Practical implementation of time-dependent reference frames

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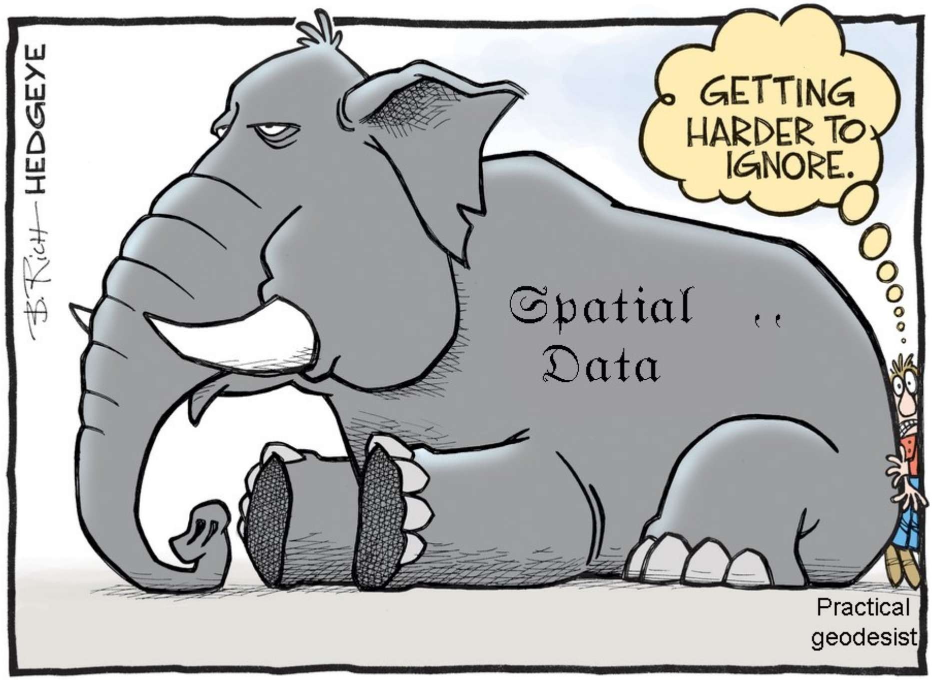
Spatial Data - The elephant in the room

- The Earth's surface is dynamic (but "apparently fixed" features are actually moving)
- Spatial data is intrinsically "static" at the time it was surveyed, captured, imaged… 2D or 3D - Moore's law
- The challenge is to somehow manage and align massive "static" spatial datasets in a dynamic environment accurately over time



Apologies to Bob Rich

Disruptive positioning technology – some considerations

- centimtre accurate real-time positioning for the mass market (in a kinematic TRF) by maybe 2030 – There could be 1 billion "surveyors" soon.
- Underlying map base (e.g. Google, Apple) and spatial data needs to keep up to date with positioning or vv. – but how?
- What positioning and dimensional tolerances should we consider for keeping reference frames fixed?
- Transforming ITRF based positioning to a "common data epoch" – localisation of global positioning (the vv.)?
- Do epoch fixed reference frames have any future?
- TRACEABILITY of position change between different epochs

The future of positioning and data (circa 2030)

multi-GNSS
+ augmentation (e.g. EGNOS, SBAS)
+ indoor positioning (e.g. Locata)
+ miniature inertial sensors

real-time
precise broadcast
orbits

4D cloud GIS

real-time positions

active transformation model

mm
accurate

real-time information currency

centralised data
+ clone

authoritative

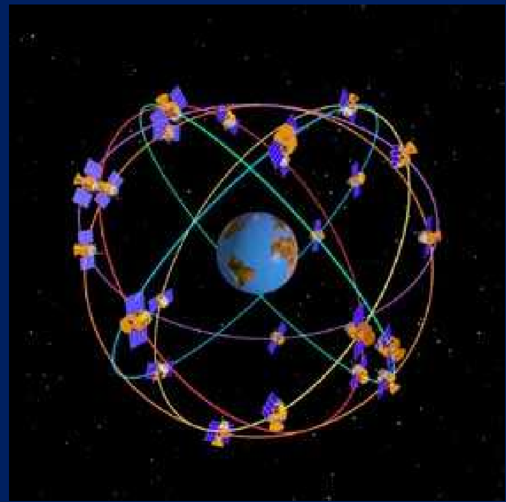
ubiquitous

5G/6G? wireless
and satellite comms.
(e.g. Beidou, Galileo)

Positioning and spatial data – future linkage

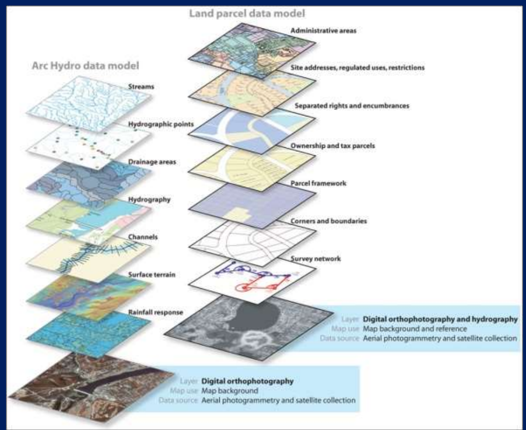
Complex time dependent transformations & deformation modelling

Software matches epoch of positioning with epoch of data in order to maintain context



