UNSW AUSTRALIA

A Deformation Model to support a Next Generation Australian Geodetic Datum

Never Stand Still | Faculty of Engineering | School of Civil and Environmental Engineering

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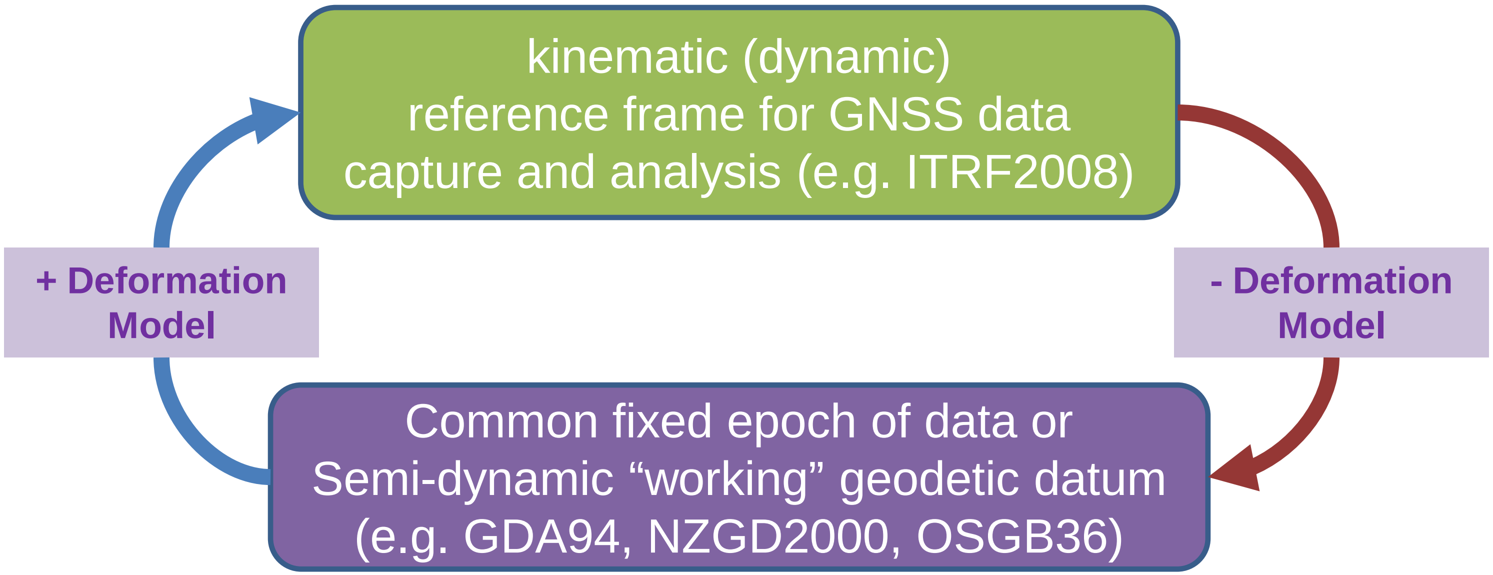
Why do we need a deformation model?

Spatial data collected at different epochs of ITRF or other kinematic (dynamic) datum often needs to be analysed at a common fixed epoch

(to model out global deformation effects within a local reference system)



Drivers for geodetic datum modernisation in Australia

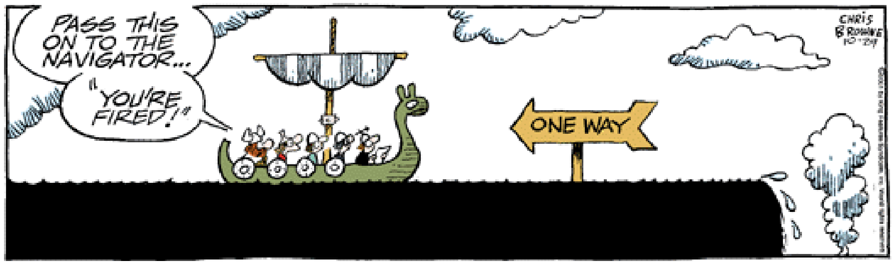
Very rapid increase in GNSS spatial data acquired at different epochs of ITRF (e.g. PPP, SPP, LiDar) – increasing user precision requirements. Non-expert users of real-time positioning tools with 5-10 cm precision.

