A Deformation Model to support a Next Generation Australian Geodetic Datum

Never Stand Still

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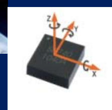
CRCSI Project 1.02 – Next Generation Australian and New Zealand Datum

Future spatial circa 2032

multi-GNSS + augmentation
+ indoor positioning
+ nanotech
inertial positioning

real-time
precise broadcast
orbits

4D GIS CLOUD

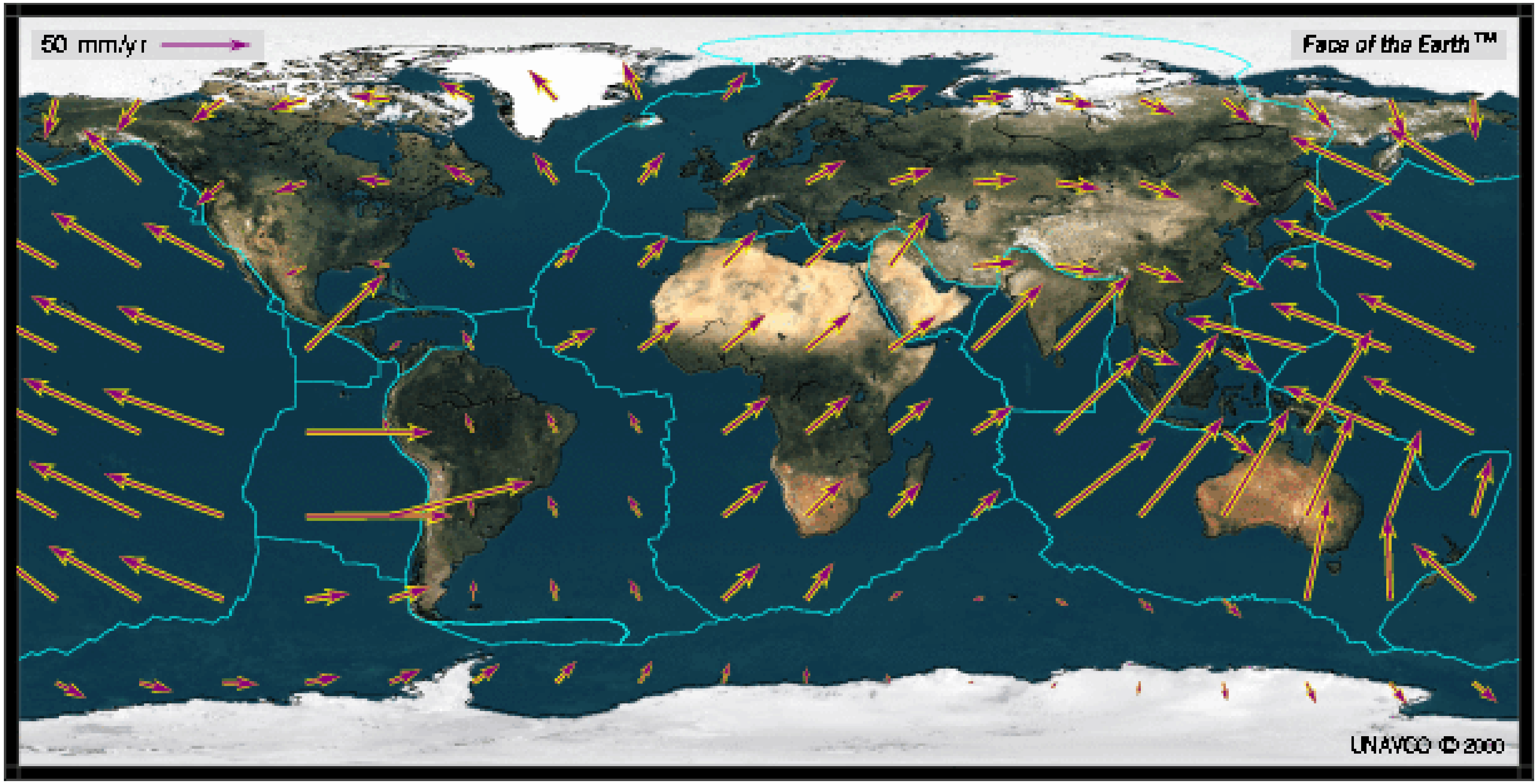
real-time positions
active deformation model
mm accurate
real-time access to live GIS
centralised data
+ clone
authoritative
ubiquitous

5G/6G wireless
NBN

mm/cm accurate real-time personal positioning

The Big Driver
A Dynamic Planet

Global Deformation
(Mostly Plate Tectonics)



Centimetre level PPP, SPP, OmniSTAR coordinates change by up to 10 cm/yr (or by metres after large earthquakes!)

Many users can now “see” these deformations & differences with “static” datums

The Next-Generation Datum Paradigm

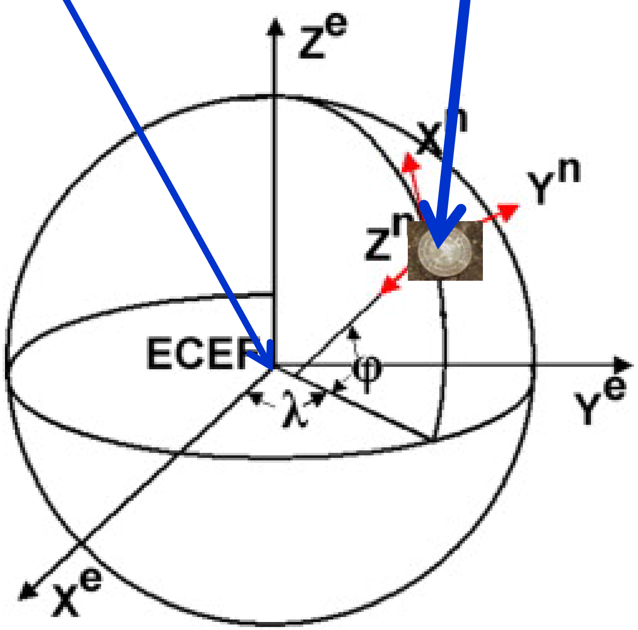
Classical Geodetic Datum

Fixed (static) coordinates of geodetic monuments on Earth's surface

Next-Generation Datum (kinematic or dynamic)

Origin and axes of ITRS system are fixed

But......
Coordinates of classical datum monuments now move due to Earth deformation processes!



Why is a Deformation Model important?

In the real world – coordinates are moving ~7 cm a year

but!

our Spatial Data Infrastructure
GIS, Maps, survey plans, feature surveys, utilities, land boundaries, mines, fields, LiDar Surveys, Terrestrial Laser Scans, and even our perception
have static coordinates (e.g. GDA94, AGD66 or local grid)
Difference between ITRF & WGS84 and GDA94 now about 1.3 metres!

so!

