A Simplified Parameter Transformation Model from ITRF2005 to any Static Geocentric Datum (e.g. GDA94)

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The motivation

Kinematic (Dynamic) Datums
(e.g. ITRF and WGS84)

are most likely to be incompatible
with a "Static"
Spatial Data Infrastructure

Kinematic Datum implications

ITRF & WGS84 Coordinates
of "fixed" locations
(e.g. survey control,
cadastral boundaries, roads)
change by up to 100 mm/yr
due to motion of the
underlying tectonic plate

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Kinematic Datum issues

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The big issue

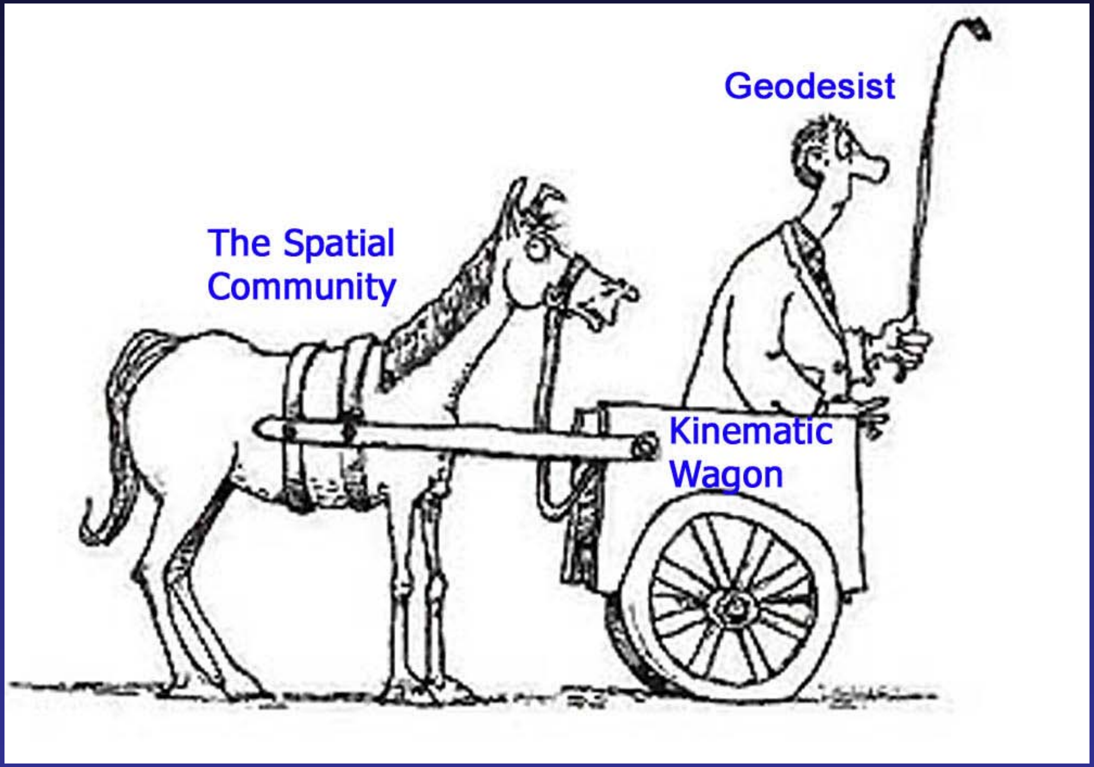
How can kinematic spatial data gathered at different epochs be seamlessly integrated ***(e.g. in a GIS or legal coordinate system)?***

Example: Epoch missing in metadata!

GNSS Point Positioning precision is sensitive to tectonic motion (i.e. handheld GNSS after c.2015)!

Most users and <u>surveyors/GIS professionals</u> are unaware of these problems!!

Kinematic coordinates or sensible parameters?



Who is driving whom?

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A solution?

