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Swiss Geodetic Commission
and Federal Office of Topography

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Commission Géodésique Suisse
et Office Fédérale de Topographie

Report on the

GEODETIC ACTIVITIES

in the years 1991 to 1995

Presented to the XXI General Assembly
of the International Union of Geodesy and Geophysics
in Boulder, Colorado, Juli 1995

Rapport sur les

TRAVAUX GÉODÉSIQUES

exécutés de 1991 à 1995

Présenté à la vingt et unième Assemblée générale
de l'Union Géodésique et Géophysique Internationale
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PREFACE

The Swiss Geodetic Commission (SGC) is an organisation within the Swiss Academy of Natural 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 with the Swiss Geophysical Commission, in particular in the field of gravimetry where research projects are being pursued jointly on an interdisciplinary basis.

The SGC has a long tradition and can trace its origin back to the formation of the "Mitteleuropäische Gradmessung". One of the prominent early leaders was H. Dufour. In 1986 the SGC celebrated its 125th anniversary.

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 similar 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 E. Gubler (Section 1), W. Gurtner (Section 2), E. Klingelé (Section 3), A. Geiger (Section 4) and H.-G. Kahle (Section 5). Our special thanks go to Dr. B. Bürki, secretary of SGC, for the 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, in particular, gratefully acknowledged.

On behalf of the Swiss Geodetic Commission, June 1995

Francis Jeanrichard
Vice-President

Hans-Gert Kahle
President

1 Positioning

The EUREF-89 GPS Campaign

by W. Gurtner

In 1989 the EUREF Commission organized the first continental GPS campaign covering the whole of Western Europe. 62 GPS receivers observed on 93 stations during two phases:

Phase A (62 sites): May 16 to May 21, 1989
Phase B (56 sites): May 23 to May 28, 1989

The data were preprocessed (i.e. reformatted into the receiver-independent exchange format RINEX) by 11 different institutions and sent to the University of Berne for merging and redistribution to various processing centers. The only full processing was done by a group of four institutions using the Bernese GPS software Version 3:

- Astronomisches Institut, Universität Bern
- Institut für Angewandte Geodäsie, Frankfurt
- Bayerische Kommission für die Internationale Erdmessung, München
- Institut Géographique National, Paris

The data screening and first solutions were done in a joint effort by the group members in Berne. For the final solution the network was divided into five subnetworks to be processed decentrally in the four institutions. This final solution was presented at the EUREF Symposium in March 1992 in Berne. The presented solution set, constrained to ETRF-89 coordinates of 21 SLR and/or VLBI sites, was accepted by the symposium as the official EUREF-89 solution.

The estimated accuracy for most of the sites was 3 to 4 cm in the horizontal and 6 to 8 cm in the vertical position. The most serious problem encountered was the poor tracking performance of some instruments on the second frequency. In addition, the satellite coverage for those days was relatively weak. This accounts for the higher than expected RMS values. Later campaigns, especially those performed after the start of the International GPS Service for Geodynamics (IGS) with its excellent orbits, showed that this accuracy estimate was rather on the pessimistic side.

The GIG'91 Campaign and the ESA'91 Campaign

by M. Rothacher and G. Beutler

In December 1990 a contract between the Astronomical Institute of the University of Berne (AIUB) and the Institute of Physical Geodesy of the University of Darmstadt (IPGD) on one side and the European Space Agency (ESA) on the other side was signed with the purpose of precisely locating the ESA tracking sites (Fucino, Kiruna, Redu, Rehbach and Villafranca in Europe, Maspalomas on the Canari Islands, Kourou in South America, Perth in Australia, Malindi in Africa, and Ibaraki in Japan) using observations of the Global Positioning System (GPS). The IPGD was responsible for the organization and the necessary observations, the AIUB for the processing part. The AIUB considered this task an opportunity to acquire first practical experiences in regional and global GPS orbit determination.

In view of the distribution of the ESA sites the task was split up into two campaigns: (a) a European ESA GPS Campaign (where the coordinates of Fucino, Kiruna, Redu, Rehbach, Villafranca, and Mas Palomas were determined) and (b) a Global ESA GPS Campaign with the goal of determining the coordinates of the *isolated* points Mas Palomas, Malindi, Ibaraki, Perth and Kourou. Mas Palomas was included in both campaigns. The European Campaign took place from May 1 to 12, 1991, where in addition to the mentioned ESA sites, one receiver was operated at Darmstadt. Moreover, the GPS observations of the European *Fiducial Sites* Herstmonceux, Kootwijk, Madrid, Matera, Metsähovi, Onsala, Tromsø, and Wettzell could be used. Continuous tracking was available at all points. The network was processed in many different ways using different arc lengths for modeling the GPS orbits, different strategies to model the troposphere, and different sets of fixed coordinates. The results were excellent, the entire network could be determined with a relative accuracy of about 0.01 ppm (or 1 to 3 cm). In order to achieve these results, it was necessary to solve the task of a Regional Orbit Determination Center. More information may be found in (Rothacher, 1992, chapter 9).

The location of the isolated sites was more difficult. Fortunately, we had access to the data of the world-wide observation campaign GIG'91 (First GPS IERS and Geodynamics Experiment) which took place from January 22 to February 13, 1991. An extended study based on simulated observations was performed in order to get the information concerning the required station distribution for such a task. These simulation studies are documented in (Rothacher, 1992, chapter 8). They may be considered as the first step towards establishing the CODE Processing Center of the IGS. The actual computation of the satellite orbits using the material of the GIG'91 campaign proved to be extremely laborious! Although the results were not comparable in quality with those obtained in the European ESA campaign, the coordinates were good to a few cm as required in the contract with ESA.

Contribution of the CODE Processing Center of IGS to the Determination of the ITRF

by M. Rothacher and G. Beutler

When the CODE Processing Center of the IGS started its official operations for the IGS on June 21, 1992 (for more information see also section 5), the proclaimed goal was to provide the best possible GPS orbits over Europe to the European GPS community. In addition, it was intended to produce and make available so-called free network solutions for all permanent European GPS tracking sites (available in time to be included in the CODE series). Originally, earth rotation parameters and global analyses were considered as secondary priority only. This was why CODE produced three types of solutions during the 1992 IGS Test Campaign (June 21 to September 23, 1993):

(a) A *global solution* consisting of (at the beginning) 22 stations (4 European stations included) with the goal of producing (global) orbits and earth rotation parameters using the GPS data from tracking sites with known coordinates from VLBI and SLR (wherever possible).

(b) A *set of European orbits* using the tracking data of 12 European tracking sites only. The coordinates of the tracking sites were kept fixed to the SLR and VLBI values wherever possible. No pole parameters were estimated, the values were taken over from the ITRF.

(c) *European free network solutions* using the same material as in analysis (b). In addition to the orbit parameters, the coordinates for all stations were estimated (loose a priori constraints were applied to avoid singularities).

This processing scheme was modified for the first time with the start of the IGS Pilot Service (November 1, 1992). The European solutions (a) and (b) were discontinued, but all European stations of (b) and (c) were incorporated as *free* stations (coordinates determined) in the analysis of (a). Thus, from that time onwards, our global orbit series emphasized the European continent. The global orbits were based on about 30 stations by the end of 1992. The CODE annual report for 1992 (in (Beutler et al., 1993) in (Charlot, 1993)) describes the CODE contribution for 1992 to the IERS based on the free network solution (c) for the time interval of the 1992 IGS test campaign and on the *free* European IGS subnet of our global analysis based on observations from November 1, 1992 to March 31, 1993.

Table 1 gives an overview of the stations (Europe and worldwide) used by the CODE processing center today and the date when the stations were first included in the CODE solution series. In addition, one may extract from Table 1 the stations which were and are kept fixed in the CODE routine solutions. The number of stations grew considerably since 1992, but even today the emphasis of the CODE analysis is on Europe.

Europe: 17 sites			
GRAZ		Graz	Jun 92
MADR	*	Madrid	Jun 92
METS		Metsähovi	Jul 92
TROM	*	Tromsø	Jun 92
HERS		Herstmonceux	Jun 92
NYAL		Ny-Alesund	Jun 92
WETT	*	Wettzell	Jun 92
MAS1		Mas Palomas	Jun 92
KOSG	*	Kootwijk	Jun 92
MATE		Matera	Jun 92
ONSA		Onsala	Jun 92
ZIMM		Zimmerwald	Mar 93
JOZE		Jozefoslaw	Aug 93
BRUS		Brussels	Nov 93
BOR1		Borowiec	Jun 94
POTS		Potsdam	Nov 94
LAMA		Lamkowko	Dec 94

Australia, Antarctica: 9 sites			
TIDB	*	Tidbinbilla	Jun 92
YAR1	*	Yaragadee	Jun 92
MCMU		McMurdo	Jun 92
PAMA		Pamatai	Jul 92
HOB2		Hobart	Mar 93
DAV1		Davis	Aug 94
CAS1		Casey	Nov 94
KERG		Kerguelen Islands	Nov 94
GUAM		Guam	Jan 95

African site			
HART	*	Hartlebeesthoeck	Jun 93

Asia: 5 sites			
TAIW		Taiwan	Jun 92
USUD		Usuda	Jun 92
TSUK		Tsukuba	Mar 94
KIT3		Kitab	Oct 94
SHAO		Shanghai	Jan 95

North America: 13 sites			
ALGO	*	Algonquin	Jun 92
GOLD	*	Goldstone	Jun 92
DRAO		Penticton	Jun 92
YELL	*	Yellowknife	Jun 92
KOKB	*	Kokee Park	Jul 92
FAIR	*	Fairbanks	Jul 92
STJO		St.John's	Jul 92
RCM5		Richmond	Oct 92
QUIN		Quincy	Nov 92
PIET		Pietown	Jan 93
WES2		Westford	Mar 93
BRMU		Bermuda	Oct 93
MDO1		Mc Donald	Nov 93

South America: 6 sites			
KOUR		Kourou	Nov 92
SANT	*	Santiago	Nov 92
FORT		Fortaleza	Oct 93
AREQ		Arequipa	Mar 94
EISL		Easter Island	Aug 94
BOGT		Bogota	Nov 94

Table 1: IGS Sites used in CODE Processing. Date of first appearance listed.
* Fixed or closely constrained in daily processing

The processing scheme was again modified on April 1, 1993, when all stations were formally introduced as unknown parameters into the daily processing. Instead of actually fixing stations (coordinates not showing up in the list of unknown parameters), we started constraining them closely at the sub-millimeter level. With this procedure it was possible to base the daily solutions on a well-defined set of ITRF station coordinates (virtually fixed), but to remove these constraints afterwards for annual or even multi-annual solutions. These so-called *free network solutions*, based on a superposition of hundreds of daily normal equation systems, could now be generated for the entire IGS network considered by CODE. Of course one has to introduce system conditions like *no net rotation* for the analysed network in order to remove singularities. Results of this kind are described in the CODE annual reports for 1993 and for 1994 (Rothacher et al., 1994), (Rothacher et al., 1995). More information concerning the coordinate solutions of the CODE Processing Center may be found in the Bibliographies of sections 1 and 5.

GPS Campaigns in the Turtmann 3D Network 1991-1994

by G. Beutler and St. Schaer

The Turtmann 3D network was set up by the Swiss Geodetic Commission in the year 1987. The ground truth refers to the epoch 1987. The Turtmann network and the establishment of the ground truth are fully documented in (Jeanrichard, 1992).

Seven GPS campaigns took place in the Turtmann network between 1987 and 1990 (Report presented to the XXth IUGG General Assembly, 1991), and four more campaigns took place between 1991 and 1994. Table 2 gives the essential characteristics for the latter campaigns.

Date	Type/Number of Receivers	Number of days	Remarks
1991	Leica SR299	2	Tests by Leica for their new receiver type SR299 and the new software SKI
1992	4 SR299, 3 Ashtech LXII3, 3 Trimble SSE	2	Sessions of about 3 h.
1993	Trimble SSE	4	Permanent tracking (24h)
1994	Trimble SSE	3	Permanent tracking (24h)

Table 2: GPS Campaigns in the Turtmann Network 1991-1994

As opposed to the earlier campaigns, only dual band receivers were used in the network during the years 1991-1994. It was thus possible to compute local ionosphere models for each of the campaigns. Whereas the 1991 campaign may be considered as a pure receiver and software test for the new SR299 of Leica Ltd., Heerbrugg, the latter three campaigns contributed significantly to the establishment of the GPS solution in Turtmann.

It is worth noting that the IGS orbits (those of the CODE Processing Center in particular) could be used to process the campaigns 1992 to 1994. This means that no reference frame inconsistencies could show up in these results.

It was even more important that, thanks to the completion of the GPS constellation, permanent tracking over four and three days could be organised in 1993 and 1994 respectively. This led to coordinate results of an unprecedented internal consistency: Typically sub-millimeter repeatabilities of the daily solutions could be achieved for the horizontal positions, 2 to 3 mm repeatabilities resulted for the station heights. The comparison of the 1993 with the 1994 results (to be published shortly) showed that not only the consistency but also the accuracy is of the same order.

All relevant GPS campaigns between 1987 and 1993 were re-analysed with the latest version of the Bernese software. This effort is extensively documented in (Jeanrichard, 1995). Unfortunately the results of the 1994 campaign are not yet included in this volume.

The Receiver Independent Exchange Format (RINEX)

by W. Gurtner

The main developments of the Receiver INdependent EXchange Format (RINEX) were done in 1989 (Version 1) and in 1990 (Version 2) (Gurtner et al., 1989, Gurtner et al., 1990). Later only small modifications related to the routine presence of Antispoofing (AS) had to be done. An up-to-date overview was published in GPS World (Gurtner, 1994). Another small modification to account for the different time system used by GLONASS and a separate RINEX format for the GLONASS navigation messages have been prepared and circulated for comments among a number of receiver manufacturers.

GPS receiver/antenna calibrations in Thun

by A. Wiget

For the evaluation of GPS receivers and along with the preparations of major GPS campaigns, the Federal Office of Topography has been conducting one or several short baseline tests annually on its test site in Thun (25 km southeast of Berne) since 1988. The main purpose was to empirically determine relative antenna phase center offsets by comparing the GPS results with the ground truth (precision of 0.2 mm (1 sigma)). Up to 11 receivers/antennae of the same type as well as of different manufacturers were tested simultaneously in two sessions per campaign. The session length varied from 5 to 24 hours, depending on the usable observation window at the time being. In a combined least squares adjustement of the terrestrial ground truth with the GPS results, "averaged" individual antenna offsets were estimated, being valid for only the actual satellite constellation and session length.

The observations of the most recent calibration campaign in fall 1994 involving four different geodetic receiver types (Ashtech Z-12, Trimble 4000SSE, Turbo-Rogue SNR-800 and Wild/Leica SR299E) were treated more rigorously at the AIUB. In the Bernese GPS Software Version 3.6, elevation- and azimuth-dependent phase center variations can be estimated from the double difference phase observations (Gurtner et al., 1994).

The new national reference system and -frame

by A. Wiget, B. Vogel and D. Schneider

In the last four years the establishment of a new GPS network in Switzerland (called Landesvermessung *LV95*) has been enlarged to a complex project for a new national geodetic reference system. The goals of the project are:

- definition and realization of a modern national geodetic reference system by establishing a new reference frame;
- integration of this national geodetic reference system (CHTRS) and frame (CHTRF95) into global and European geodetic reference systems (ITRS, ETRS) and frames (ITRF, ETRF);
- integration of the SLR station *Zimmerwald* (AIUB) as the fundamental station with permanent links to international reference frames by participating in global SLR and GPS campaigns like the Crustal Dynamics Project (CDP) or the International GPS Service for Geodynamics (IGS);
- installation and measurement of a homogenous network of stable, reliable and easily accessible 3D control points, suitable for the monitoring of crustal motion (velocity vectors);
- minimum accuracies (1 sigma) and reliabilities of differences in geodetic latitudes and longitudes at 1 cm and differences in ellipsoidal height at 3 cm nationwide;
- combined adjustments of the 1st and 2nd order triangulation networks as well as the national levelling network together with this new GPS network for improving the existing horizontal control and establishing (together with a new geoid model) a new height system;
- optimal connections to the GPS network for densifications in cadastral and engineering surveys

The most important part of this project is the new *GPS Base Network LV95*, representing the above mentioned reference frame CHTRF95. This 3D reference network consists of 104 new control points, including 5 EUREF points (see map 1). It was measured in 4 main GPS campaigns of two weeks each, conducted between 1989 and 1992. Tables 3 and 4 summarize the main characteristics and preliminary results of the campaigns. In addition, several smaller campaigns (including one local EUREF campaign) were carried out from 1992 to 1994, mainly for connecting the existing triangulation and levelling networks to the new GPS network. The data is being processed with the Bernese GPS Software (V3.5). The first phase of the project will be completed in 1995 with the publication of the point coordinates and their documentation.