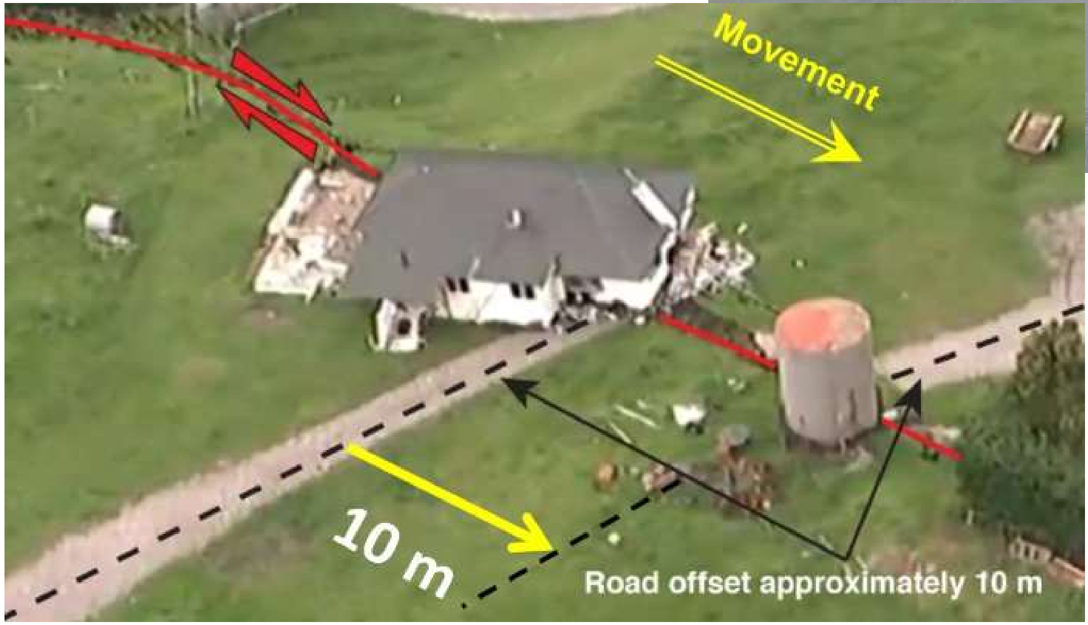
GNSS Positioning within ITRF / GGRF

Data "tagged" with datum (e.g. ITRF) and epoch metadata



Kinematic Spatial Data & GIS

Coseismic disruption

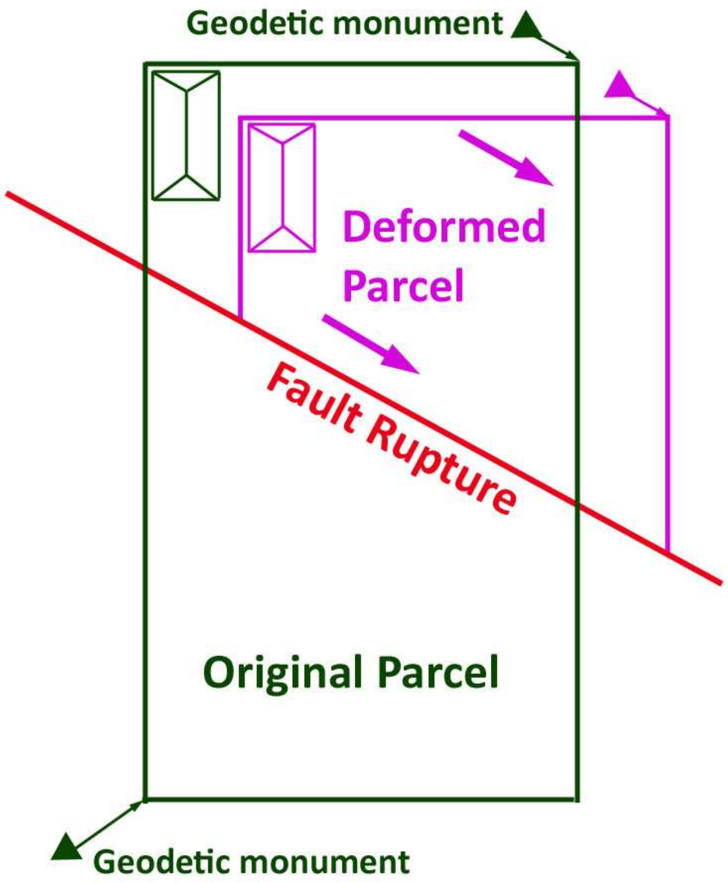


M_w 7.8 Kaikoura earthquake,

New Zealand,

14th November 2016

Effect of coseismic displacement on cadastre and geodetic connections

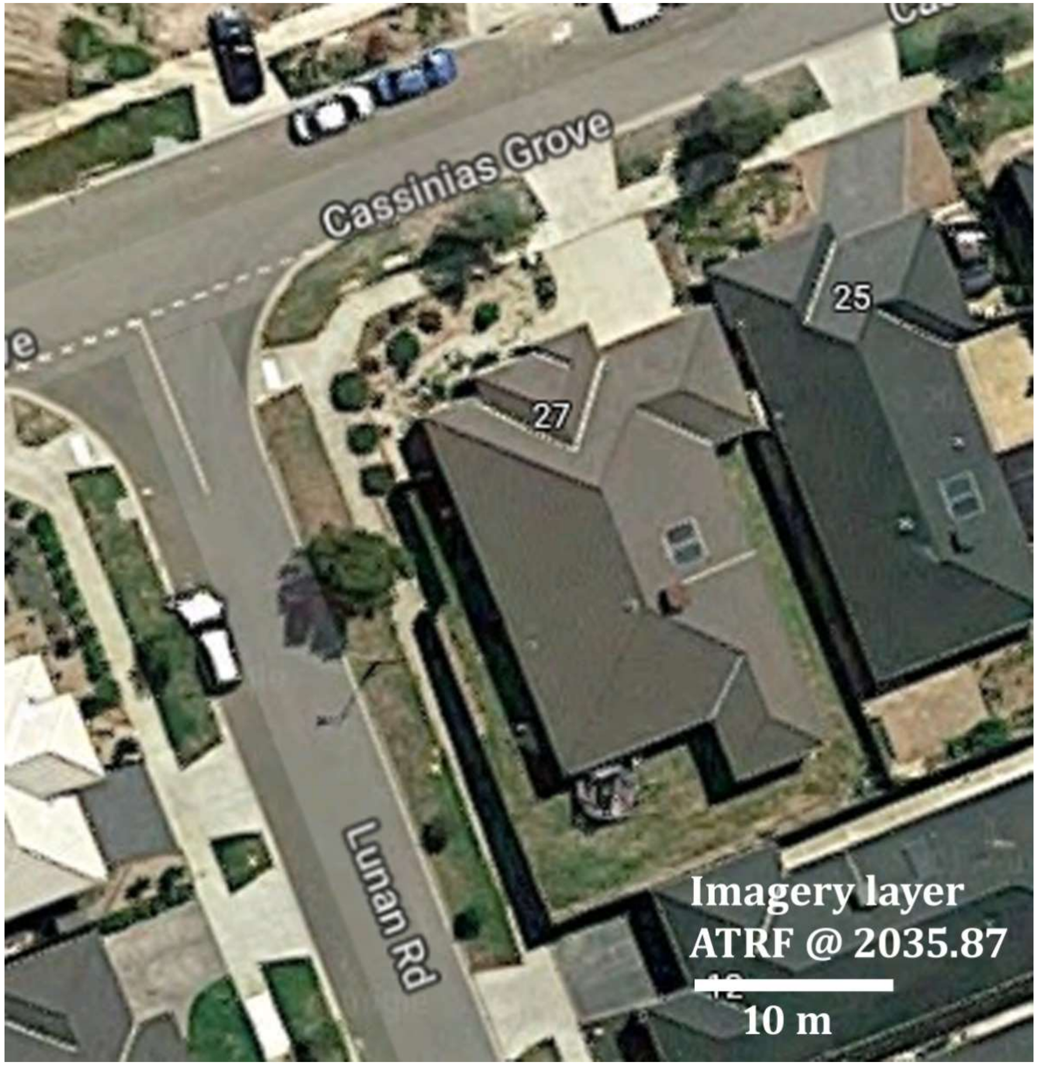


Cadastral boundaries may need to be redefined (new dimensions) after earthquakes in order to maintain the principle of occupational boundaries

and so, coordinate systems realistically require update after earthquake to reflect spatial reality and to maintain positional and dimensional tolerances

The effect of secular plate tectonics on spatial data - A case study from a very stable plate - Australia