Transformation from a kinematic ITRF to a local static datum (reference frame) can be achieved by parameterisation

Parameters can be encoded into GNSS and GIS software, so that users do not “see” coordinate changes over time (tectonic motion is modelled)

Existing WGS84 <-> local parameters (e.g. NGA) can be augmented with kinematic terms

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Precision of absolute positioning

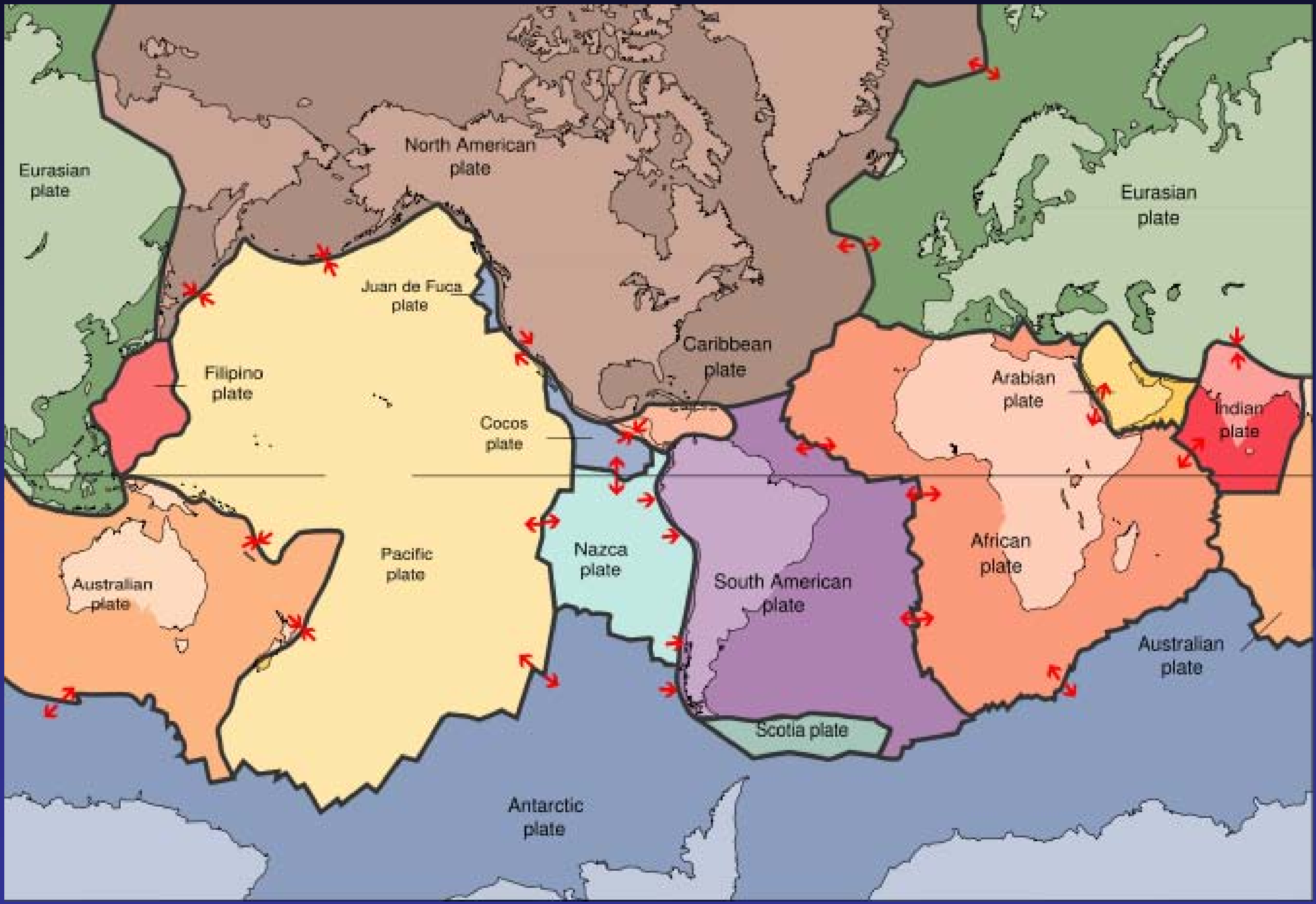
Sensitive to tectonic deformation

Service	ITRF precision	Processing method	Latency	Datums
AUSPOS	10-20 mm (24 hr dataset)	Double Differencing	Post processed (30 min-2 hrs)	ITRF2005 GDA94
NRCan	10-20 mm (24 hr dataset)	Point Positioning (using IGS orbit & clocks)	Post processed (1 min-10 min)	ITRF2005 NAD83(CSRS)
OPUS	10-20 mm (24 hr dataset)	Double Differencing	Post processed (15 min-2 hrs)	ITRF2005 NAD83(NSRS) SPCS
OmniStar -HP	70-100 mm	Double Differencing	RTK (20-30 mins)	ITRF2005 User defined
OmniStar -VBS	500-1000 mm	Double Differencing	RTK (5-10 mins)	ITRF2005 User defined
➔ GNSS (PP only)	3000-8000 mm	Pseudorange Point Positioning	Real-time	WGS84 User defined