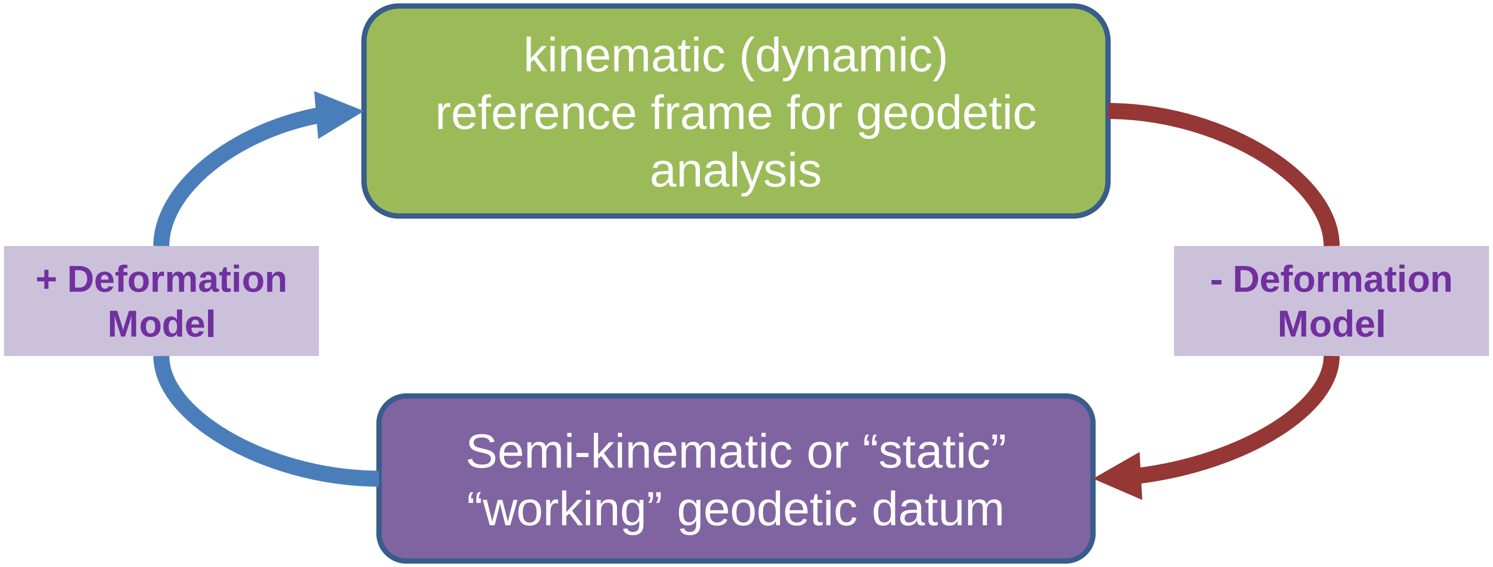
How can spatial data collected over time be merged and analysed meaningfully if there is a change of 7 cm a year in the underlying datum?
1-2 metre errors if no deformation model is applied!!

Dynamic Datum - Static Coordinates??

Kinematic (dynamic) coordinates can be transformed to a working "static" geodetic datum using a robust deformation model

Best of both worlds: The complexity of global and local deformation modelling is handled at the point of position estimation and geodetic analysis.

End users do not "see" significant coordinate changes



Enabling pre-requisites for a dynamic datum

INTERNATIONAL STANDARDS

EPSG, NIMA etc. Definition

Standard format required for 4D deformation model

EDUCATIONAL

targeted CPD – SSSI, ISVIC, ISNSW etc.

Expertise of surveyors and GIS professionals

Tertiary syllabus – academic staff knowledge

Public awareness of changing coordinates

DATA INFRASTRUCTURE

4D GIS accessed via the cloud

ALL 4D data MUST have epoch metadata!

