Reference Frames, Transformations and GIS

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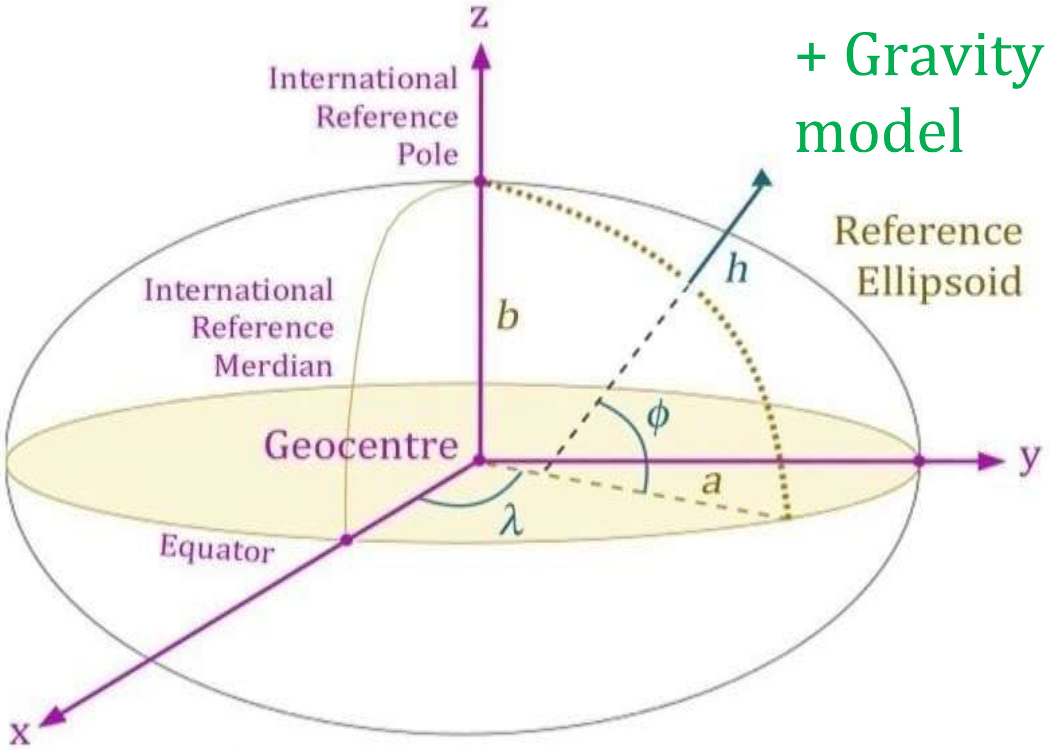
Terrestrial Reference System

