THE MONITORING OF NATIONAL AND REGIONAL GEODETIC NETWORKS

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Abstract

The Australian Surveying and Land Information Group (AUSLIG) is the agency with principal responsibility for geodesy at federal government level in Australia. AUSLIG coordinates its national geodesy activities with State and Territory agencies through the Intergovernmental Committee on Surveying and Mapping. The national geodesy program involves the monitoring of movement of the Australian landmass and offshore territories as the basis of a geodetic framework for the Australian Spatial Data Infrastructure. Crustal deformation in a global context requires global observations to best monitor the slow deformation of the earth, and to provide the information essential to support satellite based positioning systems such as GPS. Geodetic data is acquired by AUSLIG from a network of global positioning system and satellite laser ranging stations located in the region and is distributed through the internet in the form of data and analysis products to the national and global community. This contribution enables use to be made of the global systems for local application of GPS for deformation purposes. This paper describes the AUSLIG geodesy program and its contribution to the monitoring of national, regional and global geodetic networks.

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1. INTRODUCTION

The Australian Surveying and Land Information Group (AUSLIG) is the agency with responsibility for geodesy at the federal government level in Australia. It is part of the Department of Industry, Science and Tourism. AUSLIG's general responsibilities encompass:

- Policy, standards and coordination associated with delivery of national and international land information programs;
- Management of the national mapping, maritime boundary, remote sensing and geodesy programs; and
- Implementation of the Australian Spatial Data Infrastructure (ASDI) at federal government level.

Each year AUSLIG receives funding from the federal budget of around $25 million and generates revenue of around $5 million from the sale of products. Products include maps, map data, aerial photography, satellite imagery and geodetic information. AUSLIG employs 110 staff who are mainly located in its head office in Fern Hill Park, Canberra, Australian Capital Territory. A significant amount of AUSLIG's program is outsourced to the private sector, including elements of the national geodesy program.
The AUSLIG national geodesy program has three main objectives:

- To monitor the motion of the Australian tectonic plate;
- To contribute geodetic data and products for a better understanding of natural and man-induced earth processes; and
- To provide a geodetic framework at the national level that allows the generation of homogeneous mapping and spatial data products which underpin the ASDI.

The principal products from the AUSLIG geodesy program are:

- Observations and analysis of data from the regional ground network of permanent GPS, DORIS and satellite laser ranging (SLR) stations within a global framework;
- Data and reports from the national geodetic database (NGDB); and

These products are used in national, regional and global geodetic solutions and in global research programs. The AUSLIG home page contains a comprehensive description of the national geodesy program.

The AUSLIG geodesy program employs 13 professional, technical and administrative staff and receives funding of around $4 million each year. This funding includes a small amount of revenue from the sale of geodetic products and services. A major cost element of the geodesy program is the outsourced management and operation of satellite laser ranging facilities in the Australian Capital Territory and at Yaragadee in Western Australia.

2. BACKGROUND

AUSLIG's contribution to global geodesy enables the global reference frame to be maintained so that regional or localised deformations can be monitored by GPS alone or in combination with other geodetic techniques. AUSLIG has prime responsibility for providing a national geodetic framework to facilitate local surveys for deformation or general purposes, and in this context, it is interesting to examine the background to the national geodetic datums.

2.1 Australian Geodetic Datum

The Australian geodetic framework was first consolidated nationally as the AGD66 geodetic data set on the Australian Geodetic Datum (AGD), which was proclaimed in the Australian Commonwealth Gazette of 6 October 1966. This geodetic data set was upgraded in a new national adjustment in 1984 as AGD84. Some states adopted the new national coordinate set while others stayed with the original data set. AGD66 and AGD84 both use the gazetted datum, the AGD, and the coordinates differ only due to additional data and improved adjustment techniques. The difference between these two coordinate sets varies from about 2 metres in southeast Australia to about 5 metres in the northwest, but the variation is not uniform. Due to the non-systematic nature of AGD66 there are no national transformation parameters available to automatically transform between AGD66 and AGD84. This is most often done by applying a block shift based on a comparison of sites in the area, which have both AGD66 and AGD84 positions.

2.2 Geocentric Datum of Australia

In 1988 the Intergovernmental Committee on Surveying and Mapping (ICSM) recommended that Australia adopt a geocentric datum by 1 January 2000. To facilitate the move to a geocentric datum AUSLIG, in 1992, established a series of permanent GPS stations extending from Antarctica to Cocos Island , as part of the world-wide International GPS Service (IGS) campaign. Continuous GPS observations were undertaken at eight geologically stable marks which formed the Australian Fiducial Network (AFN). These points were used as the key ties to the International Terrestrial Reference Frame (ITRF). During the IGS campaign GPS observations were also carried out at a number of existing geodetic survey stations across Australia. These were supplemented by further observations in 1993 and 1994, producing a network of about 70 well determined GPS sites, controlled by the AFN , with a nominal 500 km spacing across Australia. These sites are collectively known as the Australian National Network (ANN). The locations of AFN and ANN sites are shown in figure 1.

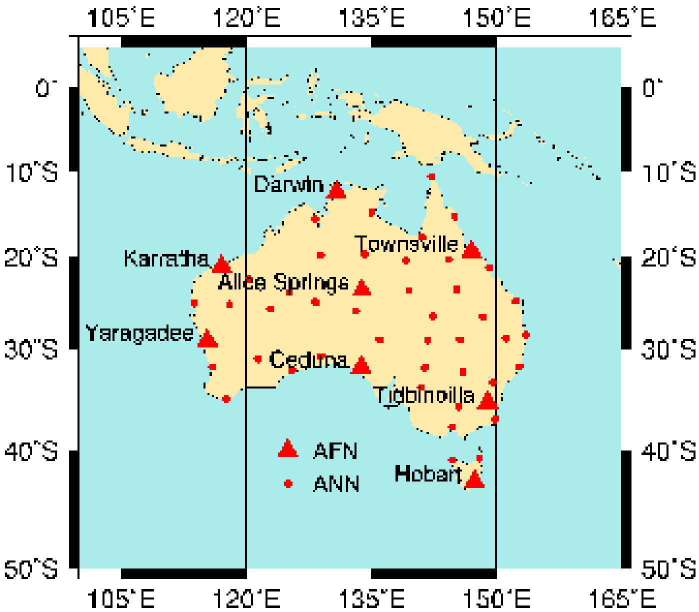


Figure 1: Locations of AFN and ANN sites

The GPS observations at both the AFN and ANN sites were combined in a single regional GPS solution in terms of the ITRF 1992 and the resulting coordinates were mapped to a common epoch of 1994.0. The positions for the AFN sites are estimated to have an absolute horizontal accuracy of about 2 cm at 95% confidence (Morgan et al, 1996), while the ANN positions are estimated to have an absolute horizontal accuracy of about 5 cm. The AFN sites were used to define the Geocentric Datum of Australia (GDA) and were published in the Commonwealth of Australia Government Gazette on 6 September 1995.

The positions of both the AFN and ANN sites were used to constrain a re-adjustment of the Australian geodetic networks, which included :

- Observations from the previous AGD66 and AGD84 adjustments;
- Conventional observations added since that time; and
- The extensive GPS networks established by the State and Territory authorities at about 100 km spacing between the ANN sites.

This resulted in a data set of more than 70,000 observations and produced GDA94 coordinates at almost 8,000 stations. These GDA94 coordinates are now being used by the State and Territory authorities to re-adjust their subsidiary survey networks onto GDA for introduction in the year 2000.

The original AGD was purposely defined to produce the best local fit to the geoid and the coordinates for Johnston, the origin station, were based on a selection of 275 astro-geodetic stations distributed over most of Australia (Bomford, 1967). Although it produced the best fit in the local region, the centre of the spheroid used did not coincide with the centre of mass of the earth. GDA was defined in ITRF92 with an origin at the centre of mass of the earth and with a best fit to the global geoid. This results in AGD and GDA positions differing by about 200 metres. National parameters are available on the AUSLIG Geodesy web site to transform between AGD84 and GDA94.

