Switzerland

Swiss Geodetic Commission

and Federal Office of Topography

Suisse

Commission Géodésique Suisse

et Office Fédéral de Topographie

Report on the

GEODETIC ACTIVITIES

in the years 1979 to 1982

Presented to the XVIII General Assembly
of the International Union of Geodesy and Geophysics
in Hamburg, August 1983

Rapport sur les

TRAVAUX GÉODÉSIQUES

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Présenté à la dix-huitième Assemblée générale
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1 Control Surveys

RETrig and the Swiss National Triangulation Net

RETrig
by N. Wunderlin

Since the RETrig solution 1979 called ED79, no new terrestrial or satellite observations for RETrig have been carried out in Switzerland, and no new adjustments or introduction of new physical data for block CH are to be reported. The only work done on RETrig was a thorough investigation of the results of ED79 (Wunderlin, 1980c).

Retriangulation of the National Triangulation Net
by H. Chablais

Between 1976 and 1978, the first and second order triangulations in the western-most part of Switzerland were remeasured by the Federal Office of Topography. The progressive renewal of the third order triangulation in the Canton of Vaud was continued and completed in 1982. The coordinates of 300 points were adjusted as part of 6 different network sections. Combining the old angle measurements with the electronic distance measurements made from 1976 to 1981 proved to be advantageous. At first the AGA Geodimeter 8 of the Institute of Geodesy and Photogrammetry at the Swiss Federal Institute of Technology Zurich was used, and for the last three years the measurements have been made with the Wild DI-20 of the Federal Office of Topography. Both instruments yielded comparable results. All of the networks were adjusted with the computer program LTOP. The coordinates of the first and second order stations obtained from the higher order network and the already adjusted third order stations were kept fixed in the adjustments.
The progressive renewal of the fourth order triangulation is being continued by the survey authority of the Canton of Vaud and will probably be completed in about 10 years.

Electronic Distance Measurements
by H. Chablais

Along with the renewal of the third order triangulation in the Canton of Vaud, the Federal Office of Topography carried out three distance measurement campaigns between 1979 and 1981. The AGA Geodimeter 8 of the Institute of Geodesy and Photogrammetry at the Swiss Federal Institute of Technology Zurich was used for the first campaign and the Wild DI-20 of the Federal Office of Topography was used for the others.
The Institute of Geodesy and Surveying at the Swiss Federal Institute of Technology Lausanne, together with the Federal Office of Topography, made distance measurements in a test net near Echallens with various Wild DI-4L and DI-20 EDM instruments. These measurements resulted in a remarkable accuracy for these instruments (standard deviation of 1 km: DI-20 = 2.0 mm, DI-4L = 2.9 mm) (Dupraz and Bonjour, 1983).

UELN (REUN) and the Swiss National Levelling Net

by E. Gubler

The remeasurement of the Swiss First Order Levelling Net is in progress. At the end of 1982, 70% or 2100 km have been measured. In the eastern part of Switzerland, the measurements are almost completed (see Map 1). The standard deviation of the remeasured parts computed from the loop misclosures of the 11 closed loops is $0.8\ mm/\sqrt{km}$.
The Swiss contribution to UELN consists of a subset of this net. It has been recomputed to reduce the measurements to the epoch 1973 by correcting for recent vertical crustal movements (Van Mierlo, 1983).
Investigations on the six Wild NA 2 levelling instruments in use (Rumpf and Meurisch, 1981) show that the influence of the magnetic field on the compensator is small.

Refraction

by F. Chaperon and R. Köchle

A national working group has been established with the aim of studying the refractive index of the atmosphere and its influence on distances measured by EDM with optical and microwave carriers.
In order to reduce a measured distance for atmospheric effects it is necessary to know the velocity of the electromagnetic waves (refractive index) along the whole path from station to station at the time of measurement. Sondes carried by an aeroplane along the path registering barometric pressure, temperature and humidity provide the necessary information. This kind of measurement will be carried out in the summer of 1983 on sides of the first order triangulation net in the Swiss Alps where Geodimeter 8 and SIAL MD 60 distances will be reduced using atmospheric data gathered with ATAR-sondes from motor gliders.
Normally, the atmospheric parameters are only measured close to the ground at both stations. A systematic error often arises in the reduced distances because conditions in the free atmosphere differ from those at ground level. The construction of portable equipment to lift a sonde a few tens of meters above ground level and transmit the information via radio-frequencies to the observer on the station is under way and will soon be completed. The meteorological sonde will be lifted above ground by a new kind of flying device called Turboplan. Alternatively, captive balloons may be used.
On the theoretical side, investigations are under way to study the refractive index as a function of altitude above sea-level using the daily records from balloon sondes of the Aerological Station in Payerne. It is hoped to discover some regularity and possibly some correlation with the weather.

Investigations in the St. Gotthard Area

The St. Gotthard area belongs to the central part of the Swiss Alps. It is situated at the crossing of the north-south running levelling line Basel–Luzern–Chiasso (see Map 1) and the so-called Rhine–Rhone line (see Section 5 Physical Interpretation). On the one hand a remarkable uplift rate is shown from repeated levellings, on the other hand a shortening of the Earth's crust between Basel and Chiasso took place in geological ages. For solving the appearing problems the geodetic activities of the last years have been concentrated on this area.

Control Surveys in the St. Gotthard Road Tunnel

by F. Kobold

In autumn 1980, the inauguration of the road tunnel through the Gotthard massif took place. This tunnel is approx. 17 km long, the mean altitude is about 1100 m above sea-level, and the axis consists of straight lines and curves (see Map 2).

It is expected that the tunnel will become somewhat deformed through time. Traffic would be one reason and, perhaps more important, the pressure of the mountains themselves. It is important to determine the extent of these deformations, and in anticipation bench marks were determined in situation and altitude. The establishment and a first determination of this system of fixed points was done shortly before the official opening of the tunnel.
The system consists of levelling and of traverse points in distances of 250 m. The levelling was carried out with Ni 1 instruments. DKM2-A theodolites were applied for the angles and Mekometers ME 3000 for the distances in the traverse. Each angle and each distance were measured at least four times under different atmospheric conditions.
The large number of observations was subjected to adjustments based upon different assumptions. The results of the last and certainly best solution are of general interest and may be summarized as follows: The standard deviation of a level difference of a distance of 1 km was found to be 0.25 mm after considering the influence of the earth magnetic field on the Ni 1 instruments. The standard deviation of an adjusted angle was 0.2 mgon, as planned. Contrary to this result the standard deviation of the distances of 250 m and 500 m was much better than expected. It was found to be 0.2 mm + 0.5 ppm whereas in earlier experiences it was 0.2 mm + 1.5 ppm. This improvement may be the result of the atmospheric conditions in the tunnel.
However, the excellent standard deviation must be regarded as an «inner accuracy». In order to obtain «absolute values» for the distances, the calibration of the Mekometers should be carried out on improved special base lines which are not yet established, but planned.