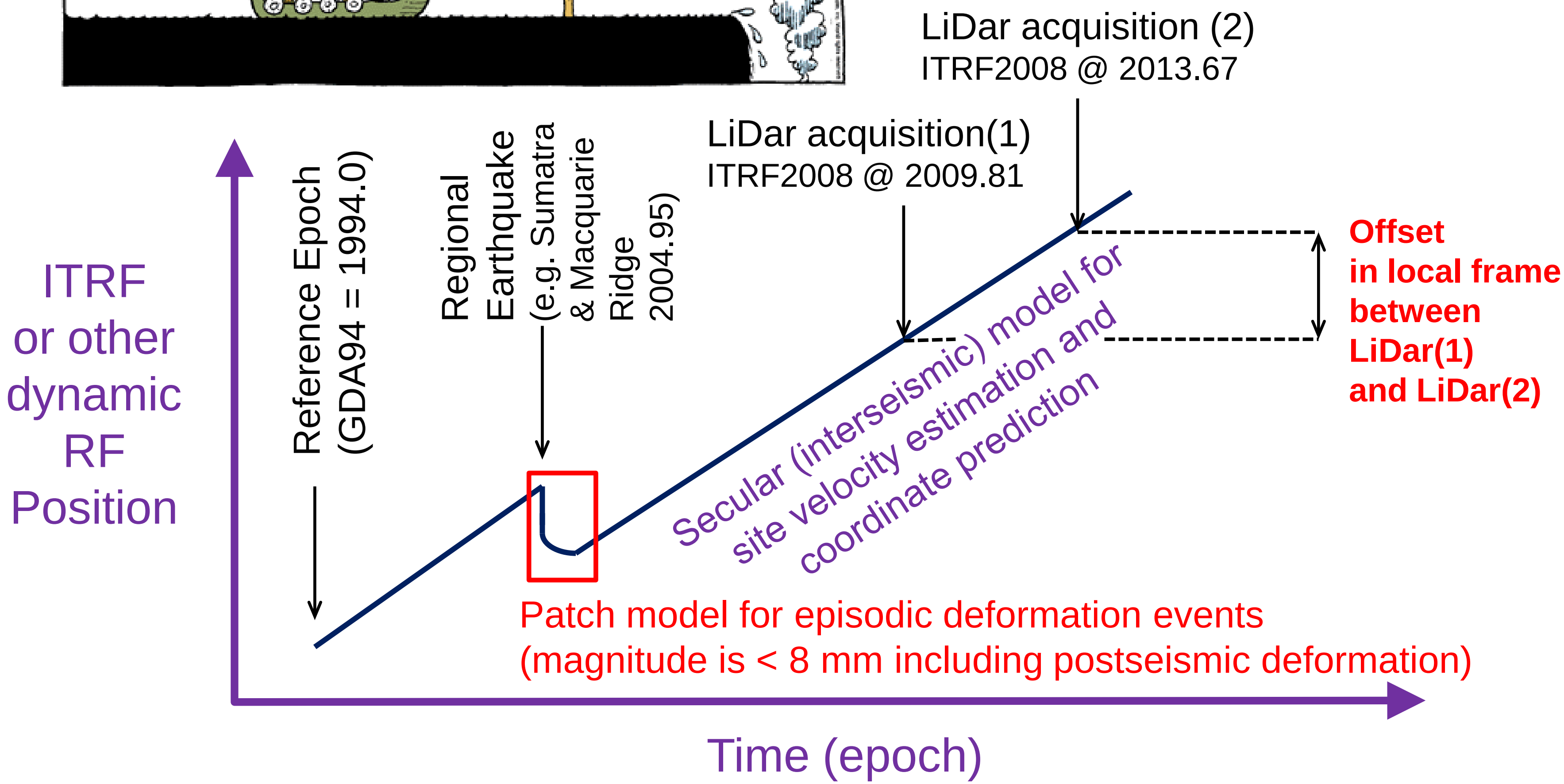
These products are inconsistent with the existing static datum, GDA94 (originally defined as ITRF92 at epoch 1994.0) due to the effects of plate tectonics and uncertainty of 20th century geodetic observations.

GNSS long baseline processing is compromised by holding epoch 1994.0 coordinates fixed if plate rotation and other deformations are unaccounted for between 1994 and now (e.g. GNSS post-processing).

e.g. ITRF2008 @ 2013.5 coordinates differ from GDA94 coordinates by between 1.1 m and1.4 m in many parts of Australia due to plate motion of 60-75 mm/yr