SOFTWARE

GIS Software – 4D deformation models

Surveying software

CTS and PPP software

eGeodesy

RTCM corrections

Digital maps & DCDB with embedded deformation model

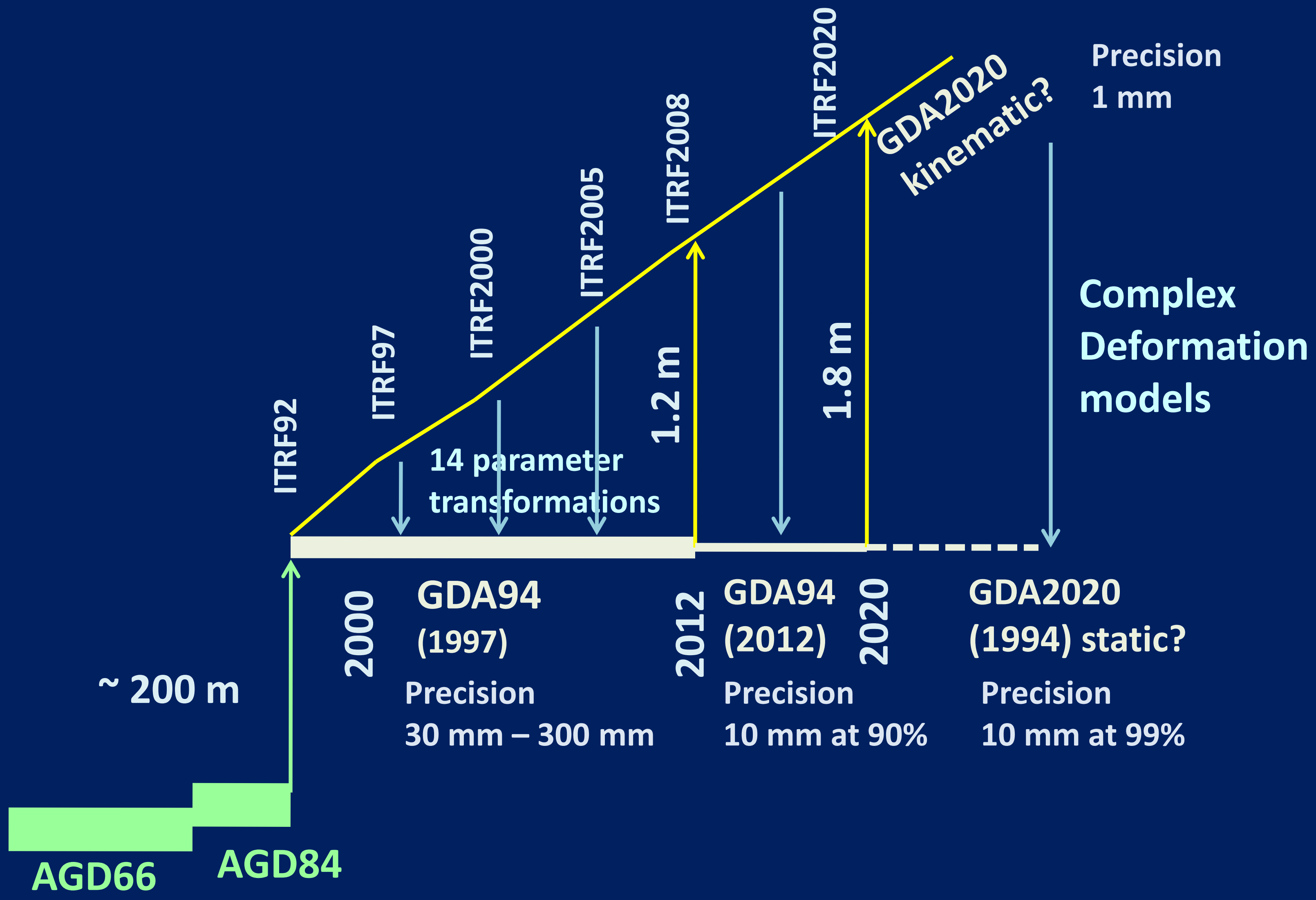
REGULATORY

Survey Directions Procedures

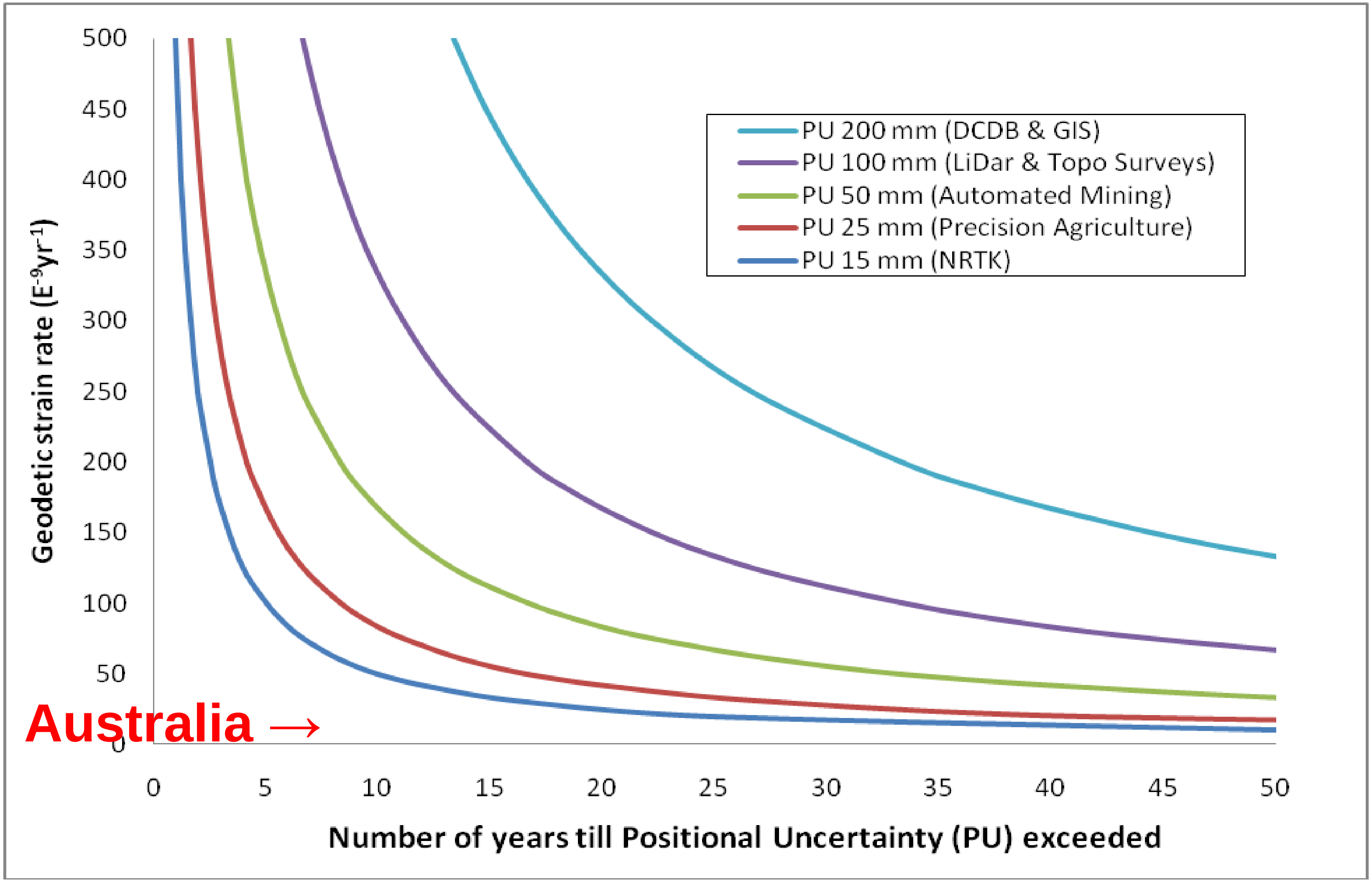
State and Territory – Survey Legislation

Regulation 13 certificates to include coordinate + epoch + deformation model

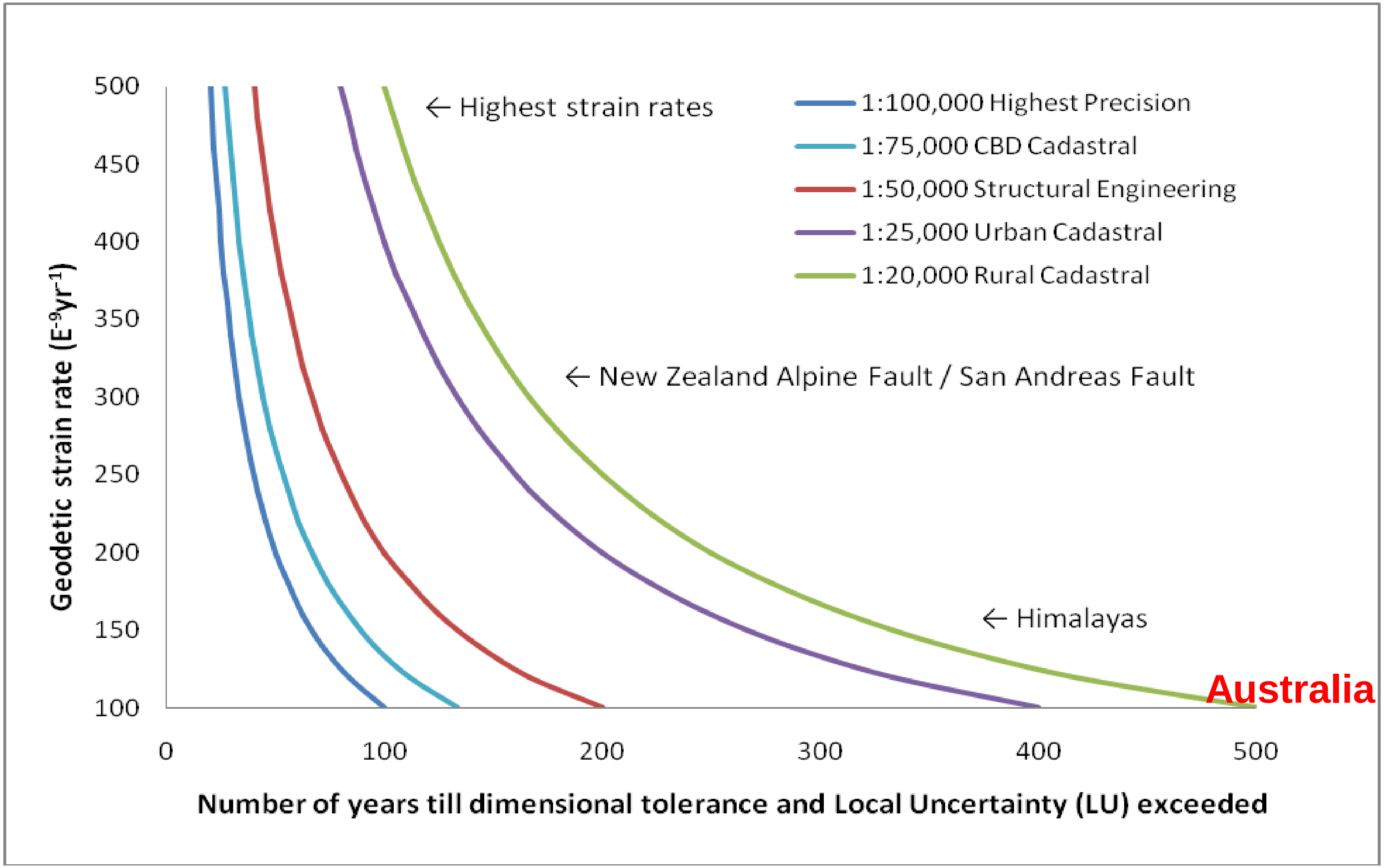
Recent evolution of Australian Geodetic Datums



