TECHNICAL REPORT 21

THE AUSTRALIAN DOPPLER SATELLITE SURVEY
1975-1977

by

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CANBERRA AUSTRALIA
1978
ABSTRACT

Beginning in early 1975 Commonwealth and State Survey Authorities carried out a Doppler satellite survey of junction points of the Australian Geodetic Survey and of other stations on Australian territory. This report describes the purpose of this survey, specified survey methods, field operations and the reduction of Doppler data. The relationship between the Australian Geodetic Datum (AGD) and the geocentric, WGS72 datum, is given in form of contours of differences in latitude and longitude. The relationship between the AGD and the geocentric NWL9D datum is given in form of contours of differences in X, Y and Z. Contours of geoid heights are provided for both of these geocentric datums to facilitate the conversion of satellite derived spheroidal heights to Australian Height Datum (AHD) heights. Differences in chord distances between AGD values and WGS72 and NWL9D values are listed for a number of selected lines including the two baselines measured for the Pageos world triangulation in 1965-70.
THE AUSTRALIAN DOPPLER SATELLITE SURVEY 1975-77

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The Australian Doppler Satellite Survey 1975-77

1. **INTRODUCTION**

The observations of Doppler satellites at junction points and other stations of the geodetic network in Australia and on some islands was begun in January 1975 under the guidance of the Division of National Mapping utilising the US Navy Navigational Satellite System (NNSS).

This survey, completed in mid-1977, was carried out with the assistance of the State Lands Departments of Western Australia, South Australia and Tasmania, the Queensland Department of Mapping and Surveying and the Royal Australian Survey Corps. Figure 1 shows the location of stations included in the survey. In addition stations on Lord Howe, Norfolk and Macquarie islands were occupied.

Most of the observations were obtained with JMR-1 satellite survey sets of which up to four were in use at the same time. Seven stations were observed with Geocivers and five with a Marconi CMA 722B.

The purpose of this survey was:

1) To test the accuracy of the 1966 Australian Geodetic Datum (AGD).

2) To provide parameters to users of the NNSS system in Australia to transform satellite derived coordinates to the AGD and AHD; and vice versa, to transform coordinates on the AGD and AHD to the geocentric world datum of the NNSS system, WGS72, and that of the US Defense Mapping Agency, NWL92D.

3) To provide a number of well spaced Doppler derived positions to be combined in a future adjustment with terrestrial observations of the Australian Geodetic Survey.

2. **DESCRIPTION OF THE NAVY NAVIGATION SATELLITE SYSTEM**

The US Navy Navigation Satellite System was developed between 1958 and 1963 for the US Navy by the Applied Physics Laboratory of the Johns Hopkins University and became generally available to non-military users in 1967.

The position of a Doppler satellite receiver is determined from a series of observations of the Doppler shift of signals received from a satellite during the period it passes through the observer’s field of view. The satellite also transmits predicted orbital parameters giving its position every two minutes. This predicted ephemeris, also referred to as on-board or broadcast ephemeris, together with the Doppler shift observation is then used to determine the position of the electrical centre of the receiving antenna in terms of the geocentric coordinate system of the satellite ephemeris.
There are at present (March 1978) five operational satellites in orbit at altitudes of about 1100 kilometres. They are equipped with stable oscillators which generate two frequencies; one about 400 Mz and the other exactly three-eighths of the first one. These frequencies are also used as carriers in the transmission of time marks and the satellite ephemeris.

Navy navigation satellites are tracked by the worldwide system of TRANET stations. This system consists of thirteen permanent tracking stations, from which a precise ephemeris for each of the satellites can be calculated. At present the precise ephemeris of only two of the five satellites is being determined due to the high cost of computation. Normally this ephemeris is available to the user two to four weeks after the satellite data has been collected. It is available through defence channels but is only provided for that part of the orbit which is visible from the station for which it is desired.

The on-board ephemeris for each of the five satellites is determined from observations taken at four tracking stations in the USA. Its predicted values and timing information are transmitted to the satellites from one of the stations. Satellites receive this updated information every twelve hours.