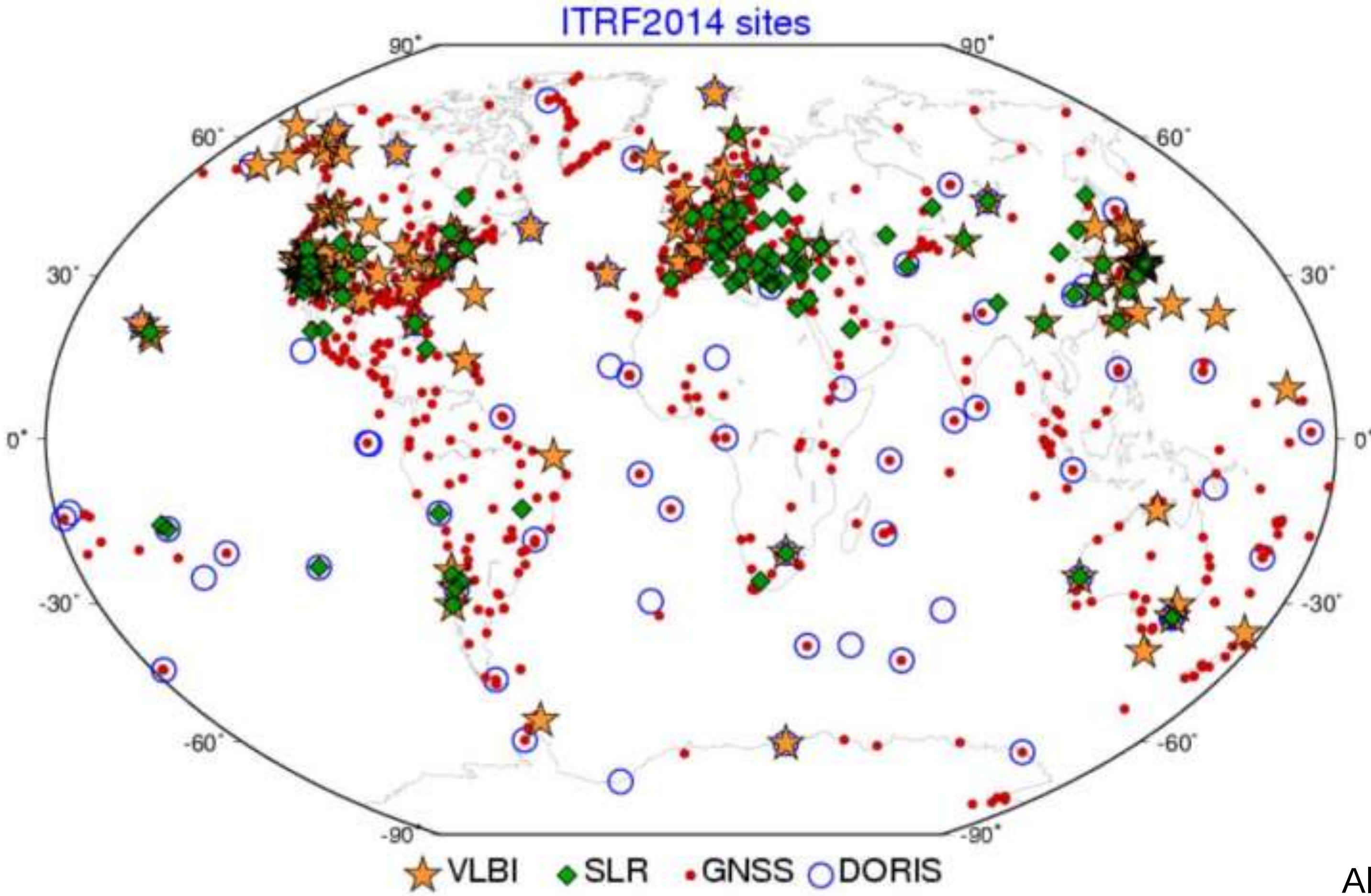


+ Gravity model

In principle a TRS should be invariant with time

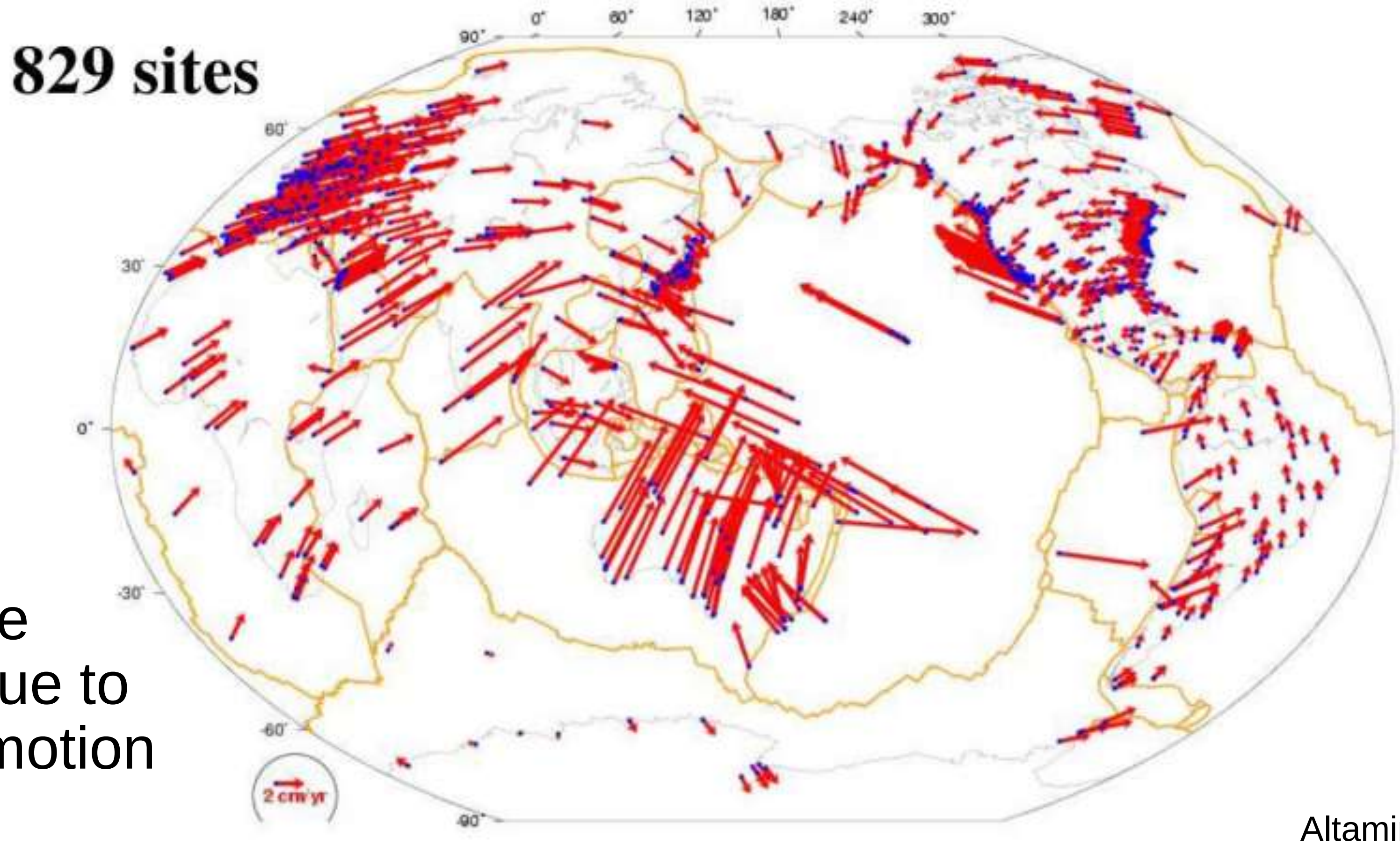
example: Geocentric ITRS

International Terrestrial Reference Frame



Altamimi et al., 2015

ITRF Kinematics – NNR site velocities (the angular momentum of all tectonic plates sums cero)

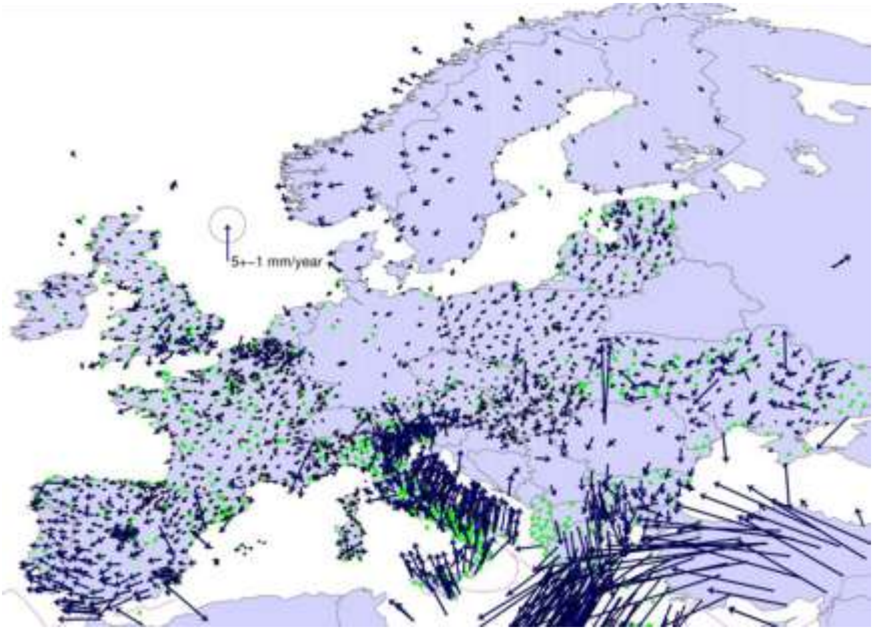


Velocities are predominantly due to secular tectonic motion and GIA

Altamimi et al., 2015

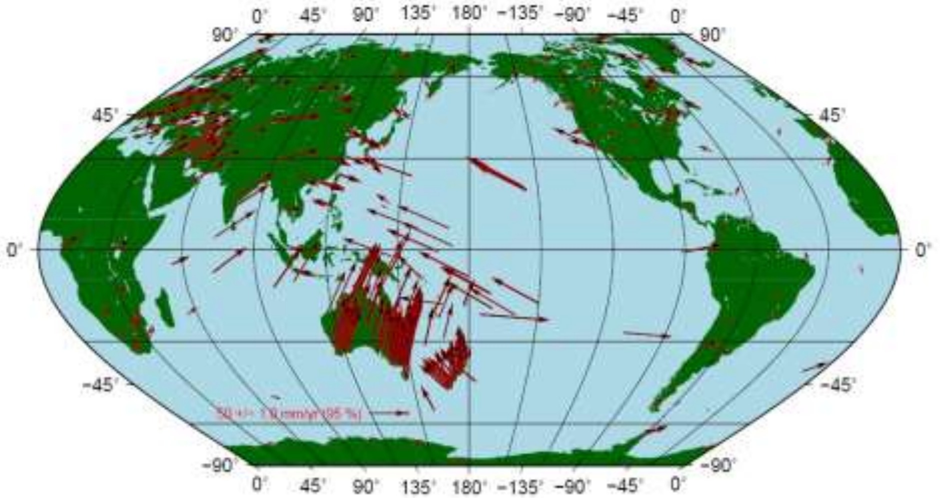
Regional Reference Frames

Plate fixed

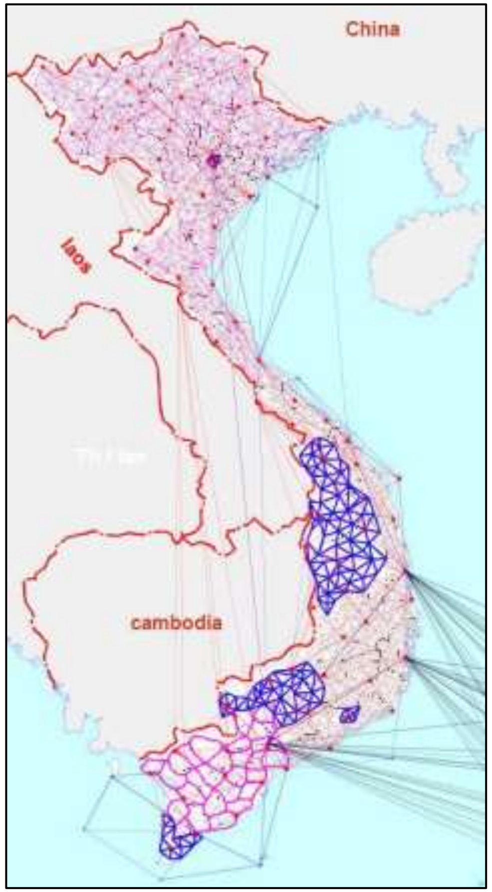


e.g. European RF (ETRF) – velocities minimised for most of Eurasian plate
(figure: EUREF, 2018)

NNR (No-Net-Rotation)



e.g. Asia-Pacific RF (APREF) – no dominant plate within frame coverage so NNR model is used (figure: Hu, 2014)



National & Local Reference Frames

Characteristics:

Now usually a fixed epoch of ITRF using GNSS (recent geocentric frames) e.g. VN2000 for mainland Vietnam (figure: Vietnam Dept. of Surveying Mapping, 2016)

or astronomical determination of frame origin (pre space geodetic era)

