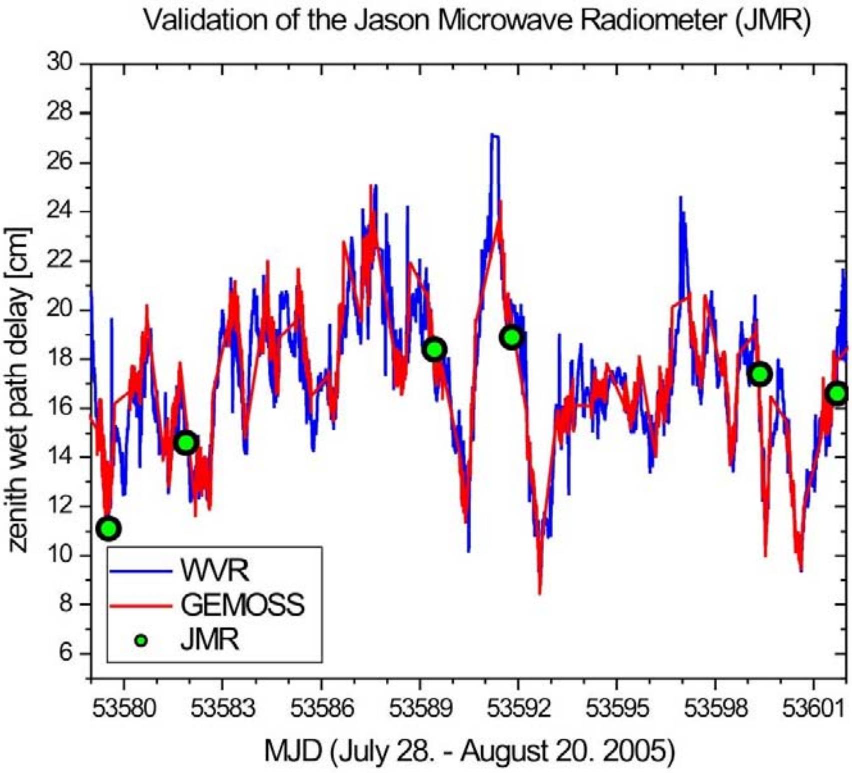

Figure 4.44: Zenith wet path delay observed with the WVR (blue), GEMOSS (red), and the JMR radiometer aboard the Jason-1 satellite (green dots). All three techniques show an excellent agreement throughout the time window observed thus providing a high level of confidence for the tropospheric corrections.

Microwave Water Vapor Radiometer (WVR)

by B. Bürki, A. Somieski, H.-G. Kahle and P. Sorber

The GGL microwave water vapor radiometer (WVR) has been deployed in several field campaigns between 2004 and 2006:

2004: Comparison campaign COMPA at Payerne (Switzerland)

2005: Jason-1 JMR Validation campaign GAVDOS at Patitiri, Island of Alonnisos (Greece), and calibration campaign at geo fundamental station Wettzell, Germany.

2006: Participation within the VLBI-project CONT 05 at Hartebeesthoeck (South Africa)

In the context of the GAVDOS project, the Water Vapor Radiometer operated as an independent technique for comparison and validation of solar spectrometric measurements and the radiometer aboard the satellite Jason-1. Fig. 4.45 shows the instrumental setup of the radiometer (at right) on top of a roof at Patitiri, North Aegean Island Alonnisos (Greece) in co-location with the Geodetic Mobile Solar Spectrometer GEMOSS (in the background). For results of these measurements, please refer to the previous contribution on solar spectrometry.

Figure 4.45: Instrumental setup of the radiometer (foreground) and the solar spectrometer (GEMOSS) at Alonnisos (Greece) during the validation campaign Jason-1.

Determination of the Spatial Distribution of Water Vapor above Switzerland using GPS Tomography

by M. Troller, A. Geiger and H.-G. Kahle

The GPS navigation system is a promising ground based technique to estimate the amount of water vapor in the troposphere. To determine height profiles, a tomographic approach was pursued. We developed the software package AWATOS which is based on the assimilation of double differenced GPS observations. The atmosphere is discretized using a voxel model. Within each voxel, the wet refractivity is introduced as an unknown constant. Applying a least-squares adjustement, the inhomogeneous spatial distribution of water vapor is determined.

