



HOW

## 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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**Day 2, Session 3** [2\_3\_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.



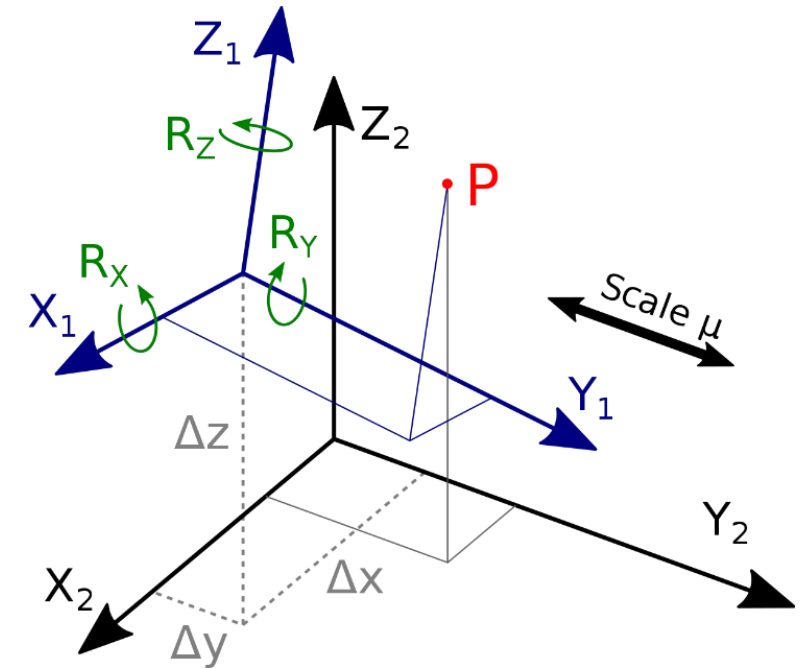
# Different Reference Frames

## 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



# Coordinate Transformation

## Helmert Transformation equation

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^B = \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix} + \mu \cdot \begin{bmatrix} 1 & r_z & -r_y \\ -r_z & 1 & r_x \\ r_y & -r_x & 1 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^A$$

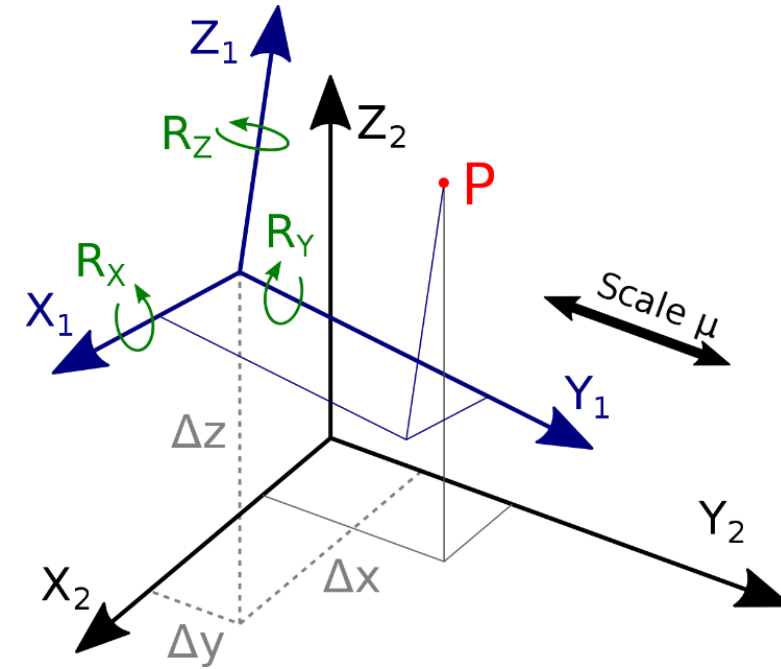
Translation (3)Scale (1)Rotation (3)

New  
Coordinates

Original  
Coordinates

7 Transformation parameters

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



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# Coordinate Transformation

Static Datum



New Geocentric  
Static Datum



7 parameter  
transformation

Static Datum



Old Geodetic Static  
Datum

Transformation

Connection between  
two different Datums

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



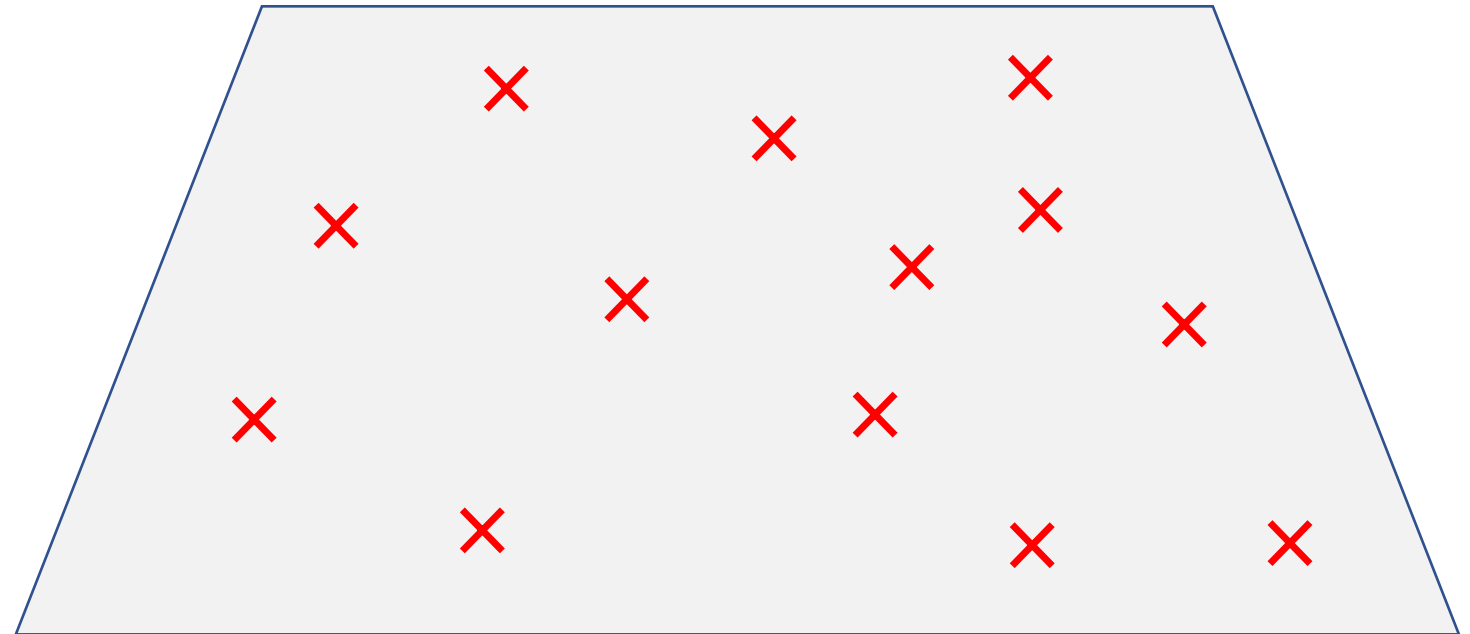
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# Transformation Parameters

