UNITED NATIONS GLOBAL GEODETIC CENTRE OF EXCELLENCE

MODERNISING GEOSPATIAL REFERENCE SYSTEM CAPACITY DEVELOPMENT WORKSHOP

Transformation parameters, plate motion models and deformation models

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HOW

Day 3, Session 1 [3_1_1]

Acknowledgements: Nic Donnelly (NZ); Jan Dostal (UN-GGCE); Anna Riddell (AUS); Chris Pearson (NZ); Alex Woods (AUS)

Summary

- A coordinate transformation refers to a change of the coordinates of a point defined in one reference frame to a different reference frame (e.g. from XYZ in ITRF1996 to XYZ in ITRF2020)
- A common geodetic transformation is known as a 7-parameter transformation which includes:
  - 3 x Translation vector: The shift of the origin of the system
  - 3 x Rotation angles: The angle by which one system is rotated relative to another
  - 1 x Scaling: Resizing due to the different scales along the coordinate axis
- To develop a 7-parameter transformation between two different reference frames, you need to know the Earth Centred Cartesian Coordinates (i.e. XYZ), in both frames at a number of points.
- When a 7-parameter transformation is insufficient to achieve the accuracy required, a 1D, 2D or 3D deformation model may be required.

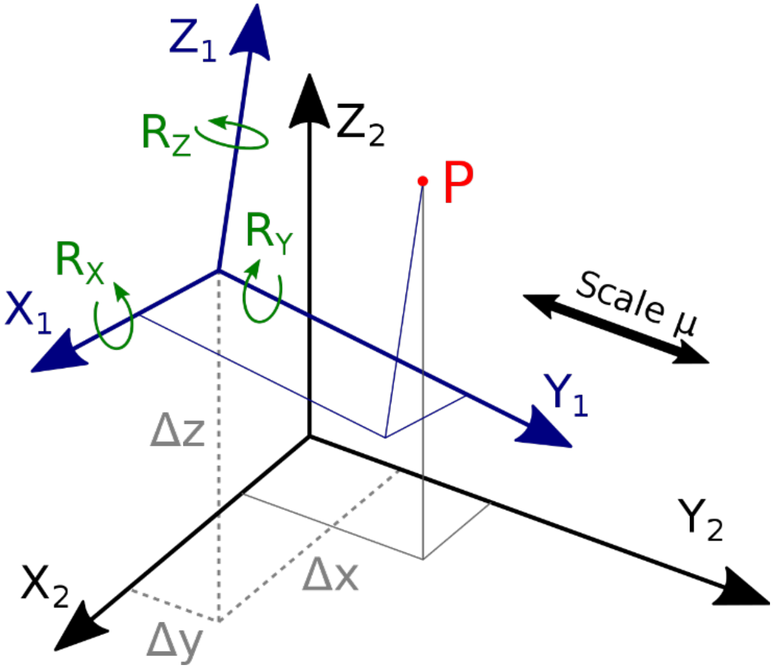
Different Reference Frames

Variety of Reference Frames

- Different scale: global, regional, national, local
- Different purpose: technical, scientific, cadastre
- Deterioration over time due to the Earth’s dynamics
- Technological evolution – increasing accuracy

Coordinate Transformation

- Transformation (change) of the coordinates of a point defined in one reference frame to a different reference frame (e.g. from XYZ in ITRF1996 to XYZ in ITRF2020)
- Common geodetic transformation parameters include:
  - Translation vector: The shift of the origin of the system
  - Rotation angles: The angle by which one system is rotated relative to another
  - Scaling: Resizing due to the different scales along the coordinate axis



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TOGETHER.

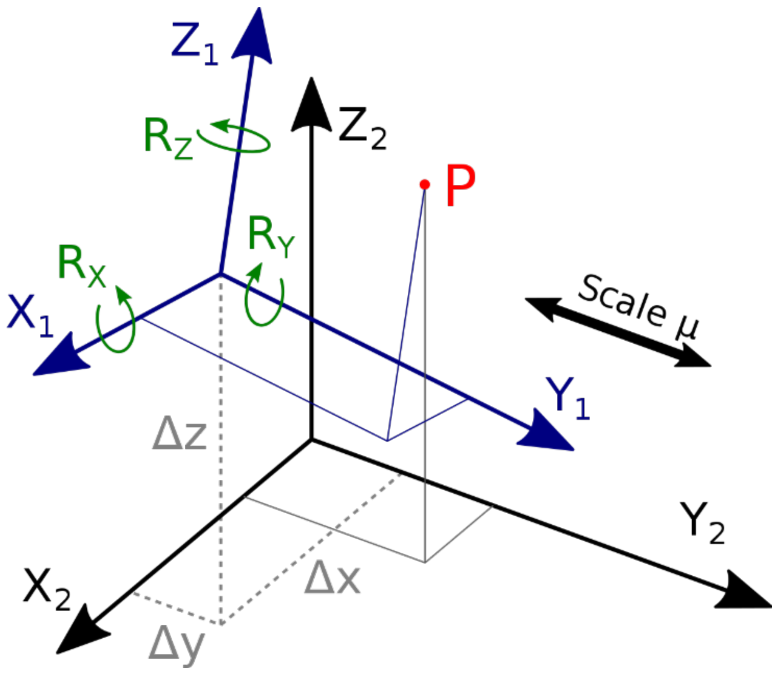
Coordinate Transformation

Helmert Transformation equation

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^B = \underbrace{\begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix}}_{\text{Translation (3)}} + \underbrace{\mu}_{\text{Scale (1)}} \cdot \underbrace{\begin{bmatrix} 1 & r_z & -r_y \\ -r_z & 1 & r_x \\ r_y & -r_x & 1 \end{bmatrix}}_{\text{Rotation (3)}} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^A$$

New Coordinates

Original Coordinates



7 Transformation parameters

- Translation (3)
- Rotation (3)
- Scale (1)

