Switzerland
Swiss Geodetic Commission

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Swiss National Report on the

GEODETIC ACTIVITIES

in the years 1999 to 2003

**Presented to the XXIII General Assembly
of the International Union of Geodesy and Geophysics
in Sapporo, Japan, June/July 2003**

Rapport National Suisse sur les

ACTIVITÉS GÉODÉSIQUES

exécutées de 1999 à 2003

**Présenté à la vingt-troisième Assemblée générale
de l'Union Géodésique et Géophysique Internationale
tenue à Sapporo, Japon, Juin/Juillet 2003**

Zurich 2003

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In addition to the bibliographies at the end of each section we recommend the following www-sites:

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 Zurich: http://www.ggl.baug.ethz.ch/

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PREFACE

The Swiss Geodetic Commission (SGC) is an organisation within the Swiss Academy of Sciences (SANW). It is devoted to research into scientific problems of geodesy including the transfer to practical application in national 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.

For the compilation of the national report covering the scientific activities of the past 4 years it was decided to follow the structure of previous national reports and divide it into five sections according to the structure of the International Association of Geodesy (IAG):

1 Positioning
2 Advanced Space Technology
3 Determination of the Gravity Field
4 General Theory and Methodology
5 Geodynamics

These main chapters were compiled by an editorial staff consisting of D. Schneider (Section 1), W. Gurtner (Section 2), E. E. Klingelé (Section 3), A. Geiger (Section 4), and H.-G. Kahle (Section 5). Our special thanks go to Dr. B. Bürki, 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 SANW. Its valuable help is gratefully acknowledged.

On behalf of the Swiss Geodetic Commission, March 2003

Erich Gubler — Vice-President of SGC

Hans-Gert Kahle — President of SGC

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1 Positioning

Contribution of CODE to the ITRF

by S. Schaer, D. Dach, M. Meindl, U. Hugentobler and G. Beutler

The global GPS data analysis at CODE is done on the basis of observations from the IGS tracking network. GPS orbits, Earth rotation parameters (ERPs), station coordinates, troposphere delays, and other specific parameters, are estimated daily in the same parameter adjustment process. For a complete documentation, we refer to the annual reports for the years 1999, 2000, 2001 (Hugentobler et al 2000, 2001, 2003). In the following we address coordinate aspects. Orbits and atmosphere issues are addressed in Section 2, ERP's in Section 5.

The number of stations processed in the global analysis was increased from 100 to 120 in June 2000 and to 150 in July 2002. Care is taken to process a homogeneously distributed set of global stations considering in particular very remote sites. A station once included into the processing scheme is, whenever possible, not replaced by an other one in order to gain uninterrupted coordinate time series. Seven daily solutions are combined using the full covariance information in order to generate a weekly station coordinate and ERP solution. The geodetic datum is defined with respect to approximately 46 IGS core stations by a minimum constraint condition (three rotations). A SINEX file is generated and made available. It contributes to the solutions of the IGS Global Network Associate Analysis Centers (GNAACs) as well as to the weekly IGS combined SINEX solution generated at the IGS Reference Frame Coordination Center (Natural Resources Canada, NRCan) where the IGS reference frame (the IGS realization of the ITRF reference system) is maintained.

In March 2000 CODE submitted its contribution to the ITRF2000 reference frame realization (see Altamimi et al, 2002). The solution was produced using GPS observations spanning a time interval of more than five years and includes coordinates and velocities for 164 stations. Fig 1.1 shows a comparison of the computed velocity vectors (arrows) with the ITRF97-derived vectors (lines) for a solution that is constrained to the ITRF97 reference frame. Finally, CODE is contributing to the IERS SINEX Combination Campaign with weekly SINEX files realigned to IGS00 covering the year 1999 (see Section 5).

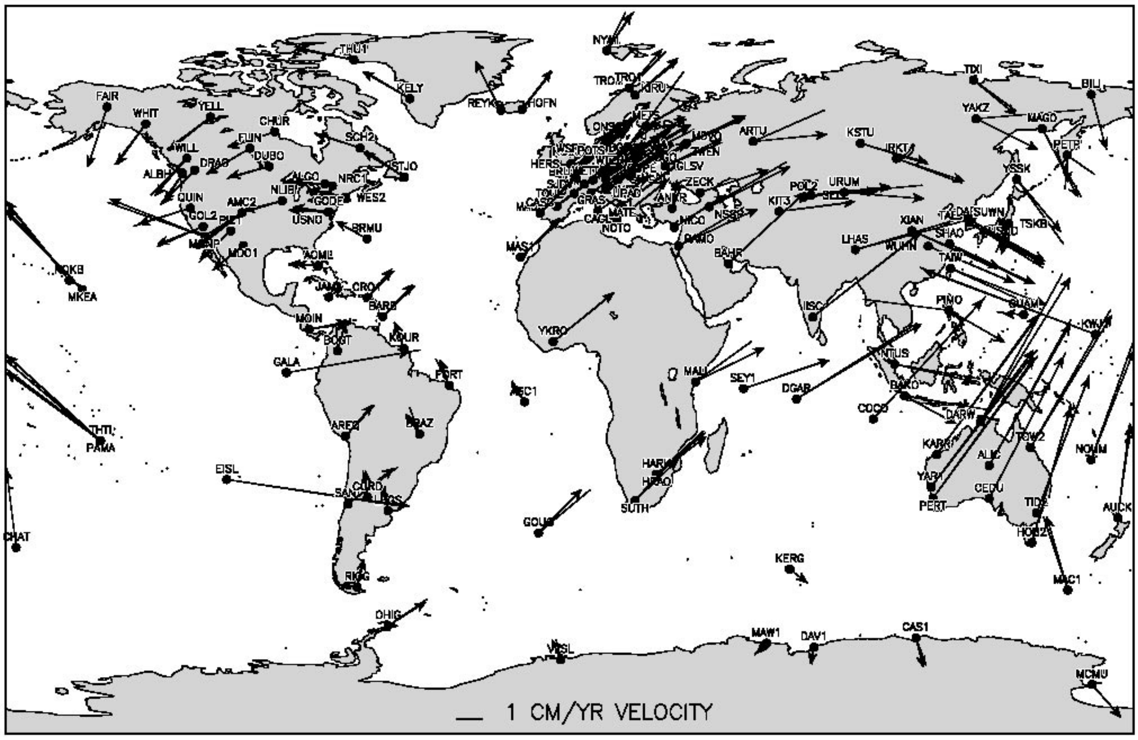


Fig. 1.1: Horizontal station velocities derived from five years of GPS data from the IGS tracking network (arrows) and from ITRF97 (lines).

EUREF Activities at CODE

by S. Schaer, M. Meindl and U. Hugentobler

The IAG Subcommission for the European Terrestrial Reference Frame (EUREF) coordinates the operations of currently more than 130 permanent GPS tracking stations. The data is analyzed by currently 16 Analysis Centers. Until July 25, 1999, the individual subnetwork solutions were combined into one unique EUREF SINEX solution by the CODE Analysis Center (at AIUB). In July 1999 the Bundesamt für Kartographie und Geodäsie (BKG, Frankfurt a. M., Germany) took over this responsibility and became the new EUREF combination center. The EUREF combined SINEX solution is sent every week to the IGS for inclusion into the IGS densified network solution. Details may be gathered from Bruyninx et al. (2002).

In September 2001 some of the processing standards were changed within EUREF. The recommended elevation cutoff angle was lowered from 15 to 10 degrees, elevation-dependent observation weighting was applied, and the Niell mapping function was introduced.

CODE is one of the EUREF Analysis Centers. It is responsible for a subnetwork of about 40 EPS stations. Weekly station coordinate results in SINEX format as well as daily sets of troposphere zenith path delay values for the processed stations are delivered to the EUREF. Apart from our official EUREF solution, eight additional test solutions are computed for comparison purposes. These test solutions include solutions for validating new, refined options such as consideration of low-elevation data, estimation of tropospheric gradient parameters, but also solutions to compare rapid and final orbit products from IGS and CODE.

Analysis of Permanent GPS Networks at swisstopo

by E. Brockmann and D. Ineichen

The permanent GPS networks analysed at swisstopo are shown in Table 1.1:

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

Table 1.1: Routine GPS data analyses at swisstopo

The data of the Automated GPS Network of Switzerland (AGNES) are being monitored since the end of 1998 on a daily basis and since December 2001 on an hourly basis (see section "GPS Meteorology: Contributions of swisstopo to COST-716"). In addition to the 29 AGNES sites, 40 EUREF sites are processed with the Bernese GPS Software Version 4.2 (Hugentobler et al., 2001) using the final IGS orbit products with a time delay of 3 weeks. This monitoring allows the detection of possible site movements. An updated multi-year solution, where the site coordinates and velocities are solved for, is automatically generated having processed an additional week of data. The results are e.g. estimated velocity and repeatability plots. They are available in the survey section of http://www.swisstopo.ch/ . As an example the horizontal velocities relative to Zimmerwald are shown in Fig. 1.2:

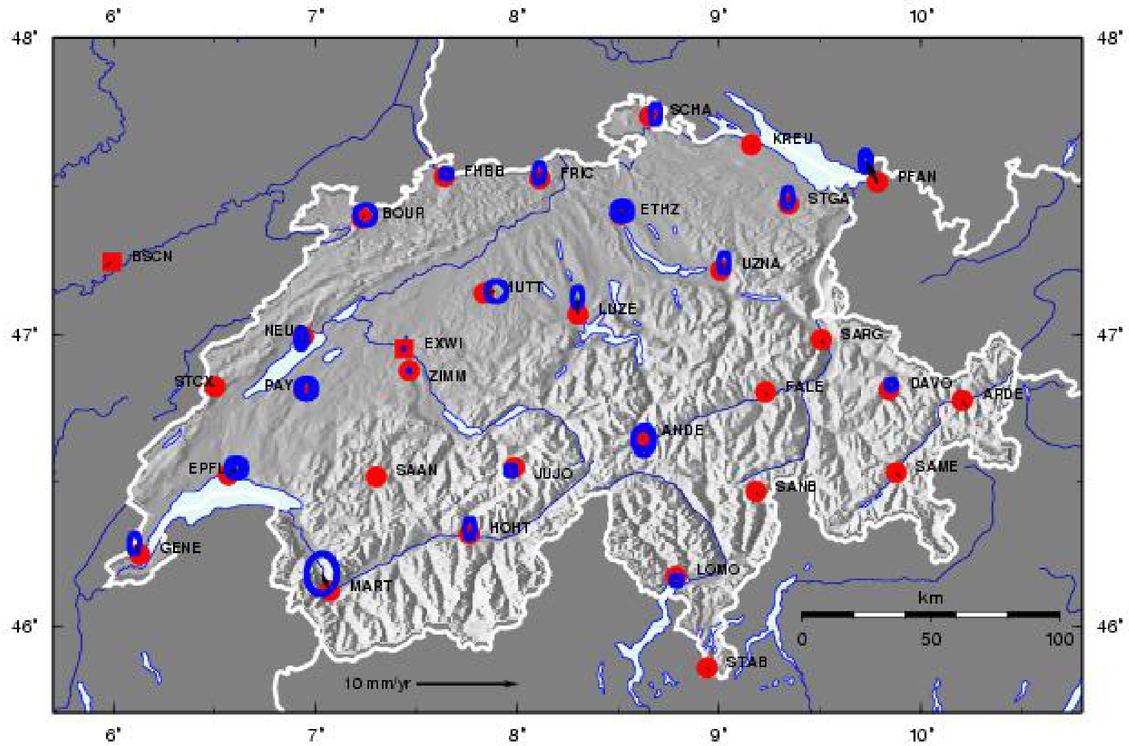


Fig. 1.2: AGNES: Horizontal site velocities in ITRF00 (relative to Zimmerwald) for sites with a "history" of more than 0.5 years (time span summer 1998 – end 2002)

National GPS Reference Network LV95

by B. Vogel, E. Brockmann and A. Wiget

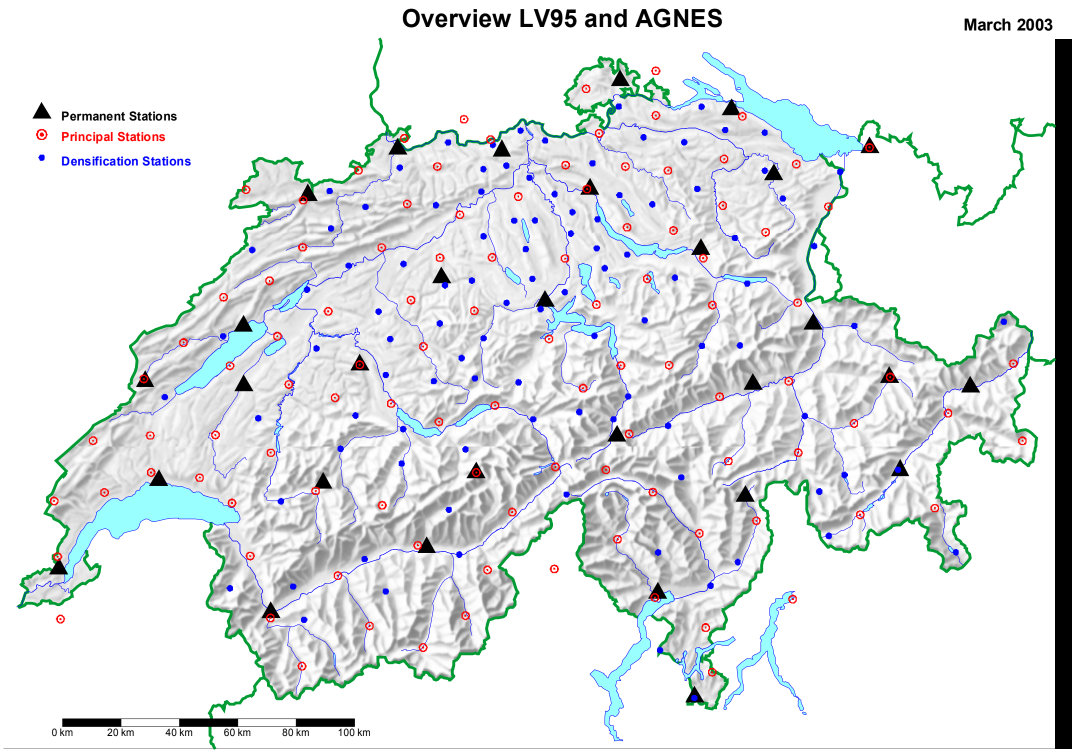


Fig. 1.3: GPS reference network LV95 (main points, densification and connections to neighbouring countries) and AGNES stations in 2003

Densification

Several publications have already dealt with the concept and results of the Swiss national reference network LV95 in detail. In the meantime the planned densification covering the entire country has also been carried out (Schneider et al., 2002). This was promoted accordingly to meet the growing demands of various users (large engineering projects, cadastral survey, etc.). The densified network features station intervals of 10-15 km in the Central Plateau and 15-20 km in the Alpine area. In view of the simultaneously developed AGNES permanent network a further densification is not planned.

Today the new complete network consists of the following station categories:

Reference Network	**Number of points**	**Mean distance** [km]	**RMS** [mm] N / E / U
EUREF EUREF (perm.)	5 [1] 2 [1]	150	2 / 2 / 5
AGNES (perm.)	29 [1]	50	2 / 2 / 5
LV95: main points	104 [1]	15 - 25	10 / 10 / 30
LV95: densification	102	10 - 20	10 / 10 / 30
Transformation: fiducial points old LV03 <-> new LV95	~ 250	5 - 20	20 / 20 / -

[1]) including Austrian station Pfänder

Table 1.2: National GPS reference networks (EUREF, AGNES, LV95): Number of points, density and corresponding accuracy

Maintenance, re-measurements and kinematic investigations

The GPS network LV95 is maintained on a regular basis. The sites are visited every five years, and a re-measurement is planned every five to ten years. The first re-measurement took place in 1998 (CHTRF98) and showed excellent agreement with the first determination (CHTRF95) (see Table 2). The selection of stations also allows kinematic studies of the earth's upper crust (project Swiss 4D) (Wiget et al., 2003). First investigations of the coordinates, however, have not shown any significant coordinate changes due to horizontal crustal movements. Further investigations based on re-measurements are planned for 2004.

Number of points	**Horizontal position**	**Height**	**Scale**
	RMS [mm]	RMS [mm]	[ppm]
138	3.3	12.7	-0.05

Table 1.3: Repeatability of GPS network LV95: comparison of the reference frames CHTRF95 and CHTRF98

Combining Levelling with GPS Measurements and Geoid Information: Recent activities for the new national height system (LHN95) of Switzerland

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

The use of GPS for height determination and for replacing expensive levelling measurements in regions where maximum accuracy is not needed requires a height system in which levelling and GPS in combination with geoid information lead to compatible results. The new national height system of Switzerland, LHN95, is based on geopotential numbers and orthometric heights obtained from a rigorous kinematic adjustment of all available levelling data since 1902 and should fulfill this task (Schlatter and Marti, 2002; Marti et al., 2002a).

But even with this new (orthometric) height system, full consistency between levelling and GPS measurements has not yet been reached. This consistency between orthometric heights, ellipsoidal heights and the geoid can be verified on GPS/levelling stations. Until now, some 150 GPS stations are connected to the national levelling network (see Fig. 1.4). The discrepancies are in the order of several mm up to 2 dm. They are most likely caused by random and systematic errors in all three data sets.

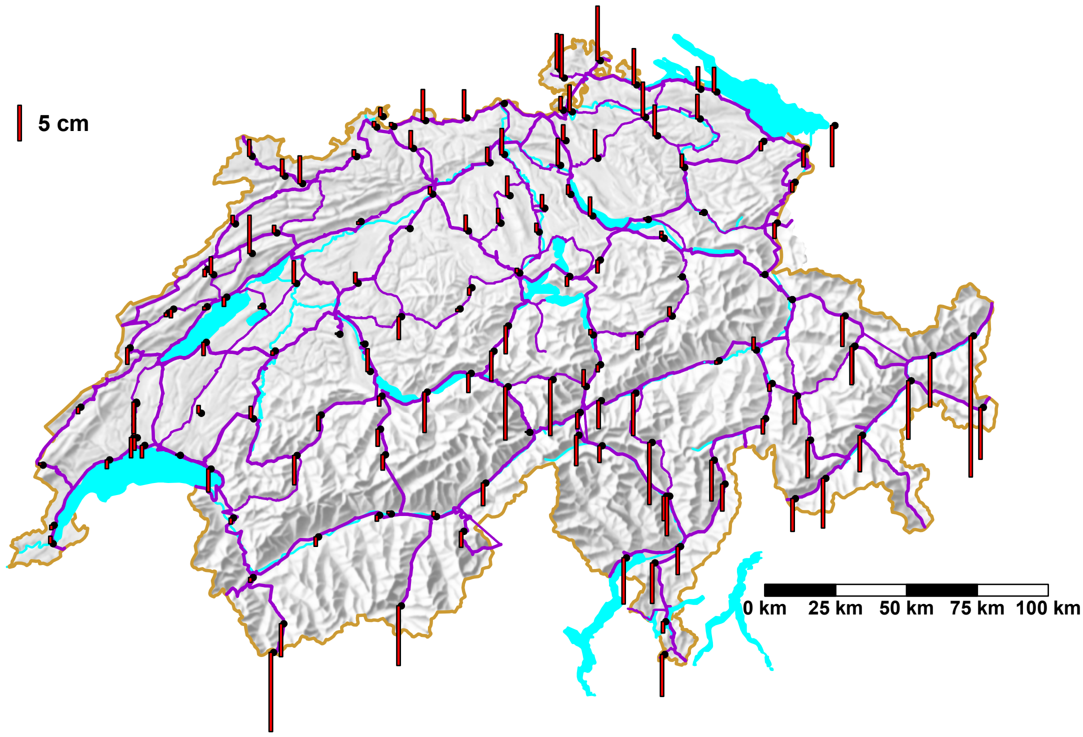


Fig. 1.4: Residuals at GPS/levelling stations (as of January 2003)

Besides regional effects, the residuals show mainly a systematic trend along the north-south axis. The aim is to obtain corrections for the data sets in a combined adjustment. The method of distributing the residuals using the complete covariance matrices for GPS, levelling and the geoid model was first presented in (Marti et al., 2001). The largest part of the discrepancies was assigned to a correction of the geoid. Therefore, swisstopo realized that an improvement of the geoid model would be one of the most important tasks in the next few years. In the scope of a project called CHGeo2003 work has already been undertaken to continue the densification of the GPS/levelling stations (Schneider et al., 2002). This is a further step towards combined geodetic networks as was proposed in EUREF Resolution No.2 in 2002 (Ihde et al., 2002).

The Automated GPS Network for Switzerland (AGNES)

by U. Wild, R. Hug, S. Grünig and E. Brockmann

During the years 2000 and 2001 the pilot configuration of 10 AGNES stations was densified to the final configuration of 29 stations (c.f. fig. 1.5). The mean distance between two stations is about 50-70 km, i.e. the maximum distance to the nearest reference station is about 35 km, which (at least under good conditions) would still allow for RTK positioning. The station heights are between 300 and 3500 meters above sea level.

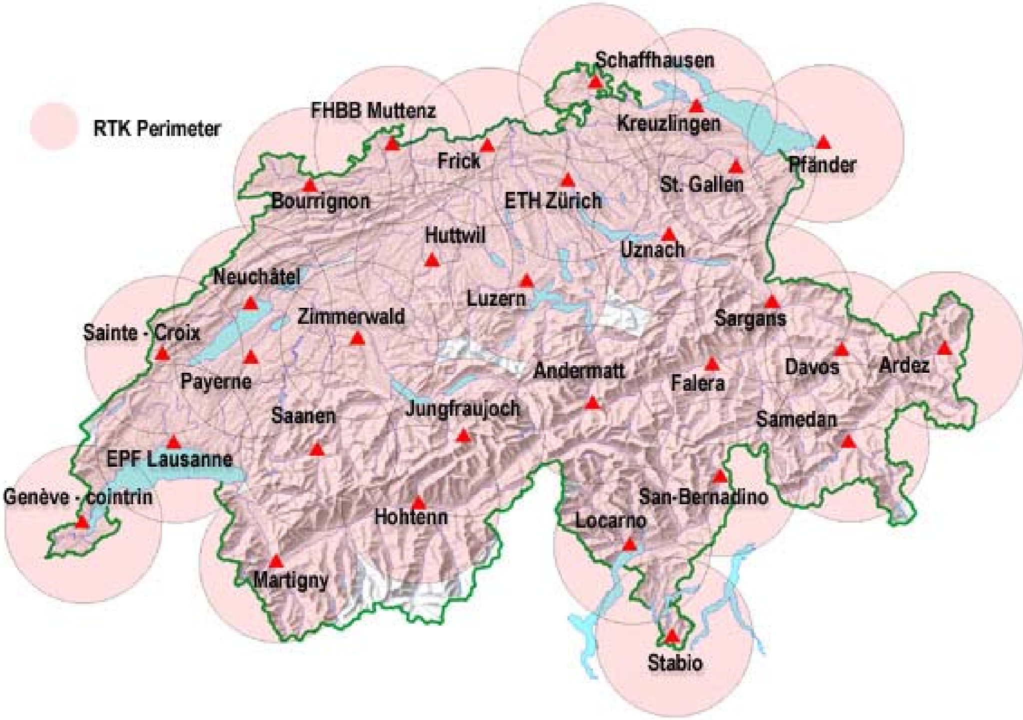


Fig. 1.5: Automated GPS Network for Switzerland (AGNES)

With respect to their monumentation, the AGNES stations are classified as follows: class A with a solid foundation on bedrock and local ties to markers in bedrock; class B without a direct foundation in bedrock (typically on buildings) but with a local tie to markers in bedrock; and class C with neither a direct foundation nor a local tie to markers in bedrock. The 9 class A AGNES stations are well adapted for geodynamical studies, whereas the class B and C stations are mainly used for surveying, positioning and for GPS meteorology.

The AGNES stations are equipped with different receiver (22 Trimble 4700, 6 Trimble 4000 SSi, 1 Leica SR530) and antenna types (21 Trimble Geodetic with groundplane, 6 choke rings, 1 Trimble Zephyr and 1 Leica AT504) without radomes. The antennas of the AGNES stations were calibrated (relative calibration) on a geodetic test network with known ground truth within the millimeter level.

Each AGNES station is equipped with a station PC, which controls the GPS receiver, stores the GPS data locally and communicates with the central control facility via the Communication Network (KOMBV) of the Swiss Federal Administration. For all post-processing applications the data are retrieved from the AGNES stations as 1hour RINEX files with a delay of several minutes after the full hour. For real-time applications in the Swiss Positioning Services (swipos), the data are sent every second in a binary format to the central control facility and to the communication server for access over GSM (Wild et al., 2001a).

Swiss Positioning Service (swipos)

by U. Wild, P. Kummer and S. Grünig

The Swiss Positioning Services (swipos) offers two different levels of accuracy:

- **swipos-NAV:**
  DGPS service over FM/RDS and GSM with meter accuracy for applications in navigation and GIS data collection with low accuracy requirements
- **swipos-GIS/GEO:**

RTK service over GSM with centimeter accuracy, based on the Automated GPS Network for Switzerland (AGNES), for applications in cadastral surveying and GIS data collection with high accuracy requirements

The service swipos-NAV became operational in January 2000 with a nationwide coverage over FM/RDS. After the suppression of the Selective Availability (SA) on 1 May, 2000, the service became unnecessary for a wide range of applications (Brockmann et al., 2001c).

Therefore, the focus was mainly on the RTK service swipos-GIS/GEO, which was established during the years 2000 and 2001 according to the increasing number of AGNES stations. swipos-GIS/GEO is based on the concept of Virtual Reference Stations (VRS), i.e. the user sends his approximate position to the central computation center and receives RTCM correction data which are interpolated for his actual position (Wild et al., 2001b).

swipos-GIS/GEO over GSM was operational in Switzerland from the beginning of 2002. By the end of 2002 and the beginning of 2003, the Swiss real-time network and the corresponding networks in Germany (Baden-Württemberg and Bavaria) were combined in order to offer seamless positioning services between Switzerland, Germany and Austria (planned for 2003) (Wild et al., 2003).

Currently an automatic Integrity Monitoring (IM) of the service is being built up and first tests for the dissemination of RTCM data over Internet (see also EUREF-IP) have been carried out (Brockmann and Wild, 2002b).

The Use of Double Difference Information from Network Solutions to generate Observations for a Virtual GPS Reference Receiver

by A. Jaeggi, G. Beutler and U. Hugentobler

In the framework of a project with the Federal Office of Topography the theoretical background for generating artificial observations for a virtual reference receiver in post processing mode was developed. The use of double difference information from network solutions allows to correct zero difference observations in a preprocessing clock estimation process where the observations can be adjusted on the level of a few millimeters. Applying simple ionosphere and troposphere modeling techniques the artificial phase observations can be calculated for any given location within the network.

The developed procedure makes full use of the ambiguity and ionosphere information from double difference network solutions in order to keep full consistency of the artificial phase observations on the double difference level. The benefit of artificial observations is demonstrated with data from the Automated GPS Network in Switzerland GPS (AGNES). Baseline solutions are found to be determined more precisely (e.g. ambiguity resolution) using a virtual receiver at one end of the baseline (Jaeggi 2001).

GPS Augmentations for Airborne Applications

by O. Perrin, A. Waegli and P.-Y. Gilliéron

Airborne applications are based on different navigation sensors. The Global Positioning System (GPS) has a great potential for navigation purposes in civil aviation. The Geodetic Eng. Laboratory of EPFL has developed activities on the integration of additional sensors to increase the precision of positioning by GPS. The vertical component was especially improved by using a digital barometer in differential mode.

EGNOS (European Geostationary Navigation Overlay Service) will be the European space-based augmentation system. This system augments the performance of GPS by broadcasting differential corrections and integrity information to the user. The Geodetic Eng. Laboratory took part in several tests in collaboration with skyguide (air traffic control in Switzerland). During these trials the EGNOS System Test Bed (ESTB), which is a prototype system for the future EGNOS system, was analyzed. The research focused on the evaluation of the corrections provided by the ESTB. As the ionosphere is the main source of errors in GPS, ESTB ionospheric corrections were compared with other models mostly based on dual-frequency GPS measurements (see fig. 1.6).

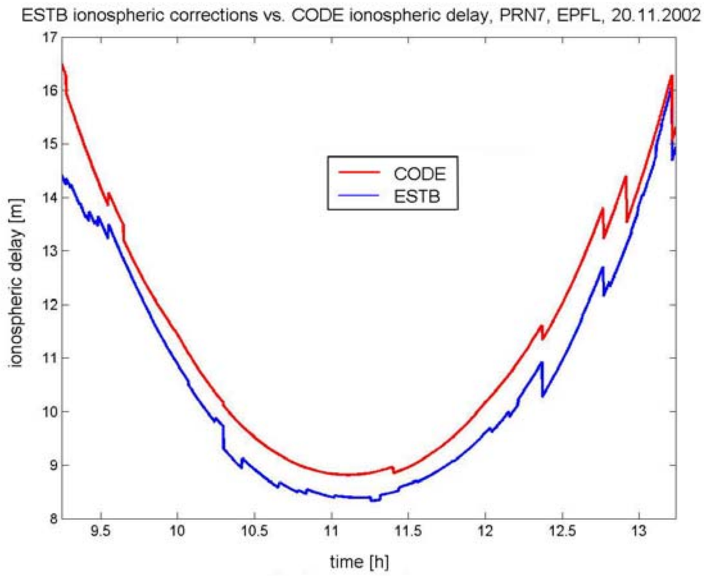


Fig. 1.6: Comparison of the CODE (Center for Orbit Determination in Europe) and EGNOS System Test Bed (ESTB) ionospheric delay

Direct georeferencing by INS/GPS in the Helicopter Environment

by J. Skaloud and J. Vallet

This research presents a self-contained, light and flexible mapping system that can be quickly deployed into inaccessible areas. Although designed to measure wind-transported snow volumes and the snow avalanche runoff over an experimental site, the system is suitable for any large-scale 3-D terrain mapping.

Airborne Data Collection System

This system is composed of an electronic device loosely linked to a light but rigid sensor block containing a camera, an IMU and a GPS antenna (fig. 1.7). The relatively small size and weight of the sensor block permits manual pointing of the camera (film-based or digital) towards either the mountain face or the bottom of a valley. Such hand-held steering allows mapping of the avalanche release and deposit zones during the same flight and also dampens the engine-induced vibration. The exterior orientation (EO) parameters of the camera are determined directly by GPS/IMU integration. The orientation performance of the navigation solution is improved by integrating the data from a second GPS antenna placed on the helicopter tail.

Fig. 1.7: The sensor block

Navigation Data Processing
In order to obtain the best positioning/attitude performance, the inertial data are integrated with GPS double differential code and carrier-phase measurements in a centralized Kalman filter configuration. It is a well-known fact that updating an inertial system with navigation information of better quality prevents the unbounded growth of position and attitude errors. Usually GPS provides a means of 'in-flight alignment' of the inertial system, eliminating the need for the system carrier to be held stationary due to the 'north-seeking' process prior to flight. The accuracy of the in-flight alignment is strongly affected by the dynamics of the carrier. Since the accelerations induced by helicopter maneuvers are considerably smaller than those of an aircraft, this problem needs to be circumvented by other means. Here, the necessary information is derived from a second GPS antenna placed at the tail. Thanks to a relatively long (5 meter) distance between the GPS antennas, a GPS-derived azimuth is sufficiently accurate and can be used as additional information aiding the IMU. Practical experience showed that this helps in achieving and maintaining alignment accuracy of 0.01-0.02 deg.

GPS Meteorology: Contributions of swisstopo to COST-716

by E. Brockmann and D. Ineichen

Since 1999 the Swiss Federal Office of Topography has been active in the European project COST-716 (exploitation of ground-based GPS for climate and numerical weather prediction application). After a successful benchmarking (van der Marel et al., 2001), swisstopo has been contributing zenith total delay estimates in near real-time (NRT-ZTD) since December 2001. Fig. 1.8 shows the stations used. In addition to the 29 AGNES sites, 20 EUREF sites are processed. Furthermore, about 12 sites from other networks, mainly in France, are being used in order to improve the station distribution in the western part of Europe. This area is important because the dominating weather conditions from the Atlantic Ocean usually pass over France before they reach Switzerland. 95% of the solutions arrive at the data archive of the UK met office within 1 hour and 45 minutes.

MeteoSwiss used the NRT-ZTD estimates in a test study for numerical weather prediction. The numerical forecast models were computed for the different test periods (summer, winter, autumn) in two different ways: A run with assimilated GPS-derived ZTD estimates and a run without assimilated ZTDs were carried out. A comparison of the results showed a positive impact of GPS (Guerova et al., 2002) for summer and a slightly negative impact for winter. A by-product of the hourly processing is the monitoring of the site coordinates. Cumulative solutions averaging 12-24 hourly solutions allow the detection of coordinate changes of the order of 2 cm.

Since January 2003, ZTD values can even be extracted from the real-time positioning software GPSNet 2.0 with accumulation intervals of 1 minute with a negligible time delay. swisstopo will also be active in the follow-up European project TOUGH "Targeting Optimal Use of GPS Humidity Measurements in Meteorology " (2003-2005).

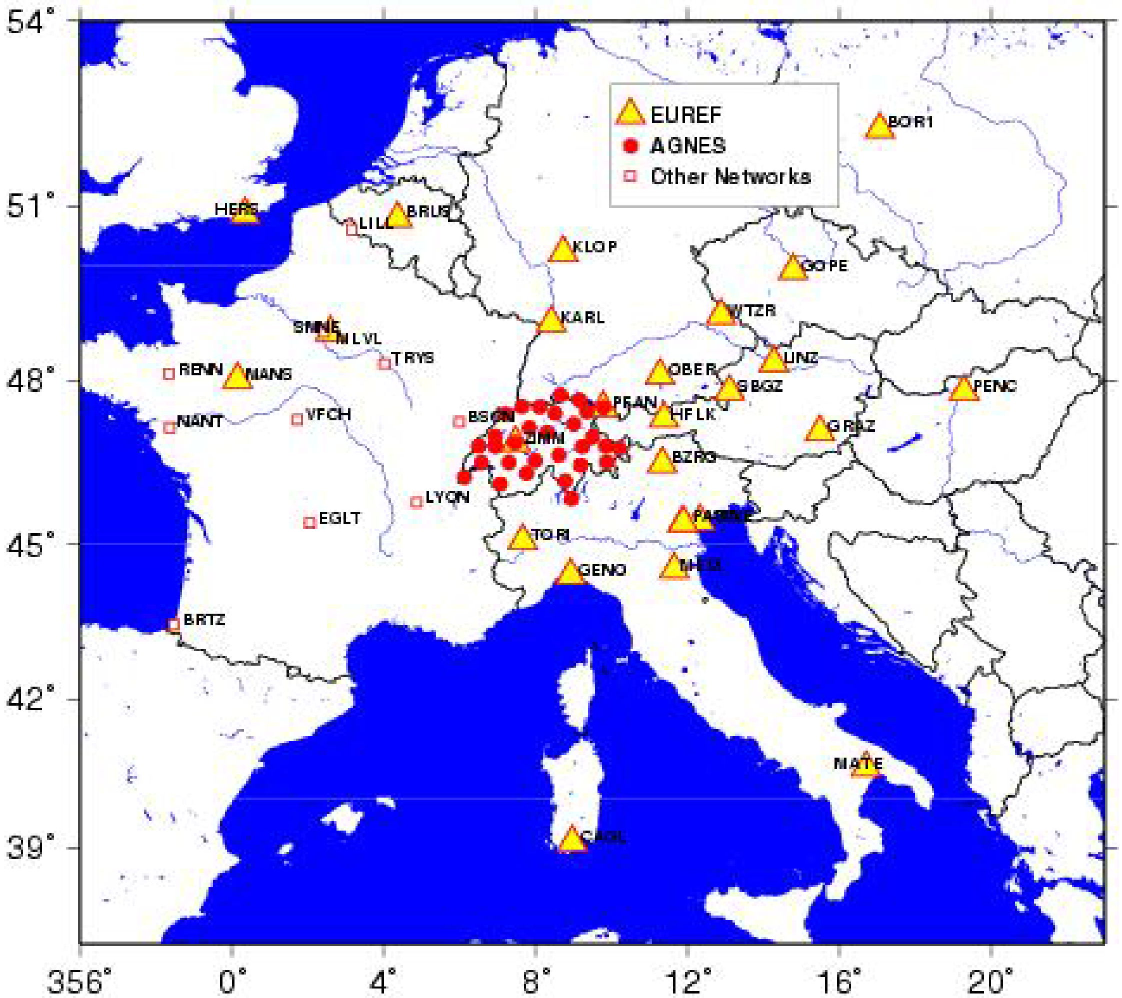


Fig. 1.8: European permanent GPS stations processed by swisstopo in the COST-716 project

Microwave Water Vapor Radiometry

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

The Water Vapor Radiometers (WVR) as developed at the Geodesy and Geodynamics Lab (GGL) in collaboration with Captec, Biel, Switzerland, have been deployed in several national and international projects. In addition to other instruments sensing tropospheric water vapor such as radio sondes, GPS, and solar spectrometers (see contribution of Somieski et al.), these instruments incorporate an independent data source. Hence they represent an external validation tool which can be applied e.g. in dedicated GPS networks designed for GPS Met purposes. In order to improve the overall performance, reliability, and high serviceability, the instruments owned and operated by the GGL have been subjected to substantial changes. The hardware as well as the software have been upgraded such that the instruments now are capable to operate unattended.

In a first application the new type of WVR has been applied in the frame of the project ESCOMPTE (http://www.ggl.baug.ethz.ch/research/wg55/escompte.html, and http://medias.obs-mip.fr:8000/escompte/maquette/projetESCOMPTE.php3).

Figure 1.9 shows the observed water vapor in terms of integrated Zenith Precipitable Water vapor content (ZPW) observed at the station Vallon Dol, France for the time period from june 13. to 22. 2001. The radiometric measurements reveal a good coincidence with solar spectrometer, radio sonde, and GPS measurements.