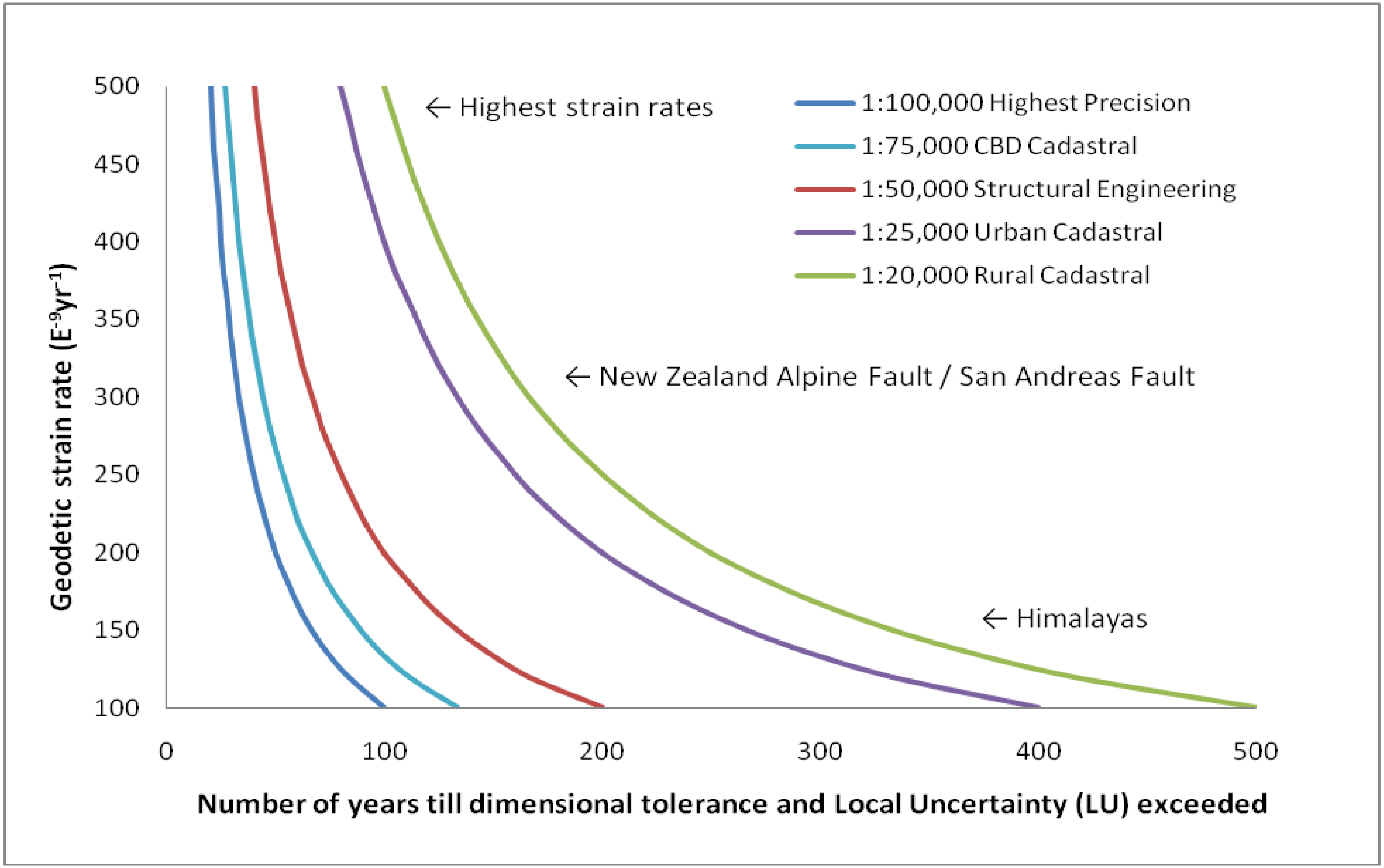
Dynamic datums and spatial data – not a nice marriage!





Dynamic Datums and data – potential pitfalls!