3. SPECIFICATIONS FOR THE AUSTRALIAN DOPPLER SURVEY

Specifications for the civilian organisations taking part in this survey were:

1) All stations to be observed as single points.
2) On arrival at the selected survey station check that the views from the centre of the antenna's ground plane is unobstructed above 10° elevation and clear vegetation if necessary.
3) Avoid stations in the vicinity of large metal objects such as active communication and power transmission towers, wire fences etc. even if these objects are below 10° elevation.
4) Erect the antenna of the Doppler receiver accurately over the ground mark of the selected survey station preferably on its own tripod. If the antenna has to be elevated above the ground mark keep the amount of elevation to a minimum.
5) The survey truck not to be parked within sight of the antenna when signals from a Doppler satellite are being received.
6) Observe all passes of precise ephemeris satellites above 10° elevation at time of closest approach. Forty-five of these passes to be above 15° elevation.
7) Dry and wet temperatures and atmospheric pressure to be taken at the instrument site at least once per day but more often if possible and to be recorded with the time of observation.
4. **FIELD OPERATIONS**

Access to most stations was by truck. Four stations were reached by helicopter and one by boat.

The civilian survey parties mostly consisted of two officers. In remote areas there were up to four officers equipped with two four-wheel drive vehicles.

The Doppler survey sets were usually set up inside a small tent when not otherwise sheltered. It was the practice of National Mapping parties to operate the sets connected to two 12 volt batteries in parallel with two batteries being charged in the meantime. Batteries were usually changed every 24 hours.

Delays due to malfunctioning of JMR satellite survey sets were few. Replacement sets were quickly provided when necessary by the Australian JMR agent under the maintenance or hire agreement.

The short antenna cables supplied with JMR sets were used exclusively. Faulty antenna connections accounted for most of the malfunctions of JMR sets and a more robust antenna and more durable connector at the antenna would improve this weak component of the otherwise robust JMR survey system.

The antenna should always be used with its tripod legs extended, as in this form they are part of the antenna design which determine the location of the electrical centre of the antenna.

The one Marconi 722B receiver which was on hire for a period of six months during 1975 developed a number of faults causing long delays. It is the opinion of the surveyors who operated this equipment that it was not suitable to the hot and dusty conditions of the Australian inland.

Part of the duties of Doppler parties was to carry out a third order two-way levelling connection from the nearest two permanent bench marks to the Doppler station if no such connection existed. Due to a number of factors, including excessive distance of permanent bench marks from Doppler stations, this was not done at the time of the Doppler survey at twenty-seven stations.

5. **REDUCTION OF DOPPLER DATA**

All observations were reduced in terms of the precise ephemerides provided by the US Defense Mapping Agency Topographic Command (DMATC) through the Director of Survey of the Australian Department of Defence. These ephemerides were in terms of the WNL9D Datum. All Doppler fixes have subsequently been transformed to the WGS72 Datum as described in the next chapter.

Data at the six stations observed with the Marconi CMA 722B set were reduced by the Surveys and Mapping Branch of the Department of Energy, Mines and Resources in Ottawa, Canada, through their program GEODOP.

Data observed at the seven stations by the Royal Australian Survey Corps with their Geocivers was reduced by them through program DOPPLR, provided by DMATC, on a Univac 1110 computer.
All data observed with JMR-1 receivers was reduced by National Mapping as follows:

1) A computing file was opened for each Doppler station with Satellite alerts, field notes and station summary attached.

2) The precise ephemeris of Doppler satellites observed at the station for the period of observation was requested from DMATC. A period of at least four weeks lapsed before this data was received through the Directorate of Survey. It was provided on 7-track tape.

3) The data recorded on cassette tape was majority-voted through the JMR cassette reader on a HP 21MX minicomputer. This took two hours per tape for as many as seven tapes per station where all satellites were recorded or two tapes per station where satellites were recorded in the pass-selected-mode.

4) The majority-voted, edited JMR data, and the precise ephemeris data was then put on 9-track tape in UPDATE form on two different files and processed through program DOPPLR on the CSIRO CYBER 76 computer in Canberra. It usually took 4-6 iterations to produce the final coordinates of the Doppler station in terms of the NWL 9D datum.

After all reductions of a Doppler fix are complete a Doppler Station Analysis sheet is prepared for the station concerned. This together with the Horizontal Control Station Summary provides a full record of surveys taken at the station. Figures 12 and 13 refer.

6. RELATIONSHIP BETWEEN WGS72 AND AGD

For the benefit of those who take Doppler fixes in Australia in terms of the WGS72 on-board ephemeris, parameters have been obtained to transform these Doppler Satellite derived coordinates to the Australian Geodetic Datum based on the geoid being 6 metres below the spheroid (N = -6 m) at the Johnston Origin.

