CORS Network and Datum Harmonisation in the Asia-Pacific Region

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SUMMARY

It is anticipated that the roll-out of Continuously Operating Reference Station (CORS) networks in the Asia-Pacific Region will result in very significant improvements in the Positional Uncertainty (PU) attainable by surveyors using Global Navigation Satellite Systems (GNSS) positioning technology. Improvements will be noticeable in remote and under-developed areas, particularly with regard to cadastral (e.g. customary land) and resource sector surveys. The basis for any regional CORS network is usually the latest realisation of the International Terrestrial Reference Frame (ITRF). As ITRF coordinates are kinematic as a result of global plate tectonics and localised tectonic deformation, it is necessary to relate kinematic ITRF coordinates of the CORS monuments to a static datum using kinematic parameters that model this deformation. In rigid plate settings (e.g. Australia and the Pacific Plate), a simple parameterisation can be applied across a wide region while still maintaining precision on a decadal timescale. Many countries in the Asia-Pacific Region (e.g. the Pacific Rim), however, are subject to significant internal tectonic deformation across plate boundaries and active fault zones. As a consequence of this, rigid-plate models have limited application in these countries.

This paper presents a datum densification and transformation strategy that can be implemented in tectonically active regions that have a limited geodetic infrastructure. Such a strategy is important to maintain the integrity of a static datum and derived legal coordinates on a decadal timescale while at the same time accounting for regional tectonic and coseismic deformation.

Transformation strategies presented are derived from models of plate, microplate and rigid crustal block rotations; deformation models and episodic parameters that account for coseismic and postseismic deformation. Methods of implementation at both CORS operator and user levels are also described.

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1. INTRODUCTION

The proliferation of CORS networks, precise point positioning (PPP) and the increased precision of pseudorange positions is presenting new challenges to surveyors and other users of these services. The effects of global tectonic deformation degrade the repeatability of positional coordinates derived from these systems if the deformation between subsequent epochs is not modelled correctly. The practical implications are quite serious. Centimetre accurate point positions related to a kinematic ITRF for fixed locations (e.g. survey control, cadastral boundaries, fixed assets and resource sector surveys) change by up to 8 cm per year (e.g. Kwajalein in the Western Pacific (derived from Altamimi *et al.*, 2007)) due to the effects of underlying tectonic deformation of the rigid plate. Larger coseismic offsets of up to several metres also occur resulting from major earthquakes (e.g. ~6.5 m observed as a result of the M_w 9.15 Sumatra-Andaman Earthquake on the 26th December 2004 (Chlieh *et al.*, 2007)). These unmodelled effects impact on the usability of any PPP technique based on a kinematic ITRF, within a localised static reference frame, and CORS networks if the baseline between stations changes and NRTK algorithms need to be recomputed.

The Asia-Pacific region encompasses a highly complex tectonic environment where the Pacific, Australian, Eurasian Plates in conjunction with numerous microplates collide around the western Pacific rim. Many countries in the region (e.g. Indonesia, Japan, Papua New Guinea and New Zealand) straddle two or more major plate boundaries and the resulting deformation impacts significantly on the integrity of their respective datums and CORS networks.

While surveys have been limited in scope, and constrained by existing local geodetic networks, tectonic deformation has only been of significance where surveys have crossed active faults, and the magnitude of the deformation has been sufficiently significant to degrade the network precision. New Zealand was one of the first countries to implement a semi-dynamic datum incorporating a deformation model to mitigate the effects of tectonic deformation on the new national geodetic network in New Zealand, NZGD2000, (Blick *et al.*, 2006). Recently, Japan has adopted a similar strategy (Tanaka *et al.*, 2007). In Papua New Guinea, a slightly different approach has been adopted, where models of microplate motion constrained by site velocities of geodynamic monitoring stations are used for datum computations across internal plate boundaries (Stanaway; 2004, 2008).

This paper presents a practical strategy for countries within the Asia-Pacific region to modernise their geodetic datums, establish CORS networks within the framework of the Asia-Pacific Reference Frame (APREF) and the International GNSS Service (IGS), and to better parameterise transformations from ITRF to a static datum with a view to mitigating the effects of global and localised tectonic deformation on national datums and CORS networks.