- 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



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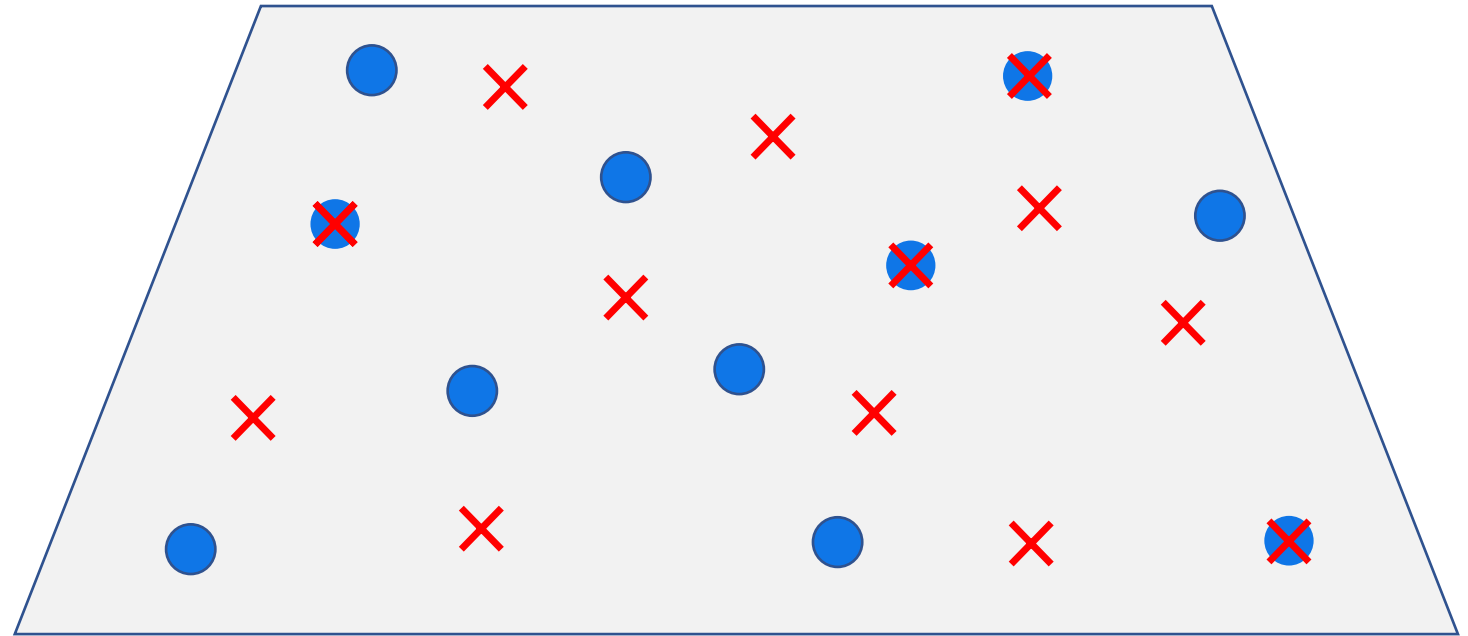
# Transformation Parameters

- 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



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# Coordinate Transformation

Original Coordinates

Latitude, Longitude, ell. Height



Cartesian Coordinates (X,Y,Z)



Transformation using parameters

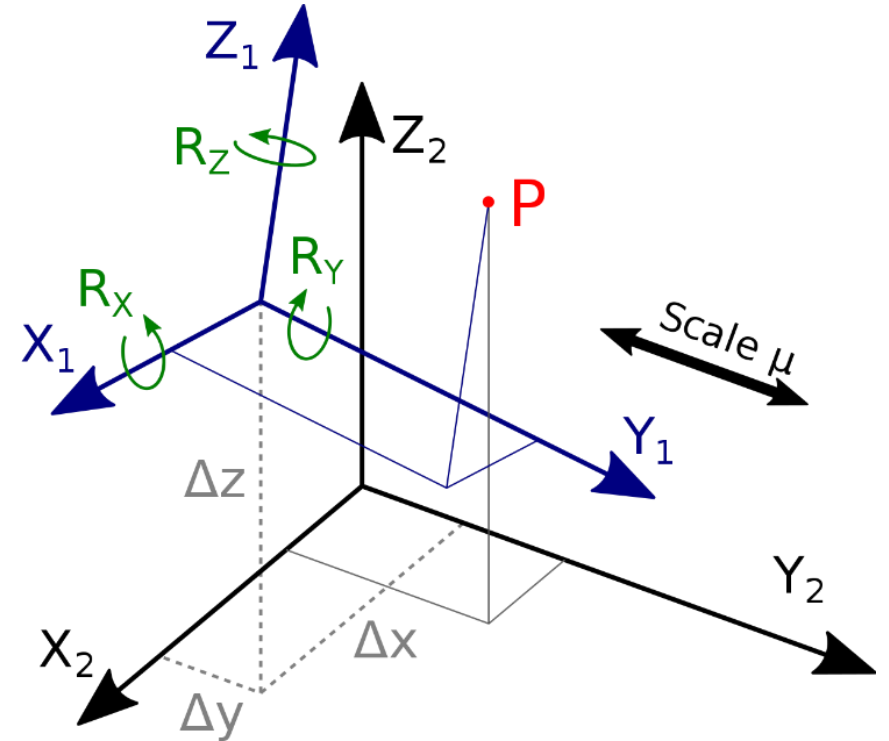


New Coordinates

Cartesian Coordinates (X,Y,Z)