The parameters of the various datums are as follows:

- **AGD**: \( a = 6378160 \text{ m} \); \( 1/f = 298.25 \)
- **NWL9D**: \( a = 6378145 \text{ m} \); \( 1/f = 298.25 \)
- **WGS72**: \( a = 6378135 \text{ m} \); \( 1/f = 298.26 \)

To convert from the precise ephemeris NWL9D datum to the on-board ephemeris WGS72 datum the following applies (Seppelin, 1974):

\[
\Delta \phi = \Delta f \sin 2\phi / \sin 1''
\]
\[
\Delta \lambda = 0'26
\]
\[
\Delta H = a \Delta \phi \sin \phi - \Delta a + \Delta r
\]

with \( \Delta r = -5.27 \text{ m} \)
\[
\Delta a = -10.0 \text{ m}
\]
\[
\Delta f = -0.112415 \times 10^{-6}
\]
\[
a = 6378135 \text{ m}
\]

To obtain WGS72 coordinates, add \( \Delta \phi \), \( \Delta \lambda \) and \( \Delta H \) algebraically to the NWL9D coordinates. Latitude is positive north and longitude is positive east.
Table 1 lists stations observed in the survey giving established AGD values, AHD and spheroidal heights, observed NWL9D values and derived WGS72 values and their spheroidal heights. Observations taken on four islands for which AGD values do not exist show height values only.

Figure 2 shows contours of differences in latitude to be added algebraically to the negative south latitudes of WGS72 to obtain AGD latitudes (absolute values of WGS72 decrease when adding these differences).

Figure 3 shows contours of differences in longitude to be added algebraically to the positive east longitudes of WGS72 to obtain AGD longitudes (absolute values of WGS72 increase when adding these differences).

Figure 4 shows the contours of N, the separation of the geoid above the spheroid in terms of the WGS72 datum over Australia determined from the differences between the (H + N) of the WGS72 values and AHD height. This enables anyone who has obtained a (H + N) height from the on-board ephemeris to convert it to an AHD height anywhere in Australia.

These values in contour form provide a much better transformation between the two datums than one set of unique transformation parameters. This becomes apparent when looking at figure 5 which has been derived as follows:

The difference in cartesian coordinates at the Johnston Origin between the AGD values and the WGS72 values were applied to the WGS72 cartesian coordinates of all Doppler stations, subsequently transformed to $\lambda$ and (N + H) with AGD parameters and compared with AGD values. The difference between these two sets of geographical coordinates are shown in vector form together with differences in height.

The size and direction of vectors differ between large regions of the Australian continent.

These differences arise from the combined effect of various factors such as systematic errors in the satellite ephemerides; poor coverage of the southern hemisphere with TRANET stations which are used to determine the precise ephemerides of satellites; atmospheric conditions at the time of Doppler observation; the performance of Doppler satellite receivers; systematic errors in the ground survey; and the adjustment procedures used to form the Australian Geodetic Datum in 1966.

7. RELATIONSHIP BETWEEN NWL9D and AGD

Doppler fixes for geodetic control purposes are best made by observing satellites for which the precise ephemerides are available. The results of such observations are then computed in terms of the NWL9D datum.

A set of figures has been prepared showing translations in $X$, $Y$ and $Z$ between the two datums in contour form over Australia (figures 6, 7 and 8).

Figure 9 shows contours of the Geoid-Spheroid separations in reference to the NWL9D datum. This enables one to convert a satellite determined H + N height to the respective AHD height.

The differences in $X$, $Y$ and $Z$ between NWL9D and AGD coordinates at Johnston were applied to all NWL9D coordinates, then transformed to $\lambda$, and H + N with AGD parameters and compared with AGD values.

Figure 10 shows the difference between the two sets of geographical coordinates in vector form and differences in height.
It is evident from figures 5 and 10 that WGS72 provides a better fit to the AGD than NWL9D as vector differences with the former are smaller.

8. COMPARISON OF CHORD DISTANCES

Table 2 lists chord distances between selected Doppler stations in terms of AGD, NWL9D and WGS72. Differences between the AGD values and the respective NWL9D and WGS72 values are listed in metres and in parts per million. The results are also shown in figure 11. Again the comparison with WGS72 is better than with NWL9D, the largest difference being -9.2 ppm between two stations in northern Australia.


The comparison given below is in terms of chord distances obtained from sets of cartesian coordinates on the Baseline Datum (BLD), AGD1966, NWL9D and WGS72 the latter two obtained from Doppler satellite observations.

