PUBLICATION OF THE NETHERLANDS GEODETIC COMMISSION

GEODETIC WORK

IN

THE NETHERLANDS

1983-1986

Report prepared for the General Assembly of the International Association of Geodesy, XIXth General Assembly of the International Union of Geodesy and Geophysics. Vancouver, 1987

1987

RIJKSCOMMISSIE VOOR GEODESIE; THIJSSEWEG 11, DELFT, THE NETHERLANDS

1 CONTROL SURVEYS

1.1 Primary triangulation

Related to the activities of the RETrig-subcommission of the International Association of Geodesy much attention was paid to the Netherlands contribution to the European triangulation network.
The existing dataset was updated with recently obtained observations mainly electromagnetic distance measurements, and extended with the connection networks to so-called space stations, points where Doppler-, SLR- or VLBI-measurements were carried out.
For the adjustment and the analysis of the terrestrial observations, the Triangulation Department of the Netherlands Cadastral Service developed a new ellipsoidal adjustment software suite, based on the general adjustment system of the Delft University of Technology.
During the analysis special attention was paid to the observed astronomical azimuths in relation to the European Longitude Network (established by the German Geodetic Research Institute) and to the junction points with the German and Belgian networks.
In order to get a reliable check on these junction points and the observations on the border, a full analysis was carried out with the help of adjacent parts of the German and Belgian networks.
This analysis showed satisfactory results.
The final Netherlands contribution to the European Triangulation Network 1987 is shown in Fig. 1. Its principal characteristics are:

- total number of points	96
- number of space stations	7
- directions	519
- distances	53
- azimuths	8

1.2 The connection of the Westerbork Synthesis Radio Telescope to the primary triangulation network

In view of the possible deployment of geodetic Very Long Baseline Interferometry, both within RETrig and other (future) projects, a connection network was established to relate the Westerbork Synthesis Radio Telescope to the surrounding primary triangulation points. In addition the polygon from the Kootwijk Observatory for Satellite Geodesy to the point Tongeren of the Malvern-Graz traverse was completed and extended to Westerbork, to define a high accuracy connection between Kootwijk and Westerbork and to further strengthen the RETrig network.

1.3 Levelling

1.3.1 *General*

The second order densification of the national levelling network has been continued and will be completed in 1988.

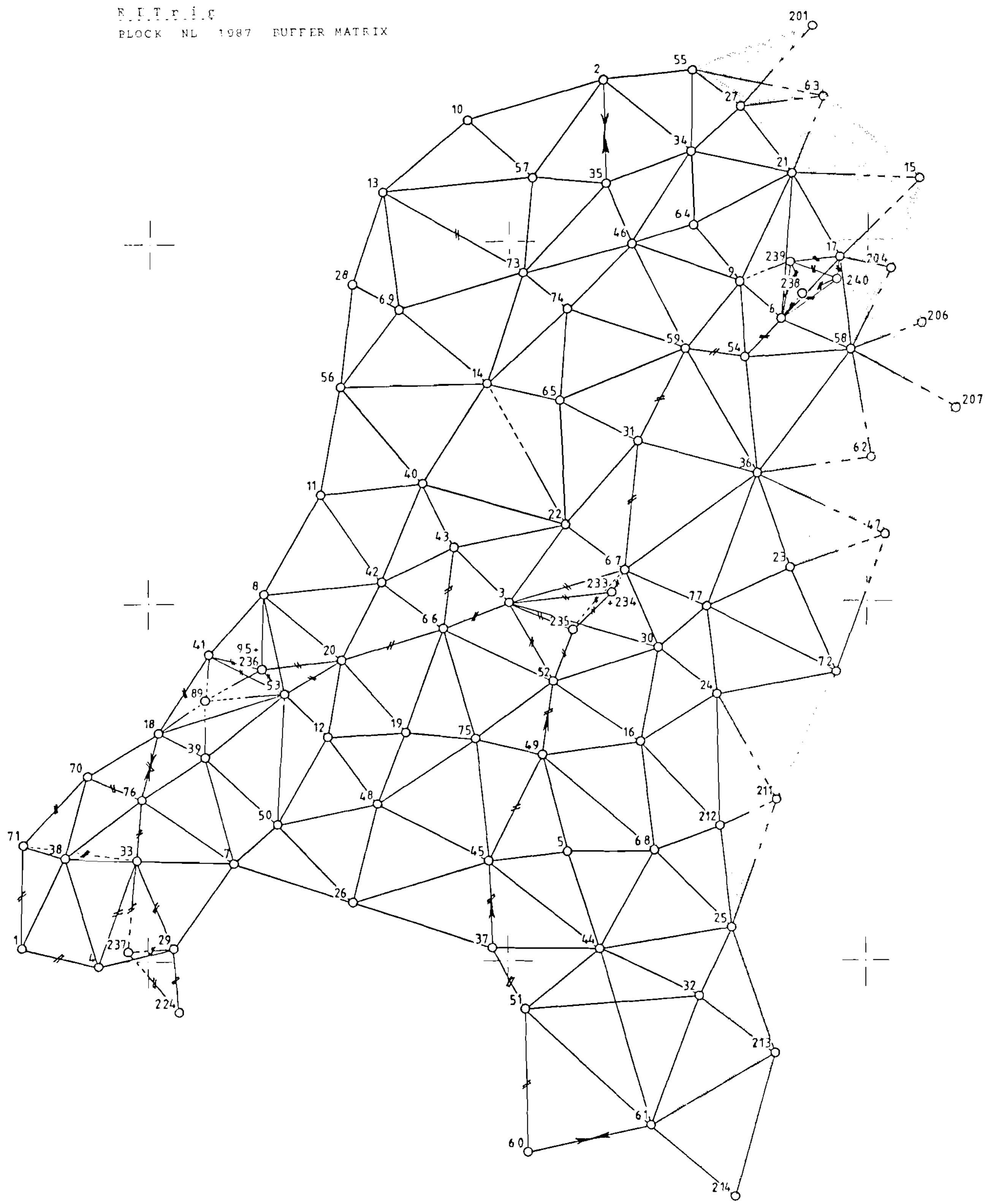


Fig. 1. Netherlands contribution to the European Triangulation Network

1.3.2 *Instruments*

For the second order levelling the Jena Koni 007 and the Wild Na2 automatic instruments were used.

1.3.3 *Datum of the network*

The datum of the network is Normaal Amsterdams Peil (N.A.P.), fixed by an underground benchmark at Amsterdam.

1.3.4 *Adjustment of the network*

A comparison has been made of the results of 3 Precise Levellings of the Netherlands (1926–1940, 1950–1959, 1965–1978). These indicate a significant uplift of 4–5 cm in the southern and eastern parts of the country. The second order levellings are in agreement with these results.

1.3.5 *Junctions with contiguous networks*

The following junctions have been measured:

Oldenzaal	-Gronau	1983
Horst	-Straelen	1984

1.3.6 *Special measurements*

In Germany a hydrostatic levelling from Alte Mellum to Norderney (31 km) was carried out. In the German coastal area 36 km was levelled hydrostatically.

