TOWARDS GEOCENTRIC DATUM: AUSTRALIAN EXPERIENCE

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1. INTRODUCTION

Geodetic datums underpin orderly spatial data infrastructures. They facilitate the collection of homogenous positions for the management of data both within and across state and national boundaries. They provide the base layer on which compatible spatial data infrastructures are built. The traditional realisation of a horizontal geodetic datum is through a local framework of accurate geodetic survey marks, classically monumented with beacons on hilltops These high vantage points were needed to allow direct measurement of distance or directions between adjacent points, in order to establish a positional framework. The application of space geodesy technology such as GPS, without the need for inter-visibility, has allowed the geodetic marks of the modern framework to be placed in more accessible and useable locations. However satellite positioning technology operates within a global not a local system. To make best use of this technology it is far preferable that the local geodetic infrastructure be directly compatible with the global system to produce maximum benefit to the full range of users of spatial information.

2. BACKGROUND

In Australia prior to 1966, there were some twenty different datums, using four different figures of the earth, but the spheroid in general use until 1961 was the Clarke 1858 spheroid. Most triangulation was computed from bases measured in British feet and there were a number of distinct astronomically determined origins. National integration of state surveys was commenced in the late 1950s and for a short period in 1962, geodetic computations were performed on the so-called "NASA" spheroid and then on a preliminary local spheroid (the "165" spheroid). In April 1965, it was decided to change to a better fitting local ellipsoid which was called the Australian National Spheroid. This figure was later adopted by the International Astronomical Union as the International Spheroid 1967. Although this ellipsoid was used to best fit to the local geoid surface in Australia, its centre did not coincide with the centre of mass of the earth - ie. it was non-geocentric.

2.1. Australian Geodetic Datum 1966 (AGD)

From May 1965 to March 1966 a complete least squares adjustment of the Australian geodetic network was carried out (Bomford, 1967). The twenty-fourth meeting of the National Mapping Council adopted the new Australian Geodetic Datum (AGD66) on the 21st April 1966. The datum was subsequently proclaimed in the Australian Commonwealth Gazette of 6 October 1966 and the grid coordinates derived from a Universal Transverse Mercator projection of the AGD66 coordinates were termed the Australian Map Grid coordinates (AMG66).

2.2. Australian Geodetic Datum 1984 (AGD84)

In 1982 a new national adjustment was performed, still using the Australian National Spheroid and incorporating all previous data as well as additional terrestrial and space-based Transit Doppler observations. It also included geoid-ellipsoid separations, which were assumed to be zero in the 1966 adjustment. This corrected a number of deficiencies in AGD66. The resultant coordinate data set was accepted by the National Mapping Council in 1984 and is known as the Australian Geodetic Datum 1984 (AGD84). In adopting these values it was recognised the need for Australia to eventually adopt a geocentric datum but it was not clear at that time which definition to use. This was reinforced in 1988 when Inter-governmental Committee on Surveying and Mapping (ICSM), which replaced the NMC, recommended the adoption of an appropriate geocentric datum by 1 January 2000.

Not all states and territories implemented AGD84 and shortcomings of the original 1966 data set and duplication and anomalies with the 1984 data set were highlighted by the increasing use of global position fixes using Space Geodesy techniques (eg Doppler and GPS). By the early 1990s it was obvious that in some areas the old coordinate sets were no longer accurate enough and the potential benefits of a direct connection with space technology in the form of GPS were very significant. Consequently it was decided to move to a single geocentric datum.

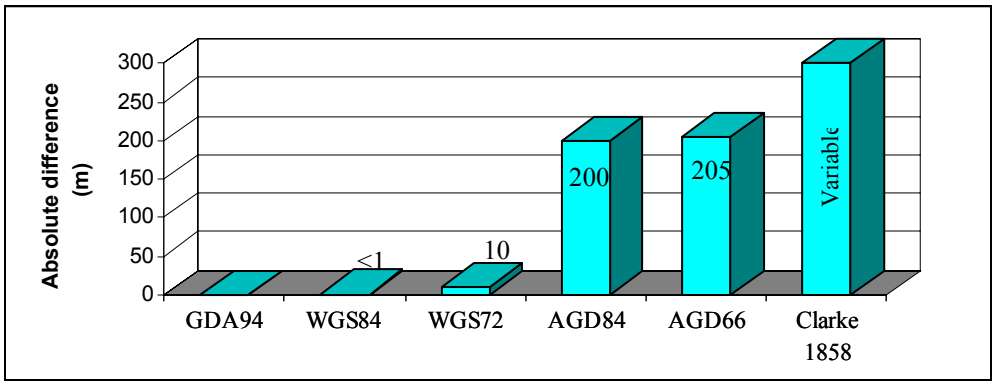

Figure 1: Indicative difference between Australian datums

3. GEOCENTRIC DATUM OF AUSTRALIA 1994 (GDA94)

In 1992, as part of the world-wide International GPS Service (IGS) campaign, continuous GPS observations were undertaken on 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 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, with a nominal 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.

