GEODETIC WORK IN THE NETHERLANDS

1987-1990

Report prepared for the General Assembly of the International Association of Geodesy, XXth General Assembly of the International Union of Geodesy and Geophysics.
Vienna, 1991

NETHERLANDS GEODETIC COMMISSION

PUBLICATION OF THE NETHERLANDS GEODETIC COMMISSION

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CONTENTS

1. CONTROL SURVEYS

1.1 Horizontal control

1.1.1 Contribution to ED87

In 1987 the finishing touch was given to the Netherlands contribution to the European triangulation network (RETrig). Much attention was paid to the quality control of the Netherlands block, with satisfactory results. The computations were carried out with the adjustment-programme ASTRID. This software suite includes sophisticated precision and reliability measures and statistical testing procedures, based on the SCAN-II software system developed by the Delft University of Technology. The buffermatrix for the Helmert-Wolf blocking method was delivered to the international computing centre (ICC) for RETrig in Munich and after having received the ICC-solution, a back substitution was carried out, so for all primary triangulation points in the Netherlands ED87 coordinates are available now.

1.1.2 Introduction of GPS

In 1987 field experiments with GPS by the Netherlands Triangulation Department were very succesful, so that the decision was made to purchase three Trimble 4000 SX single frequency receivers. One year later two more Trimble GPS receivers were bought, dual frequency SLD receivers now. Recently at the end of 1990 the number of dual frequency receivers was increased by two Trimble-SST-IIP receivers. At that moment the Netherlands Triangulation Department had the disposal of 9 GPS receivers:

- 5 ten channel Trimble 4000SL single frequency receivers;
- 2 five channel Trimble 4000SLD dual frequency receivers;
- 2 eight channel Trimble SST-IIP dual frequency receivers.

For the adjustment of the GPS observations a new software suite HANNA has been developed. This programme system is based upon an ellipsoidal adjustment model and allows the integrated adjustment of a large number of geodetic observations i.e. horizontal and vertical directions, azimuths, distances, height differences and GPS baselines. The programme can produce coordinates in the national datums RD (horizontal: Rijksdriehoeksmeting) and NAP (vertical: Normaal Amsterdams Peil). The orthometric heights are obtained via geoidal undulations from the model Van Willigen (1986).

1.1.3 The EUREF GPS campaign

In 1989 the Netherlands Triangulation Department participated in the EUREF GPS campaign. This campaign will contribute to the establishment of a new three-dimensional European reference system. In the Netherlands the points Delft, Huisduinen, Kootwijk and Westerbork (points belonging to the RETrig network as well) were occupied by Trimble 4000SLD receivers. After preliminary computations to check the integrity of the observations the data has been made available for central processing.

1.1.4 NEREF

In close cooperation between the Netherlands Triangulation Department, the Survey Department of Rijkswaterstaat and the Delft University of Technology plans have been made to densify the EUREF GPS network. As a first stage of this project 13 stations with an interstation distance of about 60-80 kilometres will be observed. This network will form the Netherlands Reference Frame (NEREF). The measurements will be carried out in 1991.

1.1.5 The impact of GPS on horizontal control

Since 1988 GPS is used as the primary survey tool for the maintenance of the Dutch horizontal reference system. Theodolite and electronic distance meter are abandoned now, exept for local measurements to connect the different reference marks. Unfortunately the existing point-field is less suitable for the use of GPS. Due to the fact that the Netherlands has a rather flat topography, church towers and other high buildings were selected as survey stations. These buildings however are poorly accessible and obstruct the sky. Therefore easily accessible and stable terrain points are preferred. Now there are plans to realize additional control points with an interstation distance of approximately 10-15 kilometres. These points should have an unobstructed view of the sky to make GPS measurements possible.
As a first phase these points should be tied to the surrounding control network (the existing network has a mean interstation distance of about 2-2.5 km). Through these points the user will have a very user-friendly access to the national horizontal reference system, while these points can be used for maintaining the existing system for those who will keep using "classical" survey methods.
In a second phase these new points will be observed as a nation-wide GPS network that will be connected to the EUREF network. By this it will be possible to compute coordinates in the new European reference system and to determine transformation parameters between the old and the new system to fulfil the requirements of the mapping and navigation community.

1.1.6 GPS project Costa Rica

In 1990 the Netherlands Triangulation Department realized with GPS a first order network in Costa Rica consisting of 33 points, mainly existing of old triangulation points. Dual as well as single frequency receivers were used. This network will serve as the National Geodetic Base and was required as one of the preparatory activities in the process to get a reliable cadastre.
During a nearly two month's campaign the observations were obtained on points with difficult access and large height differences (up to 3500 meters) under very variable meteorological circumstances.

1.2 Levelling

1.2.1 Strategy

All heights in the Netherlands are related to NAP (Amsterdam Height Datum), which is constituted by some 175 underground benchmarks. In total some 52000 benchmark heights are being published. In 1986 the 300th anniversary of the NAP was commemorated (Waalewijn, 1987).
The objective is to measure all benchmarks in the Netherlands once every 10 years via second order levelling; in areas which are unstable, i.e. areas with subsidence of over 3 mm per year, every five years. This means that for the time being no primary national levelling network is maintained (except for some hydrostatic levelling), and that the heights of underground benchmarks and tide gauges are derived from kinematic adjustment of the secondary levelling. These heights are essential for the determination of regional land subsidence in the Netherlands and the measurement of sea level rise (see section 5).
A study reconfirmed the value of hydrostatic levelling for a country like the Netherlands, with its unmatched precision and abilities (Beusekom et al., 1990), even in view of the advent of GPS.

1.2.2 Measurements

The measurement of secondary levellings in the first plan period have been completed. The remeasurement of the complete secondary network in the second plan period (1987-1996) was started. In total some 500 km primary levelling (geometric and hydrostatic) and 12000 km secondary levelling have been measured. In addition, almost 750 km tertiary levelling have been measured which had been planned for the first plan period.

1.2.3 Special projects

Several special hydrostatic levellings were performed to determine heights of offshore tide gauges in the Dutch and German parts of the Waddenzee and along the Belgium coast; e.g. (Van Beusekom, 1989).

1.3 Marine-geodetic activities of the Hydrographic Service of the Royal Netherlands Navy

1.3.1 The Netherlands

Hydrographic surveys were carried out in shipping lanes, deep draught routes, coastal areas and newly created traffic seperation zones, due to intensified mineral exploitation activities.
Critical areas are surveyed by a three dimensional seafloor mapping system. Horizontal control during the surveys was provided by a 2 MHz-radiopositioning system.

1.3.2 Caribbean

In 1988 surveys were carried out on the Saba-bank and coastal areas near St. Maarten and Curaçao. Network control was performed with NAVSTAR/GPS while horizontal control during the surveys was carried out with EDM-systems and Differential NAVSTAR/GPS.

