National Report for 1983-87
International Union of Geodesy and Geophysics

INTERNATIONAL ASSOCIATION OF GEODESY
NINETEENTH GENERAL ASSEMBLY
VANCOUVER, CANADA
9–22 August 1987

GEODESY
IN AUSTRALIA

PREPARED BY THE GEODESY SUB-COMMITTEE - NATIONAL COMMITTEE FOR SOLID - EARTH SCIENCES
AUSTRALIAN ACADEMY OF SCIENCE
Geodesy Sub-Committee

A. Stolz (Chairman)
B. C. Barlow
R. Coleman
B. A. Greene
D. L. Jauncey
K. Lambeck
D. R. Larder
C. Veenstra

Academy of Science -
National Committee for
Solid - Earth Sciences
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1 CONTROL NETWORKS

The geodetic survey of Australia as at 31 December, 1986 is shown in Fig. 1. Since 1983 most conventional geodetic surveys have been made in the larger metropolitan and town control zones. This work is almost exclusively performed by State Lands Departments or Mapping Agencies. Outside these areas, densification by TRANSIT Doppler and, more recently, by GPS techniques was favoured by State as well as Federal survey and mapping organisations, with some surveys being carried out under contract (See Section 5).

The levelling network as at 31 December, 1986 is shown in Fig. 2. Apart from about 2,000 km of 2nd order levelling in Western Australia covering the crustal deformation areas of Meckering and Cadoux, and some 1st order levelling in northern New South Wales, the levelling network extensions since 1983 were carried out to 3rd order standards (12 mm/km\(^{1/2}\)).

Adjustments of horizontal and vertical control are computed in a cooperative effort between all State and Federal survey and mapping authorities. The readjustment of the primary geodetic network, referred to as the Geodetic Model of Australia of 1982, was adopted by the National Mapping Council in 1984. The coordinates are called Australian Geodetic Datum 1984 (AGD84) coordinates, to distinguish them from AGD66 values. The upgrading, amalgamation and readjustment of the supplementary sections in terms of AGD84, using the Canadian program GANET, continues.

A preliminary readjustment was carried out of the levelling network covering a broad belt along the Queensland coast. A large amount of additional levelling was incorporated. Several adjustments were computed using the levelling data sets for the Meckering-Cadoux seismic zone. The readjustment of the Tasmanian levelling net was completed in 1983 after upgrading parts of the network.

The national geodetic data base, now containing information on more than 22,000 horizontal stations and about 86,000 bench marks, has been transferred to an HPA900 computer in the Division of National Mapping of the Federal Department of Resources and Energy.
Figure 1

AUSTRALIA
1° LATITUDE: 1° LONGITUDE: 2.5 mm
AUSTRALIAN LEVELLING SURVEY
AS AT 31 DECEMBER 1996
LEVELLING AND THE ORIGIN OF THE AUSTRALIAN HEIGHT SYSTEM
F tabular Levelling
Third Order Levelling
The 1996 Adelaide Datum
The 1996 Adelaide Datum
The 1996 Adelaide Datum
The 1996 Adelaide Datum

Provisioned by the Bureau of Meteorology, Department of Environment and Energy, 1996
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2 GRAVIMETRY

The Australian gravity base-station network consists of about 240 airport stations spread fairly evenly throughout Australia. A grid of east-west and north-south gravimeter traverses provides gravity intervals over the network, the datum and scale of which are now controlled by the USSR/Australian absolute measurements made in 1979 at six major sites. In 1980, seven LaCoste & Romberg gravimeters were used to measure the intervals between 67 of these airport stations and all six absolute sites. More recent work on the network has been limited to replacing the stations which have been destroyed. Computer adjustments of the gravimeter measurements show that the absolute determinations are consistent to within measurement error. The weighted results for the six absolute sites define the Australian National Base-station Network (Isogal-84 values) with a precision of 0.1 µm/s² and an accuracy of 0.3 µm/s². A polynomial has been determined for revising earlier gravity values so that they are consistent with the new base-station values (Wellman et al., 1984; Wellman et al., 1985).

