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A READJUSTMENT OF THE AUSTRALIAN GEODETIC SURVEY, 1979

by

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ABSTRACT

The data used for the 1966 adjustment to form the Australian Geodetic Datum has been increased by the addition of first order terrestrial observations and Doppler satellite position fixes made since 1966. The observations have been rigorously reduced from geoid to spheroid and rigorously adjusted by the Canadian Section method. The object is to give the best possible measure of the accuracy of the 1966 adjustment, which remains in use for cartographic purposes.

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1. BACKGROUND

A geodetic survey has to fulfil a number of needs. These may be divided into three groups according to the precision required:

1. Medium and small scale mapping.
2. A basic framework for homogeneous engineering and integrated cadastral control, and for large scale mapping.
3. Scientific purposes such as crustal motion studies, high precision engineering surveys, etc.

As a general rule, the sequence followed is initially to establish a data base containing all the available observations and other information. After the gaps have been filled by field measurements, this data can be adjusted to provide the control for medium and small scale mapping. For this purpose, simple mathematical models and simplified adjustment procedures may be used which do not necessarily utilize the full precision of the original observations. This procedure will satisfy the current requirements and provided that the data base is retained, subsequent measurements and improved mathematical models can be incorporated later in a process of successive refinement.

In Australia, from the mid 1950s, there was a rapid acquisition of field data which culminated in the adjustment of 1966, which defined the Australian Geodetic Datum (AGD66). The adjustment process was described by Bomford (1967a).

Over the years the resulting coordinates have been adequate for mapping but there are reservations regarding the use of the coordinates for some other purposes. Remembering that in the period 1963/66 the use of computers was still in its infancy in Australia, that computers were much smaller and that error theory was not so advanced, the precision achieved is a tribute to those involved.

By 1973, there was a significant amount of new precise measurements available in the form of laser geodimeter distances, many more Laplace stations, new sections such as the Pageos baselines (Leppert, 1971) and both a geoid model (Fryer, 1971) and a height datum (AHD).

This made it possible to refine the coordinates of the geodetic stations. The purpose of this refinement was quoted by Bomford (1973a) as:

"1. Estimating the errors in the AGD66.

2. Providing more accurate coordinates for satellite tracking stations and similar installations in Australia.

3. Providing more accurate coordinates for transformation to a world datum."

The new adjustment was described as the Geodetic Model of Australia 1973 or the GMA73 (Bomford, 1973) to differentiate the results from the AGD66.

The GMA73 was not intended to replace the AGD66 for topographic purposes but was intended to be used for scientific purposes. The adjustment was carried out by the "rod method" (Bomford, 1967a) and using the computer program Varudel (Bomford, 1973) which is an improved version of the program Varycord (Bomford 1967b).

These programs continue to be used for routine adjustments of control surveys but have been superseded for continental adjustments by program CHAOS (IAG National Report 1975-79).

2. AGD66 DATA SET

During 1975-1977 the positions of 89 junction stations were determined by Doppler satellite measurements using the Precise Ephemeris in single point mode. Attempts were made to determine a set of unique transformation parameters between the NWL9D/WGS72 values and the AGD66 values. These attempts were not successful due to the large range in the residuals after transformation. The transformations were thereafter determined from a set of doppler contour maps (Leppert, 1978).

It was realised that the difficulties were caused by the lack of refinement in the mathematical model used in the AGD66 and the small distortions introduced through the rod adjustment method.

To demonstrate the effect of the distortions, the AGD66 data set was reformed as a computer data base and archived. The statistics on the AGD66 data file are:-

TABLE 1

Geodetic Stations	2 490
Maximum Serial Station Bandwidth	102
Observed Directions	8 402
Observed Distances	2 305
Observed Laplace Azimuths	403

The effort required to collect the data, put it into a data base and verify it should not be underestimated. In terms of manpower, it is about 90% of the work and the quality of the data base contributes directly to the degree of precision of the final results.

