Global to Regional to National: A practical approach to improving access to the ITRF

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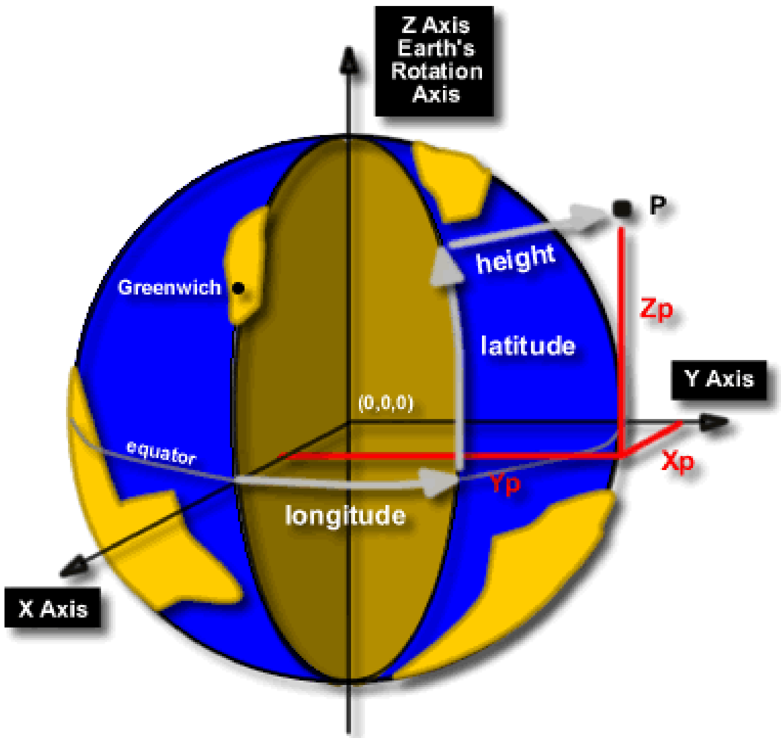
Geoscience Australia

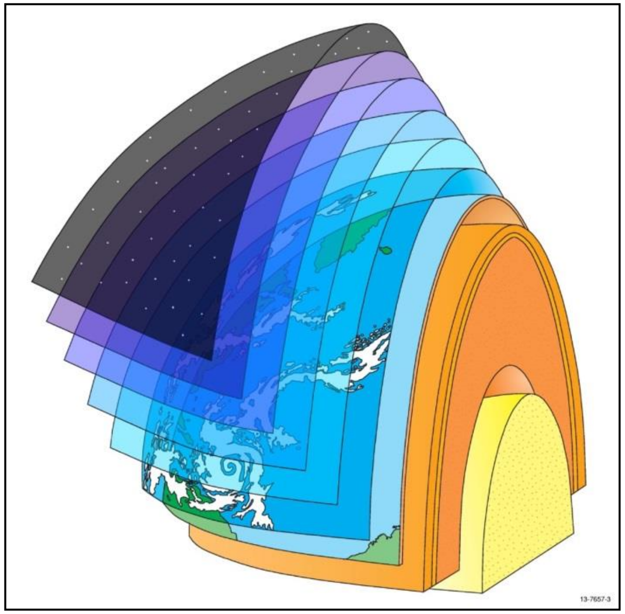
Presentation Overview

- Importance of Reference Frames
- Realising Reference Frames
  - Global
  - Regional
  - National
- Case Study: Update of the Geocentric Datum of Australia
  - Why
  - How
  - Communications with users

Reference Frames

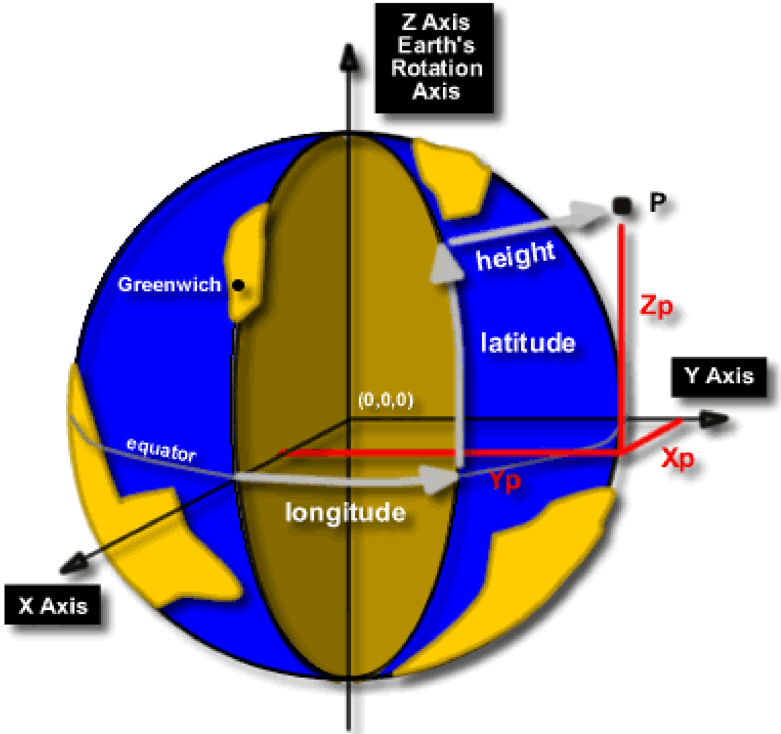


Earth System Science



- Well defined and realised station coordinates (and velocities) underpin science of the : Earth’s interior, solid Earth, atmosphere, oceans, cryosphere, space environment

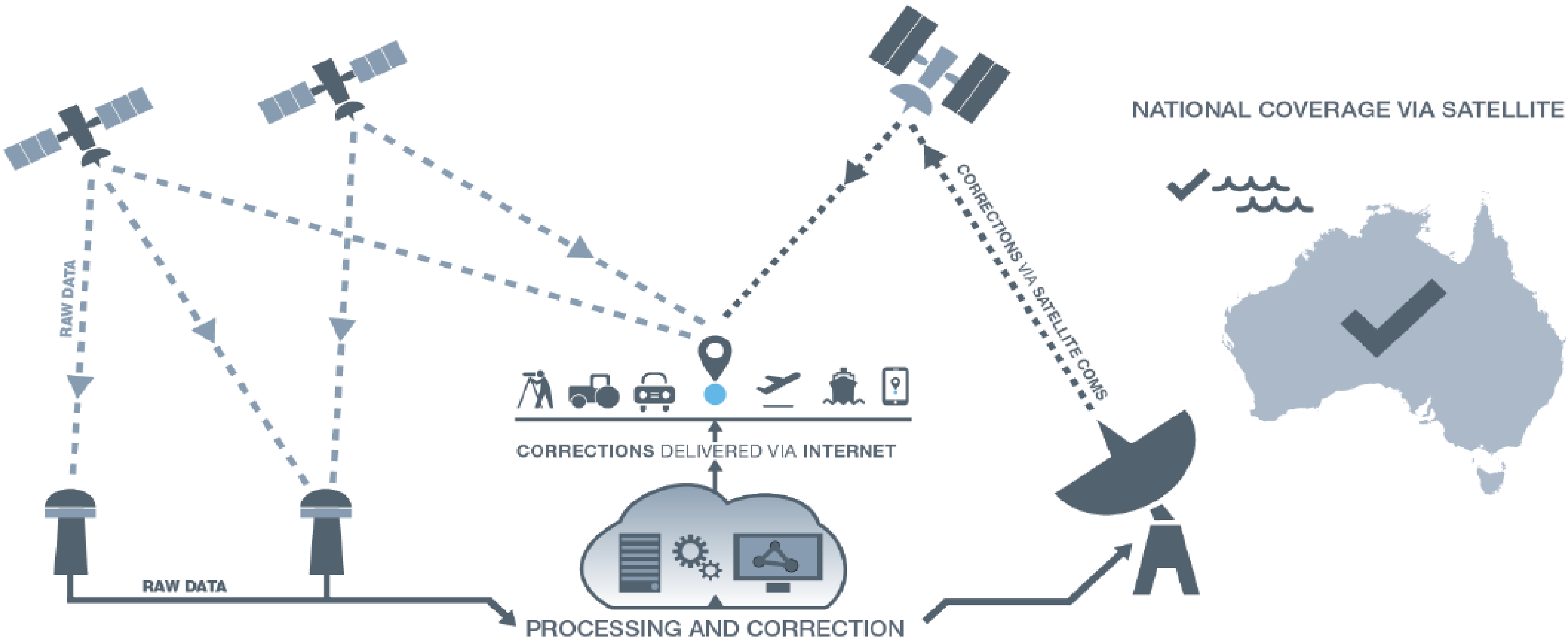
Reference Frames



Societal Applications

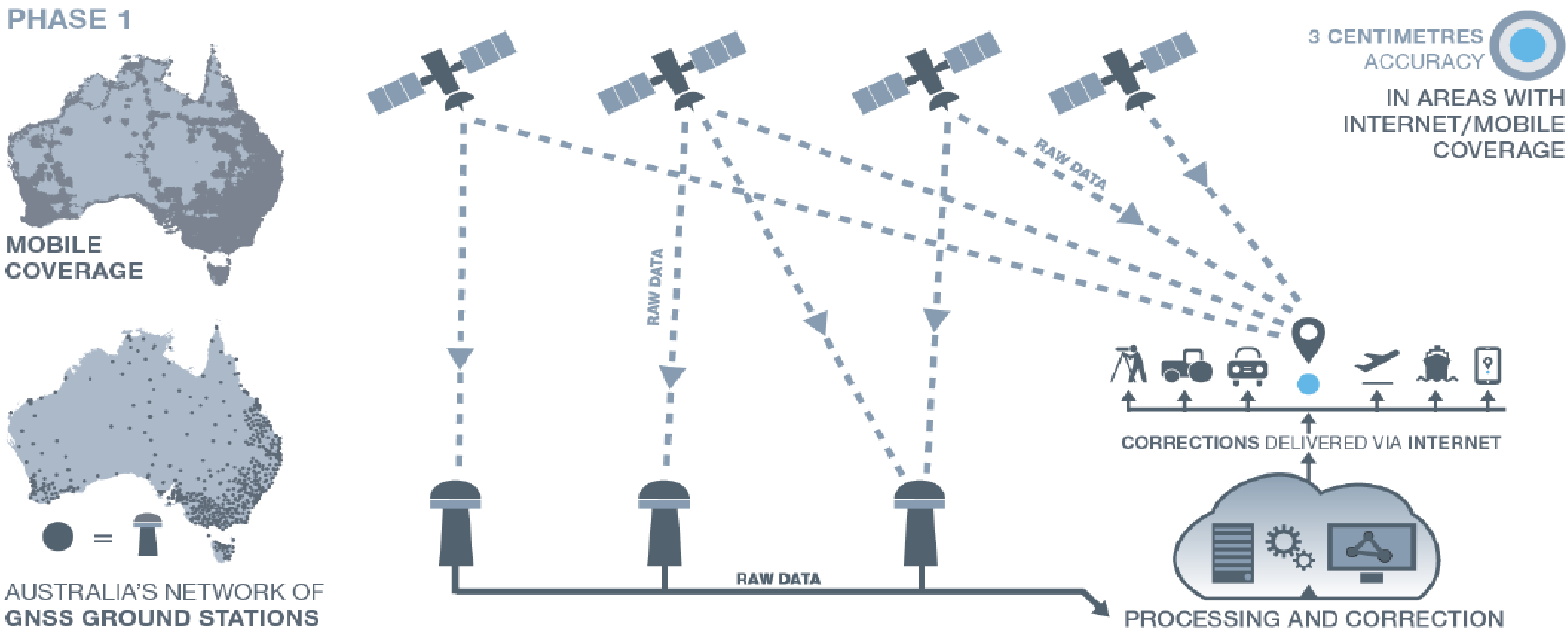
- Well defined and realised station coordinates (and velocities) supports a ever widening array of societal applications

Satellite Delivered ITRF



- Growing number of options for users to exploit satellite delivered ITRF positioning

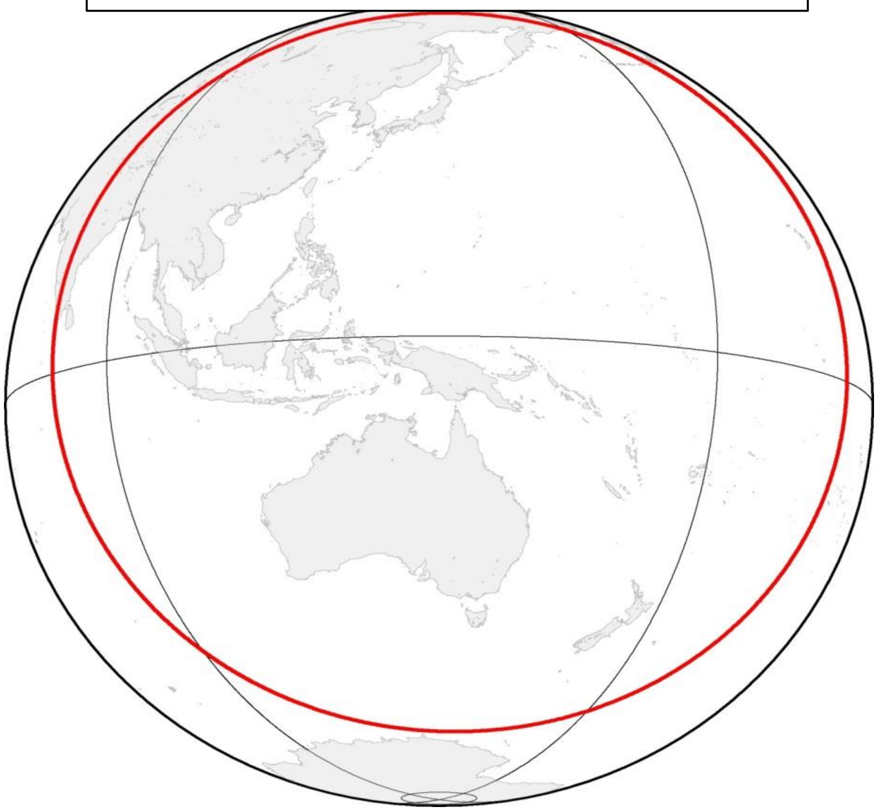
National/Regional Services

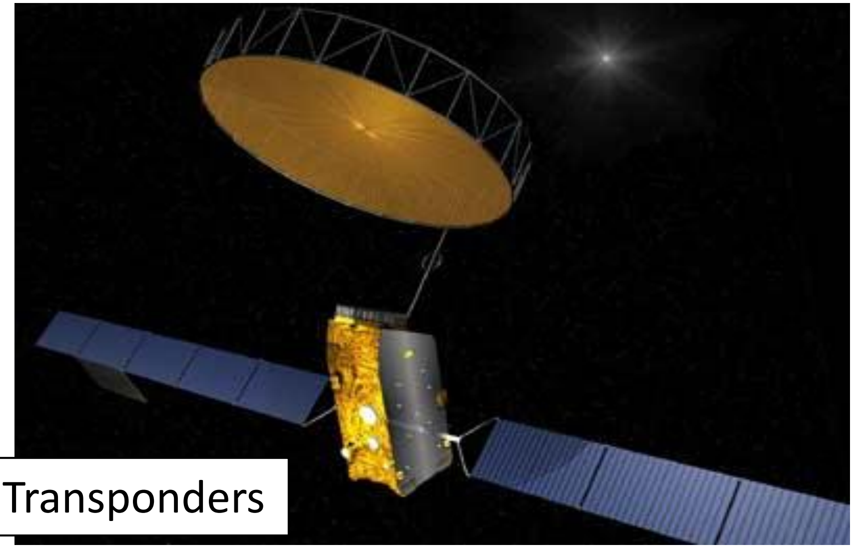


- National/Regional CORS integration and ITRF based positioning capabilities
- In Australia, the National Positioning Infrastructure project led by Geoscience Australia aims to integrate all GNSS CORS

