GDA – THE BASIS FOR BETTER SPATIAL BUSINESS IN A REGIONAL SETTING

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Introduction

Geodetic datums provide the basis for compatible spatial information. To attain the highest levels of accuracy they need to be defined within a precise global system and be able to take into account the long-term Geodynamics of plate motions. At present, excluding the PZ90 GLONASS system, there are two practical approaches to the determination of geocentric coordinates in global systems – The World Geodetic System (WGS) and the International Terrestrial Reference System, realised through the International Terrestrial Reference Frame (ITRF). This situation was recognised at the 13th United Nations Cartographic Conference in Beijing in May 1994 in a resolution which noted :

- the use of ITRF for precise positioning and its adoption by the International Association of Geodesy
- the use of the WGS 84 for mapping and charting and its adoption by ICAO and IHO.

The resolution recommended that all countries in the Asia Pacific region adopt a geocentric reference system as soon as practicable for their national spatial infrastructures. The optimal strategy being to employ ITRF for Geodesy applications to produce precise geocentric Cartesian coordinates and the GRS80 spheroid for computation of geographical coordinates. These coordinates are then comparable to WGS84 derived positions for most spatial information and mapping purposes. As background to the Geocentric Datum of Australia, it is useful to look a little more closely at the background to both these global systems

The World Geodetic System (WGS)

The National Imagery and Mapping Agency (NIMA) of the United States produces numerous mapping, charting, and geodetic products in support of the US Department of Defense activities. With the advent of inertial and satellite systems in the late 1950s and the growing availability of large amounts of geographic information, it needed a worldwide geodetic reference system to be able to collate the information which would support the widest range of local and global applications and allow data from one product to be related to information from another source.
Four such systems have been defined by NIMA (previously Defence Mapping Agency) :

- World Geodetic System 1960 (WGS 60),
- WGS66
- WGS72
- WGS84

Each version has been more accurately defined than its predecessor and a significant system upgrade in 1984 (WGS84) continued this trend by :

- Lowering the geocentre origin by 4.5 metres
- Rotating the reference meridian west by 0.814 arc second to the BIH defined zero

meridian of 1984.0

- Changing the scale by -0.6 x 10^{-6}

Being principally based on the former global network of Doppler observations, WGS84 was rated at the 2 metre level of accuracy at the time it was released. The general reference system adopted was the Geodetic Reference System 1980 (GRS80) with the parameters of the WGS84 ellipsoid being defined as *"identical to those for the GRS80 ellipsoid with one minor exception. The coefficient form used for the second degree zonal is that of the WGS84 Earth Gravitational Model rather than the notation J2 used with GRS80." (DMA, 1987)*

Since that time, NIMA has enhanced the original WGS84 reference system using a fixed earth model, but. These refinements were small in the context of mapping and charting and being within the original WGS84 specifications so the original descriptive term has been retained rather than define new WGS systems each time. In 1994 a further upgrade was introduced by re-computing the coordinates of the GPS Control Segment Monitor Stations in terms of the ITRF91 at the epoch of 1994.0 (Swift 1994). This enhancement of the WGS reference system was designated WGS84 (G730) and was implemented by the GPS Master Control Station on 29 June 1994. The result at that time was considered to be consistent with the ITRF at the 10-20 cm level (Malys and Slater, 1994).

In 1997 a further refinement was announced as WGS84 (G873) which took into account the plate motions of the master control stations to be more in line with ITRF computations (Malys et al 1997). This change would have been undetected by most users, as the effect on general GPS applications (eg local survey and navigation) is not significant.

WGS control stations are now determined within the ITRF system at the 5cm accuracy level, but absolute positions can be at best determined with an accuracy of 30 cm using specialsied point positioning software such as GASP (Malys et al 1997). The system is now rated by NIMA to be compatible with ITRF at better than ten centimetres, providing precise ephemerides are used for GPS differential positioning computations.

The International Terrestrial Reference Frame (ITRF)

Until 1984 the rotation of the earth was monitored using a rigid earth model, by the International Latitude Service from five observatories on the thirty ninth parallel of north Latitude. Earth Rotation was also measured by the International Polar Motion Service and the Bureau International de l'Heure (BIH) from a larger number of observatories undertaking latitude and time observations.

In 1984, a new conventional terrestrial system was defined by BIH and adopted with the knowledge that a rigid earth model was no longer appropriate. With the advent of increased space geodesy activities using satellites and extra terrestrial sources both the International Astronomical Union and the International Union of Geodesy and Geophysics (IUGG) recommended that an international earth orientation service be established for:

- monitoring earth orientation
- maintenance of the conventional terrestrial reference system,
- determining the relationship with the celestial reference system.