2.3 Australian Height Datum

On 5 May 1971 the Division of National Mapping, on behalf of the National Mapping Council of Australia, carried out a simultaneous adjustment of 97,230 kilometres of two-way leveling. Mean sea level was assigned the value of zero as determined from an observation period 1966-1968 at thirty tide gauges on the Australian land mass. The resulting datum surface, with minor modifications in two metropolitan areas, has been termed the Australian Height Datum (AHD) and was adopted by the

National Mapping Council at its twenty-ninth meeting in May 1971 as the datum to which all vertical control for mapping was to be referred. The levelling network in Tasmania was based on mean sea level for 1972 at the tide gauges at Hobart and Burnie and was adjusted on 17 October 1983 to re-establish heights on the Australian Height Datum (Tasmania). Where the levels on islands closely adjacent to the Australian mainland are observed to standard third order accuracy, and are referred to mean sea level at a satisfactory tide gauge, they are deemed to be part of the Australian Height Datum. The establishment of the AHD is described in Division of National Mapping Technical Report No. 12 (Roelse et al, 1975).

The AHD is an imperfect realisation of mean sea level because some of the tide gauges used for its definition were not well sited; the mean sea level determination was for a limited period and a particular epoch and no allowance was made for sea surface topography. The difference between AHD zero and mean sea level, which may be of the order of several decimetres (Mitchell et al, 1990) is not significant for conventional propagation of AHD, but may be important if connecting AHD to a more accurate determination of mean sea level.

Although the geoid is often equated to mean sea level, it may actually differ from it by the order of a metre, largely due to sea surface topography (Bomford, 1980). With improvements in gravity coverage, geoid models and GPS heighting, the difference between AHD, sea level and the geoid surfaces may become apparent, particularly over large areas, or in areas where there are rapid changes in the slope of the geoid.

3. AUSTRALIAN GEODETIC OBSERVATION NETWORK

AUSLIG maintains a number of permanent geodetic sites to monitor the position and motion of the Australian continent and its offshore territories for geodetic and spatial data infrastructure purposes. Although GPS is increasingly being used for global and regional deformation it still has some shortcomings and the quality of results can be often improved by the integration of other individual geodetic techniques. The Australian Geodetic Observation Network maintained by AUSLIG includes GPS and other geodetic techniques:

- Australian Regional GPS Network (ARGN)
- Australian SLR Network Stations; and
- Australian Doris stations.

Other important geodetic techniques to which AUSLIG contributes nationally are:

- Geodetic Very Long Baseline Interferometry (VLBI) observatories; and
- Sea level monitoring sites for vertical datum purposes.

These networks provide a national reference frame which contributes to, or are associated with, large scale deformation studies on the Australian continent. Each is briefly outlined below.

3.1 Australian Regional GPS Network

The ARGN consists of 15 permanent geodetic quality GPS receivers, on geologically stable marks, in Australia and its Territories, the locations of ARGN sites are shown in figure 2.

These sites provide the geodetic framework for the spatial data infrastructure of Australia and its territories. They also provide input observations for the measurement of global earth processes, such as crustal dynamics and sea level rise. Data from selected sites (Macquarie, Hobart, Tidbinbilla, Yaragadee, Cocos, Casey and Davis) is also contributed to the IGS data centre for use by the analysis centres.

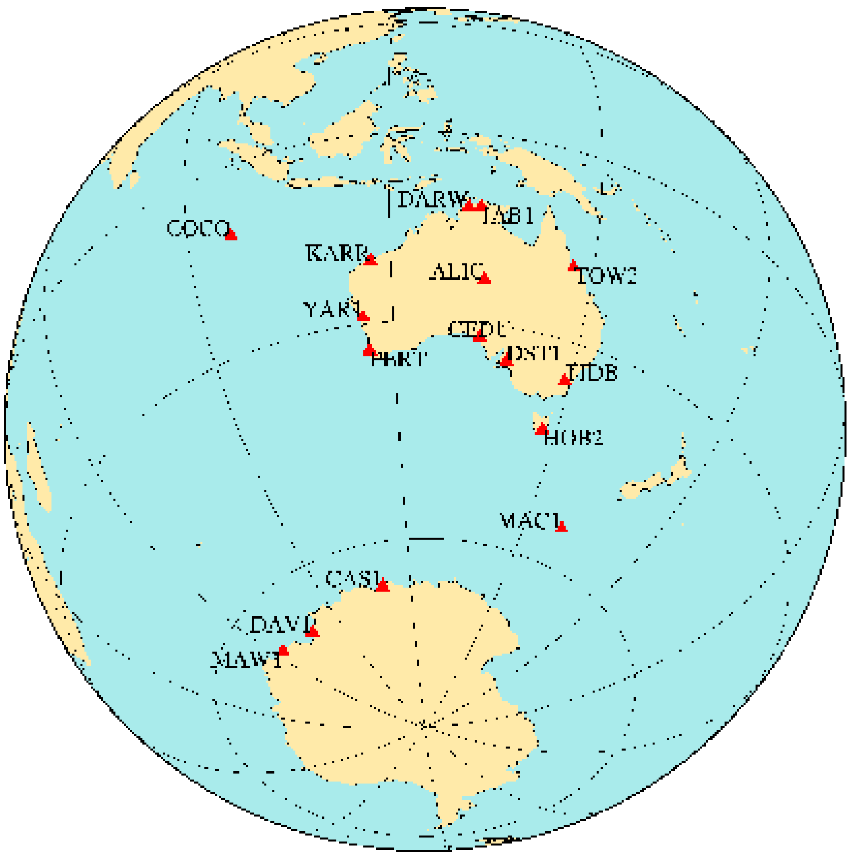


Figure2: Locations of ARGN sites

Data from ARGN sites is normally available from the AUSLIG web site within 48 hours. The data from these sites is used by the AUSLIG Space Geodesy Analysis Centre to compute daily solutions (in weekly blocks) which are sent to IGS in SINEX format. AUSLIG is an IGS associate analysis centre and the daily results and precise orbits produced are also being made available from the AUSLIG web site. The AUSLIG determined GPS orbits from the global data set are at the sub-decimetre level in the radial component when compared to the IGS combined orbit product. The estimated station coodinates compare at the sub-centimetre level with the ITRF96 set of station coordinates and those produced by the IGS global analysis centres.

Figure 3 shows the time series of results from typical ARGN sites. For each site a weekly mean is computed from continuous daily GPS solutions. The results from the GPS solutions for ARGN sites generally .indicate that points on the Australian landmass are moving at the same rate with minor deformations in some areas such as Karratha and Darwin.

3.2 The Australian Satellite Laser Ranging Network

SLR data provides information for studies of the deformation of the solid earth, together with its ocean and atmospheric systems including:

- Detection and monitoring of tectonic plate motion, crustal deformation, earth rotation and polar motion;
- Modelling of the spatial and temporal variations of the earth's gravitational field; and
- Monitoring of the millimetre level variation in the location of the centre of mass of the earth; as the origin point for vertical motion of the land and sea interfaces.