SBAS Trial – Inmarsat-4F1 GEO

Footprint (15° elevation cut-off)





L-Band Transponders

Uralla, NSW, uplink

7

Satellite Delivered ITRF

Australian and New Zealand trial of a current and next generation Satellite-Based Augmentation System (SBAS)

- Satellite 122
- 0.5 metre accuracy
- Widely implemented RTCA DO-229D standard

- 0.1 metre accuracy
- New Precise Point Positioning (PPP) technology

- 0.5 metre accuracy
- Better in challenging environments
- High availability (better for aviation)
- Regional capability

Reference Frames

Australia's Reference Frame:

- International Terrestrial Reference Frame (ITRF)
  → Asia Pacific Reference Frame (APREF)
    - APREF is a densification of ITRF
  → Geocentric Datum of Australia (GDA)
    - GDA is a densification of ITRF and APREF

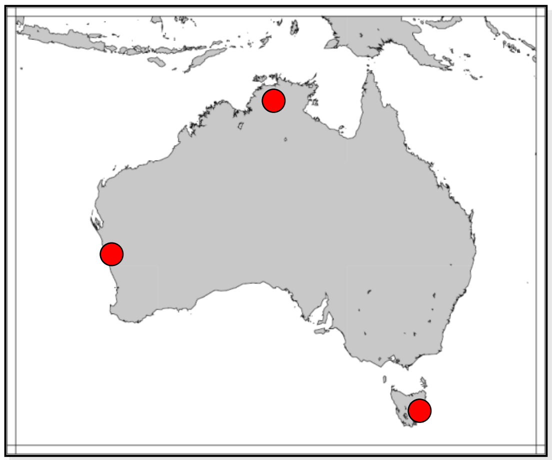
- Relationship between ITRF and GDA is well known and monitored

Reference Frames

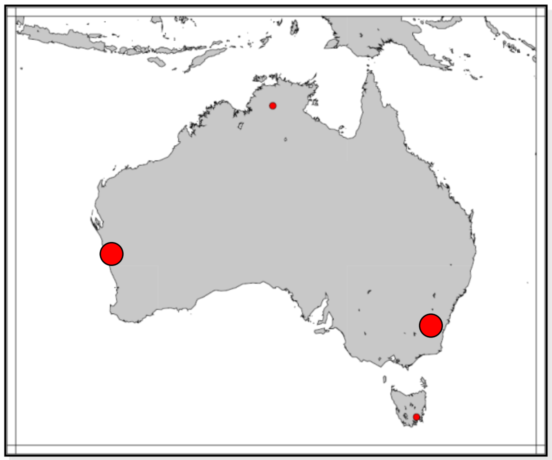
VLBI

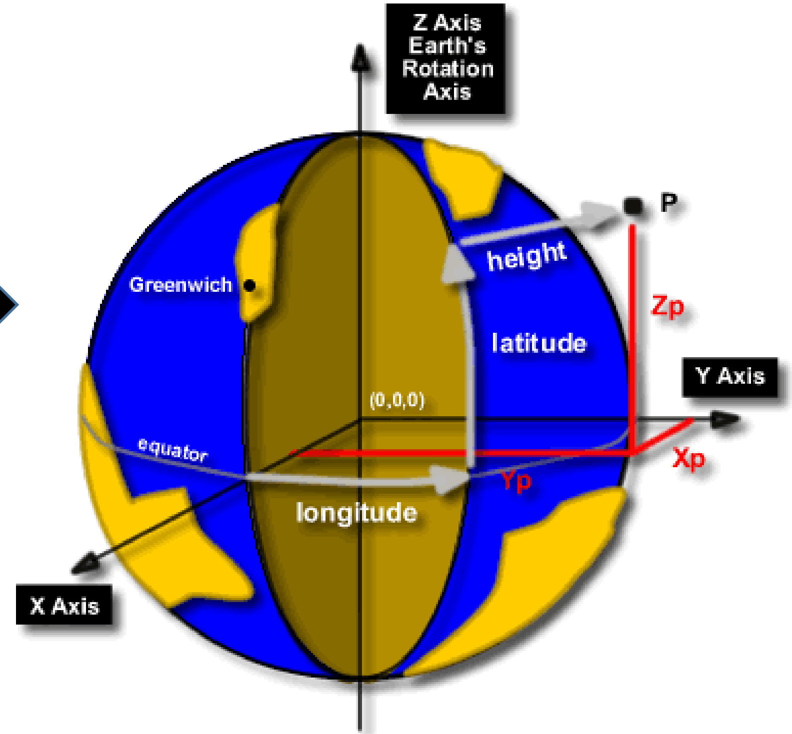
SLR

VLBI Array



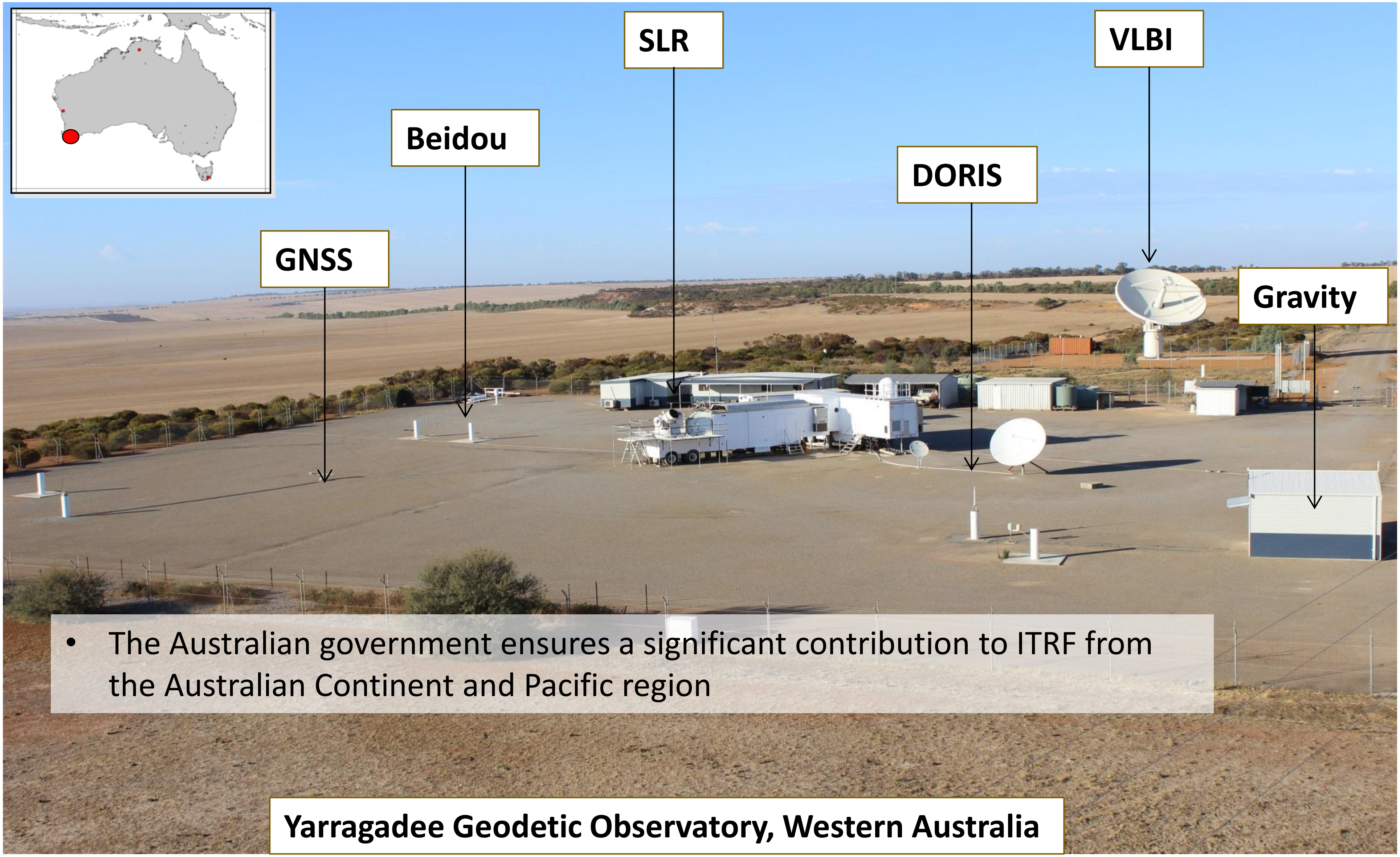
SLR





- Well defined and realised station coordinates (and velocities) are realised from a global network of geodetic observatories

Reference Frames



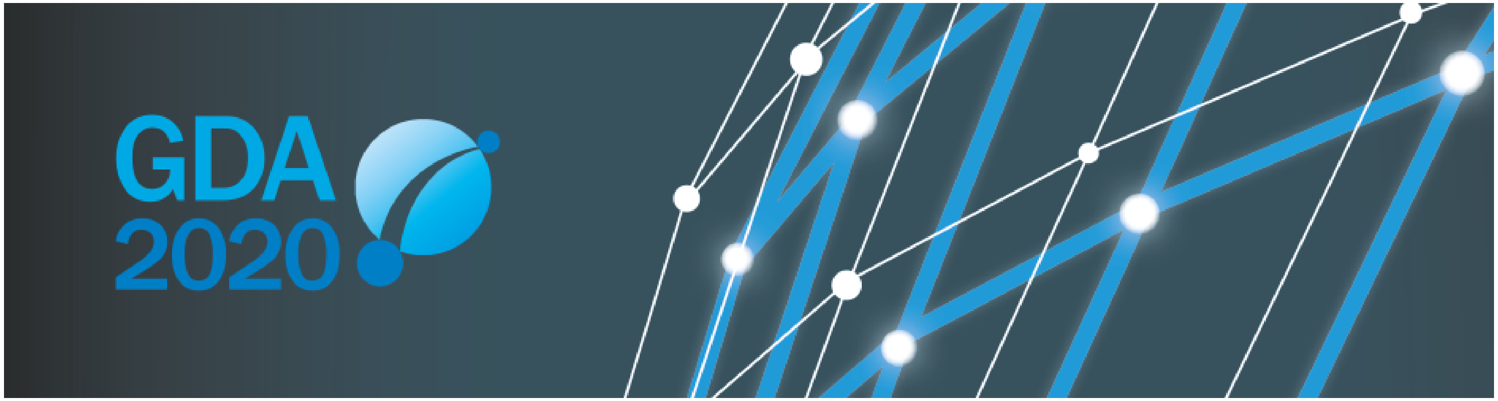
- The Australian government ensures a significant contribution to ITRF from the Australian Continent and Pacific region

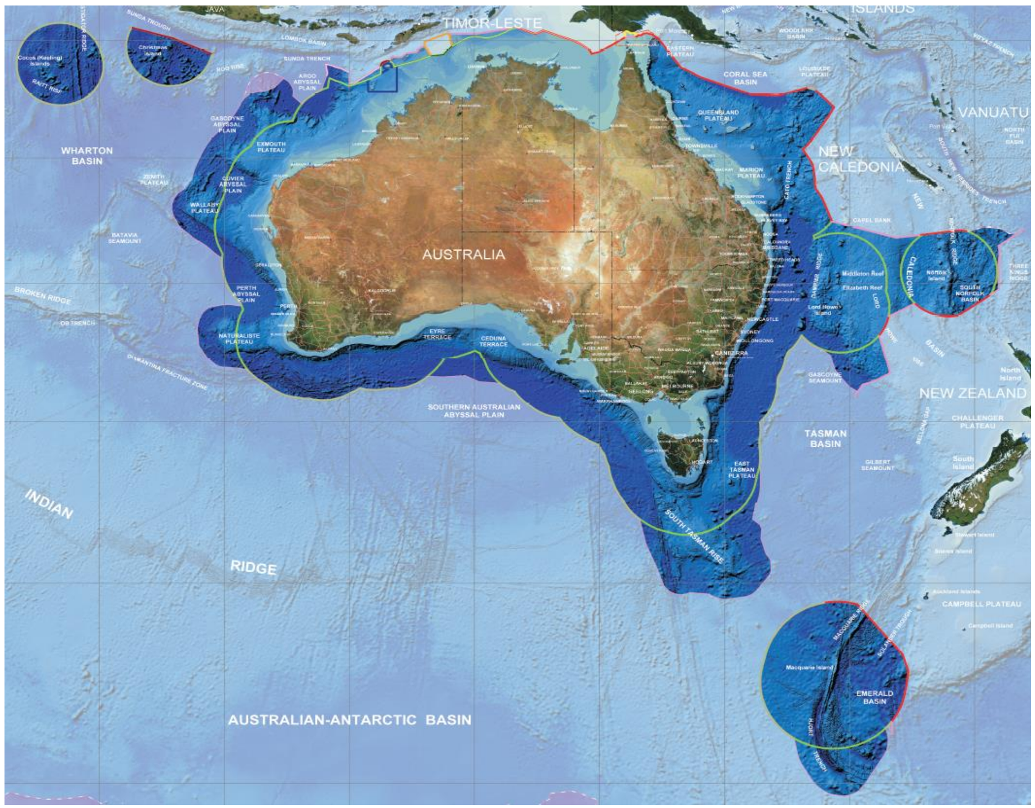
Yarragadee Geodetic Observatory, Western Australia

Reference Frames

- GNSS is the primary tool for accessing reference frame in Australia
- Data from our GNSS network is contributed to organisations like International GNSS Service (IGS) and APREF
- IGS products widely used by Australian industry and government

Australia and GDA2020





History of Australian Datums

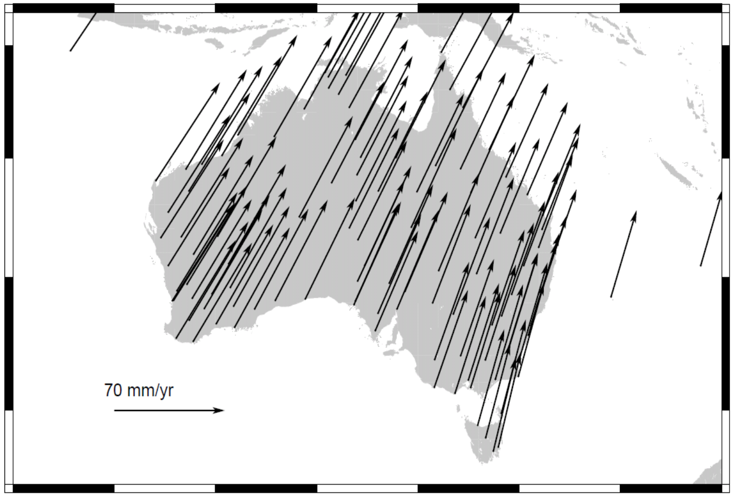
- Between 1858 and 1966 no national datum
- Australian Geodetic Datum 1966 (AGD66)
  - derived from astronomical observations all over Australia
- Australian Geodetic Datum 1984 (AGD84)
- Geocentric Datum of Australia 1994 (GDA94)
  - Geocentric, ITRF1992 @ 1994
- Geocentric Datum of Australia 2020(GDA2020)
  - ITRF2014 @ 2020