Sensitive if sub metre precision attained c. 2015

A selection of popular global positioning services

Developing a plate transformation model



Principal tectonic plates

http://commons.wikimedia.org/wiki/File:Plates_tect2_en.svg

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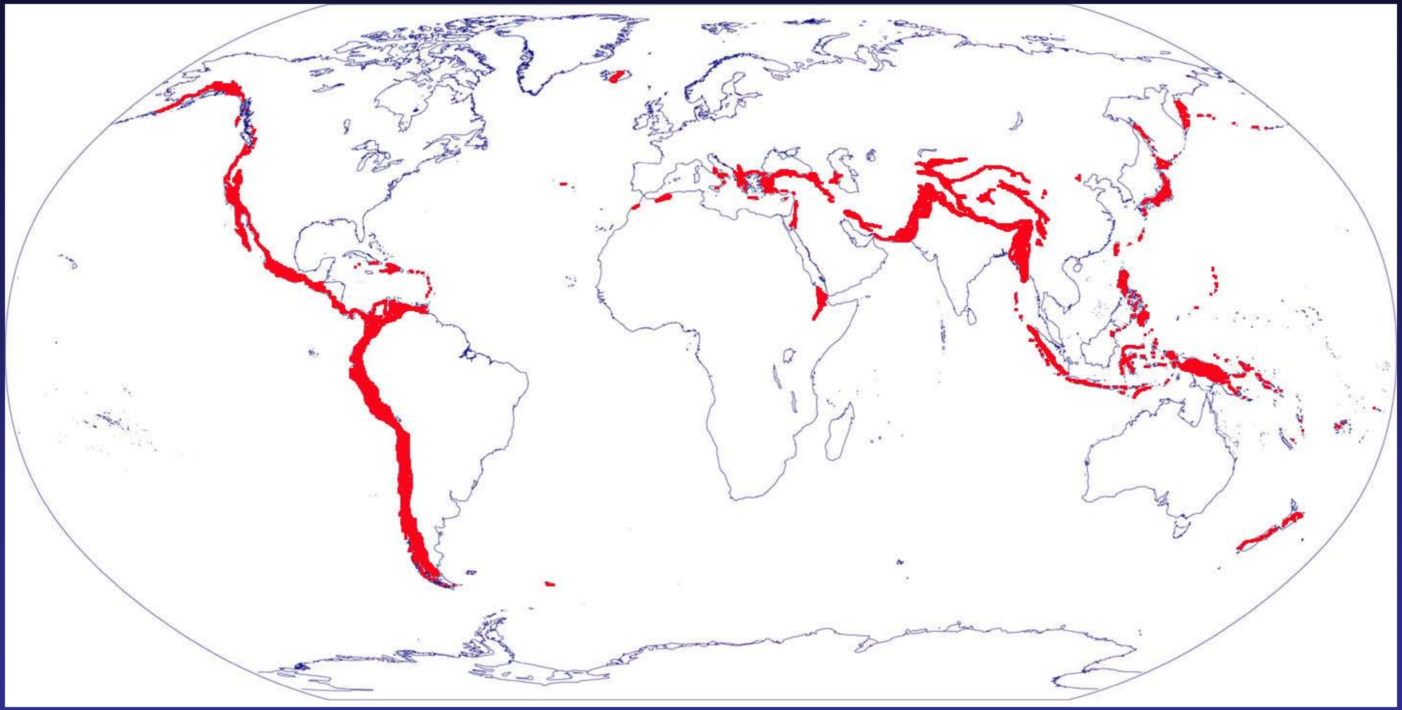
Deforming zones (plate boundaries)



Deforming zones highlighted in red
(~6% of Earth's surface)

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Recent plate motion models

Author / Reference	Plate Model	No. of Rigid Plates	No. of Deforming Zones	Fixed Plate	Input Data
De Mets *et al.*(1990)	NUVEL-1	14	0	Pacific	Geological
De Mets *et al.*(1994)	NNR-NUVEL-1A	14	0	Absolute	Geological
Sella *et al.*(2002)	REVEL2000	19	0	Absolute	mostly GPS
Bird (2003)	PB2002	52	13	Pacific	Geol. + Geod.
Kreemer *et al.*(2006)	GSRM-NNR-2	19	0	Absolute	Geodetic
Altamimi *et al.*(2007)	ITRF2005	15	0	Absolute	Geodetic
Drewes (2009)	APKIM2005D	17	5	Absolute	Geodetic