Densification of the reconnaissance gravity of the Australian land area has improved the coverage in limited areas. Most of this work has been carried out for geophysical purposes by the Bureau of Mineral Resources (BMR), State Mines Departments, mineral exploration companies and tertiary education institutions. The most significant work for geodetic studies is that carried out in South Australia by Gilliland (1983) - See Section 6. Only minor gravity surveys have been carried out in Antarctica.

Marine gravity coverage in the seas around Australia was considerably improved by data collected by BMR in the RV Rig Seismic and, by data from the Geological Survey (Bundesanstalt für Geowissenschaften) of the Federal Republic of Germany, using their RV Sonne. Line traverse data were obtained in parts of the continental margins around Australia, the Heard-Kerguelen Plateau and the Lord Howe Rise.

Magnetic tapes of the Australian gravity data were released for sale by BMR in 1985. Two data types are available: (1) the Australian National Gravity Data Base (NGDB) containing, interalia, more than 500 000 point values of observed gravity, and (2) digital terrain and digital gravity models of Australia on a 0.1°x0.1° grid. The digital models are based on the NGDB. Computer-drawn maps of a new 1:250 000 and 1:1 000 000 Bouger anomaly series are also available from BMR for a number
of onshore map sheet areas. The marine gravity data is available on magnetic tape.

References


3 LASER RANGING

The Division of National Mapping Laser Ranging System (NLRS) was installed at Orroral during 1983 and 1984. This upgrade of the former lunar laser ranging system was performed under contract to NASA, and consisted primarily of conversion of the equatorial mount to an X-Y mount, provision of high-precision encoders to permit automatic tracking of LAGEOS, acquisition of a Quantel Nd-YAG 100 picosec laser with 10 pulse per second repetition rate, a rotating transmit/receive switch from McDonald Observatory, a modern computer and timing equipment. The design allows ranging to both LAGEOS and the moon. The first observations on LAGEOS occurred in July 1984, and routine ranging to LAGEOS commenced in September, 1984. Returns from the Apollo 15 retroreflector on the moon were obtained in June and July, 1984. The NLRS has been progressively improved, principally by the introduction of a microchannel plate detector, a GPS time transfer unit and a 1 picosec resolution timing system early in 1986. A meticulous ground survey has connected the NLRS reference point to survey pillars of the AGD. The Tidbinbilla DSN VLBI has been connected to the NLRS by GPS measurements on a number of occasions.

Data on LAGEOS from June 1986, with ±1 cm precision in the internal calibration and ±4-5 cm precision in range, have been released to the NASA Crustal Dynamics Program Data Information System (CDP/DIS). Typically, many thousands of return pulses are received in each pass, including passes taken in daylight. Quick-look results are transmitted daily to the Goddard Space Flight Center and to the Center for Space Research of the University of Texas at Austin for earth rotation parameter estimation. Lunar results have been disappointing, with only four successful observing runs giving 16 cm normal points, but there is an ongoing effort to improve this situation.

The NASA laser ranging site at Yaragadee has operated continuously during 1983-87, with precision of ±1-2 cm. This site is functioning as a prime station for LAGEOS orbit determination. The station ranges to STARLETTE and the Japanese satellite AJESAI on an opportunity basis. The laser ranging results from Orroral and Yaragadee are transmitted to Goddard Space Flight Center for analysis and lodgement in the NASA CDP/DIS. In early 1987 the Yaragadee station was upgraded with a microchannel detector and discriminator package, which improved the precision to typically 0.8 cm.
The laser range measurements to LAGEOS, obtained from Yaragadee and Orroral prior to the closure of the Orroral SAO site in 1982, were analysed at the School of Surveying, University of New South Wales. Stolz & Masters(1983) determined baselines from 30-day orbital arcs of range data acquired during 1980 and 1981 with a precision of ±10 cm. Better baselines, consistent to about ±5 cm were obtained from 90-day arcs. Laser data processing at the University of New South Wales stopped in early 1985 when computer support was withdrawn.