2. STATUS OF GEODETIC DATUMS IN THE ASIA-PACIFIC REGION

Many countries in the Asia-Pacific Region have yet to modernise their geodetic datums to a geocentric realisation of ITRF. Table 1 shows a selection of countries in the region which have already adopted an epoch of ITRF as the basis for their national datum. Many datums in the region that are not aligned with ITRF are usually derived from astronomical observations or earlier artificial satellite based datums (e.g. WGS72). These datums are offset from ITRF by up to several hundred metres and the relationship between the two datums is usually unknown at a centimetre level of precision.

Country	**Datum**	**Realisation**	**Reference Epoch**
Australia	GDA94	ITRF92	1994.0
China	CTRF2000	ITRF97	2000.0
Indonesia[1]	DGN1995	ITRF2005	1995.0
Japan	JGD2000	ITRF94	1997.0
Malaysia	GDM2000	ITRF2000	2000.0
New Zealand	NZGD2000	ITRF96	2000.0
Papua New Guinea	PNG94	ITRF92	1994.0
South Korea	KGD2002	ITRF2000	2002.0

Table 1. Selection of ITRF aligned datums in the Asia-Pacific Region

2.1 APREF and the benefits of establishing an ITRF derived geodetic datum

All modern GNSS use geodetic reference systems closely aligned with ITRF (e.g. the US GPS system's WGS84). The latest realisation of ITRF (ITRF2005) has a precision of a few millimetres (Altamimi *et al.*, 2007) and forms a robust basis for any regional or national geodetic datum. As the ITRF continues to stabilise, it is anticipated that differences between future realisations of ITRF will differ from one another by less than a few millimetres at a common epoch. Transformations from instantaneous ITRF to a fixed reference epoch of ITRF are straightforward using a measured ITRF site velocity for each station defining the geodetic network, by using a deformation model, or by using a model of rigid plate motion to compute a site velocity.

A centimetre accurate geodetic datum forms the spatial foundation for any economic activity reliant on spatial data (cadastral surveys, urban and regional planning, land administration, resource extraction, agriculture, engineering, transport, asset management and navigation) as well as environmental monitoring, search and rescue operations and geophysical hazard mitigation. Sharing of data is possible without the need for any transformation, if all users (e.g. different government departments and the private sector) are using the same datum. The resulting economic savings and benefits are immense.

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[1] Roberts and Stanaway, 2009

Disparities between different geodetic datums used concurrently pose significant technical challenges and risks. Neighbouring jurisdictions (e.g. countries, states and regions) that use different datums find it difficult to share geodetic resources and integrate spatial information, especially in border regions. Large differences in datums also pose risks for accurate navigation and can hamper search and rescue operations if there is any confusion as to which datum is used. A regionally consistent geodetic datum allows for rapid reinstatement of property boundaries where surface evidence has been lost as a result of a natural disaster. The relatively small investment made by nations in their geodetic infrastructure can reap very significant economic benefits as well as reducing loss of life and economic losses arising from natural disasters.

The Asia-Pacific Reference Frame (APREF) project endeavours to provide a mutually beneficial support framework for countries in the Asia-Pacific Region to densify ITRF, develop geodetic datums and CORS networks to support regional development, monitor geophysical hazards and sea level change as well as to coordinate geodetic activities across the region. Successful implementation of the APREF will depend upon the active participation of the member countries involved in the project. Ideally each member nation should operate between 1 and 5+ CORS stations within the APREF (Dawson & Hu, 2009). This approach will significantly improve the definition of ITRF regionally.

3. STEPPING TOWARDS AN ITRF BASED DATUM – TECHNICAL ISSUES

Countries in the Asia-Pacific region which adopt a common reference epoch of ITRF as a basis for their national datums can overcome many of the integration issues described previously. Adopting a common reference epoch also enables seamless interaction of CORS networks and spatial data in border regions.