Imagery Dynamic Datum at epoch 2035.87



Cadastre
Static datum
at epoch
1994.0

Optical fibre
- as built survey
Static Datum
at epoch
2020.0

Data not correctly aligned due to lack of time-dependent transformation

Gas as-built survey Dynamic Datum at epoch 2025.15

Different data from different acquisition epochs aligned to epoch of imagery

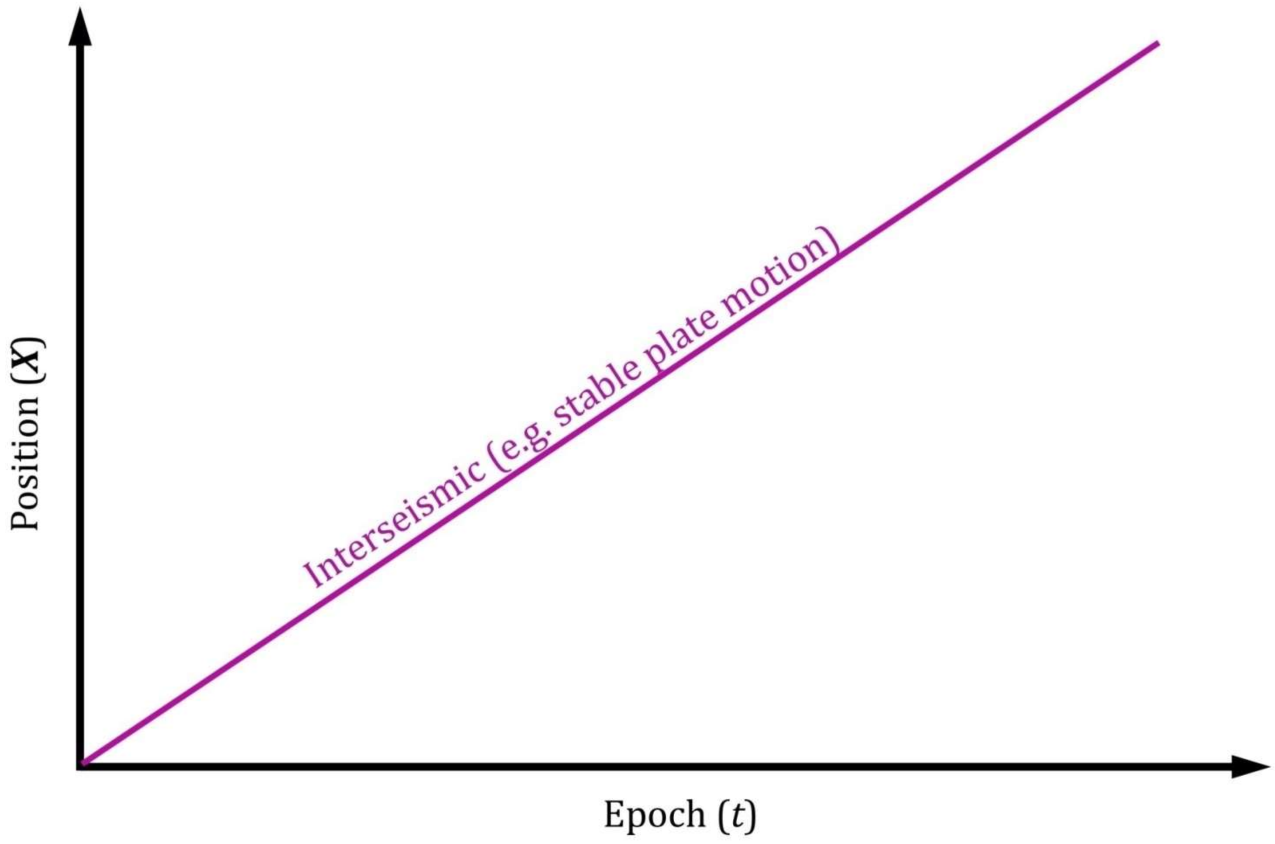
requires

time-dependent transformation

