KINEMATIC DEFORMATION MODELING

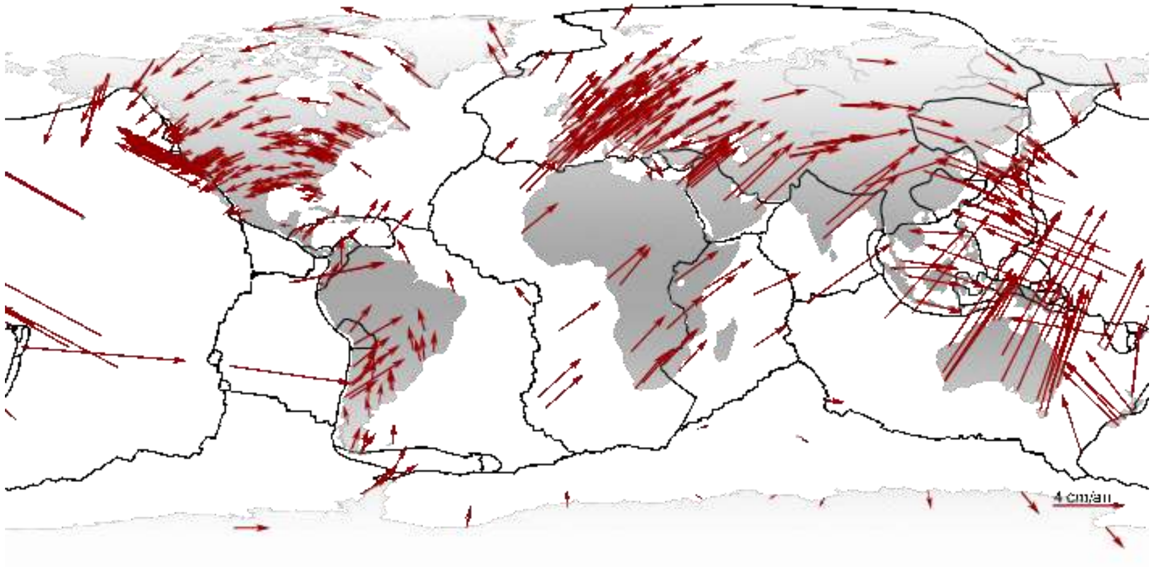
Ms. Ing. Mara A. Figueroa[1]
Dr. Demián D. Gómez[1,2]
Ms. Ing. Franco S. Sobrero[1]
Dr. Robert Smalley, Jr.[3]
Dr. Michael G. Bevis[1]
Dr. Dana J. Caccamise II[4]
Dr. Eric Kendrick[1]

1. School of Earth Sciences, The Ohio State University, USA
2. Dirección de Geodesia, Instituto Geográfico Nacional, Argentina
3. Center for Earthquake Research and Information, The University of Memphis, USA
4. National Geodetic Survey, National Oceanic and Atmospheric Administration, USA

Santiago, Chile 10-11 Nov 2022

INTRODUCTION (1)

- GNSS allows us to obtain coordinates with a millimeter-level precision.
- These coordinates are expressed in a highly stable Reference Frame.
- The global frame is sensible to velocities, interactions between tectonic plates and other geodynamic effects => these effects should be taken into account.

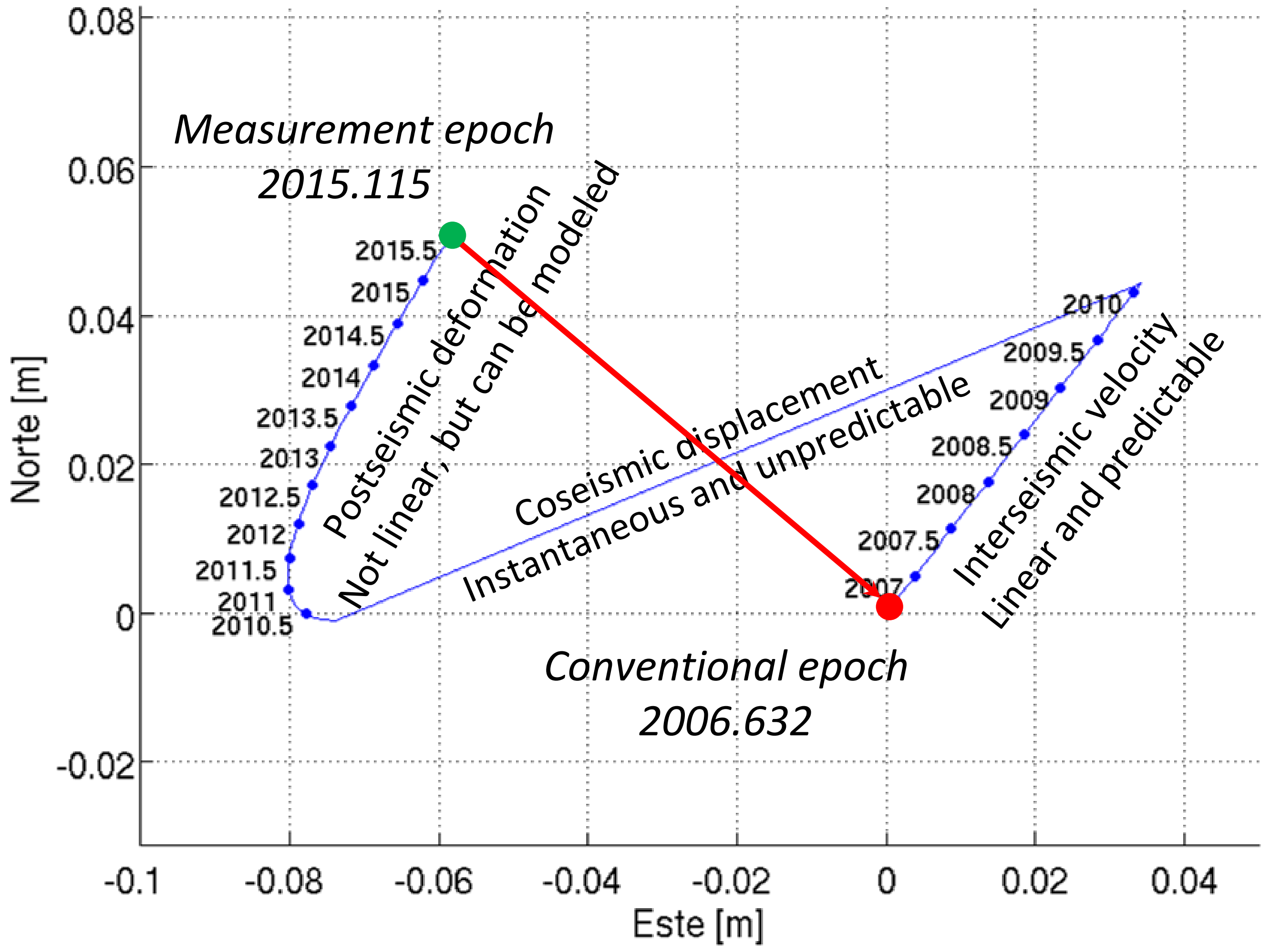


http://gnss.be/systems_tutorial.php

INTRODUCTION (2)

- POSGAR07 is the official reference frame of Argentina, which is based on ITRF2005 (conventional epoch 2006.632).
- Realized and maintained using RAMSAC.

