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Swiss Geodetic Commission
and Federal Office of Topography

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et Office Fédéral de Topographie

Report on the GEODETIC ACTIVITIES in the years 1983 to 1987

Presented to the XIX General Assembly
of the International Union of Geodesy and Geophysics
in Vancouver, August 1987

Rapport sur les TRAVAUX GÉODÉSIQUES exécutés de 1983 à 1987

Présenté à la dix-neuvième Assemblée générale
de l'Union Géodésique et Géophysique Internationale
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1 Positioning

RETrig and the Swiss National Triangulation Net

European Triangulation Net (RETrig)

by B. Bürki and E. Gubler

Within the time span from 1983 to 1987 several changes in the Swiss block of RETrig have been realized. Due to the increasing importance of satellite observations, the satellite station Zimmerwald, which is maintained by the Astronomical Institute of the University of Berne (AIUB), has been connected to the Swiss first order triangulation net using both angle and distance measurements. During a specific RETrig DOppler Campaign (RETDOC) the junction station Zimmerwald has been observed by a Doppler receiver of the Institute of Geodesy and Photogrammetry (IGP) of the Swiss Federal Institute of Technology Zurich (ETHZ). Besides these additional measurements, new computations on four baseline extensions as well as a re-measurement of the Laplace azimuth from Weissfluh to Säntis have been introduced (see Map 1).
According to the recommendations of the RETrig-subcommission, the block boundary of the Swiss block has been changed in two steps. In the first step, the common junction line to the French block was adapted in such a way that it now corresponds with the boundaries of the national triangulation networks. In the second step the junction lines with France, Germany, Austria and Italy have been converted into common junction zones (see Map 1).

Electronic Distance Measurements

by A. Elmiger and H. Chablais

The following electronic distance measurements were carried out in the years 1983–1986 by the Institute of Geodesy and Photogrammetry of the Swiss Federal Institute of Technology Zurich (ETHZ) and (in cooperation) by the Federal Office of Topography, Wabern (Berne):

- Microwave distance measurements (SIAL MD 60) in combination with meteo flights for the determination of the integral refractive index along the lines of measurement (see also "Alpine Traverse St. Gotthard", "Refraction", and Map 2).
- Laser distance measurements (Geodimeter 8) in the same region and in combination (if possible) with the above-mentioned microwave measurements.
  An additional eastern traverse Säntis–Cramosino has also been measured (see Map 3).
- Special measurements (Terrameter, Mekometer ME 5000) have been executed in the 3D Test Net Turtmann (see also "3D Test Net Turtmann").

Laser distance measurements using satellite laser ranging equipments have been performed in the Swiss Trans-Alpine Laser Experiment Monte Generoso–Jungfraujoch–Zimmerwald (see Section 5). This additional traverse across the Alps (160 km) is also depicted in Map 3.

Alpine Traverse St. Gotthard
by A. Elmiger

This combined triangulation-trilateration chain of conventional type extends in north–south direction from the Jura across the Swiss Alps (St. Gotthard) to southern Switzerland (Ticino). It consists of 38 points (first and second order) of the Swiss triangulation network and has a length of 180 km (see Maps 2 and 3).
The purpose of this net is to strengthen the Swiss triangulation net in a north–south direction – only a single Geodimeter 8 traverse existed here before – and to serve as a basis for the diagnostic adjustment of the Swiss triangulation net, for comparisons with GPS measurements and, if possible, for the future detection of crustal movements in the Alps (north–south direction).
The following measurements are introduced in this net:
- Old angle measurements (Swiss sector method) of the period of 1911–1916.
- New and a few older laser distance measurements (Geodimeter 8) of the years 1977–1986.
- Microwave distance measurements (SIAL MD 60) combined with integral refractive index determinations along the measured lines provided through meteo flights (see also "Refraction").

The evaluation and the combined adjustment (not yet finished) of these measurements yield the following provisional results:
- Laser distances (Geodimeter 8) are longer than microwave distances (SIAL MD 60) by an amount of:
  6.3 ppm, if ground station meteo values are used,
  2.4 ppm, if integral values of the refractive index along the lines of measurement are used (meteo flights).
- Distances reduced with ground-station meteo values are:
  3.5 ppm too short for microwave distances (SIAL MD 60),
  0.5 ppm too long for Geodimeter 8 distances,
  compared to the better values resulting from integral refractive index determinations.
- The scale of the Swiss triangulation network in the considered region is too small compared to Geodimeter 8 distances (optimally reduced):
  2.0 ppm in the northern part (Jura–Alps),
  7.6 ppm in the central part of the Alps (Test Net St. Gotthard),
  14.0 ppm in the southern part (south of the Alps: Ticino).

Diagnostic Adjustment
by H. Chablais

The demand for a comprehensive least squares adjustment of the Swiss 1st and 2nd order triangulation network has been voiced already years ago. Today the conditions for realizing such a project are ideal: experienced personnel is at hand and the necessary software is available.
The diagnostic adjustment should strive for the following goals:
1. Documenting as completely and uniformly as possible all geodetic measurements made in the 1st and 2nd order triangulation network during the century from 1880 to 1980.
2. Computing the best possible set of coordinates with a variance-covariance matrix of all 1st and 2nd order triangulation points.
3. Analysing statistically the accuracy of the various observations.
4. Analysing the distortions in the official 1st and 2nd order triangulation network and testing a mathematical model for these distortions.
5. Preparing a test network for new measuring techniques (Doppler, GPS, etc.) in order to discover possible systematic errors in a future GPS reference network.
6. Computing parameters for the datum transformation between the Swiss Geodetic Datum and other world-wide reference systems (in combination with the GPS reference network).
7. Investigating possible deformations of the earth's crust in Switzerland.

In a first step an inventory of all available measurements was drawn up and a pre-analysis was made. The next step is screening the original measurements and preparing them for electronic processing. This project should be finished by 1990.

UELN and the Swiss National Levelling Net

by E. Gubler

United European Levelling Net (UELN)

In order to obtain loop sizes comparable to those of the neighbouring countries, only a small subset of the 1st order levelling was delivered as the Swiss contribution to the computing centres of the United European Levelling Net (UELN). This subset is shown in Map 4. No outliers have been detected in the Swiss contribution so far. The estimated r. m. s. error of $0.8\ \mathrm{mm}/\sqrt{\mathrm{km}}$ has been confirmed. From a preliminary adjustment of UELN, geopotential numbers can be derived for the Swiss bench marks referring to the fundamental bench mark near Amsterdam. Their r. m. s. error is of the order of 2 cm. An r. m. s. error of 1 cm may be expected from a final adjustment.

Swiss National Levelling Net

The remeasurement of the Swiss First Order Levelling is continuing according to plans. Gravity measurements necessary for the height reduction are made along the levelling lines usually during the same year (see Section 3). Until the end of 1986 a total of 2400 km or 82% of the net has been remeasured. An overview is given in Map 11. In 1983 a new type of hand-held computer was introduced which collects the measurements, computes field checks and stores the data in a RAM. Furthermore, it saves the data on micro cassettes and produces a hardcopy. These data are transferred and processed automatically at the office (see Section 4).

Levelling is very sensitive to the stability of bench marks. In 1984 N. Pavoni and W. Fischer experimented with a portable seismometer and obtained surprisingly good results. This method has been improved and refined and has since been regularly used to test the stability of the anchoring sites of new and existing levelling bench marks (Fischer et al., 1987).

Rapid Precision Levelling System (RPLS)

by H. Ingensand

"Rapid Precision Levelling System" indicates the development of an economical precision levelling system with an accuracy better than 1 mm/km.

Under phase 1 of a development contract of the National Oceanic and Atmospheric Administration (NOAA), USA, to Wild Heerbrugg Ltd., the use of a highly-automated, motorized trigonometric levelling procedure has been studied. By utilizing three motorized units a theoretical performance of 5 km/hour can be obtained. Each unit requires only one operator.

Because of the influences of refraction and turbulence over an average sight length of 250 metres, even with simultaneous opposite observations, the required accuracy cannot be reached. Wild Heerbrugg, therefore, has developed a novel instrumentation concept to reduce these influences.

A dispersometer built into a high-precision tacheometer detects the displacement of blue and red light emitted from the target. For the first time, therefore, a fully automatic measurement free of the effects of refraction and turbulence is possible.

The results of the first measurements will be presented at the XIXth IUGG General Assembly in Vancouver.

Refraction

by F. Chaperon and R. Köchle

The main effort during the period from 1983 to 1986 went into improving the accuracy of geodetic distances measured by modulated light and microwave carriers (EDM) through a better knowledge of the refractive index of the atmosphere (Chaperon and Köchle, 1986). Two methods were used:

1. The higher layers of the air a few dozen metres above ground in the vicinity of the stations were probed with radio sondes suspended on captive balloons in order to eliminate ground-bias.
2. The integral refractive index along the wave-path was calculated from the atmospheric parameters as obtained from ATAR sondes carried by motor-gliders.

Of the two methods the second one proved to be the more practical and fruitful. We were able to use existing equipment (ATAR sondes) from the Laboratory of Atmospheric Physics at the ETH Zurich and built our programs for the reduction of data on the basis of one of their program packages in close and much appreciated cooperation with the said laboratory.

In most of the campaigns on the first and second order Swiss triangulation net which were carried out over the past four years, refraction data were gathered with ATAR sondes and used to correct the distances. The projects involved are the Test Net St. Gotthard, the part North and the part South of the Alpine Traverse St. Gotthard and also the special 3D Test Net Turtmann for testing GPS methods (for the salient results from these projects see "Alpine Traverse St. Gotthard" and "3D Test Net Turtmann").

Whereas the improvements in the 3D Test Net Turtmann with its relatively short sides brought about by applying ATAR corrections at the measured Mekometer distances turned out to be spectacular, the success for the other nets is more moderate, as the following data demonstrate:

The mean relative coordinate error as calculated from the residuals drops from 2.2 to 1.4 ppm for part South and from 1.6 to 1.3 ppm for part North. The first figure refers to the reduction with station meteo data and the second one to ATAR meteo data. The scale discrepancy between Geodimeter 8 and microwave distances drops similarly from 7.3 to 5.1 ppm for part South and from 6.6 to 2.6 ppm for part North. There is an improvement in every case, but not to the degree anticipated. We think that the explanation lies in the insufficient knowledge of the water vapour content of air, the parameter most difficult to measure, whose influence on microwave distances is unduly large. The problem remains under investigation.

Inertial Techniques for Geodesy

by A. Wiget and H.-G. Kahle

The study of inertial techniques, the development of measuring procedures and of data processing methods have become of particular importance for geodetic and gravimetric applications. The Institute of Geodesy and Photogrammetry of the Swiss Federal Institute of Technology Zurich has joined the corresponding IAG Special Study Group 1.77 (President: Prof. K. P. Schwarz, Calgary) as a corresponding member. In a first step theoretical investigations have been carried out, in particular with respect to the anomalous gravity field in high mountainous regions such as the Swiss Alps. The objectives included the estimability of all gravity field components, real-time models of local gravity anomalies, refinement of deep-seated mass inhomogeneities and geophysical applications (Wiget, 1985, 1986).

In addition, practical field work has been carried out in close cooperation with Prof. Schwarz's group in Calgary: High precision measurements of the deflection of the vertical in the Kananaski Valley (Canadian Rockies) and comparison of these results with Inertial Surveying System (ISS) data. The prime interest of the Zurich group is focused on the integration of ISS with GPS data and the use of strap down systems for geophysical applications.