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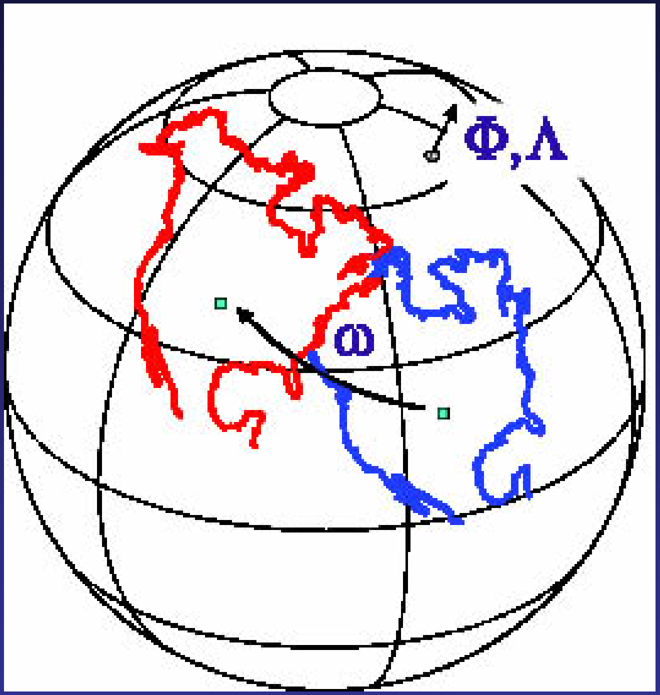
Parameterising rigid plate motion

kinematic parameters → Ω_X Ω_Y Ω_Z



Rigid plate motion defined by Euler pole

Plate	Euler pole of rotation			Equivalent Cartesian angular velocity		
	Φ (°)	Λ (°)	ω (°/Ma)	Ω_X(Rad/Ma)	Ω_Y(Rad/Ma)	Ω_Z(Rad/Ma)
Amurian	56.3	-102.8	0.269	-0.000577	-0.002543	0.003904
Antarctica	59.8	-125.3	0.223	-0.001131	-0.001597	0.003364
Arabia	49.6	5.1	0.579	0.006518	0.000577	0.007700
Australia	**32.4**	**37.4**	**0.628**	**0.007354**	**0.005616**	**0.005874**
Caribbean	39.3	-104.3	0.241	-0.000803	-0.003154	0.002665
Eurasia	56.3	-96.0	0.261	-0.000263	-0.002512	0.003791
India	49.8	21.8	0.614	0.006417	0.002572	0.008188
Nazca	45.1	-101.4	0.642	-0.001569	-0.007752	0.007937
N. America	-4.3	-87.4	0.192	0.000152	-0.003338	-0.000251
Nubia	50.0	-82.5	0.269	0.000394	-0.002995	0.003594
Okhostk	-32.0	-132.9	0.083	-0.000836	-0.000899	-0.000769
Pacific	-62.6	112.9	0.682	-0.002131	0.005052	-0.010565
S. America	-16.8	-129.6	0.121	-0.001290	-0.001557	-0.000610
Somalia	53.7	-89.5	0.309	0.000026	-0.003196	0.004344
Yangtze	59.4	-109.7	0.310	-0.000929	-0.002590	0.004658

ITRF2005 plate absolute rotation poles (Altamimi *et al,*. 2007)

Baseline changes usually insignificant within a rigid plate

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Computing static coordinates in a kinematic system

$$\begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \end{bmatrix} = \begin{bmatrix} \Omega_Y Z - \Omega_Z Y \\ \Omega_Z X - \Omega_X Z \\ \Omega_X Y - \Omega_Y X \end{bmatrix} \cdot 1\mathrm{E}6$$

$$\begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} = \begin{bmatrix} X_t \\ Y_t \\ Z_t \end{bmatrix} + \begin{bmatrix} \Omega_Y Z_t - \Omega_Z Y_t \\ \Omega_Z X_t - \Omega_X Z_t \\ \Omega_X Y_t - \Omega_Y X_t \end{bmatrix} (t_0 - t) \cdot 1\mathrm{E}6$$

Computing site velocity from rigid plate model ➔ **"Static" coordinates at a reference epoch computed from a rigid plate model using site velocity**