1.3.3 Continental Shelf Activities

On behalf of the Ministry of Economic Affairs checks were carried out on positioning data of mineral installations and on boundary and area computations.
In close cooperation with involved institutions of other North Sea countries an algorithm has been developed for the transformation of WGS84-coordinates to ED50-coordinates for exploration purposes. A publication is published by the Norwegian Mapping Authority in 1991.

1.3.4 General

On an ad hoc basis computations were carried out and related charts supplied to the ministries of foreign and internal affairs to support national and international deliberations on boundary matters.

1.4 Publications

1.4.1 Control Surveys

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GELDER, B.H.W. VAN - Introduction and Satellite Geodesy: the Model. Chapter 1 (4pp) and 2 (55pp) in Textbook GPS, Navigation and Geodetic Point Positioning with the Global Positioning System by F.J.J. Brouwer, J. van Buren, B.H.W. van Gelder, G.J. Husti, C.D. de Jong, G. de Jong, J.C. de Munck, H.J.W. van der Vegt. Delft University Press, 1989.

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1.4.2 Levelling

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WAALEWIJN, A. (ed.) - Drie Eeuwen Normaal Amsterdams Peil, Hoofddirectie van de Waterstaat, RWS-serie nr. 48, 2e herziene druk, 's-Gravenhage, 1987. In Dutch.

1.4.3 Marine-geodesy

BAKKER, G., J.C. DE MUNCK , G.L. STRANG VAN HEES - Radio Positioning at Sea, Geodetic Survey Computations and Least Squares Adjustment, Textbook, Delft University Press, 1989.

HAAGMANS, J., H.J.W. VAN DER VEGT - (Differential) GPS and Landsat TM: useful tools in hydrographic surveying ? Experiences gained in the Netherlands Antilles, 1990.

STRANG VAN HEES, G.L. - Precision of Radio Positioning Systems, Hydrographic Journal, October 1987.

2. SPACE TECHNIQUES

2.1 Introduction

In May 1987, the project "Earth Oriented Space Research at Delft University of Technology" was started as a cooperative effort of the Section Orbital Mechanics (SOM) of the Faculty of Aerospace Engineering, and the Section Fysische Meetkundige en Ruimtegeodesie (FMR) of the Faculty of Geodetic Engineering (Till medium 1990 FMR consisted of the groups Satellite Geodesy (SG) and Fysische en Meetkundige Geodesie (FM)). Both groups have a long experience in satellite laser ranging, satellite orbit mechanics, and physical and space geodesy, and already cooperate since 1976. The decision to formally join their research efforts was taken to bring together the relevant expertise of the groups and to create a larger team that could more effectively cover the large field of research topics.

The overall research theme can be divided into five major fields of interest: tracking and orbit determination, crustal dynamics, earth rotation, gravity field, and marine geoid and ocean currents. The research is funded by Delft University of Technology (DUT), Netherlands Organization for Scientific Research (NWO), Space Research Organization Netherlands (SRON) and Netherlands Remote Sensing Board (BCRS).

Research in VLBI is carried by the Survey Department of Rijkswaterstaat and the Netherlands Foundation for Research in Astronomy with support of the Geodetic Computer Centre of the Delft University of Technology. Analysis of data of the ESA Hipperacos satellite is performed by the Geodetic Computing Centre of the DUT in cooperation with the space research laboratory Utrecht of SRON.

2.2 National and international cooperation

The majority of the performed research is embedded in the following long-term international research projects:

- NASA Crustal Dynamics Project.
  This project is led by the NASA Goddard Space Flight Center and aims primarily at the detection and modeling of deformations of the earth's crust and at the determination of the earth rotation. Until 1988 the DUT team was only involved in the laser tracking of satellites and the processing of satellite laser ranging observations. In 1989 the analysis of GPS observations for geodetic and geodynamic applications has started, and since 1990 a stationary high-quality GPS receiver is operating at the Kootwijk Observatory for Satellite Geodesy. It is expected that this research will be continued in the NASA follow-on project: Dynamics of the Solid Earth.
- WEGENER-MEDLAS Project.
  This project is linked to the Crustal Dynamics Project. It aims primarily at the detection of actual crustal motions in the eastern part of the Mediterranean region. During the last years, this has primarily been achieved through the analysis of laser ranging data to the LAGEOS-1 satellite. The contribution by the DUT team is twofold: data acquisition by the Modular Transportable Laser Ranging System MTLRS-2 and the analysis of the data from various measurement campaigns.
- International Earth Rotation Service.
  This project, which is executed under the auspices of the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG), aims primarily at the determination of the rotational motion of the earth with a high temporal resolution. In 1988, the DUT team has accepted the task to act for a period of at least 10 years as one of the operational laser data analysis centers and to produce weekly semi-realtime solutions for the data analysis the earth rotation parameters from quick-look laser measurements. High-precision earth rotation parameter solutions are computed once a year from full-rate laser measurements.

- LAGEOS-2 Project.
  According to the present plans LAGEOS-2 will be launched in 1993. The DUT team intends to combine the LAGEOS-1 and LAGEOS-2 observations for their research in the framework of the NASA Dynamics of the Solid Earth Project and the WEGENER-MEDLAS Project. The combination of the data from two different satellites will allow the determination of accurate station positions from shorter measuring campaigns. It will also facilitate the computation of earth rotation parameters with an improved temporal resolution.
- ERS-1 Project.
  One of the instruments on board of ERS-1, to be launched in May 1991, is a radar altimeter. The data produced by this instrument will be processed by the DUT team, in cooperation with the Institute of Meteorology and Oceanography (IMOU, Utrecht University), the Netherlands Institute for Sea Research (NIOZ) and the Tidal Waters Division of Rijkswaterstaat. The research aims primarily at the computation of precise ERS-1 orbits, the modeling of the marine geoid and the measurement of large-scale ocean currents.
- TOPEX/POSEIDON Project.
  In 1992 the NASA/CNES TOPEX/POSEIDON radar altimetry satellite will be launched. The above mentioned Dutch radar altimeter team will also process data from this satellite. For both the ERS-1 and the TOPEX/POSEIDON projects extensive preparatory investigations have started, in which intensive use is made of altimeter data provided by the US Navy GEOSAT satellite.
- ESA ARISTOTELES Project.
  ESA and NASA will probably launch the ARISTOTELES earth's gravity and magnetic field satellite around 1997. From the start of the mission design and definition phases, the DUT team has been involved in the preparations for this mission and this team will continue its pre-launch research activities. These activities will focus on the development of suitable techniques to process the large amount of gradiometer and GPS measurements to be produced by this satellite.
- VLBI GINFEST Project.
  The Dutch Westerbork Synthesis Radio Telescope (WSRT) participated in GINFEST, being part of the European VLBI network.

