Switzerland

Swiss Geodetic Commission
and Federal Office of Topography

Suisse

Commission Géodésique Suisse
et Office Fédérale de Topographie

Report on the

GEODETIC ACTIVITIES

in the years 1987 to 1991

Presented to the XX General Assembly
of the International Union of Geodesy and Geophysics
in Vienna, August 1991

Rapport sur les

TRAVAUX GÉODÉSIQUES

exécutés de 1987 à 1991

Présenté à la vingtième Assemblée générale
de l'Union Géodésique et Géophysique Internationale
tenue à Vienne, août 1991

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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 in scientific problems of geodesy including the transfer to practical applications 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 125 th 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), I. Bauersima (Section 2), E. Klingelé (Section 3), A. Carosio (Section 4) and H.-G. Kahle (Section 5). The Swiss Federal Office of Topography (L+T) printed the 11 maps. The final editing was done by B. Bürki and B. Wirth.

The SGC expresses its severe 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 also explicitely gratefully acknowledged.

On behalf of the Swiss Geodetic Commission

Francis Jeanrichard
Vice-President

Hans-Gert Kahle
President

1 Positioning

RETRIG

by B. Bürki

The closing output of the IAG subcommission for the New Adjustment of the European Triangulation Network consists of a common adjustment of the Triangulation network in Western Europe, called the European Datum ED87. This data set represents the triangulation data which have been measured, collected and compiled during more than three decades in sixteen different countries. Beside the classical angle-and distance measurements, space derived data sets such as Doppler-, GPS- and SLR observations were introduced in order to complete and strengthen the ED87 solution.
The Swiss block in ED87 may be characterized as follows: It contains 22 internal and 58 buffer stations (including the two space stations Zimmerwald and Monte Generoso). The total number of unknowns is 209. 160 of them are coordinate unknowns and 49 are orientation unknowns. Additionally a common azimuth bias was applied on stations with measured Laplace azimuths. The terrestrial data set for block CH consists of 320 horizontal directions, 102 geodimeter8- distances and 4 baseline extensions. The astronomical data set consists of 26 deflections of the vertical with either one or two measured components and 22 Laplace azimuths. The deflections of the vertical were computed by applying a digital terrain model and prediction methods at stations where no measured deflections are available. Additionally space derived data as output from several campaigns at the stations Zimmerwald and Monte Generoso were made available to the international RETrig- computing centre at Munich in order to reinforce the data set in block CH.
To compare ED 87 with the former ED79 solution, different Helmert Transformations were computed. The best and most comprehensible comparison results from a Helmert transformation with centered coordinates revealing real changes in the orientation and in the scale of the network. They also uncover local deformations from ED79 to ED87 which may be caused e. g. by the introduction of additional observations (partly space derived), by the introduction of junction zones instead of junction lines or by the removal of outliers. The resulting difference vectors are displayed in Map 1. They are very small in the central part of block CH, whereas they increase for buffer stations (located at the border or within the coloured area), mainly in the south-western part. The biggest difference reaches here a magnitude of about 19 cm. Finally, the computed scale factor between ED79 and ED87 is in the order of 0.07 ppm.

EUREF '89 GPS Campaign

by W. Gurtner

From May 16 till May 28, 1989 the first large GPS campaign on a European scale was organized by the EUREF subcommission of the IAG. The interest of Switzerland in this campaign was manifold:

- Four well-distributed markers of the Swiss triangulation network plus the SLR reference point Zimmerwald to be observed during the GPS campaign (map 2) will guarantee excellent transformation parameters between the final European reference system and the national datum.
- These EUREF sites will also be used as a framework for the establishment of a new GPS-based geodetic network in Switzerland.
- The satellite ranging station Zimmerwald will act as one of the fundamental stations defining the European Terrestrial Reference System.
- The processing of the GPS data will give important experiences in handling large data sets and in developing suitable processing strategies.

All of the Swiss sites have been observed by the Swiss Federal Office of Topography (L+T), the Swiss

Federal Institute of Technology in Zurich (IGP/ETHZ) and the Astronomical Institute of the University of Berne (AIUB) using the four Trimble 4000 SLD owned by the L+T and one WM-102 owned by the IGP/ETHZ. A second WM-102 and three of the Trimbles in the second half of the campaign were operated on Italian and Austrian sites as well.

A receiver-independent exchange format (RINEX) developed by the AIUB was used for the first time in exchanging the EUREF data between the individual computing centers. The AIUB acted as a central data collection and redistribution center of the data that had previously been reformatted into RINEX by 11 designated preprocessing centers.

A working group consisting of members of the AIUB, the Institut Géographique National (IGN) Paris, the Institut für Angewandte Geodäsie (IfAG) Frankfurt and the Bayerische Kommission für die Internationale Erdmessung (BEK) Munich are processing the full EUREF data set in 1990 and 1991.

LV95: The new GPS Network in Switzerland

by H. Chablais and A. Wiget

With the development in satellite geodesy new possibilities in geodetic surveying are available which were almost unimaginable a few years ago. The quality of the existing geodetic network does no longer satisfy all of the demands, the accuracy is limited, the homogeneity, especially in 3rd and 4th order networks is not guaranteed and distortions show up even in the 1st and 2nd order networks. For these reasons the Swiss Federal Office of Topography (L+T) decided to establish a new national surveying network "LV95" (Landesvermessung 1995) which should implement these new possibilities in surveying. Above all, the LV95 should offer a modern reference not only for cadastral surveying but also for large construction projects such as tunnels and ultimately for geodynamic research. The goals and characteristics of the network are:

- the availability of a 3D control point system in time and space
- a homogenous network with a spacing of 15-25 km in the Plateau and 20-30 km in the Alpine region (map 2)
- very stable and easily accessible points
- accuracy (rms between the most extreme points):
    - position: 1-2 cm
    - height: 2-4 cm
- guaranteed reliability
- integration into the EUREF network
- connection to existing triangulation and levelling networks
- completion by 1995
- remeasurement depending on the need
- adaptation to new methods, improving the accuracy

The network encompasses around 110 points and is divided into 4 parts. Where necessary the location of the points was chosen in collaboration with a geologist in order to guarantee stability. The points are marked with bronze rivets with removable caps and are set directly in rock or in blocks of concrete. Eccentric rivets or underground markers in concrete allow the reconstruction of the points to millimeter accuracy.

The measurements are carried out at night and last for 6 to 7 hours. Each point is occupied at least twice with dual band GPS receivers. The satellite tracking station at Zimmerwald is occupied permanently during the whole campaign. The connections to existing triangulation or levelling points are measured classically or with single band receivers. A total of about 180 such connections will be measured.

The measurements for parts 1 and 2 are finished and the data processing with the Bernese GPS Software (V.3.2) is under way. Parts 3 and 4 will be measured in 1991 and 1992 respectively. Each campaign lasts around two weeks and 10 to 12 dual band receivers for the main network and 2 single band receivers for the connections are in operation. The antennas are set up with meticulous care (mm accuracy) and the meteo data are registered on site. Before each campaign all of the antennas are calibrated on the short baseline test site in Thun and the phase center offsets of the individual antennas are determined by

comparison with high precision terrestrial measurements to better than 1 mm.
The four parts of the network are linked together by common stations and will be combined with a fifth overlapping campaign if necessary. Special attention is given to the satellite orbits. Apart from the broadcast ephemerides, precise ephemerides provided by the NGS and DMA as well as orbits estimated by orbit improvement with data from continental fiducial sites will be used. The final adjustment of this combined network, its transformation into the EUREF reference frame and the documentation should be finished by 1995.

GPS Campaigns in the Turtmann 3D Net 1987 - 1990

by G. Beutler and A. Wiget

The Turtmann network initiated in 1987 by the Swiss Geodetic Commission consists of 8 stations and shows height differences of about 850 m. The available ground truth (SGK 1987) allows e.g. the testing of GPS techniques in the mountains and the comparison and evaluation of receivers. Additional studies carried out in the test net concerning gravity field determination are reported in section 3.
Table 1 summarizes the GPS campaigns that took place in the Turtmann 3D network since 1987. In some of them, a station on the slope of the Emshorn (2271 m) was also observed, thus leading to a total height difference of 1650 m in these GPS nets. It has to be pointed out, however, that there is no ground truth available for the Emshorn site.

Date	Type/Number of Receivers	Number of Days	Remarks
1987	4 WM-101, single band	3	8 stations of net plus station Emshorn observed
1987	6 Trimble, single band (4000SX)	3	8 stations of net plus station Emshorn observed
1988	4 Trimble 4000 SL, single band	2	4 sessions, 2 double-stations
1988	2 Trimble 4000 SL, single band, 2 Trimble 4000 SLD, dual band	3	8 stations of net plus station Emshorn observed
1989	10 WM-102, dual band, 6 Trimble 4000 ST, single band	3	8 stations of net plus station Emshorn observed
1990	2 Rogue. SNR-8, dual band, 2 Trimble 4000 SLD, dual band	1	2 double-stations
1990	4 Ashtech LXII-L2, dual band	3	8 stations

Table 1: GPS Campaigns in the Turtmann Network 1987 - 1991

The 1987 campaigns were quite similar to those of 1985 and 1986: The observations took place at the same time of the year (October), at the same time of the day (early morning hours), essentially the same satellite constellation and the same type of equipment (single band) was used. It is therefore not surprising that the quality of the results was comparable to that of the previous years (2-4 mm in position, about 1-2 cm in height). Both campaigns are processed but final results still await publication. The same is true for the 1988 campaigns. The main purpose of these campaigns, however, was to train the operators of the Federal Office of Topography. A further reason for the second campaign was a first test of the dual band receivers. In 1989 a campaign has been carried out in cooperation with different swiss research institutions and private companies resambling most of the WM-102 equipments available in Switzerland.

This campaign was most interesting due to the facts that

(a) Day time observations (8 a.m. to 1 p.m.) had to be made in July 1989;
(b) the campaign took place in a year of almost maximum solar activity;
(c) dual band equipments were available.

Facts (a) and (b) had the consequence that no high accuracy results could be obtained by processing pure single band data: analyzing the 1989 campaign in the same way as the previous campaigns led to unacceptable scale biases of about 4 - 5 ppm. Due to fact (c), it was possible to estimate an ionosphere model (method see Wild et al. 1989, 1990) and to apply it when processing L1 (or L2) observations. The 1989 analysis includes a pre-analysis and an investigation of tropospheric refraction (Beutler 1989, Beutler et al. 1989a, Rothacher et al. 1990).

Two receiver tests were performed in 1990: The two Rogue receivers of the Norwegian mapping authority were tested and compared with Trimble 4000 SLDs in early spring on the Turtmann - Susten baseline; the observations proved to be of remarkable quality. The French Institut Géographique National (IGN) tested its four Ashtech dual band receivers shortly thereafter. The results were satisfactory for the L1 carrier, problems were encountered when processing L2 data. No results of the 1990 tests have been published until now.

The 1987 GRANIT GPS Campaign

by G. Beutler, A. Wiget and A. Geiger

GRANIT was the first GPS campaign in Switzerland covering the entire country (or at least a large part of it, map 3). The campaign was organised and coordinated by AIUB, L+T and IGP. The campaign has been measured in cooperation with 6 foreign scientific institutes which provided the 7 TI-4100 receivers:

- TU Hannover
- FAF Munich
- TU Munich
- Observatory Graz-Lustbühl
- AWI Bremerhaven

In addition 5 WM-101 receivers were provided by the IGM-EPFL and the IGP-ETHZ for calibration purposes. The WM-101 have been collocated with the TI-4100 receivers. An attempt has been made to correct the ionospheric effect on the WM-101 by additional Doppler (TRANSIT) measurements.

The goals were the following:

- Linking the SLR station Zimmerwald to stable points in different geological formations.
- Establishing a geodetic link between eastern and western geophysical traverses through the Swiss Alps (in the frame of the Swiss National Research Project NFP20, compare section 5).
- Second measurement of the baselines between Zimmerwald, Jungfraujoch and Generoso.
- Linking the Swiss first order triangulation network to GPS reference sites.

The campaign took place from June 16 to June 18, 1987. The daily observation period lasted from 12.30 to 16.30 U.T. A total of six satellites were observed but only four at a time because TI-4100 receivers were used. The slope distances are in the range between 32 km and 206 km. Table 2 contains the sites and the observation times, map 3 gives an overview of the surveyed area.

Site	Observed June 1987	Altitude [m]	Geology	Tectonic Plate
Zimmerwald *)	16, 17, 18	900	Plateau Molasse	Eurasian
Chasseral	16, 17	1610	Folded Jura	Eurasian
Hütten	16, 17	900	Black Forest	Eurasian
Jeizinen	16, 17	1530	Central Alps	Eurasian
Titlis	16, 17	3240	Central Alps	Eurasian
Jungfraujoch +)	16, 17	3570	Central Alps	Eurasian
Generoso	16, 17, 18	1700	Southern Alps	African
Lägern	18	860	Folded Jura	Eurasian
Hochalp	18	1520	Subalpine Molasse	Eurasian
Andeer	18	1090	Pennine Alps	Eurasian
Gotthard Pass	18	2110	Central Alps	Eurasian
Zermatt	18	1690	Pennine Alps	Eurasian

Table 2: Schedule of the 1987 GRANIT Campaign

*) SLR site, reference point for Swiss GPS net
+) Famous tourist site, more than 3500 m in altitude

The observations were processed with the Bernese GPS software version 3, using the ionosphere-free linear combination of the original L1 and L2 phase observations. All but 2 ambiguities could be resolved successfully. Table 3 contains the essential characteristics of the final run in which the observations of the three days were combined:

Fixed station	Zimmerwald
Number of stations	12
Number of sessions	3
Number of receivers	7
Number of double difference observations	18855
Total number of parameters	65
Number of coordinates	33
Number of orbit elements	12
Number of troposphere parameters	18
Number of ambiguities	2

Table 3: Characteristics of the Final Run

Due to the limited size of the network and since no observations from fiducial sites were available, it was decided to improve only two orbit elements per satellite (namely the semi-major axis a and the argument of latitude at the initial epoch (essentially the along track error)).

From repeatability studies and from an analysis of the formal errors, it was concluded that the accuracy of the network determination was of the order of 1 cm in position and 3 cm in height.

Due to the incomplete observation schedule in 1985, it was only possible to compare the lengths of the baselines between Zimmerwald, Generoso and Jungfraujoch of the 1985 and 1987 GPS determinations. Table 4 shows that the agreement between the two determinations is really excellent.

Baseline	Lengths 1985 [m]	Lengths 1987 [m]	Difference [mm]
Generoso - Jungfraujoch	105365.000 ± .009	105365.015 ±.004	+15 ± 10
Generoso - Zimmerwald	159391.776 ± .004	159391.779 ±.003	+3 ± 5
Zimmerwald - Jungfraujoch	54172.169 ± .002	54172.168 ±.001	-1 ± 2

Table 4: Comparison of 1985 and 1987 Baseline Lengths

More information concerning the GRANIT campaign may be found in (Beutler et al. 1989b); the paper is also part of (Beutler 1990).

Kinematic GPS and Navigation

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

Satellite geodetic methods open a wide field of research and application. A main interest is focused on the introduction of GPS for kinematic surveying and moving platform tracking such as cars, vessels and aircrafts. Special emphasis is placed on the combination of GPS and aerogeophysical measurements such as aeroradiometry and aerogravimetry. Very precise positioning is required for applications in photogrammetric aerotriangulation. For this purpose, phase measurements of the satellite signal carrier are needed. For high precision positioning, the resolution of the phase ambiguities and cycle slip detection are crucial problems which are being studied in this project.

Controlling and Monitoring by GPS

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

During the reporting 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. The tunneling of the first road tunnel surveyed by GPS in Switzerland, located in the folded Jura (Vue des Alpes), has recently been terminated. The precision turned out to be in the requested order of magnitude (beyond 3 cm). A similar study was conducted for a planned 20 km Alpine railway tunnel in the canton of Grisons (Vereina). Other activities are related to the plans of construction of a new Alpine railroad tunnel (ALPTRANSIT). 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, and Varuna, Canton Grisons, which will be studied in cooperation with the Engineering Geology group of the ETH Zurich. An interesting result was shown by the GPS survey of the old Simplon railroad tunnel (canton Valais). The comparison of the original invar measurements and the terrestrial control network of 1906 with the new GPS survey showed the quality of the old surveys in the order of 3 cm over 20 km in rough terrain.