to be applied

to data

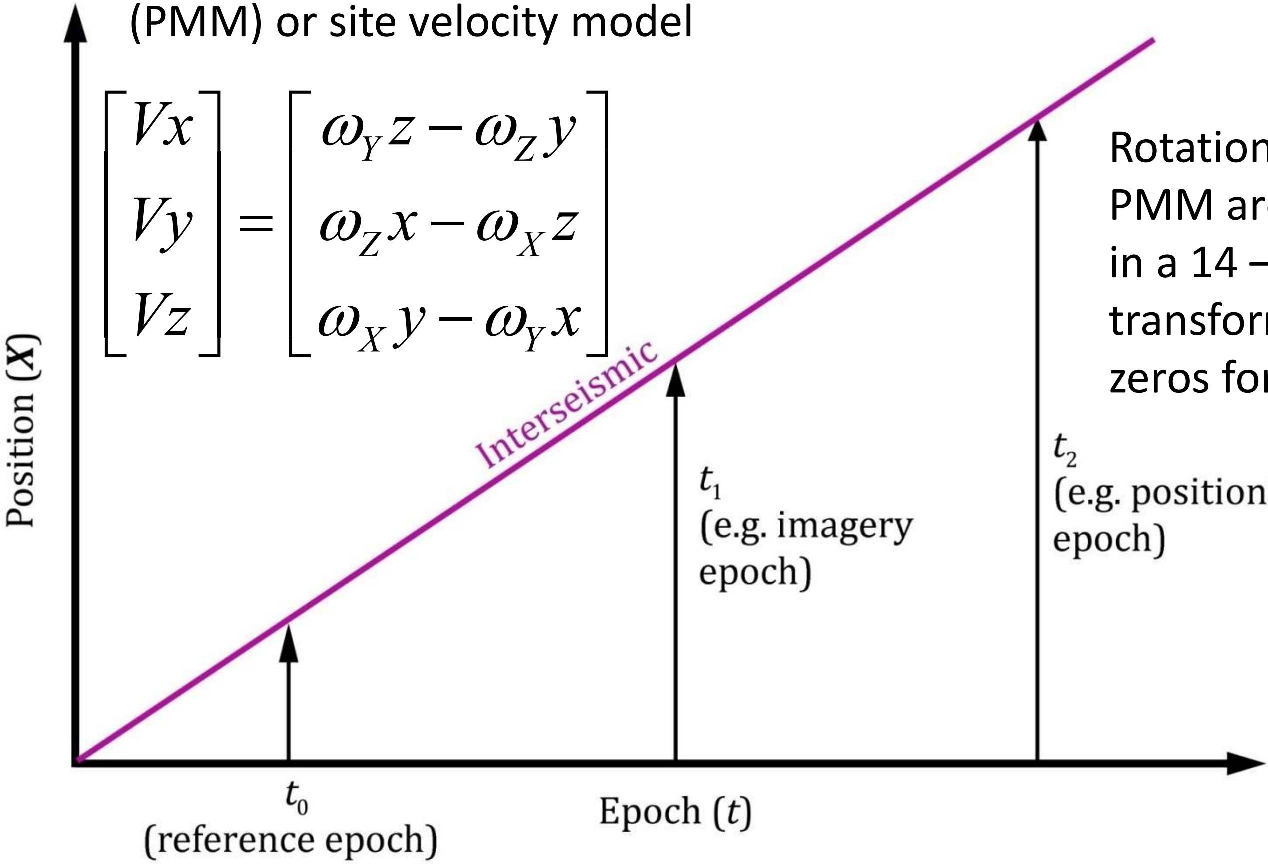
Typical site motion in stable plate zones



time-dependent transformation in stable plate zone

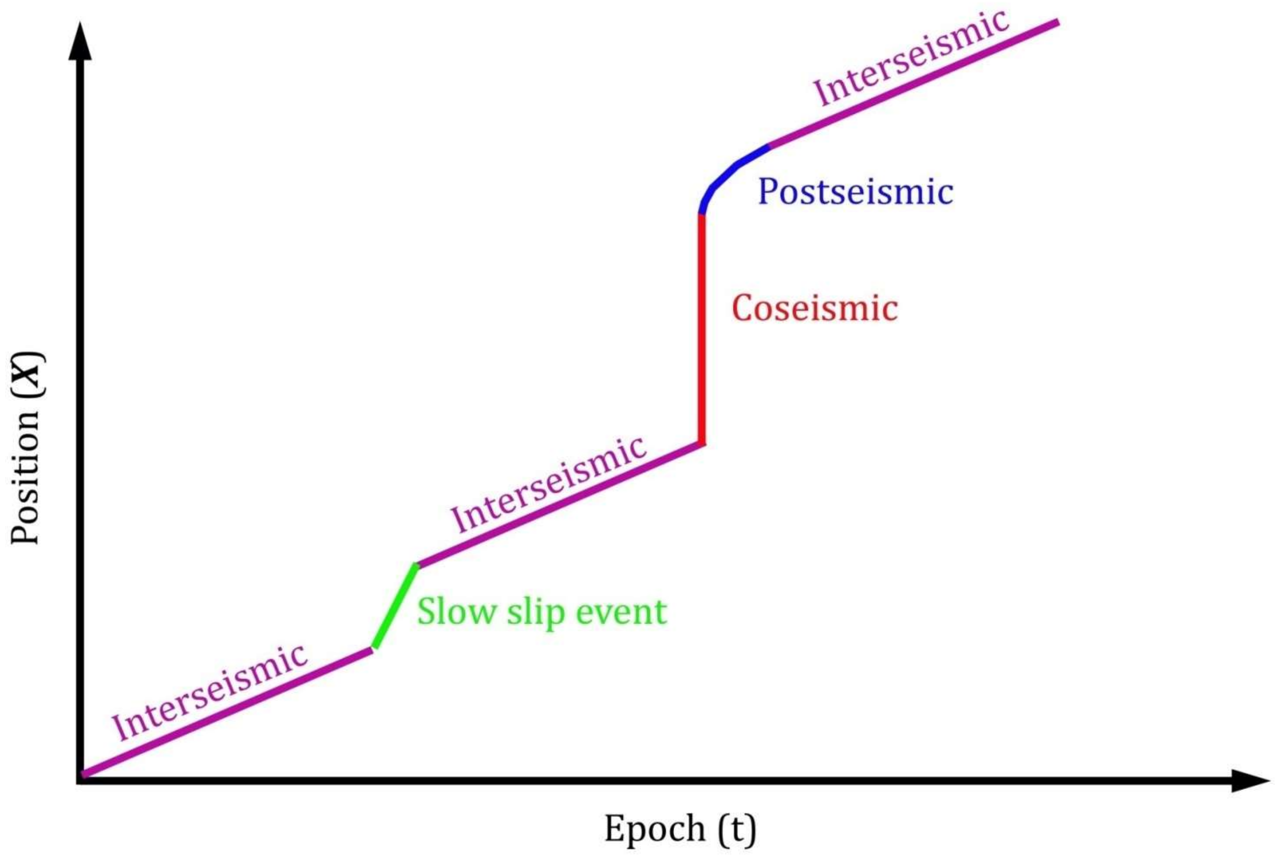
Velocity estimation from plate motion model (PMM) or site velocity model

$$\begin{bmatrix} Vx \\ Vy \\ Vz \end{bmatrix} = \begin{bmatrix} \omega_Y z - \omega_Z y \\ \omega_Z x - \omega_X z \\ \omega_X y - \omega_Y x \end{bmatrix}$$