Future

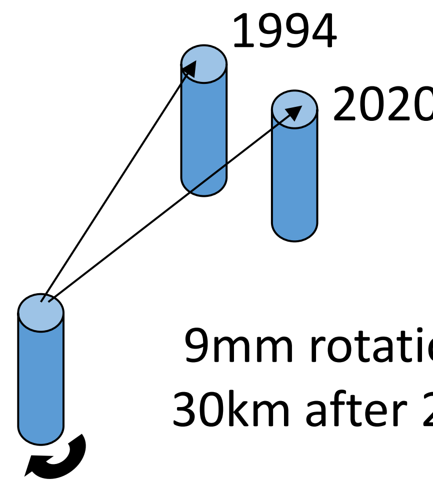
- Australian Terrestrial Reference Frame (ATRF)

Why Update GDA94

Absolute difference w.r.t. the ITRF

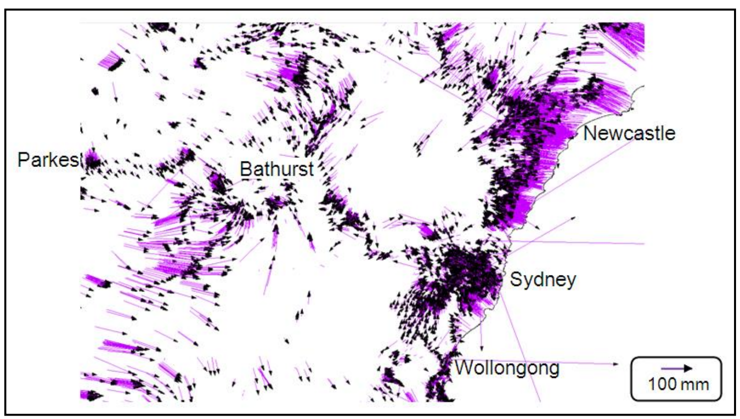


Rotation of the Australian Plate

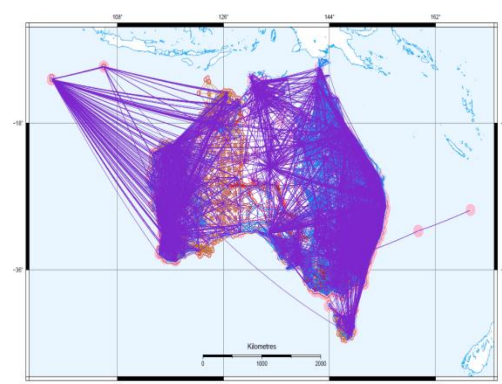


9mm rotation on a
30km after 26 years

Errors (distortions) in GDA94

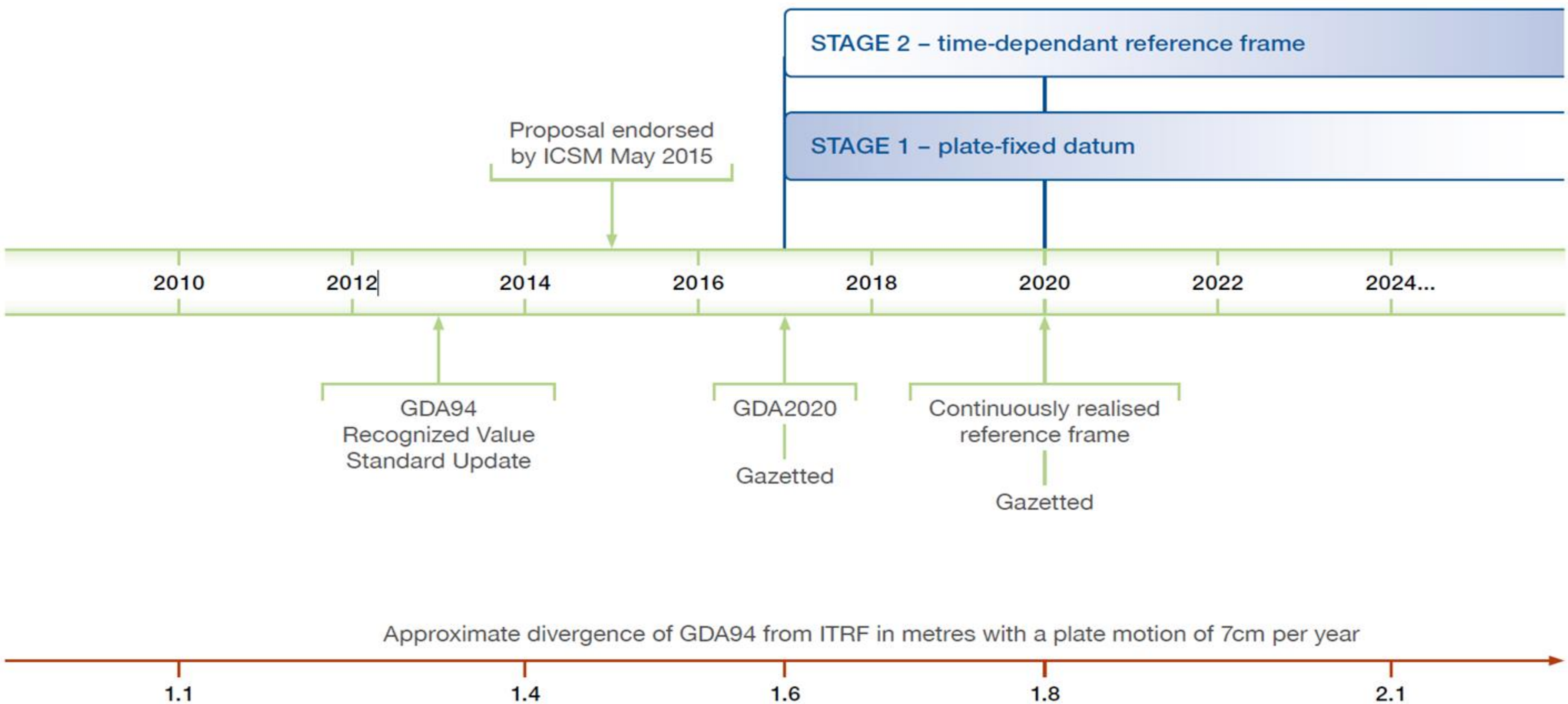


We can do it better now



GDA2020

Implementation Timeline



GDA2020 Objectives

- Support +/- 2 cm user positioning (PU 95% CL)
- Has a known relationship to the ITRF at +/- 2 cm (PU 95% CL) or better
- Fully 3-D (i.e. ellipsoidal)
- Support the computation of relative uncertainty between any survey mark

GDA2020 Objectives

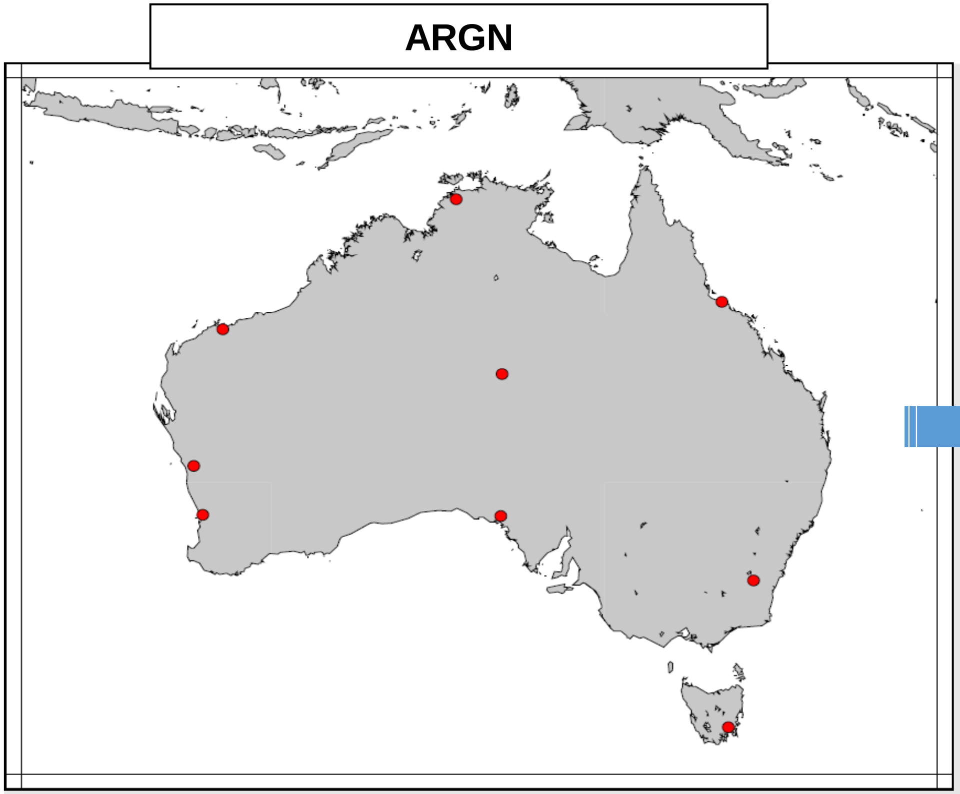
- Updated continuously as new observations are contributed and blunders detected
- Support the continuous update of the national Geoid model
- Support time-based corrections (i.e. deformation models)
- Has tools and services that facilitate its use by the mass-market

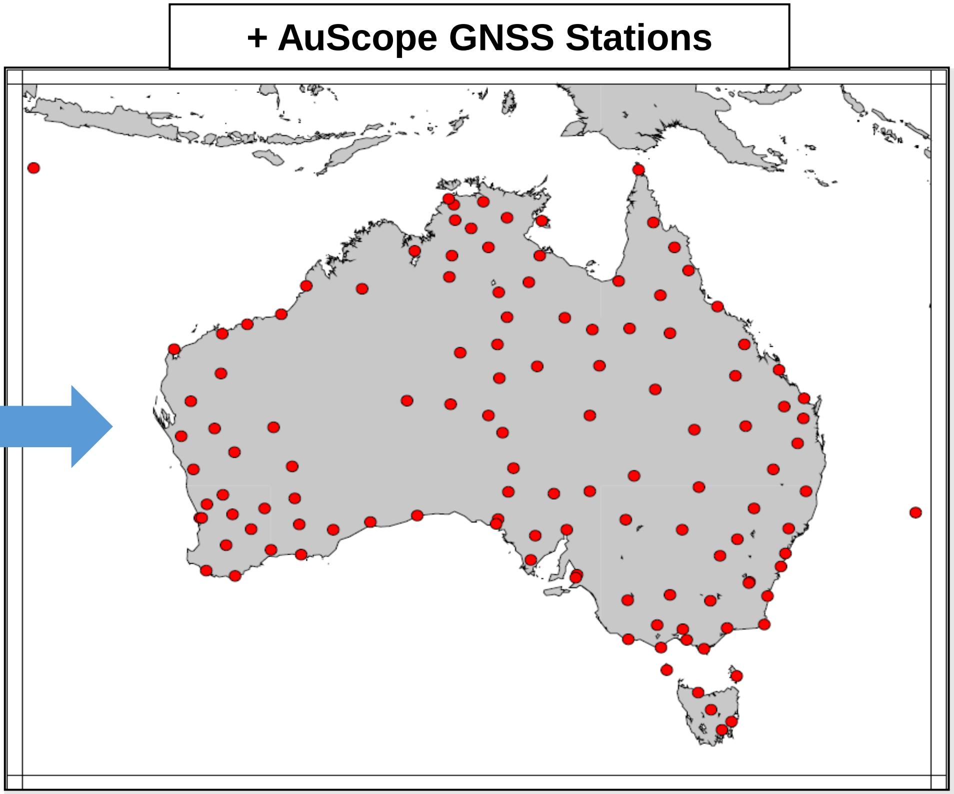
GDA2020 Approach

GDA2020

Upgrade of national GNSS Infrastructure

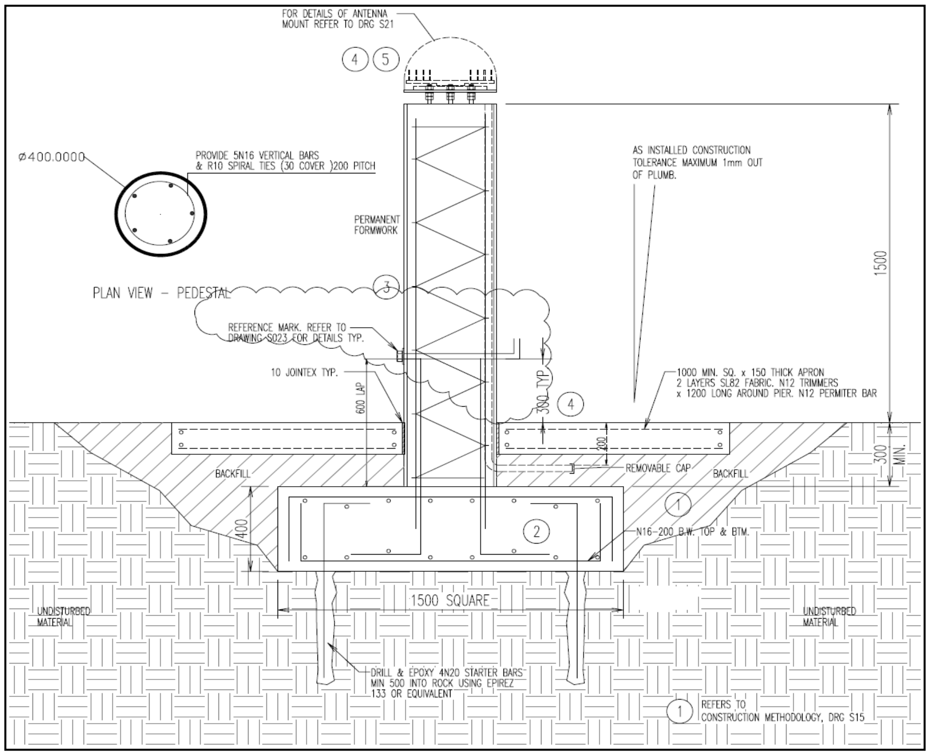
- Australian Regional GNSS Network (ARGN)
- AuScope National Research Infrastructure





National GNSS infrastructure

- Upgrade of national GNSS Infrastructure
- Care taken with monumentation



GDA2020 Analysis

Coordinates, velocities and a plate model were derived in three main stages:

1. GPS Processing (Bernese)
    - daily and weekly coordinate solutions (SINEX)
    - application of latest modelling and reprocessing

2. Velocity Estimation (CATREF)
    - combination of weekly GPS solutions (SINEX)
    - application of discontinuities
    - position and velocity estimation

3. Estimation of Plate Model (in-house)
    - derived from AUSCOPE + ARGN velocity estimates and VCV

GPS Processing

- Processing software – BERN52
- Reprocessed from 1996 to 2016
- Based on IGS orbit and ERP products
- Processing methodology based on subnetworks
- Processed on a supercomputer (approximately 50 kSU to complete)