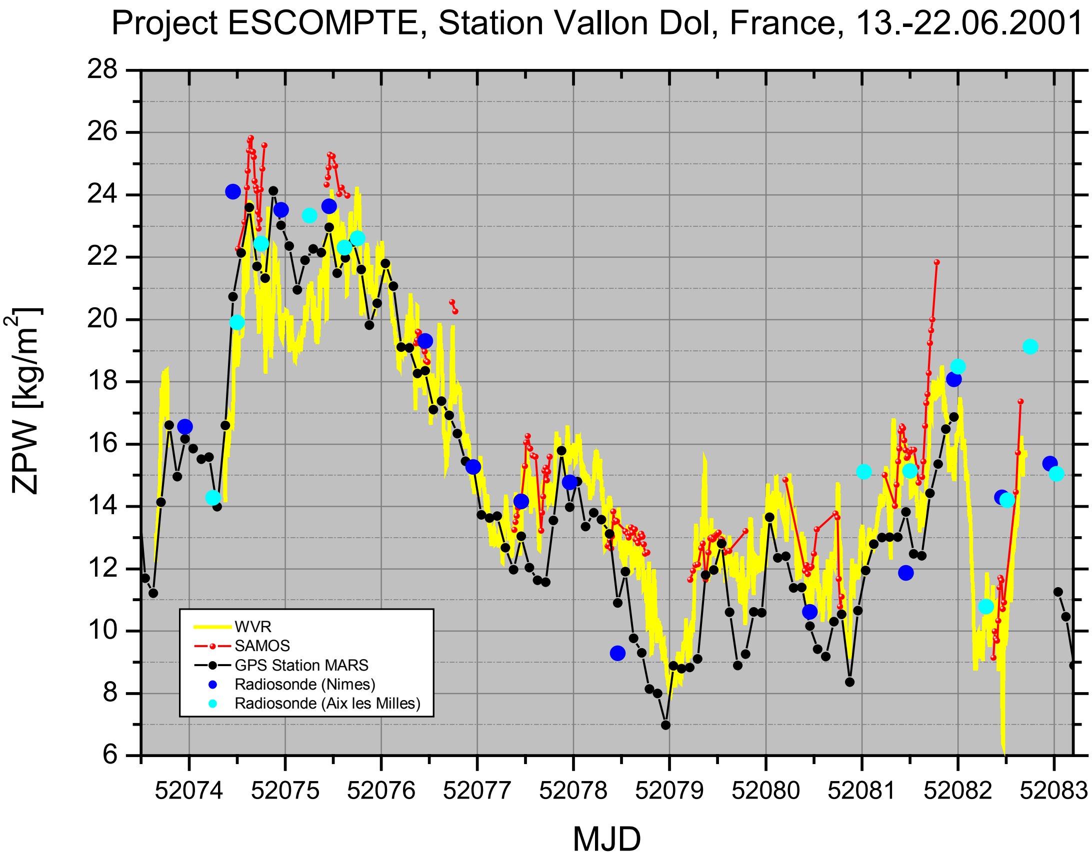


Fig. 1.9: Integrated Zenith Precipitable Water vapor (ZPW) content as observed with GPS (black), solar spectrometer (red), water vapor radiometer (yellow), and radio sondes (turquoise/blue).

During fall 2002 a common calibration campaign has been carried out at the Geo-fundamental station of Wettzell, Germany. The main goal of this project, which was carried out in collaboration with several European partners from Belgium, Germany, and Switzerland, was an intercomparison and –calibration between different types of instruments and methods.

Development of Geodetic MObile Solar Spectrometer GEMOSS I

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

The water vapor in earth troposphere causes refraction of transatmospheric microwave signals and limits the accuracy of high precision GPS positioning and satellite radar altimetry. For remote-sensing of tropospheric water vapor a new Geodetic MObile Solar Spectrometer (GEMOSS I) has been developed at the Intitute of Geodesy and Photogrammetry (IGP, Group of Prof. H.-G. Kahle) and the Institute of Spectrochemistry and Applied Spectroscopy (ISAS) in Berlin. GEMOSS I is based on an improved optical construction, which is permanently adjusted with high accuracy by 5 computer-controlled step motors. Within a single GEMOSS spectrum appr. 1900 water vapor absorption lines of sun radiation are measured in the large range between 730 nm and 910 nm simultaneously. Furthermore the optimized light sensitivity of the GEMOSS I allows its deployment under low-level radiation conditions and thus increases the time period of data acquisition. In the framework of the EU-project GAVDOS first successful measurements were carried out on the island of Crete (Greece) to calibrate the JASON altimeter satellite. Figure 1.10 shows the zenith wet path delay (ZWPD) measured by GEMOSS I at the January 11th 2003, when the JASON satellite crossed over Crete. Since the retrieval of ZWPD is based on the analysis of more 40 different water vapor absorption lines an accuracy of appr. 0.5 cm could be achieved.

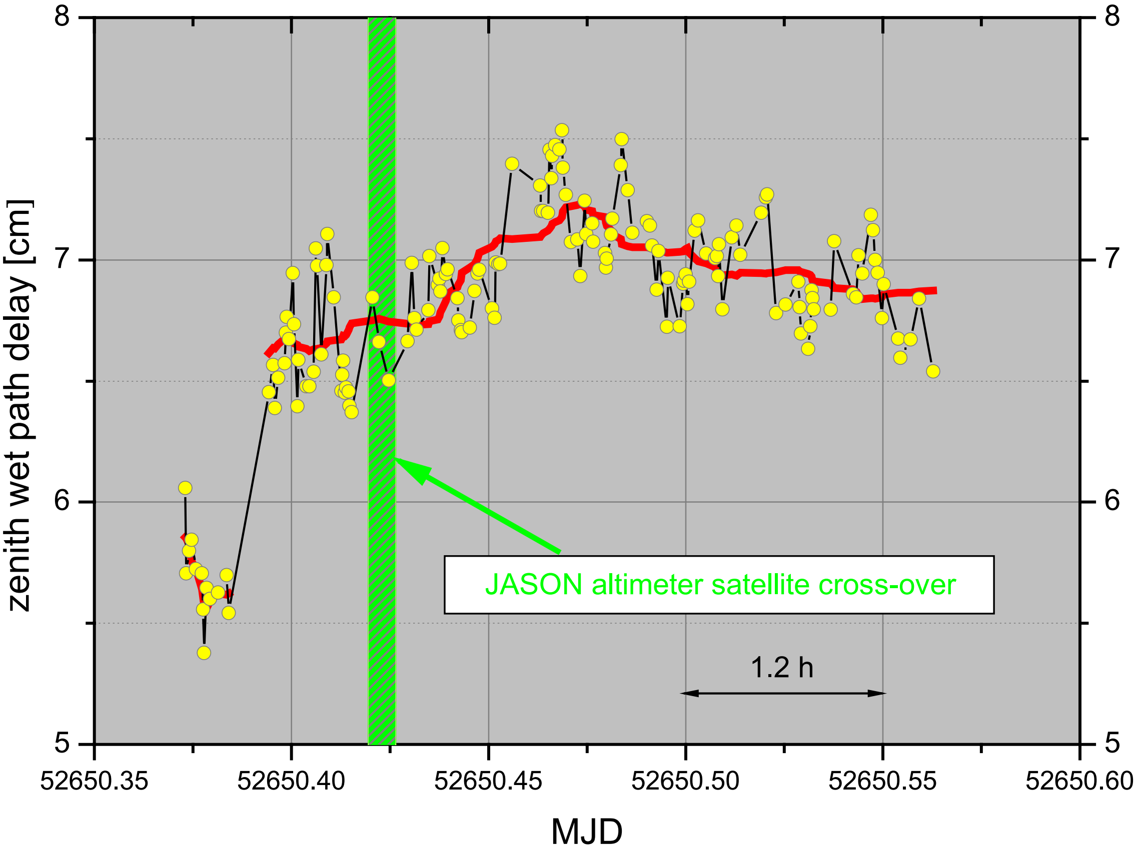


Fig. 1.10: Zenith wet path delay during the overflight of JASON satellite as observed near the ground track at Crete (Greece) by means of the Geodetic Mobile Solar Spectrometer GEMOSS I:

Determination of the 3 Dimensional Refractivity Field: GPS Tomography

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

It is commonly accepted that GPS meteorology can be successfully used to model the refraction effect on radiowave signals traversing the troposphere. We developed a method to estimate and model the spatial distribution of the tropospheric water vapor. A tomographic software package called AWATOS has been realized. It is based on the assimilation of GPS double difference observations. These are allocated to a voxel model, which is defined according to the distribution of the GPS stations. Performing a least-squares adjustment, the refractivity of each voxel is determined. Tests of the software were performed, based on simulated and real data. A field campaign was initiated on the Big Island of Hawaii, which is ideal for test purposes because of an already installed dense GPS permanent network (c.f. fig. 1.11), associated with large height differences between the stations. The tomographic profiles of the real data sets were compared with 18 radiosondes launched during the campaign. The results obtained for continuous atmospheric conditions fit well (c.f. Fig. 1.12). The statistical evaluation revealed an accuracy of around 5-20 ppm for the wet refractivity. However, the special conditions on the Hawaiian Island have to be kept in mind. The distribution of stations from sea level to a height of over 4000 m is exceptional.

Our group participated in the joint meteorological project ESCOMPTE (Field experiment to constrain models of atmospheric pollution and emissions transport). Together with six French research groups on

GPS meteorology, we operated a GPS network in the project area of Marseille. In this project, the height distribution of stations from sea level to only 600 m is very unfavourable. For comparison, a set of instruments for remote sensing of water vapor was also used. The data analysis of this project is in progress [Bock et al., 2002a, 2002b].

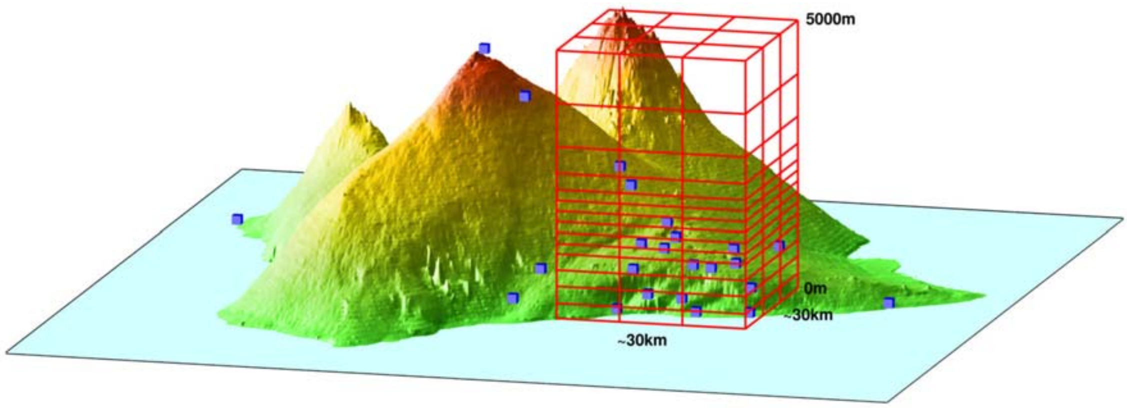


Fig. 1.11: Core of the tomographic voxel model for the Hawaiian campaign. The model consists of 16 layers of 3 x 3 core voxels. Blue boxes show the location of the GPS stations.

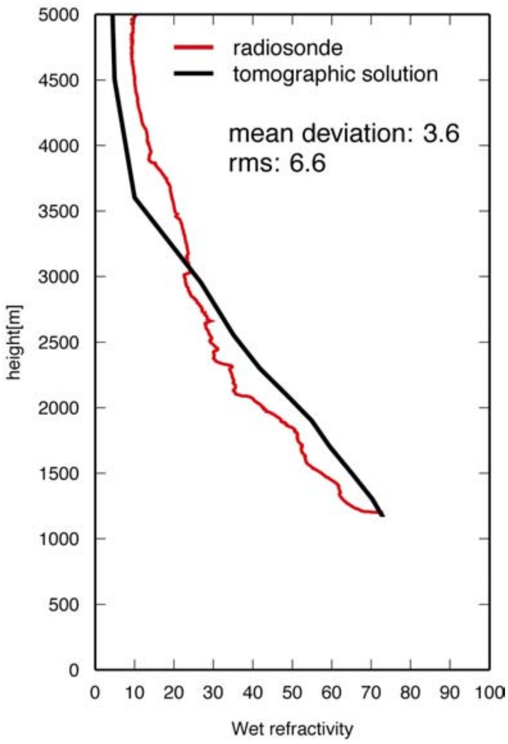


Fig. 1.12: Sample of a wet refractivity profile at station Volcano Village.

For further details see the project page on: http://www.ggl.baug.ethz.ch/research/wg56/

Modelling of GPS estimated path delays

by M. Troller, E. Brockmann, A. Geiger

High-precision GPS measurements require the modelling of the tropospheric refractivity field in order to correct for atmospheric refraction effects. Nowadays, the potential of the increasing number of GPS permanent stations can be utilized. Usually, the network is automatically processed, and GPS estimated path delays are available. We developed a software package COITROPA (Collocation and Interpolation of Path Delays) to model the GPS estimated path delays based on least-square collocation.

The AGNES network, which covers the whole Swiss territory, represents an optimal GPS network for our approach. Calculations were done during several years. Time series of various stations demonstrate that the accuracy is increasing continuously with a rising number of permanent stations. The success of this method was verified with statistical analysis. Hence, an accuracy of less than one centimeter was achieved (c.f. fig. 1.13).

For details see the project page on: http://www.ggl.baug.ethz.ch/research/wg60/

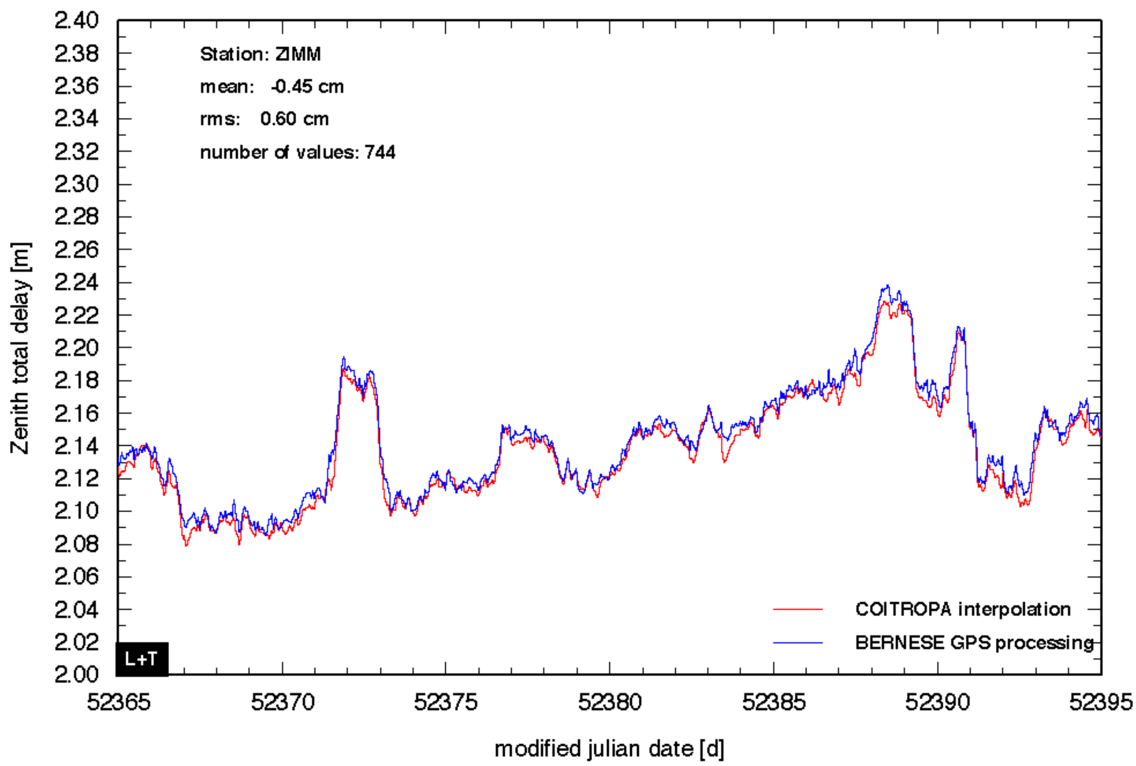


Fig. 1.13: Zenith total delay on station Zimmerwald (ZIMM) aquired with the COITROPA software package. For comparison, the GPS estimated path delay obtained with BERNESE GPS processing is plotted.

4 Dimensional Meteorological Modelling of Pathdelays (COMEDIE)

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

Tropospheric path delays represent a main error source in GPS precise positioning. We developed a software package COMEDIE to model the meteorological parameters pressure, temperature and water vapor pressure in 4 dimensions (space and time). The path delays are influenced by these parameters. COMEDIE allows to integrate the path delay along an arbitrary ray. An accurate modelling requires a dense network of meteorological measurements. The ANETZ network of MeteoSchweiz contains 72 stations, distributed over the entire Swiss territory. However, the height distribution of the network is not optimal. To obtain reliable values for the refractivity field in the upper layers of the atmosphere, radiosonde data are mandatory. So far, we used this method mainly in Switzerland. GPS estimated path delays of IGS stations (station Zimmerwald), the AGNES network and the MAGIC project (Meteorological Applications of GPS Integrated Column Water Vapor Measurements in the Western Mediterranean, station Zimmerwald) are used for comparisons and statistical analysis. The evaluations show a good agreement of the COMEDIE data with the GPS estimated values (see fig. 1.14). A RMS of around 1 cm was achieved.

For details see the project page: (http://www.ggl.baug.ethz.ch/research/wg37/)

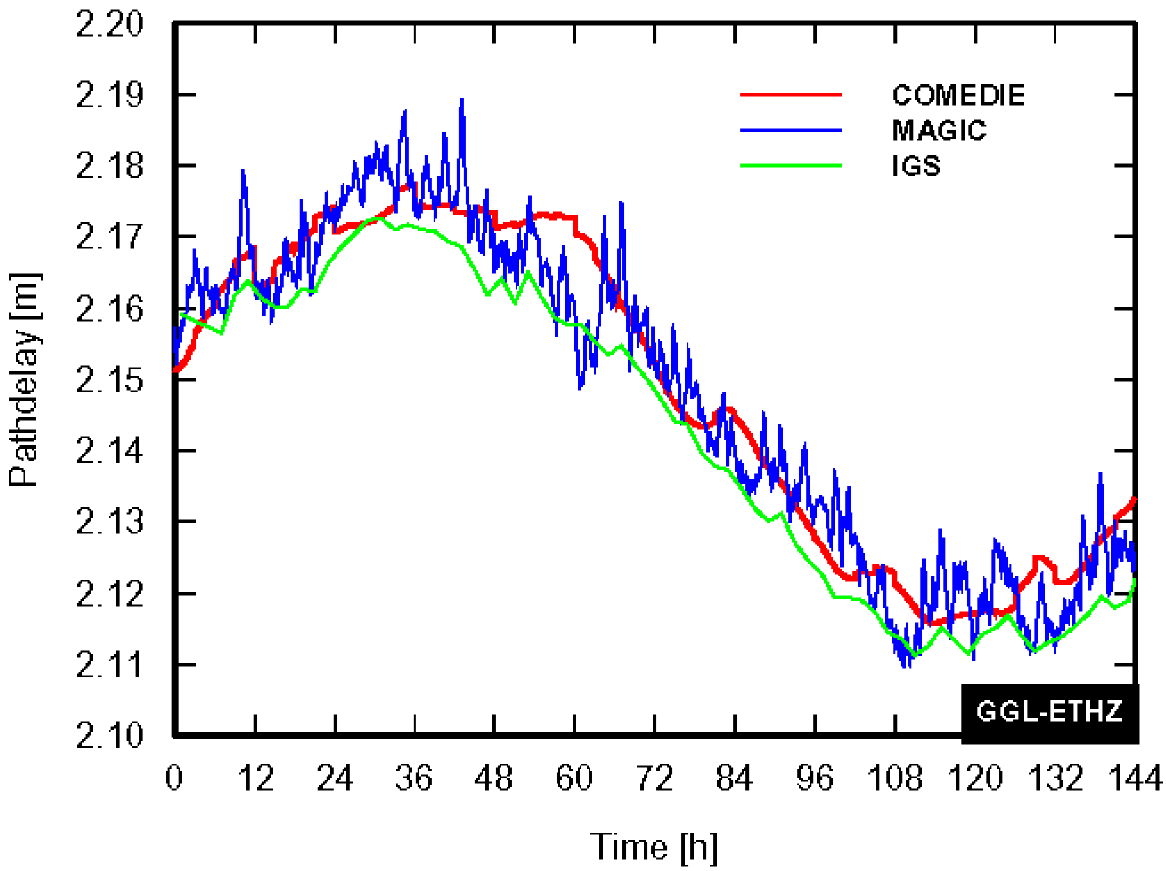


Fig. 1.14: Total zenithal delay on stations Zimmerwald (ZIMM) aquired with COMEDIE and the GPS estimated processing of IGS (2 hours mean) and MAGIC (15 minutes mean).

Precise Determination of Offshore Sea Level

by A. Geiger and M. Cocard

New buoys have been designed based on previous experiences. The newly developed buoys have a displacement of 10 kg which is a significant weight reduction compared to the predecessor. With its 40 cm diameter it can easily be handled. The dimension of the buoy, weight of battery, receiver, and antenna have optimally been chosen and designed in order to reach the exact floating balance. No ballast is needed to stabilize the buoy or to reach the foreseen floating line in the middle of the spherical buoy. The shell is fabricated from polycarbonate, which is transparent for the microwaves also. Therefore, the whole buoy can be waterproofed sealed containing the battery, receiver and antenna (fig. 1.15). The buoy is designed to accommodate Novatel DL-4 receiver. The new pinwheel antenna is used. The operation autonomy reaches about 20 hours. For the experiment the measurement rate will be set to 0.5 sec sampling interval, producing about 5 MB data per hour. First tests where successfully completed. The data is processed by own kinematic software which is able to calculate long baselines in kinematic mode.

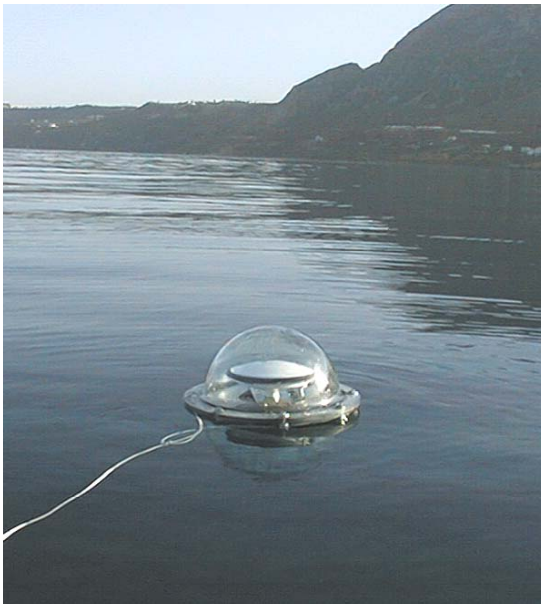


Fig. 1.15: Light weight buoy for sea level surface flow determination in a friendly sea

Sensor Attitude Determination Using GPS Antenna Array and INS

by E. Favey, A. Geiger and M. Cocard

Many airborne laser scanning systems acquire the sensor's attitude relying on a very accurate, yet expensive inertial system in conjunction with a single GPS receiver for trajectory recovery. For any type of airborne imaging sensor or laser scanning system, correct attitude measurements are crucial to the production of accurate data. We have developed an approach to acquire the sensor attitude using a combination of an array of single frequency GPS antennas together with an Inertial Measuring Unit (IMU) measuring at a sampling rate of 100 Hz. The drift of the IMU is stabilized by a 4 Hz attitude update acquired by GPS. The attitude of the two independent methods are compared with each other. The information is further merged to process airborne laser scanning data, which in turn serves to estimate the attitude quality by comparing the height of the resulting digital surface model with known ground information. The laser employed was ScaLars II owned by the Institute of Navigation, Univ. of Stuttgart. This laser also provides intensity images, which allows to verify the horizontal position of the laser footprint with known ground truth. The results from a variety of real flight data were used to estimate the total system's accuracy. Sensor dependent issues like IMU drift, GPS ambiguity resolution, and merging GPS with IMU data are also assessed. An overall accuracy of about 17 cm seems to be feasible.

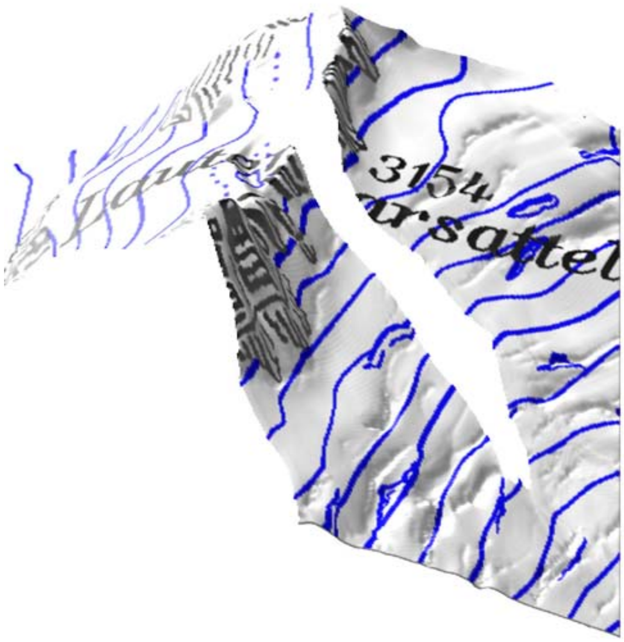


Fig. 1.16: DTM of Unteraarglacier measured by airborne Laserscanning without any passpoints. This measurement can be compared to future survey in order to determine the glacial retreat.

Monitoring Three-Dimensional Movement, Oscillations, Rotations in Structural Engineering

by A. Geiger and M. Kistler

The monitoring of the three-dimensional movement inclusive the rotations of built structures is sometimes difficult. In different cases GPS can ease the task. We developed a tool to determine the complete three-dimensional movement of a structure by GPS. It is based on multiple antennae arrays. As an example of application we mention here the determination of the exact position of the path of a cabin of a ropeway. This curve is not visualised by a cable or a rope, it is so to say a virtual curve. 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 exactly be known positioning by GPS can help. 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 using at least three GPS receivers on the cabin. In this paper it is 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 rotations) of the ropeway. The frequency and the amplitude of different oscillating modes induced by an emergency stop can clearly be determined.

Performance Analysis of Cellular Positioning Methods for LBS and Navigation

by A. Geiger, Ph. Kehl and St. Ziegler

The analysis aims at three main points: Quantitative estimation precision without knowledge of exact antenna sites, a priori analysis in regions where antennas are not yet installed and extract general characteristics of a network in view of navigation.

For these investigations we first developed and implemented algorithms which are based on continuous antenna-distribution rather than on discrete position of the antennae (see section 4). In a first step the density of base stations is defined. The density is calculated by division of the number of antennae within a defined area. Instead of fixing the value of the area we fix the number of antennae, which shall be included in a minimum circle around the point under consideration. The maximum radius of the circle is 35 km corresponding to the maximum range of operation for the GSM technique. If no antenna is found within such a circle, the density will be set to zero. The bigger the number is chosen, the smoother the density function will appear. Numbers of 4, 7, 10 have been analysed.

The algorithms for calculation of the precision of formal variances of the positioning correspond to the classical (over-determined) least square solution. However, the discrete positions of the antennas are replaced by distribution functions (or densities) and sums are converted to integrals. The fundamentals of this method have been developed for qualitative analysis in satellite geodesy and for error assessment.

The equations are modified for Cell-Identification (CID), angle of arrival (AOA), observed time difference (TDOA), and for combinations of these measurement methods. The corresponding density is calculated by setting the number of antennas within the minimum circle to 4. From densities the precision can be calculated and represented. As an example the precision (in m) of AOA is shown in figure 1.17. The area of the canton of Zurich is depicted. The precision of Cell-ID is directly correlated to the density of antenna, whereas AOA and TDOA are susceptible to the geometric distribution of the antennae. Typical error curves can be recognized for the AOA method especially when antennas are aligned along e.g. an autobahn (see red ellipse in fig. 1.17).

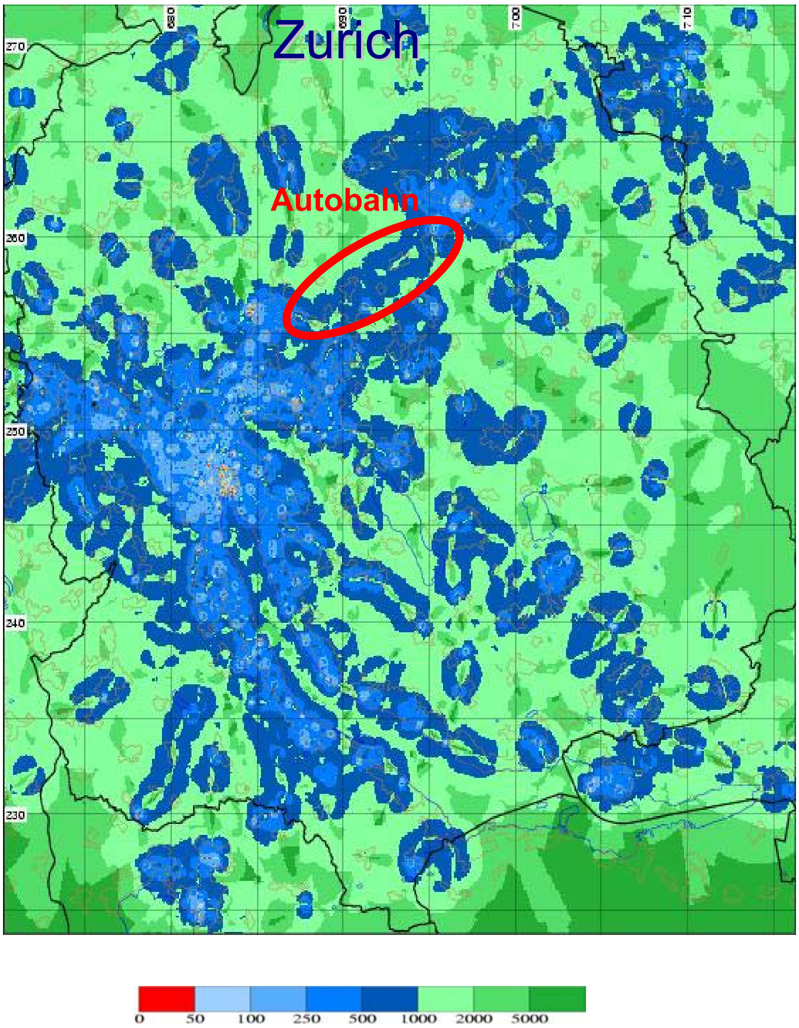


Fig. 1.17: Precision of Positioning by using angle of arrival technique (AOA) in [m]. Typical error figures can be recognized especially when antennas are aligned along e.g. motorways (indicated as autobahn).

This new method allows to deduce general statements on the performance of existing and planned networks. Antennae density can be predicted by a functional algorithm, which takes population, number of work places etc. into account. The predicted densities can directly be introduced in navigational performance analysis. The analysed data showed that the TDOA is not very sensitive to density whereas CID depends strongly on density. This may lead to the statement that CID is well suited for business centres; rural areas however, will be poorly covered by good precision from CID. The following table may sum up these findings in terms of suitability (+++ good, ---bad):

Environment	TDOA	AOA	CID
Centres	++	+++	+++
Urban	++	+	-
Rural	++	--	---

Determination of Thermal Stratification and Turbulence of the Atmospheric Surface Layer over Various Types

by A. I. Wejss and P. Flach

Refraction is a detrimental problem in terrestrial optical measurements and can be regarded as major source of systematic errors in the precise determination of distances and directions. In general, refraction is a function of the density inhomogeneities of the propagation medium. As the "classical" method of temperature-gradient determination does not meet the requirement of a representative integral determination of the refractive index gradient field, several methods to determine and correct the refraction influence have been developed further during the last few years at the Institute of Geodesy and Photogrammetry of the ETH Zürich.

The approach focuses on the determination of the refractive index gradient in measuring the turbulence of the air by scintillometry using the Scintec SLS20 displaced beam Scintillometer. The turbulent sensible heat flux can be converted by the Monin-Obukov-Similarity into temperature gradients. The advantage of optical scintillation measurements is to derive line-averaged turbulence parameters of the atmospheric surface layer. Up to now this method was said to be restricted to homogeneous surfaces and flat areas. The approach of Alexandra Weiss and Philipp Flach should determine to what extend this method can be applied in inclined areas and inhomogeneous surfaces. Several measurement campaigns – among others the Mesoscale Alpine Program (MAP) – represented the data base of this thesis. All measurements were carried out redundantly in conjunction with other methods such as Sonic, CCD-Cameras, etc.

As a main result it could be demonstrated that the turbulence approach can be extended to areas with inhomogeneous and inclined surfaces. Based on these most encouraging results, the present thesis can be considered as an important milestone in the progress of scientific geodetic and meteorological knowledge and will consequently lead to further research work.

Development of the World's Most Accurate Absolute Electronic Distance Meter (EDM)

by R. Loser

Based on the actual Mekometer principle with polarization modulation, a new EDM for precision tracking of fast moving targets has been developed and tested in a joint project of TU Munich, Leica Geosystems, and IGP/ETH. The key technology to achieve the ambitious specifications of micrometer accuracy was the change from analogue to digital synthesizing procedures and sophisticated real-time data processing. In the mean time, the sub-micrometer accuracy EDM has been successfully implemented into Leica Lasertrackers (fig. 1.18) for industrial metrology and is used in a NASA application.

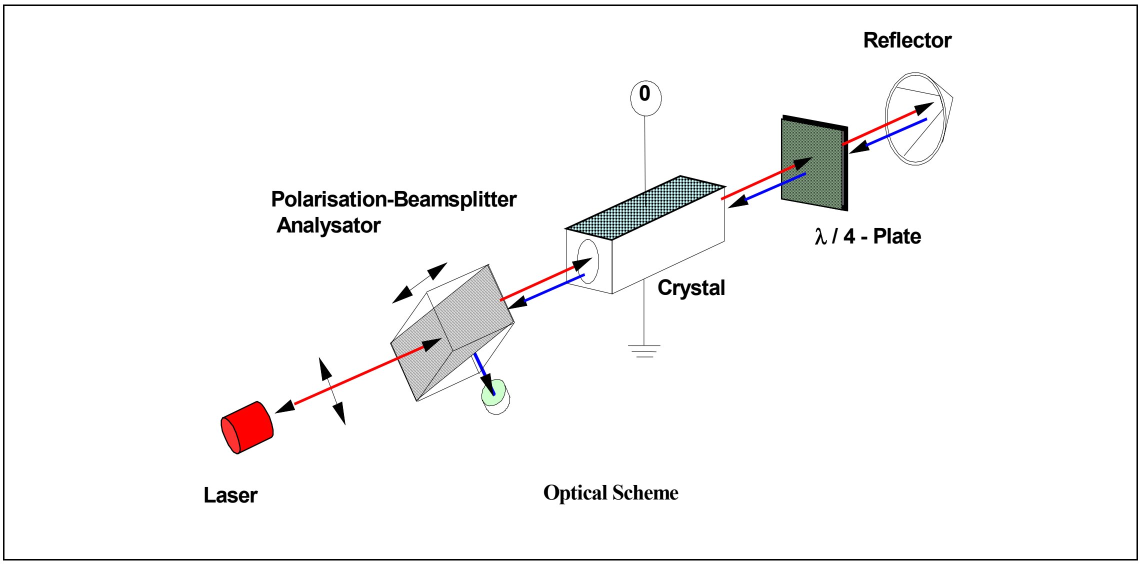


Fig. 1.18: Functional principle of the EDM

Nanometer Detection Enables Refraction-Free High-Precision Direction Measurement: Development of a Compact Laser Dispersometer

by B. Böckem

The actual limitations in direction and distance measurements are the propagation and distortion of wave fronts in the air. One approach to overcome these limitations is the so-called dispersometer technology based on a two-color method using laser beams with two extremely separated wavelengths of light spectrum. In collaboration with the ETH Laboratory for Solid State Physics we succeeded in generating an adequate laser source by doubling an infrared laser source with a Caliumniobate crystal (see fig. 1.19). For the functionality it was necessary to detect the blue and infrared laser spots in the focal plane of a short focal length geodetic telescope with a resolution of a few nanometers. This has been achieved by the new so-called GAP technology which is based on a special semiconductive effect in differential optical position-sensitive detectors.

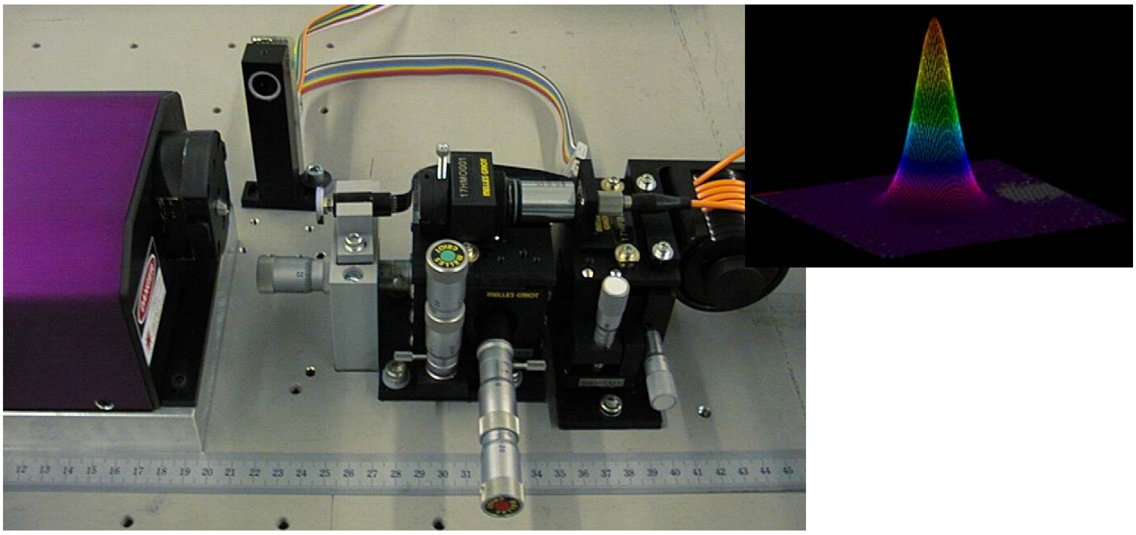


Fig. 1.19: The two-color light source of the ETH dispersometer

The effectiveness of this method is demonstrated by the fact that the noise of the refraction-free direction is white. With this method it will be possible to control the trajectory of construction machines with the required accuracy and reliability.

A New Hydrostatic Level System (HLS) for Permanent Height Monitoring of the Neutron Light Source at the Paul Scherrer Institute (PSI)

by H. Ingensand and E. Meier

A newly designed high-precision Hydrostatic Level System (HLS) has been developed to monitor the vertical position of the quadrupoles at the Paul Scherrer Institute (PSI) with an accuracy of a few microns (c.f. fig. 1.20). This development is the result of a cooperation of Edi Meier and Partners in Winterthur, Stanford Linear Accelerator (USA) and the chair of Geodetic Metrology of the ETH Zürich.

The basic function of the HLS sensor is the determination of the level of a fluid, representing the local reference horizon, by measuring the capacity between the fluid surface and the internal electrode. The circuit of the neutron light source has a length of 560 m and is sectorized into 48 girders carrying the quadrupoles. Each girder is controlled by 4 HLS sensors and can be levelled individually by electric devices. For permanent monitoring a total of 204 sensors send their signals via CAN bus system to a central computer. The HLS has been in operation since November 2000.