Special Surveys in the St. Gotthard Road Tunnel
by W. Fischer

The great number of well-determined fixed points and the extraordinary conditions for measurements in the road tunnel offered a welcome opportunity for several special surveys which were planned and performed by the Institute of Geodesy and Photogrammetry at the Swiss Federal Institute of Technology Zurich. Thanks to the generosity of the Swiss road authorities they could be carried out shortly before the official opening of the tunnel to the traffic.
In early 1980, two absolute gravity stations, named Bäzberg and Guspisbach after the names of the neighbouring ventilation shafts, were installed and determined in two cross galleries (see Section 3 Gravimetry).
In summer 1980, relative gravity measurements were carried out along the whole tunnel, using levelling points as station points. On the length of 17 km of the tunnel, a total of 45 gravity values were determined in order to demonstrate the change of gravity within the mountains. These values are to be used for the calculation of geopotential height differences.
At the same time, gravity measurements were made on several height levels in the four ventilation shafts; a rather difficult but successful experiment thanks to the elevators placed in each shaft and put at the disposal of the operators by the Swiss road authorities.
Finally, the height difference from the bottom to the top of each shaft was measured using a Mekometer ME 3000. For the two vertical shafts, a mirror equipment especially designed by Kern & Co. Ltd. was mounted on the instrument. In the two sloping shafts reciprocal vertical angles were measured. The endpoints of the shafts were connected to the neighbouring levelling points in order to determine and to compare the height differences between the points in the tunnel and on the pass. The ties to the 1st order levelling along the St. Gotthard pass were kindly levelled by the Federal Office of Topography.

St. Gotthard Pass Net
by N. Wunderlin

The triangulation for the setting-out of the St. Gotthard road tunnel – a chain of triangles connected with a precise traverse over the pass between the two endpoints of the tunnel, Göschenen and Airolo, observed 1967 – was partly remeasured in 1981. The aim of this new triangulation network (see Map 2) is:

1) to detect possible movements between 1967 and 1981 of the common points (mainly the traverse) of the two networks,
2) to connect the high-precision traverse in the tunnel (measured 1980, see «Control Surveys in the St. Gotthard Road Tunnel») with the one over the pass to build a three-dimensional loop for scientific and practical studies,
3) to deduce the length of the side between the points Badus (1st order) and Lucendro (2nd order) belonging to the Swiss triangulation network and to the test net St. Gotthard as well (see following paragraph) from the «baseline» Göschenen–Airolo.

The observations were carried out in September 1981 by the Institute of Geodesy and Photogrammetry at the Swiss Federal Institute of Technology Zurich (Prof. H.-G. Kahle): directions and height angles with Wild T2 and Kern DKM2-A, distances with Mekometer ME 3000 (Kern) and Geodimeter 6BL (AGA). The adjustment in three-dimensional geocentric Cartesian coordinates was finished by 1982, but not yet the scientific comparison with the 1967 results and the combination with the tunnel traverse of 1980.

Test Net St. Gotthard

by F. Chaperon and A. Elmiger

This network is located in the central part of the Swiss Alps, in the St. Gotthard region, and it consists of a small part of the official Swiss triangulation net of 1st und 2nd order (see Map 3). Measurements and investigations are carried out in order to study («test») the precision of EDM, simultaneous adjustments of networks of different order, and adjustments of 3D-networks (1st order) in the mountains etc. The test net St. Gotthard will serve as a framework for the combination of different precise local networks as the two nets mentioned above (St. Gotthard road tunnel, St. Gotthard pass).

The angle measurements in this network were performed in the period of 1910–1916. The Swiss method of sectors was used and measurements to points of different order were carried out at the same time. New station adjustments of all measurements of 1st and 2nd order simultaneously – the method leads to a set of correlated directions – give an accuracy (r. m. s. error) of ±0.2" to ±0.4" for the mean of an observed direction. The net adjustments (variation of coordinates, considering the correlation between the directions) give a corresponding accuracy of ±0.5" to ±0.9" for an adjusted direction. The combined adjustment of 1st and 2nd order, compared to 1st order alone, brings an improvement of the relative point precision of about 30%. The correlation between the directions has only a small influence on the results.

Electronic distance measurements with SIAL MD 60-instruments (microwaves) were carried out in 1981 (see Map 3). Only one distance was measured with Laser-Geodimeter 8 (1977). Meteorological observations were carried out in the usual way at the two end-points. Furthermore, vertical meteo-profiles up to the height of the EDM measuring paths were observed in the middle of some lines by means of balloon-sondes. The mean of the two end-point values deviates from the observed values by +2.6 °C, −4.5 mbar, −7.1% rel. humidity. The corresponding EDM scale error (+8 ppm for these point-values) is about +4 ppm, if the integral value on the whole line is considered. EDM distances reduced with end-point meteo-values are too large by this amount.

The combined net adjustment (distances, directions, correlation of directions) leads to a similar scale error of +3.5 ppm in the same sense (distances are larger than the official triangulation). The observed Geodimeter 8-distance has a similar scale error of +4 ppm.

The relative overall precision in the net is:

– Direction net, 1st order:	±1.3 ppm
– Direction net, 1st and 2nd order with correlations:	±0.9 ppm
– Combined net: directions (1st and 2nd order) with correlations and distances:	±0.6 ppm

Geodetic Astronomy

by B. Bürki and H.-G. Kahle

In a joint project of the Institute of Geodesy, Hannover, and the Institute of Geodesy and Photogrammetry, Zurich, an improved version of the Hannover-type transportable zenith camera (TZK) as well as a computer-aided data acquisition and evaluation system have been developed.
One of the Alpine regions in which geoidal undulations and deflections of the vertical are extremely disturbed by crustal and upper mantle inhomogeneities is the zone of Ivrea and its surroundings. Plans are being made for applying the new camera system to this region in order to determine short-wavelength anomalies of the deflections of the vertical. The ultimate goal is the deduction of an improved structural model for the Ivrea body (Bürki et al., 1982).

