Switzerland
Swiss Geodetic Commission

Suisse
Commission Géodésique Suisse

Report on the

GEODETIC ACTIVITIES

in the years 1995 to 1999

Presented to the XXII General Assembly
of the International Union of Geodesy and Geophysics
in Birmingham, UK, July 1999

Rapport sur les

TRAVAUX GÉODÉSIQUES

exécutés de 1995 à 1999

Présenté à la vingt-deuxième Assemblée générale
de l'Union Géodésique et Géophysique Internationale
tenue à Birmingham, UK, juillet 1999

Zurich 1999

Switzerland
Swiss Geodetic Commission

Suisse
Commission Géodésique Suisse

Report on the

GEODETIC ACTIVITIES

in the years 1995 to 1999

Presented to the XXII General Assembly
of the International Union of Geodesy and Geophysics
in Birmingham, UK, July 1999

Rapport sur les

TRAVAUX GÉODÉSIQUES

exécutés de 1995 à 1999

Présenté à la vingt-deuxième Assemblée générale
de l'Union Géodésique et Géophysique Internationale
tenue à Birmingham, UK, juillet 1999

Zurich 1999

Editor:

Swiss Geodetic Commission
ETH Hönggerberg
CH-8093 Zurich

Editeur:

Commission Géodésique Suisse
ETH Hönggerberg
CH-8093 Zurich

http://www.sanw.unibe.ch/root/portrait/sgk/sgk.index.html

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.cx.unibe.ch/aiub/

Federal Office of Topography (L+T):

http://www.swisstopo.ch/

Federal Institute of Technology, ETH Zurich:

http://www.geod.ethz.ch

Federal Institute of Technology, EPFL Lausanne:

http://dgrwww.epfl.ch/TOPO/index1.en.html

ISBN 3-908440-00-9

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. Carosio (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 geodesy science in Switzerland. Financial support was provided by the SANW. Its valuable help is gratefully acknowledged.

On behalf of the Swiss Geodetic Commission, June 1999

Erich Gubler
Vice-President of SGC

Hans-Gert Kahle
President of SGC

1 Positioning

CODE Contributions to the ITRF and its Densification

by T.A. Springer, D. Ineichen, W. Gurtner, M. Rothacher, S. Schaer, G. Beutler

At the Center for Orbit Determination in Europe (CODE) (see Section 2 of this report for more information) the distinction is made between global and regional data processing. Data are analyzed on a regular basis (with daily, weekly, and annual cycles) and stem from the IGS (International GPS Service) network. See http://igscb.jpl.nasa.gov for more information.

Global Analysis

In its global analysis CODE estimates GPS orbits, Earth rotation parameters (ERPs), tropospheric delays, coordinates, etc., in one and the same adjustment process. We refer to the annual reports for the years 1995, 1996, and 1997 for a complete documentation (Rothacher et al., 1996a, 1997d, and 1998b). Here we only address coordinate aspects. We refer to Section II for orbits and atmosphere, to Section 5 for ERPs.

The number of sites in the CODE global analysis grew from about 50 sites in 1995 to about 80 in 1997, and eventually to about 100 in 1998. Somewhat arbitrarily, the maximum number of sites in one daily analysis is kept to 100 since May 1998. Figure 1.1 shows the network currently used by CODE for the generation of its daily products.

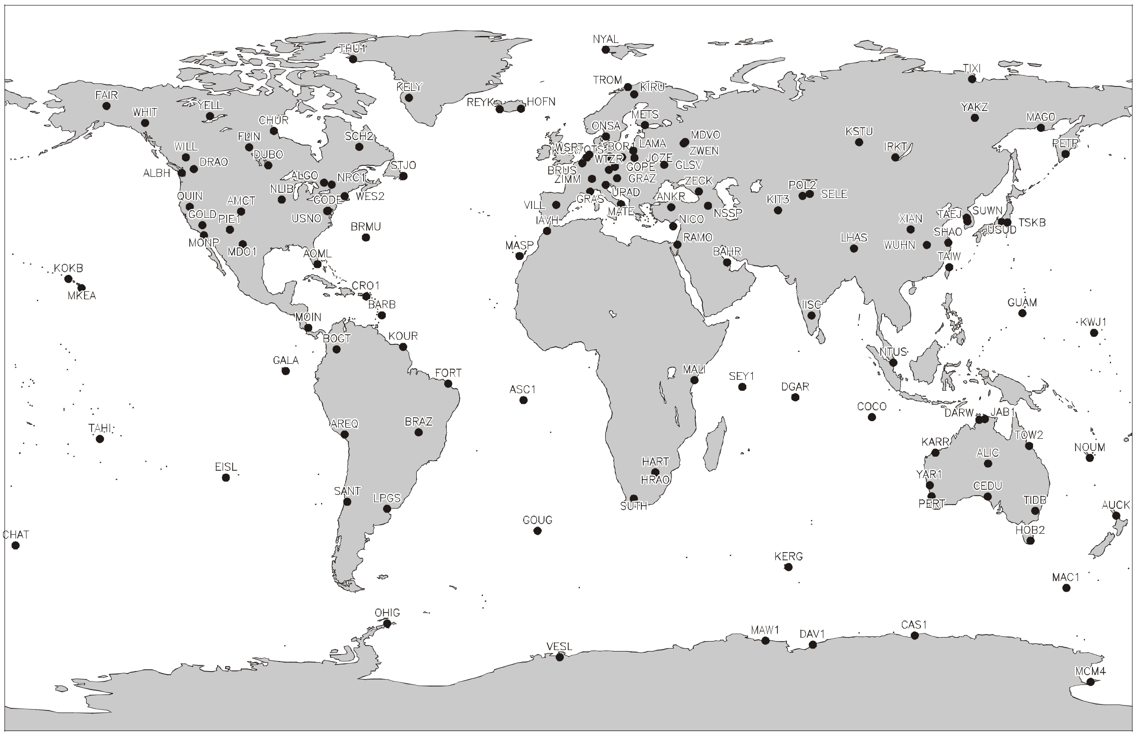


Figure 1.1: Part of IGS Network processed by CODE in 1999

Using the ADDNEQ processing program (see Section 5) the seven normal equation systems (NEQs) referring to the seven days of one particular GPS week are rigorously combined to produce one weekly set of coordinate and ERP solutions. The consistency of coordinate solutions, ERPs, etc. is maintained in this analysis. The results (coordinates and ERPs) are stored in a weekly SINEX file. SINEX is a format and stands for Software Independent Exchange format. These weekly SINEX files are further used by IGS Global Network Associate Analysis Centers (GNAACs) and by the IGS ITRF coordinating center (Natural Resources, Canada (NRCan)) to produce (what might be called) the IGS realization of the ITRF (International Terrestrial Reference Frame). This realization includes velocity estimates for the IGS stations. Thanks to the high standards of its analysis, the CODE results significantly contribute to this effort. The daily NEQs are also used by CODE to produce consistent multi-annual series of station coordinates and velocities. Such series have been made available to the IERS in the past to generate updates of the ITRF. CODE significantly contributed to ITRF93, ITRF94, and ITRF96. A continuous improvement in size and in quality could be observed for the CODE contributions. We refer to (Boucher et al., 1994, 1996, 1998) and to (IERS Central Bureau 1996, 1997, 1998) for more information. Figure 1.2 shows the velocity estimates produced by CODE for its global network. It is based on about five years of continuous data.

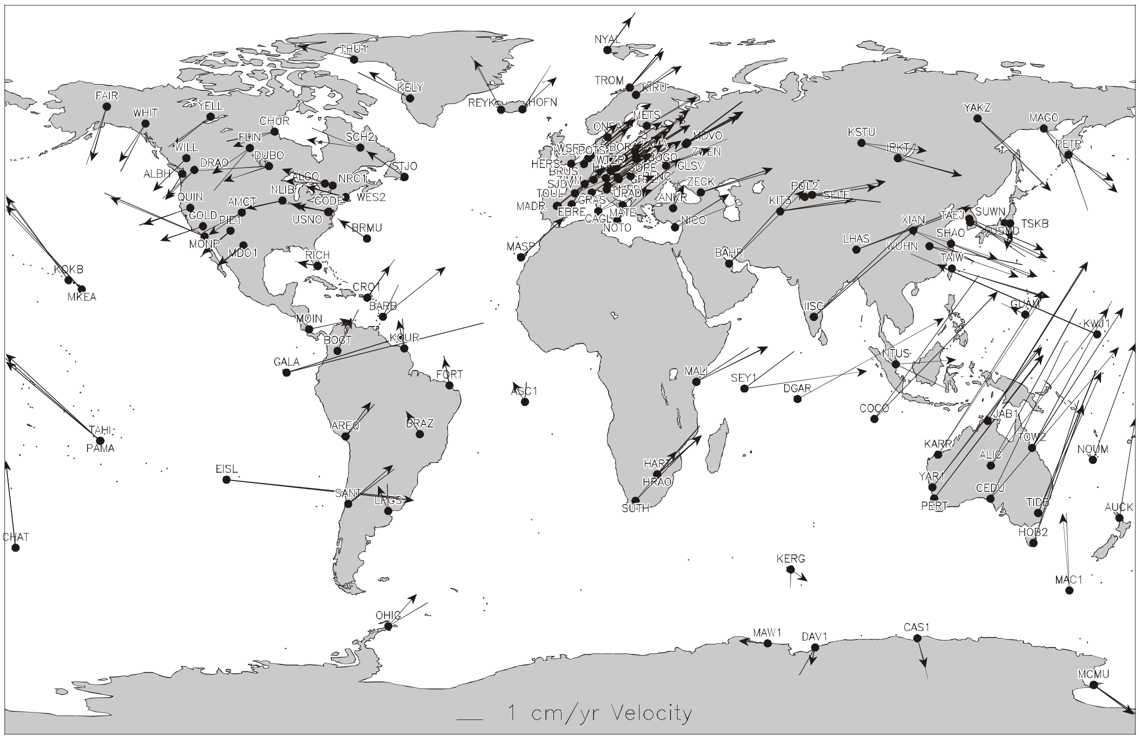


Figure 1.2: Horizontal site velocities estimated from 5 years of IGS/GPS data. ITRF96 values (thin lines) are included for reference.

There were many design reviews of the CODE global network and many changes of processing options which are relevant for the CODE contributions. We refer to the annual reports of the CODE Analysis Center 1995, 1996, and 1997 to the IGS for a complete documentation (Rothacher et al., 1996a, 1997d, 1998b).

GPS Antenna Calibration Campaigns

by M. Rothacher

During the last few years several GPS receiver antenna calibration campaigns were organized by the Swiss Federal Office of Topography to determine the phase center variations of different GPS antenna types. The antennas were set up on pillars about 10 meters apart with known coordinates. Using the Bernese GPS Software, the antennas were calibrated in two steps: (1) With the GPS data down to an elevation of 15 degrees, the mean phase center offsets (with respect to a well-defined physical antenna reference point) were determined relative to one reference antenna (Dorne Margoline T); (2) the variations of the phase center with elevation was determined relative to the mean phase center offset (Rothacher et al., 1995b, 1995e).

By combining the phase center patterns derived from several calibration campaigns and patterns from anechoic chamber measurements, a consistent set of antenna phase center variations was computed at the AIUB. This set is called IGS_01 (see ftp://igscb.jpl.nasa.gov/igscb/station/general/igs_01.pcv) and has been adopted by the IGS as the official antenna phase center corrections for the global and regional GPS processing.

EUREF Activities at CODE

by T.A. Springer, D. Ineichen, W. Gurtner, M. Rothacher, and G. Beutler

Contributions to the EUREF Permanent Network

Switzerland looks back to a long involvement in the activities of the IAG Subcommission for the European Terrestrial Reference Frame (EUREF). We refer to Section 2 for a summary for management contributions. On the technical level, the EUREF-89 Campaign (see (SGK, 1995)) was a milestone. Today, the EUREF activities are mainly based on the EUREF permanent tracking network consisting in 1999 of about 70 stations (see Figure 1.3).

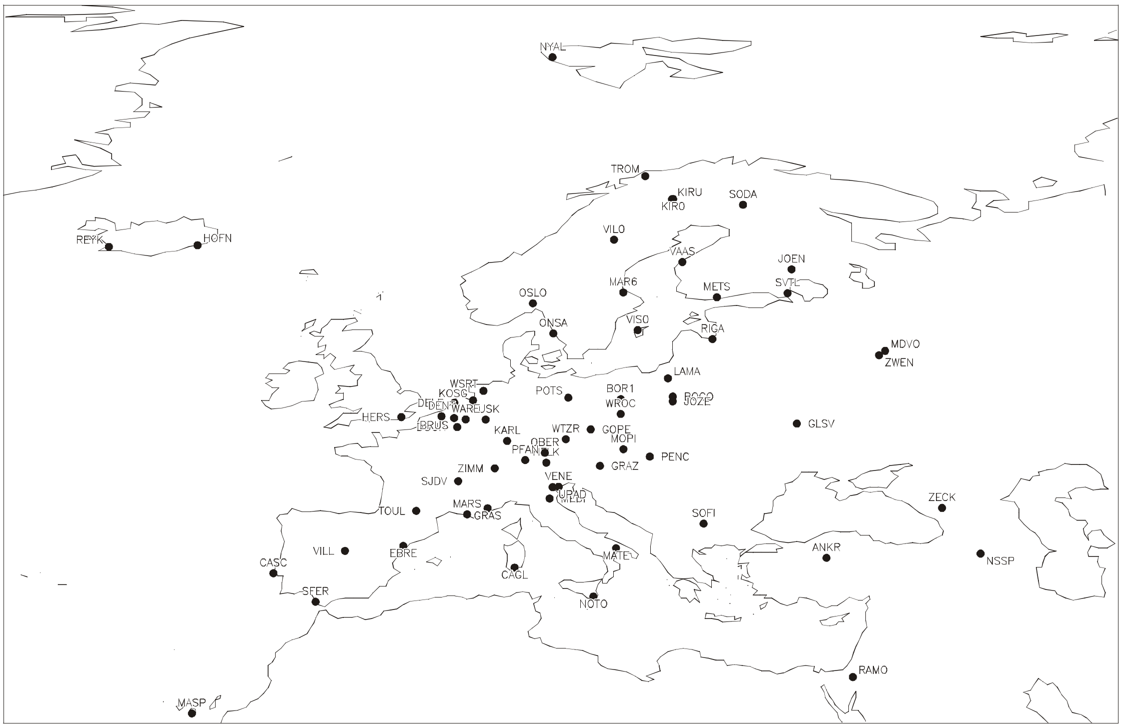


Figure 1.3: Permanent EUREF network in 1999

The analysis is performed using, to the extent possible, IGS standards and formats. In the analysis, the actual work is performed by currently 10 EUREF Analysis Centers, each of them processing an individual subnetwork. All these contributions are then combined on a weekly basis by CODE into the official EUREF solution. This solution is sent every week to the IGS for inclusion into the IGS densified network. The procedure is explained in (Bruyninx et al., 1998).

CODE is also one of the EUREF Analysis Centers. It is responsible for a subnetwork of 38 stations.

EUREF also produces multi-year coordinate and velocity solutions. A combined EUREF solution based on results from 1995 to 1998 was used as input for the generation of the ITRF97 (in preparation). Figure 1.4 shows the map of velocities of EUREF stations after subtracting the mean ITRF96 motion of the Eurasian plate.

EUVN'97

The European Vertical Reference Network 97 (EUVN'97) GPS campaign was performed from May 21 to May 29, 1997. EUVN is designed to contribute to the unification of different height systems in Europe. For the data processing the network with 217 GPS sites was divided into eight subnetworks. 10 different analysis centers were involved in the distributed network analysis. The Bundesamt für Kartographie und Geodäsie (BKG) at Leipzig and the Center for Orbit Determination in Europe (CODE) were responsible for the combination of the subnetwork solutions into the official EUVN'97 solution. The results of the official GPS solution are presented in (Ineichen et al., 1998).

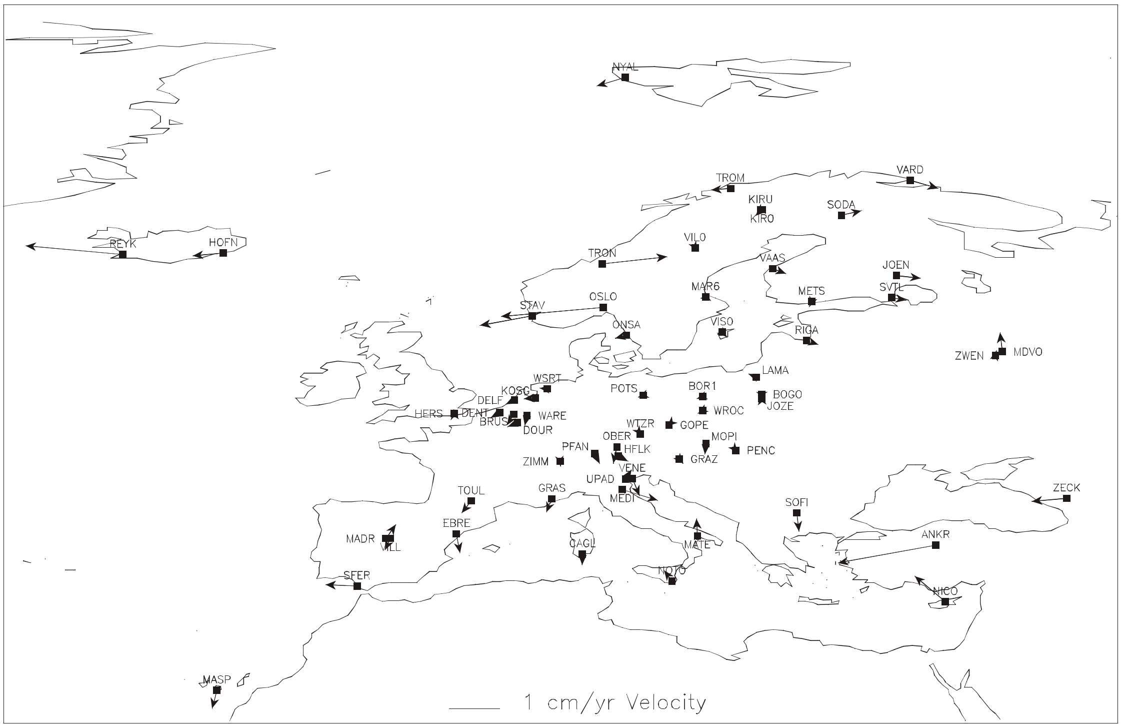


Figure 1.4: Map of the EUREF97 velocities relative to the motion of the Eurasian plate.

The Automated GPS Network for Switzerland (AGNES)

by U. Wild, R. Hug, Th. Signer, and A. Wiget

The Swiss Federal Office of Topography (L+T) is establishing a network of permanent GPS tracking stations in Switzerland, named the Automated GPS Network for Switzerland (AGNES), (Wild et.al., 1996) The main goals of AGNES are:

- Reference for national, cadastral, and engineering surveys
- Reference for differential navigation applications
- Research (geodynamics, atmosphere)

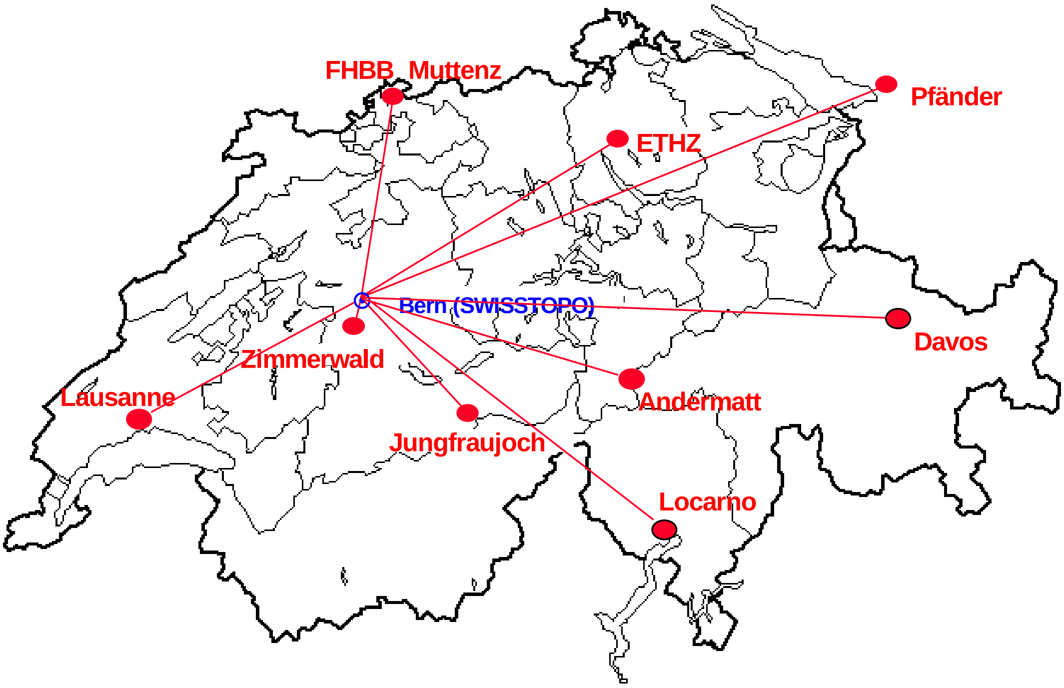


Figure 1.5: The Swiss permanent GPS tracking network AGNES

A total of nine stations is already operational (cf. Fig. 1.5). Four AGNES stations are collocated with stations of the automatic observation network of the Swiss Meteorological Institute (SMA). The data of all stations are evaluated in the control center at the S+T using the BPE – Software (Bernese Processing Engine). Since August 1998 the S+T produces daily solutions (24h data files) of all AGNES stations together with 12 permanent EUREF tracking stations. However, 1-hour solutions will soon be produced due to an increasing interest in 'near real-time' estimation of troposphere parameters for meteorology.

AGNES will be densified according to the needs for real-time kinematic (RTK) applications using an adapted WADGPS approach for phase observations. For this purpose all of the AGNES stations have to be directly connected to the computation center at the S+T by computer network (e.g. the computer network of the federal administration). Currently the possibilities for connecting the stations as well as the correct algorithms for modelling the correction data are being studied in detail. The AGNES stations may be accessed by GSM (called NATEL-D in Switzerland) for real-time kinematic (RTK) applications. Systematic field tests were carried out in spring 1999. The results look quite promising. At the same time the possibilities for broadcasting correction data over DARC or DAB are being studied.

Differential GPS (DGPS) in Switzerland

by U. Wild and M. Bühlmann

The pilot project for a nationwide Differential GPS (DGPS) Service in Switzerland, which was started in 1996 by the Swiss Federal Office of Topography (L+T), will be converted to an operational service during 1999. The GPS reference station for the DGPS service was moved to the facilities of the Swiss Broadcasting Corporation (SRG-SSR) in Zurich. The service, which disseminates RTCM corrections over FM/RDS (Radio Data System), is now offered under the label SWIPOS (Swiss Positioning Service). Currently 200 subscribers are using the service. The main applications are data collection for Geographic Information Systems (GIS) and precise positioning/navigation for vehicles of all kinds.

The first re-observation of the Swiss National GPS Control Network CHTRF98

by A. Wiget and D. Schneider

Between 1988 and 1994 the Swiss Federal Office of Topography established a new GPS-based control network called LV95 'Landesvermessung 95' (Gubler et. al., 1996; Schneider et al., 1996)). This high-precision network is integrated in the European Terrestrial Reference Frame (ETRF) through five EUREF stations and consists of 104 main points. It realizes the reference frame (CHTRF95) for the new national geodetic reference system CHTRS95. The nationwide accuracies (1 sigma) of the coordinates relative to the SLR station at Zimmerwald are better than 1 cm for the horizontal and 3 cm for the vertical components. LV95 is densified upon demand, so far by 60 additional points. Together with the new orthometric height system (LHN95) and the new national geoid (Geoid98), LV95 provides the coordinated base for a modern national control.

What this base lacks so far is a kinematic model to account for regional and local tectonic displacements. Whereas the vertical movements within Switzerland (approx. 1 mm / year) are rather well observed by repeated levellings, the knowledge on horizontal tectonic movements is still very limited. The geophysically derived kinematic models of global plate tectonics are not sensitive enough for the kinematics of interest. Nor are the results of the geodetic observations in central Europe, say by SLR or permanent GPS networks (IGS, EUREF). And the new Automated GPS Network for Switzerland (AGNES), consisting so far of nine permanent GPS stations, has just been operating for approximately one year. The only results available are some regional and local studies such as the "neotectonic" network in northern Switzerland, observed in 1988 and 1995, or the GPS test network "Turtmann" in the Alps. Nevertheless, the amount of horizontal homogeneous strain rates across the Alps are estimated to be in the order of some 1-5 mm / 100 km per year.

Modern high-precision geodetic networks are no longer considered to be static. A well-determined kinematic model for a high-precision geodetic network is important for the following applications:

- to study recent crustal movements and their coincidence with seismic observations;
- to separate tectonic phenomena from local displacements;
- to transform coordinates in time;
- to combine observations of different time epochs in a common adjustment.

The concept for the determination of a kinematic model (called CHKM95) for the CHTRS95 includes permanent and periodic GPS measurements: The continuous observations of the automated GPS network AGNES, well combined with the global network of IGS and the European permanent network EUREF, lead to a well-controlled time series of coordinates for a base network. On the other hand, the dense network of LV95 with most of its points in stable rock formations provides the spatial coverage and allows the geological interpretation of the relative displacements.

The LV95 network was therefore re-observed in 1998 for the first time. Even if the determination of a kinematic model (CHKM95) for CHTRS95 was a rather ambitious goal, the measurement of the network as a whole within one month did at least provide a more homogeneous and more precise reference for future kinematic studies at the earliest time possible. Moreover, the campaign allowed:

- a new set of coordinates (called CHTRF98) for checking and improving the accuracy and reliability of the existing CHTRF95 coordinates;
- the check of the stability of the LV95 points;
- the verification of the monumentation and of the local witness marks;
- the optimal combination of the CHTRF95 network with the AGNES and the EUREF permanent networks;
- the improvement of the connections to the modern GPS networks of our neighbouring countries.

An overview of the LV95 network observed in the CHTRF98 campaign is shown in Figure 1.6. It included 9 AGNES stations, 103 main and 61 densification points of LV95 as well as 15 additional reference points in neighbouring countries. The measurements were collected by 8 one-person crews in a total of 15 night sessions (16 hours) using 14 mobile GPS receivers. The session-wise subnetworks are linked to their neighbours by at least 2 common stations and the AGNES stations. The data will be processed using the Bernese GPS Software (Version 4.1). Finally, a deformation analysis shall be done together with the existing reference frame CHTRF95.

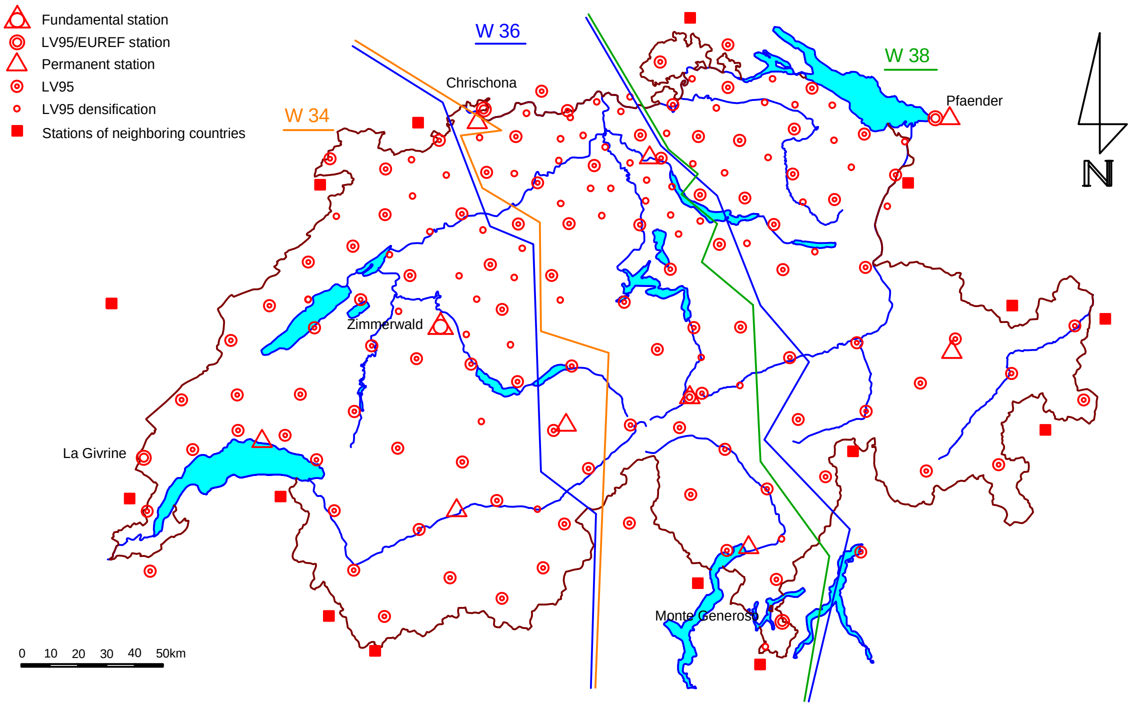


Figure 1.6: The national GPS network LV95 (W 34,36,38: week numbers of the observations in 1998).

Kinematic Methods and Airborne Geosciences

by A..Geiger, M. Cocard, E. Favey, E. Klingelé, M. Scaramuzza, and M. Cerniar

Satellite methods open new fields of expertise for geodetic sciences. Especially kinematic methods are of growing interest for a large variety of applications. Airborne surveying in geo-sciences call for precise trajectography. Examples are aero-photogrammetry, Laser scanning for terrain elevation determination or airborne geophysics (gravimetry, magnetics). To document these developments, projects are presented which show the mutual impact of kinematic applications and geodesy. An integrated Laser-Profiler system, including DGPS and attitude sensors, was implemented on an aircraft to determine profiles of sea surface heights, and to monitor glacial fluctuations at the decimetre-level. On the fly ambiguity resolution algorithms were developed to constrain the position of the aircraft below the 10-cm level. Extensive campaigns were carried out in the Ionian and Aegean Seas. This area includes one of the steepest gradients of the geoid coincident with the Hellenic subduction zone.

The satellite geodetic methods can also be used to verify and validate new procedures in civil aviation. Geodetic methods may even be integrated into operational systems (blunder detection or RAIM algorithms, on the fly carrier phase solutions). An example is given of a project for analysing and testing the feasibility of GPS-aided approaches for civil aviation in the Swiss Alps. During several test flights and dedicated ground missions various problems, such as satellite visibility, multipathing, GPS signal interference and the influence of the topography on the navigation and the GPS system were addressed. The tests showed the potential of satellite based systems for approaches, in particular for use in rugged terrain.

Investigation of Error and System-Modeling of Satellite Based En Route Navigation, Flight Approaches and Landings in Switzerland

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

A project to analyse the potential of the Global Positioning System (GPS) for navigation purposes in civil aviation, especially on approaches and landings in rugged terrain was carried out. It was integrated in a common concept pursued by various partners and co-ordinated by the Swiss Federal Office of Civil Aviation (FOCA). Apart of the FOCA and the Geodesy and Geodynamics Lab (GGL) of ETH Zurich, Swisscontrol, Crossair, Telematica, and the Swiss Federal Office of Topography participated in the trials. Based on satellite measurements, GPS allows instantaneous positioning accuracy in the range of 50 - 100 meters. This accuracy is improved to the range of meters by applying the differential GPS mode. This mode is used for navigation purpose during the approach and landing flights. Further position accuracy improvement up to centimetre to decimetre level is achieved by using carrier phase measurements. This positioning mode is used as reference.

The investigations are based on the coming standards on certification of approach and landing systems. The four Required Navigation Performance (RNP) parameters, accuracy, integrity, availability, and continuity are particularly analysed. These parameters cannot be evaluated in a statistically meaningful manner due to the small number of approaches flown until now. Nevertheless these few approaches show a mean horizontal deviation from the desired course of 0.7 % of the allowed deviation where the distribution sigma is 6 % of the allowed deviation. These results are promising for further test flights.

Theoretical analysis and simulations with respect to the RNP parameters, including e.g. flight dynamic and topography, show that the number of visible satellites as well as its constellation can become critical at low altitude and during curved flight. Improvement of continuity can be shown theoretically when using additional satellite systems, especially with the Russian GLONASS. Pseudolites improve the continuity mainly in the region of the critical parts of the final approach.

Two possible error sources, multipath and interference, are further investigated. A model describing the multipath of the GPS code signal is derived and verified with experiments. It is further shown, that the losses of the GPS signal detected during preliminary measurements at the airport of Lugano-Agno can be attributed to GPS carrier phase signal multipath.

A transmitter causing radio frequency interference was identified south of Lugano-Agno. A computer based technique for the identification of potential regions exposed to interference in the environment of a disturbing station is presented. It can further be shown that during the flight trials, no short-term degradation of the position accuracy due to interference was detected. It is to point out, that this statement is only valid for the case of Lugano and with the equipment used for the trials. An enhanced algorithm to monitor the position accuracy by using only range measurements of GPS satellites (Receiver Autonomous Integrity Monitoring, RAIM) was finally developed and tested with simulations. The probability of false alarms is slightly larger than required, whereas the probability of missed detection fulfils the requirements. An improvement of these results can be achieved by integrating altimeter measurements into the algorithm (Aircraft Autonomous Integrity Monitoring, AAIM).

To gain insight into precision, which are obtainable with current classical instrumentation a study has been carried. The precision is analysed in view of the area navigation procedures (and their further development), which are to be followed since recently.

Effects of Multipath, Interferences, Antennapattern, and Accelerations on GPS Measurements

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

The efficiency and gain of GPS antennas depend not only on propagation conditions within the atmosphere but also on the electrical characteristics of the antenna (antenna pattern) and the close surroundings. Strong multipath may even fade out the direct signal. These effects have been modelled for airport reference stations over flat ground. Different measurement flights especially over the southern part of Switzerland revealed strong interferences. Software tools have been developed to determine the location of the source of the disturbing radiation. Comparable problems in GPS data acquisition occurred also during terrestrial surveys in areas close to strong transmitters. This has also been shown by spectral analysis carried out in collaboration with the University of Stuttgart. By analysing GPS flight data we could demonstrate the different behaviour of code phase tracker and carrier phase tracker. The tracking loops show different reactions to accelerations. The effect has been studied by installing GPS receivers on a 30 m (1.5 to 2 g) diameter centrifuge.

Integration of the New Colombian Geodetic Network into the Continental frame

by Q. Ladetto, D. Egger, B. Merminod

As part of a development program at the national level, the Geographical Institute “Agustin Codazzi” (IGAC) started the restructuring and modernisation of its main infrastructures in 1992. As GPS technology gained acceptance in the world of geodesy, the need for a new national reference frame became crucial.

Completed in December 1997, the recent Colombian first order geodetic network, based on 60 stations well distributed all over the country, was integrated into the continental network SIRGAS (Sistema de Referencia Geocentrico para America del Sur). It offers a precision in position and ellipsoidal height of 5 cm and 10 cm respectively.

Through this project, some weaknesses in the existing network were discovered:

- Inadequate monumentation has caused the disappearance of more than 60% of all points;
- Lack of global compensation creates discrepancies between local networks;
- Poor documentation on the local projections (called “Cartesianas”) used for the main urban areas induces some confusion.

To solve these important problems, the choice of a new kind of monumentation and the substitution of the “Cartesianas” by local conform Gauss-Krüger projections were studied.

As Colombia covers an impressive area (1'139'000 km^2, which represents about 28 times the size of Switzerland!), distances between first order points are relatively large (120 km to 250 km), which prevents a direct use of the network for day-to-day survey purposes. Ideally, any location in the Andean region should be within 25 kilometers of a known geodetic point so that cycle ambiguities can be easily resolved. Integration of several national and international projects into the national network presents a rapid and economical alternative for densification. The project CASA (Central America – South America) attempts to model the motions of numeral tectonic plates colliding in Colombia. Its geodetic network consists of more than 160 stations, two of which are recording permanently. Several national institutions and petrol exploration companies (Water Supply Company Bogota, Cali, Shell, Ecopetrol…) have established accurate private geodetic networks that could advantageously be integrated into the national one.

There is a large diversity of point accuracies in the different Colombian GPS networks. Therefore a new definition of point standard, based on error circles rather than ellipses, has been proposed.

Dealing with GPS measurements implies naturally a precise knowledge of the zero equipotential. The Colombian geoid was determined by the geophysics team of IGAC. A digital model of the geoid and a program for interpolation were realized for the SKI package (Static Kinematic Software) of Leica. In this way, a simple conversion between ellipsoidal and orthometric heights is available to all GPS users.

GLONASS Extensions for the Receiver Independent Exchange Format (RINEX)

by W. Gurtner

In 1997 some extensions to the RINEX format needed to account for the different time system and orbit representation used by GLONASS were announced after discussions among a number of GPS software and hardware developers. The most visible extension is a separate file format for the GLONASS navigation messages. The first real test of the new format was the global GLONASS tracking campaign IGEX-98 starting in October 1998.

Optimisation of the measurement rate for GPS stop-and-go surveys

by J.-M. Rey

In many GPS software programs, the estimation of the precision neglects the correlation between the measurements; thus the results are excessively optimistic and rather unrealistic. It seemed interesting to quantify this correlation as a function of the time between measurement epochs.
By modelling the number of measured cycles by a 2^{nd} degree polynomial and by calculating the residual errors between measurements and the polynomial for several satellites and several receivers, one can estimate three kinds of correlations:

- the correlation between different receivers (for the same satellite)
- the correlation between different satellites (for the same receiver)
- the correlation between different epochs (for the same satellite and receiver).

Those computations allow the following conclusions:

- the phases between 2 receivers are not correlated
- the simple differences are strongly correlated, allowing them to be differentiated
- the statistic “time of correlation” amounts to approximately 10 seconds (based on receiver errors only)

Finally, for stop-and-go surveying, we recommend observing five epochs at intervals of five seconds, a good compromise between the amount of data to be recorded and the speed of the surveying operations.

GPS attitude determination, a comparison of approaches

by V. Gabaglio

The attitude of an airplane, a boat, a vehicle or more generally a platform is its orientation in space. The attitude parameters constitute the rotation matrix that can be used to transform coordinates or vectors between an Earth-fixed *reference frame* and a *body frame*. Actually, the body frame is defined by the positions of at least three points expressed in a vehicle-fixed coordinate system. If the position of three GPS antennae is known in a body frame, the determination of their position in an Earth-fixed coordinate system allows the determination of the attitude parameters. The first part of this research is dedicated to the parametrization of the attitude. Different ways are possible: quaternions, Euler's angles, cosine matrix or Euler's axes and angle. The advantages and drawbacks of each parametrization were discussed.
In the second part, we focused on an alternative determination of the attitude based on vectors known in two frames (usually the body frame and a reference frame). Different algorithms were examined and a new one was tested.
In the third part of the study, we compared the different possibilities of computing the attitude by a GPS multi-antennae system. Basically we can distinguish two different approaches.

- The determination in the reference frame of vectors between GPS antennae using carrier phase observations (with cycle ambiguities resolved for each vector). Thereafter, the vectors are combined with the corresponding ones known in the body frame. The algorithms studied in the second part are used to obtain the attitude. This method allows the use of a commercial software package to process the raw carrier phase data, in particular for ambiguity resolution.
- The direct determination of the attitude parameters without computing the vectors. A functional model that contains the observations (phase measurement), the vectors in the body frame and the attitude parameters (Euler's angles) is used. All ambiguities are solved using a single computation. Different algorithms were looked through.

The advantages as well as the drawbacks of the two approaches were evaluated.

Investigations on the elimination of refraction influence from geodetic measurements by automated methods

by B. Böckem, Ph. Flach, M. Hennes, and A. Weiss

Refraction effects are generally caused by an inhomogeneous propagation medium for the optical beam and are recognized as today’s major source of systematic errors in the precise determination of distances, horizontal directions, and vertical angles.

Therefore, we are developing a dispersometer theodolite. In addition, the compensation of refraction effects by other integrally working methods based on scintillation effects is envisaged. This implies basic research, especially concerning the propagation of waves in an inhomogeneous and turbulent medium. The Turbulent Transfer Model (TTM), for instance, will be investigated with respect to a modification using scintillometric data acquired by high-resolution sensors. The research is part of the project PEARL (Precise Elevation Angle measurement for Real-time Levelling), which started at the end of 1996 and enables the mutual control of three measurement approaches: the dispersion method, direct modeling (as required in tunnels) and scintillometer measurements (delivering vertical temperature profiles). A dispersometer theodolite for a metrological solution of atmospherically induced problems in high-accuracy direction observations is currently under construction. This design is capable of true, i.e., refraction-compensated angle measurements, the detrimental influence of atmospheric turbulence notwithstanding, by using the two-color method in the dispersive air. The principle of the two-color method utilizes the wavelength dependence of the refractive index. The difference of the angle between two light beams of different colors is in its first approximation proportional to the refraction angle. Correcting the apparent direction by the refraction angle, one will get the refraction-free true direction. However, the required accuracy can only be achieved by compensating the effects of atmospheric turbulence. In the currently developed dispersometer the same system will be capable of compensating both effects. The newly designed dispersometer consists of two sub-modules, the light source (a dual-wavelength laser generating blue light by frequency doubling of a semi-conductor laser diode) and the detector composed of a dispersion telescope and a semi-conductor-detection system. It is further planned to integrate each submodule in an existing motorized theodolite.