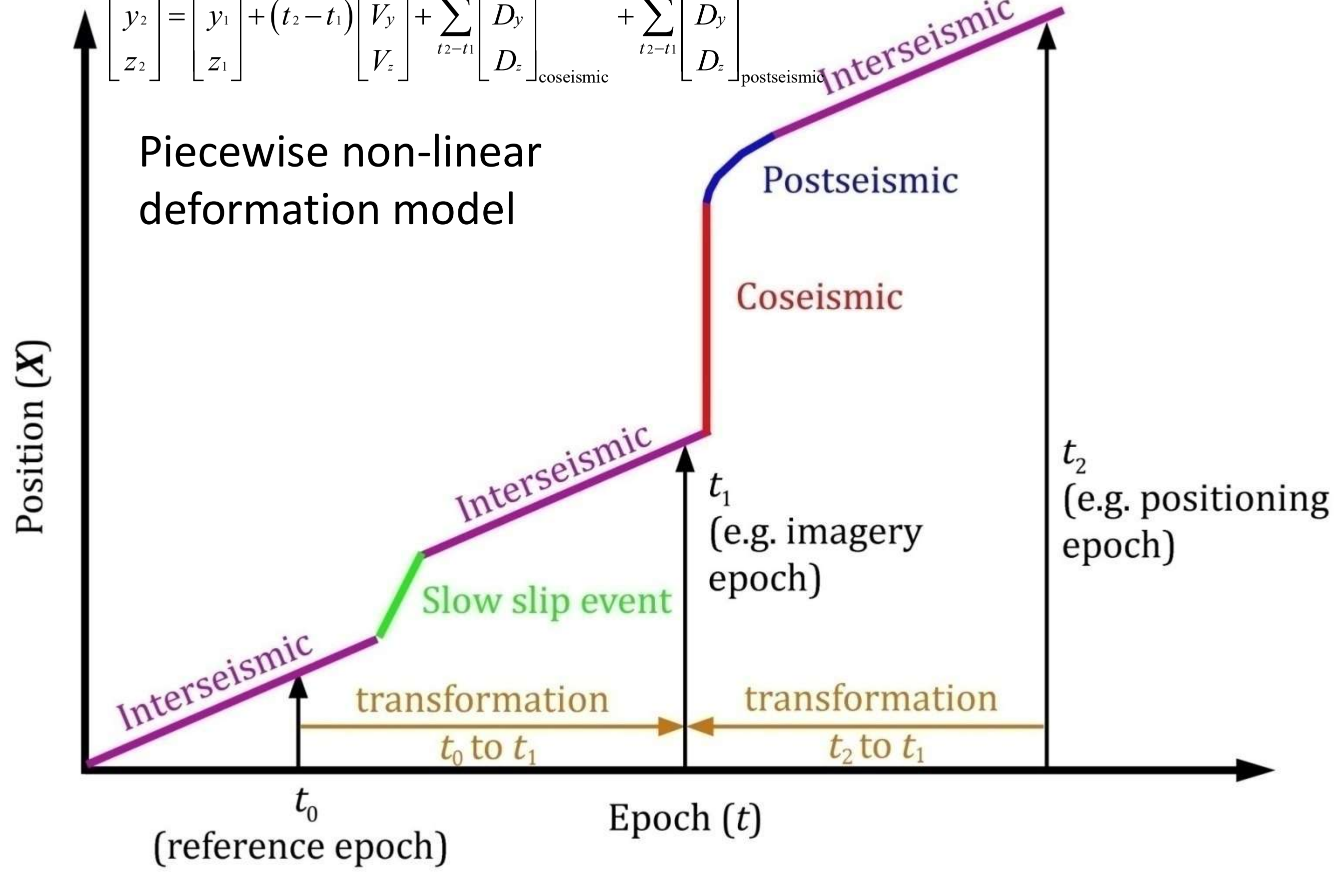
Rotation rates from PMM are rotation rates in a 14 –parameter transformation with zeros for all other terms

Typical site motion in deforming zones



time-dependent transformation in plate boundary zones

$$\begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix} = \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} + (t_2 - t_1) \begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} + \sum_{t2-t1} \begin{bmatrix} D_x \\ D_y \\ D_z \end{bmatrix}_{\text{coseismic}} + \sum_{t2-t1} \begin{bmatrix} D_x \\ D_y \\ D_z \end{bmatrix}_{\text{postseismic}}$$