(frame often not geocentric)

e.g. Australian Geodetic Datum 1966 (AGD66)

(figure: Paul Wise, 2016)

Static and time-dependent frames

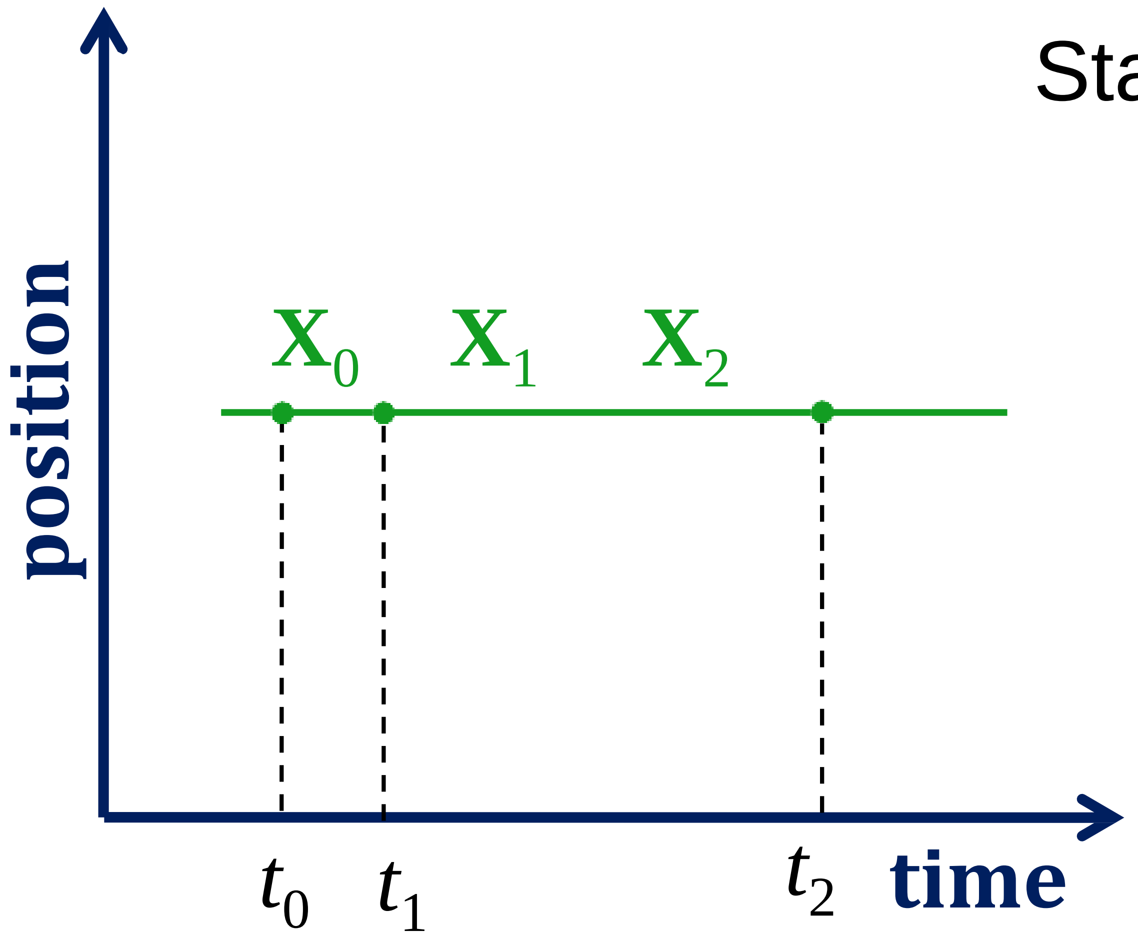
Static (time-invariant) – no displacement is assumed

Kinematic (time dependent)

- includes all displacements wrt. ITRS
(e.g., tectonic motion, glacial isostatic adjustment, coseismic deformation)

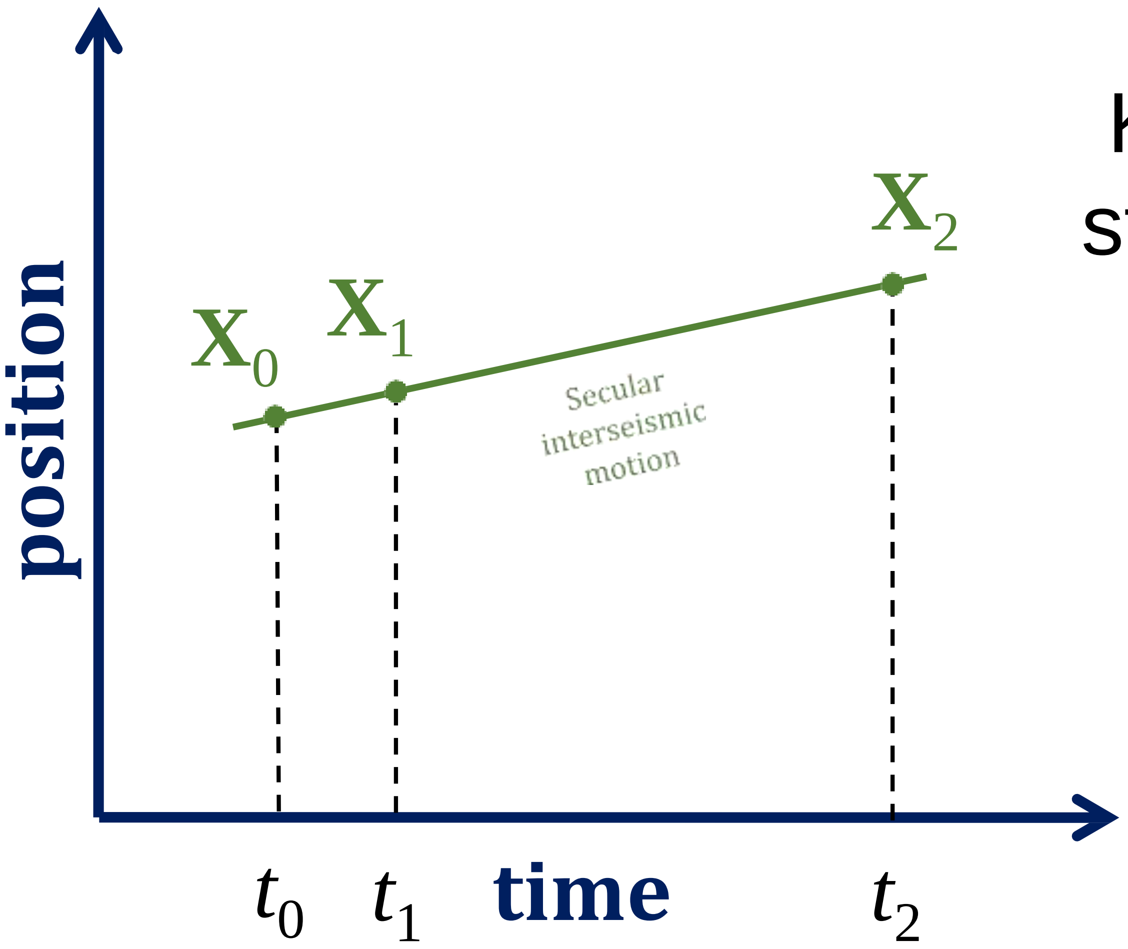
Semi-kinematic (time dependent)

- secular tectonic motion is modelled out
- coseismic displacement models applied after earthquakes