Latitude, Longitude, ell. Height



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# Coordinate Transformation (with deformation)

**Static Datum**



New Geocentric  
Static Datum



7 parameter  
transformation

**+deformation model**



**Static Datum**



Old Geodetic Static  
Datum

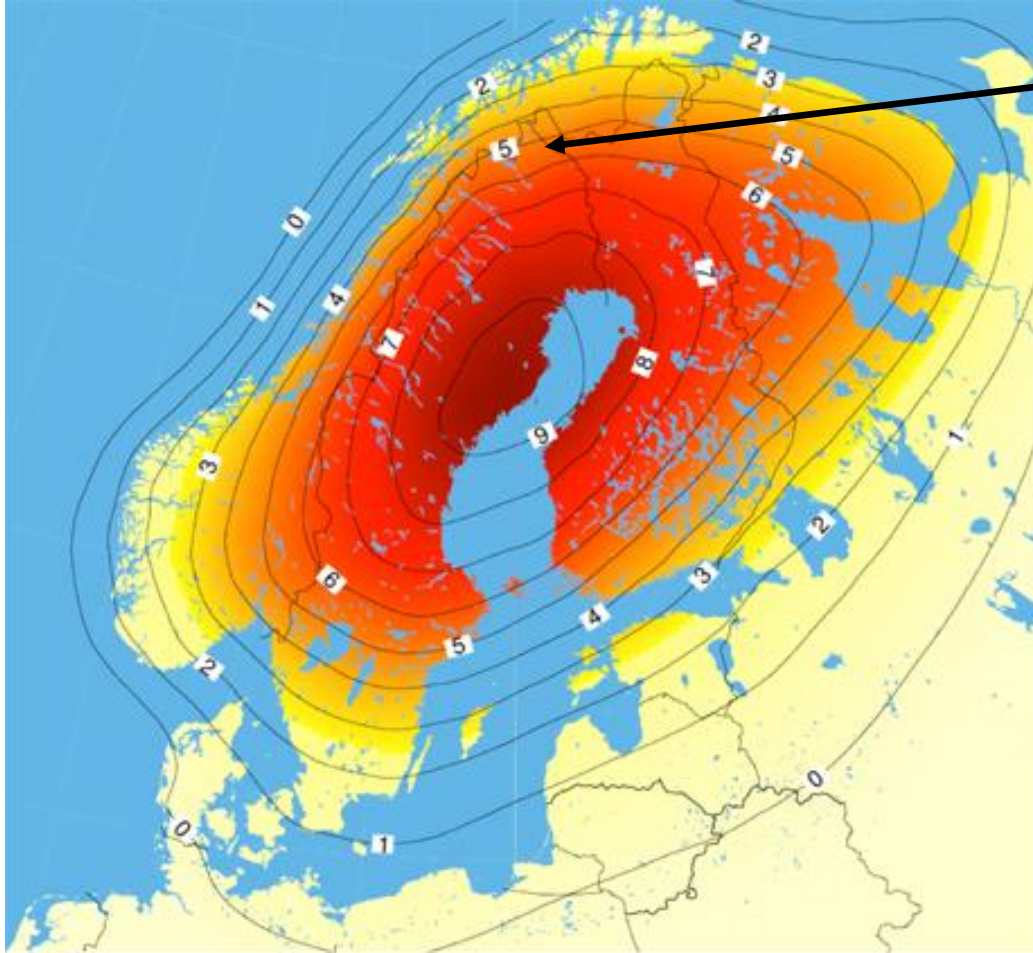
**Transformation + Deformation**

**Connection between  
two different Datums**

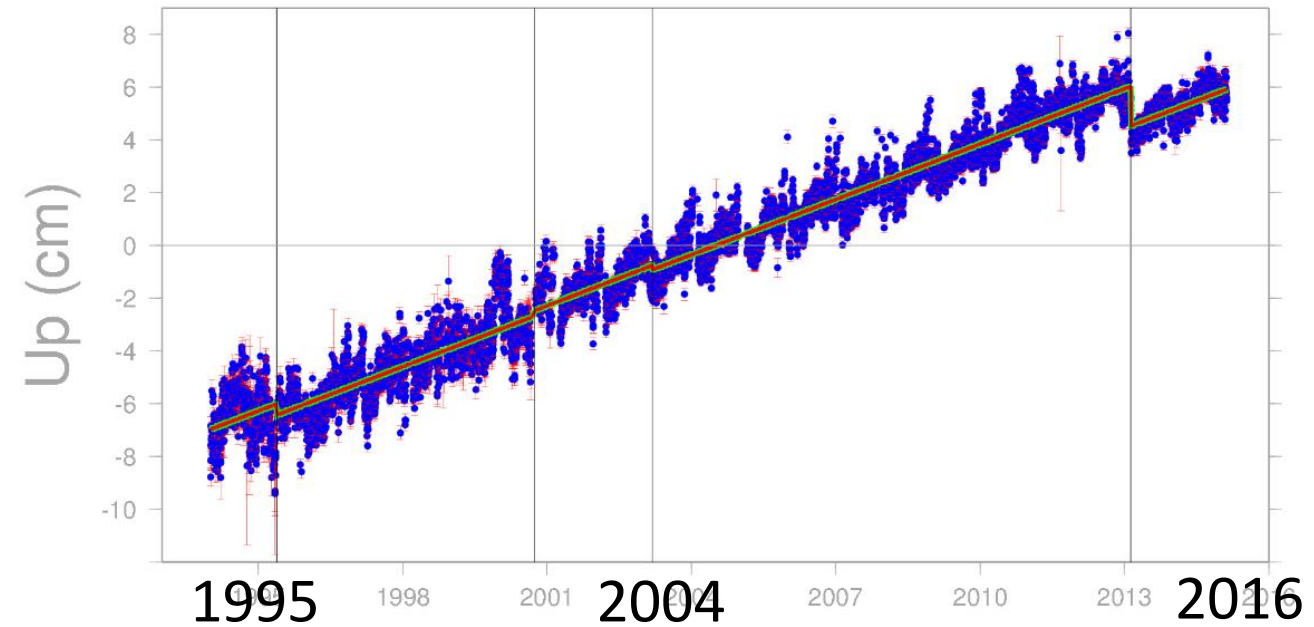
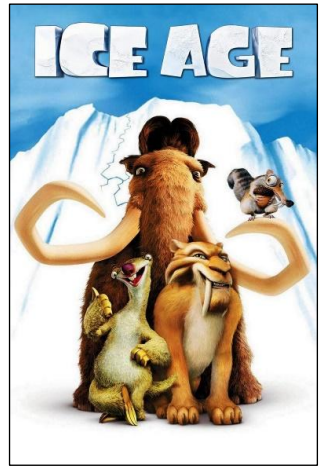