For the geodetic application of the scintillation features, we set up experiments in which scintillation data were acquired simultaneously from the scintillometer and from video-theodolites together with direct temperature-profile measurements and the determination of the variation of refraction angles for reasons of mutual comparison. Because the atmosphere of the earth is a chaotic system whose parameters change and fluctuate temporally and spatially in a wide range of order, the propagation of electromagnetic waves is influenced by the turbulence of the atmosphere. One effect is the scintillation of the wave, which is the result of fluctuations of temperature, moisture, pressure and their interactions. The SLS20 Scintillometer measures the fluctuation of the intensity of two laser beams. This quantity can be used in combination with an atmospheric model to estimate several turbulence parameters, for example the turbulent heat and momentum fluxes, the Monin-Obukhov-Length, which give an approximation of the atmospheric stability, the dissipation rate of energy, and the vertical distribution of the temperature and refractive index. Up to now, the theory allows the evaluation of turbulence parameters only over homogeneous or nearly homogeneous terrain. The aim of this work is to estimate also the turbulence parameters over complex terrain. Therefore, we refine the atmospheric modelling with the aid of field experiments. Moreover, we derive correction values from high-end theodolites and self-tracking total-stations which today are provided with video technology. Currently, we are focusing on the vertical angle measurement. We installed a data link to a video theodolite (TM3000V, Leica). During first field experiments we acquired scintillation data from the video theodolite and compared them with the variation of the refraction angle due to changing atmospheric conditions. These experiments showed a good correlation between the refraction angle and fluctuation parameters. In order to group the acquired data and the results received from the template matching algorithm in various categories such as experiment conditions, atmospheric conditions, dimension of image contents, structures of target pattern, structure of time series, calculation strategies, type of fluctuation, a data base was generated which permits inquiries with respect to different problems.

A Large Area Settlement (LAS) system based on a differential hydrostatic measurement system

by E. Meier and H. Ingensand

Up to now small height differences have usually been observed with high-resolution inclinometers or hydrostatic levels normally equiped with cylinders. As the range of the before-mentioned systems is restricted, a differential-pressure hydrostatic level instrument was developed to permit the required performance for different applications. The heights of several measuring vessels are determined by controlling the displacements of a precision membrane in a central unit. The system aims at short response times.

The actual development is a multiplexed differential pressure system with a capability of up to 24 vessels. In addition a reduction of thermal and other systematic influences can be determined by an intelligent self-calibration procedure. Some systems are set up in different applications: A permanent monitoring station has been set up in the concrete dam of Albigna (CH) since 1995. An independent reference measurement was performed in order to evaluate remaining systematic errors and to increase reliability. Another application is the determination of the settlement of soil under the compression of vehicle tires, which is part of a research project of Prof. Martin Fritsch (IfK/ETHZ). Furthermore, a project was started in co-operation with the Istituto Georisorse e Territorio, Università di Udine (Prof. Claudio Marchesini). The aim is an earthquake prediction sensor by monitoring the vertical movements in the Friaul area. The main application is the monitoring of a landslide at Basel/Münsterhügel. Furthermore, a landslide in Basel demanded a continuous monitoring, which was carried out by the LAS-system.

Engineering Geodesy – AlpTransit

by A. Ryf and M. Hennes

The planned tunnels of the AlpTransit project of the Swiss Railway Company (SBB), the longest one having a total length of approx. 57 km, represent a great challenge for geodesy and geotechniques. With the requirement of less than 10 cm lateral and 5 cm vertical standard deviation in all breakthroughs, the construction management fixed limits that call for a refinement of known measuring technologies and for the search of new, alternative methods. The complex arrangement of the different intermediate attacks such as the 800 m deep shaft of Sedrun, requires special instruments to transfer position, height and orientation to the underground. Independent methods should help to increase the reliability of the surveying tasks.

In collaboration with the project engineers of AlpTransit, the group Geodetic Metrology is analyzing existing methods and developing new ones for the following surveying tasks:

- precise plumbing in the shaft of Sedrun: different optical and mechanical plummets are being studied with the aim of trying to exclude all the known error sources as well as to reduce non-detectable systematic effects.
- precise direction transfer from the surface network to the tunnel’s level with gyroscopic theodolites or alternative methods.
- refraction-free direction transfers into the tunnel and in the intermediate attacks: see also Elimination of Refraction Influence (e.g. Dispersometry) in the appropriate chapter.
- position and orientation transfer through boreholes to minimize the breakthrough errors.

Quality Management and Calibration in Geodetic Metrology

by Ph. Flach and M. Hennes

Quality management systems enable a surveying office to assure all quality-relevant procedures and to continuously improve the working processes in conformity with the norm ISO 9001. Although this norm is composed of 20 so-called quality elements, today's quality management systems consist of a process-orientated description. In this approach, these processes encompass all of the functions and require the involvement and commitment of the entire staff, thus reaching continuous improvement through effective cooperation within the surveying office. Therefore, we investigate the control of measurement processes. We focus on the calibration of geodetic measuring instruments, which can be provided by the geodetic calibration laboratory of the Institute of Geodesy and Photogrammetry. The calibration methods include frequency control and (distance dependent) zero correction determination of EDM instruments, automated levelling rod and scale bar calibration and the determination of the line-of-sight. For the investigation of GPS equipment we developed a so-called "circle line test".

Transformation of existing surveying data into LV95

by Th. Signer and Ch. Just

The existing official cadastral surveys are based on the national control network LV03 (reference frame 1903) which shows constraints up to 30 ppm. With the new national control network LV95, Switzerland now has a new reference frame with an accuracy in position of 1 cm (1 sigma) with respect to the fundamental station Zimmerwald. This new network should serve as a common basis not only for cadastral surveying but also for all other surveying and engineering applications. It was therefore necessary to find an efficient and economic method of transforming the existing surveying data into the new reference frame.

The formulae used for transforming coordinates of LV03 into the new reference frame LV95 must function according to the following mathematical properties:

- The transformation must be continuous (the transformation of neighboring points must be analogous).
- The transformation must function in both directions (LV03⇔LV95).
- The coordinates of existing points determined in LV95 and designated as checkpoints must be identical to the transformed coordinates of that point.

Because the transformation LV03⇔LV95 is a time-consuming process executed region by region, the transformation parameters cannot be determined and introduced for all of Switzerland at the same time. Therefore, the organization must be planned as follows:

- It must be possible to carry out determinations of check points over a longer period of time.
- The definition of transformation parameters must be adjusted to regional needs.
- Once defined, the transformation parameters must remain valid as a standard for a long period of time.
- Densifications or improvements of a region may not influence the transformation in other regions.

The described requirements are met with an affine transformation using finite elements (program FINELTRA, developed at the Federal Institute of Technology in Zürich (ETHZ); cf. Section 4 'General Theory and Methodology'). All of Switzerland is divided into triangles. The coordinates of all of the angle points (corner points) must be determined in both the LV03 and LV95 reference frames. Thus, a linear function can be defined for each triangle which allows the exact transformation of each corner point. The choice of check points and the definition of triangles depends on the quality as well as on the original concept of the existing survey (LV03). The more homogeneous the data, the larger the triangles can be kept. The following principles apply to the choice of check points and the definition of triangles:

- Points qualifying for check points must be physically identical in both LV03 and LV95.
- The check points must be well-connected to neighboring points and be "representative" for the area.
- The points of the GPS control network LV95 should all be used as transformation check points in order to keep their LV95 coordinates constant after a transformation.

- When forming the triangles, all of the points inside the triangle must show a good relative accuracy to the three corner points in the frame LV03.

As a first step the existing control network of 1st and 2nd order triangulation points was divided into triangles (cf. Fig. 1.7). The coordinates in the reference frame LV95 were obtained in part through new measurements with GPS and in part through a new adjustment of the original observations (the so-called diagnostic adjustment 95). Based on test computations, it can be stated that an accuracy of 1 dm (1 sigma) is obtained for the Swiss Plateau and 1-3 dm for the Alpine area. In order to obtain greater accuracies, for example as required in cadastral surveying, the size of the triangles must be reduced. This densification will be carried out in the scope of projects as the need arises.

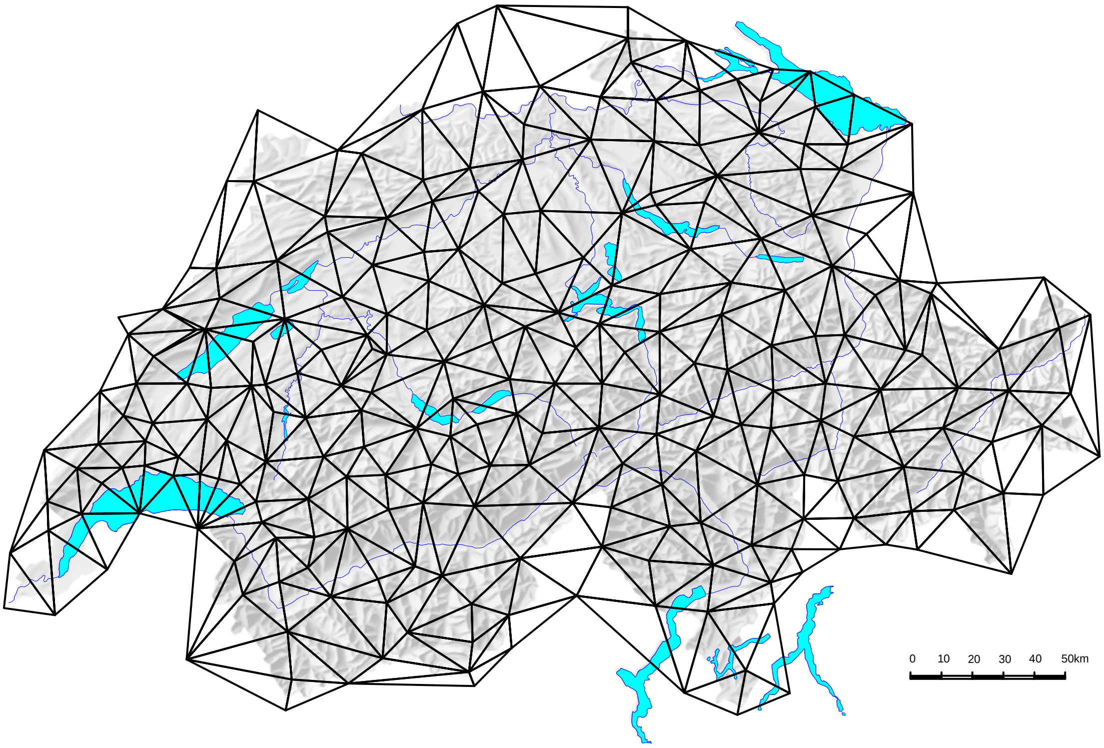


Figure 1.7: Triangles defined by 1st and 2nd order triangulation points for affine transformations using FINELTRA

In a first project the network of triangles was densified in the cantons of Uri and Ticino for AlpTransit (Alpine railway tunnel). Furthermore, the expected geometric distortions resulting from a transformation were investigated in a test project in the canton of Zug. The experiences gained with a densified network of triangles can be summarized as follows:

- The quality of the original data (LV03) cannot be improved by a transformation. However, the (absolute) accuracy resulting from a transformation into LV95 is on the same order as today's precision (relative accuracy) in LV03.
- The deformations of geometric elements (arcs, right angles, straight lines, etc.) as well as of the surface of transformed areas are within the accuracy of LV03 and can be neglected in cadastral surveying.
- Tests with various geographic information systems (GIS) using different procedures and programs for storing information have shown problems with certain systems when transforming administrative data (e.g. building numbers) or macros (e.g. representation of stairs).

It was decided to apply the following procedure for transforming the data from cadastral surveying into LV95: As a first step the transformation check points, triangles and corresponding linear functions will be determined as soon as possible. A service is to be established with experts serving as coordinators among the cantons. A definite timetable has not yet been determined.

The new national height system (LHN95) of Switzerland

by A. Schlatter and U. Marti

The existing old height system of Switzerland (LN02) consists of purely levelled heights without considering gravity measurements. This causes difficulties in the application of modern techniques such as GPS for height determination in mountainous areas and in the data exchange with neighbouring countries. Therefore, a new rigorous height system LHN95, based on geopotential numbers and the corresponding geoid, is being determined at the Federal Office of Topography (L+T) in collaboration with the Federal Institute of Technology at Zurich. LHN95 not only serves as the new National Height Network but it also fulfills the demands of large engineering projects. LHN95 is treated as a kinematic network with respect to the Alpine uplift which reaches amounts of up to 1.5 mm/year. The corresponding relative vertical movements are determined by repeated observations of the first and second order levelling lines. For LHN95, it was decided to use orthometric heights. This implies the use of the geoid as the reference because it has a smooth surface and can be interpolated easier than the quasigeoid.

The levelling observations have been available in digital form only since 1985. The hand-written observations made from 1903 to 1984 are being systematically captured. Up to now approx. 5400 km or 80% of the first and second order levelling observations have been processed and are continuously being integrated into the kinematic adjustments. First results are now available for the proposed trans-Alpine railway tunnels "Gotthard" (57 km) and "Lötschberg" (33 km).

The remeasurement of all first order lines was completed in 1991. A few of them have been observed a third time. The secondary lines are being remeasured since 1991. The observations for the definite network (see Fig. 1.8) should be finished by 2003. The dense network of repeated measurements yields very interesting information on recent crustal movements in Switzerland.

Some 80 bench marks of the LHN95 are connected to the new satellite-based national control survey LV95. The resulting undulations serve as a valuable basis for the absolute positioning of the new geoid for Switzerland (Marti, 1997, section 3).

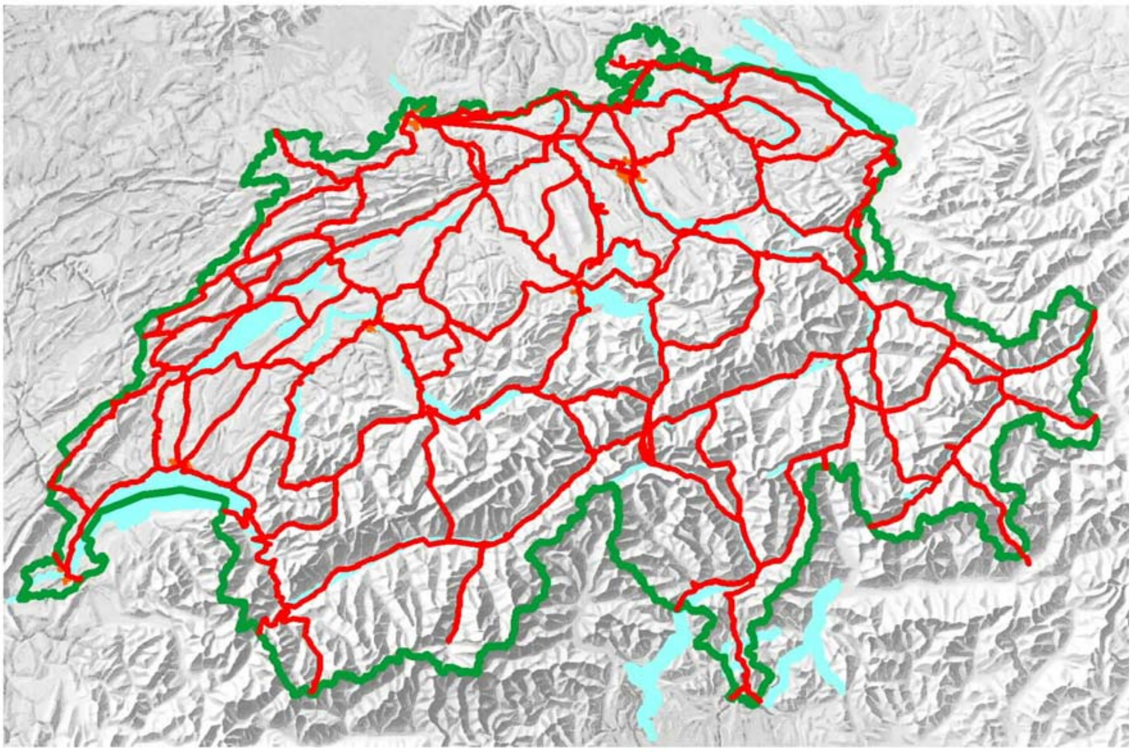


Figure 1.8: Final network of LHN95

GPS levelling and gravimetry, versus spirit levelling for a geoid refinement in Burkina Faso

by N. Jeanrichard and H. Dupraz

The Geographic Institute of Burkina Faso began creating a new national geodetic reference frame. As a first step in 1997, the GPS positioning for 55 new monuments was determined achieving a mean 3D position accuracy of ± 2.5 cm (1σ). The next step consists in choosing a new projection system and in determining a refined regional geoid with sufficient precision to obtain orthometric altitudes using GPS in the future instead of spirit levelling, which is a much more expensive method in such countries. One possibility is to refine the geoid by comparing the GPS ellipsoidic heights of well-distributed points with their existing (spirit) levelled heights, if the existing levelling network is good enough and the gravity anomalies are small enough.

The second hypothesis seems to be verified by the extreme flatness of the country and its geological homogeneity. On the other hand, the existing levelling network is rather ancient and has never been adjusted. That is why we decided to carry out gravimetry measurements with a Lacoste-Romberg G-317 instrument along several levelling lines all over the country. The reliability of the results is guaranteed by the operating procedure “forth and back” with different operators. In this way, it was possible to compute orthometric corrections that appeared very small, reaching a maximum of 28 mm at the extreme west of the country. Thus, within the limits of the set plan, one could neglect these corrections and consider the existing levelled heights as orthometric heights for refining the geoid.

Microwave Water Vapor Radiometry

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

In a joint project of the Geodesy and Geodynamics Lab (GGL) at ETH Zurich and CAPTEC, Consulting, Applied Physics, and Software Engineering, CH-2502 Biel, Switzerland, several water vapor radiometers (WVR) dedicated for field applications have been developed. These portable instruments have been applied in several European projects such as SELF II, WAVEFRONT (Kruse et al. 1999) and in Hawaii (Bürki, 1999). In order to validate wet path delay estimates as processed by GPS, one instrument is working quasi-permanently at the AGNES station ETH Zurich. These measurements provide long term comparisons with other methods such as solar spectroscopy (Sierk et al., 1998) and 4-dimensional modelling of surface atmospheric measurements including radio soundings. Several European geodetic fundamental stations plan to deploy permanently working WVR. For more information we refer to the contributions below and in section 5.

Use of GPS for Atmospheric Monitoring: WAVEFRONT (WAter Vapour Experiment For Regional Operational Network Trials)

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

This European Project is carried out within the frame of Theme 3: "Space Techniques Applied to Environmental Monitoring and Research" of the European Union (EU). Its major goal is to investigate the feasibility of the Global Positioning System (GPS) as a remote sensing tool for the determination of tropospheric water vapor. These investigations include validation of the accuracy and temporal resolution of GPS meteorology by comparison with microwave water vapor radiometers (WWR) and radiosonde profiles. WAVEFRONT aims to demonstrate the validity of GPS water vapor estimation of Integrated Water Vapor (IWV) at the 1-2 mm level and examine the feasibility of estimating water vapor at this accuracy level on a near real-time basis. A tomographic analysis, to study the three-dimentional water vapor variations over a smaller, denser GPS network will give an indication of temporal and spatial water vapor gradients present in the atmosphere. The GGL group at ETH Zurich is responsible for ground-based WVR/GPS estimation, comparison and validation. In this working package dedicated field campaigns are carried out using the portable water vapor radiometers (WVR) owned by GGL in co-location with other WVR sites involved in the project. The data sets gained provide a basis for comparisons WVR – IWV-estimates (cf. Fig. 1.9) as well as an assessment of the absolute accuracy both methods. In addition, the two techniques will be validated in side by side measurements. Long term comparisons of tropospheric water vapor retrivals by GPS and WVR will allow determination of site and season dependency on the a-priori statistics for the GPS IWV estimation procedure.

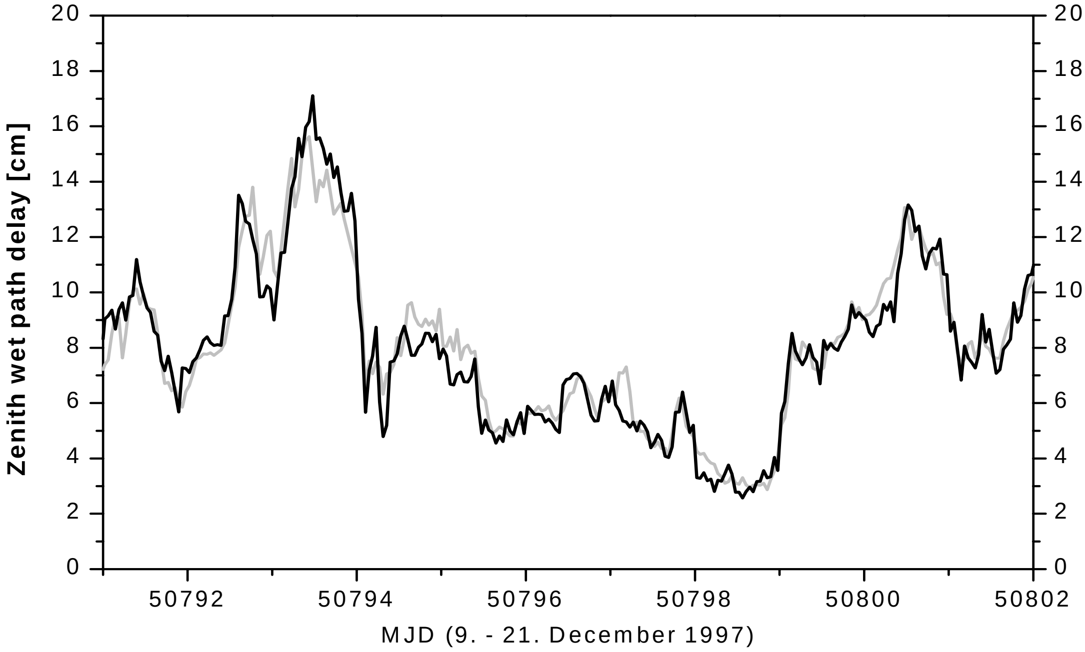


Figure 1.9: Zenith path delays as observed with Water vapor radiometers (WVR) at ETH Zurich (grey line) compared to the corresponding values as estimated by GPS (black line).

High Precision GPS Processing in kinematic mode

by M. Cocard

In the last few years the Global Positioning System (GPS) has become the most powerful navigation system world-wide. Although it was developed by the American Department of Defense (DoD) and is, therefore, primarily designated for military use, the number of civilian users is rapidly increasing from day to day. Based on satellite measurements, GPS allows instantaneous positioning accurate to within 100-200 meters. Differential processing of phase measurements allows improvement of position accuracy to few centimeters. There are numerous applications for spatial trajectories calculated with such high quality accuracy: e.g. their integration in photogrammetric aerotriangulation allows considerable reduction of the number of control points on the ground. Also in airborne gravimetry new horizons are being opened by using GPS.

A software system for processing kinematic data in the off-line mode has been developed. Its key features are presented first. A robust and flexible approach using simultaneously phase- and code-measurements in a differential way is used. For the computation the differences between the code and phase information, measured by the roving receiver as well as by a fixed reference receiver, are used in order to reduce the systematic errors, which affect both receivers in a similar way. The main differences between the phase and the code data are (a) noise (decimeters to meters for the code, millimeters for the phase) and (b) the unknown ambiguities in the phase measurements, which are known to be integer values. Processing is carried out in two steps: firstly a least squares adjustment is applied in order to determine the time-invariant parameters, using the entire data set. Parameters which are considered as invariant are the ambiguities and the coordinates of the roving receiver during stationary periods. Next, the integer values of the ambiguities are determined. In a second step the trajectory is re-processed by introducing the known ambiguities.

The key problem in obtaining high-accuracy trajectories consists in making reliable identification of the integer-valued ambiguities. It is demonstrated that a conventional sigma dependent rounding strategy, commonly used in static applications, is still a useful tool in off-line kinematic processing. In addition, a more powerful search strategy has been analyzed and simulations show that under ideal conditions the integer values of the ambiguities can be retrieved within one epoch worth of dual-frequency measurements. These simulated results have been validated by real data. With increasing distance between the roving and the reference receiver a stochastic modeling of the ionospheric path delay gave good results but also showed the limitation of instantaneous ambiguity resolution.

Using GPS data of good quality trajectories with an accuracy of a few centimeters were recovered. With increasing distance between rover and reference station (up to 100 kilometers), however, all ambiguities could not always be resolved and the quality of the resulting trajectories deteriorates to some decimeters. But even in this case it was possible to derive the velocity and acceleration of the aircraft with high accuracy from the coordinates.

Four-Dimensional Modelling of Atmospheric Refractivity Parameters

by A. Geiger and L.P. Kruse

Concerning GPS heighting the improvement of the vertical accuracy is of high priority. One of the key problem in the GPS height determination is the tropospheric refraction. In particular modelling of the water vapour content is difficult because of its high spatial and temporal variability. Therefore the GGL/ETH works on several mutually complementary techniques, such as Water Vapour Radiometry (WVR), Solar Spectrometry, GPS meteorology, and 4D-modelling.

The aim of the 4D approach is to generate a three-dimensional refractivity model for any desired epoch and location. The refractivity field is integrated along the ray path in order to determine the path delay. The algorithm accepts any meteorological measurements (pressure, temperature, and humidity) at any sampling rate and spatial distribution. In Switzerland the automatic meteorological station network (ANETZ) of about 72 stations operated by the Swiss Meteorological Service can be used for data acquisition (sampling rate at 10 minutes). The elevation of these stations ranges from 200 to 3500 m. Extension of the model will allow the introduction of integral path delay measurements thus enabling the combination of all methods developed at GGL. The final goal of this project is to provide tropospheric correction data based on all available data sources such as surface meteo, radio soundings, WVR, and solar spectrometric measurements. Figure 1.10 shows a comparison of zenith wet path delays as calculated using the software package COMEDIE (Hirter, 1998) at AGNES station ETH Zurich.

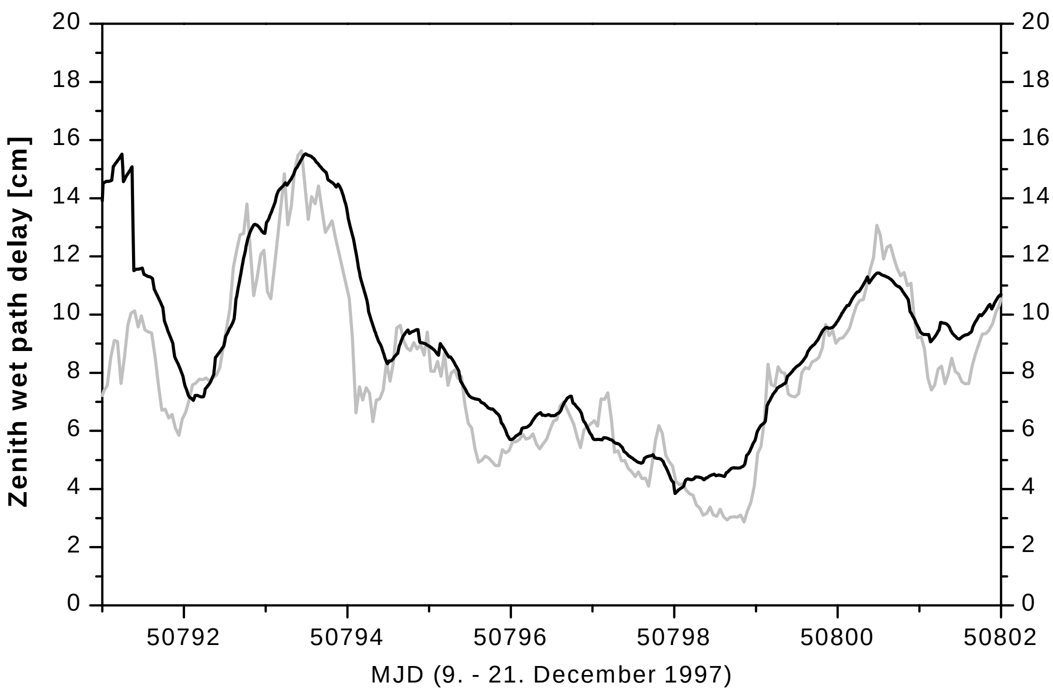


Figure 1.10: Comparison of zenith wet path delays as calculated using a 4-dimensional model (black line) and WVR measurements (grey line) observed at AGNES station ETH Zurich.

Development of a solar spectrometer for measurements of tropospheric water vapor

by B. Sierk, B. Bürki, H.-G. Kahle, St. Florek, and H. Becker-Ross

In 1997 GGL started an ETH-funded project in colaboration with the Institute of Spectrochemistry and Applied Spectroscopy (ISAS) Berlin, Germany, and the Laboratory of Atmospheric Physics at ETH (LAPETH). The goal is the development of a high resolution field spectrometer for remote sensing of tropospheric water vapor. In the first phase of the project, extensive simulation and feasibility studies have been performed. These included the selection of optimum wavelength intervals for retrieval of integral water vapor content as well as vertical profiles of humidity distribution. After the specifications of the instrument were determined construction of the prototype SAMOS (Solar Atmospheric Monitoring Spectrometer) began in Summer 1998. In January 1999 construction of the instrument was completed and first tests were performed successfully. In February 1999 the instrument was used in a field campaign on Hawaii island, where several new techniques for remote sensing of tropospheric water vapor were deployed. At present data processing and further software development is performed. Different processing algorithms will be implemented and investigated. The results will be used to calculate tropospheric refractivity fields for space geodetic observations.

A new criteria for predicting ambiguity resolution implementation in a commercial software package

by B. Merminod

Precision indicators provided by GPS commercial software packages are based on the instantaneous satellite geometry. Such modelling is appropriate for pseudo-range observables. However, the model of the carrier phase observable includes an integer unknown, the so-called cycle ambiguity, corresponding to the number of entire cycles between the satellite and the receiver at the time of locking onto the satellite signal. For a long time, there has been anecdotical evidence that GDOP or PDOP are not appropriate for selecting the length of an observation session. In the late eighties, either a constantly low or a rapidly changing GDOP were considered favourable. However, a quick change in GDOP can occur when loosing a satellite, an event which can hardly strengthen the solution. Research conducted by the author led to the following facts.

The precision of the solution with real-valued cycle ambiguities unknowns, the so-called float solution, is closely related with the change in geometry of the satellite constellation, not only with the geometry itself.

The successful resolution of cycle ambiguities to unequivocal integer values depends mostly on the precision of the float-solution. As long as the cycle ambiguities are not resolved, the phase observable is a change in range. This resembles the hyperbolic Doppler positioning well known by hydrographers. For a GPS satellite, which is far away from the Earth's surface and relatively slow, the hyperboloid may be approximated by a cone, see Figure 1.11. The change in range observed for the satellite S is equivalent to ranging from the fictitious satellite PS, situated in a direction perpendicular to the surface of the cone. The position of this fictitious satellite may be computed using the position and velocity vectors of the actual satellite.

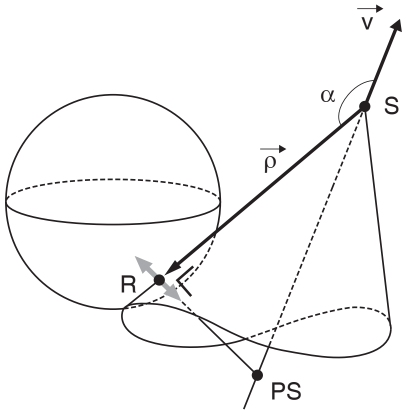


Figure 1.11: Geometric relation between a satellite and its fictitious "paired-satellite"

The advent of dual-frequency receivers made shorter sessions possible. Therefore, it became interesting to quantify the instantaneous change in the satellite geometry. This can be achieved by computing classical DOP indicators for the fictitious satellites. BGDOP – for Biased Geometric Dilution Of Precision – is the GDOP of the paired-satellites and has been used successfully by the author for optimizing the time and the duration of GPS sessions for the realisation or various projects.

Figure 1.12 illustrates a situation which occured in Southern Africa on September 10, 1992. Between 16:00 and 18:00 there were four satellites available, except around 17:00, when one satellite dropped down and another one came up. Clearly GDOP and BGDOP yield different indications as to when the solution should be better. Dual-frequency was recorded on a one km baseline using Leica 200 receivers. AS was not on, so that the full wavelength was available for L2. During the peak of BGDOP, that is, around 16:30, it took six minutes to resolve ambiguities in spite of the favourable GDOP value. On the other hand, a one minute session was sufficient to resolve ambiguities correctly during the GDOP peak at about 17:30, while BGDOP is favourable. However, the fixed solution had a 3-D sigma in excess of 20 cm, and the 3-D difference versus the ground truth was in excess of 10 cm. An extension of the session duration to 3 minutes brought the sigma value down to 4 cm and the delta value down to 5 cm. It is clear that both BGDOP and GDOP should be favourable as they predict respectively the ability to resolve ambiguities and the precision of the ambiguity fixed solution.

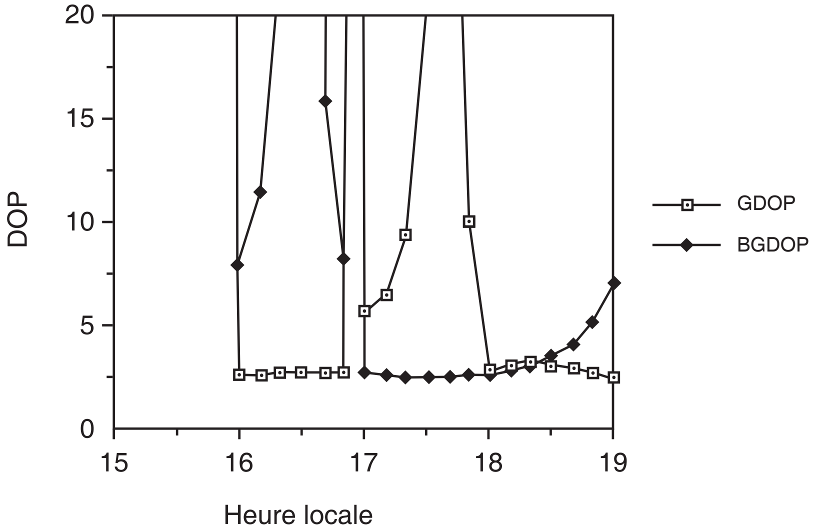


Figure 1.12: GDOP and BGDOP for Maseru, Southern Africa, on 10.09.92

Many different approaches have been proposed to develop indicators which take the added complexity of the phase modelling into account, for example by Hatch, Goad, Lommis, Euler and Weill. However the corresponding indicators, like BGDOP, had to be computed using a specific software, thus adding a workload to the standard mission preparation.

In the meantime, mission planning softwares had become very convenient, including the possibility to change the scenario interactively and to define sky obstructions. It became more desirable than ever to combine the rigour of BGDOP planning with the user-friendliness of commercial software packages. Through cooperation with Leica, this objective could be defined as a diploma thesis project. Mr. Moreno Rossetti could modify the source code of the SKI planning module, which provides GDOP and PDOP simultaneously as standard. He added a routine to compute BGDOP and substituted PDOP for the new indicator in the control of the display. The modified code was compiled and linked within the SKI environment, thus providing a separate executable file. Upon request, this file is freely available to Leica customers, via the normal distribution network. It is very easy to replace the original mission preparation file by the new special one upon installation of SKI. At last, mission planning with both BGDOP and GDOP is now possible within a user-friendly environment.

Bibliography Section 1

AMMANN, R., CAROSIO, A., DUPRAZ, H., DURUSSEL, R., JOLIDON, A., JUST, CH., SCHNEIDER, D., ULRICH, W., VOGEL, B. (1996): Konsequenzen der neuen Landesvermessung 95 für die Amtliche Vermessung. Schlussbericht Eidgenössische Vermessungsdirektion, Bundesamt für Landestopographie. Bericht: Oktober 1995, Version August 1996.

BEUTLER, G. (1995a): "the gps as a tool in global geodynamics". lecture notes in earth Sciences, Kleusberg, A. / Teunissen, P. J. G., 60, pp. 379-407, Springer-Verlag, Berlin / Heidelberg, 1996.

BEUTLER, G., J. KOUBA, AND R. E. NEILAN (1995b): "Position Paper 4: Densification of the ITRF through Rergional GPS Networks: Organizational Aspects". Proceedings of the IGS Workshop 1994 on the Densification of the IERS Terrestrial Reference Frame through Regional GPS Networks, 1995, J. F. Zumberge and R. Liu, Pasadena, California.

BEUTLER, G., S. SCHAER, AND T. A. SPRINGER (1997): "Considerations Concerning a Second Civil GPS Frequency in View of the two Existing Carriers L1 and L2". EOS Transactions of the AGU 1997 Fall Meeting, 78, November, 46, pp. F148, 1997.

BEUTLER, G. (1998a): "The Role of GPS in Space Geodesy". GPS for Geodesy, Teunissen, P. J. G. / Kleusberg, A. (eds.), pp. 625-650, Springer Verlag, Berlin / Heidelberg, 1998, 3-540-63661-7.

BEUTLER, G., R. WEBER, E. BROCKMANN, M. ROTHACHER, S. SCHAER, AND A. VERDUN (1998b): "The GPS as a Tool in Global Geodynamics". GPS for Geodesy, Teunissen, P. J. G. / Kleusberg, A. (eds.), pp. 569-598, Springer Verlag, Berlin / Heidelberg, 1998, 3-540-63661-7.

BOCK. Y., W. GURTNER et al. (1997): "Southern California Permanent GPS Geodetic Array: Continuous measurements of regional crustal deformation between the 1992 Landers and 1994 Northridge earthquakes". Journal of Geophysical Research, 102, August, 1997.

BÖCKEM, B., GERVAIX, F. (1997): Die Entwicklung des ETH-Kreisformtests als wirksame Untersuchungsmethode für GPS-Vermessungssysteme. Vermessungswesen und Raumordnung, Heft 1+2, 59. Jahrgang, S. 56-67.

BÖCKEM, B. (1998): Optische Richtungsübertragung höchster Genauigkeit durch Ausnutzung der atmosphärischen Dispersion. Beitrag zu Geodätische Woche 98, Kaiserslautern, 12.-17.10.1998. In: Progress in Geodetic Science at GW 98. Edited by W. Freeden, Shaker Verlag, Aachen, S. 34-41.

BOUCHER, C., Z. ALTAMINI, L. DUHEM (1994): "Results and Analysis of the ITRF93". IERS Technical Note, 18, Observatoire de Paris, Paris.

BOUCHER, C., W. GURTNER, G. WÖPPELMANN (1995): "The European Primary Tide Gauge Network". Bayerische Kommission für die Internationale Erdmessung, Astronomisch-Geodätische Arbeiten, 55, München, 1995.

BOUCHER, C., Z. ALTAMINI, M. FEISSEL, P. SILLARD (1996): "Results and Analysis of the ITRF94". IERS Technical Note, 20, Observatoire de Paris, Paris.

BOUCHER, C., Z. ALTAMINI, P. SILLARD (1998): "Results and Analysis of the ITRF96". IERS Technical Note, 24, Observatoire de Paris, Paris.

BROCKMANN, E. (1995): "The Contribution of an IGS Analysis Center to the Realization and Maintenance of the ITRF: Principles and Problem Areas". 1995 ITRF Workshop, Paris, May 8-9.

BROCKMANN, E., W. GURTNER (1996): "Combination of GPS Solutions for Densification of the European Network: Concepts and Results from 5 European Associate Analysis Centers of the IGS". Proceedings of the EUREF Symposium, Ankara, Bayerische Kommission für die Internationale Erdmessung, 57, München, 1996.

BROCKMANN, E. (1997): “Combination of Solutions for Geodetic and Geodynamic Applications of the Global Positioning System (GPS)”. Geodätisch-geophysikalische Arbeiten in der Schweiz, Schweizerische Geodätische Kommission, Volume 55.

BRUYNINX, C., W. GURTNER, A. MULS (1996): “The EUREF Permanent GPS Network”. Proceedings of the EUREF Symposium, Ankara, Bayerische Kommission für die Internationale Erdmessung, 57, München, 1996.

BRUYNINX, C., T. A. SPRINGER, G. BEUTLER, E. BROCKMANN, W. GURTNER, M. ROTHACHER, S. SCHAER, A. WIGET, U. WILD (1997): “The EUREF Associate Analysis Center: 1996 Annual Report”. IGS 1996 Annual Report, November 1997, IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Cal., Zumberge, J.F. / Fulton, D. E. / Neilan, R. E., pp. 271-309, Pasadena, California, 1997.

BRUYNINX, C., D. INEICHEN, T. SPRINGER (1998): “The EUREF RNAAC: 1997 Annual Report”. 1997 IGS Annual Report, IGS Central Bureau, JPL, 2, Pasadena, Cal., USA.

BUTSCH (1997): Spectral measurements for Interference source detection in the Lugano test area. Internal report. (Work in collaboration with Institute of Navigation, Uni Stuttgart, Internal Reports to Alfastar-Consortium (ALFASTAR-Project).

BÜRKI B. and, H.-G. KAHLE, (1995): Mikrowellen-Wasserdampfradiometrie für hochgenaue Messungen mit GPS. VPK, 4/95:232-240.

BÜRKI B.,, B. SIERK, L.P. KRUSE, H.-G. KAHLE, M. LISOWSKY, M. BEVIS and A. H. DODSON (1999): Field experiment for an integrated study of tropospheric water vapor in Hawaii. Geophys. Res. Abstr., 1,1:230.

CAROSIO, A., REIS, O. (1996): Geodetic Methods and Mathematical Models for the Establishment of New Trans-Alpine Transportation Routes. IGP-Bericht Nr. 260, 10/96.

CAROSIO, A. (1996): Qualitätsmanagement in der angewandten Geodäsie. IGP-Bericht Nr. 264, 11/06.