1.4 **Marine-geodetic activities of the Hydrographic Service of the Royal Netherlands Navy**

1.4.1 *The Netherlands*

Hydrographic surveys were carried out in shipping lanes, deep draught routes and coastal areas across the Netherlands part of the continental shelf of the North Sea.
Horizontal control during the surveys was carried out with a 2 Mhz-radiopositioning system.

1.4.2 *Continental Shelf Activities*

Checks were carried out on positioning data of mining installations on a routine bases.
Boundary and area computations of mining companies were checked on behalf of the Ministry of Economic Affairs.
All geodetic data about mining installations and boundaries have been put into a database management system.

1.4.3 *General*

On a ad hoc bases geodetic computations and related charts were supplied to the Ministry of Foreign Affairs in order to support international Law of the Sea deliberations in and outside Europe.

1.5 **Publications**

1.5.1 *Primary triangulation*

DENEKAMP, J. and J.J. KOK – National report, The Netherlands. Report to the 18th General Assembly of IAG, Hamburg, 1983.

KOK, J.J. – National report 1983/1984, The Netherlands. Report to the symposium of the IAG subcommission for the new adjustment of the European triangulation, Copenhagen, 1984.

DENEKAMP, J. and F.J.J. BROUWER – National report 1984/1985, The Netherlands. Report to the symposium of the IAG subcommission for the new adjustment of the European triangulation, The Hague, 1985.

1.5.2 *Levelling*

MEETKUNDIGE DIENST RIJKSWATERSTAAT – Invloed van temperatuur op precisie-waterpasinstrumenten met compensator.
MDTN-R-8613, Delft, 1986. In Dutch.

MURRE, L.M. – Hervereffening van de tweede, derde en vierde nauwkeurigheidswaterpassingen van Nederland en vergelijking van de resultaten, Delft, 1985. In Dutch.

2 SPACE TECHNIQUES

2.1 Satellite Laser Ranging (SLR)

The Observatory for Satellite Geodesy at Kootwijk, which is responsible to the Faculty of Geodesy of the Delft University of Technology, continued a programme featuring various aspects of laser ranging to artificial satellites:
1. design, construction and development of instrumentation;
2. observations;
3. data analysis and utilisation.

Until the end of 1983 the programme received substantial funding from the Netherlands Committee for Geophysics and Space Research and from then and onwards from its successor the Space Research Organization (of the) Netherlands (SRON).

2.1.1 *Instrumentation*

Stationary laser ranging equipment at Kootwijk, identified by monument number 7833, was maintained, but a planned further upgrading of the system had to be projected into the future. This delay was caused by a necessary use of practically all available resources for the implementation of a novel Modular Transportable Laser Ranging System (MTLRS) concept. Although MTLRS was built by the Institute of Applied Physics (TPD) at Delft, the observatory contributed part of the electronics and all the software. After successful testing in which the observatory had a major share, the first instrument, MTLRS-1, was taken delivery of by the Institute of Applied Geodesy (IfAG), Frankfurt am Main, FRG, in the summer of 1984. An identical instrument (MTLRS-2) was delivered to the Kootwijk Observatory in the fall of the same year. MTLRS was designed to be both surface- and/or air-transportable and has demonstrated normal point ranging precision of about 1 cm.
Technical characteristics are:

receiver aperture	40 cm
laser wavelength	539 nm
pulse width	0.3 ns
pulse energy	10 mJ
repetition rate	600 pulses per minute.

2.1.2 *Observations*

The majority of the laser range observations made were done in the framework of the Crustal Dynamics Project of the U.S. National Aeronautics and Space Administration (NASA) as part of which the observatory, jointly with the Section Orbital Mechanics of the Faculty of Aerospace Engineering of the Delft University performed scientific research.
As regards the stationary 7833-system at Kootwijk the data yield was limited to a total of 89 passes of satellites STARLETTE (1975-10A) and LAGEOS (1976-39A) taken in 1983 and a small number of passes taken during the test phase of MTLRS-1 in 1984.
The MTLRS was conceived to enable SLR observations from a number of sites during an equal number of relatively short visits within a limited time span. Thus, in cooperation with fixed or other transportable SLR systems, a network of intersite baselines can be measured and re-measured to demonstrate eventual

broad scale crustal motion. This capability enabled MTLRS-2 to take part in the Mediterranean laser ranging (MEDLAS) activities of the Workinggroup of European Geoscientists for the Establishment of Networks for Earthquake Research (WEGENER), this all in the context of NASA's Crustal Dynamics Project. To operate the system abroad the Delft University of Technology could conclude several agreements of scientific cooperation. After an initial running-in period at Kootwijk until the end of February 1985, MTLRS-2 was moved to Wettzell (FRG) to colocate with MTLRS-1 and with the permanent SLR-system there. After further preparations at Kootwijk in the spring and summer of 1985 MTLRS-2 was moved to 1701 m high Monte Generoso (Switzerland) to perform research in cooperation with the Confederal Technical University of Zürich. There a horizontal range of about 160 km to Jungfrau Joch could be directly measured. In the autumn of 1985 MTLRS-2 was moved to the first site in the Mediterranean, Cagliari (Italy). Early January 1986 MTLRS-2 was at Matera (Italy) to colocate again with MTLRS-1 and also with the permanent SLR-system of that station. Another Italian site was visited in 1986, Basovizza near Trieste, and then, after having visited the Greek sites of Roumeli of Crete and Chrisokellaria in the Peloponnesos, MTLRS-2 arrived at Kootwijk by the end of October of that year.
MTLRS-2 data yield over the period 1984–1986 can be summarised as follows:

site	monument	period	number of passes STARLETTE	LAGEOS
Kootwijk	8833	1984, Nov. 20–1985, Febr. 10	10	20
Wettzell	7596	1985, March 13–April 3	7	5
Monte Generoso	7590	1985, Sept. 18–Oct. 18	-	48
Cagliari	7545	1985, Nov. 7–Dec. 3	-	28
Matera	7541	1986, Jan. 10–March 12	-	62
Basovizza	7550	1986, March 31–May 19	-	29
Roumeli	7517	1986, May 30–Aug. 31	-	75
Chrisokellaria	7525	1986, Sept. 8–Oct. 18	-	25
		Total 1984–1986	17	292

Network design, site selection and site preparation took a considerable effort before MTLRS-2 could be deployed.

2.1.3 *Data analysis*

Analysis of the colocation measurements at Wettzell (1985) and Matera (1986) revealed a constant but statistically insignificant relative range bias between MTLRS-1 and MTLRS-2, the latter system measuring consistently long by about 1 cm.
The Monte Generose experiment led to quite interesting results. The intersite baseline between the laser ranging station at Zimmerwald (Switzerland) and Monte Generoso (about 160 km) as obtained by satellite laser ranging agreed to better than 1 part in 10^6 with the distance obtained by GPS. These combined results and the direct laser ranging from Monte Generoso to Jungfrau Joch confirmed the expected existence of an error of about 1 m in the southern part of the Swiss first order triangulation.
Several theoretical investigations in the areas of SLR data analysis and geodetic interpretation of results were performed.