3. RE-ADJUSTMENT OF THE AGD66 DATA SET

For purposes of computation in 1977/78, the data set was split into 11 blocks of data with the junction stations flagged. The adjustment was then carried out by the Section Method (Pinch & Peterson, 1974) using the program CHAOS.

The program adjusts the blocks of data individually to give coordinates of all points and a variance/covariance matrix of all points common to other blocks. These points are called junction stations. In Stage 1 each block is adjusted individually as free nets to yield least square estimates of coordinates, and the variance/covariance matrix for the common points and Doppler sites. In Stage 2 these estimates and their variance/covariance matrices are combined into a single adjustment which results in the final adjusted coordinates for the junction stations. In Stage 3, each block is adjusted separately holding the junction stations fixed to yield adjusted coordinates for all the remaining stations.

The results differed slightly from the AGD66 results but since the mathematical model had been changed, this was not surprising.

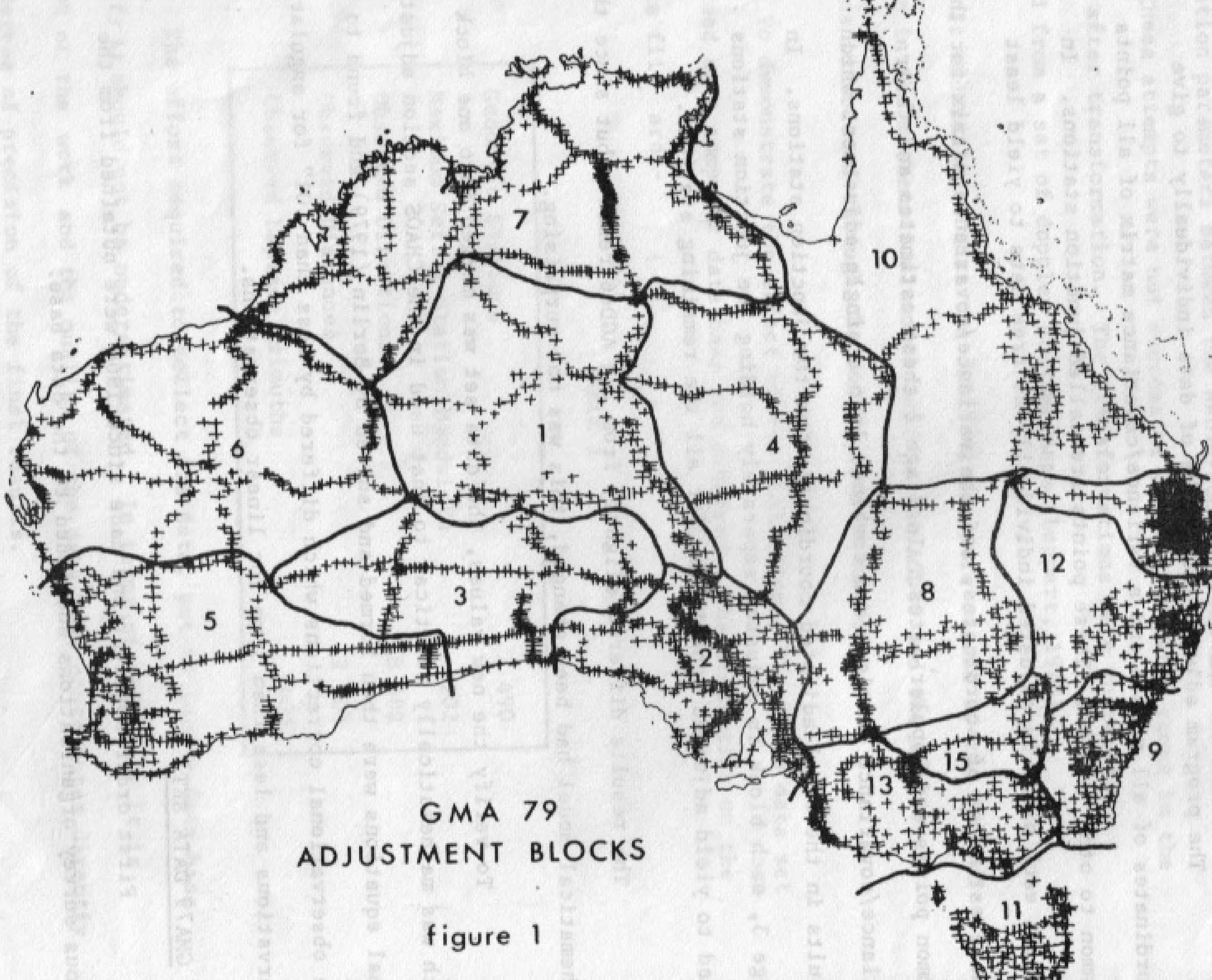
To verify the new values, the data set was merged into one block which was mathematically identical to that used in the CHAOS section adjustment. Normal equations were then formed and solved by Berlin (1979) and found to give observational corrections which differed by less than .01" for angular observations and less than 1 mm for linear observations.