The positions for the AFN sites are estimated to have an absolute accuracy of about 2 cm at 95% confidence (Morgan, 1996), while the ANN positions are estimated to have an absolute accuracy of about 5 cm. These 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 existing Australian terrestrial geodetic networks were then adjusted to these ITRF92 positions to propagate the new datum across Australia in a compatible geodetic infrastructure. As recommended by the International association of Geodesy (IAG) the Geodetic Reference System 1980 ellipsoid (GRS80) was used to express the positions as latitude and longitude and when converted to a Universal Transverse Mercator projection they are known as Map Grid of Australia 1994 coordinates (MGA94).

The meeting of the Inter-governmental Committee on Surveying and Mapping held in Canberra on 28-29 November 1994 adopted the above new geodetic datum for Australia and recommended its progressive implementation Australia-wide by 1 January 2000. The resultant Geocentric Datum of Australia 1994 (GDA94) has an origin that coincides with the centre of mass of the earth (i.e. geocentric). The distance between the centre points of the GDA and AGD ellipsoids is approximately 200 metres. When the coordinates of a point on the Earth's surface

are converted from AGD to GDA this translates to a coordinate difference of approximately the same amount. The difference varies slightly depending on where you are in Australia.

While the origin of both the the AGD66 and AGD84 datums was the Johnston Geodetic Station, today's technology means that a new datum can be based on several well-determined points and the position of the AFN points were gazetted as the positional standard for the Geocentric Datum of Australia. However though the AFN provides Cartesian coordinates in three dimensions, only the horizontal components have been adopted. Heights in Australia remain on the separate Australian Height Datum (AHD) which is based on mean sea level at coastal tide gauges.

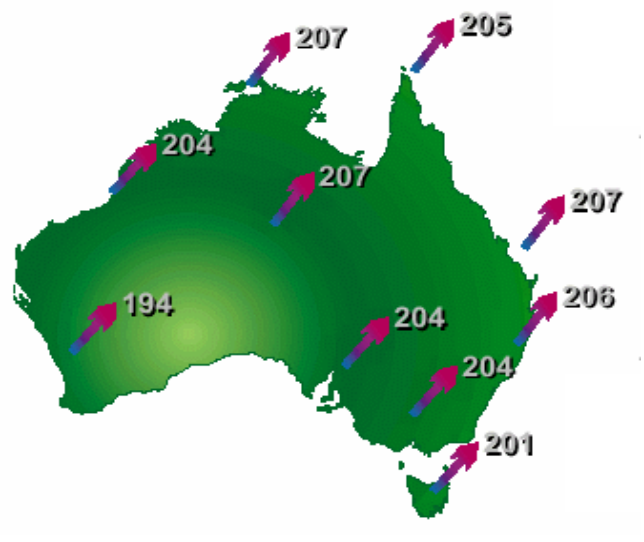

Figure 2: Indicative shift from AGD to GDA94

4. THE CHANGE TO THE GEOCENTRIC DATUM

The driving reason to change to the Geocentric Datum was so that Australia could make more efficient use of GPS to produce economic benefit. It was considered to be the most effective because it provided:

- compatibility with satellite navigation systems, such as the Global Positioning System (GPS) in use by ICAO and IHO
- compatibility with all national mapping programs being carried out on a geocentric datum, such as Defence agencies
- a single standard for the collection, storage and dissemination of spatial information at global, national and local levels.
- Benefits to precision agriculture, emergency services, fleet management, asset management,
- Compatibility with global Wide area GPS, systems
- Compatibility with resolutions of the International Association of Geodesy and the resolutions of the United Nations Regional Cartographic Committee for Asia and the Pacific.

Even in the early 1990s GPS was being widely used for navigation and positioning both by spatial scientists and the general public. Geocentric datums had been adopted for aeronautical and shipping applications due to their international capabilities.