3.1 Practical steps to establish an ITRF based geodetic datum

Most countries in the Asia-Pacific region already have a number of CORS stations in operation. These are typically operated by government geodetic and geophysical agencies, universities, or by the private sector (e.g. mining and surveying companies). A CORS network forms an ideal basis for a geodetic datum, as a connection to the ITRF can be established simply by analysis of each site's archive of GNSS data. At least five days of continuous data are required to compute the ITRF coordinates of the CORS station to a precision of 3 mm. The longer a station has been operating, the more precise the estimate of the ITRF site velocity (and derived coordinates of a reference epoch) will be. As a rule of thumb, a minimum of two years continuous operation is required to estimate an ITRF velocity with a precision of 1 mm/yr. The datum reference epoch should be chosen close to the date of measurement of the network, using the latest realisation of ITRF.

Many existing CORS stations are not fixed to geologically or structurally stable monuments, or are adversely affected by multipath (nearby trees, buildings etc..) and so geodetic ties are required to a nearby network of stable ground monuments not as adversely affected, in order to verify the stability of the CORS station. A nationwide network can be extended by establishing CORS stations at suitable places with good sky visibility such as airports, meteorological stations, observatories, offices and near tide gauges. Datum densification can be achieved by re-use of existing geodetic monumentation and construction of new monuments in areas with good sky visibility, security, stable ground and access (e.g. airports). The distribution of CORS sites within each nation should provide well distributed geographical coverage with higher concentrations in areas of urban development, resource extraction, agriculture and near geophysical hazards (active faults, volcanoes etc.). Smaller tectonic plates and crustal blocks should have at least two CORS stations located within the stable part of the plate with regular campaign style connections to a network of stable marks in order to better define the motion of the plate within ITRF. Stations used for geodynamics studies can also be adopted as datum monuments, as they usually have a history of campaign style measurements and an ITRF site velocity for the station can be computed.

A tier-based hierarchy of CORS stations could be implemented based on the quality of the site and monumentation (Rizos, 2008). In the hierarchy proposed by Rizos, ultra-stable Tier 1 stations contribute to the IGS network. Tier 2 stations are also ultra-stable CORS stations and are used primarily for national datum monitoring and densification (e.g. the AusCORS network in Australia). Tier 3 CORS are fit-for-purpose CORS stations usually run by private operators (e.g. mining companies) or regional authorities, and may not be necessarily stable enough, or have the sky visibility and low multipath environments required for datum maintenance and geodynamic monitoring.

In order to compute transformation parameters between earlier datums and any new datum, as many primary control points used to define the earlier datum as is practicable should be reobserved. Least squares analysis of the coordinates of stations common to both earlier and modern datums can be used to estimate a reasonably robust set of transformation parameters and a distortion model to relate the datums to one another. This is a much more preferable approach than using off-the-shelf transformation models (e.g. GIS software) which often give unrealistic precision for any datum transformations unless transformation precision indicators based on earlier analysis of the datums are provided.

Tide gauges should be connected to the network so that the relationship between the ITRF ellipsoid and Mean Sea Level (MSL) can be established at each gauge. The EGM2008 derived geoid model provides unprecedented precision (NGIA, 2008) and can be adopted as a national geoid model, however the offsets between local MSL, other height datums and the EGM2008 derived geoid surface should be established and applied to the model (Stanaway, 2009). A purely ellipsoidal height datum cannot be used for engineering projects where the gravity field is important (e.g. hydraulic flow in pipes or open channels).

3.2 Advantages and disadvantages of adopting a fixed reference epoch for ITRF

Fixing ITRF at a reference epoch in order to realise a geodetic datum is essential if the datum is to be kept in alignment with any spatial data derived from it. Unless spatial data (e.g. legal cadastral coordinates, assets, resources, GIS and hard-copy products such as maps and plans) are continuously updated, using kinematic ITRF as a working datum will mean that the underlying geodetic framework which underpins the spatial data will become increasingly misaligned as a function of time due to plate tectonics. This is not a desirable situation with very significant economic costs and risks associated with it.

