DEVELOPMENT OF AUSTRALIA'S NATIONAL GDA94 TRANSFORMATION GRIDS

Consultant's Report to the Intergovernmental Committee on Surveying and Mapping

by

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FOREWORD

No more than thirty years ago, geodesy was considered an esoteric science reserved for academics and theoreticians. Most practitioners in those days could avoid having to understand, much less apply, geodetic principles in their routine operations. Today however, geodetic issues occupy a prominent place in the minds of many involved in the capture, manipulation and presentation of spatial data. In particular, the widespread use of satellite positioning technologies, such as the Global Positioning System (GPS), has created the need to understand complex principles like geodetic datum definition, the relationship between the geoid and the ellipsoid, map projections and datum transformations.

For geodesists, this resurgence of their science has restored them to a position of prominence amongst spatial scientists. And rightly so we argue, after all, the world's highest mountain was named after a geodesist. But for the practitioner, the confusion brought about by the need to understand and apply geodetic principles has often been costly and in some cases catastrophic.

With the increasing availability, capability and reducing cost of hand-held positioning devices and digital mapping products, more and more non-technical people are being exposed to and are having to come to grips with geodetic principles. The challenge for geodesists today is to make their science available and accessible to an increasingly broad community with high expectations and diverse positioning and mapping needs.

In Australia, a step toward this objective has been taken by the introduction of a new geodetic datum – the **Geocentric Datum of Australia (GDA94)**. Proposed by the Intergovernmental Committee for Surveying and Mapping (ICSM) in November 1995 and recommended for adoption by January 1, 2000, GDA94 introduces a nationally consistent reference frame for all coordinate data across the country which is also compatible with the default GPS datum (World Geodetic System 1984 – WGS84).

While offering significant long-term benefits, the short-term complexities and difficulties associated with the adoption of a new datum are significant. One of the technical challenges is to provide custodians and users of spatial data with an efficient and effective strategy for the transformation of that data from the old datum to the new (and vice versa). This report describes the development of national transformation grids to support this transformation process. Two grids have been created, one to aid those who hold coordinate data related to the Australian Geodetic Datum 1966 (AGD66) and another, covering Queensland, South Australia and Western Australia to assist those who deal with data related to the Australian Geodetic Datum 1984 (AGD84).

The work summarised in this report builds upon a number of years of research and development in the Department of Geomatics at the University of Melbourne, undertaken to design, test, implement and refine a coordinate transformation strategy to suit the requirements of spatial data users in Australia.

Philip Collier 6 February 2002

SECTION A – General Background

A.1 The Need for Transformation

The introduction of the Geocentric Datum of Australia (GDA94) has created the need for a nationally consistent transformation process to be used by those involved in the collection, management, maintenance and distribution of spatial data. This need exists particularly for those who work with *compiled* data. Compiled data is that form of spatial data which is linked (either directly or indirectly) to the survey control network but which does not strictly form part of that network. Examples of compiled data include that describing the location of property boundaries, public assets, infrastructure such as water, gas, electricity, telecommunications, roads and so on. The majority of spatial data falls into this *compiled* category.

A consistent and technically sound approach to the transformation of compiled data is required to maintain the integrity and topology of existing data sets and to ensure that identical transformation results are obtained regardless of who does the transformation.

Collier et al. (1998) identified four criteria which a national transformation model should satisfy. These were :

- *Simplicity* – to facilitate understanding and adoption by users
- *Efficiency* – to minimise time and computational demands
- *Uniqueness* – to ensure only one solution exists
- *Rigour* – to provide the best possible transformation result

A.2 Grid Based Transformation

The criteria of simplicity, efficiency and uniqueness relate to how the transformation information is made available to users rather than the technical capabilities and performance of the transformation model itself. For example, it is possible to give users access to a complex and sophisticated transformation process in a way that allows the model to be applied simply and efficiently and to yield unique results. Experience in the United States and Canada has demonstrated that the provision of an otherwise complex transformation model on a regular grid is a convenient and widely accepted practice that satisfies the criteria of simplicity, efficiency and uniqueness. The important issue of the rigour of the transformation process will be discussed in Section A.3

Figure 1 illustrates how gridded transformation information can be used to determine the transformation components at a computation point. In the example of Figure 1, the unknown transformation components at P are calculated using the known transformation components at the surrounding four grid nodes. To compute the transformation components at P, the method of bi-linear interpolation (Press et al., 1992) is used. For example, to calculate the latitude transformation at Point P ($\delta\phi_P$), the following equations are evaluated :

$$\delta\phi_P = a_0 + a_1X + a_2Y + a_3XY \quad \ldots(1)$$

where;

$$a_0 = \delta\phi_1 \quad \ldots(2)$$
$$a_1 = \delta\phi_2 - \delta\phi_1 \quad \ldots(3)$$
$$a_2 = \delta\phi_4 - \delta\phi_1 \quad \ldots(4)$$
$$a_3 = \delta\phi_1 + \delta\phi_3 - \delta\phi_2 - \delta\phi_4 \quad \ldots(5)$$
$$X = (\lambda_P - \lambda_1)/(\lambda_2 - \lambda_1) \quad \ldots(6)$$
$$Y = (\phi_P - \phi_1)/(\phi_4 - \phi_1) \quad \ldots(7)$$

To compute the longitude transformation component at P ($\delta\lambda_P$), the $\delta\phi$ terms in equations (2), (3), (4) and (5) are simply replaced with the corresponding $\delta\lambda$ terms from the grid.

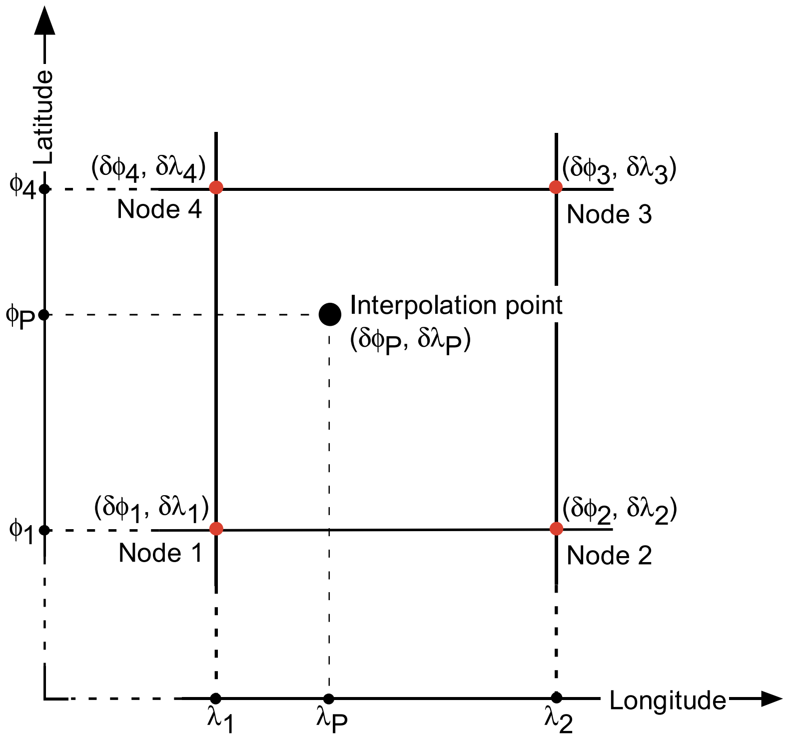


Figure 1 – The principle of grid-based transformation

A.3 The Transformation Model

Grid based transformation gives users ready access to the transformation model, however the important question as to *which* transformation model needs to be considered. There are many options for the transformation of coordinate data. Which method is the most appropriate depends on the objectives of the transformation and the existence (or otherwise) of distortion in the data to be transformed.

In the context of developing a national transformation model for Australia, it has been assumed that the basic objective of transforming spatial data to GDA94 is to at least maintain the accuracy and integrity of the original data. This objective can be achieved using a simple conformal transformation. In geodesy for example, the 7-parameter transformation is widely used for 3D applications. Alternatively a 4-parameter model can be used in 2D cases. Conformal transformation models shift, rotate and scale the coordinate data but maintain shape (there is no change in spatial accuracy). Details of the 7-parameter transformation can be found in Harvey (1986).

The transformation problem becomes more complex if there is distortion in the original data and it is deemed advantageous to improve spatial accuracy by removing some or all of that distortion through the transformation process. Methods for modelling and removing distortion from coordinate data include; multiple regression (Applebaum, 1982), least squares collocation (Mikhail, 1976; Moritz, 1980) and the fitting of minimum curvature surfaces (Briggs, 1974; Dewhurst, 1990).

Analysis of the available data across Australia has shown that coordinate distortions exist in both the AGD66 and AGD84 networks. While the magnitude of these distortions is quite variable, upper limits are typically in the order of 3 to 5 metres. In order to reduce this distortion through the transformation process and thereby improve the spatial accuracy of the transformed data, an evaluation has been carried out of the distortion modelling options mentioned above (Collier et al., 1996; Collier et al., 1997). As a result of this evaluation, it was decided that least squares collocation would provide the most appropriate distortion modelling technique for the Australian case.

A.3.1 Defining Distortion

In order to explain the distortion modelling process, it is first necessary to understand the concept of distortion. Figure 2(a) shows a subsidiary survey network (●) connected to two higher order control points (■). The coordinates of the subsidiary points have been derived from a least squares adjustment of the observations within the framework defined by the control points. Figure 2(b) shows the same network at a later date, augmented by new points (●), some new observations and connections to a new control point (■). Adjustment of the expanded network in Figure 2(b) will result in new coordinates for the points shown in Figure 2(a). The displacement vectors (→) in Figure 2(b) show the resultant change in coordinates. These coordinate differences represent the *distortion* of the old network with respect to the new.

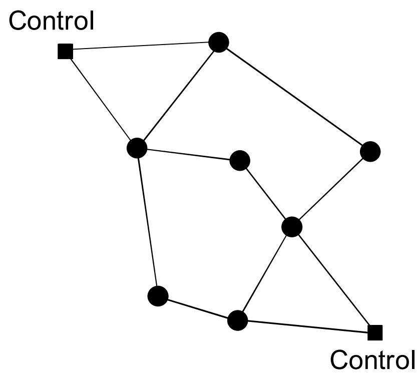


Figure 2(a) – Coordinates are calculated based on existing control and measurements

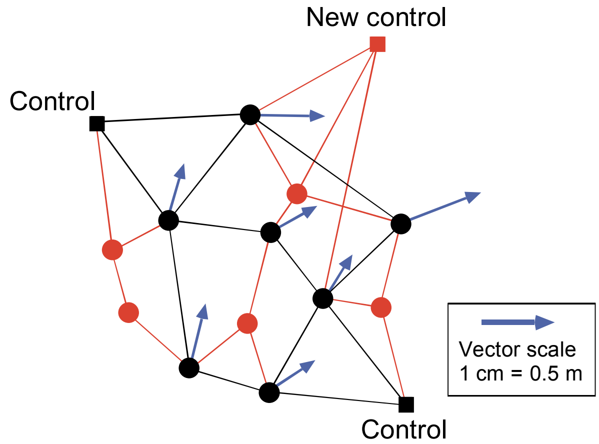


Figure 2(b) – Coordinate are re-calculated revealing distortion in original values

In the example of Figure 2, distortion occurs because of the upgrading and extension of the network over time, in addition to any real point movements that may have occurred. It should be noted that the existence of distortion is independent of a change in the underlying datum. The two epochs in the example are related to the *same* geodetic datum, even though a new control point has been added.