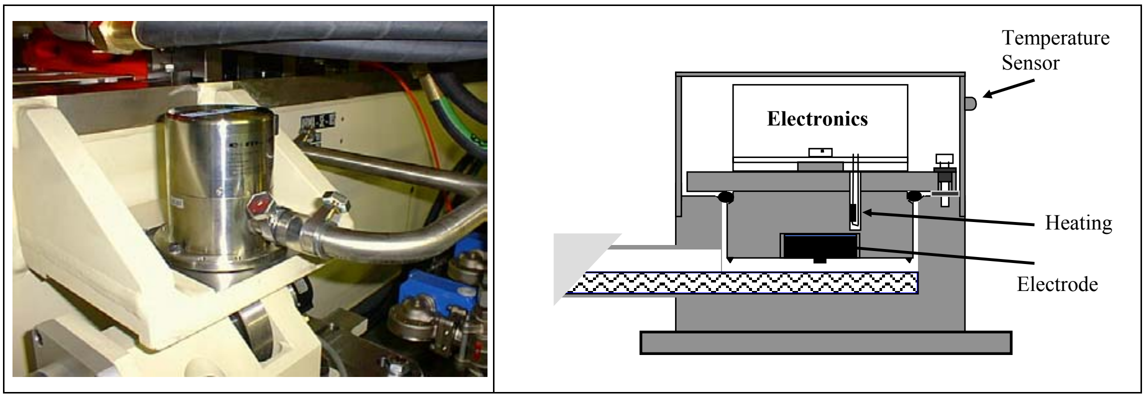


Fig: 1.20: HLS mounting and cross section of the sensor

Establishment of an Automatic Multisensor Dam-Monitoring System

by H. Ingensand and R. Stengele

With respect to the Alptransit tunnel construction in the region of dams, a high-resolution optical multi-sensor monitoring system had to be established. One detrimental effect of tacheometric optical 3-D measurement is the refraction in the area of dams because of the temperature gradients in the shadow of dams. Besides the classical correction technology with single point atmospheric data acquisition, a new approach of local scale correction has been evaluated and implemented to overcome the aforementioned effect. This joint project of Swissphoto/Gruenenfelder and ETH will have a ten year duration period.

The Development of an Alignment System for the Slab Track

by R. Glaus

On new railway lines, a novel construction technique becomes widely accepted in tunnel sections. For the so-called slab track, sleepers are – in contrary to ballast tracks – attached in concrete. The advantage of this method over conventional ballast tracks is the considerably lower maintenance expense. Paving over implicates that corrections to the track alignment are only possible with great efforts. Thus, the alignment of the track has to be carried out extremely accurately. The Institute of Geodesy and Photogrammetry developed an alignment system for staking out the slab track. The system is based on an electronic tacheometer and a track trolley as shown in figure 1.21. The track trolley serves as a platform for inclination sensors, odometers and a track gauge measuring system and was constructed by the HTA Burgdorf in collaboration with terra vermessungen AG, Zurich. The developed track alignment system combines the measurements of the involved sensors and computes correction values of the actual track with respect to the nominal track. These values are used by operators for the alignment. The system is successfully used in the Zurich-Thalwil tunnel by Grunder Ingenieure AG for installing 15 kilometers of slab track. The project is financed by KTI (Kommission für Technologie und Innovation, Bundesamt für Berufsbildung und Technologie).

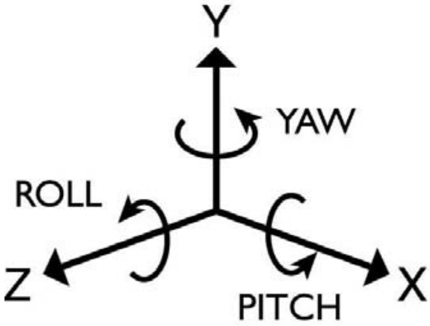
Fig. 1.21: Alignment of the slab track using the track trolley

High-Precision Alignments with 2-Axes Wire Position Sensors

by H. Dupraz, W. Coosemans, F.Ossart and V. Bourquin

HISTAR (High-Speed Train Aerodynamic Rig) is a project for constructing a highly flexible reduced-scale rig for studying the aerodynamics of high-speed trains operated in a controlled atmosphere. Besides the numerous problems associated with the propulsion and guiding system, the specifications of the facility are characterized by significant constraints of the alignment of the 250-meter track, composed of 40 six-meter steel girders and located in an underground gallery.

According to the expertise acquired at CERN over numerous years, this problem can be better treated by the construction of a "surveying train" that carries a number of sensors (e.g. the inclinometers and electric wire position measure) and performs all necessary measurements. After calculating the appropriate corrections, the adjustment of the aligning components is performed by means of a "Six Strut" support system. The basic idea is simple: the position of a rigid body in space has six degrees of freedom: X, Y, Z, and angular: pitch, roll, and yaw. A support system which uses six orthogonal links, or struts, provides "kinematic" support, that is, just enough support with no additional constraints which could stress and distort the body itself (see fig. 1.22). The struts have ball-jointed end connections, and are arranged orthogonally to simplify position adjustments.



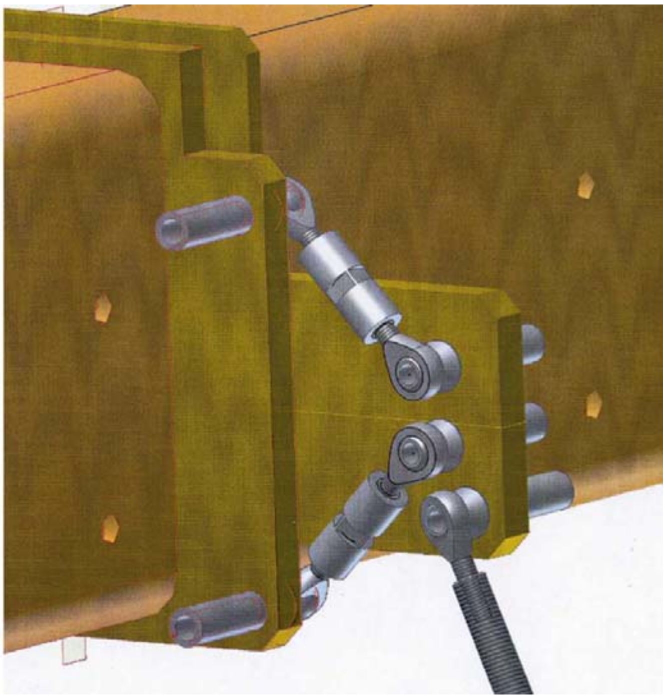


Fig. 1.22: View of the support system for alignment

A Mobile Mapping System for Automating Road Data Capture

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

Mobile mapping systems (MMS) currently integrate available navigation techniques, digital 3D photogrammetry, digital mapping and GIS technology. Such complex systems can be very productive when adapted for a complete acquisition of road data; however, their use usually requires a highly qualified team. The concept of the project *Photobus* is to provide a simple system that is based on standard components and is easy to use.

Photobus is a mobile mapping system for road data base management. Several devices are mounted in a mobile terrestrial vehicle that performs an automated survey of specific road features such as centerline, marks and signs at speeds up to 100 km/h (c.f. fig. 1.23).

These devices include Global Positioning System (GPS) receivers, an Inertial Navigation Unit (IMU), a Charge-Coupled Device (CCD) camera(s) and an optical odometer (wheel sensor). The system is user-friendly and has a fast setup time, which facilitates its portability between different vehicles. Its development is conducted at the Geodetic Eng. Laboratory (TOPO) of the Swiss Federal Institute of Technology Lausanne (EPFL).

Photobus has been used in several trials on precise monitoring of the centerline. The extraction of road geometry using this methodology has proven to work reliably. First results show that the positioning accuracy was always better than 20cm.

Current research strives to achieve a complete automation of the geo-referencing process and a real-time implementation of the feature extraction. In order to improve the positioning of the vehicle, it is planned to integrate DGPS carrier phase correction in real time.

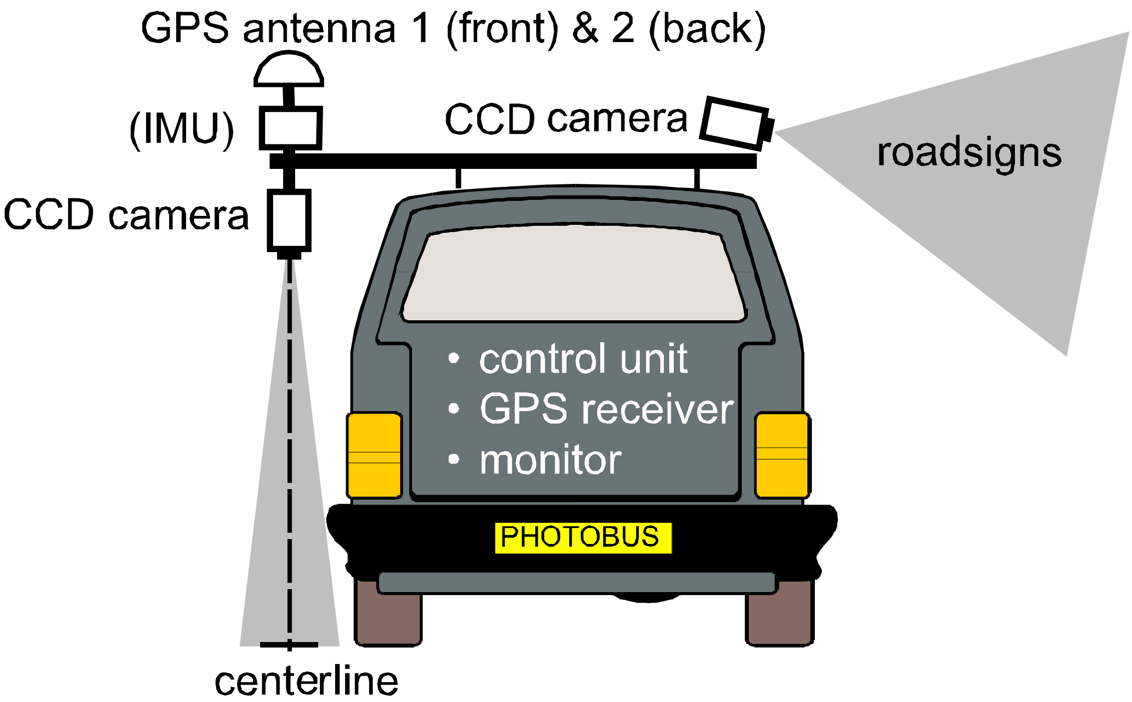


Fig. 1.23 : Architecture of the system Photobus

Athletic Motion Analysis Using Carrier Phase GPS Data

by J. Skaloud, Q. Ladetto and B. Merminod

Coaches constantly ask how and why a racer can perform better any given time. A position-velocity-acceleration (PVA) analysis gives the competitive edge of a point-by-point course performance examination and overall profiles between a racer's own performances and those of others. In downhill skiing, coaches and others devote long hours to slope recognition, attempting to quantify many factors for choosing an optimal trajectory. A skier's racecourse time only summarizes many decisions taken, and until now there were no means for separating good decision from bad ones. Applying GPS technology offers the possibility for studying each turn separately and evaluating personal performance as well as that of the equipment.

For useful analysis, a skier's position must be determined with sub-decimeter accuracy, requiring differential carrier-phase GPS (CDGPS) at 10 Hz frequency or higher. Although ambiguous, the carrier-phase measurement possesses the desired centimetre-level accuracy. The GPS carrier-phase ambiguities are currently determined in-post mission by using state-of-the-art algorithms for high-dynamic application. System evolution calls for inverse Real Time Kinematic (RTK) implementation with the mobile phone used as a data link. Extensive search of the market for suitable instruments revealed considerable performance differences between high-end GPS receivers in terms of signal acquisition and tracking under dynamic and frequent obstructions. The limits of the current technology are also reached quickly once the ergonomic factors are taken into consideration. The development focuses also on trajectory smoothing and modelling that can handle gaps in the GPS data. The trajectories are parameterised in both time and length, and additional parameters like acceleration and curvature are estimated and gate-to-gate performance is presented. An example is shown in figs. 124a and b:

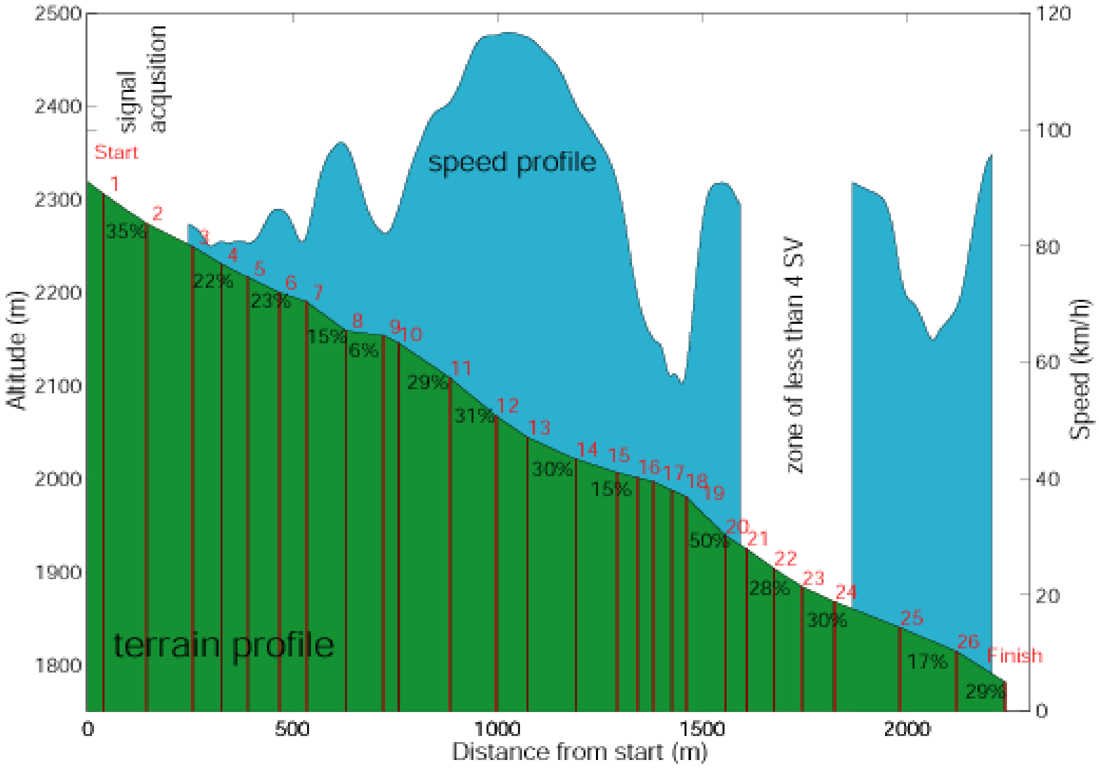


Fig. 1.24a: Speed versus the course terrain.

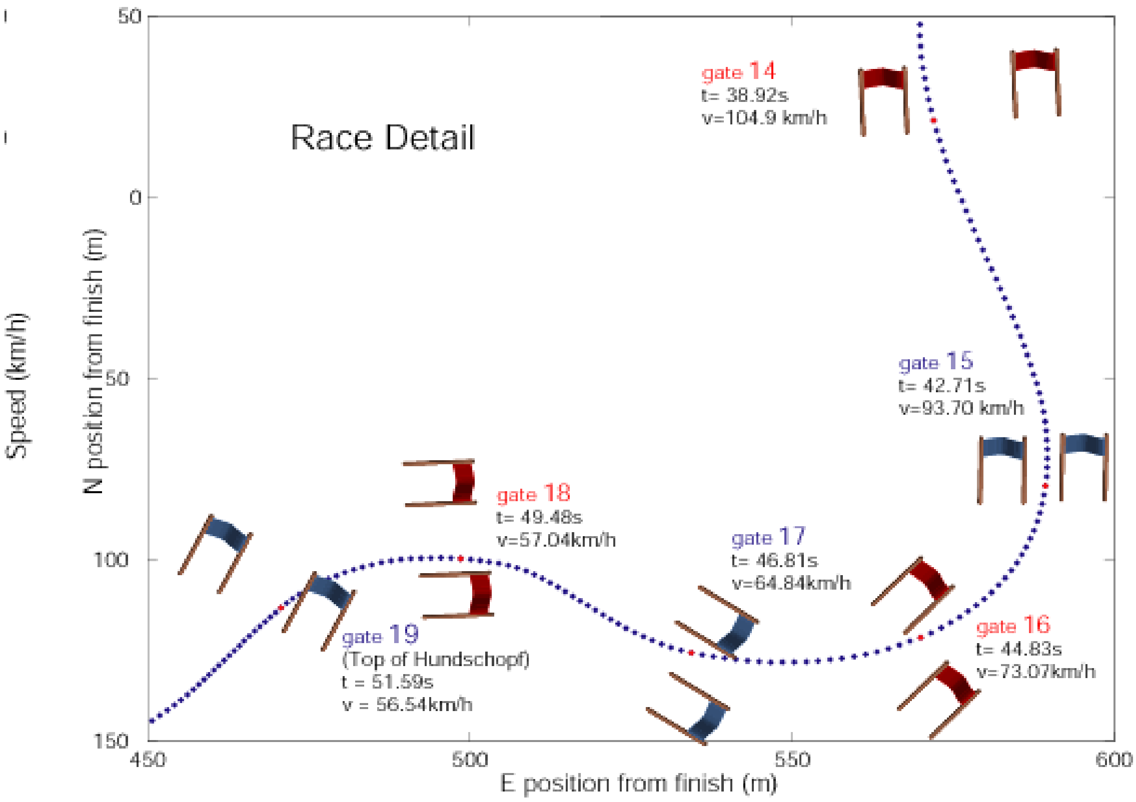


Fig. 1.24b: Racer's trajectory when negotiating an S-turn. Each dot represents GPS sampling of the competitor's position and velocity, although the value of the latter is shown only when passing a gate.

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2 Advanced Space Technology

The Zimmerwald Observatory

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

Fig. 2.1: The Zimmerwald ObservatoryDome with the Schmidt/Cassegrain telescope, permanent GPS antenna, ZIMLAT telescope (from left to right)

The Observing System for Satellite Ranging and CCD Astrometry

The 1-meter telescope, having replaced the old dedicated SLR telescope after 1995, was designed for dual use:

- Together with the new Titanium-Sapphire Laser and the necessary pulse-processing hard- and software it allows for day- and nighttime ranging to corner-cube-equipped satellites
- Four motorized tables on an instrument platform mounted on the telescope can be equipped with different focal reduction optics and CCD cameras for optical (passive) observations of all kinds of objects: Comets, minor planets, satellites, space debris, etc. Dedicated image and data processing software are used for precise position and orbit determination of these objects.

After the very experimental first observations in 1997 the system was steadily and slowly improved over the last 5 years. The main areas of activity were

- Improvement of the reliability of hardware components, especially camera and optics tables and mounts suffering from the harsh atmospheric conditions (dew, ice, low temperatures, dust)
- Improvement of the reliability and ease of operation of the Ti:Sapphire laser

- Improvement of the mirror coatings (dielectric coatings for the smaller mirrors, aluminum protected by dielectric coatings for the 1-m primary mirror) for better durability of the mirrors in the difficult environmental conditions (dew, ice, dust, pollen)
- Computer-control of all parts in the system (telescope, transmit/receive path, laser) that have to be adjusted/positioned/moved during the observations
- Computer-aided operation of the system up to remote control (i.e. operation from a remote location, e.g. the university in Berne or from home) or fully automated operation
- Improvement of the integration of CCD observations into the operation of the system, i.e. reduction of the time and steps needed to switch between the two modes of operation (SLR, CCD)
- Improvement of the accuracy of the ranging system (precision, range bias calibration)
- Web-based access to system status, parameters, and information (see http://www.aiub.unibe.ch)

Fig. 2.2: The ZIMLAT 1-meter telescope

SLR Observations

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

The years 1999 till 2003 saw a steady increase of the number of observed passes per month, mainly due to the overall improvement of the system performance (to a smaller extent of course also due to the ever increasing number of satellites to track).

As first station of the International Laser Ranging Service ILRS Zimmerwald started 2002 to supply two-color ranging data, i.e. ranges observed in two different wavelengths (423 nm and 846 nm). We hope to gain better insight into residual range biases generated by the ranging system and/or imperfect modeling of the atmospheric refraction.

With respect to the performance (data volume, constance or absence of range biases) Zimmerwald gained a position among the top 5 to 8 stations of ILRS.

Observers are provided by the Federal Office of Topography and the Astronomical Institute of the University of Berne. Funding is provided by the University of Berne, the Federal Office of Topography, the Swiss National Science Foundation, and the Swiss Academy of Natural Sciences.

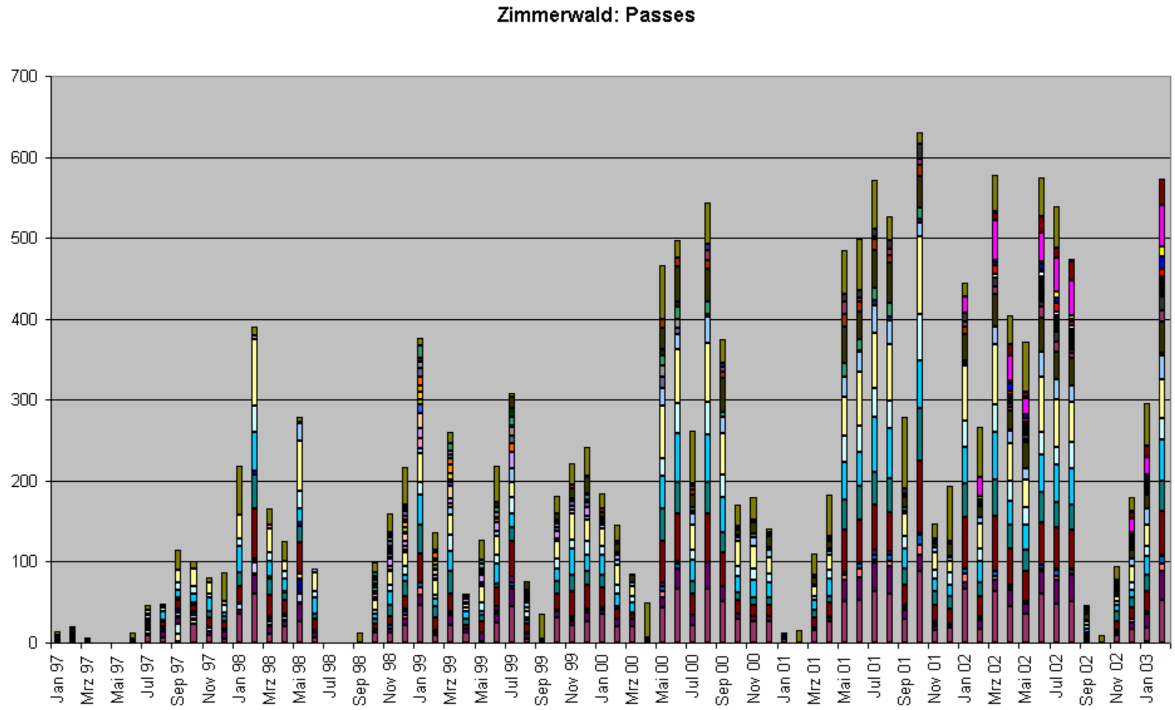

Fig. 2.3: Observed Satellite Passes 1997 - February 2003

Optical Observations using CCD Techniques

by M. Ploner and Th. Schildknecht

During the last few years, investigations concentrated on Software development for optical observations with CCD cameras. The communication between software and hardware components (Telescope, CCD cameras (2) and Timing card for epoch registration) has been carried out through a TCP/IP connection based on a Client/Server architecture.

Today, two CCD cameras are used for the optical observations. One of these (Astrocam 4240) has a frontside-illuminated chip (EEV) with 2k*2k pixels and a pixel size of 13.5um. The sensitivity of the other camera (Photometrics PM1024B) is approximately 3 times higher due to a back-illuminated chip (Site CCD with 1k*1k pixels, pixel size 24um). Although the pixel size of PM1024B is almost twice the amount of that of Astrocam, the precision in the astrometric position of objects is almost the same because of the limited seeing conditions. Due to improvements of the mapping model, the residual of a single observation could be reduced to about 0.2".

In the CCD observation program at the Zimmerwald observatory, highest priority was given to the observation of satellites in geostationary orbits (80081A, 82044F, 84035A, 85035B, 91010F, 93037B, 97049B).

These long-term observations pursue two goals - on the one hand the verification of orbit models, on the other hand the calculation of the coefficients C22 and S22 in the harmonic series of the geopotential. For the first time, osculating orbital elements have been calculated using the orbit integration program SATORB developed by Prof. Beutler. The residuals of the observations were less than 0.25”.

Also, observations of GPS satellites and objects in a geostationary transfer orbit have been performed. Observations of GPS satellites are used for the verification of our astrometric models because their orbits are extremely well known. Observations of LRE have helped to get more accurate ephemeris for laser ranging measurements.

At the beginning of 2002, simultaneous observations of the geostationary satellite 98035A were performed at the observatories Zimmerwald and at Gibraltar. This study was done in cooperation with James S.B. Dick of Observatory Sciences, Ltd. It could be verified that the combination of positions derived from two different sites leads to an improvement of the accuracy of the semimajor axis and the eccentricity, especially for short arcs.

Minor planets discovered at Zimmerwald in the past with the Schmidt telescope could also be re-observed during the last years (Goedel, Interposita, Kochera, Zwicky, Golay, Swissair, ...) by CCD. Furthermore, observations of NEOs (Near-Earth Objects) were carried out for the first time. CCD images of the NEOs 2001WA25 and 2001WH2 could be taken two days after their discovery. One of these images was displayed at the Swiss Expo02.

GPS / GLONASS Receivers at the Zimmerwald Observatory

by U. Wild and D. Ineichen

Since 1992, the permanent GPS tracking station at the Zimmerwald observatory has been operating in collaboration of the AIUB (Astronomical Institute, University of Berne) and the Swiss Federal Office of Topography (swisstopo). Three receivers are currently operating at the station:

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

The Trimble receiver is running under the GPS Base Station Software. It provides daily files to the IGS data centers. Furthermore, hourly files are generated and distributed with a time delay of a few minutes, used for the near-realtime applications of the IGS and other institutions. The delivery rate of the daily observation files was very high during the last three years: 99% for 2000 and 100% for 2001 and 2002 (with deteriorated data quality during a few days). In addition, the Trimble receiver provides epoch-wise GPS data in real-time via the Communication Network of the Swiss Federal Administration to the central AGNES server, which is one of the currently 29 AGNES stations.

In addition to the main GPS receiver, two combined GPS/GLONASS receivers are installed at site Zimmerwald: one Ashtech Z18 receiver and one Javad Legacy receiver (courtesy of manufacturer) providing data for the IGLOS-PP. This International GLONASS Service-Pilot Project of the IGS is the follow-up project of the IGEX-98 campaign and maintains a global station network and provides precise orbits for the GLONASS satellites.

AIUB Contributions to International Organizations

by G. Beutler and W. Gurtner

Many activities of the AIUB have to be seen in the framework of international collaboration. In most cases these are coordinated by the *IAG, the International Association of Geodesy*. It is therefore only natural that AIUB members are heavily involved in IAG activities. In the time period 1999 – 2003 (between the IAG and IUGG General Assemblies in Birmingham and Sapporo) AIUB members held the following positions within IAG:

- Gerhard Beutler
    - First IAG Vice-president. In this capacity he was also member of the IAG Executive Committee.
    - Member of the CSTG Executive Committee as its past president.
    - Member of the IGS Governing Board as so-called IAG representative.
    - Chairman of the IAG Planning Group for the establishment of the *IGGOS* (Integrated Global Geodetic Observing System) between 2001 and 2003.

- Werner Gurtner
    - Chairman of the Technical Working Group of the IAG Subcommission for Europe (EUREF)
    - Member of the International Laser Ranging Service (ILRS) Governing Board
    - Chairman of the ILRS permanent Working Group "Network & Engineering" till October 2002

  - Chairman of the ILRS Governing Board since October 2002. He became the first non-US and non-NASA chairman of the International Laser Ranging Service
  - President of EUROLAS, the Consortium of European Laser Tracking Stations (the European Subnetwork of ILRS), till October 2002

- Tim Springer
  - IGS Analysis Coordinator from 1999-2000, from 2001-2002 Robert Weber from Technical University of Vienna took over the same responsibility in the name of the AIUB.

It was the first IAG Vice-president's duty to conduct the profound restructuring process of the Association in the 1999-2003 timeframe. The process could be successfully concluded in 2001 at the IAG Scientific Assembly in Budapest, where the new IAG Statutes and By-Laws were accepted by the IAG Council (consisting of the National delegates). The work is documented in Beutler et al. (2002) and in the proposal Beutler (2003a). It was the purpose of the IAG planning group to set up the IGGOS as the first IAG project. The first part of the work is documented in Rummel et al. (2002).

The AIUB is developing the observational tools to perform, analyze and evaluate astrometric places based on CCD observations under the leadership of Thomas Schildknecht. Meanwhile the technique developed has reached a high degree of perfection and reliability.

It is therefore not amazing that

- Thomas Schildknecht
  - was asked to become member of the editorial board of the journal *Space Debris* in 1999.
  - is member of the ESA delegation in the *Inter-Agency Space Debris Coordination Committee (IADC).*
  - is member of the Scientific Committee of the COSPAR (Committee for Space Research) Panel on PEDAS (Panel on Potentially Environmentally Detrimental Activities in Space).

Contribution of CODE to Global Ionosphere Monitoring

by S. Schaer, U. Hugentobler and G. Beutler

The CODE analysis center 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 format and provided to the IGS.

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 IGS-conform IONEX or Bernese ION files, and, since July 2000, additionally in form of RINEX-formatted Klobuchar-style ionospheric coefficients (best fitting our IONEX data). Because of the restriction of the number of coefficients, the latter product type obviously has a much reduced information content compared to the IONEX products, but 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 almost 200 globally distributed stations. Data of about 150 stations is regularly available and analyzed. It is worth mentioning that we included the (relatively fast moving) Amundsen-Scott (AMUN) station which is located at the South Pole in January 2003. The inclusion of GPS tracking data originating from LEO satellites, like CHAMP and SAC-C, is intended for the future.

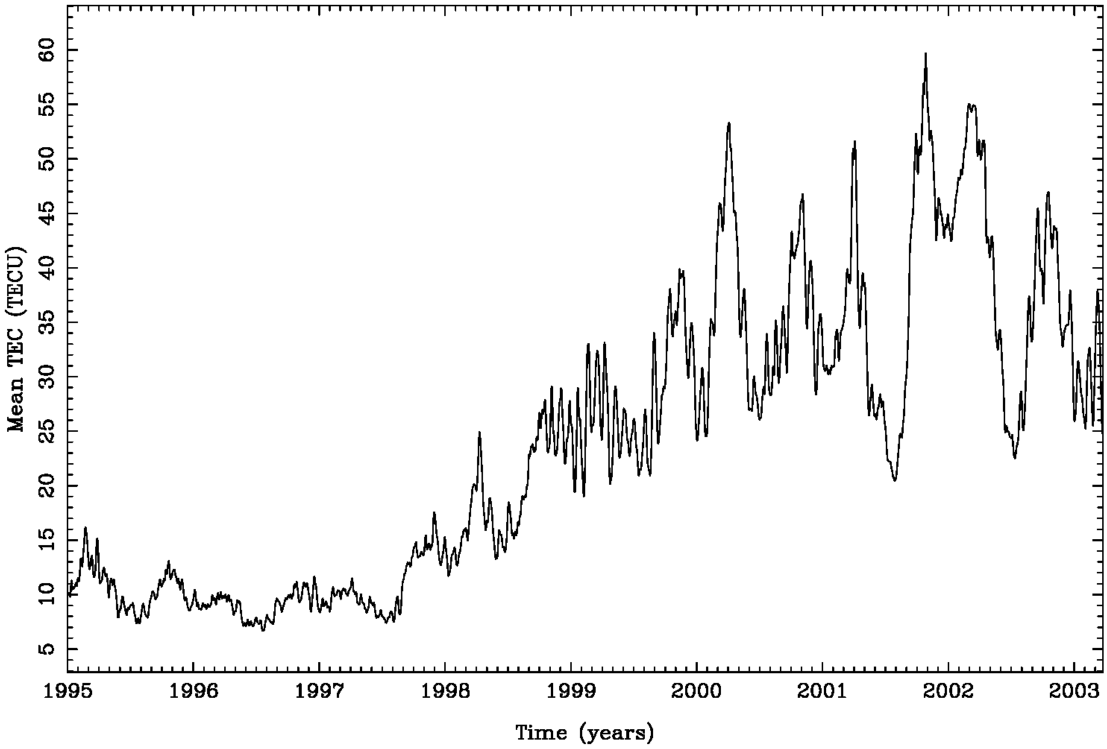

Fig. 2.4: Mean Earth's total electron content (TEC) as extracted (and slightly smoothed) from CODE global ionosphere map (GIM) time series, from January 1995 to March 2003.

Troposphere Modeling at CODE

by M. Meindl, S. Schaer and U. Hugentobler

In the CODE routine processing the tropospheric path delay is decomposed into an a priori and an estimated part. The a priori path delay (responding to the hydrostatic component of the atmosphere) is derived on the basis of the Saastamoinen model and mapped with the dry Niell mapping function. The residual part corresponding to the wet component, is estimated for each station at 2 hour intervals (mapped with the wet Niell mapping function). Since August 2001 a minimum elevation angle of 3 degrees is imposed on the analysis. One set of horizontal tropospheric gradient parameters (N-S and E-W component) is solved for per day and station to model azimuth-dependent variations of the tropospheric delay.

Studies in the context of the processing of the European GPS network confirm an improvement of about 50% in the day-to-day repeatability of horizontal station coordinates when estimating tropospheric gradients (see Fig. 2.5). To achieve such an improvement, the consideration of low-elevation observation data in conjunction with an elevation-dependent observation weighting scheme is indispensable. It is by the way remarkable that the formal errors of the estimated gradient parameters could be reduced by a factor of 3 when lowering the minimum elevation from 10 to 3 degrees (Meindl et al., 2003).

In the tropospheric results of the worldwide IGS network, a global pattern in the behavior of the gradient vectors can be observed: with a few exceptions, all mean tropospheric gradient vectors point towards the Earth's equator and reveal a latitude dependence with respect to their magnitude. This pattern is in accordance with the general increase of the average zenith path delay from the poles to the equator.

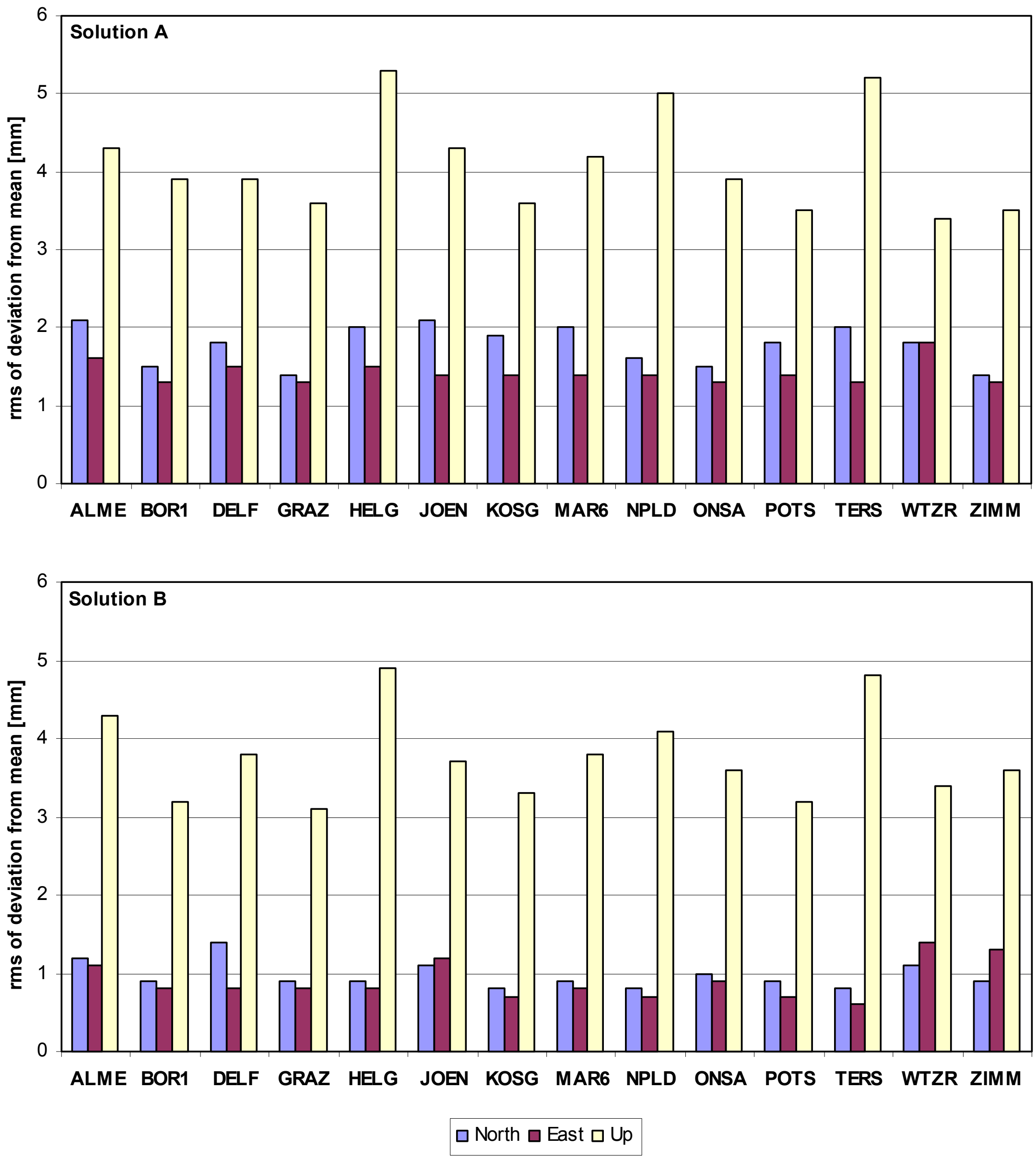

Fig. 2.5: Horizontal coordinate repeatability for 14 EUREF stations. Solution A (upper graph) was calculated without, solution B (lower graph) with estimated tropospheric gradients. The results are based on 308 days of tracking data.

Ambiguity Resolution at CODE

by S. Schaer, M. Meindl, U. Hugentobler and G. Beutler

CODE was the first IGS analysis center that started to fix initial carrier phase ambiguities on long baselines (officially since June 1995). The QIF (quasi-ionosphere-free) ambiguity resolution strategy developed for this purpose is especially suited for a receiver-mixed GPS network like the IGS network as this method does without dual-frequency code measurements. QIF ambiguity resolution is commonly performed for baselines up to 2000 km length.

In April 2002, we reviewed the ambiguity resolution scheme used at CODE. Based on detailed knowledge of GPS P1-C1 code biases, we could considerably improve the ambiguity resolution process. This improvement actually consists of several components: Ambiguity fixing is now attempted for base-lines up to 6000 km length following the Melbourne-Wuebbena approach where we take into account of P1-C1 code bias values for the GPS satellite constellation (see Figure 2.7). As part of our final analysis, an additional boot-strapping step is performed, initially considering only baselines up to 3000 km length for ambiguity resolution. A preliminary ambiguity-fixed network solution is subsequently computed to provide a basis for the extensive ambiguity resolution step. Finally, for short(er) baselines, various ambiguity resolution procedures (following different strategies) are executed in a sequential fashion. The QIF strategy is one among these strategies.

Determination and Use of GPS Differential Code Bias Values

by S. Schaer, M. Meindl, U. Hugentobler and G. Beutler

Daily sets of P1-P2 differential code bias (DCB) values for all GPS 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 plot comparing GD values derived by CODE and broadcast by GPS is posted daily to the Internet.

