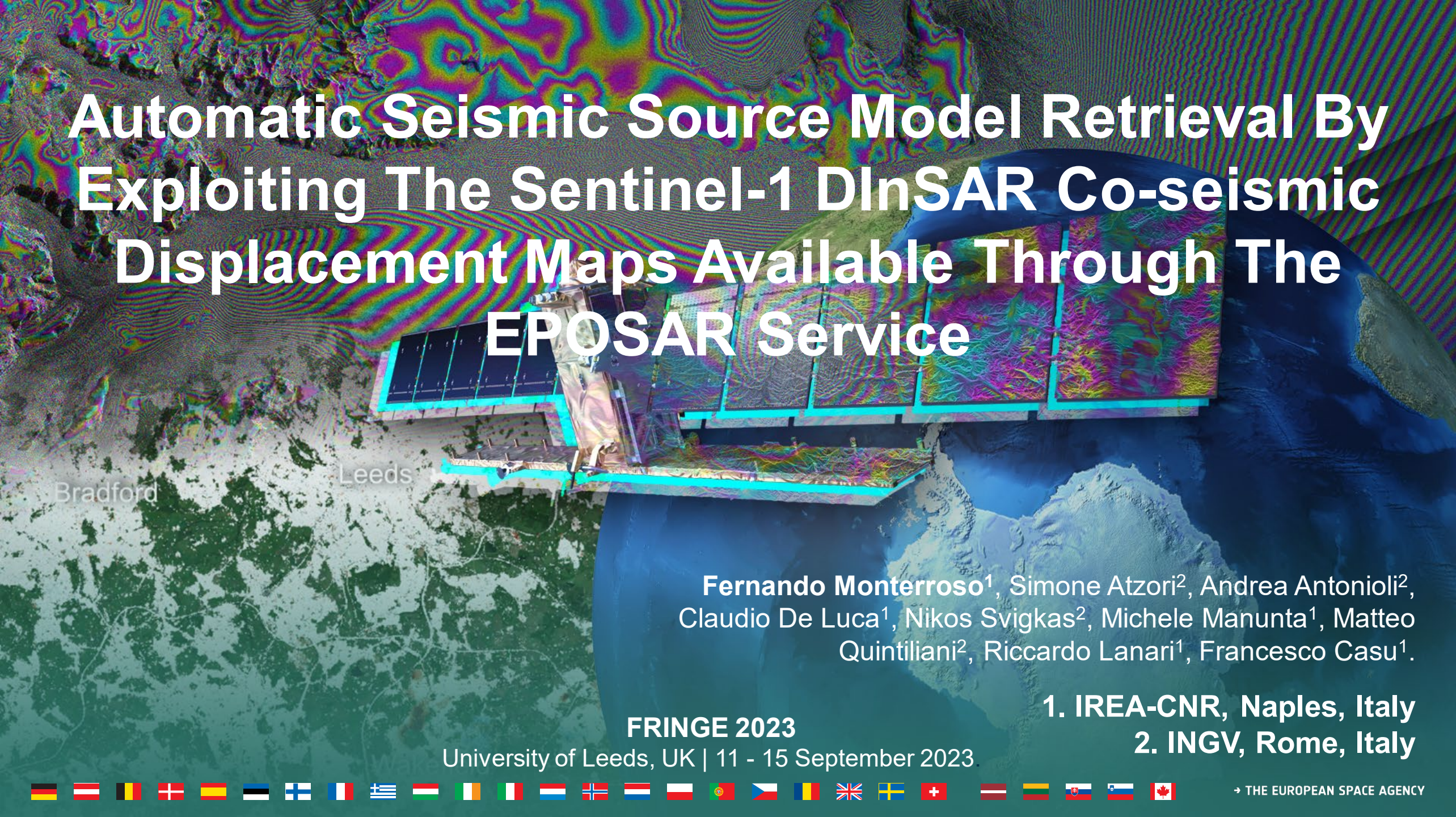
Automatic Seismic Source Model Retrieval By Exploiting The Sentinel-1 DInSAR Co-seismic Displacement Maps Available Through The EPOSAR Service

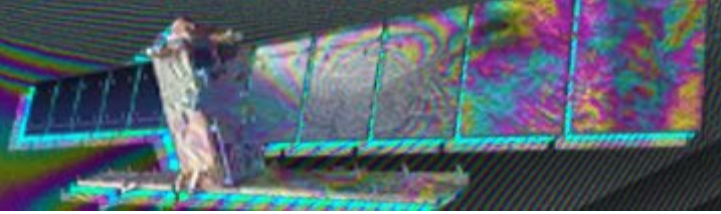


Fernando Monterroso[1], Simone Atzori[2], Andrea Antonioli[2], Claudio De Luca[1], Nikos Svigkas[2], Michele Manunta[1], Matteo Quintiliani[2], Riccardo Lanari[1], Francesco Casu[1].