To transform the common points shown in Figure 2(a) to their corresponding locations after the re-adjustment shown in Figure 2(b), would require the use of a *distortion model*. If a datum change had also taken place (e.g. the control may have been moved from AGD to GDA between the two scenarios shown) the transformation must also include a *datum shift*. The datum shift is usually represented by a conformal transformation as discussed above. The application of a conformal transformation without a distortion model assumes there is no distortion or that the distortion is minimal.

In the Australian context, as previously explained, to conformally transform from AGD to GDA and thus ignore the distortion component may leave distortion in the transformed coordinates ranging up to several metres.

A.3.2 The Distortion Model

A.3.2.1 Covariance function

Coordinate distortion can be a complex and highly variable quantity which does not lend itself to simple mathematical modelling. It is common however to find that points which are close together display a similar distortion pattern, whereas the distortion at points separated by a large distance can be quite different. This *spatial correlation* can be utilised in the development of a distortion model.

Least squares collocation (or more correctly, linear least squares interpolation in this particular context) is a technique that allows the contribution of the distortion at surrounding data points to be weighted in proportion to their distance from the interpolation point. In terms of developing a distortion grid, the objective is to use randomly distributed data to estimate the distortion components ($\delta\phi,\delta\lambda$) at each grid node. In the example of Figure 3, the distortion components at the central grid node are to be determined from the know distortion components at the seven surrounding data points. The distance of each data point from the grid node is also known (or computed).

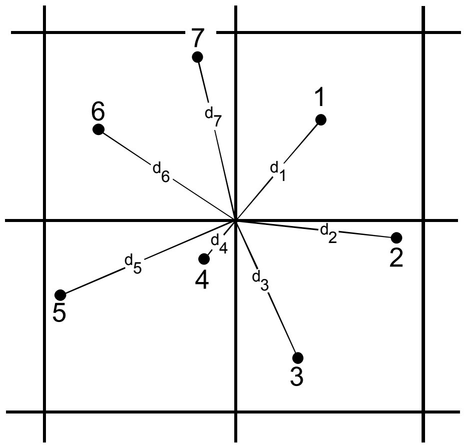


Figure 3 – Interpolating distortion components at a grid node from surrounding data

A *covariance function* is used to express the spatial behaviour of distortion as a function of distance. A typical example is shown in Figure 4. Put simply, the covariance function reflects the fact that the distortion at two points separated by a small distance will be highly correlated, whereas the distortion between points separated by a large distance is effectively uncorrelated.

In practice, the covariance function is empirically generated from the data. An analytical model is then fitted to the empirical points (Collier, 1988). The analytical model provides a convenient tool for determining the relevant covariance terms between data points and the interpolation point as required for the development of equations (10) and (11).

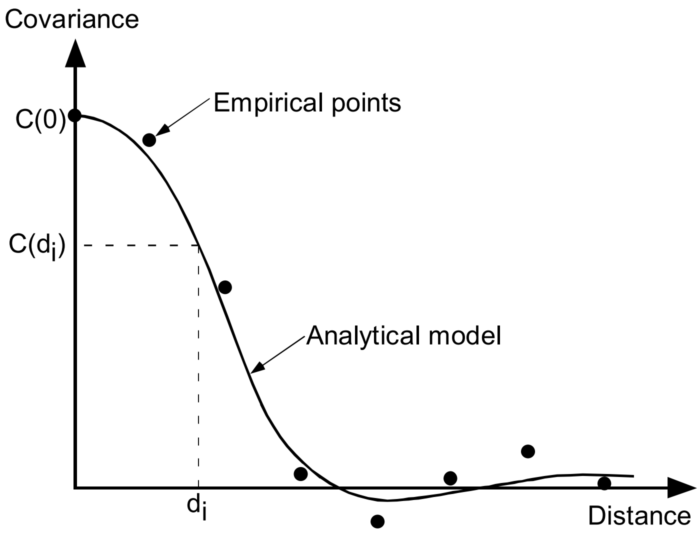


Figure 4 – A typical distance dependent covariance function

The analytical function used to model empirical covariances in this project was that developed by Reilly (1979). The adoption of Reilly's model was based on previous experience and experimentation. The equation for Reilly's covariance function is :

$$C(d) = C_0(1 - \tfrac{1}{2}(d/d_0)^2)\, e^{-\frac{1}{2}(d/d_0)^2} \qquad \ldots(8)$$

where;

d is distance
d_0 is a parameter derived from the empirical data
C_0 is the variance, the value taken by C(d) when d=0

A.3.2.2 Prediction equation

In linear least squares interpolation, the prediction equation is given by :

$$\hat{\delta} = C_\ell\, C_D^{-1}\, \ell \qquad \ldots(9)$$

As shown in equation (10), the elements of the vector C_ℓ are derived from the analytical covariance function using the distances between the data points and the interpolation point (d_1, d_2..d_7 in Figure 3). Similarly, as per equation (11), the elements of the matrix C_D are computed from the analytical covariance function using the distances between all combinations of the data points (d_{ij} is the distance between points i and j). Finally, equation (12) shows the vector ℓ which contains the distortion (in either latitude or longitude) at each of the data points.

$$C_\ell = [C(d_1) \quad C(d_2) \quad C(d_3) \quad C(d_4) \quad C(d_5) \quad C(d_6) \quad C(d_7)] \qquad \ldots(10)$$

$$C_D = \begin{bmatrix} C(0) & C(d_{12}) & C(d_{13}) & C(d_{14}) & C(d_{15}) & C(d_{16}) & C(d_{17}) \\ C(d_{21}) & C(0) & C(d_{23}) & C(d_{24}) & C(d_{25}) & C(d_{26}) & C(d_{27}) \\ C(d_{31}) & C(d_{32}) & C(0) & C(d_{34}) & C(d_{35}) & C(d_{36}) & C(d_{37}) \\ C(d_{41}) & C(d_{42}) & C(d_{43}) & C(0) & C(d_{45}) & C(d_{46}) & C(d_{47}) \\ C(d_{51}) & C(d_{52}) & C(d_{53}) & C(d_{54}) & C(0) & C(d_{56}) & C(d_{57}) \\ C(d_{61}) & C(d_{62}) & C(d_{63}) & C(d_{64}) & C(d_{65}) & C(0) & C(d_{67}) \\ C(d_{71}) & C(d_{72}) & C(d_{73}) & C(d_{74}) & C(d_{75}) & C(d_{76}) & C(0) \end{bmatrix} \qquad (11)$$

$$\ell = [\delta_1 \quad \delta_2 \quad \delta_3 \quad \delta_4 \quad \delta_5 \quad \delta_6 \quad \delta_7]^T \qquad \ldots(12)$$

Evaluation of the least squares prediction equation (9) is a relatively straight forward task, although considerable care needs to be taken in the formation and inversion of the covariance matrix C_D. The spatial distribution of the data can cause the covariance matrix to be ill-conditioned, leading to numerical instabilities during the inversion computations. The practical outcome of such a problem is either a failure to predict the distortion at the corresponding grid node because the covariance matrix could not be inverted, or the prediction of an incorrect value due to numerical rounding errors in the inverted matrix. The latter case is potentially more dangerous as an incorrectly predicted value can be very difficult to identify.

A.4 Transformation Accuracy

A benefit of performing grid based transformation is that, in addition to being able to supply the transformation components at each grid node, the accuracy of these components can also be given. The gridded accuracy information can then be used to estimate the transformation accuracy at a computation point simply by again applying bi-linear interpolation.

It is important to understand what is meant by the term *transformation accuracy*. Transformation accuracy is not the accuracy of the transformed coordinates but rather the *reliability* of the transformation itself.

Transformation accuracy will be high (a small number) if the shift data used in the collocation computation displays a smooth and uniform pattern as in Figure 5(a). In this case, the distortion model is reliably determined. If, on the other hand, the shift data is irregular, as shown in Figure 5(b), the transformation accuracy will be poorer (a larger number).

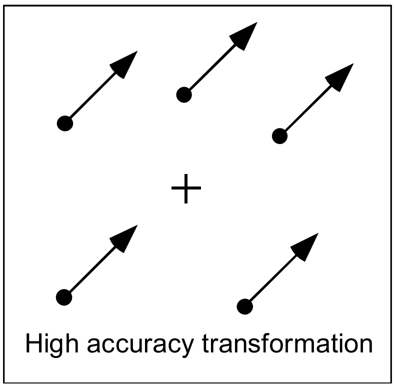


Figure 5(a) – Regular distortion pattern gives a high accuracy transformation

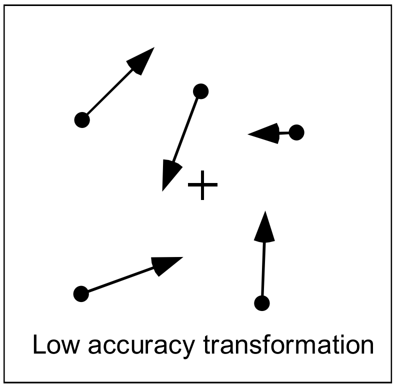


Figure 5(b) – Irregular distortion pattern gives a low accuracy transformation

The method used to compute the transformation accuracy at each grid node is based on the model proposed by Junkins and Erickson (1996) :

$$\sigma = \sqrt{\frac{\Sigma w_i^2}{(\Sigma w_i)^2} \frac{\Sigma(\delta_i - \bar{\delta})^2}{(n-1)}} \qquad \ldots(13)$$

where;

$\bar{\delta}$ is the computed shift component at the grid node (by collocation)
δ_i is the known shift component at each data point (i)
w_i is the weight derived from the covariance function and based on the distance of point i from the interpolation point
n is the number of data points

It should be noted on the basis of equation (13) that transformation accuracy is only defined at those nodes where distortion exists. Thus at grid nodes where only the conformal component of the transformation has been determined, no transformation accuracy values can be assigned. Such nodes are termed *conformal-only*. At a conformal-only node, the transformation components are derived purely from the 7-parameter transformation.

A.5 Computing a Transformation Grid

The transformation grid combines the datum shift component and the distortion component and makes an otherwise complex transformation model available to users in a simple and readily accessible form. The issue to be discussed here is how the transformation components at each grid node are actually computed.

A.5.1 The Datum Shift Component

As explained above, the datum shift component can be fully accounted for by a conformal (7-parameter) transformation. Such a transformation translates, rotates and scales the reference frame and thereby maintains the shape (though not the orientation nor size) of the transformed object.

In the context of developing national transformation grids for Australia to allow transformation from AGD66 and AGD84 to GDA94, two separate sets of national conformal transformation parameters had to be developed. Data used in the computation of these parameters was extracted from the National Geodetic Data Base (NGDB) maintained by the National Mapping Division of Geoscience Australia (formerly AUSLIG). These parameters are presented and discussed in Sections B.2 and C.2.