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Coordinate Transformation

Transformation

Connection between two different Datums

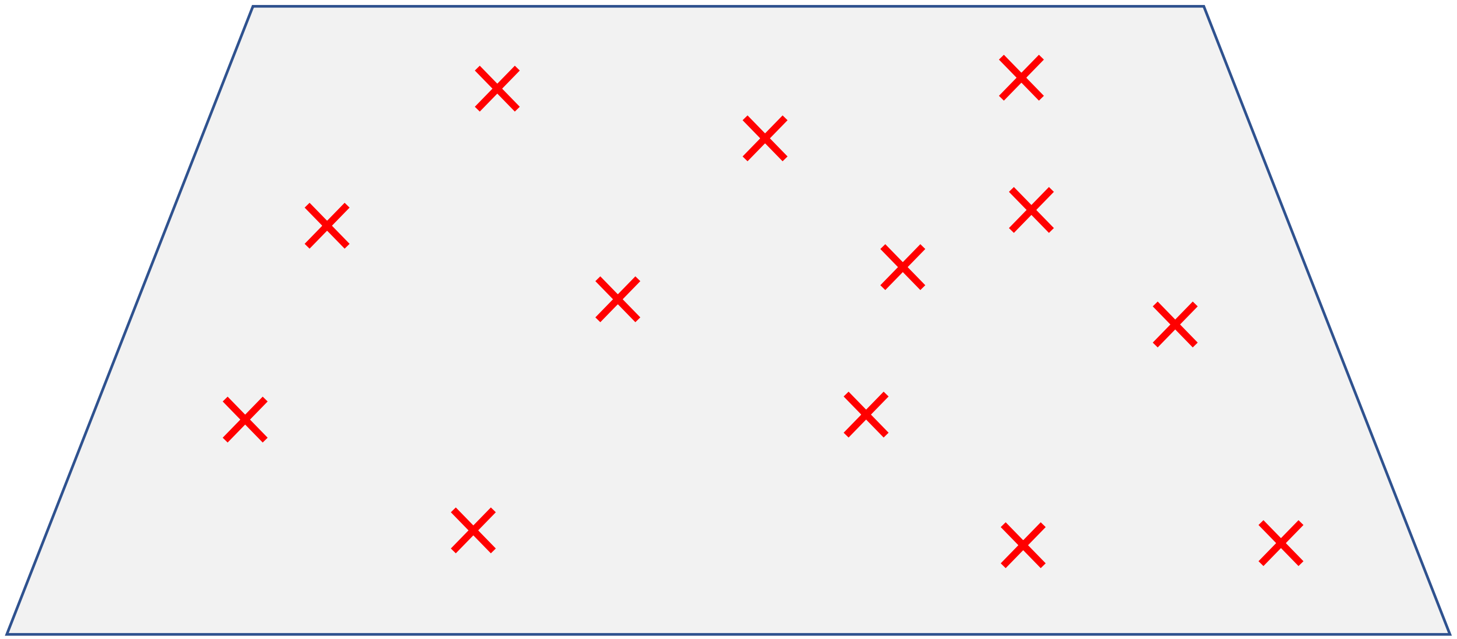
**Use case – improved management of heights (ITRF1992 and ITRF2020 have a 9 cm difference in ellipsoidal height)*

Transformation Parameters

- Estimation of the Transformation Parameters
- Common Points in OLD and NEW static datum (minimum three points)
- Inversion of the Helmert Transformation equation

Example

- Marker in Old Static Datum



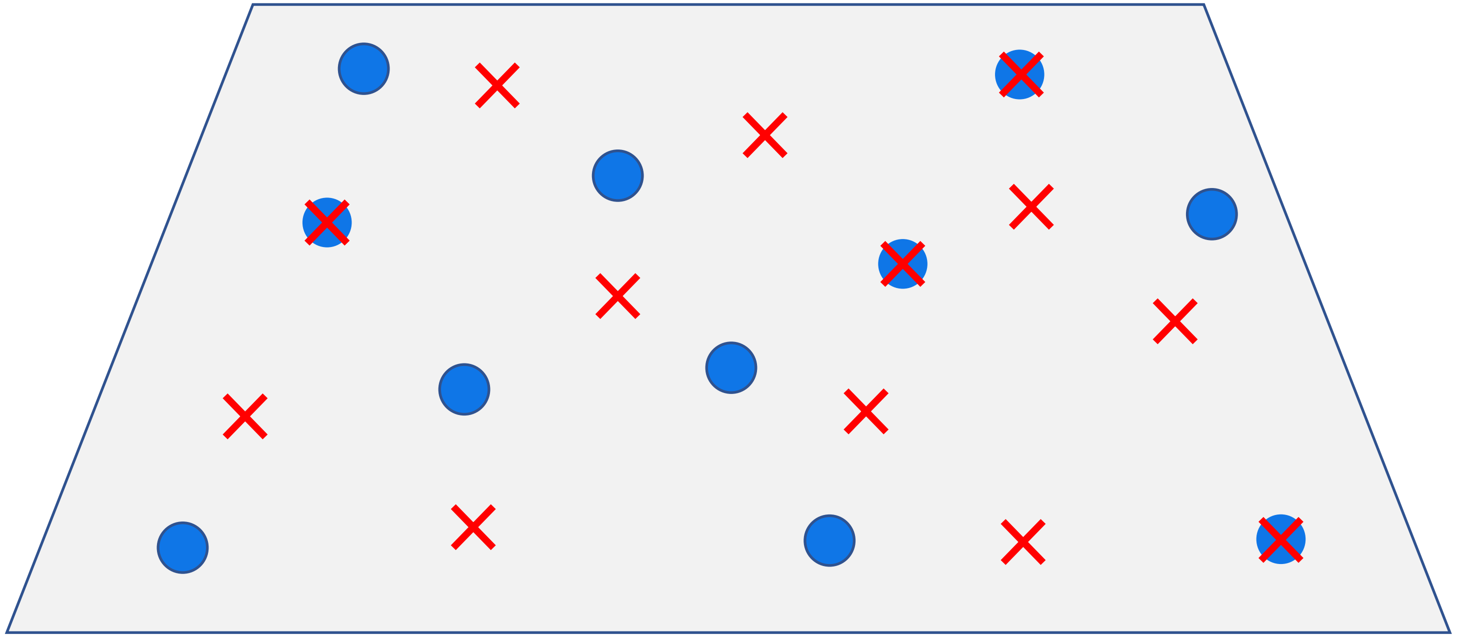
Transformation Parameters

- Estimation of the Transformation Parameters
- Common Points in OLD and NEW static datum (minimum three points)
- Inversion of the Helmert Transformation equation

Example

✕ - Marker in Old Static Datum

● - Marker in New Static Datum



Coordinate Transformation

Original Coordinates

Latitude, Longitude, ell. Height

↓

Cartesian Coordinates (X,Y,Z)