Campaigns	Year	Month	No. of stations *	No. of receivers	No. of sessions	hours per session	No. of satellites **	S/A
LV95-89	1989	Sept.	28	12	10	4	7	off
LV95-90	1990	Oct.	36	13	9	7	8	off
LV95-91	1991	Sept.	35	13	9	8	10	off
LV95-92	1992	Sept.	30	11	9	8	12	on
EUREF-CH	1992	Aug.	5	5	5	23	18	on

* stations including connections to other parts
** satellites used in the campaign
S/A "selective availability"

Table 3: Main GPS campaigns for LV95

Campaigns	No. of baselines [L3]	No. of double differences [L3]	Resolved ambiguities [%]	Sigma of single differences * [mm]	Horizontal precision ** [mm]	Vertical precision ** [mm]
LV95-89	65	171'692	100	3.7	3.0	18.9
LV95-90	94	435'264	100	3.5	4.2	11.2
LV95-91	95	511'720	100	4.9	6.5	23.1
LV95-92	88	419'144	100	4.0	3.7	9.3
EUREF-CH	40	115'239	90	4.1	3.9	12.0

* sigma a posteriori of the single difference phase observations (normalized to L1)
** precision estimated from repeatability between independent subnetworks

Table 4: Preliminary results of the campaigns for LV95

The second phase of the project is the combined adjustment of the GPS Base Network LV95 with the measurements of the existing 1st and 2nd order triangulation network (*diagnostic adjustment*). The LV95 network is linked to 125 triangulation points (see map 2). The result will be a set of "best" coordinates which, combined with a distortion model, can be used for transforming LV95 into the old national datum (CH1903) and vice versa. For this purpose a new computer program called FINELTRA is being developed by the IGP (ETH Zurich). With respect to the heights, the LV95 network was connected to 80 points of the national levelling network by levelling or by GPS (see map 3). Therefore, the combination of LV95 with the new geoid model for Switzerland (cm geoid) and a kinematic adjustment of orthometric height differences in the national levelling network will lead to the new height system, thus completing the project (c. f. Schneider et al., this section).

DGPS for kinematic Positioning

by M. Cocard, A. Geiger, H.-G. Kahle

A main interest is focused on GPS for kinematic surveying and moving platform tracking such as cars, vessels and aircrafts. Special emphasis is placed on the combination of GPS and airborne measurements such as aeroradiometry, aerogravimetry and photogrammetric aerotriangulation (see section II). These very precise positioning require carrier phase measurements of the satellite signal. For several application the resolution of the phase ambiguities is mandatory. Therefore, algorithms have been developed which allow the ambiguity resolution in favourable circumstances in one epoch only.

Controlling and Monitoring by GPS

by A. Geiger, M. Cocard, H.-G. Kahle, M. Müller

During the report period different pilot-projects using GPS for controlling and monitoring have been carried out. Special emphasis has been placed on the installation of control networks for tunneling. GPS also helps in monitoring landslides. In our case of the landslide monitoring in Braunwald (canton Glarus), the GPS solution can be combined with well loggings and terrestrial measurements. Further Regions of concern with respect to mountain sliding are Campo Valle Maggia, Canton Ticino, Mostelberg, Canton Schwyz, and Lecherette, Canton Fribourg, which will be studied in cooperation with the Engineering Geology group of the ETH Zurich and the Geology of the University of Frybourg. All of the pilot projects showed the efficiency and the high reliability of GPS surveying also for engineering geology purposes.

Kinematic DGPS and Precise Navigation

by M. Cocard, A. Geiger, H.-G. Kahle and M. Scaramuzza

Different tests of GPS on moving platforms have been performed. A special test was concerned with the dynamic behaviour of the equipment and the precision of track recovery under 1 to 2 g environment. Mounted on a circular centrifuge the track was recovered satisfactorily (< 5 cm). It has also been shown that in favourable circumstances and with dual frequency measurements it is possible to solve ambiguities in one epoch time (Cocard, 1995). During the last years GPS won tremendous importance for operational navigation purposes. The integrity requirements of civil aviation, however, are very demanding. Especially in rugged terrain GPS approaches encounter certain problems. For the feasibility study and its verification a project has been set up to investigate GPS approaches on Lugano-airport in cooperation with the Federal Office of Civil Aviation, SWISSCONTROL, CROSSAIR, Federal Aviation Factory, Avionics Centre and University of Braunschweig.

Error Source Modelling for GPS Measurements

by A. Geiger, M. Cocard, V. Eckert, B. Bürki, W. Höflinger, H. Hirter and M. Scaramuzza

Characteristics of GPS Antenna, Multipath, and Interferences

The efficiency and gain of GPS antennas depend not only on the propagation conditions within the atmosphere but also on the electrical characteristics of the antenna (antenna pattern). The scope of this project is the study and comparison of different antenna types as well as the investigation of possible sources which affect the reception conditions either by the physics of the atmosphere or by geometrical constraints in the vicinity of the antenna (multipath effects). When using different antennas in the same survey, uncalibrated cm differences in the results can occur due to the different behaviour of the phase centers. To calibrate these effects a parametrisation of the characteristics is proposed which can be estimated simultaneously with GPS coordinates. Special investigations for detecting multipath and interferences have been made at Lugano-airport where GPS approaches will be tested in the next years. It is found that in distinct regions strong interferences may occur and seriously degrade the GPS measurements. Control flights with the inspection aircraft of SWISSCONTROL help to detect this regions.

Mitigation of Atmospheric Path Delay for Satellite Measurements

The impact of the Ionospheric effect on Satellite measurements especially for kinematic applications have been studied. Simplified models, estimated from dual frequency measurements can help to correct single frequency measurements. Since the tropospheric path delay is still one of the limiting factors for precise height determination special emphasis has been put on the mitigation of this effect.

Microwave Water Vapor Radiometry

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

Due to increasing demands of accurate GPS-heights, the activities for path delay observations have been reinforced within several projects. The system of two transportable water vapor radiometers (WVR) as developed by the Institute of Geodesy and Photogrammetry has been completed. With this equipment field measurements can be carried out in parallel to GPS or other microwave based observation methods such as e. g. radar altimetry. The steering of the entire system and the data logging, handling and storage is performed by a notebook-PC. For the final treatment including tip curve analyses, all relevant data are introduced into a data base software package enabling not only the radiometer-calibrations but also the preparation of special meteo files containing the tropospheric path delay information to be used within the Bernese GPS Processing Software. In the period 1991-95 the system has been applied mainly within two projects:

- ERS-1 (European Remote Sensing Satellite 1). In addition to GPS measurements, radar frequencies as used in satellite radar altimetry are affected by tropospheric propagation delays too. Therefore extended WVR activities were carried out in Switzerland, Austria, Italy and Zimbabwe in order to determine the tropospheric corrections during the overpass of the ERS-1 satellite. The altimeter was powered on over some selected stations equiped with dedicated radar transponders. These units are designed to receive and transmit back the signals from the altimeter thus enabling a very precise height measurement of the satellites orbit. With these measurements the height of the satellite orbit could be determined with very high accuracy thus enabling reliable altimeter validations and calibrations.

- SELF (Sea Level Fluctuations: geophysical interpretation and environmental impact): see (Bürki et al., section 5).

Modelling of 4D tropospheric refractivity field

by A. Geiger, M. Cocard, H. Hirter, V. Eckert and A. Wiget.

The high precision GPS measurements make the modelling of the tropospheric refractivity field necessary in order to correct the satellite range measurements. The goal of this work is to develop a method to calculate the 4-dimensional (including space and time) distribution of refractivity by using meteorological measurements such as pressure, temperature, humidity, and integrated water vapour content arbitrarily distributed both in space and in time. Parameter estimation and collocation techniques are applied to model the atmospheric state variables. By integration along the actual microwave propagation paths the corresponding correction values are obtained. The algorithms allow to introduce operational surface measurements, balloon soundings, airborne measurements etc. The method can also be applied to other meteorological or climatic data and it also can produce tropospheric corrections for non-GPS measurements such as Radar or communication investigations. The method has been applied in cooperation with the Federal Office of Topography (L+T) who tested the correction in the LV95 0-th order reference network.

Adjustment of geodetic networks using robust estimators

by A. Carosio, F. Wicki

The traditional adjustment of geodetic networks by the method of least squares seeks to prevent gross and systematic errors by applying special measurement procedures, and to detect such errors by elaborate testing procedures, in order to fulfil as far as possible the requirements of the normal distribution model. Robust estimators allow realistic results to be obtained, and the location of gross errors to be simplified, in spite of the normal distribution assumptions not being satisfied.

In cooperation with IGP, the Federal Office of Topography and the Aargau Survey Office, a robust estimation procedure based on M-estimators has been developed and integrated into the LTOP network adjustment software of the Federal Office for Topography. This programme is widely used in surveying and is becoming the standard software for network adjustment in our country. The computation procedure can be summarised as follows :

After an adjustment by the method of least squares, the weights of all observations whose standardised residuals exceed a predetermined limiting value will be reduced iteratively, in order to bring the standardised residuals down to that limiting value. Finally the standard error of unit weight and the internal reliability indicators (influence of possible model errors on coordinates) will be computed in accordance with the changed functional model.

The method developed is already being used successfully at ETH, the Federal Office of Topography and in various private survey offices.

Linear transformation with finite elements: a flexible link between national networks

by A. Carosio, M. Plazibat

Reference networks, whether they be at a national or continental (EUREF) scale, are in course of renovation throughout Europe as a result of new geodetic methods (GPS). Conversion from the old reference system to the new is time-consuming and requires the coexistence of both systems for many years. It is thus necessary to have a flexible and homogeneous method of transformation of coordinates from one system to the other. The transformation by finite elements used for this purpose is based on the division of Switzerland into triangular facets, whose corners are in general points whose coordinates are known in both the old and the new system, thus permitting the determination of transformation parameters for each triangle.

The transformation so derived can be applied to all points within the triangle or on its perimeter. This method of transformation can be considered as a possible standard for Switzerland. Its principal advantage lies in the possibility of local densification of known points, while leaving the transformation unchanged for the remainder of the country.

Mathematical models required for very precise azimuth determination by means of a gyroscope

by A. Carosio, M. Plazibat, O. Reis, R. Stengele, M. Zanini

The construction of very long linear projects such as the new transalpine routes constitutes a real technical challenge which forces the surveyor to use gyroscopic methods in order to achieve the required accuracies (e.g. standard error of drilling less than 10cm for the new St Gotthard low level tunnel). Used in the optimum way, this instrument allows a very high level of accuracy to be achieved: for example, our institute has a Deutsche Montan Technologie (DMT Bochum) Gyromat 2000 which can provide an azimuth determination in 8 minutes with a nominal accuracy of 7cc. This demands an extremely thorough understanding of the operation of the instrument, of the various sources of error which may affect its accuracy, and hence of the means of overcoming them. In a mountainous area such as the St Gotthard massif, the influence of the earth's irregular gravity field, modelled as the deviation of the vertical, constitutes the largest risk factor. For this reason an experimental study was dedicated to this topic. This showed that the Swiss geoidal model, which allows the determination of the deviation of the vertical at any point in the country, leads to very good results which conform to the requirements laid down for AlpTransit. This work, commissioned by the Swiss Federal Railways (CFF), was done as part of the pre-project report on surveying for the new St Gotthard tunnel. It has also allowed the determination of the accuracy to which gyroscopic measurements can be introduced into the simulation computation carried out for the St Gotthard tunnel.

Height Systems

by D. Schneider, U. Marti, A. Geiger and B. Wirth

Since early 1994 the Federal Office of Topography (L+T), the Institute of Geodesy and Photogrammetry (IGP) at the ETH Zurich, and B. Wirth (Davos) have been collaborating in a research project sponsored by the L+T treating rigorous height systems for the new Swiss national levelling network "LN95" *(Landesnivellement 1995)*.

In the old Swiss national levelling network "LN02", measured height differences were originally introduced without a rigorous adjustment and without applying any gravity reductions. These old "heights" *(Gebrauchshöhen)* are to be replaced by rigorously computed heights (orthomertric or normal heights). The new national GPS network "LV95" *(Landesvermessung 1995)* (see map 3) is connected to 80 bench marks of the levelling network and yields relatively accurate ellipsoidal heights of these points (Schneider, 1993; Wiget et al., 1994). In order to make use of these heights together with the new geoid model (Marti et al., 1992) in a hybrid adjustment of "LN95", rigorous gravity corrections have to be applied to the levelling data.

The basic data set for defining and computing a new height system are the observations of the first order levelling network. Each of its lines has been observed at least twice, which means that the relative vertical velocity components can also be estimated. Furthermore, all of the lines have been observed gravimetrically and therefore potential differences can be obtained. The geopotential numbers are then used together with the mass models to calculate orthometric heights as well as normal heights.

The method applied for computing the mean gravity along the plumbline used for deriving orthometric heights is described in (Wirth, 1990). The available mass models are the same as those used in computing the new geoid of Switzerland: the topography (25-meter digital height model DHM25), the Moho discontinuity (5 km grid), the Ivrea body modelled by prisms (Bürki, 1989), a model for the molasse basin (Klingelé, pers. comm.) and other local density anomalies. These models can be used to estimate the influence on gravity, its potential and the deflections of the vertical. A changeover from the old "heights" to the new system "LN95" for cadastral surveying is only possible if a solution for the transformation from "LN95" to "LN03" and vice versa is available. Either spatial interpolation techniques or traditionally linear interpolations between the nodes of the levelling network may be applied for this purpose.

L+T continued the re-measurement of the Swiss levelling network parallel to developing methods and software for "LN95". The second observation of the first order lines was completed with the last campaign in the Jura region in 1991. Since 1992 efforts are being undertaken to re-measure the second order network and to connect the levelling network to the national GPS network "LV95". Most of the lines (except steep inclines and tunnels) were measured with the digital levelling instrument 'WILD NA3000' with automatic image processing of the rod reading. Gravity measurements along these lines are collected routinely by the IGP. All repeatedly observed lines are introduced into a kinematic adjustment of the levelling network, giving very interesting results for the investigation of recent vertical movements in Switzerland.

Height adjustment including GPS observations

by T. Burnand

The integration of GPS methods into the LTOP software having already been achieved for planimetry, it was necessary to complete the process for altimetry. This has been done in collaboration with the Federal Office of Topography.

The functional model is very similar to that used for planimetry: each part is considered as a local coordinate system whose adjustment is done by a Helmert transformation. The translation in Z has, however, been supplemented by two rotations about the X and Y axes, analogous to phi and omega model rotations in photogrammetry, with the aim of offering the maximum of flexibility in the adjustment to the operator. Up to now, these two additional degrees of freedom have not had a significant effect and their use is very rare, but the possibility of using them remains.

The model for the integration of GPS observations into the LTOP programme is thus complete. It offers the advantage of an economical solution which can be easily adopted by the many users of this software.

Direct Transformation from WGS84 to User Coordinates

by B. Wirth

In many cases the coordinates of new sites have to be determined optimally with respect to existing points with given coordinates. If whether the local geoid, nor the projection system nor the transformation parameters from the WGS84 GPS System to the local ellipsoid are known, then it is possible to apply a direct 3D-transformation from GPS coordinates to the local system.

A special spatial affine 6 parameter-transformation is used as mathematical model in a collocation solution. The remaining residual differences are interpolated and predicted in the new sites. Detailed investigations on the obtainable accuracy within an area of 3500 m by 3500 m revealed, that a transformation based on 5 evenly distributed common points only is adequate to an accuracy better than 1 cm in position and in height. In a region of 10 by 10 km, the rms error in position and height increases up to 3 cm, independent of the projection system and the geoid undulations even in mountainous areas.

DHM25 - the digital height model of the Swiss Federal Office of Topography

by M. Rickenbacher

The Federal Office of Topography (L+T) is in the process of establishing a digital height model DHM25 for Switzerland. It replaces RIMINI, which has been the only height model covering all of Switzerland so far. RIMINI was started in the 1960s and consists of height values arranged in a 250 meter grid. Map 4 shows a perspective view of the famous Matterhorn in the Swiss alps generated with DHM25.

The DHM25 is produced by an analogous digital transformation of the height content of the Swiss National Map 1:25'000 (NM25). The first basic step is extracting the DHM25 basis model in the form of vectorized contours, lake contours and digitized spot heights. This is a semi-automatic and interactive on-screen process based on the scanned map image. In the next step, the DHM25 matrix model with a 25 meter grid is interpolated from the basis model.

Independent tests show that a spot height derived from the matrix model in the Plains and the Jura has an accuracy of 1.5 to 3 m whereas a spot height in the Alps has an accuracy of 4 to 8 meters. By using a different interpolation method together with photogrammetric edge measurements, the quality of the DHM25 can be improved. The resulting progress in quality can clearly be recognized in map 5. More detailed information such as the height of buildings and forests or the three-dimensional course of roads and streets must be produced in the scope of an encompassing topographic information system (TIS). At this time about 80% of the model are completed, the entire model should be finished in the first half of 1996. The DHM25 has already been successfully used for:

- all kinds of visualizations
- ecological tolerance studies
- generating ortho photos
- noise pollution studies
- projects for directional antennas
- hydrological studies
- deriving the cm geoid
- visibility analyses
- studies in forestry

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2 Advanced Space Technology

The Zimmerwald Satellite Observatory

by W. Gurtner, T. Schildknecht and U. Wild

Instrumental Developments at Zimmerwald

In the period 1991-1994 most of the developments concerned the optical observation techniques using a CCD camera. In view of the new system to be installed in 1995 the investments into the current system were kept on a minimum level: The Loran-C timing receiver used for the real-time control of the station clock was replaced by the one-pulse-per-second signal of the permanent GPS receiver. In 1993 the developments of an aircraft detection radar were started. A commercially available small boat radar has been fixed on a separate 2-axes mount. It is driven in parallel to the laser telescope to check the presence of aircrafts near the laser beam.