4. <u>GMA79 DATA SET</u>

First order observations made since 1966 were obtained from the various survey organisations and added to the data base.

It was found desirable to further subdivide the data set into 15 blocks of terrestrial data and 1 block of satellite Doppler data (see Fig 1).

This subdivision facilitated the data verification and the



GMA 79
ADJUSTMENT BLOCKS

figure 1

correction of the inevitable coding errors. About three man years were spent in adding and verifying this additional data.

Currently the data base contains:

TABLE 2

Geodetic stations	3 052
Doppler Stations	89
Observed Directions	10 263
Observed Distances	4 441
Observed Laplace Azimuths	1 593

Some salient features of the data base are:

1. The coordinates are the latest values available and are updated by the adjustment procedure.
2. Heights are on the Australian Height Datum (AHD).
3. Astronomic azimuths corrected to CIO are recorded together with the observed astronomic positions.
4. Chord distances are recorded from ground mark to ground mark.
5. Observations are coded according to the type of measuring instrument, technique and epoch of observation.
6. Multiple occupations of a station are permitted.
7. New observations are readily added.

With such a data base it is thus an easy matter to change the reference ellipsoid, datum definition or to modify heights without having to re-reduce the observations to sea level.

The data set thus provides a starting point for the extension into a 3-dimension adjustment process; or later, to time dependent studies.

An important aspect of re-observation within an established primary network, beyond arguments of effectiveness to the overall strength of the net, is the certainty of connection to the original mark. Where possible all observations from a re-occupancy should be entered into the data base reduced to the original mark. If the original mark is missing or uncertain it should be relocated from the reference marks. If the reference marks have also gone or if there is any uncertainty in re-establishing the original mark, the old station must be considered destroyed and a new station must be created with new reference marks and a unique name and station number.

5. ADJUSTMENT OF THE GMA79 DATA SET

Once the data set was established, it was possible to readjust. It was decided to incorporate all possible refinements to the mathematical model, including corrections to the terrestrial observations for geoid-spheroid separation, skew normals and deflections of the vertical.

These corrections are often ignored as they are small. It has been shown, however, that their effect is systematic (Thompson et al, 1974) and they should be included.

This decision required an investigation into the ability of a functional model of the geoid to adequately predict the separations and deflections across Australia.

The Division of National Mapping has established a file called Deviate which contains the observed astronomic position and the geoid-spheroid separation (N) at 1203 stations scattered throughout Australia. The N-values which are based on the value of -6m at the Johnston Origin were increased by 10.9m to conform with the official datum definition gazetted in the Australian Commonwealth Gazette, October 1966, which defined the origin of the Australian Geodetic Datum (AGD) in terms of the spheroidal elevation at Johnston Geodetic Station. The Australian National Spheroid (ANS) was retained as were the coordinates of Johnston at the gazetted spheroidal latitude and longitude (this positions the centre of the ellipsoid about 200 metres from the geocentre).

The GEM8 and GEM10B geopotential models were used to calculate the deflections and separations at stations in the Deviate file using the routines prepared by Lachapelle (1976).