This new service replaced both the International Polar Motion Service and the Bureau International de l'Heure in monitoring earth rotation from 1st January 1988. The Central Bureau of the new organisation, the International Earth Rotation Service (IERS), maintains the international reference frame initially described as the IERS Terrestrial Reference Frame (ITRF). This reference frame is a realisation of the International Terrestrial Reference System with its origin at the centre of mass of the whole Earth and the orientation of its axes is consistent with that of the earlier BIH System.

The ITRF is based on the combination of sets of station coordinates of points on the surface of the earth and their crustal motion velocities, derived from observations of space-geodetic techniques VLBI, LLR, SLR, GPS (since 1991) and DORIS (since 1994). More than 200 well distributed sites from around the world are used in this analysis and local ties between collocated stations are used. The strength of the ITRF is that it uses a well distributed, large number of global points to monitor the dynamic earth surface. This dynamic model is based on the best available global data, and it is stable at the centimetre level. Transformations between respective ITRF solutions are published so that different epoch determinations for any point can be integrated and plate movement of coordinates of individual points traced using site velocities.

The number of IGS permanent GPS tracking sites is growing throughout the world while observational data, and coordinates from these sites, together with orbital ephemerides, are readily available from the Crustal Dynamics Data Information System (CDDIS) World Wide Web site (www.cddisa.gsfc.nasa.gov/cddis.html). ITRF values are also disseminated in IGS products as the IGS analysis centres use ITRF coordinates for stations in their GPS orbit computations, making the combined IGS ephemerides fully consistent with the ITRF.

Transformation parameters between ITRF solutions

The earth does not behave as a fully rigid model, so a system which best fits the globe must monitor these natural earth processes. These are currently monitored by ITRF on an annual basis and ITRF solutions for the dynamic earth are published in the IERS series of Annual Reports and Technical Notes (such as described in IERS Technical Note 15 - Boucher et al, 1993) and on the IERS World Wide Web site (www.hpiers.obspm.fr). IERS combines a number of global solutions from VLBI, SLR , DORIS, and GPS from various contributing bodies. Through this cooperation, IERS produces ITRF station coordinates/velocities and Earth Rotation Parameters. The global reference frame solutions published by IERS so far have been ITRF88, 89, 90, 91, 92, 93, 94 and more recently ITRF 96. Transformations between determinations are determined at the centimetre level and values can be mapped from one to the other.

System Comparisons

ITRF is in common use for accurate geodetic data sets and coordinates established in any epoch solution can be accepted as WGS84. WGS84 is now in common use as a datum for global spatial data sets where the highest accuracy or precision is not essential. However WGS84 coordinates can not be accepted as definitive ITRF positions. Examples of WGS84 applications are in navigation with ICAO in aviation and IHO for marine applications and in Geographic Information systems where the spatial data positional accuracy is not demanding.
ICSM decided to base the Gecentric Datum of Australia (GDA) on the civilian ITRF system for a number of reasons including :

- It was the most accurate system
- It was compatible with WGS84 at the metre level
- IGS products are ITRF compatible and readily available
- The system is maintained by IERS
- Its use is widespread for global geodesy
- It is the preferred system for the Asia Pacific region

Regional Datums

The development of a regional spatial data infrastructure, which can effectively integrate national databases, depends on the existence of a homogeneous geodetic network or the ability of data on individual networks to be linked by defined transformation parameters. Within the Asia Pacific region, individual national geodetic datums need to be capable of being readily related to a regional datum so that regional geographic information can then be assembled in a common reference system. without overlap or duplication.

National datums

When individual national geodetic networks are located wholly within a uniform single plate then the tectonic motion can be allowed for by applying a plate velocity to the geodetic coordinates. Points on neighbouring geodetic networks can then be brought to the same epoch using transformations between ITRF solutions.
As an example, for all short term purposes, the whole of the Australian plate can be considered to move as one mass. However the results of measurements between Australia and Indonesia show that a differential movement exists and to maintain the correct scientific relationship different site velocities must be applied to keep up with the real time change. Where several plate junctions are involved the situation is much more complex as differential velocities of sites may need to be allowed for within the one datum, such as in New Zealand.

Datum development in Australia

In Australia prior to 1966 there were some twenty different datums using four different ellipsoids. The Clarke 1858 ellipsoid was used for most national mapping coverage and co-ordinates of this type were conveniently referred to as 'Clarke' co-ordinates. In fact there were a number of different datums because of the different astronomically determined origin points used and the difference in co-ordinate value caused by these different datums could be as much as 300 metres. Although superseded for almost 30 years these co-ordinates continue to appear and some are held in the historical National Geodetic Data Base (NGDB) archive at AUSLIG.