1. IREA-CNR, Naples, Italy
2. INGV, Rome, Italy

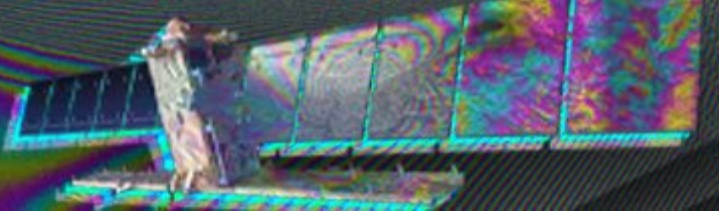
FRINGE 2023
University of Leeds, UK | 11 - 15 September 2023.

Outline



- EPOSAR service
- Automatic Processing chain implementation
    - Data setup
    - Non – linear Inversion
    - Linear inversion
- Experimental Results
- Conclusions and Future Developments

EPOSAR Service

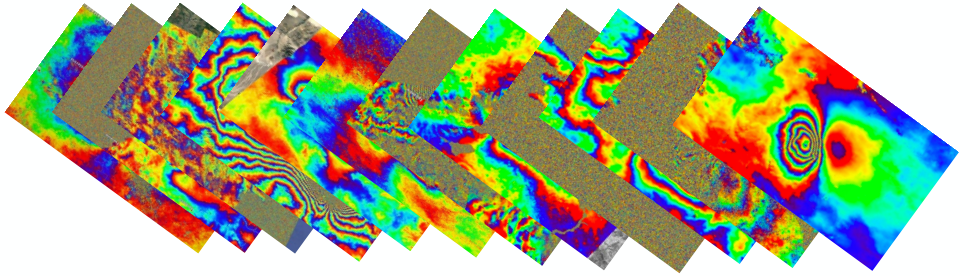


USGS

ISTITUTO NAZIONALE
DI GEOFISICA E VULCANOLOGIA

amazon web services

Sentinel-1 Automatic
DInSAR Processing

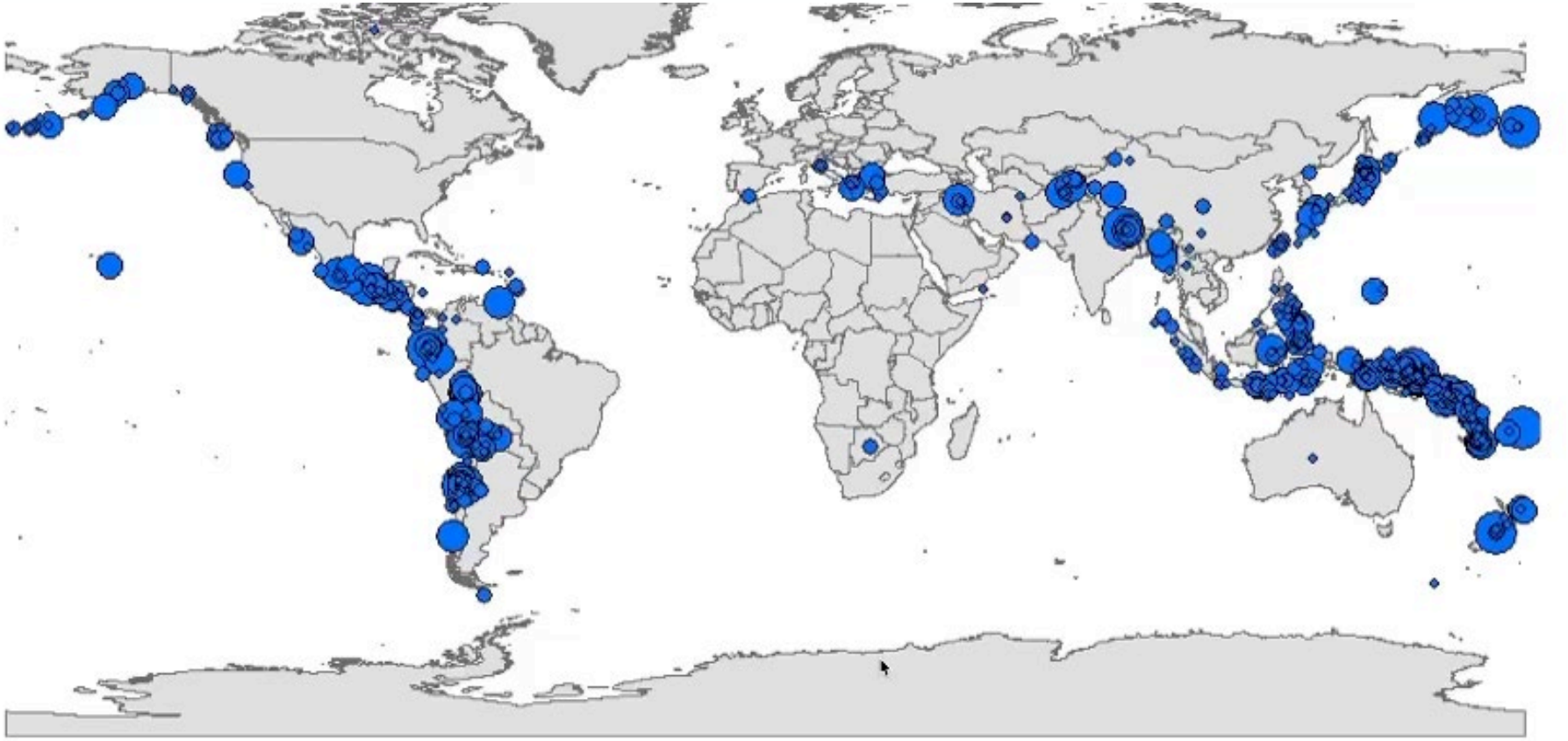


geohazards tep

EPOS
ERIC EUROPEAN RESEARCH INFRASTRUCTURE CONSORTIUM

https://www.mdpi.com/843474

EPOSAR Service



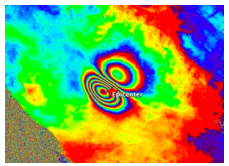
608 Earthquakes
(Sept 13,2023)

45000 products

Interferograms,
LOS Displacement maps
Coherence maps