It was decided to adopt the civilian International Terrestrial Reference Frame (ITRF) rather than the military based WGS84 system as the basis for the new geocentric datum. One reason was

that the ITRF products and satellite orbits were freely and readily available through the International GPS Service (IGS) and was based on several hundred global sites. WGS84 was a military fixed system based on five mainly equatorial control stations and at the time did not take into account velocities at those stations. GPS observations for Australian sites were computed in both ITRF and WGS84 and it was shown that the difference in positions was less than one metre. Since that time however the WGS84 reference frame has been updated on several occasions and is now compatible with the civilian reference frame being only a few centimetres different to ITRF (Malays et al, 1997). The WGS84 system now incorporates dynamic tectonic motion at the master control stations so it is expected to maintain this close connection with ITRF.

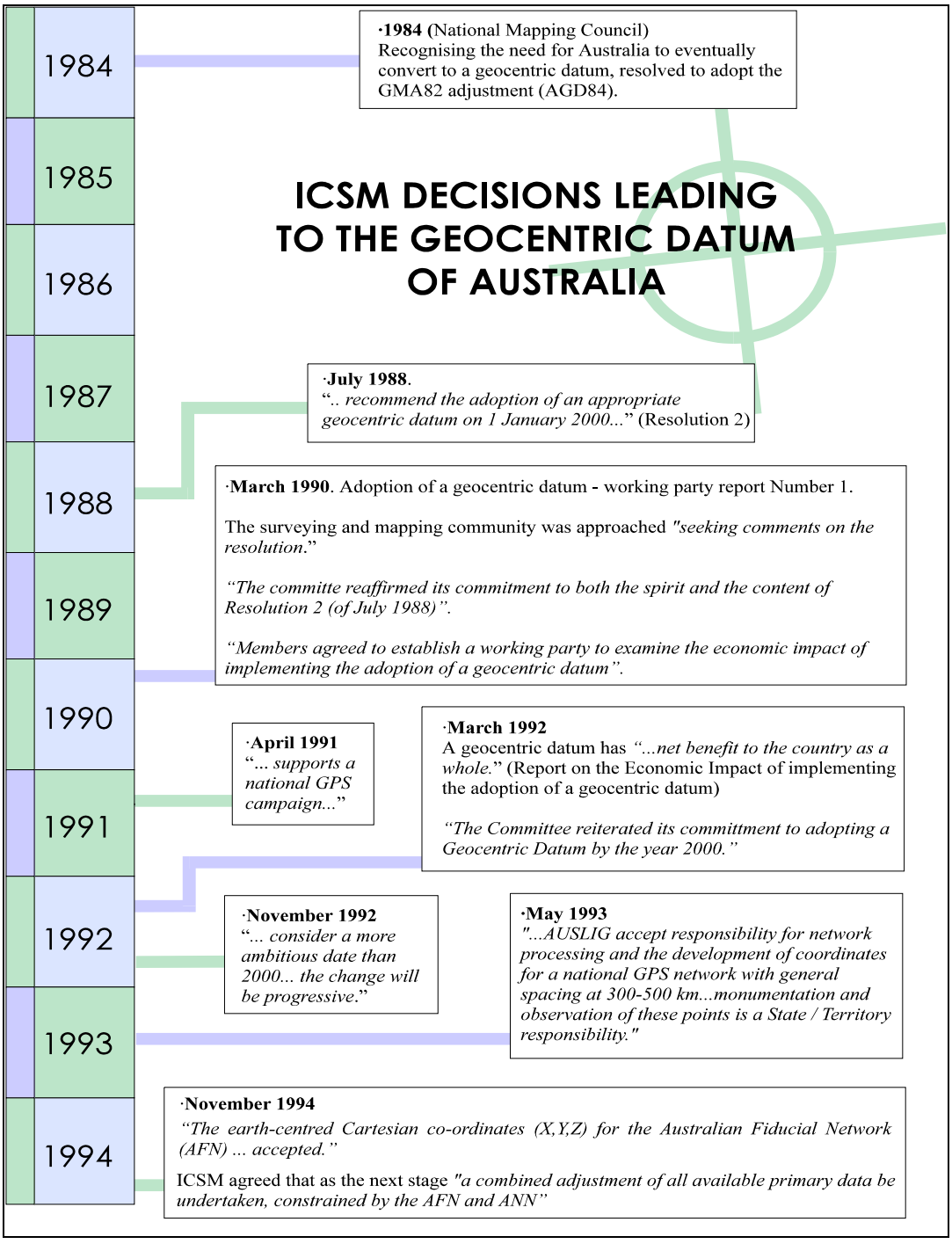

Figure 3: Timeline - initial introduction of GDA94

5. MIGRATION OF SPATIAL COORDINATES TO THE NEW DATUM

In Australia authority for national datums is with the Commonwealth of Australia Government but in practice this is done in conjunction with State and Territory governments through the Inter-governmental Committee of Surveying and Mapping (ICSM). This replaced the National mapping Council, initially established to provide national mapping coverage of the Australian continent. ICSM approved the geocentric datum and proceeded to plan its implementation as shown in figure 2.