Nevertheless, monitoring of earth deformation (e.g. volcanoes, active faults, landslides, land subsidence and tide gauge stability) require monitoring sites to be free of constraint. Modelling of GNSS orbits also require that the CORS stations used in the modelling process use instantaneous ITRF coordinates. This is an important consideration where a CORS network is used to provide a Networked Real-Time Kinematic (NRTK) service. As tectonic deformation rarely exceeds 10 mm a month, the most recent weekly (or fortnightly) ITRF solution for the CORS station can be used for orbit analysis. RTCM 3.1 supports a variety of transformation options in the message stream (1021-1028). Ideally, the broadcast station coordinates (Message 1009 and 1010) should be the current kinematic ITRF coordinates and the offset computed to the local static datum should be included in the RTCM transformation message stream. Message 1028 has been reserved for global to plate fixed transformations. In rigid plate settings, the parameters in message 1028 can be static if they define the Cartesian rotation rates of the Euler pole between ITRF and the rigid plate on which the network is fixed. This is discussed in more depth later.

The most practical solution is for a national CORS based geodetic network to use instantaneous ITRF to monitor earth deformation and to compute regional GNSS orbits for NRTK. The instantaneous ITRF coordinates would be transformed to the reference epoch of the static datum using a velocity or deformation model to support all other uses that require a static reference system. In a deforming CORS network, rover receivers would need to be equipped with a deformation model algorithm in order to recover the static datum.

3.3 Mitigating the effects of internal deformation on a national geodetic network

A precision of better than a centimetre for instantaneous ITRF coordinates is now routinely achievable for stations in a CORS network. Whenever the magnitude of internal deformation of the CORS network exceeds this precision, holding station coordinates fixed will degrade the quality of any network analysis unless the deformation is modelled.

CORS networks fixed to rigid tectonic plates are usually not subject to internal relative deformation of any significance, however networks straddling active faults in plate boundary zones require deformation across the network to be modelled during any network analysis. An instantaneous ITRF approach comes to the fore in these situations. Any network analysis (and GNSS orbit modelling) is done using instantaneous ITRF coordinates at the mean epoch of measurement and a deformation model is then used to compute an *apriori* ITRF site velocity for any new station in the network. This site velocity is then used to compute coordinates for any new station at the reference epoch of the static datum.

Any deformation model used in this way should be strongly constrained by geodetically derived site velocities (e.g. from long established CORS stations fixed to geologically stable monuments). Fault locking parameters, Finite Element Models (FEM) and interpolative methods can be used to estimate a site velocity anywhere else in the network. The CORS network and repeat measurements of stable monuments can also be used to continuously improve the precision of any deformation model used and represents a good example of a positive feedback loop.

Coseismic and postseismic deformation resulting from earthquakes also need to be modelled in the context of a static or semi-dynamic datum. For each CORS site displaced during an earthquake, the coseismic deformation can be estimated quite quickly and a coordinate step "patched" into the deformation model for each station. This step-wise technique has already been implemented in the ITRF2005 set of station coordinate (SSC) solution (Altamimi *et al.*, 2007). These patches or steps are added cumulatively to the site velocity model derivation when computing net deformation between any measurement epoch and a reference epoch. Postseismic and slow-slip event deformation vary with time and are more difficult to deal with in the modelling process as these cannot be implemented directly as a stepwise function during the period of deformation. The simplest technique (if the deformation is small) is to add the net postseismic deformation to the associated coseismic term and quarantine any static datum computations for a defined period after the earthquake. Alternatively, numerous steps can be introduced to reproduce the postseismic deformation to preserve Positional Uncertainty (PU) in the postseismic period. This approach is recommended if the magnitude of the postseismic deformation is large, geographically widespread or long in duration (e.g. the 26th December 2004, Andaman-Sumatra Earthquake).

In an NRTK environment, deformation between instantaneous ITRF and the reference epoch will need to be modelled for each rover location. A deformation model can be implemented via the rover software, or a deformation correction can be computed for each VRS position and a location specific correction sent to the rover via an RTCM message.

Where vertical deformation of a CORS site is significant (for example in an urban area where groundwater removal is occurring), the vertical site velocity needs to be modelled so that vertical positions constrained by the site are not degraded.