Operation of the Satellite Observatory

Since January 1992 the Federal Office of Topography (L+T) has been engaged in the routine satellite laser observations. In addition to students of the Astronomical Institute some 10 engineers and technicians of the L+T have been trained in the operation of the system. Maintenance and developments remain in the responsibility of the Astronomical Institute. Thanks to the substantial support of L+T and the extensive automation of the system a seven-nights-per-week coverage can be assured (daytime observations are not possible with this system).

The following satellites were routinely observed mainly for the benefit of IERS, CDP, WEGENER, ESA and NASA:

LAGEOS 1, LAGEOS 2, Starlette, Stella, ERS-1 and Topex-Poseidon, Ajisai, Meteor-3 (PRARE tests). Test observations to Etalon-1 showed that this type of satellite is on the limits of the current Zimmerwald system.

The average number of observed passes per month as showed in map 6 increased from about 50 in 1990 to about 80 in 1994. The weather conditions allowed observations (one or more passes) in 50 percent of all nights.

GPS Permanent Tracking Station

The Federal Office of Topography installed, in time for the test phase of the International GPS Service for Geodynamics (IGS), a geodetic GPS receiver (Trimble 4000SSE) and developed in cooperation with the Astronomical Institute the software for the fully automated permanent operation and data handling.

The receiver is collecting data with a one-second data rate. These data are decimated to 30 seconds, reformatted into the RINEX format, compressed, and sent to the IGS Regional Data Center (IfAG Frankfurt) and to the CODE Analysis Center in Berne for processing (see section 4) in daily batches a few minutes after midnight UT. The one-second data are discarded unless they are used for differential phase navigation purposes. Simultaneously the receiver is generating RTCM corrections sent through a modem line to the Swiss Telecom for retransmission over RDS-coded UHF.

Optical Tracking of Satellites

During 1992 the first optical observations of satellites were performed using a CCD camera mounted on the SLR telescope. The accuracy of the determined positions of slow moving objects turned out to be 0.3" - 0.5".

The following satellites have been observed in the framework of the COGEOS project: Intelsat 4A-F6, Intelsat 4-F2, China 15, Meteosat 5. Other tracked objects include some GPS and Glonass satellites, minor planets and comets.

The New Zimmerwald Laser and Astrometric Telescope

The nearly 20 years old Laser Telescope cannot anymore respond to all requirements of modern Satellite Geodesie. Daytime operation is impossible, ranging is limited to low orbiting satellites (Lageos), pass interleaving is slow, the accuracy is not any more sufficient.

During the last few years first developments and tests with astrographic tracking (CCD) of moving objects (comets, minor planets, geostationary and other satellites, space debris) have been performed on the same SLR telescope. However, neither its optical quality nor its tracking accuracy are sufficient to make use of the full potential of this method.

Since 1991 the Astronomical Institute has been evaluating a new telescope for both satellite laser ranging and astrographic tracking (Bauersima, 1991). In March 1994 the new instrument has been ordered from Télas, Cannes, a Joint Venture between the French companies Aerospatiale and Framatome. The new telescope will share the 1 m primary mirror and the secondary and tertiary mirrors between the satellite laser ranging and the astrographic tracking of moving objects. There are four camera ports, three of which are reserved for CCD cameras of different focal lengths and one for the TV guiding camera for SLR.

The telescope will allow either independent SLR or astrographic mode of operation or, with a slight reduction in imaging quality, even a simultaneous tracking mode. Switching between different tracks can be rapidly performed thanks to excellent angular velocities and accelerations of the mount.

The Laser system, the electronics equipment, the station computer, and the tracking software will be upgraded as well. The installation of the new system on site will start in June 1995. The system is financed by the Federal Office of Topography, the Swiss National Science Foundation, the University of Berne and the Canton of Berne.

GPS for precise track recovery in airborne remote sensing systems

by M. Cocard and A. Geiger

Airborne Laser profiling and SAR

The airborne Laser profiling and scanning are well suited to produce digital surface models. A self calibrating method has been developed and tested during different flight experiments. It has been shown, that the system is capable to detect height variations of lake surfaces induced by gravity. Changes in glacier thickness have also been measured on the Aletsch Glacier. For the successful application of the system the precise trajectory recovery by GPS is mandatory. E.g. in cooperation with the Federal Directorate of Cadastral Survey (disposes of a Twin-Otter survey aircraft) the geoid undulations on the lake of constance has been determined in the order of some centimeters rms.

In different campaigns directed by the RSL (Remote Sensing Laboratory) of the University of Zürich in cooperation with different german research establishments and with the support of the Institute of Geodesy and Photogrammetry of the ETH Zurich, GPS has been used to precisely determine the flight path in order to position the SAR- and scanning sensors from which digital terrain models have been derived.

Aerophotogrammetry

The use of kinematic GPS during aerophotogrammetric flights permits the number of ground control points to be substantially reduced, thus rendering the block triangulation more efficient and economical. The ETH-project 'GPS supported Aerial Triangulation', whose aim was to investigate the theoretical impact of GPS on the aerophotogrammetry and to verify these theoretical predictions by a test data set, was started in 1989.

A successful test flight was carried out in March 1992 over the test field 'Uster' near Zurich. About 100 reference points homogeneously distributed over the whole area and with a coordinate accuracy of 5 mm in planimetry and 6 mm in altitude were signalized. The photogrammetric block consisted of 8 strips with 10 photos per strips. (forward and lateral overlap 60 %) at an image scale of 1:10'000. During the whole flight GPS data at a frequency of 1 Hz were collected by a dual-frequency Trimble 4000SST receiver on board the airplane. Simultaneously a equivalent receiver situated at a distance of about 10-20 km from the test area provided for the reference data, allowing a differential computation of the coordinates.

By introducing the GPS derived photogrammetric projection centers in the bundle block adjustment an accuracy of 5 cm in planimetry and 8 cm in height was obtained for the ground control check points. Only four control points in the block corners have been included in the block adjustment. This accuracy corresponds to the values which can be obtained with a large number of ground control points (bridging distance i = 2b) but without integration of kinematic GPS data. It has been shown that in the case where the ambiguities can securely be fixed no additional drift parameters are necessary and a conventional block design without perpendicular strips may be flown.

Aerogravimetry *(see also section 3)*

In November and December 1992 an airborne gravimetric survey was carried out over Switzerland. During the flights 6 TRIMBLE SST receivers were operating (2 receivers on board the airplane, 4 receivers at ground stations). Because of the importance of the project and the long distances 4 suitably distributed reference stations were installed : Zimmerwald, Zurich, Engadin, Lausanne. (c. f. map 7).

First all reference stations were tied to the IGS site at Zimmerwald by means of static baselines. The measurements from the dual-frequency receiver on board the airplane were combined with the measurements from different reference stations. Because the constellation was often quite poor the minimum elevation angle was put to 10 deg. This led, however, to different satellite constellations due to individual topographic obstructions at the reference sites.

A quasi ionosphere free solution with real valued ambiguities was adopted and the coordinates were computed for every combination (different reference station to the same roving receiver). The comparisons showed an overall agreement in the order of 0.5 to 1 meter for the height component under reasonably good constellation (PDOP <25). For the combination with the gravimeter data the best reference station was chosen based on the best resulting constellation and the shortest distance to the airplane.

Astrometry of Fast Moving Objects using CCD Techniques

by T. Schildknecht, U. Hugentobler, A. Verdun, I. Bauersima and G. Beutler

The research work in this area was motivated by the so-called CQSSP project (Coupled Quasar, Satellite and Star Positioning). The declared goal of CQSSP (Bauersima, 1984), (Schildknecht et al., 1990) is the determination of the transformation parameters (as a function of time) between the reference frame defined by the stars and that defined by Quasars using artificial earth satellites as intermediary objects. The project is very ambitious from the instrumentation point of view. It is one of the goals that hopefully will be achieved using the new Zimmerwald telescope ZIMLAT and the HIPPARCOS star catalogue.

With the equipment readily available at the Zimmerwald observatory it was not realistic to initiate such an ambitious project. On the other hand, the 50 cm telescope of the current Zimmerwald Laser Observatory could be equipped with a CCD camera (Photometrics PM 512) and the CCD observation techniques could be developed. These developments allow to observe the relative position of fast moving objects like artificial satellites (or of natural bodies of the solar system) with respect to the stars with an accuracy of about 0.5" to 1.0" with the existing Laser telescope, already.

The techniques could be tested by observing e.g. geostationary satellites, objects in geostationary transfer orbits, and slowly moving satellites like GPS satellites and the Lageos satellites.

The currently achievable accuracy is already of interest for the detection (and orbit determination) of space debris, for the COGEOS project (determination of resonance terms in the earth's gravity field using geostationary satellites) and for the calibration of radio telescopes used for the routine orbit determination of TV satellites. Such applications led to a cooperation between the Astronomical Institute in Berne and the European Space Agency. The state of the project "CCD Astrometry of Fast Moving Objects" is described in (Schildknecht, 1994). Bibliography see also section 5.

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3 Determination of the Gravity Field

Gravity Reference Networks

by E. Klingelé, F. Arnet and T. Wyss

Gravity Measurements along re-measured first order levelling lines

In the last years gravity values have been determined simultaneously with the re-levelling of the Swiss National Levelling Network in order to correctly reduce the levelling measurements. In the period extending from 1991 to mid 1994, gravity measurements using LaCoste and Romberg gravity meters have been carried out on the following levelling lines (see also map 8):

1991:	Liestal - Olten- Aarburg	(Line A)
	Delemont - Porentruy - Boncourt	(Line B)
	Delle	
1992:	St. Maurice - Martigny - Sion	(Line C)
	Zürich - Winterthur - Frauenfeld	(Line D)
	Stein - Frick- Brugg§	(Line E)
1993:	Loeche - Sierre - Sion	(Line F)
	St. Maurice - Aigle - Roche - Les Grangettes	(Line G)
	Roche - Chillon	(Line K)
	Roche- St. Gingolph	
	Luzern - Zug- Sattel	
1994:	Zürich - Baden	(Line I)
	Frauenfeld- Steckborn	(Line J)

Gravity values have been computed on the basis of the absolute gravity value in Zürich and also linked to the Swiss National Gravity Network (c. f. map 9). The measured stations are fully documented and will be included in the new national levelling documents.

Swiss Absolute Gravity Network

In June 1994 three new absolute gravity stations (Lausanne, Basel, Monte Ceneri) were measured and two old stations were remeasured by means of a absolute gravity meter JLA 3. The measurement were done by "Austrian Bundesamt für Eich und Vermessungswesen" on behalf of the Swiss Geodetic Commission (c. f. map 10).

New fundamental gravity network of Switzerland

During 1953 and 1957, a first fundamental gravity network of Switzerland was established. Measurements for a new and precise gravity network were started in 1991. The stations of the new network were chosen coincident with the LV'95 network, the fundamental GPS network of Switzerland with about 100 stations. Unfortunatly, a lot of the GPS stations have quite a poor setup for the gravity instrument, so about 20 additional points were chosen coincident with first order levelling points with a good setup. Furthermore five absolute gravity stations were measured by the Austrian Bundesamt für Eich- und Vermessungswesen (BEV) in 1994, two on existing points and three new ones. The relative connection from the absolute stations to and within the relative gravity networks were measured with two or three LaCoste & Romberg G type gravimeters. For 1995, it is planned to make connection measurements to absolute stations in neighbouring countries.

Regional gravimetry (gravity mapping)

In the frame of a systematic gravity mapping of Switzerland at a scale of 1/100 000, the geophysical institue of the University of Lausanne, on behalf of the Swiss Geophysical Commission (SGPK) has measured about 5500 new gravity points. These stations will enable the SGPK to publish the first seven 1/100 000 maps and to prepare a set of four maps of a total of eighteen which compose the full coverage of Switzerland.

Apart from this systematic gravity mapping, two very detailed surveys were carried out by the geophysical institute of the ETH Zürich for glaciological purposes. The number of stations measured for these two surveys is approximately 200.

Airborne gravimetry *(see also section 2)*

During November 1992 the Geodesy and Geodynamics Laboratory (GGL) of ETH Zurich conduced a 6000 km line airbome gravimetric survey covering whole Switzerland in collobaration with LaCoste and Romberg Gravimeter Inc. Austin Texas. For this project LaCoste and Romberg Inc. modified specially one of their Marine gravimeter in order to match the requirement of an airborne survey. The system was mounted on a Twin Otter DeHavilland aircraft owned by the Eidgenössische Vermessungsdirektion. The aircraft was also equiped with two GPS receivers for precise positioning and one GPS receiver for navigation purposes.

The flight lines were oriented 70° E with a line spacing of 12 km (c. f. map 7). Four crossing lines were also flown for equalization purposes. A fully automated data processing system was developed for the computation of vertical accelerations, Eotvös- and altitude corrections and Bouguer anomaly computations. The first results show a difference of g in the order of 2.2 mgal at crossing points of lines flown at the same altitude.

Interpretation and Analysis

Automatic interpretation of gravity gradiometric data

The magnetic and gravity fields produced by a given homogeneous source are related through Poisson's equation. Starting from this consideration, it is shown that some 2D interpretation tools, widely applied in the analysis of aeromagnetic data, can also be used for the interpretation of gravity gradiometic data in 3 dimensions (vertical gradient). The procedures developped deal Specifically with the Werner deconvolution, analytic signal and Euler's equation methods. After a short outline of the mathematical development, synthesized exarnples have been used to discuss the efficiency and limits of these interpretation methods.

These tools could be applied directly to airborne gravity gradiometric data as well as to ground gravity surveys after transformation of the Bouguer anomalies into vertical gradient anomalies.

Upward continuation of gravimetric data in rugged topography

The problem of upward continuation of potential field data measured on rugged topography has been tackled by several authors. Its importance lies in the fact that gravity data, and to a certain extent also magnetic and aeromagnetic data, are not measured on a plane, wheras all algorithms for signal analysis and inversion are designed to work with data reduced to a plane surface. On the other hand, the need of properly prepared gravity and magnetic data does not permit careless solution of this problem. The method developed is based on the principle of equivalent-sources. In this method the equivalent-source layer has a specific geometry and depth. Therefore, only the density distribution has to be inverted. The upward continuation isperformed by means of a stepwise forward computation procedure which minimizes edge effects. The method provides a well-conditioned system of linear equations and is, therefore, quite stable and produces high-quality results (errors less than

0.04% using the whole grid to invert for the density distribution) even in the case of very rough topography, which is its main advantage.

Program for calculating gravitational effects of bodies

In order to calculate the gravitational potential, acceleration and gravity gradients of arbitrarily shaped polyhedrons a program called POTENZ, was developed. The formulas used within the program calculate the exact effects (no approximation) of constant density, flat faced bodies.

Theoretical studies

Gravimetric tests of the Newtonian Law

Since 1989 the IGP of ETH Zurich is conducting microgravimetric measurements within a dam of an electrical power plant at two stations separated by 90m in height. The measurements are performed mostly during spring when the variations of the water level are maximum. A good knowledge of the artificial lake enable the computation of the theoretical value of the vertical component of the attraction at both stations. The comparison between computed and measured gravity enables the computation of the value of the universal gravity constant. This experience will continue until sufficiently large set of data will be available for statistical test. These measurements were reapeated in 1991, 1992 and 1994.

Astronomical Geodesy

Zenith camera and determination of deflections of the vertical

by B. Bürki

Since 1991 new measurements with the transportable zenith camera system of the Geodesy and Geodynamics Laboratory (GGL) at ETH Zurich have been performed in several European countries and in Switzerland:

Catalunya: In order to determine the fine structure of the geoid, 66 stations have been observed in Catalunya and evaluated at ETH Zurich in collaboration with the 'Institut Cartogràfic de Catalunya', Barcelona, Spain).

France: Determination of deflections of the vertical in the region of the pyrenees consisting of 14 stations near the border to Catalunya, in collaboration with the 'Laboratoire de Géophysique et Téctonique', University of Montpellier, France.

Portugal: Determination of deflections of the vertical at 12 stations in the project area of the high precision network 'Geobase', in collaboration with the 'Instituto Português de Cartografia e Cadastro', Lisbon, Portugal.

In Switzerland the system has been used in order to fill up some data gaps with about 100 additional stations in the national network of deflections of the vertical. For most of these observations, stations of the new Base Network LV95 (c. f. also map 1) were chosen. Map 11 shows the basic data set for the new geoid determination of the geoid in Switzerland (c. f. Marti et al., this section), some 600 stations are available.

Computer supported on-line astronomical observations

by B. Bürki

The hard- and software systems ICARUS and AZIMUT enable on-line observations of latitude, longitude and azimuths by means of electronic theodolites, a special Time Digitizing Unit (TDU) and a notebook PC. This light weight and easy transportable system is used not only for educational purposes at ETH Zurich but also for the determination of deflections of the vertical in mountainous areas. It has been applied during several Italian expeditions in Pakistan and Nepal.

Based on the Time Digitizing Unit (TDU) a new unit (TDU pro) has been realized in order to support GPS based applications with dual-channel time-tagging possibilities. It can be used e. g. for aerophotogrammetric or other applications where accurate event recordings are important. While the TDU as used for astronomical observations is synchronized to UTC by means of low cost long wave time signal receivers, the new unit may be synchronized with the 1 PPS output from GPS receivers or adequate time devices.