CAROSIO, A., KANANI, E. (1997): Geodetical Methods, Mathematical Models and Quality Indicators for Underground Network Adjustment sowie Proceedings FIG, FIG-Symposium „Surveying of Large Bridge and Tunnel Projects“, Copenhagen, Denmark, June 2-5 1997.

CERNIAR, M. (1997): Modellierung des Multipath-Effektes auf GPS-Codemessungen, Seminar work, 1997.

CERNIAR M. (1997): Kombination INS-GPS, Vertiefungsblock 1997, GGL.

COCARD M. (1995): High Precision GPS Processing in kinematic mode. Geodätisch-geophysikalische Arbeiten in der Schweiz. Schweizerische Geodätische Kommission (ed.). Vol. 52, 139 pages

COCARD M., A. GEIGER (1995): The importance of multifrequency systems for future GNSS. ISPA95, International symposium on precision approach and automatic landing, Deutsche Gesellschaft für Ortung und Navigation (DGON), pages 475-481.

COCARD, M., KAHLE, H.-G., PATER, Y., VEIS, G., PARADISSIS, D. and S. FELEKIS (1996): The state of the permanent GPS network covering the deformation field across the Ionian Islands. 80. Journées Luxembourgeoises de Géodynamique. Proceedings Walferdange, Luxembourg.

CUCHE, L. (1997): Untersuchungen zur Positionierung mittels der Kombination von Inertialsensoren und GPS, Diploma thesis 1997, GGL, ETHZ.

CUCHE, L., C. STIEFEL (1997): Kinematische GPS Messungen auf SBB Messwagen, Vertiefungsblock 1997, GGL.

DENYS P., A. BIRKS, P. CROSS, J. POWELL, P. PESEC, B. BÜRKI (1995): Transponder altimetry: Precise height measurements over land. J. Geophys. Res., 100 (B12): 24347-24359.

DODSON, A., BAKER, H., BÜRKI, B., ELGERED, G., RIUS, A., ROTHACHER, M. (1998): The WAVEFRONT project on GPS water vapor estimation. European Geophysical Society XXIII General Assembly. Annales Geophysicae, Part I. Suppl.I to Vol 16, C376.

DODSON A.H., H.C. BAKER, B. BÜRKI, G. ELGERED, A. RIUS and M. ROTHACHER (1998): The WAVEFRONT project on ground-based GPS water vapour estimation. GNSS98 conference proceedings.

DOERFLINGER, E., R. BAYER, J. CHÉRY, BÜRKI, B. (1998): The Global Positioning System in mountainous areas: effect of the troposphere on the vertical GPS accuracy. Earth & Planetary Sciences 1998. 326, 319-325.

DOERFLINGER E., B. BÜRKI, B. SIERK, A. WALPERSDORF, R. BAYER, J. CHERY (1995): Improvement of GPS vertical repeatability using pointed WVR equipment: a new experiment in a mountainous area. Eos Trans. AGU, Nov. 7: Suppl., F150.

ELOSEGUI, P., A. RIUS, J.L. DAVIS, G. RUFFINI, S.J. KEIM, B. BÜRKI, AND L.P. KRUSE (1998): An Experiment for Estimation of the Spatial and Temporal Variations of Water Vapor using GPS Data, Phys. Chem. Earth, 23, 1: 125-130.

FANKHAUSER, S., W. GURTNER (1995): "EUREF-DK94: Denmark Euref Densification Campaign, August 29 - September 2, 1994". Bericht der Satelliten-Beobachtungsstation Zimmerwald, Astronomisches Institut der Universität Bern, 23, Druckerei der Universität Bern, Bern, 1995.

FÄH, P.(1995): Transformationsmethoden für den Übergang LV03-LV95 am Beispiel der Bahn-vermessung. IGP-Bericht Nr. 246, 6/95.

FLACH, P., HENNES, M. (1998): Image processing techniques for determination of refraction influences. Paper to: IAG-Symposium on Geodesy for Geotechnical and Structural Engineering, Comm SC4, Eisenstadt, Austria, 20.-22.04.1998.

FLACH, P., HENNES, M. (1998): Die optische Turbulenz – wirklich nur ein limitierender Faktor für geodätische Messungen? Beitrag zu Geodätische Woche 98, Kaiserslautern, 12.-17.10.98. In: progress in Geodetic Science at GW 98. Edited by W. Freeden, Shaker Verlag, Aachen, S. 65–72.

GEIGER A., M. SCARAMUZZA, M. COCARD (1996): GPS guides civil aviation in swiss alps. Royal Institute of Navigation, Navigation News: 13-14.

GEIGER A. (1997): GPS Basics. Tutorial on GPS at European Frequency and Time Forum, Neuchatel, Switzerland. Swiss Foundation for Research in Microtechnology (FSRM): 52.

GEIGER A., M. COCARD, M. SCARAMUZZA (1995): Acceptance Test of GDARS, Version 27.10.1995. Project ALFASTAR, pages 7.

GEIGER A., M. COCARD, M. SCARAMUZZA (1996): Acceptance Test of ADARS, Version 18.1.1996. Project ALFASTAR, pages 9.

GEIGER A., M. SCARAMUZZA, M. COCARD (1996): DGNSS Trials Lugano: Data Recording and Aspects of Analysis. Proceedings of Symposium on SATNAV Strategy, Munich, pages 8.

GEIGER, A., SCARAMUZZA, M., COCARD, M., KAHLE, H.-G., LANG, H., AEBERSOLD, R., MEIER, B., DOSÉ A. (1998): Testing GPS approaches for civil aviation in the Swiss Alps. In: Brunner, F. (ed.) Int. Ass. Geodesy Symposia, Vol. 118: 351-356. Advances in Positioning and Reference Frames. Springer Verlag Berlin.

GERVAIX, F. (1997): Pencomputing: Applications et Perspectives, VPK 12/97.

GUBLER, E., GUTKNECHT, D., MARTI, U., SCHNEIDER, D., SIGNER, TH., VOGEL, B., AND A. WIGET (1996): „Die neue Landesvermessung der Schweiz LV95", VPK 2-96.

GURTNER, W. (1995a): "The Role of Permanent GPS Stations in IGS and Other Networks". Proceedings of the 3rd International Seminar on "GPS in Central Europe", Penc, Hungary, 9-11 May 1995, Warsaw University of Technology, 3, 16, pp. 221-239, Warschau, 1995.

GURTNER, W. (1995b): “Guidelines for a Permanent EUREF GPS Network”. Bayerische Kommission für die Internationale Erdmessung, Astronomisch-Geodätische Arbeiten, 55, München, 1995.

GURTNER, W. (1997): “The Receiver Independent Exchange Format”. Linear Algebra, Geodesy, and GPS, Strange, G. / Borre, K. (eds.), Wellesley-Cambridge Press, Wellesley MA, USA, 1997.

GUT, T. (1997): Die Überführung von Eisenbahnachsen der SBB in den neuen Referenzrahmen der Landesvermessung. IGP-Bericht Nr. 271, 8/97.

HENNES, M. (1996): Die Möglichkeiten des Mekometers ME 5000 zur hochauflösenden Distanzmessung mit hoher Datenrate. VR 58, S. 198 - 211.

HENNES, M.; FLACH, P. (1998): Techniken zur Ermittlung von Refraktionskorrekturen aus Videobildern von geodätischen Messinstrumenten. AVN, S. 41-49.

IERS CENTRAL BUREAU (1996,97,98): “1995,97,98 IERS Annual Report”. Observatoire de Paris, Paris.

IHDE, J., W. SCHLÜTER, W. GURTNER, G. WÖPPELMANN, B. G. HARSSON, J. ADAM (1996): “Concept and Status of the European Vertical GPS Reference Network”. Proceedings of the EUREF Symposium, Ankara, Bayerische Kommission für die Erdmessung, 57, München, 1996.

INEICHEN, D., W. GURTNER, T. SPRINGER, G. ENGELHARDT, J. LUTHARDT, J. IHDE (1998): “EUVN97 Combined GPS Solutions”. Reports on the Results of the European Vertical Reference Network GPS Campaign 97, EUREF Symposium, June 10-12, 1998, Bad Neuenahr-Ahrweiler, Germany, pp. 19-36, 1998.

INGENSAND, H. (1997): Neue Verfahren zur Zertifizierung geodätischer Messinstrumente. Proceedings Geodätische Woche ,16.-22.02.1997, Obergurgl, Austria.

INGENSAND, H., BÖCKEM, B. (1997): A High-Accuracy Alignment System Based on the Dispersion Effect. Proceedings IWAA97, Fifth International Workshop on Accelerator Alignment, ANL/FNL, 13.17.10.1997, Argonne, Il, USA (http://www.aps.anl.gov/conferences/iwaa97/fin_pap.html).

INGENSAND, H., HENNES, M., BÖCKEM, B. (1997): Recent Concepts for Refractions-free Optical Measurements in Tunnels and Vertical Shafts. FIG-Symposium: Surveying of Large Bridge and Tunnel Projects, 2.-6.6.1997, Copenhagen, Denmark.

INGENSAND, H., DUPRAZ, H. (1997): Ziele und Aufgaben der Arbeitsgruppe für die Geschichte der Geodäsie in der Schweiz. VPK 10/97, Editorial S. 655, Forum S. 692.

JEANRICHARD, F. (HRSG.), G. BEUTLER, M. COCARD, A. GEIGER, M. MÜLLER, M. ROTHACHER, S. SCHÄR, D. SCHNEIDER, A. WIGET (1995): “Dreidimensionales Testnetz Turtmann 1985 - 1993”. GPS-Netz, II, Geodätisch-geophysikalische Arbeiten in der Schweiz, Schweizerische Geodätische Kommission, Volume 51, 1995.

KRUSE, L.P. SIERK, B., SPRINGER, T., COCARD, M., BÜRKI, B., and H.-G. KAHLE (1999): GPS-Meteorology: impact of predicted orbits on precipitable water estimates. Geophys. Res. Abstr., Vol. 1, No. 1: 227.

KRUSE, L.P. SIERK, B., SPRINGER, T. and M. COCARD (1999): GPS-Meteorology: impact of predicted orbits on precipitable water estimates. Geophys. Res. Lett., Vol. 26, pp14.

MARTI U., D. SCHNEIDER, A. GEIGER (1996): Das neue Landeshöhennetz, LHN95, der Schweiz. A. Gilbert and E. Grafarend (ed.), Geodätische Woche, Uni Stuttgart, Schriftenreihe der Institute des Fachbereichs Vermessungswesen, Technical Report Nr. 1997.1, Dept. of Geodesy, ISSN 0933-2839, pages 45-46.

MERVART, L. (1995a): “Ambiguity Resolution Techniques in Geodetic and Geodynamic Applications of the Global Positioning System”. Swiss geodetic commission: „Geodätisch-geophysikalische Arbeiten in der Schweiz“, Vol. 53, 1995.

MERVART, L., G. BEUTLER, M. ROTHACHER, S. SCHAER (1995b): “The Impact of Ambiguity Resolution on GPS Orbit Determination”. GPS Trends in Precise Terrestrial Airborne, and Spaceborne Applications, International Association of Geodesy Symposia, Boulder, CO, July 3-4, 1995, G. Beutler, G. W. Hein, G. Seeber, W. G. Melbourne, 115, pp. 285-289, Springer-Verlag, Berlin, Heidelberg, New York, 1996.

MERVART, L., M. ROTHACHER (1997): “Bernese 4.0 - an efficient tool for processing GPS monitoring deformation networks”. News Letter of the Eropean Geophysical Society, XXII General Assembly, Vienna, Austria, 21-25 April 1997, European Geophysical Society, 62, March, pp. 100, 1997.

MUELLER, I. I., G. BEUTLER, H. DREWES (1996): “A Fundamental Reference and Calibration Network for Space Geodesy”. EOS Transactions of the AGU 1996 Fall Meeting, November 12, 1996, 77, 46, pp. F131, 1996.

POLDERVAART, J. (1996): Effects of accelerations on GPS measurements. Internal report ETHZ.

REIS, O. (1995): Mesures gyroscopiques et déviation de la vertiale. IGP-Bericht Nr. 249, 9/95.

ROGOWSKI, J. B., M. PIRASZEWSKI, M. FIHURSKI, E. BROCKMANN, M. ROTHACHER (1995): “Common Experiment of the Analysis Centre CODE and the IGGA WUT on the Combination of Regional and Global Solutions”. GPS Trends in Precise Terrestrial Airborne, and Spaceborne Applications, International Association of Geodesy Symposia, Boulder, CO, July 3-4, 1995, G. Beutler, G. W. Hein, G. Seeber, W. G. Melbourne, 115, pp. 47-51, Springer-Verlag, Berlin, Heidelberg, New York, 1996.

ROSSETTI M. (1996) "Optimisation de l'usage des récepteurs GPS". Mensuration, Photogrammétrie, Génie Rural 04/96, 159-162.

ROTHACHER, M., L. MERVART (1995a): “Processing and Analyzing GPS Measurements”. Proceedings of the 3rd International Seminar on "GPS in Central Europe", Penc, Hungary, 9-11 May 1995, Warsaw University of Technology, 3, 16, pp. 249-270, Warschau, 1995.

ROTHACHER, M., S. SCHAER, L. MERVART, G. BEUTLER (1995b): “Determination of Antenna Phase Center Variations Using GPS Data”. Proceedings of the IGS Workshop "Special Topics and New Directions" Potsdam, May 15-18, 1995, Gendt, G. / Dick, G., pp. 205-220, GeoForschungs-Zentrum Potsdam, Potsdam, 1996.

ROTHACHER, M., S. SCHAER (1995c): “GPS-Auswertetechniken”. GPS-Leistungsbilanz '94, Beiträge zum 34. DVW-Seminar vom 5. bis 7. Oktober 1994 am Geodätischen Institut der Universität Karlsruhe (TH), Heck, Bernhard und Illner, Michael (Hrsg.): Schriftenreihe des DVW, 18, pp. 107-121, Konrad Wittwer, Stuttgart, 1995, ISSN 0940-4260.

ROTHACHER, M., R. WEBER, E. BROCKAMNN, G. BEUTLER, L. MERVART, U. WILD, A. WIGET, C. BOUCHER, S. BOTTON, H. SEEGER (1995d): “CODE Analysis Center Report”. Proceedings of the IGS Workshop in Potsdam on Special Topics and New Directions, May 15-17, Potsdam.

ROTHACHER, M., W. GURTNER, S. SCHAER, R. WEBER, W. SCHLÜTER, H. O. HASE (1995e): “Azimuth- and Elevation-Dependent Phase Center Corrections for Geodetic GPS Antennas Estimated from GPS Calibration Campaigns”. GPS Trends in Precise Terrestrial Airborne, and Spaceborne Applications, International Association of Geodesy Symposia, Boulder, CO, July 3-4, 1995, G. Beutler, G. W. Hein, G. Seeber, W. G. Melbourne, 115, pp. 333-338, Springer-Verlag, Berlin, Heidelberg, New York, 1996.

ROTHACHER, M., G. BEUTLER, E. BROCKMANN, L. MERVART, S. SCHAER, T. A. SPRINGER, U. WILD, A. WIGET, C. BOUCHER, H. SEEGER (1996a): “Annual Report 1995 of the CODE Analysis Center of the IGS”. IGS 1995 Annual Report, September 1996, IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Cal., Zumberge, J.F. / Urban, M. P. / Liu, R. / Neilan, R. E., pp. 151-173, Pasadena, California, 1996.

ROTHACHER, M., S. SCHAER (1996b): “Processing of GPS Antenna Calibration Campaigns at AIUB Using Double-Difference Phase Observations”. Proceedings of the IGS Analysis Center Workshop 1996, Neilan, R. E. / Van Scoy, P. A. / Zumberge, J. F. (eds.), pp. 321-346.

ROTHACHER, M., S. SCHAER, G. BEUTLER, W. SCHLÜTER, H. O. HASE (1996c): “Phase Center Variations of GPS Antennas Derived From GPS Observations of Specially Designed Calibration Campaigns”. Supplement to EOS, American Geophysical Union, 1996 Spring Meeting, May 20-24, Baltimore, Maryland, AGU, 77, April 23, 17, pp. G11A-6, 1996.

ROTHACHER, M. (1997a): “The International GPS Service, Orbit, and Reference Frame”. European Frequency and Time Forum (EFTF), Tutorial on Global Positioning System (GPS), Neuchâtel, Switzerland, March 3, 1997.

ROTHACHER, M. (1997b): “Die Aktivitäten des Rechenzentrums CODE im Rahmen des IGS”. 46. DVW-Seminar "GPS-Praxis und -Trends '97", September 29 - Oktober 1,1997, Frankfurt.

ROTHACHER, M., T. SPRINGER (1997c): “Combination of Antenna Phase Center Variations”. Proceedings of the IGS Analysis Center Workshop 1997.

ROTHACHER, M., T. A. SPRINGER, S. SCHAER, G. BEUTLER, E. BROCKMANN, U. WILD, A. WIGET, C. BOUCHER, S. BOTTON, H. SEEGER (1997d): “Annual Report 1996 of the CODE Analysis Center of the IGS”. IGS 1996 Annual Report, November 1997, IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Cal., J. F. Zumberge, D. E. Fulton, R. E. Neilan, IGS Central Bureau, JPL, pp. 201-219, Pasadena, CA, USA, 1997.

ROTHACHER, M., T. SPRINGER, S. SCHAER, G. BEUTLER (1998a): “Processing Strategies for Regional GPS Networks”. Proceedings of the IAG General Assembly 1997, Rio de Janeiro, September 3-9, 1997, IAG Symposia, Brunner (ed.), 118, pp. 93-100, Springer Verlag, Berlin/Heidelberg/New York, 1998.

ROTHACHER, M., T. A. SPRINGER, S. SCHAER, G. BEUTLER, D. INEICHEN, U. WILD, A. WIGET, C. BOUCHER, S. BOTTON, H. SEEGER (1998b): “Annual Report 1997 of the CODE Analysis Center of the IGS”. IGS 1997 Annual Report, IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Cal., J. F. Zumberge, D. E. Fulton, R. E. Neilan, IGS Central Bureau, JPL (in press).

RUFFINI, G., L.P. KRUSE, A. RIUS, B. BÜRKI, L. CUCURULL and A. FLORES (1999): Estimation of Tropospheric Zenith Delay and Gradients over the Madrid Area Using GPS and WVR Data, GRL Vol. 26, 447-450, 1999.

SANTERRE, R. GEIGER, A. (1998): Geometrical Interpretation of GPS Measurements. Surveying Engineering, 20-24, April 1998, Eisenstadt, Österreich.

SCARAMUZZA M., A. GEIGER (1995): Use of digital terrain model for detection of potentially interfering zones. Proceedings of Workshop GPS interference - is it a problem?, Royal Institute of Navigation, London, pages 145-150.

SCARAMUZZA M., A. GEIGER, M. COCARD (1996): Erfahrungen mit DGPS-Flugversuchen Lugano. Proceedings of DGON, SATNAV 96, pages 135-144.

SCARAMUZZA, M. (1998): Systematic investigations of error- and system-modelling of Satellite based flight approaches and landings in Switzerland. Swiss geodetic commission: „Geodätisch-geophysikalische Arbeiten in der Schweiz“, Vol. 58.

SCHNEIDER, D., E. GUBLER, U. MARTI, W. GURTNER (1995): “Aufbau der neuen Landesvermessung der Schweiz 'LV95'. Terrestrische Bezugsssysteme und Bezugsrahmen”. 3, Berichte aus der L+T, Bundesamt für Landestopographie, 8, Wabern, 1995.

SCHNEIDER, D., MARTI, U., A. WIGET (1996): Die neue Landesvermessung der Schweiz LV95 als Grundlage für die Vermessung der neuen Eisenbahn-Alpentraversen ‚Alptransit‘. Ingenieurvermessung 96: Beiträge zum XII. Internationalen Kurs für Ingenieurvermessung, Graz, 9.-14. Sept. 1996, Dümmlers Verlag, Bonn, 1996.

SCHLATTER, A. (1996): Die Landesgrenze am Übergang von nationalen zu internationalen Referenzsystemen. IGP-Bericht Nr. 261, 11/96.

SCHWIZER, P.; STÄHLI, D. (1998): Bestimmung von vertikalen Temperaturprofilen mit dem Scintillometer SLS 20. Diploma thesis, IGP, ETHZ, unpublished.

SEEGER, H., J. ADAM, W. AUGARTH, C. BOUCHER, E. GUBLER, W. GURTNER, H. VAN DER MAREL (1995): “The new European Reference System, EUREF - Status Report 1995”. Proceedings of the XXI. General Assembly of the International Union of Geodesy and Geophysics, Boulder, Colorado, July 2-14.

SGK (1995): “Report on the Geodetic Activities in the years 1991 to 1995”. Report prepared by the Swiss Geodetic Commission (SGK) for the XXI General Assembly of the IUGG in Boulder, Colorado, July 1995, Swiss Geodetic Commission and Federal Office of Topography, Zurich.

SIERK, B., BÜRKI, B., BECKER-ROSS, H., FLOREK, S., NEUBERT, R., KRUSE, L.-P., AND H.-G. KAHLE, (1997): Tropospheric water vapor derived from solar spectrometer, radiometer and GPS measurements. J. Geophysical Research, 102, B10: 22411-22424.

SIERK, B., BÜRKI, B., KAHLE, H.-G., GEIGER, A., FLOREK, S. and NEUBERT, R. (1997): A new instrumental approach for water vapor determination based on Solar Spectrometry. XXII General Assembly of European Geophysical Society (EGS). Annales Geophysicae, Part I. Suppl.I to Vol 5, C202.

SIERK, B., BÜRKI, B., KRUSE, L.-P., FLOREK, S., BECKER-ROSS, H., KAHLE, H.-G., NEUBERT, R. (1998): A new instrumental approach to water vapor determination based on Solar Spectroscopy. Physics and Chemistry of the Earth, Vol. 23, 1: 113-117.

SPRINGER, T., W. GURTNER, M. ROTHACHER, S. SCHAER (1997): “EUREF Activities at the CODE Analysis Center”. Reports on Geodesy: Proceedings of the 4th International Seminar on "GPS in Central Europe", Penc, 7-9 May 1997, Hungary, Warsaw University of Technology / Institute of Geodesy and Geodetic Astronomy, 4, 27, pp. 165-176, Warsaw, 1997, ISBN 83-85287-26-4.

TOGNACCA, CHR. (1995): Auswirkungen der LV95 auf die amtliche Vermessung. Erste praktische Untersuchungen. IGP-Bericht Nr. 251, 8/95.

WILD, U., W. GURTNER (1995): “Aufbau der neuen Landesvermessung der Schweiz 'LV95'. Geostation Zimmerwald: Satelllite Laser Ranging (SLR) und GPS-Permanentbetrieb”. 2, Berichte aus der L+T, Bundesamt für Landestopographie, 7, Wabern, 1995.

WILD, U., WIGET, A., H. KELLER (1996): The automated GPS network in Switzerland (AGNES) for Navigation and Geodesy: Concept and first test results. DSNS’96, St. Petersburg, 20.-24 May, 1996, Proc., Vol. 2, paper no. 60.

2 Advanced Space Technology

The Zimmerwald Observatory

The New Telescope

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

In May 1995 the old satellite laser ranging telescope and its dome were dismounted, the Nd:YAG laser system and much of the control electronics removed. In July of the same year the installation of the new Zimmerwald Laser and Astrometric Telescope (ZIMLAT) started. ZIMLAT is a telescope of one meter aperture, designed to be used for satellite laser ranging as well as for optical tracking of various objects (satellites, space debris, minor planets, and comets). The telescope has been built by Telas, Cannes (France), a joint venture of Aerospatiale and Framatome, France. It was financed by the University and the Canton of Bern, the Federal Office of Topography, the Swiss National Science Foundation, and the Federal Office for Education and Science.

For the first time in satellite laser ranging a Titanium-Sapphire laser was introduced into such a tracking system. Most of the control electronics and the computer hard- and software were exchanged, too. The installation of the new system turned out to be rather slow, because of unexpected delays in the delivery of the laser system and of optical components of the telescope; environmentally induced problems with angle encoders and optical and mechanical components; a difficult debugging of parts of the control software; problems with the adjustment procedures and the quality of the telescope optics.

First ranges to satellites could be observed towards the end of 1996. Regular SLR observations started mid 1997, optical observations early 1997. The unprotected aluminium coatings of the main mirrors of the telescope deteriorated very rapidly. During a break induced by a defect of the laser system mid 1998 we had all the telescope mirrors and lenses recoated. This lead to a substantial improvement of the system's transmission capabilities.

SLR Observations

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

Day- and nighttime observations to all satellites equipped with retroreflectors (up to the navigation satellites GPS and GLONASS) are now possible and routinely performed. The following satellites were observed mainly for the benefit of IERS, various geodynamics projects, IGS, ESA, and NASA: LAGEOS 1 and 2, Starlette and Stella, Etalon 1 and 2, ERS-1 and ERS-2, Topex-Poseidon, Ajisai, Westpac, GFO-1, GLONASS, and GPS.

In addition, some other satellites (TIPS, Diademes, Geos-3, Resurs-3, Fizeau) were tracked for special projects during a limited time period only. The average number of observed passes per month was more than doubled from 80 in 1994 (prior to the system upgrade) to 170 in 1998 with the new ZIMLAT telescope.

Astrometry Using CCD Techniques

by T. Schildknecht, U. Hugentobler, and M. Ploner

The new combined laser ranging and astrometry telescope ZIMLAT at the Zimmerwald observatory has been regularly used to perform optical observations with CCD cameras. There are two main projects carried out in this context:

a) optical astrometry of artificial satellites, and
b) sky survey for the detection of unknown moving objects.

The work in astrometry of artificial satellites has been concentrating on objects in the geostationary ring (GEO) and on geostationary transfer orbits (GTO). In particular observations of several Meteosat satellites over a long time span were achieved in order to determine the resonant geopotential coefficients C_{22} and S_{22}. This effort was joined by colleagues from the Institute of Theoretical Geodesy and Geophysics of the TU Vienna who contributed CCD observations using a BMK camera in Graz. Although the astrometric accuracy of a single observations was limited to about 0.5 arcsec the results are promising. The excellent agreement of the determined gravity coefficients with the JGM-3 model can be seen in Table 2.1. Observations of more satellites in different longitudes will further strengthen the determination of the coefficients in future.

Coefficients	from optical observations	JGM-3
C_{22}	$(2.43913 \pm 0.00044) \cdot 10^{-6}$	$(2.43926 \pm 0.00004) \cdot 10^{-6}$
S_{22}	$(-1.40031 \pm 0.00008) \cdot 10^{-6}$	$(-1.40027 \pm 0.00004) \cdot 10^{-6}$

Table 2.1: Resonant geopotential terms determined from optical astrometric observations of geo-stationary Meteosat satellites.

Several experimental survey campaigns for the detection of unknown objects have been conducted at Zimmerwald. Again, the techniques were optimized for objects in the GEO and GTO regions. Our results indicate that the limit for automatic detection can be expected at object sizes of about 30 to 40 cm in these regions! The work is stimulated by several ESA contracts for the development of software (observation planning, data acquisition, and data processing) for the 1m ESA Space Debris Observation System in Tenerife. Part of the surveys were also performed in the context of an observation campaign of the Inter-Agency Space Debris Coordination Committee, an organization including all major national space organizations. Recently, the software has been installed and acceptance tested at the observatory in Tenerife. We are looking forward to an exciting phase of first measurements during the commissioning phase of this system.

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 jointly been operated by the AIUB and the Swiss Federal Office of Topography (L+T). Different receiver types have been operated during these years, using software mainly developed by the L+T. In the period between 1997 and 1999 the station was modernized and a completely new station software was installed. This software allows the use of different receiver types. Zimmerwald has therefore become a kind of a receiver test station for permanent GPS (and GLONASS) tracking. Currently a Trimble 4000SSi, a LEICA SR9500, an ASHTECH-GG24, and an ASHTECH Z18 are operating at the station.

The data of the main receiver, the Trimble 4000SSi receiver, are regularly sent to the IGS, the data of the ASHTECH Z18 were used in the IGEX-98 campaign (from the end of September 1998 until the end of January 1999). Furthermore, the data of Zimmerwald are used in the Automated GPS Network Switzerland (AGNES), which serves as reference for national and engineering surveying and for differential navigation applications.

Contributions to CSTG, IGS, EUREF, and IERS (International Earth Rotation Service)

by G. Beutler, E. Gubler, and W. Gurtner

In the field of Section 2 (Space Geodetic Techniques) Switzerland was significantly contributing to

- CSTG (International Coordination of Space Techniques for geodesy and geodynamics, Commission VIII of IAG, Commission B.2 of COSPAR),
- EUREF (IAG Subcommission for the European Terrestrial Reference Frame),
- IERS, and
- IGS (International GPS Service)

We briefly review these activities, where we confine ourselves to the description of management aspects, the technical contributions being dealt with in other paragraphs of this section or in other sections.

CSTG (Commission of Space Techniques in Geodesy)

by G. Beutler and W. Gurtner

CSTG is Commission VIII of the IAG (International Association of Geodesy) and Commission B.2 of COSPAR (Commission on Space Research) on the „International Coordination of Space Techniques for Geodesy and Geodynamics“.

G. Beutler was elected as President of CSTG for the time period 1995-1999. In this time period the emphasis was put on

- restructuring the „old-established“ branches of space geodesy, namely Satellite Laser Ranging (SLR), Lunar Laser Ranging (LLR), and Very Long Baseline Interferometry (VLBI),
- the correct combination of space geodetic results stemming from different techniques,
- the exploitation of the Russian GLONASS satellite system in combination with the U.S. GPS system.

Let us comment a few of these activities:
Creation of ILRS and IVS. Dr. W. Gurtner was in the steering committee for the establishment of the ILRS (International Laser Ranging Service), which was actually created in 1998. The ILRS supersedes the former SLR and LLR subcommissions of CSTG. Right now, the ILRS, which is organized very much along the lines of the IGS (International GPS Service), is part of CSTG. Starting January 1, 1998 Werner Gurtner became chairman of the EUROLAS consortium (European part of the ILRS). In this capacity he also became a member of the ILRS Governing Board. He is also chairing the ILRS Working Group on Network and Engineering. Gerhard Beutler became the IAG representative in the same Governing Board. The IVS, the International VLBI Service, was created in 1998, as well. Gerhard Beutler is the IAG representative in the IVS Directing Board.

IGEX-98. The 1998 International Glonass Experiment was proposed and organized by the microwave subcommission of CSTG (with Pascal Willis from IGN, Paris, as Chairperson) and by the IGS. The experiment was co-sponsored by CSTG, IGS, ION (Institute of Navigation), and IERS. The activities were managed by a steering committee. Werner Gurtner and Gerhard Beutler are members of this steering committee. The actual CODE involvement will be dealt with in a separate paragraph of this section.

EUREF (European Reference Frame)

by E. Gubler and W. Gurtner

Since 1987 EUREF showed a continuously growing involvement in and developed an excellent know-how for setting up and maintaining a continent-wide reference frame for Europe. This was first done through campaign-oriented GPS activities, today through permanent GPS tracking networks (see also Section 1 of this report).

That Switzerland had a leading role in these developments may be concluded from the fact that Dr. Erich Gubler is president of the EUREF Subcommission since 1987 and that Dr. Werner Gurtner is member of its Technical Working Group which played a very active role for setting up the permanent EUREF network.

IGS (International GPS Service)

by G. Beutler, M. Rothacher, and T. Springer

Since its creation, on January 1, 1994 till December 1998 Gerhard Beutler was Chairman of the IGS Governing Board. Since January 1, 1999 he is a „normal“ member of the IGS Governing Board. Due to the retirement of Dr. Jan Kouba from Natural Resources, Canada, a new IGS Analysis Coordinator had to be found. CODE sent in a proposal to act as coordinating center with Tim Springer as coordinator. This proposal was accepted by the IGS Governing Board. Since January 1, 1999 Tim Springer from CODE is the IGS Analysis Center Coordinator and in this capacity he is also a member of the IGS Governing Board.
CODE, Center for Orbit Determination in Europe, is a joint venture of four European institutions, namely the Astronomical Institute of the University of Berne (AIUB), the German Bundesamt für Kartographie und Geodäsie (BKG), the French Institut Géographique National (IGN), and the Swiss Federal Office of

Topography (L+T). CODE is one of the Analysis Centers of the IGS. All institutions substantially contribute to the CODE Analysis Center, which is located at the University of Berne. CODE at present uses a cluster of VAX/ALPHA processors. The software used is the Bernese GPS Software, Version 4.1. The software is continuously improved by the AIUB. The version used at CODE is an „alpha-version“ of the software which is also commercially available (see Section 4 for more information about the Bernese GPS Software).

Dr. Markus Rothacher is the head of AIUB's GPS Group, Tim Springer is responsible for the CODE day-to-day operations. Stephan Schaer, Daniel Ineichen, Leos Mervart are key contributors to the development of the software. Daniel Ineichen is the successor of Dr. Elmar Brockmann who left the institute after completion of his Ph.D. thesis. Heinz Habrich from BKG contributed in the area of GLONASS processing (see below). The contributions of the CODE Analysis Center to the establishment of the ITRF (International Terrestrial Reference Frame) are dealt with in Section 1 of this report, the contributions to Earth Rotation in Section 5. The CODE contributions to atmosphere sciences, to time & frequency transfer using satellite microwave signals, and to the IGEX-98 are dealt with separately below.

Let us mention that GPS orbits are the key products of CODE. The orbits of all IGS Analysis Centers are combined (linear combination of individual orbits using the square of the rms of contributions w.r.t. the combined orbit as weight). Figure 2.1 shows the weighted rms of all contributors w.r.t. the IGS combined solution. We conclude that CODE really performed very well since 1994 and thus contributed essentially to the official IGS orbit.

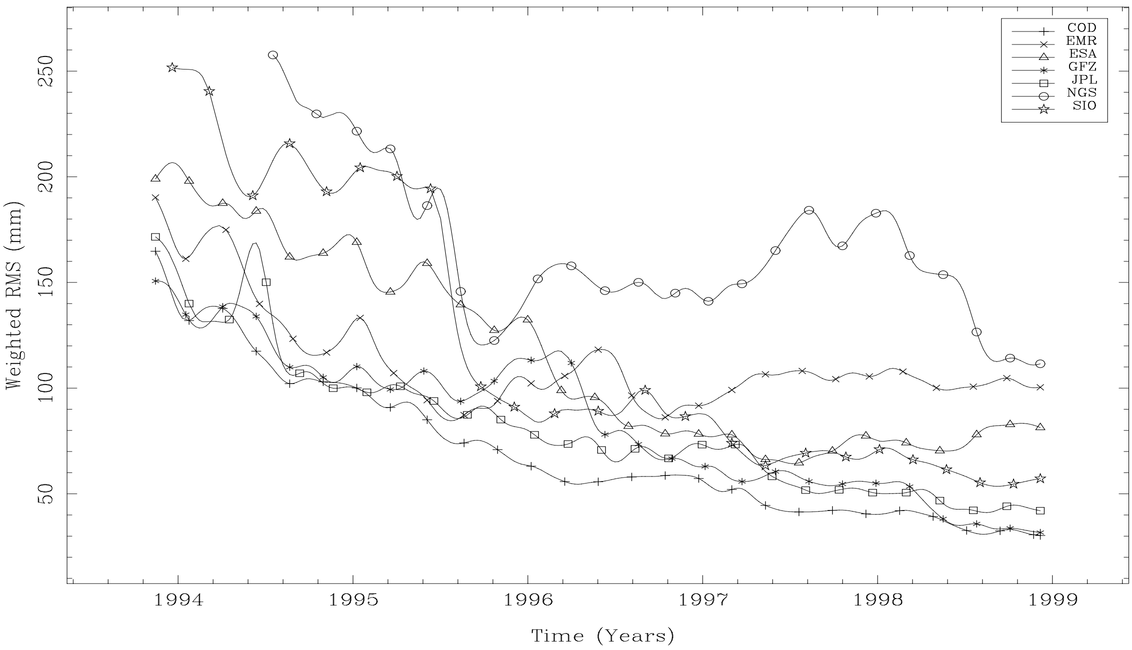


Figure. 2.1: Satellite position-rms from IGS Analysis Centers w.r. to the IGS combined orbit.

Contribution of CODE to Atmosphere Monitoring

by S. Schaer, M. Rothacher, and G. Beutler

In recent years the IGS developed more and more into the direction of an interdisciplinary service (Beutler et al., 1998f). This development is based on the observation that the IGS network may also be used to extract information which is not primarily related to geodesy or geodynamics. Of particular interest is the Earth's atmosphere, where the distinction is made between the troposphere (below about 10km) and the ionosphere (situated between about 100km to 1000km). Because the GPS satellites emit signals on two carriers and because ionospheric refraction is frequency-dependent, one may easily extract the ionospheric group delay and/or phase advance for each GPS observation. Thanks to the height of the ionospheric layers, a single IGS site has „access“ to a considerable part of the Earth's ionosphere. This means that the IGS network is well suited to construct global maps of the total electron content (TEC) with a relatively high time resolution. At CODE, Stefan Schaer was developing the necessary software tools to extract ionospheric information. Since June 1998, such maps with a 2-hour time resolution are made available through the internet (address: http://www.cx.unibe.ch/aiub/ionosphere.html). In addition, figures containing the mean and maximum daily TEC values are also made available. Figures 2.2 and 2.3 contain examples for this ionospheric information, which is updated and made available on a daily basis.

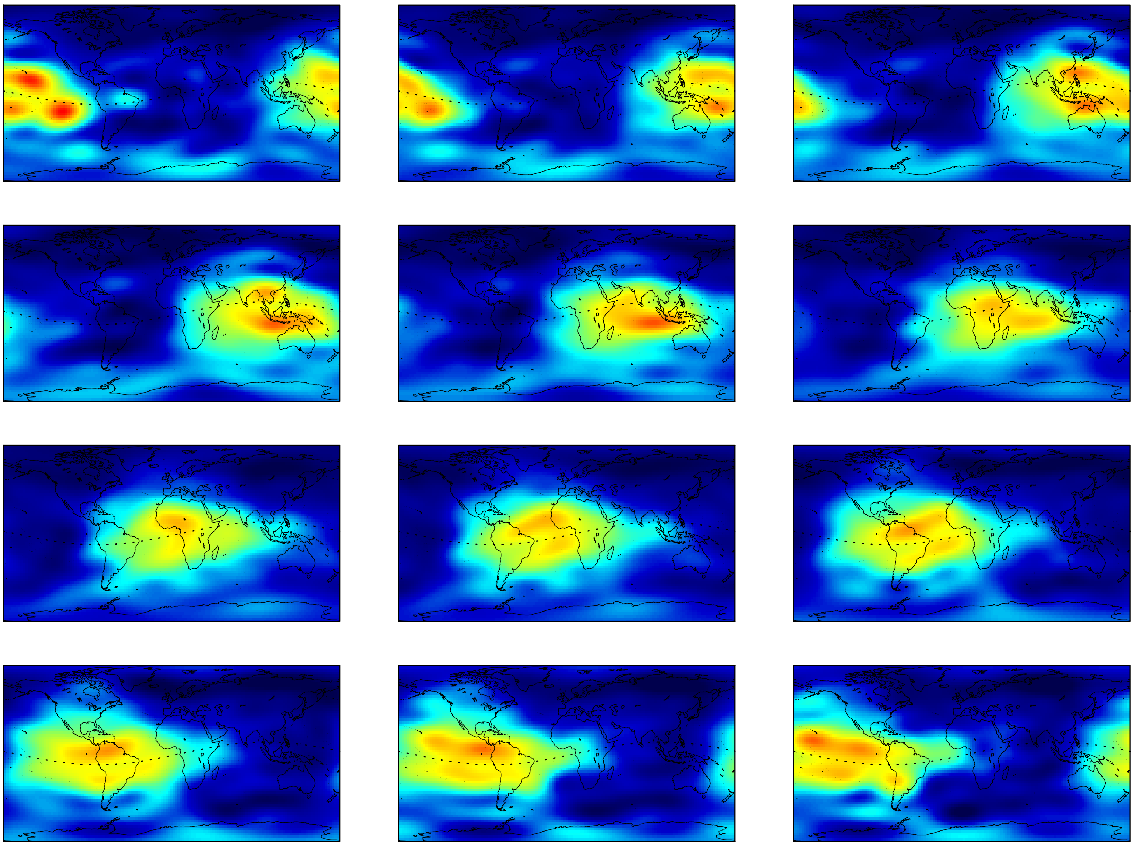


Figure. 2.2: Global TEC maps with a 2-hour time resolution referring to 1,3,5... hours UT.