Deformation vs local uncertainty of position



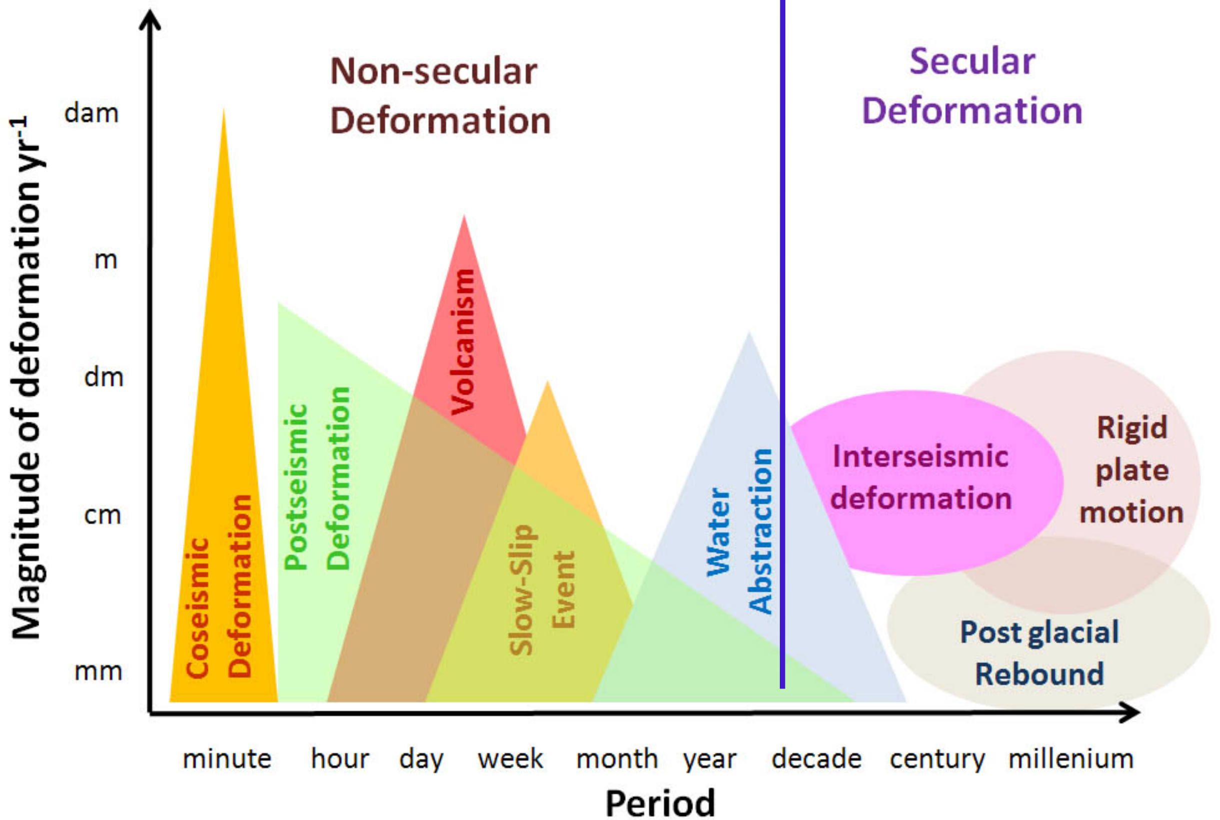
Classification of Deformation

Results in changes in coordinates of local frame

- patch model

Deformation is "invisible" in local frame

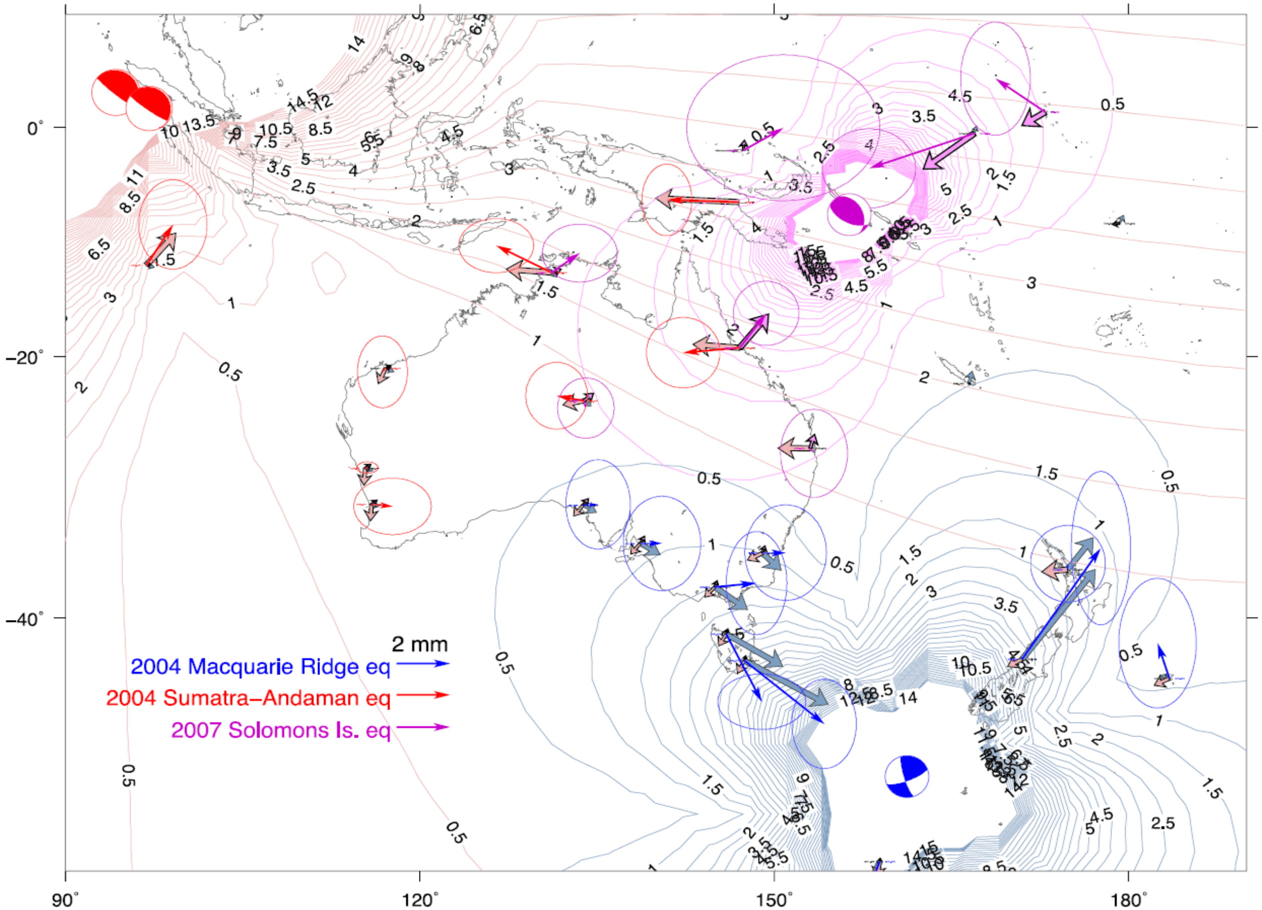
- secular model



Limitations of conformal transformation methods
(e.g. 14 parameter, 6 parameter, rigid plate models)

Localised deformation can "infect" parameter estimation from a sparse network

Far-field deformation effects (coseismic and postseismic) are not modelled correctly



from Tregoning, P., R. Burgette, S. C. McClusky, S. Lejeune, C. S.Watson, and H. McQueen (2013), A decade of horizontal deformation from great earthquakes, *J. Geophys. Res. Solid Earth, 118, doi:10.1002/jgrb.50154*.