For the campaigns, the GPS measurements had to be combined with terrestrial measurements. The necessary software developments are described in part 4 in the Chapter "Combined 3D-Adjustment of GPS-Baselines and Terrestrial Data". All of the pilot projects showed the efficiency and the high reliability of GPS surveying also for engineering geology purposes.

Diagnostic Adjustment

by H. Chablais

In 1986 the Swiss Federal Office of Topography (L+T) decided to carry out a comprehensive least squares adjustment, the diagnostic adjustment, of the 1st to 2nd order triangulation network in Switzerland (map 4). The work is under way, although with considerable delay. The acquisition of the observations from 1900 to today has been completed and the network consists of

245	triangulation points

2000	directions
300	Geodimeter 8 distances
70	SIAL distances
40	astronomical azimuths

The observations have all been checked but a few cases still need clarification. All of the original angle measurements were captured, including ambiguous measurements showing definite constraints. Eccentrically stationed heliotropes and other eccentric stations were not always documented very clearly, often causing confusion and resulting in time-consuming examinations. A new adjustment was made for each station whereby observations made more than 15 to 20 years apart were treated in a separate adjustment. Because different stations were often set up on a single site and different targets observed, a reduction to the center was necessary, sometimes even before making the definite station adjustment. As a result, there are some 280 stations and approx. 2000 directions.

About half of the Geodimeter distances were measured by the Swiss Geodetic Commission (SGK) and prepared by W. Fischer. The SIAL distances as well as about 30 Geodimeter distances were measured and prepared by the Institute for Geodesy and Photogrammetry at the Federal Institute of Technology in Zurich (ETH). The remaining distances were measured by the L+T. As was done for the angle measurements, the distances were also reduced to the center. The results were oblique distances, corrected for refraction and referring to the height of the main marker (rivet or stone). With these data various solutions can be produced and coordinates compared in order to analyze and model distortions in the existing network. This project should be completed in 1994.

Alpine Traverse St. Gotthard

by A. Elmiger

The Alpine Traverse is a triangulation-trilateration chain crossing the Swiss Alps in a north - south direction and having a length of 180 km. It is a part of the fundamental triangulation net of Switzerland (1st and 2nd order points) and also forms a part of the "Diagnostic Adjustment Net" of Switzerland (see previous contribution and maps in SGK 1987).

The purpose of these special measurements and investigations was to strengthen the Swiss triangulation net in a north - south direction over the Alps by combining all available classical measurements in this area and by introducing new, precise distances (which were missing here altogether), thus providing a basis for later comparisons with other types of measurements (e.g. GPS) and measurements of different epochs in order to determine possible crustal movements in the Alps.

The electronic distance measurements were started in 1977 and 1980, in an epoch when GPS was not yet the standard procedure in national surveying, and were carried on until 1986. The following EDM equipment was used for measuring terrestrial distances: lightwave equipment (Laser Geodimeter, Model 8, Sweden) and microwave distance equipment (SIAL MD 60, Switzerland). Special care was taken in determining the mean refractive index along the lines of the EDM measurements by using airborne sondes mounted on small airplanes (air-gliders flown by hobby pilots, see "Refraction" in this report).

Some of the results of the measurements and investigations of this Alpine Traverse are:

1) Electronic distance measurements (EDM):

Distances reduced with ground meteo values differ from the "true" values (laser distances determined by the best obtainable mean value of the refractive index from airborne sondes):

- microwave distances are too short by 3.3 ±0.5 ppm[1]
- laser distances are quite good if they are reduced with ground meteo values:
  they are too long by 0.5 ±0.5 ppm only

---

[1] After (a priori) reductions with ground meteo values. The net adjustment yields an additional (a posteriori) correction of 1.9 ± 0.6 ppm, so that altogether they are too short by 5.2 ± 0.8 ppm.

2) Scale differences:

The comparison of the measured distances in the net (after optimal meteorological reduction) to other methods of measurement on the Alpine Traverse and in Switzerland (such as GPS and SLR (Bürki et al., 1987)) yields the following differences relative to the Alpine Traverse whose scale is determined by laser distance measurements (Geodimeter):

Method	Net / Campaign	Scale Difference [ppm]	Remarks
Doppler satellites	Swissdoc 1984	+1.4	larger
EDM: Geodimeter	**Alpine Traverse Gotthard**	**0.0**	**reference**
European triangulation	ED87 (Gotthard region,Zimmerwald)	-0.4	
GPS	GRANIT 1987 (Alpine Traverse)	-0.6	
Laser ranging (terr./sat.)	Zimmerwald-Jungfraujoch-Generoso	-1.5	
Swiss triangulation	Alpine Traverse	-7.1	
Swiss triangulation	Zimmerwald - Generoso	-8.4	shorter

3) Crustal deformations in the Swiss Alps

Measurements of two epochs are combined in the Alpine Traverse: angle measurements (epoch 1910) and distance measurements (epoch 1980). The combined adjustment of all observations indicates that the two sets of observations are not compatible. A possible conclusion is that deformations of the earth's crust have taken place in the 70 years between the two epochs. However, these deformations are not homogeneous but vary from place to place. The conclusion would be that the length of the Alpine Traverse has decreased (shortened) in 70 years by (at least) about 0.7 ppm which corresponds to about 12 cm. Another method of deriving regional (and resulting integral) deformations consisted in comparing the shape of the triangles of the two epochs (one derived from the old angle measurements from the beginning of this century, the second from the newer electronic distance measurements from the 1980s). Conclusion: the deformations vary from region to region and have opposing signs; no deformation in the northern part of the net; compression just north of the Alps; dilatation south of the Alps. Summing up all regional deformations, the result is a dilatation (lengthening) of 4 ppm which corresponds to a lengthening of about 70 to 80 cm:

Region	Distance [km]	Variation of length abs.[cm]	Variation of length rel.[ppm]	Deformation
North:Lägern-Rigi	48	0	0	none
Central:Rigi-Gotthard	51	-18	- 4	shorter
South:Gotthard-Generoso	81	+94	+12	longer
Total: N-S:Lägern-Generoso	180	+76	+ 4	longer

These conclusions are, however, uncertain but with a reasonable probability. Further investigations will have to be undertaken to confirm or refute these statements (Elmiger et al. 1991).

UELN and the Swiss National Levelling Net

by E. Gubler

The Swiss first and second order levelling net was established between 1905 and 1930 and comprises some 3400 km of levelling lines, forming 18 loops with an average length of some 200 km. The standard deviation computed from the adjustment is 1.4 mm $\sqrt{D_{km}}$. For almost 50 years, parts of the net have been remeasured where needed. By now a second complete measurement will be accomplished in a few years. Since 1987 some 420 km have been remeasured. These are shown in map 5. In the second levelling the standard deviation from the adjustment reaches 0.8 mm $\sqrt{D_{km}}$. Besides the recomputation of the bench mark heights, significant vertical movements could be found (see section 5 of this report). A subset of this net was used for the UELN computations. It was shown in a former report (SGK 1987).

Height Systems

by B. Wirth

In [Wirth, 1990] the height systems were treated in more detail to enable the inclusion of GPS measurements for height determination. For that reason the gravity field has to be determined as accurately as possible, as this is responsible for the systematic differences between terrestrial and GPS-heights. A main chapter treats the orthometric correction of the precise levelling. For the computation of the mean value of the modelled gravity $\bar{g}$ in the plumb line, a closed expression was deduced and realized in a Fortran program. A further main chapter treats the local geoid determination using the proved method of Elmiger and Gurtner, where the measurements are freed from the influences of the modelled topography and the MOHO, enabling a much smoother interpolation. For the interpolation, the method of collocation and prediction was used. Two twodimensional covariance models, the Markov Undulation model of third order and a simple reciprocal distance model, were implemented in a Pascal program. With that it was possible for the first time in Switzerland to combine deflections of the vertical, directly "observed" geoid undulations from precise levelling and GPS measurements, and gravity disturbances in a self-consistent model. Applications in local areas show a satisfactory height accuracy, for example in the GPS test network Turtmann with an extent of 6 x 5 km^2, where a relative standard deviation of the geoid undulations of < 5 mm was reached.

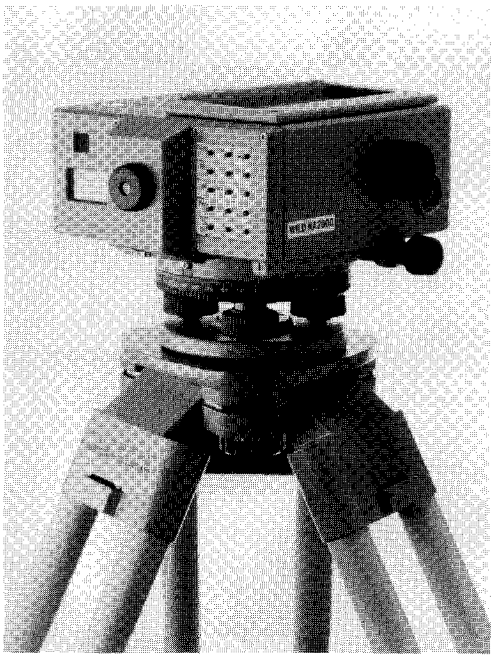
In order to allow the integration of GPS heights in the national height system, only orthometric or normal heights should be taken into consideration. With the excellent digital terrain model elaborated in a 25 m grid by the Federal Office of Topography, it will be possible to compute orthometric heights without great effort. This will be done in the next few years for the first order levelling network of Switzerland. A national research project for a new geoid of Switzerland with an improved accuracy has been approved by the Swiss National Science Foundation and the first activities have been commenced by the IGP (ETH Zurich), the L+T and AIUB.

The new Digital Level WILD NA2000

by F. Schneider

Introduction

In March 1990 Leica Heerbrugg Ltd launched the digital level "WILD NA2000", the world's first commercially available level that evaluates the image of a bar coded staff by means of electronic image processing.



System description

The instrument:
Basically, the NA2000 automatically measures the same values that are measured manually with a conventional optical mechanical level: Staff height reading and the distance between the level and the staff. The system is able to read the tenth of a millimetre on the staff over the range of 1.8m to 100m. If used together with the standard fibreglass staff, the system gives a standard deviation of better than 1.5mm per 1km double run levelling and 5cm for a distance of 100m. Together with the new invar bar code staff, the accuracy is comparable to the one obtained by the NA2 with a parallel plate micrometer.

Fig. 1: WILD NA2000

The measuring principle:
The built-in detector diode array of the NA2000 scans the bar code (on the levelling staff) from which the digital measurement signal is derived. The complete bar code sequence, visible on the staff, is stored in the instrument and is used for building up a reference signal. The instrument then compares the measurement signal with the reference signal by means of correlation procedures. The problem is solved when the best fit between measurement and reference signal is found.

The staff code:
The bar code on the staff is a binary code consisting of black and white elements which refer to the digital signals 0 and 1. The correlation procedure demands the code pattern to be pseudo-stochastic, which means that it is neither systematic nor periodical.

Operating

The observer aims at the staff and focusses as he would with the conventional level. Then he presses the measure button to trigger the measurement. The results are displayed after approx. 4 seconds and are automatically stored in an interchangeable recording module. Integrated programs for various line levelling tasks guide and support the observer. For example, heights of the points are calculated as he proceeds.

Conclusions

The market reactions prove that because of its easy use, reliability and speed, the NA2000 is particularly suitable for large scale levelling projects. A special application field is the monitoring of structures and surfaces where the capabilities of the automated level system are highly appreciated.

Development of a Robot Theodolite

by H.J. Matthias

An interdisciplinary research team at the Swiss Federal Institute of Technology in Zurich has developed a robot theodolite in collaboration with industrial firms. Such motorized instruments of the future no longer need an operator. They automatically detect the target points, which are equipped with only an optical prism, and take all of the necessary measurements. The measured values or the calculated coordinates of the target points in whatever system are transmitted wirelessly to the head of the team, the target point and to a distant data processing center. The robot can also receive operating instructions. The accuracy has been proved to be of a very high standard.

Refraction

by F. Chaperon and R. Köchle

During 1987 and 1988 the refraction group at the Institute for Geodesy and Photogrammetry, ETH Zurich participated in several campaigns involving the measurement of long distances by electromagnetic waves using the airborne ATAR sonde of the Laboratory of Atmospheric Physics, ETH Zurich (LAPETH) to obtain better values for the refractive index of the air. The projects in particular were:

1) The GRANIT campaign of June 1987 where the SLR station Zimmerwald was tied into the Swiss National Net using GPS. The refractive index was sampled from a Grumman G159 Turboprop of the Federal Office of Civil Aviation during three consecutive days at selected sites at altitudes between 2000 and 6000 m above MSL.

2) Measurements in the first order triangulation net of Switzerland during June and August 1987 with SIAL microwave equipment between the points Rigi, Napf, Rötifluh, Titlis and Brienzer Rothorn. The ATAR sondes were carried by motor-gliders and small aircraft.

3) Measurements in the Base Extension Net Heerbrugg during September 1988 where the Federal Office of Topography tested and compared GPS distances to terrestrial EDM distances measured by the Geodimeter 8 and the Kern Mekometer ME5000. The refractive index was sampled from ATAR sondes mounted on motor-gliders and motor-planes.

During the period under review, it became clear that the era of terrestrial long-distance measurement had drawn to a close only to be replaced by measurements via satellites. The equipment for Sprenger radio sondes carried by captive balloons was redesigned for free balloons with automatic data registration in the field. It will be used for sampling the atmosphere in vertical profiles with particular emphasis on the water vapour content during GPS measurements.

Lateral Refraction

by H.J. Matthias

Lateral refraction is discussed rather often in geodesy and in surveying. Doubtlessly it exists and can be of great influence. But only very little is known about its numerical size. Publications on this matter are rare. This was the reason for a small group at the Federal Institute of Technology to set up an empirical research program. Different possible methods exist. The measurement of lateral temperature gradients was chosen, from which the lateral refraction angles for different geometric dispositions were calculated. Nine objects were selected (e.g. walls of different materials, tunnel portals) with different exposures to the sun, at different seasons of the year and measurements made during 24 hours. The data collection is finished but not yet the data processing. The goal is to publish the empirical results in full and also to try to model lateral refraction with several parameters. Some of the results will be interesting and unexpected.

Integrated Geodesy

by M.V. Müller and H.-G. Kahle

Integrated geodesy allows the combined analysis of data sets related to geodetic, geophysical and geologic data. The software package OPERA, provided by Prof. G. Hein's group from Munich, was installed on the mainframe computer of the ETH Zurich. Emphasis was put on two specific areas of interest: The implementation of routines allowing the use of satellite aided information and the adaptation of covariance functions for the gravity in high-mountainous regions such as the Swiss Alps have been subjects of the investigations. Field experiments have been conducted and analyzed in the nets Jenaz (Grisons) and Turtmann (Valais) respectively along the traverse Visp-Zermatt (Valais). Comparisons with results obtained by traditional three-dimensional processing (including only deflections of the vertical as information for gravity field parameters) show a good agreement. It turned out that - because of the anomalous gravity field in the mountains - it is necessary to have a large amount of gravity data for an appropriate and sufficient representation of the gravity field. The original idea of using unreduced gravity observations within OPERA had to be revised: The unfavourable ratio between variance and correlation lenght made it difficult to find an appropriate covariance function. Nevertheless the concept of integrated geodesy for high mountainous regions has not failed: If no deflections of the vertical are available, integrated geodesy is able to improve the results considerably. And as a consequence of integrated (or operational) geodesy, the collocation model - introduced in geodesy for the first time for adjustments of heterogenous data sets - has proved its efficency in different applications.

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2 Advanced Space Technology

Satellite Observation Station Zimmerwald (Astronomical Institute, University of Berne)

by I. Bauersima, G. Beutler, W. Gurtner, M. Rothacher, T. Schildknecht

Instrumental Improvements at Zimmerwald

In the period 1987-1991 the following improvements of the Zimmerwald laser-telemeter were made:
The pulse selector and the dye-cell were rebuilt and a new active/passive mode locking system was installed. Through these measures a 100 % laser-pulse gain and a high pulse-energy stability (± 1,5 %) was achieved.
The laser was then mounted on a new optical table which is fully separated from the environment with the exception of the first mirror of the Coudé-path, which is mounted on the ground block of the laser telescope.
Furthermore a TV time transfer system TICOMT was developed, allowing an automatic comparison of the station time base with the atomic clock ensemble of the Swiss time laboratory at Wabern. A new concept of the station time base was designed and first components were built and tested. The most important element is a time standard based on Rubidium FRS-C (of the company EFRATOM) giving a reference second with an excellent long time stability. It is also well suited for clock transport.
Also, an automatic meteorological probe was installed at Zimmerwald, the readings of which (pressure, temperature and relative humidity) are automatically transferred every 30 min to the station computer (VAX Station 2).