Geoid Determinations

New Geoid Determination in Switzerland

by U. Marti, H.-G. Kahle and B. Bürki

The task of the new geoid computation in Switzerland is realised in a joint project of the Federal Institute of Technology (ETH) Zurich, the Federal Office of Topography (L+T), Wabern and the Astronomical Institute of the University of Bern (AIUB). The main objective is to calculate a geoid and a quasigeoid with an accuracy of better than a few centimetres over the whole country (200 km x 300 km), which is not only useful for combining levelling data with GPS-derived ellipsoidal heights but also for many other purposes such as for positioning and height determinations using the GPS technique.

This is realised by combining all available data of the gravity field such as gravity values, deflections of the vertical and GPS levelling. In the mountainous region of Switzerland much attention has to be given to the reduction of the observed values by means of a high resolution digital terrain model (DTM, see also Rickenbacher, section 1). The residuals are interpolated by means of collocation methods.

Since 1990 about 100 astro-geodetic stations have been observed for the geoid determination (see also chapter on astronomical Geodesy and map 11). About 60 stations of the new National GPS Network are directly connected to the 1st order levelling lines and can therefore be used as observations for an accurate geoid calculation.

About eighty percent of the new Swiss 25-meter digital terrain (height) model over the whole country are completed. In early 1996 the entire model should be available. Furthermore, the newest results of a project to determine the deep crustal structure of the Alps (NFP20) could be integrated into a new model of the depth of the Moho discontinuity. All astro-geodetic and gravimetric measurements were reduced and smoothed by means of the new mass models such as topography, Moho, Ivrea body, sediments of the Po plain, molasse basin and the water masses of the lakes.

With the remaining residuals, different variance-covariance models for the collocation could be tested. These tests revealed that a three-dimensional approach for these functions is not suitable and that an extrapolation to sea level gives unpredictable results. The a priori calculations showed that an accuracy of the geoid in the order of 3 to 4 cm can be reached over the whole country by using astro-geodetic observations only. Only in the extreme west and east we see mean errors of up to 6 cm relative to the fixed station in Zimmerwald. By including only 7 GPS levelling stations with an accuracy of 2 cm, the accuracy of the geoid calculation increases to a level of better than 3 cm in all parts of Switzerland.

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4 General Theory and Methodology

Research Work around the Bernese GPS Software Version 3

by G. Beutler, E. Brockmann, W. Gurtner, L. Mervart, M. Rothacher, R. Weber, T. Springer, T. Schildknecht, U. Hugentobler and A. Verdun

The decision of the Astronomical Institute of the University of Berne (AIUB), the Federal Office of Topography (L+T), the French Institut Géographique National (IGN), and the German Institute for Applied Geodesy (IfAG) to operate the CODE (Centre for Orbit Determination in Europe) Processing Centre of the International GPS Service for Geodynamics (IGS) (see section 5) as a joint venture, led to considerable further developments of the Bernese GPS Software Version 3. Cooperations with Leica Ltd, Heerbrugg and with the Federal Office of Metrology stimulated further research activities in the environment of the Bernese GPS team.

Let us first focus on the IGS-related activities. In the preparation phase (1991-mid 1992) the emphasis was put on the automation of the data flow and the daily processing work, on the improvement of the pre-processing procedures, and on the improvement of the modelling of the observable and of the satellite orbits. It was e.g. necessary to meet the IERS Standards (McCarthy, 1992) in our processing. This early phase of developments phase is e.g. documented in (Gurtner et al., 1993), (Fankhauser, 1993).

In 1992, during the 1992 IGS Test Campaign, the CODE Processing Centre, probably like each of the other IGS Processing Centres, was mainly preoccupied keeping the pace of routine processing, i.e. to process one day worth of data within one calendar day. Towards the end of 1992, the procedures became more and more smooth, which made it possible to develop and implement significant model improvements. This research work was co-ordinated by M. Rothacher and G. Beutler.

Let us first mention the ambiguity resolution strategies developed by L. Mervart: using the strategies presented in (Mervart et al., 1994) it was possible to safely resolve the ambiguity parameters up to baseline lengths of about 200 km; with the refinement of the strategies and with the improvement of the CODE and eventually the development of the IGS orbits ambiguity resolution became possible on baselines considerably longer than 1000 km. These results are presented in L. Mervart's Ph.D. thesis, where one also finds a discussion of the impact of ambiguity resolution on the estimated orbits and earth rotation parameters (Mervart, 1995).

Not only daily solutions, but also annual solutions, e.g. for the IERS (International Earth Rotation Service), had to be produced by the CODE Processing Centre (Beutler et al, 1993), (Rothacher et al, 1994). The research work performed by E. Brockmann are the key to such solutions: they are based on the normal equation systems stored during the daily processing. The "daily" normal equation systems may now be combined by the program ADDNEQ to give a wide variety of results. It is e.g. possible to produce free network solutions (where, as opposed to the daily routine, no stations are kept fixed), where station velocities may be solved for in addition to the station coordinates. Moreover it is possible to produce "new" series of earth rotation parameters, as soon as a change of the ITRF (e.g. transition from ITRF-92 to ITRF-93) takes place. These early stages of the ADDNEQ program are documented in (Brockmann et al, 1993).

The technique of combining normal equation systems was considerably extended and refined in 1994: since mid 1994 it is possible to produce the long arcs (three-days-arcs for the daily processing, in particular) based on one-day-arcs using the program ADDNEQ only, which led to a considerable reduction of the daily processing times. Since January 1995 the daily solutions are based on this technique. The theory underlying these developments is documented in (Beutler et al, 1995).

Let us also mention that the radiation pressure models recommended by the IERS standards were critically reviewed by (Beutler et al, 1994): long arc analyses (arc lengths up to 2 weeks) revealed that the Rock 4, Rock 42 models are one of the important accuracy limiting factors and that alternative models lead to much better results. The orbit model presented in (Beutler et al, 1994) is the model which is today used by the IGS Analysis Centre Co-ordinator for the weekly quality control (long arc analysis) of the orbits delivered by all IGS processing centres (Beutler, Kouba, Springer, 1995). The technique which is used today to combine the orbits of the IGS processing centre was developed to a considerable extent by the Bernese GPS team, too (Springer and Beutler, 1993), (Beutler, Kouba, Springer, 1995).

The atmosphere is an important accuracy limiting factor for scientific applications of the GPS. Whereas ionospheric refraction may be eliminated almost perfectly by forming the so-called ionosphere-free linear combination of the original carriers, the troposphere has to be modelled in the processing in order to obtain high accuracy results. This modelling may be performed in different ways. At CODE we are setting up 12 tropospheric zenith parameters per day and station. This number is at present reduced to 4 parameters per station and day in the program ADDNEQ. Up to 12 parameters may be used for special studies. There are strong correlations between tropospheric refraction and GPS height estimates. This is why in our results (as in all GPS results) the height is not quite as well determined as the horizontal station coordinates. Improvements of the mapping function still seem possible, however.

By forming another linear combination (the so-called *geometry-free linear combination*, i.e. the difference in meters of the L1 and L2 observations) it is possible to study the ionosphere in detail. The observations of the IGS network were used to generate regional ionosphere models (and maps) by U. Wild in his Ph.D. thesis (Wild, 1994). Moreover he studied short period variations (in space and time), so-called stochastic variations, of the ionosphere. Obviously the IGS network might be used for atmosphere studies, too. Hopefully this development will take place soon.

The Fast Ambiguity Resolution Approach (FARA) was developed by (Frei, 1991) in collaboration with the Bernese group. The impact on surveying in small areas (baselines shorter than 20 km) is considerable. Strong short period variations of the ionosphere during the maximum of the solar activity in 1990/91/92 led to considerable problems in the application of the FARA. In his diploma thesis (Schaer, 1994) developed methods to cope with this problem. The method was implemented in the Bernese GPS software Version 3.

The antennas of the GPS receivers proved to be great importance to obtain millimetre accuracies in GPS surveying. Helix-, and crossed dipole- antennas disappeared, today almost uniquely microstrip antennas are in use. The antenna problem becomes of vital importance, if different antenna types (even microstrip antennas of different manufacturers) have to be combined in the same survey. This problem was addressed several times in the time period 1991-1995. The antenna test in the Thun GPS test area of the Federal Institute of Topography in Fall 1994 was the latest of these experiments (Gurtner et al, 1994).

Let us, last but not least, mention the time transfer experiment using two special Ashtech Z12 receivers, which is under way as a co-operative effort of the AIUB with the Federal Office of Metrology. The purpose is to demonstrate (hopefully) sub-nanosecond time transfer between two external clocks (Caesium standard) connected to the two receivers. If the experiment is successful, an operational time transfer with sub-nanosecond accuracy using the GPS might be realised in the (not so near) future. For more information we refer to (Baeriswyl et al, 1993).

Regularization by digital topography and by estimating crustal parameters from gravity field data: Example of Switzerland

by A. Geiger, B. Wirth and U. Marti

Emphasis is put on the determination of crustal parameters by gravity anomalies. The determined parameters may be used for gravity field interpolation. A procedure similar to the well known 'Nettleton'-profiling for determination of homogeneous density distributions is generalized to two-dimensional data sets and varying density. Elsewhere similar approaches are used for gravity prediction, where in some way the correlation of height and anomaly is also used. The estimation of the parameters, which may also include density and trend parameters, is done by least-squares adjustment or by least-squares collocation. The applied model consists of horizontally varying crustal density, mantle density, reference depth of the Moho discontinuity, density of molassic basin and known disturbing mass distributions like the 'Ivrea' body in the southern part of Switzerland. Similar calculations are carried out to treat the deflections of the vertical. The regularization of the deflections by topographic masses is clearly demonstrated, especially in rugged topography. The stochastic part of the gravity anomaly is reduced to a few mgal.

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5 Geodynamics

Geodetic Measurement and their Impact on the Modelling of Recent Crustal Deformation in the Alpine Region

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

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

Earthquakes are commonly related to tectonic movements, sometimes of relatively small amplitudes which may correspond to far-field stresses of lithosperic plates. It is one of the main efforts of geophysical interested geodesists to determine deformations and recent crustal movements (RCM) directly from geodetic positioning at a global scale. Classical methods reveal significant results in local areas. One of the oldest high precision geodetic methods, the spirit levelling, yields reliable results for the height component of RCM. Due to the beginning of systematic high precision height determinations early in this century it has become possible to detect height changes at the mm range per year in Switzerland (Gubler, this publ.). Repeated triangulation and trilateration over the last century are not at that resolution power yet. However, modern treatment and recalculation of the whole data set will give, finally, information on horizontal strain patterns.

The upcoming modern geodetic methods, such as GPS will greatly enhance the knowledge of actual crustal movements. The question arose how geodetic data, especially uplift rates, can be compared and correlated with geophysical evidences, especially with earthquake activities. An attempt has been made to interpret geophysical and geodetic data in terms of strain energy by introducing it as boundary conditions for a mechanical crustal model and by assuming seismicity being correlated with strain energy. These stress-strain analysis of the Swiss Alps have been performed, using an elementary 2D-model as well as a more complete 3D-model. In the latter case the highly complex structure of the Alpine crust has been simplified to a multi-layer model, taking also detailed topography into account by means of digital terrain models. Isostatic forces as well as NNW-SSE compression of the Alpine chain have been introduced in finite element (FEM) calculations. To estimate the glacial rebound the thickness of the last glacial period has been taken into account. The results reveal a striking agreement of the calculated strain energy with the regional seismicity. Furthermore the uplift rates can satisfactorily been reproduced by the 3D calculations.

Active Crustal Deformation in the Marmara Sea Region, NW Anatolia, Inferred from GPS Measurements

by Ch.Straub and H.-G. Kahle

Northwestern Anatolia is a region of very rapid movements by which the morphology, geology and hydrology are significantly influenced. The aim of the project conducted was to study the interactions of these phenomena. In the geodetic part the deformation in the boundary zone between the Anatolian and Eurasian plates was determined by means of repeated Global Positioning System (GPS) measurements. Three campaigns (1990, 1992, 1994) were carried out around the Marmara Sea. The network lies within the active earthquake belt of NW Anatolia, extending from the western part of the North Anatolian Fault Zone (NAFZ) to the Aegean extensional province. Results of the dense network consisting of 52 sites clearly reveal the westward motion of Anatolia. The rates amount to 20 mm/a ± 3 mm/a on average relative to Istanbul, located at the north-eastern edge of the Sea of Marmara (c. f. map 12). Based on the trajectories for the displacements of the observation sites it is concluded that the Marmara Sea forms a transition zone between the Europe fixed region of Thrace/Black Sea (Eurasia) and NW Anatolia. The evaluation of the GPS data resulted in a deformation field which clearly shows that the main tectonic activity of dextral strike slip type takes place along the northern strand from the Mudurnu valley passing the Marmara Sea to the Gulf of Saros. At the western extremity of NW Anatolia the motion bends from W to WSW(250°). The overall motion is parallel to the known fault structures. The strain field calculated yields an E-W oriented right-lateral strike-slip movement (average 0.09 ppm/a, maximum 0.25 ppm/a) accompanied by NE-SW extension (average 0.09 ppm/a, maximum 0.32 ppm/a) at the eastern end of the Marmara Sea and N-S extension at the Aegean shore line. Comparisons with the directions of T axes derived from 65 fault plane solutions of earthquakes show considerable agreement. This is remarkable because no very strong earthquakes occurred in the investigation area between 1990 and 1994. The GPS derived deformation can be interpreted as aseismic creep which gently increases towards the Aegean extensional province. In the next step we will focus on stress determination and modeling of the regional stress field based on Finite Element calculations. We will further study in more detail neotectonic processes in conjunction with the GPS results.

GPS networks in western Greece and geodynamic processes

by H.-G. Kahle, M.V. Müller and G. Veis

Recent crustal movements detected by the analysis of repeated satellite geodetic measurements reflect the ongoing geodynamic processes in the Alpine-Mediterranean area. Superimposed on the large-scale counterclockwise rotation of the African plate, complex dynamic processes are affecting the lithospheric fragments between the African and Eurasian plates. Key features to better understand the driving forces and associated seismic activity in the Africa/Eurasia collision zone are the Calabrian and Hellenic arcs. Geodynamic investigations along the West Hellenic arc are based on different epochs of satellite geodetic measurements between 1989 and 1994, carried out using the US Global Positioning System (GPS). The resulting velocity field is presented in map 13. After having performed and analyzed the second re-occupation of the West Hellenic Arc sites the preliminary results of the first repetition have been substantially improved upon. The displacement field is much more resolved and shows a distinct movement of western Greece to the SW relative to Italy with an average of 150 mm between 1989 and 1994. There is further a clear indication for an increase towards Crete reaching 200 mm for the time span of 5 years. The maximum strain rate is 0.18 µstrain/a located in the vicinity of Lefkada, where anomalously high earthquake activity is observed. The data provide strong evidence for dextral strike-slip motion on the order of 25 mm/a along the Kephalonia Fault Zone (KFZ). The deformation field of the KFZ is interpreted as a transition zone between the kinematics of the Apulian platform and the West Hellenic fold and thrust belts.

From the five-year interval between GPS observations made in SE Apulia, in the northern Ionian Islands, in Epirus and in the Peloponnesus it was possible to detect the trend of two distinct kinematic fields of recent crustal movements. These are clearly separated by a zone aligned with the NNE-SSW tending Kephalonia Fault Zone. The Ionian Islands are the site of intense seismicity. Strong earthquakes (M>7) near Kephalonia occurred in 1953, 1972 and 1983. Source parameters of the 1983 Kephalonia island earthquake (M=7.1) have revealed a dextral strike-slip mechanism, which agrees well with the strain field calculated from the GPS observations. Strong evidence supporting a strike-slip mechanism is also provided by the NE-SW trend of aftershocks from this event. The existence of the KFZ connecting the NW edge of the Hellenic Arc with the compressional zone along the Adriatic-North Ionian coast is further supported by a new analysis of the 1972 earthquake which occurred offshore of W. Kephalonia island.

It is interesting to note that the relatively quiet seismic period in which our measurements were carried out exhibits qualitatively the same sense of movement as the fault-plane solutions derived from large co-seismic events. Based on the available and forthcoming measuring campaigns it is the aim of our efforts to compute, in a further step, the stress field and strain energy and to compare these results with neotectonic information and seismological data.

SELF (Sea Level Fluctuations: geophysical interpretation and environmental impact).

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

This project is carried out under the auspices of the European Union. It joins 11 different institutions from all over Europe in a close cooperation: Italy, Germany, Greece, United Kingdom, Switzerland and Poland. One of the main objectives of this project is to determine the heights of selected tide gauge reference markers in the Mediterranean with respect to a common reference frame by means of GPS with utmost accuracy. Furthermore these heights are used for analyses and studies of past and actual sea level variations. The GPS height connections were performed with baseline observation sessions lasting 48 hours in order to connect the tide gauge heights to either SLR or VLBI reference stations (c. f. map 14). The radiometers have been operating for dedicated tropospheric measurements simultaneously to the GPS receivers. The GPS processing was carried out with the Bernese software whereby the measured path delay patterns have been implemented. The results obtained revealed improvements of the session-to-session scatter in almost every case.