Extensive investigations have been carried out using the dense permanent Swiss national GPS network AGNES of swisstopo (e.g. Troller, 2004a; Troller et al., 2006a,b). Fig. 4.46 shows the distribution of the GPS stations in Switzerland as well as the choosen voxel model. Several time periods have been investigated and evaluated using radiosondes and the Swiss operational weather model aLMo. Since January 2006, GPS-tomography is set up in an operational manner to automatically determine the spatial distribution of water vapor. Overall, an agreement of 5 ppm (refractivity units) compared to aLMo has been reached. Fig. 4.47 shows an example of water vapor retrieval using GPS and the comparison with the radiosonde and aLMo.

Project page: https://www.rdb.ethz.ch/projects/project_pdf.php?proj_id=6126

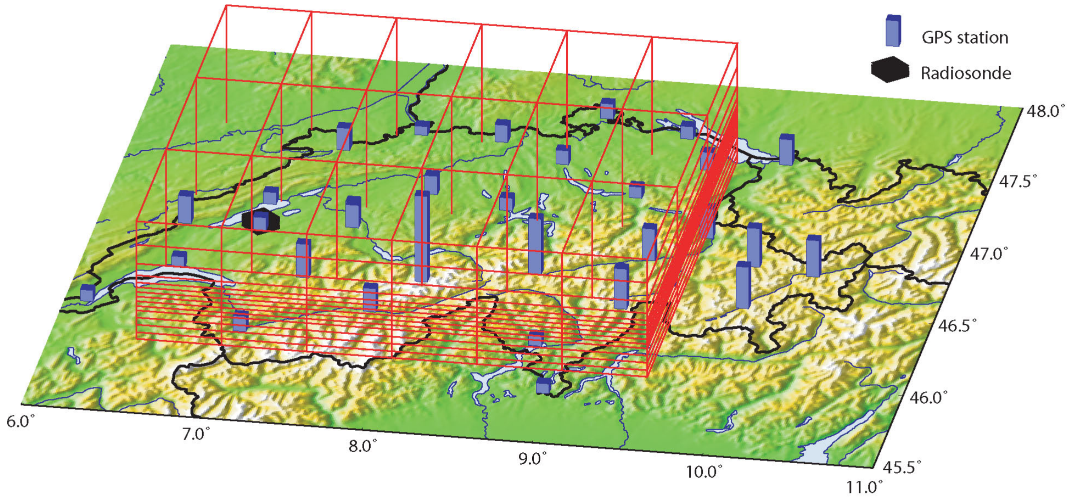

Figure 4.46: 3D view of the tomographic voxel model above Switzerland. The figure shows the core voxel model of 6x3 voxels per layer. The GPS stations of the AGNES network are shown as prisms. Radiosondes are launched at the station Payerne.

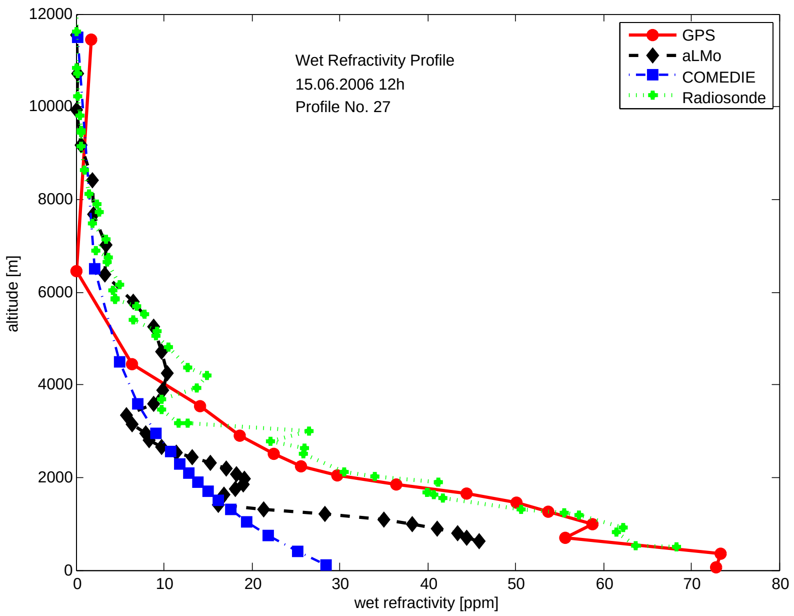

Figure 4.47: Wet refractitiy profile of the tomographic solution, a radiosonde, the data of the numerical weather model aLMo and a COMEDIE retrieval.