3.4 Using Global PPP and post-processing services in a static datum environment

Global PPP systems and post-processing services such as OmniStar, AUSPOS, OPUS and NRCan, provide instantaneous ITRF coordinates which will be invariably misaligned from any static realisation of ITRF, unless the position is also explicitly stated in a static datum (e.g. NAD83 for OPUS and NRCan; GDA94 for AUSPOS). Using a simplified plate based transformation model can enable the ITRF solution to be related to a fixed epoch. If such a transformation strategy could be implemented, users could either choose a static epoch, or use a database of existing datums with defined reference epochs and origin translations. A polygon file for each rigid plate can define the extents of rigid plates and deforming zones, so that the correct parameter set and deformation model can be implemented depending upon the user's position. Alternatively, datum specific online processing services could be developed, so that users are spared the need to perform additional transformations. An APREF online processing service could be developed in the future which detects which datum should be used based upon the location of the supplied data.

3.5 Access to the datum

Successful implementation of an integrated CORS and datum strategy is dependent upon practicing surveyors having access to the datum and CORS data. Surveyors connect their surveys to the datum by either observing coordinated monuments close to their survey area, or by obtaining GNSS data from the nearest CORS station. Many geodetic and survey agencies provide coordinate data and monument sketches through a web-portal. Free access to this information encourages compliance. New Zealand provides an excellent free, open-access geodesy web-portal (http://www.linz.govt.nz/geodetic/geodetic-database/index.aspx) for surveyors to obtain geodetic control information and would make an ideal template for other jurisdictions in the Asia-Pacific region to follow.

Access to CORS data is typically either real-time (via single-base RTK or NRTK), or by later download of data in Receiver Independent Exchange Format (RINEX) for post-processing of observations. Victoria (Australia) has a well developed fee-based CORS network (GPSnet) that can be used as a model for RTK and NRTK systems. RINEX data with a 30 second epoch interval should be made freely available to the APREF and IGS data centres, however data at a more rapid epoch interval can be made available using a similar fee structure to NRTK data. Again, New Zealand has a good portal for free access to 30 second RINEX data from its network (http://www.linz.govt.nz/geodetic/positionz/index.aspx).

Online post-processing services should be localised, so that users who submit RINEX data can obtain a position report in the local static datum, rather than a somewhat meaningless kinematic ITRF. The Australian AUSPOS and Canadian NRCan services provide excellent services free-of-charge and are a good model for implementation elsewhere (e.g. APREF).

3.6 Datum updates - how often?

Earlier realisations of ITRF such as ITRF92 and ITRF94 have inherently lower precision than more recent realisations such as ITRF2000 and ITRF2005. The Global GPS tracking network in the early 1990s was still quite sparse and orbit modelling and geodetic analysis software was not yet as refined as it is today. National datums based upon these earlier realisations (e.g. GDA94 in Australia) have precisions of several centimetres rather than millimetres as a consequence, with most of the error concentrated in the ellipsoidal heights (Stanaway and Roberts, 2009). Earlier datums have also often incorporated lower quality campaign style GPS measurements and terrestrial measurements into the geodetic analysis which have resulted in station residuals of up to a few metres, when compared to a more precise position computed directly from the zero order (fiducial) network. Such a situation is not sustainable with the increased and widespread use of precise point positioning and CORS networks. It is illogical to shift a high precision coordinate derived directly from a zero order fiducial network to fit an imprecise realisation of the same datum! Roberts *et al.* (2009) addresses this issue and describes the motivation behind the Intergovernmental Committee for Surveying and Mappings' (ICSM) move to Positional Uncertainty as a new quality measure for positioning.

In the first instance, high order stations with high residuals should have new coordinates reassigned to them (a readjustment in the classical sense) to remove any inconsistencies, or the order should be downgraded to reflect the higher PU. In the second instance, zero order fiducial stations could be recomputed using the latest realisation of ITRF at the original reference epoch, if the PU is improved significantly by doing so.