2.2 **Satellite Radio Positioning**

The Netherlands Geodetic Commission installed in 1985 the Working Group 'Applied Space Geodesy' to study, evaluate and coordinate applications of new technologies in geodesy. It is the successor of the earlier 'Doppler Satellite Positioning' group. Activities concentrated on Doppler and GPS positioning.

2.2.1 *Doppler positioning*

Government agencies own two Marconi NNSS Doppler receivers. With a strong emphasis on international cooperation, a number of observation campaigns were either executed or contributed to, viz.:

ALGEDOP-2 (24 June–24 July 1983), a project to determine the geoid in the Alps and South-central Europe. Stations in Austria were observed.
WEDOC-2 (6–16 Sept. 1983). A second West-East connection, simultaneous with the MERIT-campaign. Station Kootwijk was observed.
NEPAL (Sept.-Oct. 1983). For positioning support of an Italian research project – investigating the gravity field in the Himalayas – two stations were observed.
MERITDOC (1 Sept. 1983–begin 1985). The station Kootwijk was observed during more than one year, in support of the MERIT campaign to monitor earth rotation.
RETDOC (15–25 June 1984). Organized by the RETrig-commission of the AIG, to incorporate Doppler-campaigns, VLBI, SLR etc. into the European triangulation net. Stations Kootwijk and Leeuwarden were observed.
OSIRIS-SEAWAY project (Sept. 1984). The coordinates of four offshore gas production platforms and one coastal point were determined; they are stations of a radio navigation chain (Syledis), that was later used in a GPS project.
ITALIAN DOPPLER PROJECT (August 1986). Several stations were observed (two receivers).

2.2.2 *GPS-positioning*

A very fruitful combination of resources and efforts, and exchange of results between Delft University, various Government Agencies, Shell and several private survey firms took place. In this atmosphere the following main project were executed:

Relative static positioning tests, using phase observables.
- Quadrilateral Delft-Kootwijk-Leeuwarden-Eenrum, (50–220 km distances) was observed with TI-4100 receivers in Aug. 1985, Feb. 1986 and Jan. 1987. Purpose: to investigate the possibility to detect subsidence of oil-production platforms at large distances offshore.
- controlpoints for aerial photography (5 km distance) in Roermond area were observed with the Macrometer V-1000 (2–6 Dec. 1985) and in Jan. 1987 with the Sercel TR5S. Delft-Kootwijk-Roermond (>100 km) was also observed.

Dynamic tests in the North Sea.
- Absolute vessel positioning with the TI-4100 from the T.U. Hannover, was compared to Syledis and Hifix radio positioning (6–12 Dec. 1984).
- NAVGRAV-project (22–30 April 1986). Simultaneous with a gravity survey, data was collected to evaluate relative GPS positioning in vessel-to-shore and vessel-to-vessel mode, involving six receivers of three different types. In addition to the already mentioned organisations, the T.U. Hannover and T.U. Munich contributed receivers.

For the above tests the equipment was mostly rented or on loan. At the end of 1986 the Geodetic Commission owned two Trimble 4000S receivers and the Ministry of Roads and Waterways one Sercel TR5S.

2.2.3 *Data Analysis*

In 1986 the PHASER program, obtained from the U.S.A. National Geodetic Survey, was made operational on the PDP-VAX computer. Pseudo-range processing and alert computation programs were developed. Progress was made in analysing the acquired observations, but there is still a backlog.

2.3 **Very Long Baseline Interferometry (VLBI)**

The research project on the geodetic applications of VLBI was continued. Partners in this project were the Geodetic Computing Centre of the Delft University of Technology and the Netherlands Foundation for Radio Astronomy (NFRA); the project was sponsored by the Netherlands Organization for the Advancement of Pure Research (ZWO).
The objective of the research was an assessment of the accuracy of geodetic VLBI point positioning via own developed software for the analysis of real and simulated data.
Results of ERIDOC (European Radio Interferometry and Doppler Campaign) measurements by the European VLBI Network (EVN) were published in (Brouwer et al., 1983) with emphasis on the intercomparison aspects with Doppler. The research project resulted in a doctoral thesis (Brouwer, 1985) in which a description of the developed software suite is given together with some general tools for the optimal design of a VLBI campaign.
The Netherlands participate in the activities of the European Working Group for Geodetic and Astrometric VLBI, which meets approximately every one and a half year.
On 3–4 November, 1983 the Working Group assembled at Delft, The Netherlands: proceedings were published in (Brouwer, 1984).
This Working Group has now scheduled new EVN measurements, including the Westerbork facilities operated by the NFRA, for 1987 at its last meeting in Wettzell (FRG) of November 1986. A possible contribution of Westerbork to the new Earth Rotation Service (ERS) is still under discussion.

2.4 **Publications**

2.4.1 *Satellite Laser Ranging (SLR)*

AARDOOM, L. – The Kootwijk Observatory for Satellite Geodesy laser ranging contributions to international programs, Surveying and Mapping, **44**, pp. 353–363, 1984.

AARDOOM, L. and B.H.W. VAN GELDER – Satellite laser ranging to measure crustal motion in the Eastern mediterranean area: instrumentation and network design; Annales Geophysicae, *2*, pp. 249–259, 1984.

AARDOOM, L., B.H.W. VAN GELDER and E. VERMAAT – Design of SLR networks for studies of crustal dynamics. Reports of the Department of Geodesy, Mathematical and Physical Geodesy, Delft University of Technology, no. 83.3, 1984.

AARDOOM, L., E. REINHART, P. WILSON and E. VERMAAT – The WEGENER-MEDLAS laser tracking project, CSTG Bulletin **8**, 1985.

AARDOOM, L. and P. WILSON – A modular transportable laser-ranging system MTLRS, CSTG Bulletin, **5**, pp. 103–111, 1983.

AARDOOM, L. and P. WILSON – Satellite laser ranging to measure crustal motion in the Eastern Mediterranean, CSTG Bulletin **7**, 1984.

BLUMER, B.M.H. – COLLAS – An alternative approach for the analysis of SLR data collected during co-location tests. Thesis. Department of Geodesy, Delft University of Technology, 1986.

CAPORALI, A., A. CENCI, W. DECKER, M. FERMI, H. HAUCK, K. HERZBERGER, V. HUSSON, R. KOLENKIEWICZ, F. PALUTAN, S.W.P. PULLES, B.H.W. VAN GELDER, D.L.F. VAN LOON, E. VERMAAT and P. WILSON – Co-location of MTLRS-1, MTLRS-2 and MATLAS – Matera, January 10 to March 13, 1986 – Data analysis and results. Report presented to the 11th Crustal Dynamics Principle Investigators Meeting at Goddard Space Flight Center, Greenbelt, Maryland, October 15–16, 1986.

