ASTRONOMY, GEODESY AND THE NETHERLANDS GEODETIC COMMISSION

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Astronomy and Geodesy at the roots of statistics

Astronomy and geodesy are always bracketed together in studies on the early history of mathematical statistics[1]. In fact, the first methods of combining redundant measurements originate from three major problems in geodesy and astronomy, namely to determine the size and shape of the Earth, to explain the long-term inequality in the motions of Jupiter and Saturn, and to find a mathematical representation of the motions of the Moon. The two main reasons for performing redundant measurements are the wish to increase the accuracy of the results computed and the requirement to be able to check for errors. However, due to the intrinsic uncertainty in measurements, measurement redundancy generally leads to an inconsistent system of equations. Without additional criteria, such a system of equations is not uniquely solvable. In the middle of the 18th century, this adjustment problem had attracted the attention of many leading scientists, from both astronomy and geodesy.

The first scientist who formulated a solution to the adjustment problem was the astronomer Tobias Mayer (1723-1762). Mayer made numerous observations of the moon with the purpose of determining the characteristics of the moon's orbit. In 1750 Mayer proposed a new method for adjusting his moon data. Given a set of m equations in n unknowns, Mayer proposed to separate the m equations in n groups, followed by a group wise averaging. Mayer's *method of averages* soon became popular, since it used all observations and was very simple to apply.

The first adjustment method that made use of an objective criterion is due to the geodesist Roger Joseph Boscovich (1711-1787). He proposed in 1757 to solve the inconsistent system of equations by minimizing the sum of absolute residuals. Boscovich applied his method, now known as the *method of least absolute deviations* or L_1*-adjustment*, to the data of French and Italian arc measurements. Since the method was difficult to apply at that time, it never reached the same level of popularity as Mayer's method. In the second half of the 20th century however, the method gained in popularity due to its property of being resistent (robust) to outliers.

The most popular adjustment method is due to Adrien-Marie Legendre (1752-1833). Legendre's *method of least squares* solves an inconsistent system of equations by minimizing the sum of squares of the residuals. Legendre, who worked on many astronomical and geodetic projects, proposed his method in 1805 and applied it to the geodetic measurements of the French meridian arc from Barcelona to Dunkirk (1795). These measurements formed the basis of the metric system, whereby the meter was defined as 10^{-7} times the length of the terrestrial meridian quadrant through Paris at mean sea level. Legendre's method met with almost immediate success. His method used all the observations, had an objective criterion and most importantly, resulted in a solvable linear system of equations. Within ten years after Legendre's publication, the method of least-squares became a standard tool in astronomy and geodesy in various European countries.

Astronomy and Geodesy at the roots of the NCG

The above brief account on the history of adjustment theory, is one example of the many research topics that astronomy and geodesy share of old. Other examples are the minute execution of astronomical measurements and the continuous struggle of limiting the effects of atmospheric refraction. It are these and other areas of mutual interest that often made astronomers and geodesists pull together. It is therefore not surprising that astronomers from various Dutch research institutes (e.g. Leiden, Utrecht and Groningen) have been members of the Netherlands Geodetic Commision (NCG) from the moment the commission was set up[2].

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[1] P.J.G. Teunissen (2000): A brief account on the early history of adjusting geodetic and astronomical observations. *De Hollandse Cirkel*, 2(1/2), 12-17.

[2] Astronomers that were or are member of the NCG (in alphabetical order): prof. dr. W.N. Brouw (1976-1991), prof. dr. W. de Sitter (1923-1934), dr. G. van Herk (1952-1958, 1963-1973), prof. dr. J.C. Kapteyn (1907-1915), prof. dr. A.A. Nijland (1915-1936), prof. dr. J.H. Oort (1937-1969), prof. dr.

Following the advise of the Royal Netherlands Academy of Sciences (KNAW), the Netherlands Geodetic Commission was set up by Royal Decree of 20th February 1879. Prof. dr. F.J. Stamkart, at that time responsible for the Dutch contribution to the European arc-measurements, became the Commission's first President. The other members were: prof. dr. J. Bosscha, professor of physics at the Polytechnical School, the forerunner of the present Delft University of Technology (DUT), prof. dr. J.A.C. Oudemans, director of the Utrecht Observatory, prof. dr. H.G. van de Sande Bakhuyzen, director of the Leiden Observatory and dr. G. van Diesen, senior engineer of the Department of Public Works. The Royal Decree defined the duties of the Commission as follows: to continue and complete the triangulation measurements on behalf of the European arc-measurements; to continue and complete the precise levelling network; to coordinate the work for these two surveys. The work of the commission was divided among its members as follows: triangulation, Stamkart and Oudemans, astronomical measurements, van de Sande Bakhuyzen and Oudemans, and levelling, van de Sande Bakhuyzen and van Diesen[3].
The success of the Commission in this early period is in a large part due to the work of van de Sande Bakhuyzen. He succeeded Stamkart in 1882 as President and lead the Commission until his death in 1923. For over forty years he lead the Commission with great ability and took an active part in several of its scientific projects. These projects were concerned with primary and first order levelling as well as with geodetic-astronomical measurements. He contributed significantly to the European arc-measurement through his astronomical longitude-, latitude-, and azimuth determinations, which were also connected to the primary triangulation of the Netherlands. Apart from his work as President of the Commission, he was also active internationally. From 1900 to the end of 1916, he was Secretary General of the International Association of Geodesy (IAG) and from 1916 onwards, he held the same high office at the Reduced Geodetic Association of Neutral Nations, which was set up to continue the geodetic and astronomical measurements during the 1st World War.