- Approximately 2-3 months to complete
- Major constraint is chasing up individual outliers, and resolving issues with individual solutions

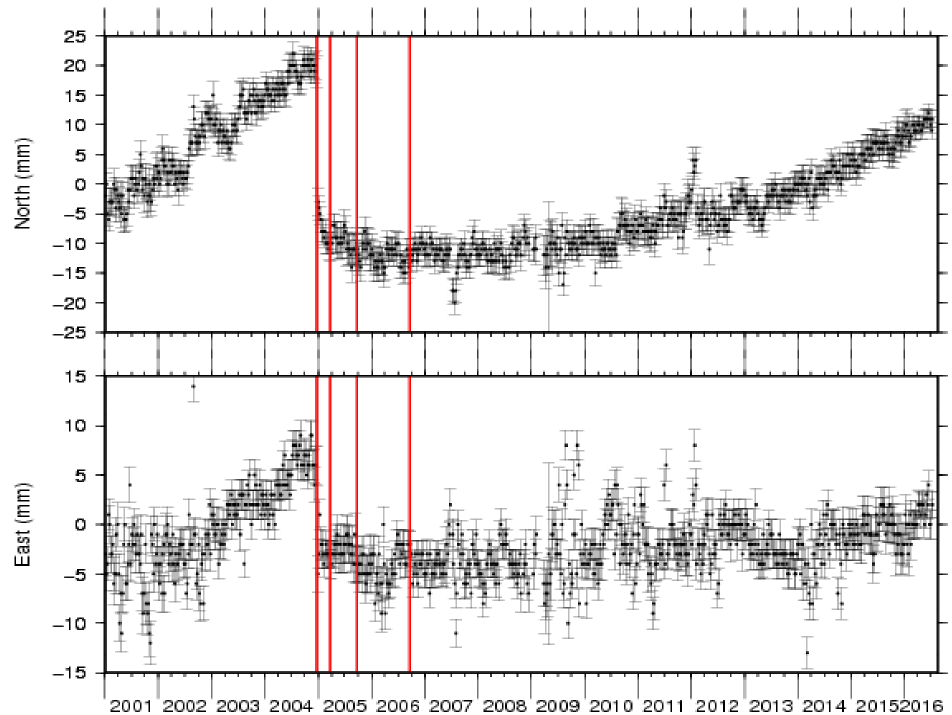
Velocity estimation

- SINEX combination undertaken in CATREF software
  - A combination of 20 year time series takes approximately 4 days to complete
  - Currently only using weekly solutions, daily solutions would take to long to run.
  - refining our reference frame station selection algorithm

- Missing discontinuities, or the misapplication of a discontinuity, in the time series impact the velocity and position estimates, so care was taken to address this

- Non-linear discontinuities to deal with large earthquakes (e.g. COCO and XMIS) were not dealt with at this stage (doesn't significantly impact Continental Australia)

Macquarie Island coordinate time-series

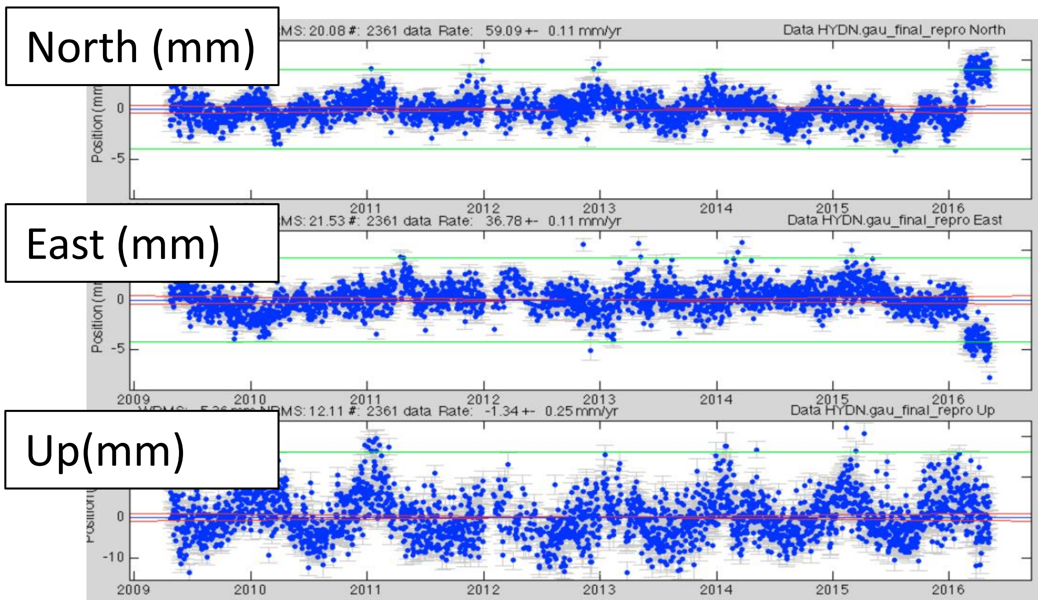


GDA2020

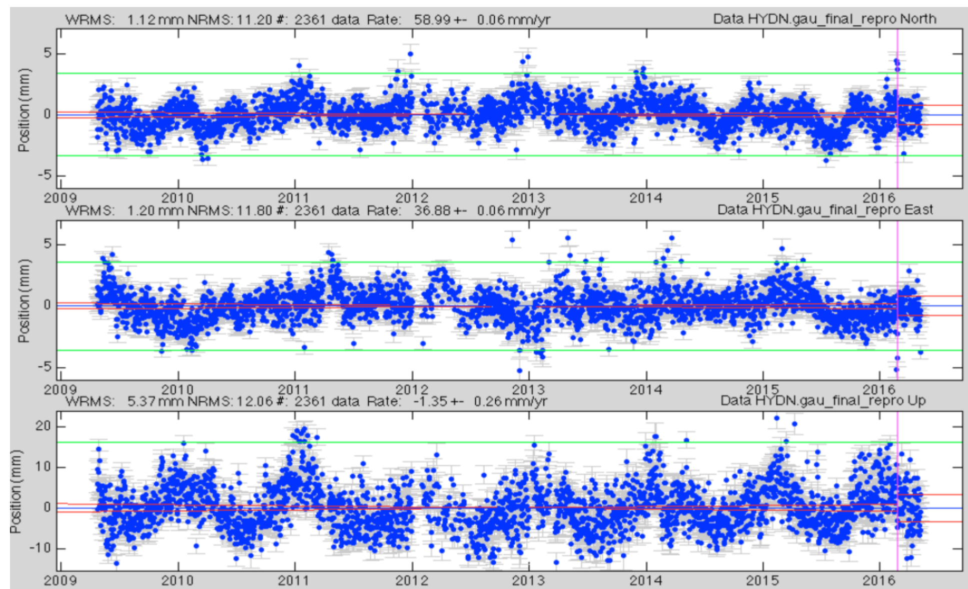
Handling of discontinuities

- For IGS core stations: apply official IGS discontinuities supplied by the IGS-RF WG.
- For AUSCOPE and APREF: TSVIEW to help aid the detection discontinuities

Before discontinuity is applied

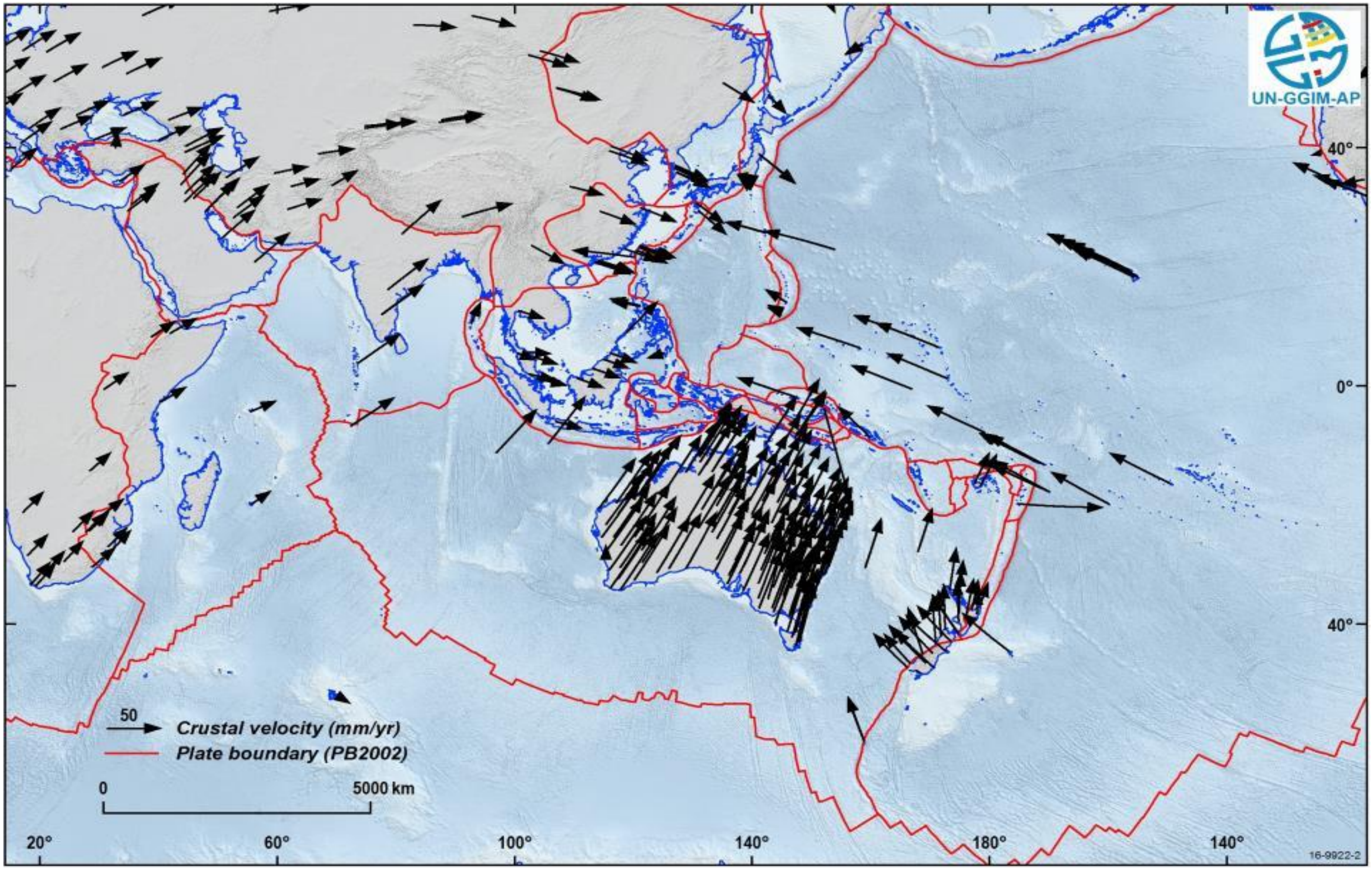


After discontinuity is applied



AuScope HYDN – note: change of antenna, mainly impacts horizontal

Velocity estimation



Australian station velocity estimates

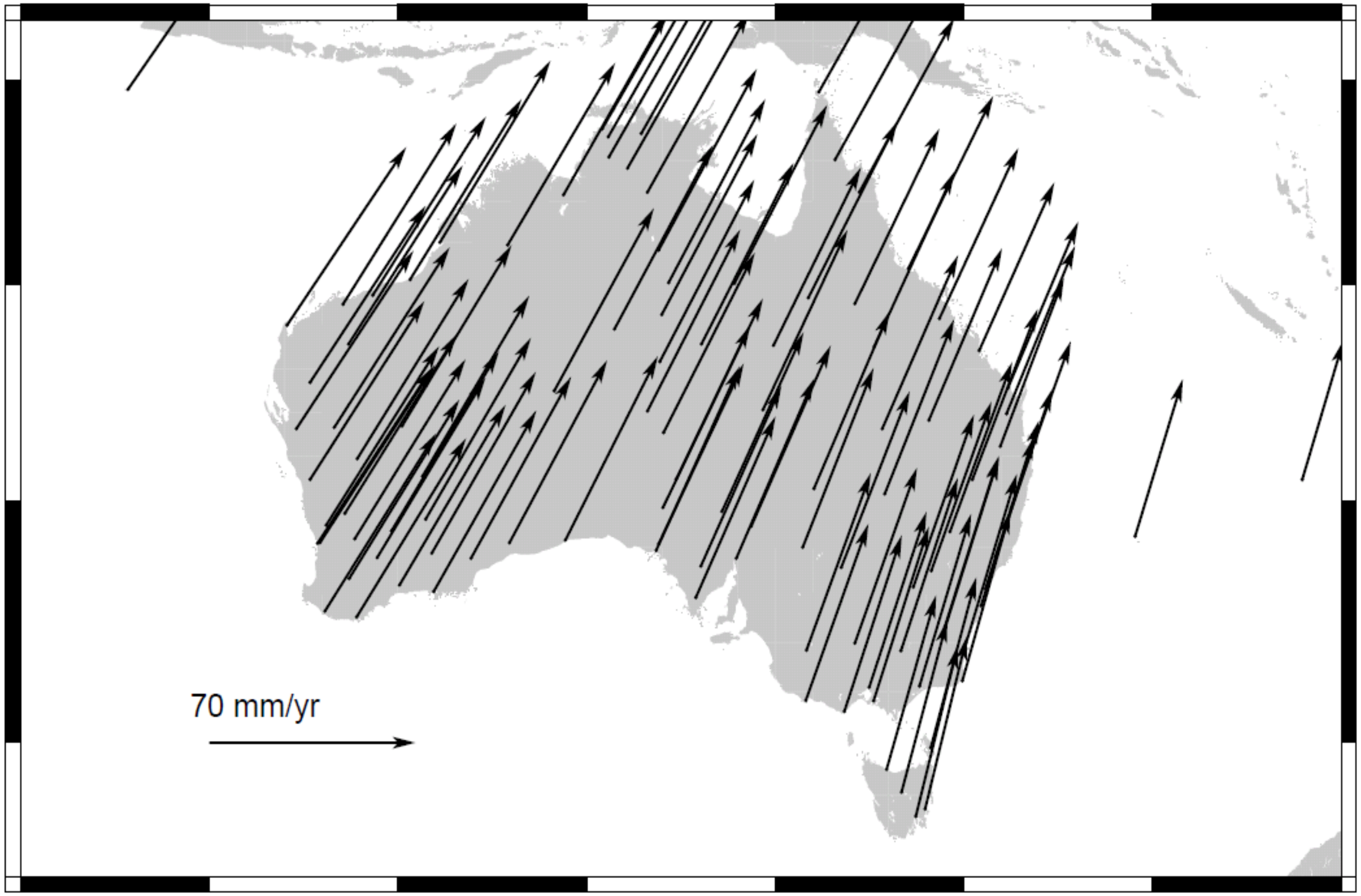
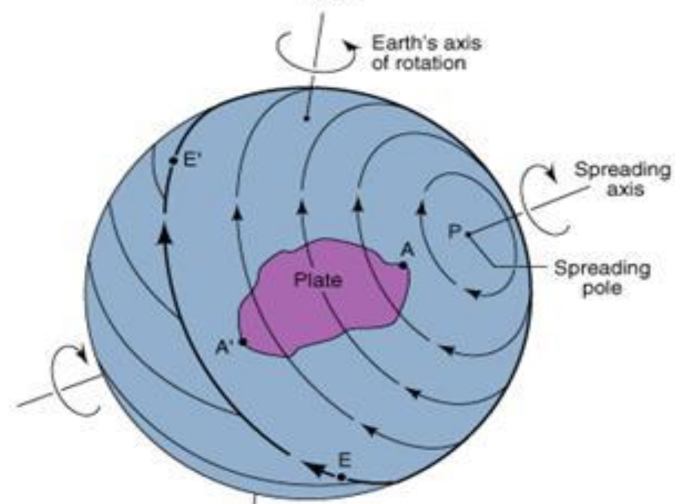