CONRAD, M., K. OTTEN and I. STIEWE – Ein Echtzeitprogramm zur Erfassung and grafischen Auswertung der Meßdaten beim mobilen Laserentfernungsmeßsystem, Die Arbeiten des Sonderforschungsbereiches 78, Satellitengeodäsie der Technischen Universität München im Jahre 1983, 1984.

DUESMANN, B.J. – The multi-epoch method applied on a SLR network for testing geophysical hypotheses. Thesis. Department of Geodesy, Delft University of Technology, 1986.
GELDER, B.H.W. VAN and L. AARDOOM – SLR network design in view of reliable detection of plate kinematics in the East Mediterranean. Report of the Department of Geodesy, Mathematical and Physical Geodesy, Delft University of Technology 82.2, 1982.
GELDER, B.H.W. VAN and L. AARDOOM – Space/airborne laser ranging (SALR) as complement to groundbased transportable satellite laser ranging (SLR), Space Laser Applications and Technology (SPLAT), ESA SP-202, 175, 1984.
GELDER, B.H.W. VAN and L. AARDOOM – SLR network design in view of reliable detection of plate kinematics in the East Mediterranean. The use of artificial satellites for geodesy and geodynamics, Vol. III, Athens, 1984.
GELDER, B.H.W. VAN and B.H.M. BLUMER – Co-location of KOOLAS and MTLRS-1 at the Kootwijk Observatory using raw laser range data to LAGEOS. Reports of the Department of Geodesy, Mathematical and Physical Geodesy 84.6, 1985.
GELDER, B.H.W. VAN, H. HAUCK, D.L.F. VAN LOON, E. VERMAAT and B.H.M. BLUMER – Co-locating MTLRS-1 and MTLRS-2 with the stationary WETTZELL laser ranging system, AGU Spring Meeting, Baltimore, Maryland, USA, 29 May 1985. Reports of the Department of Geodesy, Mathematical and Physical Geodesy 85.1, 1985.
VERMAAT, E. – Site selection for MTLRS. Reports of the Department of Geodesy, Mathematical and Physical Geodesy, Delft University of Technology 83.2, 1983.
VERMAAT, E. – Establishing ground ties with MTLRS; performance and results. Proceedings of the Fifth International Workshop on laser ranging instrumentation, Herstmonceux Castle, 10–14 September 1984, Bonn, 1985.
VERMAAT, E. and B.H.W. VAN GELDER – On the eccentricity of MTLRS. Reports of the Department of Geodesy, Mathematical and Physical Geodesy, Delft University of Technology, 83.4, 1984.
VERMAAT, E., K.H. OTTEN and M. CONRAD – MTLRS software and firmware. Proceedings of the Fifth International Workshop on laser ranging instrumentation, Herstmonceux Castle, 10–14 September 1984, Bonn, 1985.
VERMAAT, E. and H. VISSER – Description of a transportable laser ranging system, Technisch Physische Dienst TNO-TH. Rapport **A8289**, Delft, 1985.
VERMAAT, E. and P. WILSON – The Modular Transportable Laser Ranging System MTLRS 1 & 2, CSTG Bulletin **7**, 1984.
WILSON, P. and L. AARDOOM – SEASAT tracking over Europe, Satellite microwave remote sensing (T.D. Allen, ed.), Ellis Horwood Ltd., Publ., Chichester, pp. 337–351, 1983.

2.4.2 *Satellite Radio Positioning*

HUSTI, G.J. – Over de absolute en relatieve nauwkeurigheid van Doppler satellietwaarnemingen, NGT-Geodesia, 1985, No. 3, pp. 98–100. In Dutch.
HUSTI, G.J. – Puntsbepaling met Doppler satellieten ten behoeve van het SYNET-II plaatsbepalingssysteem. Reports of the Department of Geodesy, 85.2, Delft, 1985. In Dutch.
HUSTI, G.J. en P.G. SLUITER – Navigatietest met GPS op de Noordzee. NGT-Geodesia, 1985, No. 11, pp. 396–400. In Dutch.
DE JONG, C. – Relative Geodetic positioning with the Global Positioning System. Thesis Faculty of Geodesy, Delft University of Technology. August 1986.
RICHARDUS, P. – De werkgroep "Doppler Satelliet Waarnemingen" van de Rijkscommissie voor Geodesie, NGT-Geodesia, 1985, No. 3, pp. 80–85. In Dutch.
SLUITER, P.G. – Satelliet plaatsbepaling, nu en in de toekomst. NGT–Geodesia, 1985, No. 3, pp. 90–95. In Dutch.
VAN DER WAL, J.H.M. – Global Positioning System en Fotogrammetrie. NGT-Geodesia, 1986, No. 12, pp. 414-419. In Dutch.
VAN DER WAL, J.H.M. – Macrometer metingen ten behoeve van paspunt bepaling. GPS-Nieuwsbrief, 1986, No. 2. In Dutch.
THE HYDROGRAPHIC SOCIETY, Netherlands Branch. Proceedings of the Workshop on GPS. Amsterdam, July 20, 1986. Collection of various papers by O.B.M. Pietersen, P.G. Sluiter/G.J. Husti, G.J. Husti/G.L. Strang van Hees, A. Lubbes, H.J.W. van der Vegt.

2.4.3 *Very Long Baseline Interferometry*

BROUWER, F.J.J., G.J. HUSTI, W. BEYER, J. CAMPBELL, B. HASH, F.J. LOHMAR, H. SEEGER, G. LUNDQVIST, B. RÖNNÄNG, A. VAN ARDENNE, R.T. SCHILIZZI, B. ANDERSON, R.S. BOOTH, P.N. WILKINSON, P. RICHARDS and S. TALLQUIST – Data analysis of project 'ERIDOC' (European Radio-Interferometry and Doppler Campaign). Paper presented at the IUGG/IAG General Assembly, Section 2 'Space Techniques', Hamburg, 1983.
BROUWER, F.J.J. (ed.) – European VLBI for Geodesy and Astronomy, account of a working meeting, 3–4 November 1983, Netherlands Geodetic Commission, Delft, 1984.
BROUWER, F.J.J. – On the Principles, Assumptions and Methods of Geodetic Very Long Baseline Interferometry, Ph.D. Thesis, Netherlands Geodetic Commission, Publ, on Geodesy, New Series, Vol. 7, No. 4, Delft, 1985.

3 GRAVIMETRY

3.1 Land gravimetry

In 1985 the Faculty of Geodesy of the Delft University of Technology obtained a new LaCoste Romberg gravimeter, model G. With the new instrument the base gravity network was renewed. The old points are not suited for the high requirements of modern precision gravimetry. The Delft University of Technology and the Survey Department of Rijkswaterstaat designed a new gravity net. The measurements are in process and will be finished in 1988.
In the gasfield in Groningen very accurate geodetic measurements are carried out periodically in order to monitor the movements of the earth surface. The measurements are: levelling and gravimetry. In 1978 and 1984 an accurate gravity survey was carried out on 22 points. The gravity changes are corrected for the height changes (max. 8 cm).
The remaining change was about -40 gal in the center of the gasarea. This corresponds to a density decrease in the gasreservoirs of 10 kg/m.