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2 Space Techniques

Satellite Observation Station Zimmerwald

by I. Bauersima

In the years 1979–1983 the Geodynamics Group of the Astronomical Institute, University of Berne, has been working on the following projects in satellite geodesy.

Installation and Operation of the Zimmerwald Satellite Observation Station

During 1979 the existing ruby-laser telemeter was upgraded from manual to computer-controlled operation. A new night-vision television camera was put into operation. From then on the station was able to passively track relatively faint celestial objects (Klöckler, 1982). Another purpose was to determine a mount model for precise pointing, aided by new angle encoders developed in cooperation with Kern & Co. Ltd., Aarau (Gurtner, 1983).
From August to October 1980, the station took part in the «SHORT MERIT» campaign by observing passes of GEOS-C and STARLETTE satellites. The raw data were proceeded to the computing center. The achieved single shot error was still in the 60 through 100 cm range. After this campaign, the ruby-laser was in such a bad state that it was decided to replace it by a modern neodymium YAG system. Consequently, transmit and receive optics plus detection had to be adapted and redesigned.
After an evaluation phase, the remodelling of the station started and is now waiting for completion and testing.
During 1982–1983, the geodetic satellites GEOS, STARLETTE and LAGEOS, as well as NOAA-6, NAVSTAR 3 and other types of up to 40 000 km distance were optically tracked and tape-recorded. Some first orbits could be determined using angle encoder data (see following paragraph).
The station also took part in WEDOC and EDOREF campaigns (both in 1980).

Development of a Software System for Tracking, Data and Signal Processing

The tracking and ranging software was expanded and adapted to the new laser and detection package. A digital filter was implemented for on-line prediction of the optimal range-gate. A program was generated for the determination of mount-model parameters by reference star observations. Another program now permits orbit determination using direction observations. Data handling and transfer software was written and tested.

Theoretical Works

A new concept of the Zimmerwald station was formulated by Bauersima (1981a). The Global Positioning System which will fully operate from the mid-eighties on was analyzed in (Bauersima, 1982a and 1983). The theoretical goals of the coming MERIT campaign were discussed by Bauersima (1980a). In (Beutler, 1982a, b) a modern structure of the parameter determination problem in Celestial Mechanics and Satellite Geodesy was developed.

Doppler Activities at the Institute of Geodesy and Photogrammetry, Zurich

by A. Geiger and H.-G. Kahle

Since 1980, two Magnavox Doppler receivers MX 1502 are available at the Institute of Geodesy and Photogrammetry, ETH Zurich. Since that time the Institute has taken part in the following Doppler campaigns, either by cooperation or by leaving their instruments to the principal investigating Institute:

- Calibration campaigns
- Pilot project of ALGEDOP
- Testnet Steiermark (Austria)
- EDOREF (France)
- Grindelwald (Switzerland)
- TIDOC (Tyrrhenian Sea)
- Egypt
- CIDOC (Ivory Coast)
- LIDOC (Ligurian Sea)
- ALGEDOP (Alpine Geoid Doppler Project)
- several local nets for test and teaching purposes.

For post-processing purposes the GEODOP program package has been installed on a CDC computer. The data transfer is ensured by a Tektronix terminal and a linked cassette reader. A 7- and 9-track tapedrive allows the data handling of any other tapes.

Programs for the visualization and plotting of the data have been developed and are also running on CDC.

Since the ALGEDOP campaign is aimed at determining the geoid, a special campaign for geodetic purposes will be carried out in Switzerland. Efforts are being made to automatize the tropospheric corrections.

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3 Gravimetry

Gravity Base Network and Calibration

Absolute Gravity Measurements

by H.-G. Kahle and St. Mueller

In a joint effort by the ETH Zurich, the University of Trieste and the Istituto di Metrologia, Torino, seven absolute gravity sites were established in Switzerland (see Map 4). The stations are intended to be a contribution to the Swiss National Gravity Net and to geodynamic investigations associated with the ongoing Alpine uplift (Kahle et al., 1981; Marson et al., 1981).

Gravity Meter Calibration Line Interlaken–Jungfraujoch

by H.-G. Kahle and E. Klingelé

Two absolute gravity meter sites (Interlaken and Jungfraujoch: elevation = 3456 m) form the end-points of a calibration line for relative field gravimeters. The gravity range of this line amounts to $605 \times 10^{-5} ms^{-2}$ (= 605 mgal). It can be traversed by train in a relatively short time interval of less than 3 hours (Klingelé and Kahle, 1981).

Swiss National Gravity Net (SNGN)

by W. Fischer

The Swiss National Gravity Net consists of several parts which have been measured over many years using Worden and LaCoste-Romberg Model G gravity meters (see Map 4). In the years 1978–80 a strengthening of the network took place by determinating the absolute gravity values in seven places. 1980 these absolute stations were connected to the neighbouring stations of the network by relative gravity measurements. In addition, a connection net between the absolute stations was measured 1980–81 using two LaCoste-Romberg gravimeters (G 317 and G 514). The measurements on the gravity meter calibration line Interlaken–Jungfraujoch with three gravimeters (LCR G 317, G 514 and D 16) belong also to these interconnections.

A common least squares adjustment of absolute and relative gravity measurements in this connection net showed some significant discrepancies between absolute and relative determination (Fischer et al., 1981). It is tempting to suppose that the two G meters are affected by periodic errors.

In a first step the Swiss National Gravity Net has recently been adjusted without consideration of any periodic errors (Fischer, 1983). In order to acquire a more distinct knowledge on the periodic errors of the gravimeter G 317, this instrument was operated together with the D 16 in the international D-meter campaign on the Hannover-Harz calibration line in April 1983.

Gravity Maps of Switzerland

by E. Klingelé, St. Mueller and E. Kissling

In the last few years, two new gravity maps of Switzerland were completed.

Isostatic Anomaly Map

The isostatic map (see Map 5) (Klingelé, 1979; Klingelé and Kissling, 1982) has been calculated with the Airy-Heiskanen model using the following parameters:

Densities: ρ_T = 2.67 g/cm^3 for the topography above sea level

ρ_C = 2.81 g/cm^3 for the crust between sea level and compensation level

ρ_M = 3.31 g/cm^3 below compensation level

Depth of compensation level: T_0 = 32 km

These parameters were adopted from results of seismic refraction surveys.

The size of the topographic blocks used for the calculation is 12' x 12'.