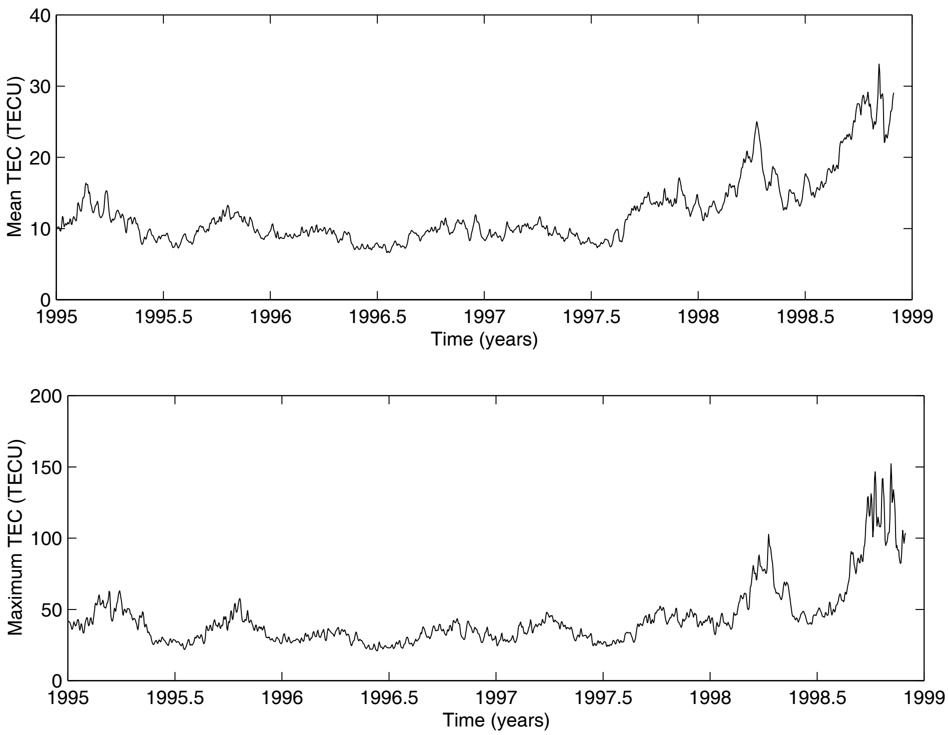


Figure. 2.3: Mean and maximum TEC values since January 1, 1995

The maps are based on the internationally adopted IONEX (IOnosphere Map EXchange) Format developed by the IGS Ionosphere Working Group (Schaer et al., 1998e). ASCII files in the IONEX format containing the two-dimensional grid values underlying Figure 2.2 are also available at the CODE ftp server (ftp://ubeclu.unibe.ch/aiub$ftp/code/codgDDD0.YYi_Z, where DDD is the day of the year, YY are the last digits of the year). For more information concerning ionosphere modeling, we refer to (Schaer et al., 1998c) and to (Beutler et al., 1998f).

It was really only after the „elimination of the orbit error“ by the IGS that tropospheric refraction was recognized to be the principal accuracy limiting factor of the GPS. If highest accuracy is sought, troposphere biases have to be set up for every site with a high time resolution (one value per two hours or more). The high time variability is caused by the so-called wet component of the total delay. This wet component is in turn of highest interest to meteorologists and to the climatologists, because it allows to extract the total water vapor content above a GPS station - provided there are reliable temperature and pressure measurements available at the station (to eliminate the hydrostatic delay from the total GPS signal). We refer to (Eyer, 1999) for additional information concerning the use of the GPS signal for meteorological applications.

Due to the closeness of the troposphere, a single site only has access to a marginal part of the Earth's troposphere. It is therefore impossible to extract global troposphere maps using the IGS network. The IGS network, however, is very useful to provide well-calibrated values for the total water vapor content for its global tracking network. CODE contributes to this coordinated IGS effort by making available its troposphere delay estimates to the IGS troposphere combination center at GFZ in Potsdam.

When solving for troposphere biases, one usually makes the assumption that there are no horizontal gradients in tropospheric refraction in the vicinity of one particular site. This assumption may not always be realistic (e.g., for stations close to a coast line or to a major mountain chain). Tests estimating troposphere gradients were made using the IGS networks. For more information concerning CODE contributions to the estimation of tropospheric delays and its gradients we refer to (Rothacher et al., 1998c).

Contributions of CODE to IGEX-98

by M. Rothacher, G. Beutler, W. Gurtner, H. Habrich, D. Ineichen, and T. Springer

The CODE Analysis Center was acting (and continues to act) as an Analysis Center for the International GLONASS Experiment 1998 (IGEX-98). Daniel Ineichen is responsible for producing the GLONASS orbits. GLONASS orbits are computed and made available on a weekly basis with a delay of about 20 days. The campaign started on 18 October, 1998. CODE was the first (and for some time the only) IGEX Analysis Center to produce GLONASS orbits.

The analysis may be summarized as follows: Only receivers recording both, GPS and GLONASS observations, were used. The distribution of these receivers is given in Figure 2.4. This procedure allowed it to keep the GPS orbits and the Earth rotation parameters fixed to the CODE final GPS solution in the GLONASS analysis. The orbital parameters for the GLONASS satellites were then estimated using double difference phase observations (including double differences between GLONASS and GPS satellites). Six initial conditions and nine radiation pressure parameters were determined per satellite (see Section 4, Methodology). In view of the sparse GLONASS network, overlapping 5-day arcs were produced and the middle day of each 5-day arc was considered to be the final CODE GLONASS orbit product for the particular day. The Zimmerwald station was constrained to the ITRF96 position. As the fixed station and all the GPS orbits refer to the same reference frame (nominally to ITRF96), the CODE GLONASS orbits refer to ITRF96, as well.

Table 2.2 contains a part of one of the weekly CODE/GLONASS Analysis Reports (GPS week 985, 22-28 November, 1998). It gives an impression on the internal consistency of the GLONASS orbits -- which clearly is on the (sub-)decimeter level. In addition, it shows how the orbits may be retrieved.

****
CODE IGEX REPORT GPS WEEK 0985 (DAYS 326-332, DATES 22-11-98 - 28-11-98)
****
Author: M. Rothacher

Submitted by: Astronomical Institute, University of Berne, Switzerland
Products available through anonymous ftp using:
ftp ubeclu.unibe.ch -or- ftp 130.92.6.17
after login: cd aiub$ftp; cd code

ORBIT REPEATABILITY FROM A 7-DAY FIT THROUGH DAILY ORBIT SOLUTIONS (CM)

	103E	104E	106E	109	110	111	113	115	116	117	118	120	122
326	6	4	6	6	13	7	5	18	12	7	5	5	3
327	7	4	3	6	23	9	6	5	5	6	4	6	3
328	5	5	5	11	12	4	4	4	6	6	2	5	5
329	3	4	3	4	19	5	5	4	4	4	4	3	4
330	7	4	7	5	16	4	3	5	4	5	6	4	4
331	7	4	9	7	24	6	7	5	3	3	6	4	5
332	7	6	8	7	12	7	5	6	6	3	10	4	5
ALL	6	4	6	7	18	6	5	8	6	5	6	5	4

****
CODE IGEX REPORT GPS WEEK 0985 (DAYS 326-332, DATES 22-11-98 - 28-11-98)
****

Table 2.2: Extraction from CODE IGEX Analysis Report (GPS Week 985)

It is attractive and very useful for the experiment that the SLR community is intensively tracking the GLONASS satellites. Tim Springer was adapting the Bernese GPS Software to process zero difference observations and SLR observations to GPS and GLONASS satellites (for more information we refer to Section 4, Methodology and to (Springer et al., 1999)). Figure 2.5 shows the residuals of the SLR measurements relative to the CODE GLONASS orbits, which were produced using only GLONASS (and GPS) microwave observations. We may conclude that the actual GLONASS orbit accuracy is well below 50cm.

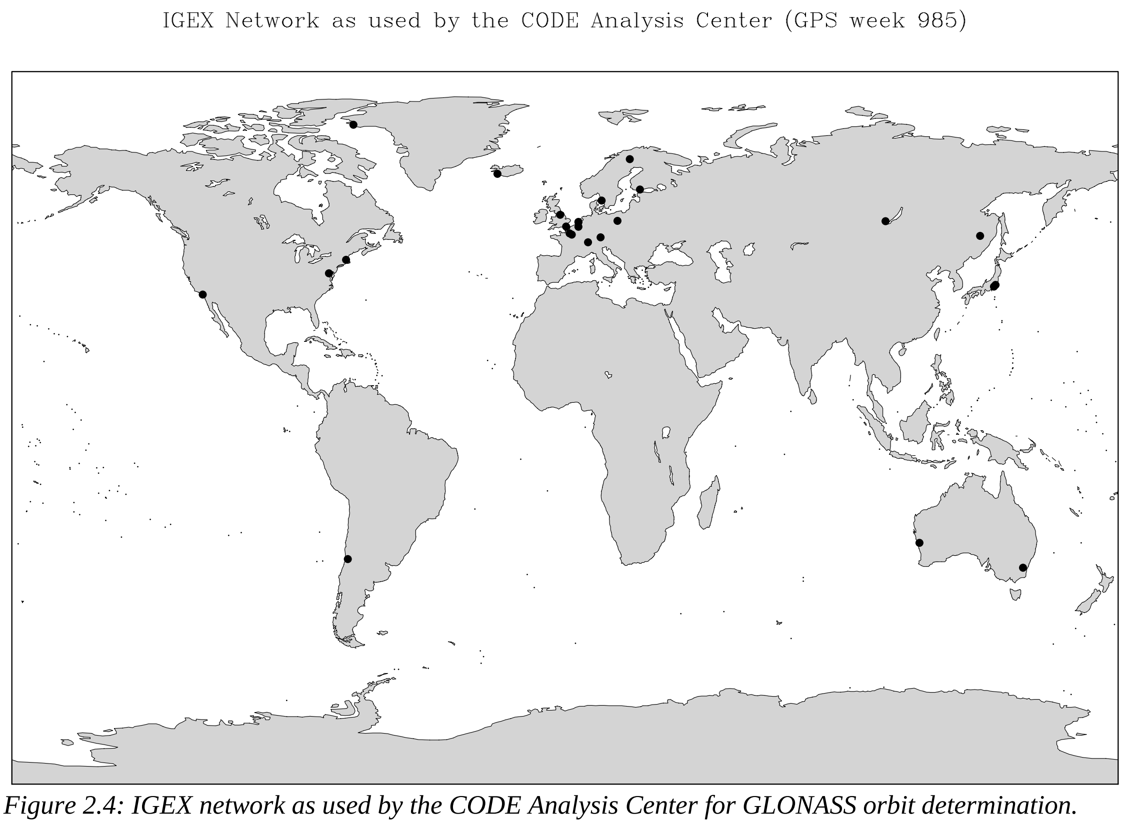


Figure 2.4: IGEX network as used by the CODE Analysis Center for GLONASS orbit determination.

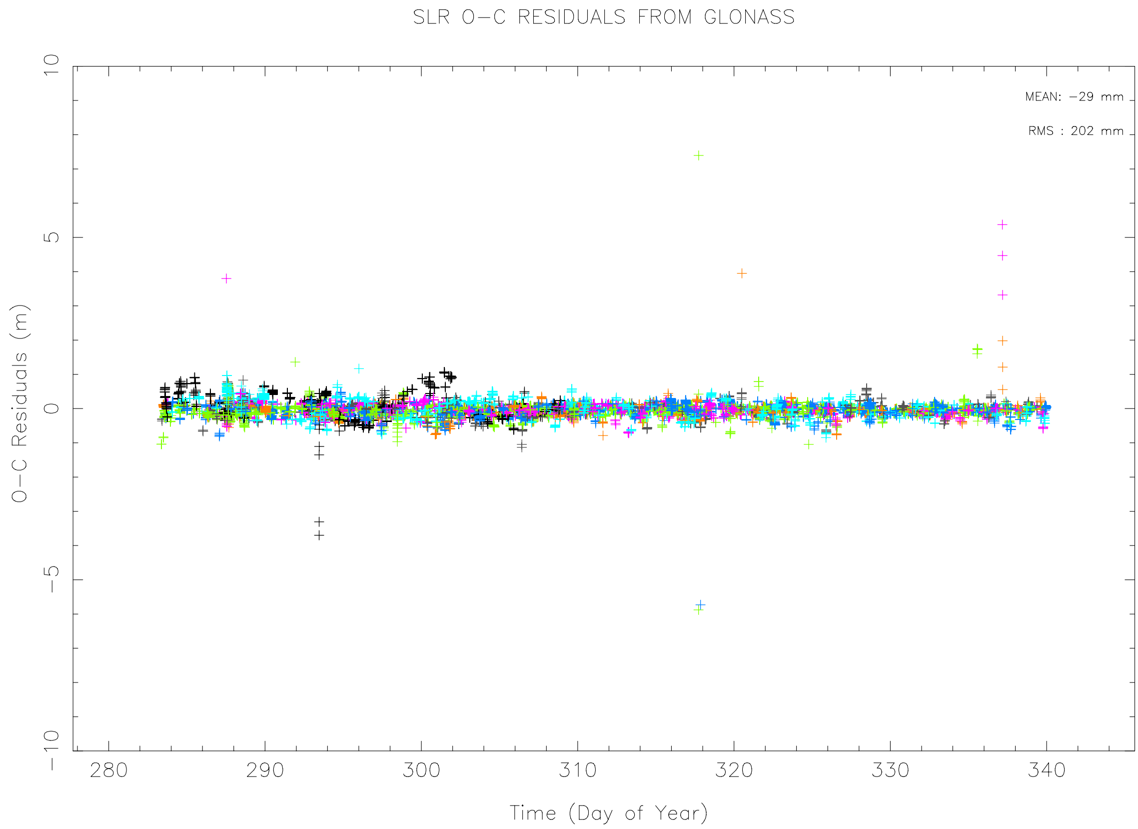


Figure 2.5: Residuals of SLR observations relative to CODE GLONASS orbits

Time Transfer Using the GPS

by T. Schildknecht, T. Springer, M. Rothacher, and G. Dudle

The GPS has been used for a long time for „moderate accuracy" time transfer. Special GPS timing receivers make use of the C/A code, and provide GPS time (or UTC) with an accuracy of about one microsecond. The accuracy is limited (a) by S/A (selective availability), (b) by the quality of the GPS orbits, (c) by atmospheric signal delays. When the timing receivers are used in the „common view" mode (i.e., if the difference of the C/A codes of two receivers are analyzed), the above error sources are greatly reduced, enabling time transfer with an accuracy of a few nanoseconds.

Modern time and frequency transfer makes use of all GPS observables (code and phase) and of all high accuracy information (satellite orbits, receiver positions, troposphere information) as provided by the IGS. It strives for sub-nanosecond time transfer and for picosecond/day frequency transfer. These activities are coordinated by the IGS/BIPM Working Group on time transfer.

AIUB, in collaboration with the Swiss Institute for Metrology, plays a very active role in this group (a) through the development of special time and frequency transfer terminals and (b) by regularly processing the permanent time and frequency comparison network as defined by the IGS/BIPM working group. The network is given in Figure 2.6. Today, this network is „de facto" a part of the global IGS network. Figure 2.7 shows the (roots of the) Allan variances of some of the hydrogen masers in the network using a 2-hour time span of data. The results clearly show the great potential of the method.

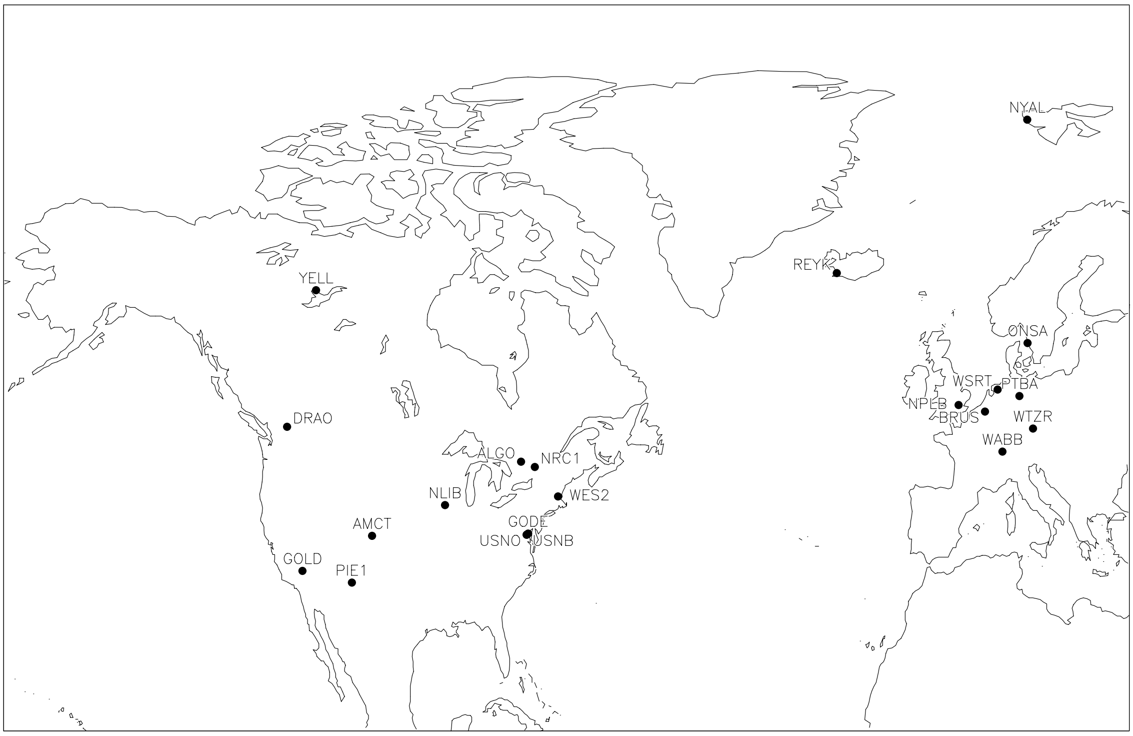


Figure 2.6: Time and frequency comparison sub-network

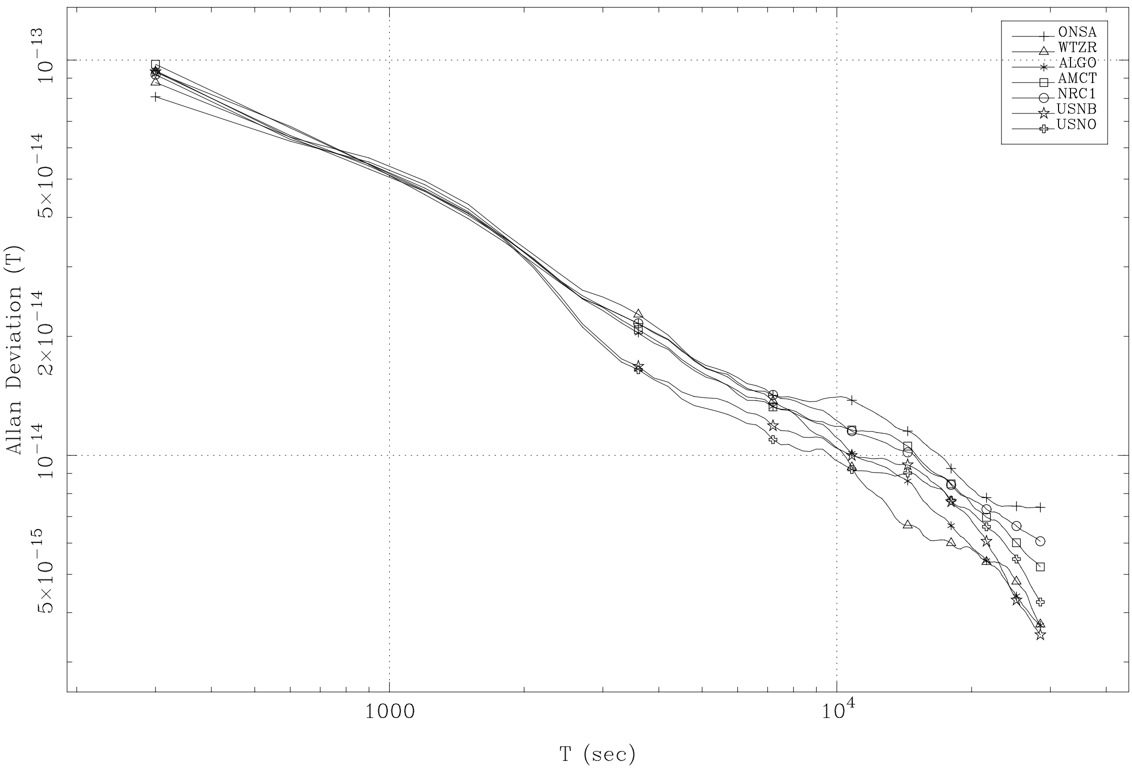


Figure 2.7: Roots of Allan variances for a subset of clocks in the „Time and Frequency Network"

For more information concerning this topic we refer to (Schildknecht and Springer, 1998g).

Attitude Control by Combination of GPS and Inertial Measurements

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

Especially in new airborne measurement systems the attitude is a crucial parameter quality. The knowledge of attitude is also of importance for terrestrial applications. Therefore, an aircraft has been equipped with seven GPS antennas and with an IMU (100 Hz) in order to work on an over-determined attitude system. The results show the effectiveness of the combination especially for the use in Laser-scanning systems and for aero-gravimetric surveys (see the corresponding sections). Studies have been carried out on aircraft and on controlled terrestrial vehicles in order to assess the potential of the algorithms and methods developed during the past years.

Bibliography Section 2

BAERISWYL, P., T. SCHILDKNECHT, J. UTZINGER, G. BEUTLER (1995): "Frequency and Time Transfer with Geodetic GPS Receivers: First Results". Proceedings of the 9th European Frequency and Time Forum, EFTF 95, Besançon, 8-10 March 1995, France, Swiss Foundation for Research in Microtechnology FSRM, pp. 46-51, Besançon, 1995.

BAERISWYL, P., T. SCHILDKNECHT, T. SPRINGER, G. BEUTLER (1996): "Time transfer with geodetic GPS receivers using code and phase observations". Proceedings of the 10th European Frequency and Time Forum EFTF 96, March 5-7, 1996, Brighton, UK, Institution of Electrical Engineers, pp. 4430-435, Brighton, 1996.

BEUTLER, G. (1995a): "Extracting Information concerning the Ionosphere using the IGS Network". 1995 Spring Meeting of the American Geophysical Union, May 30 - June 2, Baltimore, Maryland. EOS Supplement, 76, 17, pp. S86, 1995.

BEUTLER, G., I. I. MUELLER, R. E. NEILAN (1995b): "The International GPS Service for Geodynamics (IGS): The Story". GPS Trends in Precise Terrestrial Airborne, and Spaceborne Applications, International Association of Geodesy Symposia, Boulder, CO, July 3-4, 1995, G. Beutler, G. W. Hein, G. Seeber, W. G. Melbourne, 115, pp. 3-13, Springer-Verlag, Berlin, Heidelberg, New York, 1996.

BEUTLER, G., R. NEILAN (1995c): "IGS Report to the International Association of Geodesy, Advanced Space Technology Section II, 1991 to 1995". Travaux de l'association internationale de géodésie: Rapports généraux et rapports techniques (ed. P. Willis), Le Bureau de L'Association Internationale de Géodesie, 30, pp. 188-197, Secrétariat de l'Association, Paris, 1995.

BEUTLER, G., R. WEBER (1995d): "Der Internationale GPS Dienst für Geodynamik". GPS-Leistungsbilanz '94, Beiträge zum 34. DVW-Seminar vom 5. bis 7. Oktober 1994 am Geodätischen Institut der Universität Karlsruhe (TH), Heck, Bernhard und Illner, Michael (Hrsg.): Schriftenreihe des DVW, 18, pp. 169-185, Konrad Wittwer, Stuttgart, 1995, ISSN 0940-4260.

BEUTLER, G. (1996a): "Executive Summary". Proceedings of the IGS Analysis Center Workshop 1996, Neilan, R. E. / Van Scoy, P. A. / Zumberge, J. F., pp. XI-XVI.

BEUTLER, G. (1996b): "The Year 1995 in Retrospective as seen from the IGS Governing Board". IGS 1995 Annual Report, September 1996, IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Cal., Zumberge, J.F. / Urban, M. P. / Liu, R. / Neilan, R. E., pp. 9-18, Pasadena, California, 1996.

BEUTLER, G., H. DREWES (1996c): "The Role of CSTG Today and in the Near Future". CSTG Bulletin of the International Association of Geodesy (IAG), Section II, Commission VIII: Status and Programme 1995-1999, G. Beutler, H. Drewes, H. Hornik (Eds.), 12, pp. 21-30, Deutsches Geodätisches Forschungsinstitut, Abt. I - Theoretische Geodäsie, München, 1996.

BEUTLER, G., H. DREWES, H. HORNIK (1996d): "CSTG Bulletin of the International Association of Geodesy (IAG), Section II, Commission VIII". Status and Programme 1995-1999, Deutsches Geodätisches Forschungsinstitut, Abt. I, Theoretische Geodäsie, 12, München, 1996.

BEUTLER, G., M. FEISSEL, I. I. MUELLER (1996e): "The Role of Different Space Geodetic Methods in 1996: Attempt of an Analysis". 1996 Western Pacific Geophysics Meeting of the AGU: SEDI Fifth International Symposium, Brisbane, Australia, July 23-27, 1996.

BEUTLER, G., J. KOUBA, R. E. NEILAN (1996f): "The International GPS Service for Geodynamics (IGS) in 1996: Review and Outlook.". 1996 Western Pacific Geophysics Meeting of the AGU: SEDI Fifth International Symposium, Brisbane, Australia, July 23-27, 1996.

BEUTLER, G., I. I. MUELLER, K.-P. SCHWARZ (1996g): “Memorandum for the Record-Establishment of the IAG/CSTG Working Group: "IUGG Fundamental Reference and Calibration Network"”. CSTG Bulletin of the International Association of Geodesy (IAG), Section II, Commission VIII: Status and Programme 1995-1999, G. Beutler, H. Drewes, H. Hornik (Eds.), 12, pp. 95-96, Deutsches Geodätisches Forschungsinstitut, Abt. I - Theoretische Geodäsie, München, 1996.

BEUTLER, G., I. I. MUELLER, J. VONDRAK (1996h): “The International Earth Rotation Service: Current Mission and Recommendations for the Future”. IERS-Workshop, Paris, October 1996.

BEUTLER, G. (1997a): “Minutes of the CSTG Executive Committee Meetings”. CSTG Bulletin of the International Association of Geodesy (IAG), Section II, Commission VIII: Progress Report 1997, G. Beutler, H. Drewes, H. Hornik (Eds.), 13, pp. 15-19, Deutsches Geodätisches Forschungsinstitut, Abt. I - Theoretische Geodäsie, München, 1997.

BEUTLER, G. (1997b): “The Year 1996 in Retrospective as seen from the IGS Governing Board”. IGS 1996 Annual Report, November 1997, IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Cal., Zumberge, J.F. / Fulton, D. E. / Neilan, R. E., pp. 9-22, Pasadena, California, 1997.

BEUTLER, G., H. DREWES (1997c): “CSTG Activities between 1995 and 1997: Reveiw and Position Paper”. CSTG Bulletin of the International Association of Geodesy (IAG), Section II, Commission VIII: Progress Report 1997, G. Beutler, H. Drewes, H. Hornik (Eds.), 13, pp. 7-14, Deutsches Geodätisches Forschungsinstitut, Abt. I - Theoretische Geodäsie, München, 1997.

BEUTLER, G., H. DREWES, H. HORNIK (1997d): “CSTG Bulletin of the International Association of Geodesy (IAG), Section II, Commission VIII”. Progress Report 1997, Deutsches Geodätisches Forschungsinstitut, Abt. I, Theoretische Geodäsie, 13, München, 1997.

BEUTLER, G., J. KOUBA, R. NEILAN (1997e): “International GPS Service for Geodynamics: Mission, Development, Network, Structure, Products, and Current Projects”. The Global Positioning System for the Geosciences: Summary and Proceedings of a Workshop on Improving the GPS Reference Station Infrastructure, Steering Committe, Aeronautics & Space Eng. Board, CETS, NRC, pp. 77-85, National Academy Press, Washington, D.C., 1997.

BEUTLER, G., M. ROTHACHER (1997f): “The role of GPS in the study of global change (Solicited Paper)”. News Letter of the European Geophysical Society, XXII General Assembly, Vienna, Austria, 21-25 April 1997, European Geophysical Society, 62, March, pp. 96, 1997.

BEUTLER, G., P. WILLIS (1997g): “Report on the Activities of the Subcommission on Precise Satellite Microwave Systems”. CSTG Bulletin of the International Association of Geodesy (IAG), Section II, Commission VIII: Progress Report 1997, G. Beutler, H. Drewes, H. Hornik (Eds.), 13, pp. 63, Deutsches Geodätisches Forschungsinstitut, Abt. I - Theoretische Geodäsie, München, 1997.

BEUTLER, G. (1998a): “The Development of the IGS in 1997 - The Governing Board's Perspective”. 1997 IGS Annual Report, IGS Central Bureau, JPL, 2, Pasadena, Cal., USA.

BEUTLER, G. (1998b): “Executive Summary”. Proceedings of the IGS 1998 Analysis Center Workshop, Darmstadt, February 9-11, 1998, Dow, J. M. / Kouba, J. / Springer, T., pp. 9-18, Darmstadt, 1998.

BEUTLER, G. (1998c): “The IGS in 1997 - An Executive Summary”. 1997 IGS Annual Report, IGS Central Bureau, JPL, 1, Pasadena, Cal., USA.

BEUTLER, G. (1998d): “Bezugssysteme für Himmel und Erde”. Revolution der Fundamental-astronomie durch Weltraumforschung, UNIPRESS, Pressestelle der Universität Bern, April, 96, pp. 36-48, Stämpfli AG, Bern, 1998.

BEUTLER, G., H. DREWES, C. REIGBER, R. RUMMEL (1998e): “Space Techniques and their Coordination within IAG at Present and in Future”. IAG-Section II Symposium, Munich, Germany, 5-9 October 1998.

BEUTLER, G., M. ROTHACHER, S. SCHAER, T. A. SPRINGER, J. KOUBA, R. E. NEILAN (1998f): “The International GPS Service (IGS): An Interdisciplinary Service in Support of Earth Sciences”. Interdisciplinary Lecture, Advances in Space Research (in print).

DODSON, A. H., H. C. BAKER, B. BUERKI, G. ELGERED, A. RIUS, M. ROTHACHER (1998): “The WAVEFRONT project on GPS water vapour estimation”. News Letter of the European Geophysical Society, XXIII General Assembly, Nice, France 20-24 April 1998, March, 66, pp. 129, 1998.

DREWES, H., G. BEUTLER (1997): “Report of the IAG/CSTG Working Group "IUGG Fundamental Reference and Calibration Network"”. CSTG Bulletin of the International Association of Geodesy (IAG), Section II, Commission VIII: Progress Report 1997, G. Beutler, H. Drewes, H. Hornik (Eds.), 13, pp. 20-35, Deutsches Geodätisches Forschungsinstitut, Abt. I - Theoretische Geodäsie, München, 1997.

DUDLE, G., F. OVERNEY, L. PROST, T. SCHILDKNECHT, T. SPRINGER (1998): “First Results on a Transatlantic Time and Frequency Transfer by GPS Carrier Phase”. PTTI 1998 (in press).

EYER, M. (1999): “Der Einsatz des GPS zur Wasserdampfmodellierung in der Klimatologie”. Diplomarbeit an der Universität Bern, Druckerei der Universität Bern, Bern, 1999.

FELTENS, J., S. SCHAER (1998): “IGS Products for the Ionosphere”. Proceedings of the 1998 IGS Analysis Center Workshop, Darmstadt, 9-11 February 1998, Dow, J. M. / Kouba, J. / Springer, T. (eds.), pp. 225-232, ESA/ESOC, Darmstadt.

FIGURSKI, M., M. PIRASZEWSKI, J. B. ROGOWSKI, E. BROCKMANN, M. ROTHACHER (1995): “Common Experiment of the Analysis Center CODE and the Institute of Geodesy and Geodetic Astronomy of Warsaw University of Technology (IGGA WUT) on the ....”. Proceedings of the XXI. General Assembly of the International Union of Geodesy and Geophysics, Boulder, Colorado, July 2-14.

FRIDEZ, P. (1996): “Die SLR-Prognosenrechnung in Zimmerwald”. Diplomarbeit der Philo-sophisch-naturwissenschaftlichen Fakultät der Universität Bern, Druckerei der Universität Bern, Bern, 1996.

GEIGER, A., H. HIRTER, M. COCARD, B. BÜRKI, A. WIGET, U. WILD, D. SCHNEIDER, M. ROTHACHER, S. SCHAER, G. BEUTLER (1995): “Mitigation of Tropospheric Effects in Local and Regional GPS Networks”. GPS Trends in Precise Terrestrial Airborne, and Spaceborne Applications, International Association of Geodesy Symposia, Boulder, CO, July 3-4, 1995, G. Beutler, G. W. Hein, G. Seeber, W. G. Melbourne, 115, pp. 263-267, Springer-Verlag, Berlin, Heidelberg, New York, 1996.

GENDT, G., G. BEUTLER (1995): “Consistency in the Troposphere Estimations Using the IGS Network”. Proceedings of the IGS Workshop "Special Topics and New Directions" Potsdam, May 15-18, 1995, Gendt, G. / Dick, G., pp. 115-127, GeoForschungsZentrum Potsdam, Potsdam, 1996.

GURTNER, W. (1995a): “ZIMLAT: The New Zimmerwald Laser and Astrographic Telescope”. SLR Newsletter, Subcommission of the CSTG, NASA/GSFC, June, Greenbelt, 1995.

GURTNER, W., R. LIU (1995b): “The Central Bureau Information System”. J. F. Zumberge, R. Liu, R. Neilan (Eds.) : IGS Annual Report for 1994, IGS Central Bureau, JPL, Pasadena, Cal., September, pp. 43-46, Paris, 1995.

GURTNER, W., R. E. NEILAN (1995c): “Network Operations, Standards and Data Flow Issues”. Proceedings of the IGS Workshop 1994 on the Densification of the IERS Terrestrical Reference Frame Through Regional GPS Networks, 1995, J. F. Zumberge and R. Liu, JPL, Pasadena, Cal.

GURTNER, W., E. POP, T. SCHILDKNECHT, J. UTZINGER, U. WILD, J. BARBE (1996): “The New Laser and Astrographic Telescope in Zimmerwald”. Proceedings of the Tenth International Workshop on Laser Ranging Instrumentation, Shanghai.

GURTNER, W., E. POP, J. UTZINGER (1998): “Automation and Remote Control of the Zimmerwald SLR Station”. Proceedings of the 11th International Workshop on Laser Ranging Instrumentation, September 21-25, 1998, Deggendorf, Germany.

HABRICH, H., W. GURTNER, M. ROTHACHER (1998): “Processing of GLONASS and Combined GLONASS/GPS Observations”. Proceedings of the 32th COSPAR Scientific Assembly, Nagoya, Japan, July 12-19, 1998 (in press).

HUGENTOBLER, U., T. SCHILDKNECHT, A. VERDUN (1995a): “CCD Astrometry of Geostationary Satellites at the Zimmerwald Observatory”. Proceedings of the Sixth COGEOS Workshop, Walferdange, 1994, P. Paquet, A. Elipe, 1995.

HUGENTOBLER, U., T. SCHILDKNECHT, A. VERDUN (1995b): “CCD Astrometry of Geostationary Satellites at the Zimmerwald Observatory”. Cahiers du Centre Européen de Géodynamique et de Séismologie, 10, pp. 23-28, Joseph Beffort, Luxembourg, 1995.

HUGENTOBLER, U., T. SCHILDKNECHT (1996a): “Optical observations of geostationary objects in Zimmerwald”. Proceedings of the 13th Inter-Agency Space Debris Coordination Meeting (IADC), February 28 - March 1, 1996, ESA/ESOC, Darmstadt, Germany.

HUGENTOBLER, U., T. SCHILDKNECHT, G. BEUTLER (1996b): “Determination of resonance terms using optical observations of two Meteosat satellites”. Dynamics and Astrometry of Natural and Artificial Celstial Bodies: Proceedings of the 165th Colloquium of the IAU, July 1-5, 1996, Poznan, Poland, Wytrzyszczak, I. M. / Lieske, J. H. / Feldman, R. A. (eds.), pp. 355-360, Kluwer Academic Publ., Dordrecht/Boston/London, 1997, 0-7923-4574-6.

HUGENTOBLER, U. (1997a): “Astrometry and Satellite Orbits: Theoretical Considerations and Typical Applications”. Inaugural-Disseration der Philosophisch-Naturwissenschaftlichen Fakultät der Universität Bern, Druckerei der Universität Bern, Bern, 1997.

HUGENTOBLER, U., O. FUENTES-MASIP (1997b): “Geostationary Orbit Objects Survey”. Study Note after WP 1, ESA/ESOC Study Note, September 17, 1997, Astronomical Institute University of Berne, Bern, 1997.

HUGENTOBLER, U., M. PLONER, T. SCHILDKNECHT, G. BEUTLER (1998): “Determination of Resonant Geopotential Terms using Optical Observations of Geostationary Satellites”. 32th COSPAR Scientific Assembly, Nagoya, Japan, July 12 to 19, 1998.

KOUBA, J., G. BEUTLER, Y. MIREAULT (1996): “GPS Orbit / Clock Combination and Modeling”. Proceedings of the IGS Analysis Center Workshop 1996, Neilan, R. E. / Van Scoy, P. A. / Zumberge, J. F. (Eds.), pp. 3-8.

KOUBA, J., MIREAULT, Y., G. BEUTLER, T. SPRINGER, G. GENDT (1998a): “Impact of international GPS service for geodynamics in geodetic and geophysical applications”. News Letter of the European Geophysical Society, XXIII General Assembly, Nice, France 20-24 April 1998, March, 66, pp. 124, 1998.

KOUBA, J., Y. MIREAULT, G. BEUTLER, T. SPRINGER, G. GENDT (1998b): “A Discussion of IGS Solutions and Their Impact on Geodetic and Geophysical Applications”. GPS Solutions, 2, 2, pp. 3-15, John Wiley and Sons, Inc., 1998.

NEILAN, R. E., J. F. ZUMBERGE, G. BEUTLER, J. KOUBA (1997): “The International GPS Service: A Global Resource for GPS Applications and Research”. ION GPS-97, Proceedings of the 10th International Technical Meeting, Kansas City, Missouri, September 16-19, 1997, Institute of Navigation, Satellite Division, pp. 883-889.

NOLL, C. E., W. GURTNER (1995): “Global GPS Data Flow from Station to User within the IGS”. GPS Trends in Precise Terrestrial Airborne, and Spaceborne Applications, International Association of Geodesy Symposia, Boulder, CO, July 3-4, 1995, G. Beutler, G. W. Hein, G. Seeber, W. G. Melbourne, 115, pp. 24-29, Springer-Verlag, Berlin, Heidelberg, New York, 1996.

OVERNEY, F., T. SCHILDKNECHT, G. BEUTLER, L. PROST, U. FELLER (1997a): “GPS time transfer using geodetic receivers: middle-term stability and temperature dependence of the signal delays”. Proceedings of the 11th European Frequency and Time Transfer EFTF 97, 4-6 March 1997, Neuchâtel, Switzerland, Swiss Foundation for Research in Microtechnology (FSRM), pp. 504-508, FSRM, Neuchâtel, 1997.

OVERNEY, F., L. PROST, G. DUDLE, T. SCHILDKNECHT, G. BEUTLER, J. A. DAVIS, J. M. FURLONG, P. HETZEL (1998a): “GPS Time Transfer using Geodetic Receivers (GeTT): Results on European Baselines”. Proceedings of the 12th European Frequency and Time Forum EFTF 98, March 10-12, 1998, Warszawa, Poland, Tele & Radio Research Institute, pp. 94-99, Tele & Radio Research Institute, Warszawa, 1998.

OVERNEY, F., T. SCHILDKNECHT, G. BEUTLER, L. PROST, J. A. DAVIS, J. M. FURLONG (1998b): “Results of Geodetic Time Transfer on an European Baseline”. 1998 Conference on Precision Electromagnetic Measurements Digest, 6-10 July 1998, Washington D. C., USA, Nelson, T. L., pp. 326-329, IEEE Service Center, Piscataway, USA, 1998, 0-7803-5018-9.

PLAG, H.-P., B. AMBROSIUS, T. F. BAKER, G. BEUTLER, G. BIANCO, G. BLEWITT, C. BOUCHER, J. L. DAVIS, J. J. DEGNAN, J. M. JOHANSSON, H.-G. KAHLE, I. KUMKOVA, I. MARSON, S. MUELLER, E. C. PAVLIS, M. R. PEARLMAN, B. RICHTER, W. SPAKMAN, S. K. TATEVIAN, P. TOMASI, ET AL. (1998): “Scientific objectives of current and future WEGENER activities”. Tectonophysics, 294, pp. 177-223, Elsevier Science, New York/Amsterdam, 1998.

ROCKEN, C., F. S. SOLHEIM, R. H. WARE, M. EXNER, D. MARTIN, M. ROTHACHER (1995): “Application of IGS Data to GPS Sensing of the Atmosphere for Weather and Climate Research”. Proceedings of the IGS Workshop "Special Topics and New Directions" Potsdam, May 15-18, 1995, Gendt, G. / Dick, G., pp. 93-103, GeoForschungsZentrum Potsdam, Potsdam, 1996.

ROTHACHER, M. (1995): “IGS Data Processing and the IERS Standards”. 1995 IERS Workshop, Paris, May 10-12.

ROTHACHER, M., S. SCHAER, U. WILD (1997): “Troposphere modelling and estimation techniques for baselines with small and large height differences”. News Letter of the Eropean Geophysical Society, XXII General Assembly, Vienna, Austria, 21-25 April 1997, European Geophysical Society, 62, March, pp. 97, 1997.

ROTHACHER, M., G. BEUTLER (1998a): “Information about the atmosphere derived from GPS observations (Solicited paper)”. News Letter of the European Geophysical Society, XXIII General Assembly, Nice, France 20-24 April 1998, March, 66, pp. 128, 1998.

ROTHACHER, M., G. BEUTLER (1998b): “The role of GPS in the study of global change”. Physics and Chemistry of the Earth, 23, 9-10, pp. 1029-1040, 1998.

ROTHACHER, M., T.A. SPRINGER, S. SCHAER, G. BEUTLER (1998c): “Processing Strategies for Regional GPS Networks”. Proceedings of the IAG General Assembly 1997, Rio de Janeiro, September 3-9, 1997, IAG Symposia, Brunner (ed.), 118, pp. 93-100, Springer Verlag, Berlin/Heidelberg/New York, 1998.