2.2.1 Tracking and orbit determination

The determination of precise satellite orbits from various types of tracking data is instrumental for each of the fields of interest mentioned above. The DUT team is already for a long time actively involved in several aspects of satellite tracking and orbit determination.
FMR operates a third-generation mobile laser ranging system MTLRS-2, which will continue operations into the second half of the nineties. The precise coordinates of the geodetic reference point at Kootwijk will be maintained through regular observation campaigns with MTLRS-2. A top-quality GPS receiver has recently been installed at the Observatory. This event marked the start of a period in which the DUT team will be involved in the tracking of all GPS satellites and the orbit computation of these satellites, using the tracking data from the Kootwijk receiver and other globally distributed tracking systems. For this activity a special cooperation with the NASA Jet Propulsion Laboratory (JPL) has been established. In this way, the Kootwijk Observatory will become one of the fiducial stations of the global GPS tracking network.
For tracking ERS-1 and later ESA satellites, a PRARE ground station will be installed at the Kootwijk Observatory in early 1991. The availability of both a GPS receiver and a PRARE transponder at the laser site will offer the possibility to tie the global laser, GPS and PRARE station coordinates systems. MTLRS-2 will provide laser tracking support for the ERS-1 and TOPEX/POSEIDON radar altimeter missions. This support will include participation in the ERS-1 altimeter calibration experiment near Venice. MTLRS-2 will also be used to support scientific activities related to earth oriented space research, e.g. GPS reference station positioning and collocation experiments with other laser ranging systems. The table below summarizes the site occupations of MTLRS-2 and the number of LAGEOS passes actually tracked during the reporting period.

	Site	Country	Year	Period		Passes
7512	Kattavia	Greece	1987	March 23	- May 5	61
7510	Askites	Greece	1987	June 13	- August 28	131
7544	Lampedusa	Italy	1987	Sept. 16	- Dec. 12	87
7545	Punta sa Menta	Italy	1988	Jan. 15	- March 23	58
7546	Medicina	Italy	1988	April 24	- June 3	12
8833	Kootwijk	Holland	1988	June 14	- Sept. 21	53
7550	Basovizza	Italy	1989	June 5	- July 17	22
7510	Askites	Greece	1989	Sept. 1	- Oct. 25	25
8833	Kootwijk	Holland	1990	July 3	- July 30	37
7602	Tromsö	Norway	1990	August 11	- Sept. 19	50
7543	Noto	Italy	1990	Nov. 17	- Dec. 12	50

The tracking data acquired by global laser and radio-frequency tracking systems on the LAGEOS-1, LAGEOS-2, STARLETTE, AJISAI, ERS-1, TOPEX/POSEIDON and GPS satellites are and will be processed by SOM to determine very-accurate orbits for these satellites. In the orbit determination numerical estimation process, a number of force model parameters and various geodetic and geophysical model parameters are solved for simultaneously. The results will improve the model quality and may provide interesting geodetic and geophysical information. The laser measurements are and will be used primarily to determine the coordinates of geodetic reference points on earth and the long-term changes of these coordinates, and to determine earth rotation parameters. The global GPS tracking data will be processed to determine medium- and large-scale crustal dynamics.
For the ERS-1 and TOPEX/POSEIDON satellites, a major effort is being spent in the development and application of new techniques to determine the very-accurate orbits required for these altimetry missions. The altimeter data provided by these satellites will be combined with the laser and radio-frequency measurements to achieve the highest orbit accuracy.

2.2.2 Satellite Radio Positioning, GPS-Positioning

During the period 1987 to mid 1989 the Netherlands Geodetic Commission owned two Trimble 4000S receivers (one frequency). The main purpose of these receivers was to make them available to organisations of the Dutch geodetic community in order to:
- introduce GPS technology;
- enable an evaluation on practical applications;
- gain experience;
- execute research projects.

This goal was achieved in a cooperative effort between Delft University of Technology, Government agencies and private firms. They take part in a working group, established to exchange experience and ideas. In a coordinated effort the receivers were allocated to various projects.
The main research projects were the use of GPS to:
- determine camera positions during aerial photography and in general to reduce the amount of required ground control;
- monitor subsidence of offshore platforms.

In addition the receivers were used for training of students and in several international projects, viz.:
- WEGENER-MEDLAS project to monitor local deformations near satellite mobile laser ranging stations in the Mediterranean area;
- station measurements in Sicily under the auspices of the "Deutsches Geodätisches Forschungs Institut";
- kinematic measurements in the Atlantic Ocean for the Alfred Wegener Institut in Bremerhafen;
- a cooperative project with the Observatory of Penc in Hungary.

By mid 1989 many organizations had bought their own receivers. The receivers of the Geodetic Commission were sold, having fulfilled their objective of increasing the awareness of GPS in the Netherlands.

2.2.3 *Very Long Baseline Interferometry (VLBI)*

The Dutch research efforts for the geodetic applications of VLBI were continued. Contributions came from the Geodetic Computing Centre of the Delft University of Technology, the Netherlands Foundation for Research in Astronomy and the Survey Department of Rijkswaterstaat. The objective of the research activities was, as before, the assessment of the accuracy of geodetic VLBI point positioning via the design of computing models and the analysis of real and simulated data with own developed software.
Two specific fields were addressed via a graduate thesis as concerns modeling: firstly, the influence of special and general relativity on VLBI observations, and secondly the estimability of crustal dynamics from VLBI-observations. In addition, analyses were made of the GINFEST-I and GINFEST-II VLBI campaigns of June and October 1987, in which also the Dutch Westerbork Synthesis Radio Telescope (WSRT) participated, being part of the European VLBI Network (EVN) (Brouwer and Boer, 1988).
Recently, the interest shifted more to the contribution of VLBI as a "backbone" in determining the vertical crustal motion component in relative sea level rise (Brouwer and Molendijk, 1989), (Brouwer, Molendijk and Campbell, 1990). In addition, a study was started to investigate the application of geodetic VLBI analysis techniques for phase referencing VLBI for astrometry (Jongeneelen, 1989). In this field, the Netherlands also participates in the activities of the European Working Group for Geodetic and Astrometric VLBI, which meets approximately every one and a half year.
As concerns the observation facilities, the WSRT is at present equiped with a hydrogen maser and MARK-III VLBI terminal, but S/X-receiving capability (the standard for international projects like IERS and CDP) is still lacking. However, the development of a multi-frequency front-end is in progress at the WSRT.

