A SEMI-DYNAMIC GEODETIC DATUM FOR PAPUA NEW GUINEA

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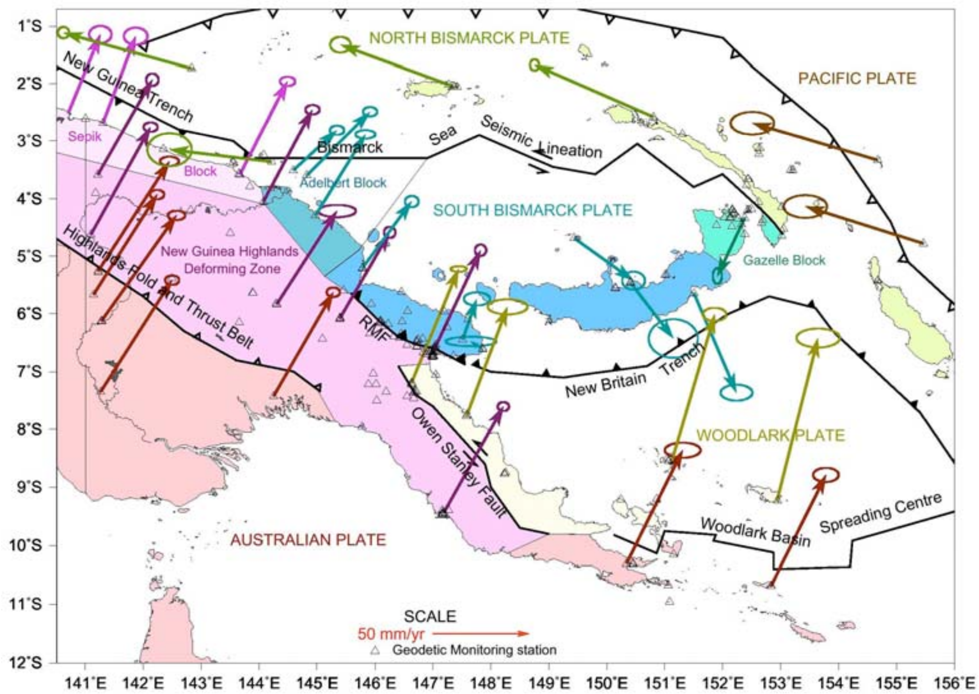
Abstract
Papua New Guinea's current geodetic datum PNG94, shares the same realisation as GDA94 in Australia. Unlike Australia, however, PNG is one of the most tectonically active and complex countries on the Earth. Internal deformation is occurring within PNG at rates of up to 120 mm/yr and coseismic deformation is often several metres in magnitude. This paper presents the findings of 12 years of analysis of PNG's geodetic network. The paper also shows how spatial professionals in PNG can mitigate the effects of this tectonic deformation.

Introduction
Papua New Guinea's current geodetic datum, PNG94, was realised at the same time as GDA94 in Australia. The coordinates of GDA94 and PNG94 are "snapshots" of the dynamic International Terrestrial Reference Frame 1992 (ITRF92) on the 1st January 1994 (Epoch 1994.0). ITRF (and WGS84) coordinates of fixed stations anywhere on the planet change at up to 100mm/yr due to the inexorable motion of tectonic plates. Unlike Australia, however, PNG is very active tectonically, due to its location on the edge of the colliding Australian and Pacific plates. Within this collision zone in PNG there are also several smaller microplates and zones of diffuse deformation, which add to the complexity of the tectonic setting (Figure 1).

Figure 1. The tectonic setting in PNG, showing plate boundaries and ITRF/WGS84 site velocities