High Resolution GPS Tomography in View of Hydrological Hazard Assessment

by S. Lutz, M. Troller, A. Geiger and H.-G. Kahle

The main objective of the project WATEC is the determination of the 4-dimensional distribution of atmospheric water vapor over a local mountainous region applying a tomographic approach based on GNSS observations. Two dedicated field campaigns were performed in the Canton of Valais to study the feasibility of the method for a non-permanent GPS densification network. The GPS-derived water vapor profiles are validated with radiosondes, solar spectrometer measurements, and the current numerical weather prediction model aLMo of MeteoSwiss.

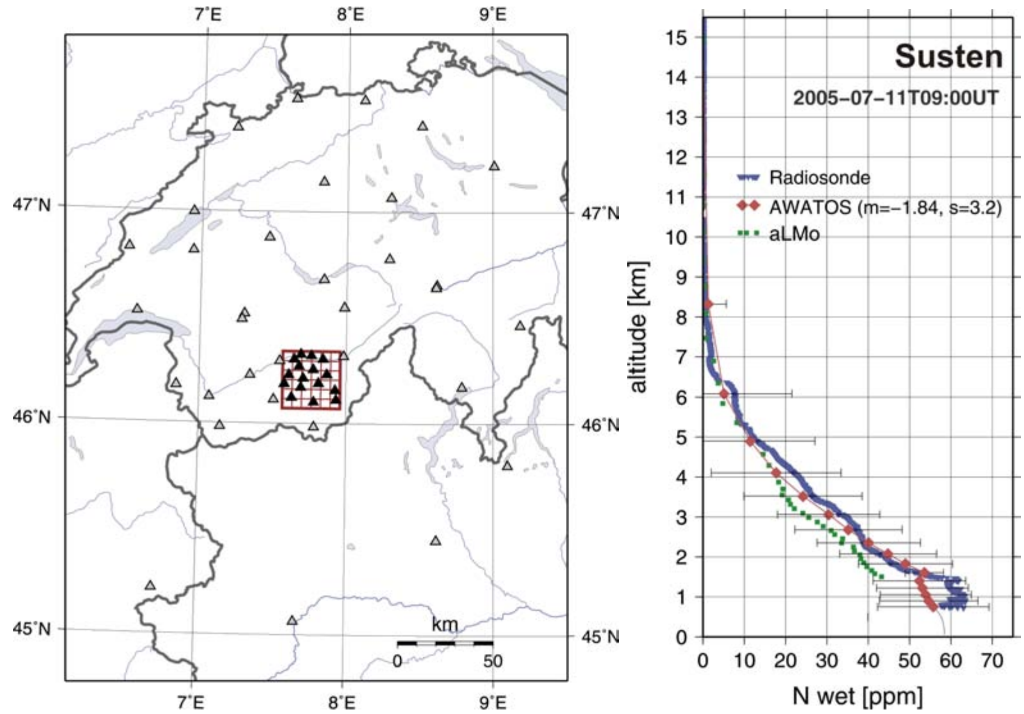

Figure 4.48: *Left panel:* The GPS network consisting of permanent stations of the AGNES and Swissat networks (light gray triangles) is densified by campaign stations (black triangles) in the South-West of Switzerland. The tomographic discretization of the atmosphere is done by a 6 by 6 voxel model with a grid spacing of about 5 km in horizontal direction (red grid). *Right panel:* Comparison of refractivity profiles above the site Susten in the north-western part of the project area. The data from the radio sounding (dark blue) at July 11, 2005, 09:00 UT, is shown, as well as a profile from the numerical weather model aLMo (dark green squares) and a tomographic hourly solution of AWATOS (red diamonds) with error bars corresponding to each layer. The layer thickness increases from 100 m at the bottom to more than 1000 m at the top. Overall, the AWATOS solution has a mean offset of m=-1.84 ppm ± 3.2 ppm compared to the radiosonde measurements.

The major results developed so far cover the pre-processing and quality analysis of all campaign data, the generation of high-quality GPS derived double difference residuals and ZTD time series. Furthermore, the data for comparison and validation purpose with the tomographic results were prepared. The influence of the boundary conditions for high-resolution GPS tomography was studied and successfully applied to the calculations with the tomographic software package AWATOS (Atmospheric WAter vapor TOmography Software).

