Dynamic Geodetic Datums: A Case Study in Papua New Guinea

R. STANAWAY AND P. TREGONING

Research School of Earth Sciences
The Australian National University
Canberra, ACT 0200, Australia
rich@rses.anu.edu.au, pault@rses.anu.edu.au

THE AUSTRALIAN NATIONAL UNIVERSITY

RSES Earth Physics

ABSTRACT

National geodetic datums that span tectonic plate boundaries and deforming zones are subject to distortion which increases in magnitude with time. National datums on rigid plates move linearly in an inertial reference system, however distortion of datums near plate margins and zones of elastic strain accumulation is often non-linear as a result of co-seismic and post-seismic displacement. Many online GPS processing services now provide users with centimetre accurate point positioning capability. Tectonic motion of the monuments that realise the datum with respect to an international terrestrial reference frame can be as much as 1 metre every decade with localised deformation exceeding 10 ppm per year. Such motions exceed many cadastral and engineering tolerances.

We have developed a strategy whereby national geodetic datums and survey networks in tectonically active regions can include a geodetic velocity field, strain models and other non-secular offset data in order to maintain the integrity of the datum. A robust least-squares adjustment program 4DADJ has been developed which includes these dynamic elements, to enable geodetic surveyors to reduce geodetic measurements made in dynamic local networks to a reference epoch. The program has applications for the monitoring of geophysical hazards and localised crustal deformation.

We apply our program to the geodetic datum of Papua New Guinea, an ideal case study to demonstrate the application of the program and the significant improvements in datum integrity that can result.

1 Tectonic Distortion of Geodetic Datums

Distortion of national geodetic datums in tectonically active regions can be dramatic. The Geodetic Datum of Papua New Guinea is a good example (Figure 1)

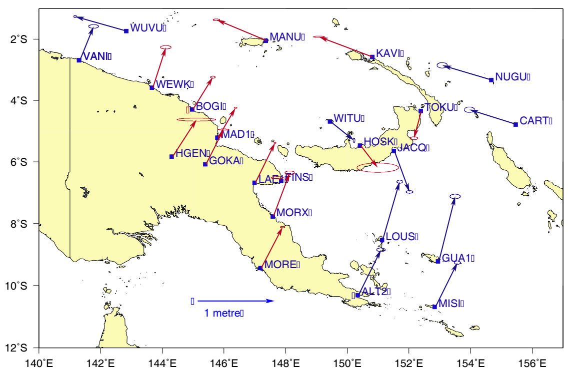

Figure 1 Plot of the distortion of the Papua New Guinea Geodetic Datum 1994 (PNG94) with respect to ITRF2000 between epochs 1994.0 and 2004.0

1.1 Relative Distortion

Distortion of the PNG geodetic network and smaller urban networks can now be observed readily with proprietary GPS technology and processing software (Figures 2 and 3). The distortion can exceed the positional and local uncertainty specifications for cadastral and engineering surveys.

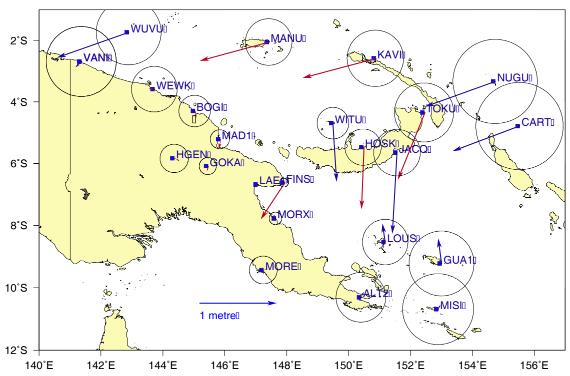

Figure 2 Diagram showing displacement vectors between LAE1 and PNG94 between 1994 and 2004; error circles show precision of baseline measurement from LAE1 using typical specifications for a dual frequency GPS receiver and broadcast ephemeris for combined 24hr observations (5mm + 0.5ppm).

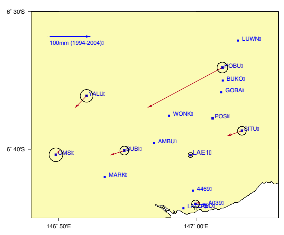

Figure 3 Diagram showing displacement vectors between LAE1 and the Lae network between 1994 and 2004; error circles show precision of baseline measurement from LAE1 using specifications for a typical single-frequency GPS receiver and broadcast ephemeris in static mode (5mm + 1ppm).

2 Episodic displacements

Coseismic and post-seismic displacement of geodetic stations can be significant in PNG (Figures 4 and 5).

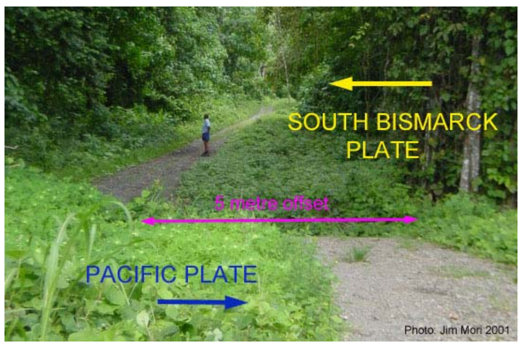

Figure 4 Coseismic motion resulting from the 16th November 2000 Mw 8.0 earthquake near the Weitin Fault, New Ireland, PNG (photo Jim Mori)