Operation of the Zimmerwald Satellite Observation Station

The years 1988 to 1991 may be characterized as the first period after the installation of the 3rd generation laser in 1984 where the collection of the observations could be performed most of the time on a routine basis. LAGEOS, STARLETTE, and AJISAI were tracked for the benefit of IERS, CDP, WEGENER, and the Japanese positioning projects. The first ETALON satellite was observed for test purposes during one pass in 1989.
The monthly average number of passes increased from about 20 in 1987, 30 in 1988, 40 in 1989 to about 50 in 1990. For a few weeks each year, the station was shut down for upgrading or maintenance purposes. The degree of automation allows a one-man operation. From 1992 on, most of the routine operation will be performed by staff of the Federal Office of Topography.

Development of GPS Software

The "Bernese GPS Software" (now version 3.2) has been improved in many ways during the last few years: computer independence, user friendliness (addition of a menu and file management system), combination of GPS data from all major geodetic receiver types, automation of preprocessing, and atmosphere modeling (Rothacher et al., 1990a). Today the software system is used by more than 50 universities and surveying agencies all over the world.
A major effort was the development of the so-called Fast Ambiguity Resolution Approach (FARA). The scientific findings are quite impressive: an in-depth analysis revealed that ambiguity resolution without a priori knowledge is possible on short baselines (< 10 km) using short data-spans (1 - 2 minutes) from dual-band receivers. When only single-band data are available, it is necessary to combine at least two short data-spans well separated in time (>1 hour). For more details see (Frei and Beutler, 1989, 1990a,b, Beutler et al., 1989a) and, last but not least, the principal investigators Ph.D. thesis (Frei, 1990c). The project was sponsored by the Swiss "Kommission zur Förderung der Wissenschaftlichen Forschung (KWF)", the institutions involved were Leica Heerbrugg Ltd and the Astronomical Institute, University of

Berne.

In reaction to the increased solar activity, methods were developed to model the ionospheric refraction. Using the raw phase data of one or more receivers, an ionosphere model can be derived which can then be used to eliminate the main effect of the ionospheric refraction in small networks: a scale factor (Wild et al., 1989 and 1990b).

In cooperation with the GPS group at the Massachussetts Institute of Technology at Boston, studies were performed using deterministic and stochastic approaches (e.g. Kalman filter) for the modeling or estimation of tropospheric refraction.

In the last few months strategies were developed for regional and global orbit determination. This has been done in connection with an ESA (European Space Agency) project to measure the globally distributed ESA tracking sites by GPS. The experiences gained from this project will be of much use for a future European orbit service.

Initial investigations concerning "High Accuracy Time Transfer using GPS" were conducted in 1989-1990. It was shown that in principle GPS is capable of synchronizing clocks separated by (up to) continental distances on the (sub-)nanosecond level. The results (Schildknecht et al., 1990a,b) are encouraging, the next step will consist of an experimental set-up of GPS receivers and clocks on short baselines.

Prior to the 1989 GPS campaign for the establishment of a European Reference Frame (EUREF 89) an exchange format for GPS observations independent of the receiver types has been developed and presented to the user community at the Fifth International Symposium on Satellite Positioning in Las Cruces (Gurtner et al, 1989c). A year later a proposal for a version 2 (which may also include observations from other satellite systems like GLONASS) has been prepared (Gurtner et al, 1990c). Currently RINEX Version 1 is internationally used as a standardized exchange format for geodetic GPS observations.

In 1989 first investigations into the problem of combining different GPS receiver types have been performed. It has been found that such combinations are possible at least on the 1 cm accuracy level (Gurtner et al., 1989b).

Processing GPS Campaigns with the Bernese GPS Software

Many (small and large) GPS campaigns were and still are processed in Berne. The GPS data from the reoccupations of the Turtmann network in Switzerland in the years 1987 through 1990 were well suited, due to the large height differences in this valley, to test local troposphere models (Rothacher et al., 1990b).

The results of the Alaska GPS Campaigns of 1986 and 1988 obtained in Berne (Rothacher et al.,1987a, 1987b, and 1989) were compared with mobile VLBI solutions and gave the possibility to compare GPS solutions (including the 1984 Alaska GPS Campaign) over a 4 year period to detect recent crustal deformations in this region.

All the data of the EUREF campaign of 1989 (a total of approximately 720 receiver days) were transformed into RINEX by several preprocessing centers, sent to Berne and redistributed to other processing centers. Processing is still under way.

In 1990 a GPS campaign to prepare the calibration of the ERS-1 altimeter was organized by a special working group. The Astronomical Institute of the University of Berne has produced a full solution of the campaign.

Coupled Quasar, Satellite and Star Positioning

Let S and Q be barycentric reference frames which do not rotate with respect to well defined sets of stars or quasars respectively. The goal of CQSSP is to determine the parameters of the transformation S --> Q as a function of time. CQSSP consists of two segments, namely CQSP and CSSP. CQSP contains VLBI (Very Long Baseline Interferometry) and SLR (Satellite Laser Ranging) contributions obtained by the IERS (International Earth Rotation Service). They are: The ICRF (IERS Celestial Reference Frame), ITRF (IERS Terrestrial Reference Frame), and the EOP (Earth Orientation Parameters). The CSSP segment consists of simultaneous opto-electronic observations of reference stars and a satellite (e.g.

LAGEOS). An analysis of these observations will give the required parameters of the transformation S --> Q, provided the results of the CQSP segment are assumed known (Bauersima, 1990, 1991). It is thus possible to make the ICRF accessible through the system of stars, an important result especially in view of the high-accuracy star catalogue being established by the HIPPARCOS space mission.
The CSSP segment is under development at the Zimmerwald Satellite Observatory since 1985. At present the CCD-camera system (used for the project) is mounted on the laser telescope. It was necessary to develop software to establish the observation technique. First promising tests of the CSSP segment were performed in 1990.

Optimizing GPS measurements

by A. Geiger

To qualify satellite constellation and GPS sites, an algorithm has been developed using integration and continuous satellite distributions. The main goal was to evaluate the disturbing effect of distorted measurements, the distortions being caused by troposphere, ionosphere, obstructions, phase center variations, errors in fixed positions etc. The effect of variation of the phase center has been pointed out especially when combinig different antenna types. When using helices and micro-strip antennas in the same survey, uncalibrated cm differences in the results can occur due to the different behaviour of the phase centers.

Microwave Water Vapor Radiometer

by B. Bürki, M. Cocard, H.-G. Kahle, E. Puliafito

The state-of-the art in GPS technology reveals that the obtained accuracies of the height component is reduced by a factor of about 2 to 3 with respect to the accuracy of the horizontal coordinates. This effect is due to uncertainties in the computation of the path length corrections which are affected not only by the ionosphere but also by tropospheric effects (path delay). The total water vapor content along the propagation path of the satellite signals affects the measured distance from the satellite to the antenna. It can be measured with specially designed microwave water vapor radiometers. With such an equipment, the total water vapor content within the troposphere can be determined by measuring the "thermal noise" emitted by the troposphere in terms of brightness temperatures in two appropriate frequencies (23.8 and 31.5 GHz).
While up to now the available radiometers are not suited to operate under field conditions, the development of a transportable radiometer system was the main objective of a project carried out at the Institute of Geodesy and Photogrammetry, ETH Zurich. The project has been carried out in cooperation with CAPTEC, Microwave Consulting Corp., Berne, and the Max-Planck-Institute for Aeronomy (MPAE) in Katlenburg, Germany. The developed equipment enables in-situ measurements of the path delay distribution pattern referring to the actual satellite constellation. For this purpose the radiometers are equiped with stepping motors enabling a direct tracking in the direction of the actual available satellites. With this information GPS measurements can be corrected by the observed path delay. First results were obtained in an international campaign within the framework of the ERS-1 project of ESA. Further applications for the near future ar planned in extended measurements within the same project.
The two systems as shown in Fig. 2 consist of four components:

- radiometers (total weight 30 kg each), operating on normal tripods as used for any surveying instruments.
- electronic unit, containing a power supply with either AC or DC (battery) input, an interface selector and the stepping motor drive.
- data logger for the measurement of the meteorological parameters atmospheric pressure, temperature and relative humidity. This device is equiped with an internal microprocessor and a non- volatile data memory. It can operate either in connection with a PC or independently as data collecting unit.
- MS DOS Laptop computer. The PC is used not only for the computation of the satellite ephemerides but also for the monitoring of the radiometer including the stepping motor control and the collection of all relevant data.

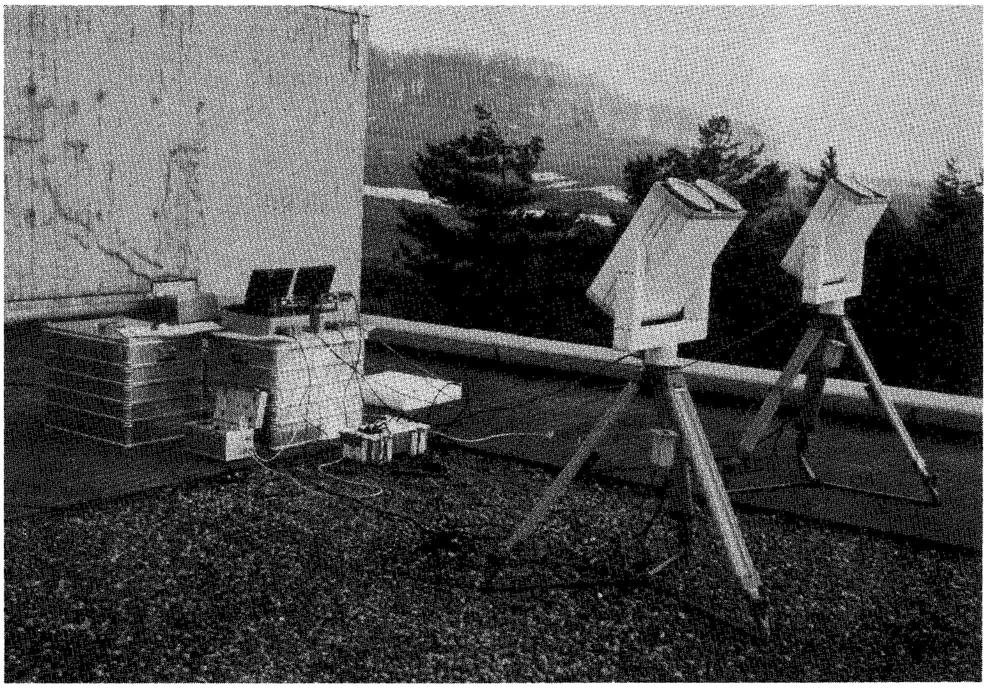

Fig. 2: Microwave Water Vapor Radiometers of the Institute of Geodesy and Photogrammetry, ETH Zurich operating onto normal tripods. On top of the transportation boxes the electronic units and the Laptop PC's are installed. The logger for the meteo data is located beside the boxes.

Modelling of Path Delay for Satellite Measurements

by A. Geiger, M. Cocard, V. Eckert

Since the tropospheric path delay is still one of the limiting factors for precise height determination, our group set up a tool for 3D modelling of meteorological parameters such as pressure, temperature and humidity. The algorithm takes meteorological point measurements on ground and balloon radio sonds into account. Radiometric data will also be included. By interpolating the met-values in a three dimensional approach, the delay on any path can be calculated. In Switzerland there exist an automatic meteo-registration network (ANETZ) and routine soundings at the Aerological Station, Payerne. With such a data set, it will be possible to determine path delays for any topocentric direction in Switzerland without meteo measurements at the GPS sites.

GPS for flight path determination of Radar Imager

by M. Cocard, A. Geiger

It is obvious that the precisely determined track of an imaging system will help to enhance the quality of the images in terms of precision. A special test campaign has been directed by the RSL (Remote Sensing Laboratory) of the University of Zürich in cooperation with the DLR (German Aerospace Research Establishment) on the Radar-Imaging side and with the Institute of Geodesy and Photogrammetry of the ETH Zurich on the GPS side. GPS will be used to determine the track of the airborne SAR imager.

Error Sensitivity Analysis of X-SAR Geometry and Processing Parameters

by M. Cocard, A. Geiger

This paper summarizes the results of a geodetic study into techniques for the design of a processor allowing the generation of high precision SAR images from the "German/Italian X-Band Radar" on the future SIR-C Shuttle Mission. The objectives of the research study were to determine the characteristics of the important processing parameters such as: Absolute Doppler Centroid, B-Parameter, Beam Center Time, Zero Doppler Shift Vector and their approximations with polynomial fits over a slant range of 50 km at maximum. Also the influences of errors in the orbit calculations and the effects due to terrain heights on the processing parameters were analysed. The mathematical model and various algorithms are presented and their results documented in several tables and plots. In comparison to former SAR sensors such as Seasat in a polar orbit, the most significant result appears from the attitude uncertainities of the unstable platform and selected high frequency band.

Study of the geophysical interpretation of high resolution gravity field information from ESA-ARISTOTELES-Mission

by E. Klingelé, H.-G. Kahle, F. Arnet

An international group of scientists from the University of California at Santa Barbara (USA), the University of Bologna (Italy) and the ETH Zürich (Switzerland) conducted for the European Space Agency (ESA) a research entitled "Study of the Geophysical Interpretation of High Resolution Gravity Field Information" in order to assess the scientific benefits in the field of the ARISTOTELES mission (Gravity Gradiometric Satellite).

The work done by the geodetic institute of the ETH Zürich was:

The modelling of the effects of tectonic and geological structures along the satellite track in terms of the vertical gradient T_{zz} has been thoroughly analyzed. Complex lithospheric structures such as oceanic ridges, mountain ranges with their crustal roots, sedimentary basins and subduction zones have been considered and their effects studied at satellite altitude in terms of T_{zz}, T_{yz} and T_{yy}. It has been demonstrated that the corresponding signatures, at orbital altitude, can be observed in the gradiometric records, provided that the nominal accuracy is in the order of 10^{-2} Eötvös.

The isostatic response function of the lithosphere related to the density distribution at depth has been analyzed by applying the admittance technique to the gradiometric data. Algorithms have been implemented and tested with synthetic data in a first step. An application to real gravimetric data has then been performed: the southern segment of the European Geotraverse has been taken into consideration because it is a line with a relatively good amount of data, in practice the best test case available at the moment and, at the same time, this line crosses complex domains exhibiting quite interesting tectonic evolutions. The choice of this test case, where the data are only available along a straight line, implies the need to assume two-dimensional tectonic structures; this would be a limitation also for other techniques, not only for the admittance technique, which could not exploit its full potentiality in this case. A follow-up of this study is being planned for the period 1991/1992.

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3 Determination of the Gravity Field

Gravity reference networks

Gravity Measurements along re-measured first order levelling lines

by E. Klingelé

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 (see also chapter on height systems). In the period extending from 1987 to the end of 1990, gravity measurements using LaCoste and Romberg gravity meters have been carried out on the following levelling lines (see also Map 6).

1987:	Fribourg - Yverdon - Vuiteboeuf	(Line A)
	Bellinzona - Brissago	(Line B)
	Visp - Zermatt	(Line C)
1988:	Vuiteboeuf - St. Imier - Biel	(Line D)
1989:	La Cibourg - Basle	(Line E)
1990:	Nyon - St. Cergnes - Vuiteboeuf	(Line F)

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

Swiss Absolute Gravity Network

by E. Klingelé, I. Marson, H.-G. Kahle

In June 1987 and May 1988 the station Bäzberg of the Swiss Absolute Gravity Network in the St. Gotthard road tunnel was re-measured by means of the improved absolute gravity meter of the Istituto di Metrologia "G. Colonnetti", Torino. A new absolute gravity campaign is planned for 1992.

Microgravimetry and gravimetric tests of the Newtonian Law

by E. Klingelé and H.-G. Kahle

Since 1989 the IGP of the ETH Zurich is conducting microgravimetric measurements in a dam of an electrical power plant at two stations separated by 90m 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 on 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 a sufficiently large set of data will be available for statistical tests.

Regional gravimetry (gravity mapping)

by E. Klingelé

In a frame of a systematic gravity mapping of Switzerland at a scale of 1/100'000, the geophysical Institute of the University of Lausanne, on behalf of the Swiss Geophysical Commission (SGPK) has measured around 1'900 new gravity points (see Map 6). These stations, mostly located in the Jura mountains, will enable the SGPK to publish in 1992 the first seven 1/100'000 maps of the 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 Zurich for hydrological purposes. The number of stations measured for these two surveys is approximately 950.