The resulting refractivity profiles match the profiles derived from corresponding radiosonde measurements within 10 ppm (refractivity units) and represent the characteristics of the different tropospheric layers in most cases with high significance. However, local atmospheric inversions are still difficult to detect. Compared to conventional methods, the density of humidity profiles can be increased substantially. Therefore, the implementation of GPS tomography in real-time will ultimately allow to forecast hydrological hazards earlier and more accurately.

4D Modeling of Path Delays Using Meteorological and GPS Data

by M. Troller, A. Geiger and H.-G. Kahle

Tropospheric water vapor is the main limiting factor in using GPS to determine crustal deformation at highest accuracy. On the other hand, it is an important variable to monitor meteorological and climatic processes. To account for this effect, we developed a software package COMEDIE to model the meteorological parameters pressure, temperature and water vapor pressure in space and time. The software is based on a collocation approach. Subsequently, COMEDIE allows to determine an integrated path delay along an arbitrary ray. Ground meteorological data of the operational Swiss meteorological network as well as radiosonde data in the vicinity of Switzerland were used.

With the increasing number of permanent GPS stations in recent years, a new approach has become applicable. GPS-derived zenith path delays are used as input data, to interpolate zenith path delays spatially and temporally. A software package COITROPA was developed which is also based on a 4-D collocation in space and time. Data of the permanent Swiss GPS network AGNES are utilized for this application.

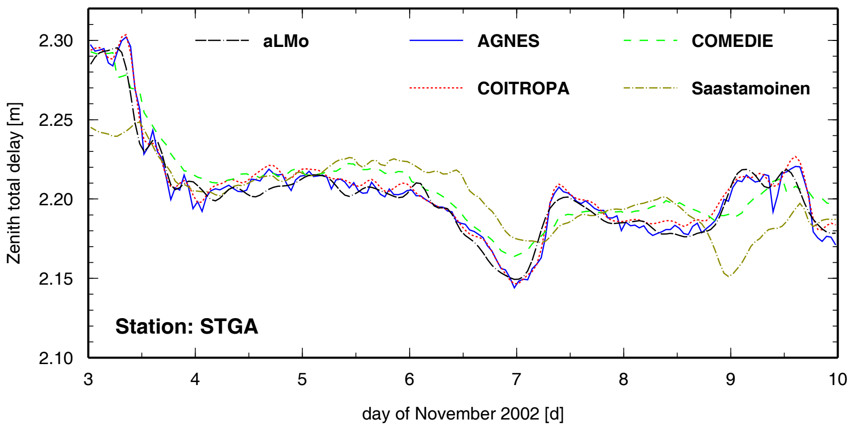

Figure 4.49: Comparison of zenith wet delays at station St. Gallen (STGA). The plot shows ZTD-retrievals of COMEDIE, COITROPA, GPS-processing (AGNES), the Swiss weather model (aLMo) and the Saastamoinen formula.

Fig. 4.49 shows a comparison between different methods for ZTD determination at the AGNES station STGA (Troller, 2004a; Troller et al., 2006b). COMEDIE and COITROPA fit accurately with GPS-derived zenith path delays at all 29 AGNES stations; COITROPA within 7mm, COMEDIE within 13 mm. Fig. 4.50 shows the distribution of ZTD in Switzerland using GPS-derived ZTD of the AGNES stations and COITROPA. The ability to detect weather fronts with GPS is clearly seen.