Plate Model

Plate Model estimation

- CATREF combined SINEX used as input
- Solution reduced to high quality ARGN and AuScope stations only
- Outliers > 1mm/yr

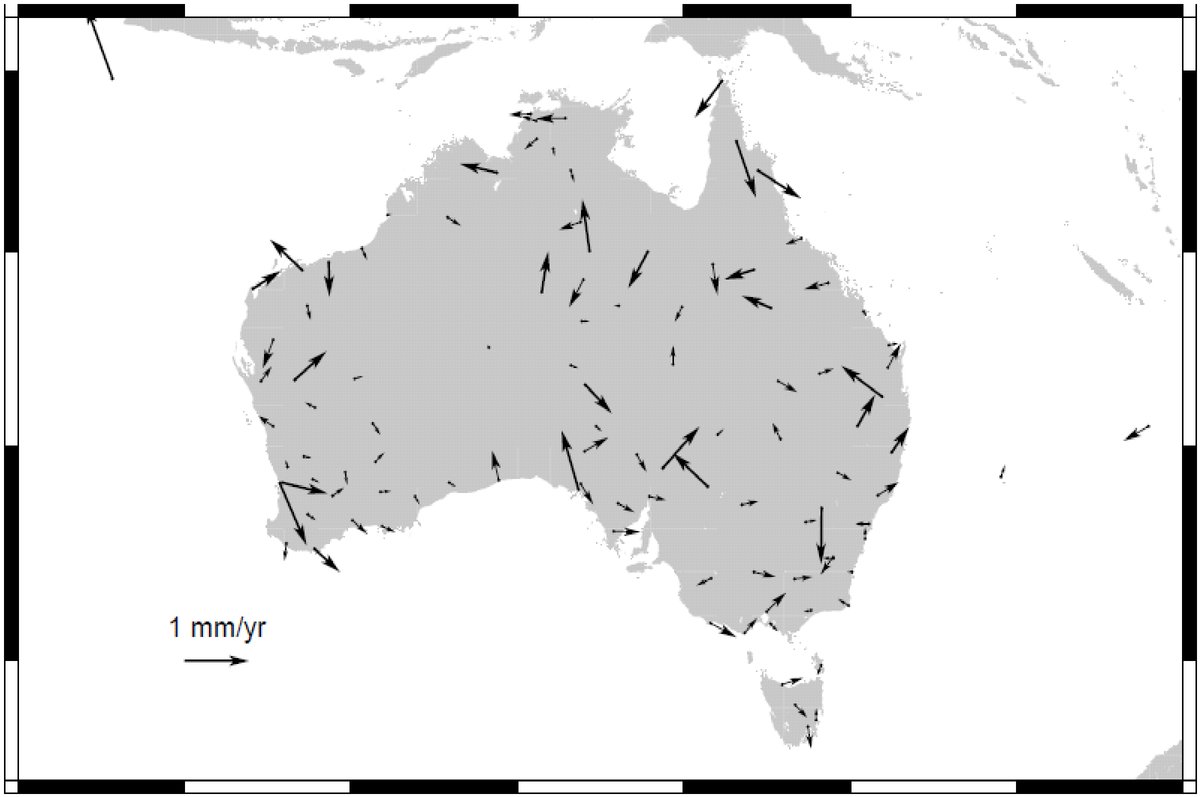
- Conventional plate model works well in Australia for geodetic applications
- Australian Plate across the Australian continent is stable at the 0.2 to 0.3 mm/yr level
- Post-seismic effects from far-field earthquake do change crustal motion Australian sites by ~0.3 mm/yr
- Co-seismic effects from far-field earthquakes at the 3 mm level but this is not an issue if they are modelled correctly in the combination



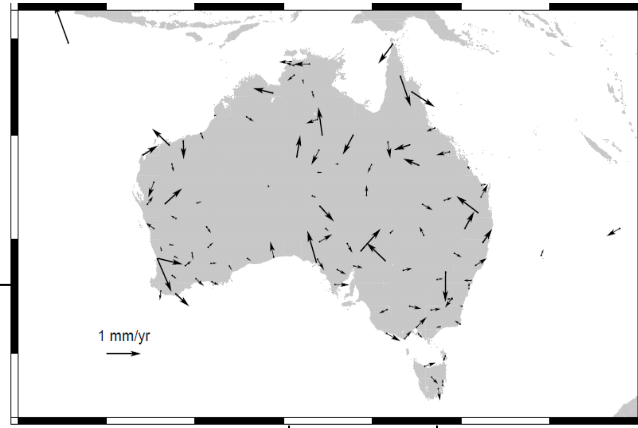
$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix} = \begin{bmatrix} 0 & z & -y \\ -z & 0 & x \\ y & -x & 0 \end{bmatrix} \begin{bmatrix} \dot{r}_x \\ \dot{r}_y \\ \dot{r}_z \end{bmatrix}$$

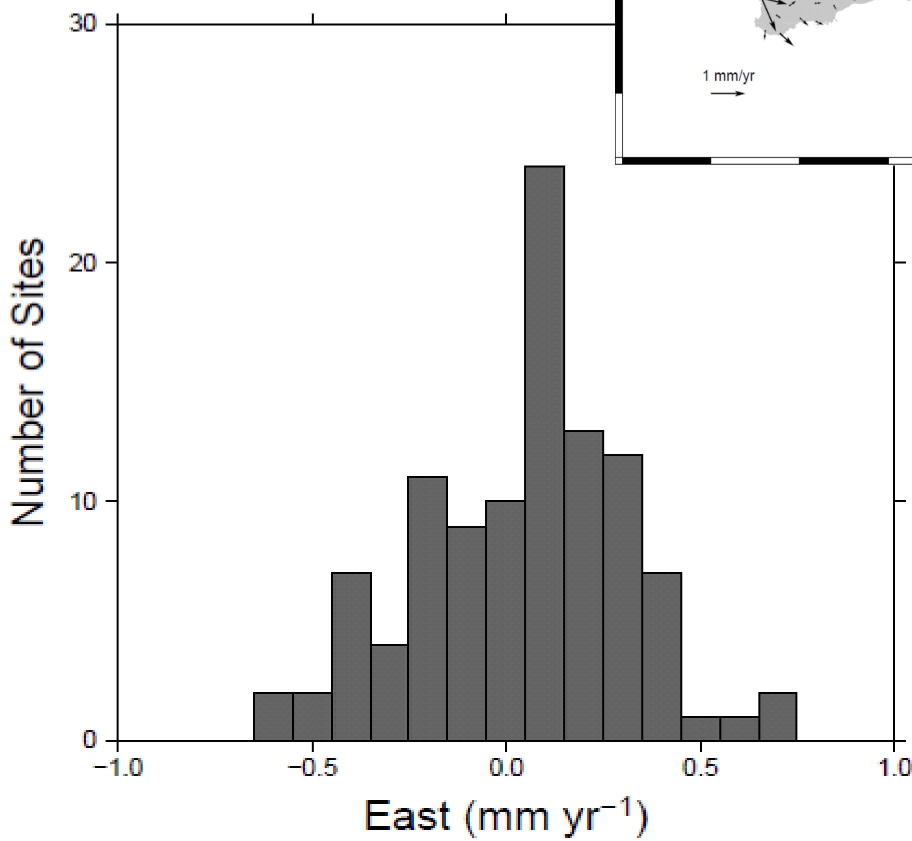
Residual velocity

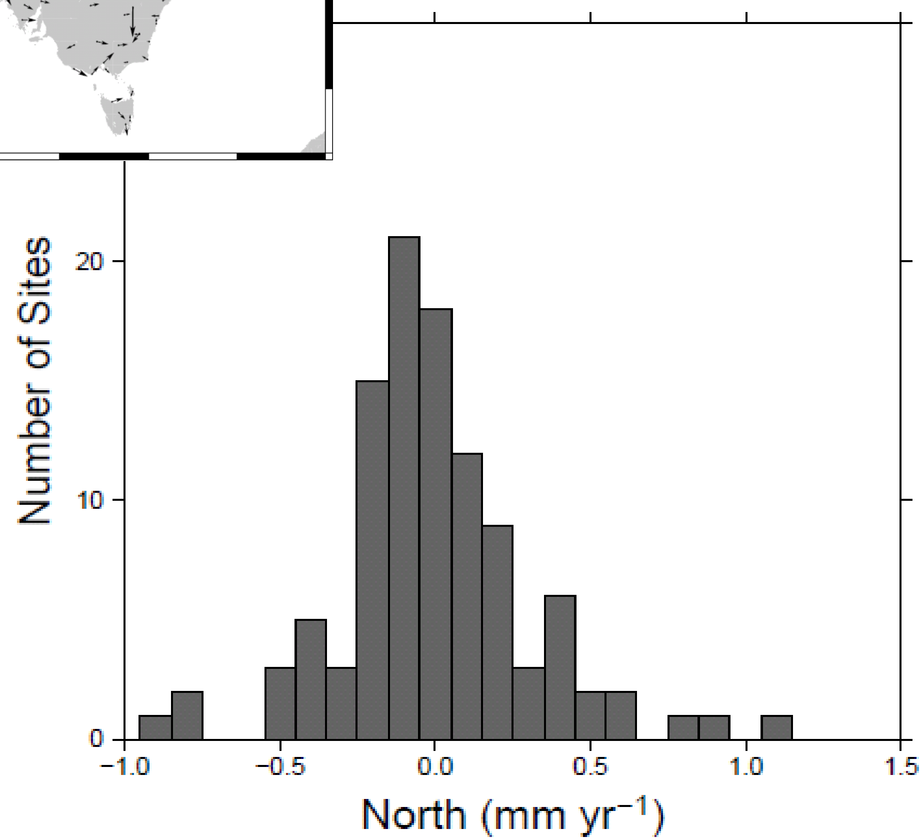
- APREF station velocities minus Plate Model velocities
- Residuals – measurement error versus geophysical signal?



Residual velocity







GDA2020

Plate Model

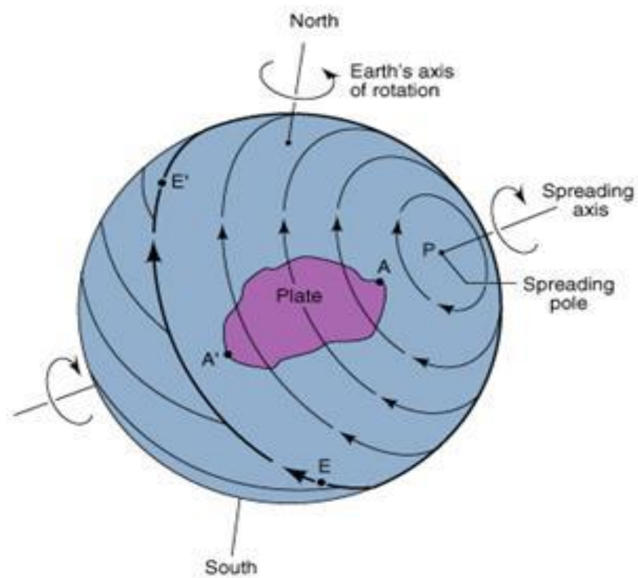
- Easy for Australians to adopt ITRF and transform to GDA2020 and vice versa

From ITRF2014 to GDA2020

$$\begin{pmatrix} X_{GDA2020} \\ Y_{GDA2020} \\ Z_{GDA2020} \end{pmatrix} = \begin{pmatrix} 1 & \dot{R}_Z\,(t-2020) & -\dot{R}_Y(t-2020) \\ -\dot{R}_Z(t-2020) & 1 & \dot{R}_X(t-2020) \\ \dot{R}_Y(t-2020) & -\dot{R}_X(t-2020) & 1 \end{pmatrix} \begin{pmatrix} X_{ITRF} \\ Y_{ITRF} \\ Z_{ITRF} \end{pmatrix}$$

Velocity of Ground marks

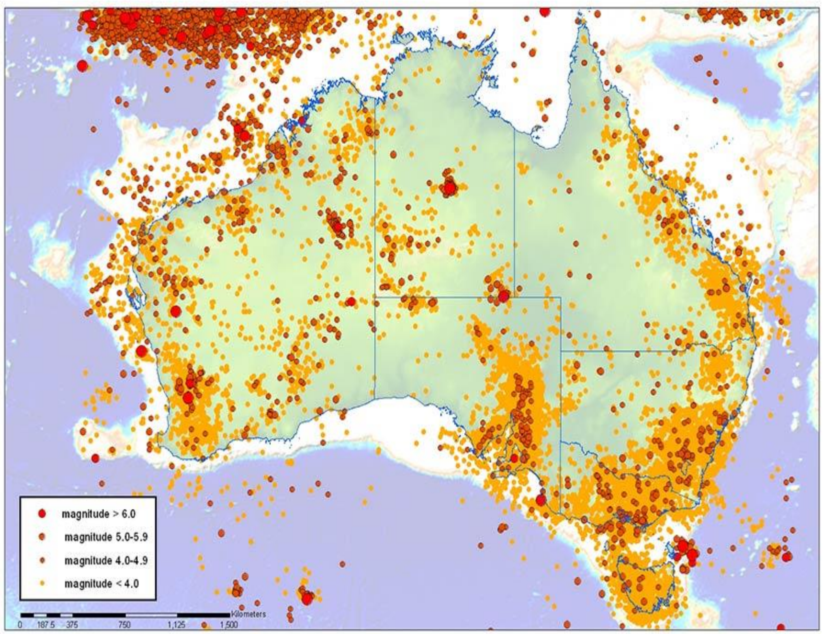
$$\begin{pmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \end{pmatrix} = \begin{pmatrix} 0 & Z & -Y \\ -Z & 0 & X \\ Y & -X & 0 \end{pmatrix} \begin{pmatrix} \dot{R}_X \\ \dot{R}_Y \\ \dot{R}_Z \end{pmatrix}$$



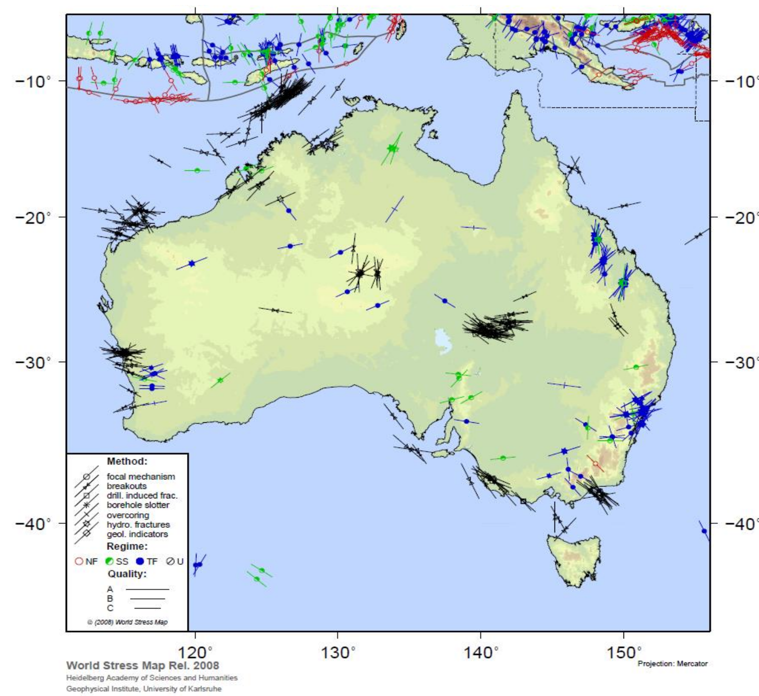
Stable Australian Plate?