Comparison of the results with the Deviate file gave the following standard deviations of the differences for the 1203 sampled stations.

TABLE 3

	Deflection		Separation
	Meridian	Prime Vertical	
GEM 8	3.2"	4.6"	2.8 m
GEM 10B	3.2"	4.7"	3.2 m

Both models were thus more than adequate for the purpose of correcting the terrestrial observations.

As the GEM8 model gave a marginal improvement and was simpler to compute, it was decided to incorporate the GEM8 model into the program CHAOS for the correction of observations from the geoid to the spheroid.

The terrestrial data was adjusted to the Stage 2 level. The geodetic values for the Doppler satellite stations were then used to determine, by a separate least squares adjustment, the transformation parameters between NWL9D and the Stage 2 Terrestrial solution.

The Doppler observations were then transformed and added with appropriate variance/covariance matrices to the Stage 2 data set.

The a priori variance of each cartesian component of a doppler fix was based on $0.83\ m^2$ (NMC Resolution 387) which corresponds to a position uncertainty of $\pm$ 1.58 m.

The Stage 2 adjustment was repeated giving final coordinates for the 224 junction stations. These values are designated as GMA79.

It should be noted that the distribution of a posteriori variance factors and the distribution of standardised corrections from the readjustment of the 1966 data set indicated that the variance of directions was too small. Examination of triangle miscloses and comparison with similar networks in other parts of the world supported this conclusion. Accordingly, for the GMA79 adjustment the variance of directions was changed from $0.25\ sec^2$ to $0.50\ sec^2$.