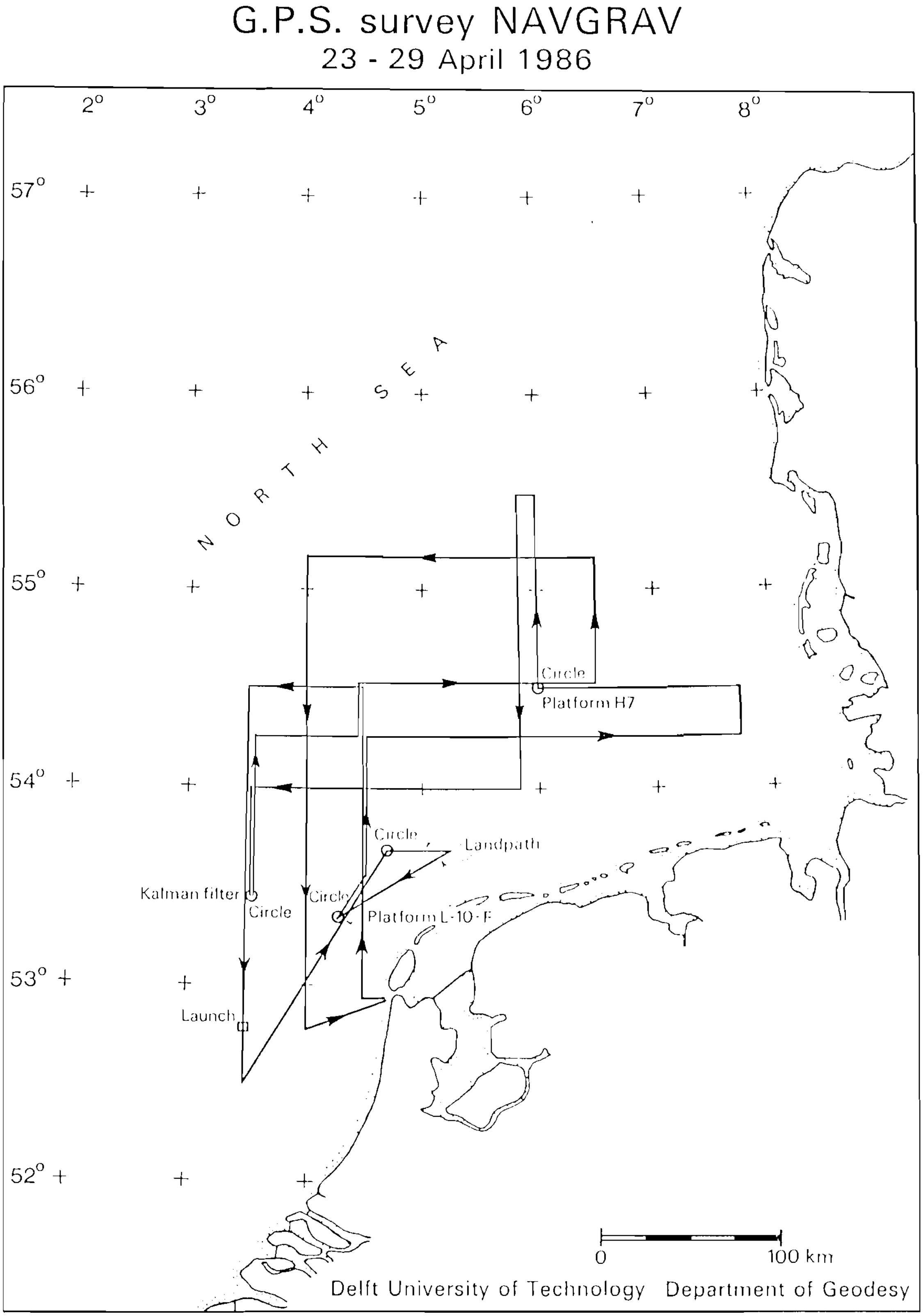
3.2 Sea gravimetry

In 1986 a research project was carried out on the North Sea, called the NAVGRAV-project. The project is a cooperation of the Faculty of Geodesy of the DUT with several government agencies, three German universities and several private companies and was sponsered by the 'Nederlandse Raad voor Zeeonderzoek (NRZ)' and some firms. On board of the oceanographic survey vessel H.M. Tydeman a 3-weeks program was carried out. A grid of survey lines was measured (see Fig. 2 and 3). On the cross-over points independent tests could be made.
The project had two main objectives:
- test of the abilities of the GPS system under dynamic conditions;
- test of the accuracy and reliability of sea gravimetry under optimal conditions.

Four GPS receivers were on board the survey vessel and two receivers on land to determine the absolute and relative precision of GPS. Besides, the terrestrial positioning systems Pulse 8, Hifix, Syledis, Hyperfix, and Loran C were used for comparison.
For the gravimetric part two gravimeters were on board, the Bodensee system KSS 5 of the Delft University of Technology and the Bodensee system GSS 30 of the University of Hamburg, Geophysical Institute. The comparison of both meters yields differences typically less than 1 mgal under good weather conditions. Comparison will be made with the results of the gravity measurements of 1979, in the same area. The processing of the data is still going on.