A.5.2 The Distortion Component

Developing and gridding the distortion component of the national transformation solutions was a complex process that utilised huge volumes of survey control data supplied by each State and Territory, in addition to the data supplied from the NGDB. The following sequence outlines the procedure used in modelling the distortion component and developing the transformation grids :

1. Apply a 7-parameter transformation to the *given* AGD coordinates to conformally move them to GDA94.

2. Compare the conformally transformed coordinates to the *given* GDA94 coordinates to determine *distortion*.

3. Identify and reject any non-conforming points – i.e. points at which the distortion is substantially different the general pattern of distortion displayed at nearby points.

4. Thin the data points to produce a more even spatial distribution for the purposes of interpolation.

5. Compute the empirical covariance functions for latitude distortion, longitude distortion and height[1].

6. Fit Reilly's analytical covariance function to the empirical covariance data.

7. Use least squares collocation, the thinned data and the derived analytical covariance functions to compute the latitude distortion, longitude distortion and height at each grid node.

8. Compute the conformal component of transformation (in latitude and longitude) at each grid node and add the distortion component.

9. Compute the transformation accuracy at each grid node.

10. Test grid performance.

The above sequence inevitably required a number of iterations for each grid. In particular, re-computations were needed to optimise the collocation parameters in order to achieve the best grid performance in each case. A purpose written software package known as *GDAGrid* was used for the grid computation process.

A.6 Grid File Format

In Canada an approach similar to that used to develop transformation grids in Australia has been employed to derive a transformation grid for the transition from North American Datum 1927 (NAD27) to NAD83. As part of the process, the Geodetic Survey Division of Geomatics Canada developed a comprehensive, yet relatively simple, grid file format, known as *National Transformation Version 2 (NTv2)*. Information regarding *NTv2* is available from the Geomatics Canada home page (http://www.geod.emr.ca:80/). The *NTv2* interpolation software and a transformation grid for Canada can be purchased from Geomatics Canada on a CD-ROM which also includes a comprehensive User's Guide and Developer's Guide.

A sample of the ASCII *NTv2* grid file format is shown in Figure 6.

[1] Though the influence of height errors on horizontal coordinates resulting from a 7-parameter transformation is small, there is no need to introduce this uncertainty. It is possible to use the collocation technique to compute the height at each grid node. It is for this reason that a height covariance function is needed. By calculating the height of each node, the conformal (shift) component of the transformation can be more accurately determined.

```
SUB_NAMEMELB
PARENT  NONE
CREATED 7/1998
UPDATED 7/1998
S_LAT    -138780.000000
N_LAT    -134406.000000
E_LONG   -526104.000000
W_LONG   -519354.000000
LAT_INC       54.000000
LONG_INC      54.000000
GS_COUNT 10332
  5.414650 -4.727520  0.002171  0.000617
  5.413610 -4.728820  0.001615  0.000235
  5.413050 -4.729720  0.001563  0.000233
  ……………………………………………………
  ……………………………………………………
  ……………………………………………………
```

Figure 6 – NTv2 data in ASCII format

The basic contents of the grid file are described in Figure 7.

```
Sub grid name
Parent grid name
Creation date
Revision date
φmin  South latitude limit (in seconds)
φmax  North latitude limit (in seconds)
λmin  East longitude limit (in seconds)
λmax  West longitude limit (in seconds)
Δφ    Latitude grid interval (in seconds)   => rows =    1+((φmax-φmin)/Δφ)
Δλ    Longitude grid interval (in seconds)  => columns = 1+((λmax-λmin)/Δλ)
Number of grid shift values (rows x columns)
      δφ  δλ  σφ  σλ  transformation components and accuracy (in seconds)
      δφ  δλ  σφ  σλ  (row 1, column 2)
      ………………………………………
      ………………………………………
      ………………………………………
      δφ  δλ  σφ  σλ  (rows, columns)
```

Figure 7 – Contents of the NTv2 grid file

There are two features that make the *NTv2* format particularly appealing and have lead to its adoption in Australia. The first is the availability of accuracy estimates for the transformation components at each grid node. The second is the facility to include sub-grids of different density. Thus, for example, in areas where the distortion pattern is more variable, the spacing of the transformation grid can be reduced compared to that used in areas where the distortion is more regular. Rules defining the *NTv2* format can be found in Junkins and Farley (1995).

A.7 Australia's National Transformation Grids

For historical reasons, two versions of the Australian Geodetic Datum exist – AGD66 and AGD84. AGD84 was adopted in Queensland, South Australia and Western Australia. The other States and Territories chose not to adopt AGD84, but rather retained AGD66, primarily for reasons of convenience and simplicity.

The adoption of GDA94 on the other hand is intended to be truly national, eliminating the confusion and problems caused by dual datums. However, to achieve national acceptance of the new datum, users need to be able to transform from either version of the AGD, thus creating the need for two transformation grids.

In November 1995 the Intergovernmental Committee on Surveying and Mapping (ICSM) proposed the adoption of a geocentric datum in Australia. Since that time, ICSM has steadily worked toward the national acceptance of the new datum. Having accepted the recommendation that the transformation process be supported by transformation grids constructed using least squares collocation, ICSM was then faced with the issue of producing a grid to support the AGD84 jurisdictions and second grid to support those still using AGD66.

At the October 1999 meeting of the ICSM Geodesy Group, it was decided that the AGD84 to GDA94 transformation grid should provide coverage of just Queensland, South Australia and Western Australia, with extensions off the West Australian coast to permit the transformation of offshore petroleum and exploration leases. Final coverage of the AGD84 to GDA94 transformation grid is shown in Figure 8. It can be seen that the AGD84 grid protrudes slightly into the AGD66 mainland states and covers large areas of offshore QLD and SA. This latter feature is simply a by-product of the requirement that grids be rectangular under the laws governing the *NTv2* grid file format. Protrusion of the grid into NT, Vic and NSW is intended to allow near-border coverage for projects crossing into these states from the AGD84 jurisdictions that have used AGD84 rather than AGD66 as the datum for coordinates.

The ICSM Geodesy Group also decided that the AGD66 to GDA94 transformation grid should provide truly national coverage of all States and Territories and also extend to the outer limit of the Exclusive Economic Zone (200 nautical miles from the line of Lowest Astronomical Tide). Final coverage of the AGD66 to GDA94 transformation grid is shown in Figure 9.

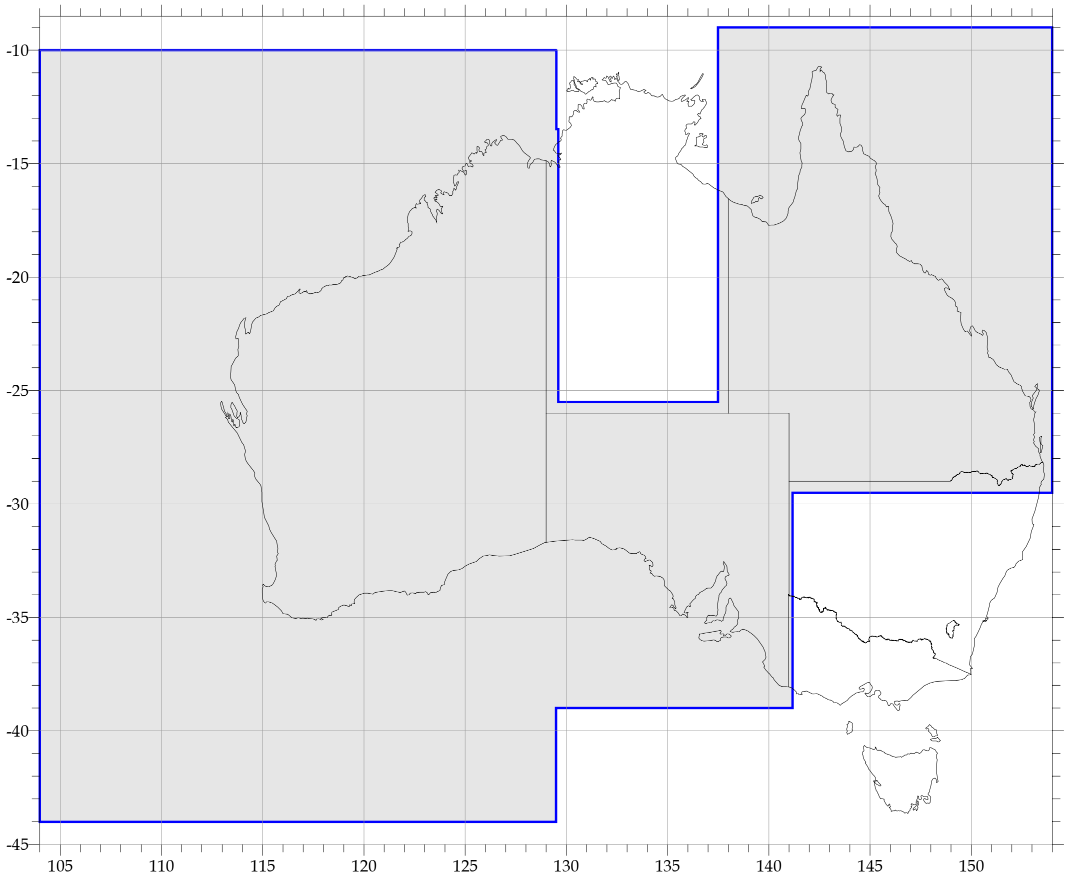


Figure 8 – Coverage of the AGD84 to GDA94 transformation grid

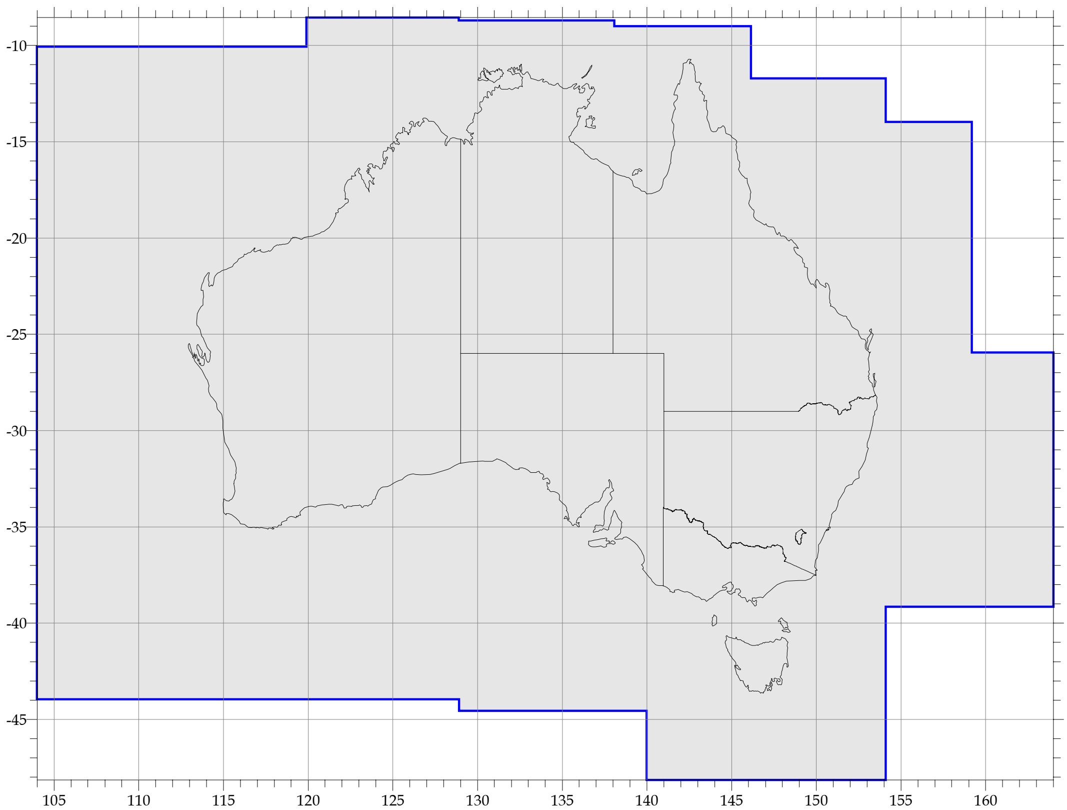


Figure 9 – Coverage of the national AGD66 to GDA94 transformation grid

SECTION B – The AGD84 to GDA94 Transformation Grid

B.1 Source Data

Grids for the three AGD84 jurisdictions were computed separately, with the appropriate data being supplied by the relevant State survey and mapping agencies. Upon completion of the individual State grids, the final step of grid integration was carried out before the national AGD84 grid was released for public use. Grid integration ensures a smooth and consistent solution across the joins between the separate grids and that nodes common to two or more grids have identical transformation components and accuracy values.