↓

Transformation using parameters

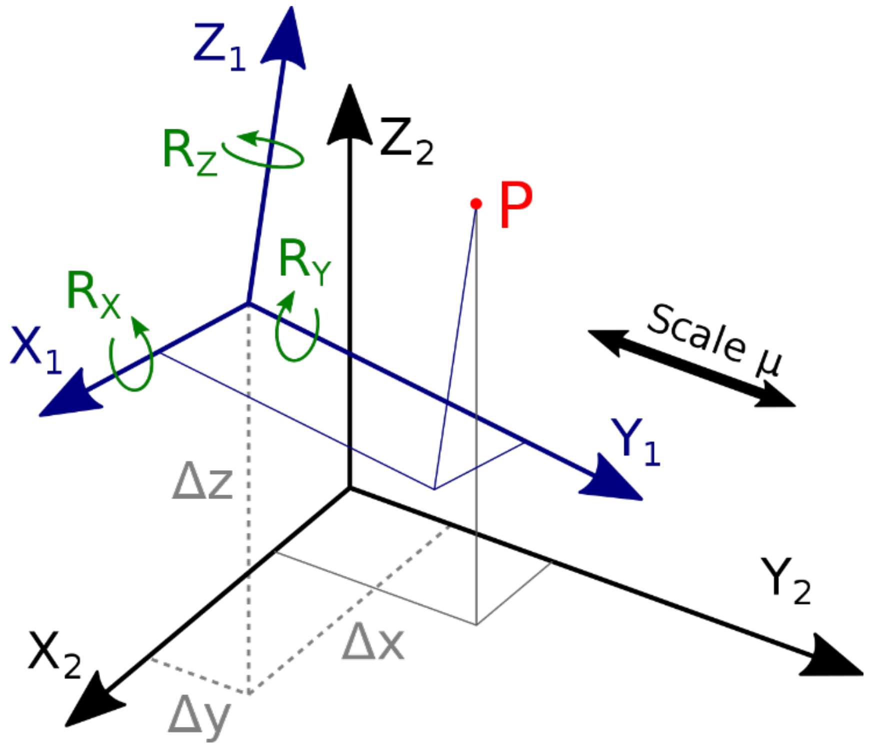
↓

Cartesian Coordinates (X,Y,Z)

↓

Latitude, Longitude, ell. Height

New Coordinates



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Coordinate Transformation (with deformation)

Transformation + Deformation

Connection between two different Datums

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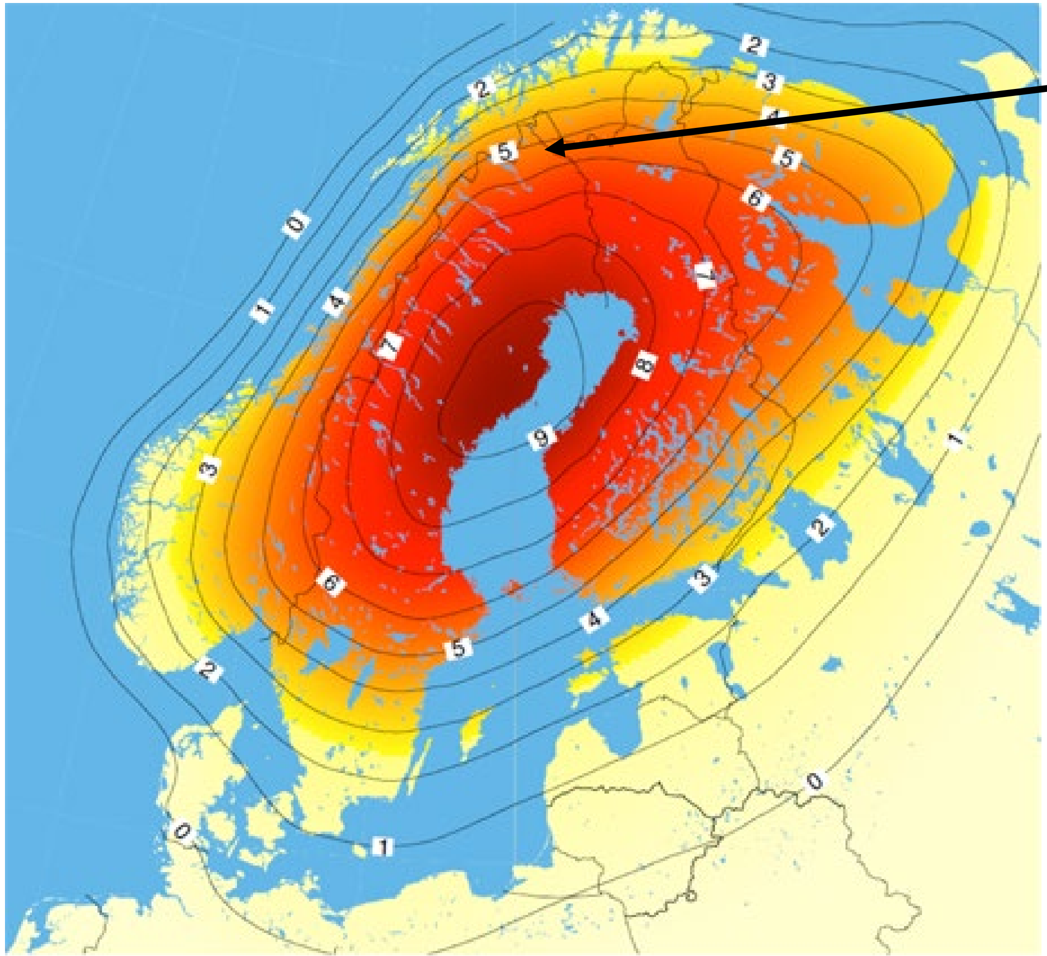
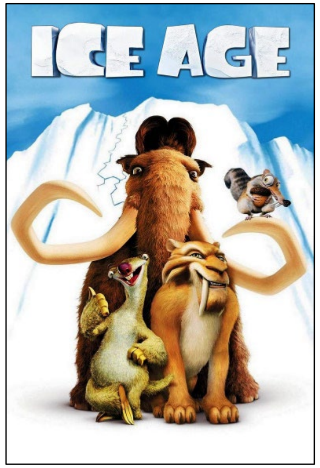
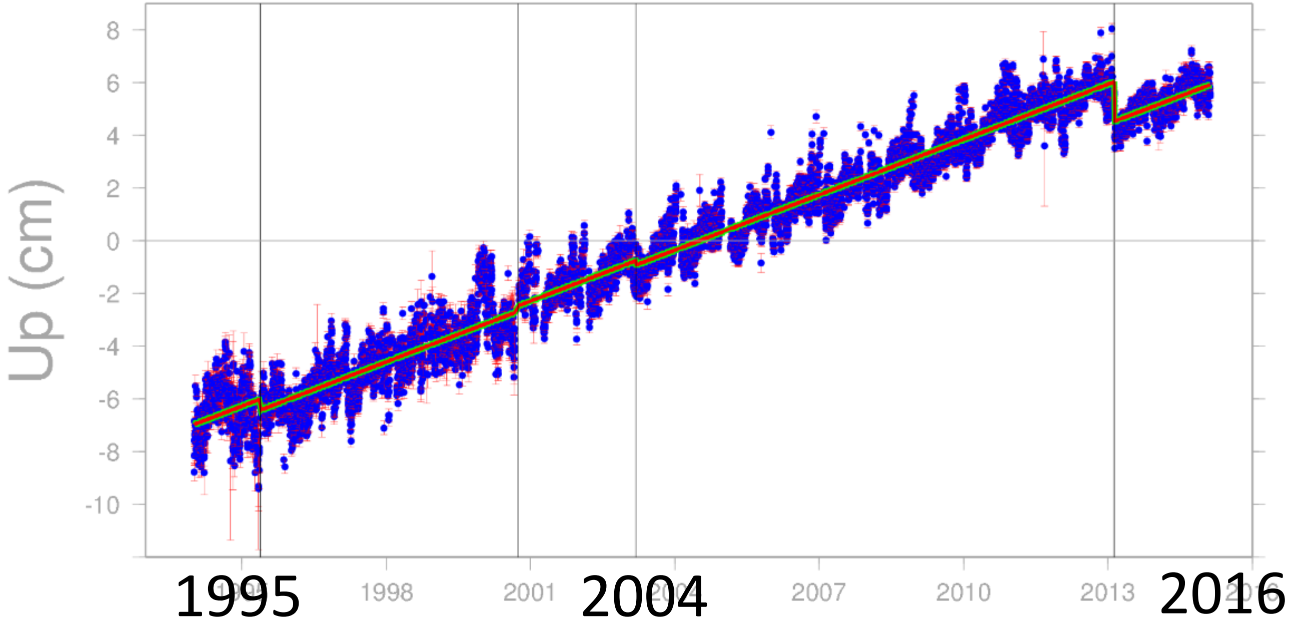
Deformation 1D (Postglacial Land Uplift)