2.3 Crustal dynamics

The major activity of the DUT team in the field of crustal dynamics has been the participation in the "Working group of European Geoscientists for the Establishment of Networks for Earthquake Research" (WEGENER). This activity will be continued at a similar level for a number of years. The mobile laser system MTLRS-2 is the Dutch contribution to MEDLAS, the satellite laser ranging project of WEGENER. This project aims at the determination of crustal motions in the Mediterranean region. This is accomplished by processing laser range observations acquired by three mobile systems which occupy a number of sites in this region.
Repeated laser ranging will be performed at various sites and the detailed analysis of these data will lead to a better understanding of the present-day crustal deformations in this very interesting geographical area. Since 1986, the DUT team acts as one of the Data Analysis Centers of the European WEGENER-MEDLAS project and processes LAGEOS-1 laser tracking data on a semi-operational basis. The purpose is the computation of precise LAGEOS-1 orbits and the accurate determination of the geodetic coordinates of the laser tracking systems. The orbits are routinely computed with an accuracy of better than a few decimeters. These results are used for the determination of motions of the earth's crust.
The first three WEGENER-MEDLAS campaigns took place in 1986, 1987 and 1989. These observations have already been processed by the DUT team. This has resulted in a series of very accurate coordinates for the sites occupied by the laser systems. From the coordinate changes, a first model for the tectonic motions in the Mediterranean region has been derived. Application of GPS to densification of the existing laser stations networks will lead to more detailed knowlegde in space and time of the dynamics of the earth's crust.

2.4 Earth rotation

In 1988 SOM accepted a commitment to determine earth rotation parameters from laser tracking data to LAGEOS-1 on a continuous basis. These parameters are transmitted weekly to the International Earth Rotation Service (IERS) Project of the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG). These earth rotation parameters are combined by IERS with results obtained by other measurement techniques to yield the best solution for the actual rotational motion of the earth. After LAGEOS-2 data will become available, SOM will produce earth rotation parameters with a higher temporal resolution, by processing both LAGEOS-1 and LAGEOS-2 measurements. The information is also used at DUT to study the mechanisms and processes which affect the earth rotation.

2.5 Satellite gradiometry

The research in satellite gradiometry is closely related to the preparations inside the European Space Agency (ESA) to launch the geopotential satellite ARISTOTELES in the second half of the nineties. ARISTOTELES shall contain a flat (two-dimensional) gradiometer capable of measuring the cross-track components Γ_{yy}, Γ_{yz}, and Γ_{zz} (y = cross-track, z = radial). It shall fly in an almost polar and circular orbit at an altitude of 200 km. In support of this project ESA also initiated two large general studies on precise gravity field determination, called CIGAR I and II, involving several European geodetic institutions. In the context of the research project "Earth Orientated Space Research" Delft has been involved in all these activities.
The purpose of satellite gradiometry is the determination of the earth's gravitational field from gradiometric measurements. In case of a global determination the gravity field usually is expressed in a series of spherical harmonics with its coefficients as unknown parameters. Principally this problem can be approached from two alternative angles. The gradiometric measurements can be con- sidered as boundary values on a surface in satellite altitude generated by the total set of orbits. In this case the gravity field at the earth's surface is derived from a solution of a uniquely or over-determined geodetic boundary value problem in finite approximation. Alternatively the measurements can be viewed as a time series along the orbit from which the spherical harmonic coefficients are derived using the methods of dynamic satellite geodesy. The two approaches are referred to as space-wise and time-wise method, respectively. With both methods error propagation studies have been performed for a variety of mission scenarios. For a truly polar orbit the two methods yield identical results. It could be shown that for a 6 months ARISTOTELES mission at 200 km with measured gradiometer components Γ_{yy}, Γ_{zy}, and Γ_{zz} the mission goals of 5mGal (5.10^{-5} ms^{-2}) in gravity, and 10 cm in geoid can be met, if a gradient measurement precision of 0,01 E (10^{-7} s^{-2}) is assumed. The space-wise method has also been applied to two months of simulated gradiometer data at 160 km altitude of the University of Texas. The applied adjustment model enforces block-symmetry of the normal equations and can be employed even for series expansions up to very high degrees and orders. The coefficients were determined up to degree 180; up to degree 160 the signal to noise ratio is greater than one.
For an actual gradiometric experiment a number of complications have to be taken into account. We mention non-symmetry of the involved accelerometers, alignment and orientation errors, calibration uncertainties, residual drag fluctuations affecting the measured cross-track gradient components, the variations in eigen-gravitation of the mass of the spacecraft due to fuel consumption and sloshing or the centrifugal and inertial rotation effect of the spacecraft rotation on the measured gradients. A very serious problem is posed by the limited bandwith of the gradiometer. It meets the precision requirement of 0.01 E only in the frequency range between 5.10^{-3} to 0.25 Hz. Our time-wise analysis method is very well suited to compute the effect of band limitation on the gravity field determination. It could be shown that this problem will result in a significant degradation of the mission. As a result it has been proposed to include space-borne GPS into the ARISTOTELES satellite. From first error simulations it can be concluded that from the combination of gradiometry and GPS the original mission goals can not only be met but even improved, (<1 mGal for gravity and <3 cm for geoid height and degrees smaller than 250). This is caused by the strength of GPS phase measurements for the improvement of the very long wavelength part of the earth's gravity field.

2.6 Marine geoid and ocean currents

The DUT team participates in the (preparation for the) ESA ERS-1 and TOPEX/POSEIDON altimeter missions. The general theme of this research includes the tracking of the satellites by the Dutch MTLRS-2 mobile laser and the PRARE system, the computation of precise orbits for these satellites from laser, PRARE, DORIS, GPS and altimeter measurements, and the processing of the satellite altimeter measurements to generate relevant geophysical and oceanographic results. Specific topics which are investigated are the modeling of the mean sea surface and the derivation of marine gravity field information, and the detection and modeling of large-scale ocean currents. The latter investigation focuses both on the semi-permanent component of the current systems and on the time-variations of these systems. Special attention is paid to the evaluation of accuracy and validity of processing models in altimetry.
In preparation for the research in these missions, the Delft team has started processing GEOSAT altimeter data, taken over the South-East Atlantic and over the North Atlantic. Models for the mean sea surface have been developed, which reflect in fine detail many bathymetric features. In addition, detailed information about the sea surface variability has been obtained. Special emphasis has been given to the development of techniques to map the long-term motion of mesoscale eddies and to determine the eddy motion characteristics, and to map the semi-permanent ocean currents.

2.7 Publications

2.7.1 Tracking and orbit determination, Crustal dynamics, Earth rotation, Marine geoid and ocean currents

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AMBROSIUS, B.A.C., R. NOOMEN, H. LEENMAN, K.F. WAKKER, R.J. DE MUYNCK - Quick-look data analysis: An overview, paper presented at the 4th International Conference on the WEGENER/MEDLAS Project, Scheveningen, June 1989, Conference Proceedings, Delft University of Technology, February 1990, pp. 349-370.