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# Deformation 1D (Postglacial Land Uplift)



GNSS station Kiruna  
Land uplift 7 mm / yr

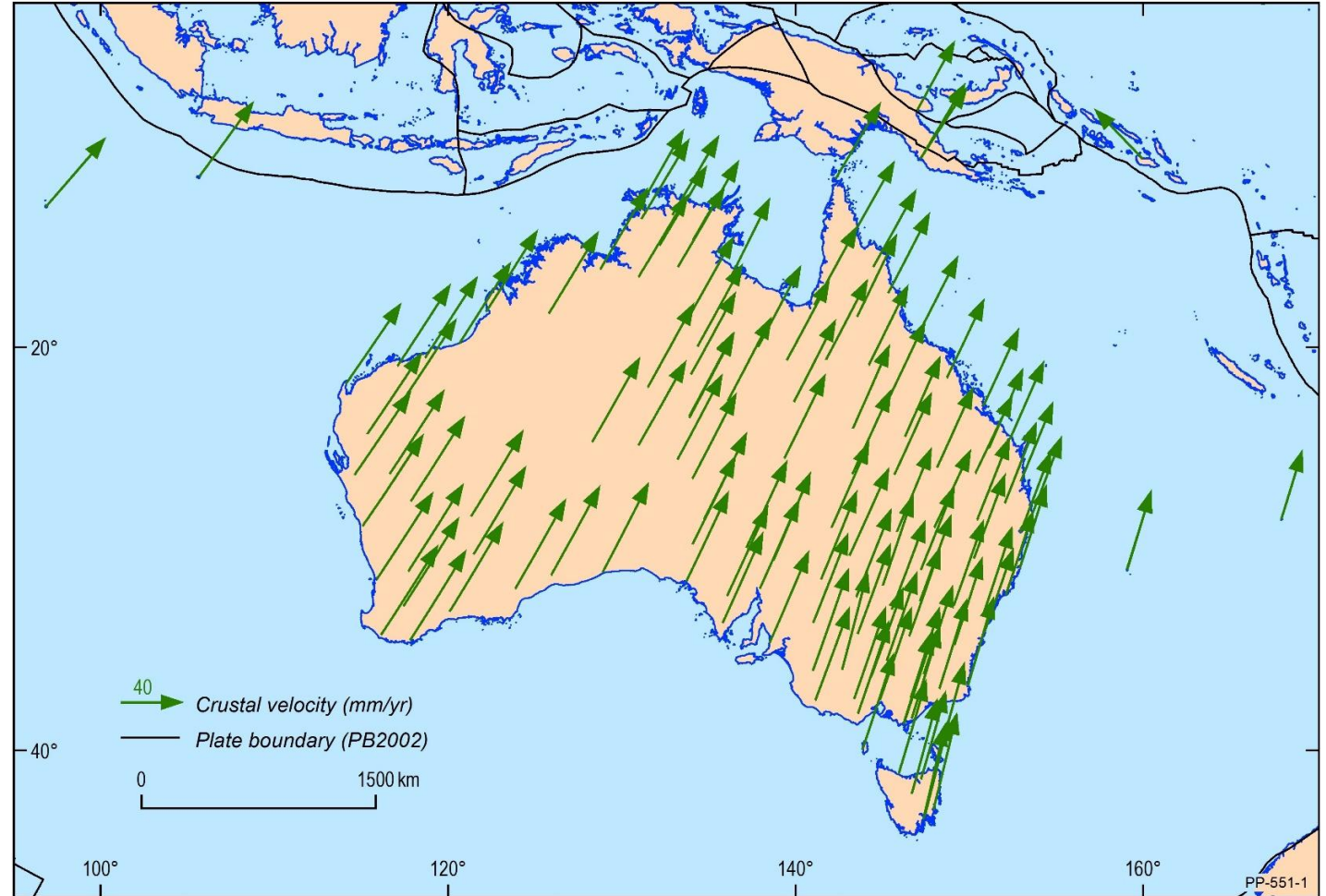


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# Deformation 2D

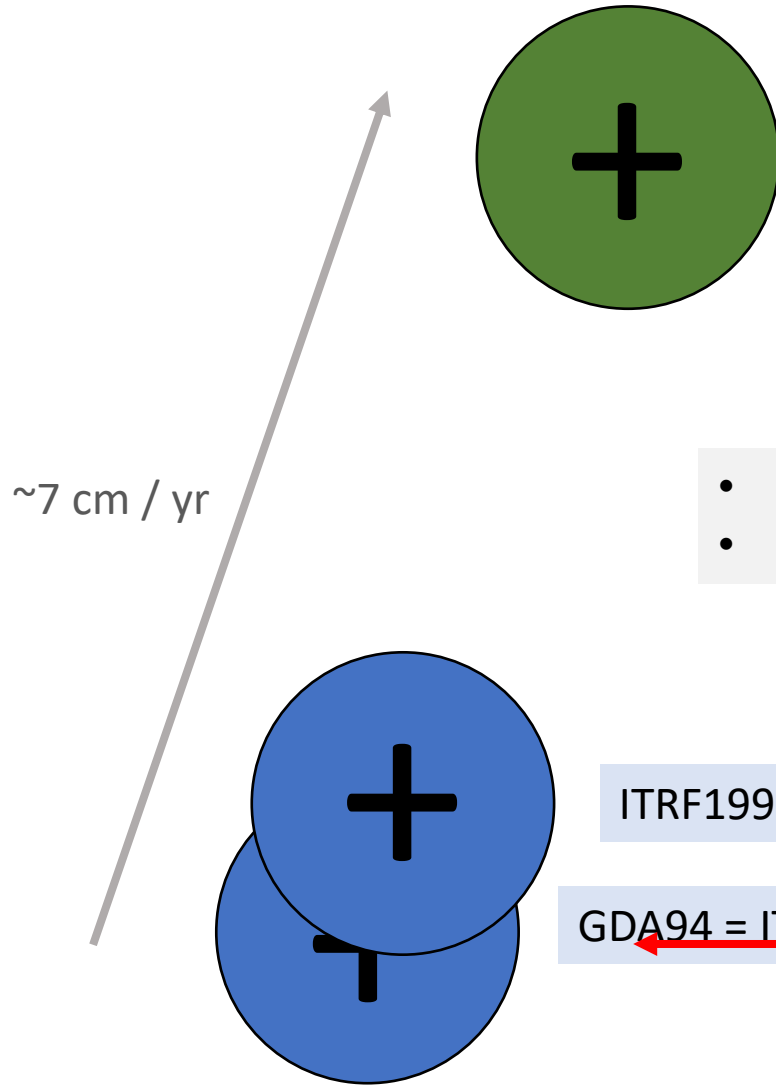
## Secular motion

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



# 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  $\sim 7$  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

ITRF1992@1995.0 (~7 cm NNE of 1994)