In addition, SLR is utilised for precise orbit determination for spaceborne radar altimeter missions, which are used for:

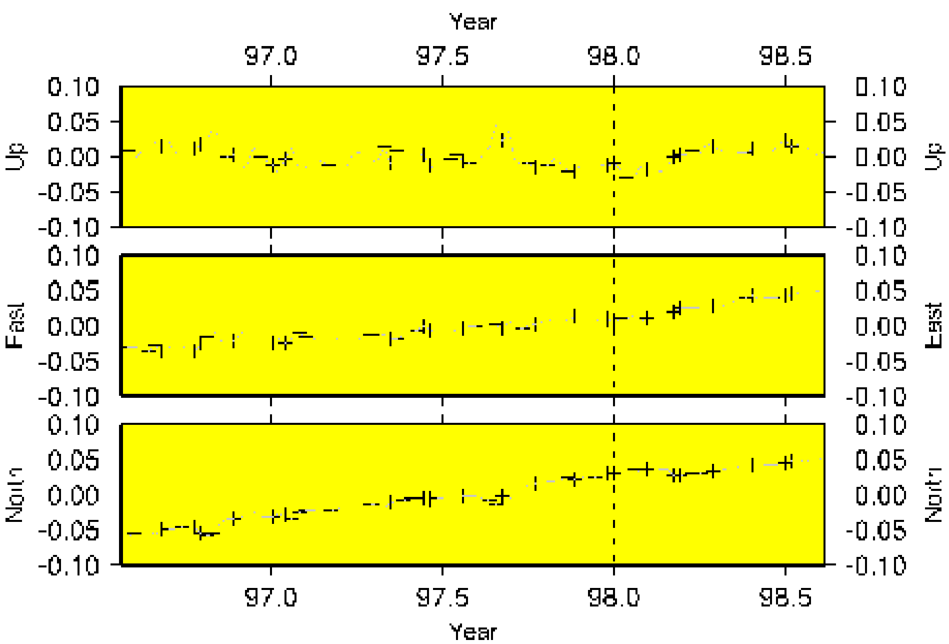
- Mapping the ocean surface;
- Monitoring global ocean level deformation patterns;

- Mapping volumetric changes in ice sheets; and
- Profiling land topography.

AUSLIG has made a significant contribution to the global satellite laser ranging network in the last fifteen years through the management and operation of the Orroral SLR station, using a National Aeronautics and Space Administration (NASA) telescope and laser equipment. Originally established as a lunar laser ranging site it has been very productive in ranging to a number of artificial satellites equipped with retroreflectors. Data has been provided to NASA, under an operational agreement, via the Crustal Dynamics Data Information Service at Goddard Space Flight Centre. AUSLIG is replacing the Orroral observatory with a new technology SLR facility at the Mt Stromlo Astronomical Observatory in the Canberra region in 1998. The new high precision SLR system was built and is operated by an Australian company Electro Optic Systems under contract. It uses a 75 cm telescope inside a sealed dome and has a potential for semi automated remote operation.

AUSLIG has recently taken over responsibility for the operation of the Yaragadee SLR station in Western Australia. This site has been operating as a world class SLR site for twenty years. Operational costs are being shared by AUSLIG and NASA until February 1999, after which time AUSLIG will solely fund the station's operations until 2002 when NASA will replace it with a new technology semi automated system capable of remote operation.

(a) Alice Springs



(b) Karratha

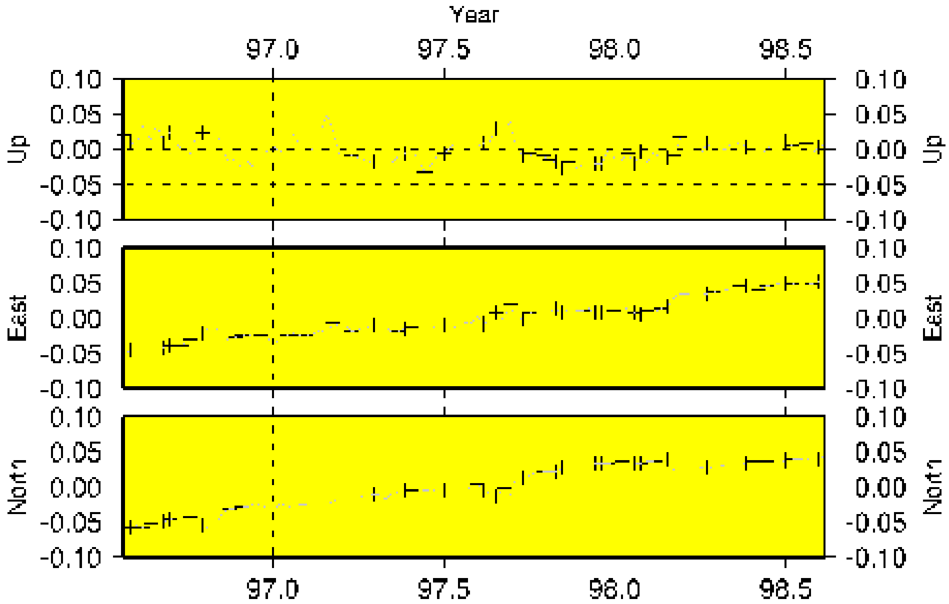


Figure 3: Time series of results from typical ARGN sites –
(a)

Alice Springs and (b) Karratha

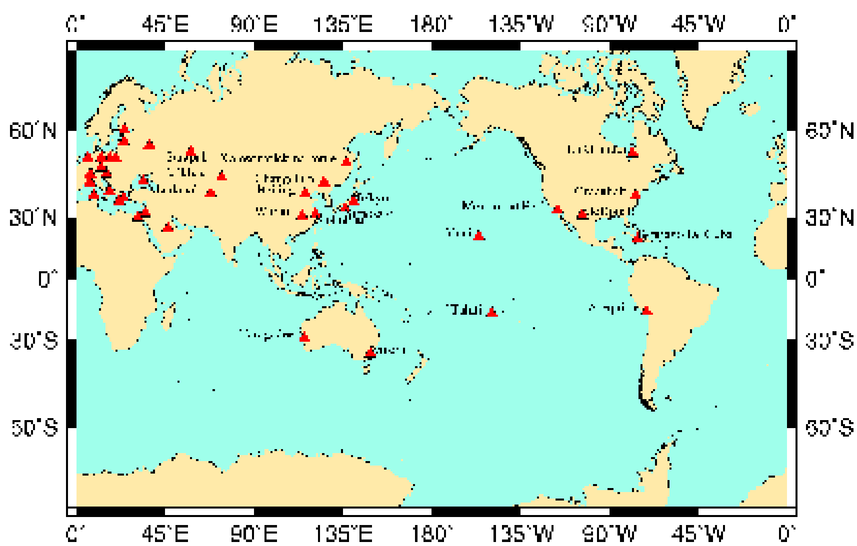


Figure 4 : Global distribution of SLR stations

In 1996 NASA reviewed its SLR operations and due to financial restrictions reduced its number of operational stations. With the relocation of a NASA SLR system from Quincy in the United States to Tahiti in 1998, there are now four SLR sites in the Southern Hemisphere. The distribution of global SLR sites is shown in figure 4. However there are over forty sites in the Northern Hemisphere, which biases the orbits and some scientific results from the satellites. The Australian sites are therefore much more important than single sites in the Northern Hemisphere. Additionally the Australian continent, being roughly in the centre of the Australian tectonic plate provides a very stable base line between the SLR sites to control global SLR models and improve the monitoring of the position of less stable sites. In 1998 the Space Geodesy Analysis Centre at AUSLIG began to use the Australian SLR data to compute global solutions and now as an associate analysis centre provides these solutions to the new

International Laser Ranging Service (ILRS). The results from the Australian solutions agree closely with the no net rotation uniform velocity model (NUVEL) developed from geophysical information. Figure 6 shows the postfit residuals, after satellite orbit, geodetic parameters and measurement biases have been estimated, for the Orroral and Yaragadee SLR stations for August 1998. This demonstrates the high quality of SLR data produced by the Australian stations and the high quality of the solutions that are routinely achieved – having a rms of the postfit residuals of between 4 – 6 mm. Over a 30-day arc of Lageos-1 and Lageos-2. The accuracies of the global solutions, expressed as the rms of the differences of the station coordinates compared to the ITRF96, is currently at the 10 mm. level.