Bouguer Anomaly Map of Switzerland Corrected for the Molasse Sediments and the Ivrea Body

This map (see Map 6) (Kissling, 1980, 1982) is based on the Bouguer Anomaly Map of Switzerland (Klingelé and Olivier, 1979, 1980).

The effect of the Tertiary sediments of the Molasse basin has been calculated with a 3-D model based on borehole and seismic data as well as on density investigations of surface rocks.

The mafic and ultramafic rocks of the Ivrea body have been modelled with a 3-D model derived from local gravity studies, density investigations on surface rock samples, and seismic results.

Map of Rock Densities in Switzerland

by H.-G. Kahle

In a cooperative effort by the Swiss Geophysical Commission and the Swiss Geodetic Commission a project for determining in-situ densities of the major tectonic units of the Swiss Alps was initiated. The following methods are being employed: Nettleton profiles, borehole and tunnel profiles (Bürki, 1979; Leuthold, 1982; Meyer, 1982).

Investigations on Gravimetric Anomalies (Helvetic Nappes/Aar Massif)

by H.-G. Kahle, St. Mueller, P. J. Cagienard and E. Klingelé

The Aar Massif belongs to that part of the Central Alpine chain which has been uplifted during the processes which were accompanied by Alpine plate tectonics. Crustal sections across the Swiss Alps based on explosion-seismic results have revealed the existence of low-velocity zones which can be envisioned as decoupling horizons for crustal wedges. During the interaction of the Eurasian and African plates these crustal slabs were superimposed while compressional forces have played a dominating role in the zones of plate contact.

In a detailed study (Cagienard et al., 1982) gravity anomalies at the contact of the Helvetic Nappes and the Aar Massif were analyzed in an attempt to delineate the dip of the contact zone. The problems of assessing the geometry and the density contrast from the gravity gradients are discussed and the results are critically evaluated in the context of Alpine geodynamics.

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4 Theory and Evaluation

Geodetic Data Banks

by R. Conzett and A. Frank

The Institute of Geodesy and Photogrammetry, ETH Zurich, has been working for years on the development of data banks for space-related data. The first effort was directed towards an exact analysis and the corresponding representation of the necessary data structures in an entity-block-diagram. This is a precondition for the use of standardized data base systems, from which data bases with the corresponding structurized data administration can be compiled.
A first version of such a data base system, which is especially suited for treating the special structures of the space-related data in most geodetic applications, was developed and implemented.
The main parts of these data structures are abstract data types called «basic geometric structures», space-related storage and access methods and a query language which is directed to graphic-numeric interactivity.
A prototype on a mini-computer is now in an advanced stage of implementation.
In the field of data processing, this concept will be developed further and tested in a wide area of applications in geodesy, quite according to its increasing importance.

Data Processing and Evaluation

Geodetic Software System of the Federal Office of Topography

by A. Carosio

In the last few years, the Federal Office of Topography has been intensively engaged in modernizing its data processing applications. After having bought a PRIME 400 computer in 1978, a geodetic software system was developed and brought into effect (Carosio, 1981). The modular concept of the system and the standardized data structure were largely responsible for the early realization of an operationally efficient system.
In a first step, existing programs were adapted to the input-output standard with a minimum of changes and were then installed and ready for production almost immediately. This was the case for the horizontal and vertical network adjustment program (Gubler, 1982) and for some auxiliary software for the interpolation of deflections of the vertical and geoidal undulations (Gurtner, 1981).
In a second step, urgently needed new programs were written. Thus, several scientific studies found their way into practice, such as the robust adjustment (Carosio, 1979; Walter, 1980) and the arithmetic mean interpolation (Carosio, 1982). Furthermore, various interactive programs for collecting and preparing input data were written, of which the primary importance was the best realization of the dialogue man–machine (Carosio, 1981). Since the installation of a Kern GP1 plotter (1981), several graphic programs have been adapted or developed for the automatic plotting of different representations used in triangulation, such as a program developed at the Swiss Federal Institute of Technology for plotting network schemes (Siegerist, 1980) and one for representing displacement vectors (Carosio, 1983a).

Multivariate Testing Procedures and Reliability
by A. Carosio

From 1979 to the end of 1982, an encompassing study concerning the mutual relationship between multivariate testing procedures and reliability was conducted under the supervision of the Institute of Geodesy and Photogrammetry at the Swiss Federal Institute of Technology Zurich.
The work treats two relatively familiar problems: Based on measurements, models are tested with the purpose of determining any possible blunders. Secondly, the characteristics (specifically the reliability) of the models are analyzed to determine their consequences. A new suggestion is made to apply the NMAX-test, which is a combination of principal component analysis and order statistics. The results are published in a three-part report (Carosio, 1983b).
The first part contains an introduction with a summary of the practical problems which have to be solved in order to obtain geodetic networks free of blunders. The characteristics of the solutions are described as well as several indications to a systematic classification of the methods.
In the second part, various statistical tests used in geodesy are described in detail. Special attention is given to the practical application of intuitive procedures and how they relate to their corresponding tests in analytical statistics. In concluding part two, the proposal for applying the analysis of principal components in evaluating residual vectors is elaborated. In other words, suitable linear functions of the residuals are sought which will yield a series of stochastically independent auxiliary random variables. These values are tested with a method of order statistics (NMAX-test). This test is very sensitive in detecting blunders in small as well as in large networks.
The third part deals with the reliability of surveying systems. The key question, namely, what is the object of reliability, i. e. what can be considered reliable or unreliable, is of central importance and is discussed in the first chapter. This is followed by a description of the methods with which the reliability of surveying systems can be tested. A short review shows the relationships between the methods, starting with the more empirical application and proceeding to the reliability theory which Baarda based on the F-test. Furthermore, a new suggestion to broaden the reliability theory is introduced. The improved sensitivity of the analysis of principal components in detecting blunders leads to a different evaluation of the reliability of surveying systems. The mathematical derivations used in calculating the reliability as well as a possible procedure for their computation conclude the report.

Crustal Strain-Analysis
by D. Schneider

The repeated observation of precise geodetic networks is a welcome source of data for the investigation of relative crustal movements. It is in the nature of terrestrial geodetic observations that they can only provide relative geometrical information on the position of network stations. It is, therefore, not possible to determine absolute positions from such measurements. There always remain 2 to 4 indeterminable datum parameters.
There is a similar information defect if displacement vector fields are to be estimated from repeatedly observed geodetic networks (kinematic networks) (Vaníček and Krakiwsky, 1982). The indeterminable parameters of the time invariant geodetic networks are replaced by 2 to 4 indeterminable kinematic parameters (2 translation components, 1 rotation, 1 scale factor). In the case of the tectonic crustal movement analysis, it is, in general, not possible to remove this defect by physically realistic assumptions. Displacement vectors are obviously not suitable values for describing crustal deformation.
The gradient of the displacement field and the subsequently derived strain components are estimated according to the method of strain analysis. In this way, the problem of indeterminacy of displacements can be circumvented.
The estimated strain components can be displayed graphically. The display of the axes of maximum shear or the shear-rosettes proved to be most appropriate for the representation of the deformation in areas with transcurrent faulting.