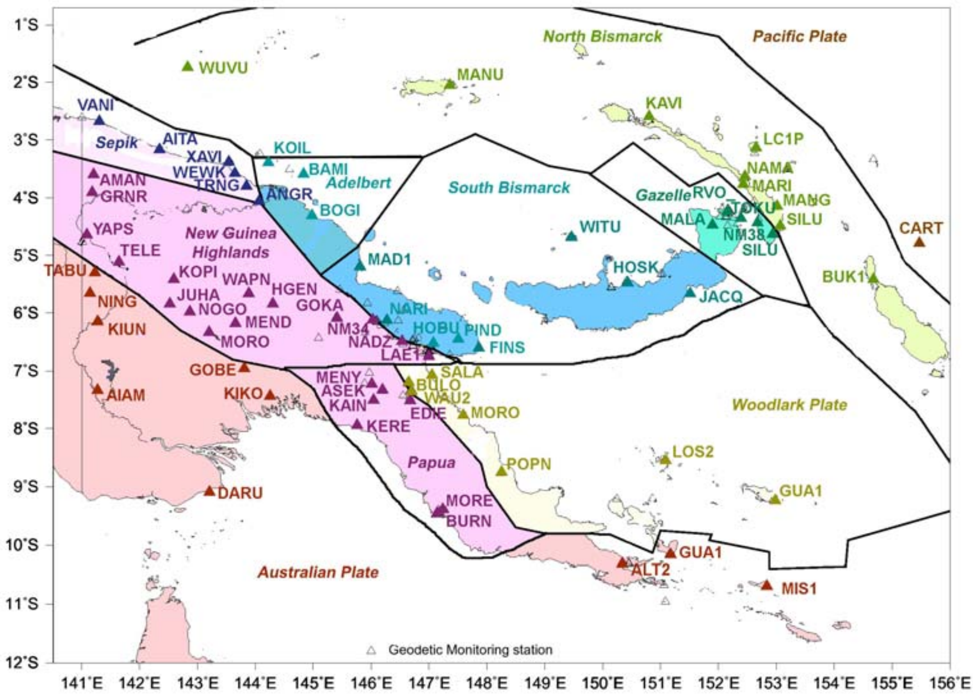


Interseismic deformation (between earthquakes) across plate boundaries within PNG is rapid (up to 120 mm/yr) and the cosesimic and postseismic deformation resulting from large shallow earthquakes can be up to several metres in magnitude. Since the beginning of 1994, there have been almost 1,500 earthquakes above Magnitude 5 in PNG including 20 above magnitude 7 (NEIC database). 14 years of tectonic deformation has resulted in baseline changes of up to six metres between many PNG94 geodetic stations. During the same period, movement between stations in the Australian Fiducial Network (AFN) has been less than 15 mm!

Such significant internal deformation of the geodetic network makes it practically impossible for users of GNSS precise point positioning (PPP) and static GPS systems to obtain any meaningful precision in PNG, unless this deformation is modelled and a fixed reference epoch is formalised. Many developed countries in tectonically active areas e.g. New Zealand (Blick *et al.*, 2003) and California have already implemented site velocity and deformation models into their geodetic datums to ensure that their geodetic infrastructure is not degraded by unmodelled deformation in the positioning process. Use of a velocity model enables site motion between the date (epoch) of measurement and a reference epoch to be computed. In this way, computed coordinates can be related to the reference epoch to ensure that coordinates of spatial datasets remain "static" within a dynamic environment. Continually changing coordinates related to arbitrary epochs have no real value in spatial systems and in fact degrade them. A datum where dynamic coordinates are regressed to a specific fixed epoch is referred to as a semi-dynamic datum. Currently there is no strategy in place within PNG to deal with tectonic deformation in such a way.

In order to gain a better understanding of the tectonic setting in PNG, researchers have established a widespread network of stable geodynamic monitoring sites in PNG, principally, the Australian National University's Research School of Earth Sciences (ANU RSES). Important collaborators have included; The PNG National Mapping Bureau (NMB), The Department of Surveying and Land Studies at Unitech, The Rabaul Volcanological Observatory (RVO), and the University of California Santa Cruz (UCSC). Several campaigns of repeat measurements of these stations have enabled centimetre accurate ITRF coordinates and site velocities, euler poles of microplates, and fault locking parameters to be estimated. The extensive network of stations and results from these studies can form the basis of very significant improvements to PNG's geodetic datum (Figure 2).

Figure 2. PNG geodetic monitoring network (primary stations) and plate zones



How accurate is PNG94?

The primary PNG94 stations (Allman, 1996) surveyed in the regional GPS campaigns between 1992 and 1994 are accurate to 5 cm or so. Many other stations have PNG94 coordinates derived by GPS where tectonic deformation has not been modelled, or by transformation from AGD66 or WGS72 using standard transformation parameters (e.g. NGA parameters widely used in GIS and data logging software). PNG94 coordinates of these stations are typically in error by up to 9 metres!

Why should PNG have a semi-dynamic datum and what accuracy is required?