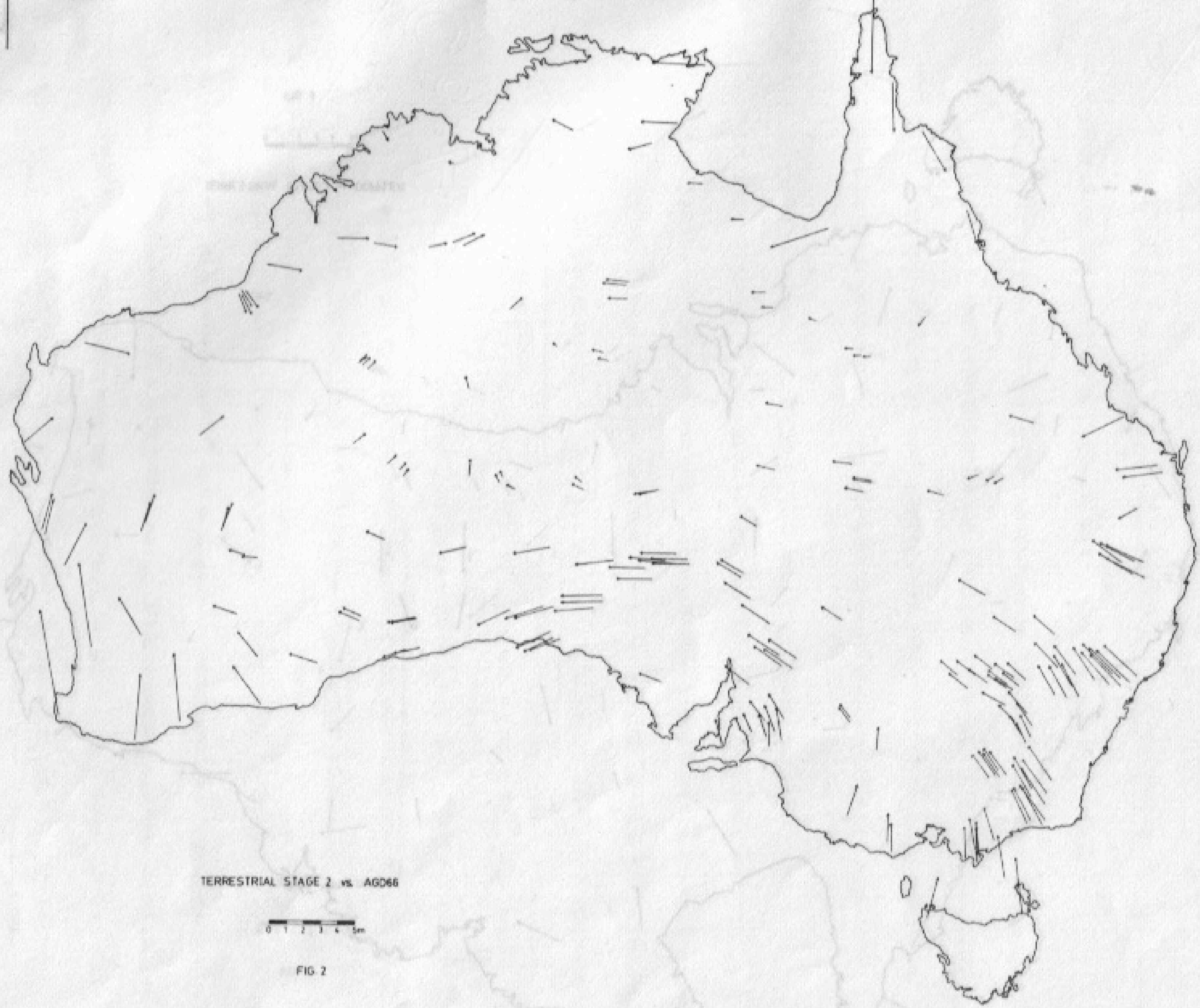
6. <u>COMPARISONS</u>

The comparison between STAGE 2 and AGD66 results is instructive and is given in displacement vector form in Figure 2. The figure clearly indicates the systematic trends and the areas of local distortion.

The vectors for the terrestrial Stage 2 to the unadjusted transformed Doppler positions are given in Figure 3. These vectors do not show any systematic trends and thus imply that they are due to random errors in the terrestrial and doppler observations.

Figure 4 gives the vectors between the results of the two Stage 2 adjustments with doppler included (GMS79) and excluded (Terrestrial Stage 2).