TRANSIT Doppler Activities: SWISSDOC

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

In 1984 a Doppler campaign SWISSDOC was carried out by the IGP in cooperation with several foreign institutes and the Federal Office of Topography of Switzerland. 17 points of the 1st order triangulation net were occupied by TRANSIT receiver systems (see Map 7). The campaign aimed at the determination of the relation between the Swiss geodetic coordinate system and a global reference system. The relation is described by a Helmert transformation whose 7 parameters are determined by least square methods.
The parameters of the transformation between the Doppler broadcast system (~WGS 72) and the Swiss reference system are:

$$\Delta x = 670.5 \pm 5.9 \text{ m} \qquad \omega_x = -0.18 \pm 0.45^{cc}$$
$$\Delta y = 35.8 \pm 5.2 \text{ m} \qquad \omega_y = 2.28 \pm 0.74^{cc}$$
$$\Delta z = 369.3 \pm 6.0 \text{ m} \qquad \omega_z = 5.53 \pm 0.48^{cc}$$
$$\text{Scale factor} = 4.6 \pm 0.6 \text{ ppm}$$

The distortions of the 1st order triangulation net are not significantly out of the accuracy range of the Doppler solution (± 30 cm r. m. s.). However, four sites show residuals above 60 cm (Monte Generoso, Pfänder, Brienzer Rothorn, Mompiccio), three being located on the peripherial region of the net. The discrepancies in the southern part of Switzerland (Monte Generoso) could also be seen in GPS control measurements which corresponded to the Doppler solution within 20 cm. The ED79 coordinate set seems to be much more homogeneous than the first order coordinates.

3D Test Net Turtmann

Objectives and Installation of the Net

by D. Schneider

In summer 1985 the GPS Working Group of the Swiss Geodetic Commission installed a high-precision 3D test net near Turtmann in the central Valais. The network was designed to meet the following objectives:

1. To test the GPS positioning techniques in the mountains.
2. To compare and evaluate different receivers.
3. To install a permanent test net for other new survey methods such as EDM, inertial systems, etc.
4. To investigate recent crustal movements by repeated measurements after a long period of time.

The 3D net Turtmann consists of 8 stations (see Map 8). The northern stations 1 and 2 are located in the Helvetic nappes (European plate), station 3 in the crystalline Aar massif and stations 4, 5 and 6 in the south are situated on the Penninic nappes (assuming similar movements as the Adriatic promontory of the African plate). The Rhine-Rhone line (FPT: Frontal Penninic Thrust) runs in a roughly east-westerly direction in the plain of the valley (see Map 9). With regard to the geodynamic objective of the network, careful monumentation of the stations (6 of them are consolidated in stable rock formations) was of great importance.

Classical Geodetic Observations

by D. Schneider

Various classical geodetic techniques were utilized in the network from 1985 to 1986. The objective of these efforts was to determine a set of most precise 3D coordinates ("ground truth") for the stations which will be subsequently compared with different results of GPS measurements.

Vertical angles were measured simultaneously and reciprocally with four theodolites in fall 1985. Six quadrilaterals were selected within the network. Repeated observations in each quadrilateral were made over a time span of 4 hours in the morning or afternoon. In this way, the whole variation of the refraction could be encountered. A new method of refraction estimation using collocation (Program REFKOL; Wunderlin, 1987) was successfully used.
Horizontal directions were observed in April 1986. A Kern E2 and a newly developed Wild T2000S electronic theodolite with automatic data collection and on-line station adjustment was utilized. At least two series were measured on each station with each theodolite. The residual deviations of the vertical axis of the theodolites were systematically recorded. The on-line station adjustments yield standard deviations of less than 0.2 mgon.
In order to obtain the orthometric height difference between the two stations 7 and 8 in the plain of the valley, reciprocal precision levelling meeting first order specifications was performed.
Astro-geodetic work was done in June 1986 (see "Geodetic Astronomy" in Section 3). The direction of the gravity gradient on 10 sites was measured by the Institute of Geodesy and Photogrammetry of ETH (IGP-ETHZ) using an automatic zenith camera (Bürki, 1985). The orientation of the network was classically determined by 17 astro-azimuths to Polaris. The observations were made by an electronic theodolite Kern E2 with automatic data collection and on-line processing on an Epson HX-20 field computer.
A first EDM campaign took place in June–July 1986. A new, high precision laser EDM instrument, Kern Mekometer ME 5000 (Meier and Loser, 1986), was used. Distances were reciprocally measured on all 28 lines of sight (in collaboration with Kern & Co. Ltd.). The collection of meteorological data for the refraction correction of the observed distances was done with special care. Meteo data was not only measured at each station site (on the ground and 6 m above the ground) but also collected from a motor-glider along each line of sight (in collaboration with LAPETH and IGP-ETHZ). The motor-glider was continuously traced by radar and its positions were recorded. The final refraction corrections were computed using the program GEOATAR (LAPETH).
A second EDM campaign using the Terrameter, a two-colour laser instrument (Gervaise and Olsfors, 1987), took place in October 1986. A choice of 21 distances (2 of them reciprocal) were measured in collaboration with the CERN survey group.

The whole set of observations was introduced into a 3D adjustment using the program RAUMTRI (Schneider and Wunderlin, 1981). The following group variance estimates $\hat{\sigma}$ were obtained:

horizontal directions:	0.22 mgon
vertical angles:	0.3 mgon
astro-azimuths:	0.4 to 0.5 mgon
astro-longitudes:	0.22 mgon
astro-latitudes:	0.15 mgon
ellipsoidal height differences:	12 mm
Terrameter distances:	0.3 mm and $3 \cdot 10^{-7} \cdot D$
Mekometer distances:	0.3 mm and 1.5 to $5 \cdot 10^{-7} \cdot D$

The minimal constrained 3D adjustment, with the 3 coordinates of station 7 fixed, yields the maximal error ellipsoid at station 6 with a semi-major axis of 10 mm and a semi-minor axis of 0.5 mm. Since the distances were observed more precisely than the 3 angles of orientation, the semi-major axis points in a tangential and the semi-minor axis in a radial direction with respect to the fixed station 7.

GPS Campaigns

by G. Beutler

Two GPS campaigns were organized in the Turtmann area. The first, in October 1985, saw Macrometer V-1000, TI 4100 and Sercel TR5S receivers in the network, the second, in October 1986, Trimble 4000SX and WM101. All observations have since been processed using the Bernese GPS software (Gurtner et al., 1985).

The scientific goals of the campaigns may be summarized as follows:
a) Comparison of network results derived from different receiver types,
b) Study of the troposphere,
c) Comparison of GPS with terrestrial results ("ground truth").

It is fair to state that all receiver types gave results of comparable quality (if evaluated separately), provided there were no removable receiver or environment problems (like interchannel calibration or multipath effects). This aspect of the campaigns will be dealt with in the final report.
The influence of tropospheric refraction on network results was discussed in some detail in the paper presented by the Swiss GPS Working Group at the Fourth International Geodetic Symposium on Satellite Positioning (Rothacher et al., 1986). It was found that the best results were obtained when using a local troposphere model as in classical EDM (and not the global Hopfield or Saastamoinen models).
Early in 1987 the high-quality ground truth (described by D. Schneider in the preceding paragraph) became available. Helmert transformations between this coordinate set and the GPS solutions reveal the excellent quality of both the terrestrial and the satellite solutions. In order to demonstrate this, we include the Helmert transformation using all 1986 satellite data with the best meteo model according to our present understanding. It is interesting to see that the east-west components are almost identical in the GPS and the terrestrial solution, whereas - as expected - the agreement is not so good in height.

Helmert transformation of GPS solution to a priori coordinates

Turtmann Campaign 1986: Trimble and WM101
Observed profile meteo values used

Residuals in local system (North, East, Up):

Nr.	Name	Residuals in meters		
1	Brunnen	-0.005	0.000	-0.004
2	Bräntschu	-0.001	-0.001	0.005
3	Jeizinen GPS	-0.004	-0.001	0.005
4	Ergisch	0.004	0.000	-0.003
5	Oberems	0.002	0.002	0.004
6	Agarn GPS	-0.001	0.001	0.007
7	Turtmann	0.003	-0.001	-0.010
8	Susten	0.001	0.000	-0.004

Number of parameters: 7
Number of coordinates: 24
R. m. s. error of transformation: 0.0044 m

Parameters:
Rotation around x-axis: $-1.12 \pm 0.16''$
Rotation around y-axis: $0.31 \pm 0.19''$
Rotation around z-axis: $-0.00 \pm 0.12''$
Scale factor: 0.25 ± 0.57 mm/km

Detailed results for the two campaigns, 1985 and 1986, will be presented at the XIXth IUGG General Assembly in Vancouver in August 1987.

Integrated Geodesy

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

Integrated geodesy deals with integrated data processing for the determination of coordinates and the gravity potential. The Institute of Geodesy and Photogrammetry of the Swiss Federal Institute of Technology Zurich has joined the corresponding Special Study Group 1.73 of the IAG (President: Prof. G. Hein, Munich). In 1986 Hein's integrated geodesy adjustment program OPERA was implemented on the VAX computer system of the ETHZ. The cooperation with Hein's group in Munich (FRG) has been quite successful. The prime interest of the Zurich group is aimed at integrating GPS-based results into the OPERA software package. Field experiments have been conducted to deduce covariance funtions for gravity in the Swiss Alps. In addition, satellite data of the GPS test net Turtmann have been applied to the adjustment program OPERA (Müller, 1986). In the future it is planned to perform further theoretical and practical investigations for including GPS and inertial data as well as geophysical and geological parameters.

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2 Advanced Space Technology

Satellite Observation Station Zimmerwald

by I. Bauersima and W. Gurtner

In the years 1983–1987 the Geodynamics Group of the Astronomical Institute, University of Berne (AIUB), has been working on the following projects in satellite geodesy (Bauersima, 1987b).

Instrumental Improvements at Zimmerwald

In 1983 the old ruby giant pulse laser system was replaced by a modern Nd:YAG system (manufacturer: Quantel). The necessary changes in the optical, mechanical, electronic and software components were simultaneously realized.
In the subsequent years further improvements of the laser telemeter-system, as e. g. real-time calibration, have been made.
In the first months of 1987 the passive mode locking of the laser was changed to the more reliable active/passive mode locking system, yielding a more stable cadence and output energy of the laser pulses.
In May 1987 the installation of the new station computer, VAX Station 2, was initiated. The new system will gradually take over the tasks of the old PDP-11/40. It also will allow image processing of CCD pictures, as will be collected for the CQSSP project (see "Coupled Quasar, Satellite and Star Positioning").

Operation of the Zimmerwald Satellite Observation Station

The satellite laser station Zimmerwald joined the MERIT campaign in 1984 observing the geodynamical satellites LAGEOS and STARLETTE and (with low priority) the satellite BEACON-C. About 25 000 distances have been measured with a single shot accuracy of ± 8 cm. These observations enabled several processing centres to determine the reference point Zimmerwald in the world-wide network of the SLR stations with an r. m. s. error of about 3 cm in each component of its coordinates.
In September and October 1985 the Zimmerwald laser station participated in the Swiss Trans-Alpine Laser Experiment Monte Generoso–Jungfraujoch–Zimmerwald (see Section 5), observing the geodynamical satellites and, as a novelty, the distance to the terrestrial reference point Jungfraujoch using the same laser telescope.
In 1986 the Zimmerwald laser station observed LAGEOS for the benefit of the WEGENER-MEDLAS Project, STARLETTE, BEACON-C and the new Japanese satellite AJISAI. A total number of roughly 40 000 single observations have been collected.