Topometric work for the National Research Programme (PNR31) "Climatic changes and natural catastrophes"

by H. Dupraz

The National Research Programme "Climatic changes and natural catastrophes" studies the impact of future climatic changes on the environment and society in Switzerland. A study of about 20 sites spread out all over Switzerland has been undertaken by a working group called "Terrain unstability"; this study includes inventory tasks of historic events, quantification of movements, correlation with climatic factors, and prediction of possible natural hazards.

In many cases the comparison of existing documents, regularly updated since many decades, enables to quantify correctly the movements in the course of years.

In 1992, for the region of Grächen (Alps of Valais), the measurements of the 1930' triangulation network were brought out of the archives, for an area of about 20 km2. A compensation by the least squares revealed erroneous observations as well as increased precision (1σ=2cm) by a factor of 3-4. For 12 points, the comparison with a recent GPS determination showed movements ranging from 15 to 48 cm over a period of 60 years. These movements are highly significant since the movements, recorded on benchmarks considered as geodesically stable, are all smaller than 2 cm.

For the landslide of la Frasse (near Leysins, Alps of Vaud), we disposed of graphic cadastral plans from several periods: 1768, 1861, 1981 (in use). An assembling of these plans through digitizing, then a comparison through common points, located in stable areas, made it possible to divide the landslide in areas of variable speed, between 0 and 20 cm/year, this over a period of two centuries. This information was sharpened through a new determination by means of GPS in 1994 which also constitutes a new reference, more precise for the follow-up of the studies.

Other works of the same type were done at Mollens (Alps of Valais) and at Conters (Canton of Grisons). The GPS method proves to be appropriate in historical triangulation nets in which a lot of optical links disappeared in the course of years as a result of changes in vegetation and built-up areas.

In order to guarantee a precision and reliability in the order of 1 cm and because of the mountainous nature of the sites and the strong altimetric differences, we generally work in rapid static mode, with baselines inferior to 5 km and with a double positioning of at least 20 minutes at each point, in order to guarantee the precision and fiability in the order of the cm.

Climatic Change Detection on Alaskan Glaciers by Satellite, Airborne and Gravity Monitoring

by T. Wyss, H.-G. Kahle, W. Haeberli, A. Geiger and E. E. Klingelé

In the forthcoming decades mountain glaciers all over the world may possibly experience important mass losses due to anthropogenic global warming. Such changes are considered as key signals for the global observation of the climate system. Despite the importance of the issue no comprehensive zero epoch data base for the 21st century has been compiled so far due to a lack of representative data sets. This absence of data can be mainly attributed to the difficult accessibility of most mountain regions, which leads to expensive and time-consuming field campaigns. In order to survey more glaciers in different geographic latitudes efficient methods must be found, which are operational as well as feasible in remote areas.

In order to address the issue the Geodetic and Geodynamics Laboratory (GGL) and the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) conducted a feasibility study with the aim to study projects and methods for monitoring glaciers within different climate zones of Alaska. In the frame of an informative meeting with representatives of the Geophysical Institute (University of Fairbanks, Alaska) and the United States Geological Survey (Section Fairbanks, Alaska) projects of mutual interest and possibilities of future collaboration were discussed. It showed that main emphasis should be put on comprehensive surveys of selected glaciers in the Brooks Range, the Alaska Range and the Kenai Mountains with the aim to produce maps that show the current state of the glaciers with sufficient accuracy. The proposed survey methods comprise airborne laser profiling and aerophotogrammetry as well as gravimetric and glaciological measurements. Of further interest is also the monitoring of around 200 glaciers in Alaska by means of satellite imagery. Necessary facilities for processing and analysing satellite data are already available at the University of Fairbanks (SAR Facility of NASA).

To prove the feasibility of the proposed projects GGL and VAW carried out test flights with a laser profiling system in the area of the Aletschglacier (Switzerland) and conducted a complete gravimetric field campaign on the Unteraarglacier (Switzerland). Supported by differential GPS the airborne survey led to promising results, which support an application of laser profiling for surveying glaciers in remote areas. Furthermore, the campaign on the Unteraarglacier showed that gravimetric surveys on suitable mountain glaciers can be carried out efficiently and that the modelling yields satisfying results even if only a small number of stations is available.

Based on the obtained findings the authors of the study conclude that the proposed glacier monitoring projects in Alaska are needed and feasible. However, successful accomplishing of such large scale projects requires a strong interdisciplinary collaboration among the international partner institutions.

Geodynamic Study of the Yellowstone Caldera

by F. Arnet, E. Klingelé and H.-G. Kahle

The Yellowstone caldera is situated in the middle of the Yellowstone National Park in the north west of Wyoming, USA. It is an active silicic volcanic system that exhibits very high heat flow (exceeding 1500 mWm^{-2}), widespread earthquake activity and high rates of current crustal deformation. The Yellowstone caldera is due to a hot spot, which started in the Snake River Planes in Idaho and moves with a velocity of about 4.5 cm towards north-east. The signs of the latest three eruptions of this hot spot are still visible. They happened 2 mio., 1.2 mio. and 0.6 mio. years ago and belong to the largest natural events, which happens on the earth. The volume of eruption 0.6 mio. years ago is about 1000 km^3.

From 1923 to 1984, the caldera experienced up to 1.0 m uplift, measured by precise levelling, followed by a subsidence until 1993 of up to 14 cm (c. f. map 15). Levelling campaigns over the whole Yellowstone National Park were carried out in 1923, 1976 and 1987. Further, annual measurements were done along the caldera crossing line from Canyon Junction to Fishing Bridge from 1984 to 1993.

To assess the temporal variations of the gravity field, a 200+ station precise gravity network was established in 1977 over the entire Yellowstone Plateau that was coincident with the levelling network. The gravity network was reobserved in 1983, 1987 and 1991 with a repeatability of ±12 mgal (1 mgal = 10^{-8} ms^{-2}). Gravity changes of up to -60 mgal were detected from 1977 to 1983. This was followed by a gravity increase of up to +60 mgal from 1987 to 1993. Additional re-observations emphasized two caldera-crossing lines in 1979, 1986, 1988, 1989, and 1990 with a average precision of ± 10 mgal. Gravity changes from 1987 to 1993 are also displayed in map 15.

In 1987, a GPS network of about 40 points along the levelling lines as well as in the backcountry areas was established and connected with a net over the area of the 7.5 Hebgen Lake earthquake of 1959 (south west of Montana). Repetition measurements of this net were carried out in 1989, 1991 and 1993. The height changes found by the GPS campaigns lie within the significance level (about ± 2 cm) of the changes found by the levelling measurements.

Models for combined interpretation of GPS, levelling and gravity data are being tested.

This project is accomplished in collaboration with the University of Utah, Salt Lake City, the University Navstar Co-operation UNAVCO, Boulder and, the US Geological Service, Vancouver.

Strain and Stress analysis and Block Movement Detection

by Geiger, A., G. Danuser, Ch. Straub, Cocard, M.

For the interpretation of geodetic measurements in view of kinematic investigation a software tool has been developed in order to detect block-movements and to determine strain fields. The block movement detection is based on robust affine transformations. For strain field calculation collocational methods and continuum mechanics have been merged. The method can be applied for local terrain slides and deformation analysis as well as for tectonic regions and plate movements detection.

Density Distribution within the Lithosphere

by H.-G. Kahle and E. Klingelé

The topics of this research area covered in the period 1991-1995 was to investigate the possibilities of utilizing gravity field data and geophysical information for improving models of the density distribution within the sedimentary layers, the crystalline basement and the lithosphere including the lithosphere/asthenosphere boundary. Emphasis was also placed on laboratory experimental work which provides velocity/density relationships for various mineralogical constitution under different temperature and pressure conditions. Knowledge of the density distribution forms the basis for geodynamic interpretation (rheological models, flexural rigidity) and it has also become important for high resolution geoid determination, especially in mountain belt regions.

The compilation of density distribution within the lithosphere presented in an IAG report (Kahle and Klingelé, 1995) covers most of the major geodynamic features, both on land as well as at sea. The report serves, however, only as an example for numerous activities in this field. Of major importance will be satellite and airborne gravimetry in the future for integrative interpretation of lithospheric structure and composition. Broad-scale programs such as the European Europrobe will substantially contribute to future activities related to the topics outlined below. The derived average density model for Europe [Yegorova et al., 1995] (see table above) will provide a highly valuable reference for interpretation of gravity anomalies and geoidal undulations in terms of geodynamic implications. This type of approach should be extended to other parts of the world. In addition to further measuring campaigns and laboratory experiments also gravimetric and gradiometric inversion techniques will play a crucial role in this interdisciplinary field of research.

Layer	v_p (kms^{-1})	ρ (gcm^{-3})
Sedimentary cover		
upper layer	2.4-4.0	2.2
lower layer	4.5-5.5	2.5
Consolidated crust		
upper layer	5.8-6.4	2.7-2.8
intermediate layer	6.5-6.7	2.9
lower layer	6.8-7.2	3.1
upper mantle	7.8-8.2	3.3

Table: Average p wave velocities (v_p) and density values (ρ) for Europe (Yegorova et al., 1995)

Yegorova, T., Kozlenko, V., Pavlenkova, N. and V. Starostenko (1995): 3-D density model for the lithosphere of Europe: construction method and preliminary results. Geophys. J. Int., 121: 873-892.

The Swiss Contribution to the International GPS Service for Geodynamics (IGS)

by G. Beutler, W. Gurtner, M. Rothacher, R. Weber, A. Wiget

Since 1991 Switzerland was contributing in the following areas to the development of the International GPS Service for Geodynamics (IGS):

- Operation of the permanent GPS receiver at the Zimmerwald observatory
- since March 1993 (see section 2),
- operation of the CODE processing center of the IGS,
- representation in the IGS Campaign Oversight Committee (1991-1993) and
- the IGS Governing Board (since 1994),
- IGS mail and the Central Bureau Information System,
- operation of a GPS Bulletin Board at Zimmerwald

Operation of the CODE Processing Center

CODE stands for Center for Orbit Determination in Europe. Today it is a joint venture of the following institutions

- the Astronomical Institute of the University of Berne (AIUB),
- the German Institute for Applied Geodesy (IfAG).
- the French Institut Géographique National (IGN), and
- the Swiss Federal Office of Topography (L+T),

These institutions contribute either through personnel or financially to the daily operations of CODE. The CODE processing center is located at the AIUB. The CODE computers are included in the cluster of VAX Alpha machines of the University of Berne. CODE has the top priority on two of these computers.

Markus Rothacher is the head of the CODE processing team. The daily operations are supervised by one research associate. T.A. Springer, L. Mervart, E. Brockmann had this position for some time since mid 1992. Since July 1993 till the end of June 1994 Robert Weber was responsible for supervising the daily CODE solutions. Many developments took place since 1990 in the environment of the CODE processing center. These developments are outlined in section 4 of this report.

The CODE products are made available to the user community in weekly batches. Orbits and earth orientation parameters (x- and y- coordinates of the pole, UT1-UTC drift) are available to the three IGS Global Data Centers, namely CDDIS (Crustal Dynamics Data Information System at Goddard Space Flight Center), IGN (Institut Géographique National in Paris), and SIO (Scripps Institution of Oceanography in San Diego). Today the CODE orbits have an rms accuracy of about 10 cm per coordinate, the earth orientation parameters are accurate to about 0.2 - 0.3 mas for the daily pole position, to about 0.04 ms/day for the length of day. More information may be found in the annual reports of the CODE processing centers to the IERS (Beutler et al., 1993), (Rothacher et al., 1994) or in the first IGS annual report (c. f. section 1). Let us also refer to the bibliography of this section.

Representation in the IGS Campaign Oversight Committee (1991-1993) and in the IGS Governing Board (since 1994)

Werner Gurtner and Gerhard Beutler were elected as members of the IGS Campaign Oversight Committee at the XX-th General Assembly of IUGG in Vienna (August 1991). G. Beutler was subsequently elected as the chairman of the committee. Many presentations at International conferences had to be made on behalf of the IGS Oversight Committee, many contributions to proceedings of conferences and to scientific journals had to be written. We refer to the bibliography of this section for more information.

The work of the IGS Oversight Committee obviously was quite successful: In spring 1993, at the IGS workshop in Berne, a first draft of the IGS Terms of Reference were presented by Prof. I.I. Mueller, at the IGS Oversight Committee meeting in Baltimore (attached to the 1993 AGU spring meeting) they were approved by the Oversight Committee. After minor modifications the Terms were accepted by the IAG at the General Meeting in Beijing (August 1993). Eventually, the IGS became an official service of the IAG on 1 January 1994. The IGS operations are now coordinated by the so-called IGS Governing Board consisting of 15 members (representatives of components of the IGS, represenatives of the IAG and the IERS). The chairman of the IGS Oversight Committee also became the first chairman of the IGS Governing Board. For more information concerning the development of the IGS we refer to (Mueller and Beutler, 1992), (Beutler et al, 1994a,b).

IGS mail and the Central Bureau Information System

Immediatly before the start of the 1992 IGS Test Campaign it became clear that an efficient tool for communication within the IGS had to be created. This is why an electronic mail box, called IGSMAIL, was established at the AIUB in Berne. The IGS mail box was later on supplemented by the IGS report series (reserved for the weekly reports of the IGS processing centers, of the IGS Analysis Center Coordinator, and for the regular analyses of IGS products by the IERS (Central Bureau and Rapid Service Subbureau).

With the start of the official IGS service on January 1, 1994 the IGS mailboxes were transfered to the IGS Central Bureau (at Jet Propulsion Laboratory in Pasadena), where they were integrated into the the Central Bureau Information System (CBIS). The CBIS was designed and developed by W. Gurtner in collaboration with the IGS Central Bureau (Liu and Gurtner, 1994).

The Swiss GPS Information System

by U. Wild

The Swiss GPS Information System was installed in 1992/93 on the station computer of the permanent GPS tracking station of the Swiss Federal Office of Topography (L+T) at the SLR observatory Zimmerwald. The information system may be accessed by computer networks (Internet) or by telephone modem.

The main options are:

- The GPS-Status files of the USNO GPS Information system are downloaded daily and may be displayed.
- The status of the permanent GPS receiver in Zimmerwald may be displayed. The status file contains information about actually tracked satellites, their elevations and azimuths. In addition for each satellite the AS flag, the User Range Accuracy (URA) and the health flag are displayed.
- Different types of orbit data are available: For campaign planning purposes the actual ephemeris files of the permanent tracking receiver is available, for high-precision GPS applications the precise orbits of the Center for Orbit Determination in Europe (CODE) at the Astronomical Institute of the University of Berne may be obtained.
- Application programs:
  Coordinate transformations between WGS-84 / ITRF and the national coordinate system (and others) may be computed. Another program allows the computation of the deflections of the vertical and geoidal heights (for the Swiss geoid) of sites within Switzerland.

Presently about 50 surveyors are using the information system regularly. We hope to be able to increase this number by offering a more user friendly environment (WWW) in the future.