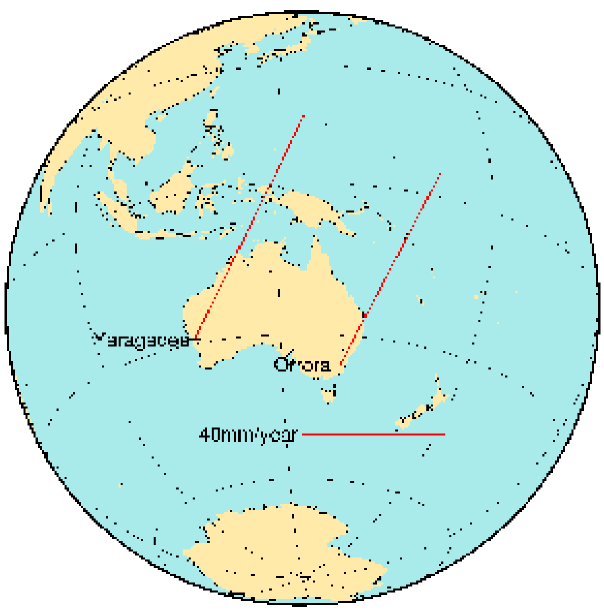
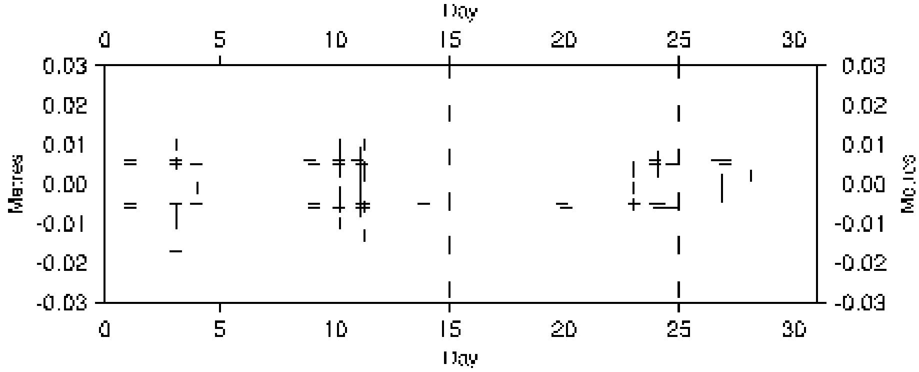


Figure 5 : SLR velocities from Yaragadee and Orroral

Figure 5 shows the SLR determined velocity vectors for Orroral and Yaragadee. Comparison of results from Yaragadee and Orroral indicate a very small deformation/ compression across the southern part of the Australian continent in the order of 2mm per year.

a) Orroral Lageos 2



b) Yaragadee Lageos 1

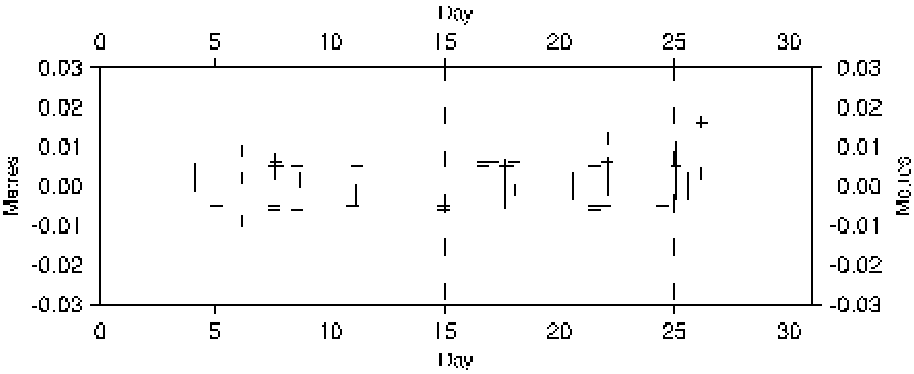


Figure 6 a) Post-fit residuals Orroral SLR to Lageos 2, August 1998, b) Post-fit residuals Yaragadee SLR to Lageos 1, August 1998.

3.3 DORIS

Doppler Orbitography and Radio Positioning Integrated by Satellite (DORIS) is a radiometric system used for satellite positioning. DORIS, which has a global distribution, is also used for ground position determination and is being used in the maintenance of the ITRF.

In the DORIS system, data from the ground beacons is received by the satellite and downloaded at a master station in France. AUSLIG maintains two DORIS ground systems; each collocated with a SLR system at Orroral (soon to be moved to Stromlo) and Yaragadee. AUSLIG is now processing regional DORIS solutions. Figure 7 shows the global distribution of the DORIS network of stations.

A rms of the postfit residuals, estimating satellite orbit parameters, station coordinates, Earth Orientation Parameters and measurement biases, of 0.15-0.18 mm/sec is routinely achieved. For example, the 3-D rms of fit for the Auslig SPOT-2 solution for the month of October 1997 showed a rms difference of 2.7, 5.5 and 1.9 mm for the east, north and up components when compared to ITRF96 – demonstrating the high quality of results currently being produced.

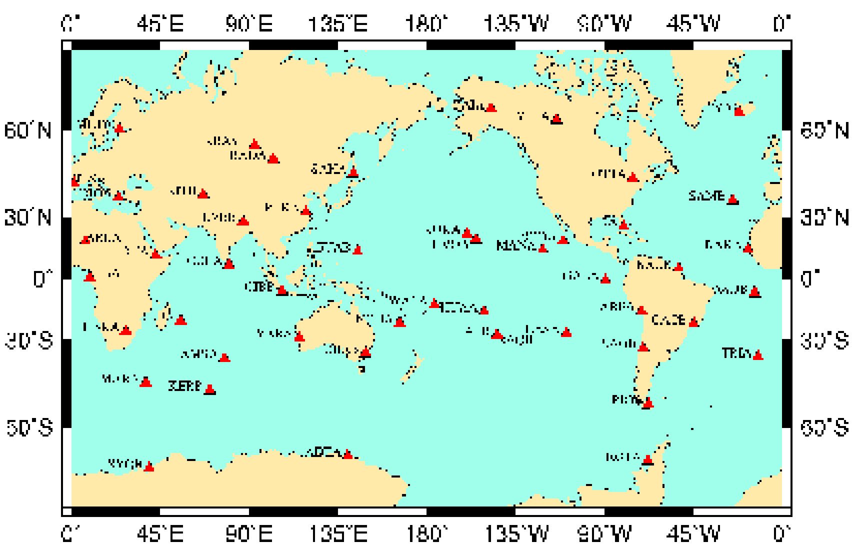


Figure 7 : Global Distribution of DORIS sites

3.4 Gravity

The Australian Geological Survey Organisation (AGSO) is the custodian of the Australian gravity database. This gravity data base is used primarily for detecting anomalies for mineral exploration. It does not have a precisely defined datum, currently relying on control by old Russian and American absolute gravity measurements made mainly at coastal sites. In 1996 AUSLIG collaborated with the Japanese Geographical Survey Institute (GSI) and AGSO to establish a reference absolute gravity site using new technology absolute gravity meters. Two FG5 absolute gravimeters from GSI were used side by side in conjunction with another from University of Queensland, to establish a fundamental gravity station at Mt Stromlo. Inter-comparison of the three instruments showed agreement to better than 2 microgals. Table 2 shows the results of the February 1996 absolute gravity measurements undertaken at Mt. Stromlo. The results indicated a 2-6 microgal ocean tidal loading indicating the ability of these instruments to detect non tidal gravity changes on the order of 1 microgal, corresponding to a vertical crustal deformation movement of 3mm. (Murakami et al 1997).

Table 2 : Absolute Gravity measurements at Mt Stromlo reference point February 1996

Gravimeter	**#104**	**#201**	**#110**
Period	*8-12/2/96*	*8-14/2/96*	*8-13/2/96*
No of measurements	13354	22959	16236
Reduced value (mgal)	979549.9230	979549.9235	979549.9228
Std dev single drop (mgal)	0.015	0.012	0.012

Other absolute gravity determinations were made in the vicinity of the VLBI sites at Tidbinbilla and Hobart to establish subsidiary values. Repeat absolute gravity readings will compliment SLR to monitor the vertical motion on Mt Stromlo at the fundamental gravity reference site. A wider program of absolute readings is being considered across the Australian continent, to provide better datum control to the gravity data base for physical geodesy purposes. Absolute gravity has the potential to monitor vertical crustal deformation at precise tide gauge sites, to contribute to the determination of absolute sea level change from tidal records.