Gridded deformation models

2 components:

Secular deformation (site velocity) model – for rigid plate motion component (used in coordinate prediction for projection RF epoch)

Episodic deformation (patch) model – summed or epoch specific deformation associated with specific deformation event (e.g. earthquake)

Currently includes postseismic deformation, however there is scope for a gridded model of postseismic decay coefficients for larger magnitude events

Australian Grid Model characteristics

- standard ASCII format (csv) – can be converted to binary format (longitude, latitude, East rate, North rate, Vertical rate)
- 1° grid size with denser grids in areas of interest
- bilinear interpolation
- planar assumption < 0.01 mm/yr error for 1° grid size
- accommodates some localised deformation and strain (depending upon grid size)

Development of Australian Deformation Grid Model

ITRF2008 Australian Plate Model used to predict site velocities for each grid point (from Altamimi *et al*. 2012)

Observed ITRF2008 velocities from 8+ year APREF time-series used to compute velocity offset model (observed minus ITRF2008 predicted). Known offsets applied before computation.

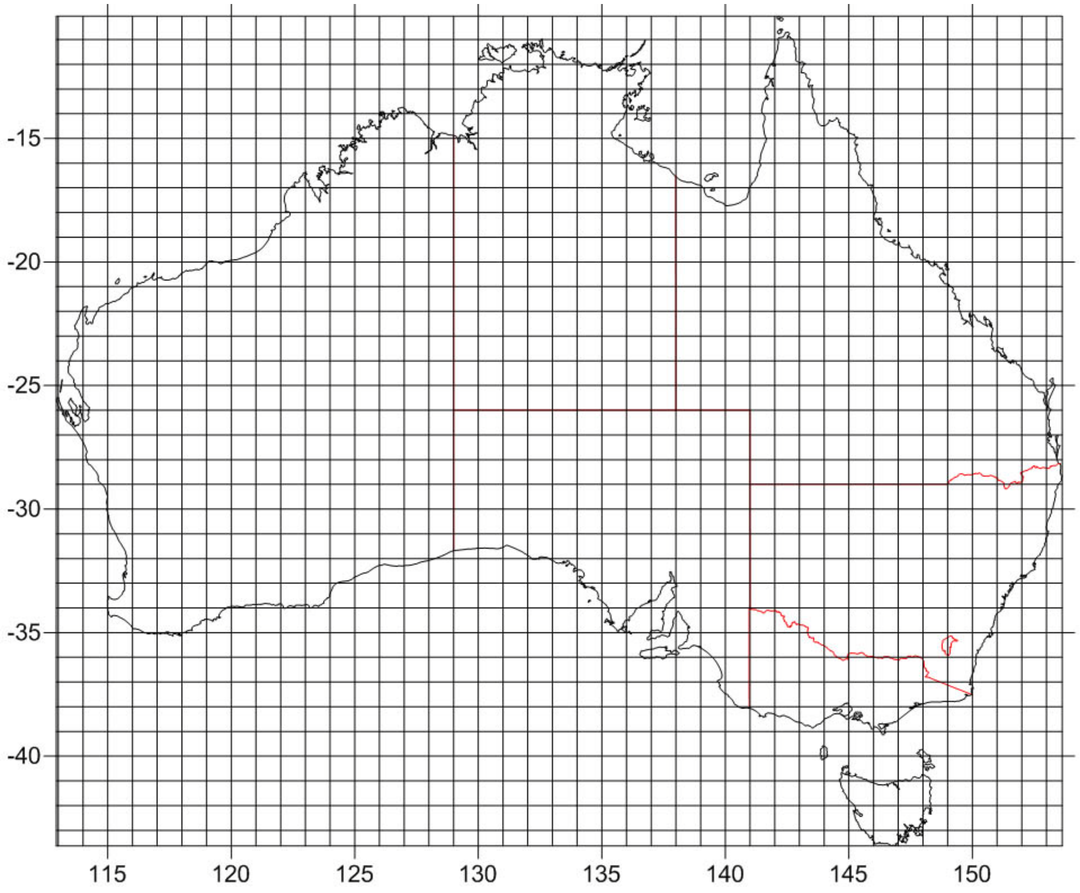
Kriging of offsets to derive velocity correction grid at epoch 2013.3

Final site velocity grid model computed by adding correction model to ITRF2008 plate model prediction grid

Corrected velocity grid used to propagate ITRF2008 epoch 2013.3 coordinates to epoch 1994.0

Kriging of coordinate differences between gazetted GDA94 and ITRF2008 @ 1994.0 to derive patch model

Australian Deformation Model Format – 2 components



1° 3D Grid Velocity Model of estimated site velocities

1° 3D Grid Patch Model of distortions and summed episodic deformation and distortion between reference epoch and epoch of patch model