It is also significant that the corrections to the transformed



TERRESTRIAL STAGE 2 vs. AGD66

FIG 2

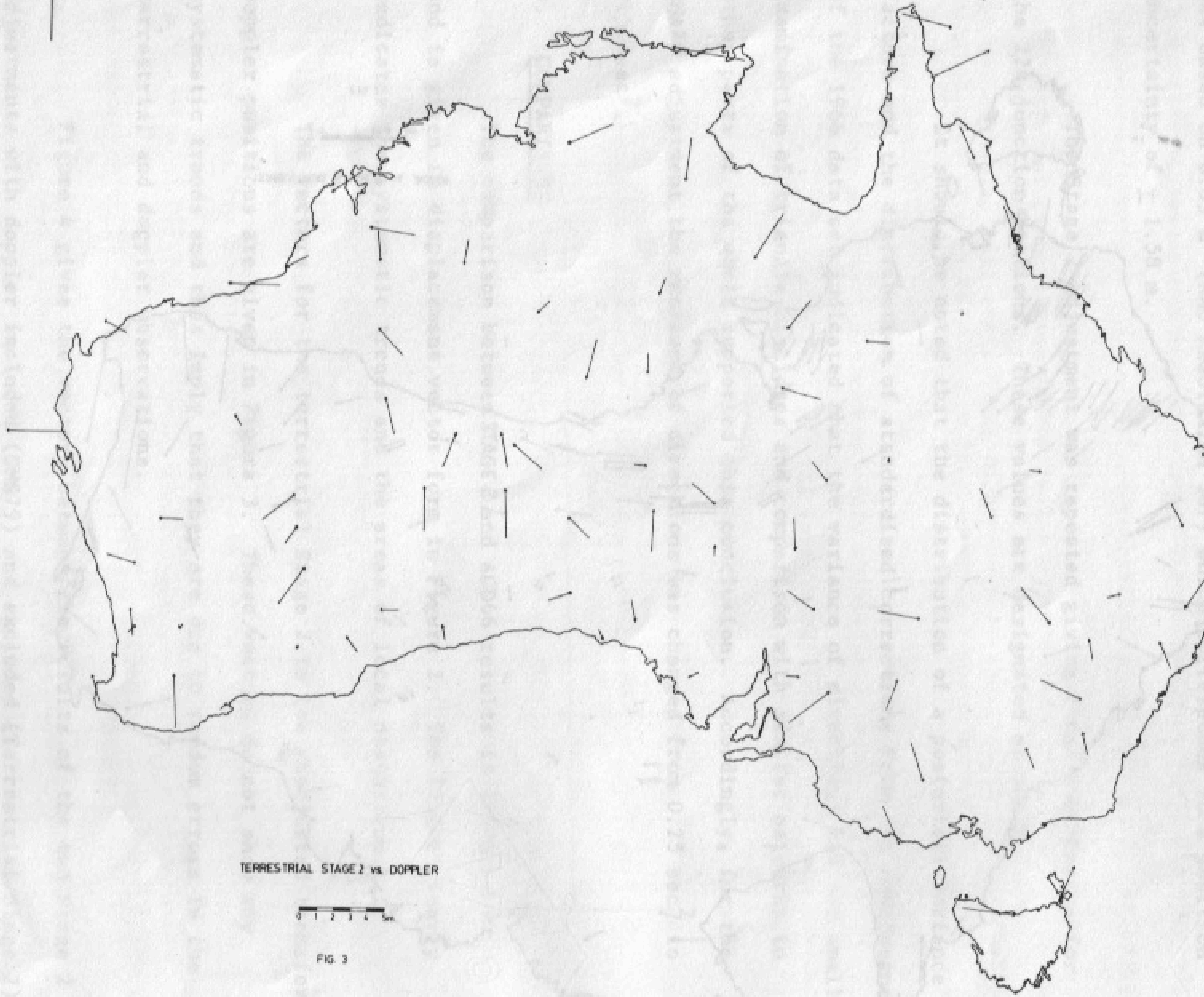


FIG. 3

GMA79 vs. TERRESTRIAL STAGE 2

0 1 2 3 4 5m

FIG 4

FIG. 5

doppler positions have a standard deviation of 1.47m i.e. about the precision expected for point positioning by Doppler satellite measurements (Leroy, 1976). These corrections are plotted as vectors in Figure 5.

7. FURTHER WORK

It should be stressed that GMA79 values are not final as two areas of refinement still remain. These are:

1. A modification to the program CHAOS to permit the simultaneous solution of the coordinates of the junction stations, including the Doppler stations, and the transformation parameters between the Doppler reference system and the geodetic datum, to be computed at Stage 2.
2. An improvement in the precision model. Examination of the statistics of the adjustment through the a posteriori estimates of the variance factors for the 15 terrestrial blocks indicate that the assessment of the precision of some of the observations was too optimistic.

The variance factors are given in Figure 6. If the blocks 08, 09, 12 and 14 which are predominately triangulation are removed, the distribution for the remaining blocks is distinctly biassed.

Since these blocks are predominately interlocking Tellurometer traverses, it suggests that $(3\text{ cm} + 3\text{ ppm})^2$ is an optimistic estimate of variance for measurements with the early Tellurometers under Australian conditions. This conclusion is confirmed by the comparison of results where the measurements have been repeated by Geodimeter 8. It is therefore proposed that the precision of the early Tellurometer measurements be downgraded and the adjustment repeated.