Again the WGS72 value from Doppler observations fit the better.

<table>
<thead>
<tr>
<th></th>
<th>BLD</th>
<th>AGD</th>
<th>NWL9D</th>
<th>WGS72</th>
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<tr>
<td></td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>m</td>
</tr>
<tr>
<td>Caversham R371</td>
<td>3163</td>
<td>618.22</td>
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<td></td>
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<td>619.29</td>
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<td>Culgoora NMC60</td>
<td>2300</td>
<td>211.83</td>
<td>207.52</td>
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<td>- Green C-251</td>
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<td></td>
<td>212.29</td>
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<td>3533</td>
<td>151.60</td>
<td>145.96</td>
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<tr>
<td>- Caversham R371</td>
<td></td>
<td></td>
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<td>154.79</td>
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</table>

DIFFERENCES BETWEEN BASELINE AND OTHER DATUMS

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<th>BLD-NWL9D</th>
<th>BLD-WGS72</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>m; ppm</td>
<td>m; ppm</td>
<td>m; ppm</td>
</tr>
<tr>
<td>Caversham R371</td>
<td>1.85; 0.6</td>
<td>-3.68; 1.2</td>
<td>-1.07; 0.3</td>
</tr>
<tr>
<td>- Culgoora NMC60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Culgoora NMC60</td>
<td>4.31; 1.9</td>
<td>-2.35; 1.0</td>
<td>-0.46; 0.2</td>
</tr>
<tr>
<td>- Green C-251</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Green C-251</td>
<td>5.64; 1.6</td>
<td>-6.10; 1.7</td>
<td>-3.19; 0.9</td>
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<tr>
<td>- Caversham R371</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9. FUTURE ADJUSTMENTS

The Division of National Mapping carries out adjustments of the geodetic survey of Australia from time to time, incorporating all the latest geodetic information available, including Doppler satellite fixes. These adjustments are not adopted for mapping control or for survey coordination, and as a rule only the coordinates of junction points of the geodetic network are determined. They are distinguished from the geodetic adjustment of 1966 (AGD 66) on which all mapping in Australia is currently based, by being called Geodetic Models of Australia (GMA 73, GMA 75 etc). The object is to provide the best available estimate of the accuracy of the 1966 adjustment and to confirm that the new data fits the previous data without strain.
It is not the present intention of the National Mapping Council of Australia to replace coordinates on AGD 66 as a basis for mapping.

10. ACKNOWLEDGEMENTS

The Division of National Mapping is grateful to the State Lands Departments of Western Australia, South Australia and Tasmania, to the Queensland Department of Mapping and Surveying and the Royal Australian Survey Corps for their assistance in the survey.

The author acknowledges the careful work done by field staff, often in remote parts of Australia, and the reduction and editing of data by office staff to obtain the best possible coordinates from Doppler observations for stations in Australia on which this report is based.

11. REFERENCES


AUSTRALIA

First Order Triangulation

First Order Traverse

Second Order Triangulation

Second Order Traverse

First Order Lateration

Geodetic Station

Doppler Satellite Station

Figure 1
AUSTRALIA

DOPPLER SATELLITE SURVEY (1975)

CONTOURS OF DIFFERENCES IN LONGITUDE

1. First Order Triangulation
2. First Order Traverse
3. Second Order Triangulation
4. Second Order Traverse
5. First Order Trilateration
6. Doppler Satellite Station

FIGURE 3
AUSTRALIA
DOPPLER SATELLITE SURVEY
CONTOURS OF IN THE TERMS OF WGS72
\( H = H_{\text{WGS72}} + H_{\text{NAP}} \)

First Order Triangulation
First Order Traverse
Second Order Triangulation
Second Order Traverse
First Order Trilateration
Doppler Satellite Station

FIGURE 4
AUSTRALIA

DOUBLER SATELLITE SURVEY 1975/76

VALUES OF VECTORS OF (AGO - AGO) AND
VALUES OF HEIGHT DIFFERENCES

First Order Trigonometric
First Order Traverses
Second Order Trigonometric
Second Order Traverses
Third Order Trigonometric
Third Order Traverses

Doppler Satellite Station
Laplace Station
Astrogeodetic Station
Aerodistant Station

VECTOR SCALE 1/200

FIGURE 5
AUSTRALIA DOPPLER SATELLITE SURVEY 1975/76

CONTOURS OF "N" IN TERMS OF NWL

\[ (N + H) \times NWL - 9D \]