Positional Tolerances vs Geodetic Deformation



Dimensional Tolerances vs Geodetic Deformation



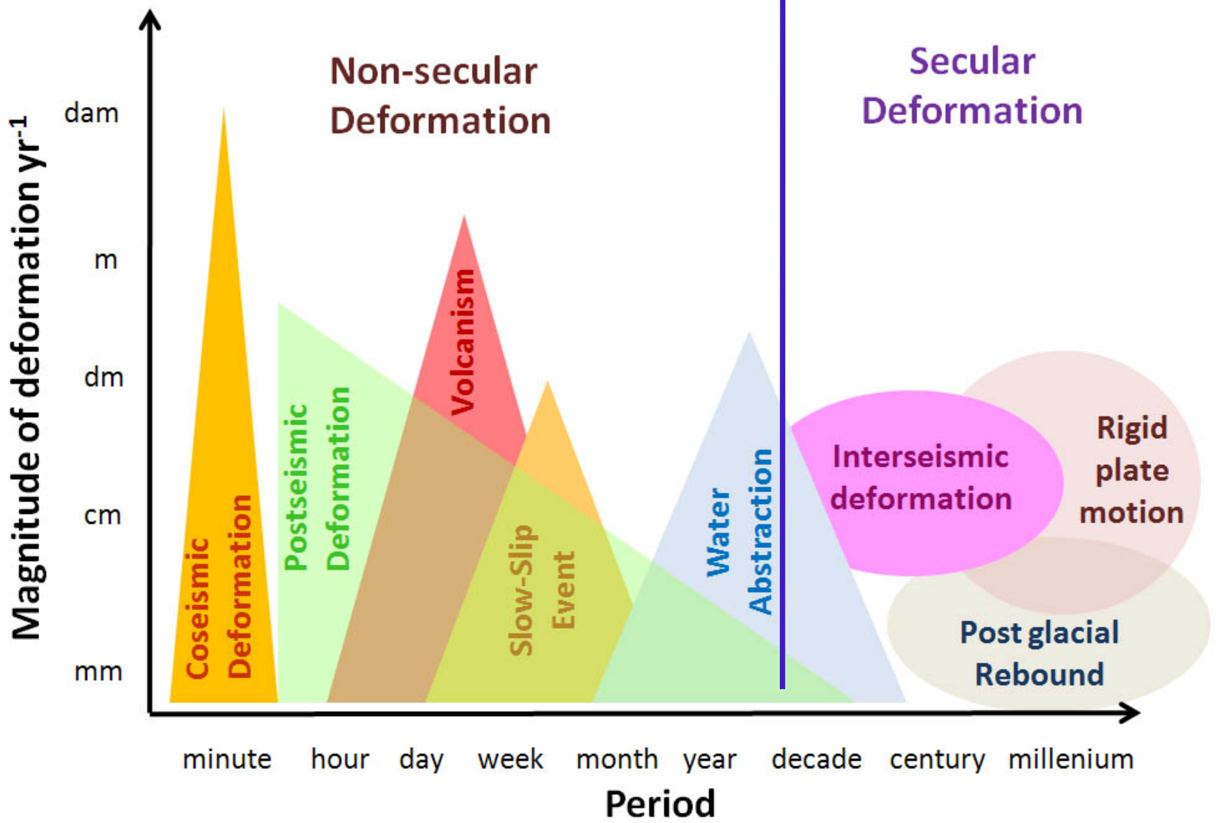
Characterisation of Deformation

Results in changes in coordinates of local frame

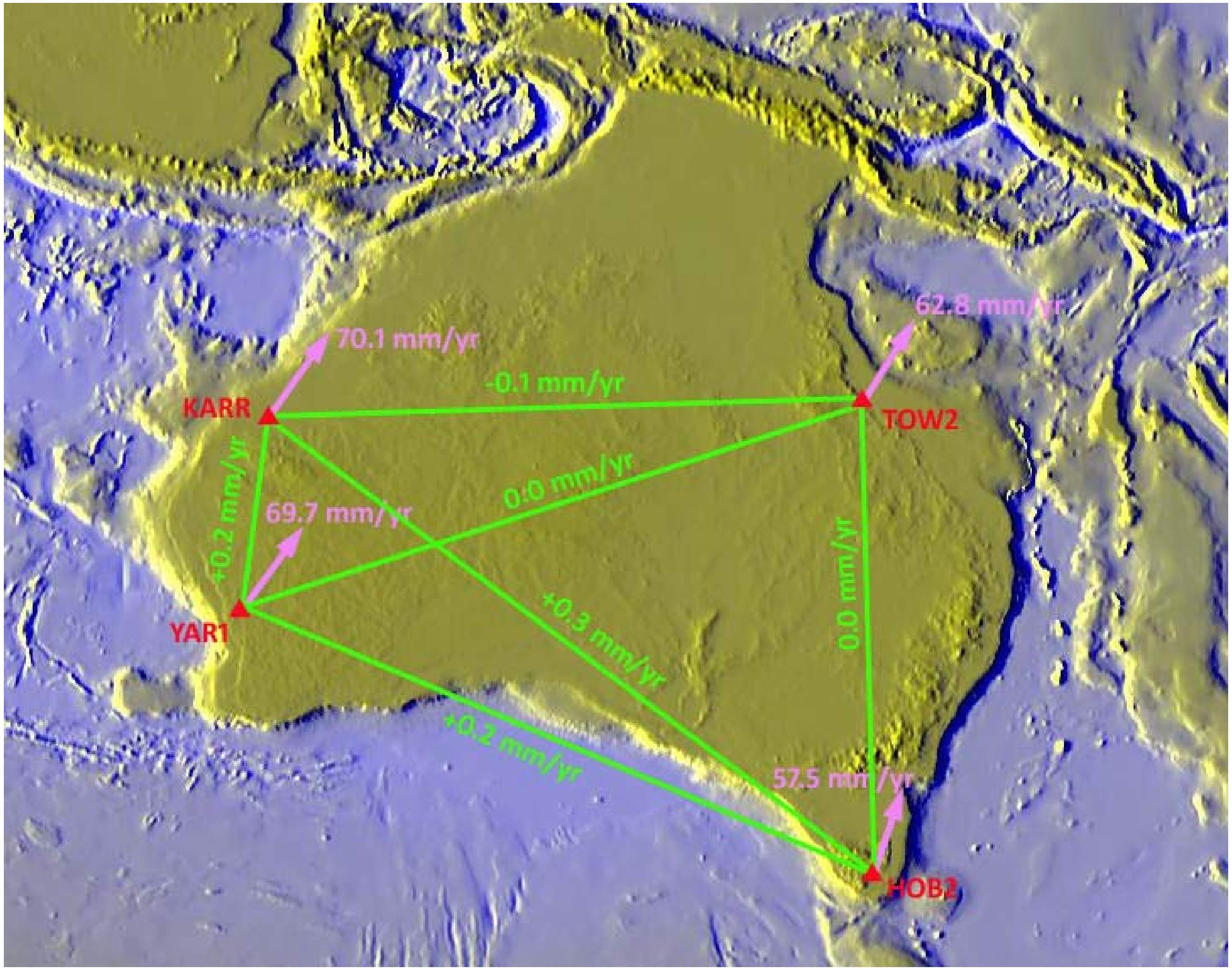
- patch model

Deformation is "invisible" in local frame

- secular model