5.1 The tools

To assist the implementation of GDA, ICSM developed a number of user tools to facilitate the change and widely distributed them via the web and free CDs. These tools include:

- Two transformation grids that cover the whole of Australia were developed for web use. One is for transforming AGD66 data to GDA94, the other for AGD84 data. The grid is available in a Canadian format known as National Transformation version 2 (NTv2) which is included in a number of GIS software packages (Collier, 1998). In addition, stand-alone software packages were developed to enables users to utilise this grid to create a high accuracy transformation process. ICSM recommended that:
  - Although Similarity and Moldensky transformation parameters were also developed for general use, the high accuracy grid-based transformation process be used whenever possible, in the interest of ensuring internal and external consistency with other custodians of spatial data.
  - Users independently test software transformation processes to ensure satisfactory results are obtained.
- The development of a GDA Technical Manual was an essential to enable users to perform a wide range of geodetic computation in terms of GDA94 and undertake data transformations (ICSM,2002)
- Test data sets and complete formulae were made available in the GDA Technical Manual to assist users perform transformation tests.
- A logo was developed to be used on GDA Compliant or GDA Compatible Products.
- A number of promotional products were developed, printed and are available on the ICSM web page, these include :

  - Published Brochures

  "Know Where You Stand with GDA"
  "Get In Step With the Geocentric Datum - Discussing the Business Issues"

  - Information Factsheets

  "Maps and the GDA"
  "Transformation Options"
  "GDA Grid Transformation Using Distortion Modelling"
  "What is the difference between WGS84 and GDA94?"

  - Promotional Video

  "Going Geocentric" also available on CD-ROM

  - Map user Information

  The National Mapping Division of Geoscience Australia made available a handy *Map Reading Guide on How to Use Topographic Maps*. This guide available in hardcopy and on the web was particularly targeted for GPS users as it deals with the practicalities of how to use this technology with hardcopy maps, including datum differences, scales and coordinate systems.

5.2 Promoting the Geocentric Datum

Whilst the technical task of computing the geodetic infrastructure on a geocentric datum took several years it was acknowledged that it would take considerable time for the change to flow down to spatial data. ICSM recognised that this migration to GDA was a complex task and organisations would require assistance in many areas. A GDA promotions and Implementation Working Group of all members was set up to monitor and facilitate a nationally consistent approach to introduction of the datum. In order to achieve this the group was tasked to carry out the following:

- Benchmark the current implementation status of GDA
- Monitor and facilitate implementation of GDA
- Produce and review promotional materials as necessary
- Identity and facilitate the development of tools and techniques to meet industry needs
- Overview the introduction of a complete technical manual

The working group substantially completed these tasks by the end of 2003.

A full time Promotions Officer was appointed to support the promotional task force which focused its activities on the following areas:

Industry Briefings
ICSM and other State and Territory representatives provided briefings to industry at workshops and seminars up to 2000.

Educational Material:
ICSM published material on a regular basis in popular industry publications and will be encouraged the education industry in Australia to include GDA implementation as part of its education programs.

Software Development:
ICSM encouraged GIS and GPS software companies to incorporate the necessary transformation routines in their products. When purchasing GIS and GPS products, organisations were encouraged to specify that the product must capture and or convert data to GDA coordinates.

On-line support through the World Wide Web:
ICSM established a web site at www.icsm.gov.au/icsm/gda/index.html, which contained detailed technical information about GDA and links to other jurisdictional sites.

The new datum was progressively propagated to lower order geodetic networks and was actively promoted as the preferred datum for all spatial information. The implementation responsibility was thus shared by governmental agencies but this needed significant explanation and education to be provided to other semi governmental authorities, local governments, and private sector organisations. Many agencies were faced with a decision to recompute coordinates or to use transformation parameters to produce GDA94 coordinates in their digital data sets.