Table 1 summarises the data supplied by each jurisdiction for the computation of the respective State grids.

Jurisdiction	**Number of Points**	**Supplied by…**
Queensland	7807	Department of Natural Resources
South Australia	4111	Department of Environment and Heritage
Western Australia	18720	Department of Land Administration

Table 1 – Data supplied for the computation of the AGD84 grids

It is not the purpose of this report to detail the computation of the separate grids. This information has been presented in separate reports prepared for each jurisdiction as each grid was completed. Details for the Queensland grid can be found in Collier (2000a) and Collier (2000d); for the Western Australia grids see Collier (2000b); for the South Australian grid see Collier (2001a). This present report will discuss the main features of the integrated grid covering the three AGD84 jurisdictions.

B.2 Conformal Transformation Parameters

The National Mapping Division of Geoscience Australia computed and published a set of conformal parameters for the transformation from AGD84 to GDA94 based on known AGD84 and GDA94 coordinates for 327 points across Australia. The computation process is described and the parameters are given in Chapter 7 of the GDA94 Technical Manual produced by ICSM (http://www.anzlic.org.au/icsm/gdatm/). Table 2 below also lists the parameters.

Parameter	Value
Shift in X (ΔX)	-117.763 m
Shift in Y (ΔY)	-51.510 m
Shift in Z (ΔZ)	139.061 m
Rotation about X (R_X)	-0.2920 ″
Rotation about Y (R_Y)	-0.4430 ″
Rotation about Z (R_Z)	-0.2770 ″
Scale (λ)	-0.1910 ppm

Table 2 – National AGD84 to GDA94 transformation parameters

In regard to the computation of the AGD84 to GDA94 transformation grids, the conformal parameters provide the basis for defining distortion (by comparing conformally transformed AGD84 coordinates to known GDA94 coordinates) and for allowing grid based conformal-only transformations to be carried out in areas where there is insufficient data for the computation of a distortion model (e.g. offshore).

B.3 Grid Specifications

It can be seen from Table 3 and Figure 10 that the national AGD84 transformation grid is made up of 14 separate grids and comprises a total of 789042 individual grid nodes. The most complex configuration of grids exists in Western Australia where the parent grid (WA_0301) is supplemented by six denser sub-grids covering major population centres and other areas where coordinate distortion was difficult to model. The necessity for the sub-grids in WA was dictated by the strict criteria placed on grid performance by the Department of Land Administration (DOLA). For example, in metropolitan areas, the grids had to be capable of achieving agreement between known and transformed coordinates to within ±0.015 m in 95% of cases tested.

The WA grid has also been supplemented by three offshore grids to allow the grid-based transformation of spatial data associated with oil and gas leases administered by the WA Department of Minerals and Energy. These grids have a node spacing of 0.5° and provide for conformal-only transformation based on the parameters given in Table 2. Note that minor differences, in the order of a few centimetres, may exist between conformal transformation based on the grid and that computed rigorously from the conformal transformation parameters (Table 2). These difference result from of a loss of accuracy due to the coarse grid spacing. Had a smaller grid interval been used, better agreement could be achieved, but this was not deemed justified in light of the consequent rapid inflation in the number of grid nodes.

The Queensland grid is a single grid of uniform density (0.5°) covering the entire State. The grid also protrudes into the north-west of South Australia and covers a considerable area offshore.

Prior to grid integration, South Australia was covered by a single grid of uniform density. However this grid overlapped both the QLD and WA grids. In order to satisfy the *NTv2* format rules, which dictate that all grids in a single grid file must be rectangular and that grids of the same density cannot overlap, the South Australian grid had to be subdivided into smaller rectangular grids to form the national grid. Note that the three South Australian grids are all of the same density (0.05°).

Grid Name	Parent Grid	South	North	West	East	Spacing	Nodes
QLD_0301	NONE	-29.50	-9.00	137.50	154.00	0.05°	136041
SA2_0301	NONE	-39.00	-29.50	137.50	141.05	0.05°	13752
SA3_0301	NONE	-35.50	-25.50	129.60	137.50	0.05°	31959
SA4_0301	NONE	-39.00	-35.50	129.50	137.50	0.05°	11431
NTHEXT	NONE	-13.50	-10.00	104.00	129.50	0.50°	416
STHEXT	NONE	-44.00	-35.50	104.00	129.50	0.50°	936
WSTEXT	NONE	-35.50	-13.50	104.00	112.50	0.50°	810
WA_0301	NONE	-35.50	-13.50	112.50	129.60	0.05°	151263
GREAT_SW	WA_0301	-35.20	-30.00	114.00	118.25	0.0125°	142197
BROOME	WA_0301	-18.50	-17.50	121.75	122.75	0.0125°	6561
GERALD	WA_0301	-30.00	-28.50	114.00	118.25	0.0125°	41261
KPH	WA_0301	-21.25	-19.75	116.25	119.25	0.0125°	29161
S_CENTRE	WA_0301	-35.20	-31.50	122.25	126.00	0.0125°	89397
SWEXTEND	WA_0301	-35.20	-30.00	118.25	122.25	0.0125°	133857

Table 3 – Grids making up the national AGD84 transformation grid

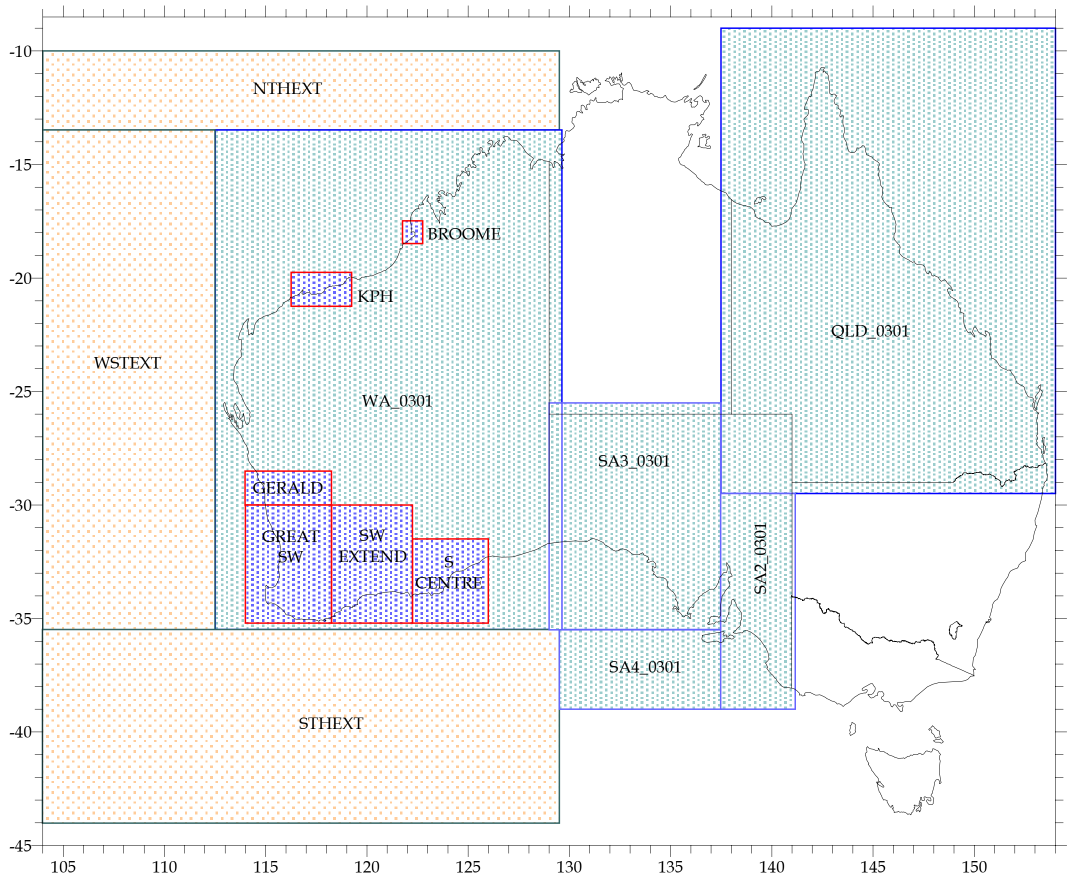


Figure 10 – Components of the national AGD84-GDA94 transformation grid

B.4 Grid Performance

It can be difficult to comprehensively test the performance of a transformation grid. One method is to use the grid to transform the AGD84 coordinates of points with known GDA94 coordinates and to then analyse the “residuals” between the known and transformed coordinates. This method is sometimes referred to as *back interpolation*. The difficulty with back interpolation is that it only evaluates grid performance in areas where such data exists, other areas of the grid remain unchecked. A second method is to contour the distortion component of the transformation grid and to visually check for inconsistencies and irregularities in the gridded distortion model. Finally, it is useful to consider the spatial distribution of the transformation accuracy, again with a view to identifying areas of the grid where problems may exist.

For a detailed analysis of the performance of the individual grids making up the national AGD84 transformation grid, using all three methods mentioned above, the reader is directed to the previously cited reports covering the computation of the individual State grids (Collier 2000a, 2000d, 2000b, 2001a).

In Tables 4, 5 and 6, a brief summary is provided of the back interpolation statistics for the national AGD84 grid, broken down into the respective States. The distribution of the data used in these tests is shown in Figure 11, from which it can be seen that the data is fairly widely spread, providing a reasonable test on overall grid performance. The tabulated back interpolation statistics show that GDA94 coordinates derived by transformation of AGD84 coordinates agree with known GDA94 coordinates to within ±0.1 m in approximately 98% of the cases tested.