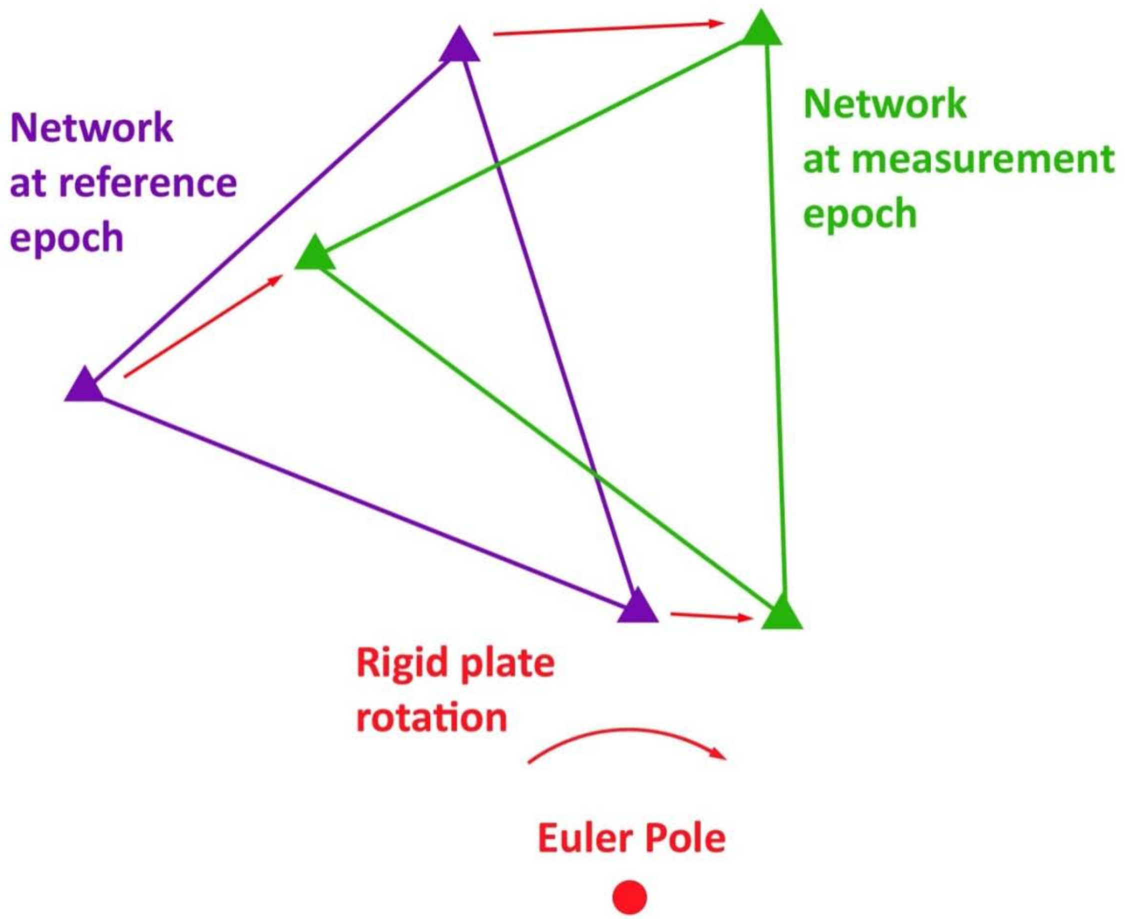


Secular deformation in Australia



purple arrows – tectonic movement, green lines – baseline changes per year

Rigid plate rotation



Australian
Plate rotates at
~0.63° / Ma

=

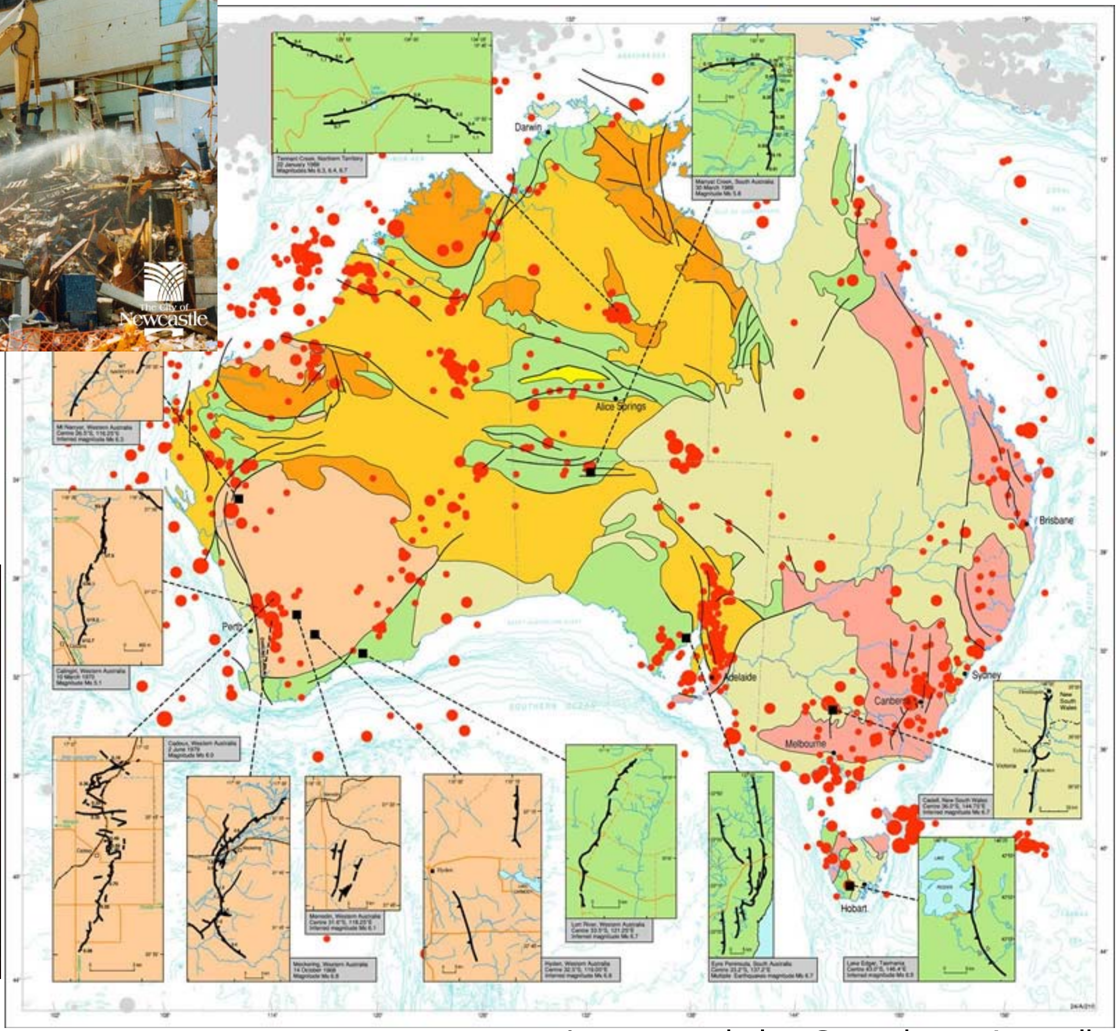
9 mm rotation of
a 30 km
GNSS baseline
after
only 26 years