4 parameters can link a kinematic datum with a static datum (on a rigid plate):

Ω_X, Ω_Y, Ω_Z and t_0

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Applying a reference frame offset

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

4 parameters can be augmented with 3 translation parameters (to account for reference frame origin differences)

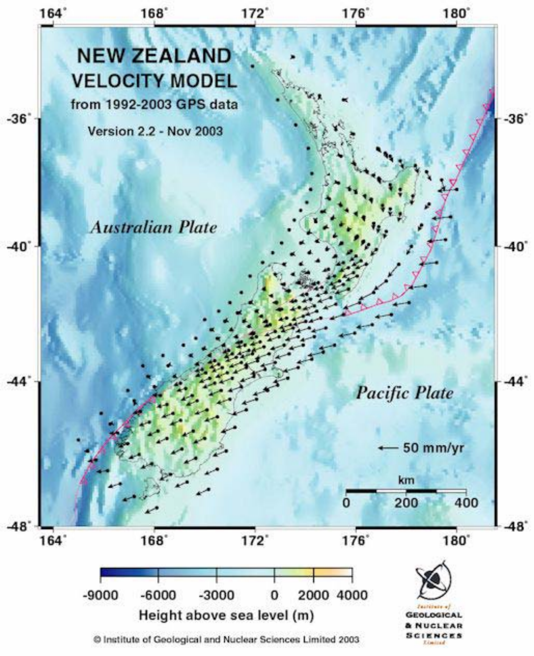
7 parameters

Ω_X, Ω_Y, Ω_Z, T_X, T_Y, T_Z and t_0

What about deforming zones?

Static model requires additional parameters

- Fault locking parameterisation required
- Finite element modelling - higher precison (e.g. New Zealand Deformation model)



Sesimic deformation

- usually localised and non-linear
- requires offset parameters at epoch of event and postseismic terms to be parameterised

A simplified static model usually fails in rapidly deforming zones!
(~6% of the Earth's surface)

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Testing a simplified model in Australia

Australian continent is tectonically stable

Baseline changes across the continent < 2 mm/yr!

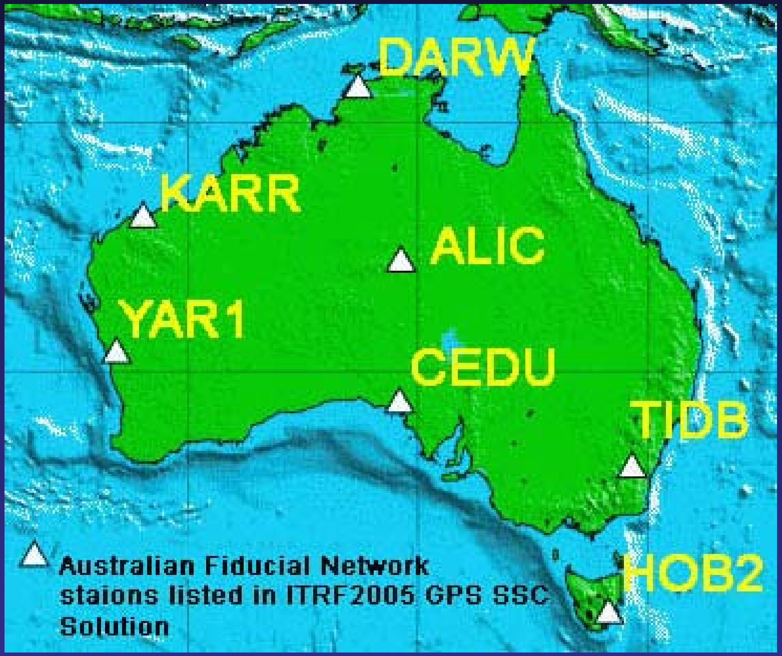
GDA94 is the current datum (ITRF92 at epoch 1994.0)

ITRF to GDA94 transformation currently used:

Geoscience Australia 14 parameter model
(7 parameter conformal transformation + rates of change)
(used by AUSPOS)

How does a 4 or 7 parameter kinematic model compare with the 14 parameter model?