In April 1965 a best fitting local ellipsoid was adopted for the Australian region and was known as the Australian National Spheroid (ANS). Immediately following, in May 1965, a complete re-computation of the geodetic surveys of Australia was begun. A central origin was defined in terms of the Johnston memorial cairn; the ANS was oriented by defining the minor axis to be parallel to the earth's mean axis of rotation at the start of 1962 and defining the origin of geodetic longitude to be 149°00'18.855" west of the vertical through the photo zenith tube at Mt. Stromlo observatory. "The size, shape, position and orientation of the spheroid were thus completely defined, and together defined the Australian Geodetic Datum (AGD)." (Bomford,1967)

The position of Johnston was based on a selection of 275 astro-geodetic stations distributed over most of Australia (ibid). The adoption of this origin and the best fitting local ellipsoid, the Australian National Spheroid (ANS), means that the centre of the ANS lies about 200 metres from the geocentre. Between 1966 and 1982, many more accurate geodetic observations were made and more rigorous adjustment techniques were available. In 1982 a new national adjustment, was performed using all the data previously included in the 1966 adjustment as well as additional, modern observations. This new adjustment also used the gazetted Australian Geodetic Datum (Allman, 1984). The co-ordinate set resulting from this adjustment was accepted by the National Mapping Council in 1984 and is known as the Australian Geodetic Datum 1984 co-ordinate set (AGD84).

When the National Mapping Council adopted the AGD84 co-ordinate set in October 1984, it recognised the need for Australia to eventually adopt a geocentric datum. ICSM was particularly concerned with the diverging use of co-ordinates across Australia (AGD66, AGD84, WGS72 and WGS84) and eventually recommended a geocentric datum to be implemented by the year 2000.

In 1992, as part of the world-wide International GPS Service (IGS) campaign, continuous GPS observations were undertaken at eight geologically stable marks at sites across Australia which form the Australian Fiducial Network (AFN). During this campaign GPS observations were also carried out at a number of existing primary survey stations across Australia. These were supplemented by further observations in 1993 and 1994, producing a network of about 70 with approximately 500 km spacing across Australia. These sites are collectively known as the Australian National Network (ANN).

The GPS observations at both the AFN and ANN sites were combined in a single regional GPS solution in terms of the International Terrestrial Reference Frame 1992 (ITRF92) and the resulting coordinates were mapped to a common epoch of 1994.0. These sites are estimated to have an absolute accuracy better than 3 cm at 95% confidence, (Morgan et al, 1996). The positions of 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 then used to constrain a re-adjustment of the Australian geodetic networks, including all 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. These State & Territory GPS networks typically had a spacing of about 100 km, 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 adjust their subsidiary survey networks onto GDA.

Many of the new GDA94 coordinates were part of the State & Territory GPS networks and also had AGD66 or AGD84 coordinates. These positions were used to determine new national transformation parameters from AGD to GDA94, replacing previous AGD to WGS84 parameters. Molodensky parameters were computed for both AGD66 and AGD84 and similarity transformation parameters were computed for AGD84. These parameters, together with formulae and worked examples, are available in the GDA Technical Manual, which is available on the ANZLIC Web site (www.anzlic.org.au/icsm/gdatm/gdatm.htm). Work is continuing on more detailed regional transformation parameters through the ICSM Geodesy Group.

ICSM implementation

The Inter-governmental Committee on Surveying and Mapping (ICSM), through its sub committee the ICSM Geodesy Group, maintains the geodetic infrastructure across the whole of Australia. For some time ICSM and its predecessor, the

National Mapping Council had been considering the move to a global geodetic datum as shown in Table 1. When the AGD84 geodetic adjustment was adopted in 1984, the need was recognized to eventually convert to a geocentric datum. But as a widely accepted global datum was not available it was decided to adopt the improved AGD84 data set on the Australian National Spheroid.
Work began in earnest in 1992 to establish key fiducial points which could be used as the framework for a geocentric datum and this eventually formed the basis for the national approach. And the adoption of the geocentric coordinates for the framework in November 1994. Beyond the national level framework of the National Geodetic Data Base the nationwide implementation of the GDA datum breakdown to regional and local coordinate sets is the responsibility of individual State/Territory jurisdictions. Implementation strategies will vary in nature and timeframe but generally the widespread implementation of the GDA will be undertaken in the year 2000.
Geodetic coordinates will be increasingly available electronically and historical national geodetic data base values in Clarke, AGD66 or AGD 84 will be maintained on the National Geodetic Data base at the AUSLIG web site (www.auslig.gov.au). Detailed local GDA values below the national level information held at AUSLIG, will become available through a distributed national geodetic data base with cross links to state/territory jurisdictions World Wide Web sites. An off line national archive back-up will be held at AUSLIG.