Uses of spatial data in PNG are increasingly diverse; Cadastral surveys (including customary land and DCDB), exploration and mining, engineering (bridges, dams, power, roads, pipelines), mapping, navigation (air, land and sea), hazard monitoring (volcanoes, earthquakes, landslides, sea-level change) all require a homogenous spatial reference system or datum. PNG94 has errors of several metres accommodated within it. Such significant errors render the datum useless for many of these applications. For some users of spatial data, an absolute accuracy or positional uncertainty of this magnitude maybe acceptable, although smaller relative uncertainties are usually required, e.g. for deformation monitoring, engineering surveys and cadastral surveys. Integration of separate and adjoining surveys, however, require and absolute accuracy of 10 cm or better. PNG94 in its current form is not sufficiently accurate for this purpose. A centimetre accurate geodetic datum is increasingly underpinning any successful modern economy. In the case of PNG, an accurate datum is especially important for large-scale engineering projects such as the LNG project, which is now entering its front-end engineering and design (FEED) stage. The success of this project which will bring an estimated US $8bn into the PNG economy is contingent on construction within a centimetre accurate survey datum.

Why shouldn't WGS84 and ITRF be used in PNG?

It also often assumed that PNG94 is identical to WGS84 and ITRF. This assumption was true in 1994, but since then coordinates in the different systems have diverged because of ongoing tectonic deformation and the differences are now a metre or more in PNG. Although the reference ellipsoids used by these three datums are similar at the sub-millimetre level, actual differences in station coordinates are now significant and the difference is increasing by several centimetres a year. By fixing a reference epoch (1st January 1994), coordinates of PNG's datum can become traceable to a physical network by means of a site velocity model. WGS84 and ITRF2000 coordinates are meaningless unless an epoch and physical datum are assigned to spatial data. For this reason WGS84 and ITRF should not be used for most surveys. ITRF will continue to be the basis for geodynamic monitoring in PNG, due to the stability and millimetric accuracy of the external reference frame. Using ITRF or WGS84 for infrastructure surveys without making corrections for tectonic deformation represents very poor surveying practice.

What problems can surveyors experience with PNG94 at present?

Surveyors using GNSS methods to establish control in remote locations will find coordinates changing significantly over periods of a few years if their base stations are located on different plates from their survey area. For example, in the case where the NMB (MORE) and Unitech (LAE1) GPS base stations are used to coordinate stations in East New Britain or New Ireland.

PPP systems such as AUSPOS and OmniStar produce coordinates in ITRF2000/WGS84 or ITRF2005. "Accurate" coordinates derived by these will change by several centimetres a year in PNG to reflect the magnitude of tectonic motion of the site. Users of these systems will notice repeat measurements of stations changing even over an interval of a few months. For example, if AUSPOS or OmniStar were used to establish geodetic control for a new mining operation in the PNG Highlands in 2002, a surveyor reobserving these stations in 2008 would notice that the ITRF2000/WGS84 coordinates would be 30cm different! A local correction has to be applied to convert new measurements back to epoch used in the 2002 survey. If the surveyor in 2002 had known what the site velocity was, they would have converted the 2002 coordinates back to epoch 1994 to be coincident with PNG94, so that the survey could be related to other surveys in the area (Figure 3).

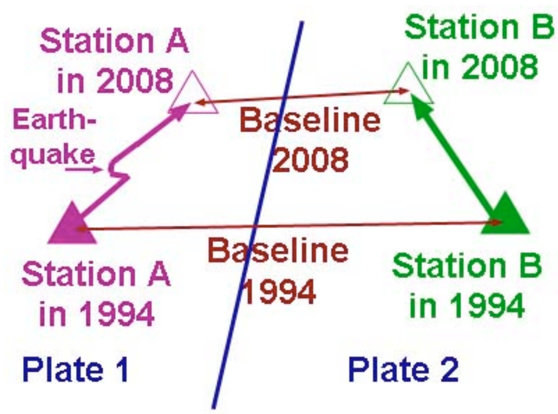


Figure 3. Effect of tectonic deformation on coordinates & baselines

Within rigid plate zones (Figure 1), away from plate boundaries (mostly south of the Highlands and Owen Stanley Range), baseline changes are likely to be small in magnitude and it is usually safe to use base stations up to 100km from a survey area within the same zone without significant degradation of relative accuracy. In broadly deforming zones that are relatively aseismic such as the PNG Highlands, West New Britain and Milne Bay Province, baseline changes may be evident for baselines longer than 100km so that the closest geodetic station should be used. Rapidy deforming plate boundary zones: e.g. North of Nadzab and Lae, the entire Gazelle Peninsula and Southern New Ireland are very seismically active and also have rapid aseismic (slow creep) deformation with baseline changes of a few centimetres each year even over a few kilometres. The baseline from Unitech Lae to Hobu a few kilometres north is shortening at 5 cm/yr. Volcanic activity and large earthquakes result in significant surface deformation. The November 2000 earthquake swarm (up to Magnitude 8.0) near southern New Ireland resulted in lateral displacements of 5-6 metres, with Tokua some 80 km from the epicentre of the lateral strike-slip event being displaced by 1m.