Automatic Processing Chain Implementation

EPOSAR Service TCS
Satellite Data



Focal Mechanism to Define area

Data Setup

Area definition
Pair selection
Data Sampling

Non – Linear Inversion

inversion setup
non-linear optimization
convergence test
setup update / end

Linear Inversion

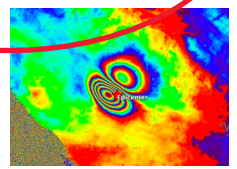
source extension/subdivision
damping definition
d = Gm design
G^{-g} calculation

source validation

Public Repository

Automatic Processing Chain Implementation

EPOSAR Service TCS
Satellite Data



Focal Mechanism to Define area

USGS

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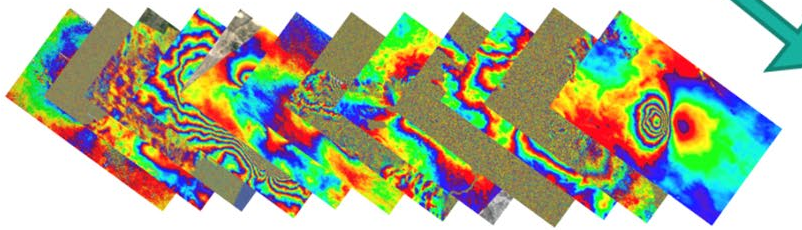
Sentinel-1 Automatic DInSAR Processing



geohazards tep

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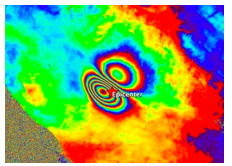
Automatic Processing Chain Implementation