GNSS station Kiruna

Land uplift 7 mm / yr





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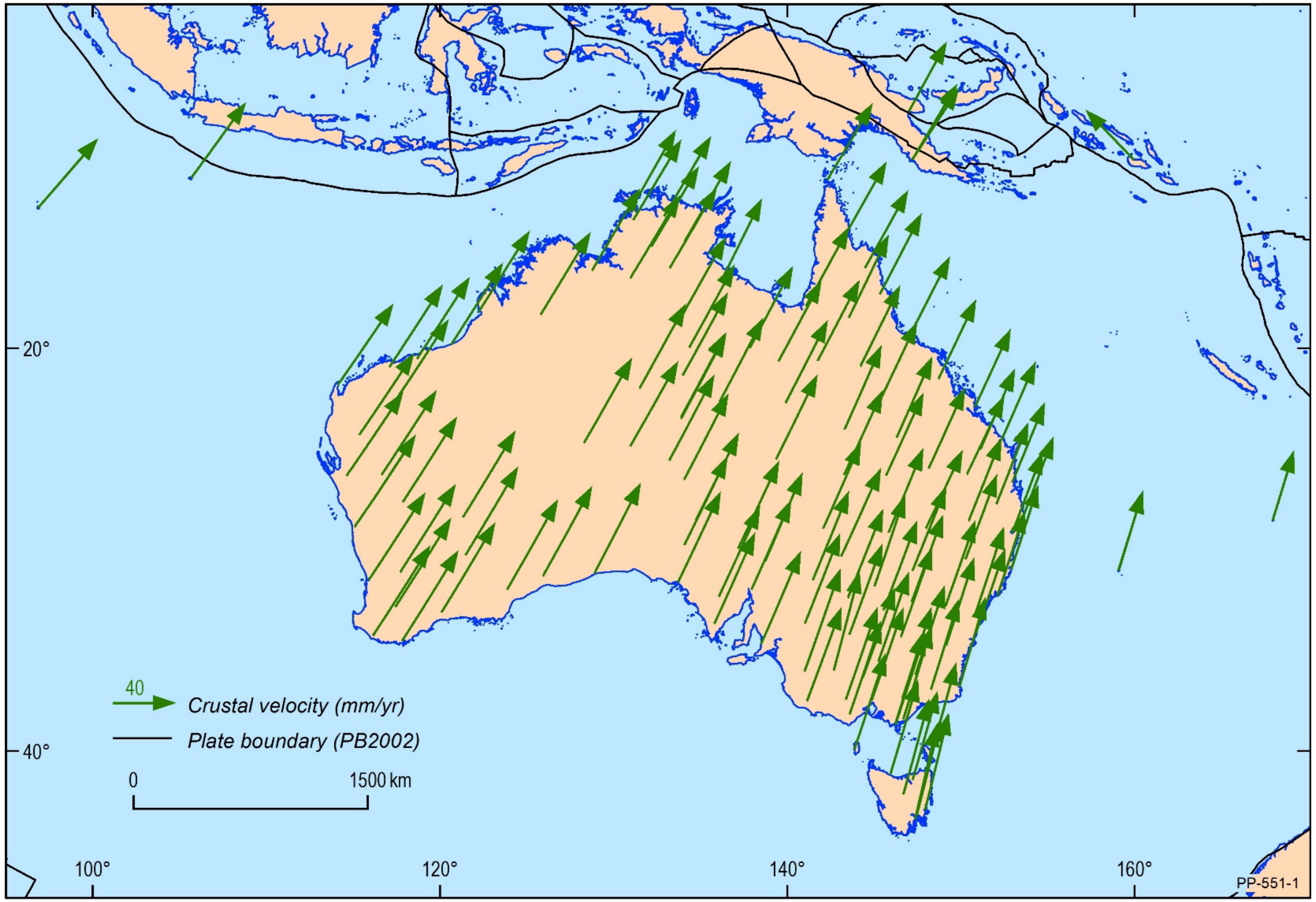
Deformation 2D

Secular motion

- Australia is the fastest moving continental plate (~7 cm/yr NNE)
- GNSS provides coordinates in ITRF (position of Australian plate now)
- Users would see ~1.8 m mismatch between GNSS positions and spatial datasets (if in GDA94).