e.g. holding GDA94
coordinates fixed
for
static processing or
RTK in 2020

Intraplate earthquakes

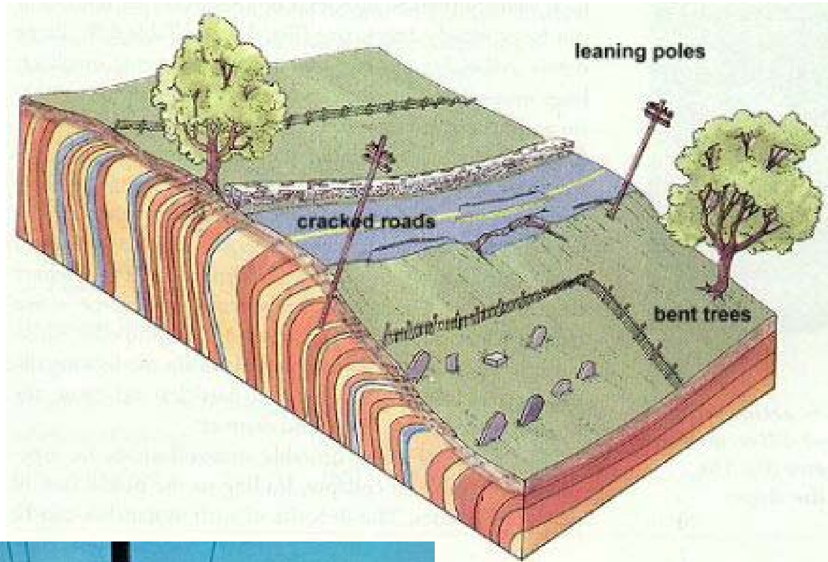
Newcastle, NSW, 1989

Meckering, WA , 1968



Images and plot, Geoscience Australia

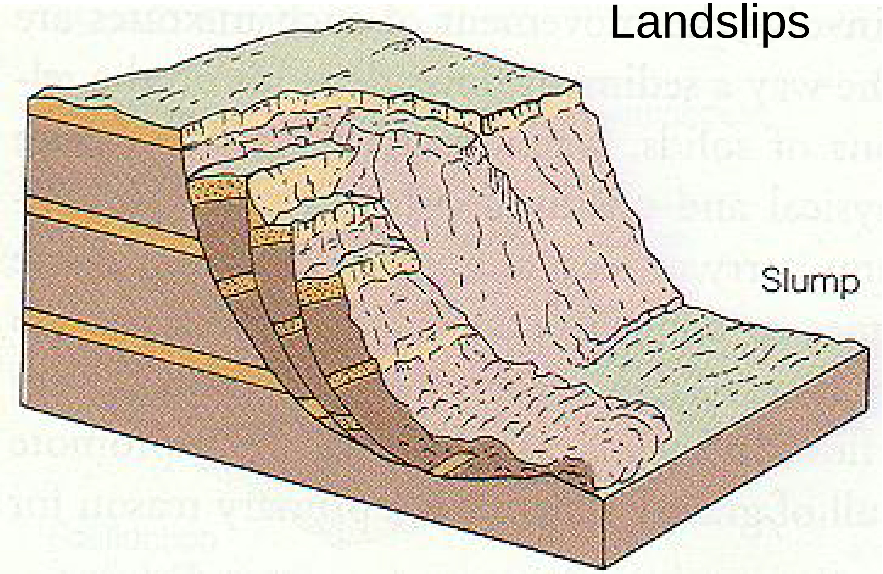
Localised deformation



Surface creep

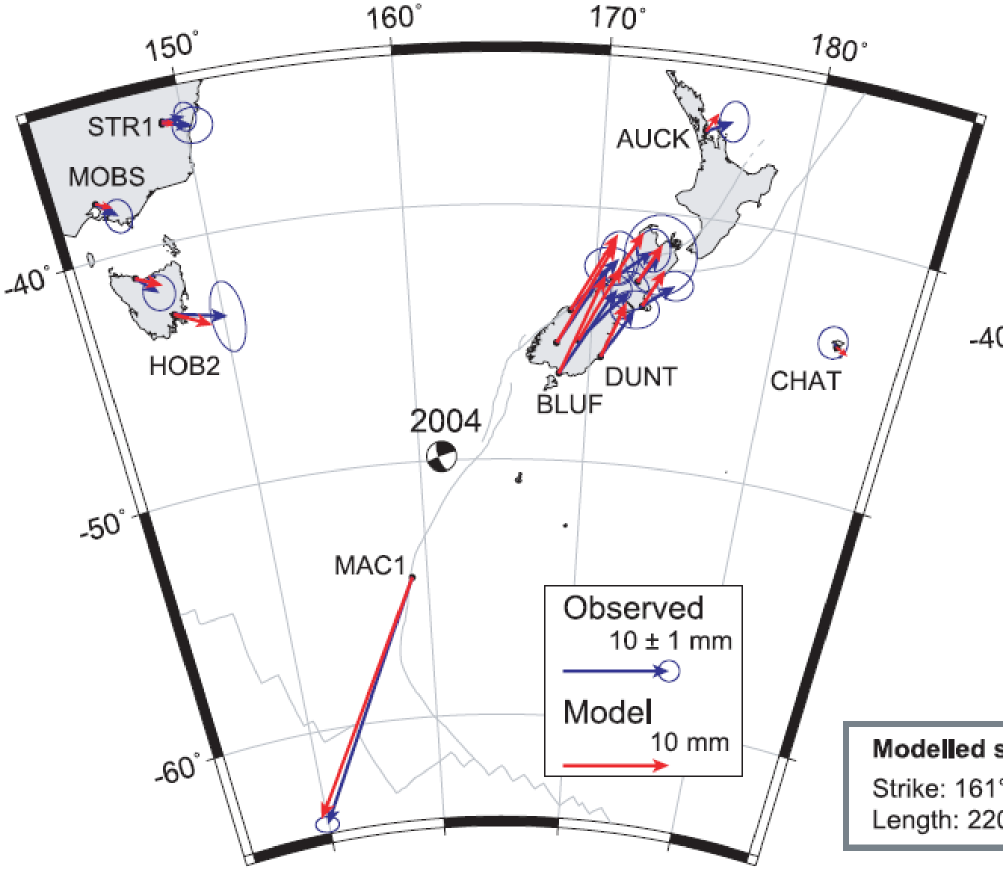
Subsidence

Landslips



Images from USGS

Far field deformation effects in Australia



Far-field deformation from great earthquakes around the Australian margin (e.g. M_w8.1 23rd December 2004 Macquarie, from Watson *et. al*, 2010)

Deformation Model Concept

Kinematic (dynamic) datum (fully consistent with ITRF)

Next-Gen GDA (kinematic model)

GNSS data capture CORS operation geodetic analysis 0.5% of users who require mm accuracy

Absolute (Secular) deformation model (e.g. rigid plate, interseismic)

Patch deformation model (e.g. earthquakes, urban deformation)

"semi-kinematic" datum fixed at epoch 1994.0 now realised by epoch projection

projected GDA94

99.5 % of users who only require 1-2 cm accuracy

Gridded deformation models

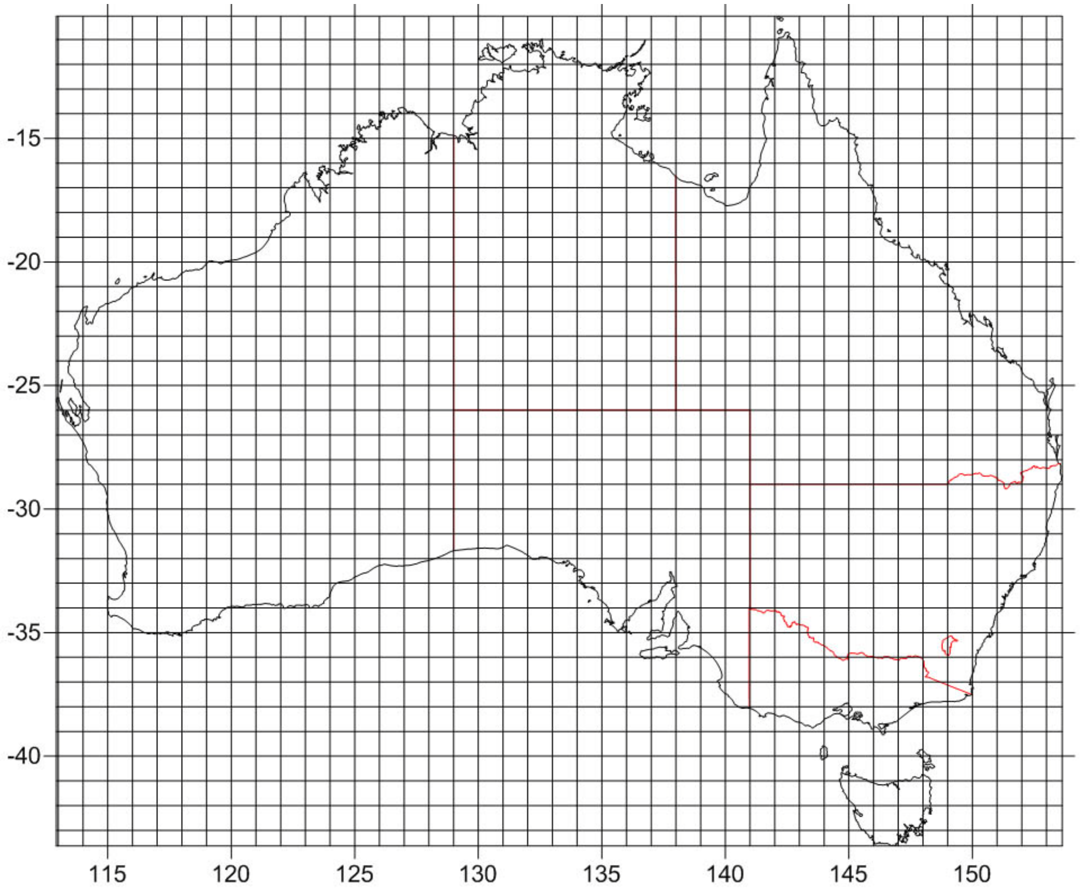
Gridded Absolute Deformation Model (ADM)

- 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)

Limitations of existing rigid plate and 14 parameter models

- localised deformation distributed over model
- does not work where differential geodetic rates occur
- assumes rigid or uniformly deforming tectonic plate