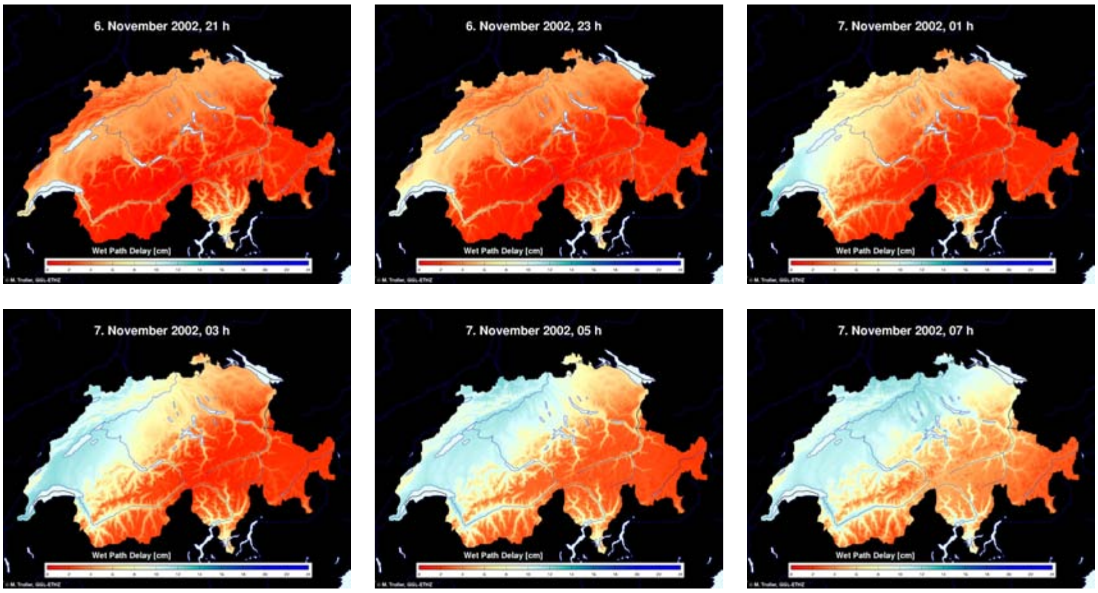

Figure 4.50: Temporal behavior of the wet path delays above Switzerland. The plot shows the situation on November 6 at 21h and 23h and on November 7 at 01h, 03h, 05h and 07h.

Project pages: https://www.rdb.ethz.ch/projects/project_pdf.php?proj_id=6115 and
https://www.rdb.ethz.ch/projects/project_pdf.php?proj_id=6127

Local Ionosphere Modeling with GPS-Measurements by Single Receivers

by M. Müller, A. Geiger and M. Scaramuzza

To be fully applicable in aviation GPS positioning has to meet high standards in accuracy and reliability. While traveling through the atmosphere the GPS-signal is influenced by free electrons and charged particles. As ionospheric characteristics can rapidly change, positioning can be negatively affected.

The main goal of the investigation was to detect anomalous ionosphere activities in real-time by GPS measurements with a few locally distributed single receivers.

During a time period with supposed ionospheric anomalies skyguide, the Swiss air navigation provider, collected GPS data of the AGNES CGPS-network of swisstopo which was analyzed focusing on anomalous ionospheric behaviour.

To be able to estimate the electron content of the ionosphere using dual frequency measurements, a method had to be developed to determine differential clock biases (DCB) of single receivers. Using data of AGNES, EUREF and IGS different approaches were considered to derive local ionosphere models for central Europe. Locale ionospheric anomalies could be detected and their influence on the position were investigated. Further, the effect of applying correction models like e.g. the Klobuchar model or other determined models was analyzed.

Finally, the method of tomography was tested to obtain the three-dimensional distribution of the atmosphere's electron density using software originally developed for tropospheric GPS tomography.

Modelling Refractivity and Forecasting Zenith Path Delays

by P. Herschke, A. Geiger, M. Troller and E. Brockmann

Already in the early stages of development of GPS it has been recognized that insufficient knowledge on the atmosphere above the receiver is one of the main limitations to the accuracy of the system. In view of high precision real-time applications these investigations focus on modeling the atmospheric effects on the GPS signal and eventually applying it to path delay forecasting. It is intended to evaluate the prediction feasibility and to determine the maximum extrapolation time for a given precision to achieve, thus answering the question: for a given error threshold how long can one predict a path delay at an arbitrary location without information at that site?

While the ionospheric effect can be removed to a great extent by linearly combining the GPS observables derived from both carrier phase L1 and L2 measurements, the troposphere where almost 90% of the atmospheric water vapor is concentrated, remains a major source of error. Based on least-squares collocation technique, also known as kriging algorithm, an efficient method for calculation of path delay had been developed earlier, yielding the COMEDIE software. The present investigations concentrate on further developments of the method towards real-time and prediction capabilities. The different methods and their underlying physics for calculating the refractivity and its decomposition into dry and wet parts have been revisited. The forecast capability was tested within the automatic GPS network (AGNES) of the Swiss Federal Office of Topography.