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GPS-Landesnetz LV95 | Réseau national GPS LV95 | National GPS Network LV95

Map 1: National GPS Network LV95

GPS-Landesnetz LV95

Anschlüsse an die Landestriangulation
1. und 2. Ordnung (LFP1)

Réseau national GPS LV95

rattachements à la triangulation
de 1er et 2e ordre (PFP1)

National GPS Network LV95

Connections to the 1st and 2nd
order triangulation networks

Map 2: National GPS Network LV95: Connections to the 1st and 2nd order triangulation networks

GPS-Landesnetz LV95

Anschlüsse an das Landesnivellement (HFP1)

Réseau national GPS LV95

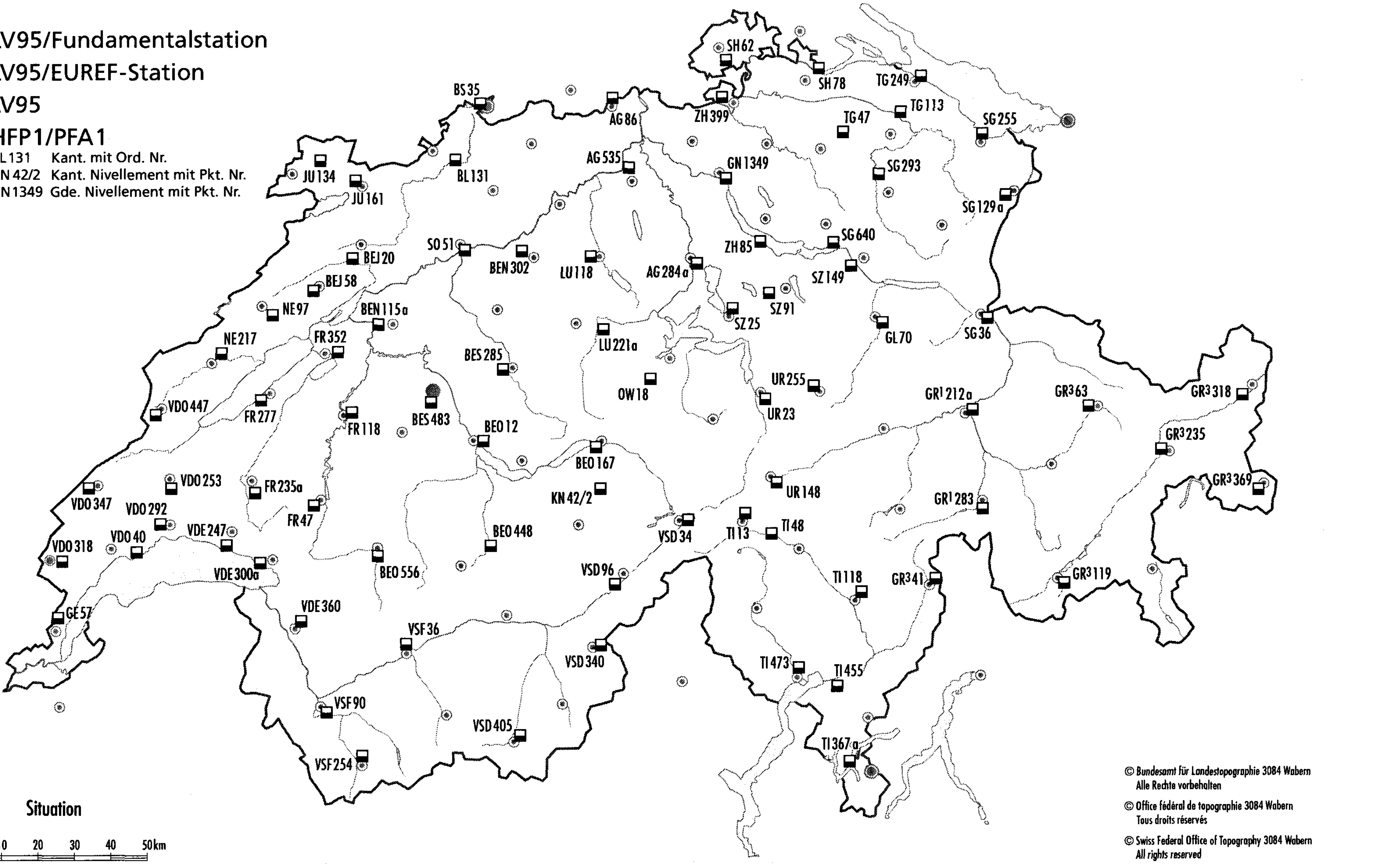
rattachements au nivellement fédéral (PFA1)

National GPS Network LV95

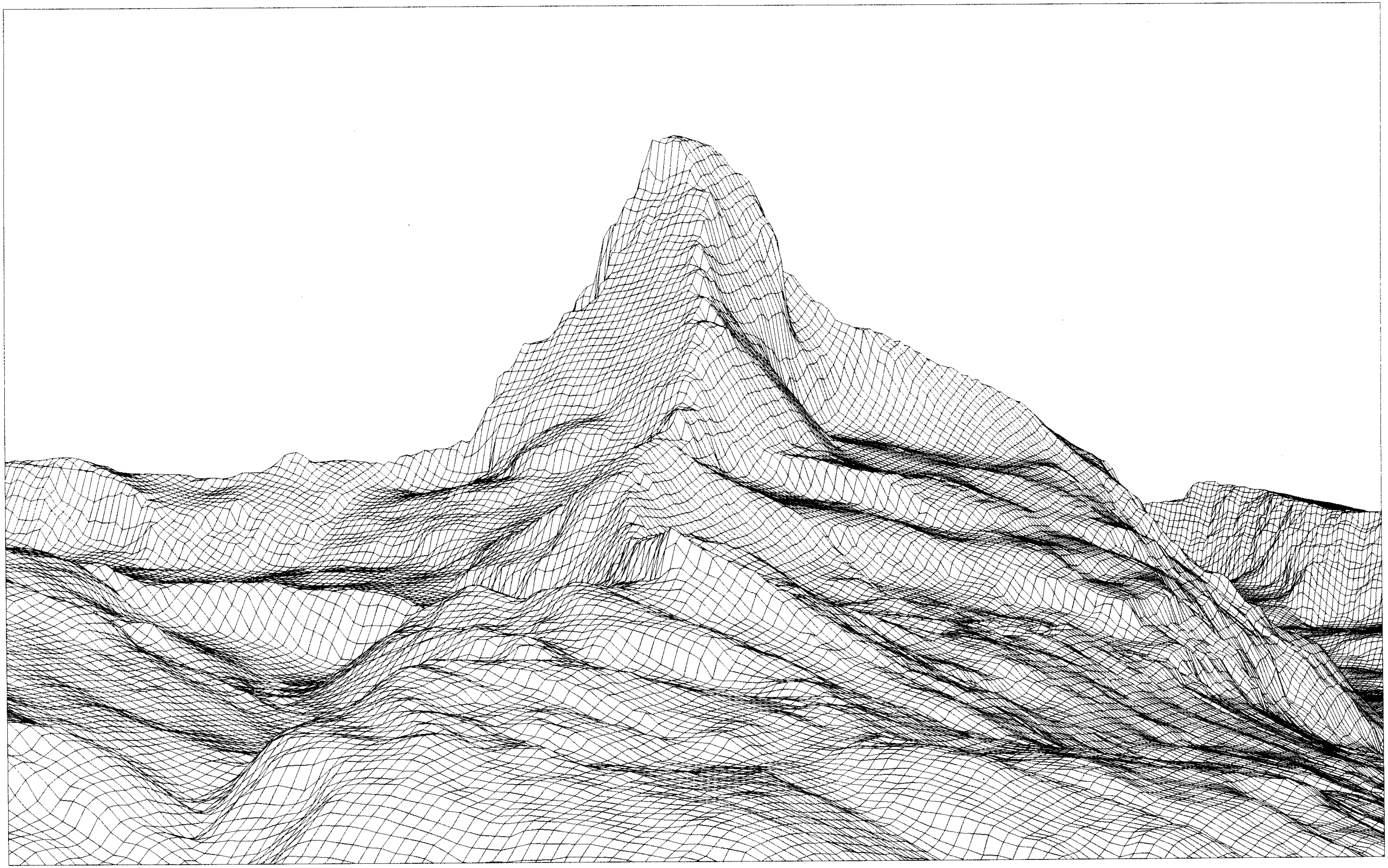
Connections to the national levelling network

- LV95/Fundamentalstation
- LV95/EUREF-Station
- LV95
- HFP1/PFA1

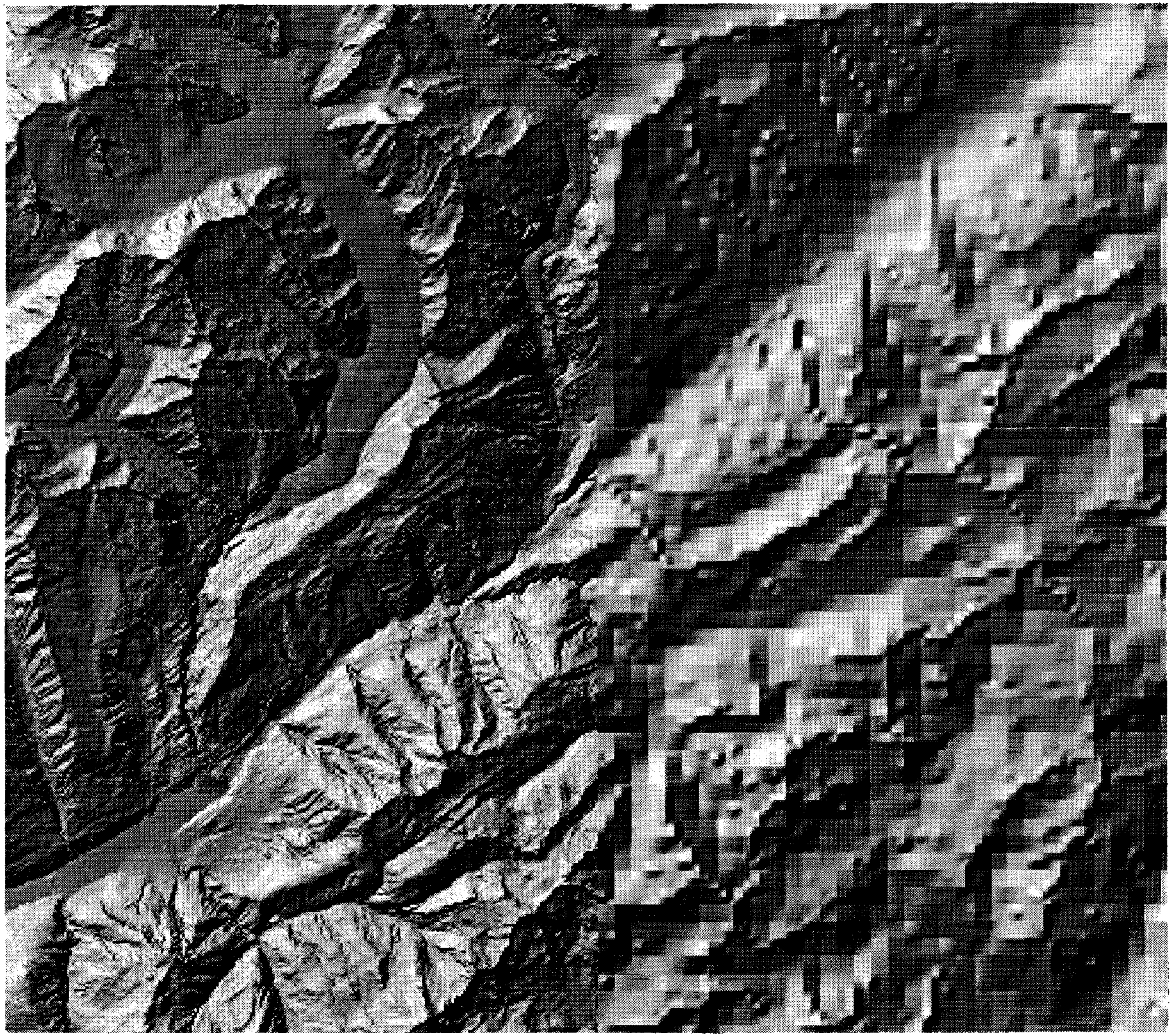
BL131	Kant. mit Ord. Nr.
KN 42/2	Kant. Nivellement mit Pkt. Nr.
GN1349	Gde. Nivellement mit Pkt. Nr.



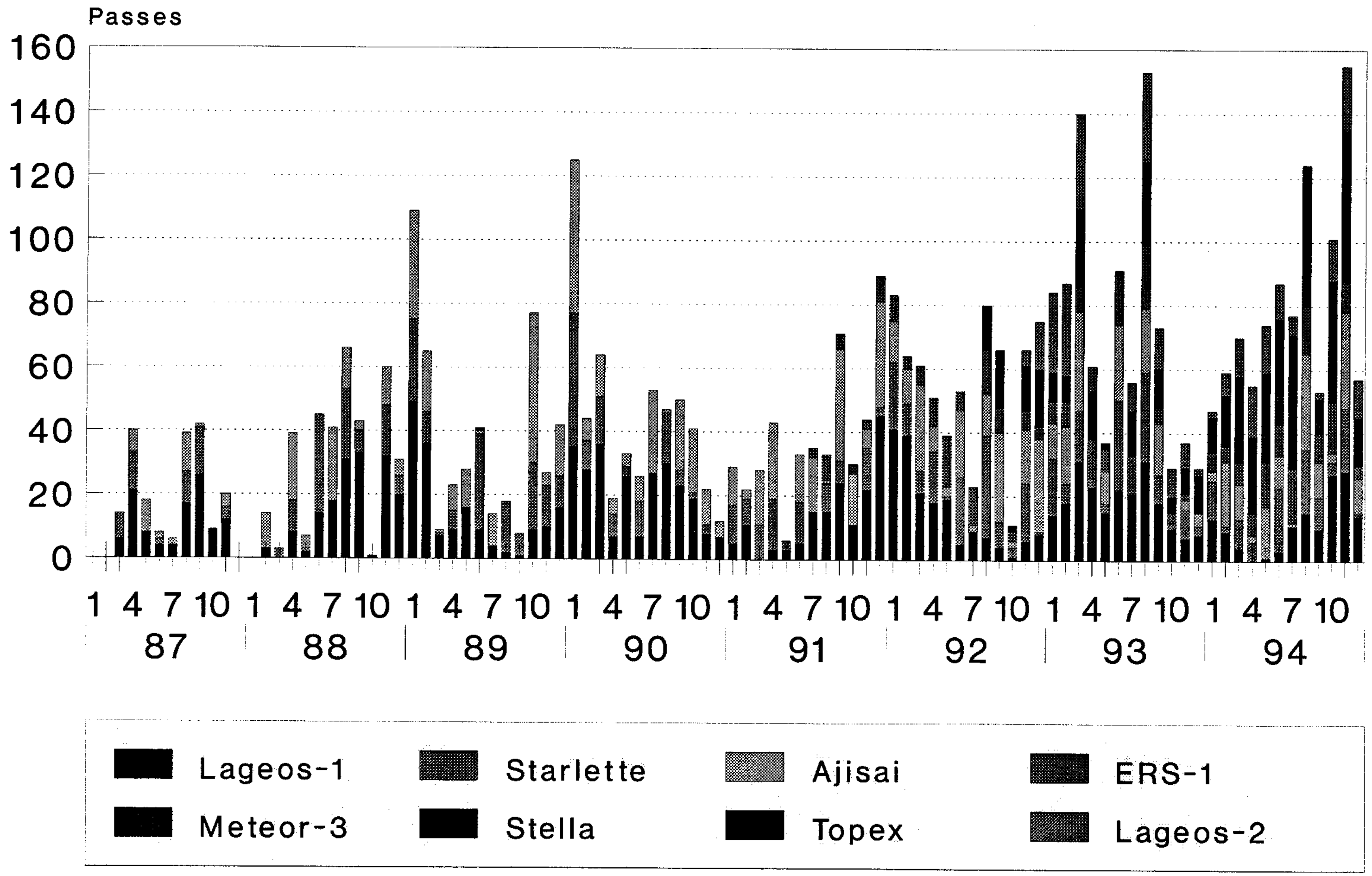
Map 3: National GPS Network LV95: Connections to the national levelling network



Map 4: Digital Height Model DHM25 in Switzerland: Section of the Matterhorn in the Valais alps

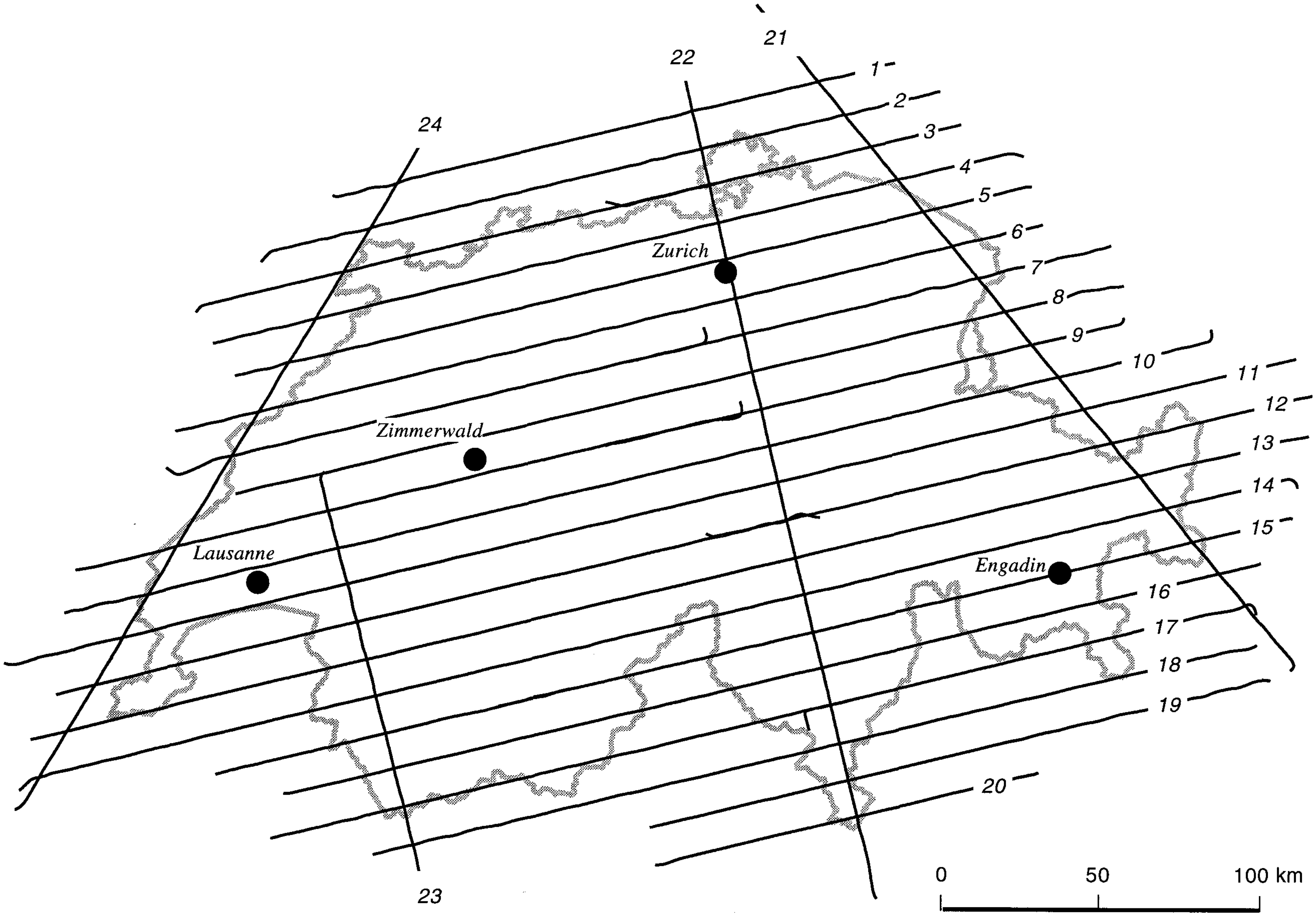


Map 5: Comparison between the new digital height model DHM25 (resolution 25 m) and the old model RIMINI (resolution 250 m) in the region of the Aletsch Glacier