As of GPS week 1056, we regularly extract 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 are still significantly detectable (see Figure 2.6). Based on ambiguity-fixed double differences conforming with the Melbourne-Wuebbena linear combination, we are even able to do a kind of "finishing" of the P1-C1 bias retrievals coming from an undifferenced analysis. The day-to-day bias reproducibility concerning this double-difference product (generated since May 2002) is of the order of only 30 picoseconds. It may be mentioned that P1-C1 bias values retrieved at CODE are recommended for use with the IGS official products. Monthly sets of DCB values are archived and made available to the public.

When dealing with P1-C1 biases, one nowadays 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 for identifying to which receiver class a particular receiver model belongs has been developed. The reliability of this method could be demonstrated several times in the past.

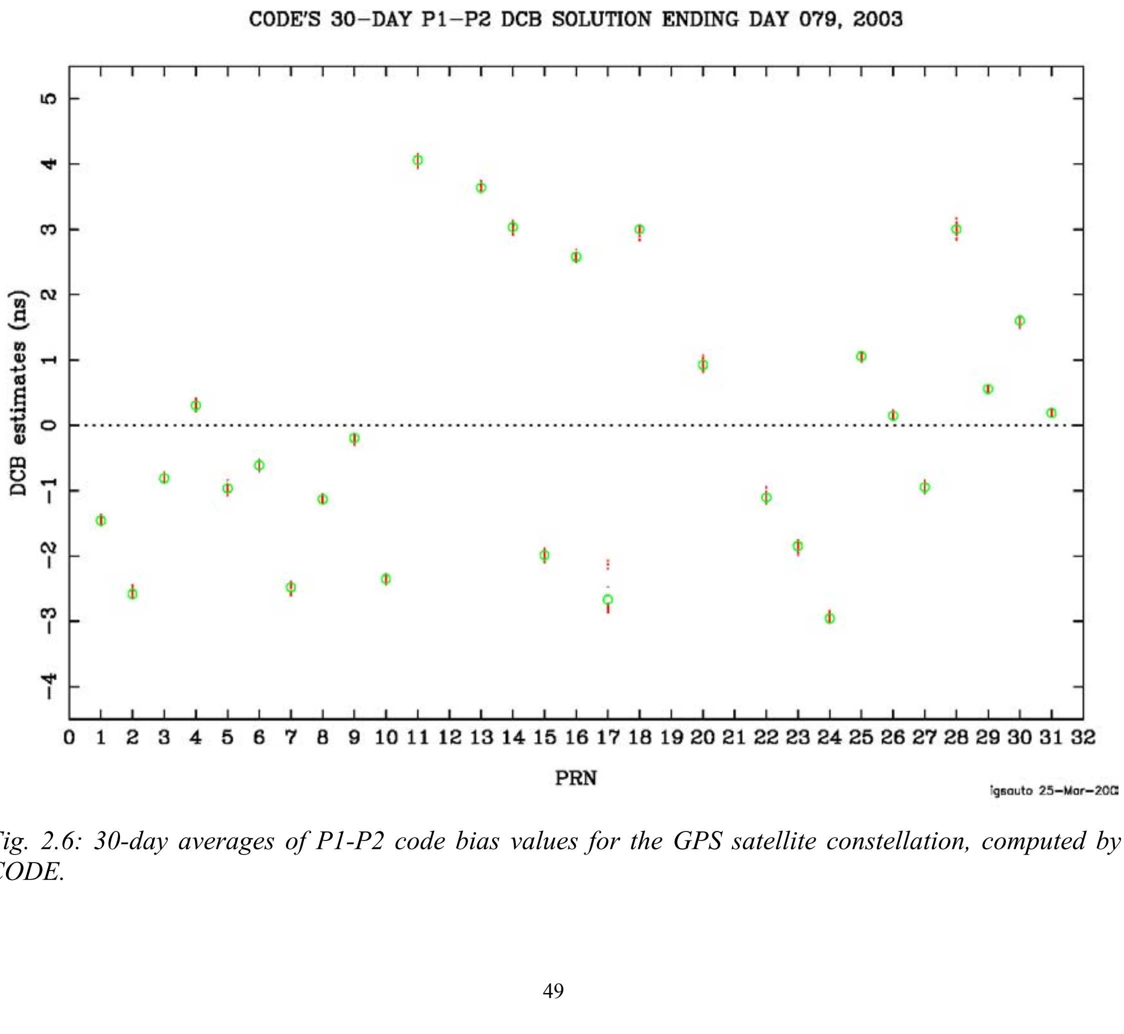

Fig. 2.6: 30-day averages of P1-P2 code bias values for the GPS satellite constellation, computed by CODE.

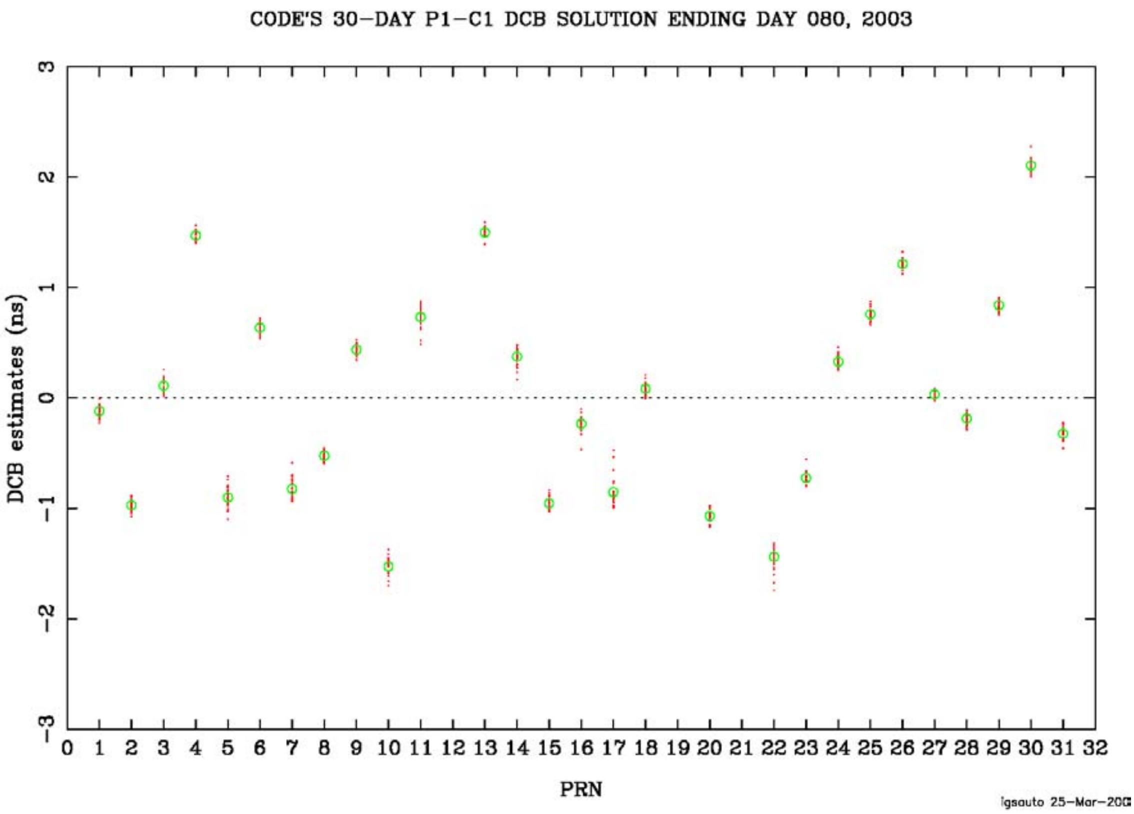

Fig. 2.7: 30-day averages of P1-C1 code bias values for the GPS satellite constellation, computed by CODE.

Estimation of Precise Satellite and Receiver Clock Offsets at CODE

by R. Dach, R., S. Schaer, T. Springer and U. Hugentobler

Essential developments were performed in the domain of processing and cleaning of undifferenced GPS observations (Springer 2000a). The CODE analysis center was computing satellite and station clock offsets based on smoothed pseudorange observations. Since May 2000, carrier phase and pseudorange measurements are simultaneously treated for clock estimation. A significant improvement with respect to the new, phase-consistent clock estimates could be noticed as of GPS week 1060 (see Figure 2.8). At the same time, CODE started to include precise clock estimates in its rapid product submissions to the IGS.

At CODE, a large number of IGS receivers is considered in the clock estimation process. This can be achieved by doing the analysis in three global station clusters and combining the resulting satellite and receiver clock offsets in a way that is very similar to the method used by the IGS Analysis Center Coordinater for the IGS clock combination. The clock offsets are generally aligned to GPS broadcast time. The clock offsets are referenced to that receiver clock that exhibits the smallest rms differences in a linear fit.

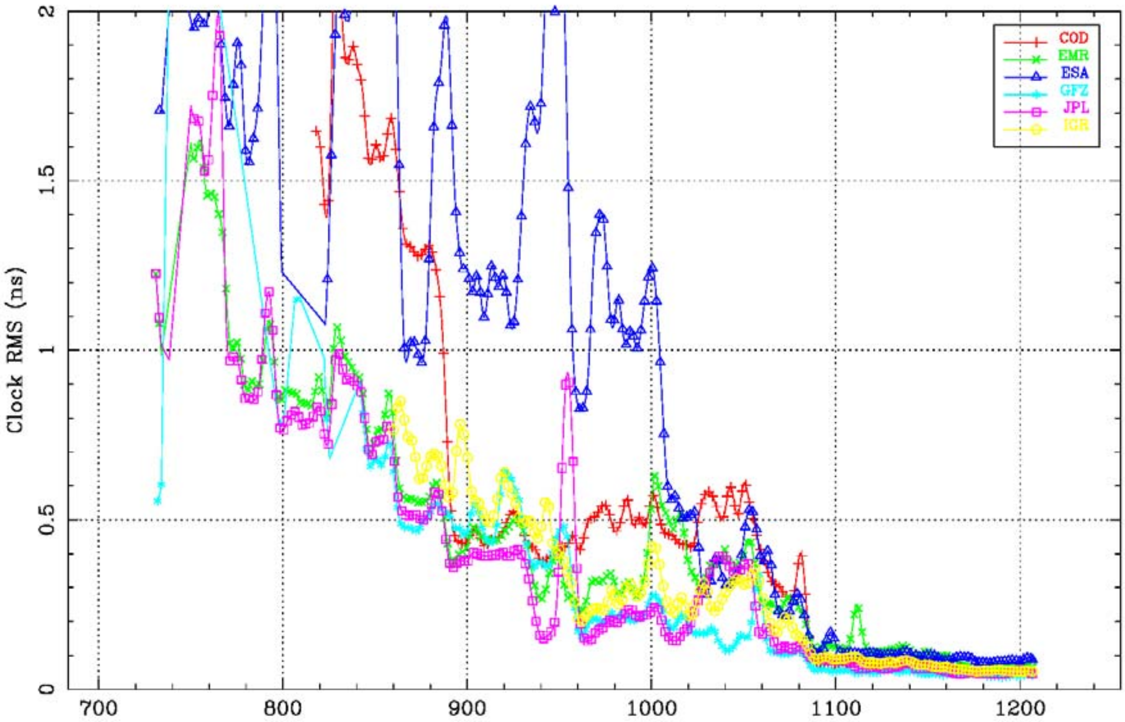

Fig. 2.8: Clock RMS of the individual IGS Analysis Centers with respect to the IGS final product. The red curve includes the CODE clock rms values.

Precise Time Transfer Using the GPS

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

In a project together with the Swiss Federal Office of Metrology and Accreditation (METAS) a time transfer experiment has been running since July 1998. In the framework of this experiment a network of 16 stations in Europe and North America is analyzed routinely. Two of the stations in this network are equipped with special Geodetic Time Transfer Terminals (GeTT) which were developed at METAS. The units are based on geodetic ASHTECH Z-XII receivers with the internal clock completely replaced by an external clock. In this way clock jumps in the time transfer results due to internal receiver resets are prevented. No additional measurements are necessary to connect the GPS results to the clock under investigation, only the cable characteristics have to be known. In order to reduce the influence of temperature variations on the time transfer results all electronic equipment is placed into a temperature stabilized box.

One of the two GeTT terminals was installed at the U.S. Naval Observatory (USNO) where it was directly connected to UTC(USNO). The other device was located at Physikalisch-Technische Bundesanstalt in Braunschweig, Germany (PTB). This GeTT was driven by a H-Maser (H2). The difference to UTC(PTB) was measured every 30 minutes with an accuracy of 1 ns. Due to this additional measurement it is possible to compare the results obtained from the GeTT observations with other independent time transfer methods for the transatlantic baseline. For maintenance the transatlantic GeTT experiment has been finished in September 2000 and the GeTT terminals were shipped back to Switzerland. At the end of this transatlantic time transfer experiment more than 2 years of (nearly) continuous time transfer results using geodetic GPS receivers are available. The advantage of the location of the two GeTT terminals is the availability of alternative time transfer techniques between these two major time laboratories.

Figure 2.9 shows the differences between the time transfer results from the GeTT experiment and the results from Two Way Satellite Time and Frequency Transfer (TWSTFT). In comparison with the time transfer using GPS carrier phase observations only a small number of experiments were done (3 times per week). Nevertheless it is a widely accepted method for the time transfer. The comparisons with the independent method confirms the potential of the time transfer technique using GPS carrier phase data. The standard deviation of the differences between the results of the two independent time transfer methods is 2 ns. An extended discussion of the results of the two years experiment is given in Dach et al. (2002).

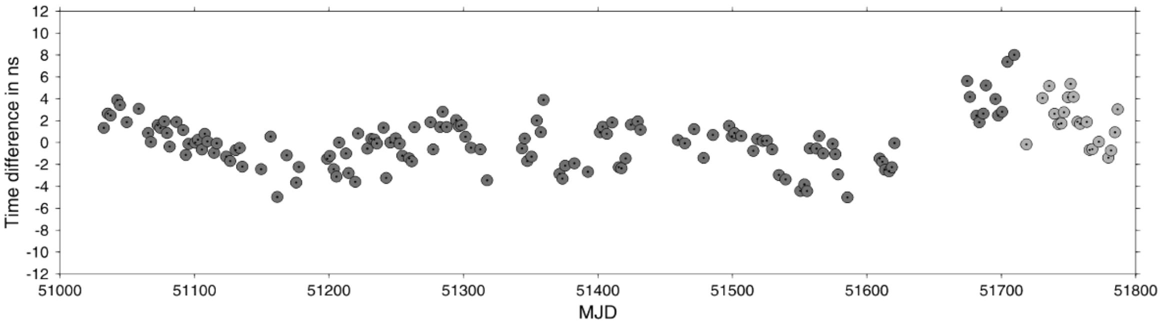

Fig. 2.9: Difference of time transfer results from GPS carrier phase and from TWSTFT on the intercontinental baseline between PTB and USNO.

Computation of GLONASS Orbits at CODE

by D. Ineichen, U. Hugentobler, H. Habrich and G. Beutler

Within the IGEX-98 experiment of the IGS (Slater et al. 1999) the CODE Analysis Center contributed precise GLONASS orbits since the beginning of the project in October 1998 until mid July 2000. The analysis was based on data recorded by combined GPS/GLONASS receivers. GPS orbits and Earth orientation parameters were fixed on CODE's final GPS solution and phase double-difference observations, also between GLONASS and GPS satellites, were used to estimate six initial conditions and nine radiation pressure parameters for the GLONASS orbits (Ineichen et al. 1999). The final orbit solution was the middle day of a 5-day orbital arc. In addition, system time difference parameters and reference frame transformation parameters between the two systems were monitored (Weber et al. 2001a).

Successful tests were carried out where combined GPS and GLONASS data from the IGEX network were combined with GPS observations from the IGS network and all parameters (GPS and GLONASS orbits, Earth rotation parameters, and site coordinates) were estimated in one processing step (Ineichen et al. 2001). The parameterization of GLONASS solar radiation pressure was extensively studied. It could be concluded that the radiation pressure effect for the GLONASS satellites in the direction of the solar panel axis (y-axis) is significantly different compared to GPS satellites. Furthermore, a significant improvement of the quality of the GLONASS orbits resulted from the simultaneous processing of the two networks.

The IGEX-98 project formally lasted until the end of 1999. It was converted into the IGLOS Pilot Project of the IGS. CODE announced its interest to participate, but due to the decreasing number of active GLONASS satellites and the tracking network still being far from ideal, the plans for implementing a combined GPS/GLONASS processing as well as the routine processing of GLONASS data was cancelled. Computation of GLONASS orbits was restarted in May 2003 in a fully combined GPS/GLONASS processing. In the meantime the emphasis was put on the analysis of the differences between GLONASS and GPS orbits.

GPS satellites orbit the Earth twice in one sidereal day and are, therefore, in deep resonance with the Earth's gravity field. The most important resonant geopotential term is J32 causing a drift in the semi-major axis of up to 6m/day. This resonance perturbation is the primary reason for most of the maneuvers of the GPS satellites. GLONASS satellites, however, orbit the Earth 2 1/8 times in one sidereal day and are, therefore, not in deep resonance. A sensitivity analysis (Ineichen et al. 2003) showed that - different from what was expected - GLONASS satellites are better suited to estimate resonant geopotential coefficients than GPS satellites. The reason are strong correlations of radiation pressure parameters with the geopotential coefficients in the case of GPS.

Precise Orbit Determination for Low Earth Orbiters

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

On July 15, 2000, the satellite CHAMP was launched, carrying among other a GPS receiver and an accelerometer. With this satellite in orbit and with missions already launched since then or to be launched in the near future (Jason, Dec. 2001, Grace, March 2002, IceSat Jan 2003, GOCE 2006) the precise orbit determination for satellites on low Earth orbits (LEOs) gains an increasing attention. Advances with respect to other tracking techniques are the high precision of the phase observable and the uninterrupted tracking.

Starting in 1999 with tracking data from the GPS receivers on-board of the satellites TOPEX/POSEIDON and GPS/MET an efficient algorithm was developed at the AIUB to reconstruct the kinematic trajectory of an orbiting GPS receiver based on code and phase observations. A prerequisite of the procedure is the availability of high rate (30 sec sampling) clock corrections for the GPS satellites. The developed efficient algorithm to generate such corrections is based on the combination of clock values derived from code and clock epoch-differences derived from phase differences from epoch to epoch using observations from the IGS tracking network (Bock et al., 2000). The epoch differences allow it to eliminate the phase ambiguities. An alternative to combining code and phase differences in a subsequent step is the processing of phase differences only and constraining the resulting corrections to high precision clock corrections which are available with a lower sampling. The resulting clock corrections prove to be good enough to allow for a sub-decimeter accuracy for kinematic LEO positions.

The implemented algorithm for the reconstruction of the kinematic trajectory of a LEO is based on the same concept as for the reconstruction of the high rate clock corrections: Code and phase epoch-differences are processed independently and epoch-wise. The resulting code-derived positions and phase-derived position differences are combined using an efficient algorithm. The advantage of the procedure is its efficiency, the drawback is the neglection of mathematical correlations between epochs. The effect of the later may be controlled by lowering the weight of the code observations with respect to the phase observations. The algorithm works with a sophisticated built-in data screening procedure.

The resulting kinematic positions of the LEO trajectory or directly the code-derived positions and phase-derived position differences may be used as pseudo-observations for an orbit determination procedure based on physical models of the motion of the satellite. An orbit determination program was developed which includes air drag as a perturbing force and which allows for a very flexible and efficient set-up of stochastic pulses (velocity changes) in order to generate a reduced-dynamic orbit. A large number of pulses may be set-up at pre-defined times, e.g. at maneuver epochs. In addition measured accelerations may be introduced in order to substitute the models of non-gravitational forces acting on the satellite by observations from the accelerometer on-board of CHAMP.

Data from SAC-C and in particular CHAMP were processed. The AIUB is participating in the CHAMP orbit comparison campaign organized by the IGS LEO Pilot Project. 13 institutions and universities participate in this project and exchange orbits for comparison computed for a defined 11-days time period. Figure 2.10 shows the difference of the kinematic trajectory resulting from our procedure for CHAMP for a particular day with a reduced-dynamic orbit computed at the Technical University in Munich. The RMS of the difference is 12 cm.

Within the European GOCE Gravity Consortium (EGG-C) the AIUB proposes to routinely compute kinematic orbits for the ESA satellite GOCE planned for launch in 2006. The consortium of 10 European institutions and universities proposes ESA to compute an Earth gravity field of unprecedented accuracy based on the gradiometric observations by the satellite GOCE. A preparatory study was carried out in 2001/2002.

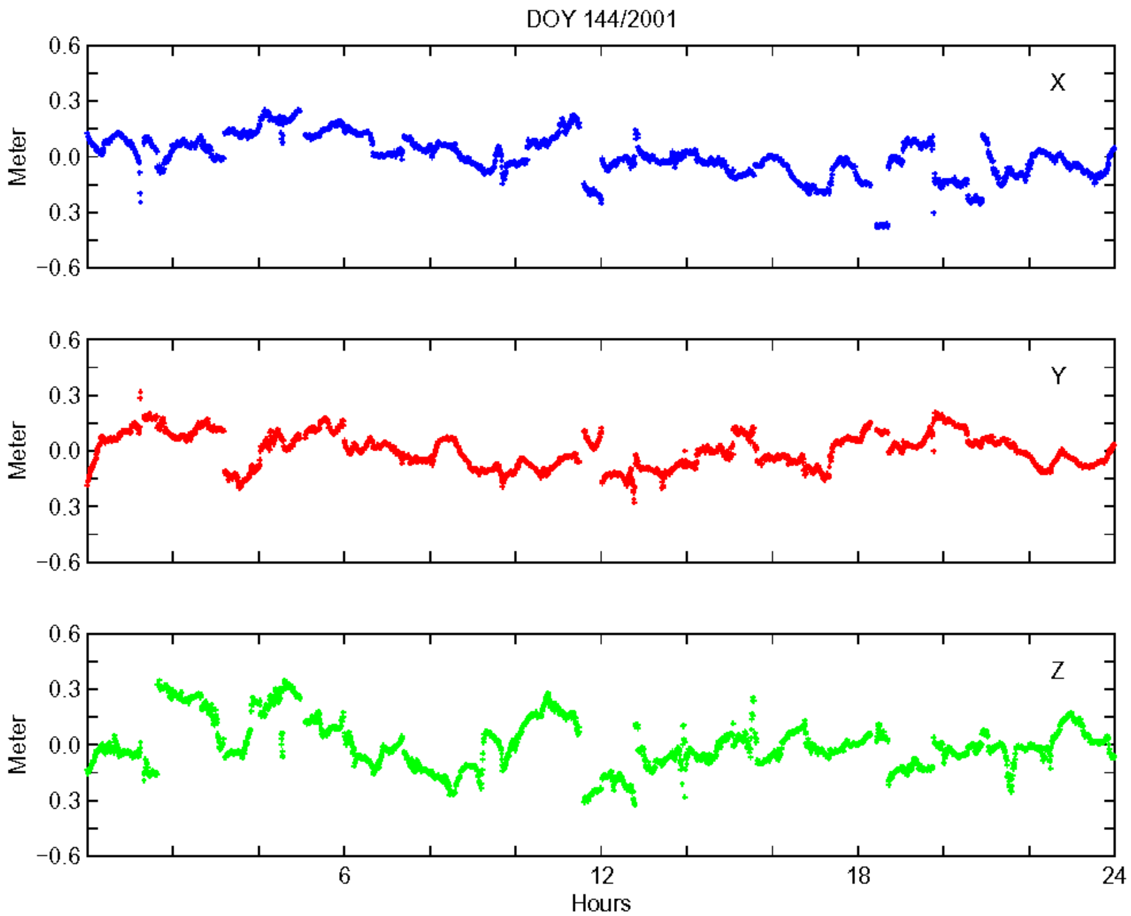

Fig. 2.10: Difference of the kinematic trajectory of the Satellite CHAMP for doy 144/2001 and a reduced-dynamic orbit computed at the Technical University of Munich within the IGS LEO Pilot Project.

EGNOS Activities Summary

by M. Scaramuzza

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 will be hosted in Zurich Airport. It will constantly monitor 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. For this purpose, specific data collection activities are organised with the EGNOS System Test Bed (ESTB), a prototype of EGNOS. They include static sessions as well as flight trials and have so far provided very promising results, even in the very challenging Alpine part of Switzerland.

GBAS Activities Summary

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.

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3. Determination of the Gravity Field

Gravity Reference Networks

Gravity Measurements along re-measured first order levelling lines

by E. Klingelé and A. Schlatter

In the last four years gravity values have been determined simultaneously with re-levelling of the Swiss National Levelling Network in order to correctly reduce the levelling measurements. In the period from 1999 to the end of 2002, gravity measurements using LaCoste and Romberg gravity meters have been carried out along the following levelling lines (see also figure 3.1):

1999	2000	2001	2002
Lucerne–Eicholzmatt Saanen–Pillon–Aigle– Andermatt–Oberalppass – Disentis Andermatt–Furkapass–Gletsch Aigle–Le Sepey Klosters–Davos Lötschberg sounding tunnel Vereina tunnel	Sarmenstorf–Sursee Walenstadt–Nieder-urnen Chur–Lenzerheide–Tiefencastel–Alva-schein Disentis–Passo del Lucomagno–Olovono –Bisaca	Axenstrasse–Altdorf Altdorf–Klausenpass–Linthal–Glarus–Nieder-urnen Sargans–Werdenberg – Lichtenstein Buchs–Wildhaus– Wattwil	Morat–La Neuveville Neuchâtel– La Chaux de Fonds Neuchâtel–Fleurier Le Hauts Geneveys– St Imier Susch–Zernez–Ofenpass–Müster

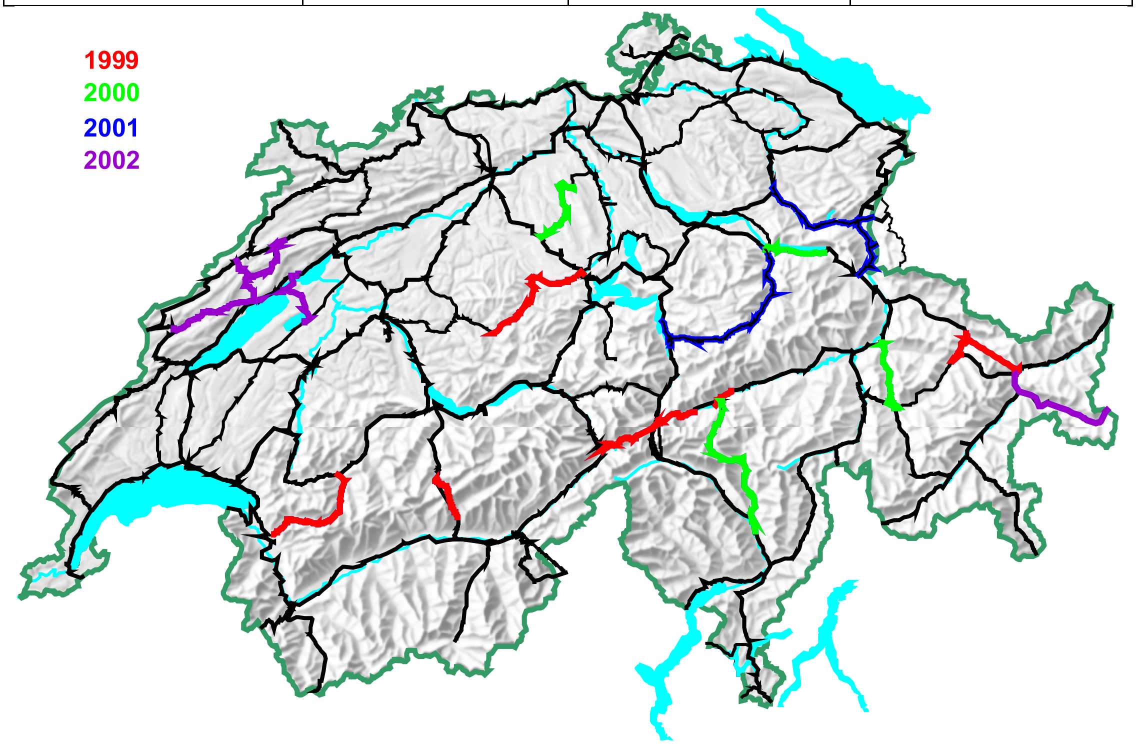

Fig. 3.1: Swiss National Levelling network (black lines). The lines outlined in different colours indicate the gravity measurements along levelling lines during the last four years.

Gravity values have been computed on the basis of the absolute gravity value in Zurich and linked to the Swiss National Gravity Network. The measured stations are fully documented and are incorporated into the new national levelling documents.

Swiss Absolute Gravity Network

by E. Klingelé

In summer 2000 a new absolute station has been installed and measured in the alpine research facilities of Jungfraujoch (3500 m a.s.l.) The measurements were carried out by means of an absolute gravimeter FG5 by the Swiss Federal Office of Metrology and Accreditation (metas).

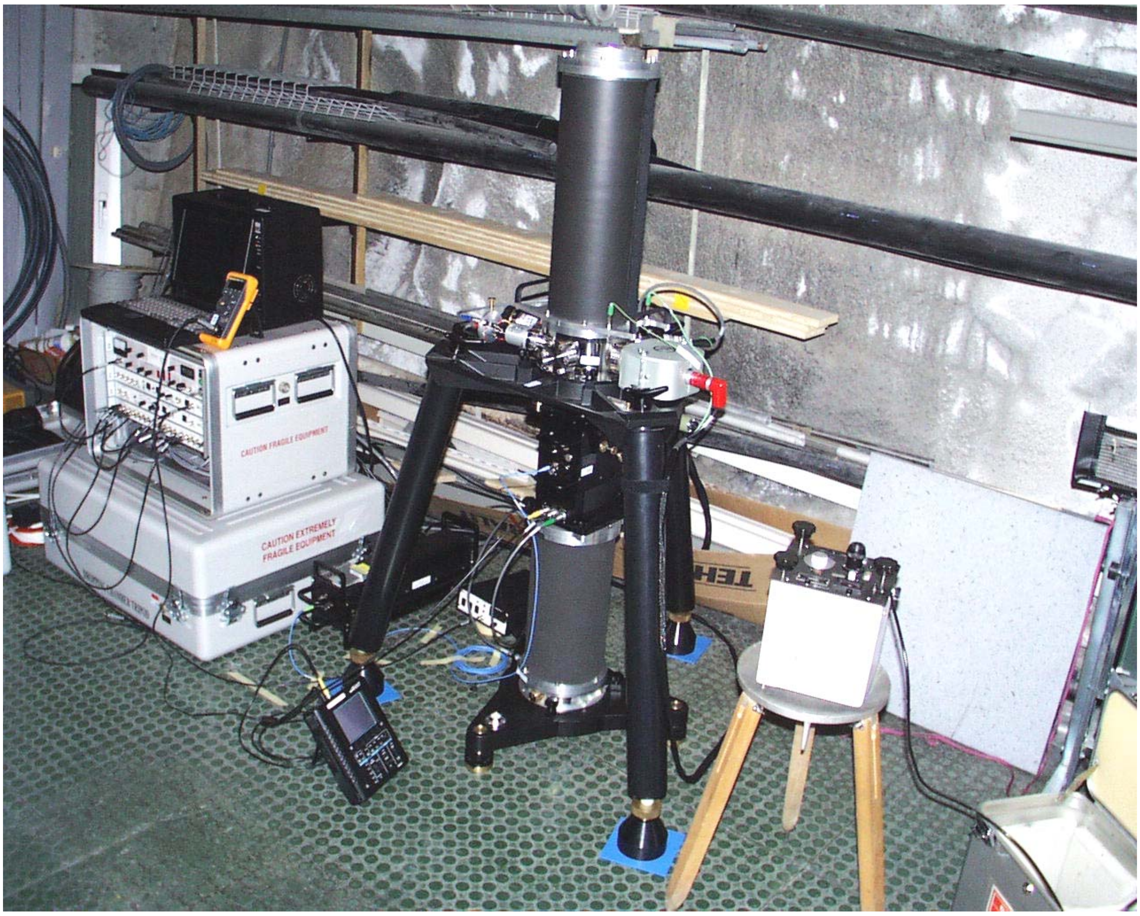

Fig. 3.2: Setup of the absolute gravimeter FG5 at Jungfraujoch. The instrument is owned and operated by the Swiss Federal Office of Metrology and Accreditation (metas).

Regional gravimetry (gravity mapping)

by E. Klingelé

In the frame of the gravity mapping of Switzerland at a scale of 1/100'000, the geophysical institute of the University of Lausanne, on behalf of the Swiss Geophysical Commission (SGPK) has measured 2433 new gravity points. These new stations have enabled the SGPK to publish the last eleven Bouguer anomaly maps of Switzerland thus completing a 20 years work. The published maps are: Vorarlberg, Panixerpass, Flüelapass, Col du Pillon, Oberwallis, Sopra Ceneri, Passo del Maloja, Haute Savoie, Val de Bagnes, Monte Rosa, and Sotto Ceneri. This new gravity atlas contains 29896 gravity points fully corrected and tied to the Swiss Fundamental Gravity Network.

Airborne gravimetry

The airborne gravity survey of the French occidental Alps (ASFAG).

by E. Klingelé

In the frame of a research program about the deep structure of France, an airborne gravity survey of the French occidental Alps has been jointly carried out by the University of Montpellier (France) and the GGL of the ETH Zurich (Switzerland).

The surveyed area extends from the pre-alps to the Po plain in Italy. The survey was carried out at a constant altitude of 5100m with the measurement lines oriented N-S and E-W (compare fig. 3.3). The line spacing was 10 km for the N-S lines and 20 km for the E-W lines. From this survey a Bouguer anomaly map was produced and compared with a map computed with ground data and upward continued to the flight altitude. This comparison showed that the differences between the two maps on the order 15 mGal are almost completely correlated with the topography. The same airborne map computed with variable density compared to a ground-based map also corrected for variable density eliminates the discrepancies (the differences are reduced to the order of 1 mGal) almost completely.

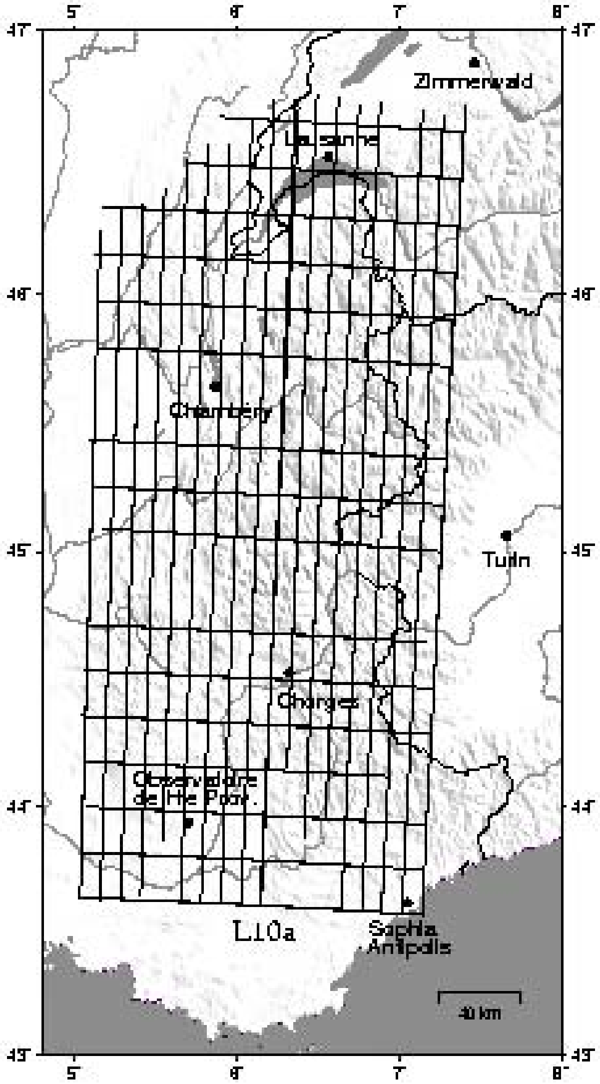

Fig. 3.3: Lines flown in the frame of the Alpine Swiss/French Airborne Gravimetry (ASFAG) project.

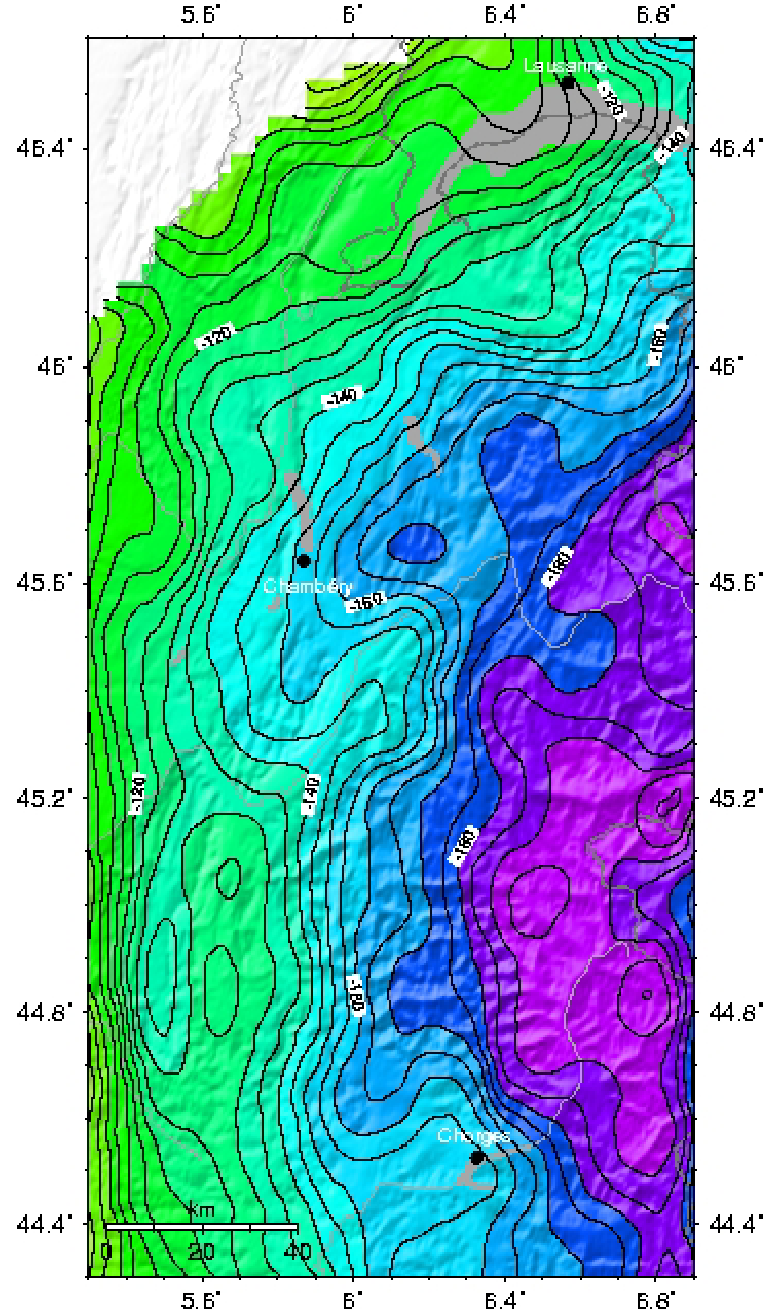

Fig. 3.4: Full Bouguer anomalies at flight altitude (5500 m asl.) of the ASFAG project.