Reference Frames in Practice

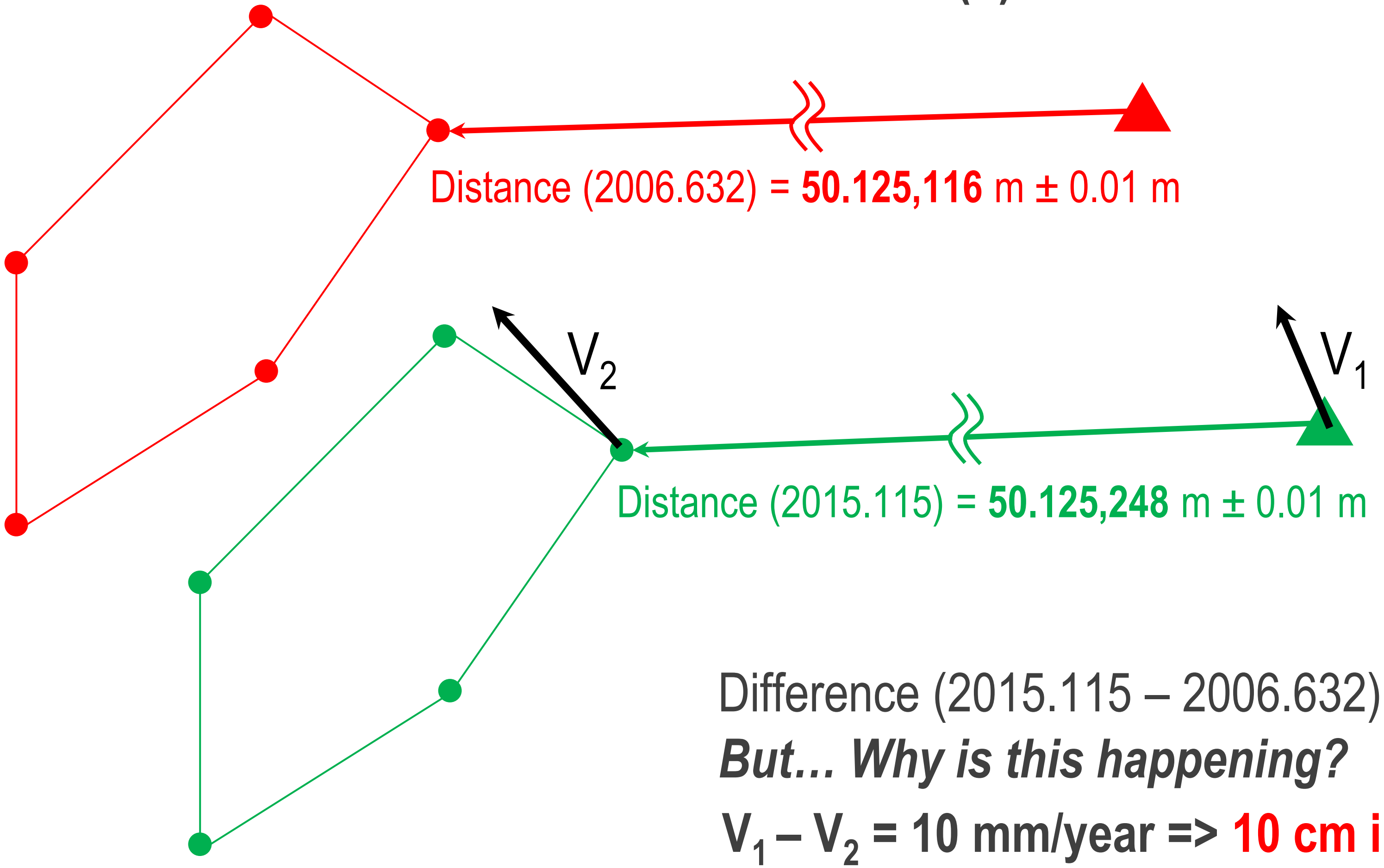


HOW DOES THIS AFFECT SURVEYORS? (1)

~50 km

Continuous GNSS station

HOW DOES THIS AFFECT SURVEYORS? (2)

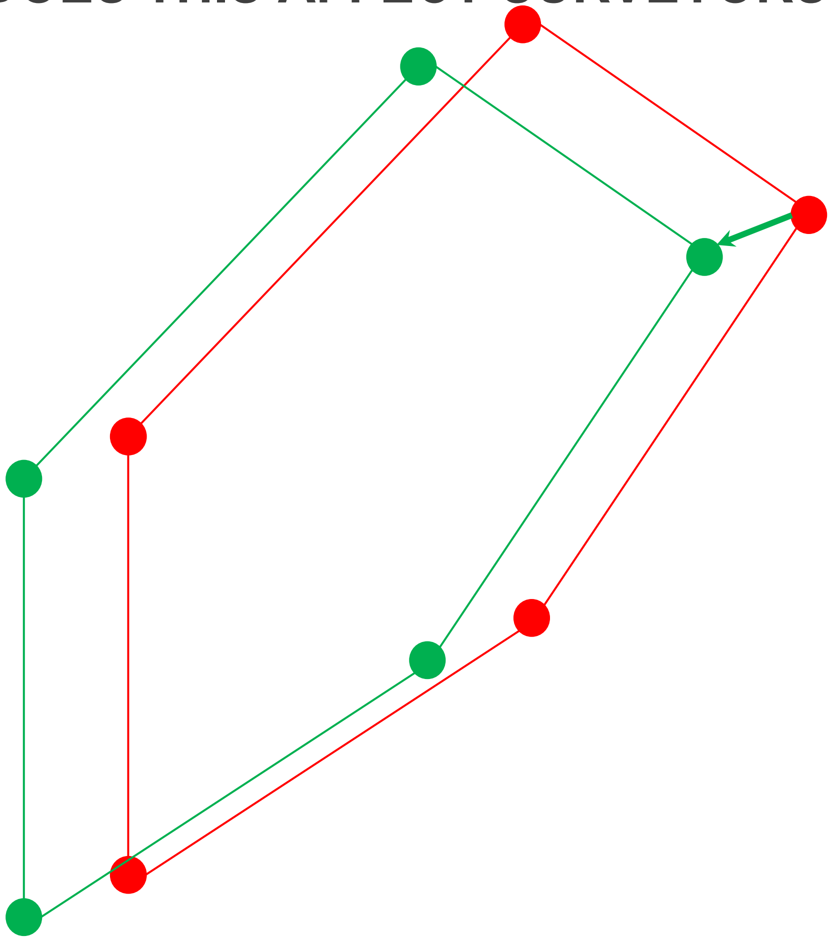


Difference (2015.115 – 2006.632): **0.132** m

But… Why is this happening?

$V_1 - V_2$ = 10 mm/year => 10 cm in 10 years

HOW DOES THIS AFFECT SURVEYORS? (3)

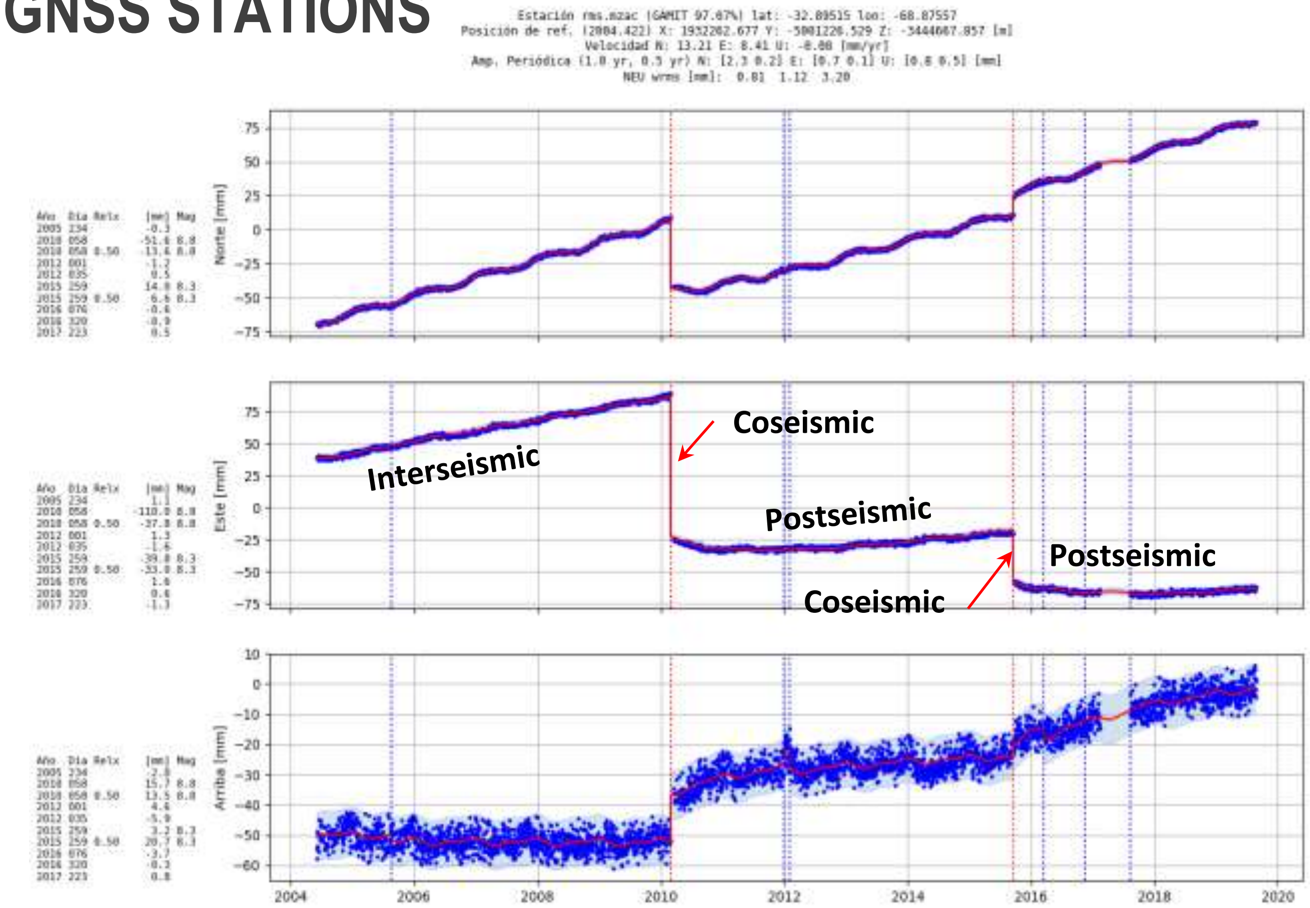


0.132 m

This effect is ***predictable***. Therefore, it is possible to reduce the difference by utilizing a model.