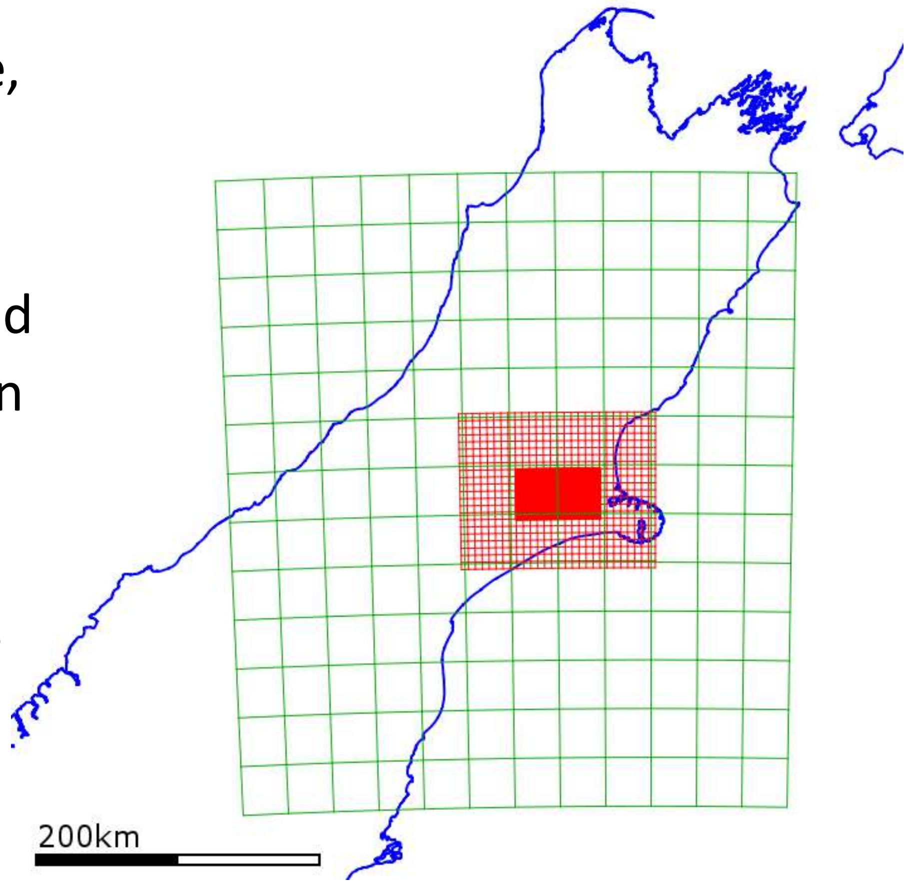


Multi-resolution grid patches (e.g. NTv2 format)

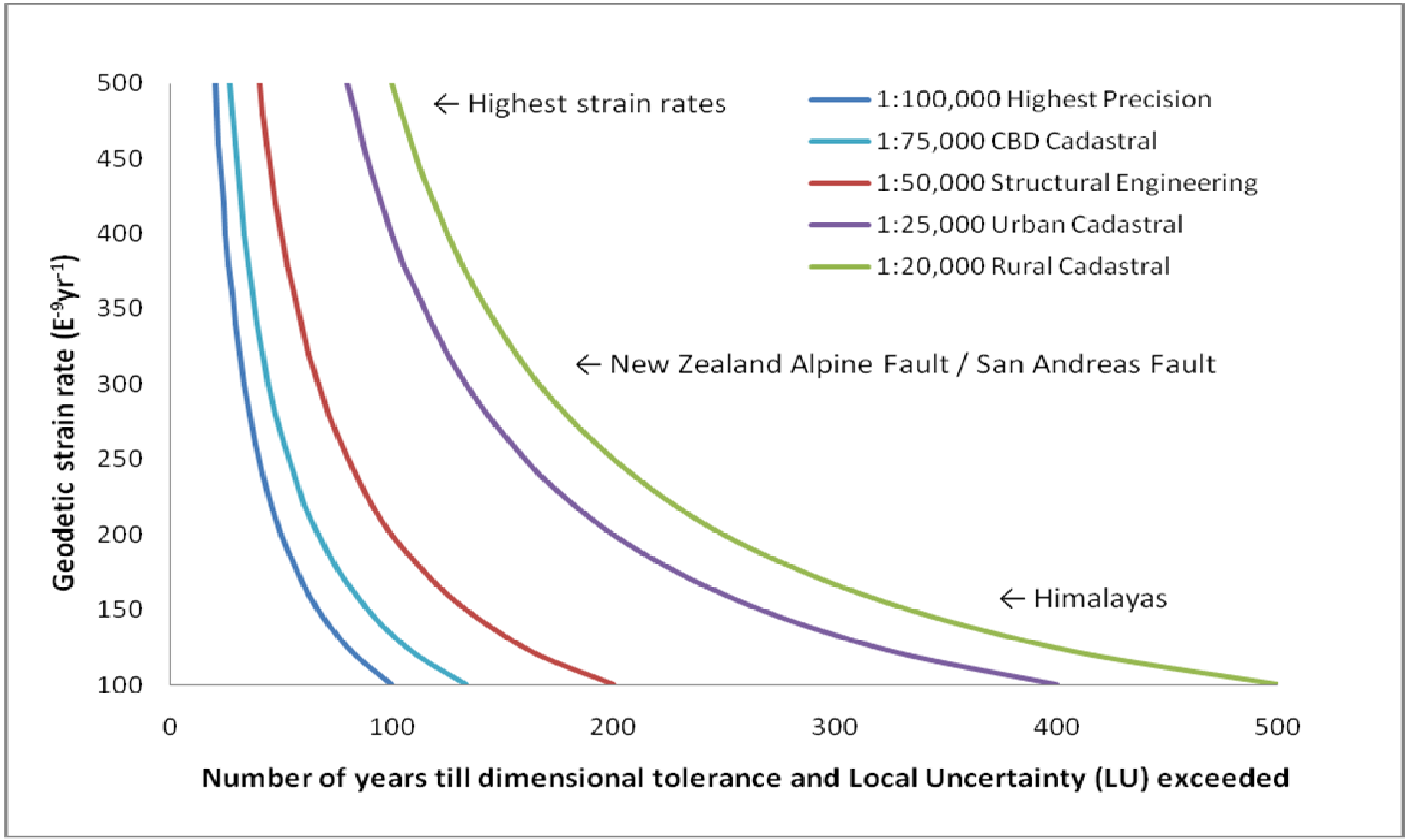
to describe site velocities, coseismic deformation, postseismic terms (type, amplitude and decay time) and uncertainty

Use of a suitable interpolation method (e.g. bilinear) to estimate deformation terms, site velocities and uncertainties.