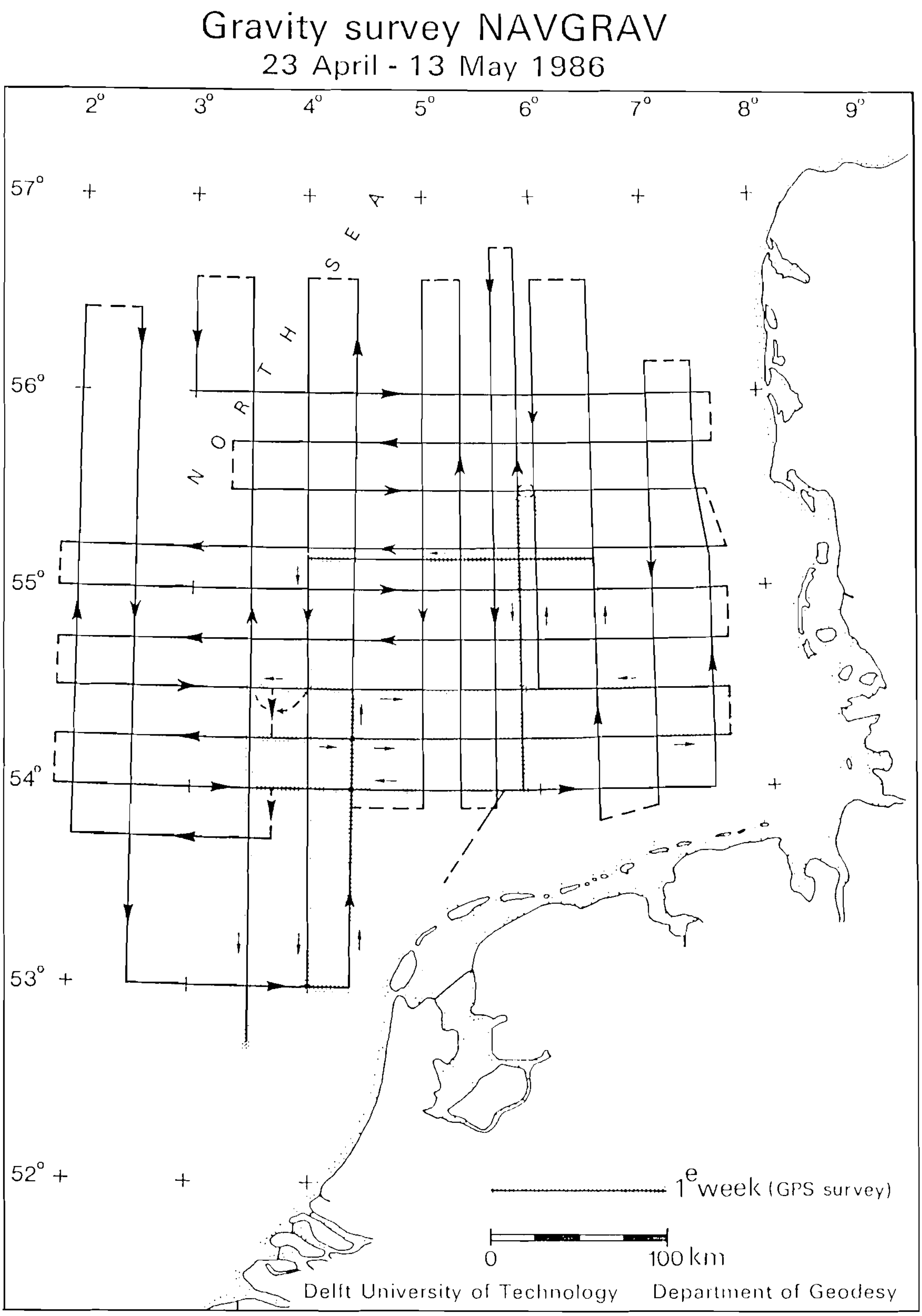
3.3 Satellite Altimetry

The ultimate objective of the altimeter project is the development of a model that connects altimetry, the geoid and an oceanographic model of the sea surface topography.
After editing the complete SEASAT-1 data set, that was kindly provided by J.G. Marsh, NASA-Goddard Space Flight Center, three alternative methods of cross-over point determination were tested. First global cross-over adjustments were carried out with the data divided into several time intervals. In order to attain a better insight into the behaviour of the radial orbit errors and their recovery from cross-overs and frozen repeat arcs an analytical description of the radial orbit error has been worked out. Independently from these investigations a detailed study of altimetry in the Mediterranean and a global determination of the ocean variability from repeat arcs are carried out.



G.P.S. survey NAVGRAV
23 - 29 April 1986
2°
3°
4°
5°
6°
7°
8°
57°
56°
55°
54°
53°
52°
NORTH SEA
Circle
Platform H7
Circle
Landpath
Kalman filter
Circle
Circle
Platform L-10-F
Launch
0
100 km
Delft University of Technology Department of Geodesy

Figure 2



Gravity survey NAVGRAV
23 April - 13 May 1986
2°
3°
4°
5°
6°
7°
8°
9°
57°
56°
55°
54°
53°
52°
NORTH SEA
1e week (GPS survey)
0
100 km
Delft University of Technology
Department of Geodesy

Figure 3

3.4 Geoid Determination

A precise, detailed gravimetric geoid has been computed, see Fig. 4 and 5. The computation is based on the classical Stokes integral and considers ellipsoid and atmospheric corrections. The geoid heights have been computed from 3′ × 5′ mean gravity anomalies in the Netherlands, 6′ × 10′ anomalies in Western Europe and the OSU-81 set of potential coefficients up to degree and order 180. Comparisons with a European gravimetric geoid and with doppler measurements slow agreement on the 10–20 cm level.

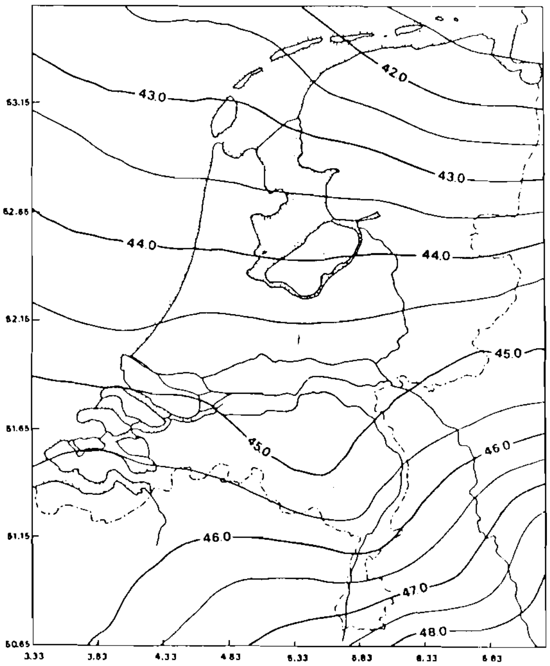


Fig. 4. Gravimetric geoid of the Netherlands in meters referring to the GRS67 system (interval 0.5 m)

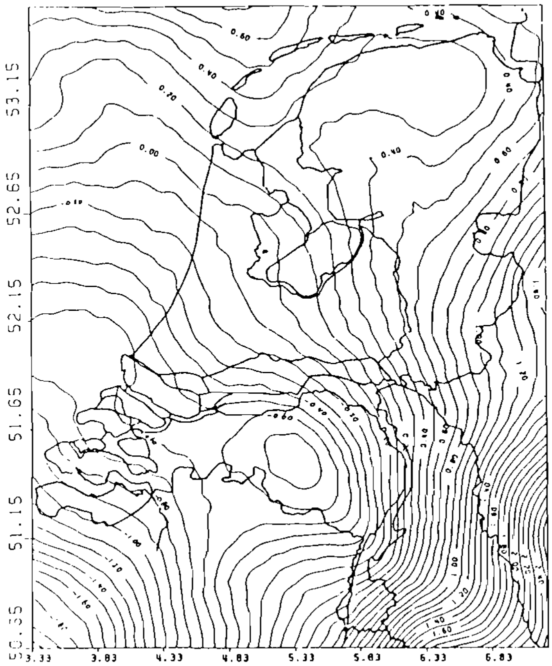


Fig. 5. Gravimetric geoid of the Netherlands in meters referring to a Bessel ellopsoid with reference point Amersfoort (interval 0.1 m)

3.5 Publications

BAKKER, G., J.C. DE MUNCK and G.L. STRANG VAN HEES - Course on radiopositioning. January 14th-17th, 1985. Department of Geodesy, Delft University of Technology, Delft, 1985.