The geodetic institute of the ETH Zürich received, in 1987, from the European Science Foundation, the duty of compiling the gravity data along the European Geotraverse. This compilation consisted of the collection, validation and re-computation in a homogenous system (1975) of more than 250'000 data coming from up to 11 different countries. The results of this compilation is in the form of two Bouguer Gravity Anomaly coulour maps at a scale of 1/250'000 and covering a strip of 250 km width and appoximately 4'500 km length.

Interpretation and analysis

Application of the admittance technique to gravity data in Central Europe

by S. Ott, E. Klingelé

The earth's Isostatic Response function has been calculated for an area of 740 x 740 km in Central Europe. This zone is delimited by the meridians 6.5°W and 17.166°E and by the parallels 47°N and 53.4°N. The gravity data were provided by the Geodetic Institute of the University of Hannover (Germany). The computed transfer function shows an interesting similarity with the one computed for North America by Dorman and Lewis (1970).

Evaluation of gravity measurements in the Gotthard Tunnel

by R. Glaus, B. Wirth

The gravity data measured in the Gotthard road tunnel have been used to predict the deviations of the vertical, the gravity anomalies and the geoid undulations by means of the collocation method. The bulk density of the surrounding mountains were also computed and yielded a value of 2.74 g/cm^3 which fits quite well with the values obtained by the classical sampling method.

Integral gravity field determination in the Ivrea-Zone and its geophysical interpretation

by B. Bürki

The main task of this work was to apply modern zenith camera systems and gravimeters in determining of gravity and astrogeodetic data simultaneously. A total of 117 astronomic stations was observed in northern Italy and southern Switzerland where the prominent zone of Ivrea-Verbano causes very significant disturbances of the gravity field. For the determination of ellipsoidal coordinates, two Doppler satellite receivers MX1502 were used in the translocation mode.

The astro-geodetic and gravity measurements were used to interpret the deep-seated mass disturbance caused by the Ivrea body in terms of location, size and density contrast. The entire structure was assembled by a series of elementary bodies which may be oriented arbitrarily in space and from which the gravitational attraction can be computed using rigorous formulae. For the geophysical interpretation, the effects of all known mass inhomogeneities were removed from the observed values.

The applied reductions include digital mass models for the following effects: topography, Moho discontinuity, sediments of the Po Plain and of the main valleys, lakes as well as geological reductions for near-surface structures. Furthermore, an appropriate mathematical model was used to perform a least-squares adjustment for estimating the following parameters: Density contrast of a single or a group of elementary structures with respect to the mean density value, changes in the geometry of every single element (either rectangular or triangular prisms); changes in the position of the spatial orientation of every element. As a result of these investigations, a new astro-gravimetric model for the Ivrea body is presented showing some new aspects with respect to the structural composition and extension of the Ivrea body.

A 2-D gravity model of the seismic refraction profile of the EGT Southern Segment
by E. Klingelé, G. Schwarz

A two-dimensional gravity algorithm was applied to a model constructed from the interpretation of the seismic refraction data as presented at the end of the follow-up meeting (in Zurich, June 1988) to the Third Earth Science Study Centre, which focussed on the Southern Segment of the European Geotraverse (EGT). A trial-and-error procedure optimized the density distribution versus depth with the seismic interfaces kept as fixed as possible. Then the physical consistency of the proposed seismic model in terms of mass distribution was tested. Algorithms for an automatic constrained optimization of the density distribution were also applied. The results of the gravity modelling show good agreement between the observed and computed Bouguer anomalies on a regional scale, with the exception of the part of the profile between the Southern Alps and the Po Plain where the gravity model shows a distinct mass deficit.

Theoretical Studies

Theoretical study of the gravity field in the Alpine area: Gravimetric Geoid of Switzerland
by A. Geiger

This work is divided in two parts which are not completely separated. In the first part, a few mathematical foundations of the functional gravity field approximation are presented.
One of the most important problems of physical geodesy, the solution of Laplace's equation has systematically been reviewed by means of the Stäkel-Separation in cartesian, spherical and ellipsoidal coordinates. Special emphasis has been put on the demonstration of the relations between the different solutions in different coordinate frames. The relation between sperical harmonics and the cartesian solution is made by means of homogeneous polynomials. The relation between Fourier transforms and the cartesian solution is shown as well.
A possibility to develop some orthogonal series approximation by the least-square method even for unevenly spaced data samples is shown. The Operator-calculus is introduced and specialized for self-adjoint operators like the Laplace-operator. By treating a few eigenvalue problems, the solution will appear in terms of reproducing kernels. The error propagation is briefly discussed.
The boundary value problem is treated using all the previously established and reviewed formalisms. The Stockes' solution is consequently elaborated by this functional approach. The Stockes' function is derived only by the use of operators solving for the Greens' functions. In view of future numerical developments, the boundary value problem has been formulated as a variational problem which can be solved by numerical methods such as finite elements or finite differences. A brief overview of spectral and approximation methods is given.
The last chapter of part I concentrates on real calculations in the framework of the gravity field. The operational approach is briefly rewied on the basis of functional theory. A small outlook in differential geometry is given. Especially the analogies of the gravity field, the lightwave propagation and the conformal mapping is pointed out.
Some examples of applying Gauss' formula to describe physical properties of the gravity field are carried out. The rigorous application of the Fourier transformation leads to a new formula for calculating the gravity vector and the potential from known density destributions. 'Parker's' formula will appear as a special case for the z-component. The multipole development might have some interest for calculating global topographic effects or for gravity field determination inside mass distributions.
In the second part, the practical evaluation of Stokes' formula is carried out. Several formulas developed in the previous chapters of part I will be applied. Some distributing effects such as time dependent gravity changes etc. are discussed. Most of them are negligible for our purposes. In a newly formulated least squares model, trend- and Moho parameters with horizontally variing crustal densities are estimated.
A simple algorithm for correcting Stokes' formula in the near zone of integration is developed. The correction of height anomalies or orthometric height corrections are derived from Bouguer anomalies.
For the calculation of the geoid GEM10C in the GRS80 has been used as a reference. The 6'x10' free air "Wenzel" anomalies as well as our own data of Switzerland have been processed. By the calculation in

the GRS80, it was possible to calibrate the existing astro-geodetic geoid with respect to this system. The a priori variances of the gravimetric geoid showed values from 12 cm to 30 cm. The comparison with the astro-geodetic solution reveals a mean deviation of 26 cm rms. Here it is to say that the regions of the Molasse basin and the Alpine forelands showed a much lower discrepancy of the order of 16 cm rms. The major contribution to the residuals are located in the Ivrea-zone and in the southern part of the canton of Valais. To examine this problem the pure 'Stokes' principle of free air anomalies has been left. Some suspect free air anomalies have been calculated by interpolation of Bouguer anomalies and by adding the corresponding topographic effect. The residuals remained in the same regions, but on a lower level. An overall precision turned out to be of the order of 30 cm.

Automatic interpretation of gravity gradiometric data

by E. Klingelé, I. Marson, H.-G. Kahle

The magnetic and gravity field 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 gradiometric data (vertical gradient). This paper deals specifically with the Werner deconvolution, analytic signal and Euler's equation methods. After a short outline of the mathematical development, synthesized examples 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 ground gravity surveys after transformation of the Bouguer anomalies into vertical gradient anomalies. An example is given of the application of the Werner deconvolution and Euler's equation methods to a microgravity survey.

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

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

In this paper emphasis is put on the determination of crustal parameters by gravity anomalies. The determined parameters may also be used for the gravity field interpolation. The crustal parameters will be restricted in our case to densities and reference depth of the Mohorovicic discontinuity in the Swiss Alpine area. A procedure similar to the well known 'Nettleton'-profiling for determination of the homogeneous density of a small scale, the topographic structure will be generalized to two-dimensional data sets and varying density. The method will still be limited to small areas. 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. In this approach different components of all the methods can be identified. The basic idea consists of reducing the gravity field anomalies by physically meaningful parameters, which have to be estimated to a more or less stochastic remainder. The applied model consists of horizontally varying crustal density, mantle density, reference depth of the Moho discontinuity 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.

Astronomical geodesy

The connection of space related observations such as satellite measurements using GPS techniques, satellite laser ranging (SLR) and Very Long Baseline Interferometry (VLBI) with terrestrial data measured in the earth's gravity field requires the knowledge of the equipotential surface at sea level represented by the geoid. The determination of its parameters in terms of deflections of the vertical and azimuths is one of the major objectives of the astronomical geodesy.

Zenith camera and Determination of Deflections of the Vertical

by B. Bürki

The upgraded transportable zenith camera measuring- and evaluation system of the Institute of Geodesy and Photogrammetry (ETH Zurich) has been used to carry out numerous new measurements serving different purposes. In order to improve the geoid determinations, deflections of the vertical are of utmost interest. Beside the geoid determination the astro-geodetic observations may be used for geophysical interpretation purposes as well.
The zenith camera system has been used within the following projects:

In Switzerland (see also Map 7):

- 30 stations in the framework of practical field courses for students in connection with several research projects
- 30 stations for the Swiss National Research Project NFP20: Exploration of the Deep Geological Structure of Switzerland.
- 26 stations for the densification of deflections of the vertical in Switzerland

In other countries:

- 20 stations in Greece for the geoid determination in the Ionian Sea area.
- 5 stations in the vicinity of Venice. The purpose of these measurements was the determination of the local geoid in the frame of ESA's ERS 1 altimeter task and furthermore height determinations.

Computer-Supported On-Line Astronomical Positioning

by B. Bürki, U. Marti and B. Wirth

The objective is to investigate new observation methods including software and hardware developments such as especially designed digital clocks and electronic theodolites in connection with Laptop computers. A comprehensive software package has been developed which enables on-line observations using different methods and modern electronic theodolites. In this system, the astro-geodetic observation procedure including digital data transfers as well as the evaluation is supported and controlled by the software running on a Laptop PC. The software makes use of rigorous evaluation algorithms based on the new star catalogue FK5 and the actual astronomical procedures and constants as defined by the IAU.
In collaboration with the Istituto Geografico Militare Italiano and the University of Padova, a total of about 30 stations has been observed in several field campaigns in Switzerland, Italy and in the Central Karakorum mountain chain in Pakistan.

Geoid Determinations

Gravimetric Geoid in Switzerland

by A. Geiger

(see under Theoretical Studies, this section)

Geoid determination in Switzerland using GPS (ALGESTAR)

by U. Marti

The objective of the project ALGESTAR (Alpine Geoid by Satellite Timing and Ranging) was to test the suitability of GPS measurements for height determinations in a rugged topography and furthermore to calculate a satellite-based geoid for Switzerland. A set of 40 stations of the Swiss triangulation network which are connected to the national levelling lines was selected in order to get accurate orthometric heights. The measurements took place in collaboration with different Swiss and German institutes in the end of August 1989. The 40 stations were measured by using 16 WM-102 double-frequency-receivers in only 4 days. The GPS solution were evaluated with the 'Bernese GPS-Software'-package. Comparisons between the solutions of every single day revealed an accuracy of the ellipsoidal heights better than 10 cm over the whole area (200 to 300 km).

The geoidal undulations at the observed stations were obtained by subtraction of the orthometric heights and the ellipsoidal heights calculated from the GPS measurements.

In the Alpine region the geoid can't be interpolated with sufficient accuracy without reducing the observed undulations by the influence of known mass models (topography, MOHO discontinuity, Ivrea body). The resulting co-geoid shows a smooth surface and can therefore easily be interpolated (e.g. by collocation methods). The geoid itself is obtained by applying Bruns' theorem. Following the 'remove-restore' technique, the gravity potential of the reduced mass models has to be added to the interpolated co-geoid.

The resulting geoid reveals an accuracy of about 10 to 15 cm over the whole of Switzerland. In most parts of the country, the differences to the astro-geodetic geoid are less than 20 cm.

Astrogeodetic Geoid-Determination in the Zone of Ivrea

by U. Marti

In the framework of a dedicated study of the gravity field in the vicinity of the Ivrea zone in southern Switzerland and northern Italy, 117 astrogeodetic stations were measured with the transportable zenith camera system of the Institute of Geodesy and Photogrammetry at the ETH Zurich. These astro-geodetic measurements were completed by some 110 additional gravity measurements.

One first principal aim of these investigations was to increase the knowledge of the location, size, shape and density of the prominent zone of Ivrea. B. Bürki has determined a detailed 3D-model of this zone (see "Integral gravity field determination in the Ivrea-Zone and its geophysical interpretation", in this section).

Based on these results, a second goal was to calculate a new geoid in this complicated region. Because of the irregular distribution of the measured deflections of the vertical (mainly caused by topography), the effects of known mass models (topography, crust mantle boundary (MOHO discontinuity), Ivrea body, sedimentations of the Po Plain and of the major Alpine valleys as well as the masses of lakes and glaciers) have been subtracted. The reduced deflections of the vertical show a smooth form and can easily be interpolated.

Presuming that all mass disturbances near the surface have been reduced, integration leads to the co-geoid of the residuals. This integration has been performed by means of collocation methods based on multivariate predictions of geoid heights, deflections of the vertical and gravity anomalies. We used the 3rd order Markov model presented in 1972 by S.K. Jordan which was already applied by W. Gurtner in his determination of the astro-geodetic geoid of Switzerland in 1978.

Since the number of measured gravity anomalies is too small to increase the accuracy of the geoid, only astro-geodetic data were used in this case. From the co-geoid of the residuals the geoid itself is then obtained by applying Bruns' theorem.

The main features of the geoid are caused by the topography. It generates differences in the undulations of 12 to 13 meters in the Alpine region. The other important mass models (Ivrea body, MOHO discontinuity and sedimentations of the Po Plain) are associated with undulation of 5 to 7 meters.

In Map 9 the geoid is shown referred to the Swiss Bessel-Ellipsoid. It has a relative accuracy of better than 3 cm over the whole region. It represents the base for future combinations of levelled heights and elevations obtained by satellite methods (GPS). The final goal is to determine a 'cm-Geoid', which is in accordance with resolutions obtained by the International Union of Geodesy and Geophysics (IUGG) 1987 in Vancouver.

High Precise Local Geoid Determination in Turtmann

by B. Wirth

In the GPS test net Turtmann (see also section 1 and report 1987), the Institute of Geodesy and Photogrammetry of the ETH Zurich (IGP) and the Federal office of Topography (L+T) have determined 10 astronomical stations with the transportable zenit camera system of the IGP. In the same area of 5 x 6 km^2 with up to 900 m height differences, the IGP measured 202 gravity stations. All these measurements were reduced for the effects of topography, the Moho discontinuity and an Ivrea model. The reduced data were used for a combined astrogeodetic gravimetric geoid determination. The two-dimensional Markov undulation model of third order was taken to predict co-geoid undulations. The characteristic distance was set to 2000 m, the standard deviations for the noise to 0.5" for ξ, 0.7" for η and 0.5 mgal for δg. The potential effects of the models were calculated in all interesting stations on mean sea level and transformed to geoidal heights by Bruns' theorem and added to the co-geoid heights. The relative accuracy of the geoid to the GPS station Turtmann in the center of the area was computed and has its maximum in the GPS station Agarn with 4.1 mm. In this example, we succeeded in computing a local geoid with subcentimeter accuracy.

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4 General Theory and Methodology

Reliability Model of the National Survey

A. Carosio

In cooperation with the IGP and the Federal Office of Topography a reliability model has been developed and integrated into the software for network adjustment, currently used in the national survey. The model is based on the classical mathematical model of Baarda (1968) with the following adaptions:
The statistical test procedure used is the test of standardized residuals, the level of significance is shown as a constant limit value instead of as the probability of an error of Type I. On this basis, definite indicators of the internal reliability (of each single observation) can be evaluated if the permissible risk of an error of Type II is stated.
Accordingly, a new concept permits the calculation of the influences of possible model errors on coordinates and their graphical presentation in oriented rectangles.
The developed method is already being in use at the ETH, the Federal Office of Topography and in various other private and public institutions.