Development of Software for Geodetic Evaluation of GPS Carrier Phase and Code Observations

Between 1983 and 1986 the Geodynamics Group of the AIUB developed the theory and a software system for geodetic applications of the Global Positioning System's carrier phase and code observations. The software system has two parts: for simulation and for evaluation. With this software a large number of observing sites (> 50) and orbital parameters can be determined simultaneously. The program processes double difference phase and/or code observations collected over a time period of up to several days. The interactive user interface of the programs running on the university's mainframe computer is mostly menu driven. This allows a fast verification of the data quality and flexible and easy use of the many program options.

Evaluation of Various GPS Campaigns with the Bernese GPS Software

During the period from 1983 to 1986 the following GPS observation campaigns, realized in different regions of Canada, the United States, and Europe, were evaluated with the Bernese GPS software by the Geodynamics Group of the Astronomical Institute of the University of Berne.

Campaign /	Year	Receivers	Number of points	Net size (km)	Relative accuracy $\pm$ dB/B (B = Base length)	through comparison with
Ottawa	83	MM	4	10 x 60	$3 \cdot 10^{-6}$	Terr. net
Quebec	84	MM	13	5 x 5	$1 \cdot 10^{-6}$	Terr. net
California	84	SX	2	140	$1 \cdot 10^{-6}$	VLBI
CERN	84	MM	7	12 x 12	$5 \cdot 10^{-7}$	Terr. net
Alaska	84	TI	8	800 x 2700	$1 \cdot 10^{-7}$	VLBI
USA (HPBL)	85	TI,MM,SX	9	2000 x 4200	$2 \cdot 10^{-8}$	VLBI
CERN	85	Sc	7	12 x 12	---	---
Turtmann	85	TI,MM,Sc	7	4 x 6	$3 \cdot 10^{-7}$	Terr. net
Monte Generoso	85	TI	3	160	---	---
Iceland	86	TI	50	250 x 450	$2 \cdot 10^{-7}$	---
Turtmann	86	Tr,WM	8	4 x 6	$3 \cdot 10^{-7}$	Terr. net
Europe	86	TI	10	1200 x 1400	---	---
Alaska	86	TI	10	800 x 2700	$3 \cdot 10^{-8}$	VLBI

Explanations: MM = Macrometer, SX = Series X, TI = Texas Instruments,
Sc = Sercel, Tr = Trimble, WM = Wild-Magnavox

Coupled Quasar, Satellite and Star Positioning (CQSSP)

Within the framework of a future "International Earth Rotation Service" (IERS), Satellite Laser Ranging (SLR) and Very Long Baseline Interferometry (VLBI) methods will be used to determine 3 Eulerian angles of the orthogonal transformation from the quasar-fixed (inertial) into the earth-fixed reference frame. Also the positions of geodynamic satellites like LAGEOS in a quasar-fixed reference frame will be gained as functions of time (Bauersima, 1987a).

If now at least one VLBI, SLR or another station – the position of which is known in the earth-fixed system mentioned above – additionally observes directions of satellites relative to fixed stars, then also the Eulerian angles of the transformation from the quasar-fixed (inertial) into the so-called "star-catalogue" reference frame can be determined as functions of time. The latter system, namely, is

defined by a catalogue of positions and proper motions of selected stars. Determination of the Eulerian angles of the last-mentioned transformation is thus equivalent to the realization of a quasar-fixed (inertial) reference frame by fixed stars (Bauersima, 1984a).
This goal especially will become promising with the coming of the HIPPARCOS project by ESA. This specific satellite will be the means for creating a "star-catalogue system" of unprecedented (relative) precision.
With the aim of simultaneously tieing the star and satellite positions to a quasar-fixed (inertial) reference frame, an opto-electronic receiver stage has been developed at the Satellite Station Zimmerwald during 1985 and 1986. The development of opto-electronic direction observation techniques will be continued.

GPS Test Measurements and Tropospheric Error Modelling

GPS Test Measurements with WM101 and TI 4100 Receivers

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

In a joint effort of the Institute of Geodesy and Photogrammetry, the Federal Office of Topography and the Astronomical Institute of the University of Berne, a GPS test net has been installed, measured and evaluated on behalf of the GPS Working Group of the Swiss Geodetic Commission. The terrestrial and the GPS measurements are described by D. Schneider and G. Beutler in Section 1.
First test measurements have been carried out by the IGP at the ETH-Hönggerberg with their own three WM101 receivers in order to study phase centre offsets and multipath effects.
In addition, a local GPS net has been established in Braunwald, Canton Glarus, where mountain slides are being detected and displacement rates are being assessed by GPS-determined coordinate changes.
GPS tests with TI 4100 receivers (Nortech, CDN) over longer distances have been organized by the IGP on the Trans-Alpine LAGEOS baseline Monte Generoso–Jungfraujoch–Zimmerwald. The GPS data evaluated by the AIUB have confirmed the laser-deduced distances in the order of 0.3 ppm (5 cm over 160 km). A first repetition of these GPS measurements is planned for 1987 in the framework of the Swiss National Research Project NFP 20 (see Section 5).

Atmospheric Effects on Geodetic Space Measurements

by A. Geiger

Rough error estimations of positioning are considerably simplified by taking continuous satellite observation distributions into account. Forming normal equations by integration allows explicit calculations of the effects of the measurement errors on position. An application of this method to tropospheric delay shows a very good correspondence with real measurements. An error in refractivity determination of 1% causes a 6 mm height error per 1 km height difference. It is shown that the tropospheric ranging errors contaminate the height errors with an amplification factor of nearly 3. The baseline determination can be treated exactly in the same way. The corresponding errors in range measurements on single-point and relative positioning with applications to tropospheric delay has been presented by Geiger (1987a).

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3 Determination of the Gravity Field

Gravity Base Network and Calibration

by W. Fischer

International D-meter Campaign

The work in the Swiss National Gravity Net (SNGN) was continued indirectly by joining the International D-meter Campaign which took place on the Hannover-Harz calibration line in April 1983. This campaign allowed the Swiss team (W. Fischer and A. Wiget) to collect valuable experiences on the management of precise gravimetric measurements.
The result of the various investigations on the 12 LaCoste and Romberg D-gravimeters involved is shortly dealt with (Becker et al., 1987) and shows satisfactory characteristics of the gravimeter D 16 belonging to Switzerland, except for a long-term drift in the order of 20–30 μgal/day.
On the other hand the geodetic type gravimeter G 317, which was operated at the same time as the D 16 by the Swiss team, was not included in the analysis mentioned above. But the comparison of the readings on the 10 mgal intervals with the adjusted gravity values of the Hannover-Harz line showed to our satisfaction that in this instrument, there exist no periodic errors exceeding the usual amount, as an earlier investigation could have suggested.

Connection Net between Absolute Gravity Stations

In 1984 the measurements in the connection net of 1980–81 between six absolute gravity stations of Switzerland was repeated using two LaCoste and Romberg D-gravimeters instead of two G-gravimeters as before. The D 16 tested on the Hannover-Harz line and the newly acquired D 86 were operated simultaneously and the net was densified in order to get smaller gravity differences and shorter time intervals between subsequent readings (see Map 10). The observation procedure was improved, taking advantage of the practical experiences acquired at the International D-meter Campaign, using the step-like scheme A – B – A – B – C – B – C as on the Hannover-Harz line.
This new connection campaign showed that there is a good agreement between the relative gravity measurements using G- as well as D-meters, whereas the discrepancies between relative and absolute measurements are still remarkable in some stations. As a consequence, it must be supposed that due to some unknown effects, the observation errors of the absolute gravity measurements considered are greater than the given precision.
In June 1987 the station Bäzberg in the St. Gotthard road tunnel was re-measured by means of the improved absolute instrument of the Istituto di Metrologia "G. Colonnetti", Torino.

Gravity Measurements along Re-measured First Order Levelling Lines

In the last years gravity values have been determined more or less simultaneously with the re-levelling of the Swiss National Levelling Net in order to reduce correctly the levelling measurements (see Section 1). In the period in consideration, gravity measurements using the reliable LaCoste and Romberg gravimeter G 317 have been performed on the following lines (see Map 11):

- 1983: Biel-Zollikofen (re-levelled already 1957), Aarburg-Zollikofen-Berne (re-levelled 1973-76), Berne-Thun-Spiez-Kandersteg-Lötschberg railway tunnel-Gampel (Fischer, 1984),
- 1984: Berne-Fribourg-Bulle-Vevey,
- 1985: Spiez-Interlaken-Brienzwiler-Grimsel Pass-Gletsch, and Brienzwiler-Brünig Pass-Sarnen-Lucerne,
- 1986: Spiez-Saanen-Bulle.

Together with the line Fribourg-Payerne-Yverdon, planned for 1987, all of the first order levelling lines within the western UELN loop of Switzerland (see Map 4) will thus be provided with actual gravity values.
Gravity values have been computed on the basis of the absolute gravity values Zurich, Interlaken, and Brig, as well as on the basis of SNGN stations (Fischer, 1983) along the lines (see Map 10). Therefore, they can be regarded as being in the system IGSN 71. As an exception the SNGN value of the station Grimsel Hostel turned out to be unstable due to the great water-level changes of the nearby reservoir Lake Grimsel of the hydro-electric power plant Grimsel.

Geoid Determinations

Gravimetric Geoid of Switzerland
by A. Geiger and H.-G. Kahle

The gravimetric geoid of Switzerland has been calculated by the integral method of Stokes. The correspondance with the astrogeodetic geoid is in the order of $\pm$ 30 cm. The comparison of both methods allowed the determination of transformation parameters between the Swiss Reference System and the International Geodetic Reference System. First attempts to compute geoidal heights by Fast Fourier Transform have been made. At present the effect of the Ivrea body is being studied to regularize the gravity field in the southern part of Switzerland.

Geodetic Astronomy
by B. Bürki, B. Wirth and U. Marti

At the Institute of Geodesy and Photogrammetry of the Swiss Federal Institute of Technology Zurich the activities in the field of geodetic astronomy have been further pursued in the past few years. Map 5 shows the stations where astronomical measurements of the direction of the vertical (corresponding to the direction of the physical plumbline) have been carried out by using the new Transportable Zenith Camera System at the IGP. The observations have been carried out partly in joint field measuring campaigns in collaboration with several European institutes.
Thus the following particular projects have been pursued in this period (see Map 5, from west to east):
- CERN (European Organisation for Nuclear Research): 8 stations for the determination of the high resolution gravity field
- 3D Test Net Turtmann: 10 stations for the determination of the high resolution gravity field
- Ivrea Project (southern Switzerland and northern Italy): 113 stations
- NFP 20 (NFP = Swiss National Research Project), eastern traverse: 30 stations
- densification of deflections of the vertical in eastern Switzerland: 8 stations
- and finally several areas of education projects: approx. 18 stations.

