THE OHIO STATE UNIVERSITY

SIRGAS
sirgas.ipgh.org

AN EMPIRICAL FORMULATION TO DETERMINE AN EARTHQUAKE'S AREA OF INFLUENCE FOR GNSS TRAJECTORY MODELING

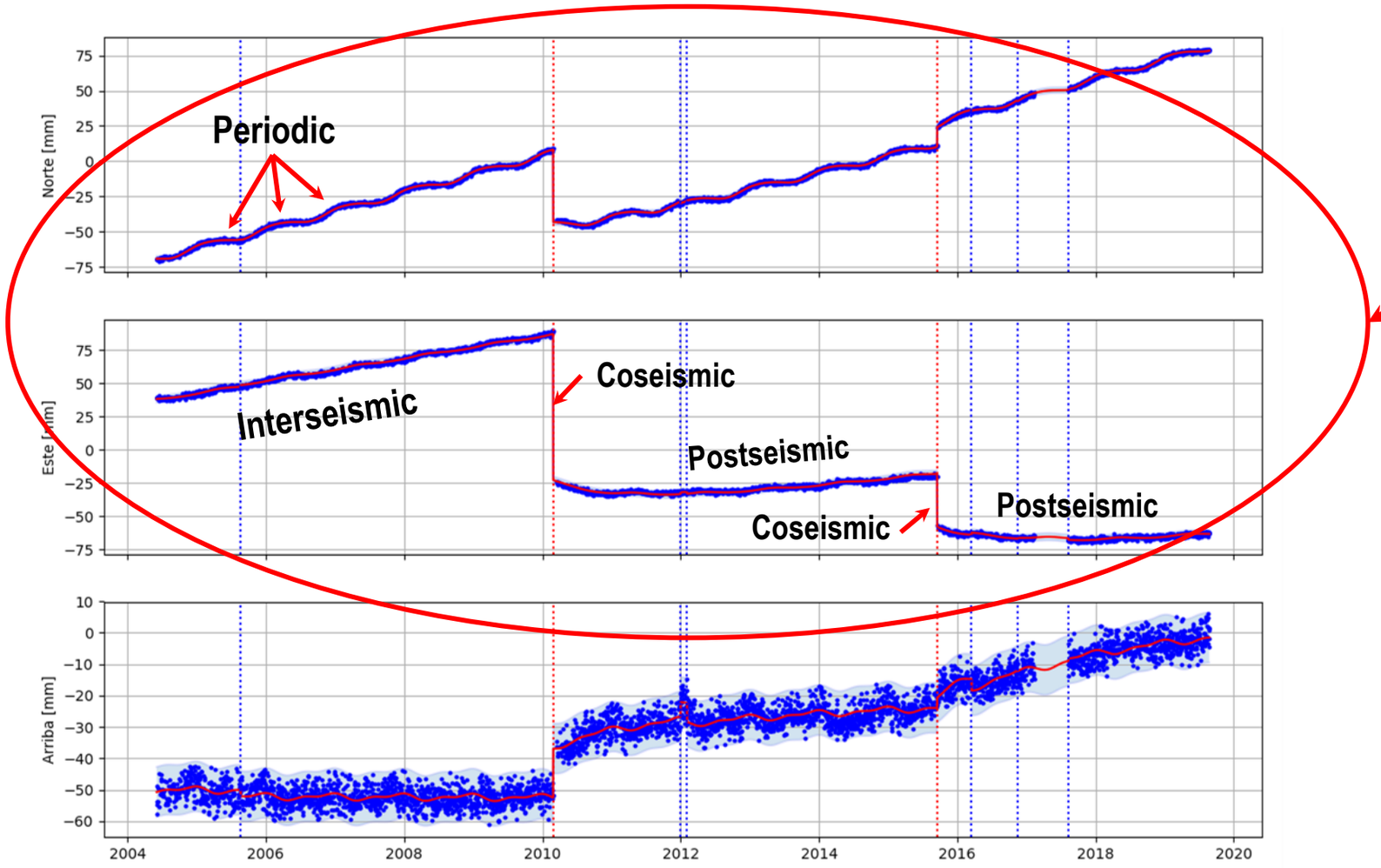
Mara A. Figueroa, Demián D. Gómez, Michael G. Bevis, Dana J. Caccamise II, W. Ashley Griffith, Jacob M. Heck, Robert Smalley Jr.

IAG
INSTITUTO PANAMERICANO DE GEOGRAFÍA E HISTORIA OEA
IGAC INSTITUTO GEOGRÁFICO AGUSTÍN CODAZZI
SERVICIO GEOLÓGICO COLOMBIANO
SIRGAS sirgas.ipgh.org

PRESENTATION OUTLINE

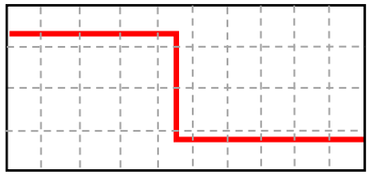
- Introduction
- Level 1 S-score
- Level 2 S-score
- Results
- Conclusions and Future work

COSEISMIC DISPLACEMENTS IN GNSS



Extended Trajectory Model (ETM)