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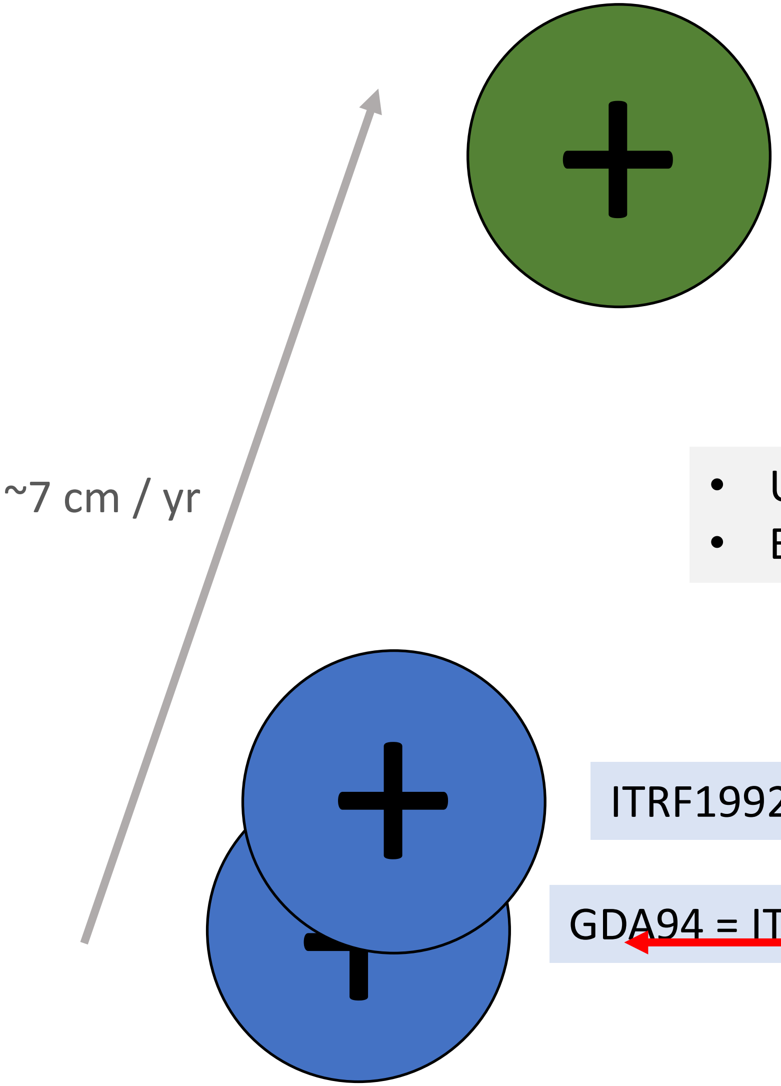
Deformation 2D (Plate motion model)

- The Australia continent is relatively free from deformation with the cumulative horizontal deformation from great earthquakes found to be <0.2 mm/yr (Tregoning et al. 2013).
- The motion of the continent can be modelled by a clockwise rotation about a Euler pole. The instantaneous velocity of this rotation results in, what appears to be, a linear motion of ~7 cm/yr in a north-northeast direction, with locations further from the pole moving faster than those closer.
- The Australian Plate-Motion Model (PMM) was created through analysis of the APREF solution, which showed that the horizontal stability of APREF stations is 1 mm/yr or less.
- The Australian PMM can be used to propagate coordinates between ITRF2014 at any epoch and GDA2020 (and vice versa).
- Denser and more accurate version of the ITRF2014 velocity model for Australia.



GDA2020 = ITRF2014@2020
ITRF2014 coordinates are different to ITRF1992 coordinates
e.g. heights are 9 cm different

Why don't they match?

1. Changes in the reference frame between the ITRF1992 and today
2. Local distortions (e.g. subsidence, earthquakes)
3. Lack of rigour in the way GDA94 coordinates were computed

- Updates to ITRF: 1994, 1996, 1997, 2000, 2005, 2008, 2014.
- Each is an improved realisation of the shape of the Earth

7 parameter transformation

ITRF1992@1995.0 (~7 cm NNE of 1994)

GDA94 = ITRF1992@1994.0

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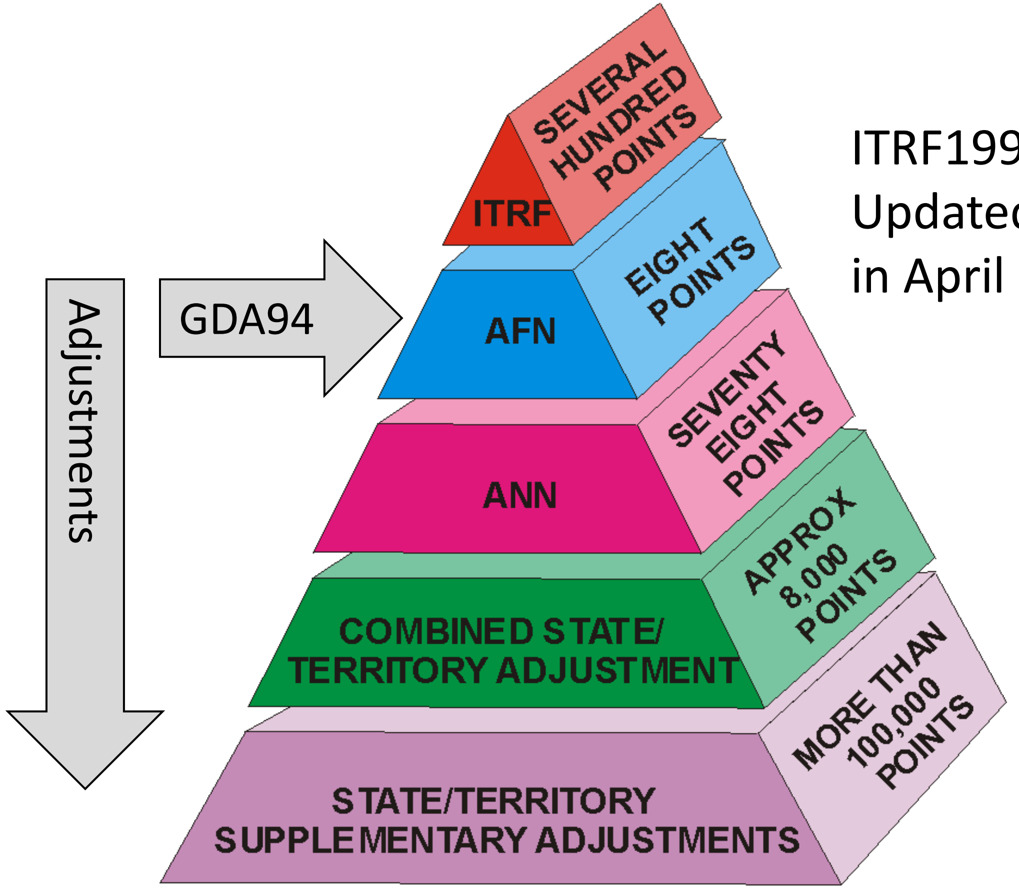
Deformation 2D

Distortion in GDA94

1. Changes in the reference frame between the ITRF1992 and today
2. Local distortions (e.g. subsidence, earthquakes)
3. Lack of rigour in the way GDA94 coordinates were computed