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

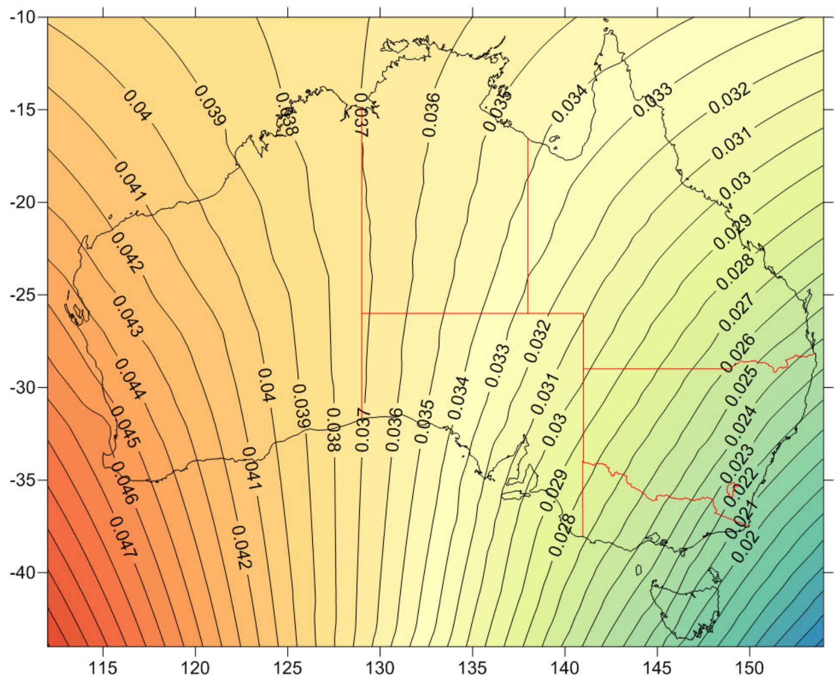
Denser Grids (0.1°, 0.01°, or 0.001° or MGA 10 m Grid) in urban areas or areas of highly variable deformation

Deformation model in detail

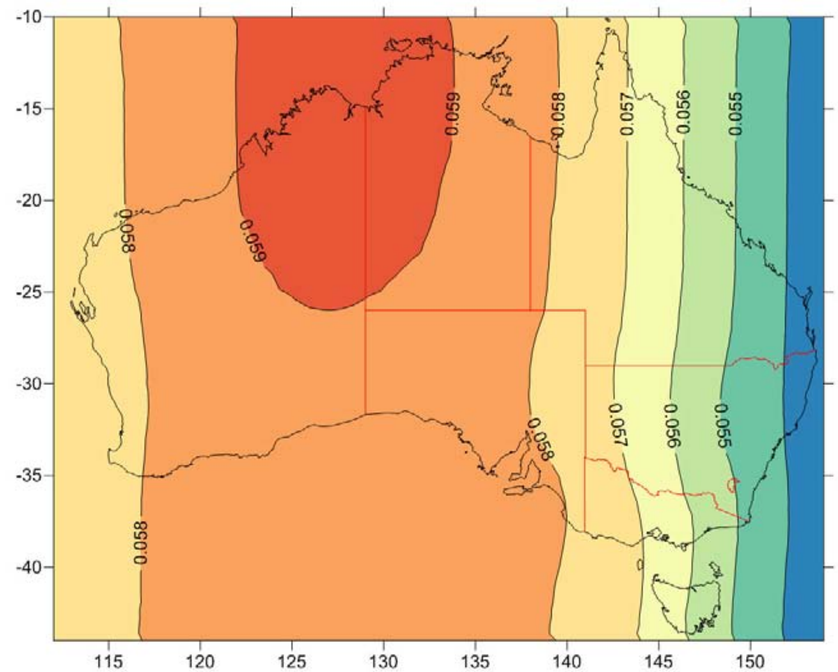
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{t_0} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{t} + \begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \end{bmatrix} \bullet (t_0 - t) - \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix}_{PATCH}$$

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)



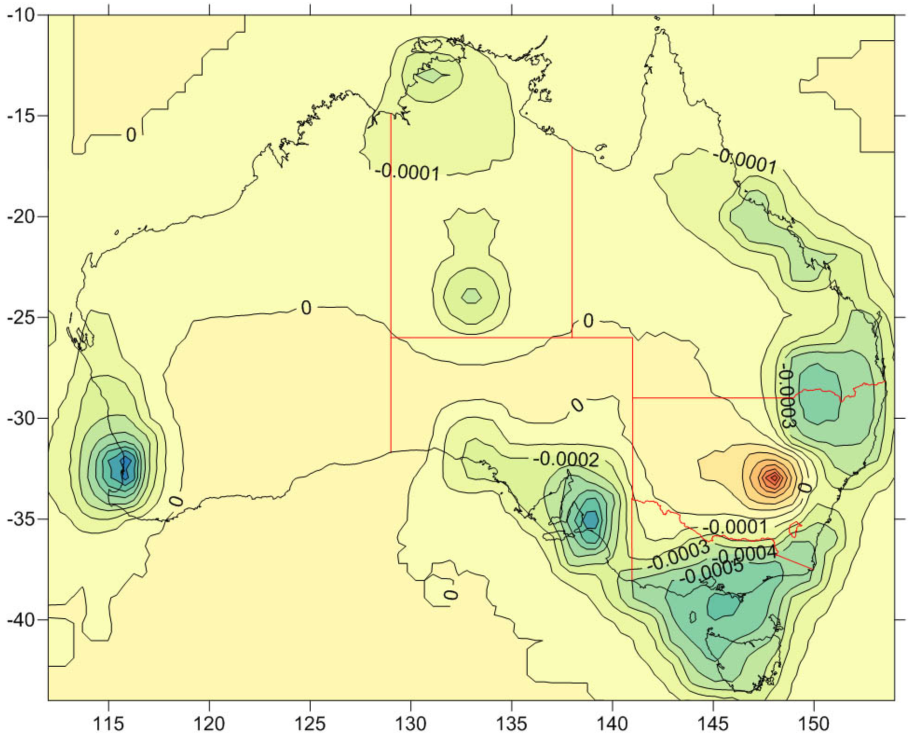
East Velocity (m/yr)



North Velocity (m/yr)

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

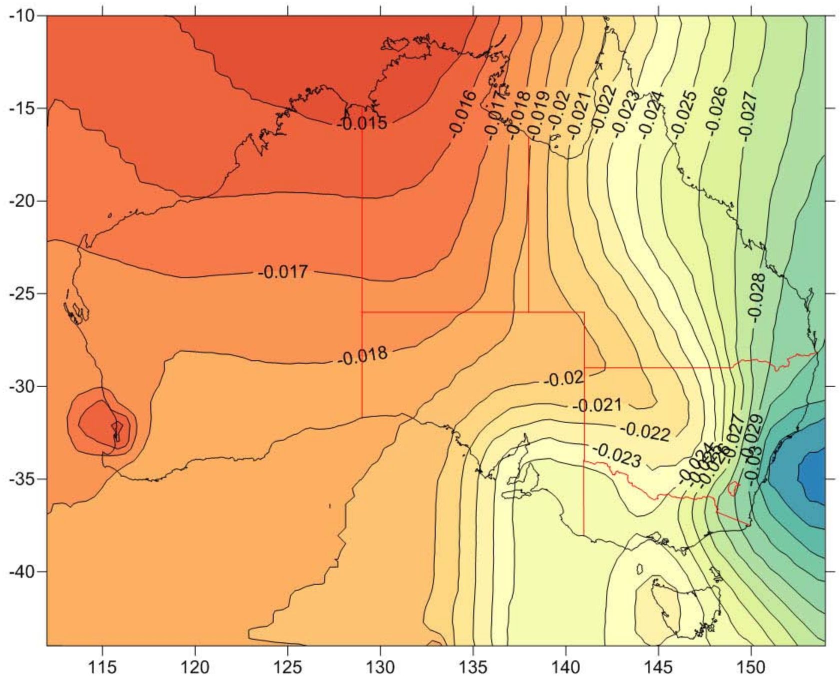
Secular Deformation Model
(Uplift rate component)