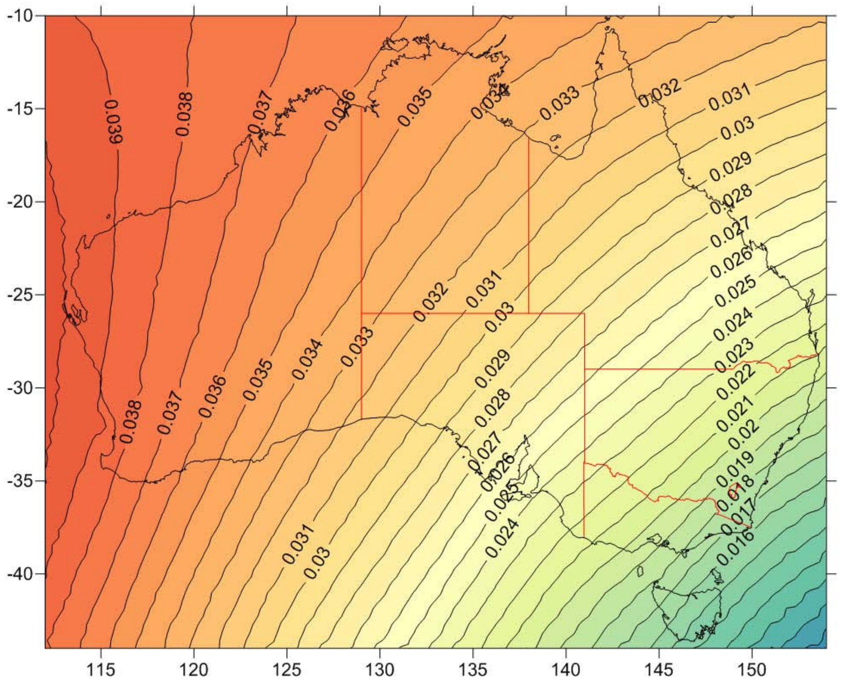
Denser Grids (0.1°, 0.01°, or 0.001° or MGA 10 m Grid) in urban areas or areas of highly variable deformation

Deformation model in detail

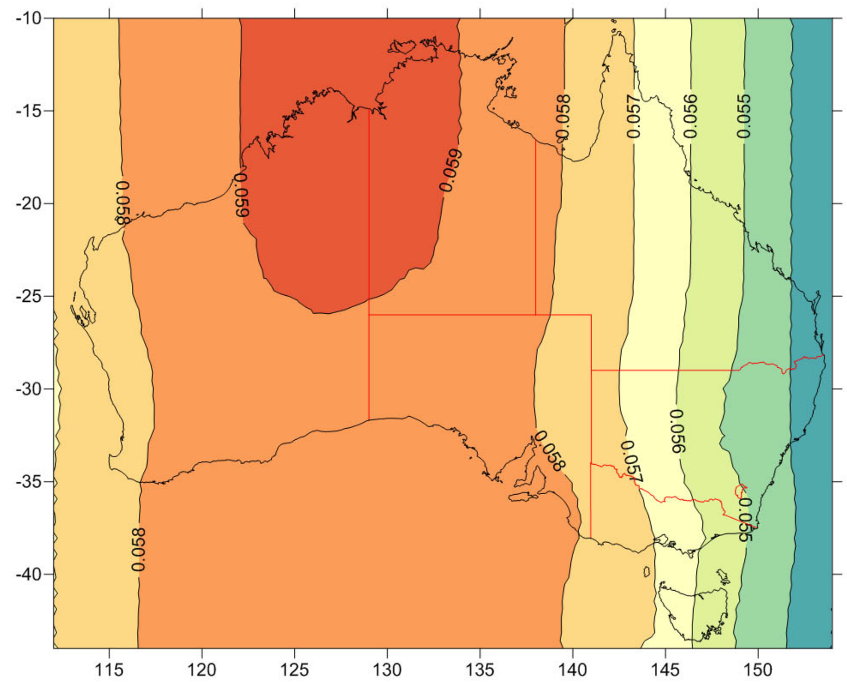
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{t_0} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{t} + \begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \end{bmatrix} \bullet (t_0 - t) - \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix}_{PATCH}$$

- t_0 is the reference epoch (in decimal years)
- t is the epoch of measurement (in decimal years)
- $(X, Y, Z)t_0$ are the coordinates computed at the reference epoch (metres),
- $(X, Y, Z)t$ are the kinematic ITRF coordinates at the measurement epoch (in metres),
- $(\dot{X}, \dot{Y}, \dot{Z})$ is the ITRF site velocity interpolated from the interseismic velocity model (m/yr),
- $(\Delta X, \Delta Y, \Delta Z)_{PATCH}$ is the accumulated seismic deformation and other distortion between the reference and measurement epochs interpolated from the most up-to-date seismic patch model (in metres)

Secular Deformation Model
(Horizontal site velocity component)