Portability of the Geodetic Software System

A. Carosio

The Swiss Geodetic Software System, which has been in use now for several years and which was developed in cooperation between the Federal Office of Topography, the IGP and other institutions, has been further extended and improved. To date only, a few modules could be delivered to the private sector because the portability of the system, especially of the interactive components, could not be guaranteed.
Within the framework of a research project the difficulties were analysed and universally applicable alternatives were developed. By developing simple basic functions for screen control, graphic operations and by applying the standard file functions of FORTRAN 77, the aim of system independancy was met to a large extent.
The present model of interaction uses standard instructions only, these being largely independent of the operating system.
The project has been completed. Test versions are running on PRIME, VAX, IBM RISC 6000 and MSDOS-Personalcomputer. The system includes adjustment of geodetic networks, registration of data in the field, geoid and deflection of the vertical, geometric transformations and interpolations, graphic displays, 3-D transformations, map projections, etc.
The Geodetic Software System meets many demands of the practitioner and is being used increasingly.
In parallel to this development, the contents of courses in Surveying and Theory of Adjustment at the ETH have been adapted to the new software, thus enabling the students to work with a modern and fully integrated system for their exercices and projects already during their education.

Planimetric adjustment including GPS observations

T. Burnand

In the last few years, the GPS method got always more importance to determine geodetic points. A lot of software is available to treat such measurements. All of there are working in 3 dimensions.
A few years ago, the Federal Office of Topography developed a software package for the treatment of classical geodetic measurements (angles, distances) LTOP. This programm was always brought up to date and is actually becoming like a "standard" software in our country. The only restriction is that the adjustment of the planimetry and the altimetry are fully separated.
The Swiss Federal Institute (ETH) of Zurich in collaboration with the Federal Office of Topography decided to try to include the GPS measurements in the LTOP-software. Actually only the planimetry is realised. The functional model can be resumed like:

All GPS-points are at first transformed into the Swiss projection system. Then we consider that the movements of the satellites-system in comparison with the earth-system are very small between two or more sessions. We can also approximate the 3D displacements as a combination of a rotation, a scale-factor and a translation in X and Y in the planimetry. Then we can consider every GPS-session as a local system, which we can then transform into the absolute Swiss system by using an Helmert transformation (2D). The operator can choose which transformation parameter he wants to appy (rotation, scale, translation). He can also set, that each of session has the same transformation parameter, for example.
After several tests, we could determine which parameters are significant and then which are necessary. We could find that a common rotation for all sessions gives good results, but we have always a new X - Y translation parameter for every new session.
The software is working well at the Federal Office of Topography and we expect to realise the same model for the altimetry in the near future.

Data processing at the Federal Office of Topography (L+T)

U. Gerber

New developments were introduced into the geodetic program system between 1987 and 1990 as well as adaptions in the sense of enhancing the quality assurance of existing software packages. Several programs are now available to government offices as well as to private firms in the MS-DOS version.
One of the most essential developments of the triangulation adjustment program LTOP are the reliability indicators which facilitate the evaluation of the quality of the net and the observations. A further innovation is the possibility of adjusting geographic coordinates as well as computing coordinate observations and their differences (Gubler, 1990).
To complete the geodetic program system, the integration of a program for the automatic computation of approached coordinates has finally been realized (Chablais, Gründig, Dufour, 1989). In collaboration with the Institute for the Application of Geodesy in Construction (IAGB) at the University of Stuttgart (Prof. L. Gründig and Dr. J. Bahndorf), it was possible to acquire the program APCO and include it in the program NAEKO.
In the area of satellite surveying (GPS) the program system of the Astronomic Institute of the University of Bern ("Bernese Software") was built into the L+T's geodetic program system (Walser, 1990).
Worth mentioning is the development of the program system for the acquisition, revision and printing of the data on the bench marks of the Swiss precise levelling network (Misslin, 1988).
Digital height models are increasingly being used for the most various applications. At the Federal Office of Topography the DHM25 is in production and is available either as a matrix model with a grid of 25 m or as a base model (contour lines in vector form). The program CONGRID was developed for computing the height matrix which is based ont he algorithm described by P. Yoeli (Dufour, Eidenbenz, 1988).

Combined 3D-Adjustment of GPS-Baselines and Terrestrial Data

by B. Wirth

The Fortran computer program RAUMTRI (Schneider and Wunderlin, 1981) has been transferred onto a Macintosh PC. The observation equations have been expanded for GPS baselines. The differences of the two cartesian coordinate systems (WGS 84 and the astronomical one) are considered by four additional unknowns of a spatial Helmert transformation. The weight matrices of the baselines are formed by the inverse of the corresponding 3x3 submatrices of the variance - covariance matrix of the complete GPS solution. In this way, the weakness of the heights are taken into account. One example of the high precision transverse Visp - Zermatt is shown in (Wirth, 1989).

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Seminar on Education in Geodesy

by H.J. Matthias

In November 1990, the two secretaries of IAG Commission IX for Europe, Prof. Dr. W. Welsch and the reporter, have organised, together with Prof. Dr. E.W. Grafarend, a Regional Seminar on Education in Geodesy at the University of Stuttgart. About 60 participants represented all educational institutions on the university level as well as the most important bodies from research and professional practice. The papers dealt with the changing world of geodesy, its actual position among scientists, the technical developments, the consequences for the tuition, curricula models, future standards in the European unification process and the demands of the practice for the educational goals. Even if the beginnings of the geodetic curricula in the last third of the 19th century and the first third of the 20th century were quite comparable in the three countries, the professional practice is nowadays greatly bound to laws, the administration and organisation. Therefore, the needs and the development do not correspond any more.

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5 Geodynamics

Recent Crustal Movements in Switzerland

Vertical Movements

by E. Gubler

Since 1971 the measurements made in the Swiss first and second order levelling net were systematically analysed with the aim of detecting recent vertical movements of the earth's crust in Switzerland. The first levelling was carried out between 1905 and 1930. The second is due to be finished in a few years. The standard deviations estimated from the adjustment of the two levellings are 1.4 and 0.8 mm/D[km] respectively. Since no accurate connection could be computed to tide gauges, only relative movements have been determined so far. These relative movements exceed their standard deviation by a factor of four and can be regarded as highly significant.

The main feature is a significant uplift of the Alpine part of Switzerland with respect to the Plateau and the Jurassic mountain belt of up to 1.5 mm/year (Map 5). Until recently no abrupt changes in vertical uplift rates could be found, but by comparing the 1990 levelling to former ones, a very significant uplift of two bench marks at Le Pont (near Vallorbe, in the western part of Switzerland) has been detected. These two show an uplift velocity of the bedrock of 0.8 mm/year with respect to all other stable bench marks in the area. An explanation could not be found until now even though a significant strike slip fault passes near by. Horizontal measurements on this fault did not show any significant displacements in the period of 1973 to 1988 (Jeanrichard 1990).

Horizontal movements

by E. Gubler

The rate of horizontal crustal deformation in the western Switzerland has been determined from a comparison of two triangulation surveys, centered approximately on the epochs of 1872 and 1912, and a trilateration survey made around 1970 (Reilly and Gubler, 1990). A heterogeneous strain model was needed to fit these data which yielded a rate of (tensor) shear strain of about 0.10 ±0.02 micro-radian/year with the axis of maximum relative shortening aligned NE-SW, parallel to the chain itself. This distribution of shear-strain rate is consistent with a complex bending in the horizontal plane, in which the (concave) normals to the axes of maximum bending rate lie in the NW quadrant (i.e. in the opposite direction to the present curvature of the Jura). Further studies will be made as soon as the diagnostic adjustment of the first and second order triangulation is accomplished (see Section 1). In the northeastern part of Switzerland a high-precision crustal motion network was measured in 1988 (Wiget et al. 1990). The next measurements are scheduled for 1992.

Gotthard

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

First measurements in a triangulation net with distance measurements were performed for the construction of the Gotthard road tunnel in 1967. In 1981/83 the net was remeasured and connected with the precision traverse through the tunnel. Since 1976, periodical deformation measurements were carried out in the region Stöckli - Lutersee (Rhine - Rhone line). This tectonic line crosses the Gotthard net perpendicularly. In September and November 1988 a new campaign took place in this region to connect the control network Stöckli - Lutersee with the Gotthard net. This was a GPS campaign with seven WM 101 receivers on the north side of the Gotthard. In addition, terrestrial distance measurements with the ME 5000 were measured. The evaluation and interpretation is done in (Ettlin and Cocard, 1990) and shows a homogeneous scale difference of 3.1 ppm between 1967 - 1981/83 and 1988, while GPS and ME

5000 did not show any scale difference at all. To get more information about this scale difference and to extend the 1988 measurements to the southern end of the net in Airolo, a new campaign was started for August 1990, where a group of geodesy students remeasured a precise traverse as part of the net in their diploma course. Five WM 102 GPS receivers were used as well as an ME 5000. This time there is a scale between GPS and the terrestrial distances of 1.8 ppm (GPS is shorter). Identical ME 5000 distances are in the mean 2.7 ppm longer in 1990 than in 1988, which means that over distances up to 3750 m with only endpoint meteo measurements, systematic errors can occur. In a three-dimensional combination of GPS 1990 and the terrestrial data 1990 in a common adjustment, the scale differences vanish. Here, it can be seen that the slope distances of GPS in a network with large height differences are very much influenced by errors in the heights caused by incorrect meteo models. In the common adjustment, the GPS baseline heights are corrected up to 10 cm. The comparison of this combined solution with the terrestrial solution 1981/83 shows a scale difference of only 0.65 ppm ± 0.32 ppm and mean differences of s_{north} = 1.0 cm, s_{east} = 1.9 cm, s_H = 1.1 cm, which proves, that the height corrections of the GPS baselines are correct.
To interpret the geodetic results in terms of geodynamic processes, a study has been undertaken (Straub 1990). The finite element model of the 'Gotthard' region (model based on geological assumptions) has been calculated with a special FEM package (TPS10) on PC. Different loadcases have been taken into account, where the deglaciation since the last 15000 years is of particular interest. However the elastic rebound is not able to explain the complete recent uplift rates determined by spirit levelling (Gubler).

Regional Geodynamics

Geodynamic Study of the Yellowstone Caldera

by E. Klingelé

Results from geodetic measurements combined with heat flow data and seismicity observations indicate that the Yellowstone area ist deforming at high rate. This project is being pursued jointly with different universities and offices in the USA. It focuses on the improvement of measuring and interpreting extremely small variations in gravity over geologically short time periods and the application of these data for geodynamic modelling. In particular, attention is paid to a combined interpretation of GPS, levelling and gravity data.

Collaboration:
- University of Utah, Salt Lake City
- USGS, Menlo Park
- US National Park Service
- University of Colorado, Boulder
- MIT, Boston

GPS networks in Greece and geodynamic processes

by H.-G. Kahle, M.V. Müller, St. Mueller, G. Veis, H. Billiris, D. Paradissis

Tectonic processes in the Mediterranean are closely related to the collision between the African and Eurasian plates. Our interest is specially focused on the West Hellenic arc. It forms a transition zone between the western and eastern Mediterranean. The Ionian Sea is a site of plate tectonic and seismic processes intervening between the subduction along the West Hellenic arc, the rotation of the Apulian platform and the distributed normal faulting in Central Greece. A GPS project has been initiated which is aimed at providing relevant data to enhance the knowledge of neotectonic deformations and the mechanism of high-energetic earthquakes. Besides the monitoring of recent crustal movements a mapping of the geoid of the Hellenic subduction zone has been started. The area of investigation includes the Ionian islands (from Othoni north of Kerkyra to Strofades) and western Peloponnissos. To the east it connects with the Central Greece GPS project pursued by the Universities of Athens, Newcastle, Nottingham, Oxford and the ETH Zurich. To the west the network is tied to the Calabrian arc which is being studied jointly by the University of Bologna and the DGFI Munich. The SLR sites Dionysos, Chrisokellaria, Karitsa, Matera and Basovizza as well as the VLBI station Noto (Sicily) have been observed in our network to serve as permanent (fixed) sites. The West Hellenic arc network has been established in 1989 and in the same year a zero epoch observation took place. Keeping the uncertainties in reduction problems in mind, a comparison with earlier terrestrial measurements (~1930 respectively 1973) on the Specchia Cristi-Othoni-Pantokrator-line between Italy and the island of Kerkyra seems to confirm a counterclockwise rotation of the Italian peninsula versus Greece of about 1 cm per year. Further campaigns are planned for 1991 and 1993. The results from the zero epoch campaign in 1989 and from the two repetition data sets of 1991 and 1993 will allow us to assess the displacement field and to model the microplate processes in this time frame. Finite element methods will be applied to analyze the ongoing kinematic processes in the subduction zone of the Ionian plate. The investigation forms an integral part of NASA's "Crustal Dynamics Project" (CDP) respectively NASA's project "Dynamics of the Solid Earth" (DOSE).

Collaboration:
- National Technical University of Athens
- University of Newcastle
- University of Nottingham
- University of Oxford
- University of Cambridge
- University of Bologna
- DGFI Munich

Tectonic activity and its interactions with groundwater-circulation, geothermics and seismicity - study area NW-Turkey. Research sub-project Geodesy

by U. Marti and H.-G. Kahle

Northwestern Turkey is a site of active plate tectonics and crustal movements by which the morphology, geology and hydrology are significantly influenced. The geodynamic processes cause frequent earthquakes, thermal springs and ore mineralisations. In order to assess the pattern of recent crustal movements and the rates of uplift and subsidence, vectors of displacement are being measured by means of satellite radio wave techniques applied to the Global Positioning System. The areas under investigation are located in the vicinity of the Sea of Marmara where the North Anatolian Fault zone breaks up into several branches, e.g. the Gulf of Izmit / Lake Sapanca, the Gulf of Gemlik and the Bursa depression. A high precision satellite geodetic network has been installed and measured for the first time in 1990.

Interpretation and Modelling

The Swiss National Research Project NFP20: Exploration of the Deep Geological Structure of Switzerland

by. B. Wirth, H.-G. Kahle, E. Gubler and I. Bauersima

Along the eastern, western and southern Swiss Alpine traverses, a total of 83 stations have been measured with the transportable zenith camera of the Institute of Geodesy and Photogrammetry of the Swiss Federal Institute of Technology Zurich. The measured deflections of the vertical were reduced for the effects of topography, Moho and the Ivrea-body. From the reduced values of all astronomical stations and all available gravity measurements in Switzerland, the density contrast at the Moho was computed to 0.37 g/cm^3 by fixing the geometry from seismic informations (Wirth and Marti, 1988). The data were also used to compute the detailed geoid (Swiss datum) along the eastern traverse. It reaches a relative minimum of 0.4 m in the Molasse basin near Wil. It increases towards north (Stein am Rhein) to 1m and southwards to 1.2 m in Sargans and 2.5 m in the southern end of the profile, in Val Madris. The standard deviation of the differences to the geoid of Switzerland (Gurtner, 1978) in the 54 new astronomical stations is 0.11 m.

Two lines of the Swiss levelling net have been relevelled for the NFP20 project. One between Bellinzona and Brissago in the south of Switzerland, the other from Visp (to the west of Brig) southward to Zermatt. On the first line no significant changes could be found even though the levelling crosses the Insubric Line, one of the major tectonic features of the southern Alps. On the second one the relative uplift rates computed for the Alpine part of Switzerland decreases from 1.5 mm/year near Visp to 0.8 mm/year in

Zermatt. These findings are consistent with the general pattern shown in Map 5 (Wiget und Gubler, 1988).

To establish a network for future detection of horizontal crustal shortening in the north-south direction and also for the comparison of levelled heights with GPS heights, 13 stations of the precise levelling line Visp - Zermatt have been established for GPS observation. They have been observed in two different campaigns by GPS and by precise distance measurements. The distance (32 km) between the two endpoints is now known with an accuracy of about 7 mm. The comparison of the GPS heights with the orthometrically corrected levelled heights shows an increase in the geoid undulations from 1.5 m in the Rhone Valley (Visp) to 2.85 m in the Alpine southern end of that line in Zermatt. The standard deviation of the height differences (after a new local geoid determination with all available observations to the disturbing potential) is 2.7 cm.

To connect the western with the eastern traverse, 12 stations were selected and measured with TI 4100 receivers (GRANIT campaign). Two other goals of this campaign were the re-measurement of the Transalpine baseline Zimmerwald-Mt. Generoso and to tie the satellite station Zimmerwald to stable geological formations.