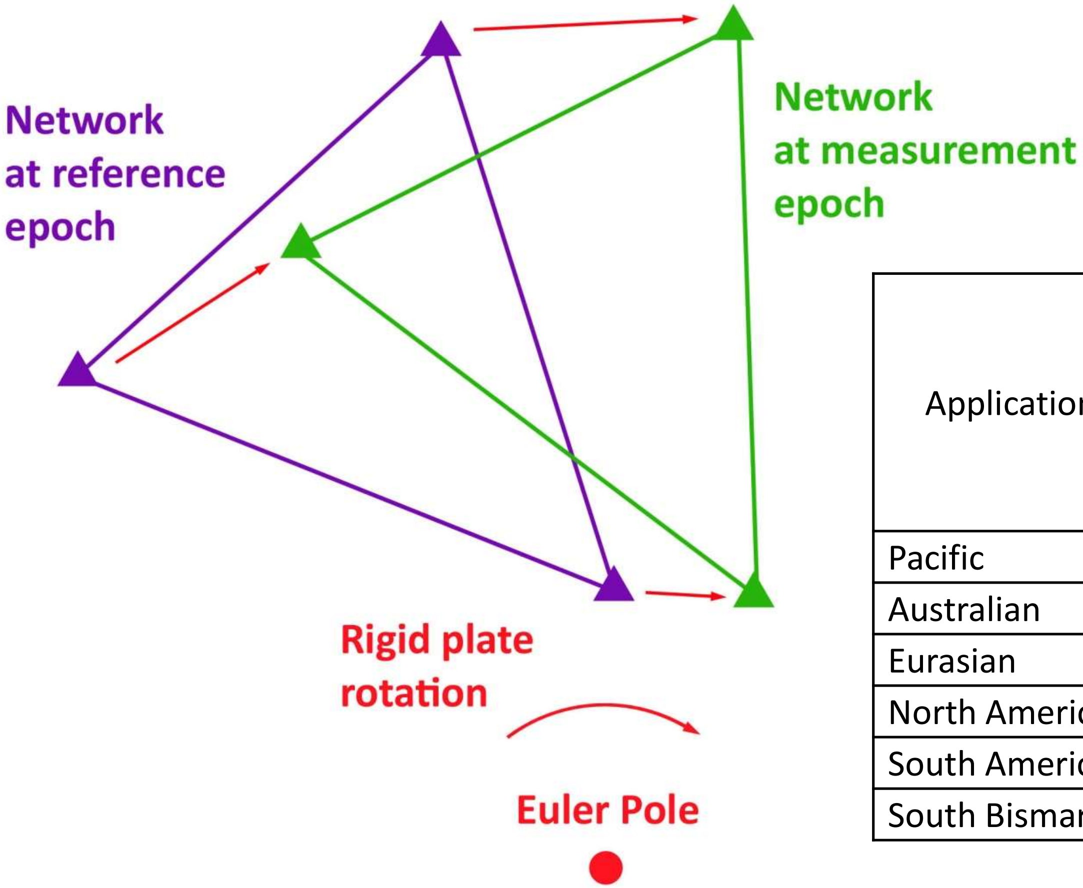
Also consider displacement tolerance at patch boundary



Effect of interseismic strain on surveying tolerances



Effect of plate rotation on GNSS vectors

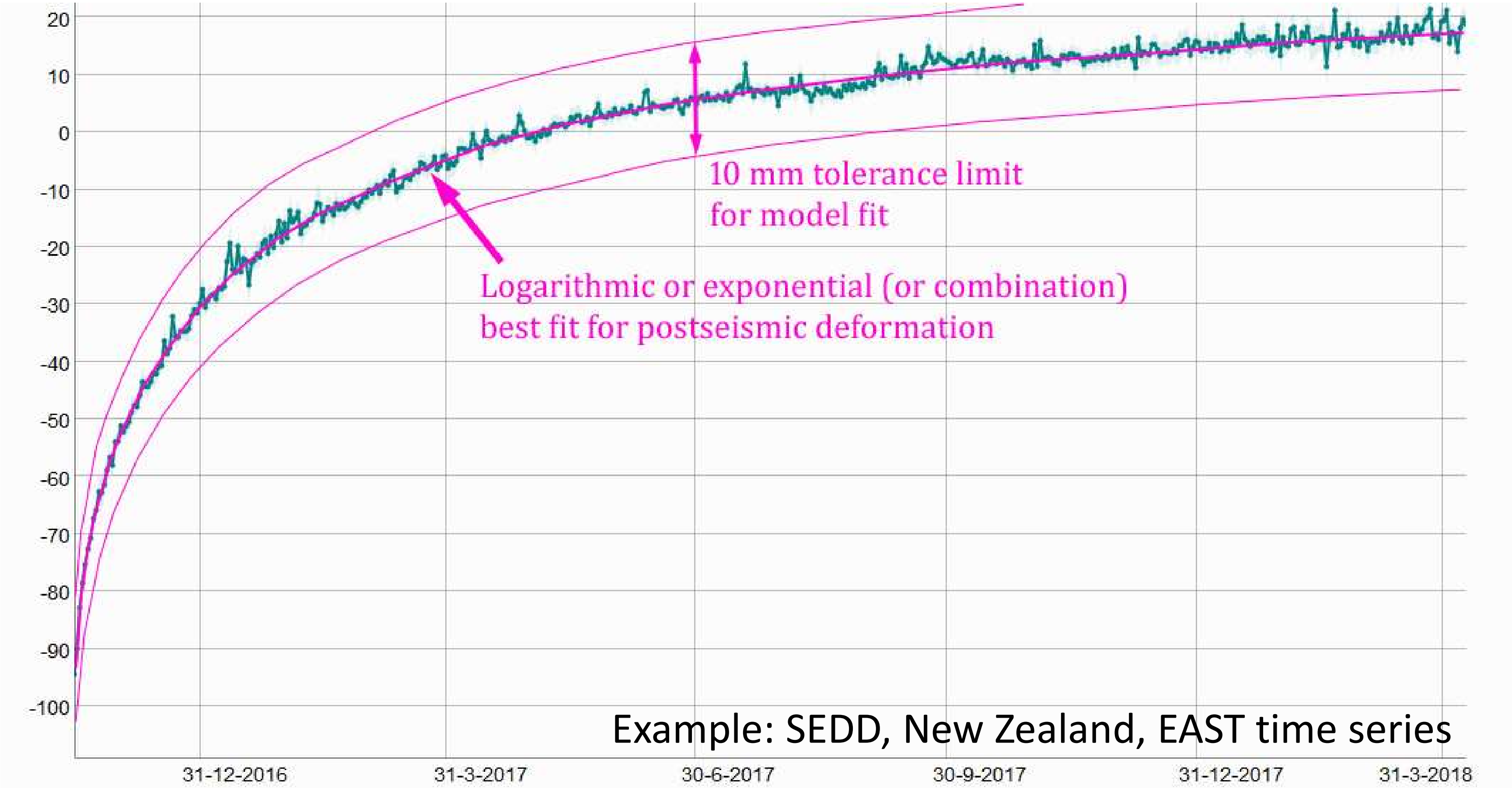


Application	Rotation Rate °Ma^{-1}	Number of years before 15 mm 3D PU for rover GNSS exceeded at 30 km range from CORS
Pacific	0.68	42
Australian	0.63	45
Eurasian	0.26	110
North American	0.19	151
South American	0.12	239
South Bismarck	8.00	3