HERMANS, H., P. VAN ES and R. RUMMEL - On the Adjustment of Individual Traverses. In: proc. Inertial Technology for Surveying and Geodesy, ed. K.P. Schwarz, Vol. 1, pp. 325–339, Banff, 1985.

RUMMEL, R. - Geodesy's contribution to geophysics. Interdisciplinary Science Review **9** (1984), no. 2, pp. 113–222.

RUMMEL, R. - The Earth's Gravity Field, in: Solid Earth Science & Application Mission for Europe, ESA Special workshop, 69–76, Ising, 1986.

STRANG VAN HEES, G.L. - Adjustment of hyperbolic patterns. Marine Geodesy **9** (1984), no. 1, pp. 113–126.

STRANG VAN HEES, G.L. - Precision of the geoid, computed from terrestrial gravity measurements, Manuscripta Geodaetica, Vol. 11, pp. 1–14, 1986.

WILLIGEN, G.W. VAN - De Gravimetrische Geoïde van Nederland, NGT Geodesia, no. 7/8, pp. 248–254, 1986.

4 THEORY AND EVALUATION

4.1 Computing Centre, Geodetic Institute, Delft University of Technology

Since 1981, the Centre participates in the FAST consortium. FAST, in which mainly French, Italian, German and Dutch institutes collaborate, is preparing the data reduction of the European astrometric satellite Hipparcos. After its launch, which is planned in 1988, Hipparcos will measure angles between stars during two and a half years. From these angular measurements a very precise star catalogue is computed, with positions, proper motions and parallaxes of some 120.000 stars. The typical precision to be realized is a few milli arc seconds. Within FAST, the Delft Centre is responsible for the so-called Reduction on Circles. This involves a least-squares adjustment with ca. 70.000 observations (half a day of measurements), ca. 2.000 stars unknowns and some 50 instrumental unknowns. During the mission, such a system has to be solved about 4.000 times. The software for this task was delivered to FAST in december 1986. It will be implemented, integrated and run at CNES (Toulouse, France).
In the field of design, measurement and computation of control surveys, studies were continued, in particular with respect to densification networks. One of the aims is an improved description of precision by artificial covariance matrices for excisting control points. This involves control points of different orders, and methods for estimating the parameters of a substitute matrix from existing networks. Research into the theory of linear inverse mapping, based on a geometric approach, together with the study of non-linear adjustment, led to the doctoral thesis of P.J.G. Teunissen. In the SCAN-II software system, improved sparse matrix techniques were implemented. The contribution of computations to UELN and RETrig was continued The SCAN-II system was installed in several institutes, also in other countries.

4.2 Linear Geodetic Boundary Value Problem

The geodetic boundary value problem (b.v.p.) has been investigated by RUMMEL and TEUNISSEN (1986) in the context of the definition of a complete physical model, consisting of observations, deterministic and stochastic model. The linearized classical b.v.p.'s in spherical approximation, scalar and vectorial are solved by linear inference. Introducing a minimum principle the same approach is applied to the solution of the overdetermined geodetic b.v.p. The result of the overdetermined problem is worked out for a combination of the observables potential, scalar gravity, vertical gradient and vertical geometry. It is discussed together with a number of specializations and with a suggestion concerning the non-linear problem. The overdetermined case is treated in parametric form as well as in the form of condition equations. The stochastic interpretation of the method provides a means to analyse the propagation of observation and discretization errors.

4.3 Satellite Gradiometry

An orbiting gradiometer measures simultaneously several gravity quantities, ideally all six second-order derivatives of the gravitational potential. These contain information on the orbit, on the structure of the gravity field, and on the attitude of the space-craft. Due to the availability of several components simultaneously it is possible to separate orbit determination from attitude or gravity field recovery. This facilities the analysis of the gradiometer measurements and allows the use of the principles of fast spherical harmonic analysis. The separation of gravity field recovery and orbit determination has been tested numerically with a simplified gravity field (with a purely zonal spherical harmonic expansion) up to degree 300. For

both the potential coefficients and for the orbit an almost exact recovery has been attained after two iteration steps.
Apart from the gravity field recovery the work in gradiometry concentrated on an elaboration of the geometric description of the gravitational field in space, a comparison of the fundamental measurement principles and on possible problem areas.

4.4 **Satellite-to-Satellite Tracking**

In (COLOMBO, 1984) a method is derived for the detailed and global mapping of the planetary gravitational field using two artificial satellites that carry devices to track each other along the same near-circular, near-polar orbit, separated by a few hundred kilometers and as low as the atmosphere would allow. They are kept aloft, in spite of air drag, by the action of small rocket engines that maintained a proof-mass inside each spacecraft in constant free fall. The signal is the relative line-of-sight velocity of the proof masses, averaged over several seconds.
A specially tailored analytical perturbation theory, where the reference orbit is periodical and obtained by numerical integration in a low-degree zonal reference field, is used here to derive a linearized model for the signal. The 'lumped coefficients' of the perturbations can be calculated very efficiently with a technique that relies heavily on the Fast Fourier Transform algorithm, and whose principle is simular to that of Gauss' method for integrating Lagrange's planetary equations. Computer simulations of the relative motion of the satellites in a field whose potential is the sum of zonal spherical harmonics up to degree 300, suggests that the model is accurate to better than 1% at most frequencies present in the spectrum of the signal.
Detailed consideration has been given to a method for estimating from the data all potential coefficients up to a high degree and order (such as 300). This method is based on the choice of a common orbit that closes upon itself after enough days have elapsed to resolve all the unknown coefficients. This orbit gives a rotationally symmetrical distribution of data. After taking care of the non-periodical component of the signal (due to orbit estimation errors and secular resonant effects) by introducing extra unknowns, the normal equations of the adjustment becomes very sparse. With a suitable ordering of unknowns, it shows an 'arrow' structure, the 'shaft' consisting of diagonal blocks. It is feasible to solve such a system (in spite of its great size) with ordinary modern computers, and also to find the formal accuracies of the results by a partial inversion of the normal matrix.
In the context of an ESA study on a satellite-to-satellite tracking (SST) gravity mission the items state of art and principles of SST, user benefits, and spectra for low-low versus high-low configurations have been investigated. The spectral analysis is carried out with a conventional signal-noise comparison as well as with a computation of the perturbations as derived from existing spherical harmonic expansions up to degree and order 180. The latter requires the computation of inclination functions up to the same high degree. The study has been carried out in cooperation with the Faculty of Aerospace Engineering, Delft University of Technology and the German Geodetic Research Institute at Munich.

4.5 **Publications**

BAKKER, G. - The closed spatial polygon. Bolletino di Geodesia e Scienze Affini XLIV (1985), No. 1, pp. 17-36.

BROUWER, F.J.J. - Account of the working meeting on European VLBI for Geodesy and Astronomy, Delft, 1983. Netherlands Geodetic Commission, Delft, 1984.

BROUWER, F.J.J. - On the principles, assumptions and methods of geodetic very long baseline interferometry. Netherlands Geodetic Commission, Publications on Geodesy, New Series, Vol. 7, No. 4, Delft, 1985.