In addition, astronomical measurements in other countries have been performed:
- Werdenfelser Land, FRG: Determination of deflections of the vertical on 8 stations
- Kananaskis Country, Alberta, Canada: Determination of deflections of the vertical on 30 stations, in collaboration with the University of Calgary.

The main objectives of these astronomical measurements can be summarized as follows: The knowledge of the direction of the vertical contributes to the computation of the geoid and its short wavelength variations. Furthermore, due to a re-inforced collaboration with Swiss geophysicists in the framework of research on geological structures (see Section 5), astronomical measurements can be used in combination with gravity measurements to determine density anomalies for interpreting the earth's gravity field in the Alpine region.

Determination of the Geoid in Europe: ALGEDOP
by A. Wiget, A. Geiger and H.-G. Kahle

ALGEDOP was an international effort initialized by Marussi in 1980 to determine the geoid in the Alpine area by satellite Doppler measurements. During the past years, points distributed over the Alpine region have been measured. The sites are located more or less in a 50 km by 50 km square grid (see Map 6). They are installed close to levelling lines. The ellipsoidal heights determined by the satellite system are compared with the levelled heights. The differences correspond to the geoidal undulations.
For refraction corrections of the ALGEDOP measurements, meteorological data of the ANETZ have been used. ANETZ is an automatic 24 hour recording meteo-observing system consisting of 62 stations spread over the whole country, operated by the Swiss Meteorological Office, Zurich. The data from this system were extrapolated to the Doppler stations so that manual meteo readings did not have to be carried out.

Gravimetric Evaluation and Interpretation
by H.-G. Kahle

Two gravimetric studies have been carried out in southern Switzerland/northern Italy in connection with astro-geodetic measurements (Santini, 1985; Wirth, 1985), aiming at a better understanding of the structure of the Ivrea body.
In 1985 a local survey was untertaken in the region of Turtmann (Valais), situated in the area of the Swiss GPS Test Net (Bernauer and Geiger, 1986). The purpose of this survey was to interpret the local anomalies in terms of the thickness of quarternary sediments as well as to determine local geoid undulations. Both sets of data will be incorporated in a later interpretation of recent crustal movements and seismotectonics still being active in this zone of contact between the Penninic nappes and the Hercynian Aar massif.

Gravity Surveys for Applied Geophysics
by E. Klingelé

Since 1982 the Institute of Geophysics, University of Lausanne, has been involved in several detailed gravimetric surveys for hydrological purposes. Those surveys, mostly concentrating on western Switzerland, comprise more than 2000 stations which are completely Bouguer-reduced for different densities.
During the same period, the Swiss Geophysical Commission organised two detailed surveys: one for oil prospection, the other aiming at geological evaluations for possible sites of nuclear waste disposal. More than 11 000 stations were measured, reduced and published in the form of maps for different reduction densities.
Furthermore, a gravimetric survey (558 stations) has been performed along a 10 km wide strip from the Lake of Constance (FRG) to Bergamo (I), perpendicular to the strike of the Alps. The Bouguer anomaly data of this profile have been interpreted in terms of deep structure of the crust and upper mantle (Schwendener, 1984).

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4 General Theory and Methodology

Geodetic and Geometric Modelling

by R. Conzett, W. Kuhn and B. Studemann

Research and development in the Land Information System (LIS) group at the Institute of Geodesy and Photogrammetry, ETH Zurich, have shifted over the last few years from the development of geodetic data bases to the conceptual modelling of application domains in geodesy and surveying, utilizing these data bases as tools.
An investigation of suitable data structures for data acquisition, processing and management in triangulation, gravimetry and tacheometry has resulted in detailed proposals of entity-block-diagrams for these areas. Based on these data structures, a program system for the interactive acquisition and preprocessing of data in triangulation and tacheometry has been implemented and used in several field campaigns. Since it is more concerned with the management of measurement data than with the modelling of geometric data, it employs a conventional data base management system, making use of this system's comfortable input/output facilities.
In the domain of data processing, a new approach to the adjustment of triangulation networks by condition equations has been developed. It is based on the potential of interactive systems and the stepwise inversion of matrices, and allows the automatic generation of a set of independent condition equations. The advantages of the method lie in the separation of the network adjustment from the calculation of coordinates and in the possibilities for the detection and localization of blunders in measurements.
The space-related information of an LIS requires facilities to store and process geometric data. It is crucial that these facilities preserve the quality of the information, i. e. that they cope with the particular integrity constraints of spatial data. This means first and foremost to preserve the mutual spatial relationships, i. e. the topology of the geometric objects. In collaboration with the University of Maine, USA, a new structure to represent geometric data ("Cell Complexes") has been developed and implemented as a general interface to a spatial data base for geo-scientific applications.
A new method for the interactive manipulation of geometric data in LIS is being developed. Contrary to the traditional constructive approach which offers an extended set of "ruler and compass" constructions, it allows the user to sketch the desired situation and to state constraints on distances, angles, areas, etc. The method is believed to have a potential to improve the ease of use and the acceptance of LIS.

Data Processing at the Federal Office of Topography

by A. Carosio

The development of computer applications at the Federal Office of Topography has been intensively continued between 1983 and 1986. Emphasis was placed on automating data gathering because the sheer amount of data to be managed and processed poses a real problem in the realization of new projects.
For the geodetic software system, the data gathering in the field was automated with the hand-held computer Epson HX-20. The readings from levellings are manually typed into the Epson, whereas in

measuring directions, the data are transferred directly from the electronic theodolite Kern E2 to the computer. Different checks and a preliminary processing are carried out immediately. Back in the office the measurements are transferred to the computer system Prime through an RS-232 interface.

In addition, programs (Gerber, 1987) were developed for gathering and preprocessing old triangulation measurements in order to compute a comprehensive least squares adjustment (diagnostic adjustment) of the 1st and 2nd order triangulation nets using all measurements obtained by conventional techniques (prior to GPS).

Another geodetic project, finished in 1986, is the recording of all non-graphic data of triangulation points and levelling bench marks and the subsequent output on standardized forms. The corresponding maps of these points are plotted automatically as well (Gerber, 1986).

The adjustment procedures were extended with modules for network analysis and the interpretation of the results (Carosio, 1986). Methods for testing the reliability and the accuracy of the results of geodetic nets were built into the triangulation software (Gubler, 1986a,b).

To meet the increasing demands of computer capacity, the 8-year-old Prime 400 was replaced by a Prime 9955/II at the end of 1986.

The gathering of topographic data has become increasingly important in the last few years. In 1984 an interactive graphic system from Scitex was installed in order to establish a close-meshed digital terrain model. After having digitized the contents of the 1 : 25 000 National Map Series with a scanner, the contour lines are retreived as automatically as possible. The training program has been completed and production is now running at full speed.

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5 Geodynamics

Gravity Anomalies and Geodynamics of Mountain Belts

by H.-G. Kahle and St. Ott

A Special Study Group dealing with the above theme was formed by the International Association of Geodesy (IAG) during the IUGG General Assembly in Hamburg, 1983. It originated from the specific aspect to establish relationships between the anomalous gravity field, the density distribution and geodynamics of mountain belts. Since mountain belts in the broadest sense include most of the present continental crust, it was agreed that only younger mountain belts, of Phanerozoic age, with pronounced elevation should be regarded in this group. The objectives were re-defined from existing interests of former SSG dealing in general with the problems of density determination within the earth's interior. Seven major topics were given priority for the better understanding of gravity anomalies and geodynamic processes in mountainous regions:

(A) Update and establish the relationships between seismic wave velocities and densities of crustal and upper mantle rocks.
(B) Interpret gravity anomalies in terms of density contrasts referred to an average or standard lithosphere, which clearly must consist of at least two layers with different densities and seismic velocities.
(C) Correct gravity anomalies for density differences in the thrust cover, i. e. perform "mass stripping" with respect to the density provinces of thrust nappes.
(D) Perform "crustal stripping", i. e. correct for geophysically determined deep structures and masses that are not directly connected to the generally deep-seated geodynamic processes. The remaining residual gravity anomalies would be considered a "lithospheric residual field".
(E) Interpret the gravity field in terms of geodynamic processes of creating and consuming plate boundaries.
(F) Interpret the wavelengths of gravity anomalies to solve outstanding geophysical problems in relation to the stress field distribution and driving mechanism of global plate tectonics.
(G) Integrated gravity field and density determination, admittance techniques.

At first an international workshop was organized and held in Zurich, May 1985. The objectives of the workshop were to discuss in an interdisciplinary manner gravity problems common to Sections III and V and to exchange the latest information on the density distribution in the earth's interior. The joint nature of this meeting enabled a valuable dialogue between geodesists and geophysicists, which should be even more encouraged in the future. Highlights of this workshop included both measuring techniques and methodological aspects for integrated interpretation of gravity and other geophysical data in terms of density structure of the lithosphere. Fifty-three scientists from sixteen countries participated actively in the presentations and discussions. The most relevant information has been documented by Kahle and Bartholomew (1985).

As a follow-up to the Zurich meeting an international symposium had been organized, which formed part of the joint Annual Meeting of the European Geophysical Society (EGS) and the European Seismological Commission (ESC). This symposium entitled "Geodynamics of Mountain Belts" was held in Kiel, FRG, in August 1986. It was organized by several members of SSG 5.97 (E. Klingelé, Switzerland; D. Dyrelius, Sweden). The main subjects included gravity interpretations of geodynamic processes still active in the European Alps and the Venezuelan Andes, as well as paleomagnetic and seismotectonic studies of the Carpatho-Balkanides in Yugoslavia and Bulgaria. The symposium also comprised a description of tectonic phases along the New Zealand active margin and discussions on the post-orogenic evolution of the SE-Highlands of Australia. It became evident again that an interdisciplinary approach of geodesists and geophysicists is of great importance for a better understanding of geodynamic processes active in the vicinity of young orogenic mountain belts. It was, therefore, proposed to arrange an interdisciplinary symposium or workshop in the 1987–1991 period, possibly in the context of Working Group I of the Inter-Union Commission on the Lithosphere (ICL).

Physical Interpretation of Gravity Anomalies

by A. Geiger and H.-G. Kahle

Physical interpretation of gravity anomalies in terms of deep-seated mass inhomogeneities requires adequate reductions 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 extensively used in order to correct 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 subtracted, e. g. 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 remaining residual field can accurately be interpolated and interpreted. Different computer programs with different algorithms have been developed in order to interpret residual anomalies. Interpolation and prediction of the deflections of the vertical can be made with a precision in the order of 1" over the entire country. Of particular interest during the past three years was the study of the highly disturbed gravity field in the vicinity of southern Switzerland where the edge effects of the prominent Ivrea body have been detected by means of the measured gravity field (gravity and deflections of the vertical).

In a mountainous test area (Canton Valais) the knowledge of geological structure and density distribution has been introduced in gravimetric calculations, especially for reductions of Bouguer anomalies. Special computer programs have been developed to define, construct and calculate three-dimensional geological structures. The calculations have shown that it is very difficult to determine the density distribution from gravity measurements in a complexly structured area because of the weak (filtered) response of the gravity measurements to density variation. With some restrictions on the possible mass models, reasonable density and boundary distributions can be obtained, e. g. the sedimentary fill of Alpine valleys can be extracted from gravity measurements as a 3D model. At the same time the crust/mantle boundary can be estimated with reasonable accuracy.