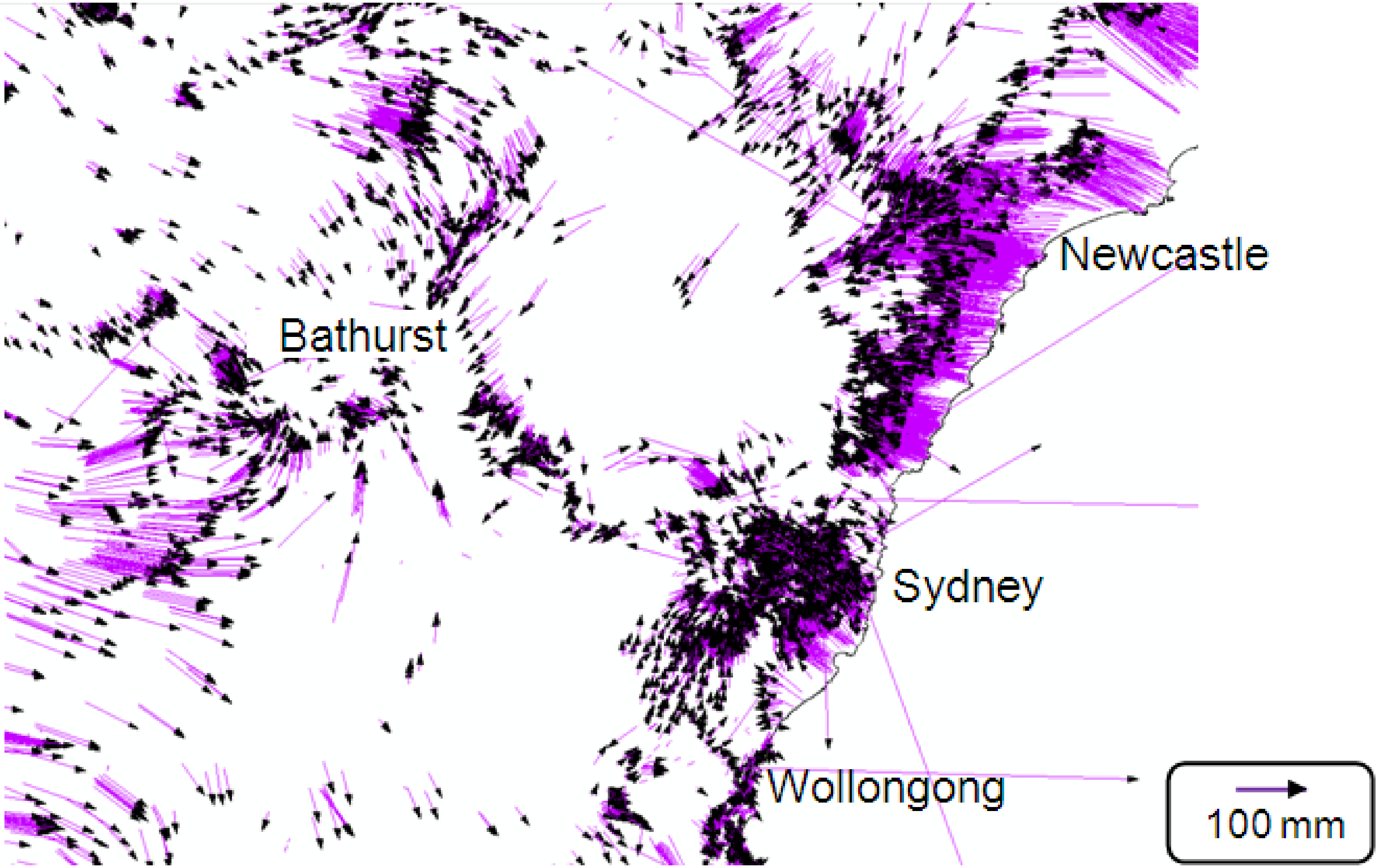


ITRF1992 @ 1994.0
Updated to 21 points in April 2012

Deformation 2D

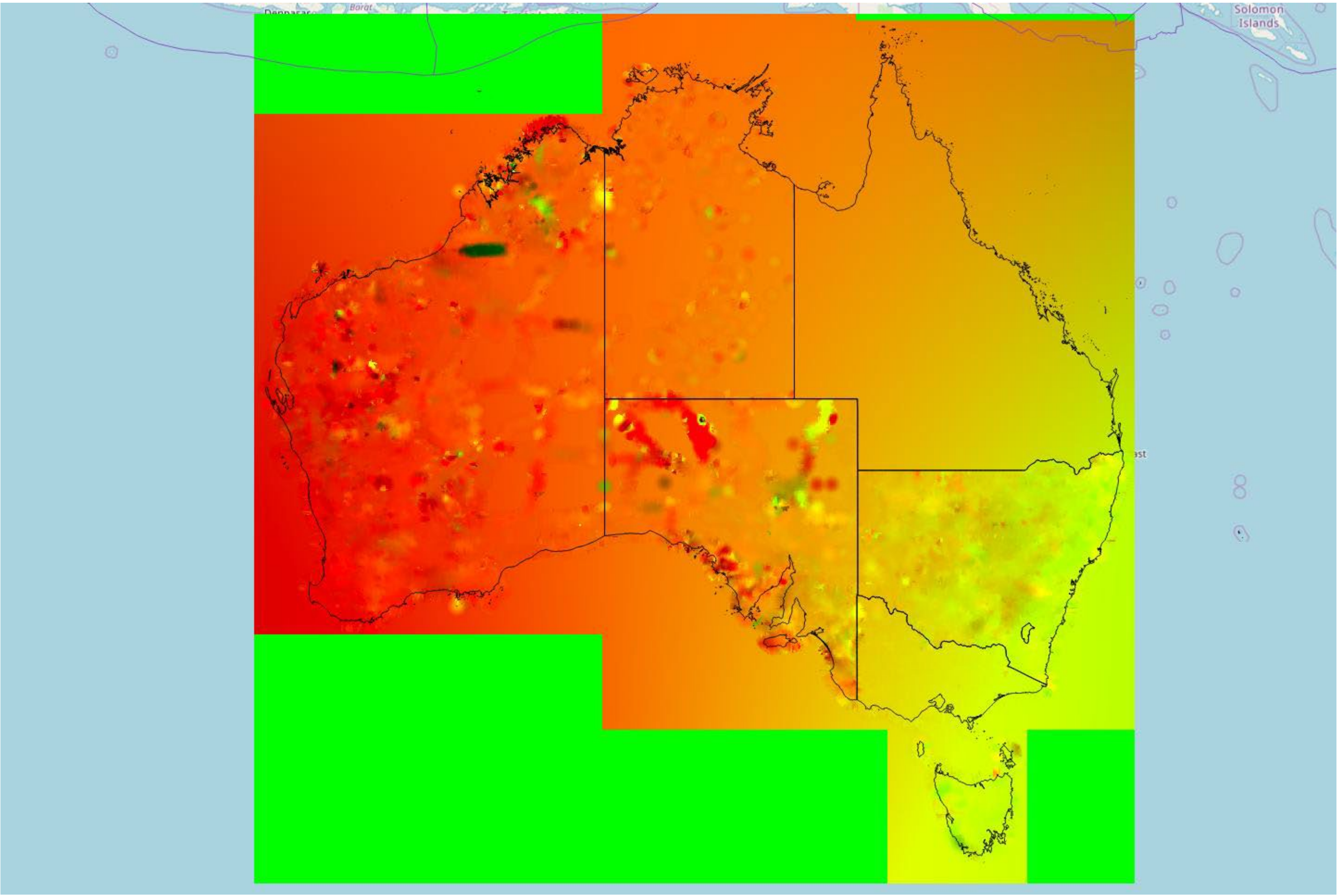
Distortion in the Geocentric Datum of Australia 1994