References


Only one geodetic VLBI experiment has been performed since that described by Harvey et al. (1983). A collaborative experiment involving the Commonwealth Scientific and Industrial Research Organisation’s Division of Radiophysics, the NASA Jet Propulsion Laboratory, the South African Council for Scientific and Industrial Research and the School of Surveying, University of New South Wales, was conducted to determine the first ever high-precision geodetic VLBI baseline between radiotelescopes located at Tidbinbilla, near Canberra and Hartebeesthoek, in South Africa. The ~9 600 km baseline was measured, on 5 and 7 June, 1986, with a precision of about 1 part in $10^7$ (Harvey et al., 1987). The positions of eight radiosources south of $-45^\circ$ declination were also determined with a precision of about $\pm 0.1$ arcsec. Repeat measurements of the Tidbinbilla-Hartebeesthoek baseline, using the more sensitive Mark III equipment, are in progress (June 1987). Repeat measurements of some of the baselines measured in the 1982 experiment are also planned (Harvey et al., 1983). The 26 m NASA radiotelescope, previously located at Orroral, was transferred to Tasmania (Hobart) in 1985. This will be used for the repeat measurements and, therefore, a much improved baseline measurement should be obtainable.

The future of VLBI in Australia, both for geophysical and astrophysical applications, is critically dependent on the developments taking place for the Australia Telescope. A network of five large antennas, each of which will be instrumented with a geodetic capability, will extend from Narrabri in New South Wales, through Coonabarabran, Parkes, Tidbinbilla to Hobart. Most importantly, the phase stable link which provides the key component of any VLBI system is expected to be distributed Australia-wide via AUSSAT or some other such satellite service. Geodetic VLBI measurements using several of the antennas of the Australia Telescope should be possible as early as 1988.

References


optical positions for southern radiosources (in preparation).
GPS

GPS, though still under development, has made a major impact on geodesy in Australia. Already GPS has been extensively used to extend and densify horizontal control networks, test networks, interalia, to compare single and dual-frequency measurements and data obtained from different receivers, have been established, campaigns have been conducted for precise orbit determination, discrepancies between levelling and MSL are being studied and data processing software for position and orbit determination is being developed, to name but a few activities.

Most State Lands Departments or Mapping Agencies have employed GPS for horizontal control surveys. By far the most noteworthy of these is the South Australian primary network densification program. The program specified the coordination of about 350 survey stations in southern South Australia at intervals ranging from approximately 10-40 km. The area of coverage is roughly 100,000 km$^2$. To render the project manageable, the survey was planned in stages. Stage 1, comprising about 100 stations, was completed during the period October to December, 1985 using up to four Macrometer V1000 instruments. Data analysis is not yet complete but current results indicate that horizontal accuracies of better than 3 ppm were obtained (Morgan et al., 1986; Jones et al., 1987). The remaining phases of the project should be completed this year.

Precise elevations in geodesy have traditionally been obtained by combining levelling and gravity measurements. GPS will in the near future be extensively used to provide elevations for control surveys and scientific studies but for these heights to be compatible with those provided by levelling and gravity the geoid height must be known. Work has begun on the recomputation of the geoid in Australia with a precision that is commensurate with GPS (Gilliland, 1986; Kearsley, 1986) - See Section 6. Moreover, an ambitious project, initiated by the New South Wales Public Works Department, is in progress to study the discrepancies between levelled elevations and MSL defined by tide gauges along 1,000 km of the eastern coast of Australia.

The Division of National Mapping has established a test network for GPS known as the South East Geodetic Measurement Evaluation Network (SEGMENT) with a view of developing specifications and recommended practices for GPS geodesy and surveying, and evaluating GPS receivers and data processing software (Govind et al., 1987). The network originally comprised six primary geodetic
stations separated by distances ranging from about 10-300 km but this was recently extended to include lines in the 50-200 km range. Since early 1985, GPS surveys have been performed on all or parts of SEGMENT with Macrometer V1000, TI 4100, WM-101, Trimble 40005 and Sercel NR52 receivers. The data collected is being analysed with National Mapping's OZPOS software.

With GPS there is no guarantee of a routine Precise Ephemeris service as is presently the case with the Transit system. Australia is contemplating a regional tracking and orbit determination capability to overcome this problem and to support a number of GPS applications throughout the Australasian region. A pilot project to determine orbits from stations in Canberra, Perth, Townsville and Darwin is planned for July 1987. The project is a collaborative effort between the Division of National Mapping, several State Lands Departments and Mapping Agencies, and the University of New South Wales, School of Surveying. Stolz et al. (1984) showed that such a network should produce orbits accurate to better than ±10 m. Software packages to support orbit determination are being developed at the Division of National mapping (J. McK. Luck, 1987, personal communication) and independently at the University of New South Wales (Masters & Stolz, 1985; Rizos & Stolz, 1985).