4. CONTRIBUTION TO INTERNATIONAL GEODESY PROGRAMS

4.1 Global Deformation

Deformation of the planet Earth refers to the changes which the Earth undergoes in shape, size, position and orientation. Deformation of the Earth's crust is a result of complex factors such as plate tectonic movement, inter-plate deformation, post glacial isostatic rebound, tidal deformation, the earths rotation and polar motion (Vanicek and Krakiwsky 1986). The identification of these changes is modelled through deformation analysis and global projects such as the NASA programs, Mission to Planet Earth and the Crustal Dynamics of the Earth.

Figure 8 : AUSLIG's contribution to IAG and IERS

Deformation monitoring of the earth's crust is by necessity a global project requiring considerable input globally distributed sites. It is currently best monitored through the International Earth Rotation Service (IERS) via the International Terrestrial Reference Frame (ITRF). AUSLIG plays an important role in the provision of data from Australian geodetic observatory sites, such as GPS, DORIS, SLR, and VLBI, to global studies. AUSLIG's international commitments to Geodesy through IAG and IERS are illustrated in Figure 8.

AUSLIG represents Australia's national geographic information interests regionally and globally through participation in relevant international forums. It also has bilateral agreements with counterpart agencies. Current activities include involvement in:

- Permanent Committee on GIS Infrastructure for Asia and the Pacific (PCGIAP);
- United Nations Regional Cartographic Conferences (UNRCC);
- Global Spatial Data Infrastructure (GSDI);
- Scientific Committee for Antarctic Research Working Group on Geodesy and Geographic Information (SCAR WG-GGI);
- Global Mapping Project;
- Managing the ASEAN-Australia Remote Sensing / Mapping Project;
- Organising the 3rd Global Spatial Data Infrastructure Conference in Canberra;
- The Antarctic Spatial Data Infrastructure Project;
- Bi-lateral agreement with Bakosurtunal (Indonesia) on regional geodesy.

The prime AUSLIG international commitments to geodesy include provision of geodetic observations to global networks and involvement in key regional and global geodesy organisations such as:

- Member of the IGS Governing Board;
- Member of the ILRS Governing Board
- Convenor of the SCAR Geodetic Infrastructure for Antarctica (GIANT) program
- Vice Chair of PCGIAP Working Group 1 – Regional Geodesy Network.

Each of these activities is important. However, the two major regions of current activities pertaining to crustal deformation studies are:

- the Asia Pacific region (through PCGIAP), and
- Antarctica (through SCAR).

4.2 Permanent Committee on GIS Infrastructure for Asia and the Pacific Regional Geodetic Network(PCGIAP)

The PCGIAP was established by the United Nations Regional Cartographic Conference for Asia and the Pacific (UNRCC-AP) at its triennial meeting in Beijing, May 1994. The aims of the PCGIAP are to maximise the economic, social and environmental benefits of geographic information in accordance with United Nations Agenda 21. This is undertaken through a forum of the 55 national survey and mapping agencies of the nations from Asia and the Pacific region cooperating in the development of the Asia-Pacific Spatial Data Infrastructure (APSDI). This in turn contributes to the establishment of a global spatial data infrastructure. PCGIAP meets annually and has an Executive Board consisting of representatives from nine key member nations. It is structured into four operational units:

- ***Executive / Secretariat***

The executive board is chaired by Malaysia and the secretariat is provided by AUSLIG

- ***Regional Geodetic Network Working Group***

Chaired by Indonesia with Australia and China as deputies, this group will implement a regional precise geodetic network, define a regional horizontal geodetic datum and investigate a regional vertical geodetic datum.

- ***Regional Fundamental Data Working Group***

Australia chairs this group which has as its main aim the development of a policy for sharing regional fundamental data, defining and facilitating integration of regional fundamental datasets, establishing a regional network of data nodes (directories), and promoting applications of spatial data.

- ***Development Needs Taskforce***

Chaired by Malaysia and including Australia, Iran and Japan, this group plans to identify members' GIS related (including cadastral) development needs and recommend support programs and funding options.

AUSLIG played a key role in establishing the PCGIAP Regional Geodetic Network Working Group at the inaugural meeting in Sydney in October 1996. AUSLIG was given the role of coordinating the Asia and the Pacific Regional Geodetic Project (APRGP97) as the first step towards establishing a precise geodetic framework for the region.

The APRGP97 data observation campaign was undertaken in October 1997. The observations were made at permanent sites to establish a precise framework for the regional integration of geodetic datums. The individual geodetic techniques utilised were:

- VLBI
- SLR
- GPS
- DORIS

Figure 9 shows the distribution of the APRGP97 stations. The project was originally designed to use only observations from permanent tracking sites as data in the campaign, but several countries subsequently requested inclusion of additional observations at significant geodetic points for national datum purposes. GPS temporary stations were utilised in Iran, Indonesia and Malaysia. The observation period was the month of October for DORIS and SLR. GPS observations were undertaken from 12th to 18th October 1997. In addition, two, twenty four hour VLBI campaigns were conducted on the 6th and 20th October. Data was assembled at AUSLIG and made available to member countries for individual solutions. A workshop was hosted by AUSLIG in Canberra in July 1998 to present the results of individual and combined solutions prior to the data being released to other researchers (AUSLIG 1998). Individual GPS results have been combined by AUSLIG using the normal equations from each of the individual solutions in the SOLVE software, to provide a rigorous combined solution and to prepare a SINEX format file. The GPS solution was then combined with the SLR and DORIS in SOLVE to produce a densification of the ITRF in the Asia-Pacific region. The results of the computations from the AUSLIG Space Geodesy Analysis Centre have been presented at Western Pacific American Geophysical Union and COSPAR conferences in 1998 (Govind et al 1998).

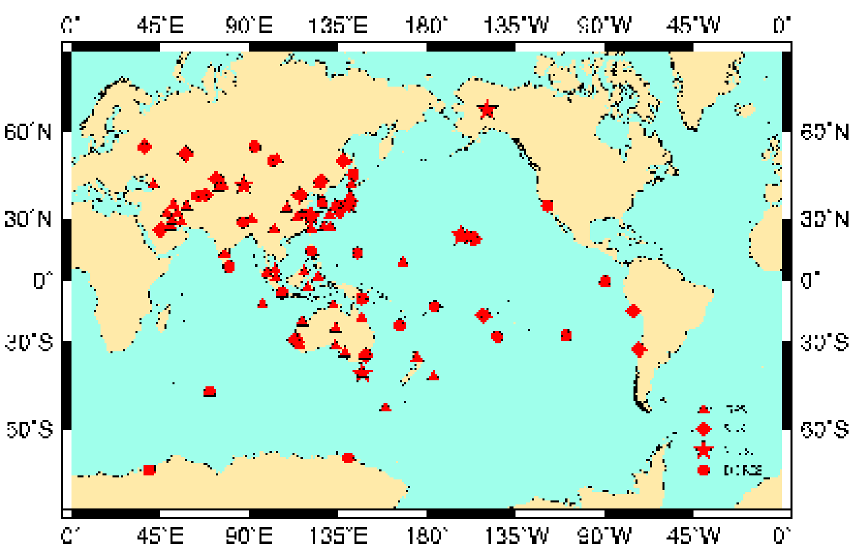


Figure 9: Geodetic stations observed in APRGP97

The regional project will be continued with a further campaign of the Regional Geodetic Network Working Group as APRGP98 in November 1998 to develop velocities of geodetic framework points in a complex plate deformation region. But the prime objective for the occupation of sites in local geodetic networks is so that transformation parameters can be developed to a regional datum (eg ITRF1996). This will in turn allow all spatial data reliant on those individual datums to be readily assembled into a uniform regional spatial data infrastructure.
AUSLIG will process and analyze the GPS, SLR, DORIS and VLBI observed data from the above campaign and submit the results to the International Earth Rotation Service (IERS) for inclusion in the ITRF. AUSLIG on behalf of the PCGIAP will continue daily regional solutions on the permanent sites on an ongoing basis. Knowledge of the differential velocities on key stations will also enable GPS epoch observations, made on an opportunity basis, on geodetic frameworks to be incorporated into a regional model at any time.
To establish the Geocentric Datum of Australia a simple strategy was used for a usable geodetic horizontal datum, by freezing all points on the same moving plate at a single epoch, ignoring local deformations within this plate. This simple approach is not applicable to the Asia Pacific region with multiple plate motions causing local deformations, so that differential velocities must be taken into account, even for points in individual countries