The Absolute Airborne Gravity project (AAG)

by E. Klingelé and H. Baumann

In collaboration with the company Micro-g solution, the Geodesy and Geodynamics Laboratory (GGL) of the ETH Zurich is developing an airborne absolute gravity measurement system. This system uses an FG5-L gravimeter working in strapped-down mode. A vertical accelerometer type Episensor, an inertial navigation system Litton 200, as well as a GPS multi-antenna array are used for monitoring the vertical disturbing accelerations induced by vibrations, pitch and roll of the aircraft.

In a first stage damping vibration systems have been developed and tested in flight configuration. In a second step tests on a ground-based vehicle were also carried out prior to the first test flight. During summer and autumn 2002 three flights were carried out above zones well covered by ground measurements (see fig. 3.5). The data processing of the ground and flight tests are in progress and the results should be available during 2003.

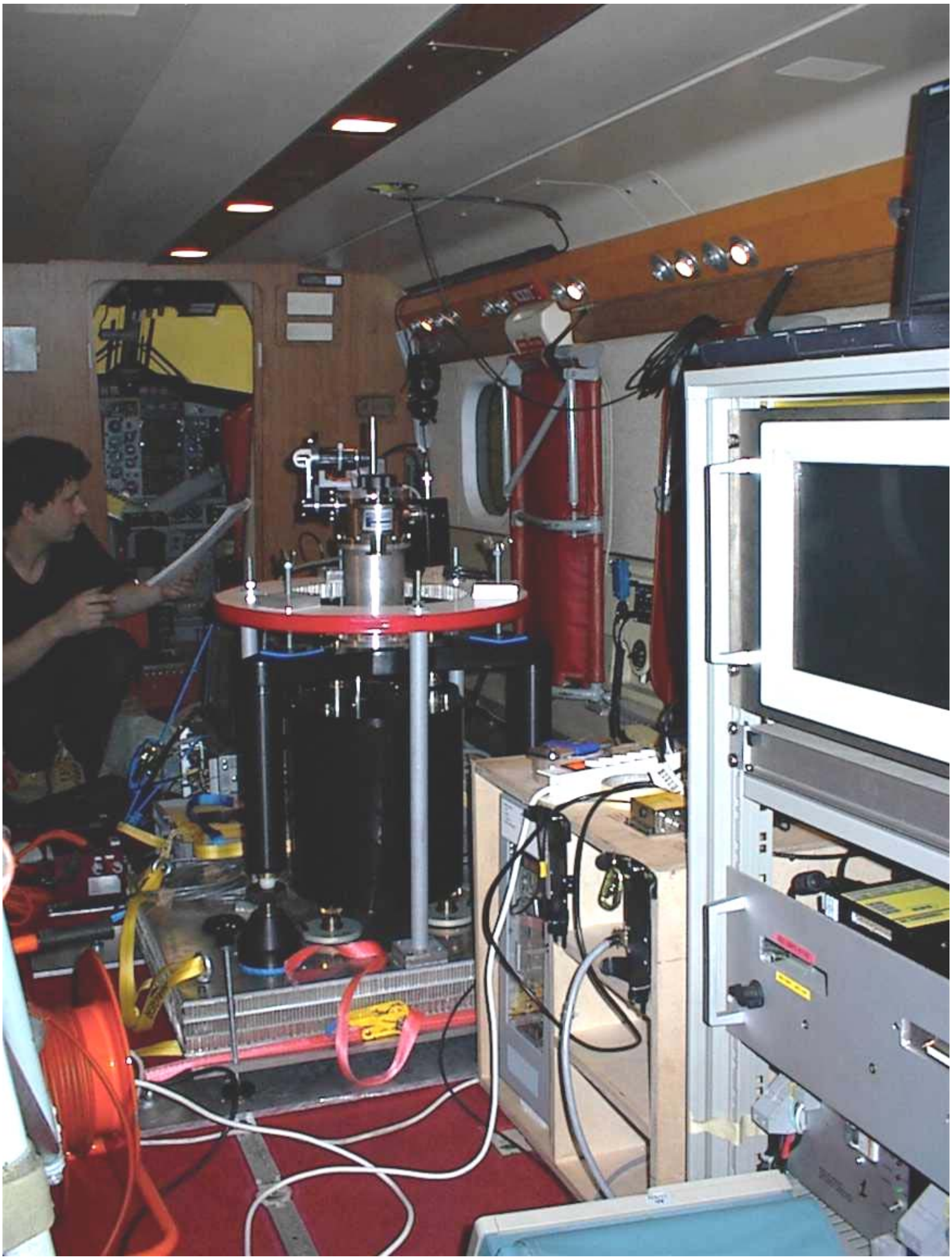

Fig. 3.5: The Experimental Absolute Airborne Gravimetric system, composed of the absolute gravity sensor, the inertial system, and the GPS rack in the airplane (De Havilland Twin Otter, owned and operated by swisstopo).

Interpretation and analysis

Processing techniques

a) Upward continuation

In the frame of the Swiss–French airborne gravimetry project a new algorithm for upward continuation of gravity anomalies between general surfaces was developed. This development was necessary for the comparison between airborne and ground survey. Numerous tests performed with very complicated synthetic examples revelaed that the method is extremely accurate and its accuracy is independent from the amplitude of the anomaly. The differences between upward continued anomaly from rugged topography and the theoretical anomaly computed on the continuation plane never exceeded 0.1 mGal.

b) Computation of orthometric altitudes

A method for computing orthometric altitudes, based on upward continuation technique has been developed. This technique is mostly based on the algorithm described in the previous paragraph. The advantage of this technique is that it does not require any information about local density variation and necessitate only the knowledge of the full Bouguer anomaly. Tests performed along a profile of 50 km crossing the Central Swiss alps (Gotthard massif) showed that it is possible to compute the true value of g along the vertical with an accuracy better than 0.5 mGal without any knowledge of the density distribution of the measured area.

c) Filtering technique

A new algorithm for designing filters for the raw data produced by the air-sea gravimeter has been developed and successfully applied in the ASFAG project. The knowledge of a reliable estimate for the filter pass-band is of great importance for determining both resolution and accuracy of a gravity survey. The algorithm produces so-called exponential low-pass filter parameters of which depend on the speed of the aircraft, the sampling rate, the minimum observable wavelength and a dimensionless variable allowing to adjust the desired resolution.

Geoid Determination in Switzerland

by U. Marti and B. Bürki

With the presentation of the Swiss geoid and quasigeoid CHGEO98 in 1998 a major goal of the determination of the gravity field in Switzerland could be reached. This geoid computation is based mainly on a combination of astrogeodetic and GPS/levelling measurements. Gravity has only been used in the downward continuation of the other data and in the determination of trend parameters. The solution CHGEO98 has an accuracy of about 2 to 3 cm in flatter areas and 3 to 5 cm in the mountains. It is widely used in numerous applications in geodesy and surveying.

After the publication of CHGEO98 the main tasks were the comparison with other independent geoid solutions of Europe (EGG97) and of neighboring countries. The comparison to EGG97 showed that the two solutions are in agreement of better than 5 cm in flatter areas. In the Central Alps the differences reach up to 20 cm and show a correlation with topography.

A further step in validating the geoid solution CHGEO98 was the analysis of independent GPS/leveling residuals. These residuals are on the order of 1 to 2 cm in flatter areas. In other areas the discrepancies can reach amounts of up to ±7 cm with some systematic trends mainly in North-South direction. Until now, no obvious reason could be found to explain these differences but a common adjustment of GPS, leveling and the geoid on the common GPS/leveling stations revealed that the geoid most probably still is the weakest part of the data sets (see figure). In this adjustment it was tried to attribute the GPS/leveling residuals to the 3 individual data sets by using the full variance/covariance information of GPS (Qh), of the geoid (QN) and leveling (QH) and to determine the corrections vh, vN and vH. out of the following formulae:

$$v_h = Q_h \ (Q_h + Q_H + Q_N)^{1} \ l$$
$$v_H = Q_H \ (Q_h + Q_H + Q_N)^{1} \ l$$
$$v_N = Q_N \ (Q_h + Q_H + Q_N)^{1} \ l$$

where l are the GPS/leveling residuals. By far the largest part of these corrections was attributed to a correction of the geoid as can be seen in the figure. In order to reach complete consistency between GPS and leveling it therefore seems to be necessary to go for a further improvement of the geoid model. This should be reached in a project CHGEO2003 of the Swiss Federal Office of Topography and the Geodesy and Geodynamics Laboratory (GGL) of ETH Zurich. The main parts of this project are the densification of the astrogeodetic stations and the GPS/leveling stations but also the full integration of the available gravity measurements. These activities are in coincidence with the development of a digital astronomical observation system for the determination of deflections of the vertical DIADEM (DIgital Astronomical Deflection Measuring system, cf. next paragraph). Further improvements are expected by introducing new models of the topography and of the density distribution of the Earth's crust.

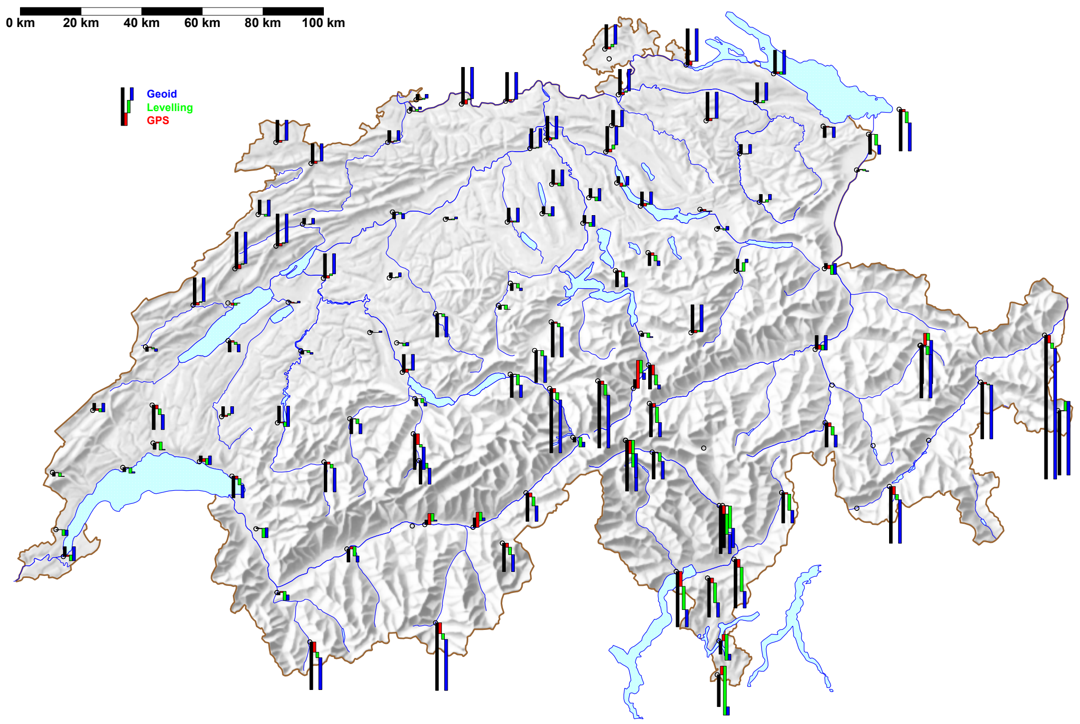

Fig. 3.6: Total GPS-levelling residuals (black) and their composition in terms of the individual sets of measurements after the common adjustment (GPS - red, levelling - green, geoid - blue)

The presently used geoid in Switzerland based on old and new stations looks as follows:

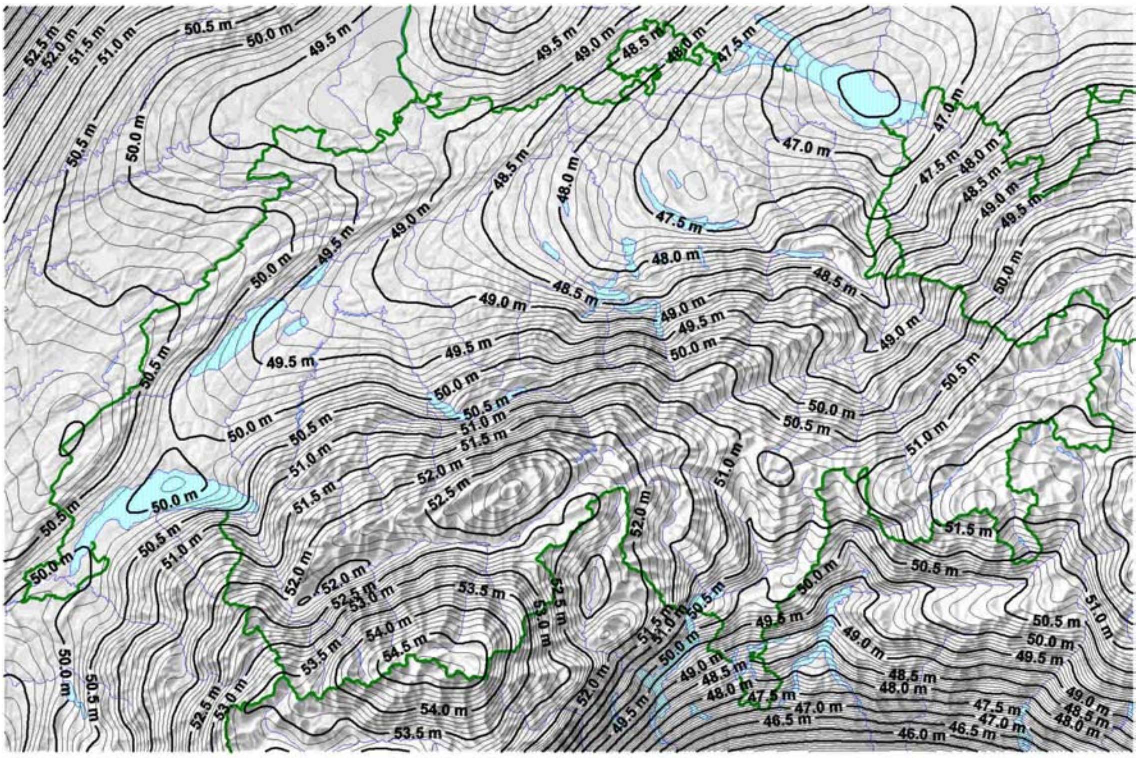

Fig. 3.7: Geoid in Switzerland referring to the datum WGS84. The equidistance outlined is 10 cm. The main topographic features (valleys, Alps) can be detected in the shape of this equipotential surface. In the South the geoid is dominated by a steep slope caused by intracrustal inhomogeneities (Moho-discontinuity, Ivrea zone).

The new Digital Astronomical Deflection Measuring system (DIADEM)

by B. Bürki, A. Müller, C. Hirt, H.P. Oesch and P. Sorber

A transportable analogue camera system (TZK) has been applied at GGL for about two decades. With this instrument, deflections of the vertical have been measured at about 500 stations in Switzerland and approx. 150 stations in Europe and Canada. In 2001 a new digital camera system has been designed and integrated into the system thus enabling on-line measurements by means of a new digital CCD sensor from DTA, Italy. The sensor consists of 3072 x 2048 pixels covering an area of 27 x 18 mm. This corresponds to a field of view of 1.5° by 1°. In addition to the digital CCD sensor, the camera as shown in fig. 3.8 is equiped with two highly accurate tilt sensors of type Wyler Zerotronic in perpendicular mounting, and totally 5 computer controlled servo motors. Three motors are used for an automated leveling procedure, one motor is used for rotating the objective by 180° in its opposite position, and finally one motor is used for placing the CCD sensor in its correct focal position. The software for steering of the system including automated leveling, exposure control by GPS, and data gathering is written under LabView from National Instruments. The software used for automated star extraction, identification and processing of the deflection of the vertical has been developed by C. Hirt at the Institut für Erdmessung at the University of Hannover, Germany.

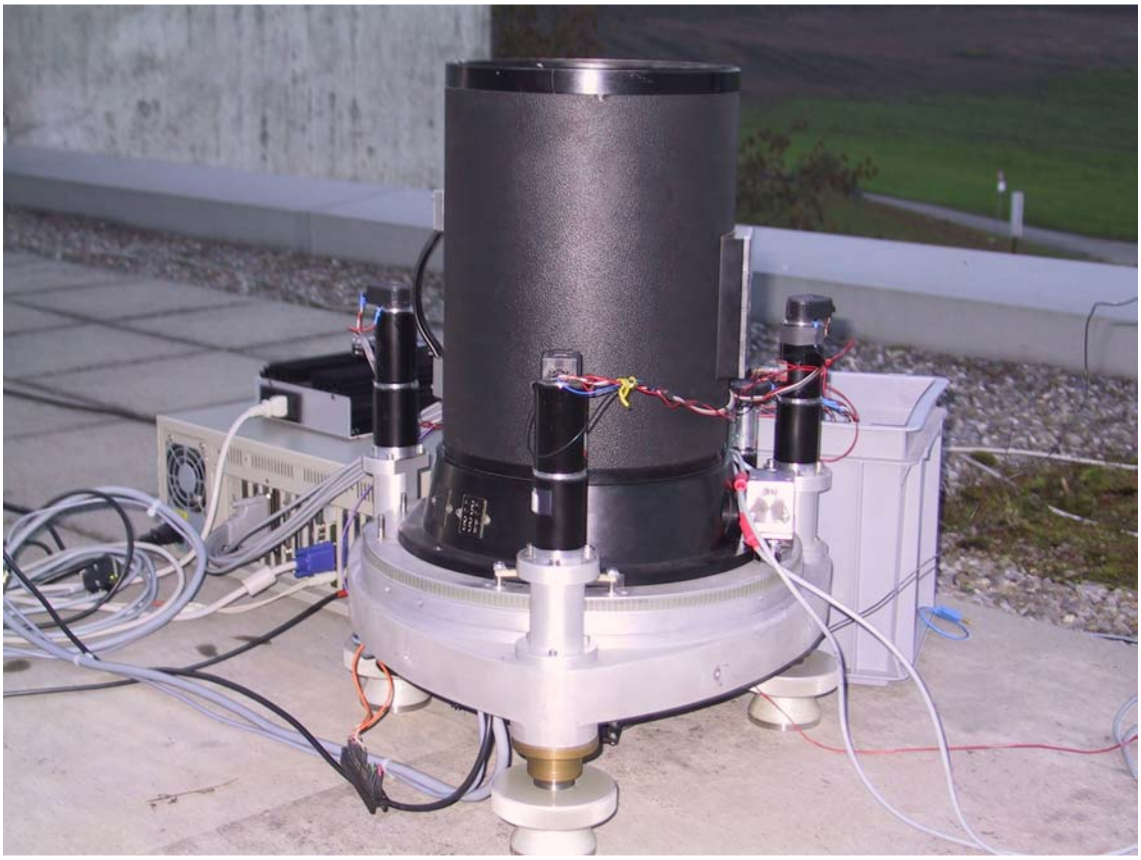

Fig. 3.8: Digital Astronomical Deflection Measuring system (DIADEM) as developed at GGL. The system is capable to perform an automated self leveling by means of three motors visible on top of the three leveling screws, two electronic levels, and a dedicated software package running under LabView from National Instruments Corp. The diameter of the (black) objective is 25 cm, the focal length is 1024 mm.

Plans for further applications

In order to improve the geoid computation and the consistency between GPS and leveling as described in the previous project, it is planned to perform additional measurements in and around Switzerland in the frame of the project CHGeo2003. These measurements will be carried out in collaboration with swisstopo and the University of Hannover, Germany. The planned stations are outlined in fig. 3.9 as red circles.

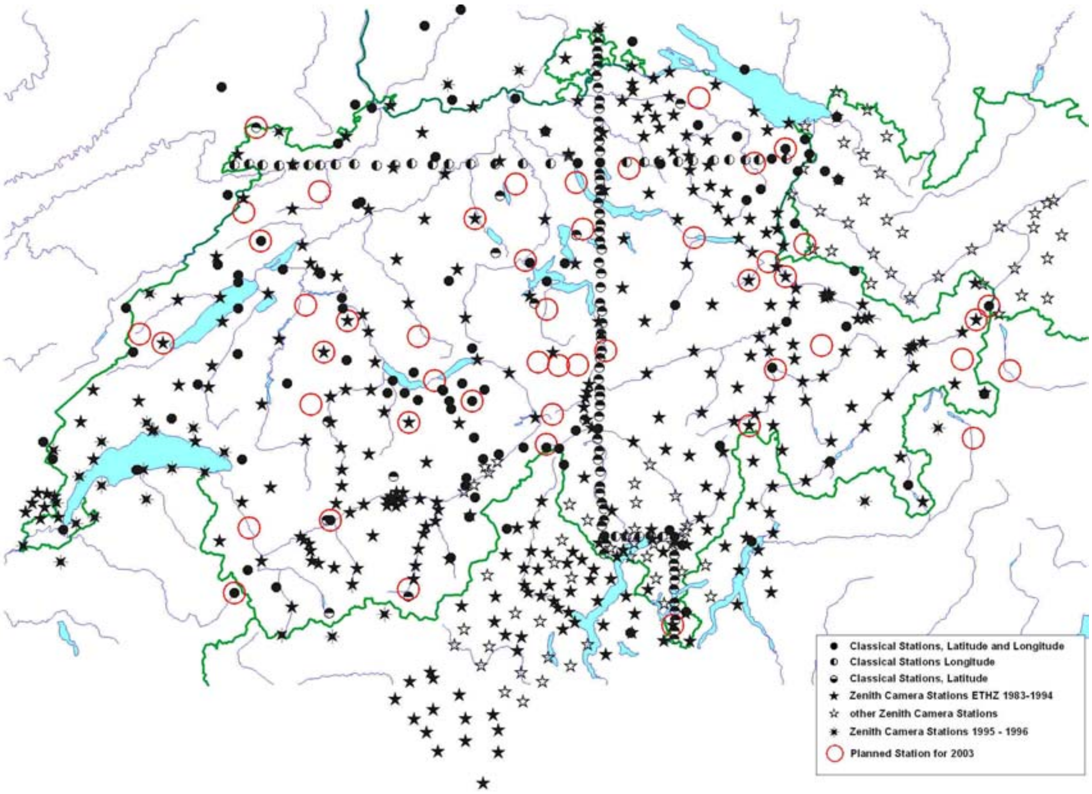

Fig. 3.9: Astro-geodetic stations in Switzerland and neighbouring countries. It is planned to replace the old measurements (drawn as small black circles with different symbols) by new measurements using DIADEM. The red circles represent potentially suited new stations.

For further details see: http://www.ggl.baug.ethz.ch/research/wg18/

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4 General theory and methodology

Bernese GPS Software

by R. Dach, H. Bock, P. Fridez, U. Hugentobler, M. Mervart, M. Meindl, M. Rothacher, S. Schaer, C. Urschl and G. Beutler

The Bernese GPS Software is the basic working tool used at CODE to generate the products for the IGS as well as for related experiments and tests. With the Bernese Processing Engine (BPE) the different routine and test solutions can be generated in fully automatic mode. The package, consisting of about 100 programs and more than 1000 subroutines is also in use by a number of institutions distributed all over the world. At the end of 1999 the version 4.2 was released together with an updated documentation of more than 500 pages (Hugentobler et al., 2001). The new release contains among others the capability to process GLONASS or GPS/GLONASS combined data, zero-difference as well as SLR processing capabilities, improved troposphere modeling and estimation, the possibility for elevation dependent observation weighting. It also contains a first test version of the new normal equation stacking program ADDNEQ2, and it is Y2K compatible.

Current developments involve improvements of troposphere and ionosphere modeling, consequent application of DCBs for satellites and receivers, processing of kinematic data, improvements of zero-difference data screening, enhancement of ADDNEQ2 with new parameters and refined preelimination options. New developments are under way in the domain of orbit determination of Low Earth Orbiters (LEOs) carrying GPS receivers. To mention is the upgrade of the software to the new IERS Conventions 2000 and the implementation of the estimation capability for Block- or even satellite-specific antenna phase center patterns. Several of these developments are carried out in close collaboration with M. Rothacher from the Technical University in Munich.

The new ADDNEQ2 program is nowadays one of the most important programs in the package apart from the main parameter estimation program GPSEST. It allows for the very efficient generation of additional solutions for validation or tests based on the manipulation of normal equations. Our routine processing makes extensive use of this tool. Almost all non-epoch parameters are now supported by ADDNEQ2. Tests are carried out for the stacking of zero-difference phase ambiguities. Efficient algorithms were developed for the generation of high rate clock corrections and for the determination of kinematic trajectories of LEOs. These algorithms use code observations as well as epoch differences of phase observations, thus eliminating the phase ambiguities. In parallel, the main parameter estimation program is upgraded in order to support the rigorous processing of LEO data in both zero-difference and double-difference mode for the computation of kinematic and reduced-dynamic LEO orbits. Additional effort is put into the dynamic and reduced-dynamic orbit modeling of LEOs. We may mention the software developments described in Beutler (2003). We refer to Section 2 for more details.

Significant effort had to be put into the development of a new graphical user interface due to problems on new generations of Windows operating systems. The interface between menu and processing programs was simplified and is now generic. In addition, the BPE was fully redesigned. It makes now use of inter-process communication. New developments in the processing programs make use of the new features of FORTRAN 90 such as parameter structures and dynamical memory allocation. A new version of the software, version 5.0, is in preparation. The release is scheduled for the second half of 2003.

Compass and Gyroscope Integration for Pedestrian Navigation

by V. Gabaglio, Q. Ladetto and B. Merminod

To complement GPS localisation for vehicle navigation using a gyroscope or placing a sensor within the steering mechanism is quite common. Widening this service to the pedestrians requires a different approach that adapts to a much larger freedom of movement. Knowing the orientation of the terrestrial magnetic field makes it possible to determine the azimuth of displacements of a person. Variations of the intensity of the magnetic field hint at magnetic disturbances. However, the use of a gyroscope has proven useful to facilitate the detection of such disturbances and to overcome them. More stable in the short term than the compass, the gyro is therefore an optimal complement (see fig. 4.1). By allowing for absolute positioning while moving, the implementation of a GPS receiver is essential to initialise and to re-calibrate periodically both the position and orientation of the system. The altitude is obtained via barometric measurements. According to the required precision, differential barometric measurements must be envisaged. The compass-gyroscope integration, together with the detection of any movement, allows for an optimal filtering of the azimuth with little or no temporal degradation.

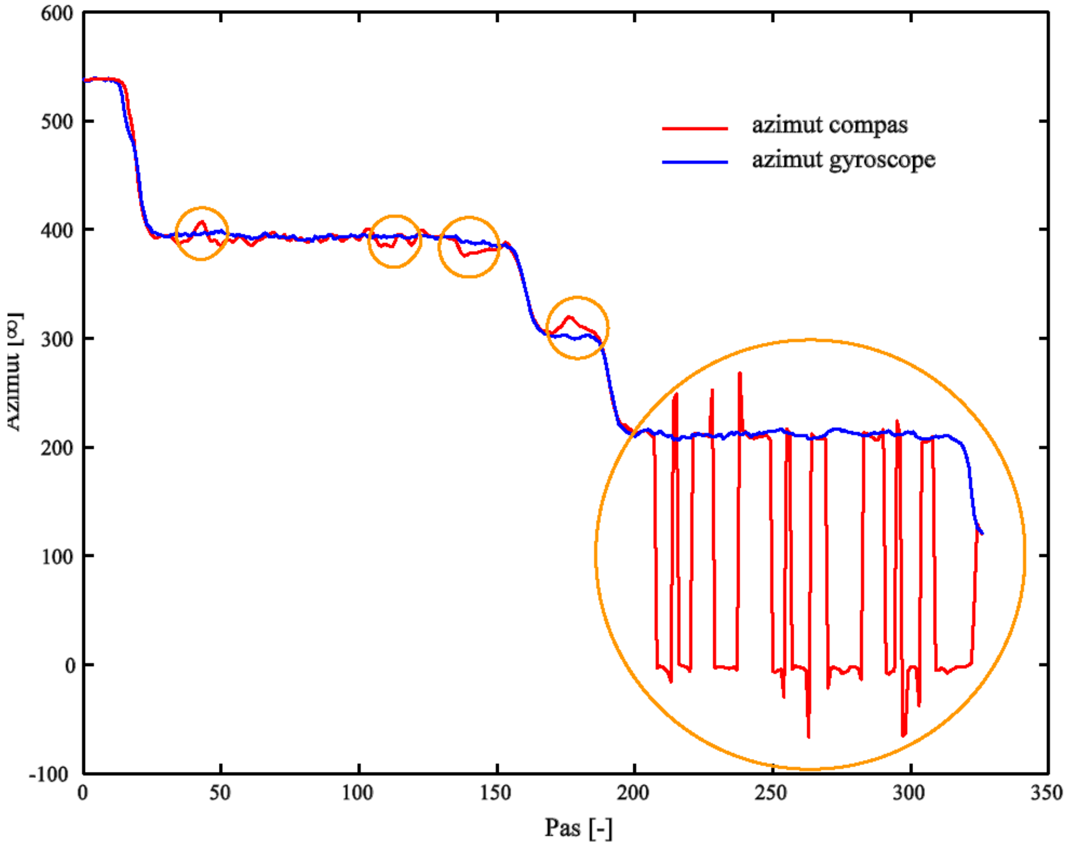

Fig. 4.1: The magnetic perturbations encountered around a commercial centre are highlighted by circles. While the cause of smaller disturbances is difficult to identify, the frequent half turn jumps of the compass (in the large circle) happen when walking behind a row of parked cars.

Step identification via Microsensors and Biomechanical Models

by Q. Ladetto, C. Steiner and B. Merminod

For dead reckoning with vehicles, the traditional approach consists in using a triad of accelerometers and gyroscopes generating signals, which are integrated to obtain the relative displacement. Unfortunately, this concept is difficult to implement with a low-cost system. The principal reason is that the sensor noise blurs the signal corresponding to the displacement of a person. In order to take these features into account, an approach by occurrences was developed, whereby the steps are detected, their type identified and their length estimated based upon a subset of sensors as well as physiological and biomechanical parameters of the walk.

The first area of interest consists in the determination of the physiological parameters necessary to quantify the speed of walk and the step length. While the variance of the accelerometer signals is a good speedometer, the frequency of the steps improves the robustness of the models. The influence of the gender added to the great human diversity implies the normalisation of the various relations deduced. Many tests carried out under everyday life conditions reveal that the variation of the stride length, especially with the slope, strongly depends on the physical training of the person as well as on the duration of the climb or descent. Characteristic patterns were identified to differentiate between the forward, backward and lateral movements. Various models were suggested and then favourably tested with some blind people, whose walking rhythm varies strongly according to the degree of confidence they have in the path that they follow.

The multiple technologies have been integrated to build an autonomous three-dimensional Pedestrian Navigation Module (PNM). During periods with a fair reception of the satellite signals, the embedded GPS receiver allows to calibrate the different sensor parameters and physiological models. An initialisation phase has been developed to individualise the parameters of the walk and to adapt them from the general model. The consideration of several phenomena specific to the displacement of humans brings artificial intelligence into pedestrian navigation. The coupling of the various sources of measurements, the influence of their precision on the computed position as well as their implication on the PNM reliability are described and illustrated in various publications.

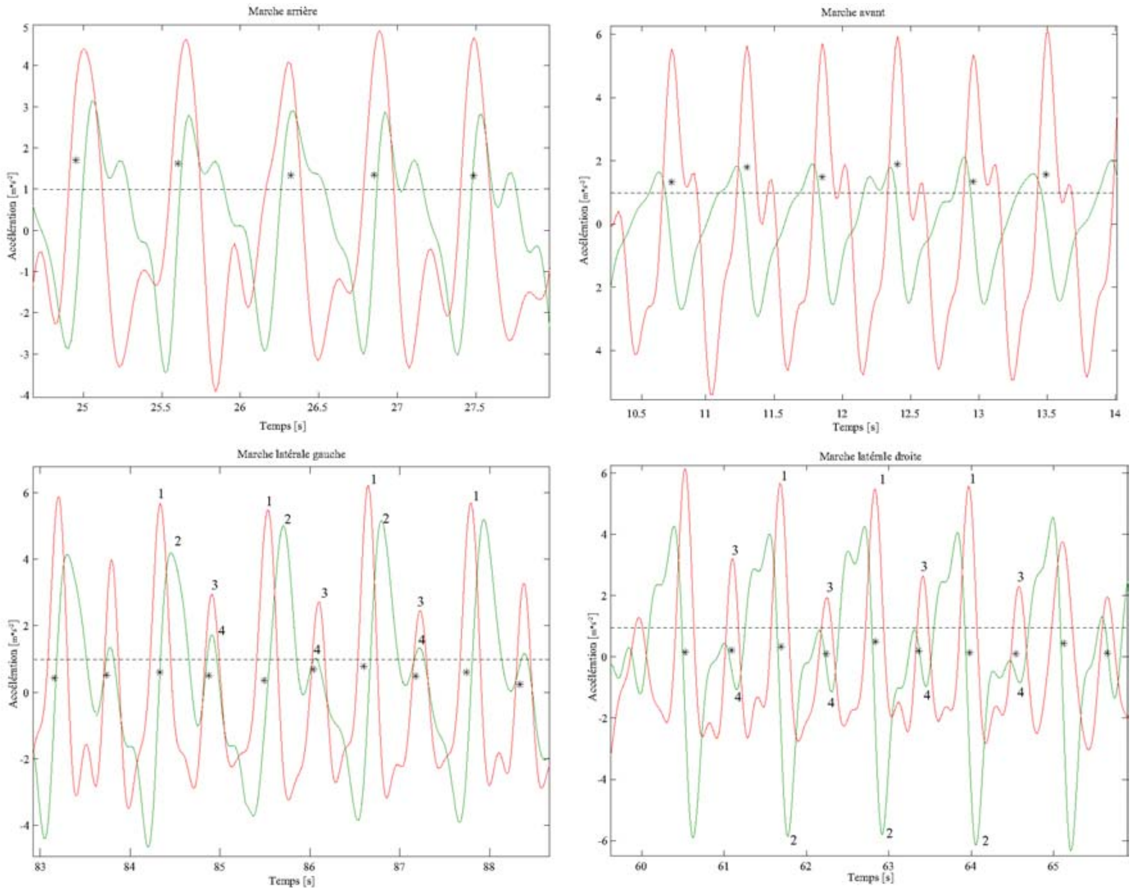

Fig. 4.2: Characteristic patterns of the accelerometric signals in the four main walking directions. The asterisks(*) indicate the values of the ratio Var(X)/Var(Y) where X is the acceleration in the front direction and Y is the lateral acceleration. A ratio clearly smaller than one indicates that the person walks sidewise.

Forward (top right graph) and backward steps (top left graph). The green line represents the vertical acceleration and the red line represents the X acceleration. The sequence of the peaks in the accelerometric signals is the main criterion to distinguish forward and backward steps. For forward steps, the peak in the vertical acceleration (impact of the heel) happens first. For backward steps, a surge in the acceleration along the line of the movement precedes the impact of the heel.

Side steps: The green line represents the vertical acceleration and the red line represents the Y acceleration, with a positive sign in the right direction. The main criterion is given by the slopes of the Y acceleration: when walking to the right (lower right), the ascending side of the signal (moving the right leg away) is less steep than the descending side (bringing the left leg closer).

From Discrete to Continuous Normal Equations

by A. Geiger

In Geodesy and Navigation positions are often determined by measurements from the observer to some reference points. E.g. distances or pseudodistances, distance differences, angles, dopplershifts etc. In order to calculate the position it is necessary to know the position of the reference points. One should know the satellite's positions, the positions of the referred markers, the locations of beacons etc. However, in many cases we would like to carry out a performance analysis rather than an exact estimation of our position. In addition, very often the exact position of the reference is not known. For these two reasons we developed a method which allows the calculation of positions without knowledge of the exact reference coordinates. The method is based on the continuous view point. The discrete reference coordinates are replaced by a density distribution of reference stations. For example the knowledge of the density of satellites over the sky is enough to calculate a GPS position and its precision. By this method it is very straight forward to derive general rules for obtainable accuracies. An example for a terrestrial application is given in section 1 where a performance analysis of cellular phone positioning has been carried out without knowledge of the antennae coordinates.

Modelling the Differences between levelled heights and orthometric heights

by U. Marti

The introduction of a new national height system, as it is prepared now in Switzerland, introduces the need for an accurate and efficient transformation method between various data sets containing height information. The official Swiss Height Systems (LN02) is based on pure levelling without taking into account the gravity field. The use of LN02 in combination with GPS and the data exchange with neighbouring countries causes many problems and it was decided to introduce a new height system called LHN95. This height system is based on geopotential numbers obtained from a rigorous adjustment of all available levelling data since 1902. Out of the geopotential numbers orthometric heights and normal heights are calculated. The orthometric height is obtained from the geopotential numbers by division through the mean gravity along the plumbline. This mean gravity is calculated strictly from surface gravity measurements and using mass models (25 meter digital terrain model and a simple 3D density model of the earth's crust). The surface gravity can be interpolated with an accuracy of 1 to 3 mgal (1 mgal = 10^{-5} ms^{-2}) everywhere in the country [Marti, 2001] which is sufficient for levelling and the determination of orthometric heights. The conversion between normal and orthometric heights (or between quasigeoid and geoid) requires the difference of mean gravity along the plumbline and the mean normal gravity, which is often approximated by the Bouguer anomaly.

The strict differences can be expressed by the following formula:

$$H_{orth} - H_{norm} = \frac{\bar{\gamma} - \bar{g}}{\bar{g}} \quad H_{norm}$$

and are often approximated by

$$H_{orth} - H_{norm} = \frac{-\Delta g_{Boug}}{g} \quad H$$

This approximation works very well except in high mountain areas and has the advantage that the Bouguer anomalies are rather easy to interpolate whereas the differences between the mean gravity along the plumbline and mean normal gravity shows some very high frequency parts, correlated with topography. The long wavelength structures are the same in both formulas.

The differences between orthometric heights and normal heights follow theoretical concepts and can be computed rigorously from the geopotential numbers if we have an appropriate model of the mass distribution of the interior of the earth. The situation is a little bit more complicated if we want also to compare the official heights LN02, which have been produced without considering the gravity field. It is distorted due to the limited accuracy of methodology and instrumentation of the 19th century and it does not take into account the uplift of the Alps, which can reach up to 1.7 mm per year in some regions. These vertical movements accumulate until today to an amount of more than 20 cm, which were never corrected in the official heights. If we compare the LN02 heights with orthometric heights we get differences from

-20 to +45 cm at the levelling benchmarks which are correlated with elevation but also include network distortions and the influence of vertical movements. These differences are larger than the differences between orthometric and normal heights (0 to +50 cm) which show a much clearer correlation with height. The smallest differences are obtained if we compare the LN02 heights with normal heights. They are in the order of -20 cm to +10 cm and they are practically not correlated with elevation. These differences mainly represent the influence of the gravity reduction, network distortions and the influence of vertical movements. These differences between normal heights and LN02 heights show a very smooth distribution which can be easily interpolated. The differences show a trend more or less in north-south direction, which indicates mainly the influence of the gravity field. The fact, that the differences between normal heights and LN02 heights can be interpolated easily with an accuracy of better than 1 cm, helps us also to model the differences between orthometric heights and LN02 heights. They are separated in a part of differences between normal and LN02 heights, which only depends on the horizontal position and a part of differences between orthometric and normal heights depending mainly on elevation and the gravity field.