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



Jumps: earthquakes, equipment replacement

Bevis & Brown, 2014

INTRODUCTION

Unmodeled offsets

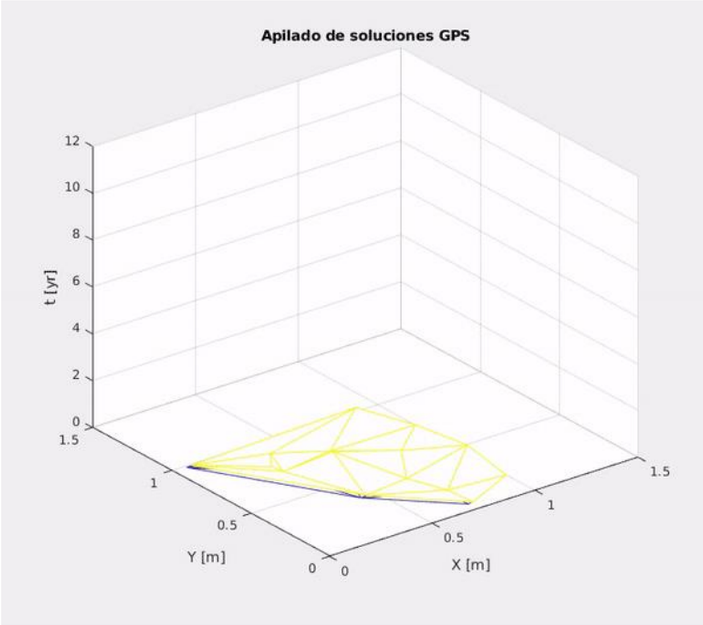
BIASED ETM

GNSS solutions

Stacked and aligned

ERRORS

Reference Frame realization

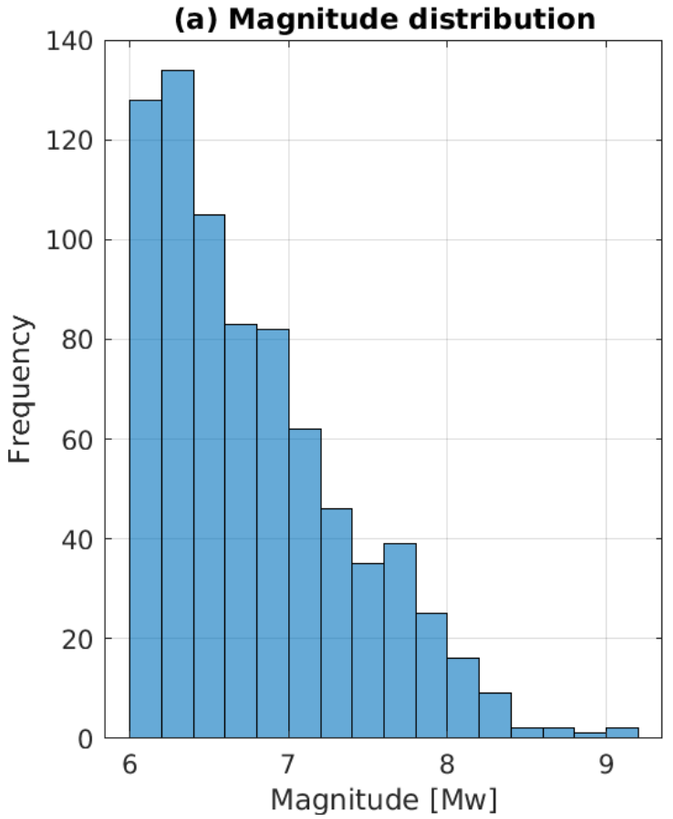


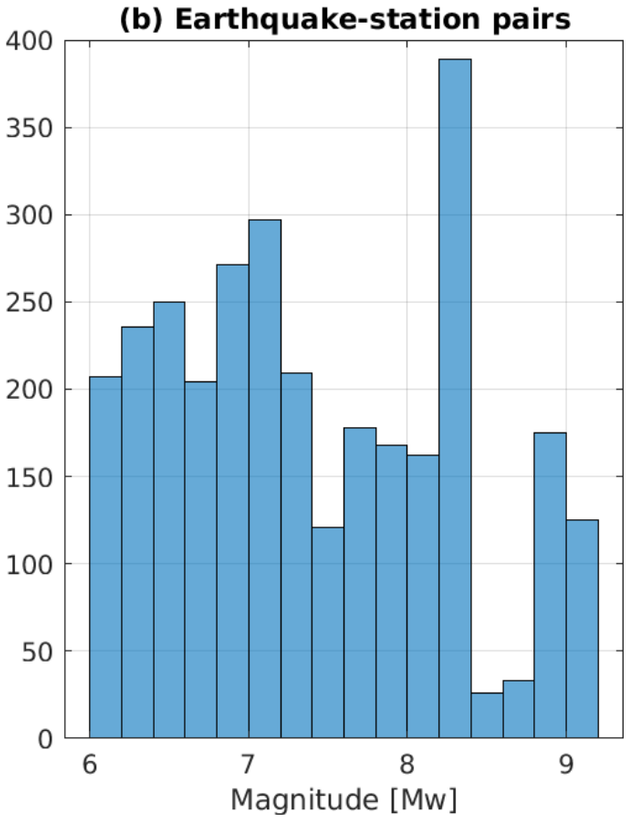
INTRODUCTION

- ~20,000 continuous GNSS stations in the world (~6,000 in OSU archive)
- +5,100 Mw ≥ 6.0 earthquakes since 1990
- ~4,700 earthquake-GNSS station pairs analyzed in this study

- Reviewing thousands of GNSS time series for displacements is impractical
- Conservative predictive models often overestimate the earthquake influence zone, leading to unnecessary corrections

- **Automation and unsupervised algorithms are required**





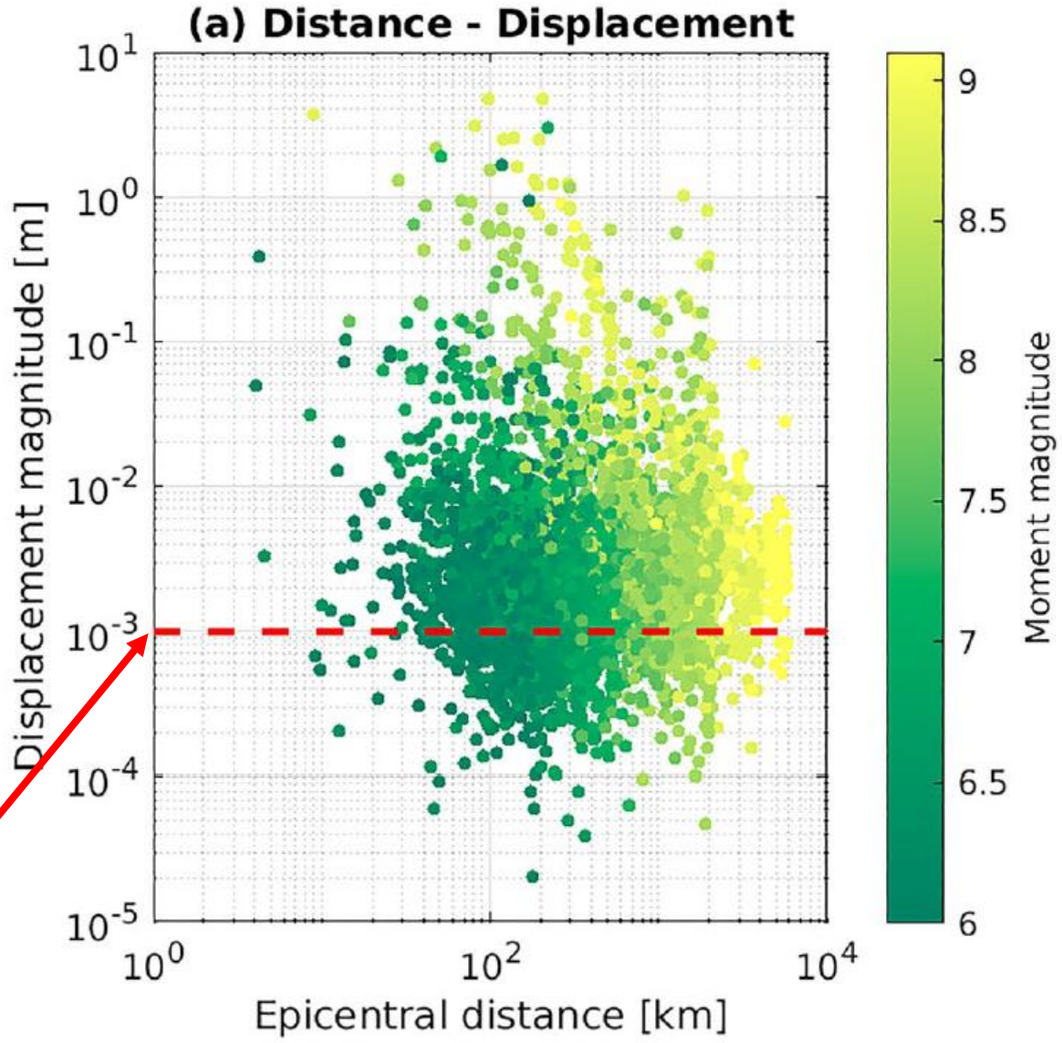
NGL POWER-LAW

Maximum earthquake epicentral distance below which trajectory models of GNSS stations require the incorporation of co- and postseismic parameters

$$d_{max} = 10^{(a \cdot M_w + b)}$$

$$a = 0.5$$
$$\mathrm{b} = -0.79$$

Lower observable displacement limit of 1 mm, slightly below an optimistic noise floor for GNSS data