We need to find $\mathbf{V_1}$ and $\mathbf{V_2}$!

V_1 : CONTINUOUS GNSS STATIONS



EXTENDED TRAJECTORY MODEL (ETM)

- Methodology to model all components observed in time series.

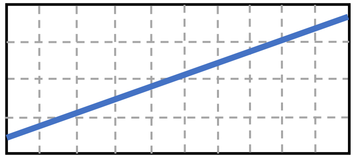
- **ADVANTAGES:**

1) Produces trajectory models that predict station position for longer periods of time.
2) Shares the constant velocity model base.

- **DISADVANTAGE:** Some of the modeled components are not orthogonal, so there might be leakage from one component into another.

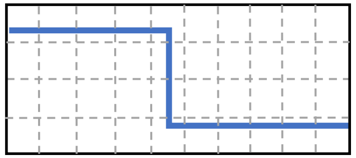
COMPONENTS MODELED WITH THE ETM

$$\sum_{i=1}^{n_p+1} \mathbf{p}_i (t - t_R)^{i-1}$$



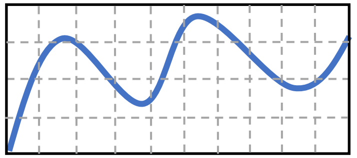
Linear: plate tectonics

$$\sum_{j=1}^{n_j} \mathbf{b}_j H(t - t_j)$$



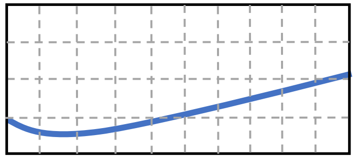
Jumps: earthquakes, equipment replacement

$$\sum_{k=1}^{n_F} [\mathbf{s}_k \sin(\omega_k t) + \mathbf{c}_k \cos(\omega_k t)]$$



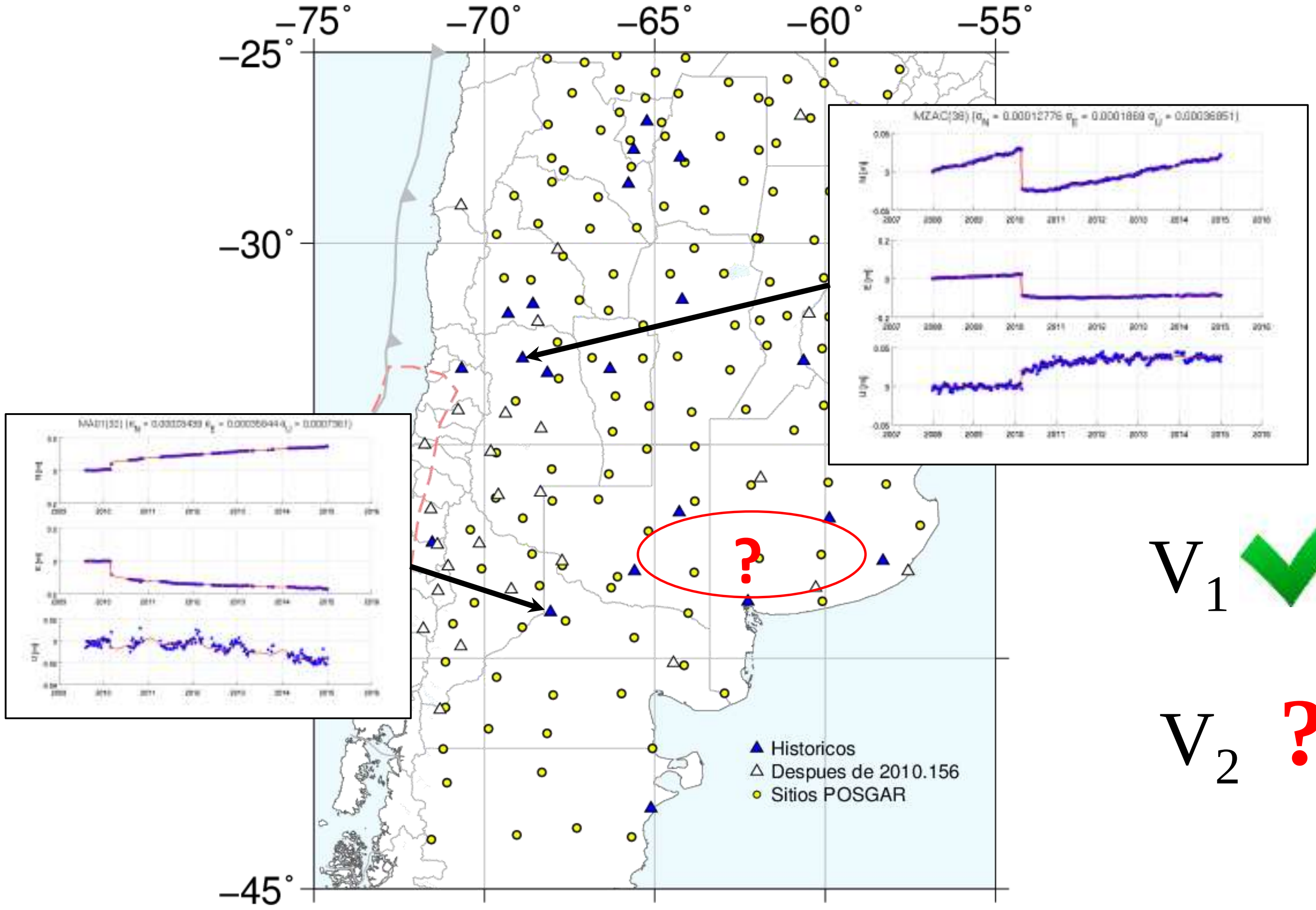
Periodic: annual, semi-annual

$$\sum_{i=1}^{n_T} \mathbf{a}_i \log[1 + (t - t_{EQ})/T_i]$$



Logarithms: viscoelastic relaxation

Reference Frames in Practice



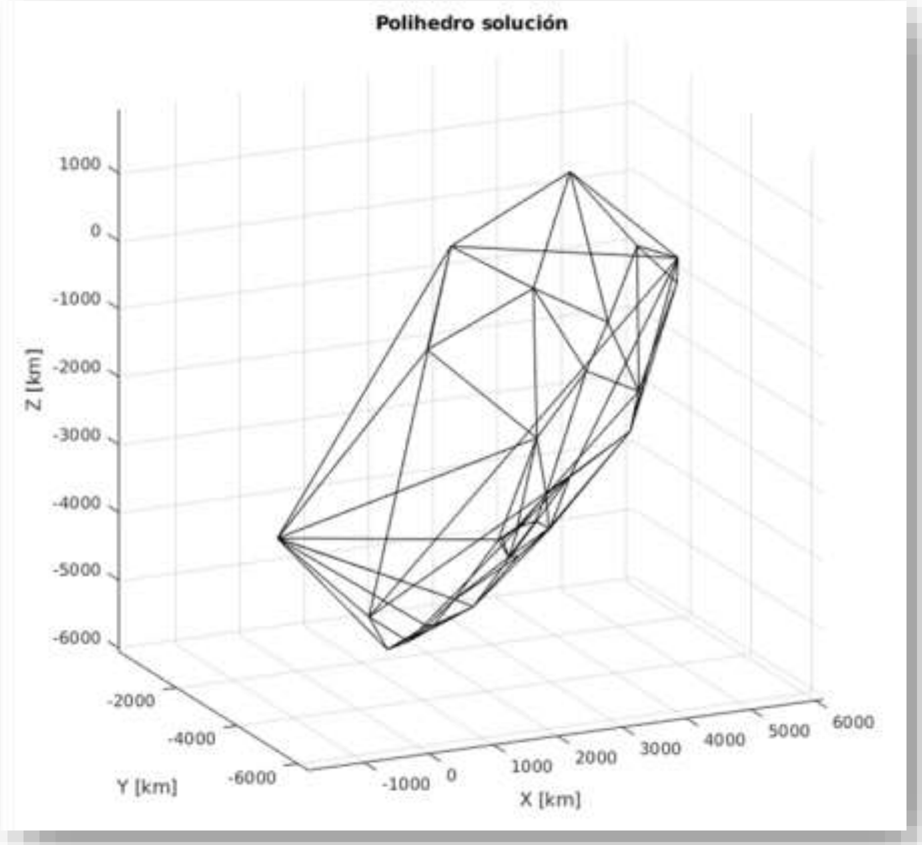
V_1 ✓

V_2 ?