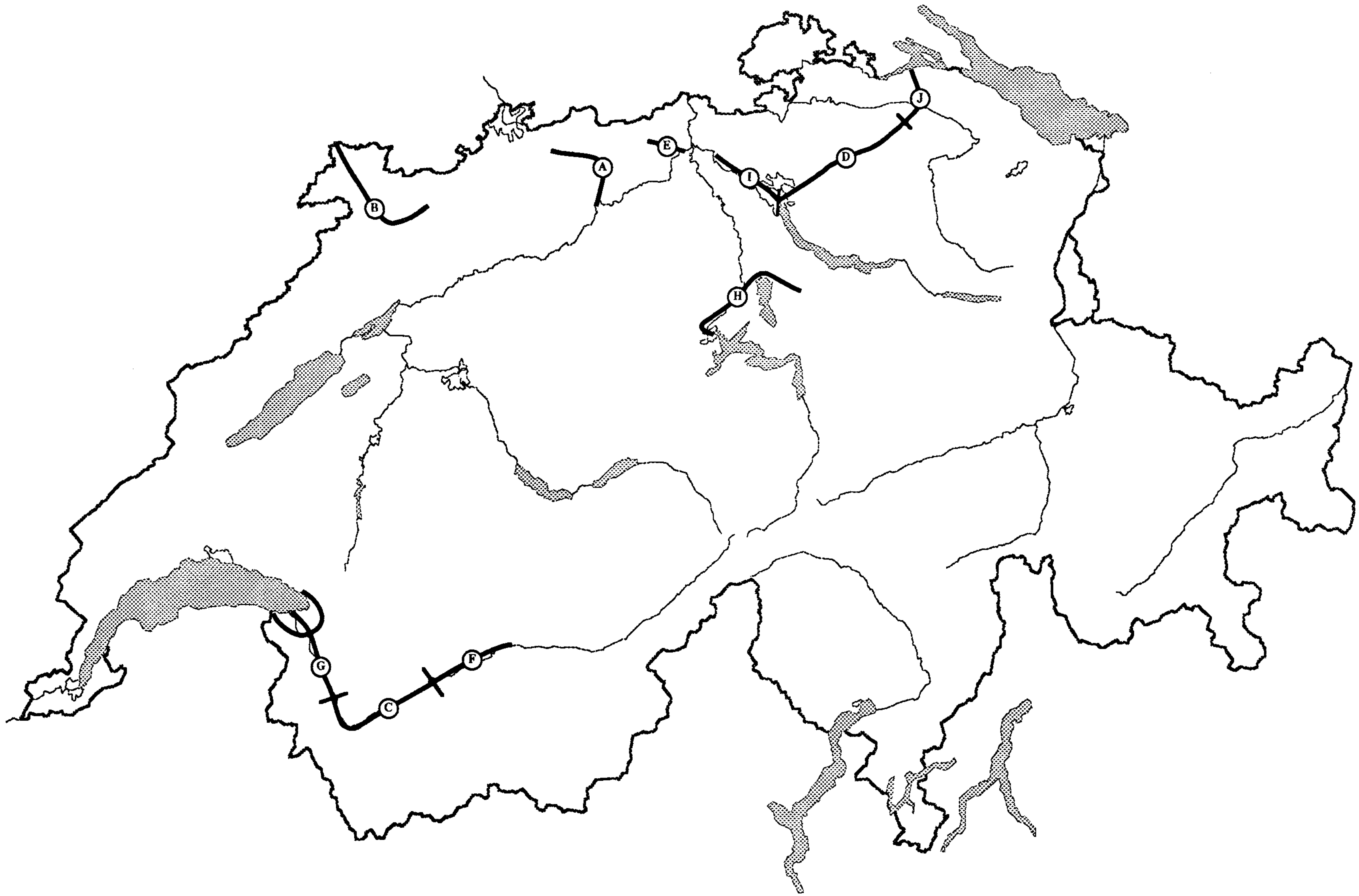


Read bars Lageos-1 to Lageos-2 from bottom to top.

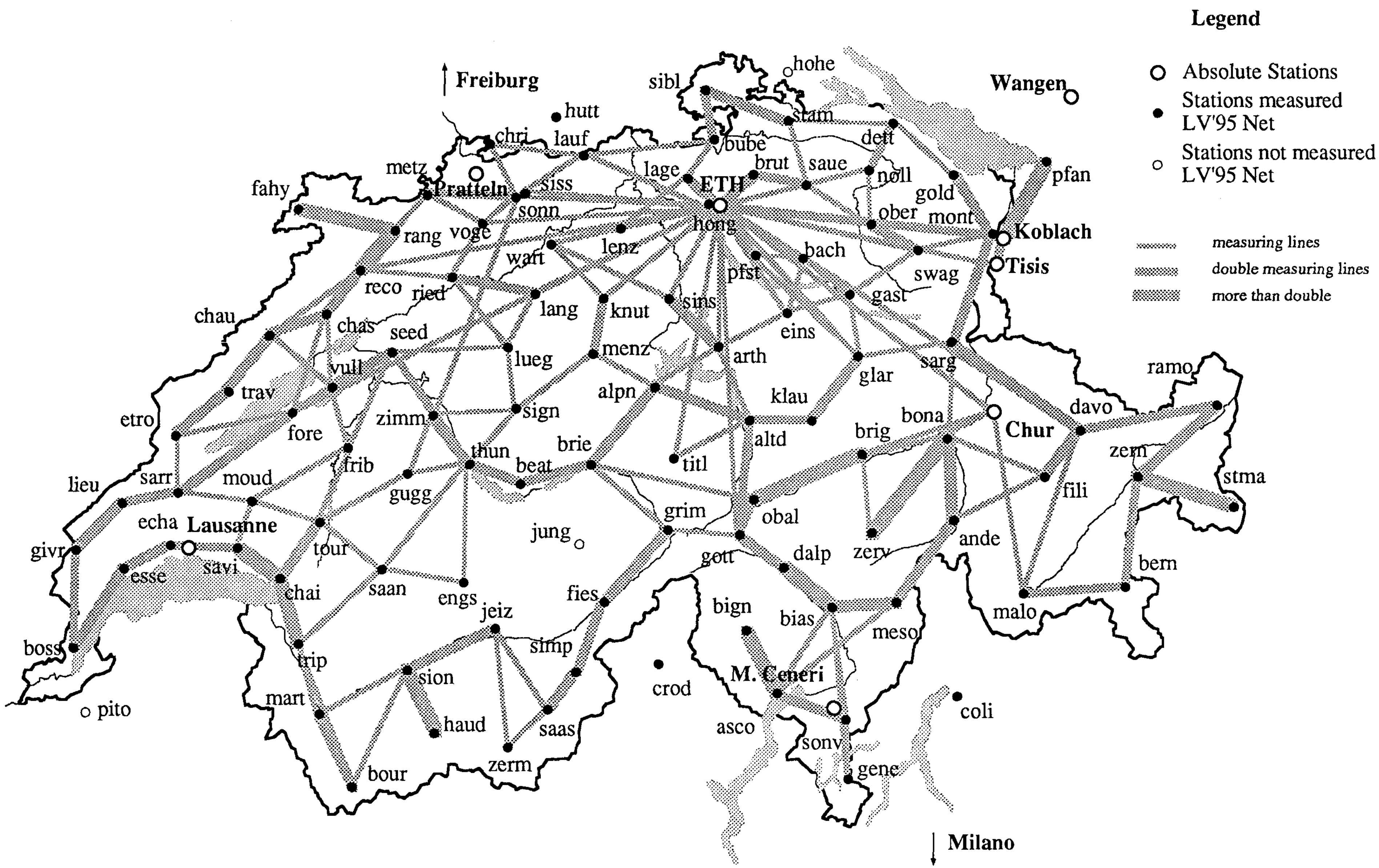
Map 6: Zimmerwald SLR-Observatory: Passes per Month



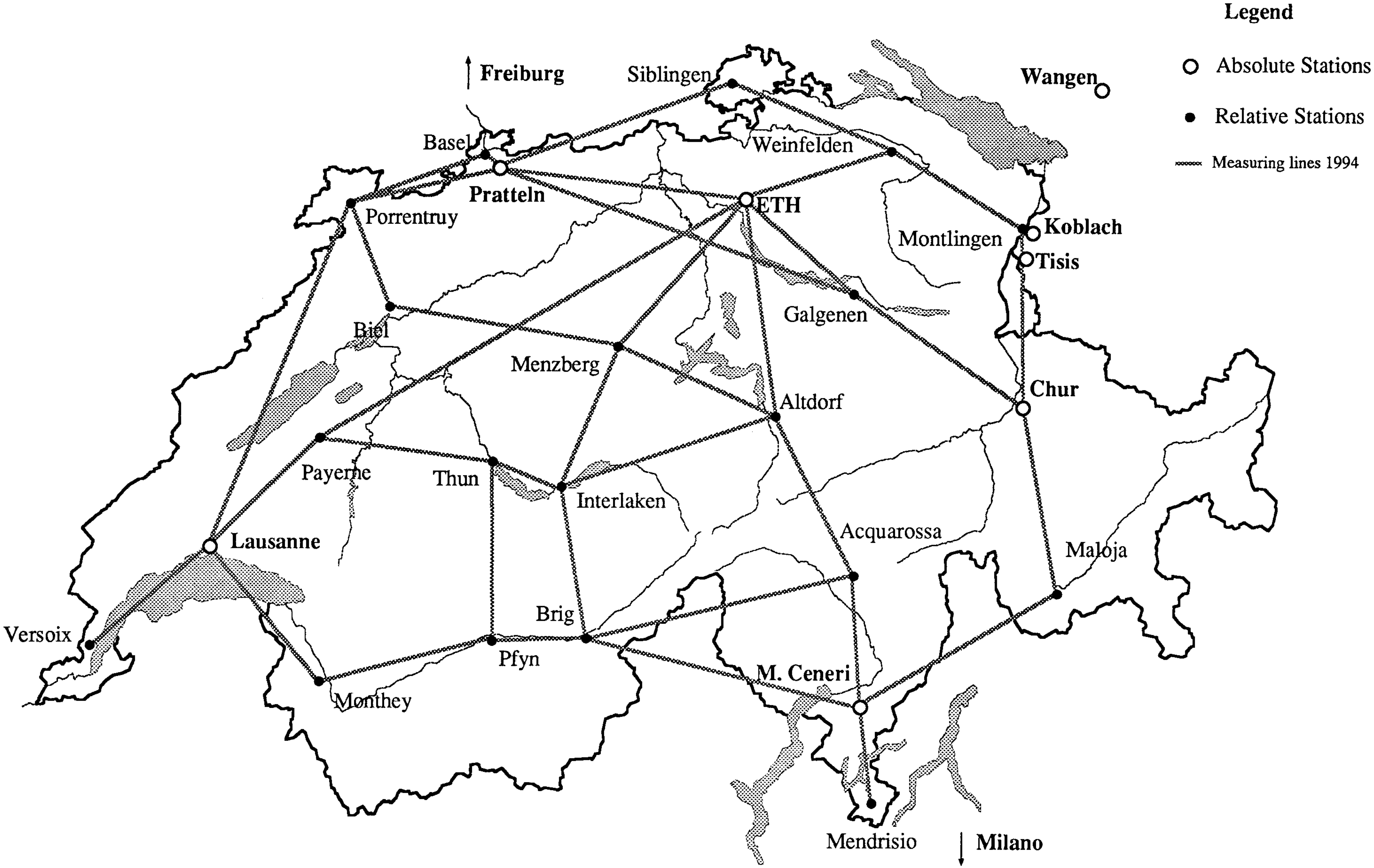
Map 7: Design of the surveying lines in the 'Aerograv 92' project



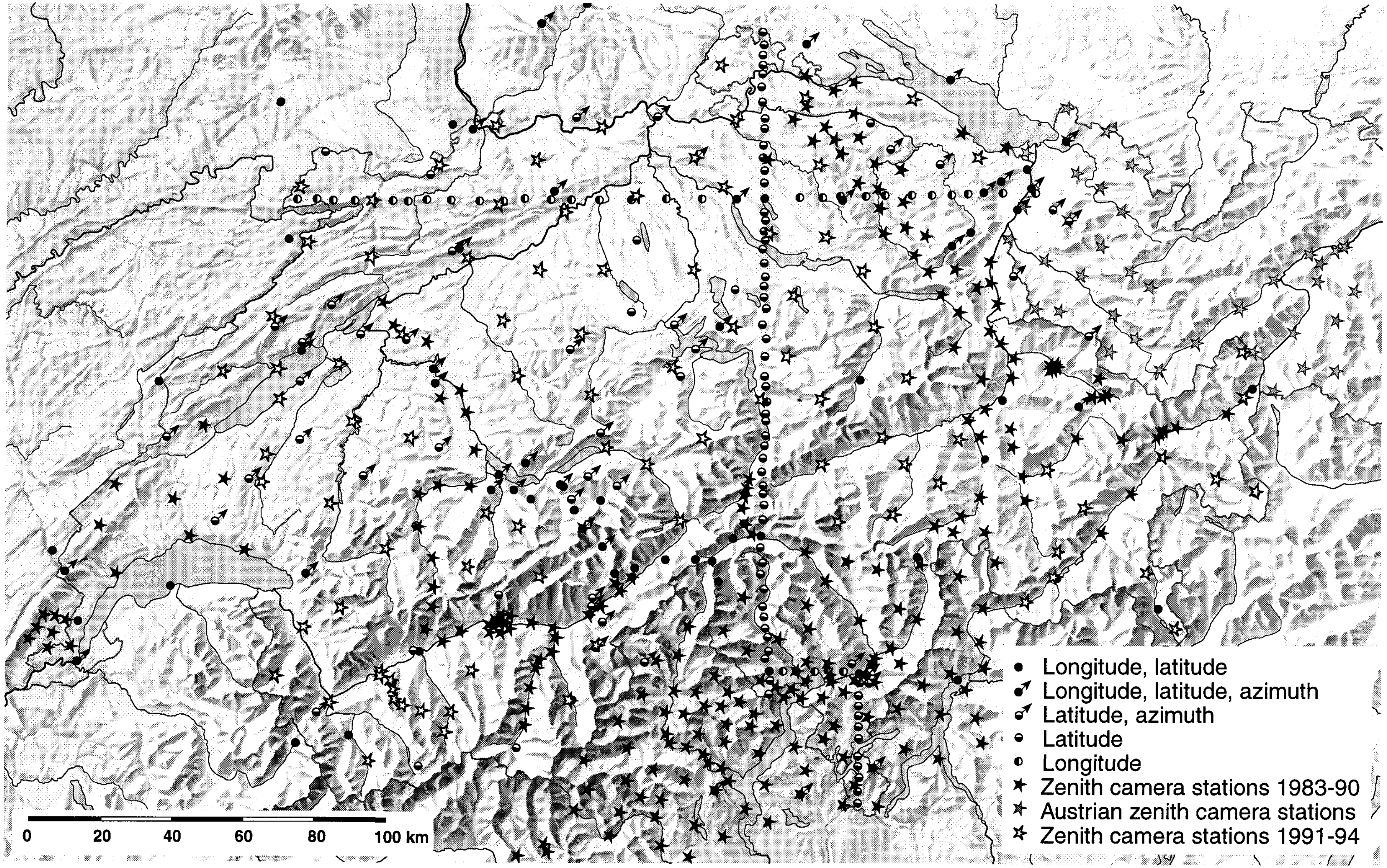
Map 8: Gravimetric Measurements on Precision Levelling Lines