4.3 Antarctic Geodesy

Australia has a long history of leadership in Antarctic mapping and geodesy activities and has chaired the Scientific Committee on Antarctic Research (SCAR) Working Group on Geodesy and Geographic Information (WG-GGI) since its formation in 1958. In 1988 responsibility for mapping in the Australian Antarctic Territory was transferred to Antarctic Division but AUSLIG retains responsibility for Antarctic Geodesy as an Australian offshore territory. For the last six years AUSLIG has been program coordinator for the SCAR Geodetic Infrastructure of Antarctica (GIANT) program. Details of individual sub projects on the GIANT program for the period 1998 to 2000 are summarised on the WG-GGI web site maintained BY AUSLIG. There are currently seven projects in the GIANT Program :

- Permanent Geodetic Observatories;
- GPS Epoch Campaigns;
- Physical Geodesy;
- Evaluation of GLONASS as a geodetic and navigation system;
- Differential GPS Base Stations;
- Remote Geodetic Observatories; and
- Information Access

Results on progress on individual projects will be presented at the WG-GGI Antarctic Geodesy Symposium (AGS99) in Poland in July 1999 and at the working group meeting during the SCAR XXVI meeting in 2000 in Japan.
The GIANT program objective is to establish a zero order geodetic framework across Antarctica for all spatial data within a global reference system to provide data and products to meet physical geodesy requirements by :

- Providing a common geographic reference system for all Antarctic scientists;
- Contributing to global geodesy for the study of the physical processes of the earth and the maintenance of the precise terrestrial reference frame; and
- Providing information for monitoring the horizontal and vertical motion of the Antarctic land mass and ice cap.

A major project in the GIANT program is the establishment of permanent geodetic observatories, project details are :

4.3.1. Permanent Geodetic Observatories

(Project Leader: John Manning, Australia)
This is a typical ongoing GIANT project which achievd a difficult goal of establishing permanet geodetic observatories at manned sites on the Antarctic continent.
Goal: To develop an infrastructure of permanent geodetic stations to bring all individual geodetic

networks to a common datum, and to provide geodetic information for the global monitoring of natural earth processes.

Key activities:

- Collaborate with other SCAR scientists to identify requirements for space geodetic sites
- In conjunction with SCAR working groups, design an extended network of continuous geodetic observatories;
- Support the continuation of the O'Higgins VLBI site for scientific purposes and as an important contribution to the global reference frame
- Establish priorities for on-line satellite data retrieval from ground stations
- Deliver regular space geodesy solutions to IGS and IERS
- Post details of all permanent sites on web site
- Develop and publish GPS base station specifications
- Evaluate accurate local ties between collocated techniques
- Facilitate tide gauge data to southern ocean sea level Centre

AUSLIG computes daily solutions of all Antarctic permanent GPS tracking sites. The GPS data is regularly retrieved using communication satellites. New sites are currently being established, however, not all sites have the capability to transmit data out on a regular basis. AUSLIG has been involved with summer GPS episodic campaigns which

- Aim to densify the geodetic infrastructure established from the permanent observatories, and
- Study the deformation of the Antarctic tectonic plate and the differential movement of the continent in relation to the surrounding southern continents.

This project has been particularly successful in establishing a number of permanent GPS base stations; six of which make data available on a daily basis for deformation studies. Two VLBI sites have been established as well as and seven absolute gravity sites. Figure 10 shows the distribution and site velocities from the permanent GPS base stations. These contribute to the newly formed multidisciplinary study groups established by SCAR as Antarctic Tectonic Plate (ANTEC) project.

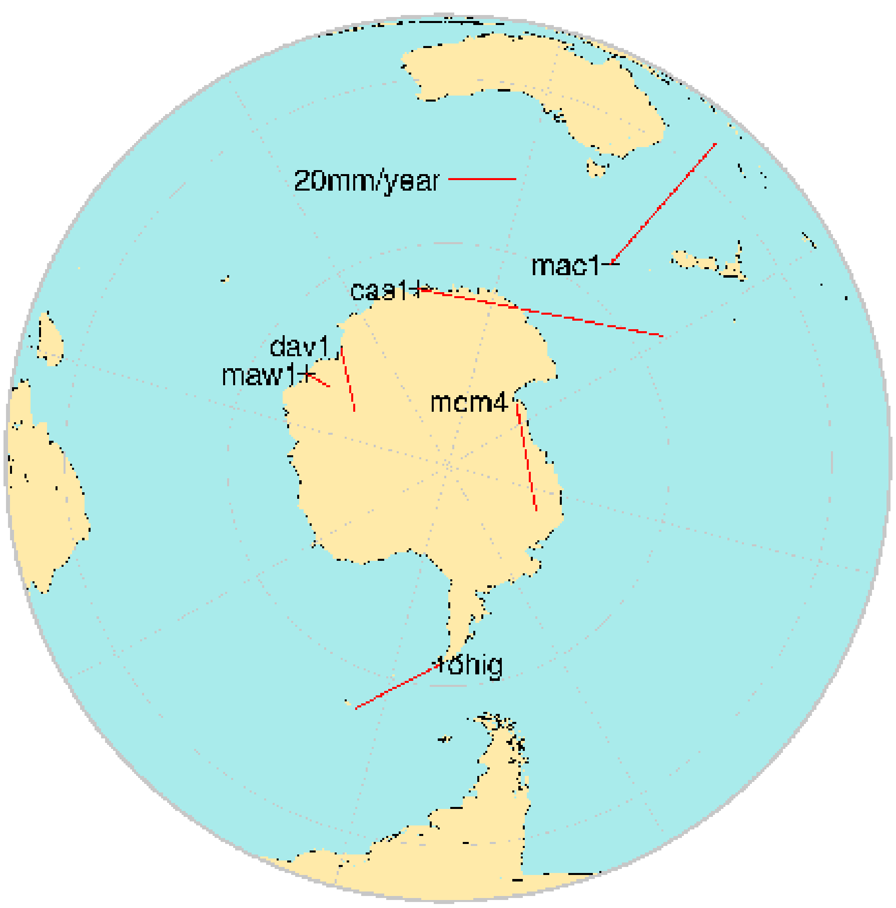


Figure10: Antarctic permanent GPS sites with velocities

4.4 The Asia Pacific Space Geodynamics Program

The objective of the Asia Pacific Space Geodynamics program is to develop international collaboration between scientists and geodesists who are working in the Asian-Pacific region to:

- advance research in crustal motion, deformation, and sea level change;
- provide basic information on the causes of and means of mitigating natural disasters;
- enrich our knowledge of the dynamics of the Earth,
- promote international scientific exchange and cooperation, and
- contribute to raising the scientific research level in the developing countries.