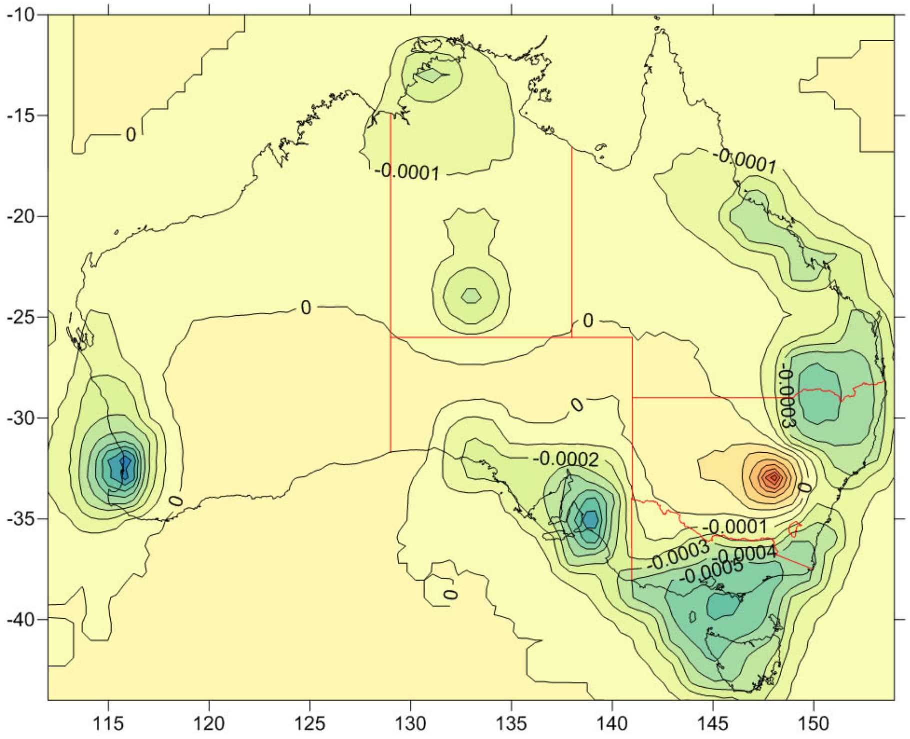
East Velocity (m/yr) σ 0.0002 m/yr



North Velocity (m/yr) σ 0.0002 m/yr

Base ITRF2008 Australian plate model with velocity correction applied
(derived from kriging of observed APREF site velocities > 8 yr time-series)

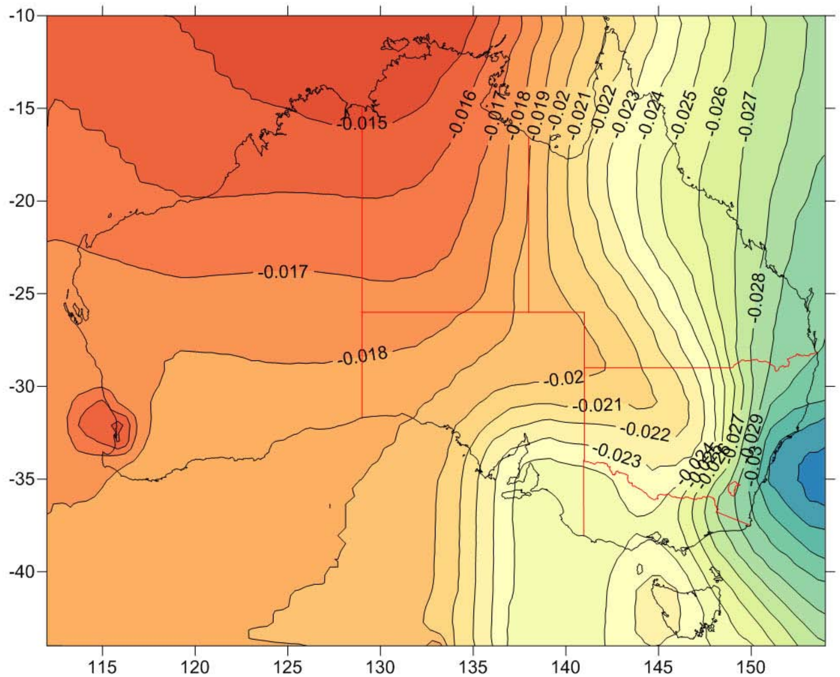
Secular Deformation Model
(Uplift rate component)