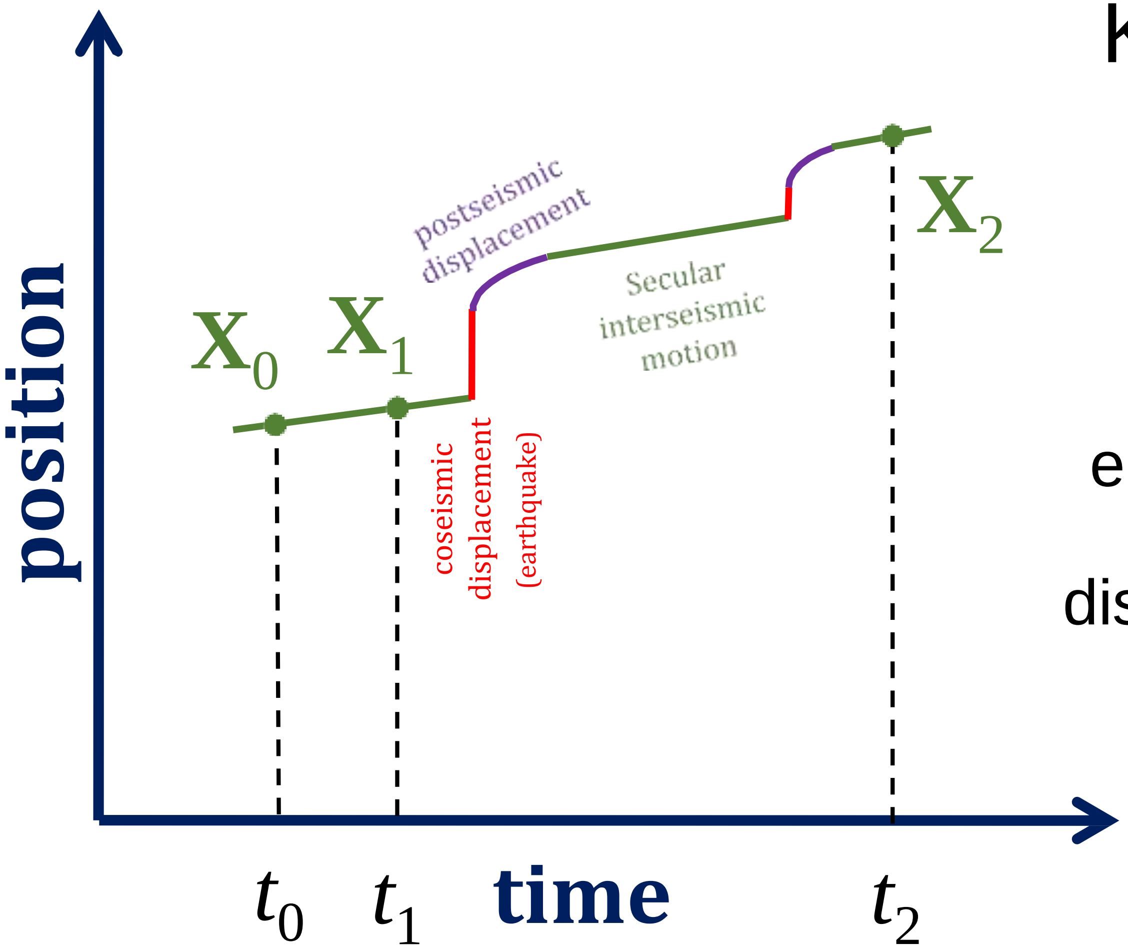
Static reference frame

position does not change with time (except perhaps for readjustments)



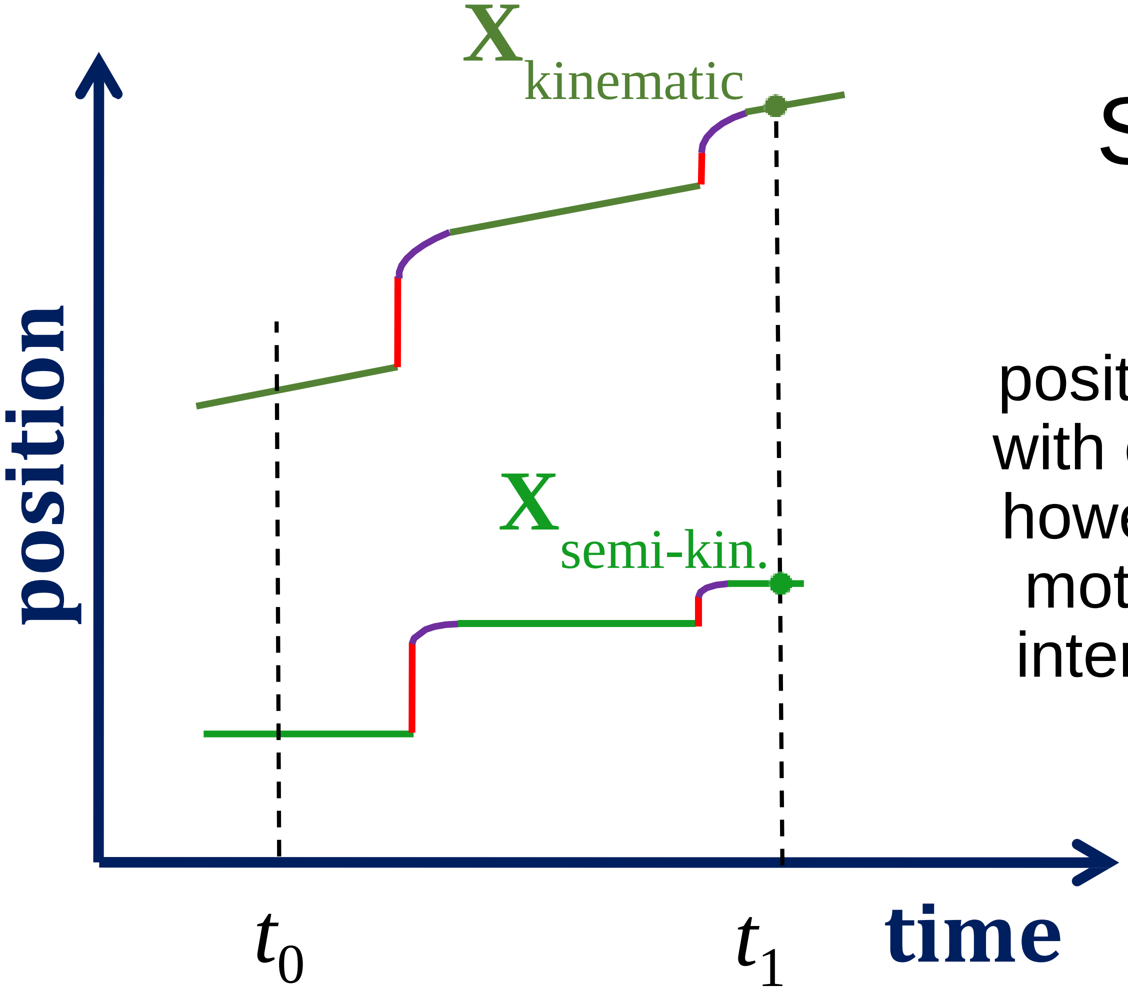
Kinematic frame – stable plate regions

position changes slowly (< 8 cm yr^{-1}) due to secular plate motion and GIA (interseismic motion)



Kinematic frame – plate boundary zones

position changes episodically with coseismic and postseismic displacements resulting from earthquakes