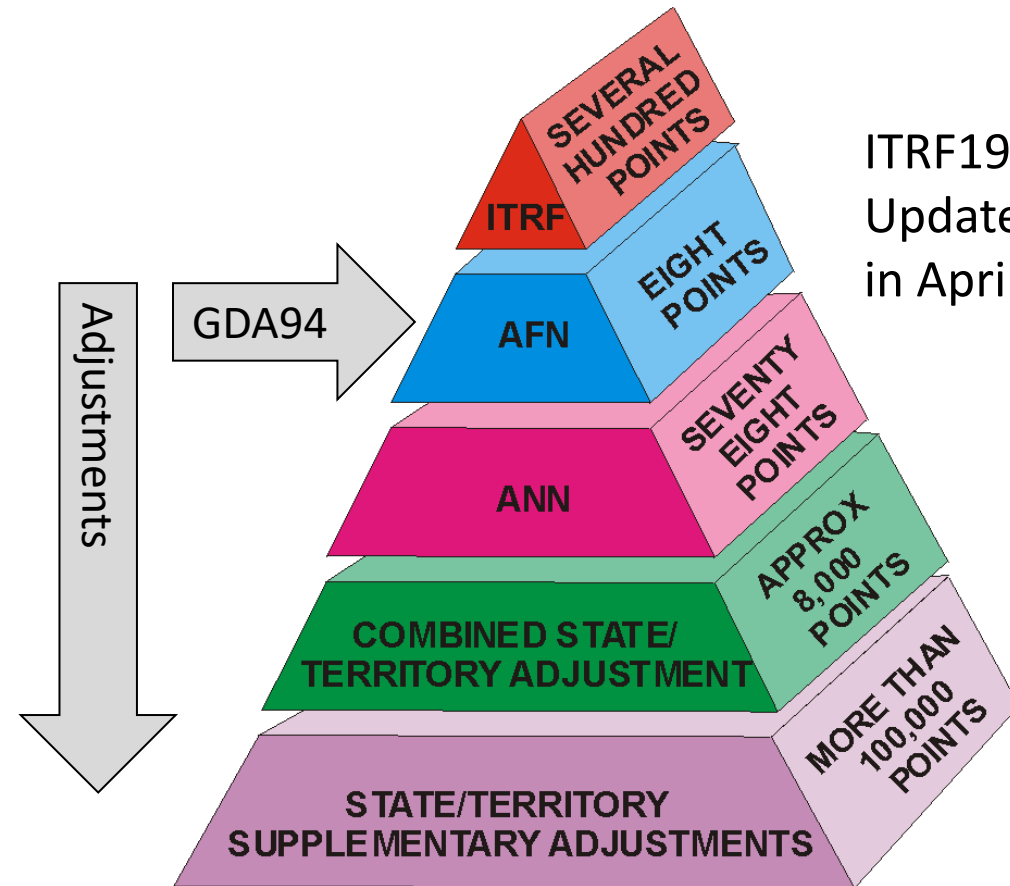
GDA94 = ITRF1992@1994.0



# Deformation 2D

## Distortion in GDA94

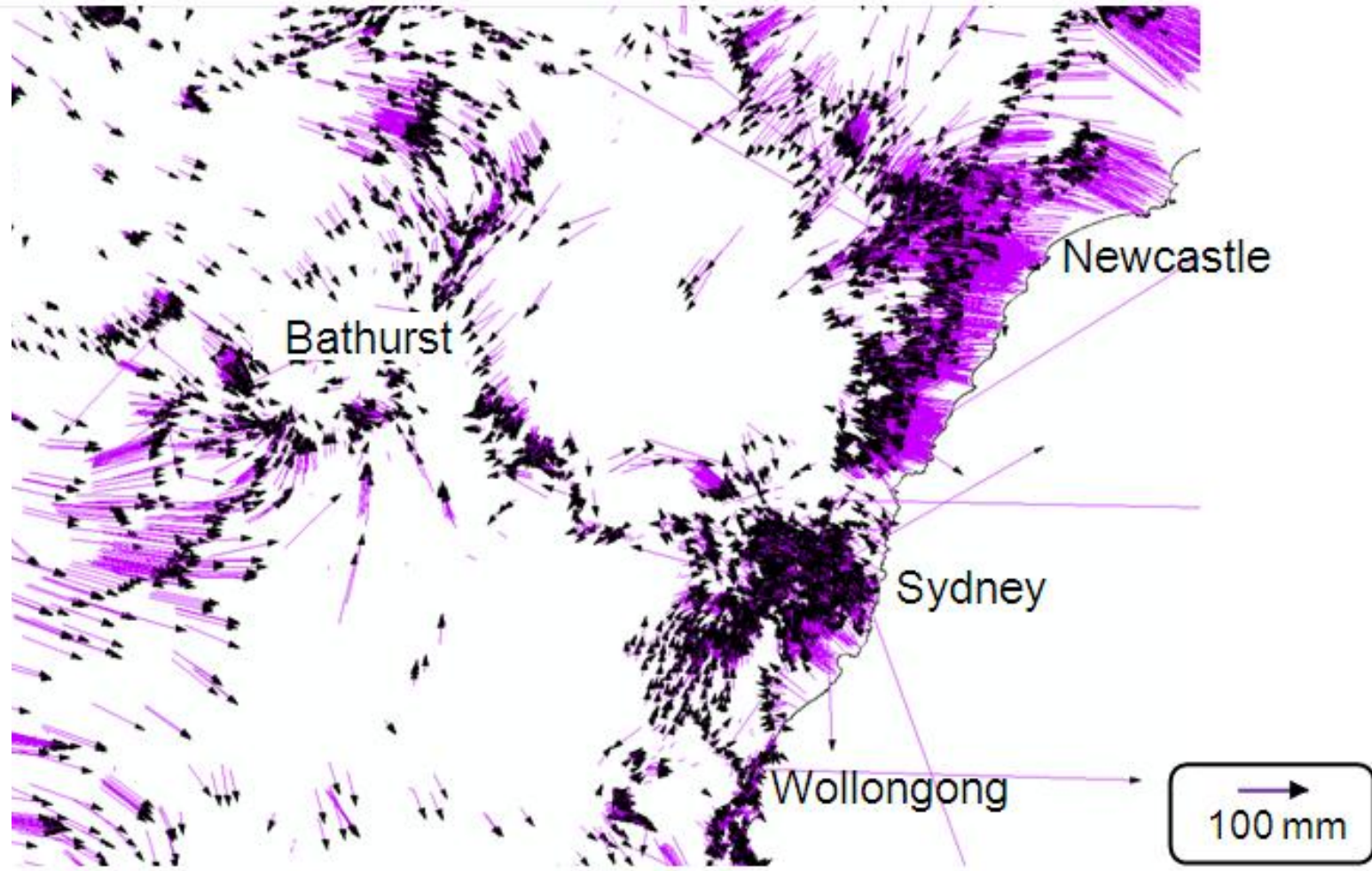
1. Changes in the reference frame between the ITRF1992 and today