A software package CRUSTRAIN for the simultaneous adjustment of repeatedly observed geodetic networks and the approximation of strain tensor-fields has been developed (Schneider, 1982). The method was tested with simulated networks as well as with a real kinematic configuration observed in the Jura. Subsequently it was applied to an investigation of an extensive kinematic network near Hollister, California (Savage et al., 1979), which spans the active San Andreas and Calaveras faults (Schneider, 1983). All computer programs are installed on the computer system of the Federal Office of Topography.

Two small quadrilaterals in the zone of the «Décrochement de Pontarlier» near Le Pont in the Jura have been observed three times (1973, 1974 and 1978) by the Federal Office of Topography (Jeanrichard, 1974). Precise EDM observations were made with the Kern Mekometer ME 3000 together with precise angle measurements. The crustal strain analysis of the presently available data yield no significant deformations of the southern quadrilateral on the 95% level of probability. The analysis revealed, however, that the design of the network is not optimal. It is recommended that the configuration be enlarged. In this way, it would be possible to determine whether accumulation of shearing strain or rigid block motion takes place. The possibility of computing pre-analyses with CRUSTRAIN should be used to improve the network design.

Treatment of the Third Dimension in Switzerland

3D-Adjustment

by N. Wunderlin

At the Institute of Geodesy and Photogrammetry at the Swiss Federal Institute of Technology Zurich a computer program in FORTRAN has been developed for least squares adjustments of terrestrial observations in a three-dimensional geocentric Cartesian coordinate system. This program RAUMTRI is in use for different purposes, both practical and didactical (Elmiger and Wunderlin, 1981, 1983; Schneider and Wunderlin, 1981; Wehrli and Wunderlin, 1983; Wunderlin, 1981).

Computation of Geoidal Heights and Deflections of the Vertical

by A. Elmiger and W. Gurtner

The methods of computation of geoidal heights and interpolation of deflections of the vertical currently used in Switzerland are based on least squares prediction, using astro-geodetic deflections reduced by means of a mass model. The astro-geodetic geoid determination of Switzerland was presented in the last National Report of 1975–1979.

Due to Switzerland's rough topography and taking into account the present inhomogeneous distribution of the vertical deflection points, all direct methods for the computation of an astro-geodetic geoid and for the interpolation of deflections of the vertical give rather poor results. Much better accuracies are obtained using so-called reduced deflections by subtracting from the observed deflections the influence of a model of the topography and the crustal structure (Moho discontinuity and an important mass anomaly: the Ivrea body). The reduced deflections, which are free from the curvature of the plumb line, define the well-known cogeoid. Its surface is much smoother than the geoid itself. The least squares prediction has shown to be a method very well suited for the computation of the cogeoid and it allows a simultaneous interpolation of reduced deflections. By adding the indirect effect of the mass model we obtain equipotential surfaces and deflections of the vertical in all desired altitudes. The computation of the quasigeoid is also possible (Gurtner, 1981; Gurtner and Elmiger, 1983).

The r. m. s. errors of the geoidal heights (relative to a reference point) turn out to be less than 10 cm in most parts of Switzerland. The r. m. s. errors of geoidal height differences between neighbouring points are so small ($< \pm 5$ mm/km) that their influence on the reduction of slope distances can be neglected. Surface deflections of the vertical can be interpolated in most parts with a r. m. s. error better than $\pm 1''$.

The developed software package can be used for the study of the fine structure of the geoid as well. Furthermore, it allows the computation of level surfaces, of height anomalies (quasigeoid elevations) and of the curvature of plumb lines.
In a further step, gravity measurements, consistently reduced by means of the same mass model, can be introduced in the computation of the cogeoid. The geoid is always obtained by adding the indirect effect of the mass model.

Height Determination of the Absolute Gravity Station Jungfraujoch (3456 m)
by F. Chaperon and A. Elmiger

Today absolute gravity measurements are possible with a high accuracy of some µgal (1 µgal = $10^{-8}ms^{-2}$ corresponds theoretically to a height-difference of 3 mm). Therefore, the height of such gravity stations should be determined, if possible, with corresponding accuracy in order to allow a reasonable interpretation of possible later changes of the gravity values.
The absolute gravity station Jungfraujoch is situated at an altitude of 3456 m above sea-level. The next official levelling line (of 2nd order) ends at Lauterbrunnen (altitude = 797 m a. s. l.) at a distance of about 8 km.
In order to determine the height of the gravity station Jungfraujoch, this point was connected with the levelling points in Lauterbrunnen by means of a triangulation network consisting mainly of interconnected EDM traverses (EDM equipment: generally infrared instruments, steep lines: Laser-Geodimeter and Mekometer ME 3000). Trigonometric measurements were executed with Kern theodolites DKM2-A.
Trigonometric height differences were computed in two systems:

a) orthometric heights (above the geoid): vertical angles were reduced to the geoid, applying the plumb line curvatures,
b) ellipsoidic heights: vertical angles were reduced to the ellipsoid by means of deflections of the vertical.

Both corrections were determined by the computer program LAG (Gurtner and Elmiger, 1983).
The height difference of about 2650 m could thus be determined with an accuracy (r. m. s. error) of ± 16 mm. These measurements, performed with reasonable but not highest accuracy, should be repeated at a later time.

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5 Physical Interpretation

Recent Crustal Movements

General Review
by E. Gubler and H.-G. Kahle

The present-day kinematics of the Swiss Alps can best be illustrated by the results of repeated precise levellings carried out by the Federal Office of Topography (Gubler, 1976). Between Basel and Aarburg (see Map 1) no significant changes have been noticed. Further south, however, the changes in elevation indicate an uplift of the following pattern: Near Luzern, where the Molasse submerges beneath the Helvetic Nappes, an annual uplift of 0.3 mm is observed. Between Luzern and Andermatt the recent crustal movements reach 1 mm/year. From the observed undulatory pattern of deformation in the St. Gotthard railway tunnel (Funk and Gubler, 1980) it can be surmised that the tunnel seems to have been subjected to compressional stress for the past few decades. While the uplift of the crystalline massifs terminates at the St. Gotthard, the most recent uplift still increases and reaches a maximum of 1.4 mm/year near Biasca, at a location within the Penninic Nappes (about 15 km north of Bellinzona). From thereon the uplift decreases towards Chiasso/Como, where a value of 0.8 mm/year has been determined.