Instead of finding V_2, could we use a **HELMERT TRANSFORMATION** to transform from the measurement epoch to the conventional epoch?

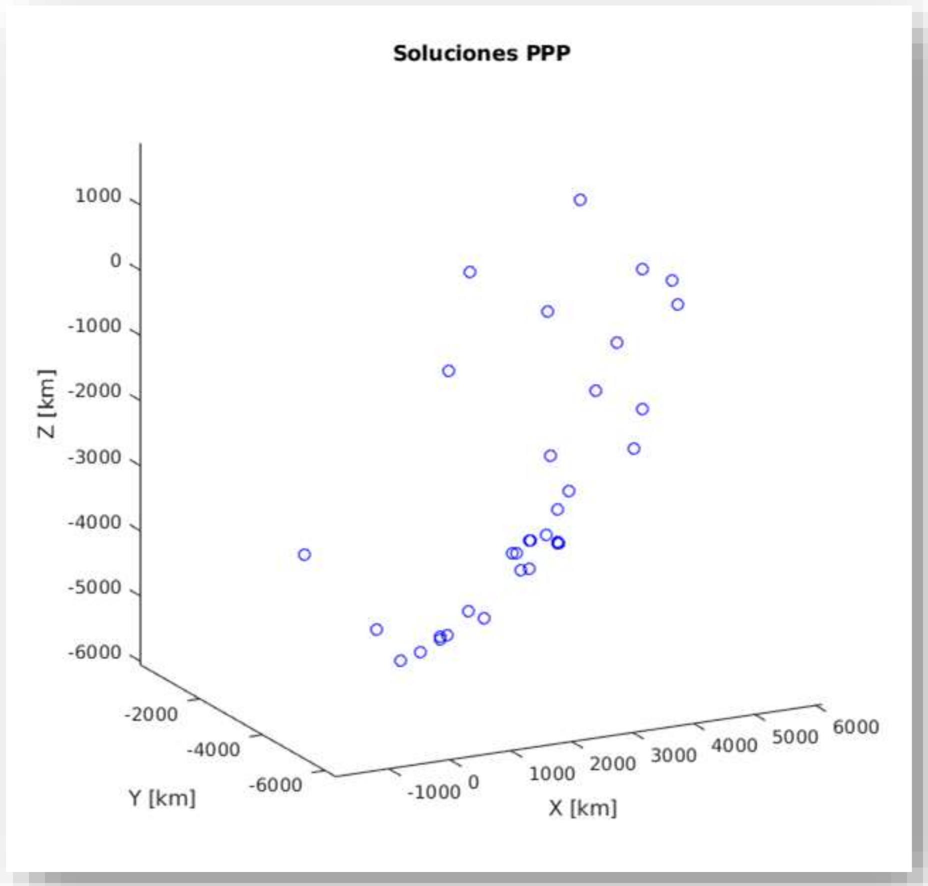
INNER GEOMETRY

- Geometric figure (in this case it is tridimensional) with arbitrary position and orientation.
- The information is in the ΔX, ΔY, ΔZ between the vertices.
- It could have an arbitrary scale => $\alpha(\Delta X, \Delta Y, \Delta Z)$



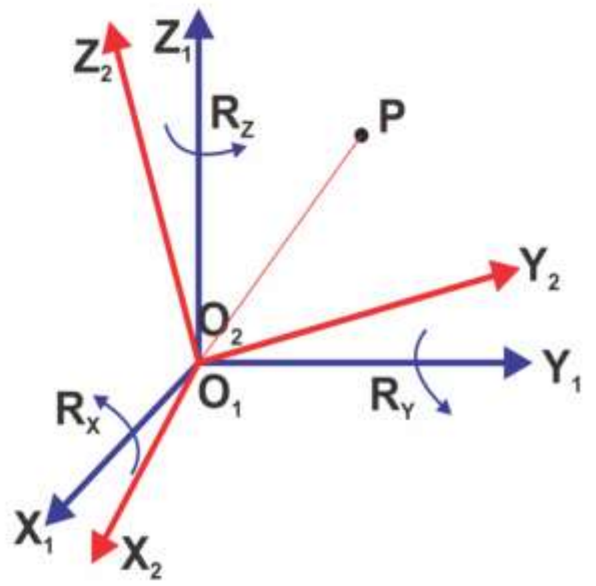
OUTER GEOMETRY

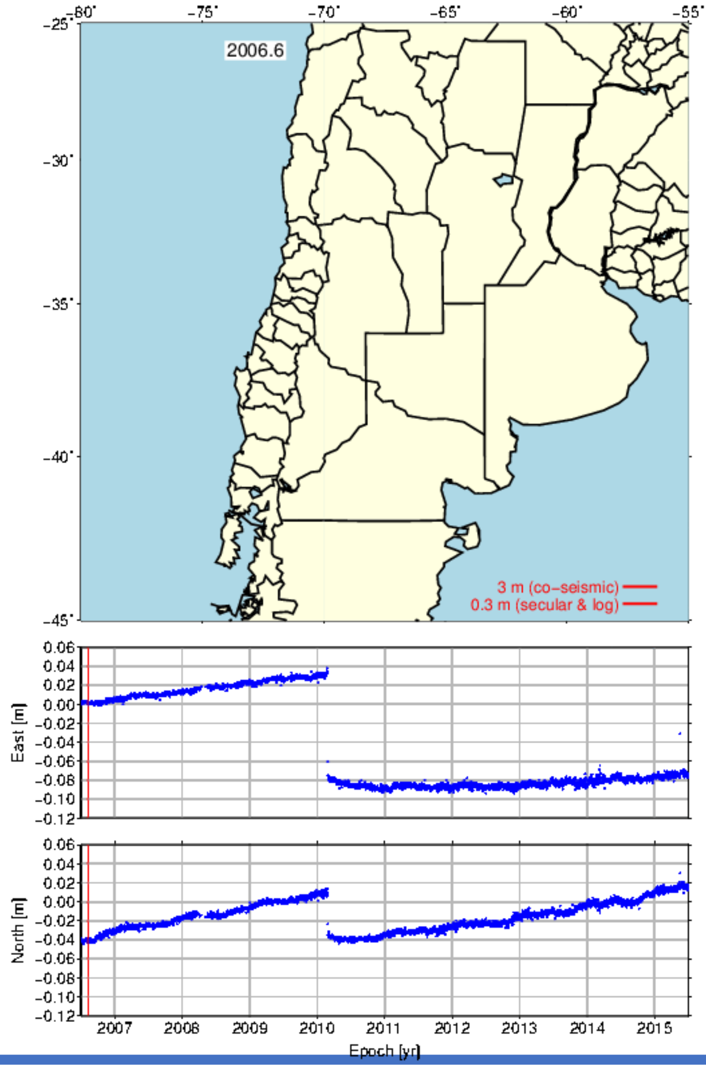
- The X, Y, and Z coordinates of the vertices of the polyhedron, which are given in a specific reference frame.