AMBROSIUS, B.A.C., R. NOOMEN, K.F. WAKKER - The DUT approach of the SLR data analysis for IERS. Report for the International Earth Rotation Service (IERS), Paris and Washington, November 1990.

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3. GRAVIMETRY

3.1 Land gravimetry

In 1988 the Survey Department of Rijkswaterstaat, in cooperation with the Delft University of Technology, completed the first measurement of the new primary gravity network. The measurements were carried out using gravimeters that were kindly provided by the Munich University of Technology and the Stuttgart University of Technology. The primary network consists of 22 points in the Netherlands, and is connected to the neighbouring countries by means of 6 points (3 in Germany, 3 in Belgium). The points in the Netherlands consist of first order underground benchmarks. These benchmarks are founded in the upper reaches of the Pleistocene layers, and therefore satisfy the high requirements of modern precise gravimetry.
In 1990 a second measurement of the primary network was started; this will be completed in 1991. The decision whether the frequency of measurement will be adjusted in the coming years, will be based on the comparison between the results of the two campaigns.
Also in 1990, the measurement of a second order gravity network was started by the Survey Department of Rijkswaterstaat. In cooperation with the Delft University of Technology a network with a density of 1 point per 5 km^2 was constructed. This density seems to be sufficient right now, but it may be changed during the project. The measurement of the network is expected to be completed in 1993.
The new LaCoste Romberg gravimeter (type G) of the Survey Department of Rijkswaterstaat, which was obtained in 1990, and the gravimeter of Delft University of Technology will be used for the measurement.
Preparations have been made for a first absolute gravity measurement in Dutch history. This will be carried out in September 1991 on three fundamental stations: Kootwijk, Westerbork and Delft. Apart from the application as constraints for the Dutch gravity networks, the absolute gravity measurements are also expected to improve discrimination between land subsidence and sealevel rise, matters of major concern for the Netherlands.
Tidal registrations have been made in Delft and at the satellite observatory in Kootwijk. The difference between the registrations and the theoretical computed tides shows a mean standard deviation of about 6 microgal.

3.2 Geoid determination

The previously mentioned second order gravity network will be used to calculate the (relative) geoidal height in the Netherlands with an expected 1-cm precision. Theoretical research on this topic is being carried out at Delft University of Technology. Taking into account the expected year of completion for the measurement of the second order network, this high-precision geoid will not be available until 1994.

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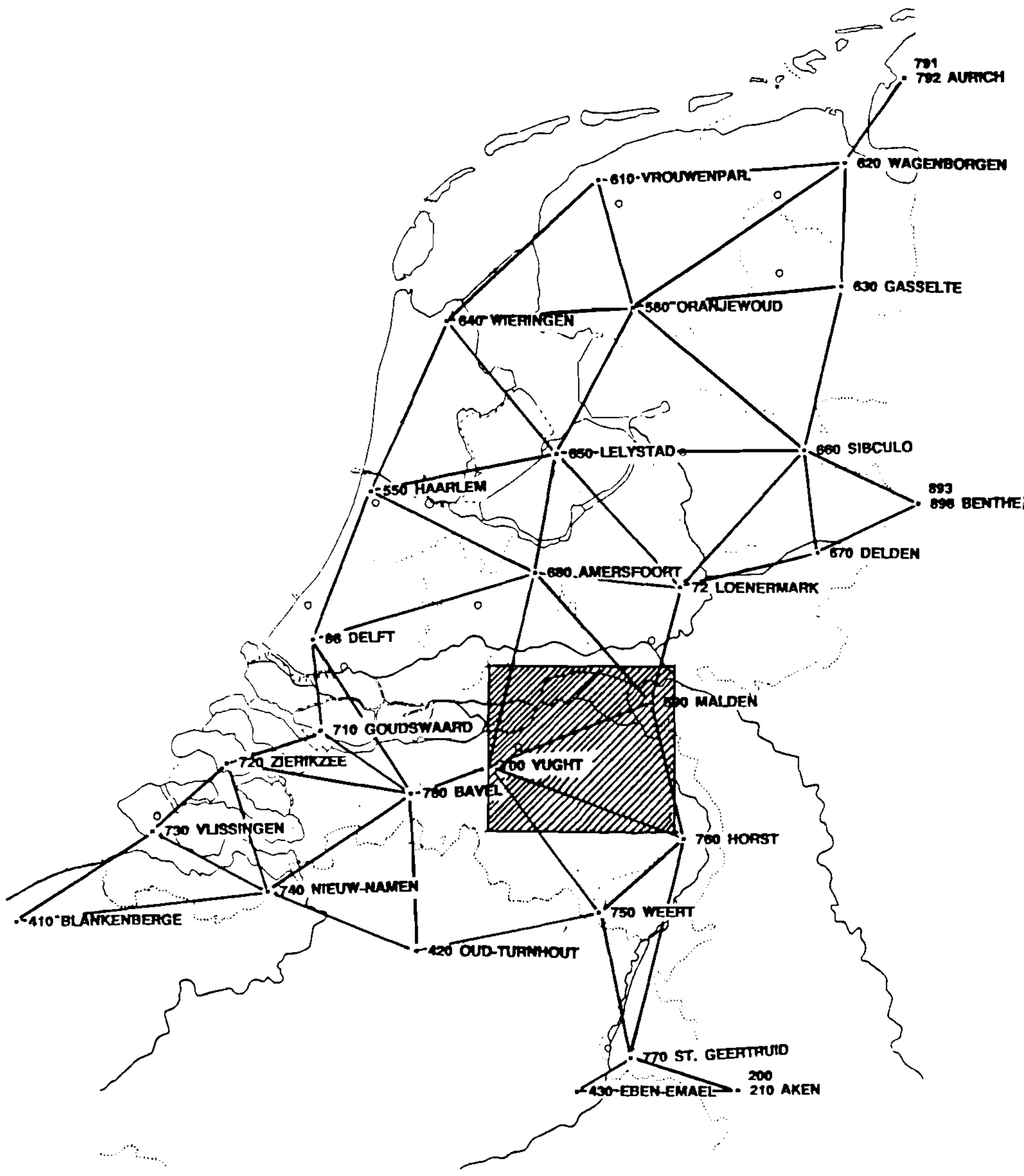

Fig. 1 Primary gravity network of the Netherlands (1990). Shaded: measurement of a second order gravity network in 1990.