Some tests have been made to evaluate the Fast Fourier Transform (FFT) method. Trials to estimate a density distribution for the entire area of Switzerland by correlation methods revealed the main geological features. However, the fine structure could not be elucidated. It is, therefore, recommended to apply topographically smoothed values. The Alpine region clearly showed up as a distinct feature in contrast to the adjacent basins and the Jurassic mountains. Attempts to calculate geoidal undulations by direct Fourier calculus were carried out. The Fourier Transform of the effect of stratified layers has been generalized to a transform of all three components of the gravity field. We are now in the process of applying FFT to isostatic problems and to the interpretation of different types of gravity anomalies.

WEGENER-MEDLAS Project: The Swiss Trans-Alpine Laser Experiment Monte Generoso–Jungfraujoch–Zimmerwald

by H.-G. Kahle, B. Bürki, A. Geiger, W. Gurtner and St. Müller

Since 1984 Switzerland is participating in NASA's Crustal Dynamics Project. The objectives of the Swiss participation is aimed at studying the relative plate motion in the region of the so-called Adriatic promontory of the African plate which governs the tectonic processes in the Apennines, the Alps and the Dinarides. The push of the African plate against the Eurasian plate through the Adriatic promontory results in an underthrusting motion beneath the southern Alps (as, for instance, in the 1976 Friuli earthquakes). Superimposed on this thrusting process is a rotational motion caused by the counterclockwise rotation of the Apennine peninsula. This component, in turn, results in a counter-reaction in the region of the central (Swiss) Alps and their northern foreland where earthquake zones of left-lateral strike-slip motion have been identified. The objective of the Swiss contribution to NASA's Crustal Dynamics Project is to assess the kinematics and dynamics of the Alpine area by terrestrial and space related methods. The terrestrial measurements include repeated precise levellings, detailed gravity surveys, in-situ stress measurements, deep-seismic soundings, seismic surface-wave observations, fault-plane solutions of earthquakes, geodetic-astronomical observations with the aid of an automatic zenith camera and other geodetic/geophysical investigations. The space-related techniques involve GPS measurements, Satellite Laser Ranging and, in the future, Very Long Baseline Interferometry. The investigations form an important part in the joint efforts directed towards a better understanding of crustal dynamics and earthquake occurrence in the Alpine zones of plate collision.

The European activities have been joined in the WEGENER-MEDLAS Project (WMP) under the leadership of P. Wilson (IfAG, Frankfurt); see also (Mueller et al., 1985). WEGENER-MEDLAS stands for Working Group of European Geoscientists for the Establishment of Networks for Earthquake Research – Mediterranean Laser Project.

A combined SLR/TLR/GPS experiment (including Satellite Laser Ranging to LAGEOS, Terrestrial Laser Ranging, and GPS measurements) was carried out in autumn 1985, extending over Trans-Alpine baselines of 60, 100 and 160 km lengths, respectively (see Map 3). Height differences along these lines range up to 2670 m. The 160 km baseline is identical with the WMP line Monte Generoso–Zimmerwald. The strike of it is parallel to the trend of maximum crustal shortening in the Alpine region. A one-day observation per baseline with two TI 4100 (L_1 and L_2) receivers revealed a preliminary precision of 0.2 ppm. A comparison with the terrestrial Laser measurements performed during WMP on the 160 km baseline shows a consistency of the order of 0.6 ppm.
By rigorous modelling, these preliminary results can be improved to reach the 0.1 ppm limit. This test campaign demonstrated the usefulness of GPS and TLR as a supporting method for SLR in the distance range 100–200 km, in particular for detecting and monitoring geodynamic processes in high-mountainous regions such as the Swiss Alps.
The SLR- and TLR-measurements on Monte Generoso (Bürki et al., 1986) were performed by the Technical University of Delft using the Modular Transportable Laser Ranging Station MTLRS-2 (N. Rodenburg and D. Samson) and in Zimmerwald by the AIUB (W. Gurtner and T. Schildknecht). The GPS measurements were carried out by NORTECH (Calgary, Canada) with support of the IGP of the ETHZ. The evaluation has been carried out by NORTECH as well as independently by AIUB in collaboration with the IGP, using the Bernese 2nd generation software package (Gurtner et al., 1985; Beutler et al., 1986).
On the one hand, the GPS campaign on the SLR/TLR sites Monte Generoso, Jungfraujoch, Zimmerwald can be considered as an initial measurement for geodynamic objectives. On the other hand, with the help of the established data, Doppler- (Wiget and Geiger, 1985), GPS- and MTLRS-Laser-measurements can be compared directly with each other. In this connection, the examination of the correction models for the ionosphere and the troposphere play a significant role. As a next step, the entire European Laser network which was operational during the Swiss Laser campaign will have to be included in the analysis.

The kinematic parameters of geodynamic processes in the Alpine belt (Kahle and Mueller, 1984) should become apparent in a few years time. The chosen SLR/TLR- and GPS-network sites are of particular importance because they correspond to a baseline which is almost perfectly parallel to the direction of maximum crustal shortening in the Alps (Pavoni and Mayer-Rosa, 1978). Therefore, temporal changes of the baseline are most likely connected with the collision process between the Eurasian and the African lithospheric plates, one of the major scientific objectives that are defined as a prime target for the WEGENER-MEDLAS Project (Mueller et al., 1985).
In summer 1987 this network has been extended across the central Swiss Alps in order to connect the various tectonic units geodetically. Examples are the Helvetic and Penninic nappes as well as the Aar and Gotthard massifs, respectively. A first experiment in this direction was the establishment of the local GPS test net Turtmann (Canton Valais), which has been measured with TI-, Macrometer-, Sercel-, Trimble- and WM101-receivers (Rothacher et al., 1986; Geiger et al., 1986).

The Swiss National Research Project NFP 20: Exploration of the Deep Geological Structure of Switzerland

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

From June to September 1986 the Institute of Geodesy and Photogrammetry of the Swiss Federal Institute of Technology Zurich selected 48 points along the eastern Alpine traverse for astronomical measurements. 35 sites have been measured up to now with the transportable zenith camera of the IGP. The measured deflections of the vertical were reduced for topographic effects. They clearly show the geological depth structures, e. g. the Mohorovicic discontinuity. In 1987 another 20 astronomical stations will be measured along the western traverse and 10 points along the southern traverse. The precise levelling line from Visp to Zermatt will be remeasured by the Federal Office of Topography after a pause of 57 years. It is hoped to obtain new recent uplift rates along that line. At the same time the IGP will determine the horizontal position of some selected sites by GPS measurements. The computations will be performed by the Astronomical Institute of the University of Berne. These data, together with some future measurements, are expected to reveal horizontal crustal movements along the strike of major crustal shortening between the African and Eurasian plates.

The Geological Structure of the Zone of Ivrea-Verbano

by B. Wirth, B. Bürki and H.-G. Kahle

Between 1983 and 1986 the IGP of the ETHZ determined deflections of the vertical on 113 stations in southern Switzerland and northern Italy in the so-called Zone of Ivrea-Verbano. The measurements were performed in close collaboration with the Institut für Erdmessung, TU Hannover (FRG), the University of Rome (Italy), the Istituto Geografico Militare, Firenze (Italy) and the Technical University Graz (Austria). The astronomical coordinates were measured by zenith cameras while the ellipsoidal coordinates were determined by Doppler observations on TRANSIT satellites. On 108 sites gravity was also measured. All these data were reduced for topographic effects, for the surface features of the Zone of Ivrea-Verbano, the sedimentary fills of the valleys, as well as for the lakes and sediments of the Po Plain. Furthermore, gravitational effects of the crustal-mantle boundary were calculated. The reduced data clearly reveal the edge effects of the Ivrea body. The deduced new model of the Ivrea body is characterized by significant modifications compared to earlier geophysical interpretations, especially in the north-eastern and south-western part.

Strain Energy and Recent Crustal Movements in the Alpine-Mediterranean Region Analyzed in the Swiss Alps

by A. Geiger, H.-G. Kahle and E. Gubler

The most recent results of uplift rates determined by repeated precise levelling (see Map 11) are analyzed in terms of geodynamic processes still going on in the region of the Alpine-Mediterranean plate boundary. Special emphasis is focused on levelling nets in the Swiss Alps which have been measured for the second time (see Section 1). A comparison of these geodetic results with geophysical information such as gravity anomalies, explosion seismic results as well as seismicity, provides further evidence that these sets of data are interrelated with each other. Attempts are made to estimate the strain energy associated with crustal deformation by introducing first-order stress-strain relationships. A comparison with the actual seismicity zones in Switzerland revealed a striking coincidence between the calculated strain energy derived from the uplift rates and the seismicity observed by the Swiss Earthquake Service of the Institute of Geophysics (ETHZ).

Earth Tide Measurements

by A. Wiget, R. Edge, E. Klingelé and H.-G. Kahle

A LaCoste & Romberg earth tide gravity meter has been installed by R. Edge of the Institute of Oceanographic Sciences (I.O.S.), Bidston Observatory, England, at the ETH-Hönggerberg, Zurich. High precision earth tide data were continuously recorded for the period between November 1985 and June 1986. The data will be analysed by the I.O.S. together with similar tidal experiments at various sites with different distances from the ocean, e. g. Bidston (UK), Brussels (Belgium) and Bad Homberg (FRG). The results are expected to contribute to a better understanding of tidal gravity. Especially the study of ocean tide loading effects and their spatial variations will be persued. One aspect of tidal gravity investigations is to satisfy the increasing demand for earth tide and ocean tide corrections required by modern geodetic space techniques.

In summer 1987 a second site has been occupied in Chur, Canton Grisons, where earlier measurements were conducted some years ago. This station is located near the centre of highest uplift rates in the Swiss Alps and is almost identical with the site of absolute gravity measurements performed with the Italian absolute apparatus of the Istituto di Metrologia "G. Colonnetti" (Marson et al., 1981).