1. Changes in the reference frame between the ITRF1992 and today
2. Local distortions (e.g. subsidence, earthquakes)
3. Lack of rigour in the way GDA94 coordinates were computed



Source: Joel Haasdyk and Tony Watson, LPI NSW, APAS Conference 2013

Deformation 2D (Conformal + Deformation Grid)



Courtesy of Alex Woods, DELWP

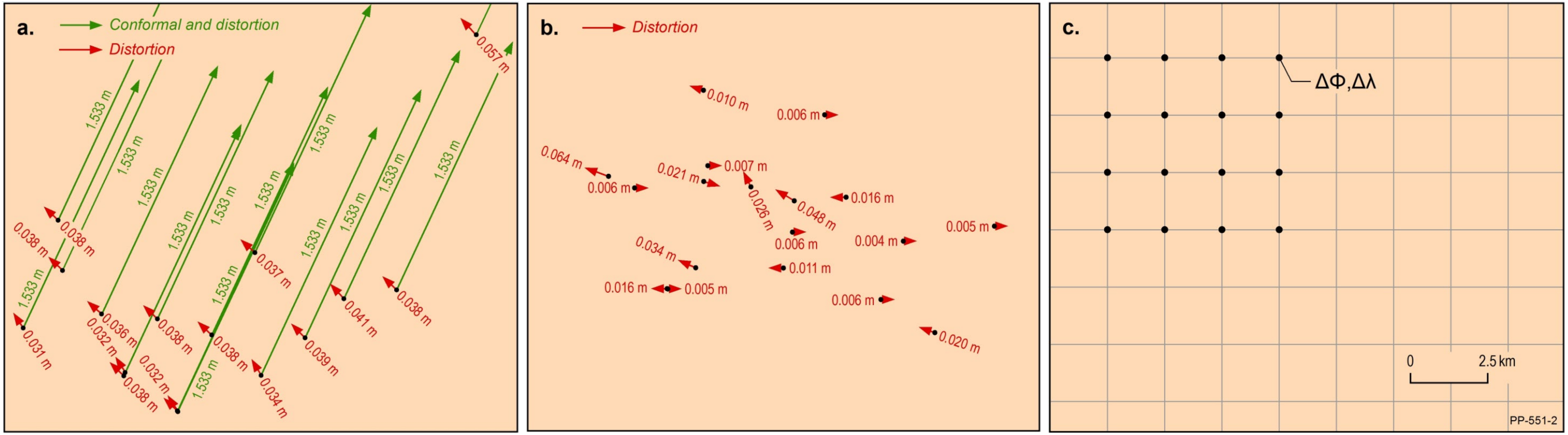
Input:

- Conformal grid
- Survey marks
  - Published GDA94
  - Adjusted GDA2020

Application:

- 2D
- Data aligned with survey control mark network

Deformation 2D
(Conformal + Deformation Grid)



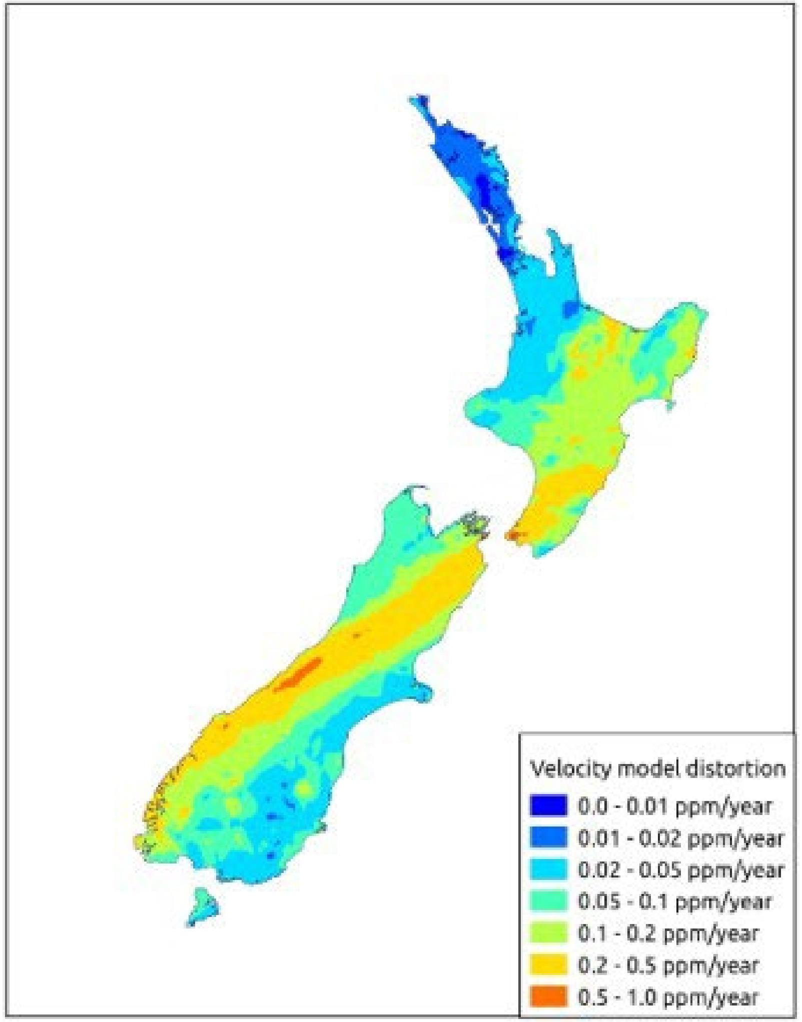
a) conformal (green) and distortion (red) components of the transformation grids;
b) low reliability of distortion component;
c) the grid has a latitude component and longitude component.

Deformation 3D

Deformation models are used to estimate:

- The deformation of the Earth's crust, including tectonic movements, fault lines, and earthquakes.

New Zealand (NZGD2000) is defined through its relationship to ITRF via the deformation model.