4. THEORY AND EVALUATION

4.1 Delft Geodetic Computing Centre

4.1.1 *Hipparcos*

Since 1982, the Delft Geodetic Computing Centre (LGR) participates in the FAST consortium (Van der Marel, 1988). FAST, in which French, Italian, German and Dutch institutes collaborate, is on behalf of ESA doing the data reduction of the European astrometry satellite Hipparcos. Hipparcos was launched on the 8th of August 1989 by an Ariane 4 launcher, but failed to reach the correct orbit. As a consequence operations were seriously hampered, the start of the scientific mission was delayed, 30% of the scientific data is lost and the expected life time of the satellite is reduced. The scientific data is, however, not seriously affected and is of excellent quality. The reduction procedures have now been validated and routine data reductions are now being started. From the half daily solutions averages of 3-4 mas in one of the coordinates are routinely obtained. However, in order to successfully determine proper motions and parallaxes at least 2.5-3 years of scientific data is required.

4.1.2 RETrig and EUREF

LGR served as an International Computing Centre in the Readjustment of the European Triangulation Network, ED87. Its task was to perform quality control and outlier detection for station in junction zones and the space stations. The final results were published during the Lisbon RETrig-Symposium (Brouwer et al., 1989), where ED87 was officially adopted.

In May 1989 a European GPS-campaign was carried out under the auspices of the EUREF-subcommission (European REferende Frame) of Section I (Positioning) of the IAG. The objective of the campaign is to densify the existing network of VLBI and laser stations in Europe with GPS stations. Over a period of two weeks 100 stations were occupied using 60-70 dual-frequency GPS receivers, which resulted in about 3500 hours dual-frequency GPS observations. The Delft University of Technology (DUT), one of the three processing centres, has committed itself to compute a partial solution and the quality analysis of the network (Van der Marel and Kösters, 1989). The first results are promising although there is quite a lot of unusable data due to receiver problems. The processing centres are expected to finish their work by the end of 1991.

4.1.3 Subsidence evaluation

In 1988 a three year feasibility study of monitoring small offshore vertical deformations by the GPS was started on behalf of Shell Internationale Petroleum Maatschappij (SIPM). The objective of this study is to monitor subsidence of offshore platforms with an accuracy of better than 5 cm/year. GPS dual frequency phase measurements are used to determine the height differences between the offshore platform and stable onshore stations annually. The research involves actual data treatment as well as simulations, showing that the goals can indeed be obtained. In 1990 the research project "Geodetic Deformation Analysis" between the LGR, the NAM and the Survey Department of Rijkswaterstaat was started. The objective of the project is the development of a modular software system for the multi-epoch analysis of one-dimensional deformations (Verhoef and De Heus, 1990). Presently a preliminary analysis of the Groningen levelling data is performed with a first version of the software system SCAN/DEFO.

4.1.4 Adjustment of the Oman network

The project is carried out at the request of the Petroleum Development Oman (PDO), in cooperation with SIPM. It was formally accepted in March 1985; the DUT received the first data in August 1985. The geodetic control in Oman, measured and computed over a period of decades under responsibility of PDO, consists of a network of traverses (horizontal directions, astro-azimuths and distances) of various density, constrained by recent coordinates derived from Doppler campaigns. The block validations were completed by the end of 1987. Adjustments of the total network were performed in 1988 (provisional adjustment) and 1989 (final adjustment). The computed coordinates (UTM) of all stations and all the output on analysis and adjustment, resulting from the SCAN-II run, were made available to PDO in July 1989 (Kok, 1990).

4.1.5 Densification networks

In the field of design, measurement and computation of geodetic surveys, studies were continued, in particular with respect to densification networks. In 1990 the research project "Integrated Cadastral Surveys" between the LGR and the Dutch Cadastre was started. The objective of the project is the development of a modular software system for the integrated adjustment and model validation of cadastral survey data. A first version of the software system SCAN/DETAIL has been installed with the Cadastre.

4.1.6 Aerial photogrammetry

The LGR has extended its SCAN family of adjustment and quality analysis software (System for the Computational Adjustment of Networks) to photogrammetry. A state of the art bundle adjustment software was developed which, in particular, is tuned to accept preprocessed in-flight GPS-measurements as an important additional source of observations. The experimental version is installed and being tested at the Survey Department of Rijkswaterstaat.

4.2. Estimation in nonlinear models

The theory of nonlinear estimation has been investigated by Teunissen (1989a, 1990). Practical measures of nonlinearity and the distributional properties of nonlinear estimators were derived. Also the numerical properties (local and global convergence; rates of convergence) of some iterative optimization methods were investigated. These numerical methods were investigated from a differential geometric point of view. The theory of the Symmetric Helmert Transformation as introduced by Teunissen, was extended in (Teunissen, 1988a). Expressions for the bias in the estimators of the Symmetric Helmert Transformation were found in (Teunissen 1989b). Also an efficient two-step procedure for nonlinear estimation in ruled-type manifolds was introduced. This method has also found its application in medical studies of the electromagnetic field of the brain. A procedure for diagnosing nonlinearity in the inversion of geodetic and geophysical data has been proposed in (Teunissen, 1990). This procedure separates intrinsic and extrinsic nonlinearities, and can easily be applied with existing least-squares algorithms.

4.3 Quality control in integrated navigation systems

Real-time estimation of parameters in dynamic systems becomes increasingly important in the field of high precision navigation. The real-time estimation inevitably requires real-time validation testing of the models underlying the navigation system. A real-time recursive testing procedure that can be used in conjunction with the well-known Kalman-filter has been developed by Teunissen and Salzmann (1988, 1989). This research has resulted in the development of a Detection, Identification and

Adaptation (DIA) method for the real-time quality control of integrated navigation systems (Teunissen, 1990b). The DIA-method consists of three steps: (1) Detection: the objective of detection is to test the overall validity of the mathematical model; (2) Identification: after the overall model has been invalidated a search among all candidate model errors is performed for the most likely model error and most likely starting time; (3) Adaptation: adaptation follows identification and is needed to eliminate in real-time the presence of identified biases in the filtered statevector. The DIA-method is complemented with diagnostics for the design of integrated navigation systems.

4.4. Linear geodetic boundary value problem

Investigations into the overdetermined geodetic boundary value problems, started by Rummel and Teunissen, were continued (Rummel, Teunissen and van Gelderen, 1989). Least-squares by observation equations was applied to the various geodetic boundary value problems. This resulted in analytical integral solutions for the observables potential, scalar gravity, astronomical latitude and longitude, gravity gradients and three dimensional geocentric position coordinates. Horizontal type boundary value problems and their relation with astronomic levelling were investigated in (Rummel and Teunissen, 1989).
The problem of vertical datum connection and the role played by the geodetic boundary value problem was investigated in (Rummel and Teunissen, 1988). An adjustment method, based on integrating the necessary satellite data with potential and gravity anomalies, has been proposed as a solution to the problem of globally connecting vertical datums.