For most of the AGNES stations implicated it is possible to yield to a meaningful forecast during 9 hours after the last data were available. Both the standard deviation and RMS of the zenith path delay ZPD differences are less than 1 centimeter during the first 12 hours of the forecast. The ZPD extrapolation error evolves at an approximate rate of half a millimeter per hour.

Orbit Determination for EGNOS Satellites

by M. Meindl and U. Hugentobler

The satellites of geostationary augmentation systems such as EGNOS (European Geostationary Navigation Overlay System) are equipped with single-frequency microwave transponders. The tracking data contain a GPS-like signal corresponding to the GPS C/A-code in the L1-band of the electromagnetic spectrum. In 2004/05 we studied the opportunities and limitations of an orbit and clock determination for geostationary EGNOS satellites based on these signals (see Meindl et al., 2005; Beutler et al., 2005).

The orbit determination procedure is basically split up in two parts:

1. Tracking data from the GPS constellation is used to determine station coordinates, troposphere parameters, and receiver clock corrections.
2. Orbits for the EGNOS satellites are computed using observations from the geostationary satellites. The results from the first step are introduced as known.

The studies showed that it is possible to determine C/A-code based orbit for geostationary satellites. Orbit overlaps at subsequent day boundaries suggest an orbit quality of a few meters. However, the results could not be compared to orbits from an independent source and thus remain unverified. During the analyses it became clear that a good distribution of ground stations is essential for the achievable orbit quality (Fig. 4.51 shows the tracking network used in this study and the approximate position of the geostationary satellite S31). A receiver network located only in a relatively small geographical region (e.g., central Europe) is not well suited for precise orbit determination. Instead, a large extension in longitude would be desirable. Multi-day orbital arcs (e.g., 3-day arcs) significantly improve the orbit quality. The along-track component (and thus the longitude of the satellites) benefits in particular from a long-arc analysis. Frequent station keeping manoeuvres of the satellites may, however, invalidate a long-arc combination.

In general the results of our studies are, however, quite promising concerning microwave observation-based orbit determination for geostationary satellites. There are still some open issues: Exploiting phase observations, using a more sophisticated radiation pressure model, and the influence of differential code biases are topics for further studies.

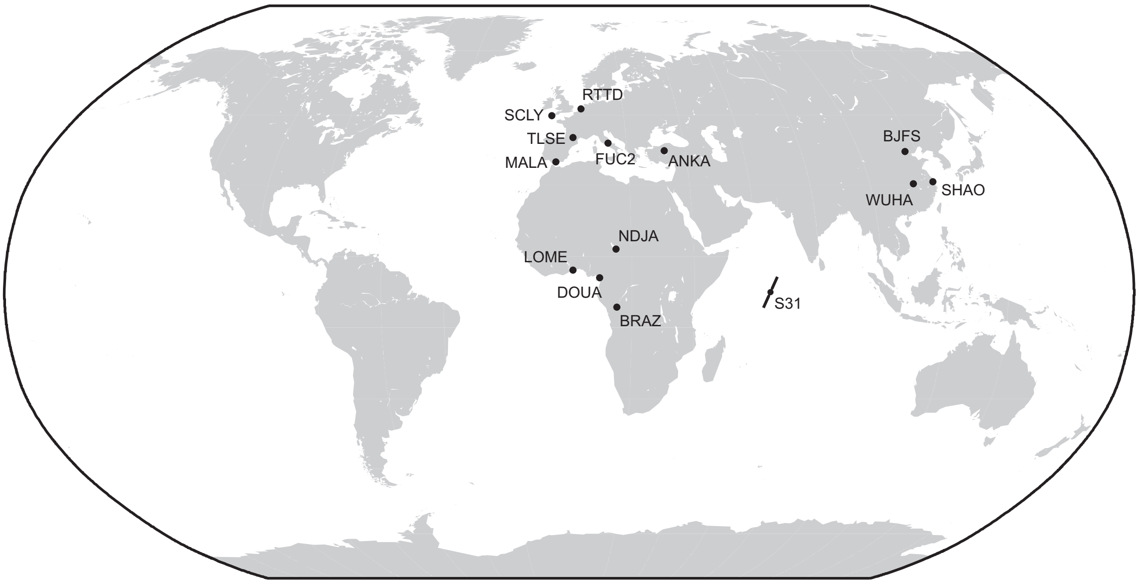

Figure 4.51: Tracking network and approximate position of geostationary satellite S31.