LEVEL 1 S-score

$$\log_{10}(d_{max}) = a \cdot M_w + \mathrm{b}$$

$$a = 0.526$$
$$\mathrm{b} = -1.148$$

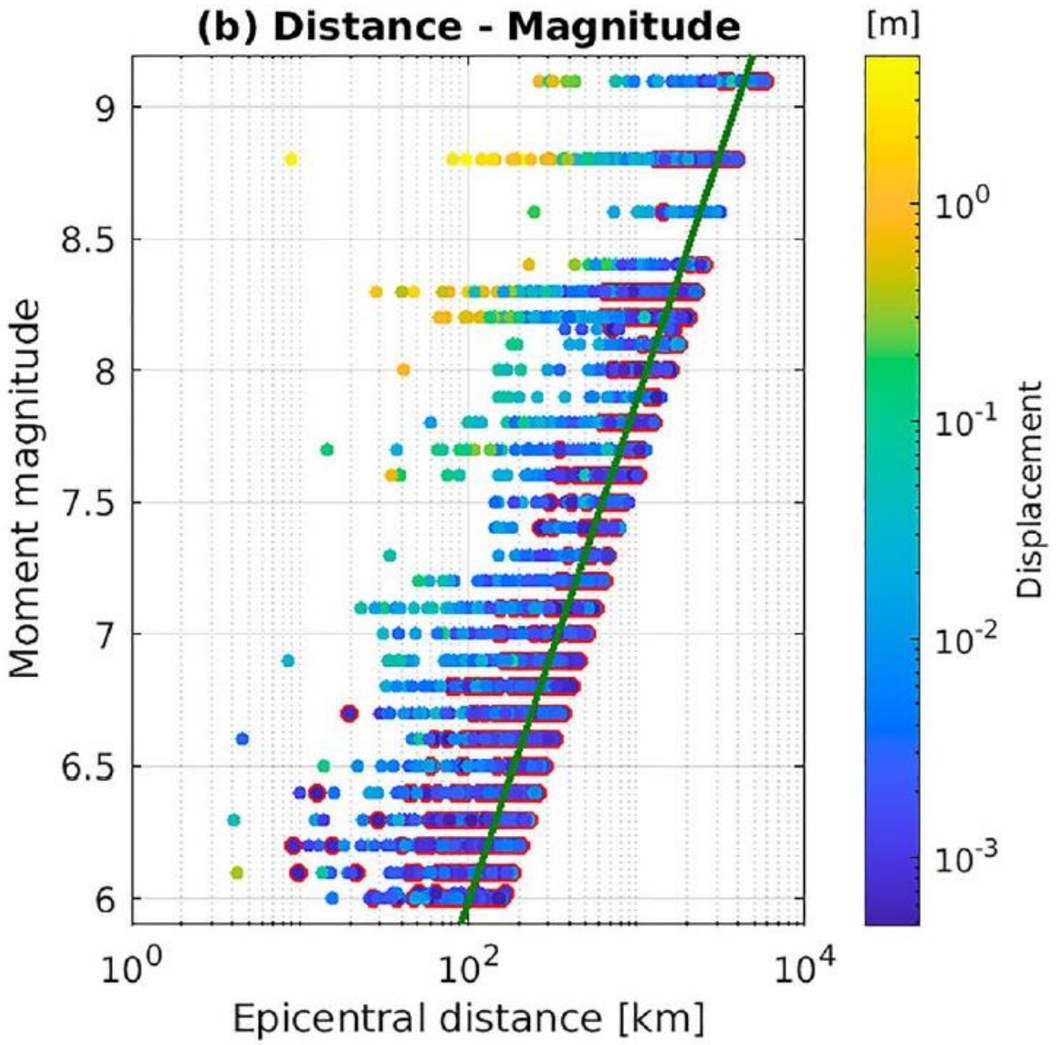
$$0 = 0.526 \cdot M_w - \log_{10}(d_{max}) - 1.148$$

$$\mathrm{S} = 0.526 \cdot M_w - \log_{10}(d) - 1.148$$

$\mathrm{S} > 0 \rightarrow$ include co- and postseismic components

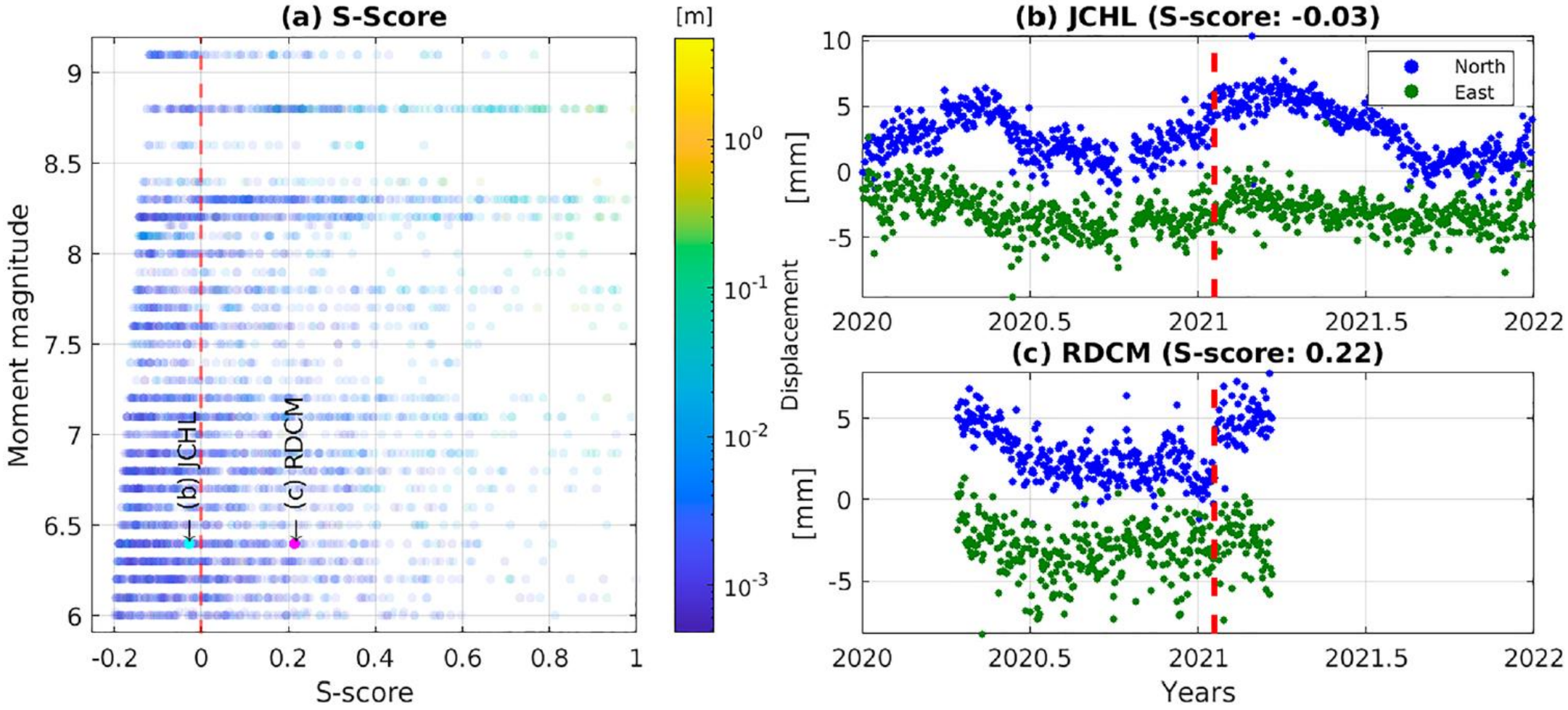
$\mathrm{S} \leq 0 \rightarrow$ don't include co- and postseismic components

It does not account for the earthquake's surface displacement field pattern



LEVEL 1 S-score

EXAMPLE: Mw 6.4 Jan 18, 2021, San Juan, Argentina



LEVEL 2 S-score

USGS NEIC database

Hypocenter location (epicenter + depth)

Focal mechanism data (strike, dip and rake)

Magnitude (Mw)