2. Local distortions (e.g. subsidence, earthquakes)
3. Lack of rigour in the way GDA94 coordinates were computed



# Deformation 2D

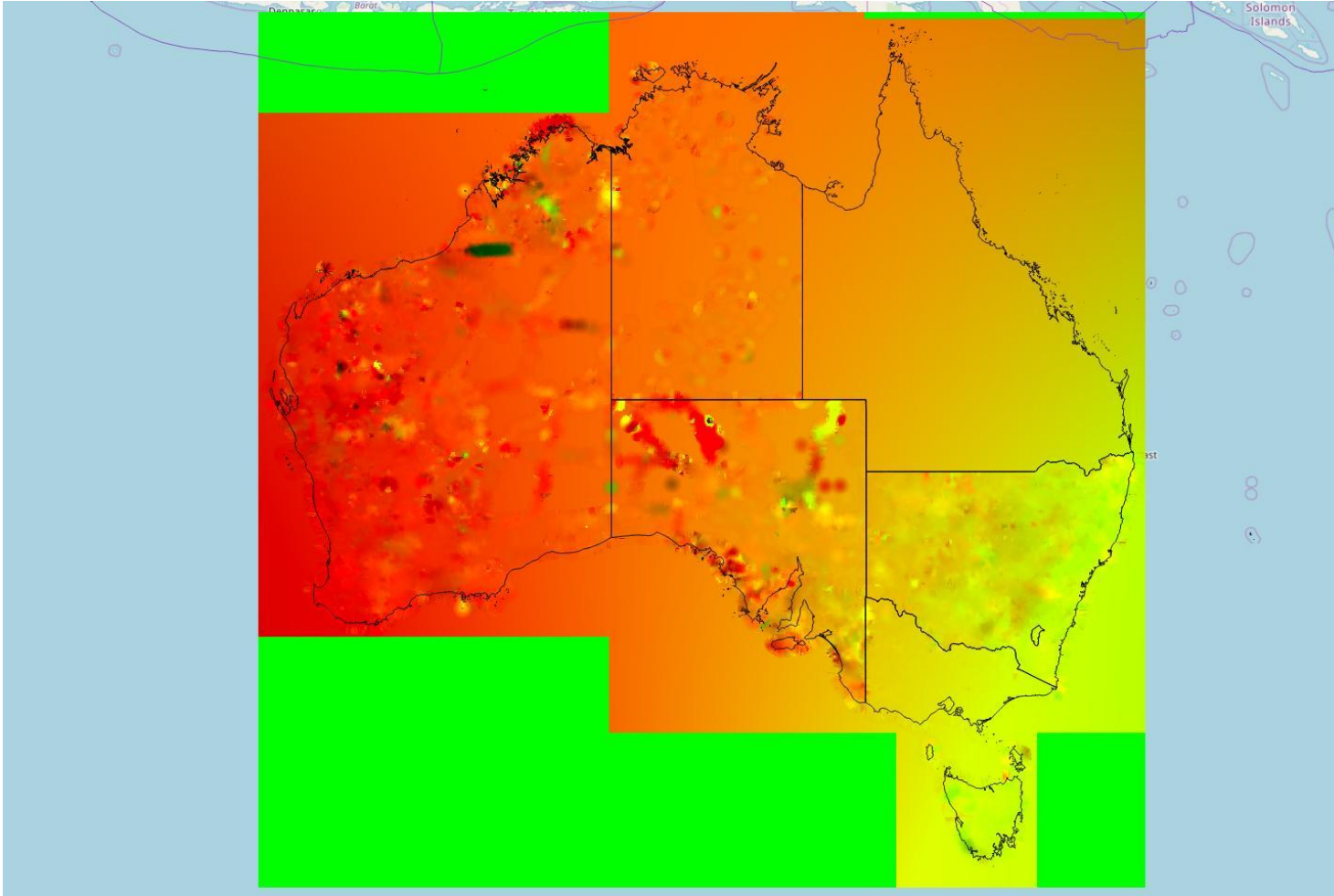
## Distortion in the Geocentric Datum of Australia 1994