- Estimates of the regional seismic moments (e.g., Kostrov, 1974) lead to predictions of the deformation of the Australian plate of 0.65 ± 2 mm/yr (95% confidence level) (Leonard, 2008)

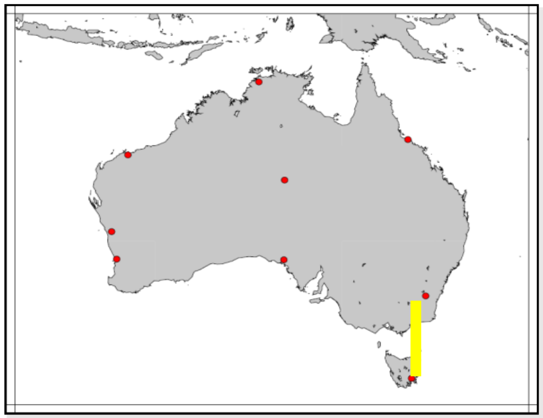
Australian earthquakes



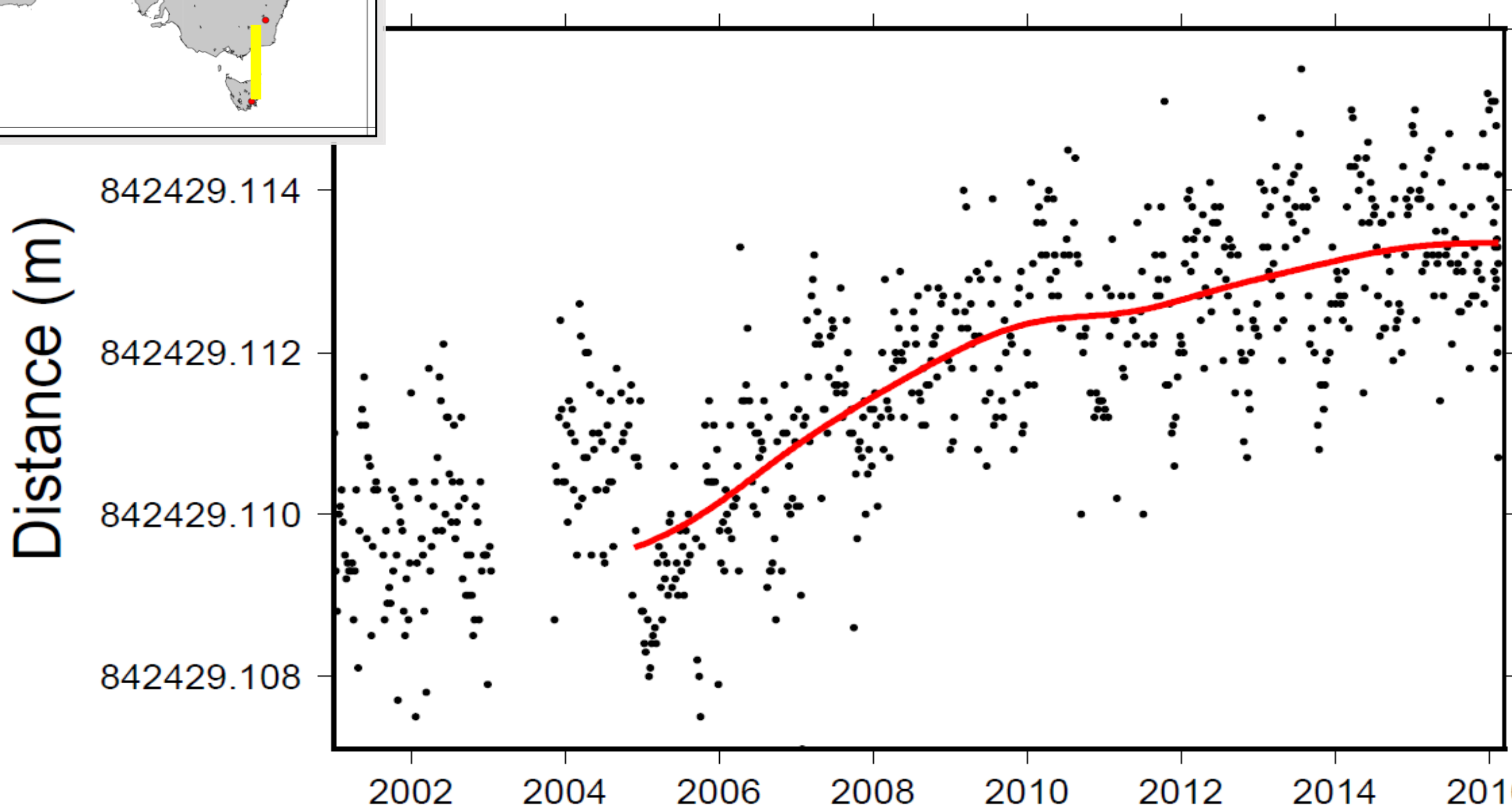
Australian stress orientation



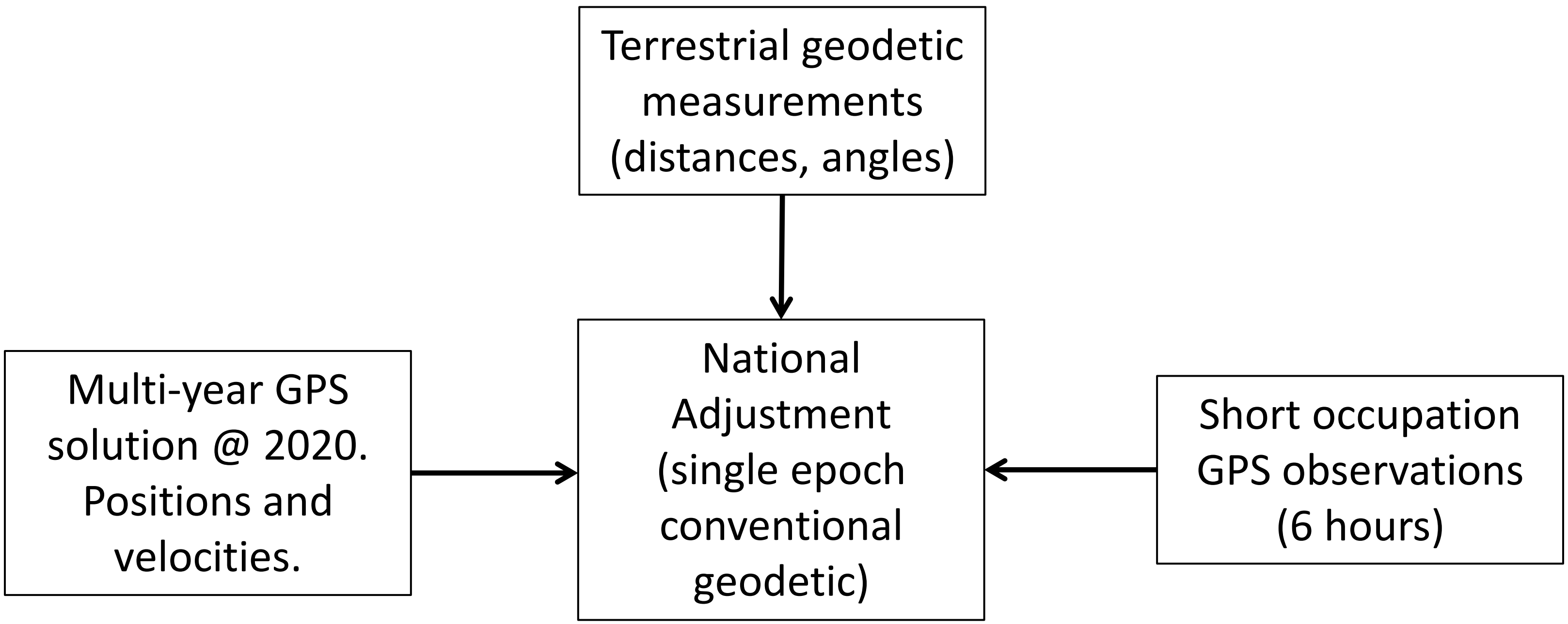
2004 Mw=8.1 Macquarie Ridge earthquake



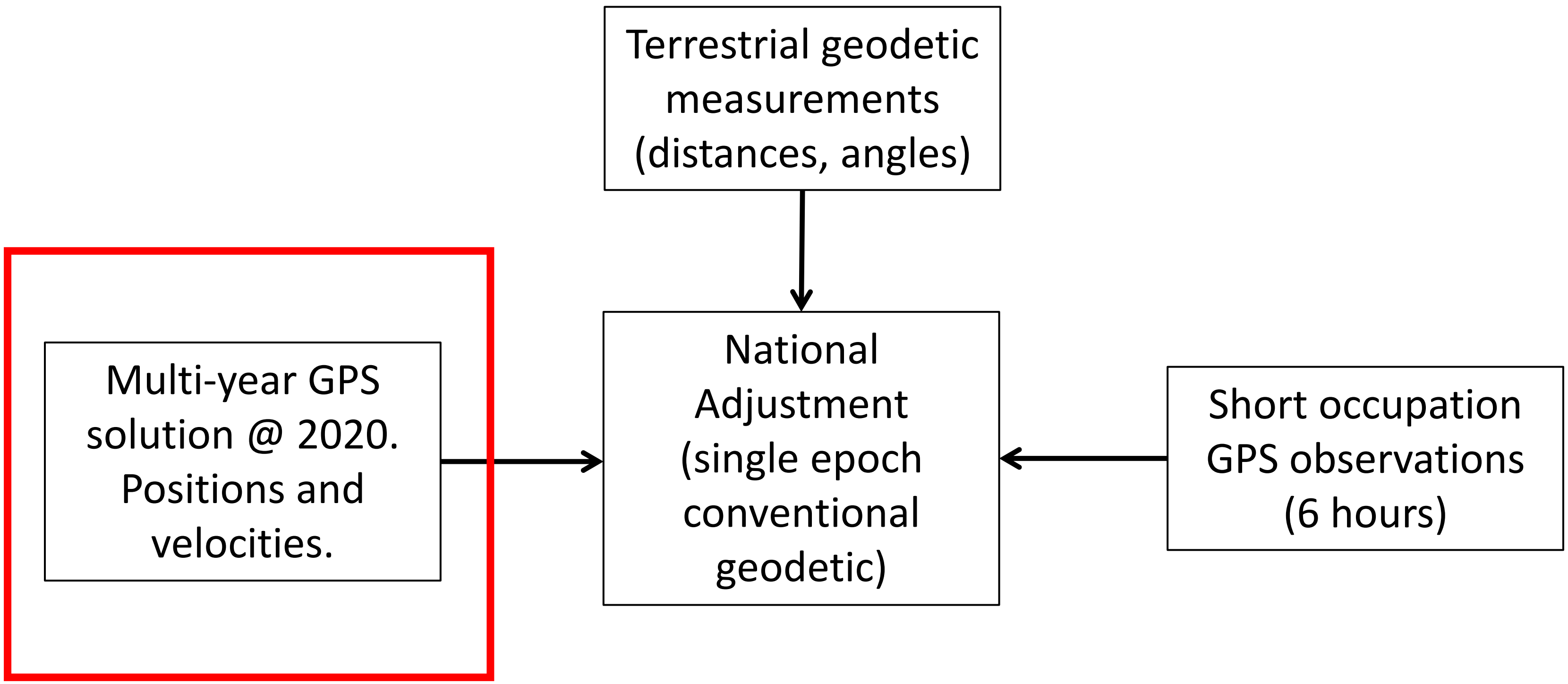
Canberra to Hobart (GA Operational Solution)



Geodetic Adjustment Strategy

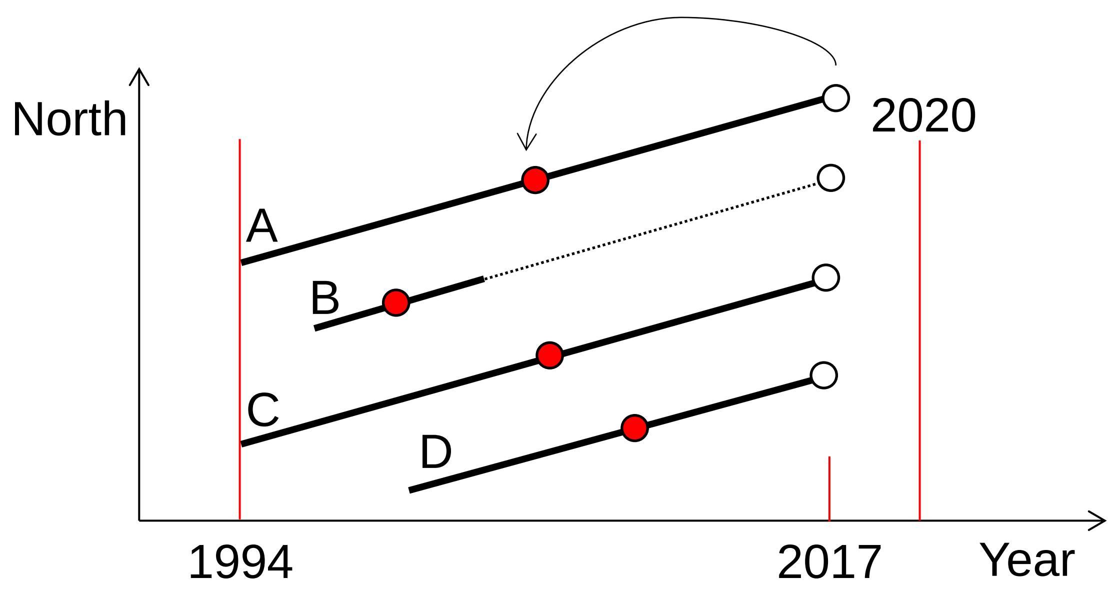


Geodetic Adjustment Strategy



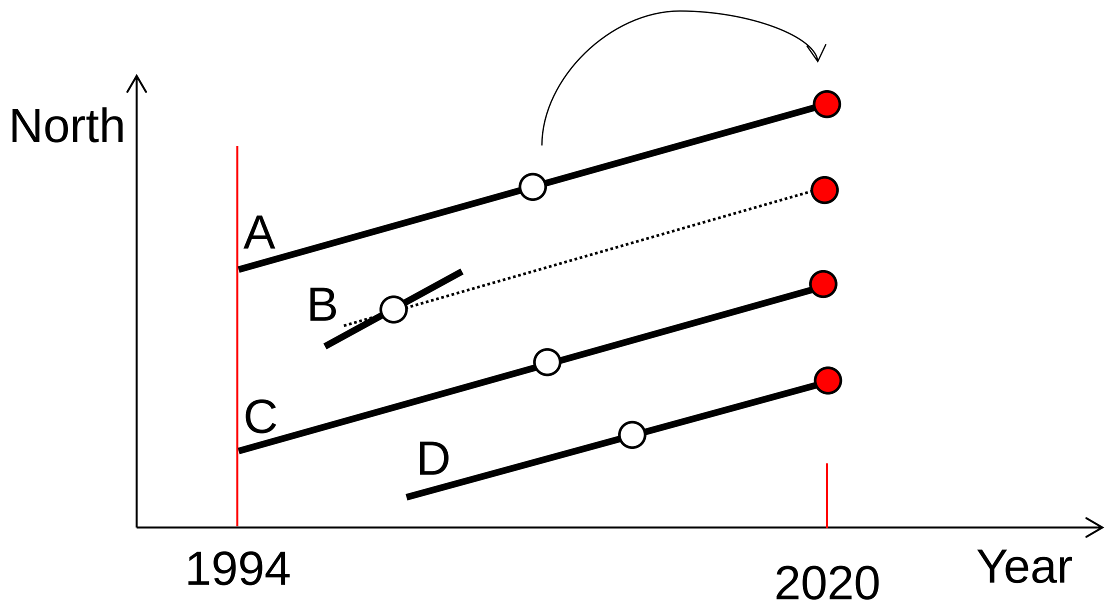
Generating a solution at 2020

- Multi-year GPS solution was the datum constraint for all further geodetic adjustments
- Includes all GNSS CORS in Australia including short-span stations
- Interpolate all coordinates (and the VCV) to individual site mean epochs