HELMERT TRANSFORMATION

- Transformation of 7 parameters (or 6, if we do not consider the scale factor):
- Translation from the origin (TX,TY,TZ)
- Rotations around axes (RX,RY,RZ)
- Scale factor (1+μ)

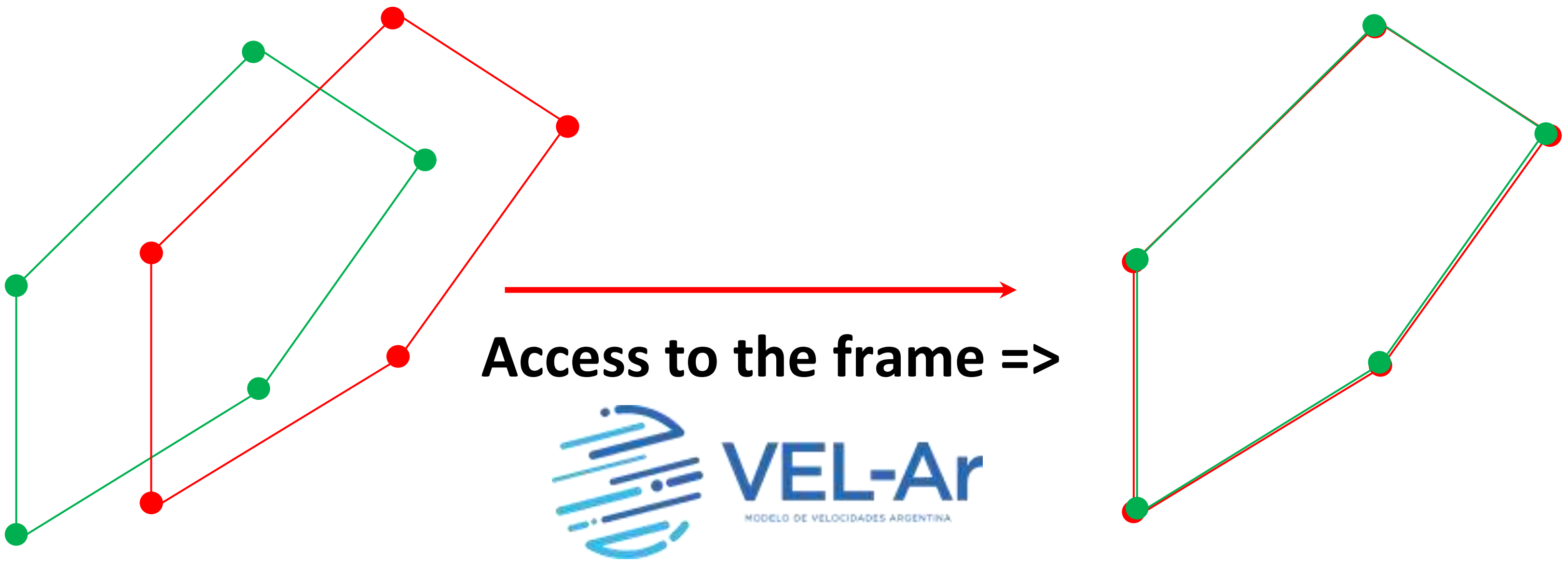



2006.6
3 m (co−seismic)
0.3 m (secular & log)
East [m]
North [m]
Epoch [yr]

The **HELMERT TRANSFORMATION** is a rigid-body transformation. Therefore, it is not possible to apply it if there was **INNER DEFORMATION.**

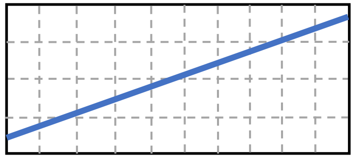
SOLUTION TO THE PROBLEM

- A **Trajectory Prediction Model, continuous in space and time,** that allows us to predict the behavior of passive benchmarks.
- This model ensures the access to a geodetic reference frame after big earthquakes utilizing postseismic coordinates.



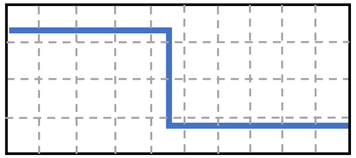
COMPONENTS MODELED WITH THE ETM

$$\sum_{i=1}^{n_p+1} \mathbf{p}_i (t - t_R)^{i-1}$$



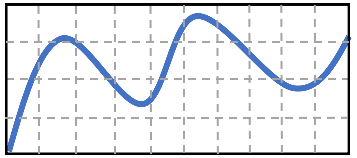
Linear: plate tectonics

$$\sum_{j=1}^{n_j} \mathbf{b}_j H(t - t_j)$$



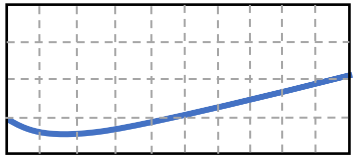
Jumps: earthquakes, equipment replacement

$$\sum_{k=1}^{n_F} [\mathbf{s}_k \sin(\omega_k t) + \mathbf{c}_k \cos(\omega_k t)]$$