EPOSAR Service TCS
Satellite Data

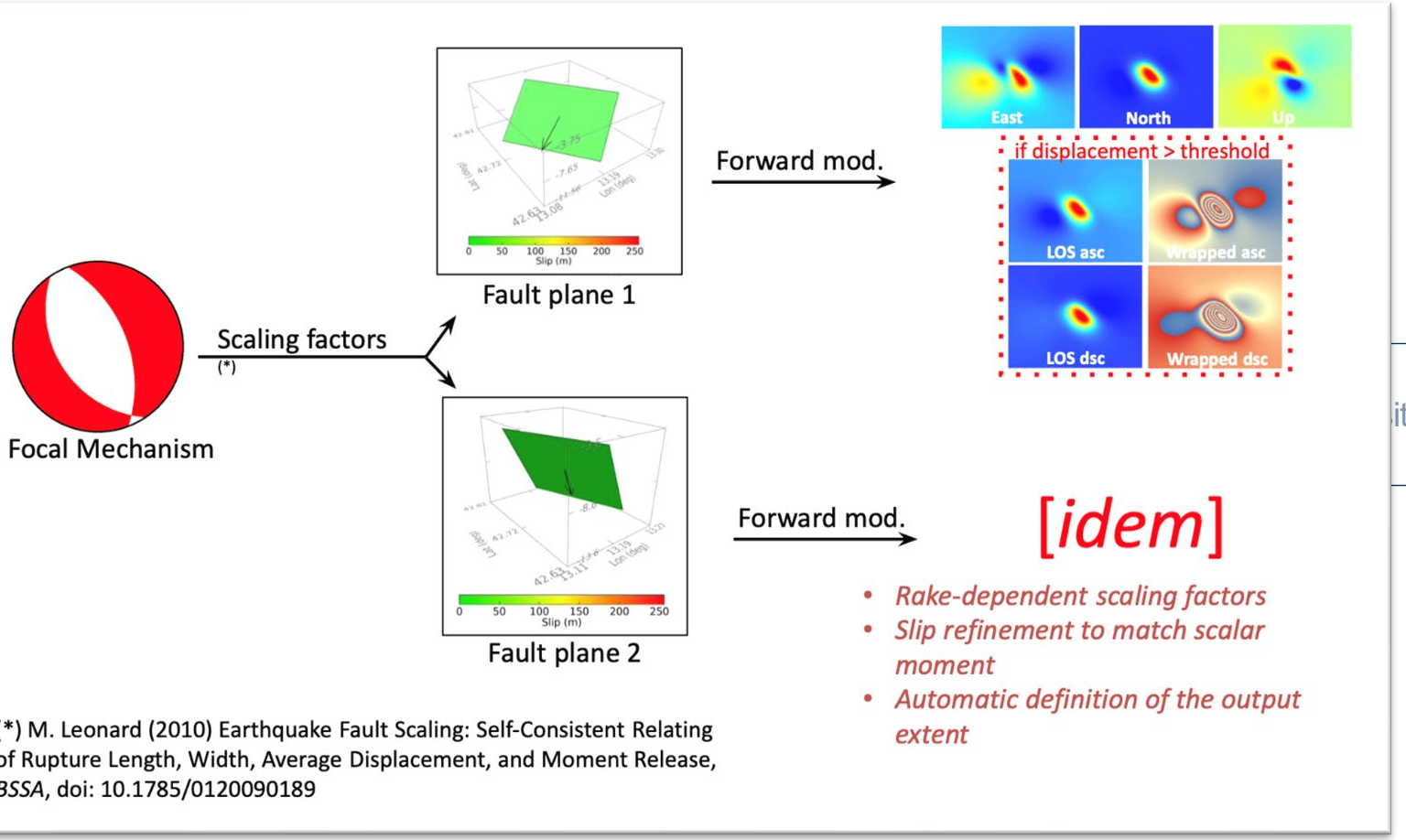


Data Setup

Area definition
Pair selection
Data Sampling

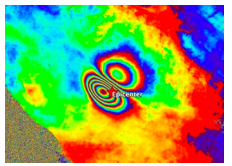
Focal Mechanism to Define area

Expected area affected by ground displacement



Automatic Processing Chain Implementation

EPOSAR Service TCS
Satellite Data



Focal Mechanism to Define area

Data Setup

Area definition
Pair selection
Data Sampling

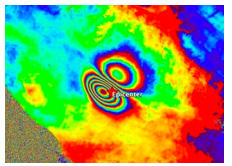
Expected area affected by ground displacement

- **Criterial**
  - the number of ascending and descending orbits used in the inversions must be the same;
  - shortest temporal baseline for each available track;
  - when the number of available ascending and descending tracks is different and a selection is necessary according to the first rule, priority is given to those better covering the affected area.
- **LOS unit vector files**
- **DEM**