Generating a solution at 2020

- Short-span CORS stations generally have unreliable velocity estimates but Plate Model velocities very reliable
- Replace the observed station velocities with modelled velocities if the they differ by an amount larger than a threshold value (1 mm/yr)
- Map all coordinates to 2020

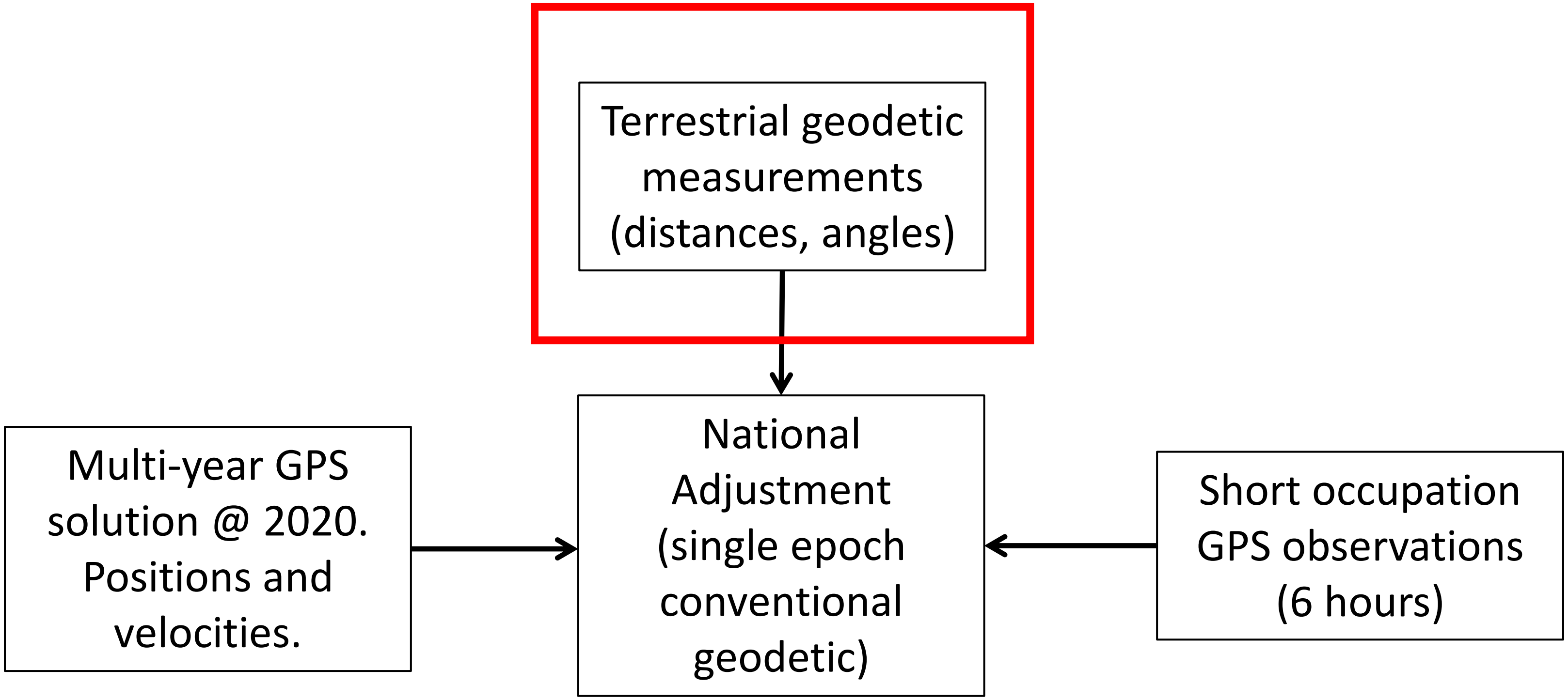


Coordinate Transformation

- GDA94 to and from GDA2020 important next step
- Input:
  - Official GDA94 defining station
  - New coordinates from the multi-year GPS solution at 2020
- Compute 7-parameter transformation using CATREF software

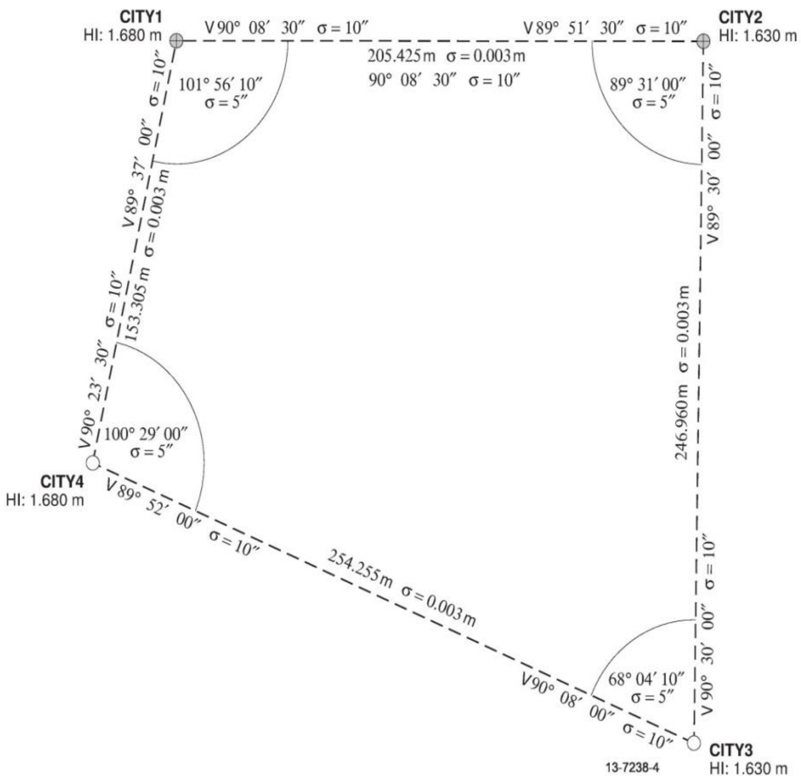
$$\begin{pmatrix} X_{GDA2020} \\ Y_{GDA2020} \\ Z_{GDA2020} \end{pmatrix} = \begin{pmatrix} T_x \\ T_y \\ T_z \end{pmatrix} + (1 + S_c) \begin{pmatrix} 1 & R_z & -R_y \\ -R_z & 1 & R_x \\ R_y & -R_x & 1 \end{pmatrix} \begin{pmatrix} X_{ITRF} \\ Y_{ITRF} \\ Z_{ITRF} \end{pmatrix}$$

Geodetic Adjustment Strategy

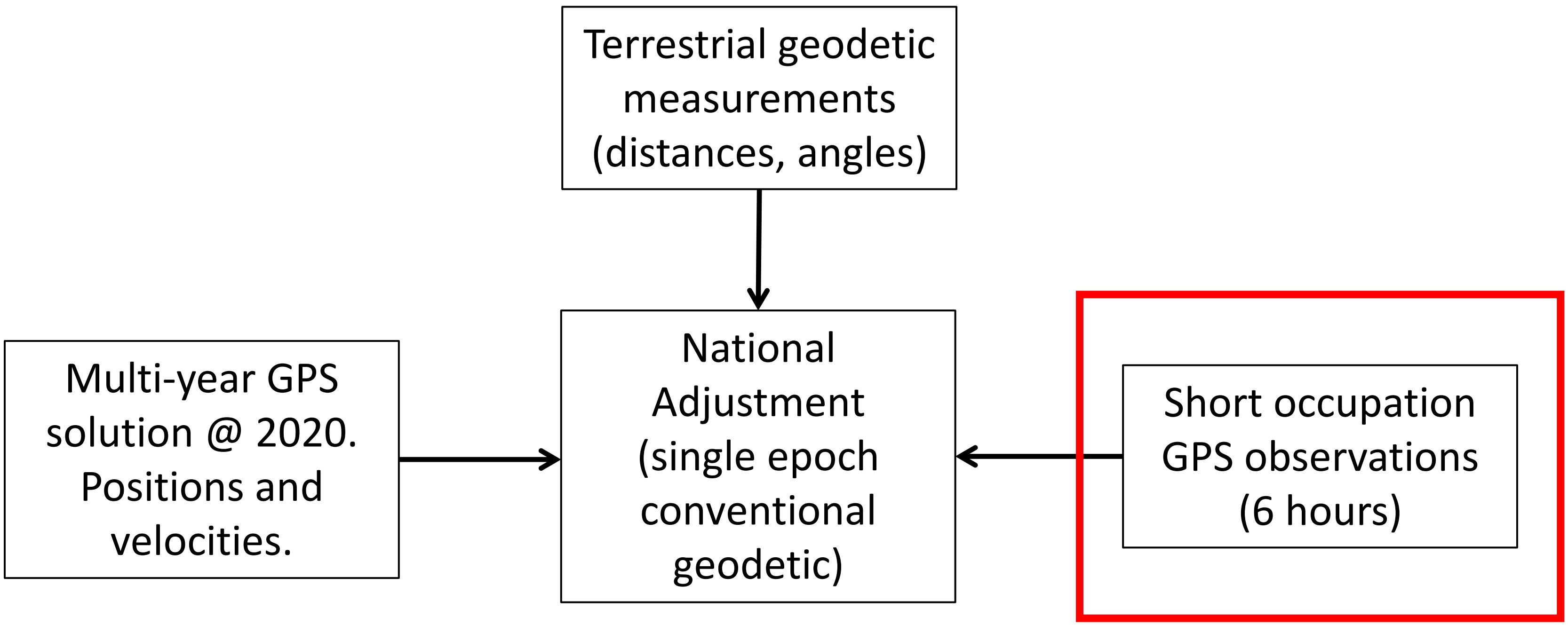


Terrestrial geodetic observations

- Terrestrial (angles, distances) geodetic observations
- 580,000 measurements
- 245,000 stations