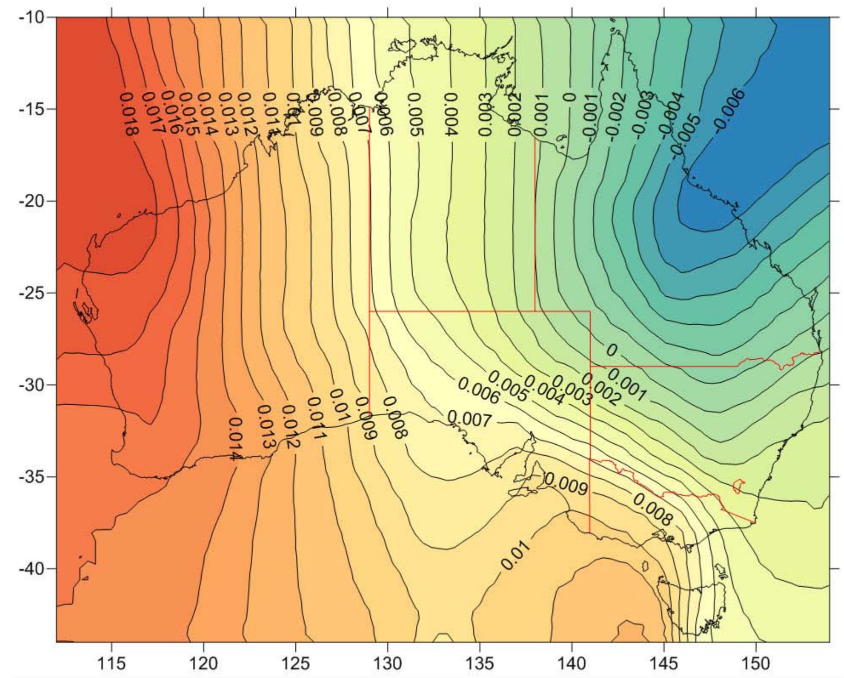
Vertical velocity (m/yr)

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)

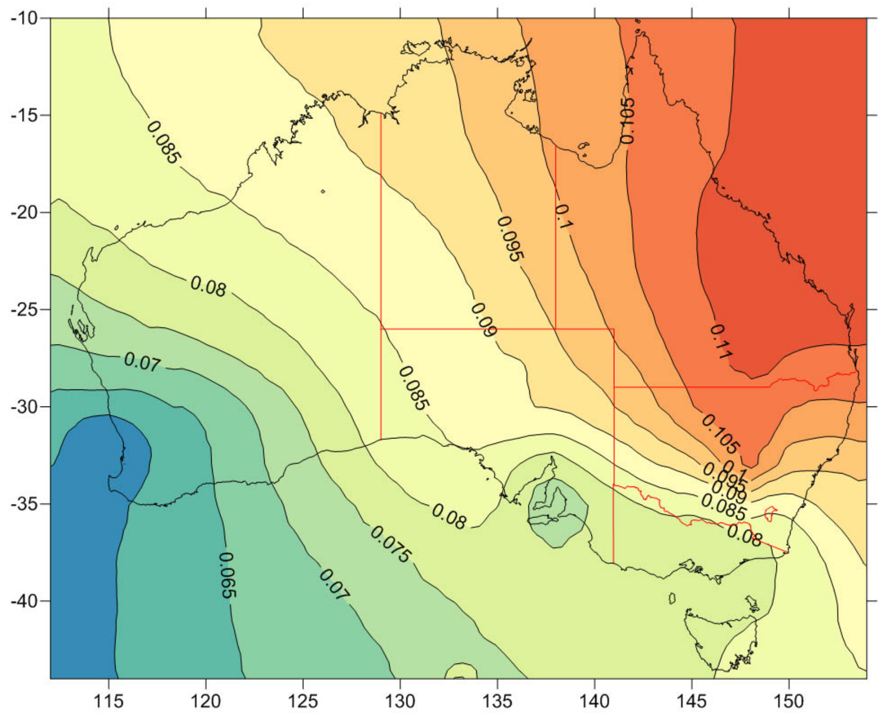


North correction (m)

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)

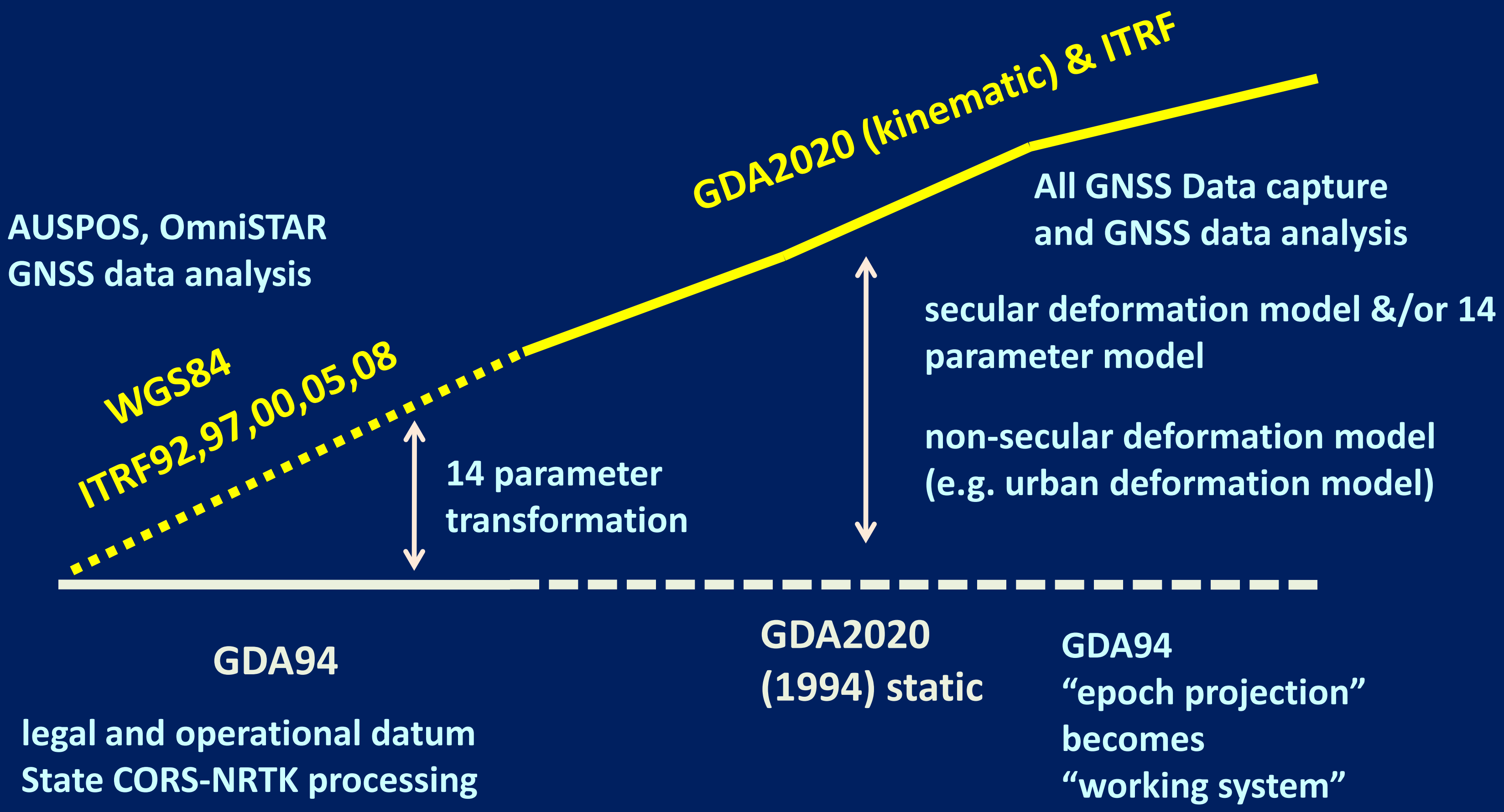


Up correction (m)

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

Interim Geodetic Model (2012 – c. 2032)



In the pipeline ...... 2013 - 2014

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)

Aim: To mitigate the effects of deformation at the user level

SEAMLESS INTEGRATION AND CORRELATION OF SPATIAL DATA COLLECTED AT DIFFERENT EPOCHS!

THANK YOU!