Monterroso et al (2022)
https://doi.org/10.1016/j.jag.2023.103445

Automatic Processing Chain Implementation

EPOSAR Service TCS
Satellite Data



Focal Mechanism to Define area

The Non–Linear optimization defines the fault location, geometry, and rupture mechanism with uniform slip

Data Setup

Area definition
Pair selection
Data Sampling

Non – Linear Inversion

inversion setup
non-linear optimization
convergence test
setup update / end

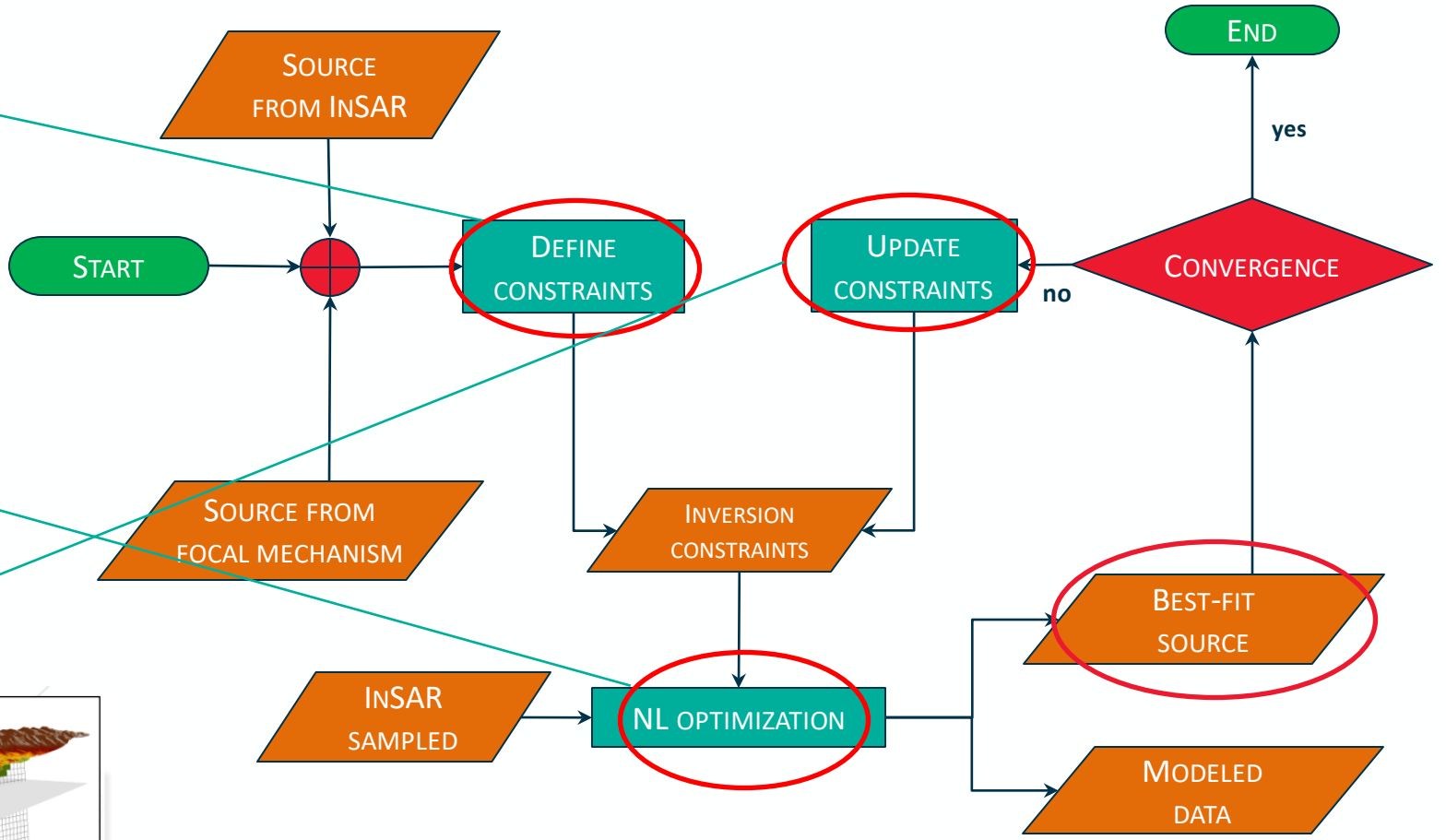
Linear Inversion

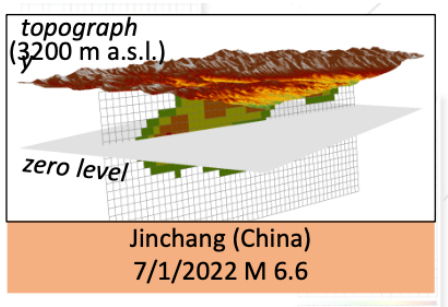
source validation

Public Repository

Automatic Non-Linear Inversion

- Define constrains
  - Range interval for every source parameter (Fault dimension, position, depth, orientation, rake and slip)
- Non linear optimization to find **the best - fit solution**, using the Levemberg – Marquardt scheme (Marquardt, 1963).
- Update Constrains algorithm





(a) from Atzori et al. (2019) https://doi.org/10.1016/j.rse.2019.1114
(b) William and Wedge (1998) https://doi.org/10.1029/98GL01136