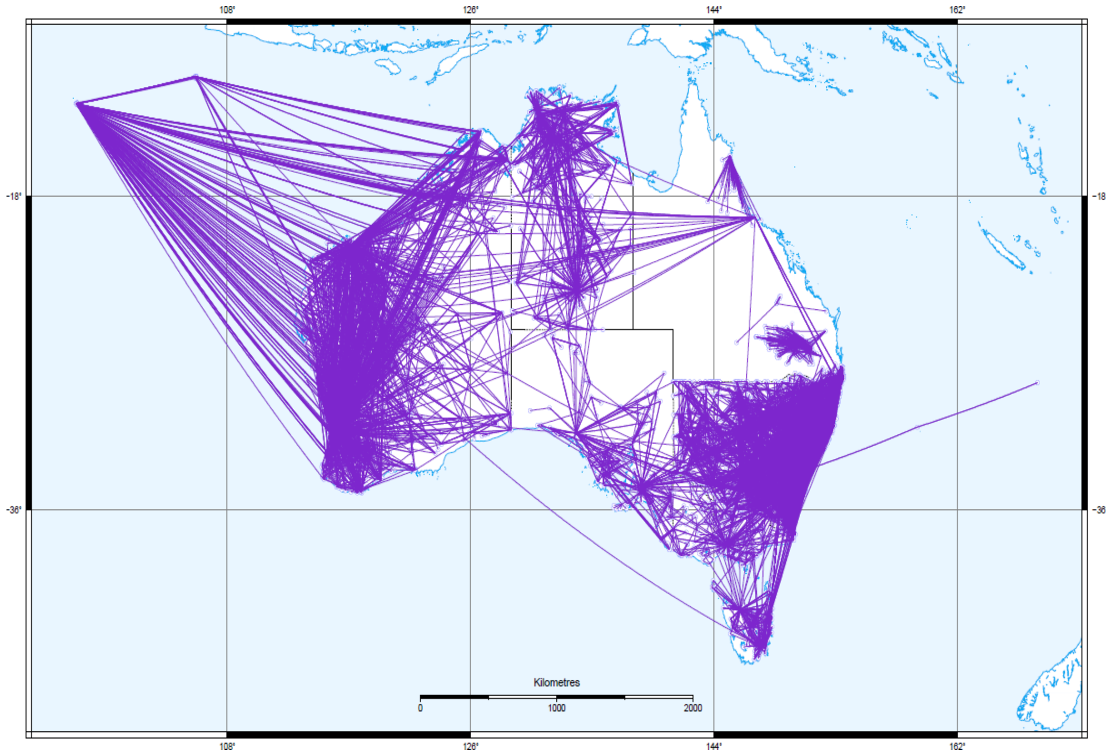


Geodetic Adjustment Strategy

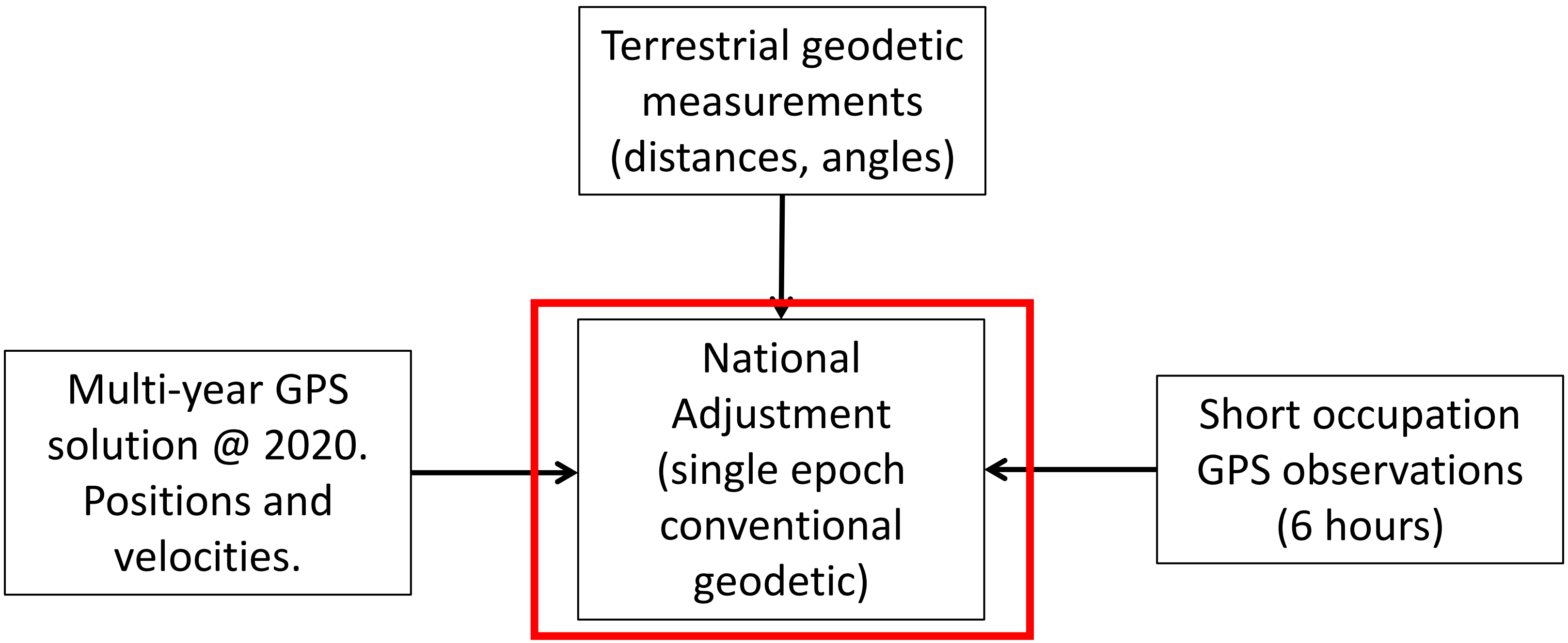


GPS

- Created a large observation archive of GPS data observed by Australian government agencies
- 9000 RINEX files that were 6+ hours
- 6092 stations
- Processing automated (AUSPOS engine)



Geodetic Adjustment Strategy



Geodetic adjustment

- Phased Least Squares adjustment technique implemented in DynaNet software
- Automated sub-network segmentation
- Generates rigorous solution of very large geodetic adjustments

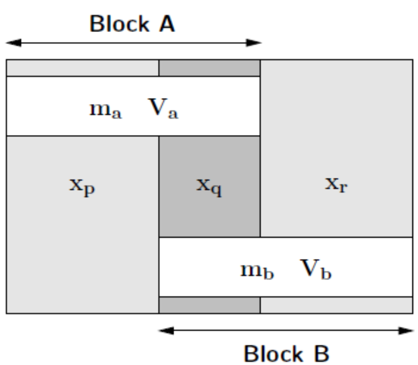
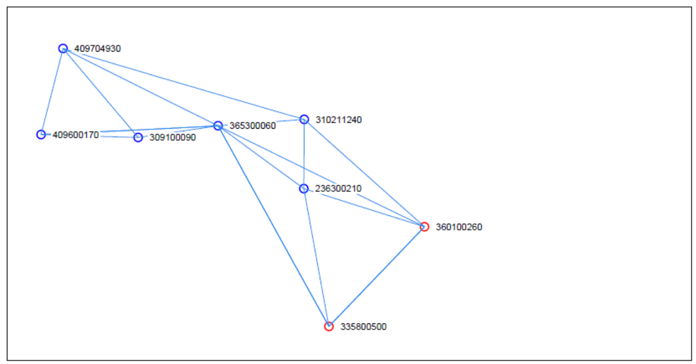
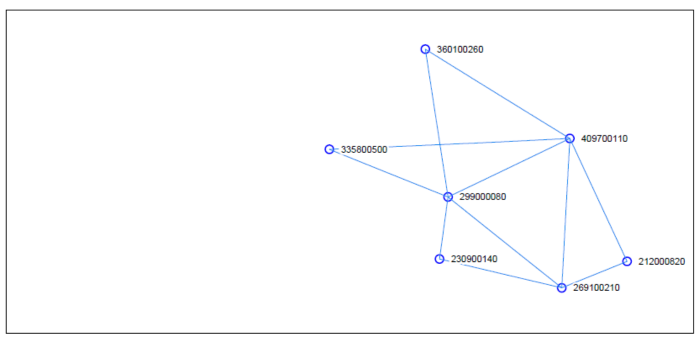


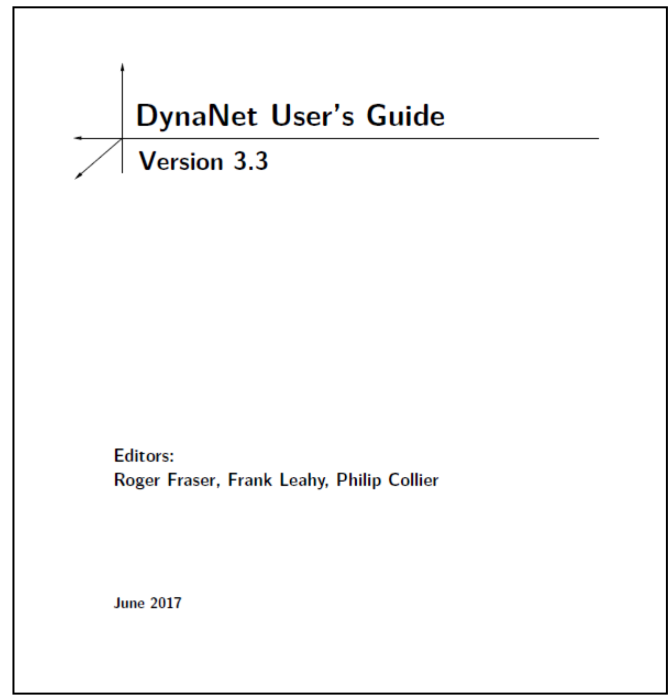
Figure 6.1: Network segmentation concept



(a) First block (Block A)



(b) Second block (Block B)



DynaNet User's Guide

Version 3.3

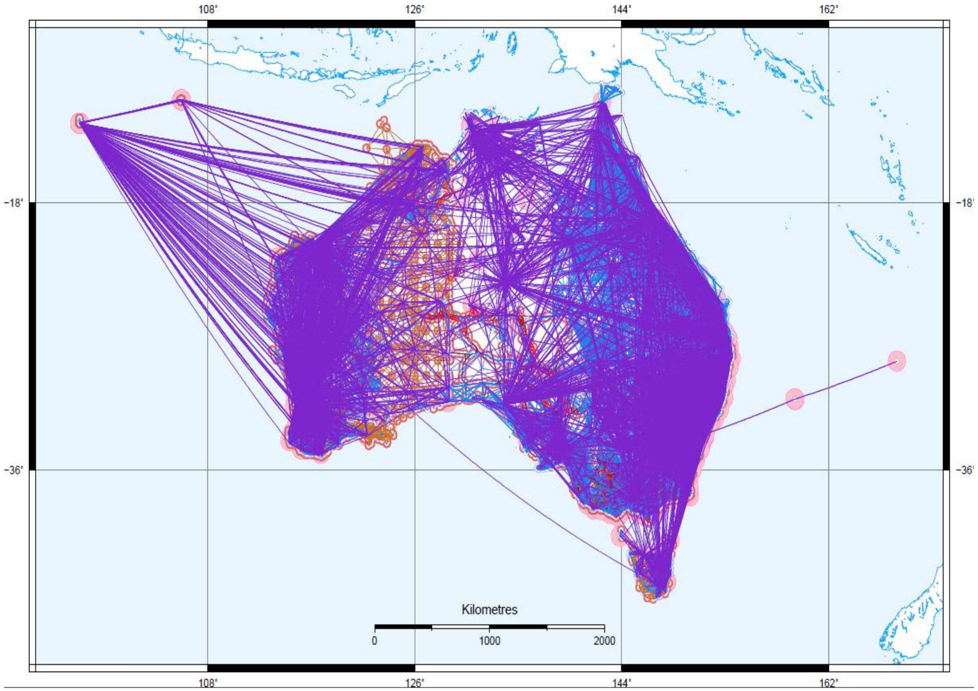
Editors:
Roger Fraser, Frank Leahy, Philip Collier

June 2017

Source: Roger Fraser *et al* 2017

Geodetic adjustment

- 1,969,705 measurements to 245,774 stations
- 4 iterations at 22 hrs/iteration and requires ~20GB of RAM
- $\sigma_0 = 1.012$



(A) Horizontal angle:	0
(B) Geodetic azimuth:	1711
(C) Chord dist:	0
(D) Directions:	324020
(E) Ellipsoid arc:	7652
(G) GPS baseline:	1212357
(H) Orthometric height:	131336
(I) Astronomic latitude:	0
(J) Astronomic longitude:	0
(K) Astronomic azimuth:	87
(L) Level difference:	3376
(M) Mean sea level arc:	195930
(P) Geodetic latitude:	0
(Q) Geodetic longitude:	0
(R) Ellipsoidal height:	0
(S) Slope distance:	46064
(V) Zenith angle:	3
(X) GPS baseline cluster:	45483
(Y) GPS point cluster:	1686
(Z) Vertical angle:	0

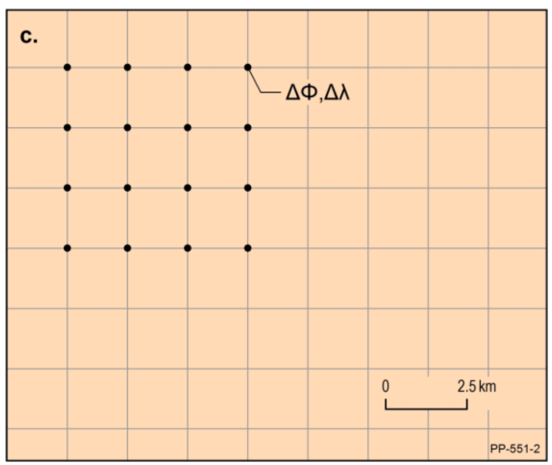
Source: Craig Harrison 2017

GDA2020

Transformation GDA94 to GDA2020

- The GDA94 – GDA2020 grids were developed using over 170,000 points at which both GDA94 and GDA2020 coordinates were available
- Available for implementation in GIS software

$$\begin{pmatrix} X_{GDA2020} \\ Y_{GDA2020} \\ Z_{GDA2020} \end{pmatrix} = \underbrace{\begin{pmatrix} T_x \\ T_y \\ T_z \end{pmatrix} + (1 + S_c) \begin{pmatrix} 1 & R_z & -R_y \\ -R_z & 1 & R_x \\ R_y & -R_x & 1 \end{pmatrix} \begin{pmatrix} X_{GDA94} \\ Y_{GDA94} \\ Z_{GDA94} \end{pmatrix}}_{\text{Helmert transformation}} + \underbrace{\begin{pmatrix} D_x \\ D_y \\ D_z \end{pmatrix}}_{\text{Distortion model NTv2}}$$



GDA2020 Communications

DATUM MATTERS

01 Australia's datum modernisation: *what you need to know*

Changes are being made to the system that underlies Australia's location information. The changes will bring Australia's national latitude and longitude coordinates into line with global satellite positioning systems, enabling smartphones and other positioning technologies to accurately locate features marked on our maps.

Australia's national grid of latitude and longitude coordinates moves with the drift of the continent, but satellite positioning systems base their coordinates on a framework that is fixed to the centre of the Earth.

Australia's coordinate system moves along with the continent

The changes are needed because national and global location information systems operate differently, and they are diverging.

Australia's national grid of latitude and longitude coordinates moves with the drift of the continent, like a giant net tied to known reference points on the landscape. Together, these reference points and latitude and longitude coordinates are known as a geodetic datum.

How do the changes affect you?

The key thing to remember is that, in order to be reliable, location information must be identified by the datum as well as the coordinates. People who work with accurate spatial information and rely on location positioning technologies will need to keep up to date with the important changes being made to Australia's datum. For others, the datum shift will be largely invisible, apart from improvements to the location services provided by smartphones.

Every country has its own datum

The datum Australia uses now is called the Geocentric Datum of Australia 1994, or GDA94. The coordinates of features on our maps, such as roads, buildings and property boundaries, are all based on GDA94, and they do not change over time.

GDA 2020 *Modernising Australia's Datum* www.icsm.gov.au ICSM INTERGOVERNMENTAL COMMITTEE ON SURVEYING & MAPPING

DATUM MATTERS

01 Australia's datum modernisation: *what you need to know*

In the eyes of satellite positioning systems, location coordinates are fluid

In contrast, satellite positioning systems base their coordinates on a framework that is fixed to the centre of the Earth. So in their eyes, the coordinates for features on moving parts of the Earth's surface, such as Australia, are always changing, like slow-moving ships at sea.

Discrepancies between the two systems will soon become more obvious

Historically, location differences of a metre or so have not been an issue, because positioning systems have been broad-brush to say the least. When GDA94 was adopted in 2000, GPS locations were 'accurate' to 100 metres.

Since then, however, two important things have happened. Australia has moved about 1.5 metres north-east, effectively moving the location of mapped features and their associated GDA94 coordinates. At the same time, positioning technology has evolved considerably.

By 2020, Australia will have moved 1.8 metres north-east of where it was in 1994, and many of us will own devices that pinpoint places as small as, well, a smartphone. With real-time access to precise satellite positioning at our fingertips, we'll notice discrepancies with GDA94-mapped features. The upshot is that Australia's datum needs updating so we can reap the benefits of 21st Century positioning technology.

We're moving Australia's coordinates into line with global systems

To allow for the complexity of the change, Australia is modernising the datum in two stages. Stage 1 begins in January 2017 and involves defining a new datum 1.8 metres to the north-east of GDA94. Called GDA2020, this new continent-fixed datum will bring the coordinates of Australia's mapped features back into line with global systems in 2020.

In 2020, Stage 2 of the modernisation will establish a different kind of location reference system, similar to the global one, that will continually model Australia's movement. Then the location information we rely upon will always be in perfect alignment with the devices we use to access it.

Who is implementing the change?

The Intergovernmental Committee on Surveying and Mapping (ICSM) has formed a group to oversee the modernisation of Australia's datum. The GDA Modernisation Implementation Working Group is helping users and government agencies to build transitional tools and technical resources, and providing information for software developers, equipment providers and users of spatial information.

In 2020, a driverless tractor using satellite positioning to work a paddock mapped under GDA94 will need to know the paddock and its national coordinates have moved 1.8 m since GDA94 was established.

Further information

Information about the datum modernisation, including a simple explainer animation, frequently asked questions, fact sheets and progress updates, is available on the ICSM website, www.icsm.gov.au.

GDA 2020 *Modernising Australia's Datum* www.icsm.gov.au ICSM INTERGOVERNMENTAL COMMITTEE ON SURVEYING & MAPPING 2

Global to Regional to National: A practical approach to improving access to the ITRF

Dr John Dawson

Chair Geodesy Working Group UN-GGIM Asia Pacific