ROTHACHER, M., T. A. SPRINGER, S. SCHAER, G. BEUTLER, D. INEICHEN, U. WILD, A. WIGET, C. BOUCHER, S. BOTTON, H. SEEGER (1998d): “Annual Report 1997 of the CODE Analysis Center of the IGS”. IGS 1997 Annual Report, IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Cal., J. F. Zumberge, D. E. Fulton, R. E. Neilan, IGS Central Bureau, JPL (in press).

RÜHRNÖSSL, H., F. K. BRUNNER, M. ROTHACHER (1998): “Modellierung der troposphärischen Korrektur für Deformationsmessungen mit GPS im alpinen Raum”. Allgemeine Vermessungsnachrichten (AVN), 105, 1, pp. 14-20, Herbert Wichmann Verlag, Hüthig GmbH, Heidelberg, 1998, ISSN 0002-5968.

SCARAMUZZA, M., GEIGER, A., LANG, H., AEBERSOLD, R., DOSÉ, A., MEIER, B., KUMMER, H. AND HUWILER, M. (1997): Lugano-Trials: Experiences and First Results. EUGIN, DGON, GNSS 97. Proceedings of the 1st European Symposium on Global Navigation Satellite Systems, DGON (ed), Vol. 1: 287-293.

SCHAER, S., G. BEUTLER, L. MERVART, M. ROTHACHER, U. WILD (1995): “Global and Regional Ionosphere Models Using the GPS Double Difference Phase Observable”. Proceedings of the IGS Workshop "Special Topics and New Directions" Potsdam, May 15-18, 1995, Gendt, G. / Dick, G., pp. 77-92, GeoForschungsZentrum Potsdam, Potsdam, 1996.

SCHAER, S., G. BEUTLER, M. ROTHACHER, T. A. SPRINGER (1996a): “Daily Global Ionosphere Maps Based on GPS Carrier Phase Data Routinely Produced by the CODE Analysis Center”. Proceedings of the IGS Analysis Center Workshop 1996, Neilan, R. E. / Van Scoy, P. A. / Zumberge, J. F. (Eds.), pp. 181-192.

SCHAER, S., M. ROTHACHER, G. BEUTLER (1996b): “Global Ionosphere Maps Based on GPS Carrier Phase Data From the IGS Network Produced by the CODE Analysis Center”. Supplement to EOS, American Geophysical Union, 1996 Spring Meeting, May 20-24, Baltimore, Maryland, AGU, 77, April 23, 17, pp. G11B-3, 1996.

SCHAER, S., M. ROTHACHER, G. BEUTLER (1996c): “Mapping the Deterministic and the Stochastic Component of the Ionosphere Using GPS”. EOS Transactions of the AGU 1996 Fall Meeting, November 12, 1996, 77, 46, pp. F142, 1996.

SCHAER, S. (1997): “How to use CODE's Global Ionosphere Maps”. Internal Report, Astronomical Institute, University of Berne, Berne, 1997.

SCHAER, S. (1998a): “CODE's Global Ionosphere Maps (GIMs), http://www.cx.unibe.ch/aiub/ionosphere.html, automatically updated WWW site”.

SCHAER, S. (1998b): “Towards an IGS Combined Ionosphere Product”. IGS 1997 Annual Report, IGS Central Bureau, JPL, 1, Pasadena, Cal., 1998.

SCHAER, S., G. BEUTLER, M. ROTHACHER (1998c): “Mapping and Predicting the Ionosphere”. Proceedings of the 1998 IGS Analysis Center Workshop, Darmstadt, February 9-11, 1998, Dow, J. M. / Kouba, J. / Springer, T. (eds.), pp. 307-318, ESA/ESOC, Darmstadt, 1998.

SCHAER, S., J. FELTENS (1998d): “Terms of Reference for the IGS Ionosphere Working Group”. IRI News, 5, September, 3, pp. 2-5, 1998.

SCHAER, S., W. GURTNER, J. FELTENS (1998e): “IONEX: The IONosphere Map Exchange Format Version 1”. Proceedings of the 1998 IGS Analysis Center Workshop, Darmstadt, February 9-11, 1998, Dow, J. M. / Kouba, J. / Springer, T. (eds.), pp. 233-247, ESA/ESOC, Darmstadt, 1998.

SCHILDKNECHT, T., U. HUGENTOBLER (1995a): “Algorithms for optical space debris detection”. 11th Space Debris Advisory Group (SDAG) Meeting, June 8-9, ESA/HQ, Paris, France.

SCHILDKNECHT, T., U. HUGENTOBLER, A. VERDUN (1995b): “Algorithms for Ground Based Optical Detection of Space Debris in GEO and GTO”. Space Forum (Special Issue): 1st International Workshop on Space Debris, Moscow, Russia, October 1995, Kleber, P. (ed.), 1, 1-4, pp. 39-49, Gordon and Breach Science Publ., 1996, 90-5699-072-1.

SCHILDKNECHT, T., U. HUGENTOBLER, A. VERDUN (1995c): “Algorithms for optical detection of space debris in GEO and GTO”. Proceedings of the First International Workshop on space Debris, Moscaw, Russia, 9-12 October 1995.

SCHILDKNECHT, T., U. HUGENTOBLER, A. VERDUN, G. BEUTLER (1995d): “CCD Algorithms for Space Debris Detection”. Final Report, European Space Agency Contract Report, ESA/ESOC Contract No. 10623/93/D/IM, 1995.

SCHILDKNECHT, T., U. HUGENTOBLER, A. VERDUN, G. BEUTLER (1995e): “CCD Algorithms for Space Debris Detection”. Executive Summary, European Space Agency Contract Report, ESA/ESOC Contract No. 10623/93/D/IM, 1995.

SCHILDKNECHT, T., U. HUGENTOBLER, A. VERDUN, T. FRIEDLI, H. TIETZ (1995f): “CCD Off-Line Data Processing System”. Final Report, European Space Agency Study Proposal, ESA/ESOC, RFQ No. 3-8376/95/D/IM, 1995.

SCHILDKNECHT, T., G. BEUTLER, U. HUGENTOBLER (1996a): “Geostationary orbit objects survey”. ESA study proposal RFQ/3-8680/96/D/IM.

SCHILDKNECHT, T., G. BEUTLER, U. HUGENTOBLER (1996b): “Level-1 telescope control and on-line data processing system”. ESA study proposal RFQ/3-8873/96/D/IM.

SCHILDKNECHT, T., U. HUGENTOBLER (1996c): “1 m Zeiss telescope: Off-Line Data Processing System”. 13th Space Debris Advisory Group (SDAG) Meeting, June 6-7, DUT Delft, Delft, The Netherlands.

SCHILDKNECHT, T., U. HUGENTOBLER, A. VERDUN (1996d): “Optical Observations of Space Debris with the Zimmerwald 1-m Telescope”. Advances in Space Research: Proceedings of the 31st COSPAR Scientific Assembly, Birmingham, United Kingdom, 14-21 July, 1996, 19, 2, pp. 221-228, Pergamon Press, 1997.

SCHILDKNECHT, T., U. HUGENTOBLER, A. VERDUN (1996e): “CCD astrometry of artificial saatellites with the Zimmerwald 1 m telescope”. Proceedings of the 165th Colloquium of the IAU, July 1-5, 1996, Poznan, Poland.

SCHILDKNECHT, T., U. HUGENTOBLER, A. VERDUN, H. TITZ (1996f): “CCD Off-Line Data Processing System”. Software Requirements Document, ESA/ESOC Progress Report, October 24, 1996, Astronomical Institute University of Berne, Bern, 1996.

SCHILDKNECHT, T. (1997a): “GPS time and frequency transfer”. Tutorial on the Global Positioning System (GPS), 11th European Frequency and Time Forum EFTF 97, 4-6 March, 1997, Neuchâtel, Switzerland.

SCHILDKNECHT, T., U. HUGENTOBLER (1997b): “Techniques for Optical Observation of Space Debris - Performance tests with the new 1 m Zimmerwald telescope”. Proceedings of the Second European Conference on Space Debris, March 17-19, 1997, Darmstadt, W. Flury, ESOC, pp. 93-98, 1997.

SCHILDKNECHT, T., U. HUGENTOBLER (1997c): “Optical measurements of space debris in GEO”. Proceedings of the 48th International Astronautical Congress, October 17-19, 1997, Turin, Italy.

SCHILDKNECHT, T., U. HUGENTOBLER (1997d): “Ariane 502 - optical observations of payload”. 16th Space Debris Advisory Group (SDAG) Meeting, November 26-27, 1997, ESA/ESOC, Darmstadt, Germany.

SCHILDKNECHT, T., U. HUGENTOBLER, H. SDUNNUS, R. WESTERKAMP, E. GARCIA (1997e): “Geostationary transfer orbit survey”. ESA study proposal AO/1-3251/97/D/IM.

SCHILDKNECHT, T. (1998a): “The Potential Role of GPS in the ACES Project”. ESA ACES Utilisation Workshop, Neuchâtel, June 12, 1998.

SCHILDKNECHT, T. (1998b): “Time and Frequency Transfer using Geodetic GPS Receivers”. IGS-BIPM Workshop, June 22-23, 1998, BIPM, Paris, France.

SCHILDKNECHT, T., U. HUGENTOBLER (1998c): “Optical Measurements of Space Debris in GEO and GTO”. 17th Space Debris Advisory Group (SDAG) Meeting, July 1-2, 1998, ESA/ESTEC, Noordwijk, The Netherlands.

SCHILDKNECHT, T., U. HUGENTOBLER, P. FRIDEZ, P. KUNSZT (1998d): “CCD Off-Line Data Processing System”. Executive Summary, ESA/ESOC Study (Final Issue), November 29, 1998, Astronomical Institute University of Berne, Bern, 1996.

SCHILDKNECHT, T., U. HUGENTOBLER, P. FRIDEZ, A. VERDUN, H. TITZ (1998e): “CCD Off-Line Data Processing System”. Architectural Design Document, ESA/ESOC Study (Final Issue), November 29, 1998, Astronomical Institute University of Berne, Bern, 1996.

SCHILDKNECHT, T., U. HUGENTOBLER, M. PLONER (1998f): “Optical Surveys of Space Debris in GEO”. 32th COSPAR Scientific Assembly, Nagoya, Japan, July 12 to 19, 1998.

SCHILDKNECHT, T., T. SPRINGER (1998g): “High Precision Time and Frequency Transfer using GPS Phase Measurements”. PTTI, December 1-3, 1998, Reston, Virginia (in print).

SIERK, B., BÜRKI, B., KAHLE, H.-G., GEIGER, A., FKOREK, S., AND R. NEUBERT (1997): A New Instrumental Approach for water vapor determination based on Solar Spectrometry. XXII General Assembly of the European Geophysical Society (EGS). Annales Geophysicae, Part I. Suppl. I, Vol. 5, C202.

SIERK, B., BÜRKI, B., BECKER-ROSS, H., FLOREK, S., NEUBERT, R., KRUSE, L.-P. and H.-G. KAHLE (1997): Tropospheric water vapor derived from solar spectrometer, radiometer and GPS measurements. J. Geophysical Research, 102, B10: 22411-22424.

SIERK, B., BÜRKI, B., KRUSE, L.-P., FLOREK, S., BECKER-ROSS, H., KAHLE, H.-G. and R. NEUBERT (1998): A new instrumental approach to water vapor determination based on Solar Spectrocospy. Physics and Chemistry of the Earth. Vol. 23, 1: 113-117.

SIERK, B., FLOREK, S., BECKER-ROSS, H., BÜRKI, B., KRUSE, L.-P. and H.-G. KAHLE (1999): Measuring tropospheric water vapor by high resolution absorption spectroscopy of solar radiation. Geophys. Res. Abstr. 1,1: OA22.

SIERK, B., BÜRKI, B., KRUSE, L.-P., FLOREK, S., BECKER-ROSS, H. (1999): High-resolution solar spectrometry for retrieval of tropospheric water vapor: first results and comparisons. IUGG proceedings. In press.

SPRINGER, T., J. ZUMBERGE, J. KOUBA (1998): “The IGS analysis products and the consistency of the combined solutions”. Proceedings of the IGS 1998 Analysis Center Workshop, Darmstadt, February 9-11, 1998, Dow, J. M. / Kouba, J. / Springer, T. (eds.), pp. 37-54, ESA/ESOC, Darmstadt, 1998.

TITZ, H., T. SCHILDKNECHT, U. HUGENTOBLER, A. VERDUN (1996): “CCD Off-Line Data Processing System”. Technical Report of Work Package 2/1, ESA/ESOC Study Progress Report, August 14, 1996, Astronomical Institute University of Berne, Bern, 1996.

VERDUN, A. (1996): “Friedrich Wilhelm Bessel (1784-1846) und die Begründung der Fundamentalastronomie”. Eine Würdigung seiner Arbeiten anlässlich des 150.Todestages, ORION, Schweizerische AStronomische Gesellscdhaft, 54, 273, April, pp. 97-102, Glasson SA, Bulle, 1996.

VERDUN, A. (1997): “High Precision Centroiding of Fast Moving Object Images on CCD Frames”. Inaugural-Disseration der Philosophisch-Naturwissenschaftlichen Fakultät der Universität Bern, Druckerei der Universität Bern, Bern, 1997.

WEBER, R., G. BEUTLER, M. ROTHACHER (1995): “Aufgaben und Produkte des CODE-GPS-Rechenzentrums im Rahmen von IGS”. GPS-Leistungsbilanz '94, Beiträge zum 34. DVW-Seminar vom 5. bis 7. Oktober 1994 am Geodätischen Institut der Universität Karlsruhe (TH), Heck, Bernhard und Illner, Michael (Hrsg.): Schriftenreihe des DVW, 18, pp. 186-199, Konrad Wittwer, Stuttgart, 1995, ISSN 0940-4260.

WILLIS, P., G. BEUTLER, W. GURTNER, G. HEIN, R. NEILAN, J. SLATER (1998): “IGEX: International GLONASS Experiment, Scientific Objectives and Preparation”. Advances in Space Research (accepted for publication).

3 Determination of the gravity field

Gravity Reference Networks

Gravity Measurements along re-measured first order levelling lines

by E. Klingelé

In the last years gravity values have been determined simultaneously with re-levelling of the Swiss National Levelling Network in order to correctly reduce the levelling data. In the period from 1995 to mid 1999, gravity measurements using LaCoste and Romberg gravity meters have been carried out on the following levelling lines (see also map 1.8) :

1995	1996	1997	1998
Chillon-Lausanne	Lausanne-Nyon	Sonceboz-Moutier-Delémont	Neuhausen-Hallau Biaschina-Bodio-Osogna
Gisikon-Bremgarten-Brugg	Gampel-Visp-Brig	Innertkirchen-Sustenpass	Nyon-Genève-Moillesulaz Genève-Meyrin Mendrisio-Gaggiolo
Bern-Wabern-Zimmerwald		Baden-Kaiserstuhl	Rueras-Valzeina Bern-Langnau-Escholzmatt Sustenpass-Wassen
		Hospental-Maettli	Chur-Sargans-Walenstadt Gampel-Visp-Brig
		Gotthard Tunnel	Maettli-Gotthardpass-Motto Bortola

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

Absolute Gravity Network and new Fundamental Gravity Network of Switzerland

by E. Klingelé

In autumn 1998 two new absolute stations (Zimmerwald and Wabern) were measured by means of an absolute gravimeters of the Metrological Institute A Colonetti of Torino (Italy). The new gravity network of Switzerland , which was measured between 1991 and 1994 has been tied to references stations in Austria, Italy and Germany. It has been integrated in the new European Gravity Network, in1996. The entire network was then equalised and the results published in a special publication of the Swiss Geodetic Commission.

Airborne gravimetry: The airborne gravity survey of the French occidental Alps.

by E. Klingelé

The French Ministries of Industry and Research and of Public Education initialized the Geo France 3D research program about the deep structure in France. In this context an airborne gravity survey of the French occidental Alps from the pre-alps to the Po plain in Italy, has been jointly carried out by the University of Montpellier (France) and the GGL of the ETH Zurich (Switzerland). The survey area is limited in the west direction by a meridian passing west of the city of Grenoble and in the east by a second one passing through the city of Cuneo (Italy). The northern and southern boundaries of the survey are the parallel passing through the city of Nice (France) and by the 47 N parallel.

The survey was done at a constant altitude of 5100m with the measurement lines oriented N-S and E-W. The line spacing was 10 km for the N-S lines and 20 km for the E-W lines. The mean ground speed of the aircraft was around 270 km/h. The total distance of all lines flown is around 10'000 km to which more 3'000 km for positioning and de-positioning have to be added. The sampling rate of the gravimeter was at one second giving a mean distance of 75 m between two measurements. The aircraft was equipped with the following devices:

- Two GPS receivers, L1+L2, working at a frequency up to 5 Hz.
- Two GPS receivers, L1, working at a frequency up to 20 Hz,
- One GPS receiver, L1+L2, working at a frequency of 2 Hz.
- One GPS receiver, L1+L2, working at a frequency of 1 Hz
- One high-precision Inertial System delivering angular velocities and tri-axial accelerations at rates between 50 and 100 Hz.
- One airborne gravimeter LaCoste and Romberg, type SA, Number 114, mounted on a laser gyro stabilised platform and working at 10 Hz for the determination of the beam position and at 1 Hz for the determination of the spring tension.

In addition five GPS permanent ground stations were installed in order to provide the reference frame. A comparison between the g values obtained along four lines using two different computation algorithms is presented. The first algorithm uses the beam position and the spring tension sampled at 1 Hz, the second algorithm uses the same data but sampled at 10 Hz. Both data sets were filtered with the same kind of filters.

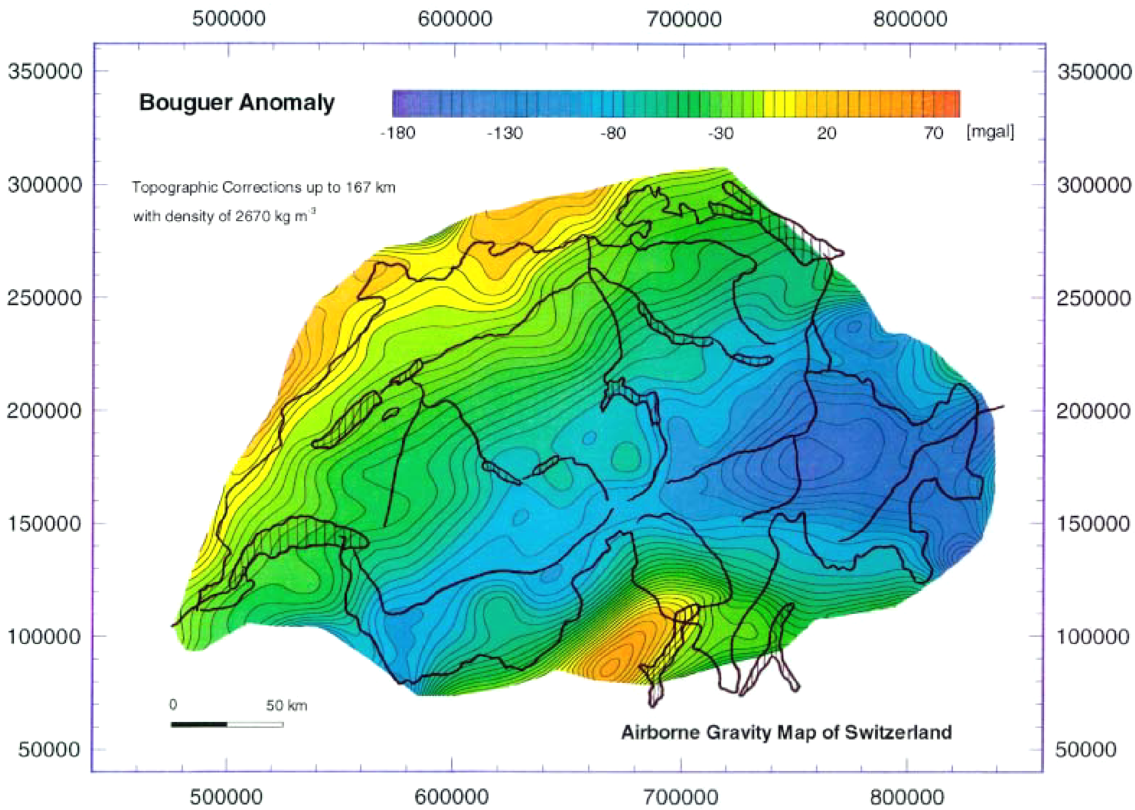


Figure 3.1: Airborne gravity map of Switzerland after Klingelé et al. (1996).

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 has measured, on behalf of the Swiss Geophysical Commission (SGPK), 4506 new gravity points. These stations has enabled the SGPK to publish the first eleven Bouguer anomaly maps of Switzerland. The published maps are: Basel, Bözberg, Bodensee/Lindau, Besancon, Bienne, Beromünster, Toggenburg, Vallorbe, Saane, Brünigpass and Le Léman.

Interpretation and analysis

Gravity interpretation of Northern Anatolia

by E. Klingelé

In the frame of a Swiss-Turkish geological research project, the Bouguer anomaly map of NW Anatolia was digitised to form a regular grid of gravity data. These data were then corrected for the effect of topographic masses with densities differing from that used for the standard topographic corrections. These corrected data were used to compute the depth of the Mohorovicic discontinuity by means of a new inversion technique developed in the frame of this research project.

Inversion techniques

by E. Klingelé

A technique using artificial intelligence has been developed for gravity interpretation. In the absence of any information regarding the shape of the target, the interpretation tends to be ambiguous. In the developed technique Artificial Neural Networks is first used to find the most probable model for a given anomaly. With this technique the ambiguity between similar anomalies generated by different disturbing bodies can be solved without using information about density contrasts.

An inversion technique has been developed that also uses Artificial Neural Networks for quantitative inversion. It is very simple and remarkably precise. The average error of inversion for the geometrical parameters of simple bodies lies by 2% and is never higher than 5%. The technique employs only small and simple networks, it is therefore easy to learn and to understand. It uses advanced training algorithms and it has been designed to make the interpretation easy and less time consuming than classical inversion techniques.

Astronomical Geodesy

Zenith camera and determination of deflections of the vertical

by B. Bürki

The Swiss national network of deflections of the vertical has been completed by means of the zenith camera system of the Geodesy and Geodynamics Lab. In order to provide an optimal data set for the new geoid computation in Switzerland, some remaining data gaps have been filled upwith some additional observations. Apart from these measurements in Switzerland, the system has been deployed in Portugal where a new first order network consisting of about 25 stations has been established. The aim of this network is to provide the basic data set for the new astro-geodetic geoid determination in Portugal. It is planned to densify this network by means of an improved and updated software package using high precision motorized theodolites and a special GPS equipment for the time keeping. Figure 3.2 shows the presently available data set of deflections of the vertical as used for the new geoid determination in Switzerland.

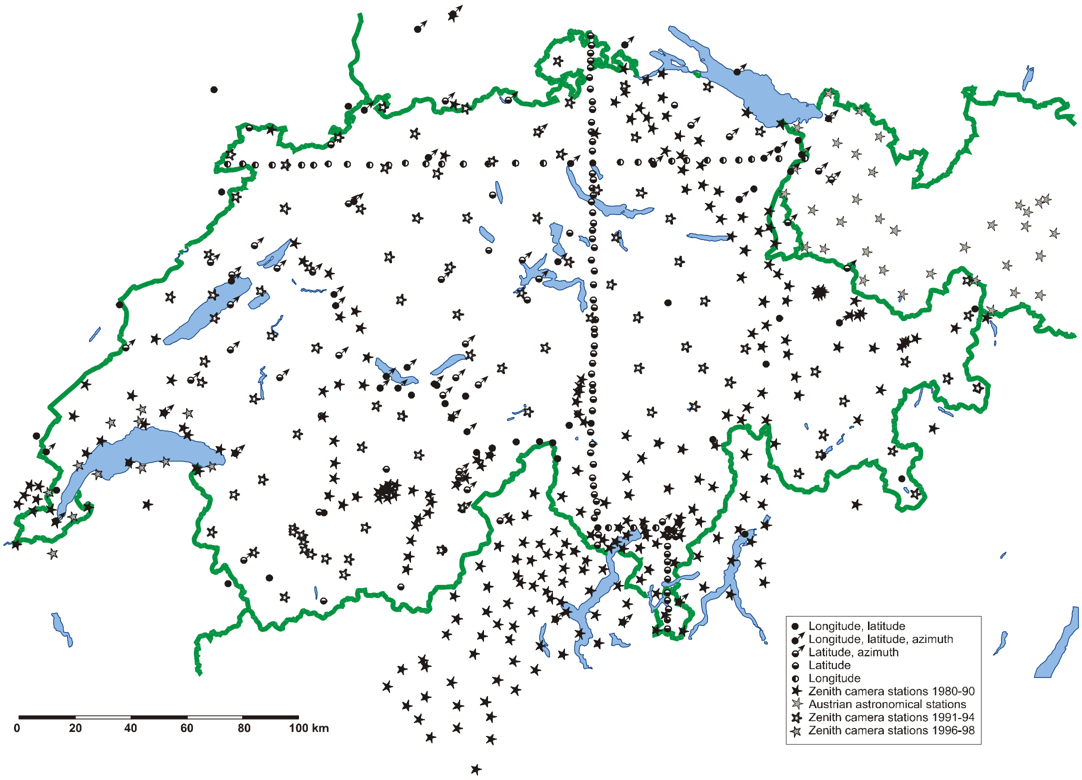


Figure 3.2: Stations with observed deflections of the vertical in and around Switzerland as used for the new geoid determination in Switzerland (Marti, 1997).

Geoid determination in Switzerland

by U. Marti, H.-G. Kahle, B. Bürki, and A. Geiger

For high precision geodetic applications the geoid undulation must be determined with an accuracy of a few cm over a distance of 100 km. Different methods for determining the geoid from gravity measurements or from astrogeodetic observations exist since the last century. These data were combined with modern satellite observations and were processed with the integrated statistical method of collocation in order to determine a new high precision geoid in Switzerland. About 600 observations of the deflections of the vertical, 2400 gravity measurements, and 80 GPS leveling stations were processed. Apart from these measurements, models of known disturbing masses, which are essential for a modern geoid determination in a rugged area, were implemented. Special attention was paid to a new model of the topography, which was extracted from the digital height model DHM25 (lateral resolution 25 metres) of the Swiss Federal Office of Topography (L+T). Beside the geometrical determination of the model, a simple procedure for taking into account density anomalies at the topography by means of polygons has been employed. Furthermore, a new model of the crust mantle boundary, stemming from a national project for the determination of the deep structure of Switzerland (NFP20) was implemented instead of a classical isostatic model.

Thus it was possible to demonstrate that from astrogeodetic observations alone, the geiod can be determined with an accuracy of 3 to 4 cm with respect to the fundamental station in Zimmerwald, (cf. Fig. 3.3). By including some GPS levelling stations, it is possible to eliminate the systematic long wavelength errors of the astrogeodetic solution. For better accuracy in local areas, the gravity measurements have also to be considered. The combination of all available measurements yield a relative geoid accuracy of ≤ 2 cm throughout Switzerland. The 1-cm contour line is reached at a distance of 70 to 150 km. In these calculations it was assumed that no systematic errors were affecting the measurements and all indirect effects have been eliminated by means of mass models.

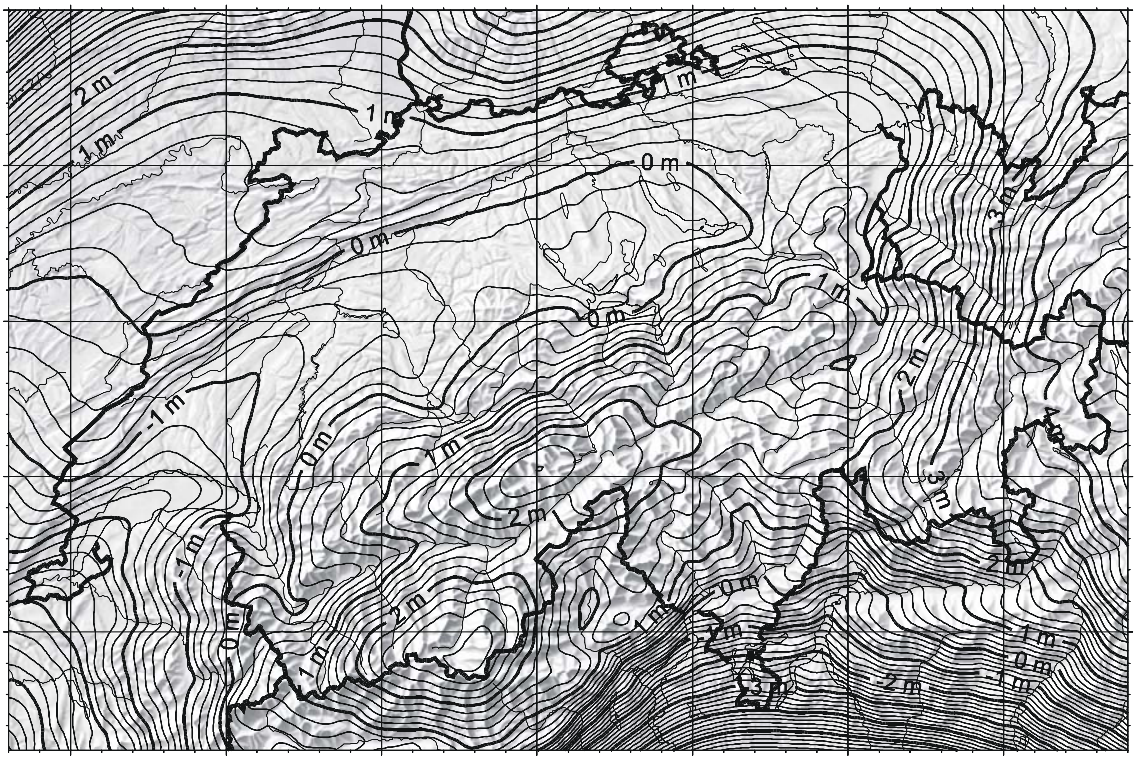


Figure 3.3: Contour plot of the new high precision astro-geodetic geoid in Switzerland (Marti, 1997). Contour interval is 0.2 m.

The geoid was also calculated in different ways. These investigations revealed discrepancies in southeastern Switzerland of more than 10 cm between the deflections of the vertical and the GPS levelling measurements, which could not be sufficiently explained. The chosen method of eliminating a global trend resulted in systematic differences on the same order when the gravity measurements were introduced. For the final result, the solution with astrogeodetic observations, combined with GPS levelling was chosen. This solution is still provisional because the digital terrain model was not complete at the time of the calculations.

The solution obtained has been compared to the geoid of Gurtner (1978) and the new European quasigeoid EGG96 that was calculated at the University of Hannover, Germany. This comparison gives information about the absolute accuracy of the Swiss solution. In quite smoothed terrain these two independent solutions coincide better than 5 cm whereas in more rugged areas these differences can reach 15 cm.

Gravity gradiometry

by E. Klingelé

The GGL, ETH-Z participated in a project sponsored by the European Space Agency ESA and dealing with the study of advanced reduction methods for spaceborne gravity gradiometry data and their combination with other geophysical data (CIGAR IV). The general aim of this project, divided in five working packages, was to study the optimal processing data for realistic mission scenarios and to the scientific exploitation of the results of a real spaceborne gravity gradiometry mission.

Our working package was dedicated to the study of the possible use of satellite gravity gradiometric data for mapping the bedrock basement under large ice covered area like Antarctica and Greenland. The study was carried out by simulations of the gravity gradiometric effects of ice covers, bedrocks and supposed geologic structures in Antarctica and Greenland at satellite altitude for different track parameters. From these data an analysis was conducted on the effects of incomplete coverage (loss of data) both in term of anomaly amplitude and anomaly wavelengths.

Bibliography Section 3

ARNET, F., KAHLE, H.-G., KLINGELÉ, E.E., SMITH, R.B., MERTENS, C. and L. DZURIZIN (1997): Crustal deformation of the Yellowstone volcanic field inferred from temporal gravity changes and supplementary leveling and GPS data. Geophysical Research Letters, 24, No 22: 2741-2744.

ARNET, F. und KLINGELÉ, E.E. (1997): SG95: Das neue Schweregrundnetz der Schweiz. Schweiz. Geodätische Komm. (Hrsgb.). Geodätisch-geophysikalische Arbeiten in der Schweiz. Band 54, 37 pp.

ARNET F., E.E. KLINGELÉ, C. STRAUB (1995): Bestimmung der Gravitationskonstante G in der Staumauer Gigerwald. Institut für Geodäsie und Photogrammetrie, ETH Zürich, Bericht Nr. 250. ISBN 3-906513-62-9. 69 pages

COCARD, M., GEIGER, A., KAHLE, H.-G., VEIS, G., MILAS, P. (1997): Regional sea surface determination by using Airborne Laser techniques. Annales Geophysicae. XXII General Assembly of European Geophysical Society (EGS). Annales Geophysicae, Part I. Suppl.I to Vol 5, C191.

DUMONT, B., KLINGELÉ, E.E., LOGEAN, Ph., OLIVIER, R: and F. PERRET (1994): Atlas Gravimétrique de la Suisse 1:100000, Anomalies de Bouguer. Cartes No 26, 27, 28, 30, 31, 32, 33, 35, 36, 37, 40. Office Fédéral de topographie, Wabern.

FAVEY, E., SCHLATTER, A. (1998): Geoidbestimmung am Lac Léman, Switzerland. IGP Report 282, ISBN 3-906467-14-7, 130 pp.

GRÊT, A. and E.E. KLINGELÉ (1999): Application of Artifitial Neural Networks for Gravity Interpretation in Two Dimension. Institut für Geodäsie und Photogrammetrie ETHZ. Bericht Nr 279. ISBN 3-906467-10-4. 88 pages

GRÊT, A., KLINGELÉ, E.E., and KAHLE, H.-G. (1999): Application of artificial neural networks for gravity interpretation in 2D. Submitted to Computers and geosciences. Special Issue on "Virtual intelligence applications in the Geosciences" .

GRÊT, A. and E.E. KLINGELÉ (1998): Application of Artifitial Neural Networks for Gravity Interpretation in Two Dimension. Geodäsie und Photogrammetrie ETH-Z. Bericht Nr 279. ISBN 3-906467-10-4. 88 pages

KLINGELÉ, E.E., WYSS, T., and F. ARNET (1995): PROGRAV: Fortran Programs for Processing and Interpretation of Gravimetric Data. Geodäsie und Photogrammetrie ETH-Z. Bericht Nr 250. ISBN 3-906513-71-8. 69 pages

KLINGELÉ, E.E., HALLIDAY, M., COCARD, M. and H.-G. KAHLE (1995): Airborne gravimetric survey of Switzerland. VPK, 4/95: 248-253

KLINGELÉ E.E., M. HALLIDAY (1995): Airborne Gravimetry Survey of Switzerland. Proceedings of the IAG Symposium on Airborne Gravity Field Determination, IUGG XXI General Assembly Boulder Colorado, July 2-14, pages 109-115.

KLINGELÉ E.E., M. HALLIDAY, M. COCARD, H.-G. KAHLE (1995): Airborne Gravimetric Survey of Switzerland. 1st Congress of Latin-American Geophysical Union, Extended abstracts, pages 214-217.

KLINGELÉ, E.E, COCARD, M., HALLIDAY, M., & H.G. KAHLE (1996): The Airborne Gravimetric Survey of Switzerland. Matériaux pour la géologie de la Suisse, série Géophysique, no. 31. 104 pages.

KLINGELÉ, E.E, MEDICI, F., and F. ARNET (1996): ESA, Study of advanced reduction methods, for spaceborne gravimetry data, and of data combination with geophysical parameters. CIGAR IV. Final report. ESA contract 152163, p 213-260.

KLINGELÉ, E.E, COCARD, M., HALLIDAY, M., & H.G. KAHLE (1997): Kinematic GPS as a source for airborne gravity reduction in the airborne gravity survey of Switzerland. J. Geophys. R, vol 102, No B4, 7705-7715.

KLINGELÉ, E.E. and KAHLE, H.-G. (1997): Seismic Velocity-density relationships: a critical review. XXII General Assembly of European Geophysical Society (EGS). Annales Geophysicae, Part I. Suppl.I to Vol 5, C8.

KLINGELÉ, E.E., COCARD, M., KAHLE, H.-G. and M. HALLIDAY (1997): Kinematic GPS as a source for airborne gravity reduction: The airborne gravity survey of Switzerland. J. Geophys. Res., 102, B4: 7705-7715.

KLINGELÉ, E.E. and MEDICI, F. (1997): Gravimetric studies of the Marmara Sea region. In Schindler and Pfister (eds.), Active tectonics of northwestern Anatolia - The Marmara Poly-Project. VdF Hochschulverlag AG an der ETH Zürich: 487-502.

KLINGELÉ, E.E. (1997): 2-D gravimetric study of the crystalline basement of the Rawyl depression. In : Deep structure of the Swiss Alps, results of NRP 20. O.E. Pfiffner, editor. Birkhäuser Verlag, Basel, Boston. pp. 154-159

KLINGELÉ, E.E: and F. MEDICI (1997): Gravimetric studies of the Marmara Sea Region In : Active Tectonics of the Northwesten Anatolia. C. Schindler and M: Pfister editors. Vdf Hochschulverlag AG. Pp. 487-502.

MARTI, U and KAHLE, H.-G. (1995): Provisional results of the new Geoid computation for Switzerland and comparisons of different solutions. XXI IUGG General Assembly, Boulder, Colorado, USA, Abstract Volume B, p. 53.

MARTI, U., BÜRKI, B., and KAHLE H.-G. (1995): National Geoid investigations in Switzerland. Int. Ass. Geodesy, Special publication, Bulletin d'information No 77, IGES Bulletin No 41: 181-190.

MARTI, U. and KAHLE, H.-G. (1995): Die neue Geoidbestimmung in der Schweiz: Gegenwärtiger Stand und Genauigkeituntersuchungen. VPK, 4/95: 241-247

MARTI, U. (1997): Geoid der Schweiz. Geodätisch-geophysikalische Arbeiten in der Schweiz, Volume 56, 140p. Swiss Geodetic Commission.

VONDER MÜHLL, D., W. HAEBERLI and E.E. KLINGELÉ (1996): Geophysikalische Untersuchungen zur Struktur und Stabilität eines Moränendammes am Grubengletscher (Wallis). Internationales Symposium INTERPRAEVENT 1996 - Garmisch-Paterkirchen Tagungspublikation, Band 4, Seite 123-132.

WYSS T., E.E KLINGELÉ, A. KAAB (1995): Gravimetric investigation in the confluence area of the Unteraar glacier (Switzerland). Institut für Geodäsie und Photogrammetrie, ETH Zürich, Bericht Nr. 243. ISBN 3-906513-64-5. 59 pages.

YANG L., E.E. KLINGELÉ, and H.-G. KAHLE (1995): Determining variations in rock elasticity with Earth tides. Institut für Geodäsie und Photogrammetrie, ETH Zürich, Bericht Nr. 242. ISBN 3-906513-63-7. 47 pages

4 General Theory and Methodology

Bernese GPS Software

by M. Rothacher, L. Mervart, S. Schaer, T. Springer, and G. Beutler

Developing and maintaining a software package like the Bernese GPS Software (consisting of more than 100 processing programs and about 1000 subroutines) is a major undertaking. A milestone in this process was the completion of the documentation for Version 4 (Rothacher and Mervart, 1996). Version 4 is a complete revision of the software package, containing most of the tools developed in the environment of the CODE processing center. Let us mention in particular the processing program ADDNEQ (allowing to combine normal equation systems (NEQs) referring to, e.g., subsequent days), the „Bernese Processing Engine“ (developed for regular processing of data from permanent (regional or global) GPS networks), the ionosphere part (results already presented in Section II), and the orbit part. In addition, the new version is about one order of magnitude faster than its predecessors. It is designed to process big networks.

Many modifications and improvements were made since 1996. Let us briefly address the following topics:

- New ADDNEQ using FORTRAN-90
- New CODE orbit model
- Double, single, zero differences
- Processing GLONASS observations
- Elevation dependent weighting of observations
- Tropospheric gradients

ADDNEQ. The program ADDNEQ proved to be a key element of the Bernese GPS Software. Its first version was designed and developed by Dr. Elmar Brockmann (Brockmann, 1997). Although this program was rather flexible and general, it was decided to re-write it from scratch based on a new design which emerged from IGS applications. It was, e.g., decided to store the NEQs always without weight information and to use the new Fortran-90 language. This work was performed by Dr. Leos Mervart in 1997 and 1998 (documentation in preparation). This new version of ADDNEQ is used in the CODE analysis since fall 1998.

ORBIT MODEL. Tim Springer made extensive use of the Bernese empirical orbit model (Beutler et al., 1994). This empirical orbit model allows for nine deterministic radiation pressure parameters per satellite. A thorough analysis (Springer et al., 1998b, 1998e) showed that a much simpler orbit model, actually replacing the famous ROCK4/42 models, could be deduced from the empirical model. The model and the corresponding parameters are given in (Springer et al, 1998b).

ZERO AND SINGLE DIFFERENCES. Originally the Bernese GPS Software was a pure double difference software package. This approach, when accompanied by efficient algorithms to model mathematical correlations, is very performing. Some recent applications (using the GPS for high accuracy time transfer, including SLR observations to GPS satellites), however, ask for zero or single difference processing. T.Springer generalized the processing programs GPSEST and ADDNEQ of the Bernese package to process undifferenced observations as an alternative to double difference observations. These developments are used at CODE for the generation of satellite and receiver clock estimates (the results given in Figure 2.7 were generated with this version of the software). For more information we refer to (Springer, 1999). The same software developments (augmented by some additional modifications in the field of tropospheric refraction) could also be used to process SLR observations to GPS or GLONASS satellites, either in a stand alone mode, or in combination with the microwave observations. Figure 2.5 is based on such a program run.