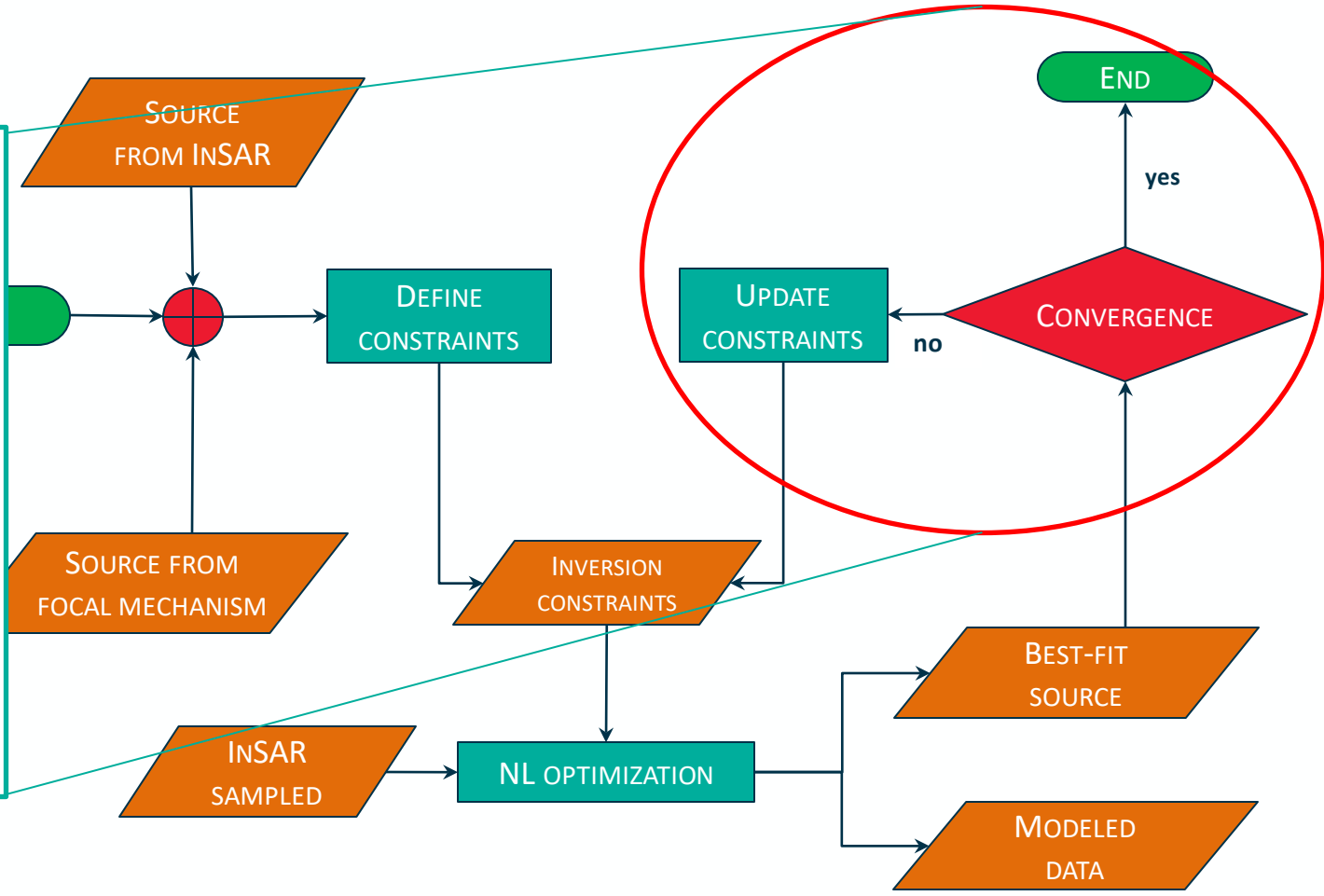
Automatic Non-Linear Inversion

criterials to define the best fit source

1. all the parameters not constrained have best-fit values within their minimum/maximum ranges **(corresponds to a successful non-linear optimization).**

2. the direction of the slip vector, in the 3D space, different from that of the focal mechanism (more than 55◦, by default)

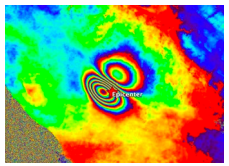