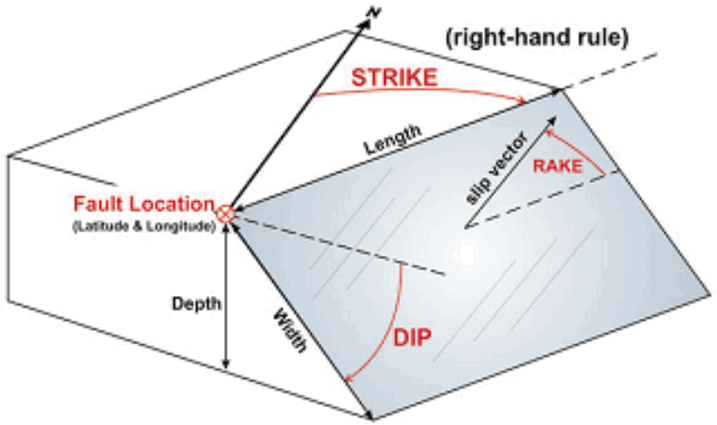
Down-dip length [km]

Along-strike length [km]

Average slip magnitude (m)

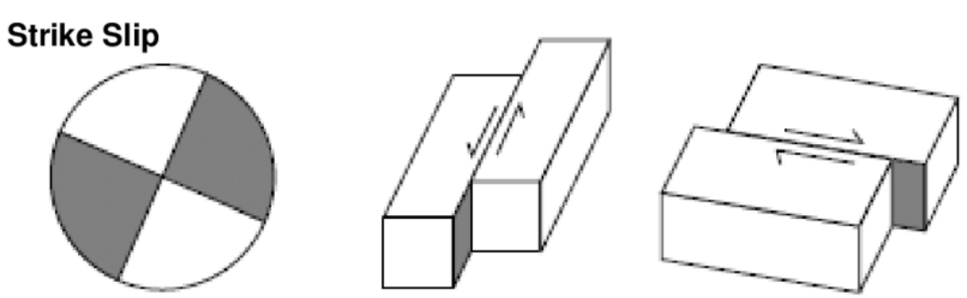
OKADA'S FORMULATION (elastic half-space)

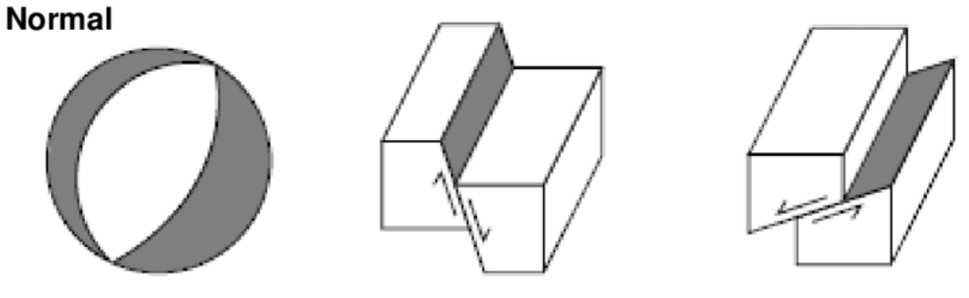
SURFACE DISPLACEMENT FIELD
(~20 x along-strike length)

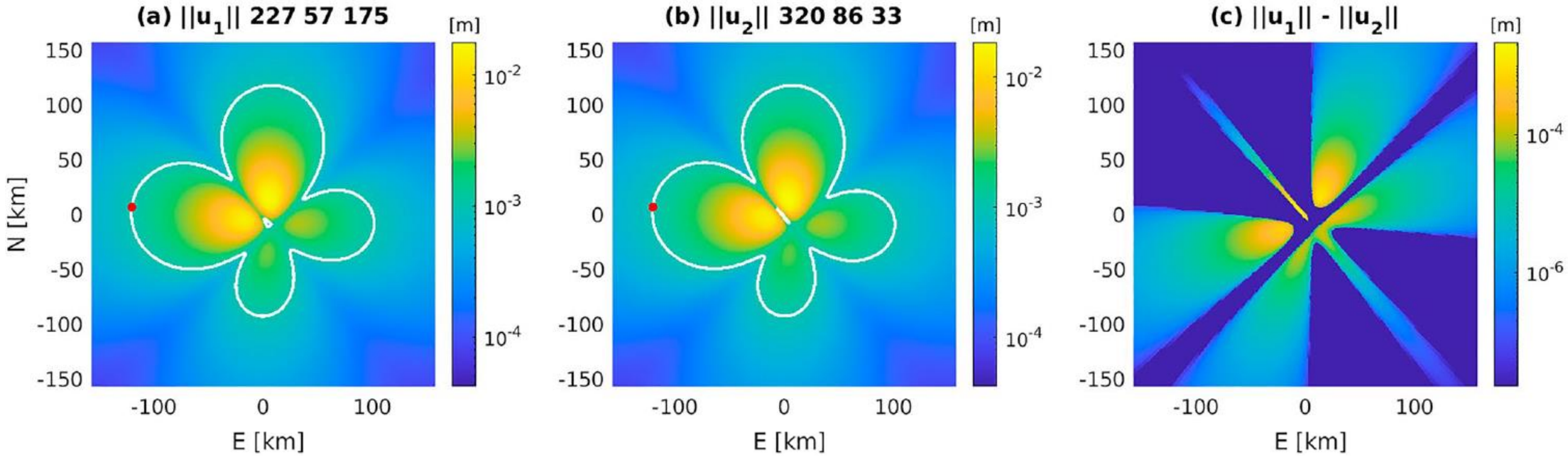


Wells & Coppersmith formulations

LEVEL 2 S-score







LEVEL 2 S-score

SURFACE DISPLACEMENT FIELD
(~20 x along-strike length)

→ **MASK**
1 mm displacement contour

→ Combine both nodal plane masks
OR operator

→ d_Z → distance of furthest point on contour to the epicenter

For hypocenter depth Z

For shallowest depth fault

SURFACE DISPLACEMENT FIELD
(~20 x along-strike length)