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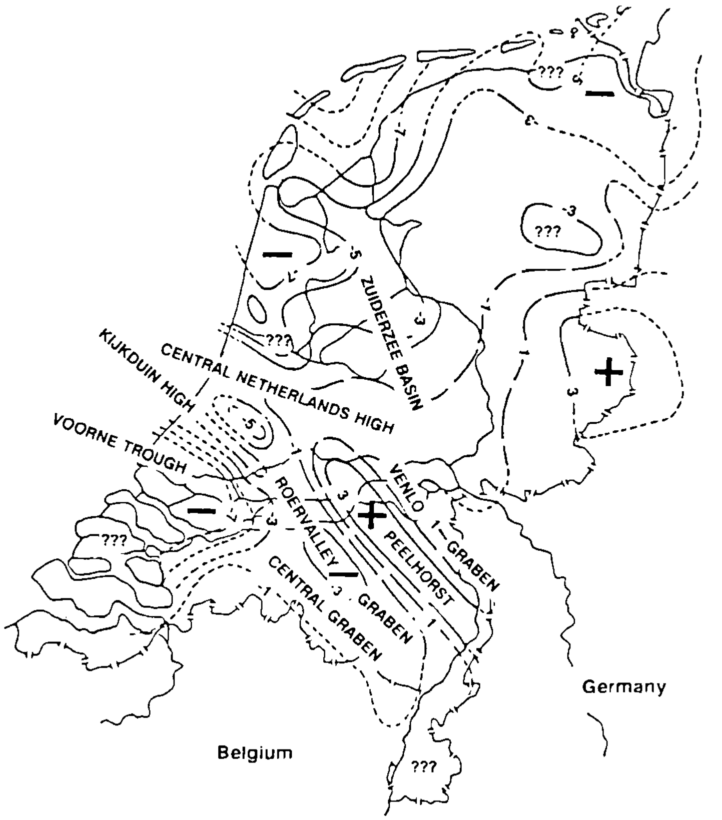
5. PHYSICAL INTERPRETATION

5.1 Regional land subsidence and sea level rise

Since the 1920's (second primary levelling of the Netherlands) special underground benchmarks have been placed in the upper reaches of the Pleistocene layers, representing the most stable markers for the NAP (Amsterdam Heigh Datum), as they are not influenced by movements of the top-soil. When after World War II new levellings became available, the realisation gradually grew from observed discrepancies in the levelled heights, that even these underground benchmarks were not as stable as required. Therefore a project was started in the 1980's to re-evaluate the primary levellings in a kinematic way, to assess regional vertical movements in the Netherlands. The objective was threefold: (a) to improve the user-heights of NAP-benchmarks, (b) to derive from the measurements additional geological knowledge of the Dutch subsoil and (c) to be able to seperate between eustatic sea level rise and land subsidence in the observed relative sea level rise, the latter being of major importance in view of the study of the effects of global warming.
A provisional analysis of all primary levellings in the period 1928-1987 shows a subsidence rate between -7 and +8 cm per century. The total picture is shown in figure 2. From these provisional results it can be concluded that the heights of benchmarks must be corrected for these vertical movements in which the human factor (e.g. gas extraction see 5.2) is excluded as well as possible. The same applies to tide gauge observations along the coast. A reconsideration of the stability of the NAP datum system deems necessary.



————	movement geodetically calculated [significant: > 2 x st.dev.]
— — —	movement geodetically calculated [not significant]
- - - - - - - -	movement geologically validated
????????????	movement geologically inexplicable / geodetic data not sufficient

Fig. 2 Preliminary regional map of recent vertical movements (cm/cy) at the top Pleistocene in the Netherlands.

The vertical movements, as deduced from the primary levellings, are related to the geological structure of the subsoil in the Netherlands, caused primarily by compaction of sediments. The levellings are therefore an important aid for the testing of hypotheses about geological movements. As an example, figure 3 shows the levelling line 2330-2220 across the eastern edge of the Central Graben in the South-East of the country. The precision levellings provide a broad view of the movement of the Netherlands as a whole.
Because of many industrial activities concentrated in a few regions, combined with intensive land use for agriculture and recreation in the remaining regions, the maintenance of a stable reference network is very difficult. Levelling results have to be corrected for the influence of these human activities before the movements of the deep strata can be determined and conclusive geological hypotheses can be tested.
Due to the time-consuming levelling technique, a project was started in 1990 to determine heights and heights changes of the tide gauges along the coast using GPS. The Survey Department of Rijkswaterstaat engaged a project in conjunction with NEREF (see section 1.1.4) called NEREF-MAREO to annually determine heights of the main tide gauges along to Dutch coast, relative to the EUREF stations. Results of this project to be used for the determination of increased sea level rise are expected until a few years from now.

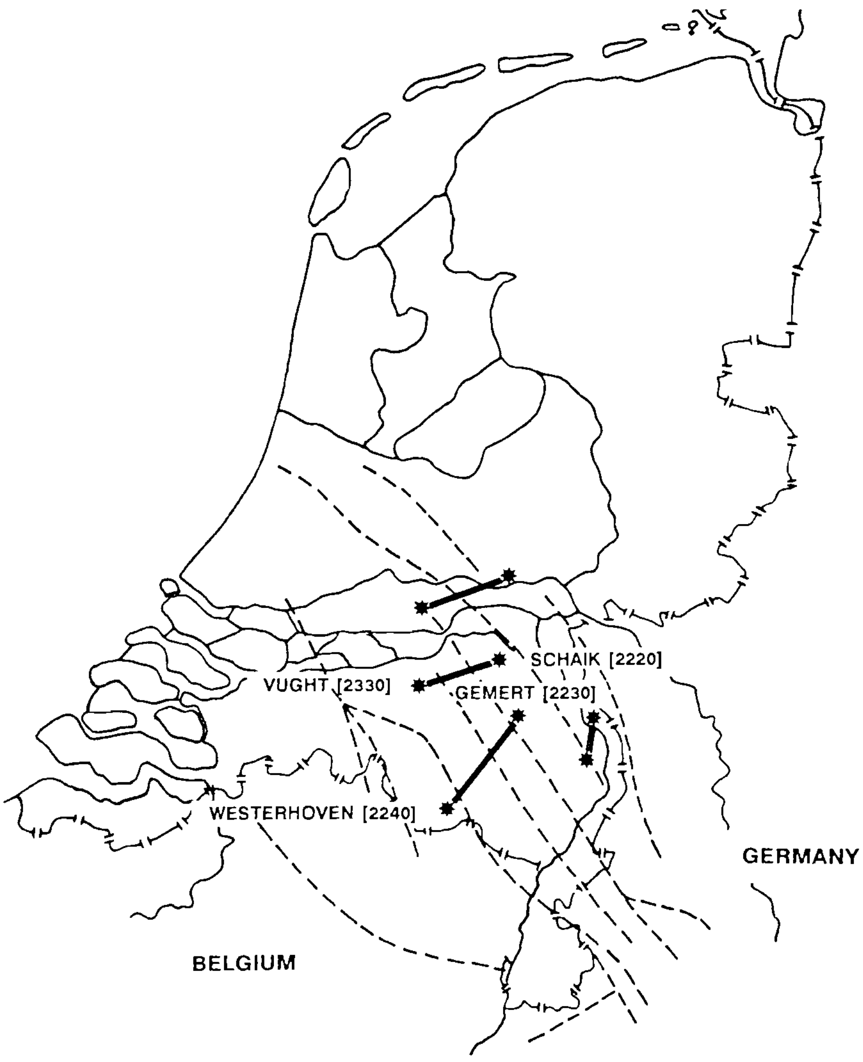


Fig. 3 Location of the levelling lines in the Southern part of the Netherlands, selected for geological fault movement analysis.