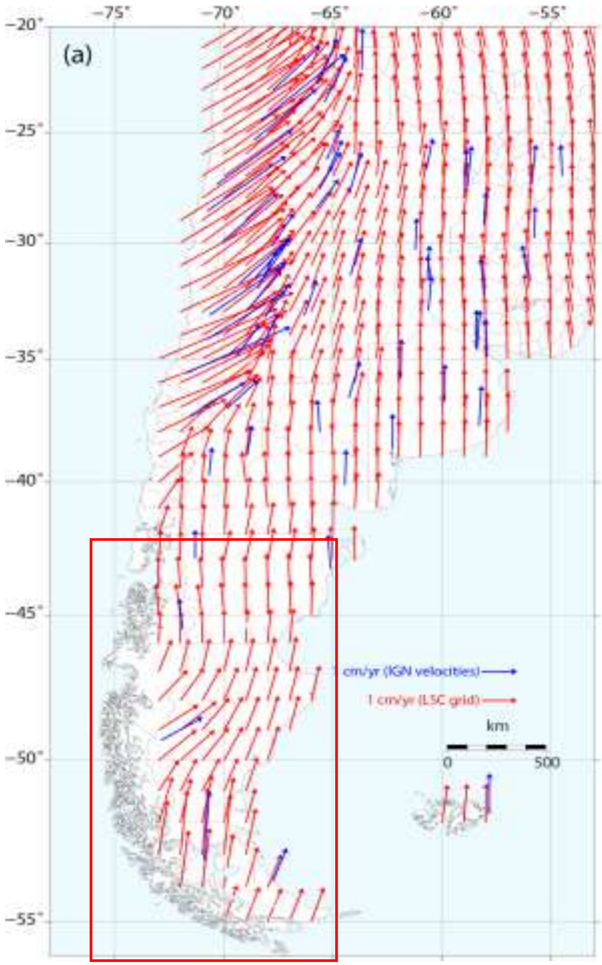
Periodic: annual, semi-annual

$$\sum_{i=1}^{n_T} \mathbf{a}_i \log[1 + (t - t_{EQ}) / T_i]$$

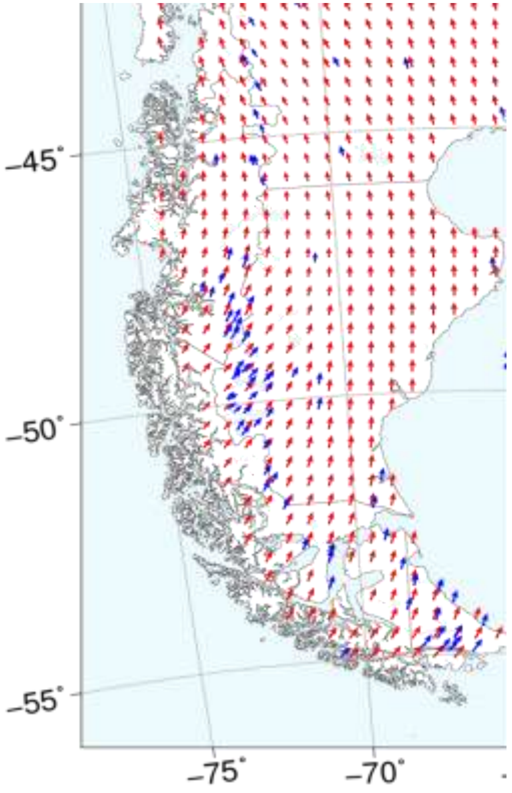


Logarithms: viscoelastic relaxation

INTERSEISMIC COMPONENT

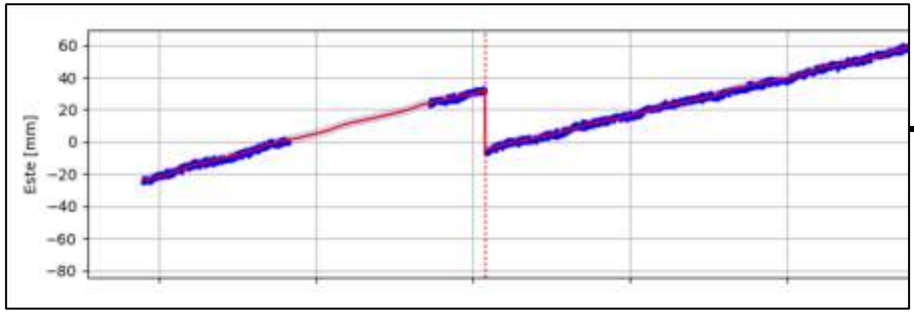


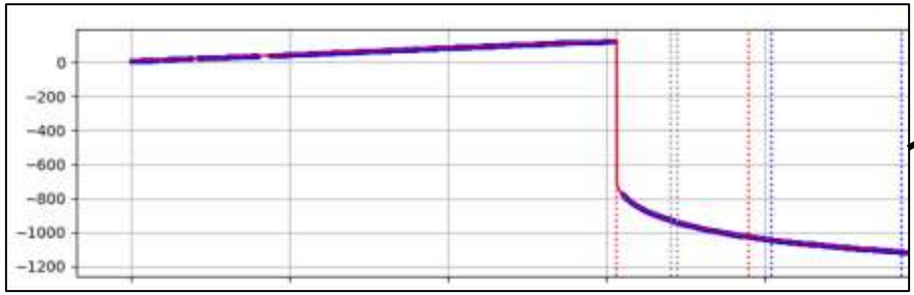
2015 Version