An Australian example - ITRF to GDA94



Location	Site ID	X	Y	Z
Yarragadee	YAR1	-2389025.394	5043316.852	-3078530.860
Tidbinbilla	TIDB	-4460996.069	2682557.144	-3674443.874
Darwin	DARW	-4091358.744	4684606.844	-1408580.642
Hobart	HOB2	-3950071.274	2522415.218	-4311638.511
Karratha	KARR	-2713832.155	5303935.187	-2269515.197
Alice Springs	ALIC	-4052051.767	4212836.216	-2545106.026
Ceduna	CEDU	-3753472.126	3912741.040	-3347961.031

AFN GDA94 coordinates included in the ITRF2005 GPS SSC (IERS, 2007)

Site ID	X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$
YAR1	-2389025.674	5043316.892	-3078530.575	-0.0476	0.0094	0.0499
TIDB	-4460996.239	2682557.081	-3674443.556	-0.0371	0.0006	0.0455
DARW	-4091358.908	4684606.712	-1408580.294	-0.0350	-0.0146	0.0569
HOB2	-3950071.478	2522415.210	-4311638.238	-0.0403	0.0087	0.0408
KARR	-2713832.395	5303935.107	-2269514.854	-0.0445	0.0014	0.0540
ALIC	-4052051.959	4212836.105	-2545105.682	-0.0395	-0.0056	0.0541
CEDU	-3753472.368	3912741.008	-3347960.718	-0.0417	0.0007	0.0511

AFN ITRF2005 coordinates and velocities at epoch 2000.0 (from ITRF2005 GPS SSC)

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Comparing plate models with ITRF2005

Plate Model	Euler pole of rotation			equivalent Cartesian angular velocity		
	Φ (°)	Λ (°)	ω (°/Ma)	Ω_X (Rad/Ma)	Ω_Y (Rad/Ma)	Ω_Z (Rad/Ma)
NNR-NUVEL-1A	33.9	33.2	0.646	0.007831	0.005124	0.006288
REVEL2000	34.9	38.3	0.627	0.007043	0.005563	0.006261
ITRF2005	32.4	37.4	0.628	0.007354	0.005616	0.005874
APKIM2005D	33.2	36.3	0.633	0.007450	0.005473	0.006049

Selected models of Australian plate motion

Model / AFN Station	NNR-Nuvel-1A		REVEL2000		ITRF2005 Model		APKIM2005D	
	ΔE	ΔN	ΔE	ΔN	ΔE	ΔN	ΔE	ΔN
YAR1	0.000	-0.009	-0.014	0.009	0.002	0.000	-0.001	-0.001
TIDB	0.006	0.012	-0.014	0.012	0.003	0.005	0.001	0.008
DARW	-0.007	-0.006	-0.015	0.004	0.002	-0.004	-0.003	-0.003
HOB2	0.009	0.011	-0.014	0.012	0.003	0.005	0.002	0.008
KARR	-0.004	-0.008	-0.015	0.010	0.001	0.000	-0.003	0.000
ALIC	0.001	0.002	-0.013	0.010	0.004	0.002	0.001	0.003
CEDU	0.008	0.002	-0.009	0.010	0.008	0.002	0.005	0.003
Mean Δ	**0.002**	**0.001**	**-0.013**	**0.010**	**0.003**	**0.001**	**0.000**	**0.003**
σ	**0.006**	**0.009**	**0.002**	**0.002**	**0.002**	**0.003**	**0.003**	**0.004**

Predicted minus observed ITRF2005 at epoch 1994.0
(computed from the ITRF2005 GPS SSC solution)

A rigid plate transformation model
can have ~5mm precision within Australia

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How "precise" is GDA94?

Location	Site ID	X	Y	Z
Yarragadee	YAR1	-2389025.388	5043316.836	-3078530.874
Tidbinbilla	TIDB	-4460996.016	2682557.077	-3674443.829
Darwin	DARW	-4091358.698	4684606.800	-1408580.635
Hobart	HOB2	-3950071.236	2522415.158	-4311638.483
Karratha	KARR	-2713832.128	5303935.099	-2269515.178
Alice Springs	ALIC	-4052051.722	4212836.139	-2545106.007
Ceduna	CEDU	-3753472.118	3912741.004	-3347961.025