PROCESSING GLONASS OBSERVATIONS. At first sight, the Russian GLONASS is very similar to the U.S. GPS. There is, however, one key difference, which required a thorough review of the entire processing scheme: Whereas all GPS satellites transmit different code information on (nominally) identical carrier frequencies, the GLONASS satellites transmit identical codes on (slightly) different carrier frequencies. Heinz Habrich from BKG (Bundesamt für Kartographie und Geodäsie) in Germany developed and implemented in collaboration with the Bernese team all required generalizations into the Bernese GPS Software. Today, a correct processing of all GPS and GLONASS observations stemming from the most advanced receivers is possible. Such receivers are combined dual-band GPS/GLONASS receivers observing all GPS and GLONASS satellites in view, and recording code and carrier phase on both frequencies. Major challenges for combined processing schemes are cycle slip repairs and ambiguity fixing. The Bernese software, after implementation of all modifications, was used by the CODE Analysis Center and by BKG to process data from the IGEX-98 (see Section II). For more information we refer to (Habrich et al., 1998).

Tropospheric refraction and multipath effects are responsible for a considerable increase in the „noise“ of GPS observations made at low elevations. On the other hand it is clear that low elevation data strengthen solutions considerably -- in particular the global solutions where the distance between receivers may be of the order of thousands of kilometers. In order to use all available observations of a site, but to account for the reduced accuracy at low elevations, a so-called „elevation-dependent weighting“ scheme, using the square of the cosine of the zenith distance as a weight, was introduced as an option into the Bernese software. All CODE results since October 1997 are based on this elevation-dependent weighting scheme using data down to 10 degrees elevation.

This change of the processing scheme led in particular to improved height estimates and Earth rotation parameters. For more information we refer to (Rothacher et al., 1998).

FINELTRA : Software for the Linear Transformation with Finite Elements

by Miljenko Plazibat and Alessandro Carosio

GPS-Technology has made possible the determination of high order reference frames in all countries of the world with excellent precision. Consequently, there is an increased demand for flexible and simple methods to transform coordinates of existing reference frames into new ones.

To solve this problem a new procedure based on finite elements has been established. This method, after its further developments, has become a standard tool in Switzerland for the transformation process of coordinates between different epochs.

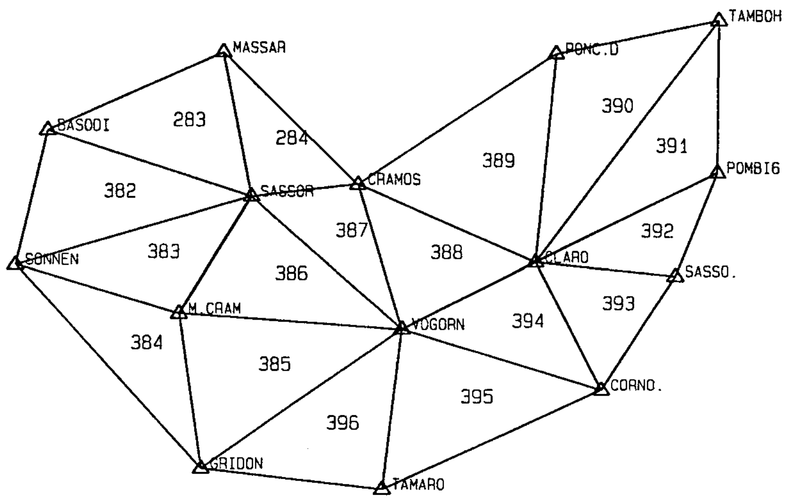


Figure 4.1: Triangular elements defining a network

The principal idea of the method is to provide a simple continuous transformation by dividing the area of interest into a finite number of elementary areas (in our case triangles, cf. Fig. 4.1). An Affin transformation based on the finite elements is then performed for each triangle. The triangle corners (nodes) are the points with coordinates in the old and new coordinate systems (control points). Transformation parameters are computed for each triangle depending only on the coordinates of their corners.

If a simple linear transformation based on the new determined control points is not enough the linear transformation based on the finite elements can be used for the approximation process of other transformation methods (e.g. collocation, polynomial interpolation, etc.). In these cases the previously transformed points can be also used as control points.

The advantages of this method are listed below:

- Further introduction of additional control points influences the transformation parameters only in their localities.
- If necessary, local improvement of transformation in a section of the triangle network can be realised by using the previously transformed points as control points.
- This type of linear transformation can be used to approximate any other type of a more complicated transformation procedure by introducing the previously transformed points as control points.
- Affin transformation is continuous and as a linear function it is reversible and easily to be calculated.
- This transformation process makes possible the continuous densification of control points where an improvement is needed without changing the transformation parameters in the other places.

As disadvantage can be mentioned the discontinuity of the direction of transformed straight lines which are passing from one finite triangle to another. However, this disadvantage has a little influence in the practical applications.

After its comparison with several alternative procedures has been proved that this method is a very useful tool in the transformation process of coordinates determined in different systems.

This method has been implemented in the software FINELTRA and is a component of the national geodetic software package.

Universal Procedure for the Computation of Projections' Corrections in Geodetic Networks

by Entela Kanani and Alessandro Carosio

The use of adjustment software packages beyond the national territory is normally not possible. The evaluation process takes place in map projection, therefore, every observation value should be corrected respectively. These corrections are calculated for the different observations types through approximated series and have been developed in the past for the own projection system of each country. Therefore, the respective computer programs can not be used internationally. In order to use the national adjustment software (LTOP) also abroad a new procedure for the reduction of the observations in the projection system has been developed. This procedure calculates all needed corrections based only on the ellipsoid dimensions and on the original map projection function (Long,Lat -> X,Y).

The universal procedure for observations' corrections are implemented in the triangulation software of the Swiss Federal Office of Topography (LTOP) and can already work with the Gauss-Krüger and Lambert map projection system. Therefore, it is possible to use LTOP in Germany, France, Albania, Croatia, etc. The implementation of further map projection systems or ellipsoids is possible within a short time and without difficulties.

Robust Estimators for the Adjustment of Geodetic Networks

by Fridolin Wicki and Alessandro Carosio

For the Least Squares adjustment of geodetic networks normal distribution is a precondition. To fulfil as far as possible the requirements of the normal distribution model testing procedures are applied in order to prevent the influence of gross errors (outlier detection), while with employment of robust estimators good results can be obtained even if the normal distribution assumptions are not met.

At the Institute of Geodesy and Photogrammetry of the ETHZ between 1996 and 1998 investigations on the application of robust estimators in geodesy has continued. Specially, theoretical investigations has been concluded in establishing optimal estimators for the evaluation process of geodetic networks.

The result is a Maximum-Likelihood estimator which bounds the influence of standardised residuals. This estimator gives for normal distributed measurements the same results as the Least Squares method. When gross errors are present this estimator gives very good results, even in geodetic network with irregularly distributed redundancies.

The results of this new procedure are described in the doctoral thesis of F. Wicki and are implemented in the national adjustment software LTOP. This procedure has become a fundamental tool in the praxis and allows thousands of unknown parameters to be estimated at the same time.

Robust Estimators with High Breakdown Point for the Geodetic Transformation

by Entela Kanani and Alessandro Carosio

The high breakdown estimators and their implementation in geodetic applications are an interesting field of the robust statistics. Although this group of estimators is generally associated with a large amount of calculation time, their implementation for the analysis of deformation measurements can be of considerable value. The geodetic task in the deformation measurements involves the transformation of coordinates from one reference system in the other. Linear functions are often used either in 2- or 3-dimensional space. The number of parameters to be estimated in a linear transformation is limited (4, 6, 7 and so on), which restricts the calculation time to manageable proportions. Preliminary work undertaken at ETH Zurich has been very promising.

Our research aimed to investigate and develop new concepts of robust estimators for linear geodetic transformations (Helmert and Affin). The inserting of a robust estimator with a high breakdown point in the replacement or completion of the compensation process in the determination of transformation parameters in the linear transformation has the following noteworthy advantages:

- high breakdown estimators give very good results even when 50% of data is corrupted
- provides a significant improvement in the speed of the network's evaluation (instead purging the outliers continuously through outlier diagnostics, the employment of robust estimators gives good results in one go)
- guarantees an efficient analysing tool for deformation measurements, comparing model variants, monitoring and others.

From the class of high breakdown estimators the Least Median of Squares (LMS) was investigated considering the particularities that are present in the geodetic transformation:

- small redundancy (the Least Median of Squares estimator has a solution only if the number of control points is twice as much as the number of unknown parameters)
- we should have a definite solution for all unknown parameters, therefore, the determination of the observations' equations should be done carefully
- when the number of control points in both systems is higher than 20 the introduction of a Maximum-Likelihood estimator which bounds the influence of the standardised residuals is recommended in order to keep the calculation time in manageable proportions.

The established algorithms are implemented in the transformation software TRANSINT of the Swiss Federal Office of Topography.

Individual vs. Uniform Weighting of Measurements and Constraints in Industrial Measurement Networks

by Alfons Meid

Leica's industrial measurement software Axyz enables users to apply individual weighting and uniform weighting to parameter estimations like point determinations, coordinate transformations or form fittings.

Weighting means the introduction of uncertainty information for measurements or constraints, commonly called observations. The first approach is individual weighting, which means the equations of single observations or groups of observations are manipulated such that high weights are introduced for accurately known observations, low weights for observations of poor accuracy. The weight is a factor which is derived from the accuracy of the corresponding observation by calculating the squared inverse of its the standard deviation. The second approach is uniform weighting, which means there is no manipulation of the equations at all.

- Parameter computations can be based on observations of one or more types. A polar point determination, for instance, is based on two types of observations: angles and distances. In order to account for their different dimensions, individual weighting is required.
- If there is only one observation type, e.g. coordinates for a form fitting, it is the accuracy of each single contributing coordinate, which can vary. If it does not vary, uniform weighting applies.

If it varies, the decision whether individual or uniform weighting applies depends on the accuracy of the reference information. A circle fitting application is used to explain this alternative:

On a mechanical tool, which should represent a circle, measurements have been performed, which allow to compute coordinates of points with standard deviations of ±0.05mm for the x,y and z coordinates. If the physical shape of the tool is a perfect circle, i.e. its deviations from a perfect circle are as small or smaller than 0.05 mm, individual weighting of the contributing point coordinates applies to the circle form fitting. If, on the other hand, these deviations are significantly larger than 0.05mm, uniform weighting applies to avoid artificial shape deformations caused by the varying standard deviations of the contributing points.

Geodetical Methods and Quality Indicators for Underground Network Adjustment

by Alessandro Carosio

In connection with the drilling of two new railway tunnels in the Swiss Alps, the Swiss Federal Railways asked the Swiss Federal Institute of Technology (ETHZ) to study new geodetical methods regarding gyroscope observations and quality indicators focused to the accuracy and reliability of the tunnel breakthrough.

Between 1995 and 1999 the ETHZ has undertaken some investigations concerning the temperature calibration of high precision gyroscope (Gyromat 2000). Observation campaigns that took place under constant temperature conditions (in summer with temperatures both inside and outside the tunnel ranging from 15^{o} to 25^{o}C), gave always good results. In contrary to that, measurements that have been conducted in winter (temperatures ranging from -20 ^{o}C to +20^{o}C) have shown significant errors. Further tests carried out in the experimental climate chamber of the Institute of Geodesy and Photogrammetry of the ETHZ gave interesting results.

The Gyromat 2000 is very sensitive to a change in temperature. Therefore, it is recommended to measure under constant temperature. For its practical use a very precise and laborious calibration curve was determined. The calibration process was carried out at temperatures steps of 5C in order to record all variations of the temperature. The gyroscope was left for about 4 hours after each change of temperature in order to acclimatise. The outcoming results have shown that the nominal precision of 7 ^{cc} to 10^{cc} (centesimal seconds) can be reached after the measurements are corrected with the values delivered from the calibration curve.

Another field where our investigations has been directed to has to do with the indicators for the reliability. The indicators of relative reliability were developed according to the swiss reliability model. The relative reliability rectangles that are implemented in the swiss triangulation software LTOP give the biggest difference of coordinates that can happen with a probability β, when an unfavourable error escapes despite passing the statistical test. This indicator is very suitable for examination of consequences that may arise from an undetected gross error in the breakthrough of a tunnel.

Bibliography Section 4

BEUTLER, G., E. BROCKMANN, W. GURTNER, U. HUGENTOBLER, L. MERVART, M. ROTHACHER (1994): “Extended Orbit Modeling Technique at the CODE Processing Center of the International GPS Service for Geodynamics (IGS): Theory and Initial Results”. Manuscripta Geodetica, 19, pp. 367-386.

BEUTLER, G. (1995): “GPS Satellite Orbits”. Lecture Notes in Earth Sciences, Kleusberg, A. / Teunissen, P. J. G., 60, pp. 37-101, Springer-Verlag, Berlin / Heidelberg, 1996.

BEUTLER, G. (1998): “GPS Satellite Orbits”. GPS for Geodesy, Teunissen, P. J. G. / Kleusberg, A. (eds.), pp. 43-109, Springer Verlag, Berlin / Heidelberg, 1998, 3-540-63661-7.

BOTTON, S., M. ROTHACHER, T. SPRINGER, G. BEUTLER (1997): “Reprocessing of about 15 months of global IGS data using an improved orbit model”. Publications du LAREG, Série Communication, Laboratoire de Recherche en Géodesie, IGN, April, CM 38, LAREG, Paris, 1997.

BROCKMANN, E. (1997): “Combination of Solutions for Geodetic and Geodynamic Applications of the Global Positioning System (GPS)”. Geodätisch-geophysikalische Arbeiten in der Schweiz, Schweizerische Geodätische Kommission, 55, E. Zingg, Zürich, 1997.

CAROSIO, A., KANANI, E.(1995): Universale Reduktionsformeln für die Landesvermessung. VPK 4/95, S. 195.

CAROSIO, A. (1996): Les méthodes de la statistique robuste au service de la compensation de réseaux géodésiques. IGP-Bericht Nr. 257f, 4/96.

CAROSIO, A., KANANI, E. (1996): Formule di riduzione universali per la misurazione nazionale. IGP-Bericht Nr. 265, 11/96.

CAROSIO, A., KANANI, E. (1997): Formula reduksioni universale per ne gjeodezine e larte. Revista Gjeodezike 1/97, S. 22-28. Albanian Society of Surveyors, Tirana.

CAROSIO, A. (1998): Fehlertheorie und Ausgleichungsrechnung, Band 1, Auflage 1998, S. 340.

CRIPPA, B. (1996): Algoritmi e metodologie statistiche per la gestione degli elementi spaziotemporali die GIS dinamici. Dissertation, IGP-Bericht Nr. 253, 1/96.

FLACH, P. [1997]: Qualitätsmanagement in der geodätischen Praxis. VPK 4/97.

GEIGER A. (1996): Verzerrungs-Analyse, Interpolation and Approximation. Institut für Geodäsie und Photogrammetrie, ETH Zürich, Bericht Nr. 254. ISBN 3-906513-75-0, 1/96, pages 48

GRÊT, A., KLINGELÉ, E. (1998): Application of artificial Neural networks for Gravity Interpretation in 2D, Institut für Geodäsieund Photogrammetrie, Bericht Nr 279, 88 Seiten.

HABRICH, H., W. GURTNER, M. ROTHACHER (1998): “Processing of GLONASS and Combined GLONASS/GPS Observations”. Proceedings of the 32th COSPAR Scientific Assembly, Nagoya, Japan, July 12-19, 1998 (in press).

MARTIN-MUR, T. J., T. SPRINGER, Y. BAR-SEVER (1998): “Orbit Predictions and Rapid Products”. Proceddings of the 1998 IGS Analysis Center Workshop, ESA/ESOC, Darmstadt, Germany, February 1998, Dow, J. et al. (eds.), pp. 73-88, ESA/ESOC, Darmstadt.

MEID, A. (1998): Individual vs. Uniform Weighting of Measurements and Constraints in Industrial Measurement Networks. Presented paper at the Coordinate Measurment Systems Committee Conference ’98 in St. Louis; paper available on http://www.cmsc.org/-1998_presentations.htm

MUR, T. J. M., T. SPRINGER, Y. BAR-SEVER (1998): “Orbit Predictions and Rapid Products”. Proceedings of the 1998 IGS Analysis Center Workshop, Darmstadt, 9-11 February 1998, Dow, J. M. / Kouba, J. / Springer, T. (eds.), ESA/ESOC, Darmstadt.

ROTHACHER, M., G. BEUTLER, U. HUGENTOBLER, R. WEBER (1995a): “Analysis of about Three Years of GPS Orbits as Determined by the CODE Processing Center of the IGS”. Proceedings of the XXI. General Assembly of the International Union of Geodesy and Geophysics, Boulder, Colorado, July 2-14.

ROTHACHER, M., G. BEUTLER, L. MERVART (1995b): “The Perturbation of the Orbital Elements of GPS Satellites Through Direct Radiation Pressure and y-Bias”. Proceedings of the IGS Workshop "Special Topics and New Directions" Potsdam, May 15-18, 1995, Gendt, G. / Dick, G., pp. 152-166, GeoForschungsZentrum Potsdam, Potsdam, 1996.

ROTHACHER, M., L. MERVART, G. BEUTLER, E. BROCKMANN, S. FANKHAUSER, W. GURTNER, J. JOHNSON, S. SCHAER, T. SPRINGER, R. WEBER (1996): “Bernese GPS Software Version 4.0”. Astronomical Institute of the University of Berne, September, Bern, 1996.

ROTHACHER, M. (1997): “GPS Satellite Orbits, Orbit Determination, and the IGS”. Lecture Notes of the Nordic Autumn School on "Geodetic Applications of GPS", Bastad, Sweden, August 26-31, 1996, Nordic Geodetic Commission (NGK): Jonsson, Bo (ed.), pp. 55-108, Trycksam, Gävle, 1997, ISSN 0280-5731.

ROTHACHER, M., T. SPRINGER, S. SCHAER, G. BEUTLER (1998): “Processing Strategies for Regional GPS Networks”. Proceedings of the IAG General Assembly 1997, Rio de Janeiro, September 3-9, 1997, IAG Symposia, Brunner (ed.), 118, pp. 93-100, Springer Verlag, Berlin/Heidelberg/New York, 1998.

SPRINGER, T., G. BEUTLER, E. BROCKMANN, M. ROTHACHER (1996a): “Orbit Improvement of GPS Satellites Using GPS and SLR Observations”. EOS Transactions of the AGU 1996 Fall Meeting, November 12, 1996, 77, 46, pp. F135, 1996.

SPRINGER, T., G. BEUTLER, M. ROTHACHER (1996b): “Towards a New IGS Orbit Model”. Proceedings of the IGS Analysis Center Workshop 1996, Neilan, R. E. / Van Scoy, P. A. / Zumberge, J. F. (Eds.), pp. 279-297.

SPRINGER, T., M. ROTHACHER, G. BEUTLER (1996c): “Using the Extended CODE Orbit Model: First Experiences”. Proceedings of the IGS Analysis Center Workshop 1996, Neilan, R. E. / Van Scoy, P. A. / Zumberge, J. F. (Eds.), pp. 13-21.

SPRINGER, T., G. BEUTLER, M. ROTHACHER, S. SCHAER (1997): “Improving the GPS Orbit Model”. EOS Transactions of the American Geophysical Union, AGU 1997 Fall Meeting, December 8-12, 1997, San Francisco, Cal., AGU, 78, November, 46, pp. G22A-8, 1998.

SPRINGER, T., G. BEUTLER, M. ROTHACHER (1998a): “A new Solar Radiation Pressure Model for GPS”. Advances in Space Research: COSPAR Scientific Assembly, Nagoya, Japan, July 12-19, 1998, November, 1998.

SPRINGER, T., G. BEUTLER, M. ROTHACHER (1998b): “A new Solar Radiation Pressure Model for the GPS Satellites”. GPS Solutions, August, 1998.

SPRINGER, T., G. BEUTLER, M. ROTHACHER (1998c): “A new Solar Radiation Pressure Model for the GPS Satellites”. Proceedings of the IGS 1998 Analysis Center Workshop, Darmstadt, February 9-11, 1998, Dow, J. M. / Kouba, J. / Springer, T. (eds.), pp. 89-105, ESA/ESOC, Darmstadt, 1998.

SPRINGER, T., G. BEUTLER, M. ROTHACHER (1998d): “Impact of the improved GPS orbit model”. News Letter of the European Geophysical Society, XXIII General Assembly, Nice, France 20-24 April 1998, March, 66, pp. 124, 1998.

SPRINGER, T., G. BEUTLER, M. ROTHACHER (1998e): “Improving the Orbit Estimates of the GPS Satellites”. Journal of Geodesy, November, 1998.

SPRINGER, T., M. ROTHACHER, G. BEUTLER (1998f): “GPS Orbit Biases”. (Invited Poster), EOS Transactions of the American Geophysical Union, AGU 1998 Fall Meeting, December 6-10, 1998, San Francisco, Cal., AGU, 79, November, 45, pp. G71B-04, 1998.

SPRINGER, T. (1999): “Positioning, Timing, and Ranging using the Global Positioning System”. PhD. Thesis, Druckerei der Universität Bern, Bern, 1999.

WASSOUF, Y. (1997): La représentation conforme de l’espace à deux dimensions dans lui-même. Transformation conforme de deuxième degré. IGP-Bericht Nr. 268, 1/97.

WASSOUF, Y. (1997): Sur l’approximation d’une surface de second degré sur un ensemble des points de l’espace R3 Interpolation de la déformation. IGP-Bericht Nr. 273, 12/97.

WICKI, F. (1999): Robuste Schätzverfahren für die Parameterschätzung in geodätischen Netzen. Mitteilung Nr. 67, 1/99, Institut für Geodäsie und Photogrammetrie, ETHZ, ISBN Nr. 3-906467-16-3.

5 Geodynamics

CODE Contributions to Earth Rotation

by M. Rothacher and G. Beutler

CODE, like all other IGS Analysis Centers, is requested to deliver daily values of the x and y component of the Earth's rotation axis (actually the Earth-fixed coordinates of the ephemeris pole) and daily estimates of (excess) length day length (LOD). Polar motion (PM) and LOD time series with a 1-day time resolution, as produced by the IGS Analysis Centers, and the combined, official IGS series, as produced by the IGS Analysis Center Coordinator since May 1995, are unique. From such series it is possible to compute daily values of the three components of an „external“ angular momentum vector acting on the solid Earth. Such series may be compared with angular momentum series stemming from meteorology (called atmospheric angular momentum) or from oceanography.

Figure 5.1 shows daily angular momentum values as derived from the official CODE Earth rotation parameter (ERP) series for the year 1997 and the corresponding series stemming from the IERS Sub-bureau for Atmospheric Angular Momentum (AAM)(Salstein, 1997). The correlation is rather high for the first two components (top, correlation coefficients for x and y are 0.62 and 0.75, respectively), it is striking for the third component (bottom, left correlation coefficient 0.93). Figure 5.1 also gives power spectra for periods ranging between 1 and 30 days. We recognize (as was to be expected in view of the correlation coefficient) that the spectra of the two series are quite similar, but we also see significant differences. This material is not yet thoroughly analyzed.

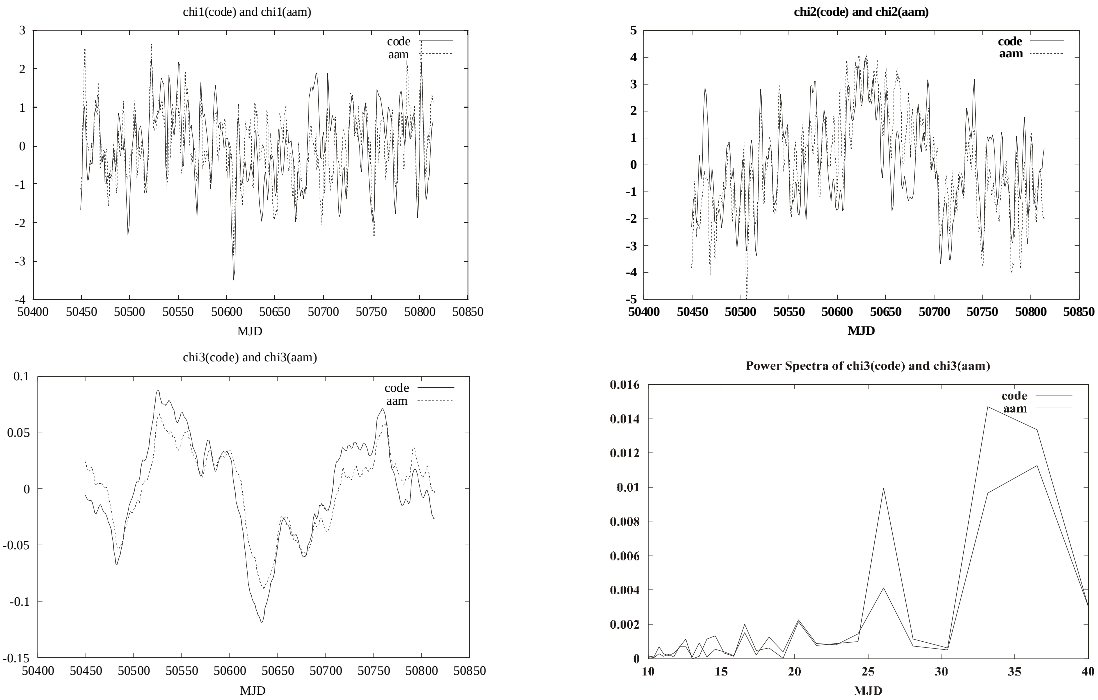


Figure 5.1: Three components of angular momentum as computed from CODE ERP series (solid line) and from meteorological data (taken from IERS ftp server); power spectrum in the domain 1-30 days for third component.

We refer to (Rothacher et al., 1998g) for more information concerning the official CODE ERP series.

Internally, CODE uses since January 1995 a 2-hour resolution to account for polar motion and LOD. Each component of this high-resolution polar motion series (and the corresponding integrated LOD series) is approximated by a straight line within each 2-hour sub-interval and continuity is enforced at the interval boundaries. The sub-daily variations of polar motion and UT correspond very well to models derived from oceanography using altimetry data. For more information we refer to (Rothacher et al., 1998f).

Earth rotation parameters are required to make the transition from the Earth-fixed to the inertial coordinate frames. The full set consists of polar motion (components x and y), UT1-UTC (or its first derivative, length of day, LOD), (precession plus) nutation in longitude and nutation in obliquity. Due to correlations with the orbit elements, satellite geodetic methods are not able to solve for UT1-UTC and the nutation offsets. They are, however, sensitive to the first derivatives of these terms. Since April 1994 nutation drifts in longitude and in obliquity are estimated for each day at CODE. From the first three years of this series it was possible to estimate nutation amplitudes for periods up to about 30 days with an accuracy comparable to the best VLBI estimates (which are based on a much longer time series). Figure 5.2 shows amplitude spectra for the CODE nutation drift series in obliquity and longitude (relative the IAU 1980 model). The spectra are very similar to the corresponding VLBI spectra. For more information we refer to (Rothacher, 1998d).

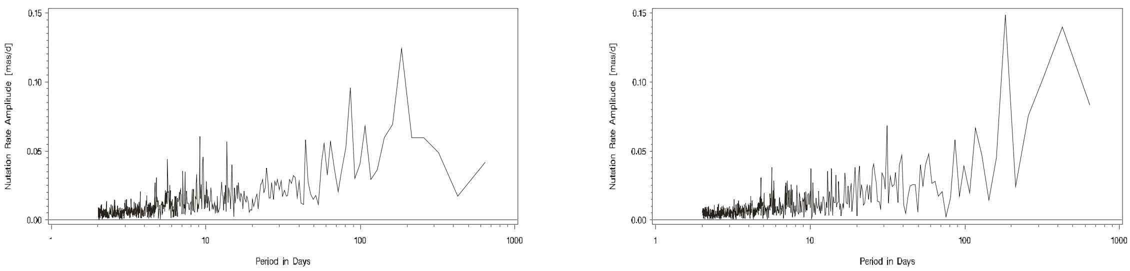


Figure 5.2: Amplitude spectra of CODE nutation drift estimates in obliquity (left) and in longitude (right).

We acknowledge that Drs. Robert Weber from TU Vienna, Jan Hefty from TU Bratislava, and Prof. Tom Herring significantly contributed to the „advanced CODE ERP activities“.

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

by A. Geiger,H.-G. Kahle, D. Schneider, A. Schlatter, 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 (see e.g. Jeanrichard, 1995), as well as terrestrial levelling lines carried out in Switzerland since the last century, have been used to assess the strain rate tensor in the Swiss Alps. 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 these 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 highly complex structure of 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. Also 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 contribution *Schlatter*).

Investigations of recent uplift rates in Switzerland using repeated first order levellings

by A. Schlatter

The study of recent crustal uplift in Switzerland using repeated first order levellings has a long tradition at the Swiss Federal Office of Topography (L+T), Wabern, and the Swiss Federal Institute of Technology (ETH) in Zurich. Already in the 1970s it was possible to confirm significant uplift rates in the Alps determined from first order levelling. Highly accurate observations and results have been available in Switzerland since the beginning of this century. The networks and bench marks were carefully maintained so that it was possible to include many of the original points in subsequent levelling campaigns. Today great emphasis is placed on choosing geologically stable terrain for establishing additional points, thus providing the possibility of obtaining significant results also in the future.

As part of the project LHN95 (cf. *Schlatter and Marti*: „The new national height system (LHN95) of Switzerland" in Section 1) the observations of the first and second order levelling lines have been systematically compiled since 1996 for digital processing in the kinematic adjustment. In addition, each year approx. 130 km of precision levelling lines are observed along the old lines. By including equally accurate lines of second order and new measurements in the kinematic adjustment, knowledge and understanding of the Alpine uplift are continually increased and improved. The following figure shows a general view of recent vertical movements in Switzerland resulting from the adjustment of the currently available observations.

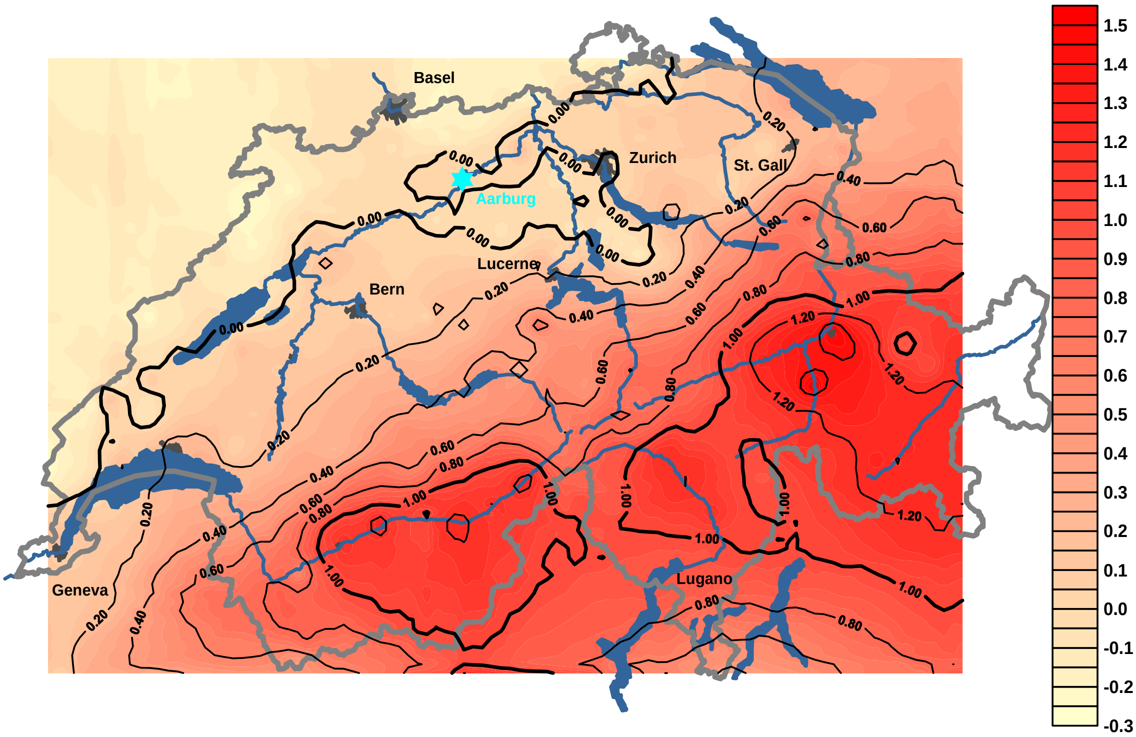


Figure 5.3: Recent vertical movements [mm/yr] referred to a station near Aarburg (displayed as a star).

Besides scientific purpose, private and public organizations are 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

In addition to tectonic effects, the comprehensive data set also revealed some rather surprising results: it was possible in 1997/98 to demonstrate that manmade subsidence of the entire rock formations in the Gotthard area play a crucial role in the uplift pattern. This effect is largely due to the drainage which occured during the construction of the Gotthard road tunnel between 1970 and 1980.

GPS, Seismology and INSAR in the region of the Adriatic/Hellenic plate boundary system

by H.-G. Kahle, D. Nuesch, J. Ansorge, E. Kissling, M. Cocard, F. Haslinger, and Y. Peter

While geodetic measurements allow to determine long-term crustal deformation, seismic data yield information about earthquake mechanisms and hence about the co-seismic movements. The detection of pre-seismic movements is of particular interest for earthquake prediction research. Rheological information can be obtained from post-seismic creep and deformation. It is only with this information that reliable estimates of seismic energy, stress release and rheological parameters of the earth‘s interior can be made. Very recently new satellites have enabled to detect crustal movements by remote sensing techniques using radar images. It deals with Radar - Interferomety, which has been proven already in airborne and spaceborne applications for establishing digital terrain models. The three technologies, satellite geodesy, seismology and Radar - Interferomety, have been applied in N-W Greece, one of the seismically most active areas of Europe to study the accumulation of strain and stress in the earth‘s crust.

In an area of about 100 x 100 km2 centered around the Ionian island of Kefalonia, a continuously measuring GPS-network has been set up to observe at the same time in the same area an earthquake network with mobile seismographs. With some connecting stations this network was tied to regional networks (West Hellenic Arc and Central Greece). The data are being processed interdisciplinary to compile a geodynamic model for the seismotectonic processes. SAR Images of the ERS –1/2- satellites of the European Space Agency ESA were used as data material for differential SAR Interferometry (INSAR). The work was conducted in the frame of the Inter-University-Collaboration „Earth Observation and Geoinformatics„ of the ETH and University of Zurich. On an international level a cooperation was set up with the TU Athens, Greece. First results can be found in Peter et al. (1999), Cocard et al. (1999), Kahle et al. (1999), Haslinger et al.(1999), and Egli(1998). A discrete subsidence of about 6 cm was detected by the INSAR method associated with the Konitsa earthquake sequence of August 1996 (M= 5.7). (Egli, 1998).

An application of differential SAR-interferometry (INSAR): The earthquakes from August 1996 in the region of Konitsa (Northern Greece)

by D. Nuesch, T. Egli, E. Meier , H.-G. Kahle, and Y. Peter,

New satellites (the European Remote Sensing satellite ERS2) have enabled crustal movements to be detected using differential interferometry of synthetic aperture radar images (Kahle, Nuesch and Mueller, 1996). Pairs of these images are used to calculate interferograms (Prof. Dr. D. Nuesch, Dr. E. Meier, T. Egli). A significant anomaly was found in connection with the Konitsa earthquake (August 1996, NW Greeece) (Egli, 1998). The ongoing GPS/INSAR research forms an integral part of the joint project between the ETH and the University of Zurich, entitled the Inter-University Collaboration for Earth Observation and Geoinformatics of the ETH/University Zürich (IPEG).

In August 1996 two medium-strength earthquakes occured in the area of Konitsa (near the greek-albanian border). The first event occurred on 5th of August with a magnitude of 5.7 at Richter-scale, the second one on the 20th of the same month with a magnitude of 5.3. In order to detect the topography displacements the 2-pass method of differential SAR interferometry was applied.

For the execution of the 2-pass method a digital elevation model (DEM) and at least two SAR scenes are required. The two SAR scenes are used to generate an interferogram (real interferogram). The phase of this interferogram correlates with topography and changes in topography. To analyze the Topographical displacements the topography-dependant part of the phase needs to be eliminated, requiring a DEM. The height values need to be recorded and converted to synthetic phase-values (synthetic interferogram). In a next step the phase-values of the real and synthetic interferogram have to be subtracted from each other. In this way residual phase-values are obtained, resulting in a differential interferogram, which is uniquely correlated to variations in the topography. However, before computing the amount of displacement, the influence of errors arising from the DEM or baseline-induced phasetrends have to be determined. For the phase investigation six suitable SAR scenes were found. From these six scenes 3 interferometric pairs were produced. But only two of them could be used for the interpretation. To generate the synthetic interferograms a DEM calculated from SPOT data was used.

A first interferometric pair was acquired during the ERS tandem-mission (mid-May 1996). As a result, the time difference between the two acquisitions was just one day, yielding a reference differential interferogram not influenced by any earthquakes. It was used to assess the DEM-accuracy, which was proven to be high in the range of the Konitsa plaine. For the most important interferometric pair of our investigation, data from July and August were acquired. The time difference between these two acquisitions is 35 days. It is during this time period that the two earthquakes mentioned above took place. Despite of the long time period between the two acquisitons, the coherence-values are unexpectedly high (about 0.5). This is probably due to the lack of major variations in the vegation during this time. In contrast to the differential interferogram acquired in May 1996, there are very obvious phase trends existing; two fringes are clearly visible. The two fringes mainly cover the Konitsa plaine and the hilly area further north of the plain. Comparing this July-August interferogram with the differential interferogram of May, we can exclude DEM-error as a primary phase influence source. With a height of ambiguity of 135m for the July-August pair a DEM-error would have been about 270m in magnitude. This is impossible, because otherwise the May pair would have displayed a similar of phase-pattern.

A baseline-induced phase trend as the cause for the two fringes can also be excluded, as filtering gave no evidence to support this. It can be shown that the differential phase from the fringe-margin to the fringe-centre represents a subside movement. Because of the soft subsoil of the Konitsa plaine, this is the expected displacement direction. In spite of a lack of geological maps, which would have aided in the determination of exact correlations between the differential fringes and the bedrock, two points should be noted: At the southeastern edge of the Konitsa plane, the fringes stop abruptly. In this area the mountains reach elevations of over 2000m a.s.l. This phase pattern can be explained by an abrupt transition between the soft subsoil of the Konitsa plaine and the step mountains. At the northern edge of this plaine the situation looks different. The fringes also cover some of the hilly region further north. Comparison with the topographical map indicates that this hilly area seems to be subject to much erosion, which implies soft subsoil and hence a reason for the spreading out of the fringes in this area.

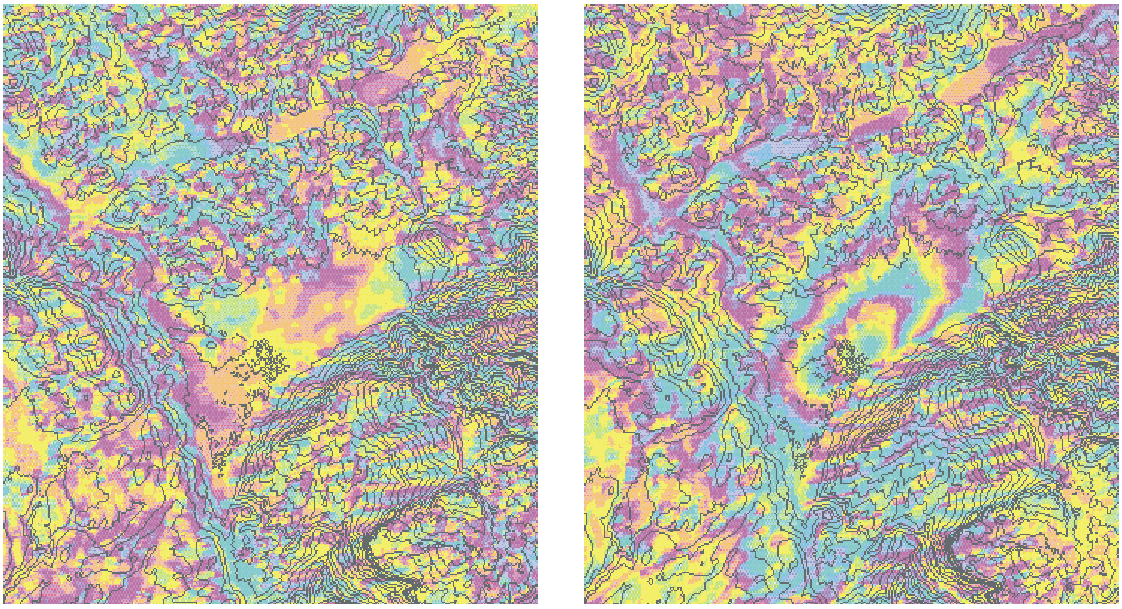


Fig. 5.4: Two differential ERS1 interferograms showing the area of the Konitsa plain. The left interferogram was acquired during the ERS1/2 tandem mission in May 1996, the right one in July and August after two earthquakes occured in this region. A local soil subsidence due to the impact of the two earthquakes is clearly visible in the right interferogram documented by the fringes in the middle (after Egli and Nuesch and Meier, 1999).