The School of Surveying, University of New South Wales, was approached in early November 1986 by the University of Texas at Austin, Center for Space Research to collaborate in a campaign to simultaneously observe the GPS satellites from Australian and U.S. sites for orbit determination. For eight days from 24 November to 1 December, 1986, a TI4100 receiver was operated at the Tidbinbilla Deep Space Network station near Canberra. The U.S. tracking configuration comprised stations located at Austin (Texas), Mojave (California) and Westford (Massachusetts). Preliminary results indicate that the orbits for some of the satellites computed from the U.S. station data alone change by as much as 1.5 km when the Australian measurements are included. Analysis of the data continues.

References


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6 GEOID COMPUTATIONS

The determination of the geoid primarily involves the task of computing the geoid-ellipsoid separation by some technique which utilises one or more of the following types of data: (i) gravity measured at the surface of the earth; (ii) tracking data to artificial satellites; (iii) three-dimensional satellite derived positions of the the surface of the earth i.e. satellite altimetry over the oceans or Transit/GPS data on land; (iv) geodetic levelling; and (v) astronomical observations. Table 1 summarises the relevant data collected in Australia for the period 1983 to 1987.

The main impetus for geoid computations within the period 1983-87 has been in support of the satellite positioning systems, in particular, GPS. A knowledge of the geoid height or relative geoid undulations is required to compare satellite height determinations with the conventional height datums based on a geopotential surface. Work is in progress to compute improved geoid undulations over regional areas where sufficient data is on hand to convert GPS ellipsoidal elevations to orthometric heights. An improved gravity data set South Australia was developed by Gilliland(1983b) and used to compute a free-air geoid. This geoid was compared against that obtained from astro-geodetic techniques, Doppler methods and prior gravimetric solutions(Gilliland, 1983a; 1984; 1985). The data requirements for computing precise (±5 cm) geoid heights from gravimetry were studied by Kearsley(1984, 1986a). Theoretical work on numerical analysis techniques used in the gravimetric solution is given by Kearsley(1985; 1986b) and Kearsley et al.(1985). Geos-3 and SEASAT altimetry data were used to construct marine geoid maps from standard geodetic cross-over techniques. These maps were subsequently employed for oceanographic and geophysical investigations(Coleman, 1984; Lambeck et al., 1984). Marine gravity data around the Australian coastline was compared against altimeter-derived gravity anomalies by Kearsley(1983).

References


TABLE 1: Data Available for Geoid Studies in Australia

(a) Land Gravity
-additional gravity data at 0.5°x0.5° spacing were collected in the vicinity of selected trigonometric stations in South Australia to support gravimetric geoid studies (Gilliland, 1983a; 1983b).
-a new 0.1°x0.1° mean free air gravity anomaly data bank for the Australian region, referenced to GRS80 and the recent Australian control gravity network, was compiled by J.R. Gilliland in a cooperative program with the Bureau of Mineral Resources.

(b) 3-D Satellite Positioning
-a number of Transit and GPS surveys were carried out in various regions of Australia (See Section 5) and point geoid height information was computed from these surveys using the satellite determined height and the corresponding Australian Height Datum value.

(c) Geodetic Levelling
-2nd order levelling surveys were conducted in support of some of the Transit/GPS network surveys.


A number of studies have been carried out which can be characterised as the application of geodetic measurements to geophysical problems. Geodetic results alone are generally inadequate for understanding the geophysical processes producing deformations of the earth and the emphasis of many of these studies has been to incorporate geological, geomorphological and geophysical data.

Stolz & Lambeck (1983) reviewed some of the geodetic methods that could be used for monitoring crustal motion and deformation in the Australasian region, and preliminary VLBI experiments have been conducted in eastern Australia (See Section 4). Coleman & Lambeck (1983) and Lambeck & Coleman (1984) examined terrestrial geodetic evidence for crustal deformation in this region and other evidence for stress and deformation is reviewed by Lambeck et al. (1984a). Crustal deformation in central Australia is discussed by Stephenson & Lambeck (1985a; 1985b).