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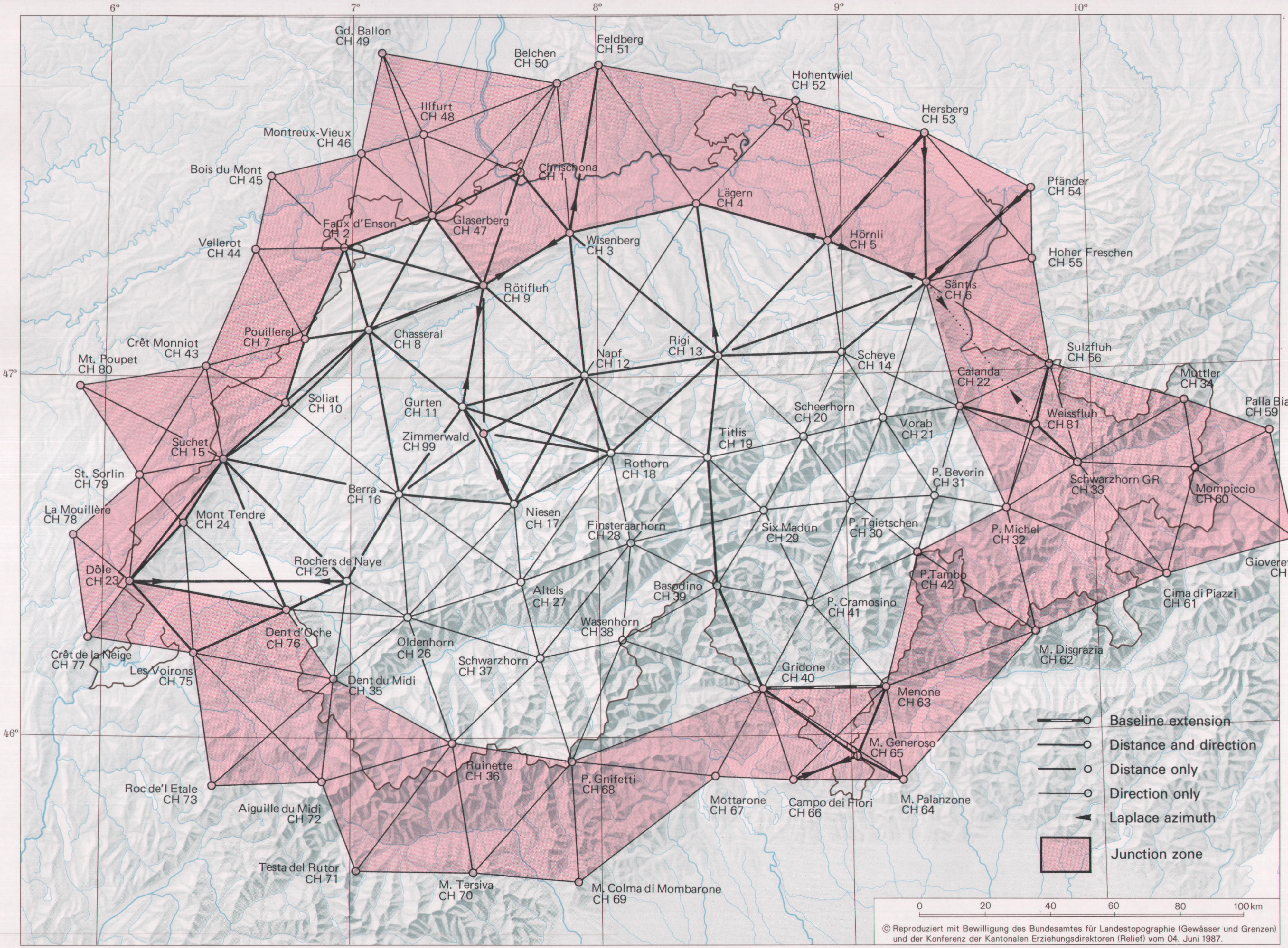

Map 1 Block CH of the European Triangulation Network (RETrig)

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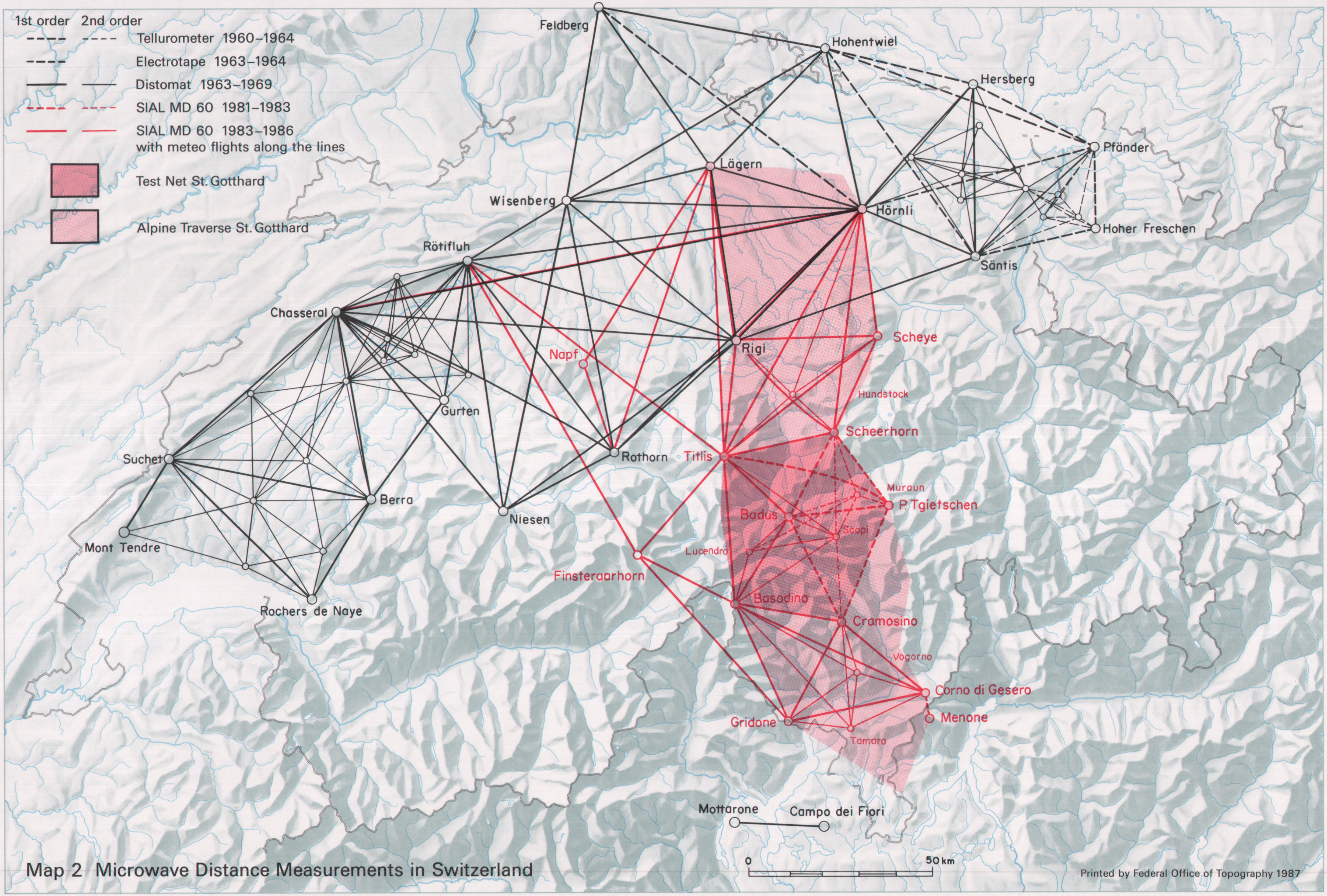

Map 2 Microwave Distance Measurements in Switzerland

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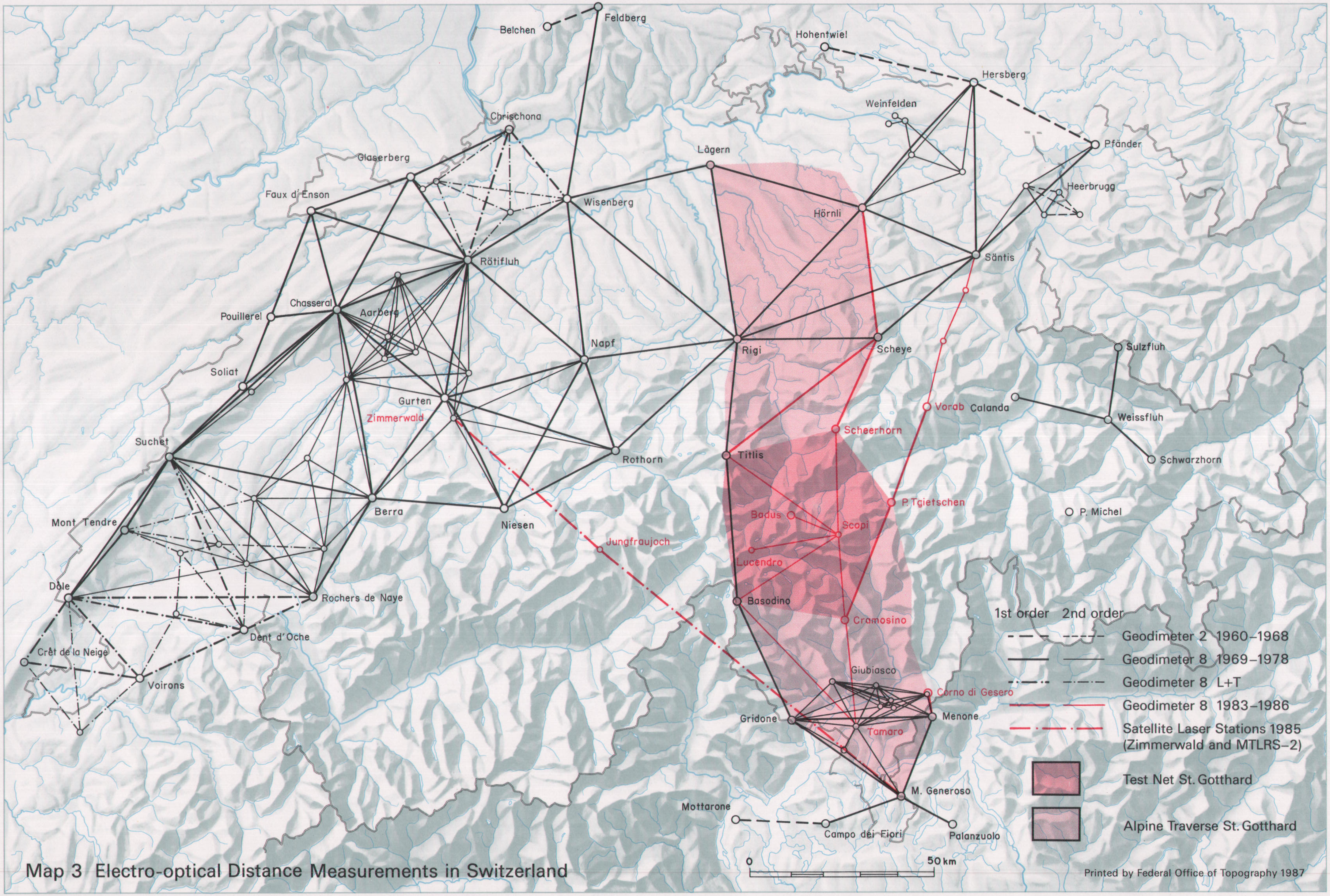

Map 3 Electro-optical Distance Measurements in Switzerland

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Map 4 Swiss Contribution to the United European Levelling Net (UELN)