Essentially anyone producing or using spatial data needed to develop a migration strategy from the AGD to the GDA and these options were strongly promoted through the presentation of papers such as "*Know where you stand with GDA*" (Burbidge and Zammit, 1998). These papers stressed the need for migration strategies, identified the impact on software suppliers, and addressed the challenge for hardcopy records. For example a considerable amount of geographical information is even now still held in paper maps. Much of this information may not require conversion, or it will not be economically feasible to convert. But shipping navigation charts and aeronautical charts are examples of maps that have been quickly converted to GDA or the compatible WGS84 datum.

Some organisations in Australia will progressively update their maps in future through their revision programs. The technicalities of converting maps to GDA include deciding whether to move the graticule and keep even latitude and longitude, or maintain the existing graticules, resulting in non-integer latitude and longitude neat lines. If the map sheet area is changed, then there may be slivers and gaps where the converted data will either appear on two map sheets or be missing altogether. Bleed edges have sometimes been used to overcome the gaps between map sheets.

Depending on how digital mapping data is stored, the conversion method chosen and results achieved will differ. Digital data can be stored in both tiled and 'seamless' databases. The tiled data will suffer similar dilemmas to paper map sheets but in some cases may be more complicated to rectify. If the data is indexed using tile boundaries or using unique feature identifiers, which are referenced to a tile, then there may be some difficulties encountered if consistency is required though the migration process.

5.3 Implementation status

As the implementation continued, the flow on moved more slowly, with utilities and some private sector organisations taking more time, but inevitably anyone receiving or producing spatial information needs to work in the geocentric system. According to ICSM's GDA Implementation Working Group, data sets owned by the public sector can be defined under the five fundamental elements of:

- Primary Reference;
- Administration;
- Natural Environment;
- Socio-Economic and
- Built Environment

Data within each Australian State or Territory are systematically being transformed to GDA and from a national perspective, as illustrated in the graph below, the Primary Reference and Administration data sets are well on the way to becoming fully GDA compliant across all jurisdictions. Currently some compliancy gaps appear in Natural Environment, Socio-Economic and Built Environment data as these data sets fall outside the ICSM members' immediate sphere of influence or have a lesser imperative due to their lower spatial accuracy requirements.

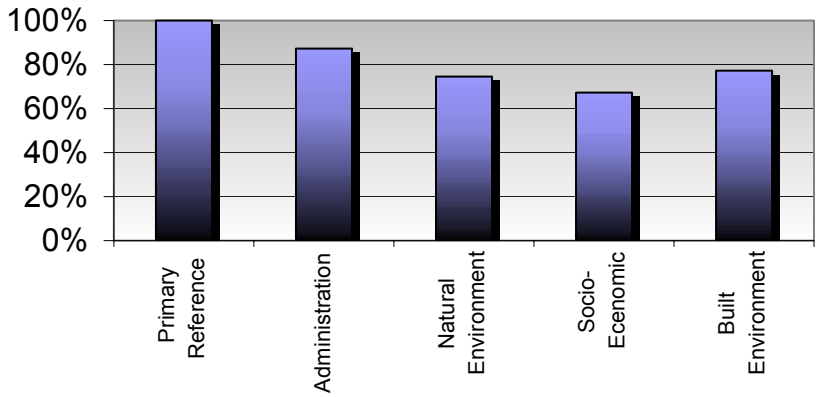

Figure 4: GDA national compliant public sector data sets

6. CONCLUSION

It takes a long time and many resources to change a national datum beyond the field survey stage. It is a complex task and the impact of unforseen implications in boundaries and other legislation changes to be considered. Not all hardcopy records are capable of change in the short term.

It is important to also consider that the change to a single uniform set of fixed coordinates within the datum will probably not last forever as the space positioning technology continues to produce more accurate positioning. Since declaring the geocentric datum in Australia GPS has improved its utility with the end of selected availability and hand held positions of better than five metres are normally available, and post processing is readily available to achieve a few centimetres. The ongoing demand is for near real time positional accuracy of several centimetres to be available to a wide variety of users. So the journey to real time centimetre positioning has been commenced with RTK and wireless mobile location devices.

The geodetic infrastructure positions in Australia have already moved almost 70 cm from the declaration date of 1 January 1994 due to tectonic plate motion approaching 1½ mm week. To counter this in the short term the AUSPOS on line GPS service has been developed in order that GPS coordinates can be readily computed in terms of GDA using a plate deformation model.

But in Australia despite the hard work involved in the introduction of a Geocentric datum, It has already produced a massive benefit to the navigation and spatial data community which is now flowing on to all users of space positioning.

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