Arbitrarily changing the epoch of an ITRF based datum to keep a static datum in alignment with instantaneous ITRF, however, has very serious implications. The economic costs and risks are likely to be very substantial (Roberts and Stanaway, 2009). The cost of implementation (software changes, legal aspects such as amendments to survey Acts and Regulations, transformation of existing hardcopy and spatial data, public awareness, professional education and implementation, reprinting of hard-copy spatial products such as maps and street directories) should be considered. There is also the issue of how data captured at different datum epochs can be integrated seamlessly. Furthermore, the small magnitude of difference between subsequent epochs of the datum will make it very difficult to positively identify and discriminate between the different epochs in the absence of metadata.

Provided that adequate kinematic transformation models are incorporated into GNSS devices at the user level, there shouldn't be a need to keep a static datum in constant alignment with instantaneous ITRF.

4. TRANSFORMATION FROM ITRF TO A STATIC DATUM

Transformations from kinematic ITRF to a static datum are conventionally done by either using the site velocity (measured directly or computed from a plate motion model) to compute the displacement between the reference and current epochs (1), or by a conformal transformation augmented with time dependent parameters to account for rigid plate motion e.g., Geoscience Australia's 14-parameter model (Dawson and Steed, 2004).

$$\begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} = \begin{bmatrix} X_t \\ Y_t \\ Z_t \end{bmatrix} + \begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \end{bmatrix} \left(t_0 - t\right) \tag{1}$$

where;

(X_0, Y_0, Z_0) are the ITRF Cartesian coordinates at reference epoch,

(X_t, Y_t, Z_t) are instantaneous ITRF Cartesian coordinates at epoch t (epoch in decimal years), and

$(\dot{X}, \dot{Y}, \dot{Z})$ is the ITRF Cartesian site velocity and t_0 is the reference epoch.

Most larger tectonic plates (e.g. the Pacific and Australian Plates) move as a rigid body with almost insignificant intraplate deformation away from the plate boundaries (with the exception of spasmodic and rare intraplate earthquakes) (Beavan *et al*, 2002; Tregoning, 2003). Plate movement is conventionally defined by a rotation rate about an Euler Pole. An Euler pole expressed by the three equivalent Cartesian rotation parameters can be used and difference in epoch can be also be used to relate kinematic ITRF coordinates with a static realisation (Stanaway and Roberts, 2009). While this strategy is not as rigorous as using a 14-parameter transformation, the precision achievable is often several millimetres on a decadal time scale within any rigid plate. A PU of 1 cm is acceptable for the vast majority of spatial applications and the use of only 4 parameters is much easier to implement in generic software systems. By applying an additional 3 translation parameters and a scale parameter, a plate based transformation can also account for any differences in the reference frame origin and scale (2).

$$\begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} = \begin{bmatrix} T_X \\ T_Y \\ T_Z \end{bmatrix} + S \cdot \left[\begin{bmatrix} X_t \\ Y_t \\ Z_t \end{bmatrix} + \begin{bmatrix} \Omega_Y Z_t - \Omega_Z Y_t \\ \Omega_Z X_t - \Omega_X Z_t \\ \Omega_X Y_t - \Omega_Y X_t \end{bmatrix} \cdot \left(t_0 - t \right) \cdot 1\text{E-}6 \right] \qquad (2)$$

where;

(X_0, Y_0, Z_0) are the ITRF Cartesian coordinates at the reference epoch t_0 (in decimal years),
(X_t, Y_t, Z_t) are instantaneous ITRF Cartesian coordinates at epoch t (epoch in decimal years),
(T_X, T_Y, T_Z) is the translation of the reference frame origin (from ITRF to local),
$(\Omega_X, \Omega_Y, \Omega_Z)$ are the Cartesian rigid plate/block rotation parameters (from Table 2), and
S is the reference frame scale factor (from ITRF to local).

Cartesian Plate Rotation parameters for selected plates are listed in Table 2. Further work is needed to better define zones of rigidity (discrete crustal blocks and microplates) within deforming zones by a process of segmentation, so that a plate based model can be used more extensively (Fig. 1).