BROUWER, F.J.J. and G.E.L. VERKUIJL - Philosophy and practice of 3D fusion of ellipsoidal and cartesian coordinates. In: Report on the Symposium of the IAG subcommission for the new adjustment of the European Triangulation (RETrig), The Hague, Nov. 25-28, 1985. IAG, Section I, München, 1986, pp. 147-155.

COLOMBO, O.L. - The global mapping of gravity with two satellites. Netherlands Geodetic Commission, Delft, 1984.

DAALEN, D.T. VAN - General considerations on Reduction on Circles, proceedings FAST Thinkshop, Asiago, May 1983.

DAALEN, D.T. VAN - The current state of the Reduction on Circles, proceedings second FAST Thinkshop, Marseille, February 1985.

DAALEN, D.T. VAN - The astrometry satellite Hipparcos, in: F. Sanso (ed.), Proc. first Marussi-Hotine Symp., Roma 1985, pp. 259–284.

DAALEN, D.T. VAN and H. VAN DER MAREL - Geodetic, Geometric and Computational Aspects of Hipparcos, in: Manuscripta Geodaetica (1986) 11: pp. 146–166.

HEUVEL, F.A. VAN DEN and D.T. VAN DAALEN - Grid step inconsistency correction during Reduction on Circles, proceedings second FAST Thinkshop, Marseille, February 1985.

HEUVEL, F.A. VAN DEN - Astrometric satellite Hipparcos: gridstep-inconsistency correction during Reduction on Circles, master thesis T.U. Delft, April 1986.

KOK, J.J. - On testing and reliability in levelling networks. Proceedings Symposium, Precise levelling, Hannover, 1983, Bonn, 1983, pp. 353–379.

KOK, J.J. - The United European Levelling Network (UELN-73). A short review of the status and future activities. In: IAG Subcommission for the new adjustment of European Triangulation, No. 15, München, 1985.

MAREL, H. VAN DER - Numerical Smoothing of Attitude Data, proceedings, FAST Thinkshop, Asiago, May 1983.

MAREL, H. VAN DER, M. PINARD, I. STELLMACHER, J. KOVALEVSKY and L. SAINT-CRIT - Hipparcos Attitude Simulation, proceedings FAST Thinkshop, May 1983.

MAREL, H. VAN DER - Astrometric Satellite Hipparcos: Test computations for Reduction on Circles and Smoothing of Attitude Data, master thesis T.H. Delft, September 1983.

MAREL, H. VAN DER - Starabscissae Improvement by Smoothing of Attitude Data, proceedings second FAST Thinkshop, Marseille, February 1985.

MAREL, H. VAN DER - Large Scale Calibration during Reduction on Circles, proceedings second FAST Thinkshop, Marseille, February 1985.

MAREL, H. VAN DER and D.T. VAN DAALEN - On the Geodetic Aspects of the Astrometry satellite Hipparcos, in: proceedings C.S.T.G. symposium Toulouse, June 1986.

MAREL, H. VAN DER, F. VAN DEN HEUVEL and D.T. VAN DAALEN - Testruns Reduction on Circles on CERGA dataset I, in: proceedings of the Hipparcos Data Simulation workshop, Royal Greenwhich Observatory, September 1986.

TEUNISSEN, P.J.G. - The geometry of geodetic inverse linear mapping and non-linear adjustment, Netherlands Geodetic Commission, Publications on Geodesy, Vol. 8, No. 1, Delft, 1985.

TEUNISSEN, P.J.G. - A note on the use of Gauss' formulas in non-linear geodetic adjustment. Statistics & Decisions (1985), No. 2, pp. 455–466.

TEUNISSEN, P.J.G. - Quality control in geodetic network. In: Optimization and design of geodetic networks (eds. E.W. Grafarend and F. Sansò), Berlin, 1985.

TEUNISSEN, P.J.G. - Zero order design: general inverses, adjustment, the datum problem and S-transformations. In: Optimization and design of geodetic networks (eds. E.W. Grafarend and F. Sansò), Berlin, 1985.

RUMMEL, R. - From the observational model to gravity parameter estimation. In: Proceedings of the International Summer School on Local Gravity Field Approximation. Beijing, China, August 21-September 4, 1984 (ed. K.P. Schwarz). University of Calgary, Calgary, 1985, pp. 67–106.

RUMMEL, R. - Satellite Gradiometry, in: Mathematical and Numerical Techniques in Physical Geodesy, ed.: H. Sünkel, pp. 317–363, Lecture Notes in Earth Sciences, Vol. 7, Springer, 1986.

RUMMEL, R. - Satellite Altimetry as Part of a Geodetic Model, in: proc. 1st Hotine-Marussi Symposium on Mathematical Geodesy, Vol. 2, pp. 757–786, Milano, 1986.

RUMMEL, R. - Satellite Gradiometry - A Promising Concept for 25 Years, in: Die Arbeiten des SFB 78 Satellitengeodäsie der Technischen Universität München, Hrsg.: M. Schneider, Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung, 48, pp. 123–139, München, 1986.

RUMMEL, R. and O.L. COLOMBO - Gravity field determination from satellite gradiometry. Bulletin Géodésique 59 (1985), No. 3, pp. 233–246.

RUMMEL, R. and P.J.G. TEUNISSEN - Geodetic Boundary Value Problems and Linear Inference, Int. Symp. Figure and Dynamics of the Earth, Moon and Planets, Prague, 1986.

SCHRAMA, E.J.O. - Estimability of Potential Coefficients from Orbit Perturbations. Report of the Department of Geodesy, 86.1. Mathem. and Physical Geodesy, Delft University of Technology, Delft, 1986.

STRANG VAN HEES, G.L. - Testing of geodetic networks, Quaterniones Geodesiae 5 (1984), No. 3, pp. 163–184.

5 PHYSICAL INTERPRETATION

5.1 Recent movements of the Earth's Crust

5.1.1 *Levellings in the Groningen gasfield*

Levellings in the Groningen gasfield area have been carried out in the years 1982, 1983, 1984, 1985, 1986. These were levellings of about 500 km length. In 1987 a more dense network of 2000 km length will be measured. The subsidence of the gasfield has continued according to predictions with a maximum rate of 1.5 cm/year.

5.1.3 *Levelling in mining area*

New levelling lines in the Limburg mining area have been measured during the years 1982-1986, to detect further vertical movements.

5.2 Publications

LEMMENS, M.J.P.M., W.R. JACOBY and E. SEIDLER - Plate motions, the driving mechanism and the geopotential. Annales Geophysicae **3** (1984), no. 2, pp. 333-342.

PÖTTGENS, J.J.E. - Ground movements caused by mining activities in the Netherlands, Proceedings of the Third International Symposium on Land Subsidence, Venice, March 1984, pp. 651-659.

RIETVELD, H. - Land subsidence in the Netherlands, Proceedings of the Third International Symposium on Land Subsidence, Venice, 19-25 March 1984, pp. 455-464.