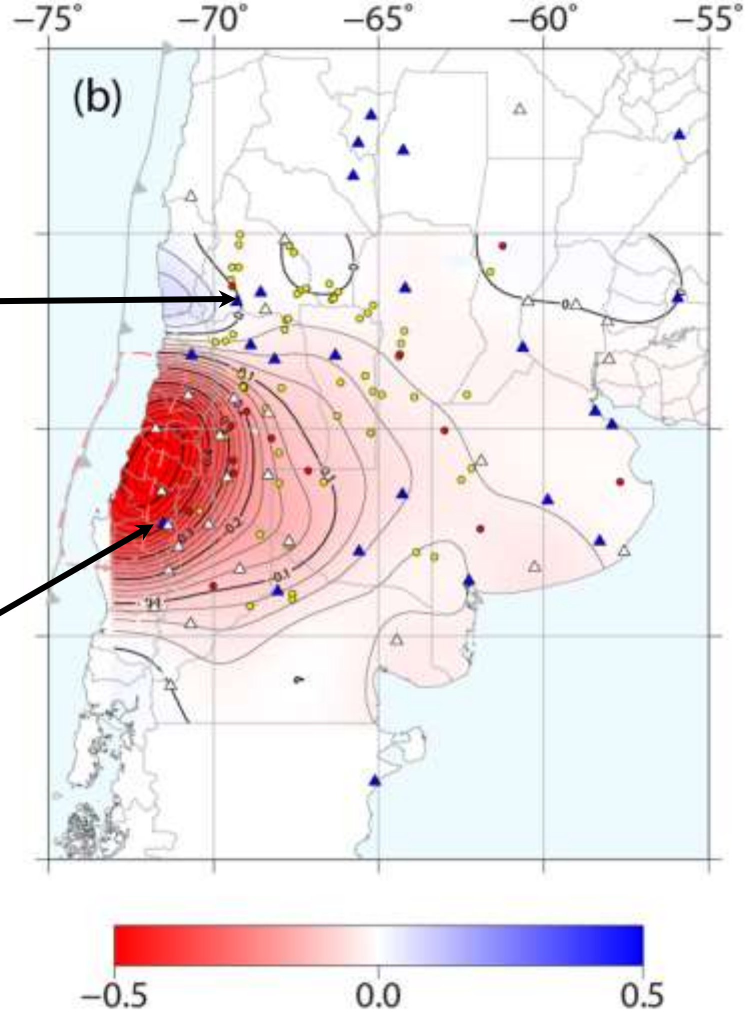


2020 Version
+ Campaign data
+ Grid density

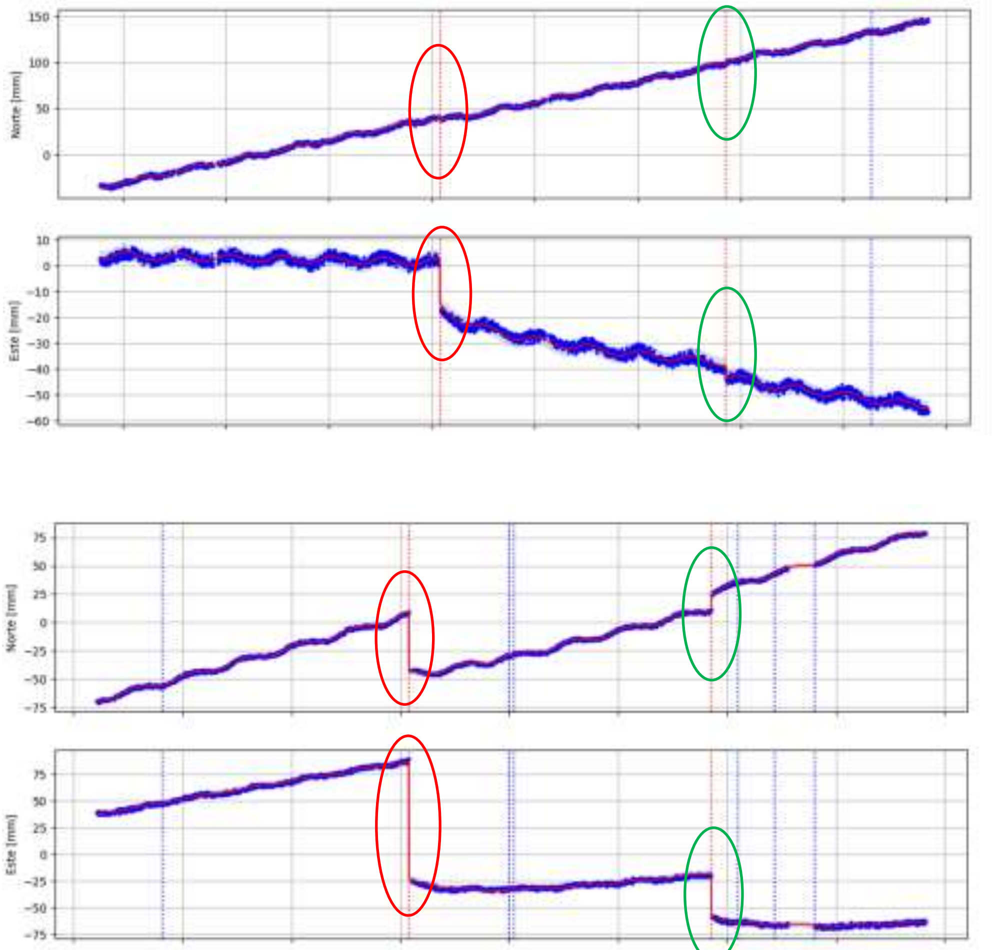
POSTSEISMIC COMPONENT







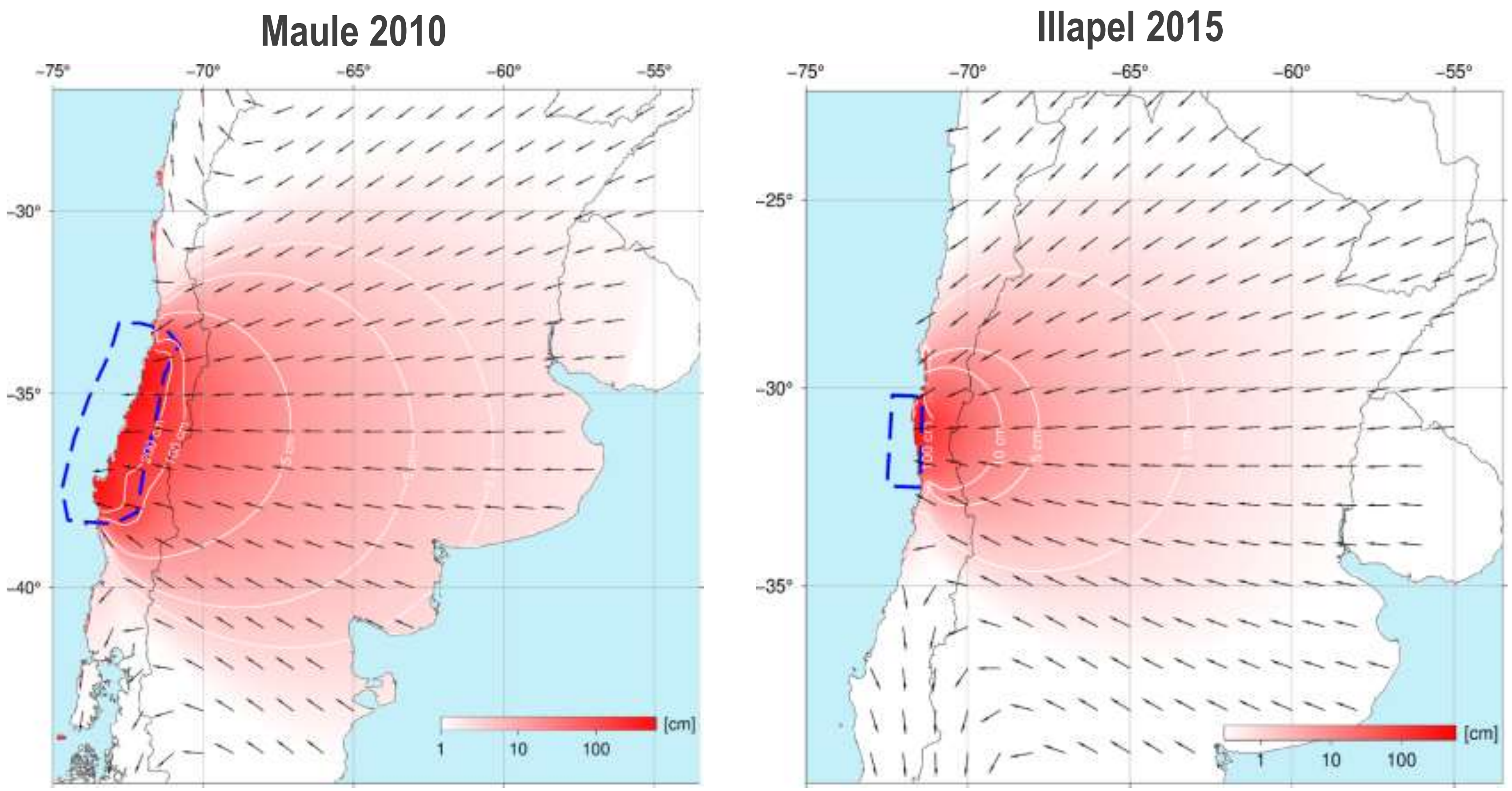
COSEISMIC COMPONENT



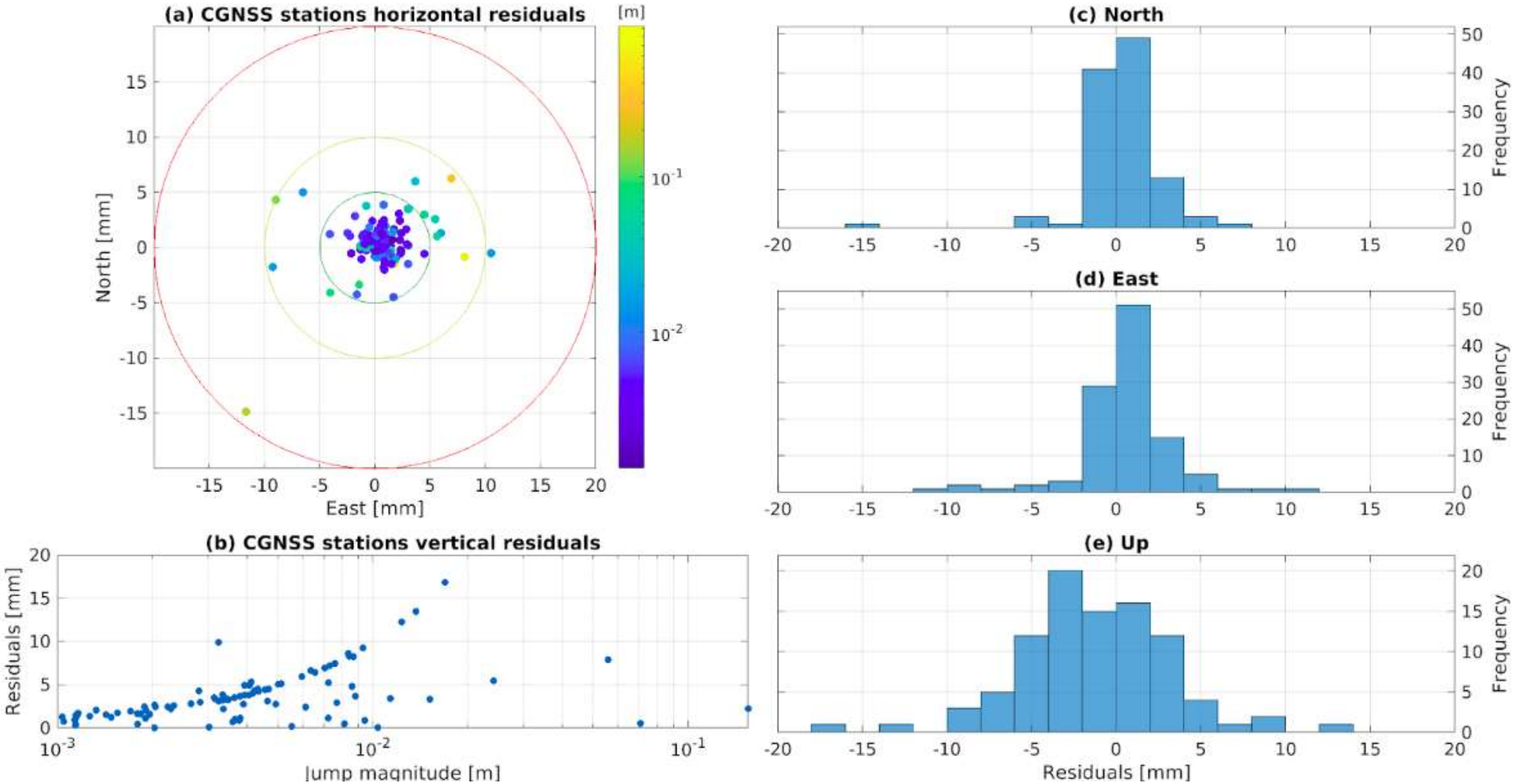
VEL-Ar 2015 Version: Maule (2010)

VEL-Ar 2020 Version: Illapel (2015)