5.2 Gas and oil extraction

Deformation measurements, mainly by levelling, are regularly executed in the areas in the Netherlands where minerals are extracted. These measurements have a dual purpose: on the one hand they provide a check on the movements predicted by the operating concerns, and on the other hand they have a signal function with a view to the prevention or limitation of damage caused by the movements.
The greater part of the Netherlands gas fields lies in the coastal region or under the shallow Waddenzee between the North coast and the Frisian Islands. Part of the coastal region is reclaimed land, where the shallow subsoil consists of layers of sand, clay and peat, strongly variable in thickness. For the interpretation of the results of levelling, a detailed analysis of the accuracy and reliability of the measurements proves to be increasingly important. By a constrained adjustment the levelling networks are tied to the primary underground benchmarks of the national datum NAP.
In the Groningen gas field, large levellings covering the whole field have been measured at ten epochs; they are supplemented by thirteen sparser levellings between these epochs. Up to now actual subsidence values were derived from the two most recent levellings now amounting to almost 19 cm for the centre of the field since the beginning of the gasextraction in 1963. The vast amount of height data now available makes it possible to analyse the deformations in more detail by determining for each benchmark the rate of subsidence as a function of the decrease of gas pressure in the reservoir. In this kind of analysis the dependence between the determinations of benchmarks is largely eliminated. The NAM (Netherlands Petroleum Company) and the Survey Department of Rijkswaterstaat have commissioned the Geodetic Computing Centre of the Delft University of Technology to execute a thorough analysis of the quality of the levellings with a view to subsidence research (see section 4.1.3).

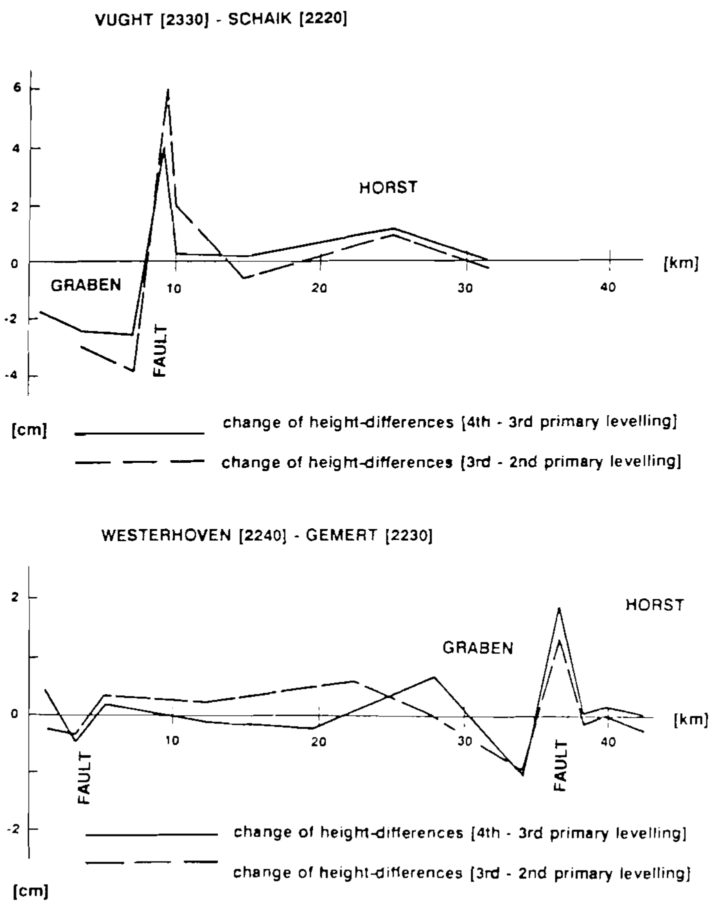


Fig. 4 Change of height-differences over geological faults.

In the period 1986-mid 1991 there have been five minor earthquakes in the non-seismic area in the northern part of the Netherlands. The Ministers of Economic Affairs and Public Works have announced a multi-disciplinary investigation into the question whether the decrease of pressure in oil- or gas reservoirs can cause movements along faults and thus induce seismic activity. When gas or oil is extracted, the pore pressure decreases; since the effective stress thereby increases, the probability of movement in faults becomes smaller and so does the probability of earthquakes and tremors.
In the case of small fields at great depth there will develop a stress above the reservoir, which may cause a sudden shifting along a natural fault plane. Such induced seismic activity has been reported with respect to some deep high-pressure gas and oil fields elsewhere. The earthquakes had a magnitude of 3.5 on Richter's scale; no buildings or other constructions were damaged.

5.3 Publications

BROUWER, F.J.J. - Kwaliteit en resultaten van waterpasmetingen. In: Proceedings symposium bodemdaling in Nederland. Delft, 8 november 1990, Delft, 1990, p. 117-124. In Dutch.

GROENEWOUD, W., G.K. LORENZ, F.J.J. BROUWER, R.E. MOLENDIJK - Geodetic determination of land subsidence in the Netherlands. In: Land Subsidence, IAHS-publication nr. 200. (Ed.: A.I. Johnson), Institute of Hydrology, Wallingford, Oxfordshire, 1991.

LORENZ, G.K. - Recent vertical movements in the Netherlands. In: Precise Vertical Positioning. (Ed.: H. Pelzer, A. Witte), Dümmler Verlag, Bonn, 1991.

PÖTTGENS, J.J.E., F.J.J. BROUWER - Land Subsidence due to gas extraction in the Northern part of the Netherlands. In: Land Subsidence, IAHS-publication nr. 200. (Ed.: A.I. Johnson), Institute of Hydrology, Wallingford, Oxfordshire, 1991.

VERHOEF, H.M.E., F.J.J. BROUWER - Methodology for the Analysis of the Groningen Gasfield Levellings. A First reliability analysis of some kinematic models. In: Precise Vertical Positioning. (Ed.: H. Pelzer, A.Witte), Dümmler Verlag, Bonn, 1991.

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