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)



## Input:

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

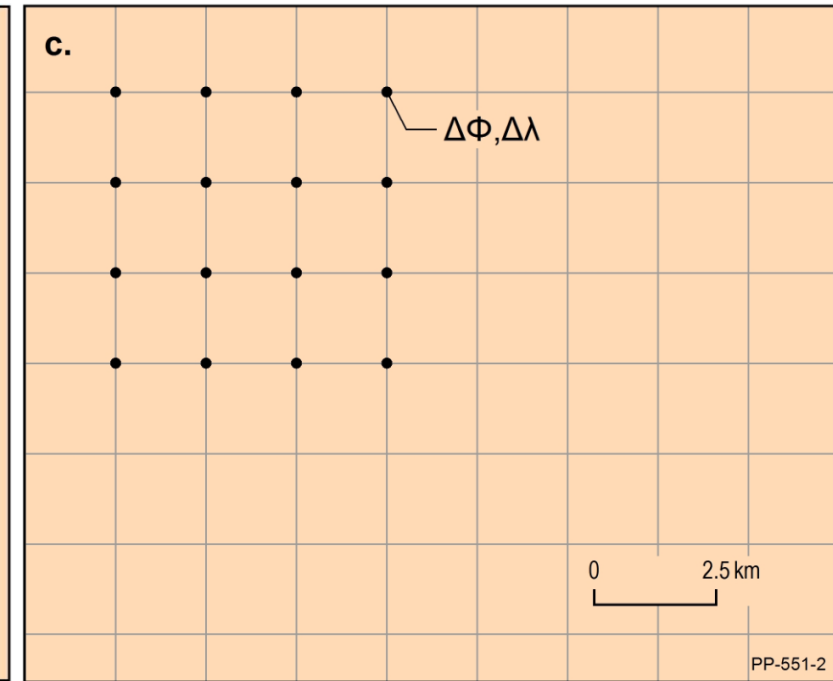
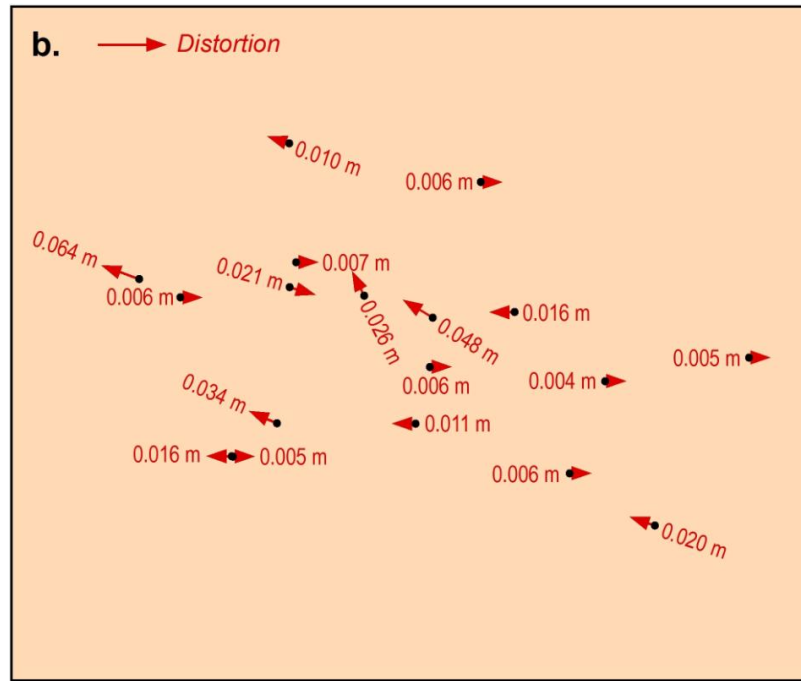
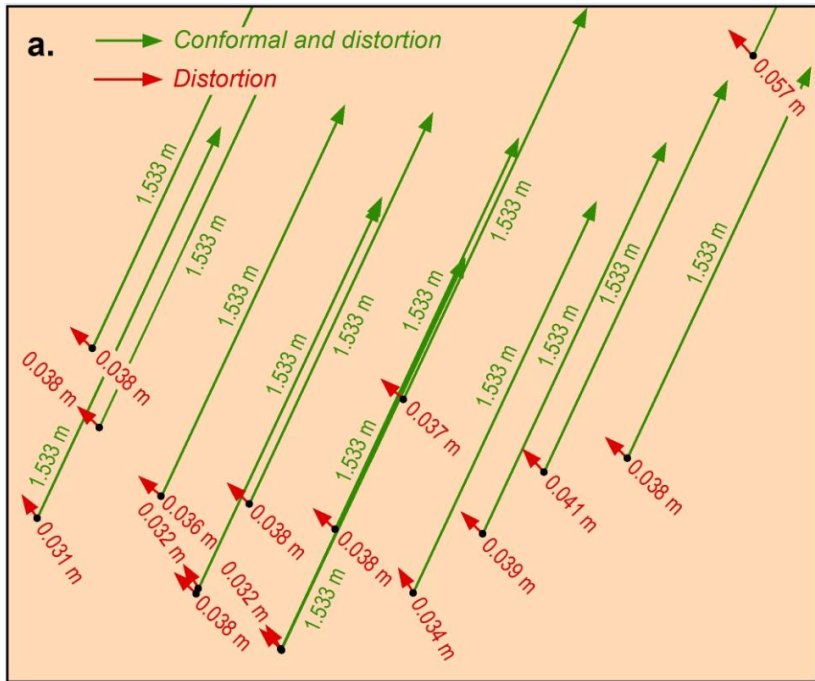
## Application:

- 2D
- Data aligned with survey control mark network

Courtesy of Alex Woods, DELWP



# Deformation 2D (Conformal + Deformation Grid)



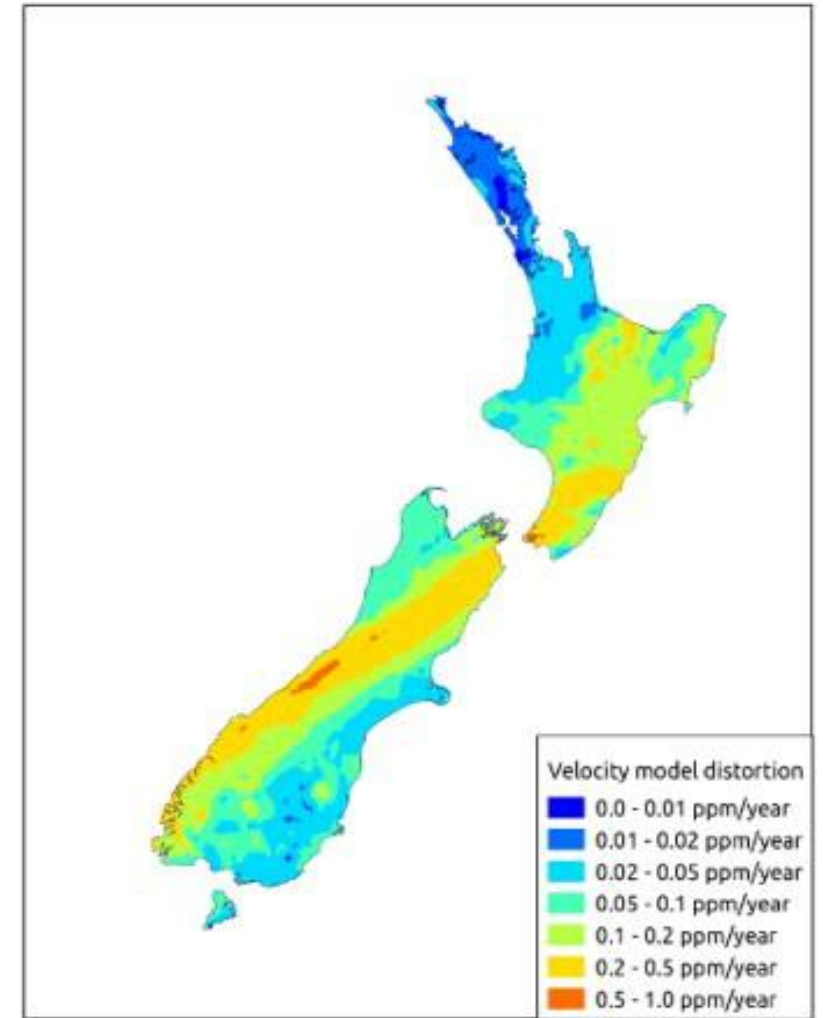
- a) conformal (green) and distortion (red) components of the transformation grids;
- b) low reliability of distortion component;
- c) the grid has a latitude component and longitude component.

# 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
<b>Description</b>	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.
<b>Purpose</b>	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.
<b>Scenario</b>	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.
<b>Usage</b>	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 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](https://www.icsm.gov.au/sites/default/files/2022-08/AGRS_Compendium_20220816.pdf)

# Resources: Transformation Services

## GDA94 – GDA2020 Online Transformation Service

### Purpose

The online transformation service (powered by FME) provides a reference standard that enables software developers and spatial professionals to transform their data from the Geocentric Datum of Australia 1994 (GDA94) to the Geocentric Datum of Australia 2020 (GDA2020). Users can simply drag and drop files onto the page and receive an email with a link to download the output file.

Please note, this service is not intended to enable users to transform all their data from GDA94 to GDA2020; instead it aims to provide a method of checking systems and processes implemented by government or the spatial industry to ensure the transformation results are correct. The online transformation service accepts the following formats at this time: Shapefiles, CSV, ASCII Grid, GeoTIFF, ECW, JPEG2000, GeoJSON.

Drop  
File(s)  
Here

Allowed input file types

CSV Shapefile JPEG2000 GeoJSON GeoTIFF ASCII Grid ECW

### Choice of Transformation

Three different transformations are provided for you to choose from:

- 7-parameter similarity
- Conformal
- Conformal and Distortion

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

<https://github.com/GeoscienceAustralia/GeodePy>

## EUREF Permanent GNSS Network

### ETRF/ITRF Coordinate Transformation Tool (ECTT)

On-line coordinate transformation between coordinates (position and velocity) expressed in any ETRFxx realisations of the European Terrestrial Reference System (ETRS89) and any ITRFyy realizations of the International Terrestrial Reference System (ITRS). In case output coordinates are requested at a different epoch than the provided input coordinates, it is mandatory to also input station velocities.

For transformations to and from the Galileo Terrestrial Reference Frame (GTRF), use ITRF. GTRF is aligned to current versions of the ITRF.

Explanation and examples are available from the following [tutorial](#). However, note that with the introduction of the most recent transformation tool (August 2022), this tutorial has become slightly outdated. If you use the ECTT tool, please cite [doi:10.24414/ROB-EUREF-ECTT](https://doi.org/10.24414/ROB-EUREF-ECTT).

Change epoch format:

INPUT

Frame:  Epoch:

```
# Lines starting by # are treated as comments
# Fields (in decimal format) should be separated by at least one space
#
# --> Example without velocity <--
# Stationname (no space character) X[m] Y[m] Z[m] :
# Station_1 4027894.006 307045.600 4919474.910
#
# --> Example with velocity <--
# Stationname (no space ch.) X[m] Y[m] Z[m] VX[m/yr] VY[m/yr] VZ[m/yr] :
# Station_2 4027894.006 307045.600 4919474.910 0.01 0.2 0.03
```

TRANSFORM TO

Frame:  Epoch:

[https://www.epncb.oma.be/\\_productsservices/coord\\_trans/](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