The coordinates of the sites observed during the GPS campaigns GRANIT and ALGESTAR (a total of 42 sites) were compared with the coordinates of the triangulation network of Switzerland by means of collocation in order to detect distortions. After a Helmert transformation of the transformed GPS to the national coordinates, mean differences of 40 cm remain. The largest differences are located at the Alpine border of Switzerland (Wallis, Tessin, eastern Grisons and the region of Lake Constance). With collocation it is possible to predict maximum and minimal scales, angle and axis distortions in any points from coordinate differences in discrete sites. The distortion of the right angle of the two axes X and Y in [^{cc}] after the transformation are shown in Map 10. They are smaller in the Alpine foreland (0 - 5 cc) than in the Alps (± 10 ^{cc}), where the triangulation was much more difficult to perform. The extreme scale values reaching up to ± 20 ppm (after subtraction of a mean scale of -6.6 ppm) are shown in Map 11. The search for tectonic effects is a prime objective for further analysis in the next years.

Three-Dimensional Modelling of Recent Crustal Movements

by A. Geiger

In order to calculate the distribution of elastic energy produced by deforming forces we applied a plate model and treated it by the finite difference method. The energy distribution calculated from measured uplift data correlated well with the earthquake distribution (Geiger, Megel, Kahle, 1988). For more complicated structures, the finite element method has been considered to be the appropriate approach.

For our purposes, we used a FEM-Program-system called 'FLOWERS' developed at the Institute of Informatics of the ETH Zurich (Anderheggen et al 1987) and a PC compatible FEM-Program-package (TPS10, T program). To model the Alpine region, a block of 265x365 km and 70 km depth cut into 4 layers has been assumed.

Special emphasis has been put on the effect of topographic structures like valleys or isolated mountains. The results showed a strong influence of the surface shape. Especially the stress pattern near the surface is strongly disturbed. This fact has consequences for in situ stress measurements which are carried out in near surface regions. A similar statement would hold for geodetic measurements where mountains show a different behaviour compared to valleys. Thus the interpretation of such measurements would request a careful examination and a detailed modelling of nearby surroundings. The results are in good agreement with the levelled uplift rates. They show a correlation with the topography. This effect can partially be explained by the mechanical behaviour of the Alpine structure. Different loadcases have been considered. Special emphasis is placed on the response of the crust to the deglaciation in the Alpine area.

High mountainous areas undergo stronger height changes than points down in the valleys. This means that parallel to E-W (or perpendicular to the compressional direction) running valleys, considerable stress fields will be built up. The FEM has also been applied to regional structures such as the West Hellenic Arc.

Physical Interpretation and Determination of Crustal Parameters from Gravity Data

by A. Geiger, H.-G. Kahle and B. Wirth

Physical interpretation of gravity anomalies in terms of deep-seated mass inhomogeneities requires adequate reduction of topographic effects. Extensive terrain modelling has to be made especially in high mountainous regions such as the Swiss Alps. Over the past four years, digital terrain models have been used in order to regularize measurements of gravity anomalies as well as of deflections of the vertical. Since a digital model exists over the entire area of Switzerland in a 500 m x 500 m grid and in the interesting regions with 50 m spacing, all measurements can easily be corrected for topographic effects. In many cases other known structures are considered, e.g. the relief of the Mohorovicic discontinuity as well as sedimentary structures. In such a way the measurements can be 'smoothed' and 'regularized' to a very high degree.

The basic idea of regularizing the gravity field consists of reducing the gravity anomalies by physically meaningful parameters, which have to be estimated to a more or less stochastic remainder. The applied model consists of horizontally varying crustal density, mantle density, reference depth of Moho discontinuity, trend parameters and known disturbing mass distributions like the 'Ivrea' body in the southern part of Switzerland. The estimation of the parameters is done by least-squares adjustment or by least-squares collocation. The determined parameters may also be used for the gravity field approximation in unsurveyed areas. The estimation of a horizontally varying crustal density reveals interesting geophysical information such as density anomalies in the Alpine area and helps to regularize the gravity data by a considerable amount. The present status of analysis yields a remaining scatter of about 6 mgal over the whole area considered.

The estimated parameters are the following:

Density contrast at the Moho discontinuity	0.40 g/cm3
Reference depth of Moho discontinuity	29 km
Horizontal variation of crustal density	2.37 to 3.07 g/cm3

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see Section 2.

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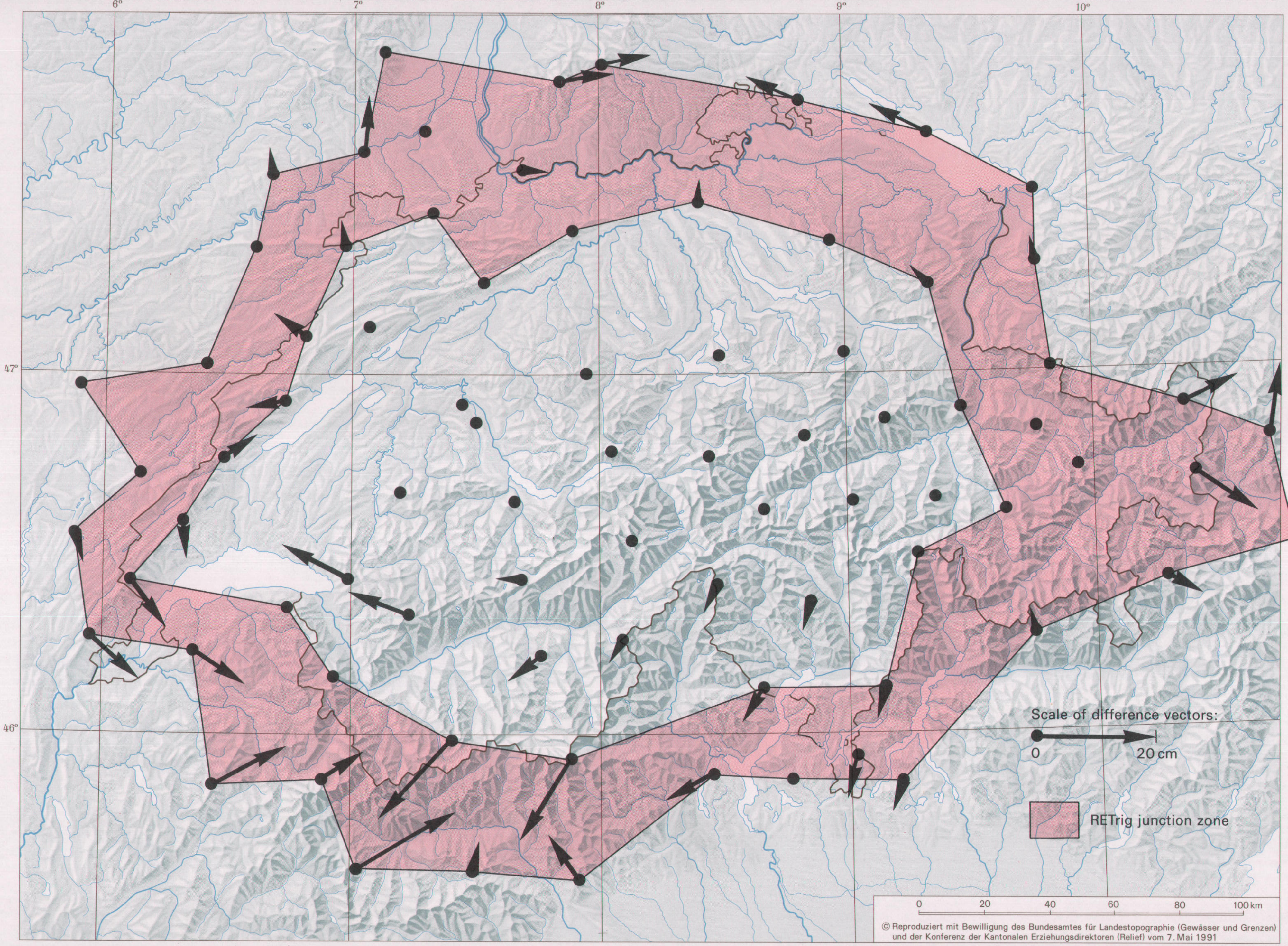

Map 1 Comparsion of RETrig coordinates: ED87 – ED79 (Helmert transformation without scale factor)

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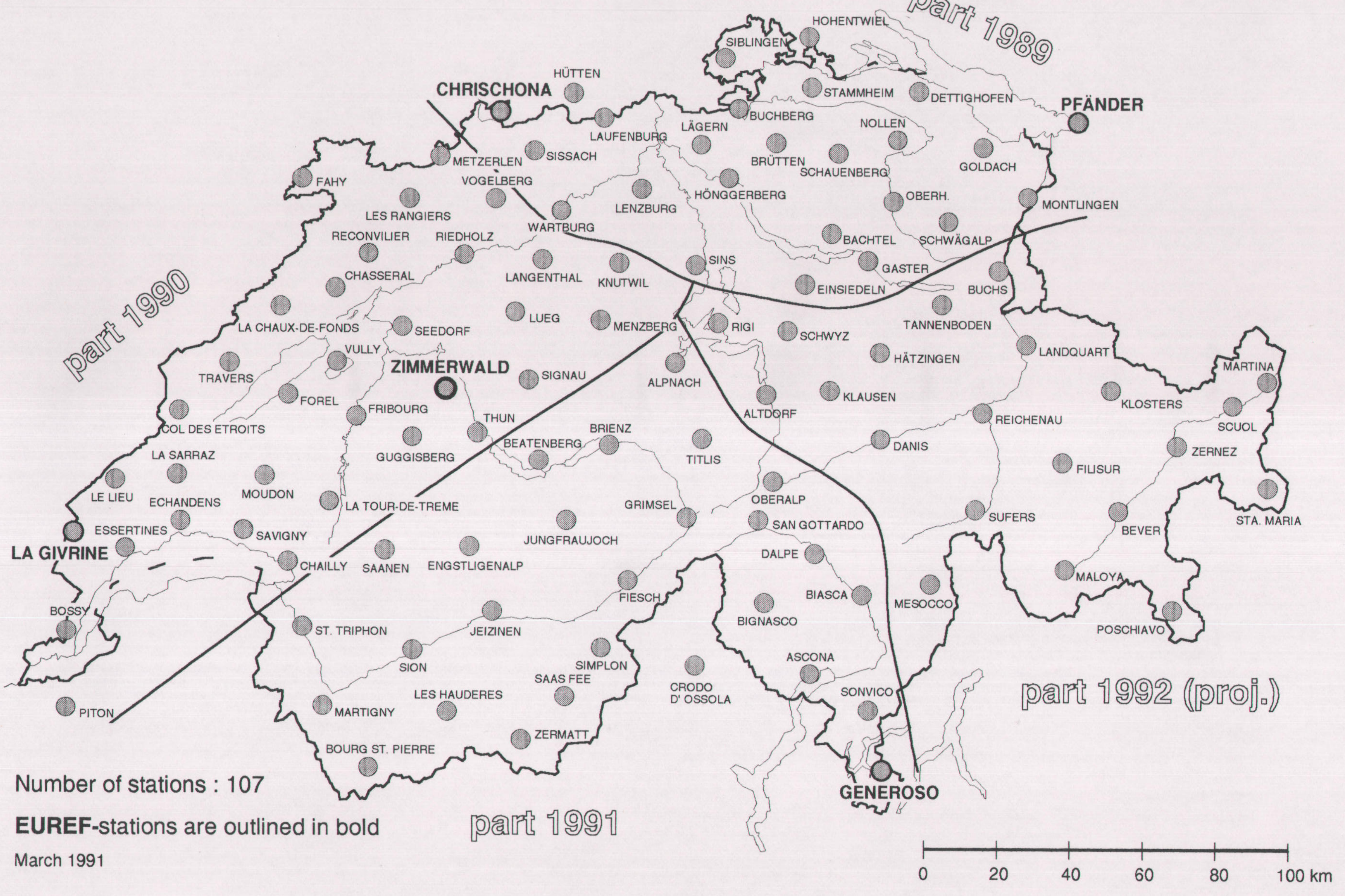

Number of stations : 107

EUREF-stations are outlined in bold

March 1991

Map 2 The new GPS Network in Switzerland (LV 95)

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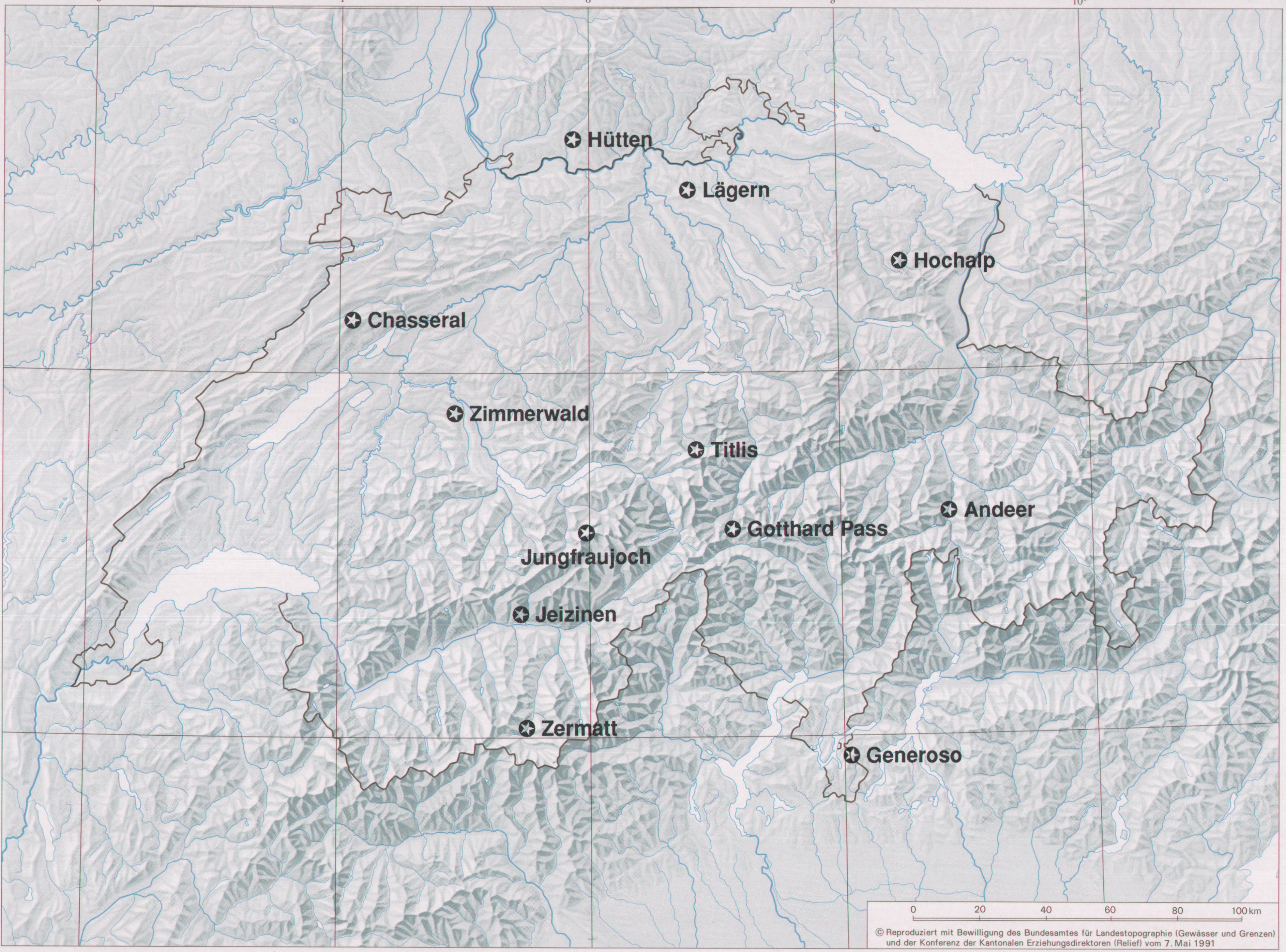