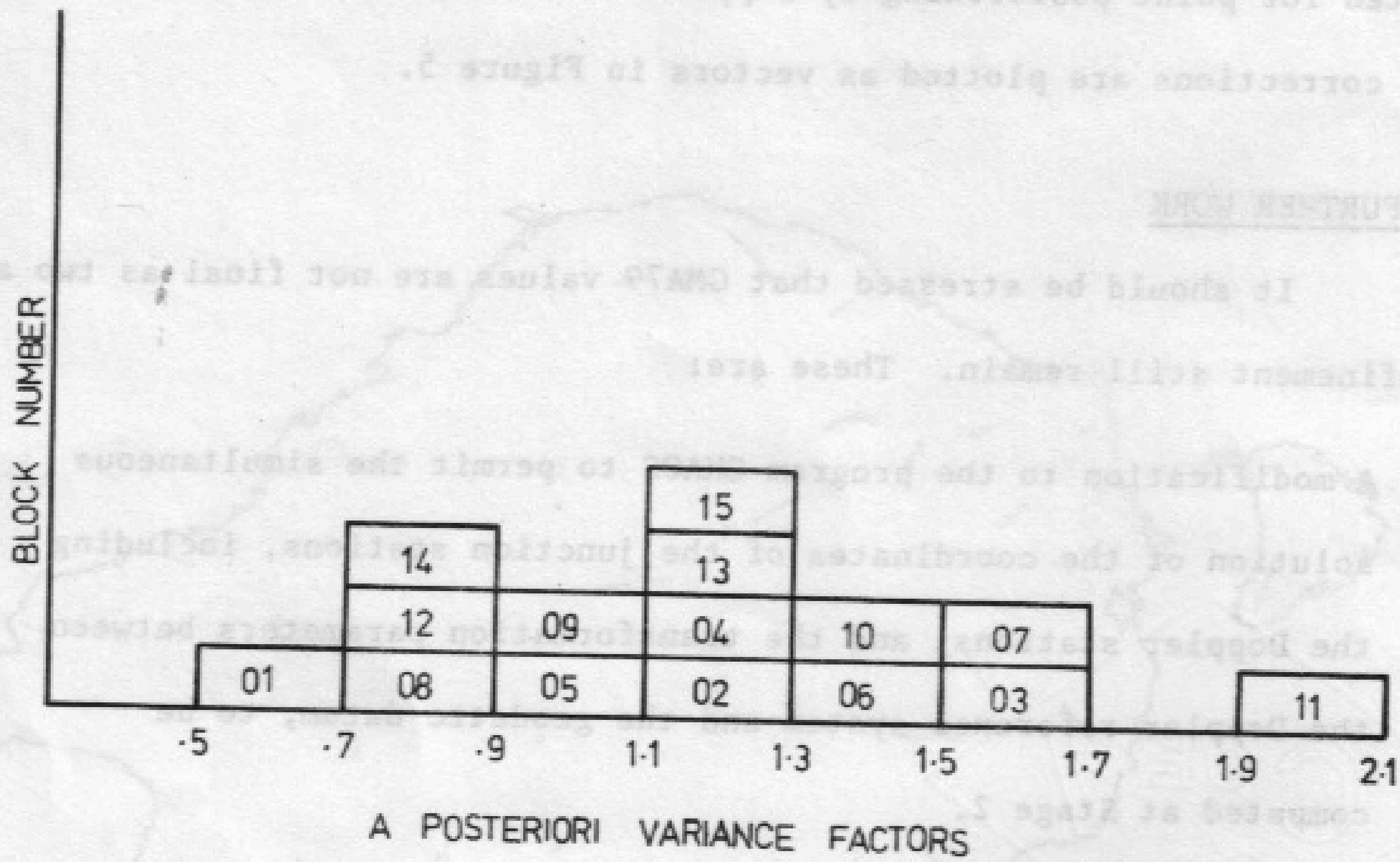


FIGURE 6

Both refinements should be completed early in 1980. The final values will be designated GMA80.

Further significant improvement to the adjustment would only come from the addition of new observations. The recommended type of observation is precise relative position by multi-station doppler techniques such as the SAGA approach (Brown, 1976). The recommended areas for re-survey include:

1. across parallel traverses especially in very flat terrain where grazing rays were a possible source of systematic error,
2. regions of crustal strain,
3. areas of poor geometric strength such as the Cape York open ended traverse, the Gulf of Carpentaria HIRAN survey and the Bass Strait connection between Tasmania and the mainland.

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