For the modelling 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 the Bouguer anomalies are provided. Both of them car easy to interpolate and we obtain the differences with the formula

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

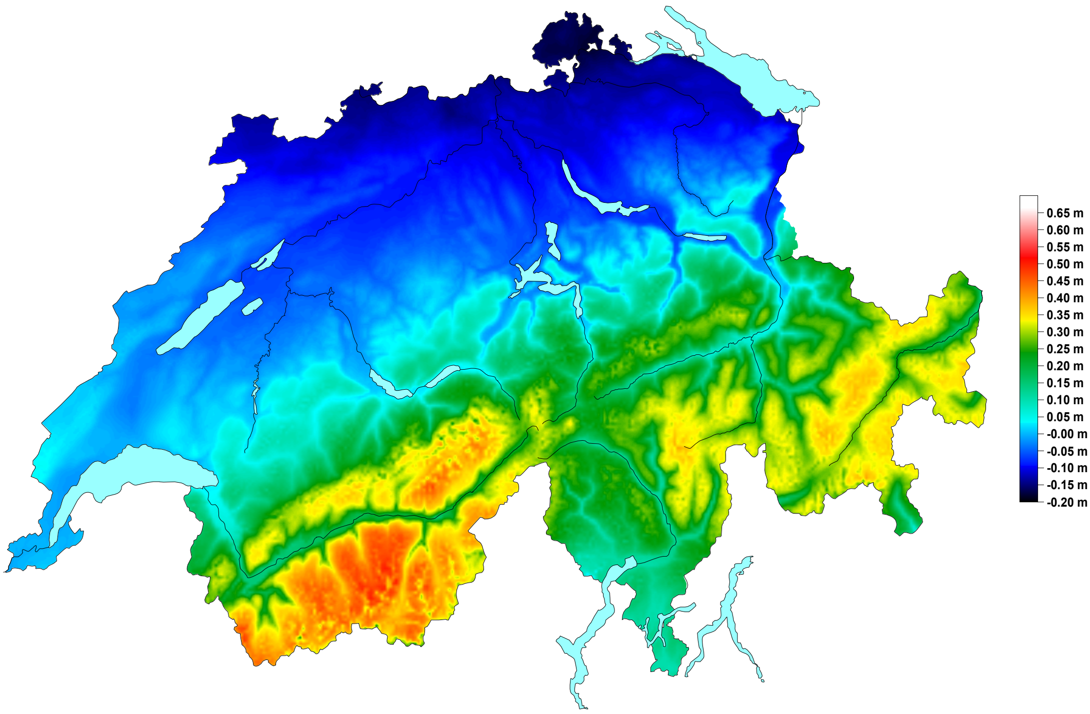

Fig. 4.2: Differences of orthometric heights (LHN95) minus levelled heights (LN02)

Robust Estimator in Geodesy and GIS

by A. Carosio

Since the seventies the ETH Zurich (Swiss Federal Institute of Technology) has a top position in the field of robust statistics. Names like Huber and Hampel are well known worldwide. We recognized the importance of such procedures and developed further these methods for the needs of geodesy. However, a broad use of robust estimators for the adjustment of geodetic networks did not occur for a long time. In 2001 a turning point has been reached and robust statistics in Geodesy could claim an international success thanks to the long period of our researching activities: following the initiative of our group the IAG (International Association of Geodesy) organised at ETH Zurich the First International Symposium on "Robust Statistics and Fuzzy Theory in Geodesy and GIS". This Symposium took place from 12 to 16 March, 2001 at the ETH Zurich. The suggested methodologies met a significant international approval by over 50 experts coming from 18 different countries. At the IAG General Assembly 2001 in Budapest, the Symposium was mentioned as a highlight of the geodetic research and a whole session was dedicated to this topic. The robust statistics will take an important position in geodesy.

Changing coordinate reference frame of GIS-Data using model-driven approach

by A. Morf and A. Carosio

During the last years, the responsible authorities of the federal office of topography in close collaboration with various experts developed a detailed concept for changing the coordinate reference frame to a new one (LV95, GPS-based) which satisfies today's demands. The basic idea to solve this problem with an acceptable effort leaded to the resulting 'linear transformation with finite elements' approach, where a region is divided into triangles of adjusted size to reach demanded accuracy. A first implementation of the evaluated algorithm was achieved at our group and tested successfully in different pilot schemes.

Due to the large GIS-datasets available today, the operators are confronted with the problem of performing the transformation task on different systems and data models. The well established conceptual data modelling language 'INTERLIS' lead us to the following idea: a tool which is able to parse an arbitrary conceptual data-model, read according geo-data and perform the transformation, should minimize operating expenses in a significant manner. The resulting software was tested on various datasets and is now at an operational stage.

Geodesy: Theory and Methodology

by D. Salvini and A. Carosio

The grandiose project of building the new Swiss Alpine Transversals fronts the geodetic engineers to new and unknown practical situations, especially considering the 60 km length of the major of the planned tunnels. One of the main aspects to take under control is the effect of this work on other infrastructures, providing a regular stability monitoring of buildings and other constructions, e.g. dams that are lying over and in proximity of the tunnel. It has to be mentioned that acquiring exact positions inside the tunnel can not be considered as the usual practice, especially due to the unique conditions given by this project (length, diameter, clime, etc.). Our group works in providing good solutions for the mentioned problems. The information gathered on the construction side are applied to check and iteratively to adapt the stochastic and functional models of the global adjustment of all available measurements. The most sensitive parameters in this system are the reductions, whether of distance or whether of azimuths; and the model of the geoid applied e.g. to derive the deviation of the vertical. In order to increase the reliability of the measurements the surveying includes also gyroscopic observations. These measurements are considered in the global compensation with an unknown parameter that represents the orientation of each session of gyroscopic measurements.

Fuzzy-Logic Introduced in Geodetic Data Analysis Processes

B. Graeff and A. Carosio

By means of fuzzy logic decision processes in a wide range of technical applications could be improved. The implementation of fuzzy sets, once developed by Zadeh in the 1960s, in complex regulation and decision tasks allows faster but not less accurate computation. Therefore, the introduction of fuzzy methods in all time-consuming calculation processes is highly recommended, various applications in the field of geodesy included. More complex estimation or evaluation of statistical parameters, decisions made by hypothesis testing, or time-consuming calculations required by pattern or image matching approaches could be facilitated by their fuzzification. Instead of clearly defined parameters, fuzzy sets of parameters are introduced. The decision, estimation or calculation process or, in general, the "regulation" process is made in a fuzzified parameter context. After defuzzification, that is the projection of the fuzzified regulation result towards the non-probabilistic context, decisions and results are usually obtained in less time than by conventional processing. Geodetic researches in the field of data analysis by means of an intelligent symbol matching in topographic maps made by the Swiss Federal Institute of Technology show satisfying results which could not be obtained by conventional non-fuzzifying methods in the same time.

A Simplified Approach in Utilizing Information from Permanent Reference Station Arrays

by Hans-Jürgen Euler, Frank Takac and Benedikt Zebhauser (Leica Geosystems AG, Switzerland)

Permanent reference station networks are already operational; however, the means of communicating information derived from these networks to the user has not been defined in detail. One networking scheme, the Virtual Reference Station (VRS) concept, bases on generation of artificial observations of a non-existing reference station. These observation information is transferred via RTCM SC104 standard messages. However, these standard messages are defined only for the transfer of original receiver observations. A second scheme uses a spatial correction parameter set (FKP). The content of the parameter set is only coarsely defined while describing the size and resolution of parameters to be transferred. None of the descriptions of these two schemes are guarantying interoperability, since the calculation steps for deriving networking information are not documented in detail. A novel scheme of using information from permanent references station networks was proposed by Euler et al. (2001) and Zebhauser et. al. (2002). The method preserves the integrity of the original observations. Only simple, well described calculations are used to reduce the size of the required information. This method is called the Master-Auxiliary Concept since it is based on single differences between so-called master reference station and auxiliary reference stations.

A major contribution of reference station network software is the collection of observations at a central processing facility. While the software installed at the processing facility can operate uninterrupted, it will have the optimal information for solving integer ambiguities between the permanent reference stations utilized in the network. Fixed ambiguities are also a key feature of the VRS and FKP approaches. Only correctly fixed ambiguities permit the essential step of determining precise information about the biases caused by tropospheric, ionospheric and orbit errors. When the correct integer ambiguities between reference stations have been removed, all observations satisfying this condition will have the same ambiguity level throughout the whole network. Users receiving ambiguity leveled observations can utilize this information without the need to model inter-station ambiguities onboard the sensor. The delivered information is sufficient for processing multiple parallel reference stations in one single solution onboard with its limited processing power since only one set of integer ambiguities have to be estimated and fixed. The Master-Auxiliary concept reduces the computational load at the rover. However, ambiguity leveled observations have, in principal, the same size as the raw observations of a GNSS receiver. The amount of observations to be transmitted to the rover would be proportional to the number of reference stations in the network. Most of the variation between observations of different reference stations is due to satellite and station geometry and common biases for troposphere and ionosphere. Single differencing between a designated master reference station and an auxiliary reference station plus the removal of satellite-station geometry significantly reduces the magnitude of the variation in comparison to the original observations. The remaining information, termed a correction difference, describes the regional effects of the atmospheric refraction, the differenced orbit biases and the uncorrelated errors of each reference station. The correction differences for auxiliary stations around the mobile user can be used to correctly model or simply interpolate for the user’s current position. Together with the raw observations of the master reference station, the user can significantly reduce distance dependent errors and, therefore, extend the range of operation from reference stations.

The fundamental principles embodied in the Master-Auxiliary concept are also inherent in the VRS and FKP approaches. However, the interface of the Master-Auxiliary concept is more easily definable because the calculations are either already standardized or of a simple nature. The result will be seamless inter-operability for service providers utilizing the Master-Auxiliary Concept and the mobile units complying with the standard. The Master Auxiliary Concept was introduced into standardization discussions in the RTCM SC104 committee in 2001. The same principles were voiced in RTCM66 (2002) and currently a joint proposal is under discussion to become the standard for networked reference stations.

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BRZ Bulletin des Rechenzentrums (Bundesamt für Landestopographie, swisstopo)

VPK Vermessung, Photogrammetrie, Kulturtechnik

5. Geodynamics

CODE Contributions to Earth Rotation

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

The orbit determination process for GPS satellites allows it to estimate Earth rotation parameters (ERPs), i.e., to measure the 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). Not directly accessible by GPS is the absolute orientation of the Earth. UT1 is, therefore, usually constrained to an external value such as the value published by the IERS (e.g., Bulletin A). CODE computes ERPs with a 1-day resolution and delivers them in SINEX format to the IGS for combination. Separate time series are provided directly to the IERS (International Earth Rotation Service) for analysis. Today a time series of more than 9.5 years is available from CODE. Figure 5.1 shows the Chandler wander of the Earth's rotation axis starting with June 1993. The accuracy of the daily values as compared to other techniques is a few 0.1 mas.

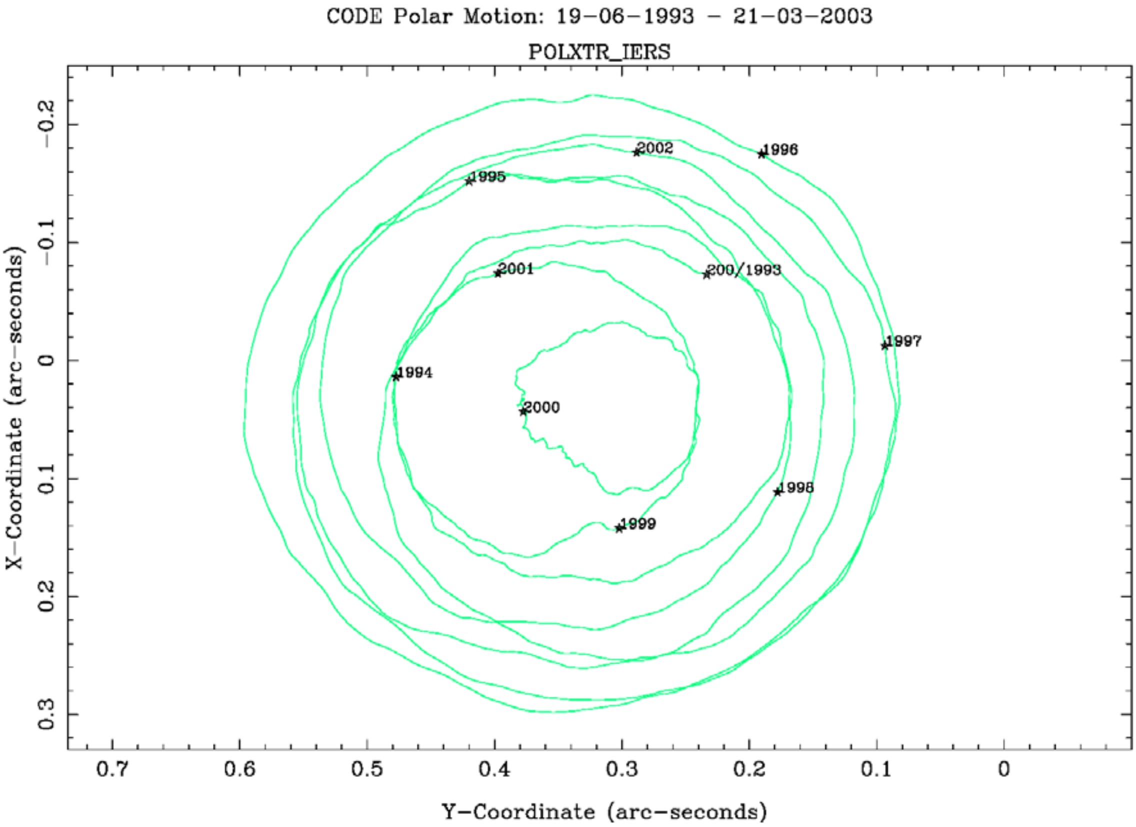

Fig. 5.1: Polar motion covering a time period of more than 9.5 years.

Figure 5.2 displays the variations of excess length of day for the same time period of more than 9.5 years. Prominent features are the fortnightly variations due to tidal deformation of the Earth, the annual variations, and a seemingly secular drift. This drift is in fact part of a decadal variation caused by core-mantle coupling and overlying to the secular increase of the length of day of about 2 msec/day per century.

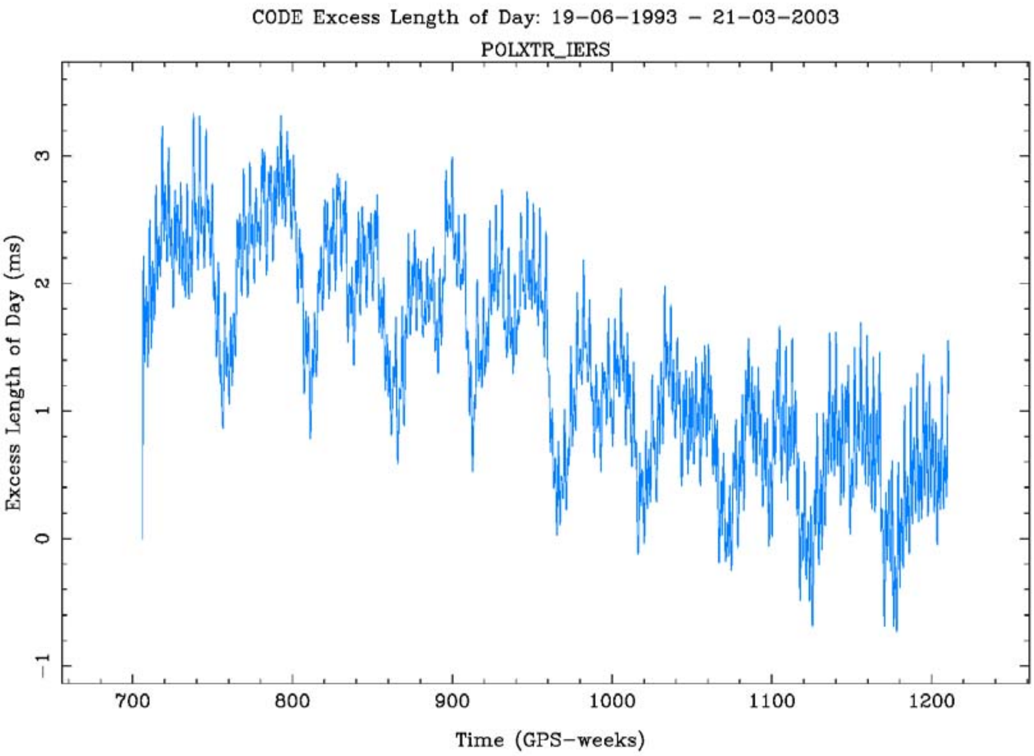

Fig. 5.2: Development of excess length of day over a time period of more than 9.5 years.

The annual variations nearly entirely due to seasonal variations of mass distribution in the Earth's atmosphere. Figure 5.3 shows a comparison of the axial angular momentum of the solid Earth as computed from the GPS LOD measurements and provided by the NCEP numerical weather model (reanalysis time series produced by the IERS Special Bureau for the Atmosphere) for a time interval of nearly 9 years. For the comparison the tidal variations and a second-degree polynomial were removed from the CODE time series. The correlation coefficient of 0.98 between the two time series indicates that the annual variations in the excess length of day are almost entirely explained by the interactions between the solid Earth and the atmosphere. Since January 1995 CODE is internally using a 2-hour resolution for polar motion and LOD parameters. Each component in this high-resolution series is represented by a piece-wise linear function with respect to a subdaily model. Results derived from this unique time series covering now more than 8 years may be obtained from Rothacher et al. (2001). Due to correlation with orbit parameters GPS is not sensitive to nutation offsets. Drifts in nutation are, however, observable using GPS measurements. Since April 1994 daily values for drifts in nutation in longitude and obliquity are estimated at CODE. The time series covers more than 9 years by now.

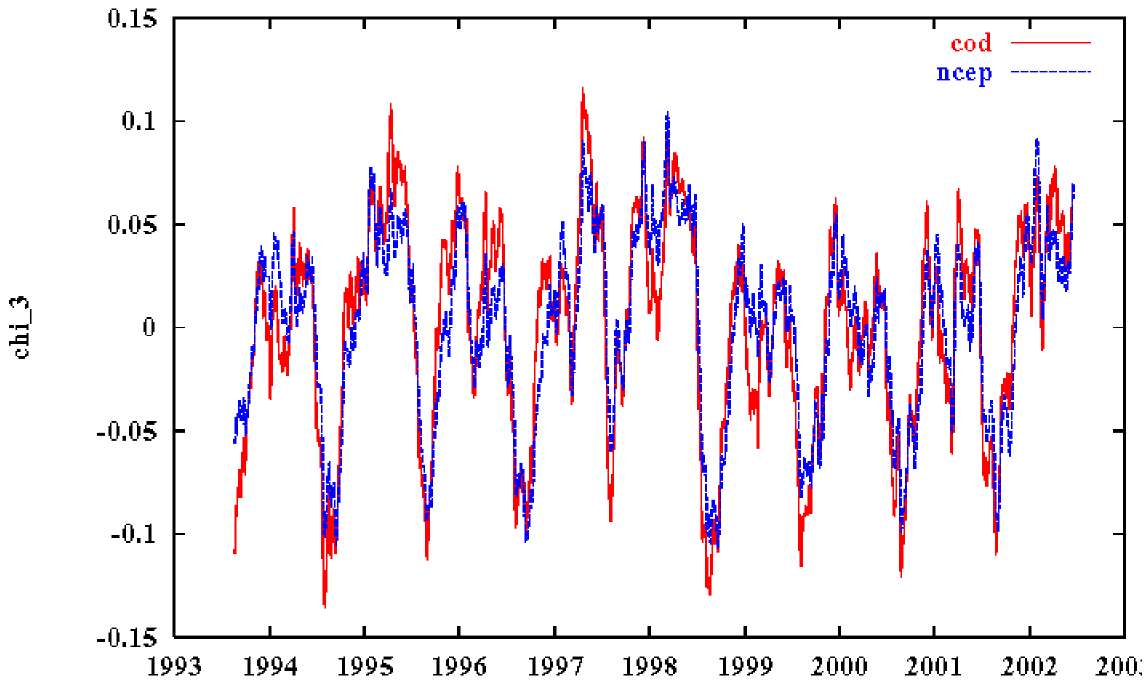

Fig. 5.3: Comparison of the axial angular momentum of the solid Earth as derived from GPS LOD measurements (red, tidal variations and second-degree polynomial removed) and the values derived from the atmospheric angular momentum as provided by global numerical weather models (blue).

Recent crustal vertical movements in Switzerland: Activities for the new national height system 'LHN95'

by A. Schlatter, U. Marti and D. Schneider

The analyses of recent crustal movements from repeated precise levelling has been investigated in Switzerland for several decades. The 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 Section 1) all measurements since 1902 were systematically captured in digital form. Up to now, about 8500 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. With the so-called kinematic adjustments of precise levellings, it is now 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). Figure 5.4 shows a selection of suitable bench marks with their annual height changes and the corresponding double standard deviation.

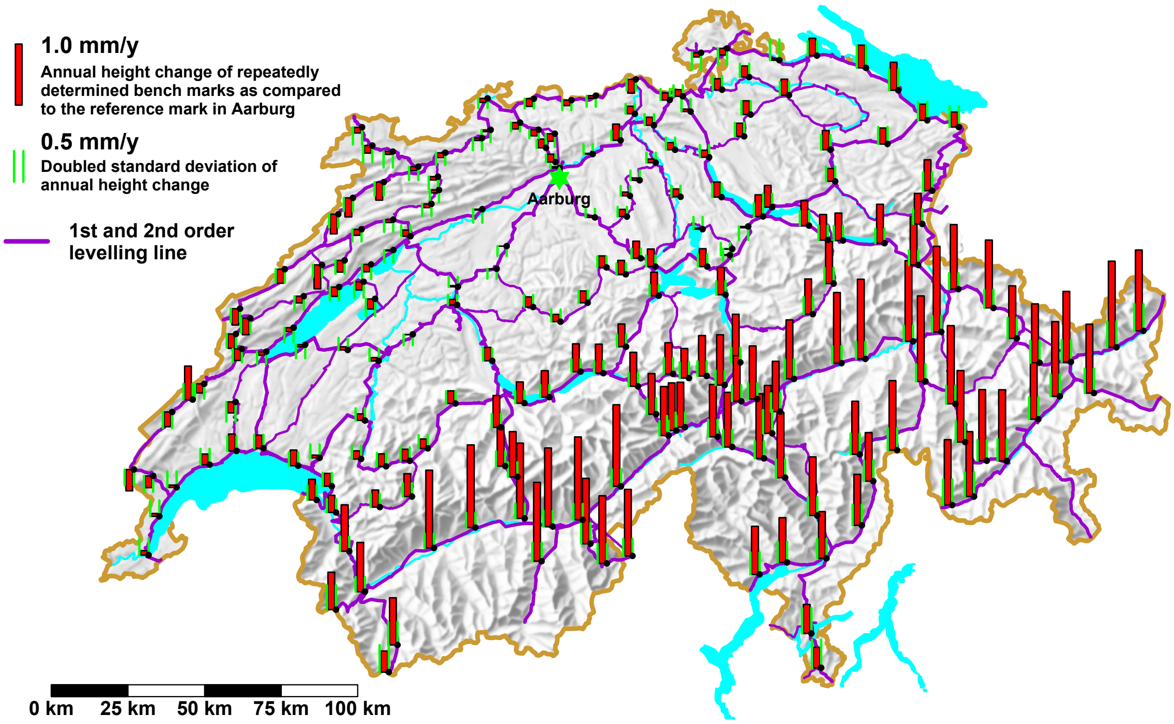

Fig. 5.4: Recent vertical movements of selected bench marks of the National Height System LHN95 (relative to Aarburg, southern Jura Mountains)

The most recent investigations (Figures 5.4 and 5.5) clearly show the zones with significant uplift rates reaching up to 1.5 mm/yr in the central Alps and the Engadin. From the main Alpine Massif towards the northern and southern Molass Basins (Central Plateau and Po delta) a very clear decrease in the uplift rates is evident. In the region of the western part of the Jura Mountains there is even a predominant subsidence. The causes for these significant uplifts in the Alpine area haven't been completely clarified yet. Three main reasons seem to be a possible explanation for the vertical movements:

- uplift as a direct result of an orogenetic, tectonic process such as the penetration of the European crust by the Adriatic spur
- uplift as an isostatic state of equalisation caused by erosion, or
- uplift as an isostatic state of equalisation caused by postglacial rebound

The recent vertical movements derived from precise levellings will still serve as an ideal and interesting data base for investigations in earth sciences as well as for long-term scenarios for storing radioactive waste. Besides the aspects of earth sciences and engineering techniques, vertical movements are significant for geodetic applications. The kinematic investigations show that for the main part of Switzerland precise height information is not a static matter. In order to calculate height information for the majority of the points with only one observation and at a certain moment, a kinematic model is necessary.

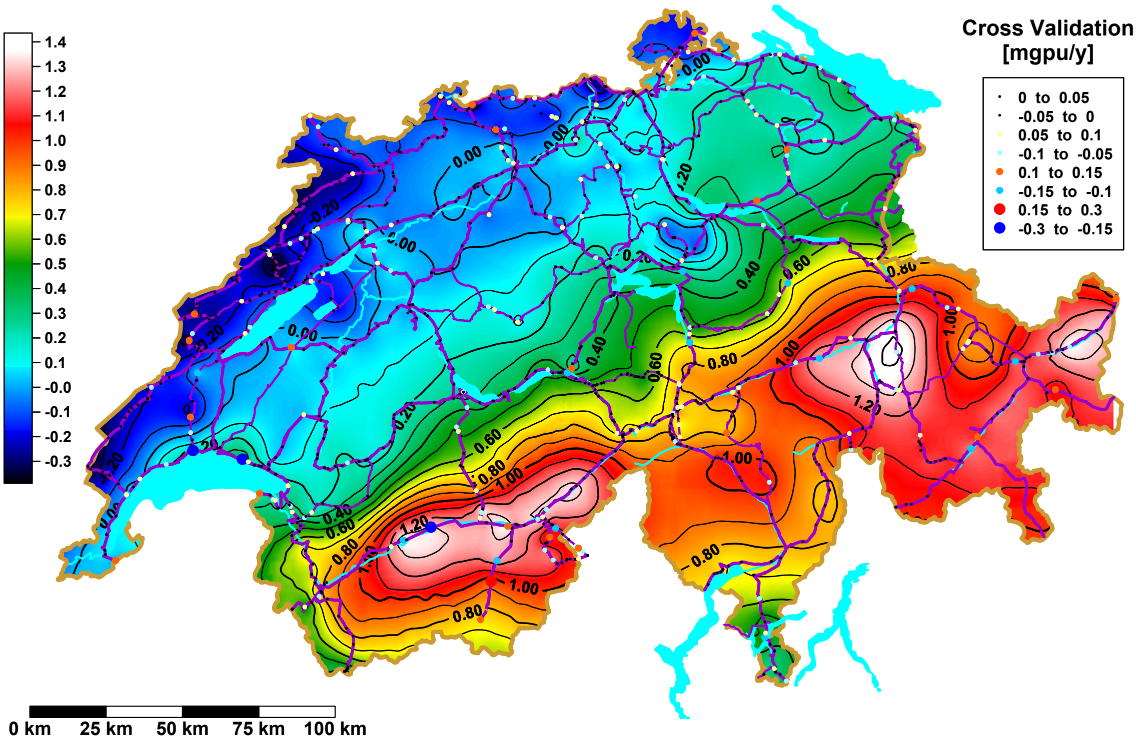

Fig. 5.5: Kinematic model of the National Height System LHN95 and cross validation of the bench marks

From the kinematic adjustment of the LHN95 data set there are more than 1000 levelling points with which a kinematic model can be defined (s. Figure 5.5). A first step for testing the model was to predict the vertical movements of each bench mark derived from its neighbouring points. This allows the elimination of unstable points and provides first information of the quality of the model. In Figure 2 the residuals from the cross validation are presented in different colours. Figure 5.6 shows the distribution of the residuals. The standard deviation from the normal distribution is 0.04 mm/yr; this gives an idea of the obtainable accuracy.

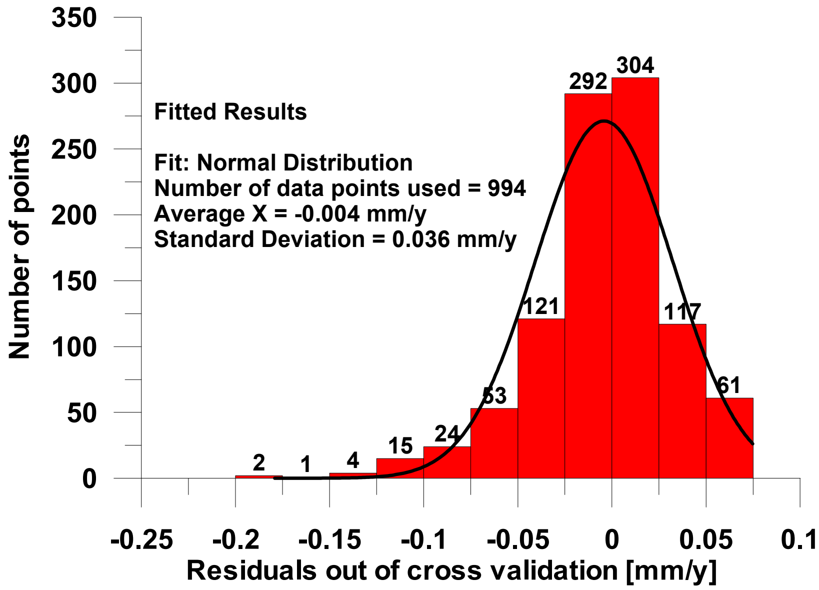

Fig. 5.6: Distribution of the residuals from the cross validation

Geodetic Measurements and Modelling of Recent Crustal Movements (RCM) in the Alpine Region

by A. Geiger, H.-G. Kahle, D. Schneider, A. Schlatter, M. Kistler and E. Gubler

Geodynamic processes which are ascribed to relative motions between the Eurasian and African plates govern the ongoing plate tectonic activity in the central Mediterranean/Alpine region. Superimposed on the underthrusting of the Adriatic block beneath the Southern Alps is a rotational motion caused by the counter-clockwise rotation of the Italian peninsula. Recently established GPS networks, as well as terrestrial levelling lines carried out in Switzerland since the last century, are used to assess the strain rate tensor in the Swiss Alps. A crucial problem relevant for geodynamic research is the interpretation of the detected recent crustal movements in terms of stress and driving forces.

Earthquakes are commonly related to tectonic movements, sometimes of relatively small amount which correspond to far-field stresses of lithospheric plates. One of the classical high-precision geodetic methods, levelling, yields reliable results for the height component of RCM. Due to the beginning of systematic high-precision height determinations early in the last century it has become possible to detect height changes at the mm range per year in Switzerland. Modern geodetic methods, such as GPS, greatly enhance the knowledge of lateral crustal movements.

The question arose how geodetic data, especially uplift rates, can be compared and correlated with geophysical data, especially with earthquake activities. Attempts have been made to interpret geophysical and geodetic data in terms of strain energy by introducing boundary conditions for a mechanical crustal model and by assuming seismicity being correlated with strain energy. The stress-strain analysis of the Swiss Alps has been performed, using 2D-model as well as 3D-models. In the latter case the Alpine crust has been simplified by a multi-layer model, taking also detailed topography into account. Isostatic forces as well as NNW-SSE compression have been introduced in finite element (FEM) calculations. The results reveal a striking agreement of the calculated strain energy with the regional seismicity in the cantons of Grisons and Valais. Furthermore the uplift rates can satisfactorily be reproduced by the 3D calculations. Special emphasis has been placed on the central Alpine chain in the vicinity of the Gotthard region, where significant local subsidence rates have been detected (see also Schlatter et al.).

Besides scientific purpose, private and public organizations are becoming more and more interested in the results. Different studies have been contracted such as:

- tectonic investigations for long-term scenarios for the planned storage of radioactive waste
- tectonic investigations for the construction of planned railway tunnels through the Alps

Recent publications:

Verdun, J., Geiger, A., Brockmann, E., Kahle, H.-G., and D. Schneider, 2002.

For details see:

http://www.ggl.baug.ethz.ch/research/wg06/ and http://www.ggl.baug.ethz.ch/research/wg58/

Modelling the Kinematics of the Deformation of the Swiss Geodetic Reference Network: Project SWISS-4D

by A. Wiget , A. Geiger, M. Kistler, H.-G. Kahle and D. Schneider

Not only the strong earthquake, which struck Basel 650 years ago, bears witness to the geodynamic forces in central Europe – or more specifically in Switzerland. But also results from repeated levellings, the first measurements being 100 years old, show a still ongoing movement and uplift of the Alpine structure. The amount of maximal 1.5 mm per year is not negligible. During the last years GPS has become a major tool for detecting horizontal crustal movements. Whereas first analysis of GPS campaign-type measurements over an interval of ten years was not able to significantly prove tectonic movements, the permanent measurements at the 29 stations of the Automated GPS Network in Switzerland (AGNES), operated by the Swiss Federal Office of Topography (swisstopo) may indicate small movements (fig. 5.7). Whether these movements are of a geotectonic nature is not yet clear. The project SWISS 4D, initiated by swisstopo and commissioned to the Geodesy and Geodynamics Lab (GGL/ETHZ) shall shed light on different questions concerning the geodynamics and the changes in time of the three-dimensional coordinates of the reference network. In a joint approach levelling data, GPS data and seismic information shall be combined in order to generate a consistent model of the changes of 3D coordinates with time. This kinematic model, being an essential component of the new Swiss geodetic reference system, will allow the calculation of the time-dependent three-dimensional deformations of the surface of Switzerland. Spatial continuous velocity or strain rate fields are determined to describe the deformation process within the reference network (fig. 5.8).

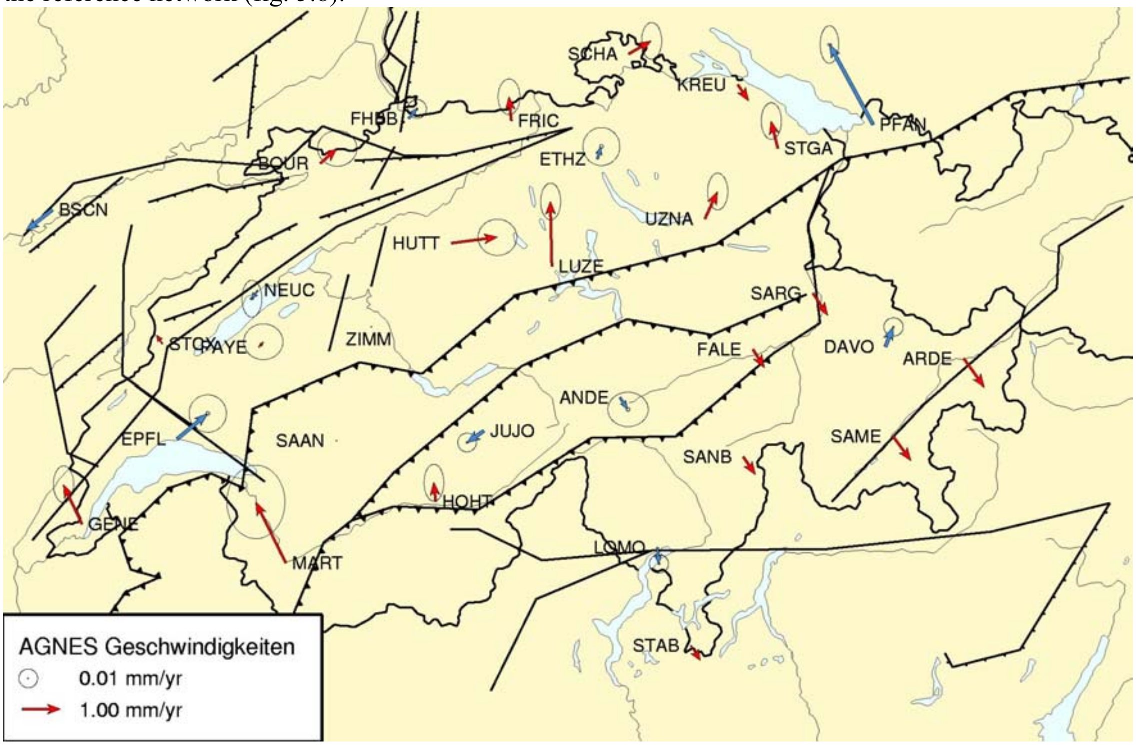

Fig. 5.7: Velocity field (relative to Zimmerwald, ZIMM) in Switzerland deduced from the Swiss permanent GPS network AGNES (see also contribution in section 1). The lineaments indicate the major tectonic features.

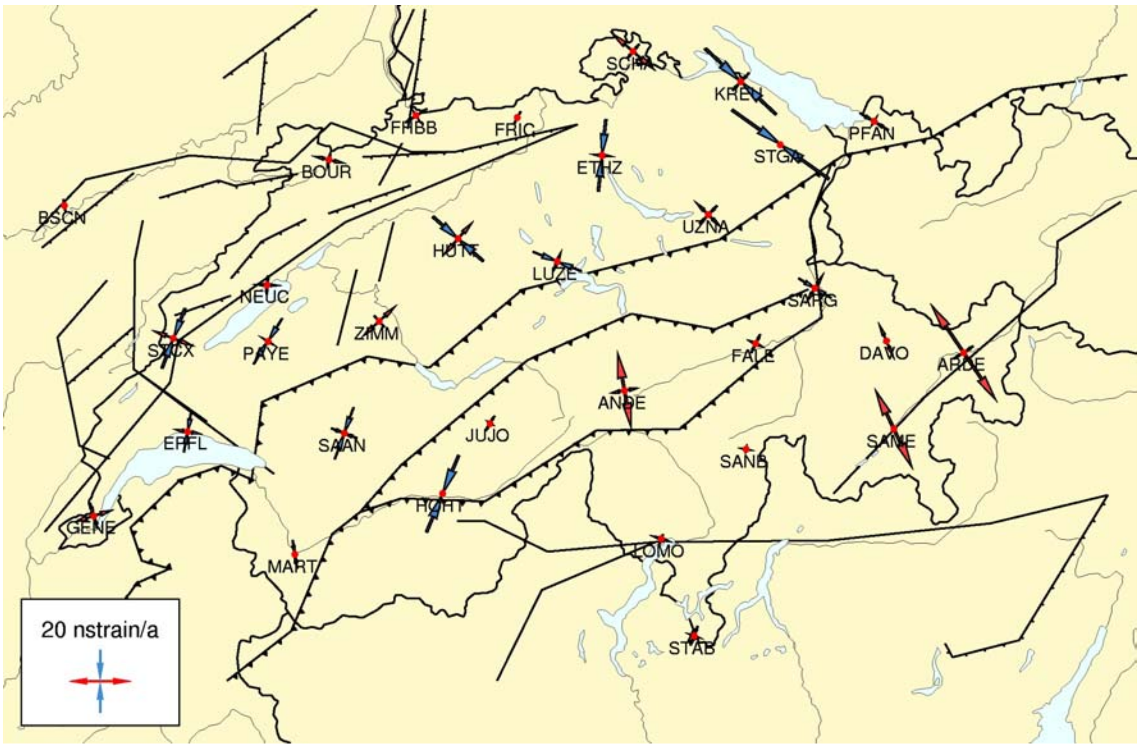

Fig. 5.8: Strain rate field deduced from the velocity field as shown in figure 5.7.