	Residuals for all points		**Residuals in the range ± 0.1 m**	
	Lat	**Long**	**Lat**	**Long**
Mean (m)	0.000	-0.002	0.000	-0.001
Std Dev (m)	±0.029	±0.031	±0.017	±0.016
Max (m)	0.299	0.385	0.099	0.093
Min (m)	-0.364	-0.504	-0.099	-0.085
Count (pts)	7738	7738	7624	7631
Percent (%)			98.53	98.62

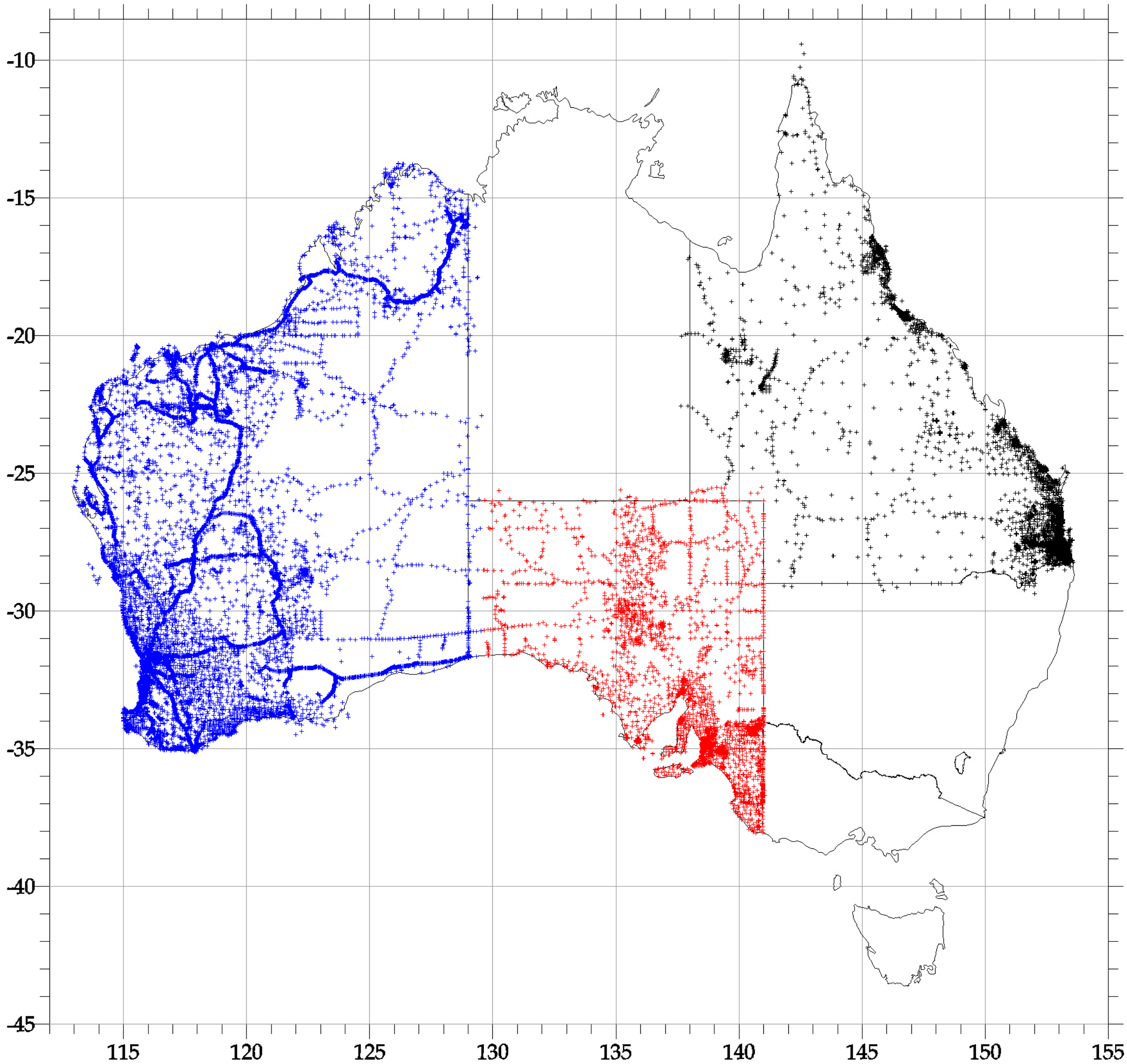
Table 4 – Back interpolation performance of the national AGD84 grid in QLD

	Residuals for all points		Residuals in the range ± 0.1 m	
	Lat	Long	Lat	Long
Mean (m)	0.002	0.001	0.001	0.001
Std Dev (m)	±0.035	±0.031	±0.023	±0.023
Max (m)	0.316	0.385	0.099	0.100
Min (m)	-0.409	-0.445	-0.100	-0.096
Count (pts)	3881	3881	3780	3805
Percent (%)			97.40	98.04

Table 5 – Back interpolation performance of the national AGD84 grid in SA

	Residuals for all points		Residuals in the range ± 0.1 m	
	Lat	Long	Lat	Long
Mean (m)	0.000	0.000	0.000	0.000
Std Dev (m)	±0.029	±0.031	±0.015	±0.016
Max (m)	1.365	0.970	0.100	0.100
Min (m)	-0.549	-0.647	-0.099	-0.100
Count (pts)	18472	18472	18254	18241
Percent (%)			98.82	98.75

Table 6 – Back interpolation performance of the national AGD84 grid in WA



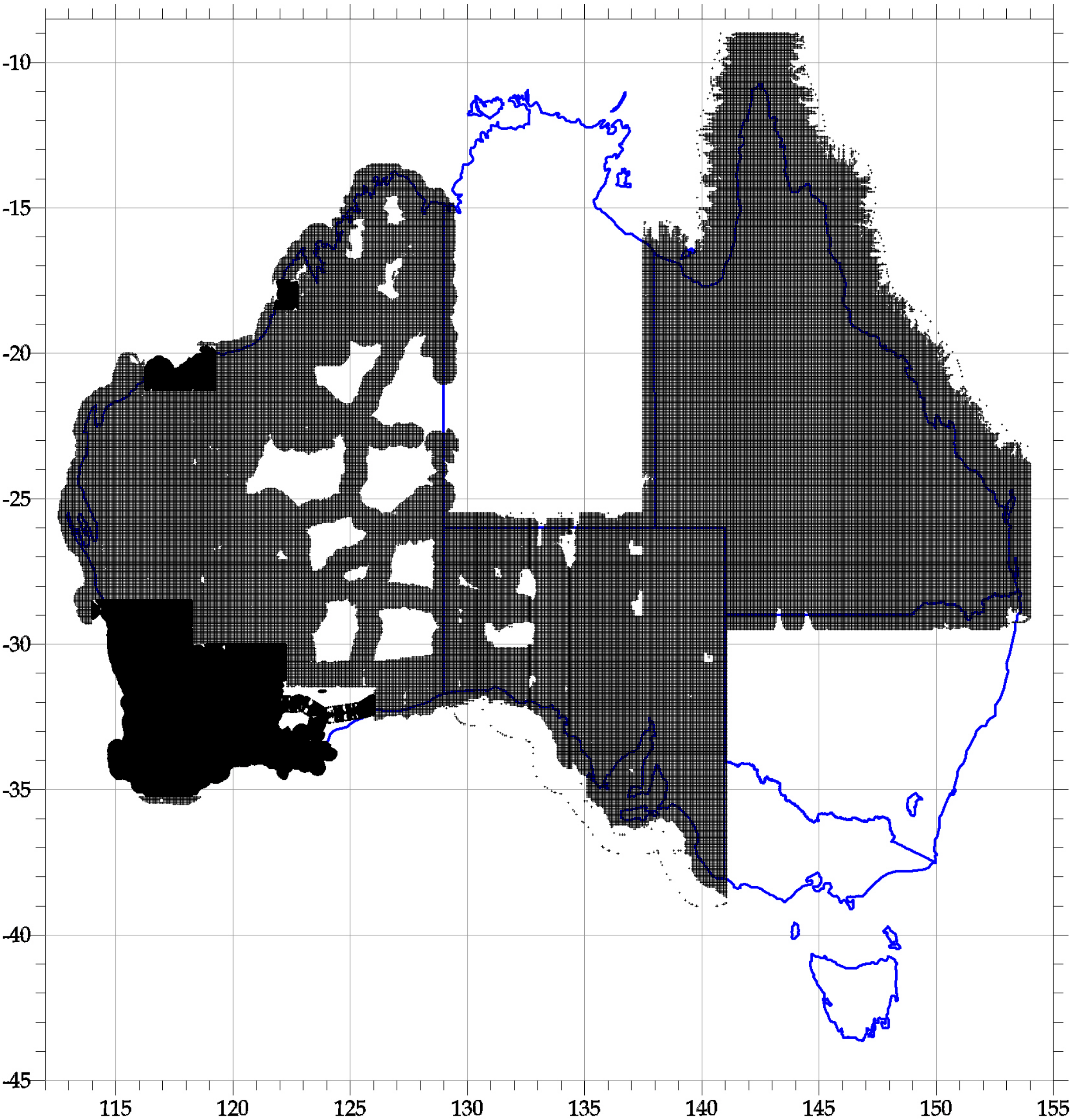
<u>Figure 11</u> – Distribution of data used to test the national AGD84 transformation grid

When computing a transformation grid, at any node within the grid it is possible to obtain two possible solution types :

Type 1 – *conformal-only nodes*. In this case, the transformation shifts are determined only on the basis of the 7-parameter transformation, no distortion component can be computed. The absence of a distortion component is usually due to a lack of data from which the distortion model could be derived. This occurs for example offshore, but also in other cases where insufficient data is available. Again it is pointed out that it is impossible to compute transformation accuracy in the absence of a distortion model.

Type 2 – *conformal+distortion nodes*. When data exists to allow the distortion model to be computed, it is possible to supplement the conformal component of transformation with the distortion component. In this case, transformation accuracy can be computed.

Figure 12 shows the conformal+distortion nodes for the national AGD84 transformation grid. Table 7 summarises the distortion statistics for these conformal+distortion nodes for each of the separate grids making up the national AGD84 transformation grid. From Table 7 it can be seen that the range of distortion accommodated by the AGD84 transformation grid is about ±3 m, as expected.



<u>Figure 12</u> – Conformal + distortion nodes in the national AGD84 transformation grid

An interesting feature of Figure 12 is the fact that the distortion model extends beyond the coastline and thus beyond the limit of the available data. This offshore extension is a by-product of the collocation technique and the way in which distortion is represented by the covariance function. The covariance function expresses the spatial correlation of the distortion component and thereby allows extrapolation past the edge of the data set to the point where that correlation reduces to zero.

A second feature of Figure 12 which is worthy of comment is the occurrence, in the case of the QLD and SA grids, of offshore conformal+distortion nodes offset from and parallel to the edge of the distortion model. Pseudo-points[2] were added during the computation of the QLD and SA grids to force a smooth transition from the conformal+distortion nodes to the conformal-only nodes. The conformal+distortion nodes referred to above are a result of extrapolation beyond these pseudo-points. Despite appearances, the distortion at these conformal+distortion nodes is in fact (effectively) zero.

With regard to the need for pseudo-points, earlier experience had demonstrated that abrupt steps could occur in the transition to the conformal-only nodes. Thus pseudo-points were added offshore and in areas where no real data existed to smooth this transition and ensure a continuous transformation result. Note that, at the request of DOLA (see Collier, 2000b), pseudo-points were not used in the WA grid. As a consequence there are some regions of the WA grid where a rather sharp transition to the conformal-only nodes occurs.