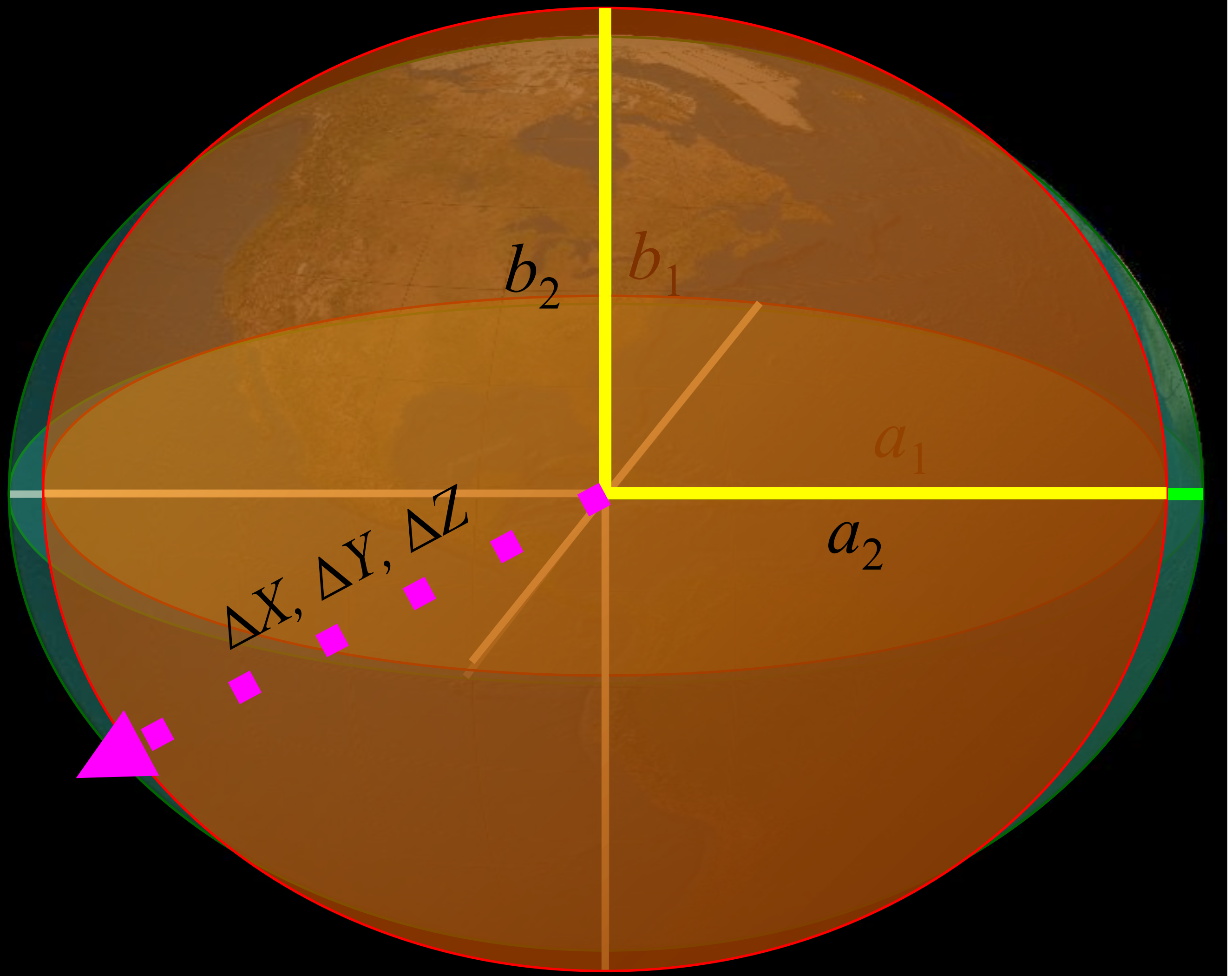
Semi-kinematic frame

position changes episodically with coseismic displacements however secular interseismic motion is modelled out until interseismic strain threshold is reached

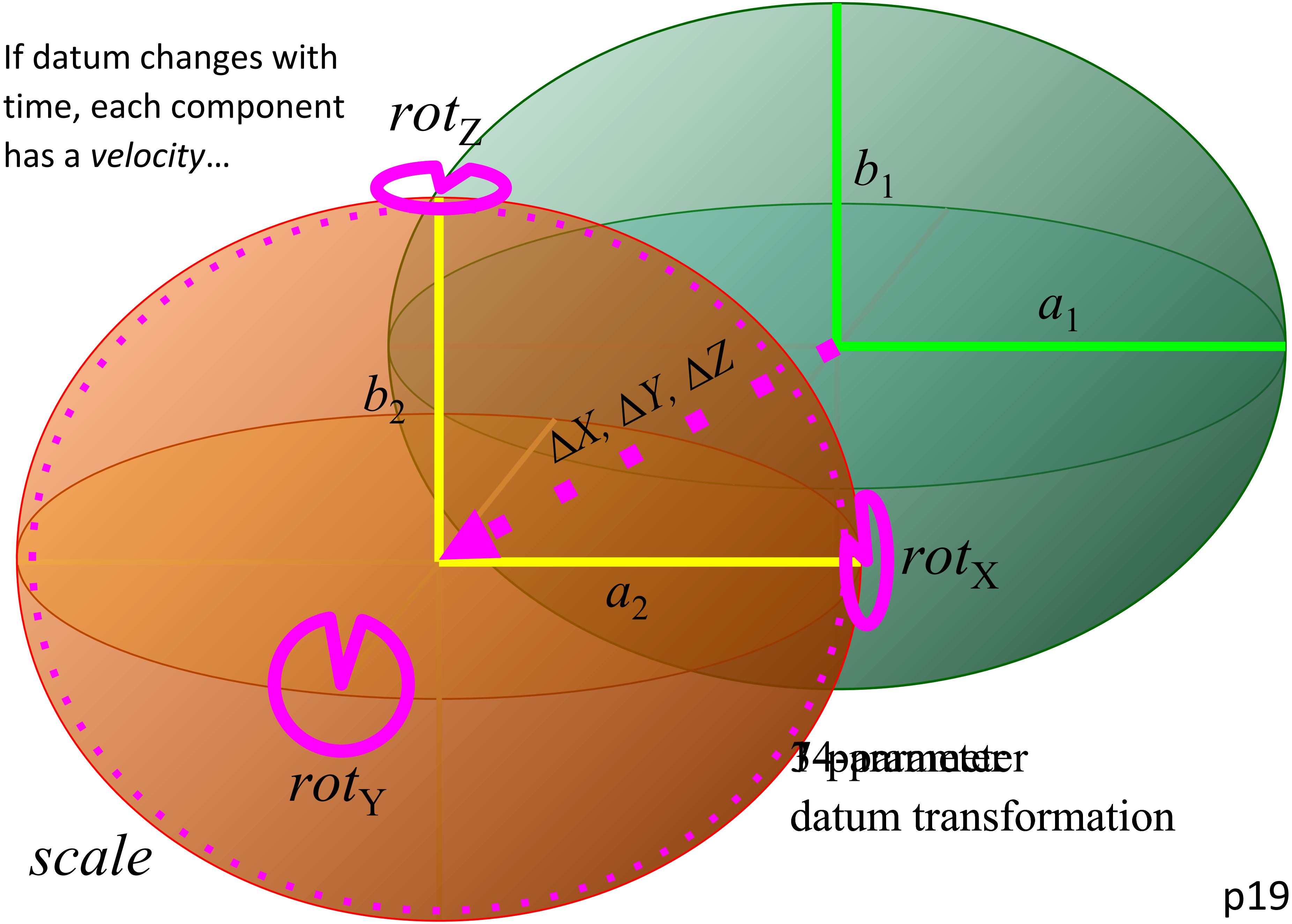
Interframe transformations

	Static frame	time-dependent frame
Conformal Parametric	3 parameter 7 parameter	14 parameter (7 parameters at reference epoch + rates)
Grid model	displacement grid distortion grid	interseismic velocity model + coseismic displacement grid + postseismic decay term grid

Geometric datum transformations



If datum changes with time, each component has a *velocity*…



14-parameter
datum transformation

Datum transformations

- **Typical geodetic datum transformations**
  - **3-parameter:** 3-dimensional translation of origin as ΔX, ΔY, ΔZ (*just like a GPS vector*)
  - **7-parameter:** 3 translations *plus* 3 rotations (one about each of the axes) *plus* a scale
  - **14-parameter:** A 7-parameter where each parameter changes with time (each has a *velocity*)
  - Transformations that also model distortion and tectonic motion, such as the NGS programs NCCAT and HTDP
- **Vertical datum transformations**
  - Can be simple shift or complex operations that model distortion, gravity, and tides, such as NGS programs NCCAT and VDatum