SAR Interferometry for Deformation Analysis: First applications at swisstopo

by D. Schneider, U. Wegmüller, A. Wiget and E. Brockmann

Within the above described swisstopo project Swiss-4D it is planned to verify the potential of differential SAR interferometry for land subsidence monitoring. This will be done in close cooperation with the Swiss company Gamma Remote Sensing. Investigations using SAR interferometry are planned in selected areas with recent or ongoing motion of the earth's surface, say over the last 12 years. Its results shall be validated with levelling data as well as GPS data at permanent reference stations.

The GPS velocity and deformation field in the northern Aegean region before and after the Izmit earthquake.

by M. Cocard, H.-G. Kahle, Y. Peter, G. Veis, D. Paradissis, S. Felekis and H. Billiris

The main seismotectonic feature in the northern Aegean Sea region is the North Aegean Trough (NAT). It is generally accepted that the NAT forms part of the western extension of the dextral North Anatolian Fault Zone (NAFZ). The link between the NAT and NAFZ can be traced along the seismic zone Adapazari - Izmit - northern Marmara Sea - Gulf of Saros. The recent Izmit and Düzce earthquakes have ruptured the crust on the order of up to 5 m in a dextral sense. Shortly after the Izmit earthquake the GPS sites in the wider NAT area have been re-observed in order to estimate the extent of the rupture process towards the west. Following the repeat times of GPS campaigns in the Aegean Sea the rates determined between 1992 and 96 were compared with the ones obtained between 1996 and Sep. 1999, respectively.

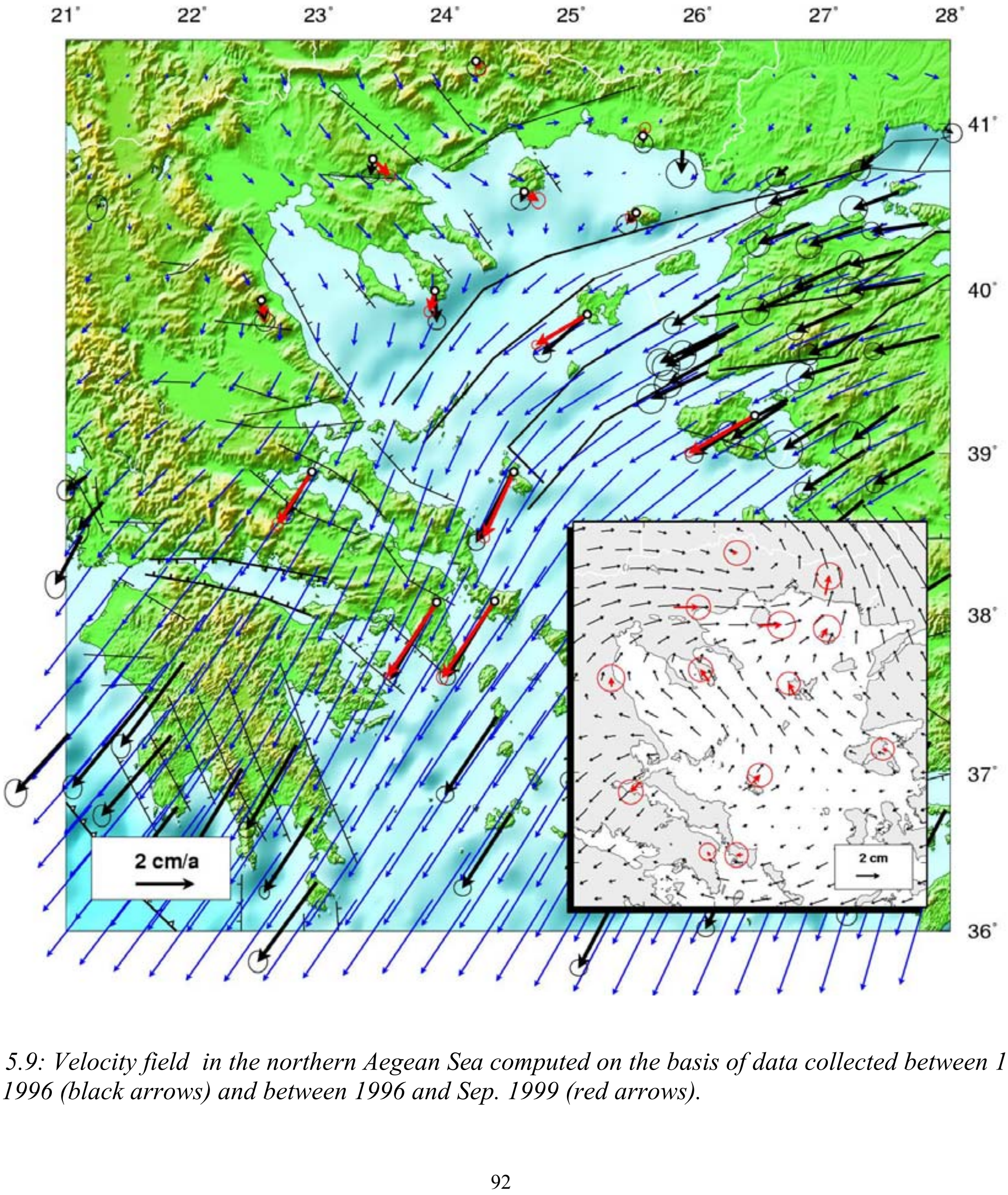

Fig. 5.9: Velocity field in the northern Aegean Sea computed on the basis of data collected between 1992 and 1996 (black arrows) and between 1996 and Sep. 1999 (red arrows).

The velocities indicated in Fig. 5.9 are calculated in the ITRF96 and rotated into the Eurasian fixed frame. The interpolated field (blue arrows) was obtained by collocation. The inset shows inferred displacements centered on the time of the Izmit earthquake as deduced from the velocity differences. These displacements are smaller than 20 mm and are within the margin of error.

As a main result it was included that the Izmit earthquake had only minor effects on the displacement field in the NAT area. The station closest to the Biga peninsula (NW Anatolia) was the island of Lesvos. It shows a co-seismic displacement of only 4 mm towards northwest, which is within the margin of error. The stations north of the NAT show larger east components of velocities for the period 1996-1999 compared to the one for 1992-1996. This might be an indication for transfer of dextral strike-slip displacement into extension.

Recent publications:

Cocard, et al. 1999., Demir et al., 1999., McClusky, S. B. et al., 1999.

Kahle, H.-G., et al.1999., Cocard, M., et al., 2000., Pfister, M. et al., 2000., Reilinger, R.et al. 2000.

For details see: http://www.ggl.baug.ethz.ch/research/wg34/

Continuous GPS networks in western Greece

by C. Hollenstein, H.-G. Kahle, A: Geiger, Y. Peter, G. Veis, S. Felekis, D. Paradissis and H. Billiris

The Kephalonia Fault Zone (KFZ) is one of the most active seismo-tectonic feature in the collision zone between the African and Eurasian plates. Due to the plate movements along this dextral strike slip fault, earthquakes are quite frequent in this region. A CGPS network of 13 stations was installed across the KFZ as outlined in figure 5.10:

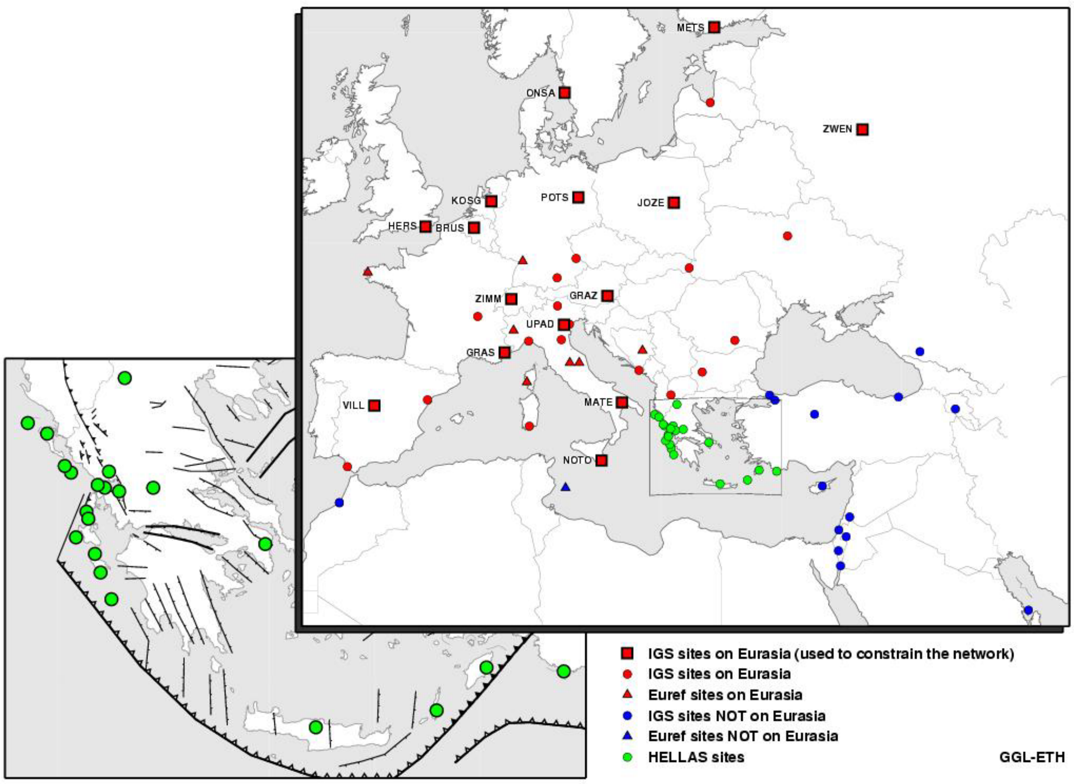

Fig. 5.10: Location of the CGPS network in Western Greece. Location of KFZ: see fig. 5.14

In a first step, the GPS analysis was carried out on a daily basis leading to time series of the coordinates for every station (figs. 5.11-5.13)

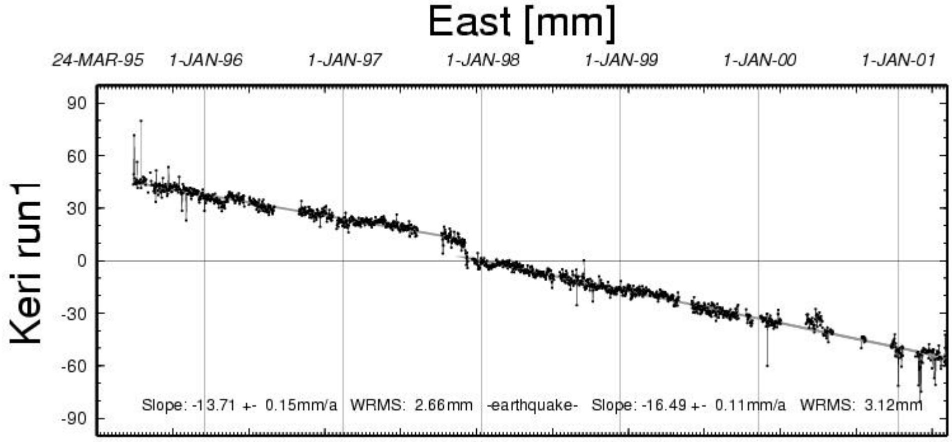

Fig 5.11. Time series of the east component (relative to Eurasia) of the station Keri in the Ionian Sea. Keri run 1: Provisional raw time series after the first evaluation run.

In order to improve these raw time series the offsets caused by antenna changes were corrected, and a generalized common-mode filter was applied:

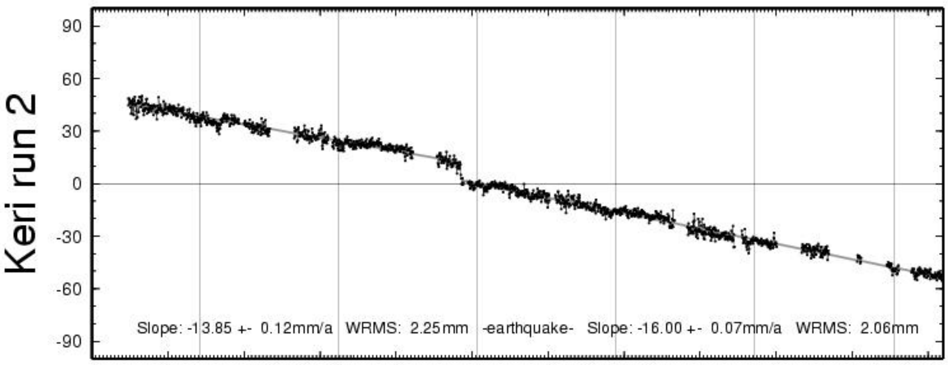

Fig. 5.12: Common-mode: Weighted common-mode signal (of 9 greek stations) used to filter the east component time series.

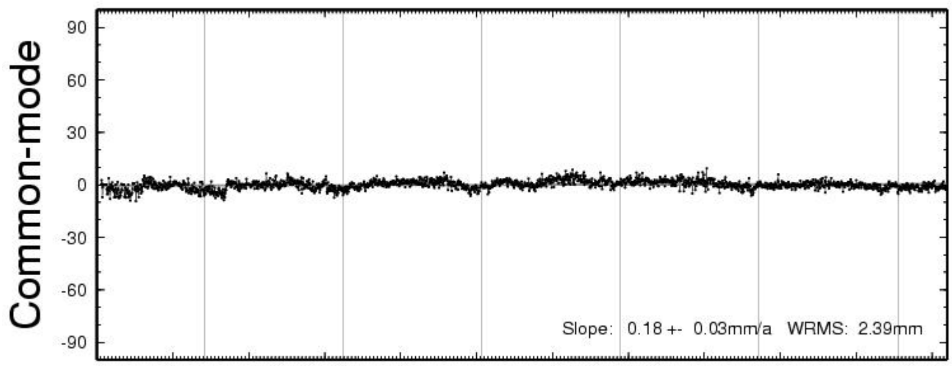

Fig.5.13: Keri run 2; time series after the improvement. Offsets, outliers and irregularities have disappeared, and the precision was improved. The remaining offset in 1997 is a coseismic displacement.

With this approach the accuracy was improved by about 30-45 %. Besides the reduction of noise, the common-mode filter has the advantage to eliminate signals that are common to all sites and are therefore considered not to be of tectonic origin.

The comparison of the power spectra before and after the common-mode filtering also indicates the reduction of noise and signals of lower frequencies. The improved time series allow for a better temporal resolution of the velocity field in this area.

Recent publications:

Peter, Y., Kahle, H.-G., Cocard, M., Veis, G., Felekis, S. and D. Paradissis, (1999).

Peter, Y., (2000).

Hollenstein, C., Peter, Y., Kahle, H.-G., Cocard, M., Veis, G., Paradissis, D., Felekis, S. and H. Billiris, (2000).

Hollenstein, Ch., Kahle, H.-G., Cocard, M., Veis, G., Paradissis, D., Felekis, S., Billiris, H., (2002).

Hollenstein, Ch., Kahle, H.-G., Cocard, M., Veis, G. and D. Paradissis, (2002).

For details see: http://www.ggl.baug.ethz.ch/research/wg57/

Geodynamics of the West Hellenic Arc

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

The West Hellenic arc marks the leading edge of the Aegean microplate. Along the southern Dalmatian coast (Montenegro, Albania, NW Greece) thrusting mechanisms in seismic events occur all the way to the Ionian Islands. The belt of NE-SW shortening in Albania is associated with extensive transcurrent fault systems. One of these fault systems is the Kephalonia Fault Zone (KFZ), which has been recognized as a major discontinuity between the Apulian platform and the transition to the West Hellenic Arc. It is generally accepted that the Hellenic subduction zone terminates against this major strike slip fault, which follows the submarine Kephalonia valley west of the island chain from Levkada to Kephalonia. Its importance is emphasized by structural trends on land and offshore , by the alignment of earthquakes and by displacement rates determined from campaign-type GPS observations. From marine geophysical data the KFZ is considered as one of the branches, which – together with the Calabrian and West Hellenic Arcs – possibly forms a triple junction in the Ionian Sea juxtaposing near its SW extremity the Calabrian and Mediterranean accretionary wedges. While information on co-seismic slip vectors is available from seismological investigations along the KFZ, GPS observations have revealed information about the kinematic field in the neighboring area and how the fine structure of deformation looks in the transition zone between the Apulian block and SW Greece (see figure 5.14).

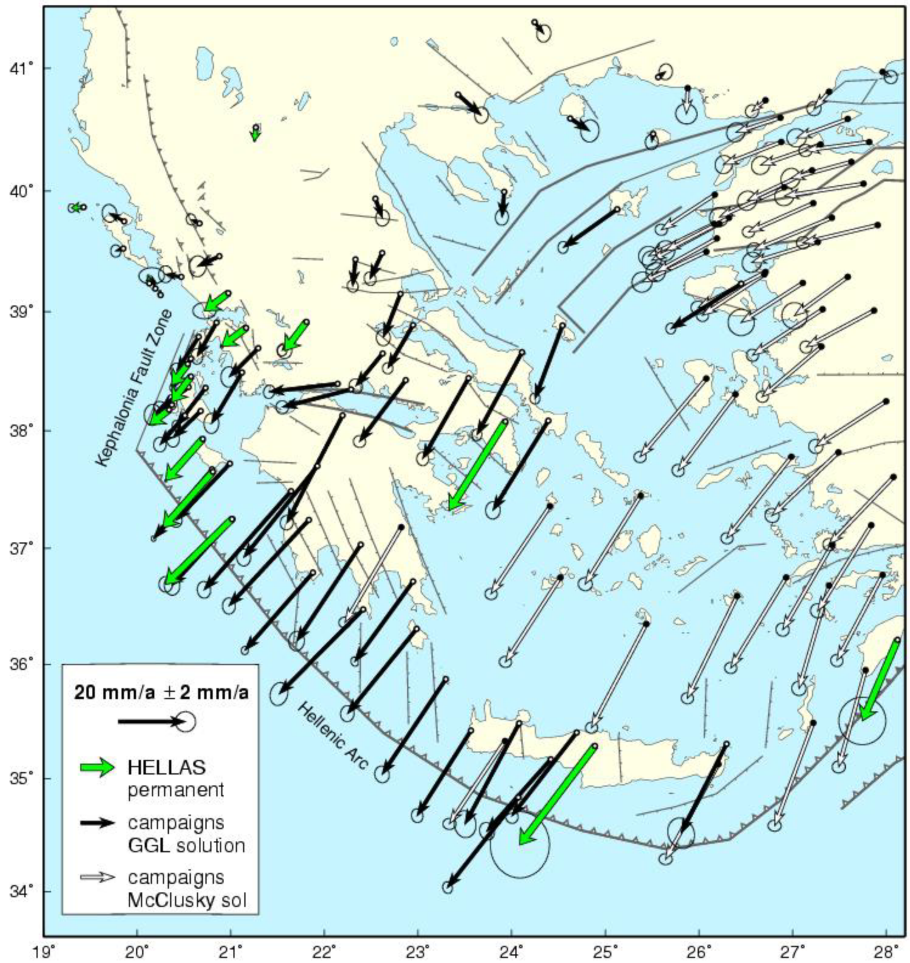

Fig.5.14: Rates of crustal motion (relative to Eurasia) from continuous GPS measurements 1995-2001 and from GPS reoccupation campaigns (Cocard et al., 1999; McClusky et al., 2000).

Recent publications:

Cocard, M., Kahle, H.-G., Peter, Y., Geiger, A., Veis, G., Felekis, S., Billiris, H. and D. Paradissis, (1999).

Cocard, M., C Hollenstein, H Kahle, Y Peter, G Veis, D Paradissis, H Billiris, S Felekis, (2000).

Haslinger, F., Kissling, E., Ansorge, J., Hatzfeld, D., Papadimitriou, E., Karakostas, V., Makropoulos, K., Kahle, H.-G., and Y. Peter, Y., (1999).

Hollenstein, C., Peter, Y., Kahle, H.-G., Cocard, M., Veis, G., Paradissis, D., Felekis, S. and H. Billiris, (2000).

GPS derived strain accumulation in the Eastern Mediterranean

by H.-G. Kahle, C. Hollenstein, M. Cocard, A. Geiger,G. Veis, R. Reilinger, A. Barka, S. McClusky, R. King and V. Kotzev

The GPS velocity field for the Eastern Mediterranean and Near East was used to determine the crustal deformation strain rate field in an area as shown in fig. 5.15. We project the compressional and shear strain rate components normal and parallel onto known faults and compare these with seismological data. Uncertainties in the calculation of the strain rates reach 50 nstrain/a in sparsely observed central and eastern part of Anatolia whereas errors less than 20 nstrain/a are estimated for densely observed parts of the network, such as in the Aegean and Marmara regions. The Arabian plate is indenting into the Eurasian plate, thereby forming the Bitlis suture zone (BSZ) and the Zagros Thrust and Fold belt.

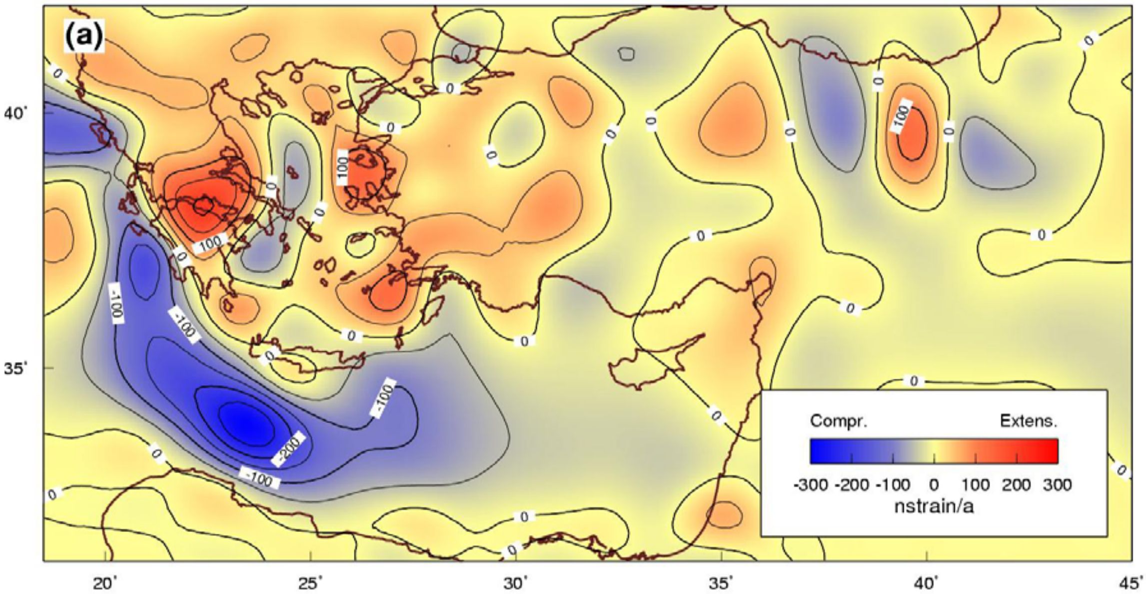

Fig. 5.15: Dilatation rates in the Eastern Mediterranean [Kahle et al., 2000]

Compressional strain rates along the BSZ are small, reaching only 50 nstrain/a. Larger compressional strain rates occur north of the suture in eastern Turkey along the eastern end of the East Anatolian Fault Zone (EAFZ) and on other faults east of the Karliova Triple Junction (KTJ: intersection of the North and East Anatolian Faults). The largest compressional strain rates in the eastern part of our study area occur along the Greater Caucasus mountain front, 500 km north of the BSZ, reaching 115 nstrain/a. The Gulf of Iskenderun, which occurs near the EAFZ-Cyprus Arc-Dead Sea Fault (DSF) triple junction, appears as an extensional feature with NW-SE oriented strain rates of up to 110 nstrain/a. Small, but significant sinistral shear strain rates are observed along the eastern segment of the EAFZ, the northernmost segment of the DSF, and the Ecemis fault in eastern Anatolia. Location of the tectonic features: see fig. 5.17

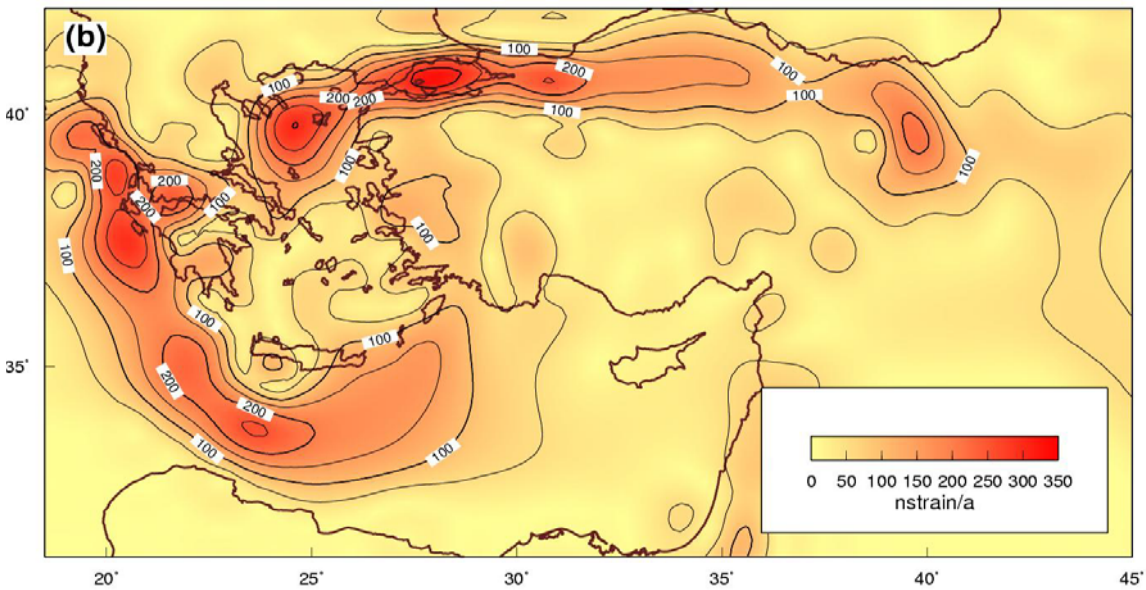

Fig. 5.16: 2D shear strain rates rates in the Eastern Mediterranean [Kahle et al., 2000]

The North Anatolian Fault Zone (NAFZ) is the clearest feature in the shera strain rate field and is expressed as a pronounced dextral strike-slip fault zone. The western end of it is associated with strong right-lateral shear motion, reaching shear strain rates of up to 170 nstrain/a. NE-SW oriented portions of the NAFZ are compressional and NW-SE oriented segments are extensional, thereby indicating restraining and releasing stress behavior. Dextral shear strain rates reaching 55 nstrain/a extend well east of the KTJ, but are offset to the north of the eastward projection of the NAFZ. To the resolution of our measurements, central Anatolia, representing the core of the Anatolian block, is almost strain-free. The strain rate field in western Anatolia is extensional. The principal axes of extension vary around the N-S direction with strain rates of up to 85 nstrain/a. Extensional areas mostly coincide with graben features and normal faulting earthquakes.

The central and south-western Aegean Sea (fig. 5.16) is strain-free with values far below 40 nstrain/a. The seismic cluster around the Dodekanissa islands, south-eastern Aegean Sea, coincides with NW-SE oriented extension, attaining GPS strain rates of up to 90 nstrain/a, also accompanied by recent active volcanism. The Hellenic arc shows compressional strain rates perpendicular to the arc along its entire length. The Pliny and Strabo troughs along the eastern segment of the arc show left-lateral shear strain rates reaching 80 nstrain/a. Large extensional components of the strain rate tensor are found in Central Greece, with a NNE-SSW oriented maximum of 120 nstrain/a centered around the Gulf of Corinthos. A striking feature in NW Greece is the Kephalonia Fault Zone, which is a distinct dextral fault zone, separating Apulia from the rapidly moving Aegean microplate.

Recent Publications:

Clarke, P., Cocard, M., Hollenstein, C., Kahle, H.-G. et al., (2001).

Geiger, A., Cocard, M., Kahle, H.-G., and Y. Peter, (1999).

Geiger, A., Kahle, H.-G., Cocard, M., Hollenstein, C., Jenny, S., Goes, S. and D. Giardini, (2001).

Giardini, D., Cocard, C., Geiger, A., Goes, S., Jenny, S. and H.-G. Kahle, (2000).

Jenny, S., Goes, S., Giardini, D., Kahle, H.-G. and M. Cocard, (2001).

Kahle, H.-G., Cocard, M., Peter, Y., Geiger, A., Reilinger, R., McClusky, S., King, R., Barka, A., and G. Veis, (1999).

Kahle, H.-G., Cocard, M., Geiger, A., Peter, Y., Reilinger, R., McClusky, S., King, R., Barka, A., Veis, G. and V. Kotzev, (1999).

Kahle, H.-G., Cocard, M., Peter, Y., Geiger, A., Reilinger, R., S., Barka, A. and G. Veis, (2000).

McClusky, S. B. Aktug, H. Aygul, S. Balassanian, A. Barka, C. Burchfiel, R. Cakmak, S. Ergintav, M. Hamburger, H. Kahle, K. Kastens, R. King, V. Kotzev, S. Mahmoud, M Nadariya, H. Ozener, M. Prilepin, R. Reilinger, H. Seeger, E. Tari, A. Turkezer, and G. Veis, (1999).

McClusky, Balassanian, S., Barka, A., Demir, C., Georgiev, I., Hamburger, M., Hurst, K., Kahle, H.-G., Kastens, K., Kekelidze, G., King, R., Kotzev, V., Lenk, O., Mahmoud, S., Mishin, A., Nadariya, M., Ouzounis, A., Paradissis, D., Peter, Y., Prilepin, M., Reilinger, R., Sanli, I., Seeger, H., Tealeb, A., Tokzoz, M. and G. Veis, (2000).

WEGENER: Kinematics and dynamics, strain and stress in the African-Eurasian/ Arabian plate boundary zones

by H.-G. Kahle

WEGENER has three scientific objectives which are related to plate-boundary processes, sea-level changes, and post-glacial rebound. The projects do not only pursue these objectives but also contribute to improving and developing the observation techniques as well as the modeling theories. The Alpine-Mediterranean area (fig. 5.17) is an extraordinary natural laboratory for the study of seismotectonic processes. The wealth of observations acquired in WEGENER activities together with new space-geodetic observations allow the test of geophysical hypotheses linking three-dimensional deformations of the Earth's surface to the structure and dynamics of the lithosphere/asthenosphere system.

Subduction processes, plate collision and crustal structure

The Eurasia/Africa collision is closely related to continental subduction and the evolution of foreland fold and thrust belts (Eastern Anatolia, Carpathians, Alps, Apennines, Tell and Atlas mountains, Betic Cordillera).

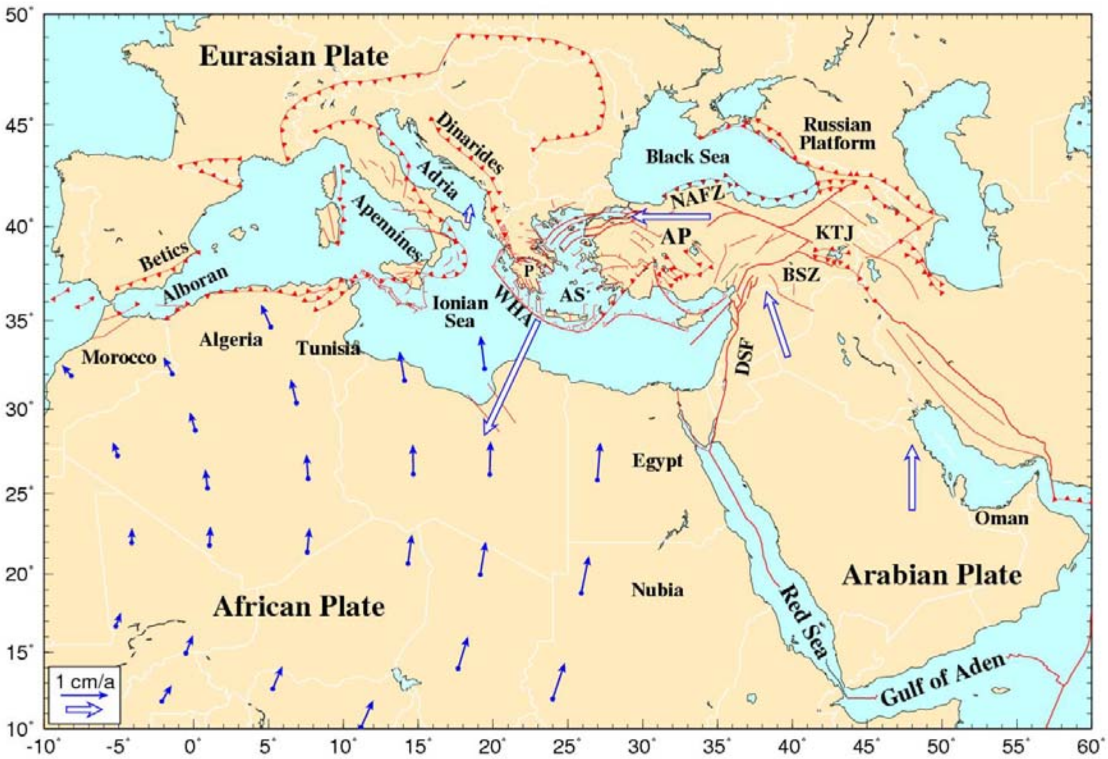

Fig. 5.17: Superimposed on the large-scale counterclockwise rotation of the African plate, complex dynamic processes affect lithospheric fragments between the two major plates.

At advancing boundaries the transmission of compressive stress across the plate boundary is large, and shortening occurs in the overriding plate. Examples are the Alps and the Himalaya. Earthquakes in convergence zones where plates collide exhibit a compressive mechanism, as for example thrust faulting observed in the Gulf of Cadiz, across North Africa and in the Alps. The belts of compressional deformation and mountain building are mostly accompanied by convergent processes which can be traced around the Adriatic block including the Calabrian and Hellenic arcs.

The western and central Mediterranean Sea consists of a number of young basins that have formed since the earliest Miocene until the Present. Most of these basins are underlain by thinned continental crust whereas some are floored by young oceanic crust. Surrounding that part of the Mediterranean domain is an almost continuous chain of mountain belts which are only slightly older than the basins they embrace. The Alboran Sea constitutes the westernmost extension of the Mediterranean Sea. It is closed off to the west by the Gibraltar arc and opens towards the South Balearic basin in the east. A horseshoe-like structure encircles the Alboran Sea consisting of the Betic Cordillera in southern Spain, the central part with the Strait of Gibraltar, the Rif in Morocco and the Tell Atlas of North Africa. Flysch deposits accumulated in the Subbetic and Intrarif zones as well as in the Alboran Sea area. Consumption of this flysch basin took place by northward-directed subduction. The continent/continent collision is indicated by the thrusting of flysch nappes onto the external zones. Post-collisional deformations continued on both margins of the Alboran Sea during the Middle Miocene and Pliocene. Volcanism of the same age associated with subduction was found in southeastern Spain, in the Alboran basin as well as in the internal and external zones of the Rif and Tell. Various GPS networks have been established in the recent past to study the ongoing processes around the Alboran Sea as well as along the Azores-Gibraltar boundary system.

The Central Mediterranean is a complex region which makes it difficult to understand the present kinematic displacement field. In the Calabrian Arc and Ionian area there is a complex distribution of compressional and tensional stress regimes. In particular the presence of extrusional tectonics in the Sicily Channel, which lies along the North African compressional boundary indicates that the tectonic pattern in this region cannot easily be explained.

In addition to the African and Eurasian plates, the Arabian plate is an important feature in assessing the overall stress regime governing the Eastern Mediterranean. It is, therefore, necessary to focus a great deal of attention to the kinematic and dynamic field associated with this plate and its interaction with the Eurasian plate along the Caucasus, Zagros and Makran ranges. Significant recent results from space geodetic observations in this region include

- Quantification of the northward motion of the Arabian plate.
- Crustal shortening and mountain building processes in the Caucasus.
- Estimates of present-day rates of strain accumulation along the North Anatolian fault from the Karliova triple junction to the Sea of Marmara, along the East Anatolian fault and the Dead Sea fault.
- Quantification of counterclockwise rotation of the Anatolian block and rapid southwesterly motion of the southern Aegean region.

An important application of geodetically determined strain rates is the comparison with seismically estimated moment tensors for seismic hazard assessment. Apparent deficits in seismically-released strain were localized in the Eastern Mediterranean. Strain rate tensor and velocity tensor calculations based on seismic events (fig. 5.18) were used to determine active crustal deformation from the Azores triple junction to the Middle East. Shortening across the Caucasus, constrained by GPS observations is substantially faster than indicated by rates deduced from summing seismic moment tensors. Here too, comparisons with geodetically observed deformation rates will be significant for assessing seismic hazards.

The multidisciplinary approach is one of the important aspects of WEGENER‘s activities. New instrumentation and improved measuring techniques permit a more accurate interpretation of vertical movements, as they are associated with thrusting, rifting, subduction processes and mountain building. In parallel, mutual improvements of the measurement techniques, testing of new technological means, synthesizing of multidisciplinary quantities and the inversion of the observations for geodynamically relevant parameters form part of the WEGENER activities. In hazardous areas either continuous GPS (CGPS) or repetitive measuring campaigns at shorter time intervals are being continued and enforced. This allows for the determination of the space and time variations of the regional strain and stress tensors. It will also demand for atmospheric modeling including water vapor radiometry and solar spectrometry.