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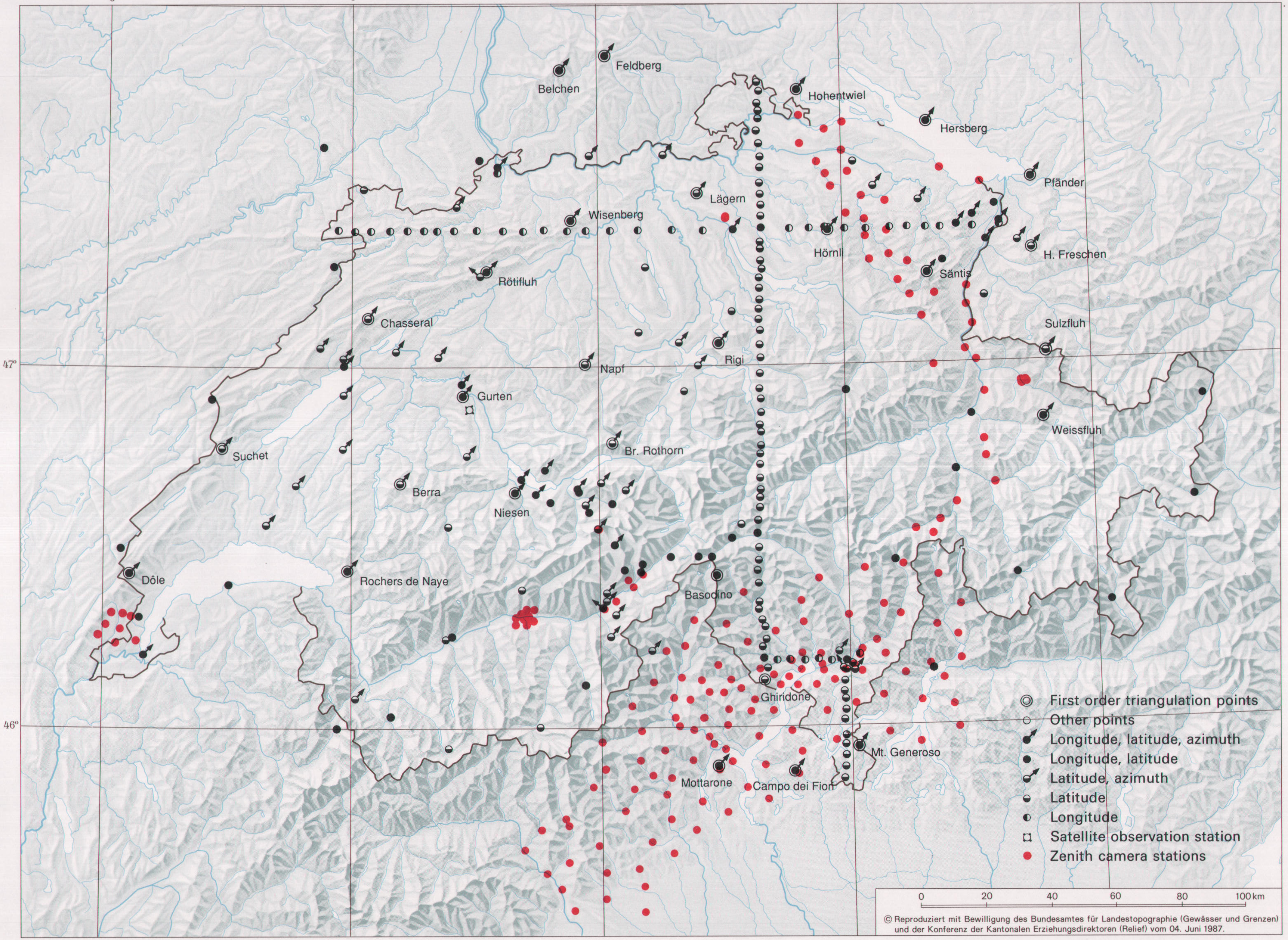

Map 5 Astronomical Stations in and around Switzerland

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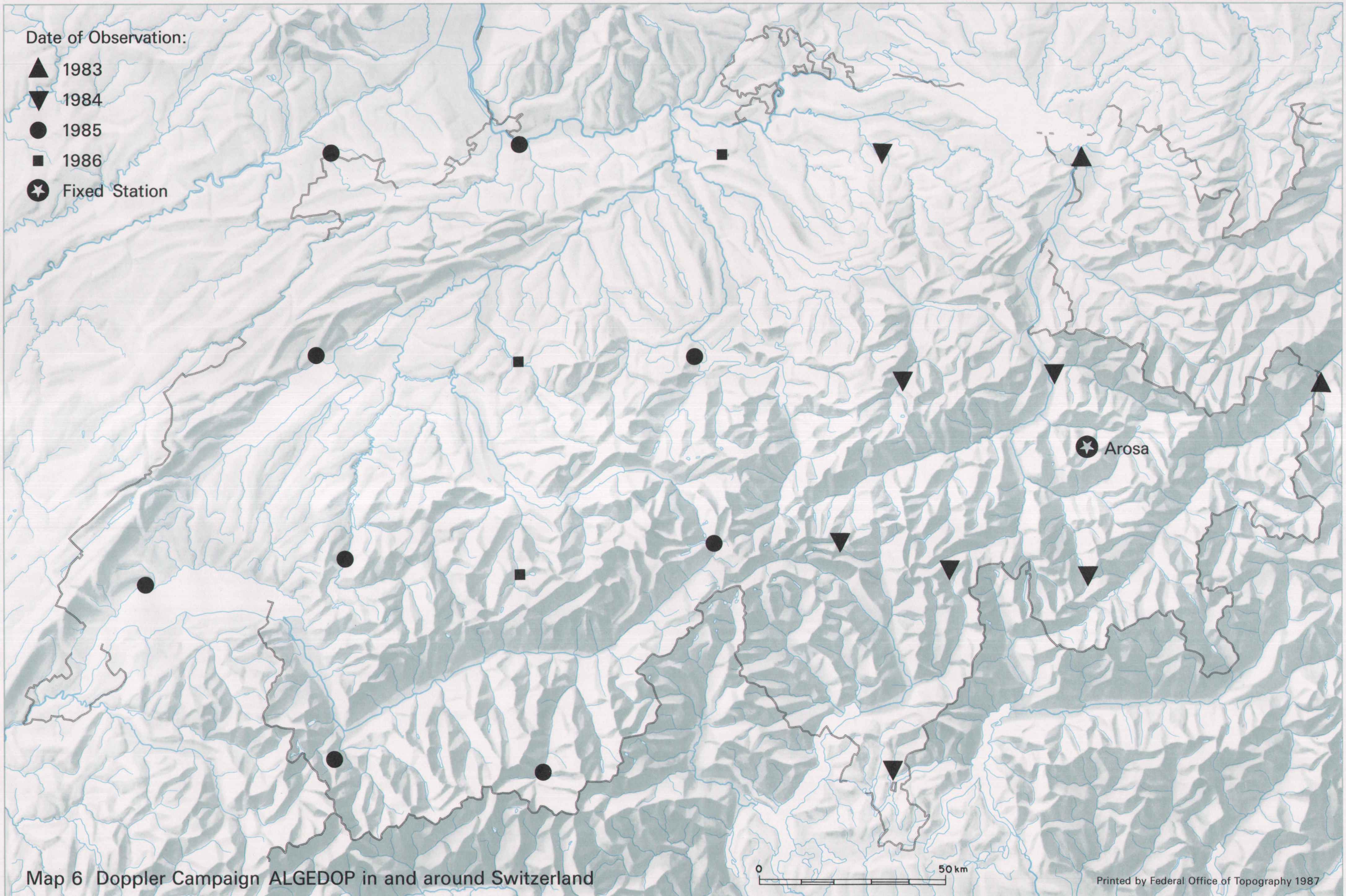

Map 6 Doppler Campaign ALGEDOP in and around Switzerland

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Map 7 Doppler Campaign SWISSDOC 1984

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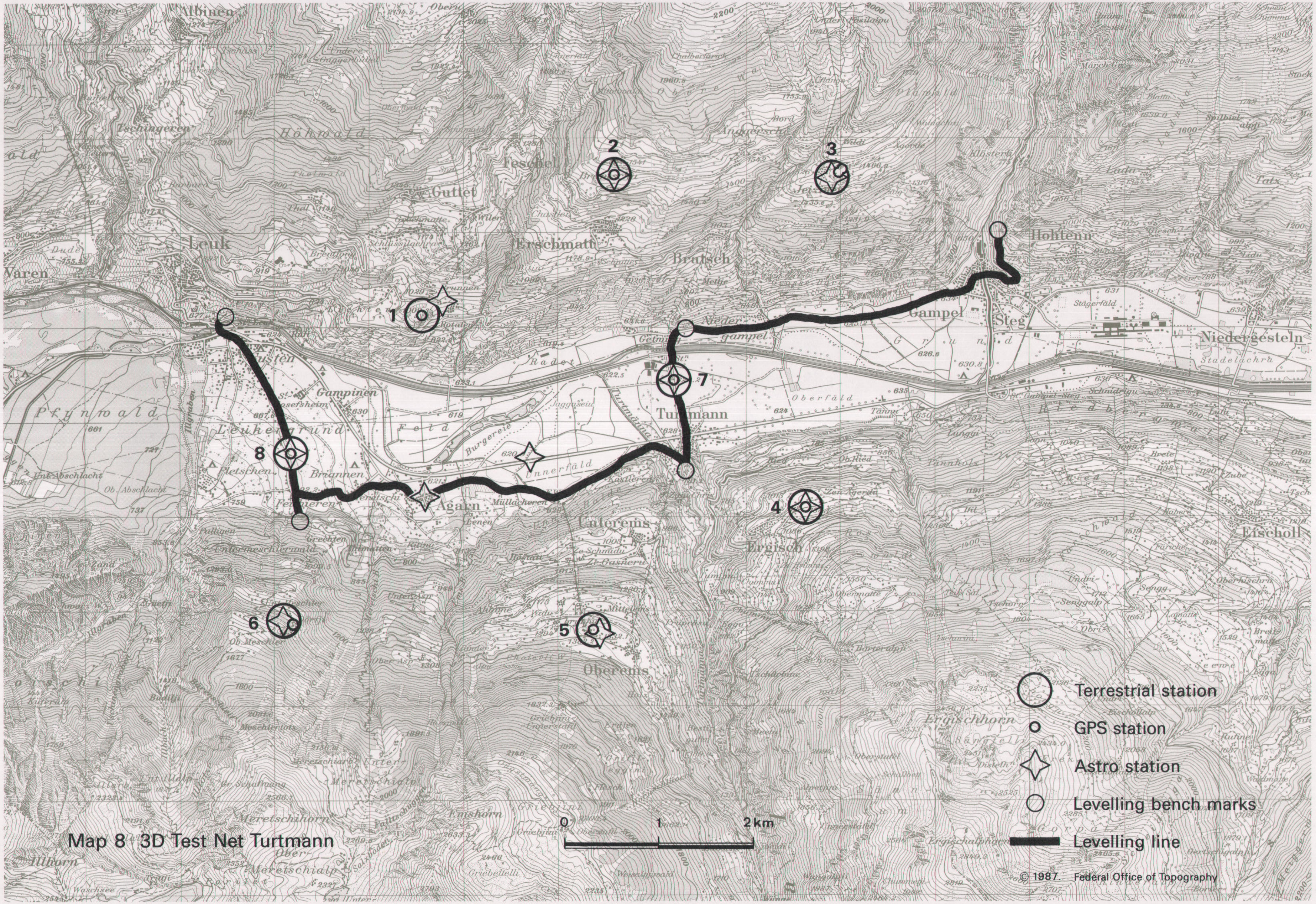
Map 8 3D Test Net Turtmann
Terrestrial station
GPS station
Astro station
Levelling bench marks
Levelling line
0
1
2 km
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1
2
3
4
5
6
7
8
Leuk
Varen
Erschmatt
Bratsch
Gampel
Steg
Hohtenn
Niedergesteln
Turtmann
Agarn
Unterems
Oberems
Ergisch
Eischoll
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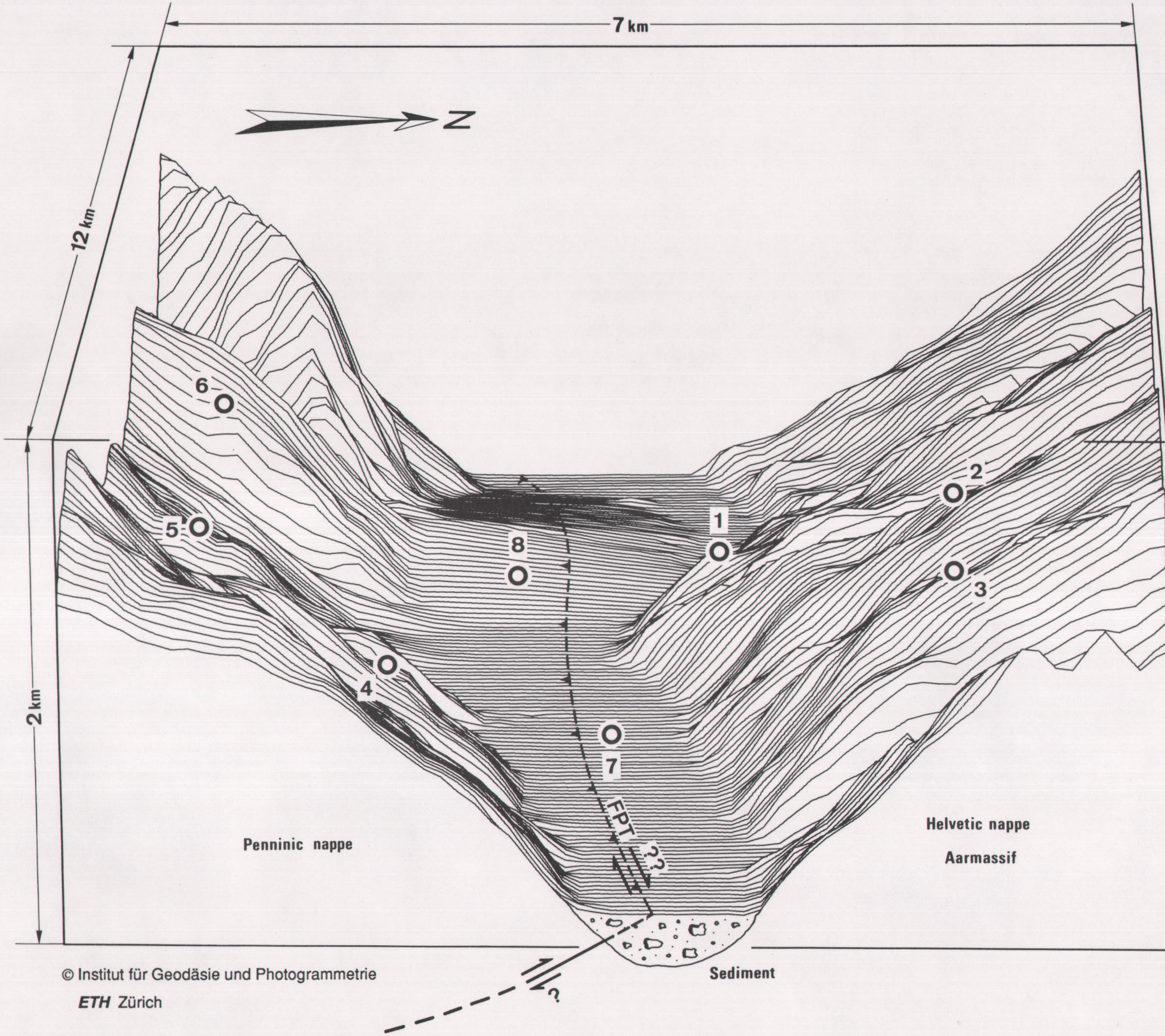
Gampinen
Ergischhorn
Meretschihorn
Emshorn
Illhorn