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Deformation 3D

	Reverse Patch	Forward Patch
Description	A reverse patch corrects coordinates in the past to account for deformation that has occurred since a specific reference epoch.	A forward patch projects coordinates into the future or corrects them to the present to reflect ongoing deformation.
Purpose	To adjust historical coordinates (e.g., survey data collected years ago) to align with the modern NZGD2000 reference frame, which represents the Earth’s surface at a specific reference epoch (2000.0)	To adjust current or past coordinates to account for crustal movement that will occur (or has occurred) after the reference epoch (2000.0) to align them with their real-world position.
Scenario	Suppose coordinates were measured in 2012. To use them in the NZGD2000 frame as it was in 2000, a reverse patch is applied to "undo" the tectonic movement that occurred between 2000 and 2012.	If a survey is conducted today (e.g., in 2025), the coordinates would need a forward patch to "predict" the movement since the 2000.0 epoch.
Usage	Typically applied when integrating older datasets into a modern geodetic framework or when comparing historical data with present-day coordinates.	Essential for applications like real-time GNSS positioning, where coordinates need to reflect the current Earth's surface rather than the 2000.0 reference frame.

Resources

GeodePy

https://github.com/GeoscienceAustralia/GeodePy

AUSTRALIAN GEOSPATIAL REFERENCE SYSTEM

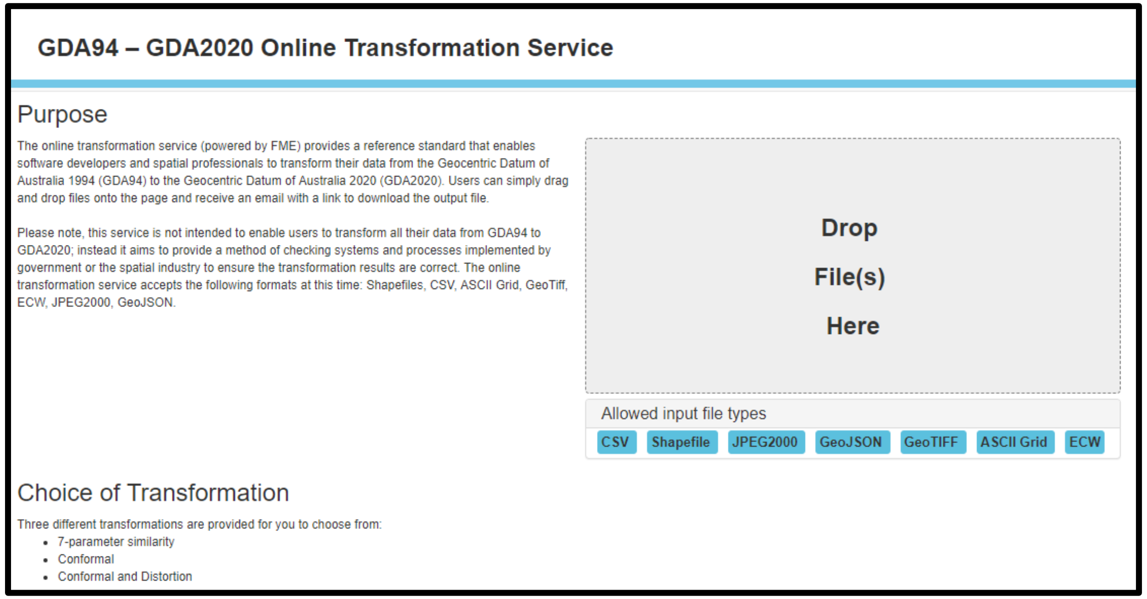
ICSM
ANZLIC COMMITTEE ON SURVEYING & MAPPING

Australian Geospatial Reference System Compendium

Intergovernmental Committee on Surveying and Mapping
Geodesy Working Group
16 August 2022

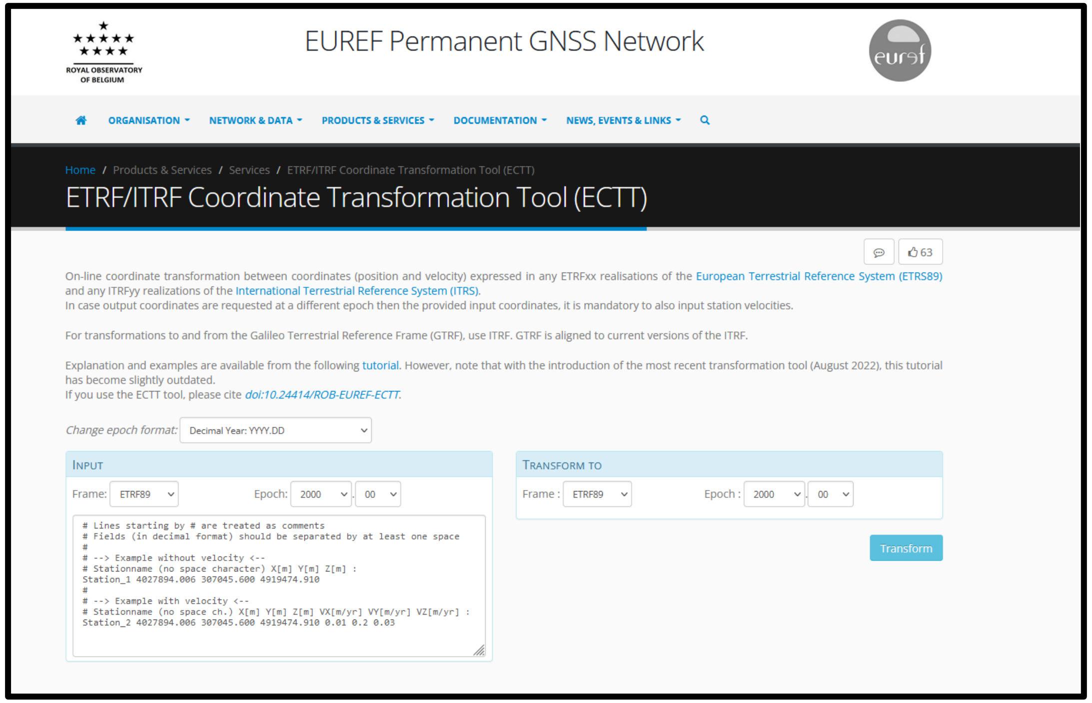
https://www.icsm.gov.au/sites/default/files/2022-08/AGRS_Compendium_20220816.pdf

Resources: Transformation Services



http://positioning.fsdf.org.au/

https://github.com/GeoscienceAustralia/GeodePy



https://www.epncb.oma.be/_productsservices/coord_trans/

Current status

- Update accuracy of GDA94-WGS84(generic) EPSG code (1150) from 1 m to 3 m
- Introduction of GDA94-GDA2020 EPSG codes
- Introduction of GDA2020-ITRF2014 EPSG code (8049)

Future

- Discussions with OGC+EPSG to recognise WGS84 as time-dependent