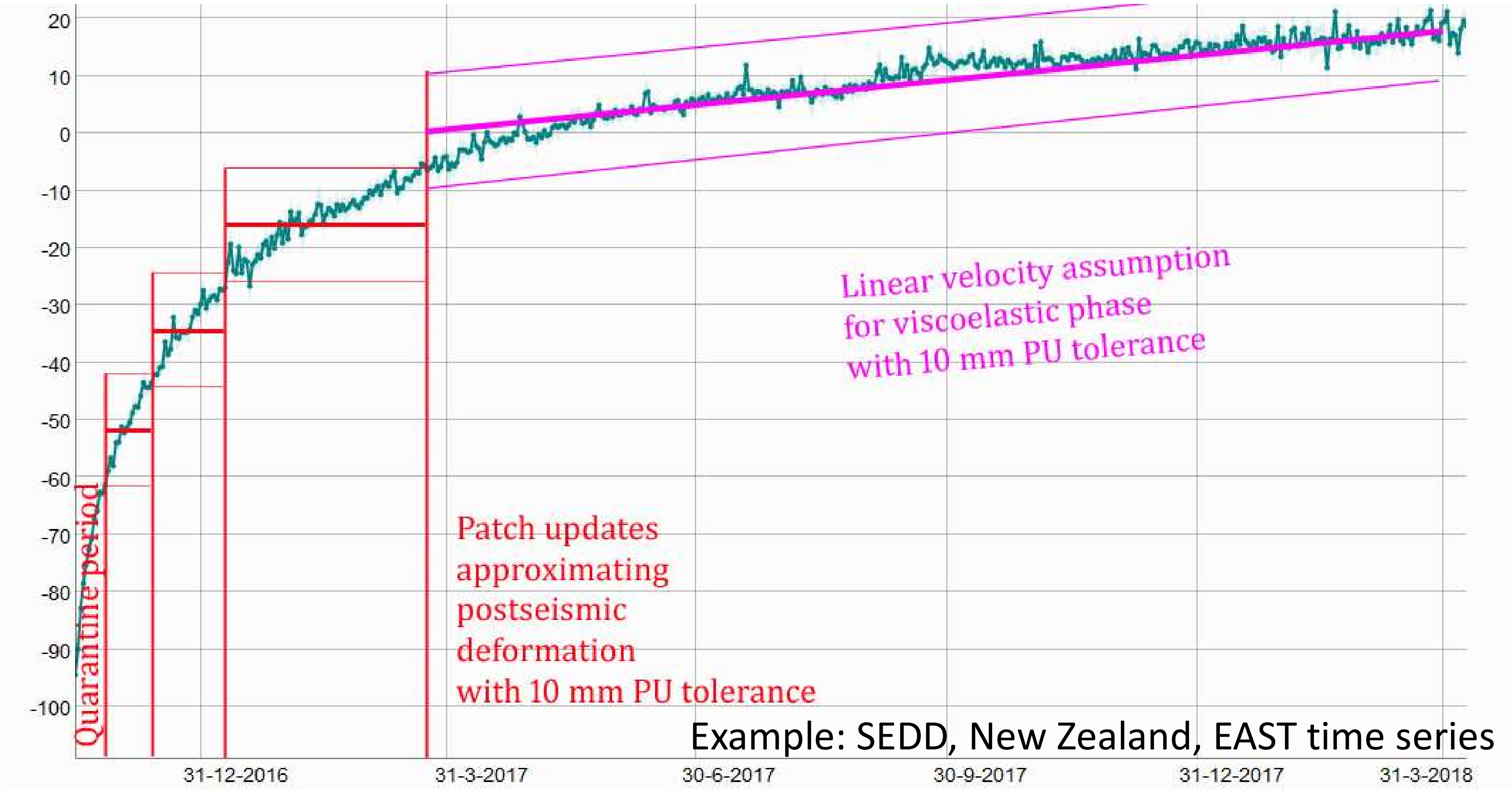
Approaches to handling complex displacements

Slow-slip event deformation, example is East time series GISB, New Zealand

Modelling postseismic deformation



Piecewise approximation of postseismic deformation



Example: SEDD, New Zealand, EAST time series

The dual-frame option – kinematic + static!

Kinematic TRF (e.g. ITRF/GGRF)

GNSS frame for
PPP and long baseline processing
“raw” GNSS data capture

14-parameter transformation or site velocity model (interpolation from gridded model)

Static local RF and Geodetic/Geographic CRS (a working “fiction”)

Static RF epoch maintained until internal deformation exceeds dimensional tolerances

Projected CRS

Mapping projection
e.g. UTM/UPS/LCC
Scale factor < 500 ppm

Project Grid - engineering
e.g. Local TM/Stereographic/LCC
Scale factor < 50 ppm

When to apply band aids (coseismic patches)?

Cosesimic deformation can trigger requirement for CRS patch if positional and dimensional tolerances are exceeded.

Patched coordinates can still refer to underlying CRS but should be referenced with a patch version or CRS epoch update to positively distinguish pre and post-earthquake coordinates

e.g. NZGD2000(20130801)

To transform pre-earthquake data to post-earthquake only the coseismic displacement model (CRS patch) is applied.

For ITRF to NZGD2000(latest patch) transformation only the secular site velocity model is used.

To summarise

- A reference epoch is still recommended for spatial data stacking within a kinematic frame (dynamic datum)
- Correction to coordinates at the reference epoch after each deformation event (maintains underlying RF definition)
- Reference epoch update required when most stringent dimensional tolerances are exceeded due to interseismic strain
- Model format standardisation recommended (e.g. EPSG and ISO TC/211
- Piecewise non-linear model approach recommended for transformation across episodic deformation events
- TRACEABILITY and REPLICABILITY of models is essential

Teşekkür ederim