What strategies can surveyors use to connect to PNG94?

Static GPS and PPP (OmniStar. AUSPOS etc..) are two of the principal methods (other than classical terrestrial methods) that surveyors in PNG can use to connect their surveys to PNG94. Dual-frequency GPS receivers can typically measure baselines of up to 50 km with a precision of less than 20mm using a broadcast ephemeris. Baselines measured by single-frequency receivers and RTK methods are typically limited to 10 km or less. GPS surveys in PNG should consider the following points:

The base station and rover station should be on the same plate (i.e. the baseline between them should not cross a plate boundary as shown in figures 1 and 2). In areas or rapid relative deformation, surveyors must use the closest geodetic station available to them as use of stations even 10 km from the project area may have undergone significant relative deformation between 1994 and the epoch of measurement.

If a baseline measurement has to be made across a plate boundary or deforming zone, the ITRF coordinates at the epoch of measurement of the base station should be computed first using the site velocity. The coordinates of the rover station are then converted back to PNG94 using the site velocity computed from the plate motion model.

ITRF coordinates derived by AUSPOS or OmniStar need to be converted to PNG94 using the site velocity computed from a PNG plate motion model, or by comparing PPP coordinates with the closest primary PNG94 station in order to estimate any corrections in the local area

The following expressions can be used to compute PNG94/PNGMG coordinates from ITRF UTM at different epochs:

$$\text{Easting(PNG94)} = \text{Easting}(t) + \text{Velocity(E)} * (1994 - t) + \Sigma qe$$
$$\text{Northing(PNG94)} = \text{Northing}(t) + \text{Velocity(N)} * (1994 - t) + \Sigma qn$$

Where;

t = Epoch of measurement in decimal years
(e.g. 31st July (day of year 213) 2008 is 2008 + 213/366 = 2008.582)
Easting(*t*) is the ITRF2000/WGS84 Easting at the epoch of measurement (at time ***t***)
Northing(*t*) is the ITRF2000/WGS84 Northing at the epoch of measurement (at time ***t***)
Σqe and **Σqn** are the total coseismic and postseismic displacements (East and North components) between epoch ***t*** and 1994
Velocity(E) and **Velocity(N)** are the site velocity components in Easting & Northing, in metres per year

Conclusions - How can be PNG94 be improved?

PNG94 is in urgent need of improvement. The risk to multi-billion dollar resource projects and the PNG economy by having errors of several metres in the geodetic datum is not well appreciated either within or outside the spatial science professions. Many projects in PNG have already suffered costly losses and delays resulting from uncertainties in the datum. Accurate survey information underpins the viability of the PNG economy by providing the homogeneous spatial framework, necessary for the definition of land boundaries and integrated engineering projects. PNG94 needs to account for the significant tectonic deformation occurring in PNG and it needs to be made more accessible to surveyors. Up-to-date coordinate listings and station data should be made freely available over the internet, in order to encourage compliance.

The existing network of geodetic monitoring sites (Figure 2) can be used to densify the existing datum. In order to make PNG94 more accessible to surveyors, geodetic stations should be located in more secure areas with good sky visibility such as airports, helipads and the grounds and roofs of government or commercial offices. Stations located on remote mountain tops, gardens and public areas are generally unsuitable because of the high risk of destruction, lack of security, difficulty of access and lack of maintenance. Fortunately most airstrips in PNG already have at least one geodetic station within their perimeters, though many do not yet have sufficiently accurate PNG94 coordinates. To facilitate RTK surveying, base stations and antenna masts can be established within offices with power supply, referenced to the local geodetic network of ground stations. Only several hours of GPS observations are required on these stations in order to update coordinates to centimetre level accuracy. Many resource companies would benefit from a collaborative effort between their survey consultants and the National Mapping Bureau Geodetic section to establish PNG94 in their operational areas.

An online calculator and software package should be developed to enable spatial professionals to extract a site velocity using PNG specific plate models and a database of historical earthquake displacements, by entering site coordinates (either ellipsoidal or UTM) or to compute coordinates at a specific epoch. Ultimately, an online service such as PNGPOS could be developed to enable users to submit GPS data to a central processing facility in order to produce PNG94 coordinates in much the same way as AUSPOS currently does in Australia.

In order to make these datum improvements a reality PNG surveyors need greater exposure to well targeted CPD workshops and seminars in order to update their professional skills, especially with the use of GPS. Ultimately, it will be these surveyors who will take PNG forward.

References

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