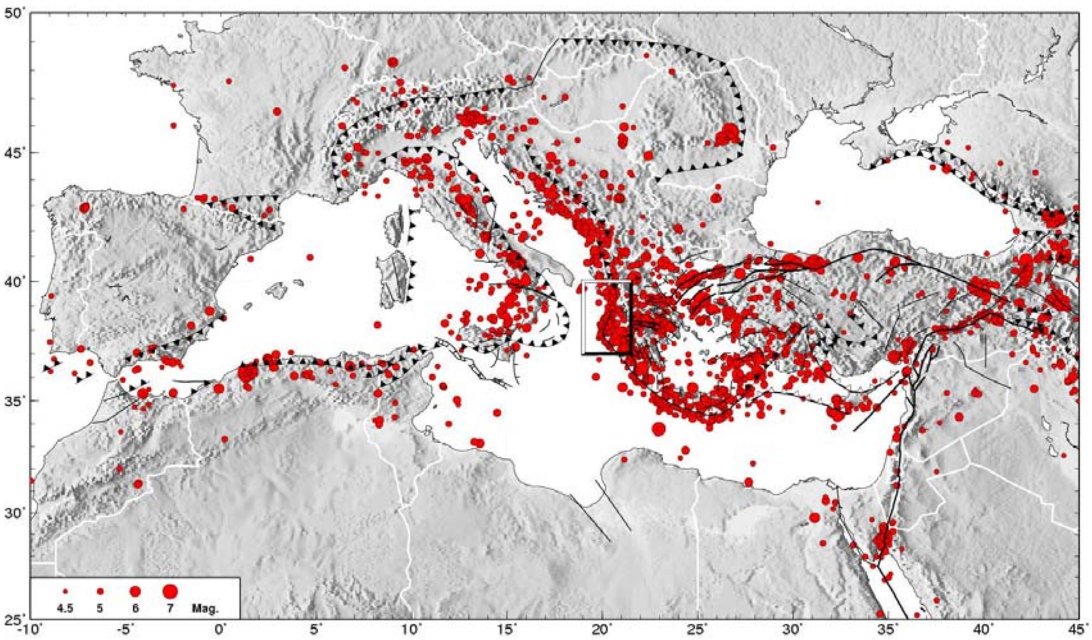

Fig. 5.18: Seismic results indicate the presence of subducted lithosphere below the Alpine-Mediterranean collision belt. The belt displays pronounced differences in structural style, convergence and foredeep basin geometry. At retreating boundaries the transmission of compressive stress is small, and horizontal extension in the form of a back-arc basin occurs in the overriding plate. Examples of such retreating subduction zones are: The Gibraltar Arc, the Calabrian and Hellenic Arcs and the Pannonian Basin.

The results obtained so far can be considered as a first important step towards a better understanding of the complex geologic evolution, geophysical structure and present-day dynamics in the Alpine-Mediterranean region. However, most of the deformation processes are not yet fully understood. The evolution of slab detachment in space and time along strike of convergence zones, appears to be one of the engines driving the kinematic and tectonic evolution of the Alpine-Mediterranean. Mapping the kinematic pattern (horizontal and vertical motions) in specific areas where detachment seems to be active or may have faded out recently, will render important kinematic data as boundary conditions for modeling arc evolution and back-arc basin development. The height components of deformations on a regional scale are to this date almost completely unknown. In summary some of the major scientific issues pursued are being listed.

First-Order Plate Boundaries

- Relative rotations Africa/Eurasia, Arabia/Eurasia and Arabia/Africa and comparison with NUVEL and REVEL models
- Continent/continent collision (Alps, Carpathians, Eastern Turkey/Caucasus, Tell-Atlas)
- Ocean/ocean convergence (Gibraltar Arc)
- Triple junction Azores

Second-Order Plate Boundaries:

- Distributed strain across the Hellenic/Adriatic plate boundary zone
- Seismotectonics and kinematics of the Adriatic block
- Lithospheric subduction along trenches (Cyprus arc, Hellenic arc, Calabrian arc)
- Relationship between the Hellenic/Cyprus arcs and the Isparta triangle(overriding blocks and subducting slabs)
- Crustal extension in back-arc basins (Pannonian, Aegean, Tyrrhenian, Alboran)
- Rifting and graben formation (Sicily channel, Dead Sea rift, Western Turkey)
- Volcanism and hot spots (Aegean, Tyrrhenian)
- Crustal motion, block rotation and strike-slip faulting (Anatolian/Aegean block)
- Crustal shortening and associated mountain building in E. Turkey and the Caucasus

WEGENER offers the unique opportunity to study in detail the kinematic pattern of the major types of collisional features and thus provides the necessary boundary conditions to understand the driving forces and associated seismic activity. With modern space-geodetic techniques it will become possible to provide significant data which ultimately will enable light to be shed on the plate tectonic processes of the Alpine-Mediterranean region and better understand the geologic evolution of plate collision.

For details see: http://www.survey.ntua.gr/wegen/wegener.shtml

Overall GPS strain determination and assessment of seismic hazard in Greece (SING)

by H.-G. Kahle, C. Hollenstein, M. Cocard, P. Cross, G. Veis, S. Stavrakakis, P. England, B. Parsons, P. Briole, H. Lyon-Caen, B. Ambrosius, P. Clarke and P. Cruddace

This project was funded within EU Framework IV Environment and Climate Program (Seismic Risk): EU-Project PL 971151. Its objectives were as follows:

- Identify areas of high seismic hazard in Greece.
- Obtain an all-embracing assessment of strain accumulation throughout Greece, and in specifically targeted areas.
- Develop new and more efficient operational and computational procedures for the use of GPS to deliver high-quality positional data within regional and global control networks.

- Improve the understanding of the relationship between strain accumulation and seismic hazard assessment by integrating geodetically derived strain data with the existing seismic catalogue and other geological data.

10 working packages were pursued:

WP 1: Calculation of the motion of the Greek permanent stations

WP 2: Development of a database of geodetic (GPS) strain measurements to produce an integrated kinematic model throughout Greece

WP 3: An observation plan for use in acquisition of geodetic GPS data

WP 4: GPS data acquisition

WP 5: Geodetic GPS data processing

WP 6: Vertical motion monitoring and analysis in specifically targeted areas

WP 7: Development and testing of algorithms for the improvement of the modelling of atmospheric delays of the GPS signal within an area of permanent GPS sites

WP 8: Development and testing of a methodology for continuous observing and processing regional GPS networks within the IGS framework

WP 9: Modelling of geological, geophysical and seismic data

WP 10: Comparison between geodetic and seismic strains

The Swiss group (ETH) was involved in WP's 2, 3, 5, and 7-10

Recent Publications:

Clarke, P., Davies, R., Billiris, H., Galanis, J., Paradissis, D., Veis, G., Cross, P., Cruddace, P., Briole, P., Lyon-Caen, H., Kahle, H.-G. and B. Ambrosius, (1999).

Cruddace, P., Cross, P., Lilje, M., Veis, G., Billiris, H., Paradissis, D., Galanis, J., Parsons, B., England, P., Lyon-Caen, H., Briole, P., Ambrosius, B., Kahle, H.-G., Cocard, M. and G. Stavrakakis, (1999).

Clarke, P., Cocard, M., Hollenstein, C., Kahle, H.-G. et al., (2001).

For details see: http://www.ggl.baug.ethz.ch/research/wg53/

Sea Level Fluctuations in the Mediterranean and their Interactions with Climate Processes and Vertical Crustal Movements (SELF)

by H.-G. Kahle, B. Bürki, L. Kruse, B. Sierk and S. Zerbini

The project was studied jointly within the EU Project SELF II . It was based on the collaboration of Italy, Greece, France, U.K., Germany, Spain, Bulgaria, Russia and Switzerland. It formed an integral part of the International Lithosphere Program (ILP) theme 1. Coordinator was Prof. Dr. S. Zerbini of the University of Bologna.

Main objectives of SELF II were:

- to improve the long-term monitoring of sea-level variability by applying the most advanced geodetic techniques, including satellite radar and airborne laser altimetry
- to study the past sea levels in the Mediterranean in order to better understand the current processes
- to study the effects of the atmosphere/ocean interaction and of crustal movements in order to provide a basis for hazard assessment
- Main goals of the Swiss contributions were:

- optimize the GPS and gravity observation strategies for a cost-effective determination of height changes, in particular, by deploying water vapor radiometers in order to determine changes in the tropospheric propagation properties for microwaves as used with GPS.
- determine the spatial variations of the sea-surface topography in the Ionian Sea from airborne laser profiling, and connect it with the results of satellite radar altimetry (s. fig. 5.19).

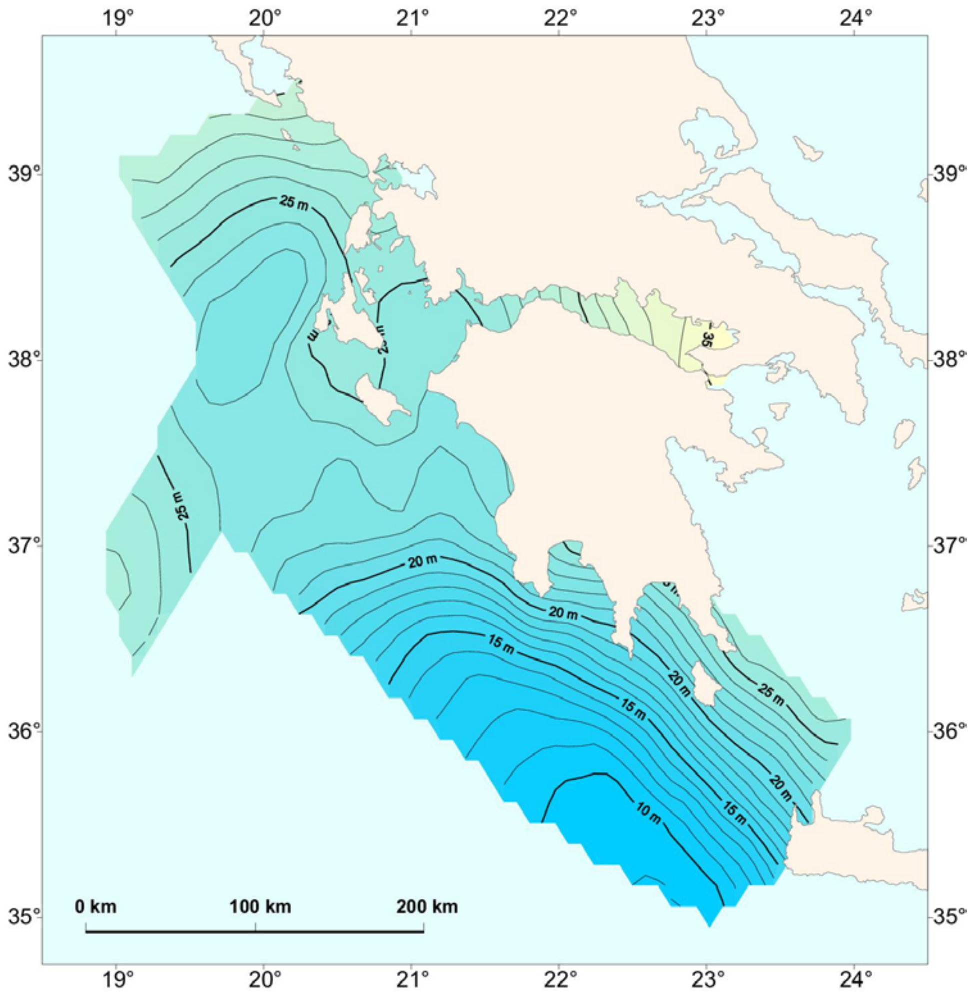

Fig. 5.19: Sea surface heights in the Ionian and Aegean Seas as measured by means of airborne laser, differential GPS, inertial navigation and attitude sensors. ERS1 and ERS2 altimetry passes crossing the area were also recorded.

Further Publications:

Baker, T., Cazenave, A., Cocard, M., Kaas, E., Kahle, H.-G., Lozano, I., Marson, I., Plag, H.-P., Romagnoli, C., Von Storch, H. and S. Zerbini, (2000).

Becker, M., S. Zerbini, T. Baker, B. Bürki, J. Galanis, J. Garate, I. Georgiev, H. -G. Kahle, V. Kotzev, V. Lobazov et al., (2002).

Cocard, M., Kahle, H.-G., Papafitsorou-Marti, A. and A. Geiger, 2002. Kruse, L.-P., Sierk, B., Springer, T., Cocard, M., Bürki, B. and H.-G. Kahle. (1999).

Favey, E., Wehr, A., Geiger, A. and H.-G. Kahle, 2002.

Kruse, L.-P., Cocard, M., Sierk, B., Geiger, A., Bürki, B., Kahle, H.-G., Lisowski, M., M. Bevis, (2000).

Sierk, B., Florek, S., Becker-Ross, H., Bürki, B., Kruse, L.-P. and H.-G. Kahle, (1999).

Sierk, B., Bürki, B., Kahle, H.-G., Kruse, L., Florek, S. and H. Becker-Ross, (2000).

For details see: http://www.ggl.baug.ethz.ch/research/wg42/

Establishment of a European radar altimeter calibration and sea-level monitoring site for JASON, ENVISAT and Euro-GLOSS: EU Project GAVDOS

by H.-G. Kahle, E. Favey, A. Geiger, S. Mertikas et al.

The primary objective of this project is the establishment of an absolute sea level monitoring and altimeter calibration facility on the isle of Gavdos, south of the island of Crete, Greece. The GAVDOS project will determine consistently and reliably (1) the altimeter biases and drifts for each of these missions and (2) the bias among different missions. It will also determine the mean sea level and the earth's tectonic deformation field in the region of Crete, Greece. When the project becomes operational, continuous altimeter measurements of similar quality and reliability and over long time periods will be ensured. It will also supply useful data for global change, geophysics, geodynamics, geodesy, oceanography and seismology. The isle of Gavdos, situated south of the island of Crete, Greece, has been selected to host absolute sea level monitoring and altimeter calibration facilities due to its offshore location under a crossover point of the Topex/Poseidon and Jason-1. Gavdos is to be found in the middle of fig. 5.20.

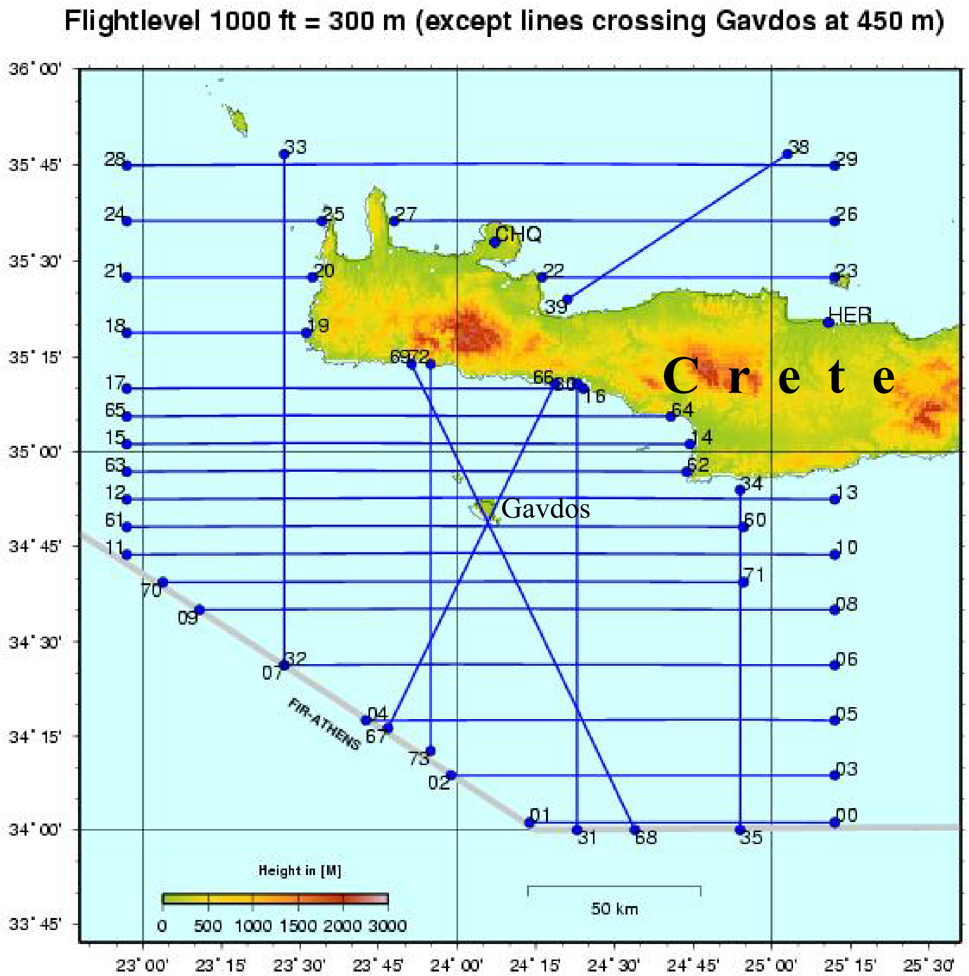

Fig. 5.20: Flight lines for airborne laser monitoring of the sea surface height around the island of Crete, Greece.

This objective of the Swiss group (ETH) was achieved by carrying out a regional airborne survey, combining gravimetric and laser profiling. The survey was carried out in close cooperation with the National Survey and Cadastre of Denmark and the Institute of Solid Earth Physics of the University of Bergen, Norway.

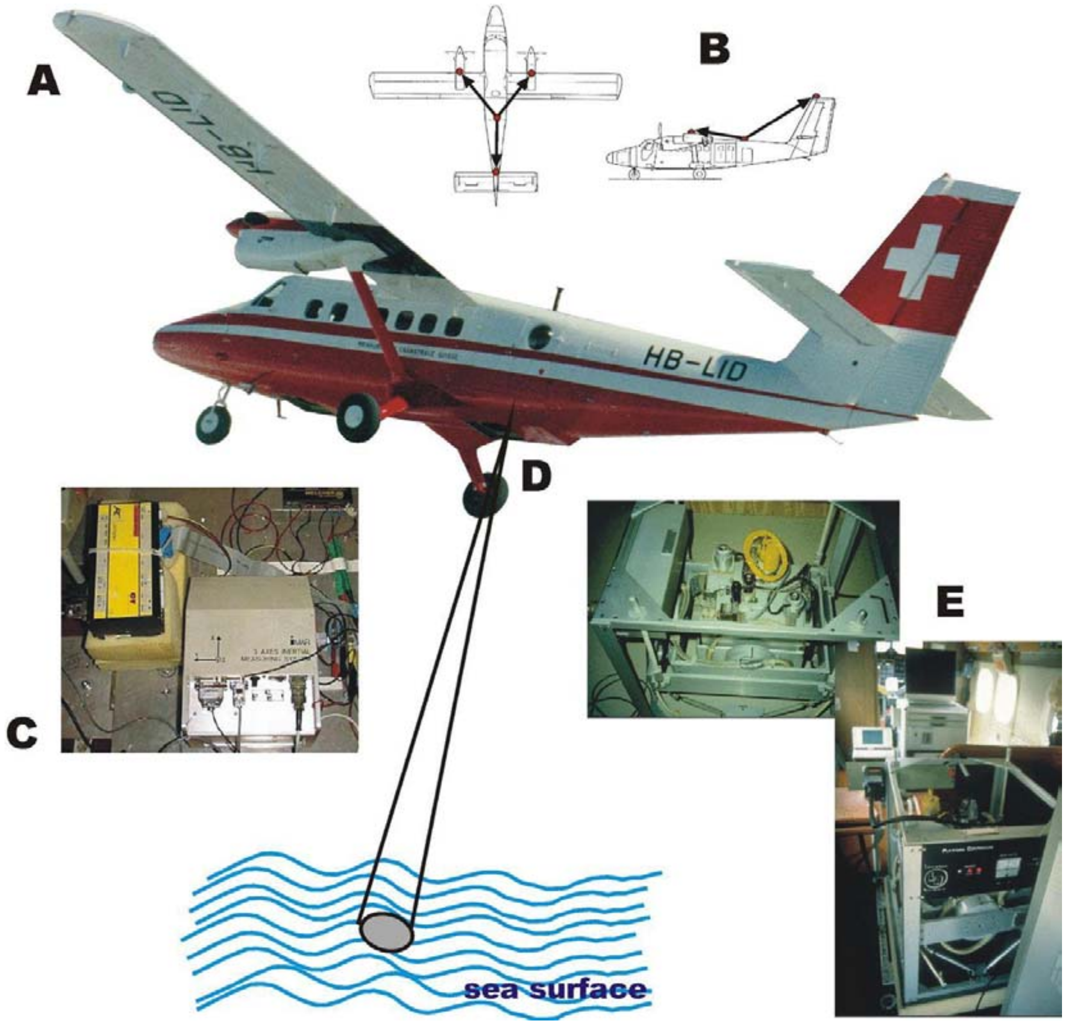

Fig. 5.21: Conceptional scheme of airborne laser and gravity measurements. The survey was carried out with a de Havilland Twin Otter aircraft owned and operated by swisstopo (A). The cross sections (B) indicate the location of the four GPS antennae onto the wings of the aircraft. (C) shows the sensor unit for measuring the spatial attitude of the laser beam scanning the sea surface (D). The gravity meter was suspended in a special rack mount (E).

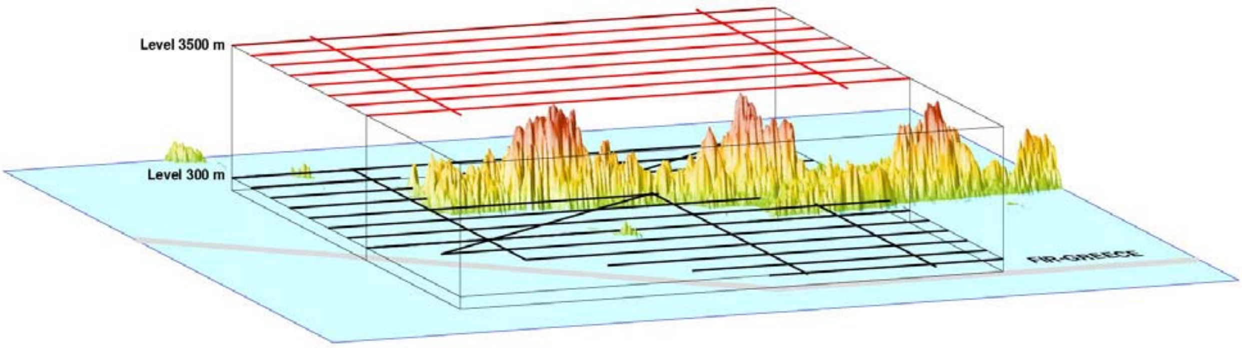

Fig. 5. 22: 3D view of low level (black) and high level (red) flight lines over Crete and Gavdos.

Coordinator of the project Gavdos is Prof. Mertikas of Technical University of Crete, Geodesy & Geomatics Lab,Greece.

The project is being carried out in cooperation with

- Joint Center for Earth Systems Technology, University of Maryland Baltimore County, USA.
- Aristotle University of Thessaloniki, Department of Geodesy and Surveying, Greece.
- Institute of Marine Biology of Crete, Department of Oceanography, Heraklion, Greece.
- Space Research Institute, Department of Satellite Geodesy, Austrian Academy of Sciences, Austria.
- KMS (National Survey and Cadastre of Denmark), Geodynamics Department, Denmark.
- ETH Hoenggerberg, Geodesy and Geodynamics Laboratory, Institute of Geodesy and Photogrammetry, Switzerland.
- Observatoire de la Cote d'Azur (OCA), Centre d'Etudes et de Recherches en Geodynamique et Astrometrie (CERGA), CNRS France.
- Hellenic Navy Hydrographic Service, Athens, Greece.
- University of Bergen, Institute of Solid Earth Physics, Norway.

Further Links see: http://www.gavdos.tuc.gr/introduction_whole.htm

Further Publications:

Mertikas, S., Cocard, M., Geiger, A., Kahle, H.-G. et al., (2002)

Pavlis, E., Mertikas, S., Cocard, M., E., Geiger, A., Kahle, H.-G. et al., (2002).

Contribution to Monitoring of change of Glacier Volume by Airborne Laser Scanning

by E. Favey, A. Geiger, A. Fehr and H.-G. Kahle

Monitoring volume changes of small alpine glaciers is important for a number of reasons. Alpine glaciers are sensitive to changes in local climate, and may contribute significantly to sea level variations. Estimates of volume changes can be used to validate calculations of net mass balance based on traditional stake methods, and to test theoretical concepts about the response of glaciers to changes in climate. Determination of net mass balance with the glaciological method (stake measurements) is time consuming and is, despite its importance, only made for a small number of glaciers in the world. Airborne laser scanning (ALS) is well suited for the production of Digital Elevation Models (DEM), and can, in contrast to photographic methods, be used to acquire a DEM independently of surface texture and external light sources. ALS, thus, serves as a tool to generate DEM of firn areas where photogrammetric methods often fail.

ALS is a young technology opening new possibilities for qualitative and quantitative determination of surface elevation changes of glaciers. Its rise was possible through the combination of several modern measuring methods, such as high-precision DGPS positioning in kinematic mode, attitude measurements using inertial systems, and laser distance measurements to non-cooperative targets.

We investigated the feasibility and improvements of the ALS technique with respect to the special circumstances of determining surface elevation changes of glaciers. This consists of an error analysis of the method as well as the scrutiny of its limitations, and its application to remote, alpine areas without the need of in-situ measurements. The key problem consists in bringing together all necessary elements for georeferencing the laser data, where the quality of each contributing part has to be monitored regarding accuracy and systematic effects. The quality of the GPS trajectory can be degraded by various factors like atmospheric refraction, radio frequency interference, or obstruction of satellite visibility. The reliable identification of the integer-valued carrier phase ambiguities can be hindered or even made impossible by such effects. The attitude solution was realized using an inertial measurement unit. A separate attitude solution with lower accuracy using a GPS multi-antenna array was developed and used to control and correct IMU drift and offset errors. A self-calibration procedure for determining was elaborated. The used laser scanning system showed increased blunder effects with low received signal power. An approach for detecting and removing blunder was implemented.

Using the laser scanning solution presented in this work, a height accuracy of 0.3 m could be realized flying over a runway at 500 m above ground. Higher flying height above ground and turbulences impede the realization of this data quality in the mountains; it amounts to about 0.5 m. In the test area at Unteraargletscher, Bernese Alps, Switzerland (fig. 5.23), measurements for a temporal analysis were repeatedly carried out using the ALS technique. For the lower parts of Unteraargletscher, digital surface models originating from photogrammetry are available for comparison. The determination of the surface elevation change distribution was shown to be feasible with an accuracy of 0.5-0.7 m.

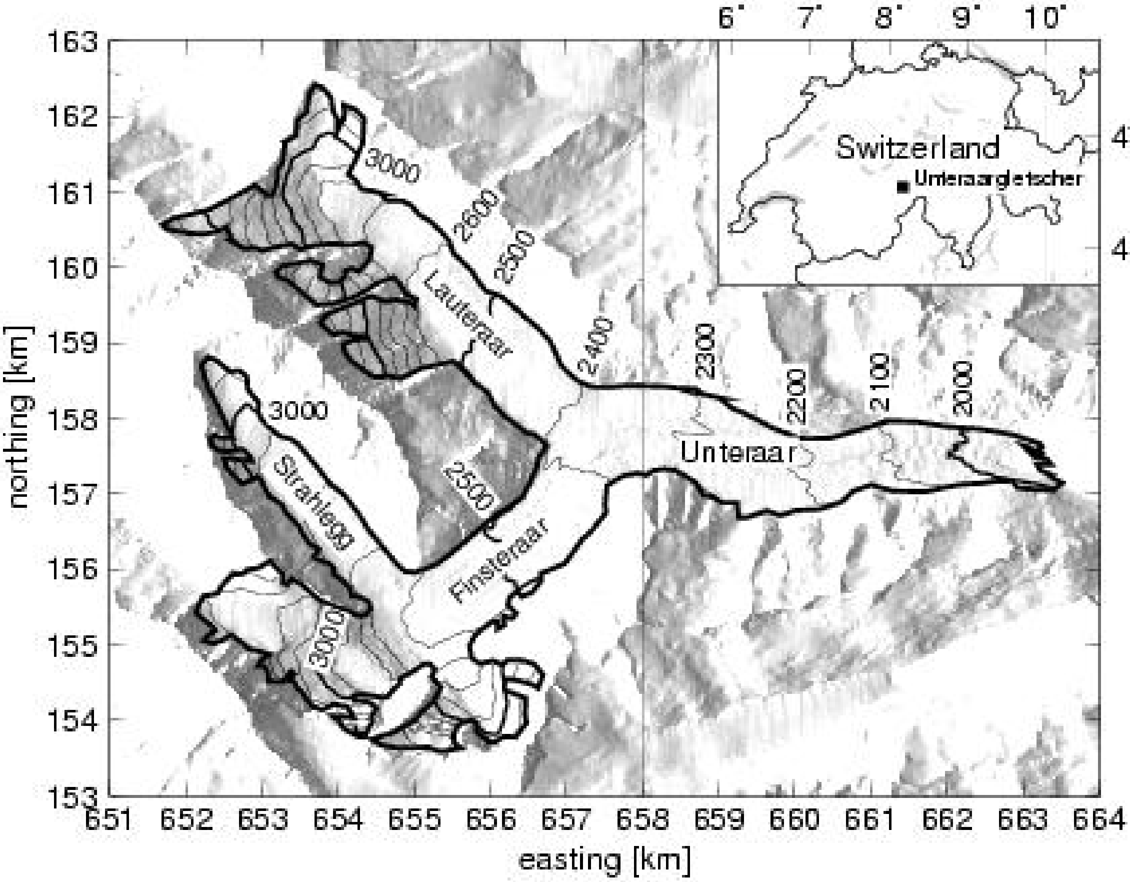

Fig. 5.23: Location of the project area Unteraargletscher, Bernese Alps, Switzerland.

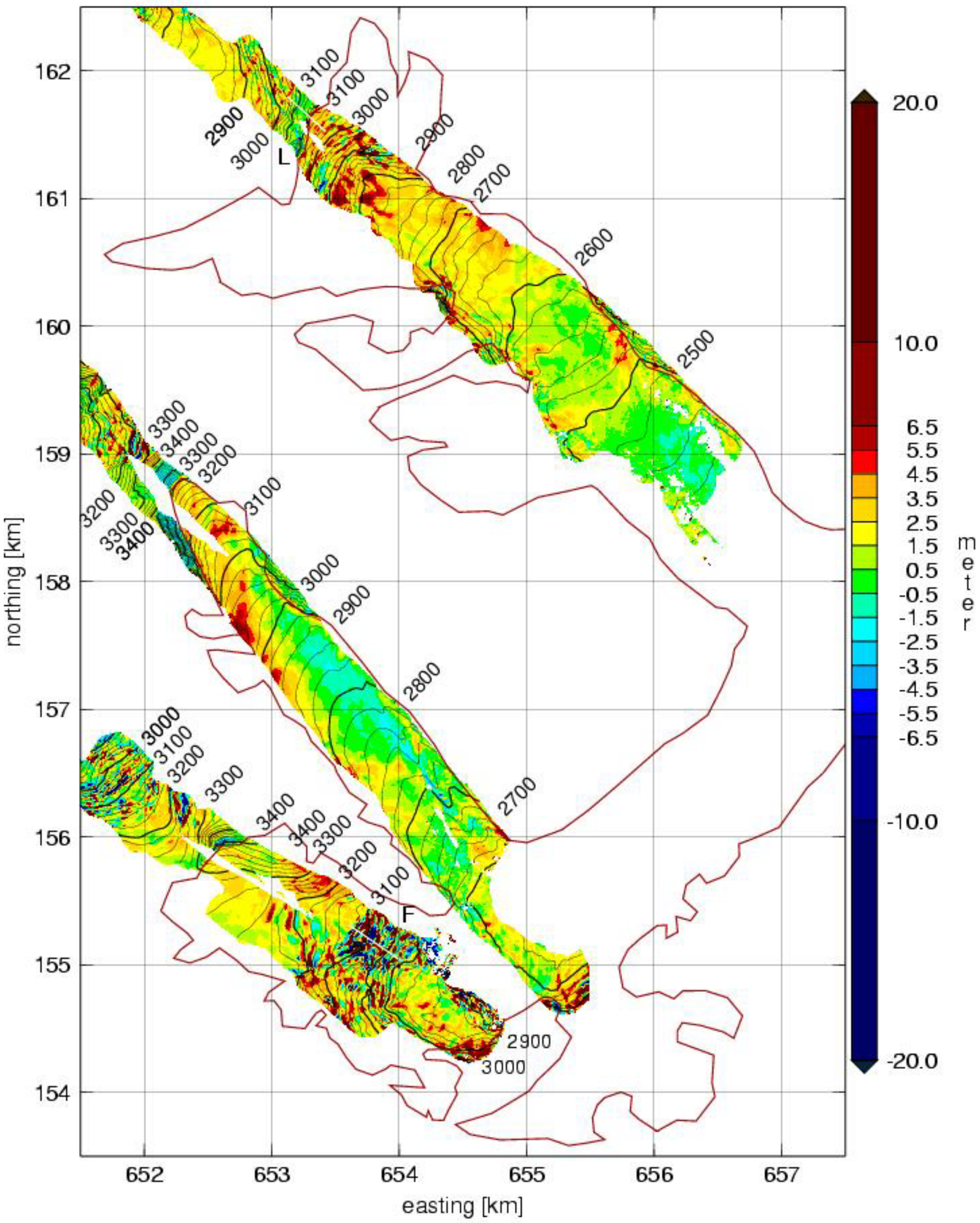

Fig. 5.24: Temporal height differences in [m] of the years 1999 minus 1998 determined from the laser scan data. Note the zero difference in the saddle area of the middler glacier (Lauteraargletscher), where cliffs are exposed.

The areas covered by airborne laser scanning are situated between 2500 and 3400 m above sea level. For the period 1998-1999, a surface elevation increase of 2-4 m was measured. This positive change can be related to the immense amount of snowfall during the winter 98/99.

Thanks to the ALS technique the coverage of Unteraargletscher with measurements of surface elevation change could be completed up to the remote firn areas. The ALS project is an interdisciplinary collaboration of the Geodesy and Geodynamics Lab (ETH), with the Laboratory of Hydraulics, Hydrology and Glaciology (ETH), and the Institute of Navigation, University Stuttgart.

Recent Publications:

Favey, E. (2001).

Favey, E., Wehr, A., Geiger, A. and H.-G. Kahle, (2002).

Further Links see: http://www.ggl.baug.ethz.ch/research/wg49/

The Earth's Tides Observatory of Switzerland

by E. Klingelé

The Earth's tides observatory of Switzerland was built in 1995 under the initiative of the Institute of Astronomy of the University of Berne and the Geodesy and Geodynamics Laboratory of the ETH Zurich. The station forms an integral part of the Zimmerwald Observatory (see also section II). The first aim of the tidal station is to produce data for accurate corrections for field and laboratory gravity measurements. A second aim is to use the recorded data in conjunction with satellite laser ranging information for the determination of the elasticity parameters of the Earth's crust in Switzerland.

It consists of a specially designed underground double room supposed to be free of vibrations. The laboratory is equipped with three pillars of concrete on which the instruments are installed. At the end of 1995 an Earth's tide gravimeter Lacoste and Romberg had been installed and set in function. The gravity-meter with a mechanical feed-back system driven by a PC running LabView software under Windows. The tide's data, the level information, the temperature and the air pressure data at a rate of 1 reading/second are recorded. The gravity-meter has a double oven with a working temperature of 48.8 deg. Celsius. According to the specifications given by the manufacturer its resolution should be better than 1µgal and the drift below 0.5 mGal per month. Apart from the gravity-meter a temperature and humidity sensor OMEGA RH 411 with a resolution of 1 degree Celsius for temperature and 1% for relative humidity as well as an atmospheric pressure transmitter, type PAB-9, from Keller, Winterthur with a resolution of 0.1 mbar were installed in the laboratory (figure 5.25):

Fig. 5.25: General view of the Earth Tide Observatory of Zimmerwald, Bern.

The recorded data are: Date and time, observed and theoretical tides, unfiltered position of the gravity meter beam, average value of the counter, positions of the long and the cross levels, atmospheric pressure in the outer oven, room temperature and humidity, atmospheric pressure at the gravimeter location. The mechanical feed-back system worked satisfactory from the beginning of 1996 until May 1998 when the step motor got blocked. It was decided to replace it by an electronic system made by the Observatoire Royal de Belgique and due to Michel Van Ryumbeck (System MVR). During the period necessary for the upgrading of the instrument a field gravimeter LaCoste and Romberg type G, #514, equipped with an electronic feed-back was installed in the laboratory in order to enable continuos recording. The new system (Windows 98) started working in July 1999. Four months of work the new system showed numerous failures and mostly wrong recorded data. We finally concluded that the humidity of the room was too high and produced mould on the boards of the PC which ended in malfunctioning of the system. A moisture remover was installed in the laboratory and at the same time the RAM of the PC was expended to 512Mb. During Christmas 1999 an extremely strong windstorm prevailed in Switzerland, breaking completely the energy supply of the laboratory. It was only possible to fully restart the system after one month. This accident showed clearly that an UPS system was absolutely necessary for maintaining a more or less continuous recording of the Earth's tide. The UPS system designed and made at our institute works with two high energy 12 volts batteries which are alternatively charged by a five cycle charging system.

Until the end of 2002 about 2'000'000 earth's data were collected, corrected, cleaned and prepared for further processing. In parallel a complete package of software was developed for reformatting, de-spiking, filtering, compacting and graphical analysis of the data. This software package allows to process and analyze the data independently or prepare them for the software package ETERNA 3.2 (H.-G. Wenzel 1994). This package is subdivided into 14 different programs that can either work sequentially or independently.

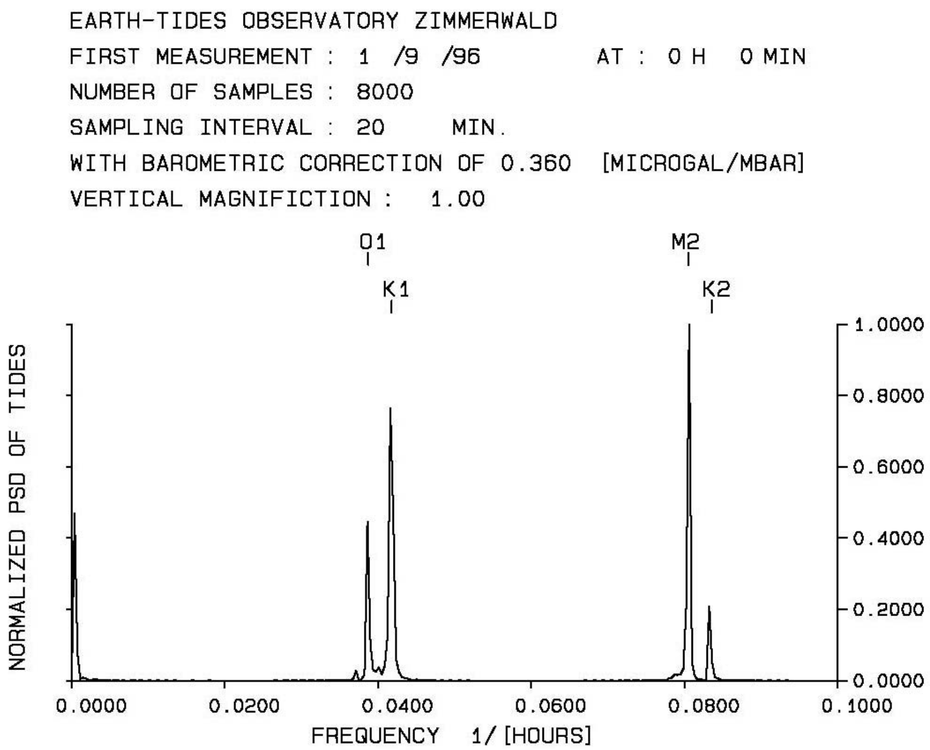

Fig 5.26: Example of a Power Spectrum Density (PSD) obtained as calculated with the software described

Details of the hard- and software used can be found on the project homepage:

http://www.ggl.baug.ethz.ch/research/wg43/

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