Clark and Jaeger (1969) have found comparable uplift rates in the Alps for the period of the last 30 million years from geochronological studies. In this context it must be emphasized, however, that there are significant temporal and geographical changes in the uplift history as revealed by geological investigations (Truempy, 1973; Buechi and Truempy, 1976) and by age determinations on rock-forming minerals (Wagner and Reimer, 1972; Koeppel and Gruenenfelder, 1975; Purdy and Jaeger, 1976; Wagner et al., 1977).

Pavoni (1975) emphasized the close association between uplift rates and crustal stresses in the Alpine area, as derived from an analysis of focal mechanisms (Pavoni, 1976; Mayer-Rosa and Mueller, 1979). Jaeckli (1958) has ascertained denudation rates for the Alpine region which agree with the determined uplift rates.

Along the Rhine–Rhone line a significant lateral change in the uplift pattern has been observed: From Andermatt to Chur and to Brig/Visp, respectively, the uplift rates increase linearly to 1.7 mm/year. Since this pattern seems to correlate with a corresponding linear decrease in isostatic anomalies it is tempting to postulate a significant contribution of isostatic forces to the overall uplift mechanism.

Actual Results from the First Order Levelling Net
by E. Gubler

In 1971, studies to determine recent vertical crustal movements from first order levellings were undertaken (Jeanrichard, 1975). With the gradual progress of remeasuring the first order levelling net, the eastern part of Switzerland has been completed and vertical velocities have been computed relative to an arbitrarily chosen reference bench mark in Aarburg on the southern foot of the Jura (see Map 1).

Considering the error estimates, the new results agree well with the partial results published earlier (Gubler et al., 1981). The maximum vertical velocity was found to be + 1.5 ± 0.22 mm/year in the area of Brig in the Rhone Valley, whereas the vertical velocity in the area of Chur shows an uplift of + 1.4 ± 0.17 mm/year relative to the Swiss Plateau and the southern foot of the Jura.
Local investigations were made in the St. Gotthard railway tunnel (Funk and Gubler, 1980) and in the area of the Simplon pass and the Simplon railway tunnel (Gubler, 1981). Discontinuous movements in space and time were found in the area of Andermatt on the Rhine-Rhone line (Eckardt et al., 1983).

Displacement Profiles

by W. Fischer

In the year 1976, a measuring site was installed in a particular area of the Rhine-Rhone fault line, called Stöckli-Lutersee. It is situated east of Andermatt at a height of about 2400 m above sea-level. Reciprocal distances using the Mekometer ME 3000 and vertical angles have been measured every second year on six profiles perpendicular to the fault line. In one profile relative height changes in the order of 1.7 mm/year have been found between points on both sides of the fault line, while the other profiles seem to have been stable in the past years (Eckardt et al., 1983).

Gravimetric Geoid of Switzerland

by A. Geiger and H.-G. Kahle

After the completion of the new gravity maps of Switzerland (see Section 3 Gravimetry) it has become possible to make the gravity data available for gravimetric geoid calculations. We are at present studying this problem for the mountainous part of Switzerland.