Finally, Figure 12, shows the presence of some conformal-only holes – areas of the grid where no distortion model could be computed due to lack of data. These holes are particularly prominent in the eastern half of the WA grid, but also occur to a lesser extent in the north and west of the SA grid. The occurrence of conformal-only holes coincides with gaps in the data as can been seen from a comparison of Figures 11 and 12.

Table 8 summarises the transformation accuracy statistics for the national AGD84 transformation grid. It can be seen that worst case accuracies are either at about 0.5 m or 1.0 m. The reason for this is that upper limits were imposed on transformation accuracy during the grid computation process. When transformation accuracy exceeded the set limit (which was a rare occurrence), the node was set to conformal-only. On a national basis, the transformation accuracy is better than or equal to 0.1 m at over 85% of the conformal+distortion nodes. This is an encouraging result for users, indicating the reliability with which the distortion component has been determined in the majority of cases.

[2] A pseudo-point is a fictitious data point with zero distortion. The GDA94 coordinates for a pseudo-point are derived by applying the relevant conformal transformation parameters (Table 2) to the adopted AGD84 coordinates.

Grid name	Total Nodes	Distortion Nodes		Distortion (m)			
				Mean	Std Dev	Max	Min
QLD_0301	136041	90365	φ	0.006	±0.351	1.037	-1.186
		(66.4%)	λ	-0.053	±0.400	1.433	-1.573
SA2_0301	13752	11039	φ	0.230	±0.228	0.739	-1.669
		(80.3%)	λ	0.135	±0.253	1.385	-0.745
SA3_0301	31959	23714	φ	-0.096	±0.186	0.798	-0.972
		(74.2%)	λ	0.197	±0.354	1.744	-0.725
SA4_0301	11431	540	φ	0.098	±0.062	0.240	-0.004
		(4.7%)	λ	0.004	±0.038	0.075	-0.146
WA_0301	151263	87213	φ	-0.029	±0.469	2.646	-2.919
		(57.7%)	λ	0.179	±0.624	3.090	-2.692
GREAT_SW	142197	105189	φ	0.080	±0.364	2.520	-2.334
		(74.0%)	λ	0.295	±0.292	2.435	-1.698
BROOME	6561	5405	φ	-0.150	±0.099	0.298	-1.113
		(82.4%)	λ	-0.332	±0.375	1.525	-2.330
GERALD	41261	36684	φ	-0.480	±0.182	1.489	-2.476
		(88.9%)	λ	-0.187	±0.254	2.127	-2.252
KPH	29161	20760	φ	0.321	±0.142	1.577	-1.112
		(71.2%)	λ	0.380	±0.167	1.369	-0.441
S_CENTRE	89397	28115	φ	-1.005	±0.707	2.574	-3.060
		(31.4%)	λ	0.826	±0.989	3.035	-2.713
SWEXTEND	133857	112662	φ	-0.220	±0.186	2.002	-2.356
		(84.2%)	λ	0.544	±0.441	3.053	-1.900

Table 7 – Distortion statistics for grids in the national AGD84 transformation file

Grid name	Latitude (m)				Longitude (m)			
	Mean	σ	Worst	% > 0.1	Mean	σ	Worst	% < 0.1
QLD_0301	0.064	±0.066	0.492	19.4	0.085	±0.087	0.565	31.0
SA2_0301	0.067	±0.093	0.972	21.2	0.050	±0.057	0.409	13.3
SA3_0301	0.046	±0.045	0.501	12.5	0.085	±0.087	0.757	27.2
SA4_0301	0.030	±0.020	0.083	0.0	0.018	±0.014	0.063	0.0
WA_0301	0.054	±0.075	0.999	12.8	0.057	±0.079	0.987	14.5
GREAT_SW	0.026	±0.051	0.989	3.9	0.024	±0.047	0.989	3.4
BROOME	0.048	±0.070	0.978	10.7	0.109	±0.159	0.992	30.2
GERALD	0.034	±0.068	0.985	5.9	0.037	±0.080	0.998	5.9
KPH	0.070	±0.102	0.994	20.6	0.094	±0.144	0.987	24.4
S_CENTRE	0.137	±0.174	0.999	34.7	0.128	±0.149	0.999	36.9
SW_EXTEND	0.032	±0.062	0.995	4.4	0.037	±0.067	0.996	5.8

Table 8 – Accuracy statistics for grids in the national AGD84 transformation file

SECTION C – The AGD66 to GDA94 Transformation Grid

C.1 Source Data

Separate grids for each State and the Northern Territory were firstly computed (the ACT was covered by the NSW grid). The necessary data was supplied by the relevant State survey and mapping agencies and by the National Mapping Division of Geoscience Australia. Upon completion of the individual State grids, the final step of grid integration was carried out before the national AGD66 grid was tested, refined and released for public use. The grid integration process ensured a smooth and consistent solution across the joins between the separate grids and that nodes common to two or more grids would have identical transformation components and accuracy values.

Table 9 summarises the data supplied by each jurisdiction for the computation of the respective State grids.

Jurisdiction	Number of Points	Supplied by…
Tasmania	639	Office of Surveyor General
Victoria	20071	Land Victoria
New South Wales	4867	Surveyor General's Department
Northern Territory	914	National Mapping Division
Queensland	903 30	National Mapping Division Department of Natural Resources
South Australia	1576	National Mapping Division
Western Australia	2946	National Mapping Division

Table 9 – Data supplied for the computation of the AGD66 grids

Details regarding the computation of the State grids will not be given here. With the exception of QLD, SA and WA this information has been presented in separate reports prepared for each jurisdiction. For details of the Tasmanian grid see Collier (1998) and Collier (2001b); for the Victorian grid see Collier (1999c) and Collier (2000c); for the New South Wales grid refer to Collier (1999b) and Collier (2000c); for the Northern Territory grid see Collier (1999a) and Collier (2000e). The present report will discuss the main features of the final national AGD66 transformation grid, as compiled from the separate State grids.

C.2 Conformal Transformation Parameters

In the first instance, regional (State-specific) conformal transformation parameters were computed for Tasmania, Victoria and New South Wales (combined) and the Northern Territory based on the data supplied by the respective State agencies. The computation of regional parameters was the only option in the early stages of the grid computation process as no national data for the development of a national set of conformal transformation parameters was available.

Early in 2001, the National Mapping Division provided AGD66 and GDA94 coordinate data for 9897 points across Australia. From this data set, the first ever set of national AGD66 to GDA94 transformation parameters suitable for the 7-parameter model was computed. These parameters are given in Table 10.

Parameter	Value
Shift in X (ΔX)	-117.808 m
Shift in Y (ΔY)	-51.536 m
Shift in Z (ΔZ)	137.784 m
Rotation about X (R_X)	-0.3035″
Rotation about Y (R_Y)	-0.4457″
Rotation about Z (R_Z)	-0.2336″
Scale (λ)	-0.2896 ppm

Table 10 – National AGD66 to GDA94 transformation parameters

With a view to integrating the separate State and Territory grids and particularly for the purposes of computing conformal-only offshore extensions to the AGD66 grid, the adoption of a single national set of conformal transformation parameters was preferred to the use of separate regional parameter sets. Combining grids based on different parameters would inevitably lead to discontinuities. Thus the various regional parameters were superseded by the national parameters in Table 10 as the basis for the computation of distortion and the determination of transformation components in areas where no data was available to allow a distortion model to be computed. The transformation grids for all AGD66 jurisdictions were therefore re-computed using the new national parameters prior to the formation of the national AGD66 transformation grid.

C.3 Grid Specifications

It can be seen from Table 11 and Figure 13 that the national AGD66 transformation grid is made up of 20 separate grids and comprises a total of 290225 individual nodes. Nine of the grids are conformal-only extensions to allow the national grid to extend offshore to the outer limits of the Exclusive Economic Zone as required by ICSM. These conformal-only extensions have been computed at a grid node spacing of 0.3°. The grids for WA, SA, QLD (the AGD84 jurisdictions) and the NT, have been computed at 0.15°. TAS, NSW and VIC have been computed at 0.03° with sub-grids of 0.015° covering the Melbourne and Hobart greater metropolitan areas.

Note that all grids are rectangular to meet the requirements of the *NTv2* grid file format.

Grid Name	Parent Grid	South	North	West	East	Spacing	Nodes
EX1_0601	NONE	-13.35	-10.05	104.00	128.90	0.3°	1008
EX2_0601	NONE	-35.55	-13.35	104.00	112.40	0.3°	2175
EX3_0601	NONE	-43.95	-35.55	104.00	128.90	0.3°	2436
EX4_0601	NONE	-44.55	-39.15	128.90	142.40	0.3°	874
EX5_0601	NONE	-48.15	-44.55	140.00	154.10	0.3°	624
EX6_0601	NONE	-44.55	-39.15	149.00	154.10	0.3°	342
EX7_0601	NONE	-39.15	-25.95	154.10	164.00	0.3°	1530
EX8_0601	NONE	-25.95	-13.95	154.10	159.20	0.3°	738
EX9_0601	NONE	-10.05	-8.55	119.90	128.90	0.3°	186
NSW_0601	NONE	-35.01	-27.00	140.90	154.10	0.03°	118188
NT__0601	NONE	-26.10	-8.70	128.90	138.05	0.15°	7254
QLN_0601	NONE	-11.70	-9.00	138.05	146.15	0.15°	1045
QLS_0601	NONE	-27.00	-11.70	138.05	154.10	0.15°	11124
SAE_0601	NONE	-39.15	-27.00	138.05	140.90	0.15°	1640
SAW_0601	NONE	-39.15	-26.10	128.90	138.05	0.15°	5456
TAS_0601	NONE	-44.55	-39.15	142.40	149.00	0.03°	40001
HOB_0601	TAS_0601	-43.50	-42.24	146.75	148.01	0.015°	7225
VIC_0601	NONE	-39.15	-35.01	140.90	154.10	0.03°	61299
MEL_0601	VIC_0601	-38.55	-37.32	144.26	146.15	0.015°	10541
WA__0601	NONE	-35.55	-13.35	112.40	128.90	0.15°	16539