Plate Motion Model

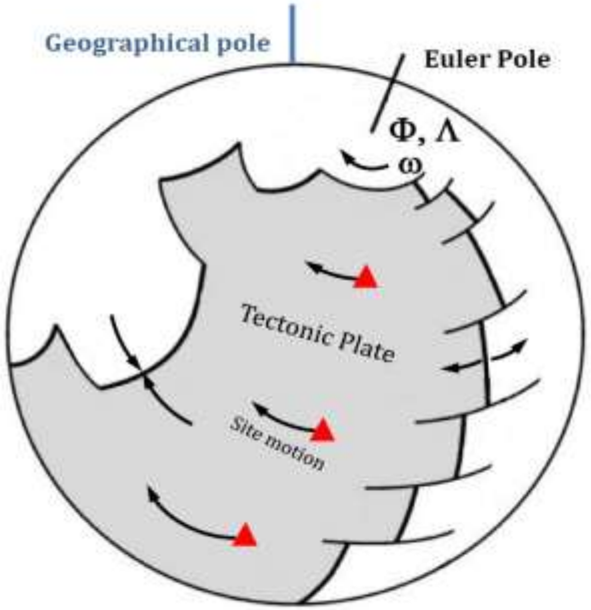


Plate	Euler pole of rotation			Equivalent Cartesian angular velocity		
	Φ (°)	Λ (°)	ω (° Ma⁻¹)	Ω_x (Rad Ma⁻¹)	Ω_y (Rad Ma⁻¹)	Ω_z (Rad Ma⁻¹)
Antarctic	58.8	-127.4	0.219	-0.001202	-0.001571	0.003272
Arabian	51.2	-6.7	0.515	0.005595	-0.000659	0.007001
Australian	32.4	38.1	0.631	0.007321	0.005730	0.005890
Eurasian	55.1	-99.1	0.261	-0.000412	-0.002574	0.003733
Indian	51.6	-0.2	0.516	0.005595	-0.000024	0.007049
Nazca	45.8	-102.2	0.629	-0.001614	-0.007486	0.007869
North American	-5.2	-88.0	0.194	0.000116	-0.003365	-0.000305
Nubian	49.7	-80.8	0.267	0.000480	-0.002977	0.003554
Pacific	-62.6	111.3	0.679	-0.001983	0.005076	-0.010516
South American	-19.1	-131.9	0.119	-0.001309	-0.001459	-0.000679
Somalian	47.7	-98.7	0.332	-0.000587	-0.003849	0.004286

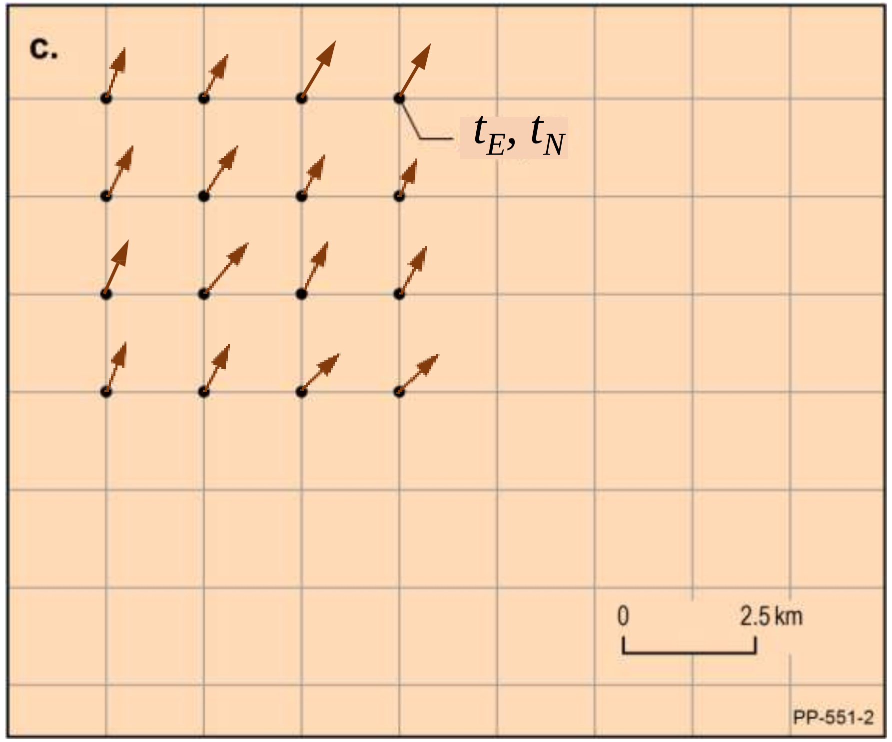
ITRF2014 Plate Motion Model (from Altamimi *et al.*, 2017)

Euler pole can be estimated by LS inversion of interseismic site velocities within a stable plate

$$\Omega_x = \cos(\Phi)\cos(\Lambda)\omega$$
$$\Omega_y = \cos(\Phi)\sin(\Lambda)\omega$$
$$\Omega_z = \sin(\Phi)\omega$$

Rotation rates can be used in a 14-parameter model with zeroes for other parameters (now used for GDA2020 to ITRF2014 transformations)

Displacement and Distortion Grids



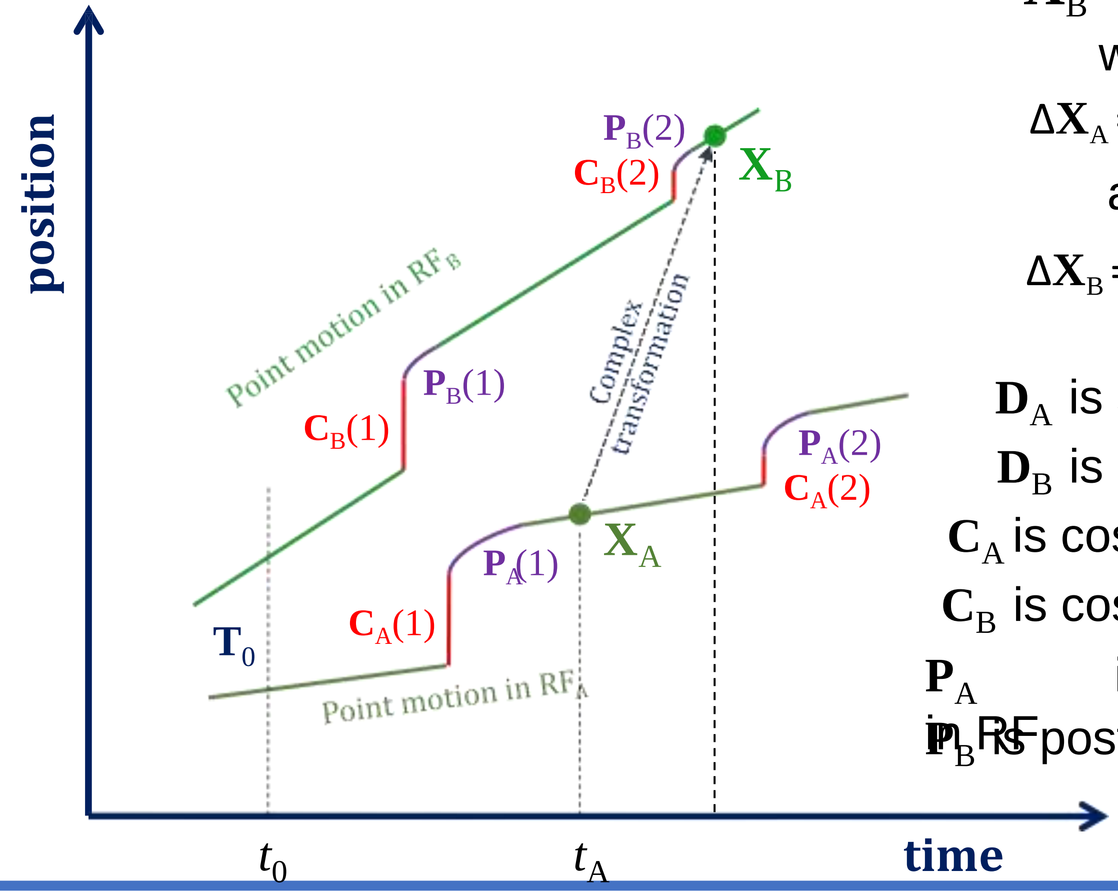
adapted from GDA2020 Technical Manual, ICSM, 2018

$$\begin{bmatrix} E \\ N \end{bmatrix}_B = \begin{bmatrix} E \\ N \end{bmatrix}_A + \begin{bmatrix} t_E \\ t_N \end{bmatrix}$$