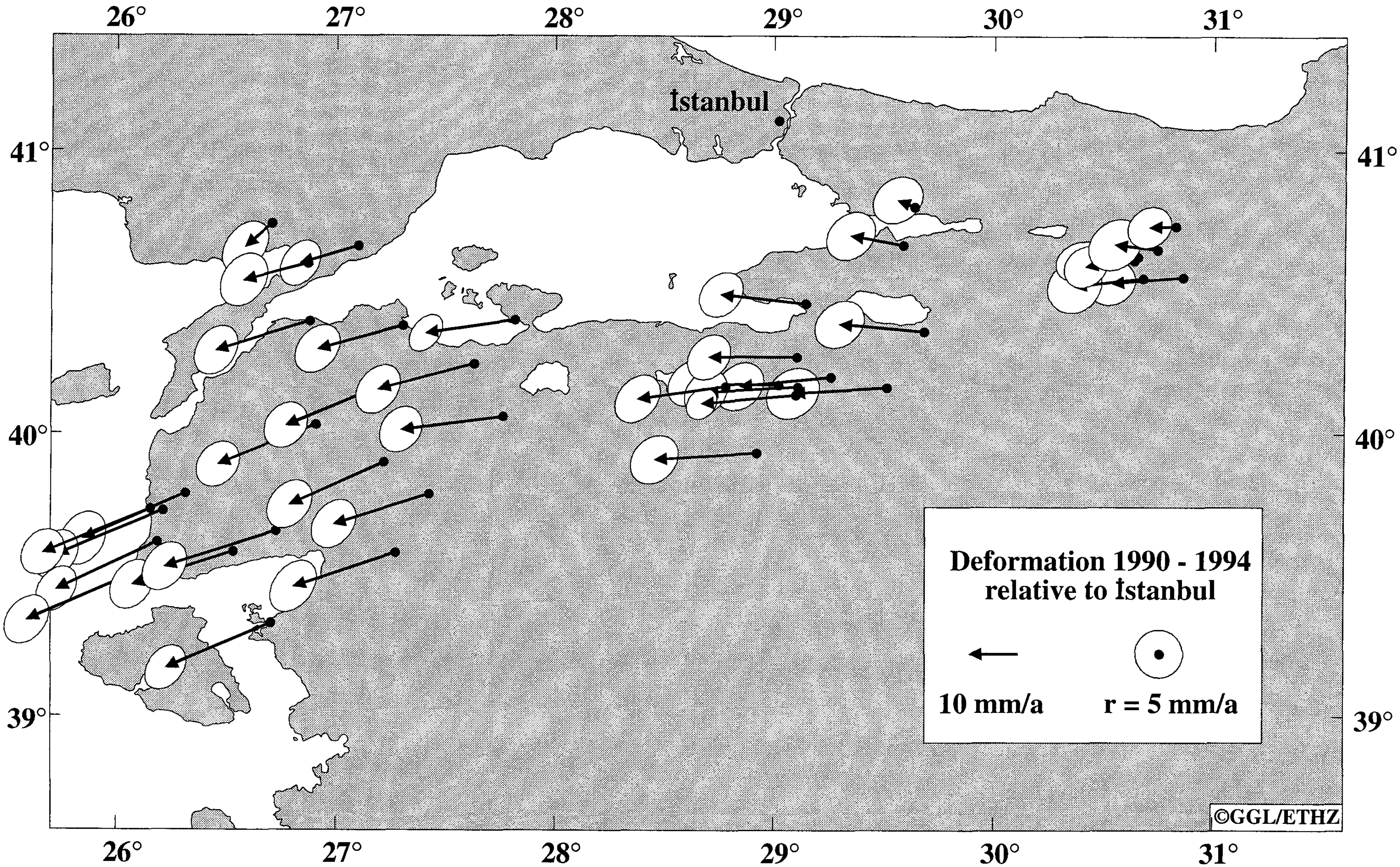
Map 9: New Fundamental Gravity Net of Switzerland: Measuring lines 1992, 93



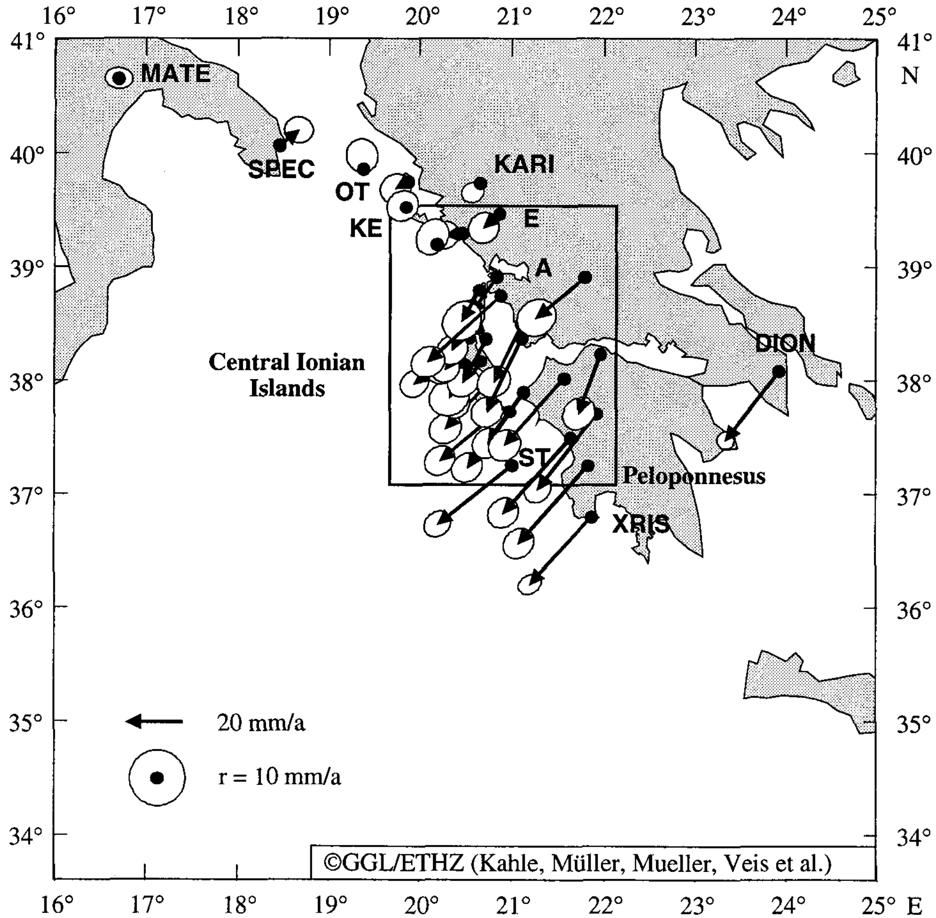
Map 10: New Fundamental Gravity Net of Switzerland: Absolute and 1st order stations 1994

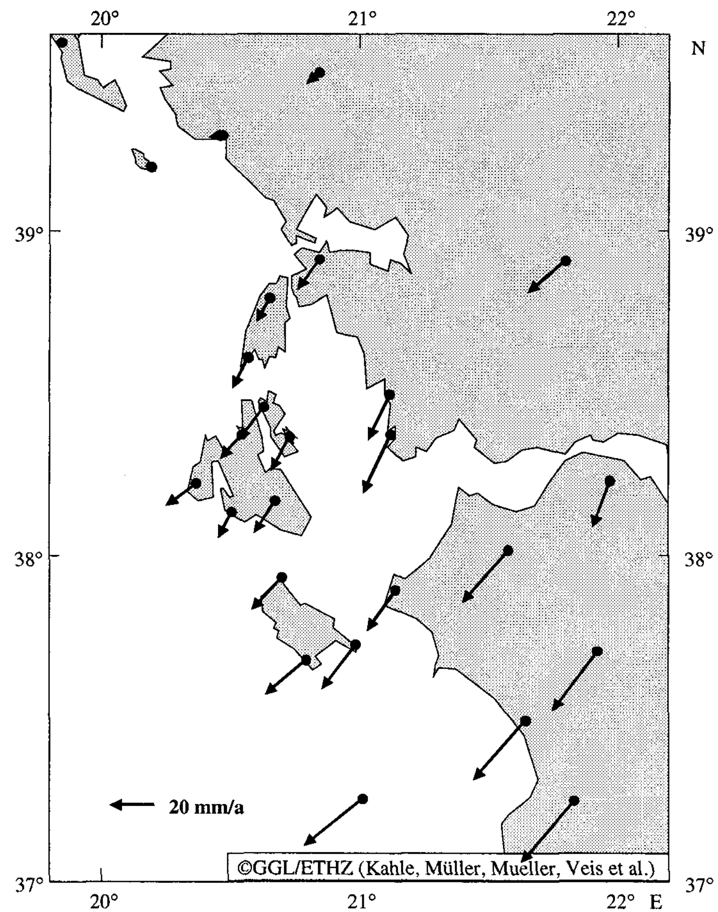


Map 11: Astronomical stations in Switzerland

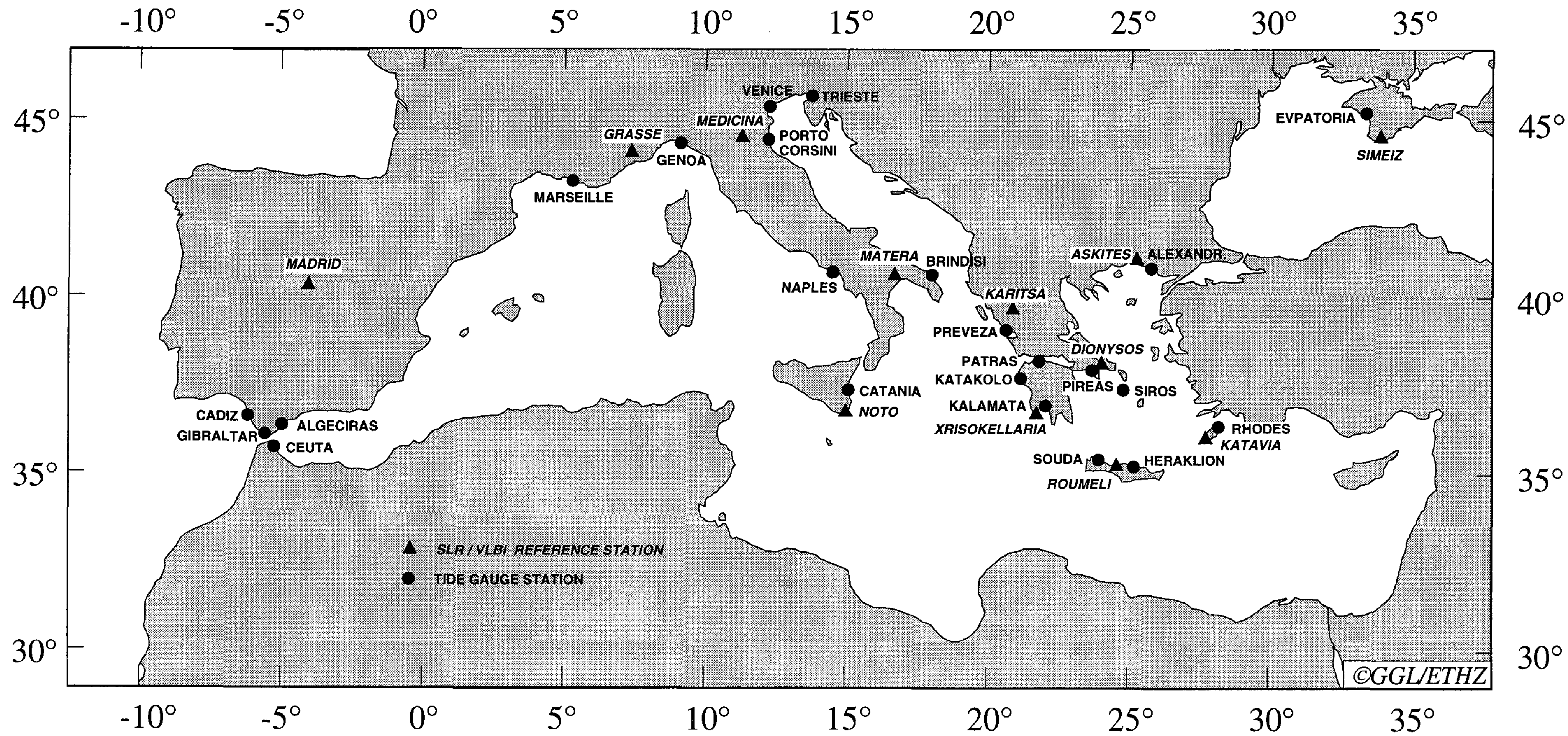


Map 12: Rates of Displacements in North-West Anatolia, referred to Istanbul (Straub & Kahle, 1995)





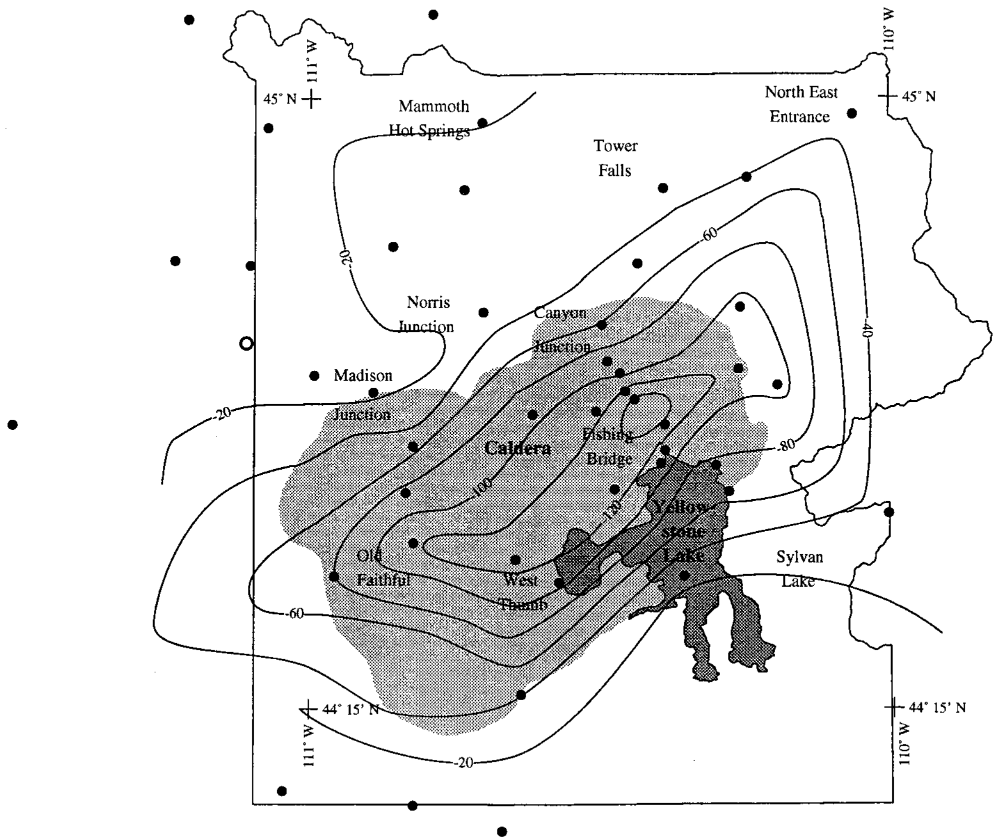
Map 13: Rates of Displacements in Western Greece, referred to Matera, SE Italy (Kahle et al., 1995)



Map 14: Tide gauge stations in the Mediterranean as observed 1992-94 in the frame of the Project SELF (Sea Level Fluctuations)

Yellowstone Height Changes

GPS campaigns 1987 and 1993

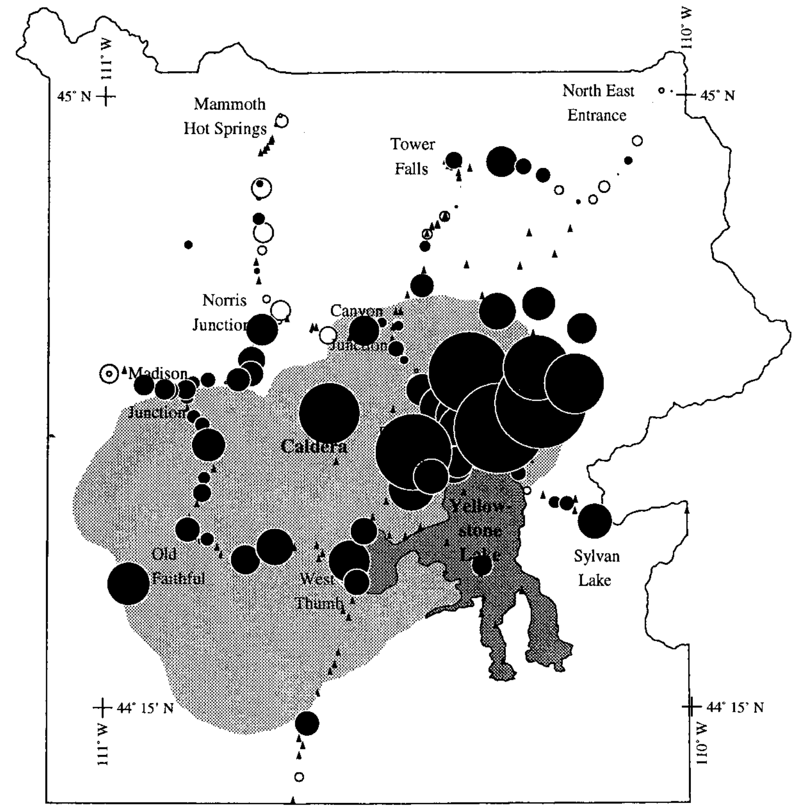


Height changes in mm
Contour interval : 20 mm

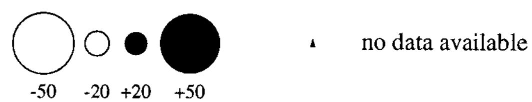
O Fixed station (airp)
• Benchmarks

Yellowstone Gravity Changes

1987 to 1993



Gravity Changes (µgal) :



Map 15: Project Yellowstone: Height and Gravity Changes between 1987 and 1993