If we view the complete 120-year period of the Commission's existence, we come to the conclusion that geodetic-astronomical measurements played a prominent role in the Commission's work, especially in the time frame preceding the 1970s. Some typical and important examples hereof are:

- The above mentioned longitude-, latitude-, and azimuth measurements (end of the 19th century).
- Astronomical measurements contributing to the international research on Earth rotation (beginning of the 20th century).
- Measurement of Laplace stations for the re-adjustment of the European triangulation network (shortly after the 2nd World War).
- With reference to the International Geophysical Year (1957), the development of a geodetic-astronomical observatory in Curacao .
- Measurement of the deflections of the vertical for the purpose of geoid determination with Vening Meinesz' integral (1974-1977).

The traditional ties between astronomy and geodesy changed with the advent and operationalization of satellite geodesy. Instead of relying on astronomical direction measurements, geodesists started to make an increasing use of artificial satellites. First spatial triangulation by means of photographic satellite tracking, then spatial trilateration by means of satellite laser ranging, which finally was followed by the use of 'active' satellites for precise positioning, first based on the Transit Doppler System, but nowadays very successfully based on the Global Positioning System. Despite the adoption of these new measurement techniques, the cooperation in the Netherlands between astronomers and geodestists continued. Although the cooperation was perhaps not as frequent as before, important examples can be given of the continued cooperation between the two sciences. One example is the geodetic usage of Very Long Baseline Interferometry (VLBI), a measurement technique originally developed for radioastronomy. Another example is the contribution of Dutch geodesists and astronomers to the astrometric satellite mission *Hipparcos* of the European Space Agency (ESA). And

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J.A.C. Oudemans (1879-1906), prof. dr. R.T. Schilizzi (1997-present) and prof. dr. H.G. van de Sande Bakhuyzen (1879-1923).

[3] For this presentation the author made a liberal use of the excellent paper: 'History of the Netherlands Geodetic Commission' by N. van der Schaaf, published in '*The Century of the Netherlands Geodetic Commission*' (Editor: N. van der Schaaf), 1979, pp. 51-129.

a third example is the joint organisation of two successful international scientific symposia on atmospheric refraction[4].

Astronomy and Geodesy reunited at the Westerbork Observatory

With the recent transfer of DUT's space geodetic measurement equipment from Kootwijk to the astronomical observatory in Westerbork, a new opportunity has arisen to strengthen the traditional ties between the Dutch astronomers and geodesists. In order to take this opportunity, the NCG felt it necessary - in accordance with its tradition - to take the initiative of exploring the scientific added value of this unification. To that end, the NCG established the taskforce 'Geodetic-Astronomical Station Westerbork' under the leadership of prof. Aardoom. This taskforce was given the task to draw up a first plan showing how the surplus value, of having the astronomical and geodetic measurement techniques united at the same geographic location, could be employed for the benefit of both sciences[5]. Although the proposals of the taskforce will need further elaboration and execution, it has already become clear to all parties concerned that the scientific infrastructure now available at Westerbork indeed provides for important new challenges and opportunities. It is therefore now up to the scientific groups involved, to take these opportunities and to formulate concrete scientific projects that make use of this unique infrastructure as well as of the combined astronomical and geodetic expertise. In closing, the NCG sincerely thanks prof. Aardoom and all the taskforce members for a job well done and expresses the wish that the scientific joint venture initiated by the taskforce may be successfully continued.

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[4] *Electromagnetic Distance Measurement and the Influence of Refraction* (1977), P. Richardus (ed.), Publications on Geodesy, Green Series, No. 21, and *Refraction of Transatmospheric Signals in Geodesy* (1992), J.C. de Munck and T.A.TH. Spoelstra (eds.), Publications on Geodesy, New Series, No. 36.

[5] De wetenschappelijke rol van het astrometrisch-geodetisch observatorium Westerbork (The scientific role of the astrometric-geodetic observatory Westerbork), Uitkomsten van een verkenning door de Taakgroep Geodetisch-Astronomisch Station Westerbork van de Nederlandse Commissie voor Geodesie.