→ **MASK**
1 mm displacement contour

→ Combine both nodal plane masks
OR operator

→ d_0 → distance of furthest point on contour to the epicenter

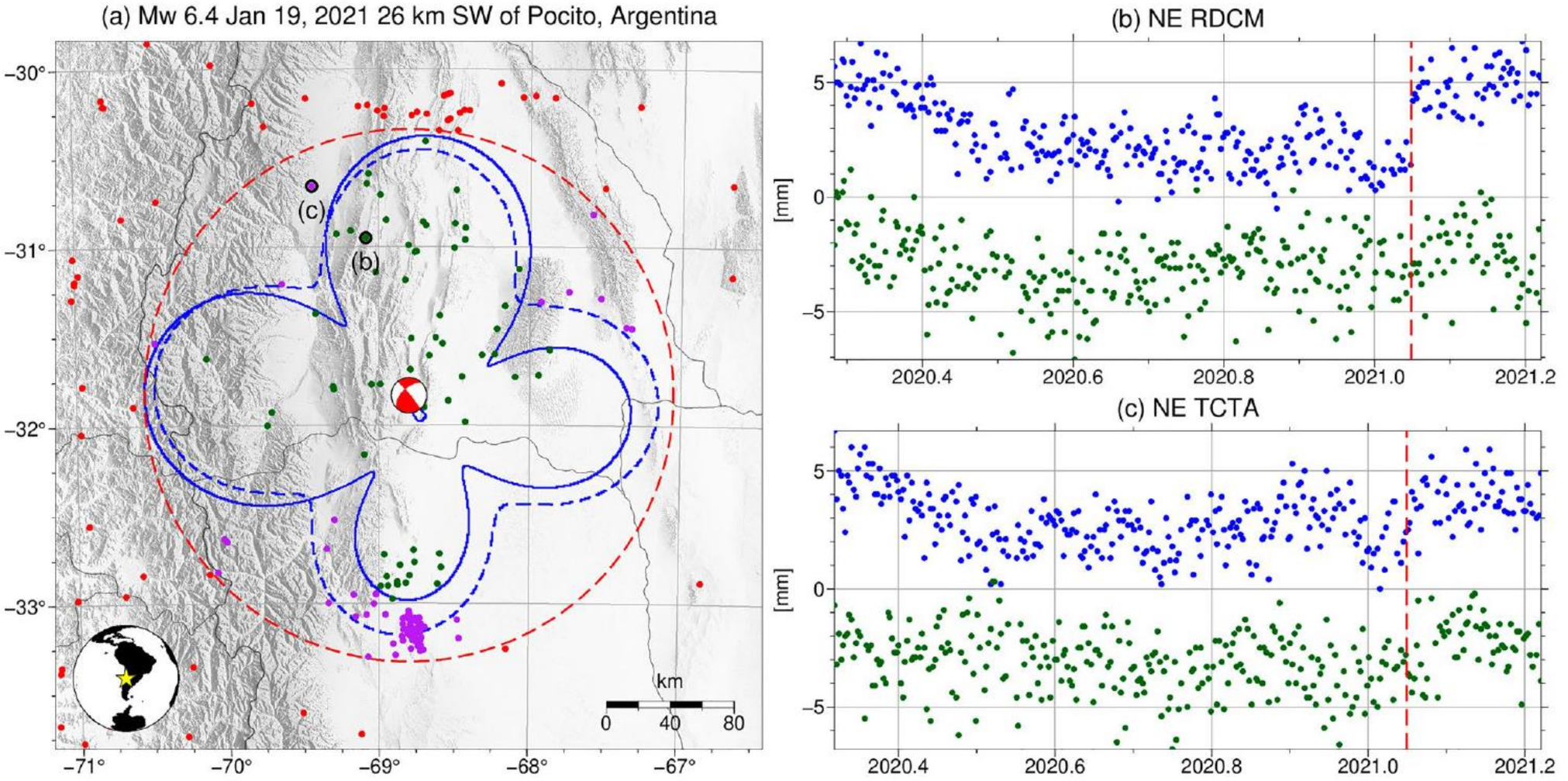
Choose $max(d_Z, d_0)$ →

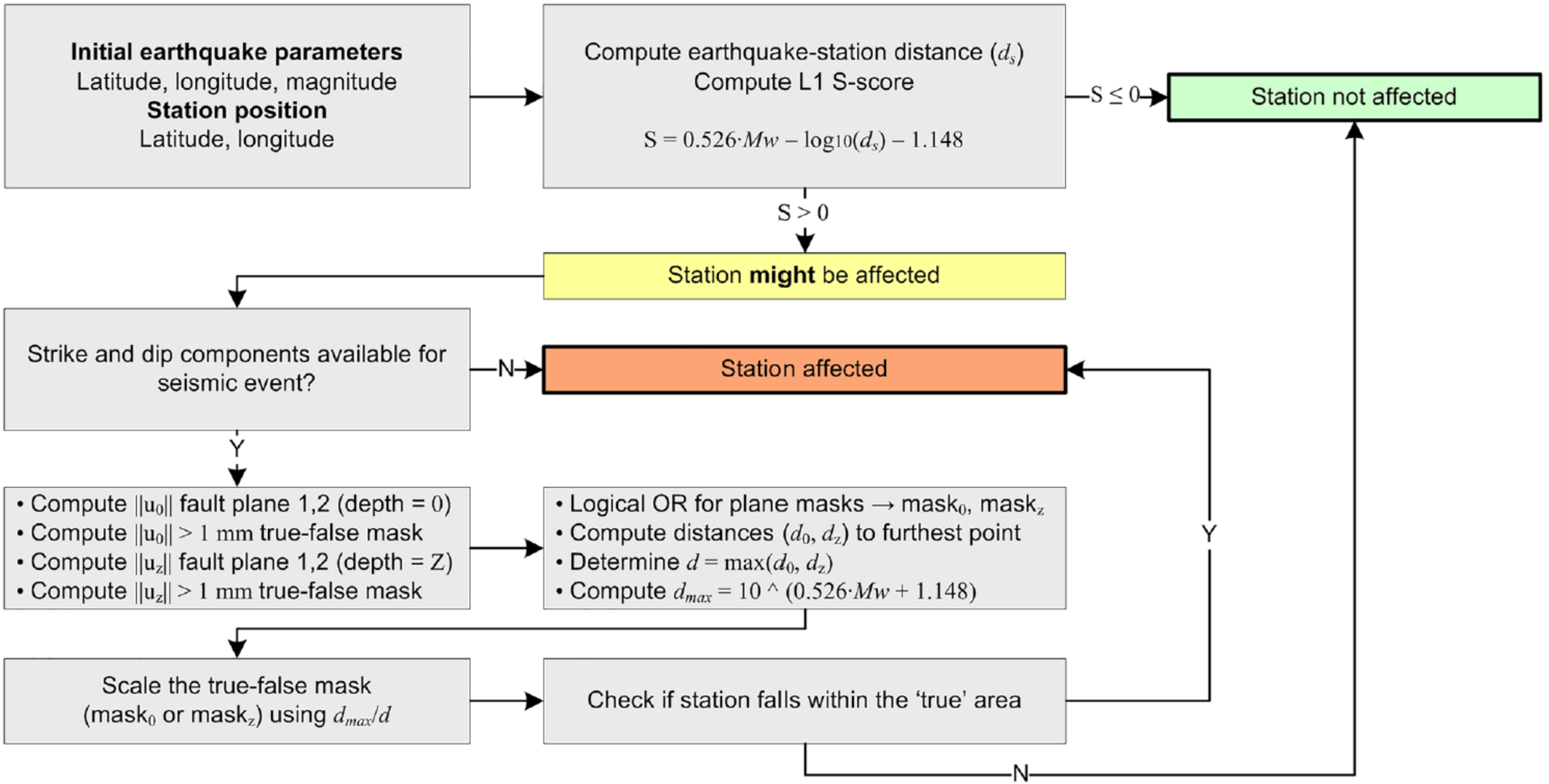
Scale contour

$$d_{max}/d$$

d_{max} → from Level 1

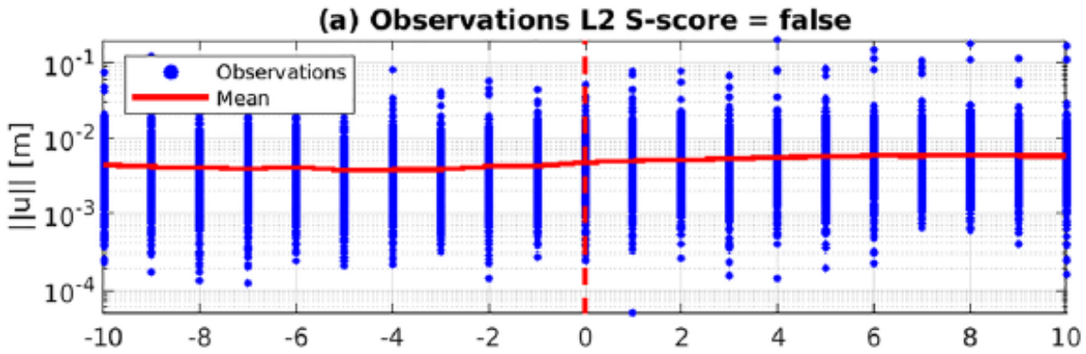
EXAMPLE: Mw 6.4 Jan 18, 2021, San Juan, Argentina