Map 3 GRANIT Stations

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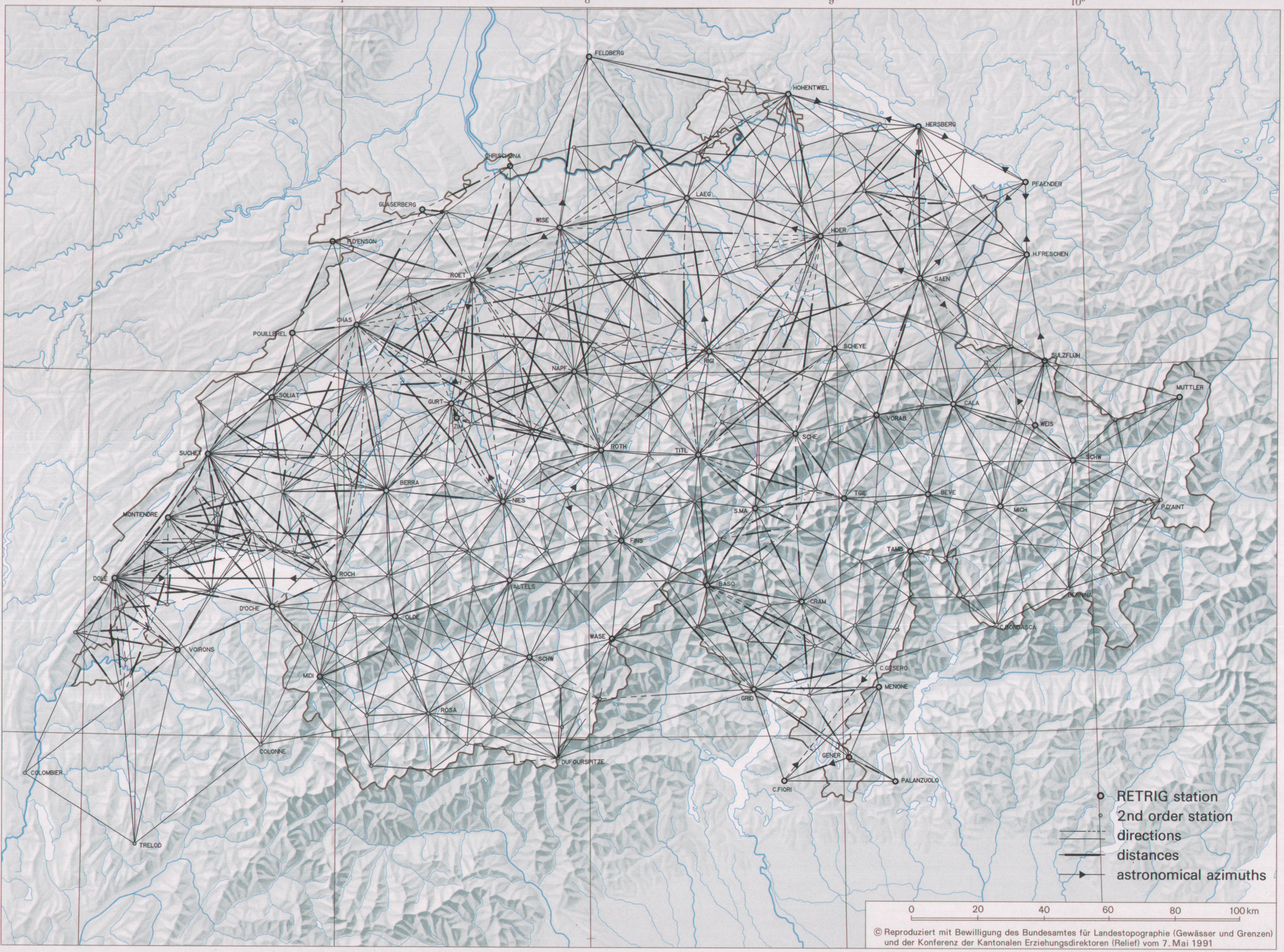

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Map 4 Diagnostic Adjustment of 1st and 2nd Order Triangulation

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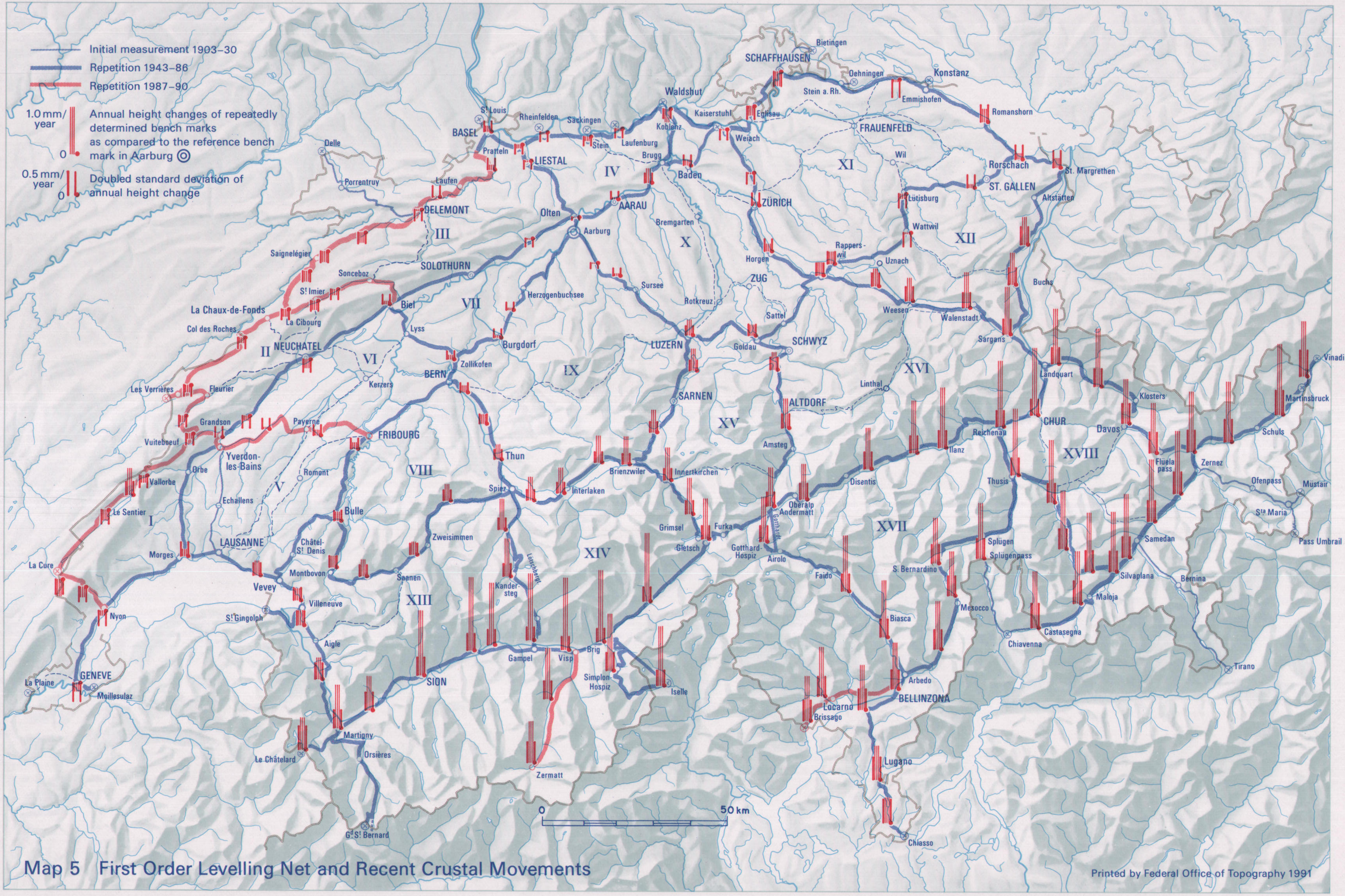

Map 5 First Order Levelling Net and Recent Crustal Movements

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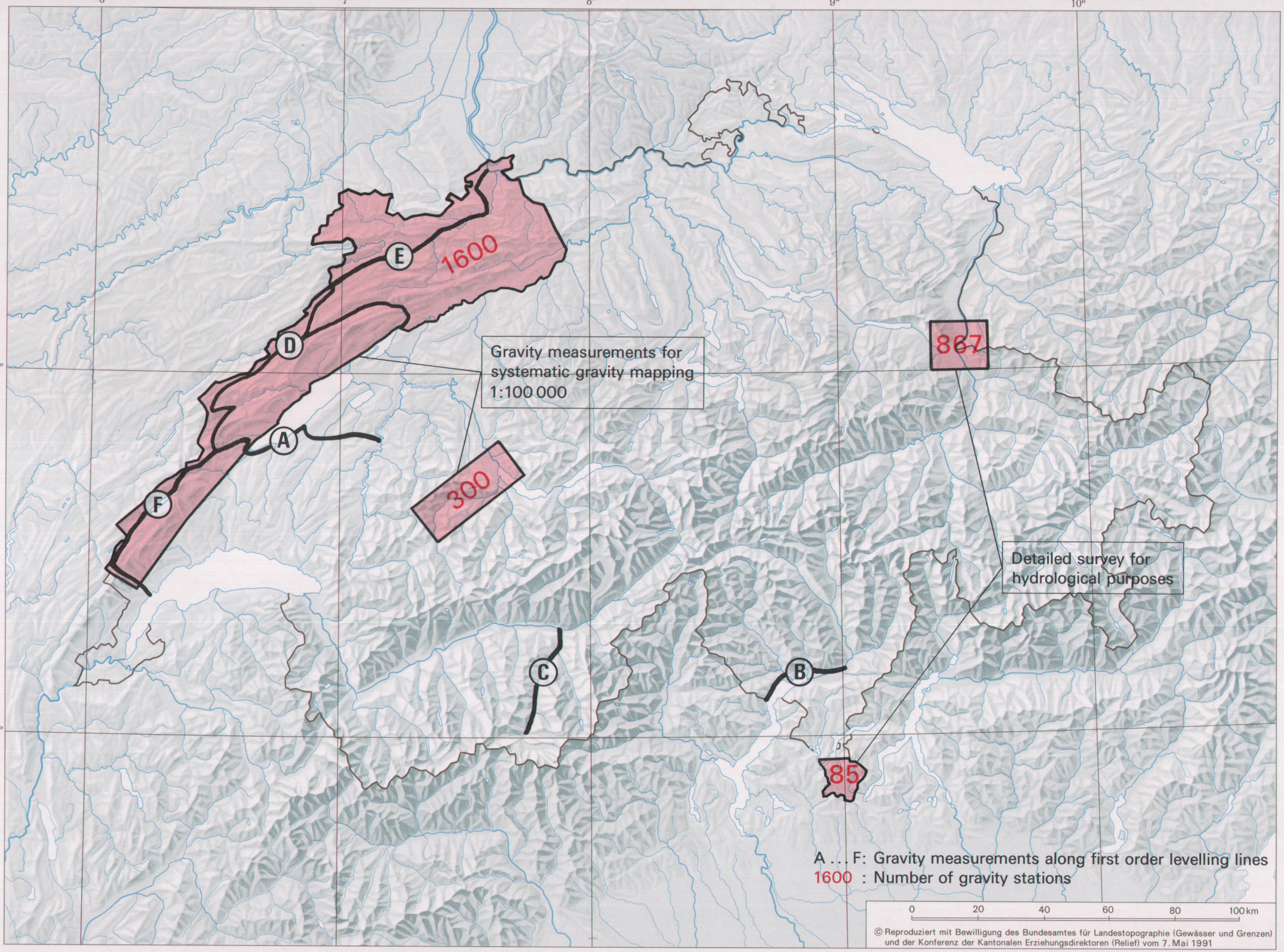

Map 6 Gravity Measurements in Switzerland 1987–1991

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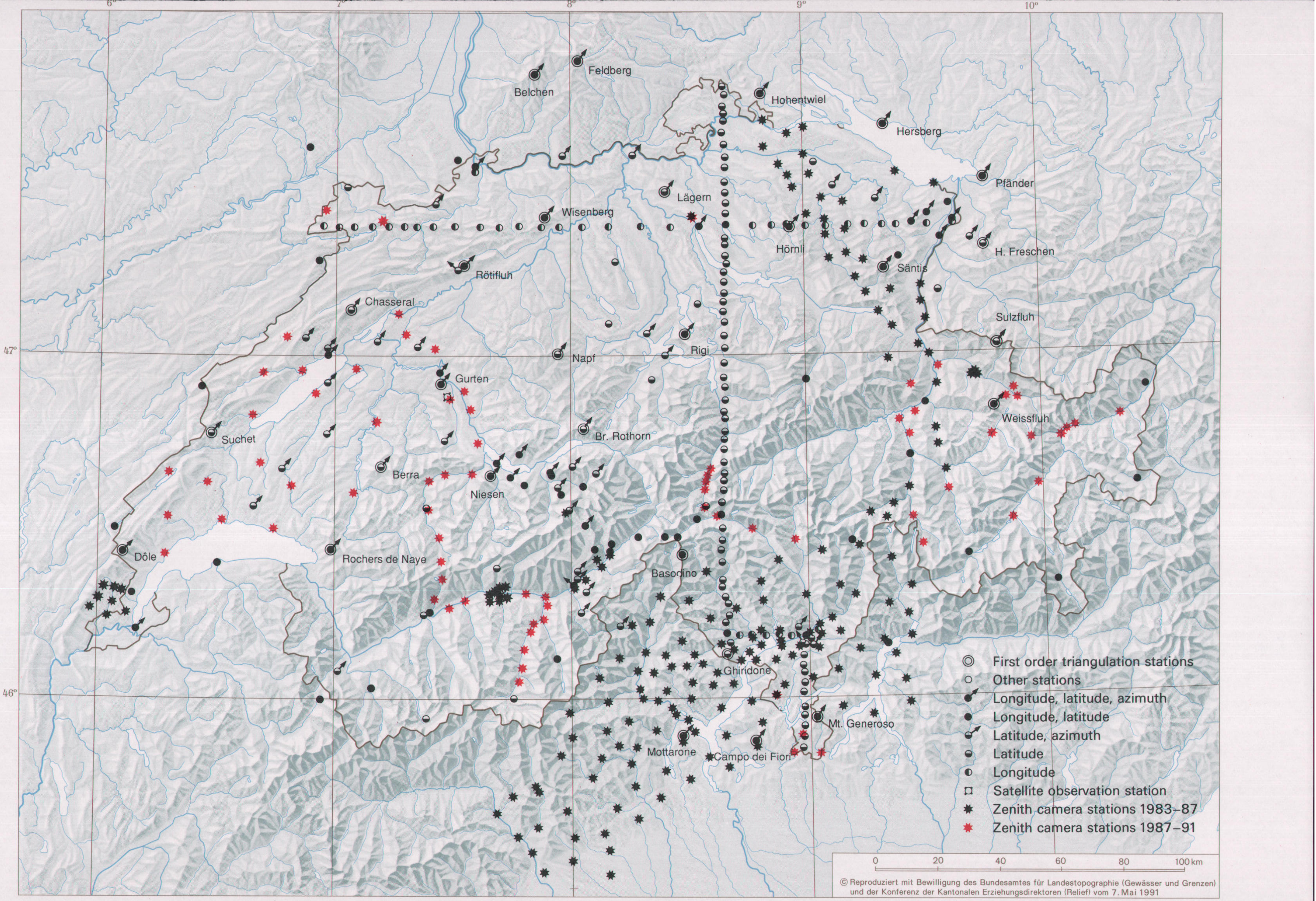