AFN ITRF2005 coordinates at epoch 1994.0

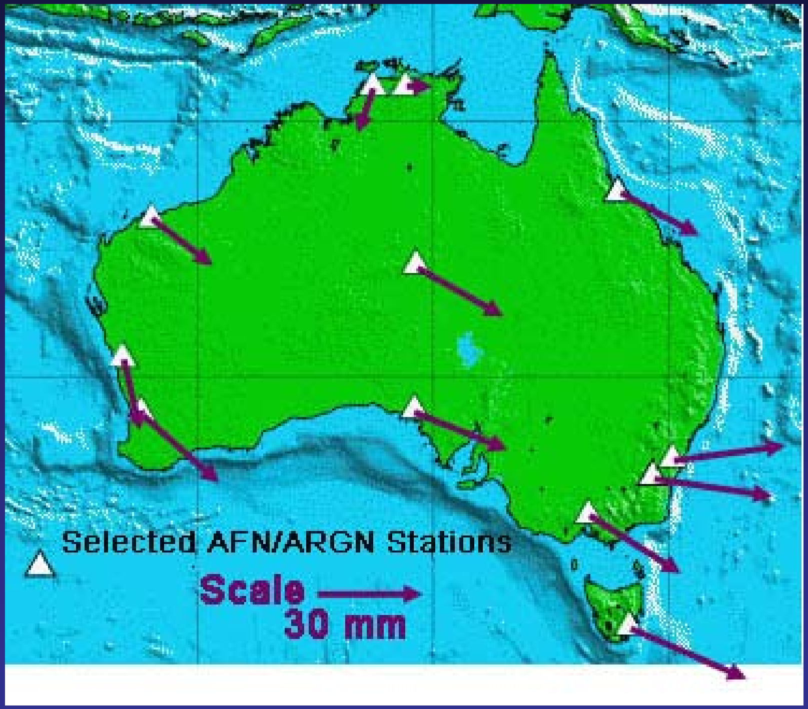
Location	Site ID	Cartesian Coordinates			Topocentric coordinates		
		ΔX	ΔY	ΔZ	ΔE	ΔN	ΔHt
Yarragadee	YAR1	0.006	-0.016	-0.014	0.002	-0.020	-0.009
Tidbinbilla	TIDB	0.053	-0.067	0.045	0.030	-0.010	-0.092
Darwin	DARW	0.046	-0.044	0.007	-0.006	-0.007	-0.064
Hobart	HOB2	0.038	-0.060	0.028	0.030	-0.023	-0.066
Karratha	KARR	0.027	-0.088	0.019	0.016	-0.015	-0.091
Alice Springs	ALIC	0.045	-0.077	0.019	0.021	-0.017	-0.087
Ceduna	CEDU	0.008	-0.036	0.006	0.019	-0.012	-0.030
	Mean Δ	**0.032**	**-0.056**	**0.016**	**0.015**	**-0.015**	**-0.068**
	σ	**0.019**	**0.025**	**0.019**	**0.015**	**0.006**	**0.031**

ITRF2005 epoch 1994.0 minus GDA94

Residuals arise from ITRF92 and ITRF2005 differences

Precision of a 4 - parameter transformation

$\Omega_X = 0.007354$ $\Omega_Y = 0.005616$ $\Omega_Z = 0.005874$ $t_0 = 1994.0$



Location	Site ID	Topocentric residuals		
		ΔE	ΔN	ΔHt
Yarragadee	YAR1	0.004	-0.021	-0.002
Tidbinbilla	TIDB	0.034	-0.005	-0.091
Darwin	DARW	-0.004	-0.012	-0.069
Hobart	HOB2	0.033	-0.017	-0.061
Karratha	KARR	0.018	-0.014	-0.085
Alice Springs	ALIC	0.025	-0.014	-0.088
Ceduna	CEDU	0.026	-0.010	-0.041
	Mean Δ	**0.019**	**-0.013**	**-0.063**
	σ	**0.015**	**0.005**	**0.032**

ITRF2005(1994.0) - GDA94)
for the AFN using a
4-parameter plate transformation
derived from ITRF2005 plate model