The Digital Astronomical Deflection Measuring System (DIADEM)

by B. Bürki, A. E. Somieski, P. Sorber, H.-G. Kahle and C. Hirt

Technical system enhancements: After first field experiments the system has been upgraded in different aspects.

1. The rigid tripod has been replaced by a platform which is equipped with three electromechanical cylinder motors. The system is placed on a special transport trolley and can be transported with a van. At the station to be observed the system can be unloaded by means of simple aluminum profiles (see Fig. 4.52). The observer can then easily uplift the complete camera system from the trolley using a joy-stick device and the cylinder motors thus preventing the impact of disturbances from the wheels of the trolley on the levelling process.

2. In addition to the electronic tiltmeters (Zerotronic by Wyler, Switzerland), a second pair of high resolution tiltmeters, manufactured by E. Lippmann, Germany, has been mounted.
3. To avoid mutual interferences caused by parallel running tasks during data capture and storage, a second computer was implemented. While the first computer monitors the CCD camera, the second one captures all other data from the sensors. The mutual data exchange is organised by means of a small peer-to-peer network.
4. The round ground plate was mounted on a turnable pivot bearing thus allowing to change the azimuthal orientation. This measure helped to avoid instrumental errors depending on the azimuthal orientation during the observation.
5. The system is equipped with totally 9 motors:
    - 3 motors for fine levelling (on top of the levelling screws)
    - 3 motors on top of the electromechanical cylinders
    - 1 motor for the focussing mechanism
    - 1 motor for the rotation of the optics
    - 1 motor for the rotation of the whole system

This design allows to deploy the instrument in a fully automated mode including automatic levelling, exposures, data handling, and selectable orientation procedures.

Figure 4.52: Instrumental transport and setup of DIADEM by means of a special trolley and electromechanical cylinders. These allow to lift up and lower the whole instrument. For recently performed observations and results, please refer to the contribution in section 2, page 47.

Measurement of Astronomical Azimuths

by B. Bürki, F. Buol, S. Guillaume and D. Grimm

The quality control of azimuthal orientations between terrestrial targets in underground construction sites is a crucial point. In projects with long tunnels the stakeout of the tunnel axis is usually checked by means of north finding gyroscopes. Actually this aspect is in the focus of the engineering survey within the project Alptransit in Switzerland. Since single sections of the new railway tunnel underneath the Swiss Alps (total tunnel length 57 km) reach lengths of up to 16 km, the control of the drilling equipment's heading is of utmost importance. In order to provide an independent validation of the gyroscopic measurements, the astrogeodetic azimuths on five terrestrial reference lines have been measured. These measurements were carried out in the framework of a student project course organised by the Institute of Geodesy and Photogrammetry (IGP) and the Geodesy and Geodynamics Lab (GGL). The equipment consisted of a total station by Leica Geosystems TCA 1800, a dedicated GPS receiver for timing purposes, and the on-line measuring system ICARUS/AZIMUT developed at GGL (see Fig. 4.53).

Figure 4.53: Student observing an astronomical azimuth near the Alptransit construction site Sedrun, Canton Grisons, Switzerland. The on-line measuring system ICARUS/AZIMUTH enables an automated measurement regime. The computer steers the total station (Leica TCA 1800), a dedicated GPS time receiver, and calculates the results of the observations in real time.

The results of the measurements revealed an inner accuracy (precision) on the order of 0.2 to 0.8 arcsecs. The comparison of the astronomical azimuths with the corresponding azimuths observed with the gyroscope confirmed adequate results. Fore more information, we refer to the contributions in this section, page 108 and 146.

On-line Astro-Geodetic Measurement System ICARUS/AZIMUTH

by B. Bürki, S. Guillaume, U. Marti, P. Süess and St. Münch

ICARUS/AZIMUTH developed at GGL is an easy to handle, semi-automatic on-line measuring system for the observation of deflections of the vertical and astronomical azimuths. Its advantages are as follows:

- No special and expensive hardware equipment is required. The observations can be carried out by means of an ordinary motorized total station.
- The only extra equipment needed consists of a small interface box and a GPS timing receiver.
- No preconditions and preparations are required to run the software.
- The software steers the connected instruments and calculates the result in real time.

The observation of deflections of the vertical is based on the method of equal zenith angles. The program for the observation of azimuths allows to observe either Polaris (most commonly) or any other known star.