Map 7 Astronomical Stations in and around Switzerland

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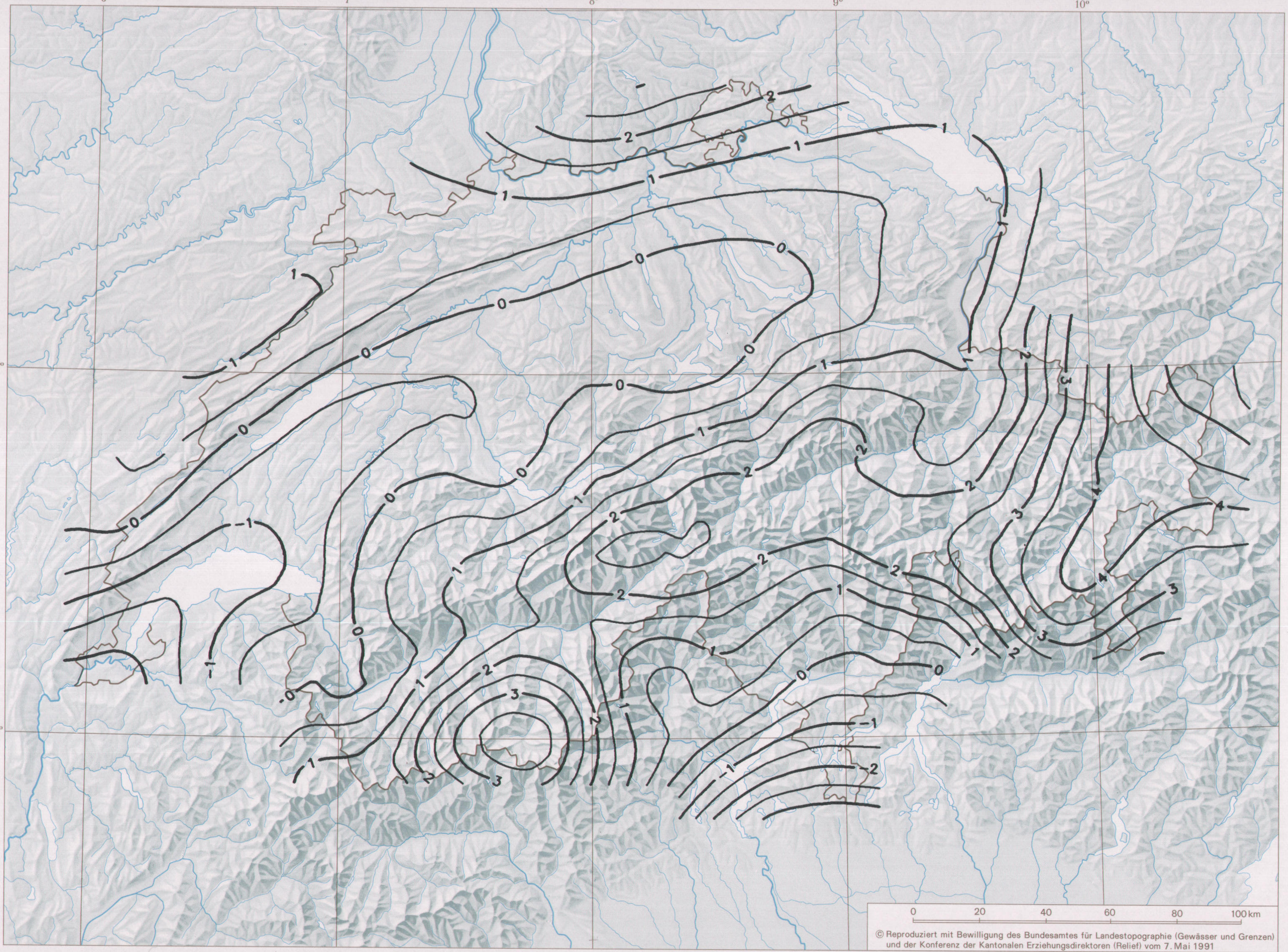

Map 8 Gravimetric Geoid in Switzerland (Swiss datum) [m]

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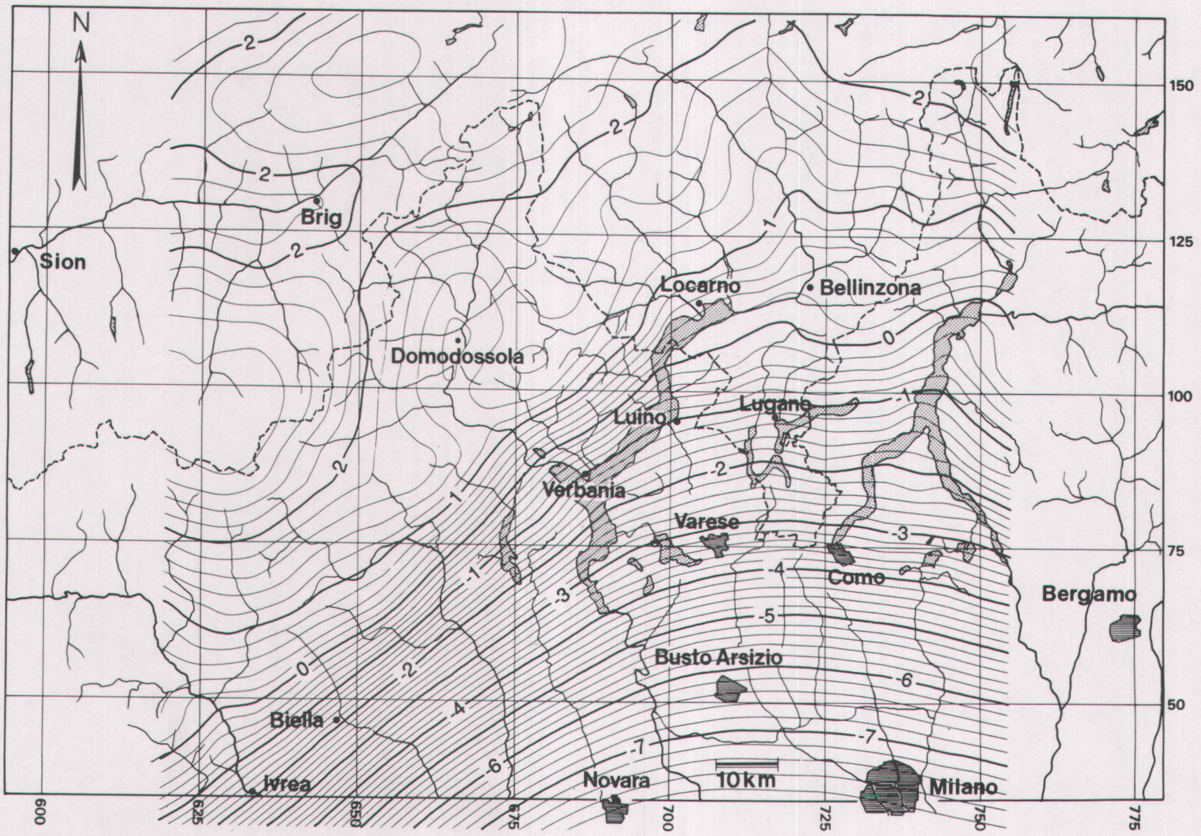
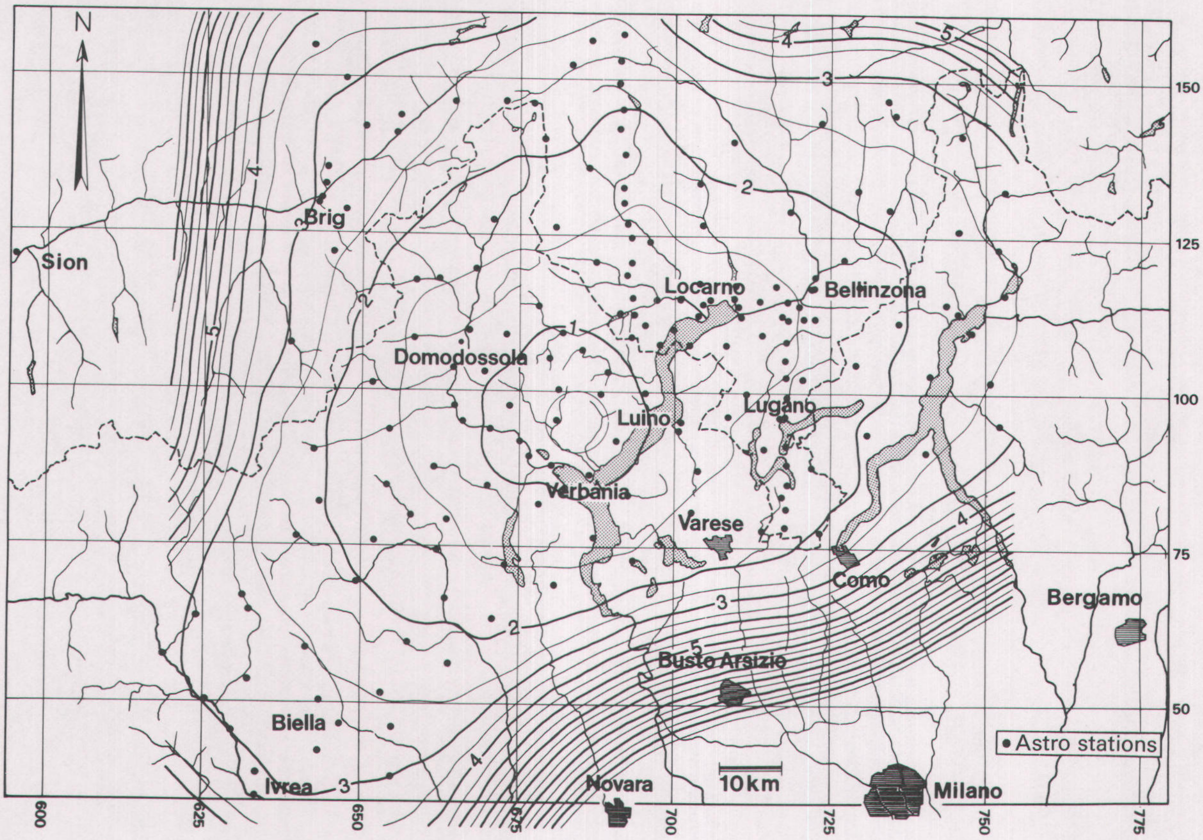
Astrogeodetic Geoid referring to the Swiss Bessel Ellipsoid [m]



Mean Relative Errors of the Geoid [cm]



Map 9 Local Astrogeodetic Geoid in the Ivrea Zone

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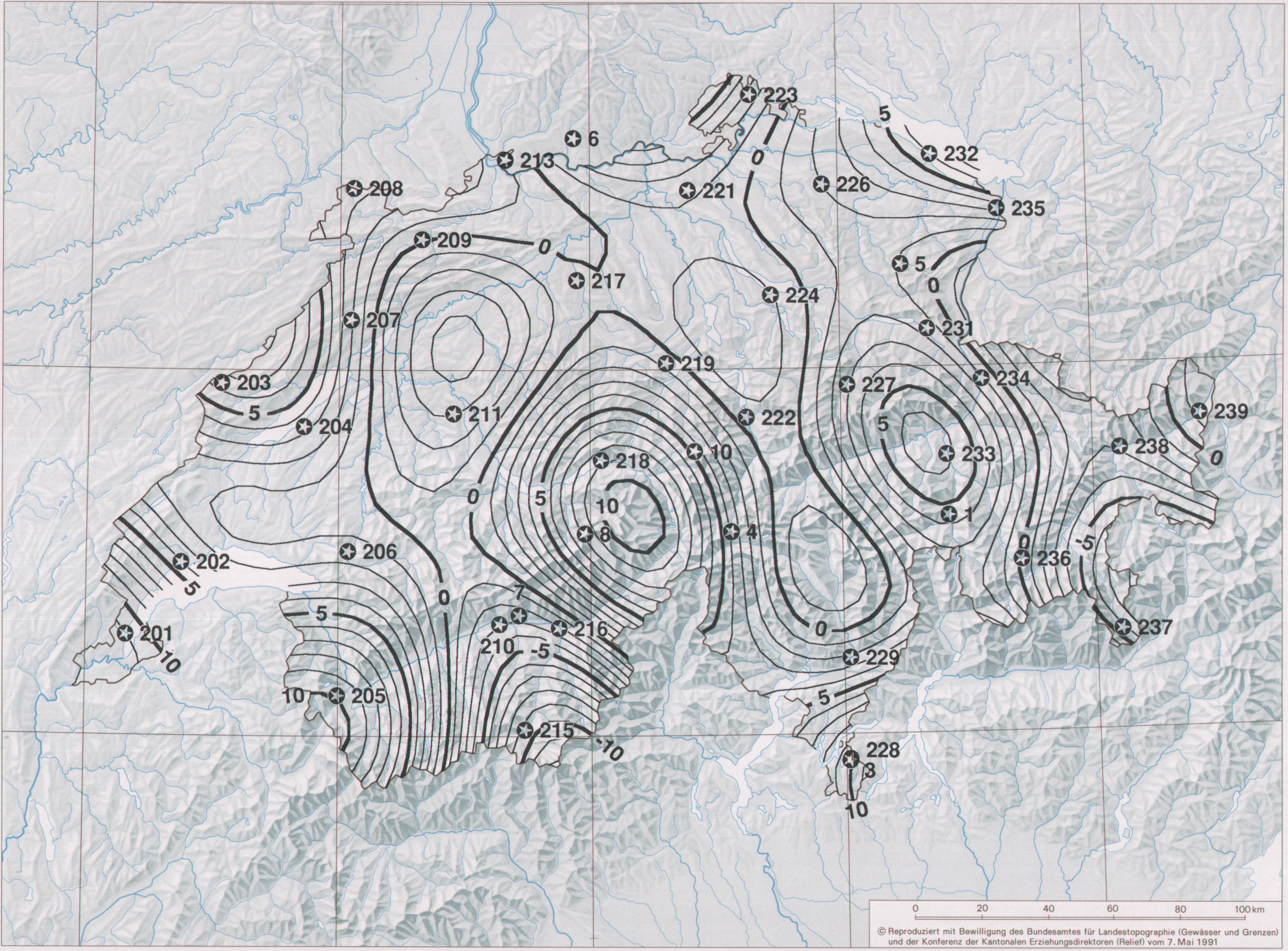

Map 10 Distortion of the Perpendicularity of the Coordinate-Axes in the Swiss Triangulation Net, determined by GPS [^{cc}]

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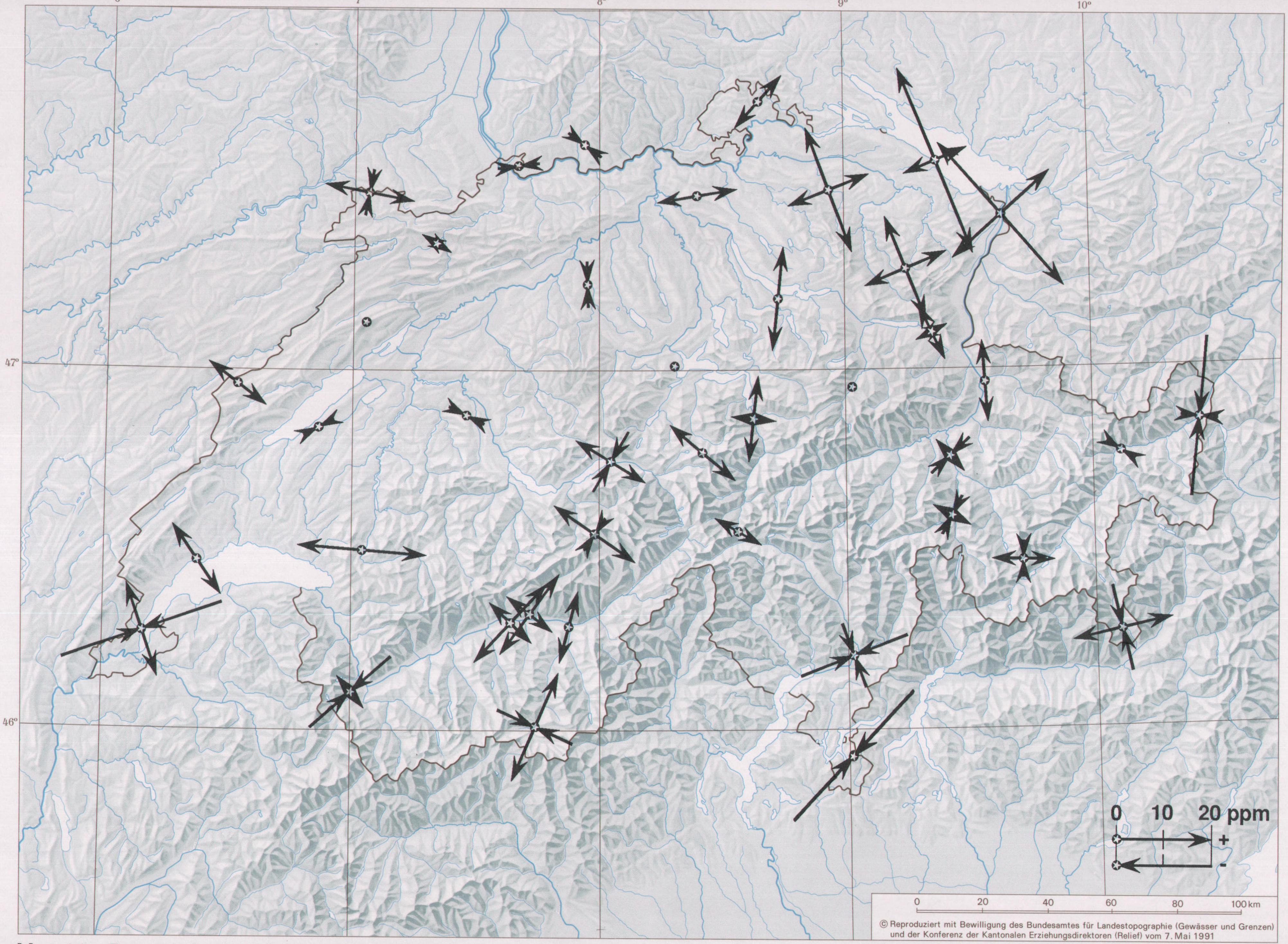

Map 11 Extreme Scale Values in the Swiss Triangulation Net

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