Table 11 – Grids making up the national AGD66 transformation grid

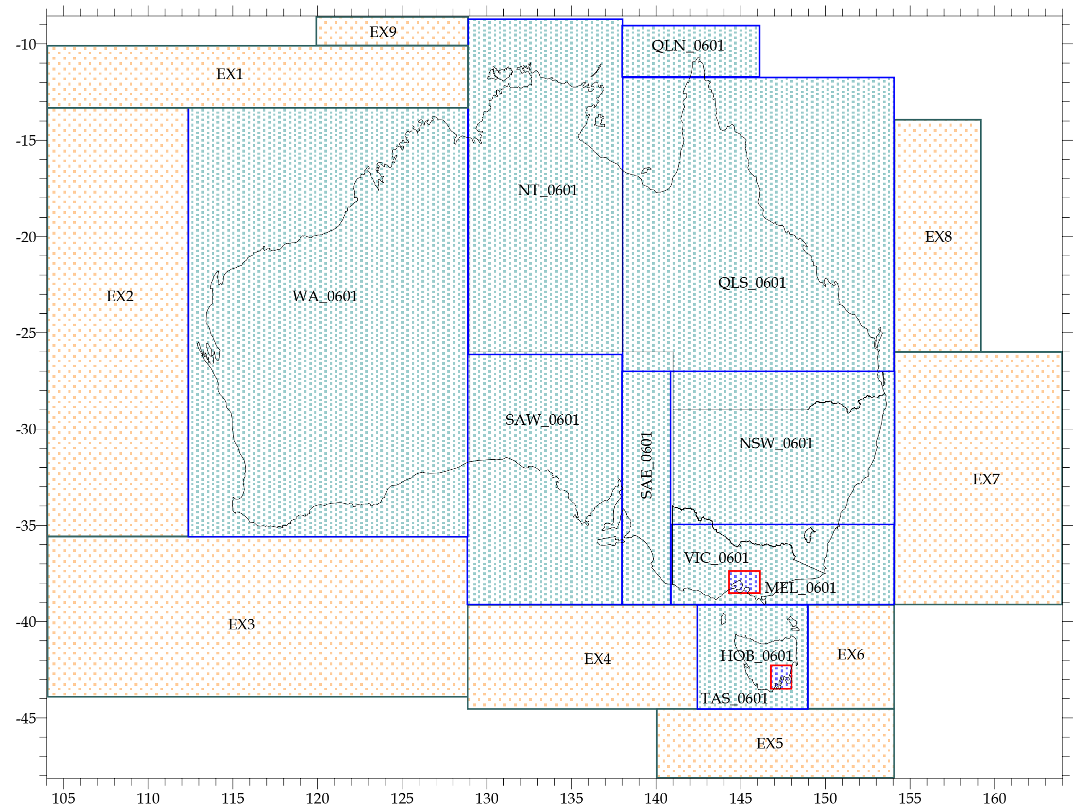


Figure 13 – Components of the national AGD66-GDA94 transformation grid

C.4 Grid Performance

Strategies for the evaluation of grid performance have been described in Section B.4. One option is the method of back interpolation. Tables 12-18 summarise the back interpolation statistics for the national AGD66 grid, presented on a State by State basis. Statistics for the non-AGD66 States (QLD, SA and WA) are presented in Tables 12-14. In QLD and SA, over 80% of the points tested had back interpolation residuals within ±0.1 m. In WA, this reduced to about 65% of points tested. In the remaining jurisdictions (VIC, NSW, TAS and NT), over 90% (and as high as 99%) of points satisfied the ±0.1 m test on the residuals.

The poorer back interpolation performance in the non-AGD66 jurisdictions is primarily due to the more erratic distortion patterns in these States. This is an expected result and likely explains why these jurisdictions opted to abandon AGD66 in preference for the more consistent AGD84 solution.

The distribution of the data used to derive the statistics presented in Tables 12-18 is shown in Figure 14, from which it can be seen that large parts of the grid could not be tested by back interpolation due to the lack of overlapping AGD66 and GDA94 data.

	Residuals for all points		**Residuals in the range ± 0.1 m**	
	Lat	**Long**	**Lat**	**Long**
Mean (m)	-0.001	0.001	-0.007	0.003
Std Dev (m)	±0.129	±0.102	±0.036	±0.034
Max (m)	1.075	0.621	0.100	0.100
Min (m)	-0.707	-0.784	-0.098	-0.100
Count (pts)	913	913	742	772
Percent (%)			81.27	84.56

<u>Table 12</u> – Back interpolation performance of the national AGD66 grid in QLD

	Residuals for all points		**Residuals in the range ± 0.1 m**	
	Lat	**Long**	**Lat**	**Long**
Mean (m)	0.003	-0.007	0.001	-0.001
Std Dev (m)	±0.127	±0.116	±0.040	±0.040
Max (m)	1.045	0.766	0.100	0.100
Min (m)	-0.877	-0.926	-0.100	-0.100
Count (pts)	1592	1592	1312	1281
Percent (%)			82.41	80.46

<u>Table 13</u> – Back interpolation performance of the national AGD66 grid in SA

	Residuals for all points		Residuals in the range ± 0.1 m	
	Lat	Long	Lat	Long
Mean (m)	-0.001	-0.004	0.000	0.000
Std Dev (m)	±0.161	±0.159	±0.049	±0.049
Max (m)	1.081	0.973	0.100	0.100
Min (m)	-1.084	-1.143	-0.100	-0.100
Count (pts)	2946	2946	1899	2003
Percent (%)			64.46	67.99

Table 14 – Back interpolation performance of the national AGD66 grid in WA

	Residuals for all points		Residuals in the range ± 0.1 m	
	Lat	Long	Lat	Long
Mean (m)	0.000	0.000	0.000	0.000
Std Dev (m)	±0.023	±0.018	±0.019	±0.015
Max (m)	0.221	0.223	0.097	0.089
Min (m)	-0.350	-0.309	-0.099	-0.100
Count (pts)	3711	3711	3685	3699
Percent (%)			99.30	99.68

Table 15 – Back interpolation performance of the national AGD66 grid in NSW

	Residuals for all points		Residuals in the range ± 0.1 m	
	Lat	Long	Lat	Long
Mean (m)	0.001	-0.001	0.000	-0.001
Std Dev (m)	±0.036	±0.028	±0.019	±0.021
Max (m)	0.554	0.343	0.100	0.100
Min (m)	-0.829	-0.614	-0.100	-0.100
Count (pts)	13805	13805	13586	13647
Percent (%)			98.41	98.86

Table 16 – Back interpolation performance of the national AGD66 grid in VIC

	Residuals for all points		Residuals in the range ± 0.1 m	
	Lat	Long	Lat	Long
Mean (m)	0.004	-0.001	0.005	0.000
Std Dev (m)	0.050	0.033	0.030	0.030
Max (m)	0.276	0.131	0.099	0.093
Min (m)	-0.251	-0.161	-0.093	-0.099
Count (pts)	635	635	590	623
Percent (%)			92.91	98.11

Table 17 – Back interpolation performance of the national AGD66 grid in TAS

	Residuals for all points		Residuals in the range ± 0.1 m	
	Lat	Long	Lat	Long
Mean (m)	-0.002	-0.002	-0.004	-0.001
Std Dev (m)	0.066	0.060	0.033	0.032
Max (m)	0.627	0.336	0.100	0.100
Min (m)	-0.408	-0.606	-0.097	-0.100
Count (pts)	636	636	581	596
Percent (%)			91.35	93.71

Table 18 – Back interpolation performance of the national AGD66 grid in NT

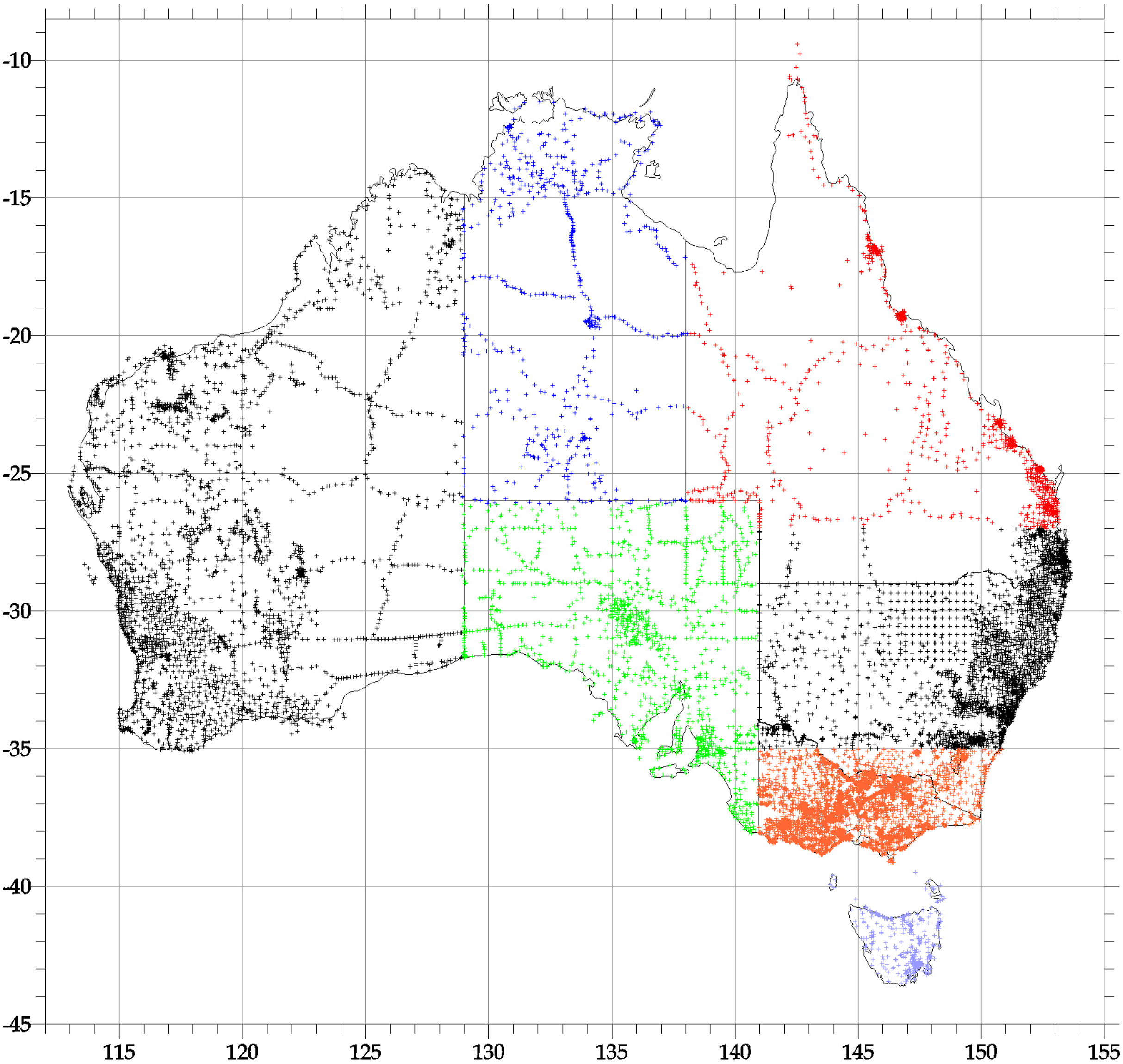


Figure 14 – Distribution of data used to test the national AGD66 transformation grid

As explained in Section B.4, there are two types of node possible within a transformation grid; conformal-only nodes and conformal+distortion nodes. Figure 15 shows the conformal+distortion nodes for the national AGD66 transformation grid. Table 19 summarises the distortion statistics for these nodes for each grid making up the national AGD66 grid (excluding the conformal-only grid extensions). From Table 19 it can be seen that the range of distortion accommodated by the AGD66 transformation grid is about ±5 m, as expected.