Figure 4.54: Astro-geodetic observation system ICARUS/AZIMUT. A Laptop computer and a small interface box complete the low-cost system which enables the determination of astronomical latitude, longitude, and azimuths in real-time.

The complete system comprises the following parts:

1. Motorized total station (e.g. Leica TCA series, or Topcon GTS series)
2. Special eyepiece for high elevation angle measurements
3. GPS time signal receiver providing epoch information such as e.g. Trimble Acutime 2000, or μ-blox LBR series (or similar)
4. Interface box matching all cables to the devices. The tiny GPS receiver from μ-blox can even be integrated within the box.
5. Laptop running DOS

Based on the star catalogue FK5/6 the software calculates in a first step the ephemerides. Prior to the observations the observer has to point to one single (selectable) star for the orientation of the system. Afterwards the system works in a semi-automatic mode by automatically pointing to any chosen star. So far the transit observations (epochs) of the star through the almucantar are then carried out by pressing a special stop button device. The GPS provides the corresponding precise epoch and the software calculates the results in real time based on precisely calculated apparent places of the stars. For more details we refer to the contributions in this section, page 108 and page 145.

Calibration and Algorithms for Direct Georeferencing by GPS/INS

by J. Skaloud, K. Legat, Ph. Schaer and B. Merminod

The direct georeferencing (DG) of airborne sensors by GPS/INS is now a widely accepted approach in the airborne mapping industry. Implementing DG not only speeds up the mapping process and thus increases the productivity, but also opens the door to new monitoring applications. Although the system manufactures tend to claim that DG is a well established technique and no longer a research topic, the technology users often encounter pitfalls due to undetected sensor behaviour, varying data quality and consistency. These investigations aim to mitigate such problems in the following fields:

First area of research seeks the potential improvements in the essential features, methods and processes, the combination of which could substantially increase the reliability of DG without setting large side penalties.

Second research topic addresses the problem of performing the DG in the non-Cartesian coordinate system, as that based on national (often conformal) projection. This approach requires special attention when coping with the earth curvature and the length distortion of the national map projection. Until recently, the problem alleviation by modified transformation of GPS/INS-derived EO was not correctly addressed openly.

Third research domain proposes a rigorous method for estimating some of the calibration parameters in airborne laser scanning (ALS), namely the three bore-sight angles and the range-finder offset. The developed technique is based on expressing the system calibration parameters within the direct-georeferencing equation separately for each target point, and conditioning a group of points to lie on a common surface of a known form. The method has been successfully applied to airborne laser scanners from three leading manufactures.

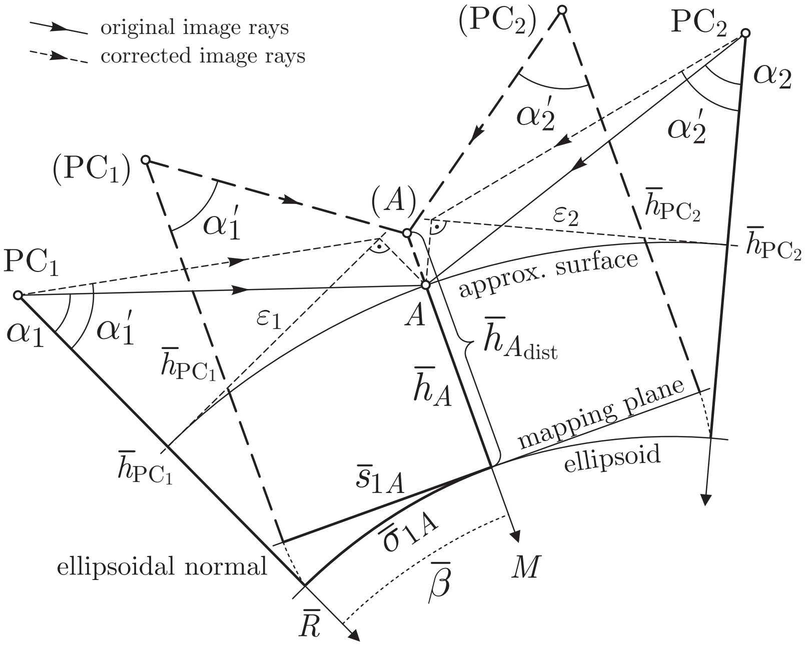

Figure 4.55: Residual height distortion after the approximate earth-curvature correction and mapping in case of passive imaging.

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