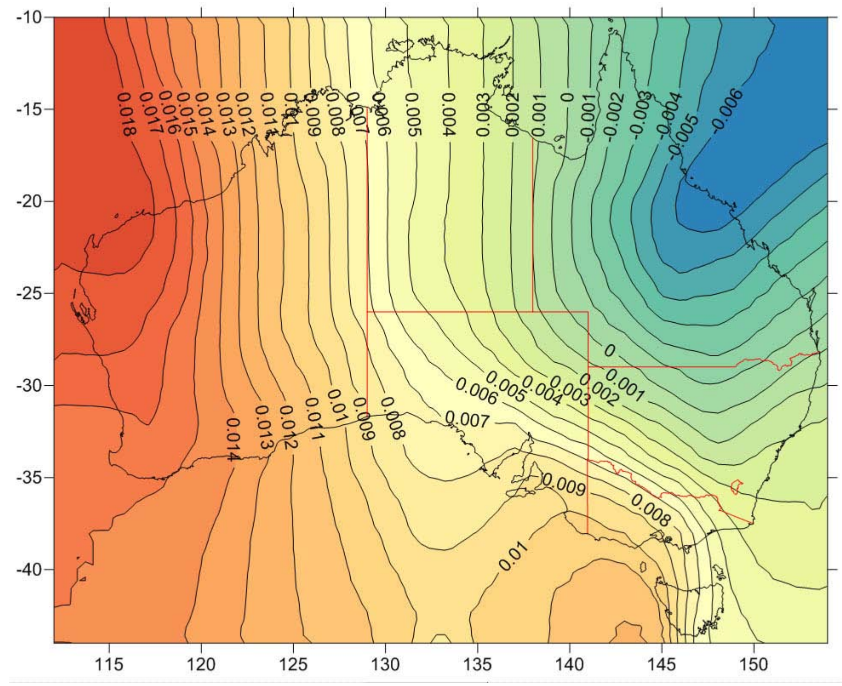
Vertical velocity (m/yr)
σ 0.0003 m/yr

Derived from kriging of APREF time-series vertical component
Still quite speculative until InSAR analysis of uplift or subsidence is modelled
Strongly influenced by APREF stations not constructed on bedrock
Subsidence where water abstraction is occurring (e.g. Perth Basin)

Patch Model
(Horizontal component)



East correction (m) σ 0.007 m

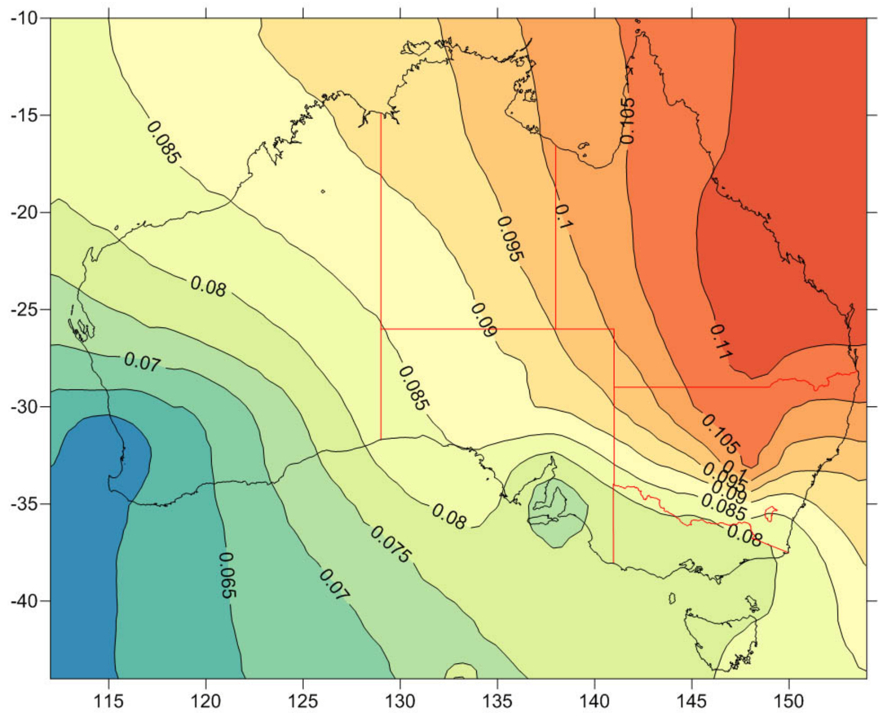


North correction (m) σ 0.005 m

Derived from kriging of differences between gazetted GDA94(2012) and secular model regressed to epoch 1994.0

Models imprecision of ITRF92 realisation as well as far-field coseismic and postseismic deformation arising from major earthquakes on Australian plate boundary

Patch Model
(Vertical component)



Up correction (m)
σ 0.012 m

Derived from kriging of differences between gazetted GDA94(2012) ellipsoid heights and secular uplift model regressed to epoch 1994.0

Models imprecision of ITRF92 ellipsoid height realisation

Research focus in 2013 and 2014

Modelling postseismic decay coefficients in a grid format

Gridded Uncertainty Models associated with Deformation Models

Formalise Vertical velocity model with InSAR in areas of interest

Develop Urban Deformation Models

Integration of deformation models into GIS software, DynaNet and other positioning software (e.g. GNSS post-processing software, CORS-NRTK, AusPOS, PPP, Personal GNSS devices using SPP, DGPS or augmentation)
(collaboration with ESRI, OmniStar, APREF organisations)

Conclusions

Deformation models are essential for managing and analysing spatial data within a kinematic (dynamic) reference frame

Gridded deformation models with secular and episodic components overcome disadvantages of 14 parameter transformation strategies

Deformation models can be used to project ITRF spatial data to a common reference epoch (e.g. ITRF2008 @ 2013.5 to epoch 1994 for GDA94)

Deformation models can become an integral component of GIS and positioning software (so that users can choose not to “see” coordinate changes in a local reference frame)

Australia is moving towards a dynamic datum or reference frame and the Australian Deformation model will become an essential tool to manage the transition from GDA94 to the new datum.
(GDA94 could be realised by epoch projection from a dynamic datum)


DAS IST DIE WELT? UND DIE WILLST DU UMSEGELN?
SICHER! WARUM NICHT?
MAN MUSS NUR VORSICHTIG SEIN, WENN MAN UM DIE ECKEN 'RUMFÄHRT!

Danke Schön!