Satellite altimeter data has been used for studies of the isostatic compensation of seamounts by Lambeck et al. (1984b). Coleman (1984) also used the altimeter data to study the variability in the sea surface topography of the Tasman Sea. Theoretical questions of thermal isostacy are discussed by Nakiboglu & Lambeck (1985a; 1985b) and Nakada & Lambeck (1987a). Models of isostatic rebound of eroding terrain have been developed by Stephenson (1984) and applied to the highlands of eastern Australia by Stephenson & Lambeck (1985b) and Lambeck & Stephenson (1986). McQueen (1986) has examined similar models for the eastern margin of Australia.

A number of studies have focussed on sealevel changes for different geological time scales. For the present time scale, Nakiboglu & Lambeck (1983) examined the contributions made to present-day sealevel by ongoing rebound of the late Pleistocene ice sheets and the loading effect of the melt water. Nakiboglu et al. (1983) studied the Late Pleistocene and Holocene sealevels, as have Lambeck & Nakada (1985), Lambeck & Nakiboglu (1986) and Nakada & Lambeck (1987a; 1987b). In these studies conclusions are drawn about the melting histories of the ice sheets, the earth's viscosity and tectonic displacements. On longer time scales, of $10^7$-$10^8$ years, sealevel fluctuations deduced from sedimentary records and from seismic stratigraphy have been modelled by tectonic processes by Cloetingh et al. (1985).
Studies of the earth's viscous response to long-period forces are discussed by Lambeck (1984) and Lambeck & Nakiboglu (1983) in the context of observations of the LAGEOS satellite. Analysis of existing gravity field models have been carried out by Lambeck & Coleman (1983; 1986) and a review of gravity fields of the terrestrial planets is given by Phillips & Lambeck (1984). The earth's rotational motion has been studied by Morgan et al. (1985).

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The Australian region is ideally suited for crustal movement studies. Internal deformation of the Australian sector of the Australian plate is believed to be small, making the continent a good platform for measuring the relative motions of some of the faster moving plates or fragments of adjoining plates. A nationally coordinated program to measure crustal movements in the Australian region has been proposed. A comprehensive report was prepared (Stolz et al., 1985). Specifically, the report outlines the scientific implications and applications of the new space techniques of satellite laser ranging, VLBI and GPS, puts a case for a serious effort in this field and makes recommendations at ensuring that Australia can contribute to, and benefit from, the development and application of these techniques to the geosciences. The high priority items for bringing the program to fruition are: (1) the establishment of tracking stations in Australia for determining the orbits of the GPS satellites, and (2) the acquisition of a mobile satellite laser ranging system. The report was endorsed by the Council of the Australian Academy of Science and submitted to the Australian government for action. This is where the matter stands at present.

In December, 1985 and June 1986, first epoch GPS surveys were conducted over small areas in the Southwest Seismic Zone east of Perth. No results were available at the time of writing this report (June 1987). Harvey (1985) studied methods for determining regional strain from the combination of VLBI and terrestrial data. A method in which the transformation parameters are related to the coordinates of the network before adjustment is recommended. Tests for the presence of systematic errors in the data should be applied beforehand. Because of their long historic record, terrestrial geodetic measurements provide a powerful means of measuring crustal deformations. Wellman suggested in 1981 that the terrestrial geodetic surveys of southeastern Australia carried out in the late 19th century and again in 1970 to 1980 are indicative of substantial crustal deformation with strain rates of the order of $50 \times 10^9 \text{ yr}^{-1}$ (Wellman, 1981). Lambeck & Coleman (1984) examined the same data and concluded that there has not been any significant crustal deformation and that what Wellman found was a distortion within a geodetic network.

Repeat levelling and gravity measurements have been studied for evidence of vertical ground movement in the Southwest Seismic Zone. Identified height changes characteristically have amplitudes
of 100 mm or more and wavelengths of about 50 km. Only some of the areas in which the height changes occur are associated with known seismic activity such as the Meckering and Cadoux earthquakes. The results of the repeat gravity surveys carried out in 1980-1981 and in 1983 are inclusive in that the measurement errors are of the same order as the residuals between the surveys (0.1 µm s⁻²).

References


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