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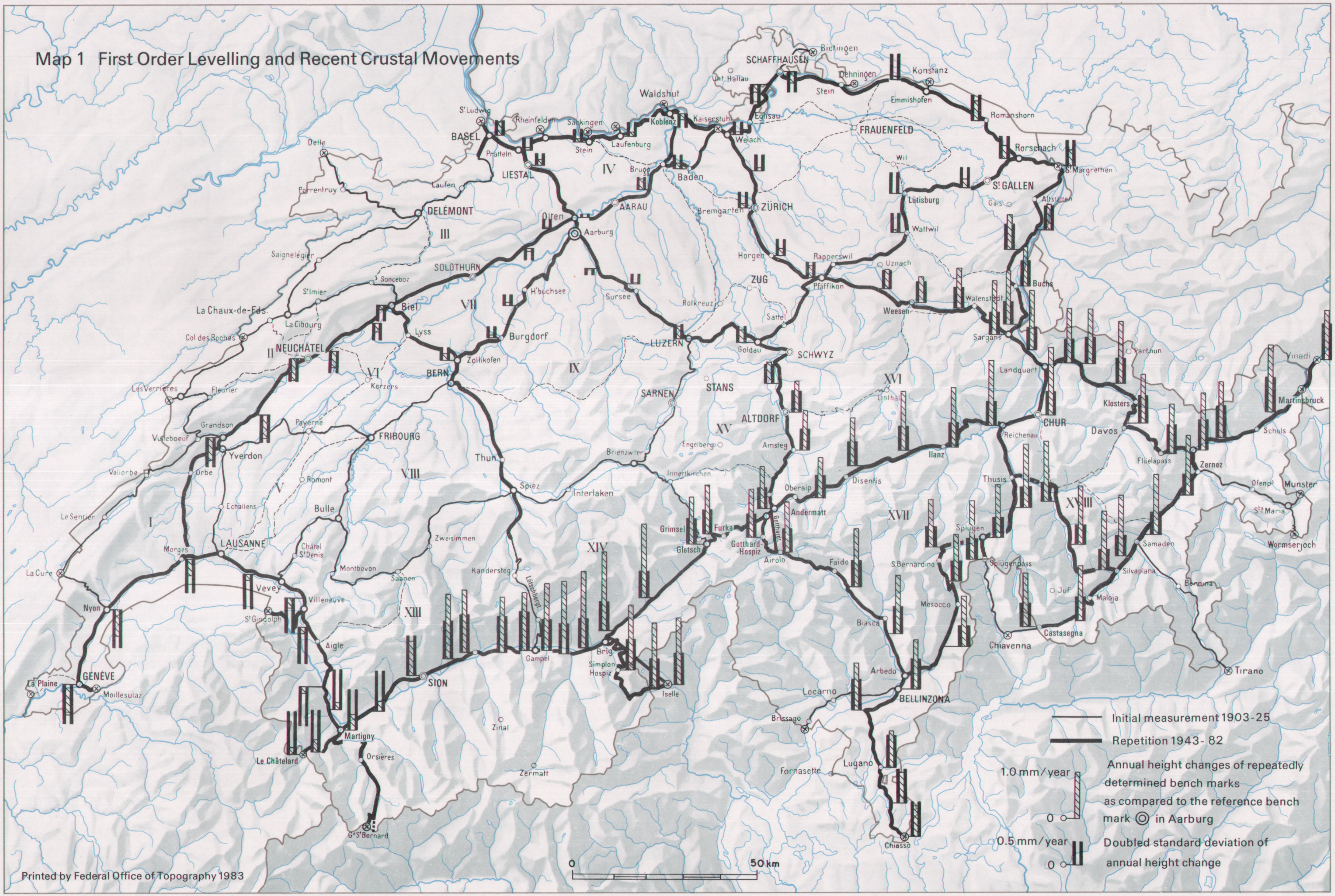
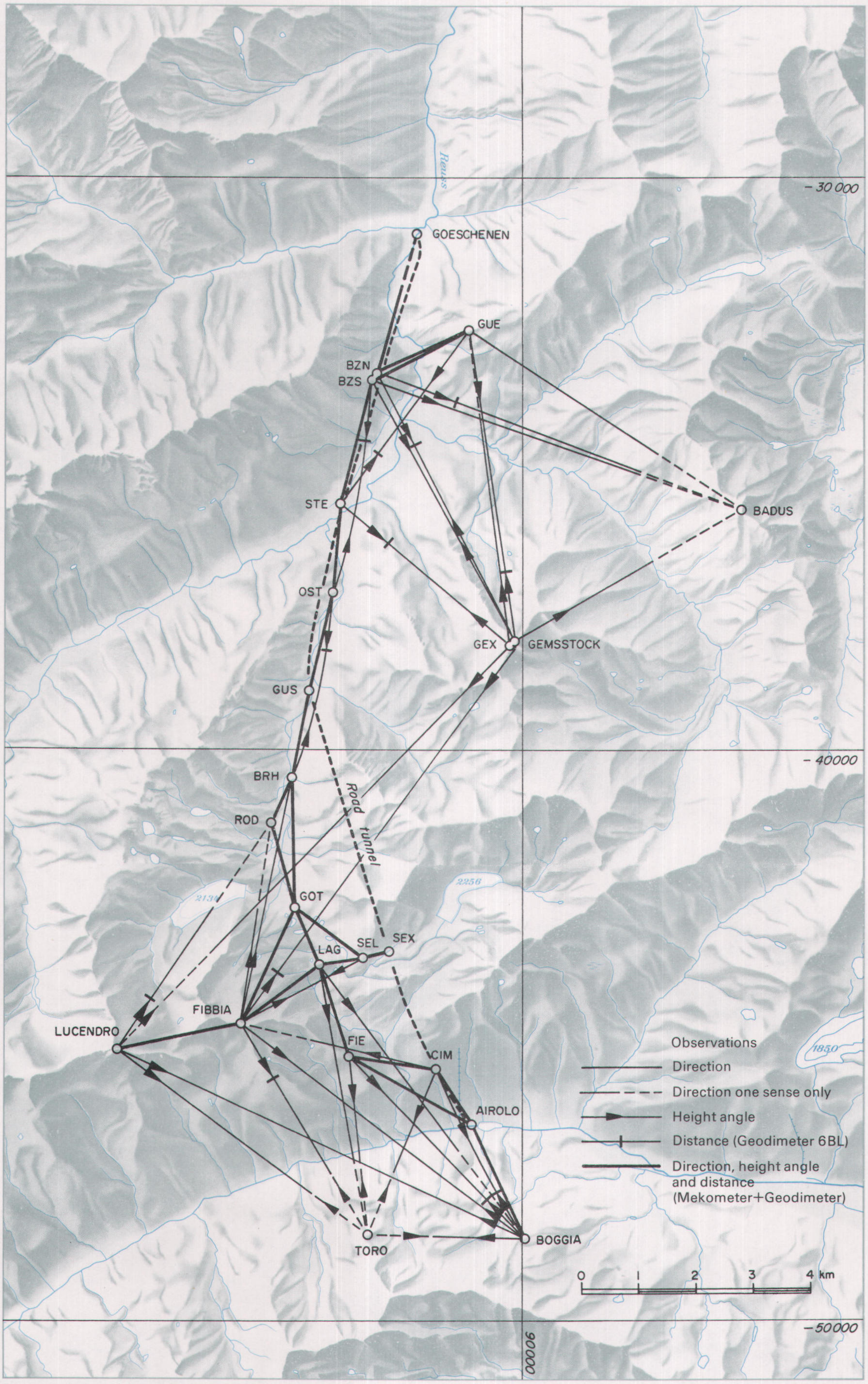
Map 1 First Order Levelling and Recent Crustal Movements