All the points mentioned above support a tectonic cause for these differential fringes. However, it is difficult to quantify the crustal movements exactly, because of too few differential interferograms with which to compare the data. Because one fringe corresponds to a slant-range difference of a half-wavelength (wavelength of ERS1/2=5.6cm), this also provides us with an estimate of the order of magnitude of the crustal displacement. That explains why a maximum subsidence of 2*1/2-wavelength (5.6 cm) was seen.

Active crustal deformation in the Marmara Sea region, NW Anatolia, inferred from GPS measurements

by H.-G. Kahle and C. Straub

One of the seismotectonically most active deformation zones in the Alpine-Mediterranean region is the North Anatolian Fault Zone (NAFZ) (e.g., McKenzie, 1972; Mueller and Kahle, 1993; Mueller et al., 1997). It runs from eastern Anatolia (41°E) parallel to the coast of the Black Sea all the way to the Marmara Sea over a length of more than 1200 km (Barka, 1992). The NAFZ is a right-lateral fault system, which forms the boundary between the Black Sea block (Eurasia), and the Anatolian plate. It connects the compressional regime in eastern Anatolia (Turkey) with the extensional domain in the Aegean Sea. Geologic evidence collected in the Marmara Sea region shows that the last phase of neo-tectonics started 3-4 m.y. ago, during Pliocene, and that it is still active (Pfister et al., 1997).

A dense network of 52 Global Positioning System (GPS) sites was used to determine the velocity field and strain rate pattern at the western end of the North Anatolian Fault Zone (NAFZ) in the Marmara Sea region, NW Anatolia. Based on four GPS campaigns carried out biannually between 1990 and 1996, the detailed kinematic field of crustal motion was calculated. The southernmost station shows an average rate of 22±3 mm/yr oriented westward relative to Istanbul (Eurasia). This value is indicative of the dextral strike-slip motion of NW Anatolia relative to the Black Sea. The GPS velocity field reveals that the sites located on the Thrace-Black Sea block show negligible motion relative to Istanbul. The GPS-based deformation pattern of three sections crossing the westward prolongation of the NAFZ is compared with neotectonic data. Both the GPS and the neotectonic data give clear evidence that most of the deformation occurs along a relatively narrow E-W oriented zone. This belt extends from the single fault trace of the NAFZ through the Gulf of Izmit, the Marmara Sea, the Sarköy region, and the Gulf of Saros into the North Aegean Trough (NAT). In addition, the cross sections show the increasing influence of the N-S oriented extension in the Aegean Sea region. From the comparison of the directions and rates of shear and normal strain deduced from GPS data with geologic and seismic observations it was concluded that the most active zone of dextral shear follows a line along Mudurnu Valley, the northern Marmara Sea and the Saros Trough where it joins the NAT (Straub et al., 1997).

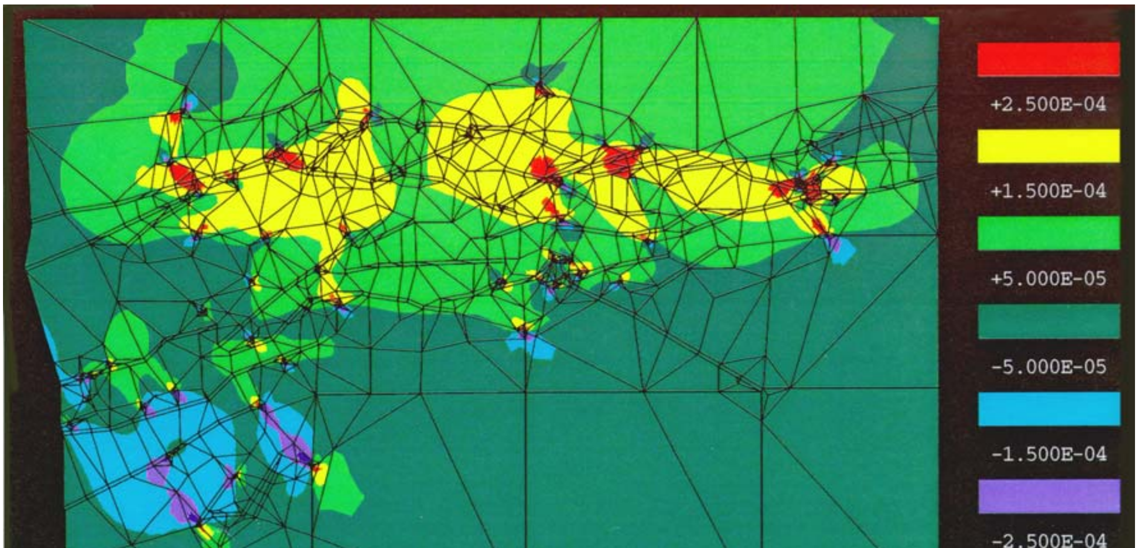


Figure 5.5: Shear strain rates for a Finite Element Model with constant Young's modulus and Poisson's ratio. GPS rates were used as boundary conditions. Positive values=dextral motion; negative=sinistral. Enhanced dextral shearing is seen along the northern strand of the North Analoian Fault Zone (NAFZ).

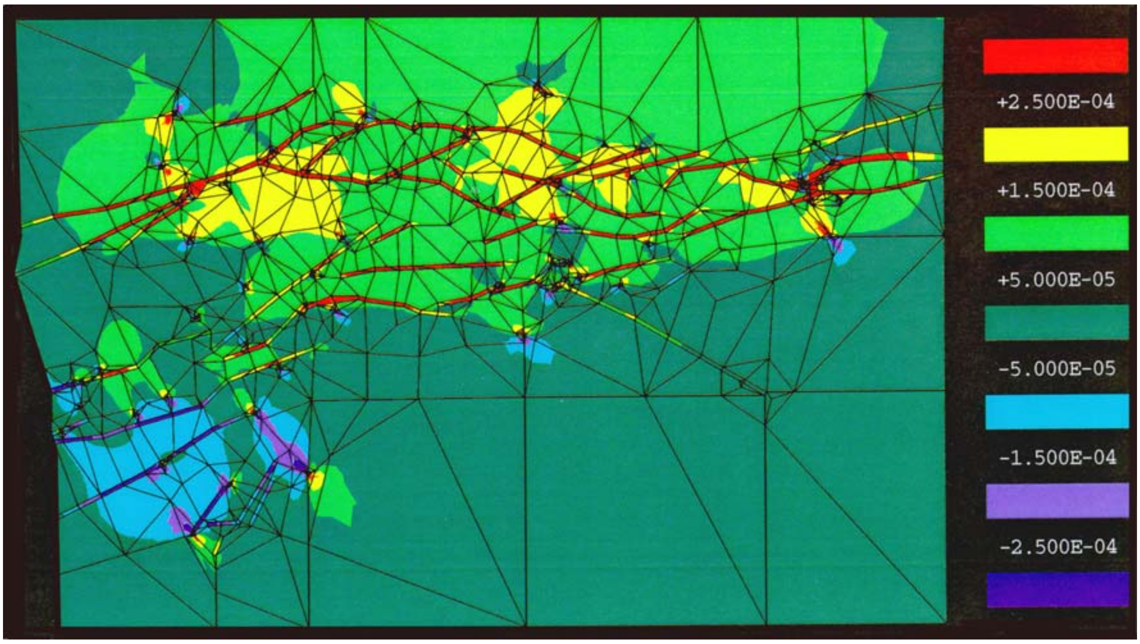


Figure 5.6: Same as Fig. 5.5 exept 16% reduced Young's modulus for the fault zones introduced. It is clearly seen that the shear processes are concentrated along the weakened zones (red color). There are areas (stepovers between fault segments) where no faults are known but the shear strain remains high. It is surmised that these regions are areas of enhanced seismic risk.

Geodynamic processes in the region of the Aegean microplate

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

The Mediterranean-Alpine region is the broad transition zone between the African/Arabian and Eurasian plates. From a recent analysis, using worldwide GPS data from the International GPS Service for Geodynamics (IGS), Argus and Heflin calculated a rotation rate of the African plate of 0.07°/Ma relative to Eurasia. This corresponds to a rate of 9 mm/a (N40°W) in the area of the Ionian Sea, central Mediterranean. While these relatively small displacement rates hold true for the African margin, the Eurasian margin in the Eastern Mediterranean is characterized by a completely different kinematic pattern, both in direction and rate. In addition to the overall shortening between the African and Eurasian plates other tectonic processes are active, such as rifting in the Straits of Sicily, extension in the Tyrrhenian Sea and rapid motion of the Anatolian/Aegean region. These processes add significantly (on the order of tens of mm/a) to the displacement field in the Eastern Mediterranean and are associated with frequent large-size earthquakes.

GPS derived strain accumulation in the Eastern Mediterranean

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

The GPS velocity field of the Eastern Mediterranean and Near East, based on measurements between 1988 and 1998, was used to determine crustal deformation strain rates and compare these with seismological data (Kahle et al., 1999). The strain rate field was calculated using the method of collocation. The East and Central Anatolian Fault Zones are associated with distributed left-lateral shear strain rates on the order of 50 nstrain/a. The Gulf of Iskenderun, which connects the East Anatolian Fault with the Cyprus arc, appears as an extensional feature with NW-SE oriented strain rates of up to 110 nstrain/a. The North Anatolian Fault Zone (NAFZ) is clearly expressed as a pronounced dextral strike-slip fault zone. In particular the western end of it is associated with strong right-lateral shear motion, reaching shear strain rates of up to 170 nstrain/a (see Fig. 5.7)

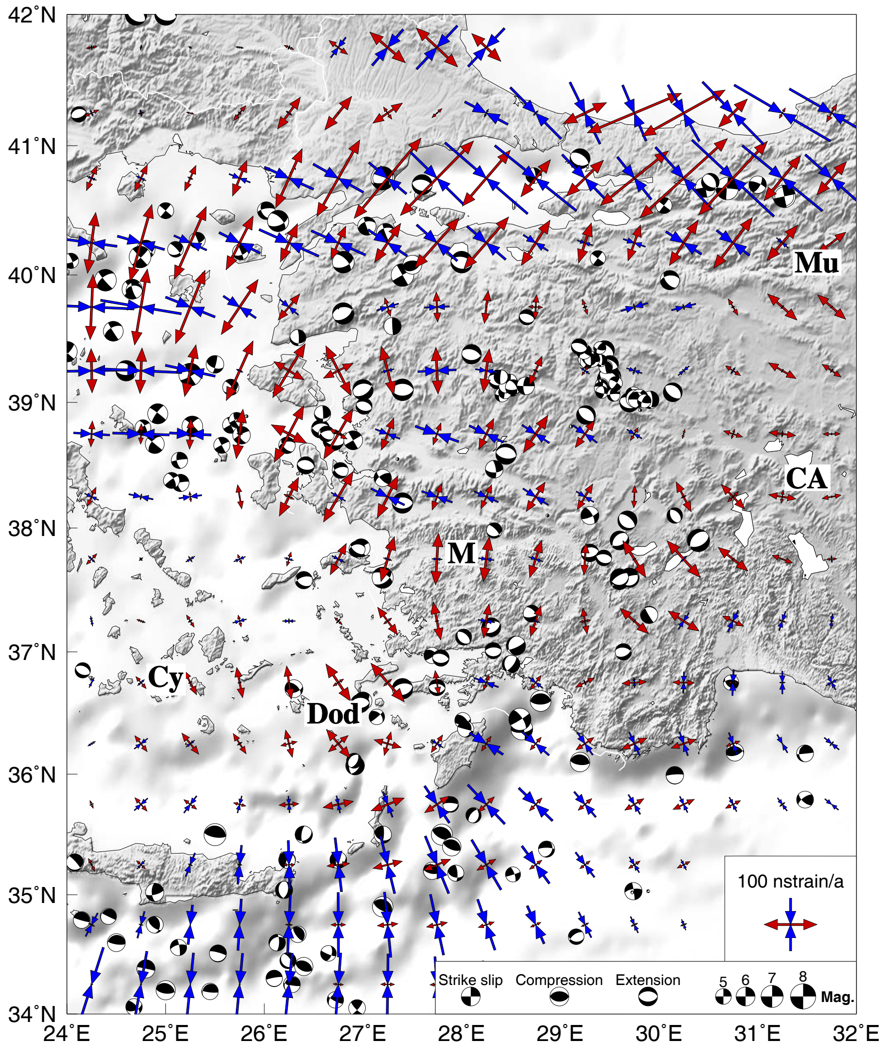


Figure 5.7: Principal strain rates calculated from the GPS velocity field obtained by the combination of the results from McClusky (1999) and Straub (1997). Blue arrows are shortening strain rates, red ones are extensional. Seismic focal planes solutions after Straub (1996) and http://www.seismology.harvard.edu/CMTsearch.html.
CA =Central Anatolia, Cy =Cycladic islands, M =Menderes Graben, Mu =Mudurnu Valley, Dod =Dodekanissa Islands. The relatively small strain rates around the Cy islands are on the order of the noise level.

The region following the line Marmara Sea, North Aegean Trough, northern central Greece, and the central Ionian islands is associated with strong right-lateral shear motion, with maximum shear strain rates of 180 nstrain/a ($180x10^{-9}$/a). In the central northern Aegean Sea, N-S oriented extensional processes prevail, reaching 100 nstrain/a. The southern Aegean is characterized by relatively small strain rates. Maximum extensional components of the strain rate tensor, reaching 150 nstrain/a in a N-S direction, are found in central Greece. The Hellenic arc is associated with moderate arc-parallel extension and strong compression perpendicular to it. Projections of the strain rates parallel to the major fault zones reveal that the northern Aegean is associated with strong dextral shearing (maximum 180 nstrain/a), accompanied by numerous large earthquakes in this century (Kahle et al., 1998).

Continuous GPS networks in Western Greece

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

The Kephalonia Fault Zone (KFZ) is an offshore fault system to the west of the island of Kephalonia, NE Ionian Sea, characterized by a deep bathymetric trough, striking at N20E with excessive water depths of more than 3000 m. From marine geophysical data it has been surmised that this trough is a transform fault which demarcates the north-western end of the Hellenic subduction zone. Fault plane solutions from earthquakes in the area of the KFZ have revealed right-lateral mechanisms. On the island of Kephalonia itself, thrusting was observed in the M=7.2 Kephalonia earthquake of 1953, where 85% of the houses were destroyed. In order to study the strain accumulation in detail and compare it with seismic stress released in earthquakes, a continuous GPS network has been installed across the KFZ operating at a sampling rate of 5 s. First results have revealed significant co-seismic motion associated with the Strofades earthquake of Nov. 18, 1997 (cf. star for station Keri, island of Zakynthos in Fig. Peter et al., 1998).

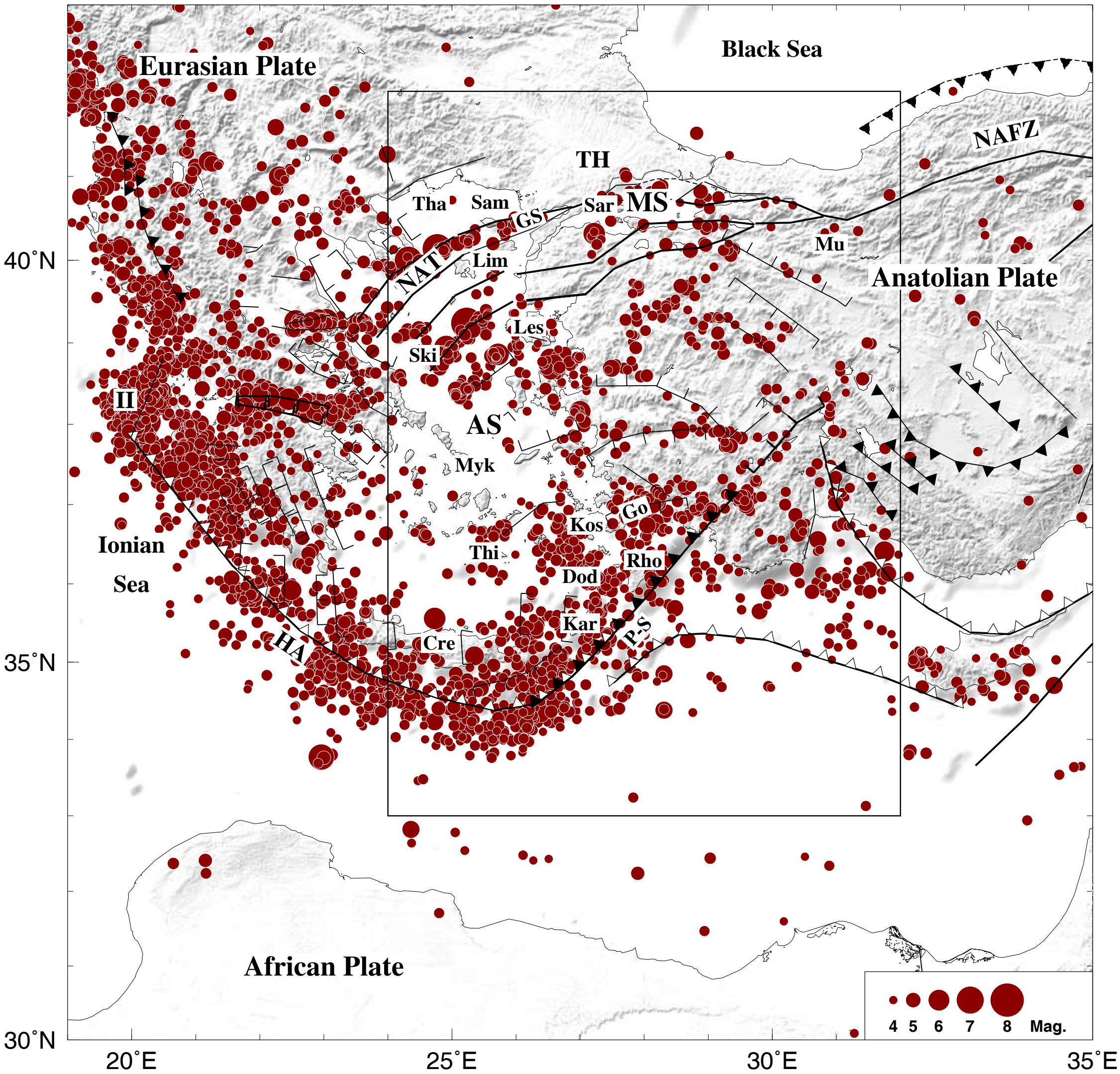


Fig. 5.8: Geodynamic framework of the Eastern Mediterranean and seismicity between 1979-1995 (After NEIC (1995)). The Aegean/Anatolian block is bounded in the north by the Northern Aegean Trough (NAT), the Marmara Sea (MS) and the North Anatolian Fault zone (NAFZ). The southern boundary is formed by the Hellenic arc (HA) and the Pliny-Strabo (P-S) troughs. The box shows the study area. AS=Aegean Sea, Cre=Crete, Dod=Dodekanissa islands, Go=Gokova graben, GS=gulf of Saros, II=Ionian Islands, Kar=Karpathos, Kos=Kos, Les=Lesvos, Lim=Limnos, Mu=Mudurnu, Myk=Mykonos, Rho= Rhodos, Sam=Samothraki, Sar=Sarkoy, Ski=Skiros, TH=Thrace, Tha=Thassos, Thi=Thira.

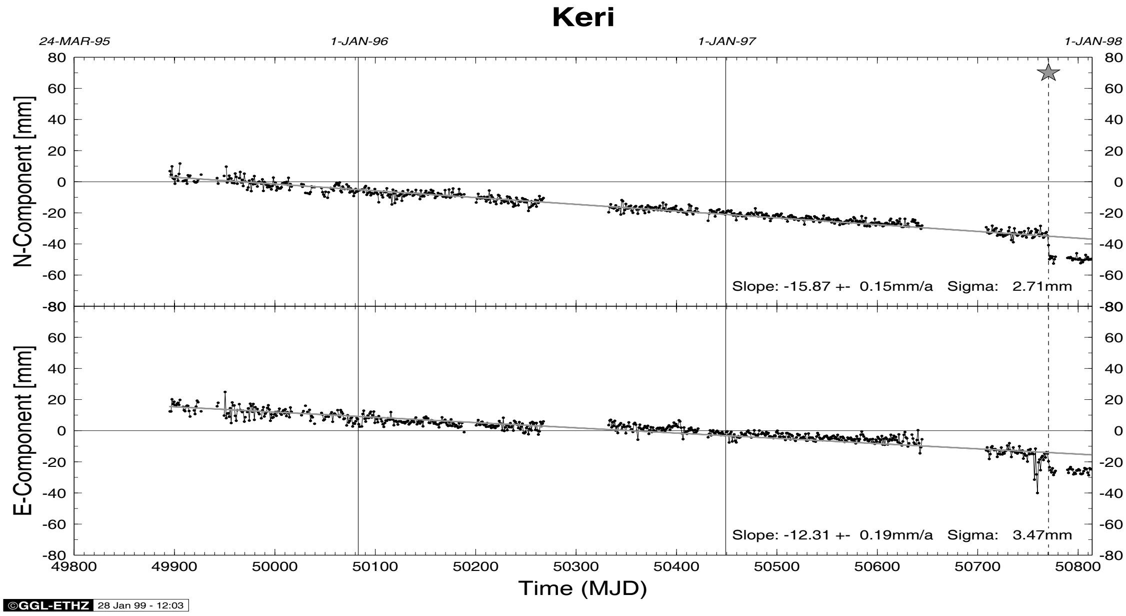


Fig. 5.9: Time series of the continuous GPS station Keri (Zakinthos Island) relative to Eurasia. The star marks the Strofades earthquake (Mw 6.6, 18 Nov. 1997), which epicenter is located about 40km south of the station. A distinct co-seismic displacement of the station in SSW direction is to be found in the solution.

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

by H.-G. Kahle

The „Working group of European Geoscientists for the Establishment of Networks for Earth-science Research" (WEGENER) was first established in the beginning of the 1980s as an interdisciplinary group centered on the application of space-geodetic techniques to the study of geodynamics in the Alpine-Mediterranean plate boundary region. In 1991, the WEGENER activity „Geodetic Investigations Related to the Kinematics and Dynamics of the African, Arabian and Eurasian Plates" was established as Special Commission SC6 of the International Association of Geodesy (IAG). WEGENER has promoted the development of space-geodetic activities in the Mediterranean and in the European area for the last fifteen years. It has contributed to the establishment of geodetic networks designed particularly for Earth science research. WEGENER presided by S. Zerbini, University of Bologna, has three scientific objectives which are related to plate-boundary processes, sea-level changes, and post-glacial rebound (Plag et al., 1997).

The Alpine-Mediterranean area is an extraordinary natural laboratory for the study of seismotectonic processes. The wealth of observations acquired in previous WEGENER activities will 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. A comprehensive overview of the evolutionary, structural and dynamic features of the broad transition zone between the African/Arabian and Eurasian lithospheric plates has been given by Mueller and Kahle (1993). It was shown that - superimposed on the large-scale counterclockwise rotation of the African plate (1st order plate boundary) - complex dynamic processes affect lithospheric fragments (2nd order plate boundaries) between the two major plates. What has been missing so far is a rigorous multidisciplinary interpretation of the individual geodetic, geophysical, geologic and neotectonic data sets. Therefore, most of the deformation processes are not yet fully understood. The height components of recent plate tectonic movements and deformations on a regional scale are to this date almost completely unknown. Results from seismic tomography of the lithosphere and mantle below the European-Mediterranean region indicate the presence of subducted lithosphere below the entire Alpine-Mediterranean collision belt (Spakman et al., 1993). There is only one region, the Hellenic arc extending from the Peleponnesus to Rhodes, below which the subducted slab is imaged as a continuous zone from the surface to great depth. In other regions the subducted lithosphere seems to be detached from the upper part of the lithosphere. The evolution of slab detachment in space and time along strike of convergence zones, appears to be the main engine driving the kinematic and tectonic evolution of the Alpine-Mediterranean region during the Tertiary to present (Wortel and Spakman, 1992). Mapping the kinematic pattern (horizontal and vertical motions) in specific areas renders important kinematic data as boundary conditions on modeling the dynamics of arc evolution and back-arc basin development. Specific areas of interest are the Apennines-Calabrian arc, the Hellenic and Cyprus arcs, as well as the Carpathian arc. Significant recent tectonic results from space geodetic observations include:

Detection of southwestward motion and counterclockwise rotation of the Anatolian block

Estimates of present-day rates of strain accumulation along the North Anatolian fault from the Karliova triple junction to the Sea of Marmara, and along the East Anatolian fault

- Detection of northward motion of the Arabian plate
- Detection of coseismic and postseismic displacements for the Erzinçan earthquake of March 1992
- Detection of counterclockwise rotation of the Anatolian block and rapid southwesterly motion of the southern Aegean region
- 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 northern Dead Sea fault.
- Detection of northward motion of the Arabian plate
- Crustal shortening/extrusion and associated mountain building processes in the Caucasus
- The role of the Kephalonia fault system as important part of the boundary between the Apulian and the Aegean microplates

One important new technique involves interferometric SAR (INSAR) which will be applied in conjunction with continuous GPS monitoring (CGPS). This allows for the determination of the space and time variations of the regional strain and stress tensors. Both GPS and INSAR demand for atmospheric modeling including water vapor radiometry and solar spectrometry (see e.g. Sierk et al., (1997)).

An important application of geodetically determined strain rates is the comparison with seismically estimated moment tensors for seismic hazard assessment. Based on SLR observations apparent deficits in seismically-released strain were localized in the Eastern Mediterranean (Jackson et al., 1994), particularly in the SE Aegean and Central Greece. Strain rate tensor and velocity tensor calculations based on seismic events were used to determine active crustal deformation from the Azores triple junction to the Middle East (Kiratzi and Papazachos, 1995). Similarly, shortening across the Caucasus, constrained by GPS observations at about 10 mm/a (Reilinger et al., 1997) is substantially faster than indicated by rates deduced from summing seismic moment tensors (Jackson and McKenzie, 1988). In summary the following scientific issues are addressed:

(I) First-Order Plate Boundaries:

- Relative rotation Africa/Eurasia, Arabia/Eurasia and Arabia/Africa
- Continent/continent collision (Alps, Carpathians, Eastern Turkey/Caucasus, Tell-Atlas)
- Ocean/ocean convergence (Gibraltar Arc)

(II) Second-Order Plate Boundaries:

- Distributed strain across the Hellenic/Adriatic plate boundary zone
- 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
- The Black Sea tectonic regimes

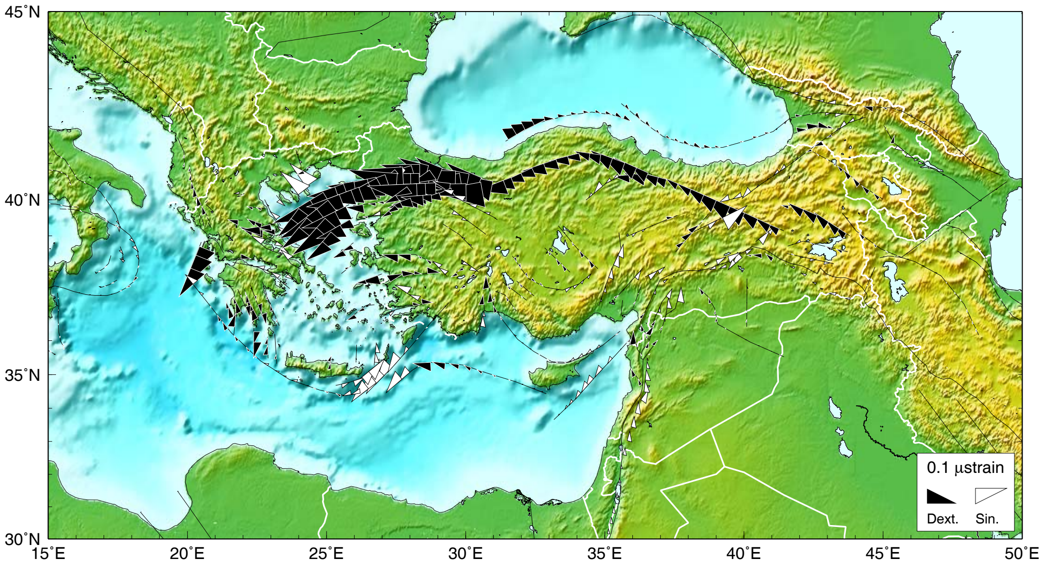


Fig. 5.10: Shear strain rates projected onto major fault structures. The NAFZ and its westward continuation along the NAT, passing Central Greece and the KFZ are the dominant shearing structures of the Eastern Mediterranean. Shear-strain rates of sinistral type prevail in the area east of Crete, towards the island of Rhodes. The southern Aegean Sea and central Anatolia are shear-strain free regions.

NE-SW oriented portions of the NAFZ are compressional and NW-SE oriented are extensional, thereby indicating restraining and releasing stress behavior, possibly due to transpressional and transtensional mechanisms. Central Anatolia and and the south-western Aegean Sea are nearly strain-free. The strain field in western Anatolia is extensional. The principal axes of extension are varying around N-S direction with strain rates of up to 85 nstrain/a. The extensional areas mostly coincide with graben features.

The Hellenic arc is occupied by compressional strain rates. Large extensional components of the strain rate tensor are found in Central Greece, with a maximum of 120 nstrain/a centered around the Gulf of Corinth. In general, the areas of high geodetic strain rates are accompanied by distinct seismic clusters whereas the strain-free regions are nearly aseismic (Kahle et al., 1999).

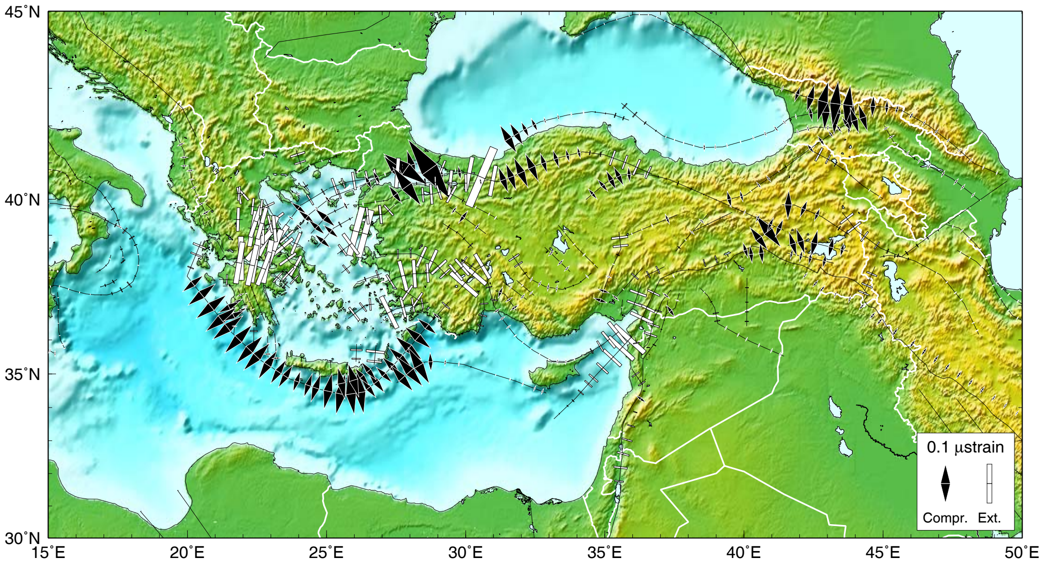


Fig. 5.11: Normal strain rates projected onto major fault structures. Extension governs western Anatolia, the Aegean Sea, Central Greece, and the Gulf of Corinthos, in particular. The WHA is occupied by compression. The areas around the Marmara Sea are characterized by both extensional and compressional strain rates. The NE-SW trending portions of the NAFZ are associated with compression, the NW-SE oriented segments with extension. This can be related to transpressional and transtensional stress behavior along the NAFZ.

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

by B. Bürki, M. Cocard, H.-G. Kahle, and S. Zerbini

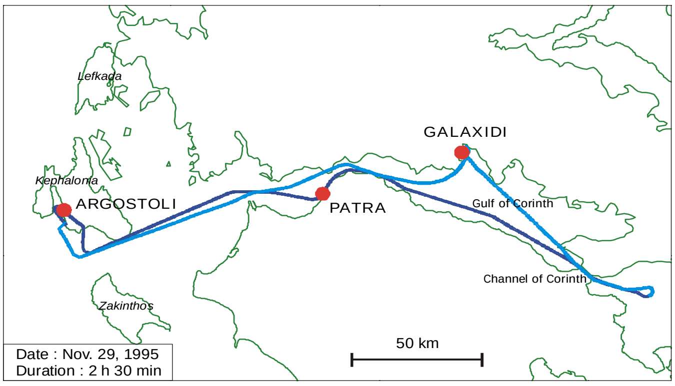
Sea Level Fluctuations in the Mediterranean and their Interactions with Climate Processes and Vertical Crustal Movements were studied jointly within the EU Project SELF II. SELF II used the determination of absolute sea level and its variations to study the present and past interactions between the ocean, the atmosphere and the Earth's crust, and to develop appropriate models to assess future aspects.
Main topics 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

Particular objectives 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 applied with the 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.

Experiments have revealed differential path delays of the GPS radio signals on the order of several cm (Sierk et al., 1997). In SELF II also Airborne Laser Profiler Systems, including differential GPS, inertial navigation and attitude sensors, were used to determine the sea surface heights. Experiments have been carried out in the Ionian and Aegean Seas (Cocard et al., 1998; Kahle et al.,1998). For calibration purposes well-distributed tide gauges and buoys, carrying GPS receivers, were overflown. ERS1 and ERS2 altimetry passes crossing the area were also recorded (Kahle et al., 1997). SELF II is based on the collaboration of Italy, Greece, France, U.K., Germany, Spain, Bulgaria, Russia and Switzerland. It forms an integral part of ILP theme 1. Coordinator is Prof. Dr. S. Zerbini of the University of Bologna. Detailed calibration studies have been carried out over the lake of Geneva, Switzerland (Favey and Schlatter, 1998).



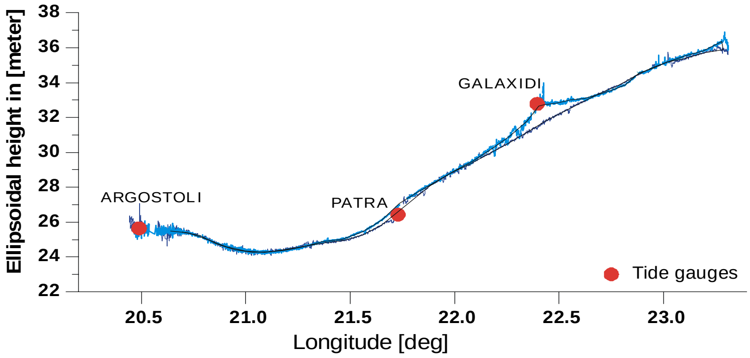


Figure 5.12: Measured ellipsoidal heights along an E-W oriented profile in the Ionoian Sea (Greece) between Argostoli (isle of Zakinthos) and the Gulf of Corinth (upper graph). The ellipsoidal heights of the tide gauges overflown are marked as red dots.

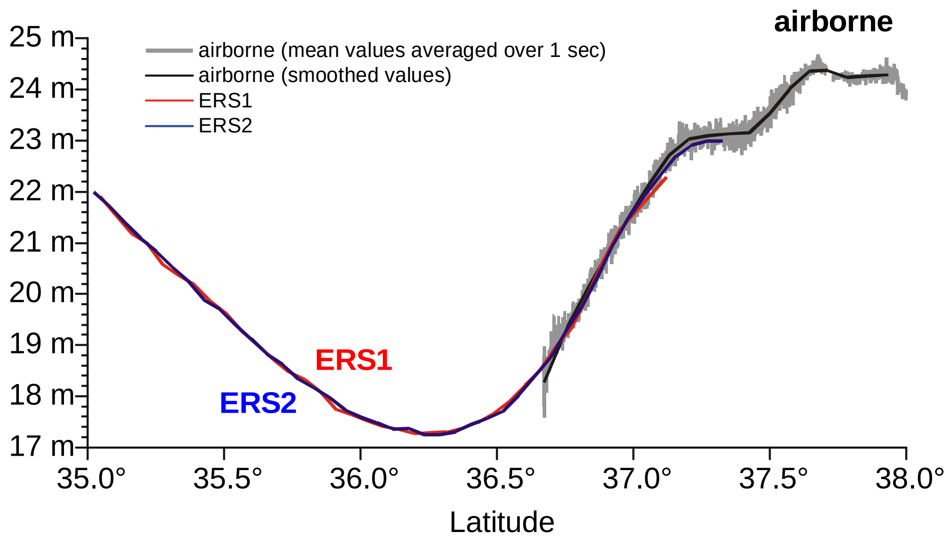


Figure 5.13: Comparison of the ellipsoidal height of the sea surface along a profile over the Ionian Sea as observed by spaceborn radar (ERS1/2) and airborne laser altimetry.

Regional crustal deformation, caused by the 1997 Cariaco earthquake, from repeated GPS observations.

by H. Drewes, K. Kaniuth, M. Hoyer, H.-G. Kahle, E. Wildermann, M. Cocard, A. Geiger, and M. Cerniar

A precise geodetic network of about 20 stations has been installed along the Bocono-El Pilar fault system in Venezuela. This network was observed during 3 GPS campaigns in 1993, 1996 and 1999. As a result an overall crustal deformation pattern has been obtained which clearly shows differential movement between the South American and Caribbean plates. The deformations are on the order of cm/a. Immediately after the Carriaco 1997 earthquake in eastern Venezuela, a repetition measurement of the network was performed in the vicinity of the epicenter. The results reveal relative displacements between sites north and south of the fault on the order of 20 cm. In March 1999 an additional GPS campaign has been carried out to study the ongoing deformation process (Drewes et al., 1999).

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

by H.-G. Kahle., M. Cocard., Y. Peter, P. Cross, P. England, B. Parsons, P. Briole, H. Lyon-Caen, B. Ambrosius, P. Clarke, and P. Cruddace

This project is funded with in EU Framework IV Environment and Climate Program (Seismic Risk): EU-Project PL 971151. Its objectives are 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.

-

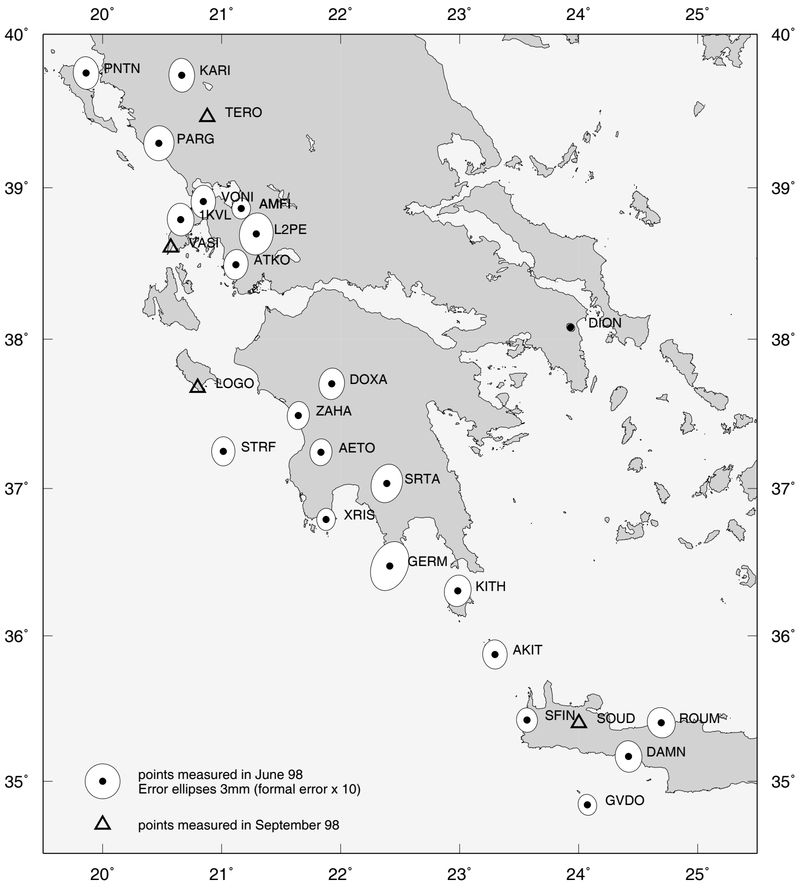


Figure 5.14: GPS stations observed in the WHA98 campaign of July 1998. Error ellipses show the formal error of the GPS solution. Stations marked with a triangle were observed in a secondary campaign in September 1998.

State of work of Swiss group (ETH)

- Two GPS campaigns in NW-Greece (Reoccupation of WHA sites)
- Integration of the data from the CGPS network CION
- Maintenance and management of the reference station at Kastoria (NW-Greece)
- Integration and reprocessing of data collected between 1990 and 1998
- SING status reports at University College London (UK)

Current publications: (Clarke et al., 1998, Kahle et al., 1999).

Geodynamics Study of the Yellowstone Caldera

by E. Klingelé,H.-G. Kahle,F. Arnet,R. Smith,C. Meertens, and D. Dzurisin

Monitoring of height changes from 1923 to 1993 in the Yellowstone caldera, north-east of Wyoming, USA, showed high rates of vertical movements. An uplift of 0.8 mm/year betwenn 1923 and 1984 and a down lift of around 14 cm since then. Gravity measurement carried out between 1977 and 1993 showed and increase of g up to 60 μgal until 1986 and a decrease of the same amount until 1993. In addition, horizontal displacements up to 3 cm towards the middle of the caldera were observed. The main objective of the monitoring of height and gravity changes was to develop theoretical models that allow better understanding of the mechanics of this area.