Topocentric shifts estimated by bilinear interpolation of grid model (e.g., in NTv2 format)

Ideal for heterogeneous RF transformations and handling local distortions

Complex time-dependent transformations



t_B

$$\mathbf{X}_B = \mathbf{X}_A - \Delta\mathbf{X}_A + \mathbf{T}_0 + \Delta\mathbf{X}_B$$

where

$$\Delta\mathbf{X}_A = \mathbf{D}_A + \sum_{t_0 \geq \mathbf{C} > t_A}^{n} \mathbf{C}_A + \sum_{t_0 \geq \mathbf{P} > t_A}^{n} \mathbf{P}_A$$

and

$$\Delta\mathbf{X}_B = \mathbf{D}_B + \sum_{t_0 \geq \mathbf{C} > t_B}^{n} \mathbf{C}_B + \sum_{t_0 \geq \mathbf{P} > t_B}^{n} \mathbf{P}_B$$

$\mathbf{D}_A$ is secular displacement in RF$_A$

$\mathbf{D}_B$ is secular displacement in RF$_B$

$\mathbf{C}_A$ is coseismic displacement in RF$_A$

$\mathbf{C}_B$ is coseismic displacement in RF$_B$

$\mathbf{P}_A$ is postseismic displacement in RF$_A$

$\mathbf{P}_B$ is postseismic displacement in RF$_B$

$\mathbf{T}_0$ is interframe translation

Topocentric frame

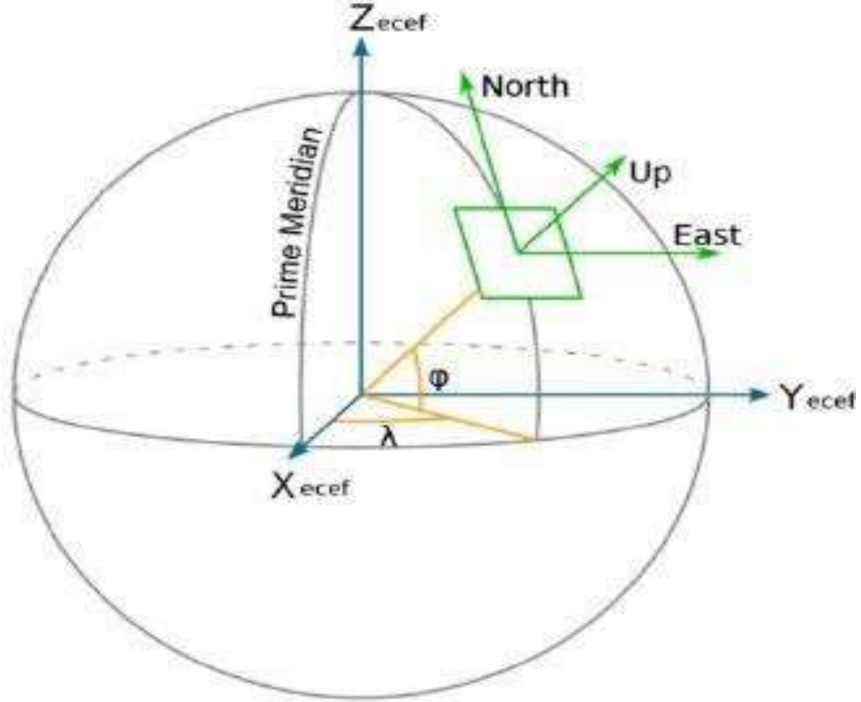


Image: Haasdyk and Janssen, 2011

A topocentric projection canvas is useful for complex transformation computations involving displacement grids

Converting geocentric translation to topocentric (rate or shift)

$\sin\varphi$ Z

U

Converting topocentric translation to geocentric (rate or shift)