Plate	**Absolute Pole Cartesian angular velocity**		
	Ω_X (Rad/Ma)	**Ω_Y (Rad/Ma)**	**Ω_Z (Rad/Ma)**
Amurian	-0.000577	-0.002543	0.003904
Australian	0.007354	0.005616	0.005874
Eurasia	-0.000263	-0.002512	0.003791
India	0.006417	0.002572	0.008188
Pacific	-0.002131	0.005052	-0.010565
Yangtze	-0.000929	-0.002590	0.004658

Table 2. ITRF2005 plate absolute rotation poles in the Asia-Pacific Region (Altamimi *et al.*, 2007)

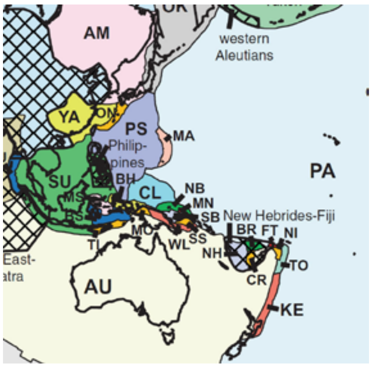

Fig 1. Tectonic plates and microplates in the Asia-Pacific Region (from Bird, 2003)

Country	**Region**	**Plate**
American Samoa		Pacific
Australia		Australian
Brunei		Sunda*
Cambodia		Sunda*
China	SE	Yangtze
	NE	Amurian
	Rest of	Eurasian (def.)
Cook Islands		Pacific
East Timor		Timor*
Fiji		Australian (def.)
French Polynesia		Pacific
Guam		Mariana*
Hong Kong		Yangtze
Indonesia	W. Timor, Flores	Timor*
	Sulawesi (SE), Seram	Banda Sea*
	Sulawesi (N), Buru	Molucca*
	West Papua (NW), Halmahera	Birds Head*
	West Papua (S.)	Australian
	Rest of	Sunda*
Japan	Honshu (N), Hokkaido	Okhotzk*
	Honshu (S), Kyushu	Amurian
	Ryukyu Is.	Okinawa*
Kiribati		Pacific
Laos		Sunda (def.)*
Malaysia		Sunda*
Marshall Islands		Pacific
Micronesia		Pacific
Nauru		Pacific
New Caledonia		Australian
New Zealand	Northland, Waikato (W), Taranaki, S. Island (NW)	Australian
	N. Island (E)	Kermadec*
	Canterbury, Otago, Southland	Pacific (def.)
Niue		Pacific
North Korea		Amurian
Northern Marianas		Mariana*
Palau		Philippine Sea*
Papua New Guinea	S. of Highlands / Owen Stanley R.	Australian
	PNG Highlands	N. Guinea Highlands*
	N. of Sepik River	Sepik Block*
	Huon Peninsula, New Britain	South Bismarck*
	Manus, New Ireland	North Bismarck*
	Bougainville	Pacific
	N. Coast E. of Lae, Trobriand Is.	Woodlark*
Philippines	N. Luzon	Philippines (def.)*
	Rest of	Sunda (def.)*
Samoa		Pacific
Singapore		Sunda*
Singapore		Sunda*
Solomon Islands	Rennell Is.	Australian
	Rest of	Pacific
South Korea		Amurian
Taiwan		Philippine Sea*
Thailand		Sunda*
Tonga		Tonga*
Tuvalu		Pacific
Vanuatu		New Hebrides*
Vietnam		Sunda*
Wallis & Futuna		Pacific

Table 3. Tectonic plates by country and region
(def. indicates deforming zone). *Microplates (Bird, 2003) not yet defined in ITRF2005.

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BIOGRAPHICAL NOTES

Richard Stanaway is an external part-time PhD student at the School of Surveying and Spatial Information Systems at the University of New South Wales. He is also the director of Quickclose, a company which specialises in geodetic datum analysis, high precision GNSS support for industry and surveying software. After graduating from QUT with a surveying degree in 1998, he worked in Papua New Guinea (PNG) as a geodetic and mining surveyor. In 2000, he expanded the Australian National University's geodynamic monitoring network in Papua New Guinea. This work lead him to completing an MPhil at ANU in 2004 looking at the feasibility of a kinematic datum in PNG. During his time at ANU, he also contributed to geodynamics studies in Antarctica and South Australia. In recent years he has provided geodetic support for mining and petroleum operations in PNG and geodetic validation for airborne laser scanning surveys in both Australia and PNG.

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