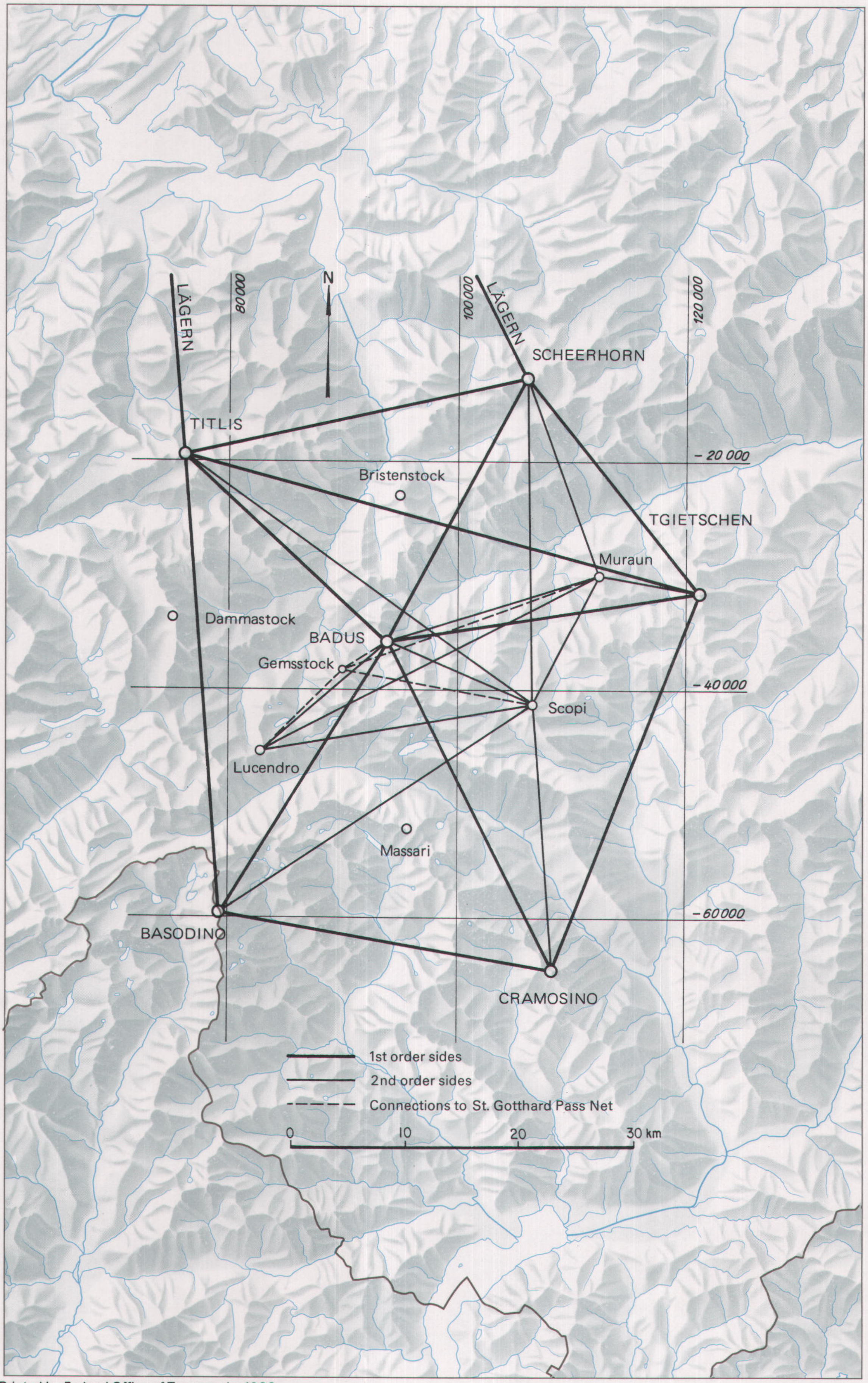
Printed by Federal Office of Topography 1983

Map 2 St. Gotthard Pass Net 1981



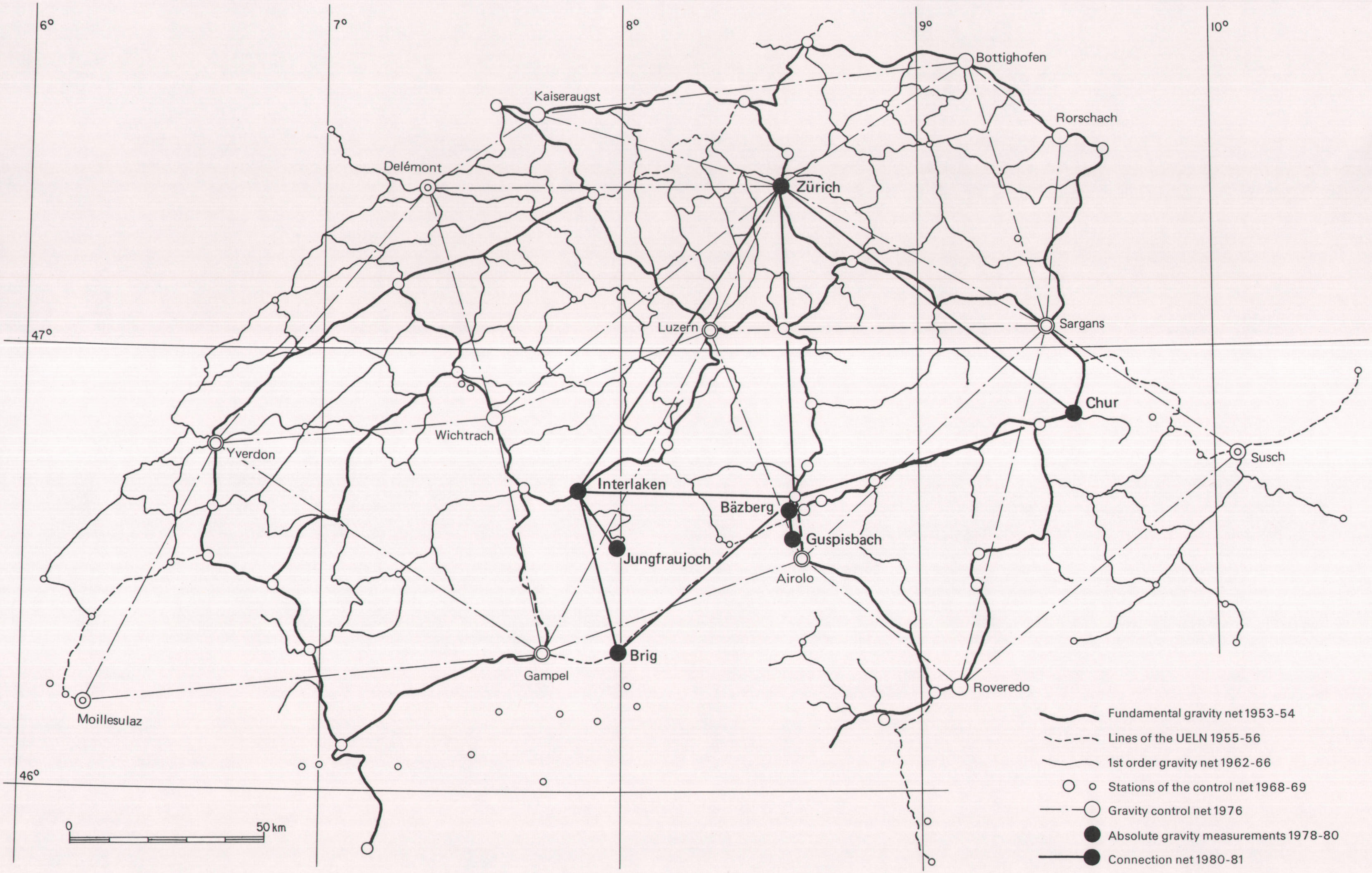
Printed by Federal Office of Topography 1983

Map 3 Test Net St. Gotthard



Printed by Federal Office of Topography 1983

Map 4 Swiss National Gravity Net



Map 5 Isostatic Anomaly Map

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Map 6 Corrected Bouguer Anomaly Map

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