Map 9 3D Test Net Turtmann (Perspective)

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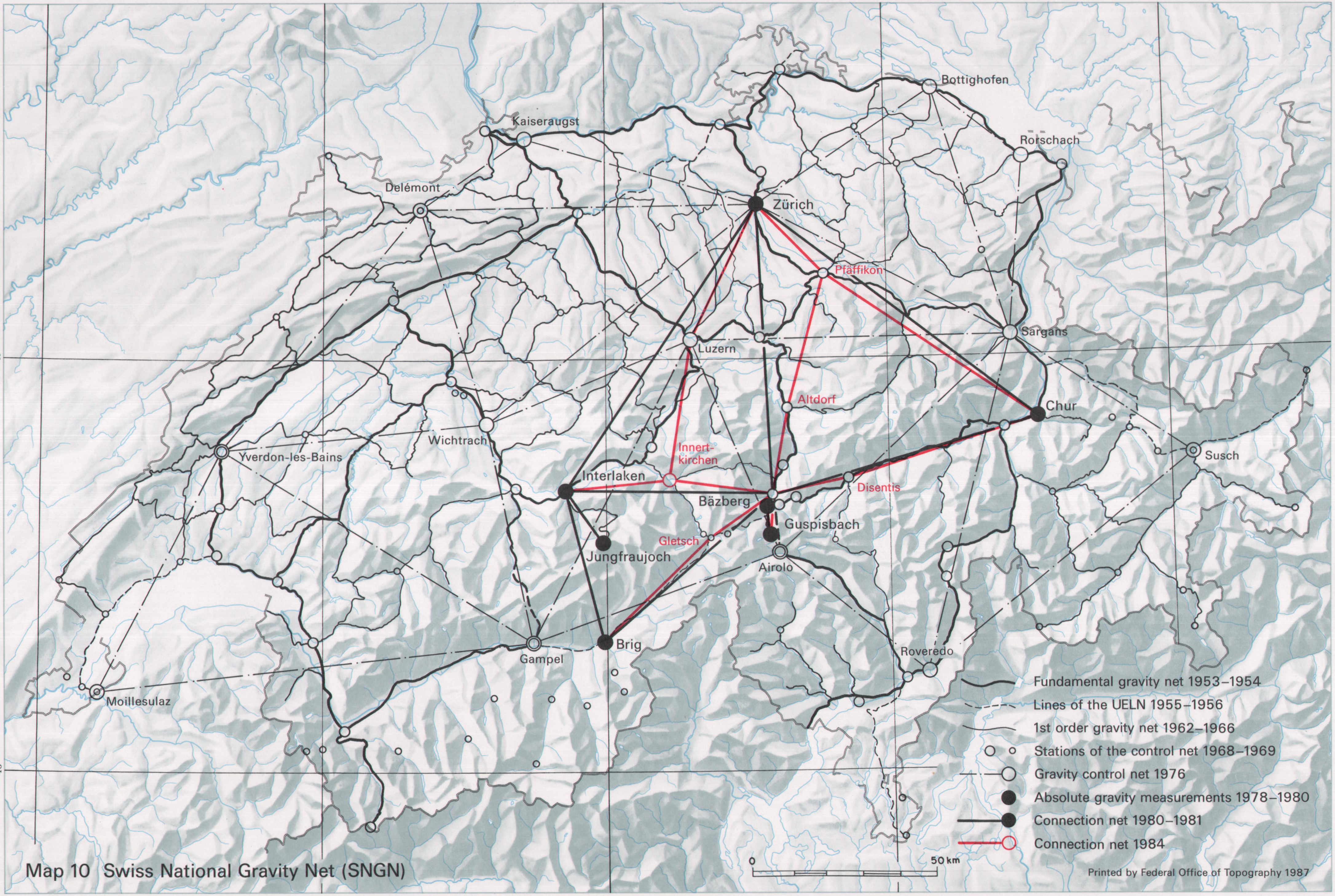

Map 10 Swiss National Gravity Net (SNGN)

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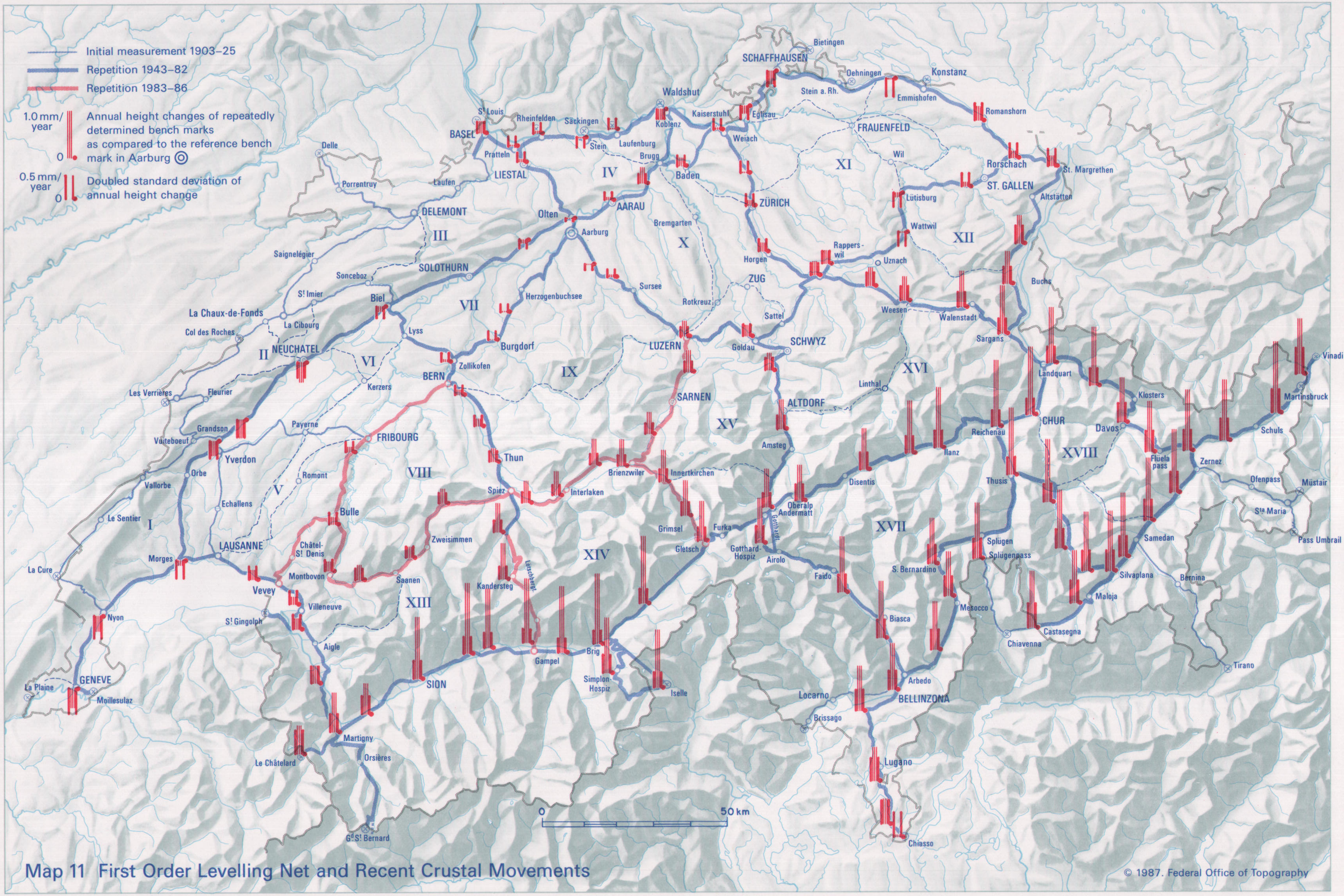

Map 11 First Order Levelling Net and Recent Crustal Movements

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