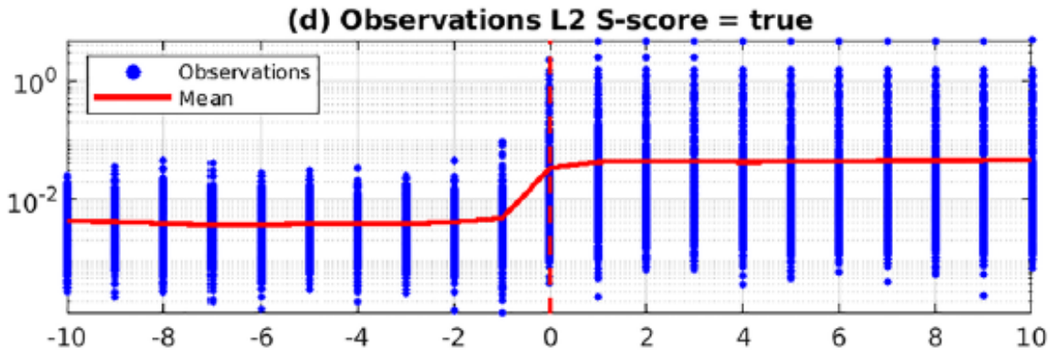


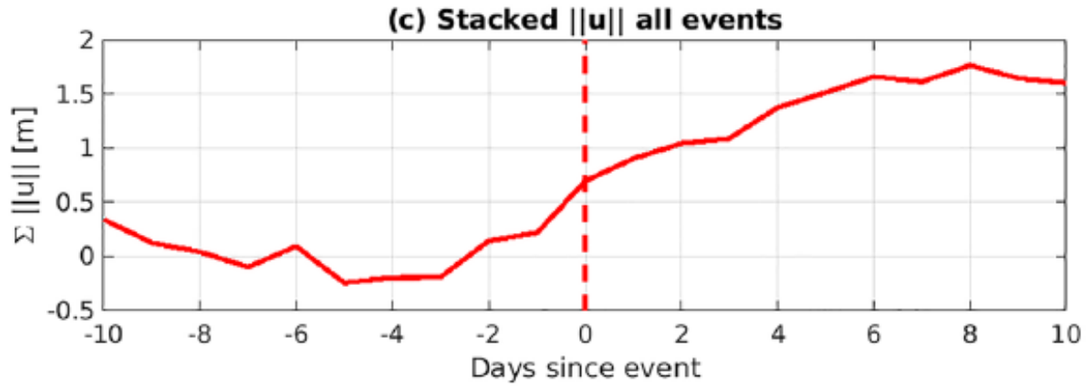

Initial earthquake parameters
Latitude, longitude, magnitude
Station position
Latitude, longitude
Compute earthquake-station distance (d_s)
Compute L1 S-score
$S = 0.526 \cdot Mw - \log_{10}(d_s) - 1.148$
S ≤ 0
Station not affected
S > 0
Station **might** be affected
Strike and dip components available for seismic event?
N
Station affected
Y
• Compute $||u_0||$ fault plane 1,2 (depth = 0)
• Compute $||u_0|| > 1$ mm true-false mask
• Compute $||u_z||$ fault plane 1,2 (depth = Z)
• Compute $||u_z|| > 1$ mm true-false mask
• Logical OR for plane masks → $mask_0$, $mask_z$
• Compute distances (d_0, d_z) to furthest point
• Determine $d = \max(d_0, d_z)$
• Compute $d_{max} = 10 \wedge (0.526 \cdot Mw + 1.148)$
Y
Scale the true-false mask ($mask_0$ or $mask_z$) using d_{max}/d
Check if station falls within the 'true' area
N

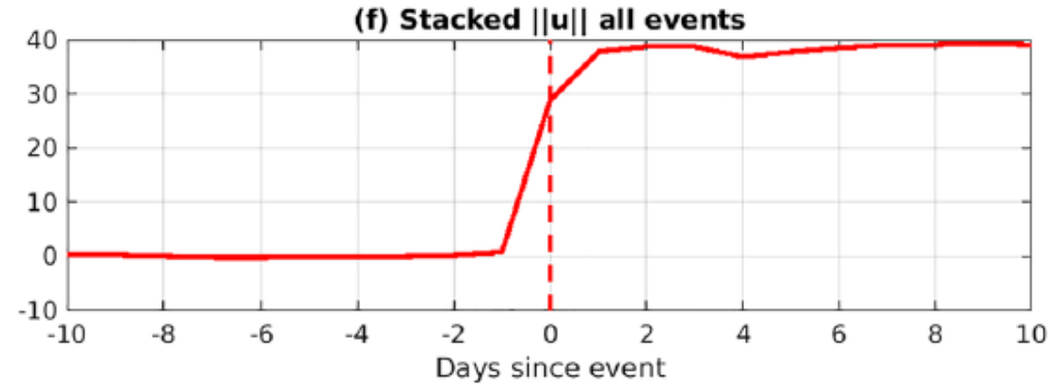
RESULTS

We applied our level 2 method to a database of ~ 4700 event-station pairs and showed that it removed ~ 55% of the total pairs, all of which had been falsely selected by Level 1