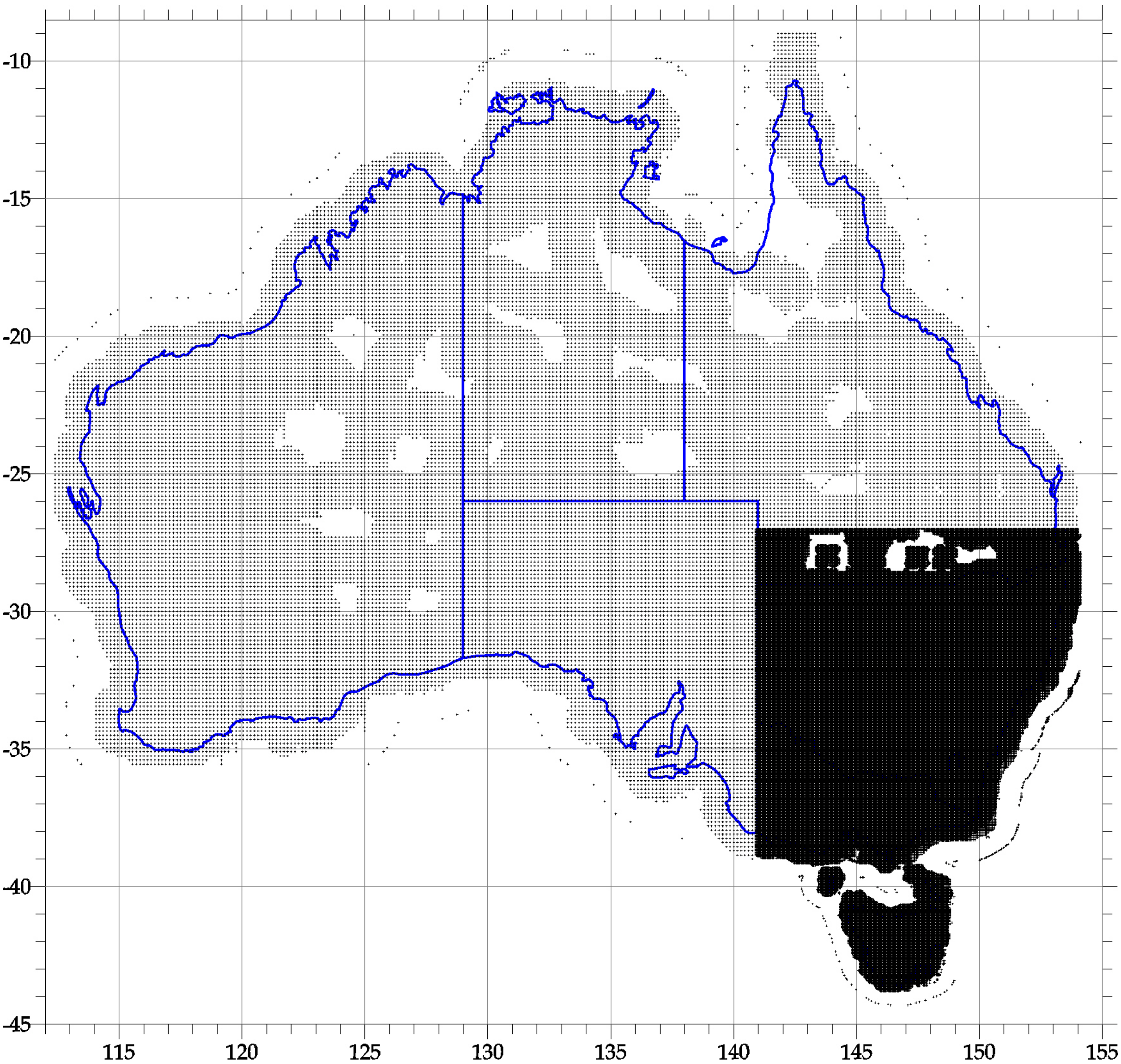


Figure 15 – Conformal + distortion nodes in the national AGD66 transformation grid

As was the case with the AGD84 grid, and for the same reasons (see Section B.4 and the discussions relating to Figure 12), the AGD66 conformal+distortion nodes extend offshore by virtue of extrapolation beyond the edge of the available data. Furthermore, the series of offset conformal+distortion nodes running parallel to the outer edge of the distortion model again appears and is due to the fact that pseudo-points were used to smooth the transition to the conformal-only nodes (see Footnote on p.21). Conformal-only holes are apparent in many places throughout the grid, particularly in remote areas, and are due to the lack of adequate data to determine the distortion model in these localities (compare Figures 14 and 15). The higher density of the VIC, NSW and TAS (MELB and HOB) grids is evident from Figure 15. Coarser grids were used in the other States primarily because of limited data.

Grid name	Total Nodes	Distortion Nodes		Distortion (m)			
				Mean	Std Dev	Max	Min
NSW_0601	118188	107062	ϕ	0.204	±0.711	1.646	-1.430
		(90.6%)	λ	-0.316	±0.451	0.698	-1.755
NT__0601	7254	5344	ϕ	-1.059	±1.277	1.589	-4.193
		(73.7%)	λ	0.545	±0.949	5.151	-1.388
QLN_0601	1045	260	ϕ	1.688	±1.032	3.582	-0.140
		(24.9%)	λ	-1.666	±1.032	0.135	-3.950
QLS_0601	11124	6070	ϕ	-0.315	±0.692	3.634	-2.043
		(54.6%)	λ	0.200	±0.664	2.857	-2.583
SAE_0601	1640	1484	ϕ	0.631	±0.507	2.043	-0.806
		(90.5%)	λ	-0.618	±0.763	1.345	-2.170
SAW_0601	5456	3474	ϕ	1.152	±0.599	2.444	-0.814
		(63.7%)	λ	-1.440	±0.789	0.253	-3.118
TAS_0601	40001	17143	ϕ	-0.153	±0.340	0.893	-0.978
		(42.9%)	λ	0.359	±0.367	1.990	-0.232
HOB_0601	7225	7110	ϕ	-0.657	±0.125	-0.085	-0.985
		(98.4%)	λ	0.312	±0.111	0.665	-0.094
VIC_0601	61299	42162	ϕ	0.319	±0.346	1.449	-0.375
		(68.8%)	λ	0.316	±0.412	1.346	-0.777
MEL_0601	10541	10541	ϕ	0.182	±0.096	0.470	-0.055
		(100%)	λ	0.760	±0.072	0.967	0.393
WA__0601	16539	11636	ϕ	0.392	±1.068	3.314	-3.208
		(70.4%)	λ	0.379	±1.389	4.776	-3.309

Table 19 – Distortion statistics for grids in the national AGD66 transformation file

Table 20 summarises the transformation accuracy statistics for the national AGD66 transformation grid. On average, transformation accuracy is worse in the non-AGD66 States, as would be expected due to the poorer quality of the AGD66 network in these jurisdictions. An extreme example can be seen in the QLN grid (North Queensland) where average accuracy approaches 0.8 m. This can be explained by the fact that the QLN grid covers a relatively small area and there was only very sparse and poorly distributed data available for the development of the distortion model (see Figures 13 and 14). On a national basis, transformation accuracy is better than or equal to ±0.1 m at over 75% of the conformal+distortion nodes. For users, this result indicates the reliability with which the AGD66 distortion component has been determined in the majority of cases.

Grid name	Latitude (m)				Longitude (m)			
	Mean	σ	Worst	% > 0.1	Mean	σ	Worst	% < 0.1
NSW_0601	0.068	±0.072	0.608	19.7	0.066	±0.079	0.741	16.2
NT_0601	0.271	±0.230	1.201	73.4	0.205	±0.148	1.147	76.8
QLN_0601	0.783	±0.265	1.240	91.5	0.775	±0.262	1.136	93.8
QLS_0601	0.204	±0.157	1.342	72.3	0.195	±0.163	1.238	64.7
SAE_0601	0.128	±0.110	0.601	47.2	0.121	±0.081	0.421	55.1
SAW_0601	0.136	±0.123	0.668	46.7	0.141	±0.113	0.622	50.9
TAS_0601	0.089	±0.057	0.392	32.4	0.132	±0.117	0.739	45.4
HOB_0601	0.083	±0.052	0.286	26.7	0.060	±0.030	0.216	10.4
VIC_0601	0.042	±0.033	0.274	7.1	0.056	±0.058	0.374	15.6
MEL_0601	0.020	±0.014	0.147	0.1	0.023	±0.031	0.225	3.3
WA_0601	0.242	±0.193	1.442	71.3	0.220	±0.196	1.490	69.6

Table 20 – Accuracy statistics for grids in the national AGD66 transformation file

C.5 Grid Node Substitution

C.5.1 The SEAust Transformation Grid

In July 2000, the SEAust transformation grid was completed, covering the states of Victoria and New South Wales and integrating the VIC, NSW and MELB grids (Collier, 2000b). The SEAust grid was based upon the SEAust conformal transformation parameters (Collier, 1999b), not the national AGD66 parameters (Table 8), since these were not available at the time the SEAust grid was computed.

In the period between the release of the SEAust grid and the computation of the national AGD66 grid (based on the national conformal parameters), the SEAust grid was used extensively, particularly by government authorities in NSW, to transform a large amount of spatial data.

When the beta version of the national AGD66 grid was released for testing (June, 2001), NSW authorities expressed concern over some minor differences between the national grid and the existing SEAust grid. These difference arose due to the impact of the national conformal parameters compared to the SEAust parameters. Though small and fairly isolated in location, the differences were regarded as significant from a practical perspective, and so a strategy for their elimination was sought.

It should be noted that the point of contention was not which grid was best, but simply that the new grid had the potential to give (slightly) different results to the existing and previously widely used SEAust grid.

C.5.2 The Process of Node Substitution

To overcome the problems in NSW, it was decided to overwrite the relevant nodes in the national grid with those from the SEAust grid. This could be done relatively simply and without a detrimental effect on the national grid. For the sake of completeness, all nodes in both NSW and Victoria (and extending 3 nodes offshore and north of the QLD-NSW border) in the national grid were replaced[3] by the corresponding nodes from the SEAust grid. Extensive testing of the grid after the grid node substitution proved the success of the process.

Conclusion

The AGD66 and AGD84 national transformation grids have been completed and are now available via the on-line GDA Technical Manual produced by ICSM (http://www.anzlic.org.au/icsm/gdatm/index.html). The grids are supplied in standard binary *NTv2* format and can be accessed and used by most commercial GIS software, as well as purpose-written packages such as *GDAit*, *GDAy* and *GEOD* (see the GDA Technical Manual for download links for these applications). Though the transformation model used to compute the grids is quite complex, this complexity is hidden from users, making grid-based transformation both simple to apply and computationally efficient.

The reason for developing and promoting a national approach to the transformation of spatial data has been to ensure consistency of the transformed coordinates. Correct application of the transformation grids will guarantee that any users transforming the same AGD coordinates will get identical GDA94 results.

A further benefit of the grid-based approach is that users are able to compute an estimate of transformation accuracy. When the distortion model has been determined with a high degree of reliability, transformation accuracy of ±0.1 m or better will be achieved. As the reliability of the distortion component reduces, transformation accuracy will become poorer, approaching ±1-1.5 m in extreme cases. As transformation accuracy deteriorates, users need to exercise some caution in the application and interpretation of transformed coordinates. In the case that no distortion model exists and only a conformal transformation can be carried out, no transformation accuracy is supplied to the user.

The national AGD66 and AGD84 transformation grids, when used in conjunction with appropriate transformation software, provide users with the technical tools needed to move coordinate data from AGD to the new geocentric datum. The next few years will see users widely employing the transformation grids as the transition to GDA94 is fully implemented.

[3] The grid node substitution work was carried out by Mr Peter Todd of the Department of Natural Resources and Mines, Queensland.

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