AUSLIG is a member of the APSG Management Board and is convenor of the SLR Technique Measurement Panel. Additionally it has the role of coordinating the integration of regional GPS campaigns planned for 1998:

  - APRGP98
  - WING
  - IGEX98
  - China98
  - South Pacific
  - Geodyssea98

4.5 Western Pacific Laser Tracking Network

AUSLIG is a foundation member of the executive board of the Western Pacific Laser Tracking Network (WPLTN), which has the objective to enhance the contribution of laser ranging to space geodesy in the Western Pacific through a total commitment to quality and scientific and engineering excellence. It aims to achieve these objectives by encouraging international goodwill and mutual understanding amongst regional SLR stations by :

- Organising measurement campaigns for key regional phenomena.
- Establishing regional analysis centres for regional campaigns.
- Promote staff exchange between member nations;
- Initiate joint development programs involving multi-national teams;
- Provide support for individual national priorities of member nations.
- Promulgate standards for calibration, process control, documentation & performance.
- Devise and promote new laser measurement techniques;

WPLTN arranged the regional SLR observational campaign for the APRGP97. AUSLIG maintains an information web site for WPLTN.

5. NEW DIRECTIONS IN GLOBAL GEODESY

There are number of new developments in Global geodesy relevant to the use of GPS for deformation and also for navigation. Again, the use of a combined techniques will often provide a better result than GPS alone. Some key developments are outlined below.

5.1 GLONASS

The International GLONASS Experiment (IGEX) is a joint project of:

- International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG)
- The International GPS Service for Geodynamics (IGS)
- The Institute of Navigation (ION).

The main purpose of IGEX-98 is to conduct the first global GLONASS observation campaign for geodetic and geodynamics applications and to evaluate the results in an international workshop in 1999. The campaign duration of three months is intended to simulate an ongoing operational system as opposed to a campaign-oriented strategy. The main objectives of IGEX-98 are:

- set up a global GLONASS observation network,
- test GLONASS data processing software
- study common GPS/GLONASS processing strategies
- determine accuracy of the determined GLONASS orbits in ITRF
- gain insight into GLONASS orbit modeling peculiarities (Solar radiation pressure, attitude, etc.)
- determine transformation parameters between the GLONASS operational
- reference frame and ITRF and WGS 84 (the GPS operational reference frame)
- connect the GPS and GLONASS time systems
- compare and contrast the separate and combined satellite systems on a global basis

AUSLIG is coordinating the Australian contribution and involvement in IGEX98. The campaign commences in September 98 and in its first stage continues for three months with a view to becoming an ongoing service similar to GPS. Australia cooperative partners in the first pilot stage are.

- The University of New South Wales
- Curtin University of Technology with The Department of Land Administration, WA
- National Measurement Laboratory
- Airservices Australia
- University of Tasmania

5.2 International Laser Ranging Service

Following the success of the International GPS Service in providing a free to the community GPS service on data, GPS orbits and related products, the SLR community is establishing ILRS as a similar service to the global community. AUSLIG will provide data from its ground stations and products as a Regional Associate Analysis Centre.

5.3 International VLBI Service (IVS)

The International VLBI community is following this service trend closely and has proposed to establish an International geodetic VLBI network service (IVS). In the past VLBI has been a by product of Radio Astronomy but the current move to produce timely products and to regularise observations by CSTG is precipitating a refocus on Geodetic VLBI observations and analysis. AUSLIG as a key participator in both IGS (GPS) and ILRS (SLR) and is currently considering become increasingly involved in the proposed IVS.

5.4 The International Terrestrial Reference Frame

With increasing demands for a more accurate global reference frame in which to measure and collate site motions, problems with combined solutions in the Asia Pacific region have become apparent. These also show in the time series applications of annual ITRF solutions. There is a need for greater densification of the reference frame in the region. AUSLIG will continue to provide regular combined solutions to the IERS, to fill this need.

5.5 Atmospheric Research from GPS

GPS is increasingly being utilised as a technique for providing information on the atmosphere through determination of water vapour through signal delays of different frequencies. The potential is great for the use of GPS on LEO or atmospheric specialist satellites, particularly using occulatations of satellite to satellite and satellite to ground receivers. Experiments in near real time for meteorology purposes are proposed to employ water vapour information. AUSLIG is working cooperatively with atmospheric scientists for possible Australian applications.

5.6 Increased DORIS accuracy using multiple satellites

DORIS originally was designed as a system for satellite in-flight positioning. It also had the capability for approximately determining the location of the ground receiver to a few metres. Advances in the use of the system have demonstrated a capability to better determine ground positions accuracies from permanent receivers to less than a decimetre. This, coupled with a wide geographic coverage and data capture technique has produced stable results which are now being used in the maintenance of the ITRF. Further advances in the accuracy of the system will be made when a number of satellites are launched in the near future, greatly increasing the volume of observational data at each site. AUSLIG will undertake analysis of this data in cooperation with CNES and centimetre accuracy is forecast.

5.7 Universal Vertical Reference Frame

GPS alone does not provide a strong solution for precise vertical crustal deformations. Whilst a strong reference frame will produce ellipsoidal heights useful for most applications, height above sea level, or perhaps a geoid is preferred. To be able to link different datums on land and marine environments, there is a move to establish a global vertical reference system. AUSLIG is considering the implications for the existing Australian Height Datum and the possible future requirement to have a number of harmonious vertical datums of different types.

6. GEODESY IN AUSTRALIA

As a framework for geodetic applications such as deformation measurement by GPS the infrastructure of geodesy in Australia is undertaken at different levels by a number of groups:

- Federal agencies
- State /Territory agencies
- Academia
- Private Sector

The Geodetic activity of Federal and State agencies is broadly coordinated through the Intergovernmental Committee for Surveying and Mapping, and implemented through the ICSM Geodesy Group. The academic sector is loosely focused through the Academy of Science Geodesy Sub Committee. A good example of cooperation between Federal agencies and the Academia is the recently released national geoid model for Australia (AUSGeoid98). This is an excellent example of Government facilitation of academic research, to the benefit of the community.

6.1 The Australian Geoid Project

In 1998 a new model known as AUSGEOID98 will replace the existing national geoid (AUSGEOID93). This new model will include about 50% more gravity data (approx. 800,000 points) and will use the latest algorithms, including terrain corrections which were not available in AUSGEOID93. AUSGEOID98 data files and interpolation software will be freely available from AUSLIG's WWW site.

The initiative came through Curtin University via an Australian Research Council grant (ARC A49331318). The research group was formed through cooperation between several Australian universities and consisted of:

- Associate Professor Will Featherstone and Dr Jon Kirby, School of Spatial Sciences, Curtin University of Technology;
- Associate Professor A.H.W. Kearsley, School of Geomatic Engineering, University of New South Wales; and
- Professor John Gilliland, School of Geoinformatics, University of South Australia.

The data required for the project was copious and came from a variety of Australian Government and international sources including:

  - The EGM96 Global Geopotential model produced by the US National Imagery and Mapping Agency (NIMA) and NASA's Goddard Space Flight Centre (Leoine et al., 1997);
  - Satellite Altimeter derived gravity anomalies from the Scripps Institute for Oceanography (Sandwell et al., 1995);
  - The 1996 Australian Geological Survey Organisation's (AGSO) Australian gravity data base;

- The AUSLIG/AGSO 9" Digital Elevation Model (Carrol and Morse, 1996).

The provision of the national data sets was facilitated by AUSLIG, while the research group examined the current theories, developed enhanced computational techniques and produced leading edge software. These techniques and software were then used by AUSLIG to generate a national geoid. The end result is available from AUSLIG's WWW site and allows GPS users to efficiently obtain AHD heights, without recourse to time-consuming traditional methods.

7. NEW DIRECTIONS WITH AUSLIG GEODESY

AUSLIG is presently looking at ways of strengthening linkages with geodesy stakeholders. An initial action will be to establish a Geodesy Consultative Group to complement existing links with ICSM and the international geodesy community. The Geodesy Consultative Group will comprise representatives from Australian education, research, industry and client organisations and will provide input to the AUSLIG geodesy program. AUSLIG facilitates the national approach to Geodesy and will continuously improve it performance through service charters and commitments to provide data, information and products. Some details from its current forward program are given below.