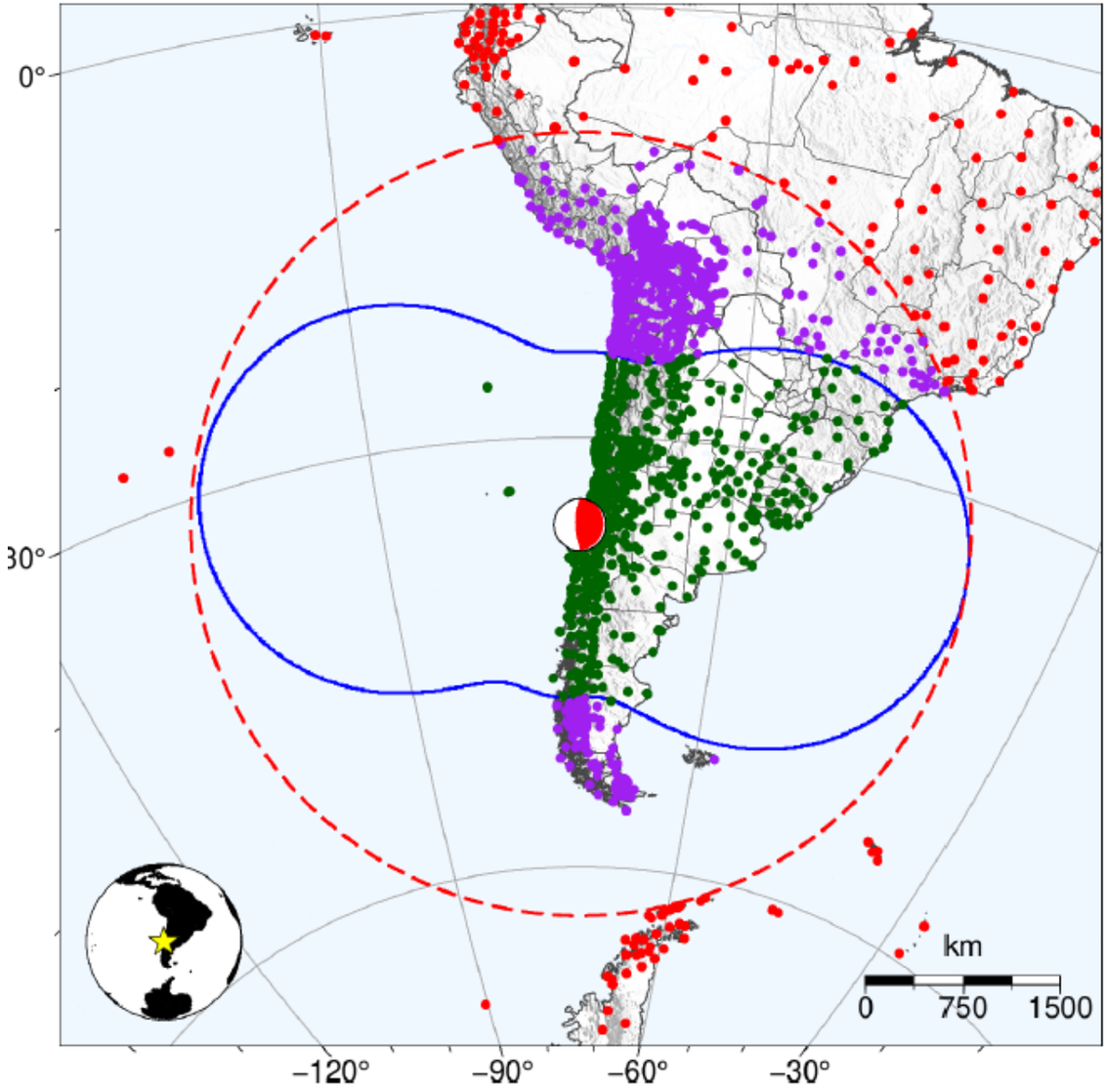




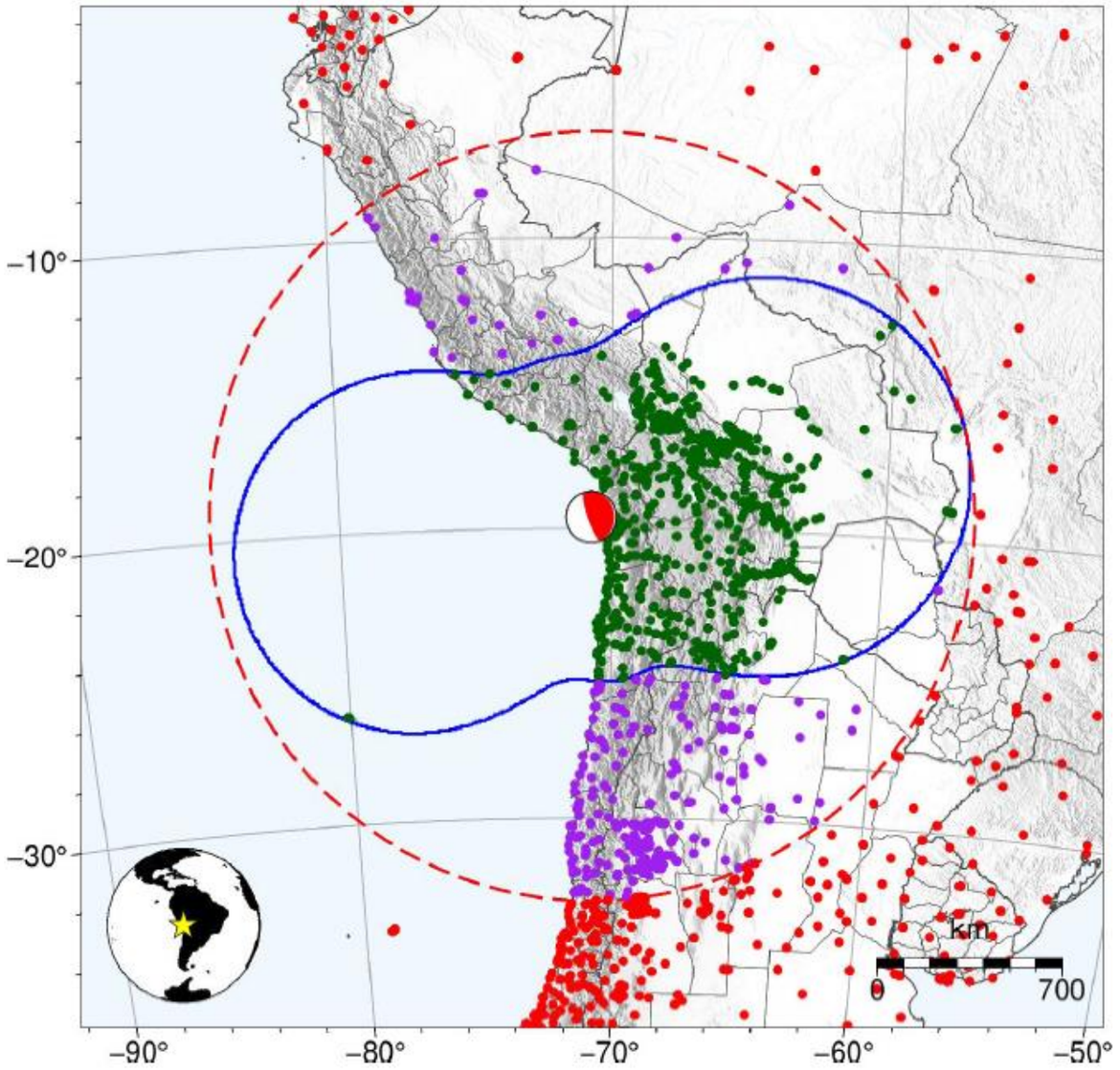




Mw 8.8 Feb 27, 2010 36 km WNW of Quirihue, Chile

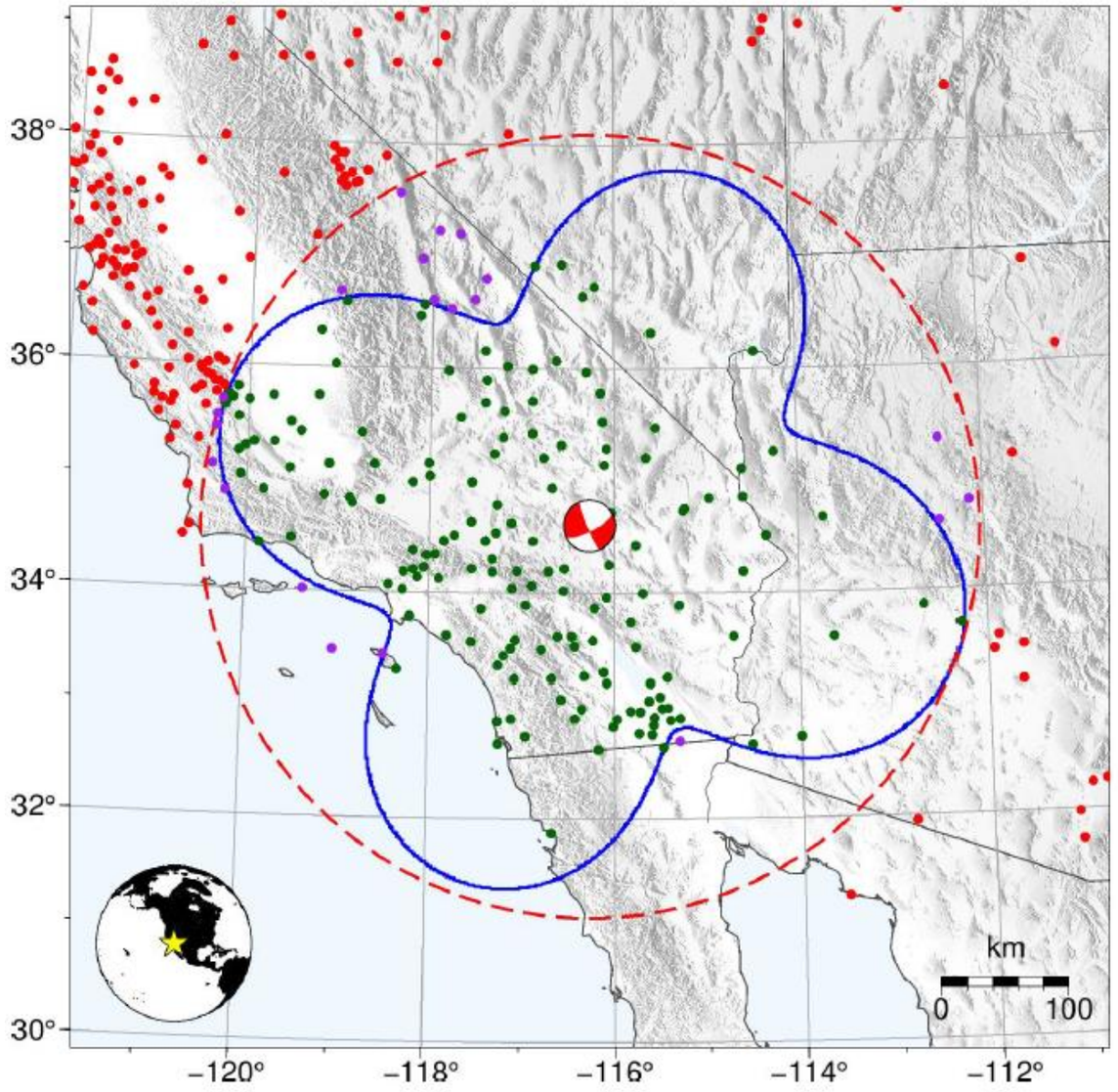


Mw 8.2 Apr 01, 2014 93 km NW of Iquique, Chile

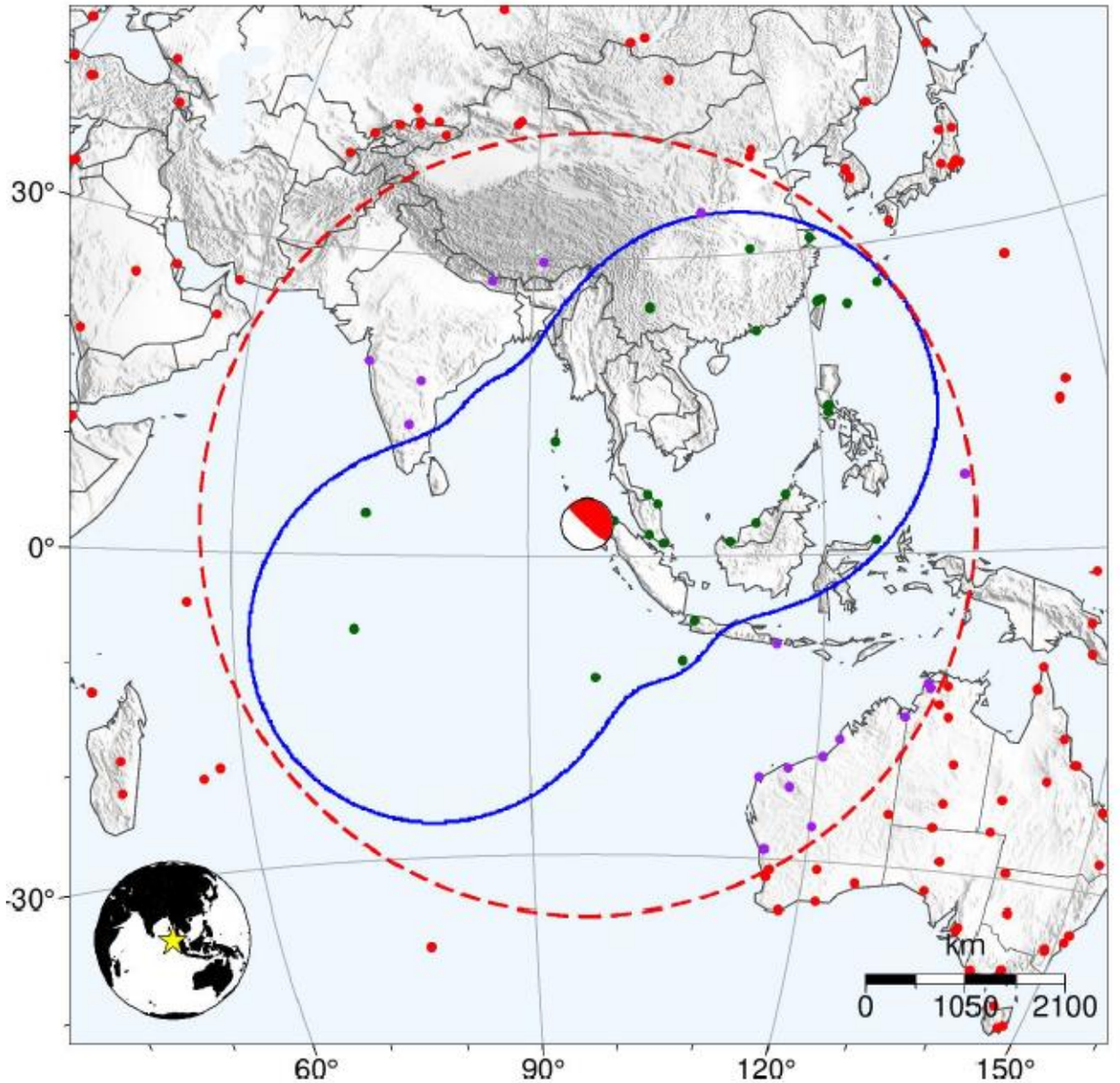


RESULTS

Mw 7.1 Oct 16, 1999 Hector Mine, CA Earthquake



Mw 9.1 Dec 26, 2004 2004 Sumatra - Andaman Islands Earthquake



CONCLUSIONS AND FUTURE WORK

CONCLUSIONS

- This tool efficiently identifies GNSS stations that genuinely require coseismic corrections, contributing to higher stability and reliability in global geodetic networks.
- Our method also defines a clear, quantitative boundary for the implementation of coseismic deformation models.

IMPLICATIONS

- Automated coseismic adjustment selection is now feasible, enhancing real-time GNSS applications.
- Improved accuracy supports more robust reference frame realization.

FUTURE WORK

- Our results suggest a postseismic signal in the data with L1 S-score > 0 and L2 = false, although the stations recorded no coseismic displacements. Another version of the S-score (or scale factor) could be derived to predict the maximum distance at which stations require postseismic transients without invoking coseismic step functions.