4 - parameter transformation can achieve ~25mm precision

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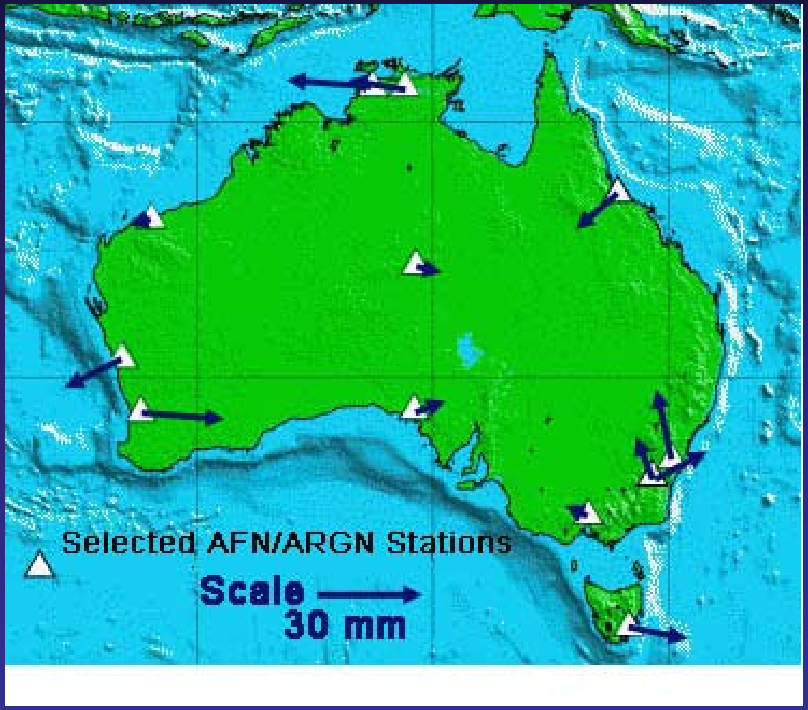
Precision of a 7 - parameter transformation

Ω_X=0.007354 Ω_Y=0.005616 Ω_Z=0.005874 t_0=1994.0
T_X=-0.029 T_Y=0.057 T_Z=-0.017



Location	Site ID	Topocentric residuals		
		ΔE	ΔN	ΔHt
Yarragadee	YAR1	-0.015	-0.008	0.060
Tidbinbilla	TIDB	0.015	0.008	-0.029
Darwin	DARW	-0.023	0.001	-0.007
Hobart	HOB2	0.014	-0.004	0.001
Karratha	KARR	-0.001	-0.001	-0.023
Alice Springs	ALIC	0.006	-0.001	-0.026
Ceduna	CEDU	0.007	0.003	0.021
	Mean Δ	**0.000**	**0.000**	**0.000**
	σ	**0.014**	**0.005**	**0.032**

ITRF2005(1994.0) - GDA94)
for the AFN using a
7-parameter plate transformation
derived from ITRF2005 plate model

7 - parameter transformation can achieve ~15mm precision

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Comparison of models on test data

Location	Site ID	4-parameter topocentric residuals			7-parameter topocentric residuals			14 -parameter* topocentric residuals		
		ΔE	ΔN	ΔHt	ΔE	ΔN	ΔHt	ΔE	ΔN	ΔHt
Mt. Stromlo	STR1	0.030	-0.005	-0.021	-0.003	0.014	0.033	0.000	0.004	0.058
Perth	PERT	0.021	-0.021	-0.108	0.022	-0.002	-0.044	0.003	0.001	-0.054
Jabiru	JAB1	0.004	0.000	0.026	-0.014	-0.003	0.090	-0.008	0.004	0.114
Townsville	TOW2	0.021	-0.012	-0.102	-0.011	-0.010	-0.044	-0.005	-0.013	-0.007
Melbourne	MOBS	0.025	-0.018	-0.056	-0.005	0.003	-0.001	-0.004	-0.009	0.018
Sydney	SYDN	0.032	0.007	-0.049	-0.004	0.021	0.004	0.000	0.013	0.032
	Mean Δ	**0.022**	**-0.008**	**-0.052**	**-0.003**	**0.004**	**0.006**	**-0.003**	**0.000**	**0.027**
	σ	**0.010**	**0.011**	**0.050**	**0.013**	**0.011**	**0.051**	**0.004**	**0.009**	**0.057**

Differences between estimated ITRF2005 at epoch 1994.0 (using the ITRF2005 Model) and GDA94 for selected ARGN stations using simplified plate models and the GA 14-parameter model.

(* ITRF2005 coordinates were first transformed to ITRF2000 at epoch 2000.0 using Altamimi *et al.*, (2007))

Residuals could be reduced to sub 4 mm should GDA94 be readjusted to ITRF2005 at Epoch 1994.0 e.g. GDA94(2010)

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To summarise

Simplified rigid plate transformation models provide cm level precision in rigid plate regions on decadal timescales (~94% of the Earth's land surface)

Additional parameters required in deforming zones

GIS/GNSS software can include kinematic parameters to relate ITRF/WGS84 to local static datums

Kinematic datums should be used for geodetic analysis, datum maintenance and geophysical purposes only

Very significant limitations using a kinematic datum for most fixed earth spatial applications

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