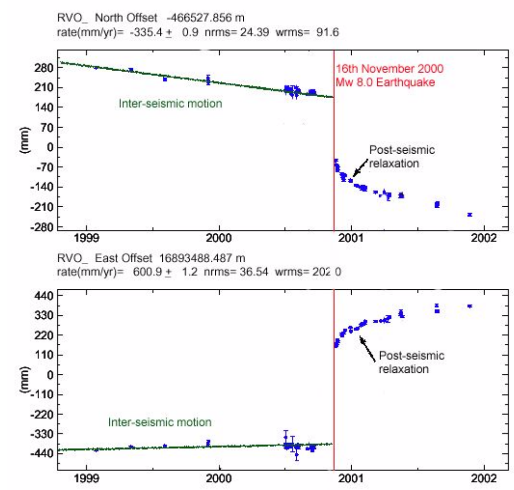

Figure 5 Timeseries for RVO (Rabaul Volcanological Observatory, PNG) site showing co-seismic offset and post-seismic relaxation as a result of the 16th November 2000 Mw 8.0 event. The earthquake epicentre was c. 30 km from the site

Figure 6 PNG Geodetic station on the Duke of York Islands used to monitor the Weitin Fault (visible in the background)

3 An approach to adjustment of Dynamic Networks

A program 4DADJ has been developed to enable computation of coordinates at a specified epoch in a dynamic reference frame from a robust least squares adjustment of a network of baseline measurements made at different epochs. 4DADJ allows for linear and episodic motion of site coordinates. Coordinates can be computed at a specified epoch using the following equation;

$$\begin{bmatrix} X_{t_e} \\ Y_{t_e} \\ Z_{t_e} \end{bmatrix} = \begin{bmatrix} X_{t_0} \\ Y_{t_0} \\ Z_{t_0} \end{bmatrix} + (t_e - t_0) \begin{bmatrix} V_X \\ V_Y \\ V_Z \end{bmatrix} + \begin{bmatrix} \sum \Delta X_{Coseis_{(t_e - t_0)}} \\ \sum \Delta Y_{Coseis_{(t_e - t_0)}} \\ \sum \Delta Z_{Coseis_{(t_e - t_0)}} \end{bmatrix} + \begin{bmatrix} \sum \Delta X_{Postseis_{(t_e - t_0)}} \\ \sum \Delta Y_{Postseis_{(t_e - t_0)}} \\ \sum \Delta Z_{Postseis_{(t_e - t_0)}} \end{bmatrix}$$

4DADJ applies corrections to the baseline measurements, derived from the tectonic model to form quasi-observations at the time of the adjustment epoch before performing the adjustment. Interpolation of the post-seismic input data is performed by a logarithmic fit of observations at a site during the post-seismic relaxation period. A simplified fault locking model is used to estimate a strain correction to be applied to stations located near active boundary zones.

3.1 4DADJ

To show how 4DADJ removes the effects of tectonic distortion, a sample ensemble of GPS baseline observations from a typical PNG national network were analysed. The network was initially adjusted in static mode with no time variation assigned to constraint and free stations (Figure 7). The same data were then run by 4DADJ in dynamic mode for a reference epoch of 1994.0 and the adjustment results compared (Figure 8). It is clearly shown that a dynamic approach to network adjustments in PNG produces a statistically more rigorous estimation of station coordinates.

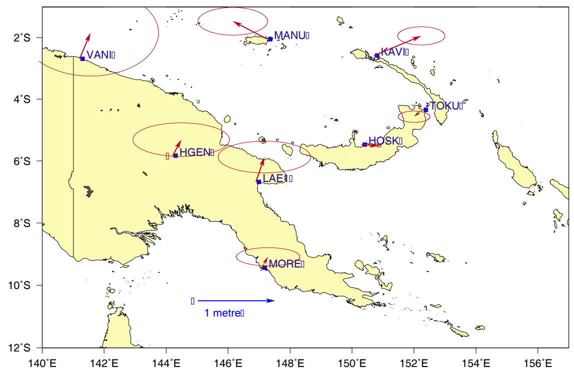

Figure 7 Typical PNG Network adjustment with no time variaton assigned to constraint stations. Tectonic distortion is indicated in both the magnitude of the residual vectors and the error ellipses of the positional uncertainties.

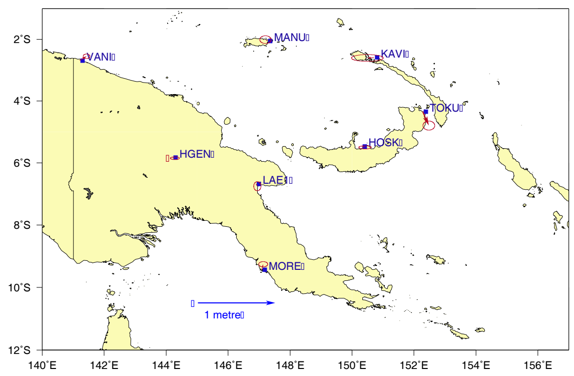

Figure 8 The same network adjusted with 4DADJ applying time variation of constraint stations. Including a model of plate motion, strain and coseismic offsets largely removes the effects of distortion.

4 Conclusions

- Tectonic distortion of geodetic datums is now impairing the application of existing positioning technology for positioning.
- Where the distortion exceeds positioning specifications for land surveys, the distortion should be modelled during the survey analysis and network adjustment.
- 4DADJ and other related programs enable linear and non-linear time variation of geodetic coordinates to be accommodated in network adjustments, removing the first order affects of tectonic deformation.

References

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