1984	Recognised the need for Australia to eventually convert to a geocentric datum
July 1988	Resolution 2 recommended the adoption of an appropriate geocentric datum on 1 January 2000
March 1990	Following approaches to the surveying and mapping community, the Committee reaffirmed its commitment to the adoption of a geocentric datum
March 1992	Following discussion on the economic impact of implementing a geocentric datum the Committee reiterated its commitment to adopting a geocentric datum by the year 2000.
May 1993	AUSLIG to manage the processing and the development of coordinates for the Australian National Network of GPS stations. GPS observations to be a cooperative ICSM project
November 1994	ITRF92 coordinates (@1994.0) adopted for the AFN & ANN
September 1995	GDA definition published in the Commonwealth Gazette
March 1997	Results of the combined GDA94 adjustment of State & Territory geodetic networks, constrained to the AFN and ANN, accepted by ICSM
November 1997	National transformation parameters from AGD66 & AGD84, to GDA94, accepted by ICSM.

Table 1: ICSM Decisions leading to the Geocentric Datum of Australia (GDA94)

Beyond GDA94

GDA is a horizontal datum and has no direct impact on the heights on the Australian Height Datum (AHD71). This height datum was based on the assumption that the 30 mean sea level determinations used around the Australian coast defined a flat surface of zero height, with heights above this plane computed as normal orthometric heights. Although not perfect in theory, this approach has proved to be a very workable basis for a level datum which has stood for over twenty five years.
With the increasing use and accuracy of satellite based positioning and improved geoid models, both on land and sea, there is an inevitable move towards, not just global horizontal datums, but also vertical datums. Ideally this could be done in Australia with a single three dimensional adjustment - but there is much work required before it could be initiated.
A by-product of the GDA national adjustment is a highly accurate GPS network across Australia, and additional, denser State and Territory GPS networks with 3 dimensional values. The ITRF92 ellipsoidal heights at the AFN and ANN sites have been propagated through these networks to many sites that also have optically levelled AHD heights. Although the assumptions used in the definition of the AHD have remained hidden from most users since 1971, the availability of accurate GPS results and geoid models, such as AUSGEIOD98, can be expected to start to reveal the inadequacies of the AHD. The extensive GPS networks being established provide an opportunity to assess the AHD and consider options for refinement.

Conclusion

The Geocentric Datum of Australia permits spatial data to be readily assembled and integrated locally, nationally, regionally and globally. The short term cost of implementing GDA will produce more compatible data as an increasing benefit to a larger community of spatial data users. In the future there is likely to be a need to consider a strategy for integrating an upgraded third dimension to into national and regional spatial data through modern satellite positioning applications.

References

Allman, J.S. & Veenstra C., 1984, *Geodetic Model of Australia 1982*.

National Mapping Technical Report 33, Division of National Mapping, Department of Resources & Energy.

Bomford, A.G. (1967) The Geodetic Adjustment of Australia, 1963-1966
Survey Review, No. 144, Vol XIX, 1967, pp57-58.
Department of Defense, 1987. "Department of Defense World Geodetic System 1984
"Its Definition and Relationships with Local geodetic Coordinate Systems",
DMA Technical Report 8350.2
IERS Technical Note 15, ITRF92 and its Associated Velocity Field, Boucher, C.,
Altamimi, Z. and Duhem, L., Observatoire de Paris, October 1993.
Malys, S. and Slater, J. (1994) Maintenance and Enhancement of the World
Geodetic System 1984. Proceedings of ION GPS-94, Salt Lake City,
Utah. September 1994.
Malys, S., Slater, J., Smith. R., Kunz,L., and Kenyon,S. (1997) Refinements
to the World Geodetic System 1984. Proceedings of ION GPS-97, Kansas City,
Missouri. September 1997.
Morgan et al, (1996). "A Zero Order GPS Network for the Australian Region"
Unisurv Report S-46, 1996, School of Geomatic Engineering, University of NSW.
Swift, E.R., Improved WGS84 Coordinates for the DMA and Air Force GPS
Tracking Sites. Proceedings of ION GPS-94, Salt Lake City, Utah.
September 1994.

Related URLs

www.auslig.gov.au	AUSLIG
www.anzlic.org.au/icsm/gdatm/gdatm.htm	GDA Technical Manual
cddisa.gsfc.nasa.gov	Crustal Dynamics Data Information System (CDDIS)
hpiers.obspm.fr	International earth Rotation Service (IERS)

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