Static finite-element models were developed taking into accout only pure elastic material and no fault zone. These models cannot explain simultaneously the measured horizontal and vertical displacements. Therefore, the upper part of the Yellowstone caldera cannot be considered as an elastic medium. At the present stage of deformation, the gravity changes determined are not significantly contributing to distinguish between different kind of models, e.g. between model with only temperature changes or one with active pressure. The displacements must be at least five to ten time larger than those measured before the gravity changes as displayed in fig. 5.15 can significantly contribute to sustain or to reject one of the models (Arnet et al., 1997).

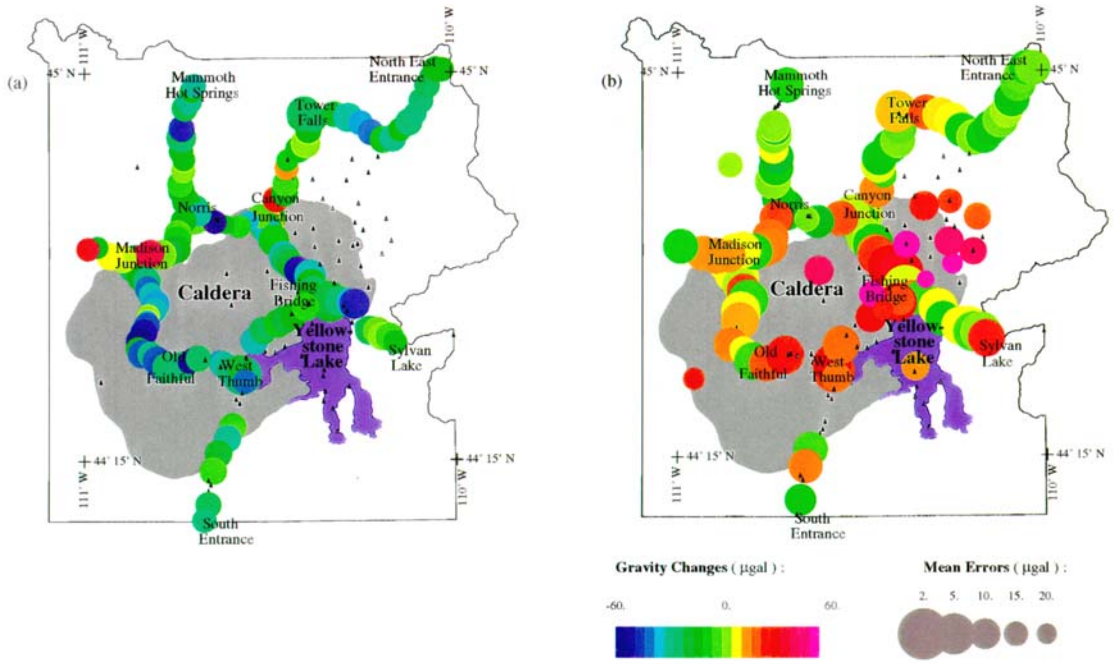


Fig. 5.15: Observed gravity changes 1977-83 (left) and 1987-93(right) in the area of the Yellowstone caldera. The green and blue dots indicate land uplift (reduced gravity values), yellow and red dots indicate land subsidence (increased gravity values). The size of the dots are drawn proportional to the corresponding rms.

Determination of the contemporary state of stress in the Jura Mountains and the Molasse basin by slotter tests.

by A. Becker and E. Klingelé

In the frame of this project twenty-two sites were visited and the contemporary state of stress measured by means of a bore slotter instrument. All the measurement is already processed. With these results it could be considered that the recent tectonic state of stress of the whole Jura area is now known. It is possible to differentiate five different provinces of stress. One with a NW-SE to E-W orientation of S_H (S_H = Maximal horizontal principal stress) located in the tabular par of the chain; a central province with a NNW-SSE to NNE-SSW orientation of S_H extending between Baden, The Vallée de Joux and Belfort. The third province in the region of Besançon shows a NW-SE to E-W orientation of S_H. The southern province located in the external Jura and in the Bresse graben has an N-S to NE-SW orientation of S_H. Finally the Southeast province with an NE-SE to E-W orientation of S_H which cover an area located south and west of Geneva. All the limits of these provinces are not correlated with any known tectonic lines of the Jura Mountains. From this fact it could be concluded that with a high probability the Jura Mountain is today not an active thin-skinned folded belt.

Contribution to Glacier Volume Change Monitoring by Airborne Laser Scanning

by E. Favey, A. Geiger, G.H. Gudmundsson, and A. Bauder

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 generation 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.

The potential of an integrated airborne laser scanning system -comprising of a laser scanner, precise differential GPS, and a gyro platform - for DEM generation of firn areas is currently being assessed. As part of a pilot project aimed at determining the mass-balance distribution of Unteraargletscher, Bernese Alps, Switzerland, without the use of in-situ information, ALS measurements were conducted in 1997 and 1998. The ALS part of the 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.

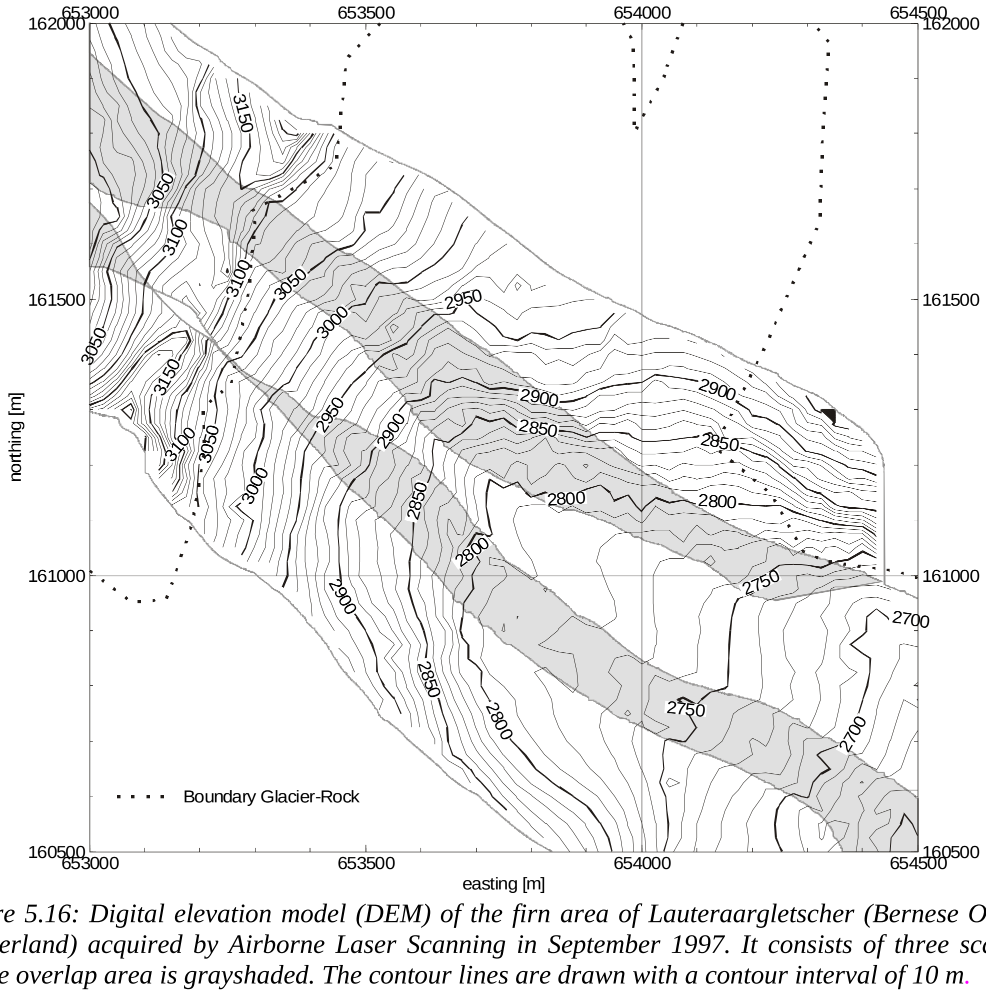


Figure 5.16: Digital elevation model (DEM) of the firn area of Lauteraargletscher (Bernese Oberland, Switzerland) acquired by Airborne Laser Scanning in September 1997. It consists of three scan paths whose overlap area is grayshaded. The contour lines are drawn with a contour interval of 10 m.

Bibliography Section 5

Abbreviations:

AGU	=	American Geophysical Union
EPSL	=	Earth and Planetary Science Letters
ETHZ	=	Eidgenössische Technische Hochschule Zürich
GJR	=	Geophys. J. Royal. astr. Society (now: Geophys.J.Int)
IAG	=	International Association of Geodesy
IGP	=	Institute of Geodesy and Photogrammetry
IUGG	=	International Union of Geodesy and Geophysics
JGR	=	Journal of Geophysical Research.
NFP	=	Swiss National Research Program
SANW	=	Schweiz. Akademie für Naturwissenschaften (Swiss Academy of Sciences)
SGK	=	Schweiz. Geodätische Kommission (Swiss Geodetic Commission)
VPK	=	Vermessung, Photogrammetrie, Kulturtechnik

ARNET, F., KAHLE, H.-G., KLINGELÉ, E, R. SMITH, MEERTENS, C. and D. DZURISIN (1997): Crustal deformation of the Yellowstone volcanic field inferred from temporal gravity changes and supplementary leveling and GPS data. Geophysical Research Letters, 24, No. 22: 2741-2744.

BAKER, T., CERUTTI, G., CORRADO, G., KAHLE, H.-G., MARSON, I., MUELLER, M.V., PARADISSIS, D., PEZZOLI, L., PLAG, H.P., POMREHN, W., RICHTER, B., ROMAGNOLI, C., SPENCER, N., TOMASI, P., TSIMPLIS, N., VEIS, G., VERRONE, G., WILSON, P. and S. ZERBINI (1995): Sea level fluctuations: Geophysical interpretation and environmental impact (SELF). In: I. TROEN (ed.), Proceedings. Symposium on Global Change: Climate change and impacts. Copenhagen. Eur. Comm. Sci. Res. Devel., EUR 15921 EN: 323-338.

BEUTLER, G. and DREWES, H. (1997): CSTG activities between 1995 and 1997 –review and position paper. In: Int. Ass. Geodesy (IAG) CSTG Bulletin No. 13: 7-14.

BÜRKI, B., KAHLE, H.-G., MÜLLER, M.V. and A. GEIGER (1995): A critical assessment of precise height determinations using GPS, water vapor radiometry and Meteo modeling: experiences in the SELF project. Annales Geophysicae. Suppl.1 to Vol. 13. Abstract, p. C 162.

BÜRKI, B. und H.-G. KAHLE (1995): Mikrowellen-Wasserdampfradiometrie für hochgenaue Messungen mit GPS. VPK, 4/95: 232-240.

BÜRKI, B., SIERK, B., KRUSE, L.-P., KAHLE, H.-G., LISOWSKY, M., BEVIS, M., and A. DODSON (1999): Field experiment for an integrated study of tropospheric water vapor at Hawaii. Annales Geophysicae. In press.

CLARKE, P., DAVIES, R., ENGLAND, P., PARSONS, B., BILLIRIS, H., PARADISSIS, D., VEIS, G., CROSS, P., DENYS, P., ASHKENAZI, V., BINGLEY, R., KAHLE, H.-G., MÜLLER, M.V. and P. BRIOLE (1998): Crustal strain in Central Greece from repeated GPS measurements in the interval 1989-1997. Geophysical J. Int., 134, No.4, Oct.: 195-214.

COCARD, M., GEIGER, A., KAHLE, H.-G., PETER, Y., HÜBSCHER, R., GUGGER, ESCHER, M., BAUMBERGER, M., VEIS, G., MILAS, P., ZISSOPOULOS, T., RAPTAKIS, K., FELEKIS, S. and D. PARADISSIS (1996): Sea surface heights from precise DGPS and Laser altimetry: First results from the Ionian Sea Project. Annales Geophysicae. Suppl.1 to Vol. 14. Abstract, p. C 219.

COCARD, M., KAHLE, H.-G., PETER, Y., VEIS, G., PARADISSIS, D. and S. FELEKIS (1996): The state of the permanent GPS network covering the deformation field across the Ionian Islands. 80. Journees Louxembourgoises de Géodynamique. Proceedings Walferdange, Louxembourg.

COCARD, M., GEIGER, A., KAHLE, H.-G., VEIS, G., MILAS, P. (1997): Regional sea surface determination by using Airborne Laser techniques. Annales Geophysicae. XXII General Assembly of European Geophysical Society (EGS). Annales Geophysicae, Part I. Suppl.I to Vol 5, C191.

COCARD, M., GEIGER, A., KAHLE, H.-G., VEIS, G., MILAS, P. (1997): Airborne Laser altimetry: First flights, analysis and preliminary results from the Ionian Sea within SELF II Project. Annual report

COCARD, M. (1998): Airborne Laser Altimetry. Advanced study course: Environment and Climate Programme of the Commission of the European Union. Sea level changes on micro to macro time scales: Measurements, modeling, interpretation and application.. In press. Proceedings Summer School Kos, Greece.

COCARD, M., KAHLE, H.-G., PETER, Y., GEIGER, A., VEIS, G., FELEKIS, S., BILLIRIS, H. and D. PARADISSIS (1999): New constraints on the rapid crustal motion of the Aegean region: recent results inferred from GPS measurements (1993-1998) acrosss the West Hellenic Arc, Greece. Earth and Planetary Science Letters Submitted.

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): An interdisciplinary approach to studying seismic hazard throughout Greece. IUGG Proceedings. In press.

DENYS, P., CROSS, P., VEIS, G., BILLIRIS, H., PARADISSIS, D., ASHKENAZI, V., BINGLEY, R., ENGLAND, P., CLARKE, P., KAHLE, H.-G. and M.V. MÜLLER (1995): GPS networks for determining the accumulation of current crustal strain in central Greece. Proceedings of 1st Turkish International Symposium on deformations, Vol. 2: 748-758. Istanbul.

DREWES, H., KANIUTH K., STUBER, K., TREMEL, H., KAHLE, H.-G., STRAUB, C., HERNANDEZ, N., HOYER, M. and E. WILDERMANN (1995): The CASA '93 GPS campaign for crustal deformation research along the South Caribbean Plate Boundary. J. Geodynamics, vol. 20, no. 2: 129-144.

DREWES, H., KANIUTH, K., STUBER, K., TREMEL, H., HERNANDEZ, N., HOYER, M., WILDERMANN, E., KAHLE, H.-G. and C. STRAUB (1998): Deformaciones de la Corteza terrestre a lo largo del limite de las placas del Caribe y de Sudamerica en Venezuela determinadas por el proyecto CASA. Proceedings Maracaibo Symposium.

DREWES, H., KANIUTH K., STUBER, K., TREMEL, H., HERNANDEZ, N., HOYER, M., E. WILDERMANN, and H.-G. KAHLE (1999): Regional crustal deformation caused by the 1997 Cariaco earthquake from repeated GPS observations. EOS Trans. AGU, 80(17), Spring Meet. Suppl., S228.

EGLI, T. (1998): Eine Anwendung der differentiellen SAR-Interferometrie: die Erdbeben vom August 1996 in der Region Konitsa (Nord-Griechenland). Master Thesis. Geographical Institute University of Zurich.

GEIGER, A., COCARD, M., PETER, Y. and H.-G. KAHLE (1995): Determination of sea surface heights by precise DGPS and laser altimetry. Annales Geophysicae. Suppl.1 to Vol. 13. Abstract, p. C 150.

GEIGER, A., SCARAMUZZA, M., COCARD, M., KAHLE, H.-G., LANG, H., AEBERSOLD, R., MEIER, B. and A. DOSÉ. Testing GPS approaches for civil aviation in the Swiss Alps. In: Brunner, F. (ed.) Int. Ass. Geodesy Symposia, Vol. 118: 351-356. Advances in Positioning and Reference Frames. Springer Verlag Berlin.

GEIGER, A., COCARD, M., KAHLE, H.-G., and Y. PETER (1999): On error estimates of GPS derived strain rate fields. Geophys. Res. Abstr., 1,1: 201.

GEIGER, A., COCARD, M., SCARAMUZZA, M., KAHLE, H.-G. and E. FAVEY (1999). The mutual impact of modern kinematic methods and airborne geosciences. IUGG proceedings. In press.

GLAUS, R., BÜRKI, B. and H.-G. KAHLE (1995): Recent results of water vapor radiometry in assessing vertical lithospheric movements by using space geodetic radiowave techniques. J. Geodynamics, Vol. 20, No. 1: 31-39.

HASLINGER, F., KISSLING, E., ANSORGE, J., HATZFELD, D., PAPADIMITRIOU, E., KARAKOSTAS, V., MAKROPOULOS, K., KAHLE, H.-G., and Y. PETER, Y. (1999): 3D crustal structure from local earthquake tomography around the Gulf of Arta (Ionian region, NW Greece). Tectonophysics, 304: 201-218.

HEFTY, J., R. WEBER, T. SPRINGER (1997): „Possibilities of Observation of Atmospheric Tides by GPS". Proceedings of the Journées 1997, Prag, September 1997, Vondrak, J./Capitaine, N. (eds.), Observatoire de Paris, 1997.

JEANRICHARD, F. (Ed.), (1995): Dreidimensionales Testnetz Turtmann 1985-1993, Teil II (GPS-Netz). Authors: Beutler, Geiger, Rothacher, Schaer, Schneider and Wiget. Geodätisch-geophysikalische Arbeiten in der Schweiz, Volume 51, 169pp. Swiss Geodetic Commission (Ed.).

KAHLE, H.-G., MÜLLER, M.V., PETER, Y., COCARD, M., VEIS, G., PARADISSIS, D. and S. FELEKIS (1995): The break-up of western Greece near the Ionian Islands as inferred from GPS measurements. Abstract. Fall Meeting American Geophysical Union (AGU). EOS, Supplement, Nov. 7: F 636.

KAHLE H.-G., M.V. MÜLLER, Y. PETER, M. COCARD, G. VEIS, D. PARADISSIS, S. FELEKIS (1995). The break-up of western Greece near the Ionian Islands as inferred from GPS measurments. Eos Trans. AGU, Nov. 7: Fall Meet. Suppl., F636, 1995.

KAHLE, H.-G., BARKA, COCARD, M., PETER, Y., A., REILINGER, R.and G. VEIS (1998): Geodynamics of the African/Arabian/Eurasian plate boundary: The Eastern Mediterranean and the Near East. Proceedings 9th General WEGENER Assembly, published by Statens Kartwerk, Norway: 47-50.

KAHLE, H.-G., MÜLLER, M.V. und Ch. STRAUB (1995): Satellitengeodäsie und Geodynamik: Aktuelle Projekte der ETH Zürich in Griechenland und Anatolien. VPK, 4/95: 227-231.

KAHLE, H.-G. and E. KLINGELÉ (1995): Density distribution of the lithosphere. Report Special Study Group of Int. Ass. of Geodesy. Travaux Géodésiques.

KAHLE, H.-G., MÜLLER, M. V. and G. VEIS (1996): Trajectories of crustal deformation of western Greece from GPS observations 1989-1994. Geophysical Research Letters, 23, No.6: 677-680.

KAHLE, H.-G., STRAUB, C., MÜLLER, M.V., KASTENS, K., GILBERT, L., HURST, K., VEIS, G., BILLIRIS, H. and D. PARADISSIS (1996): Estimates of strain rates in the Eastern Mediterranean, inferred from GPS measurements. Abstract. American Geophysical Union (AGU). EOS, Supplement, April 23, Vol. 77, no. 17: S73.

KAHLE, H.-G., MÜLLER, M.V., GEIGER, A., DANUSER, G., MUELLER, St., VEIS, G., BILLIRIS, H. and D. PARADISSIS (1995): The strain field in NW Greece and the Ionian Islands: results inferred from GPS measurements. Tectonophysics, 249: 41-52.

KAHLE, H.-G., COCARD, M. und A. GEIGER (1996): Grundlagen und Anwendungen des Navigationssystems GPS. In: B. Oddsson (Hrsg.), Instabile Hänge und andere risikorelevante natürliche Prozesse. Nachdiplomkurs in angewandte Erdwissenschaften: 85-104. Birkhäuser Vlg. Basel, Boston, Berlin, 1996.

KAHLE, H.-G. (1996): The Mediterranean Basin. European Geophysical Society. Newsletter, 59: p. 15.

KAHLE, H.-G., NUESCH, D. and ST. MUELLER (1996): Crustal dynamics in the Adriatic-Aegean plate boundary zone based on GPS, ERS1/2 and microseismic studies. Space research in Switzerland. Report to COSPAR by the Swiss Committee on Space Research of the Swiss Academy of Sciences: 5-6.

KAHLE, H.-G., Y. PETER, M. COCARD St. MUELLER, F. HASLINGER, J. ANSORGE, E. KISSLING, G. VEIS, S. FELEKIS, D. PARADISSIS and V. KARAKOSTAS (1997): The Adriatic-Aegean plate boundary around the Gulf of Arta, NW Greece: First results from continuous GPS data and a microseismicity survey. EOS Trans. American Geophysical Union (AGU), 78(17). Supplement. S. 321.

KAHLE, H.-G., MARTI, U., GEIGER, A., WIRTH, B., GUBLER, E., ROTHACHER, M., GURTNER, W., BEUTLER, G. and I. BAUERSIMA (1997): Recent crustal movements, geoid and density determination: Contribution from integrated satellite and terrestrial measurements. In: O. Pfiffner et al. (eds.), Deep structure of the Swiss Alps: results of NRP 20: 251-259. Birkhäuser Vlg. Basel, Boston.

KAHLE, H.-G. UND B. BÜRKI (1997): Schweizerische Geodätische Kommission, Jahresbericht 1997. Schweizerische Akademie der Naturwissenschaften, Jahrbuch 1997: 24-27.

KAHLE, H.-G., CAZENAVE, A., COCARD, M. and A. GEIGER (1997): Airborne Laser and Satellite Radar Altimetry: First results from the EU Project SELF II. Proceedings EU Workshop on Sea Level Rise research in Europe, a state of the art and future research needs, Laboratori d'Enginyeria Maritima. Barcelona, Spanien.

KAHLE, H.-G. AND B. BÜRKI (1997): Sea level fluctuations in the Mediterranean: Interactions with climate processes and vertical crustal movements (SELF II). Umweltforschungskatalog. Schweiz. Bundesamt für Umwelt, Wald und Landschaft. Schriftenreihe Umwelt Nr. 285/I (Forschung): p. 258.

KAHLE, H.-G., BÜRKI, B., COCARD, M., GEIGER, A., KRUSE, L.-P., SIERK, B. and Y. PETER. (1997): Geoscience of global change and contemporary dynamics. Contribution. Swiss National Report to International Council of Scientific Unions, Inter-Union Commission on the Lithosphere, Report 21: 108-110.

KAHLE, H.-G., GEIGER, A. and M. COCARD (1998): Surface of the Ionian Sea from Airborne Laser altimetry and geophysical interpretation. Progress Report. Proceedings. EU Workshop. Toulouse, Frankreich.

KAHLE, H.-G. AND ST. MUELLER (1998): Structure and dynamics of the Eurasian-African plate boundary system. J. Geodynamics. Vol. 25:3-4: 303-325.

KAHLE, H.-G., STRAUB, C., REILINGER, R., MC CLUSKY, KING, R., HURST, K., VEIS, G., KASTENS, K. and P. CROSS (1998): The Strain Rate Field in the Eastern. Mediterranean, estimated by repeated GPS measurements. Tectonophysics, 294: 237-252.

KAHLE, H.-G., BÜRKI, B., COCARD, M., GEIGER, A., KRUSE, L.-P., SIERK, B. and Y. PETER (1998): Geoscience of global change and contemporary dynamics. Contribution. Swiss National Report to International Council of Scientific Unions, Inter-Union Commission on the Lithosphere, Report.

KAHLE H.-G., B. BÜRKI, M. COCARD, A. GEIGER, M.V. MÜLLER, C. STRAUB (1996): Geoscience of global change and contemporary dynamics. Swiss National Report to the International Council of Scientific Unions, Inter-Union Commission on the Lithosphere, vol. 21.

KAHLE, H.-G., COCARD, M., PETER, Y., GEIGER, A., REILINGER, R., MCCLUSKY, S., KING, R., BARKA, A. and G. VEIS (1999): The GPS strain rate field in the Aegean Sea and western Anatolia. Geophys. Res. Letters. In press.

KAHLE, H.-G., COCARD, M., GEIGER, A., PETER, Y., REILINGER, R., MCCLUSKY, S., KING, R., BARKA, A., VEIS, G. and V. KOTZEV (1999): GPS derived fault motion and strain accumulation in the Eastern Mediterranean. Geophysical Research Abstr., Vol. 1, No.1: 203.

KANIUTH, K., DREWES, H., STUBER, K., TREMEL, H., ZERBINI, S., PEZZOLI, L., CORRADO, G., KAHLE, H.-G., MÜLLER, M.V., MUELLER, St., VEIS, G., BILLIRIS, H., and D. PARADISSIS (1995): GPS based deformation estimates in the Calabrian and West Hellenic Arcs. XXI IUGG General Assembly. Boulder, Colorado, USA. Abstract Volume A: p. 32.

KANIUTH, K., DREWES, H., STUBER, K., TREMEL, H., HERNANDEZ, N., HOYER, M., WILDERMANN, E., KAHLE, H.-G., GEIGER, A. and C. STRAUB (1998): Crustal deformation along the Caribbean-South America plate boundary derived from the CASA GPS project. In: Forsberg et al. (eds.) Int. Ass. Geodesy Symposia, Vol. 119: 417-422. Geodesy on the Move. Springer Verlag Berlin.

KLINGELÉ, E.E. and H.-G. KAHLE (1997): Seismic velocity-density relationships: a critical review. XXII General Assembly of European Geophysical Society (EGS), Annales Geophysicae Part I. Suppl.I to Vol. 5. Abstract, p. C8.

KRUSE, L.-P., SIERK, B., SPRINGER, T., COCARD, M., BÜRKI, B. and H.-G. KAHLE (1999): GPS-Meteorology: impact of predicted orbits on precipitable water estimates. Geophys. Res. Abstr. 1,1:227.

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 (1999): GPS constraints on crustal movements and deformations in the Eastern Mediterranean (1988-1997): implications for plate dynamics. J. Geophys. In press.

MC CLUSKY, S., B. AKTUG, H. AYGUL, S. BALASSANIAN, A. BARKA, C. BURCHFIEL, R. CAKMAK, S. ERGINTAV, M. HAMBURGER, H.-G. 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): GPS Constraints on Active Tectonics in the Eastern Mediterranean Region. Proceedings UNAVCO. In press.

MUELLER, St., KAHLE, H.-G., and A. BARKA (1997): Plate-Tectonic Situation in the Anatolian-Aegean Region. In Schindler and Pfister (eds.), Active tectonics of northwestern Anatolia - The Marmara Poly-Project. VdF Hochschulverlag AG an der ETH Zürich: 13-28.

MUELLER, ST. and H.-G. KAHLE (1995): Lithospheric dynamics in the Central Eastern Mediterranean based on space geodesy and seismology. Annales Geophysicae. Suppl.1 to Vol. 13. Abstract, p. C 170.

MUELLER, S. and KAHLE, H.-G. (1993): Crust/Mantle structure and dynamics in the Mediterranean-Alpine region. In: Smith and Turcotte (eds.), Contribution of space geodesy to Geodynamics: AGU Geodynamics Series, Vol. 23: 249-298.

MÜLLER M.V. (1996): Satellite Geodesy and Geodynamics: Current deformation along the West Hellenic Arc. Mitteilungen IGP, Nr. 57, ETH Zürich.

PETER, Y., KAHLE, H.-G., COCARD, M., VEIS, G., FELEKIS, S. and D. PARADISSIS (1997): Continuous GPS monitoring across the subduction zone of the West Hellenic Arc. EOS Trans. American Geophysical Union (AGU), Vol. 78, No. 46. Suppl., F168.

PETER, Y., KAHLE, H.-G., COCARD, M., VEIS, G., FELEKIS, S. and D. PARADISSIS (1998): Establishment of a continuous GPS network across the Kephalonia Fault Zone, Ionian Islands, Greece. Tectonophysics, 294: 253-260.

PETER, Y., KAHLE, H.-G., COCARD, M., VEIS, G., FELEKIS, S. and D. PARADISSIS (1999): Continuous GPS monitoring across the Kefalonia Fault zone of the West Hellenic Arc, Greece. EOS Trans. American Geophysical Union (AGU), 80,17: S77.

PEZZOLI, L., BAKER, T., BÜRKI, B., KAHLE, H.-G., MARSON, I., MÜLLER, M.V., PLAG, H.-P., ROMAGNOLI, C., TOMASI, P., VEIS, G., VERRONE, G. and S. ZERBINI (1995): Sea level fluctuations: Geophysical interpretation and environmental impact - The SELF Project. Annales Geophysicae. Suppl.1 to Vol. 13. Abstract, p. C 163.

PEZZOLI, L., BAKER, T., KAHLE, H.-G., RICHTER, B., VEIS, G., and S. ZERBINI (1995): Sea level fluctuations: Geophysical interpretation and environmental impact - The SELF Project. XXI IUGG General Assembly. Boulder, Colorado, USA. Abstract Volume B: p. 316.

PFISTER, M.,BALDERER, W., GREBER, E., KAHLE, H.-G., MAYER-ROSA, D., MUELLER, St., RYBACH, L., SCHINDLER, C., SELLAMI, S. and C. STRAUB (1997): Synthesis of the Marmara Poly-Project. In Schindler and Pfister (eds.), Active tectonics of northwestern Anatolia- The Marmara Poly-Project. VdF Hochschulverlag AG an der ETH Zürich, 539-565.

PFISTER, M., GREBER, E., SCHINDLER, C., STRAUB, C., KAHLE, H.-G. and L. RYBACH. Geodynamics of the Marmara Sea region. Submitted. Geol. Soc. Amer. Bull.

PLAG, H.-P., AMBROSIUS, B., BAKER, T., BEUTLER, G., BIANCO, G., BLEWITT, G., BOUCHER, C., DAVIS, J., DEGNAN, J., JOHANSSON, J., KAHLE, H.-G., MUELLER ST., ZERBINI S. et al. (1998): Scientific objectives of current and future WEGENER activities. Tectonophysics, 294: 177-223.

REILINGER, R., MCCLUSKY, S., KAHLE, H.-G., MÜLLER, M.V., STRAUB, C., KASTENS, K., GILBERT, L., HURST, K., M., VEIS, G., PARADISSIS, D. and A. BARKA (1995): GPS evidence for westward continuation of dextral strike-slip motion from the North Anatolian Fault Zone across the North Aegean and North-Central Greece. Abstract. American Geophysical Union (AGU). EOS, Supplement, Nov. 7: F620-F621.

REILINGER, R., MCCLUSKY, S., KING, R. TOKSÖZ, N., BARKA, A., DEMIR, C., VEIS, G., OUZOUNIS, A., PRILEPIN, M., KOTZEV, V., GEORGIEV, I., KAHLE, H.-G., PETER, Y., SEEGER, H. and A. TEALEB (1998): Velocity field for the Eastern Mediterranean. European Geophysical Society XXIII General Assembly. Annales Geophysicae, Part I. Suppl.I to Vol 16, C99.

ROTHACHER, M., G. BEUTLER, E. BROCKMANN, R. WEBER (1995a): „Towards a Subdiurnal Resolution of Earth Orientation Parameters at the CODE Processing Center of the IGS“. Internal Memorandum, Astronomical Institute, University of Bern.

ROTHACHER, M., R. WEBER (1995b): „Estimation of UT1-UTC from GPS Observations at CODE“. Invited presentation for the 1995 Spring Meeting of the American Geophysical Union, May 30 - June 2, Baltimore, Maryland. EOS, 76, 17, pp. S83, 1995.

ROTHACHER, M., T. SPRINGER, G. BEUTLER, R. WEBER (1997a): „Routine Sub-Daily ERP Determination at the CODE Analysis Center of the IGS“. Invited presentation at the AGU Spring Meeting 1997, Baltimore, May 27-30, EOS Transactions, 78, 17.

ROTHACHER, M., R. WEBER, T. A. SPRINGER, G. BEUTLER (1997b): „Routine Sub-Daily ERP Determination at the CODE Analysis Center of the IGS“. Invited presentation at the AGU Spring Meeting 1997, Baltimore, Maryland, EOS Transactions, 78, 17, pp. 110.

ROTHACHER, M. (1998a): „Recent Contributions of GPS to Earth Rotation and Reference Frames“. Habilitationsschrift der Philosophisch-naturwissenschaftlichen Fakultät der Universität Bern, Druckerei der Univeristät Bern, Bern, 1998.

ROTHACHER, M. (1998b): „The Contribution of GPS Measurements to Earth Rotation Studies“. Proceedings of the Jounées 1998 "Systèmes de Référence Spatio-Temporels", (in press), Capitaine, N. et al. (eds.).

ROTHACHER, M., G. BEUTLER (1998c): „Estimation of nutation terms using GPS“. Proceedings of the 1998 IGS Analysis Center Workshop, Darmstadt, February 9-11, 1998, Dow, J. M. / Kouba, J. / Springer, T. (eds.), pp. 183-190, ESA/ESOC, Darmstadt, 1998.

ROTHACHER, M., G. BEUTLER, T. A. HERRING, R. WEBER (1999): „Estimation of Nutation Using the Global Positioning System“. J. Geophys. Res., 104, B3:4835-4859.

ROTHACHER, M., G. BEUTLER, R. WEBER (1998e): „High-Frequency Earth Rotation Variations Based on Four Years of GPS Data“. (Invited Paper), EOS Transactions of the American Geophysical Union, AGU 1998 Fall Meeting, December 6-10, 1998, San Francisco, Cal., AGU, 79, November, 45, pp. G71I-03, 1998.

ROTHACHER, M. G. BEUTLER, R. WEBER, J. HEFTY (1998f): „High-frequency Earth rotation variations from three years of Global Positioning System data„, in „Recent Contributions of GPS to Earth Rotation and Reference Frames“. Habilitationsschrift der Philosophisch-naturwissenschaftlichen Fakultät der Universität Bern, Druckerei der Univeristät Bern, Bern, 1998.

ROTHACHER, M., T. A. SPRINGER, S. SCHAER, G. BEUTLER, D. INEICHEN, U. WILD, A. WIGET, C. BOUCHER, S. BOTTON, H. SEEGER (1998g): „Annual Report 1997 of the CODE Analysis Center of the IGS“. IGS 1997 Annual Report, IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Cal., J. F. Zumberge, D. E. Fulton, R. E. Neilan, IGS Central Bureau, JPL (in press).

SALSTEIN, D.A. (1997): „IERS Sub-bureau for Atmospheric Angular Momentum Report“, in 1996 IERS Annual Report, pp. I57-I66, Observatoire de Paris, Paris.

SPRINGER, T., G. BEUTLER, M. ROTHACHER, E. BROCKMANN (1995): „The Role of Orbit Models when Estimating Earth Rotation Parameters using the Global Positioning System“. EOS, Transactions of the American Geophysical Union, 1995 Fall Meeting, December 11-15, 1995, San Francisco, California, USA, 76, November, 46, pp. F-60, 1995.

SPRINGER, T., J. HEFTY, R. WEBER (1997): „Analysis of GPS-monitored Earth rotation variations induced by ocean tides and AAM“. News Letter of the Eropean Geophysical Society, XXII General Assembly, Vienna, Austria, 21-25 April 1997, European Geophysical Society, 62, March, pp. 69, 1997.

STRAUB, C. and H.-G. KAHLE (1995) Active crustal deformation in the Marmara Sea region, NW Anatolia, inferred from GPS measurements. Geophys. Res. Letters, 22,18: 2'533-2'536.

STRAUB, Ch., KAHLE, H.-G., AKSOY, A. and I. KINIK (1995): Active crustal deformation in the Marmara Sea region. Annales Geophysicae. Suppl.1 to Vol.13. Abstract, p. C 172.

STRAUB, Chr. and H.-G. KAHLE (1996): Deformation analysis of GPS data applied to the Marmara Sea region. Annales Geophysicae. Suppl.1 to Vol. 14. Abstract, p. C 252.

STRAUB, C. and H.-G. KAHLE (1997): Recent crustal deformation and strain accumulation in the Marmara sea region, NW Anatolia, inferred from repeated GPS measurements. In Schindler and Pfister (eds.), Active tectonics of northwestern Anatolia - The Marmara Poly-Project. VdF Hochschulverlag AG an der ETH Zürich: 417-447.

STRAUB, C, KAHLE, H.-G. and C. SCHINDLER (1997): GPS and geologic estimates of the tectonic activity in the Marmara Sea region, NW Anatolia. J. Geophysical Research, 102, B12: 27587-27601.

TONTI, M. DI CORI, M. NEGUSINI, S. ZERBINI, H.-G. KAHLE, Y. PETER, H. DREWES, H. TREMEL, K. KANIUTH, and G. VEIS (1998): Crustal movements in the central Mediterranean from the WHAT A CAT GPS network. Proceedings. 9th General WEGENER Assembly, Norway, p.59-63.

VONDER MÜHLL, D, W. HAEBERLI, E.E. KLINGELÉ (1996): Geophysikalische Untersuchungen zur Struktur and Stabilität eines Moränendammes am Grubengletscher (Wallis). Tagungspublikation: Internationales Symposium INTERPRAEVENT 1996 - Garmisch-Patenkirchen, Band 4, pages 123-132.

WEBER, R., G. BEUTLER, E. BROCKMANN, M. ROTHACHER (1995): „Monitoring Earth Orientation Variations at the Center for Orbit Determination in Europe (CODE)“. Proceedings of the XXI. General Assembly of the International Union of Geodesy and Geophysics, Boulder, Colorado, July 2-14.

WEBER, R.:, T. SPRINGER, G. BEUTLER, M. ROTHACHER (1996): „High-Frequency ERP Variations Deduced From GPS Data“. EOS Transactions of the AGU 1996 Fall Meeting, November 12, 1996, 77, 46, pp. F144, 1996.

WEBER, R., M. ROTHACHER (1998a): „High Frequency Earth Rotation Variations over the CONT96 Period deduced from GPS Data“. Proceedings of the Jounées 1998 "Systèmes de Référence Spatio-Temporels", (in press), Capitaine, N. et al. (eds.).

WEBER, R., M. ROTHACHER, T. SPRINGER (1998b): „Monitoring Earth rotation variations by GPS (Solicited paper)“. News Letter of the European Geophysical Society, XXIII General Assembly, Nice, France 20-24 April 1998, March, 66, pp. 133, 1998.

WEBER, R., M. ROTHACHER, T. SPRINGER (1998c): „Monitoring Earth Rotation Variations by GPS“. EGS Annales Geophysicae, Supplement I, 16, pp. C391.

YANG LINGZANG, KLINGELÉ., E. and H.-G. KAHLE (1995): Determining the variation of rock's elasticity by Earth Tides. Annales Geophysicae. Supp l.1 to Vol. 13. Abstract, p. C 112.

YANG LINGZANG, KLINGELÉ, E. and H.-G. KAHLE (1995): Determining variations in rock elasticity with Earth tides. IGP report Nr. 242._Plag, H.-P., Ambrosius, B., Baker, T., Beutler, G., Bianco, G., Blewitt, G., Boucher, C., Davis, J., Degnan, J., Johansson, J., Kahle, H.-G., Kumkova, I., Marson, I., Mueller St., Pavlis, , E., Pearlman, M., Richter, B., Spakman, W., Tatevian, S., Tomasi, P., Wilson, P. and S. Zerbini, 1998. Scientific objectives of current and future WEGENER activities. Tectonophysics, 294: 177-223.

ZERBINI, S., BAKER, T., BÜRKI, B., CERRUTI, G., CORRADO, G., KAHLE, H.-G., MARSON, I., MÜLLER, M.V., PARADISSIS, D., PEZZOLI, L., PLAG, H.-P., ROMAGNOLI, C., TOMASI, P., TSIMPLIS, N., VEIS, G. and G. VERRONE (1995): Sea level fluctuations: Geophysical interpretation and environmental impact (SELF). Proceedings of 6th General Assembly of WEGENER, St. Petersburg: 214-225.

ZERBINI, S., BAKER, T., BÜRKI, B., KAHLE, H.-G., MARSON, I., PLAG, H.-P., RICHTER, B. and G. VEIS (1995): Sea level fluctuations: Geophysical interpretation and environmental impact (SELF). EU project SELF, Contract No. EV5V-CT91-0049. EC Ecosystems research report, 14 (ed. C. Nolan): 113-114.

ZERBINI, S., WILSON, P., PLAG, H.P., VEIS, G., KAHLE, H.-G., BAKER,T. and M. SZTOBRYN (1995): Sea level fluctuations: Geophysical interpretation and environmental impact. EU project SELF, Contract No. EV5V-CT91-0049. Final report.

ZERBINI, S., PLAG, H.-P., BAKER, T., BECKER, M., BILLIRIS, H., BÜRKI, B., KAHLE, H.-G., MARSON, I., PEZZOLI, L., RICHTER, B., ROMAGNOLI, C., SZTROBRYN, M., TOMASI, P., TSIMPLIS, N., VEIS, G. and G. VERRONE (1996): Sea level in the Mediterranean: a first step towards separating crustal movements and absolute sea-level variations. In: Global and Planetary Change, Vol. 14, nos. 1-2: 1-48.

ZERBINI, S., BAKER, T., CAZENAVE, A., KAHLE, H.-G., MARTINEZ, J., PLAG, H.-P., RICHTER, B. and G. VEIS (1998). Sea level fluctuations in the Mediterranean: the European Union Projects SELF I and SELF II. Annales Geophysicae. Suppl.1 to Vol. 14. Abstract, p. C 272.