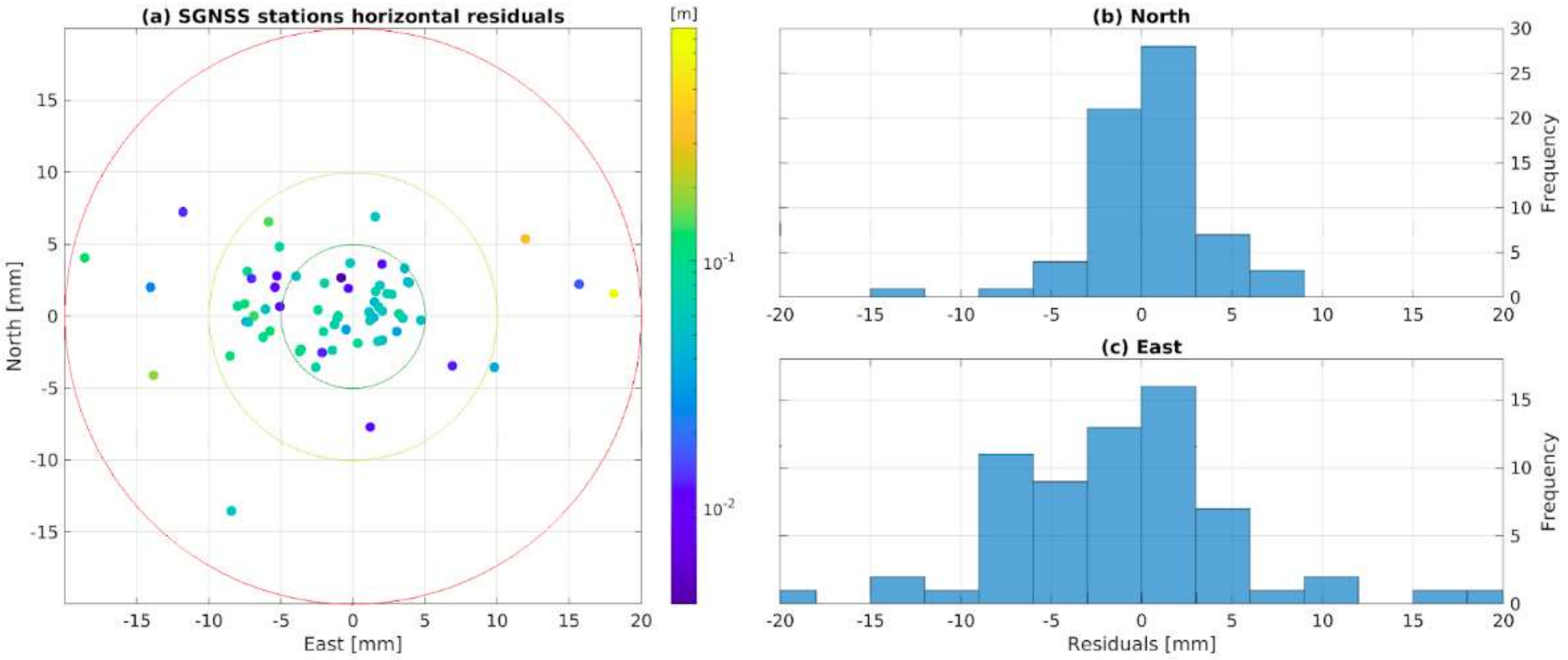
COSEISMIC COMPONENT



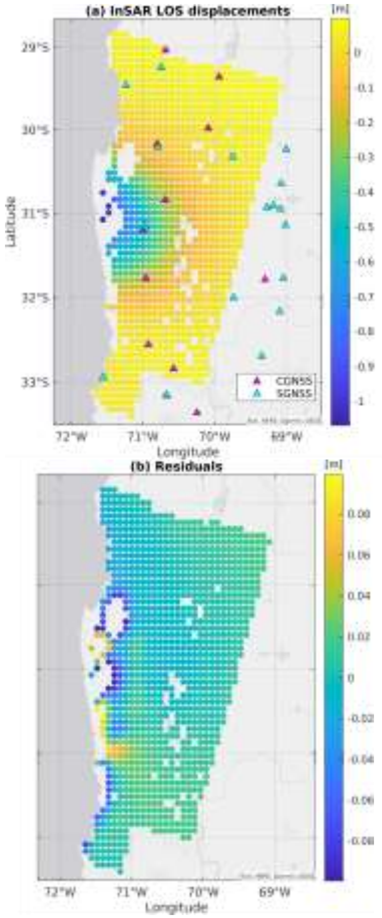
PREDICTION CAPACITY OF THE ILLAPEL MODEL (CGNSS)

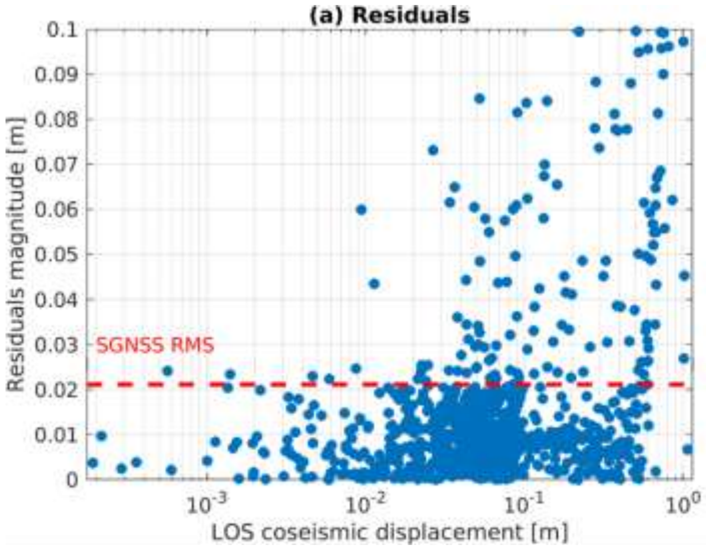


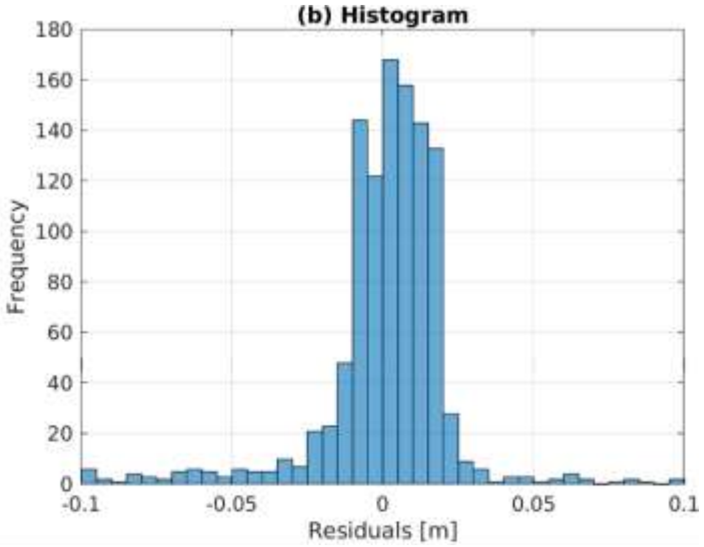
PREDICTION CAPACITY OF THE ILLAPEL MODEL (SGNSS)



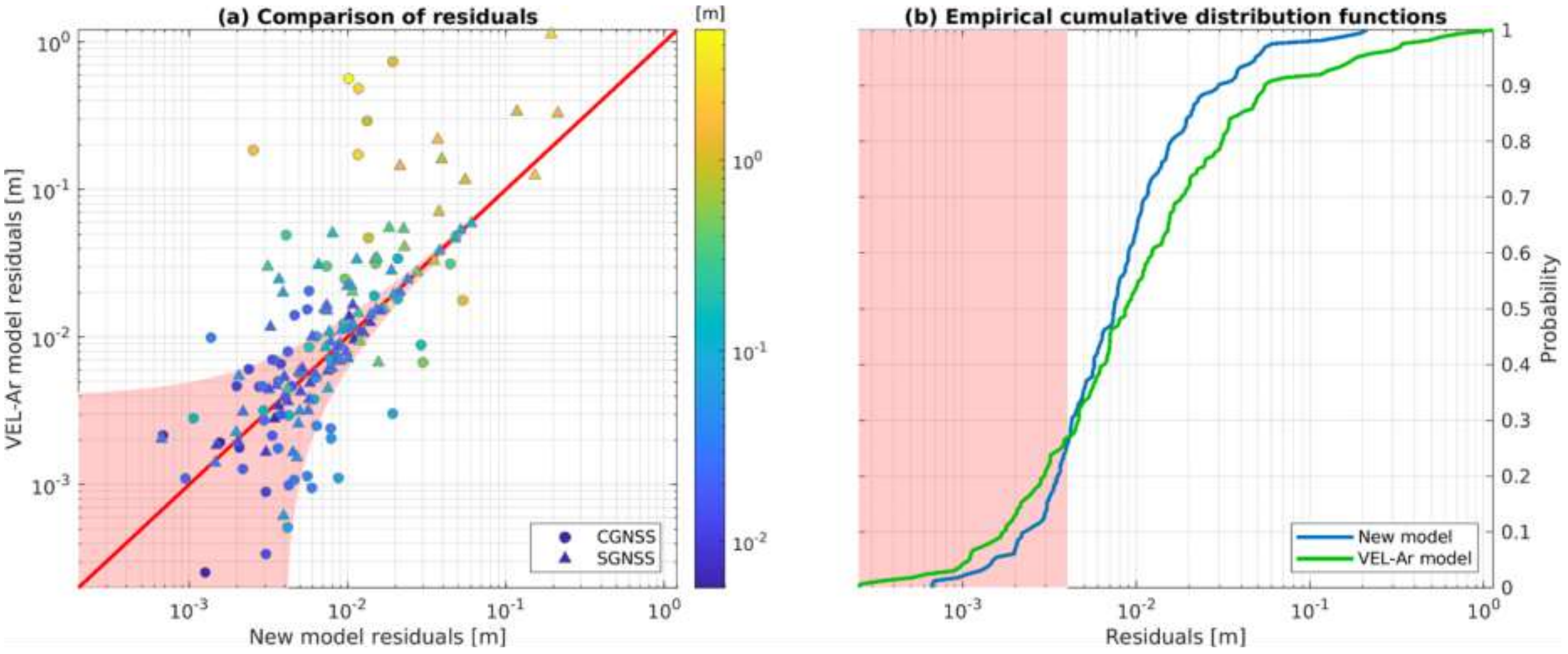
PREDICTION CAPACITY OF THE ILLAPEL MODEL (InSAR)







COMPARISON OF NEW MAULE COSEISMIC MODEL VS. PREVIOUS VERSION IN VEL-Ar



SERVICES BASED ON VEL-Ar

CONCLUSIONS

- Extended trajectory models ensure a more precise model of GNSS time series.
- It is possible to extend the use of ETMs to produce a Trajectory Prediction Model.
- VEL-Ar ensures the access to the official reference frame of Argentina utilizing postseismic coordinates with an error of < 3 cm (~91%).
- We presented the new version of VEL-Ar (2020), which incorporates the Illapel earthquake.

THANK YOU!

Contact: figueroaberroca.1@osu.edu

VEL-Ar publications:

Gómez DD, Piñón DA, Smalley R, et al (2015) Reference frame access under the effects of great earthquakes: a least squares collocation approach for non-secular post-seismic evolution. J Geod. https://doi.org/10.1007/s00190-015-0871-8

Gómez DD, Figueroa MA, Sobrero FS, Smalley R, Bevis MG, Caccamise DJ, Kendrick E. (under review) On the determination of coseismic deformation models to improve access to geodetic reference frame conventional epochs in low-density GNSS networks. J Geod.