Figures:
- First Order Triangulation
- Laplace Station
- First Order Travels
- Geodetic Station
- Second Order Travels
- High Station
- First Order Trilateration
- Doppler Satellite Station

NMP/78/074
NMP/78/075
132°
53°
54°
55°
56°
AUSTRALIA

DOPPLER SATELLITE SURVEY

VECTORS OF (AGD translated from NWL/9D)

VALUES OF HEIGHT DIFFERENCES

VECTOR SCALE 1/200
**OBSERVING AUTHORITY:** DIV. OF NATIONAL MAPPING  
**STATION:** GREEN 0-251  
**STREET:** THURSDAY ISLAND  
**OBSERVER:** K. LEPPERT & J. GUILFOYLE  
**STATE:** QLD

The satellite observations were taken at the station mark, the height of the electrical centre of the serial was 0.518 m above this mark.

All values shown on this summary refer to the station mark and are quoted in either seconds of arc or metres.

**Geodetic Datum:**

- **Australian Geodetic (AGD)**
- **Derived Australian Geodetic (AGD)**

Geoidal heights $H$ are referred to the Australian Height Datum (AHD).

N values are in terms of $N = -6, \text{m}$ at Johnston Geodetic Station.

**GEODETIC DATUM:**

- Australian Geodetic (AGD)
- Derived Australian Geodetic (AGD)

Ephemeris coordinates converted to AGD using either 1, 2 or 3:

- $\phi$:
  - $\Delta x =$
  - $\Delta y =$
  - $\Delta z =$
- $\lambda$:
  - $\Delta x =$
  - $\Delta y =$
  - $\Delta z =$
- $H$:
  - $\Delta x =$
  - $\Delta y =$
  - $\Delta z =$
- $N$:
  - $\Delta x =$
  - $\Delta y =$
  - $\Delta z =$

**SATELLITE DATUM:**

- $\phi = -10.3508,0381$
- $\lambda = 142.1235,6545$
- $N + H = 126,732$
- $X = 4,955,361,459$
- $Y = 3,842,276,233$
- $Z = -1,163,841,731$

**Internal Accuracy**

<table>
<thead>
<tr>
<th>$\phi$</th>
<th>$\lambda$</th>
<th>$N$</th>
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<tbody>
<tr>
<td>0.34</td>
<td>0.42</td>
<td>0.27</td>
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**Station uncertainty relating to AGD and AHD**

Estimate: $\pm \delta m$

**COMPUTER PROGRAM USED**

- DOPPLER (JMR VERSION)

**SATELLITES OBSERVED**

<table>
<thead>
<tr>
<th>SAT</th>
<th>NO. OF PASSES</th>
<th>EPHemeris</th>
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<td>58</td>
<td>19</td>
<td>PRECISE IN TERMS OF M79/90D</td>
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<td>68</td>
<td>20</td>
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**Compiled by:** M. N. DOCH  
**Date:** 24.10.77

**Certified free of transcription errors:** S. Howard  
**Date:** 24.11.77

**Approved by:**  
**Date:** 8/3/78
Station Number and Name: C 251 GREEN
Order: SECOND

Date: 1942

Station Marked by: Royal Australian Survey Corps
Date: 1942

Datum: Australian Geodetic Datum 1966

Reference Books:
- Army trig 1942 1/F6 Bty: Torres Strait 1973
- UN 30123, 30124, 10047, 10191, 10192, 13119, 13723, 13874, 14042, 14118, 14513, 14712, 14754, 14776, 14777, 14834.

Rectangular Coordinates: Australian Map Grid:
- In Metres:
  - 14-04-2, 14-118, 14-513, 14-712, 14-754, 14-776, 14-777, 14-804...

Heights: In Metres on the Australian Height Datum

Access and Locality:
- By vehicle from the township to the top of the hill.

TABLE 1
<table>
<thead>
<tr>
<th>STATIONS</th>
<th>TERMINAL</th>
<th>AGD</th>
<th>NM-GD</th>
<th>NOS 72</th>
<th>AGD-NM</th>
<th>PPM</th>
<th>AGD-NOS</th>
<th>PPM</th>
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<td>JOHNSTON</td>
<td>A 432 MT ISA</td>
<td>872 208.711</td>
<td>872 207.669</td>
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<td>A 468 HIRAN 32</td>
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<td>C 251 GREEN</td>
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<td>1 842 234.224</td>
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**SUPPLEMENTARY DISTANCES**

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