X $[-\sin\lambda \quad -\sin\varphi\cos\lambda \quad \cos\varphi\cos\lambda]$

E

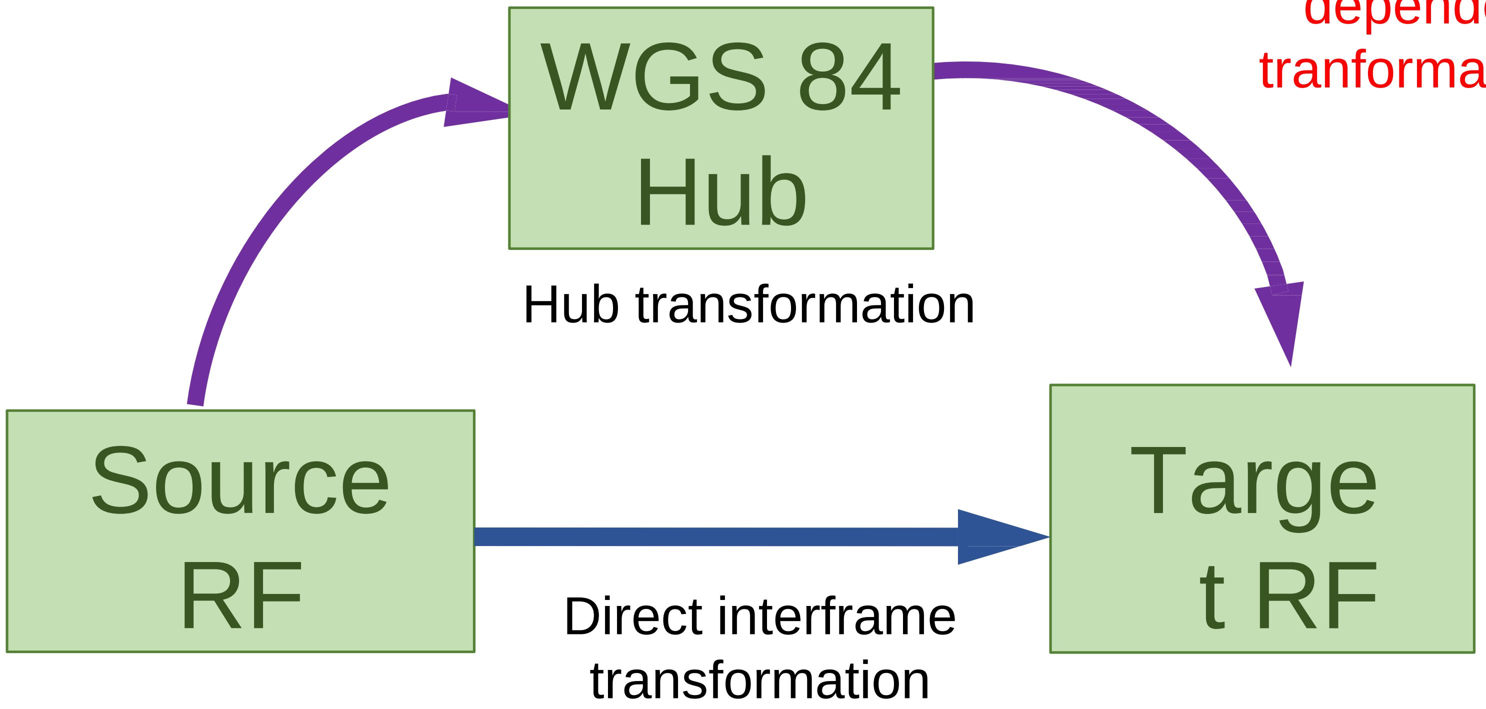
0 U

GIS transformations

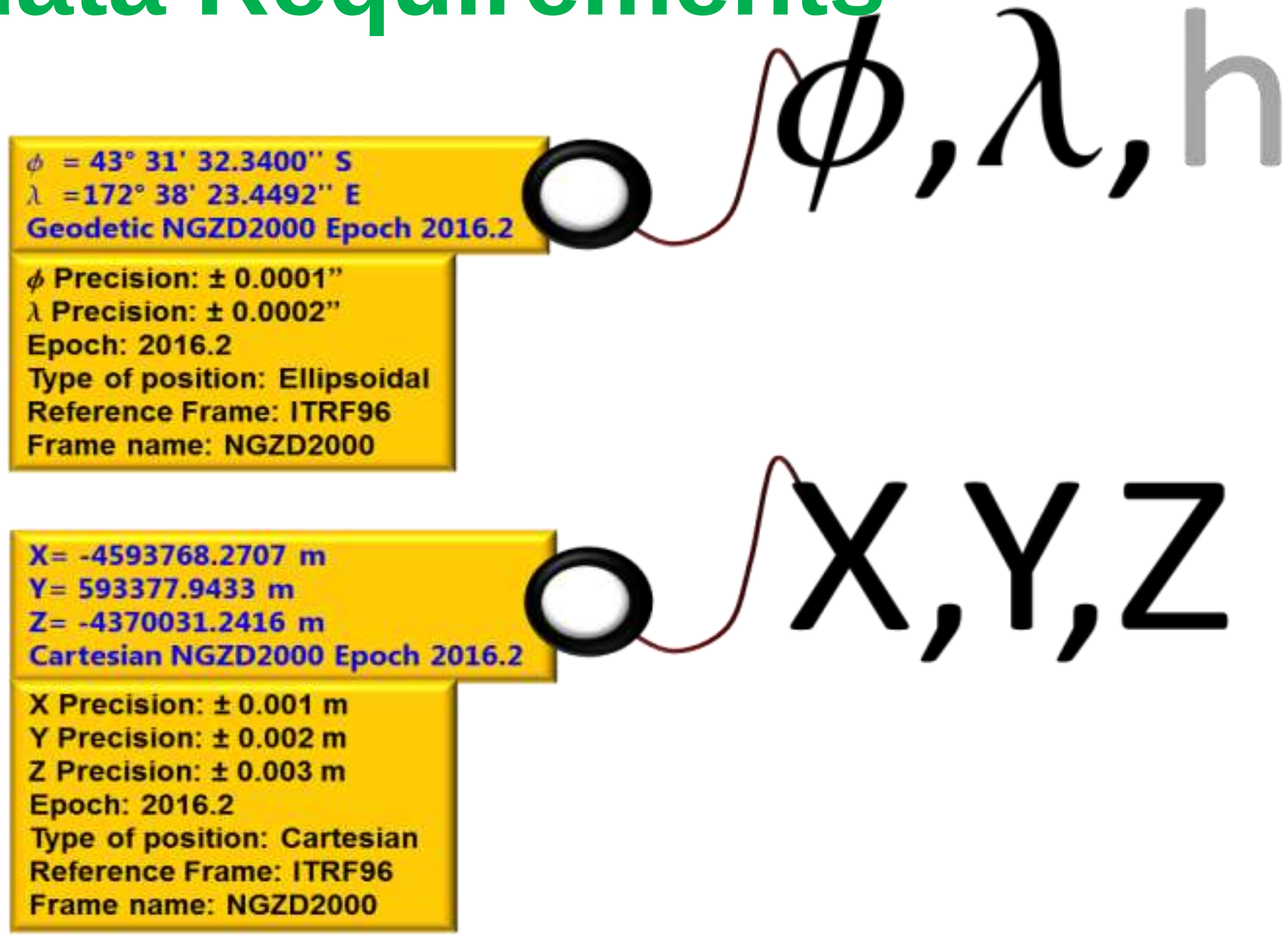
- All these transformations are used while working with GIS
- The main consideration is the alignment of precise data, defined in different RFs and **projections**.
- Geodetic Registries (EPSG and ISO Geodetic Registry) standardize definitions and transformation workflows for use in GIS, however there are still limitations with complex time-dependent RF.
- e.g. No standard for coseismic and postseismic displacement grids and no standardised epoch of WGS 84 when used as a hub transformation.
- Direct interframe transformations are the preferred option.

GIS transformations

Hub method not recommended for time-dependent tranformations



GIS Metadata Requirements



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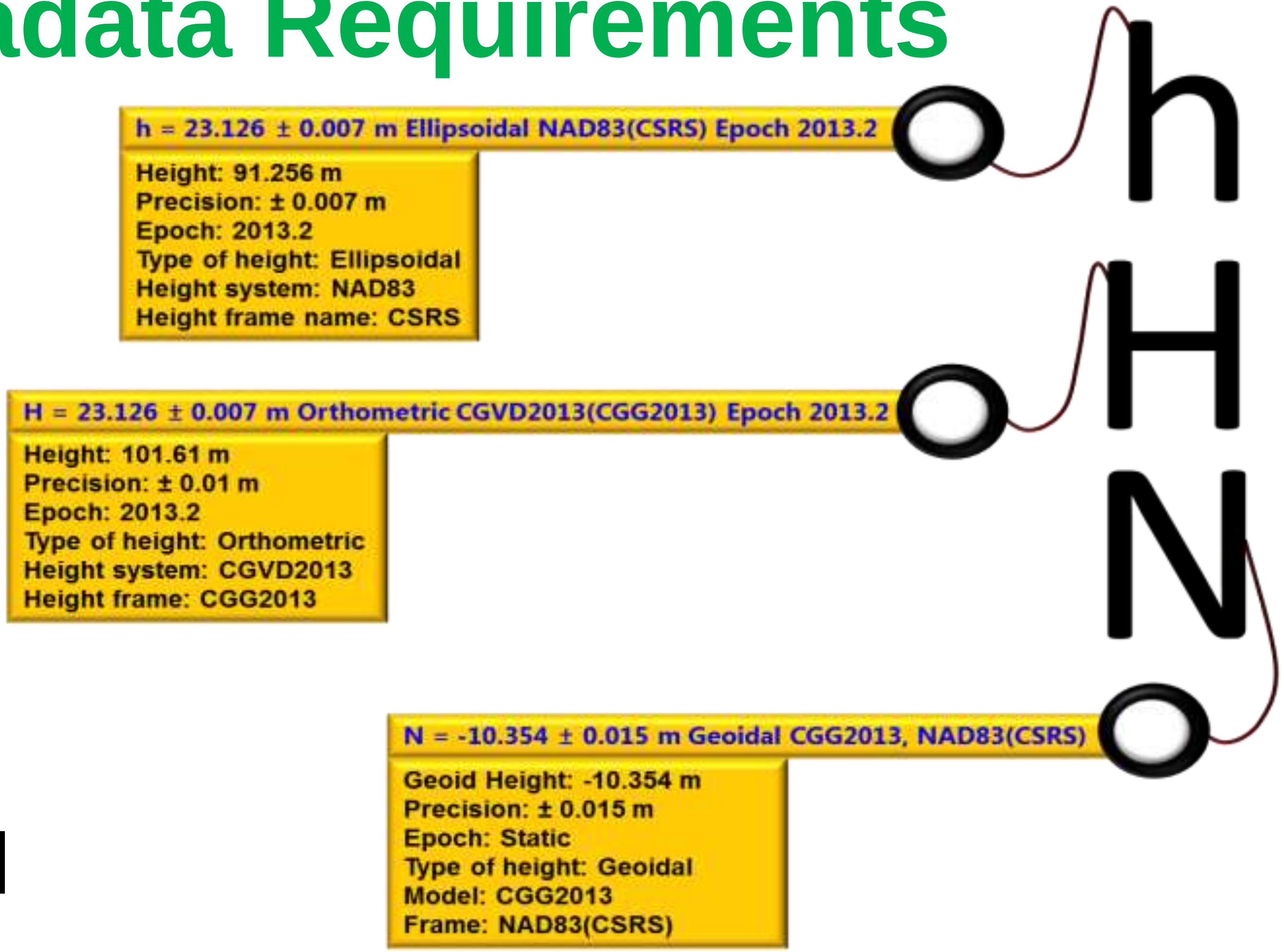

$$H = h - N$$

Thank you!
Gracias!