An empirical tool for predicting the presence or absence of coseismic displacements at GNSS stations

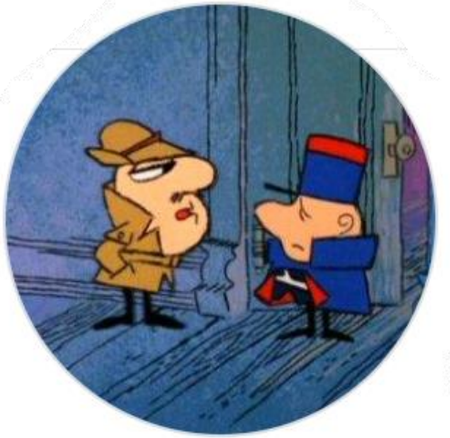
Original Article | Open access | Published: 05 October 2024

Volume 28, article number 214, (2024) Cite this article

Download PDF

You have full access to this open access article

Demián D. Gómez, Michael G. Bevis, Dana J. Caccamise II, W. Ashley Griffith, Jacob M. Heck & Robert Smalley Jr



Demian Gomez
demiangomez

Follow

I'm a geophysicist and a geometrical geodesist doing active research on reference frame realizations, both regional and global.

Popular repositories

Parallel.GAMIT

Python wrapper to parallelize GAMIT executions

Python 37 20

Module pyOkada

THE OHIO STATE UNIVERSITY

SIRGAS
sirgas.ipgh.org

¡Gracias!
Thank you!
Obrigado!

Mara A. Figueroa
figueroaberroca.1@osu.edu

Demián D. Gómez
gomez.124@osu.edu

IAG · Instituto Panamericano de Geografía e Historia OEA · IGAC Instituto Geográfico Agustín Codazzi · Servicio Geológico Colombiano · SIRGAS sirgas.ipgh.org