7.1 National Geodetic Data Base

A prime source of Australian geodetic information has always been the National Geodetic DataBase (NGDB). As part of the AUSLIG commitment to provide data and information at the lowest distribution cost, increased use will be made of electronic media access. The NGDB will be extended in its scope over the next two years to be part of an Intergovernmental Committee on Surveying and Mapping (ICSM) distributed data base with links to State and Territory geodetic information. The AUSLIG component of the database will be further developed in 1998 giving improved electronic access to national level historical data in five parallel sections:

- GDA94
- AGD84
- AGD66
- Clarke (pre 1966)
- Antarctica

7.2 Space Geodesy Analysis Centre

The routine activity of the Space Geodesy Analysis Centre is to process global data from several high precision space geodetic observation techniques to determine the orbits of several geodetic satellites, and geodetic parameters. Output products include tracking station coordinates and velocities, Earth Orientation Parameters (EOP) and geocentre variations. These products will be delivered to international bodies on a routine basis as a contribution to the development, maintenance and monitoring of the International Terrestrial Reference System (ITRS) and the International Celestial Reference System (ICRS) and their mutual relationship.

7.3 GPS

AUSLIG will provide GPS data from an increasing number of sites to the International GPS Service to meet their stringent performance guidelines. This existing data will be open to downloading from the AUSLIG web site to facilitate local research and for use by the private sector at no cost. This system is in a pilot phase at present and the increased availability of this data will facilitate deformation studies across Australia. Where AUSLIG is involved with cooperative partners on specific projects the data may not be available in some circumstances until the cooperative project is completed, but it will then be freely available.

AUSLIG plans to improve the reliability of GPS through a site backup strategy, although this will still be dependent on the respective satellite or telephone communication lines. To ensure information is readily available to users we intend to:

- Make all ARGN data less than 6 months old available via the Internet (WWW and FTP);
- Establish a mechanism to ensure that 90% of all requests for archived data (older than 6 months) are satisfied within 10 working days;

- Provide statistics on the availability, quantity and quality of data for each site.

To produce GPS related products AUSLIG will continue to compute and submit weekly GPS solutions of the ARGN (Australia and Antarctica) to IGS as a Regional Network Associate Analysis Centre .This will include all permanent GPS tracking stations in the Asia-Pacific and Antarctic regions. It will continue to support the computation of daily high precision GPS satellite orbits and related geodetic parameters - in the light of requirements for high precision orbits for Low Earth Orbiting satellites carrying GPS receivers.

7.4 Satellite Laser Ranging

AUSLIG currently has three SLR station responsibilities:

- Orroral
- Stromlo
- Yaragadee

This year Orroral will be closed down as the new system at Mt. Stomlo settles down. When Stromlo is fully operational all ranging data will be delivered to the CDDIS data centre in Washington within 48 hours, where it will be electronically available together with all other global SLR data . AUSLIG has taken over the operational responsibility for Yaragadee under an arrangement with NASA and will fund operations for the next three years. Past and current data from Orroral and Yaragadee will continue to be available through CDDIS. Global SLR has undergone a significant change, perhaps similar to the IGS network.
A new International Laser Ranging Service (ILRS) is being established and AUSLIG, as well as providing observational data from its SLR base stations, will provide a regional analysis function through the work of its Space Geodesy Analysis Centre. As an ILRS regional analysis centre AUSLIG will:

- Provide regular five-day Satellite Laser Ranging (SLR) solutions for Laser Geodynamics Satellites (Lageos-1 and Lageos-2) for orbits and EOP, as an Analysis Centre of the International Laser Ranging Service (ILRS)
- Compute monthly solutions of tracking station coordinates from the combined global SLR data to several satellites (Lageos-1, Lageos-2, Stella, Starlette, Etalon-1 and Etalon-2) for the ILRS/International Earth Rotation Service (IERS).
- Monitor and report, through data analysis, the performance of the SLR observatories within the Western Pacific Laser Tracking Network (WPLTN).

7.5 DORIS

AUSLIG is working on an expansion of the Australian DORIS ground network which currently consists of two sites, Orroral and Yaragadee. With the closure of Orroral the unit there will be relocated at Mt. Stromlo for collocation with the SLR system. With the increased importance of the DORIS system to global geodesy, AUSLIG will make a contribution to the maintenance of the International Terrestrial Reference System by:

- Undertaking regular processing of data for the SPOT-2 satellite and submit the solutions for the geodetic parameters to the IERS for incorporation into the ITRF.
- Extending DORIS computations to include data from the SPOT-4 satellite.

7.6 GLONASS

Process both the GLONASS radiometric and SLR data from the three-month pilot International GLONASS Experiment (IGEX-98) – compare and calibrate the orbits, clocks and time systems of these satellites and determine transformation parameters to GPS. The IGEX project will be carried out in cooperation with National Measurement Laboratory as well as New South Wales, Tasmania, and Curtin universities

7.7 VLBI

AUSLIG intends to establish the capability to undertake geodetic VLBI data analysis in cooperation with CSIRO Division of Radiophysics and NASA Goddard Space Flight Center with a view to eventually contributing to the International VLBI Service for Geodesy and Astrometry and hence to the ICRS and ITRS.

8. CONCLUSIONS

Geodesy has become increasingly global in nature through the development and applications of space geodetic techniques. This is producing significant benefits to the user community through ease of positioning for business and recreational purposes. Australia plays a most important role in developing and maintaining the global infrastructure which underpins this global geodesy, due to its geographic location between Antarctica and Asia. The relative stability of its baselines within Australia plays an important part in the monitoring of the deformations in the Asia Pacific region, where tectonics contribute to major hazards in heavily populated areas.
Advances in deformation measurement utilising GPS depend on the performance of the satellite systems and the quality of the reference frame, as well as field methods and data processing. AUSLIG contributes to the global performance of the satellites and to the maintenance of the reference frames so that the benefits can be realised at the local level. Despite recent advances in the system, there are still inherent weaknesses in GPS, particularly in the vertical dimension and better results can often be produced using a combination of techniques.
Within the Australian Geodetic community there is an opportunity for improved communication and interaction between the various sectors using geodetic science techniques, to maximise benefit from technology advances. AUSLIG has a vision to facilitate this interaction between Government, Academia and business sectors to maximize the benefit from global developments back to the Australian community.

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10. GLOSSARY OF TERMS

AFN	Australian Fiducial Network
AGD	Australian Geodetic Datum
AGD66	Australian Geodetic Datum 1966 coordinates
AGD84	Australian Geodetic Datm 1984 coordinates
AHD	Australian Height Datum
ANN	Australian National Network
ARGN	Australian Regional GPS Network
ASDI	Australian Spatial Data Infrastructure
AUSLIG	Australian Surveying and Land Information Group
GDA	Geocentric Datum of Australia
GDA94	Geocentric Datum of Australia 1994 coordinates
GIANT	Geodetic Infrastructure for Antarctica
GPS	Global Positioning System
ICSM	Intergovernmental Committee on Surveying and Mapping
IGS	International GPS Service
ILRS	International Laser Ranging Service
ITRF	International Terrestrial Reference Frame
NGDB	National Geodetic Database
SCAR	Scientific Committee for Antarctic Research
SLR	Satellite Laser Ranging
VLBI	Very Long Base Interferometry
IVS	International VLBI Service
IERS	International Earth Rotation Service
GDA94	Geocentric Datum of Australia 1994

NASA	National Aeronautics and Space Administration
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
PCGIAP	Permanent Committee for GIS infrastructure for Asia and the Pacific
APSG	Asia Pacific Space Geodynamics
UNRCC	United Nations Regional Cartographic Conference
CDDIS	Crustal Dynamics Data Information Service
APRGP97	Asia Pacific Regional Geodetic Project 1997
AGSO	Australian Geological Survey Organisation

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