3. the maximum number of iterations is reached (30, by default).



(a) from Atzori et al. (2019) https://doi.org/10.1016/j.rse.2019.111461
(b) William and Wedge (1998) https://doi.org/10.1029/98GL01136

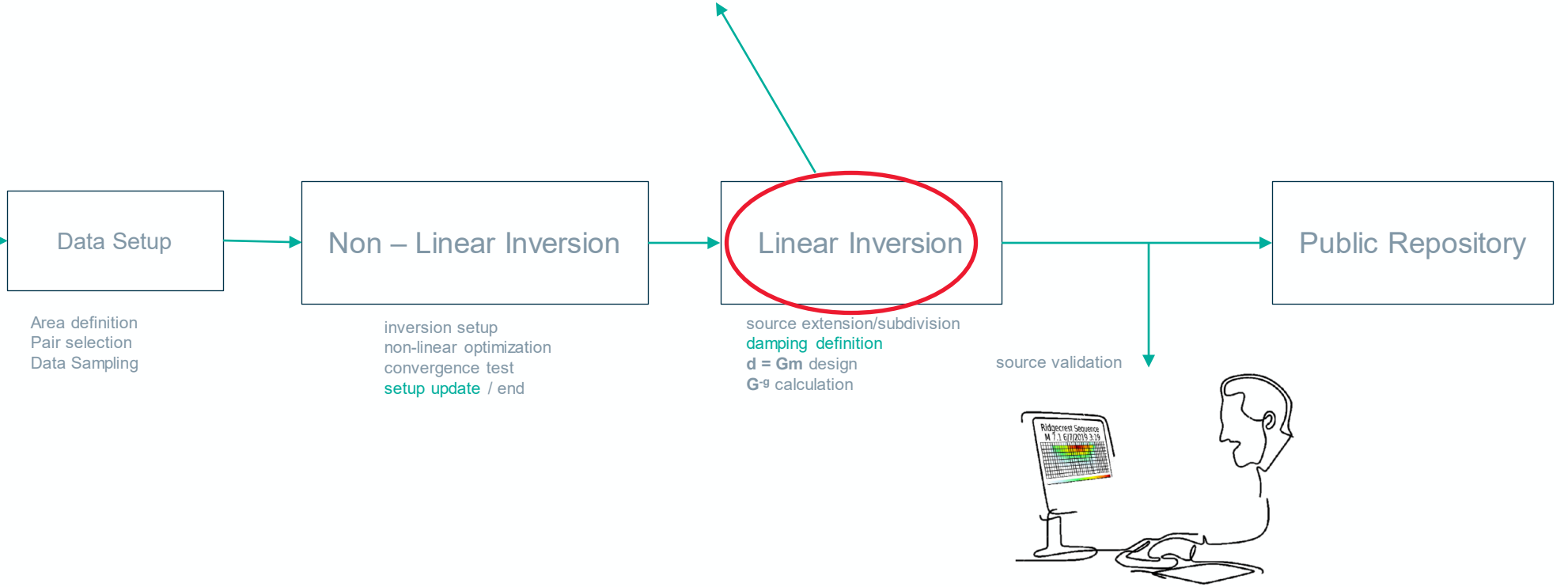
Automatic Processing Chain Implementation

EPOSAR Service TCS
Satellite Data



Focal Mechanism to Define area

Goal of the linear inversion is to retrieve the distribution of the shear dislocation over the fault plane identified by non-linear inversion.

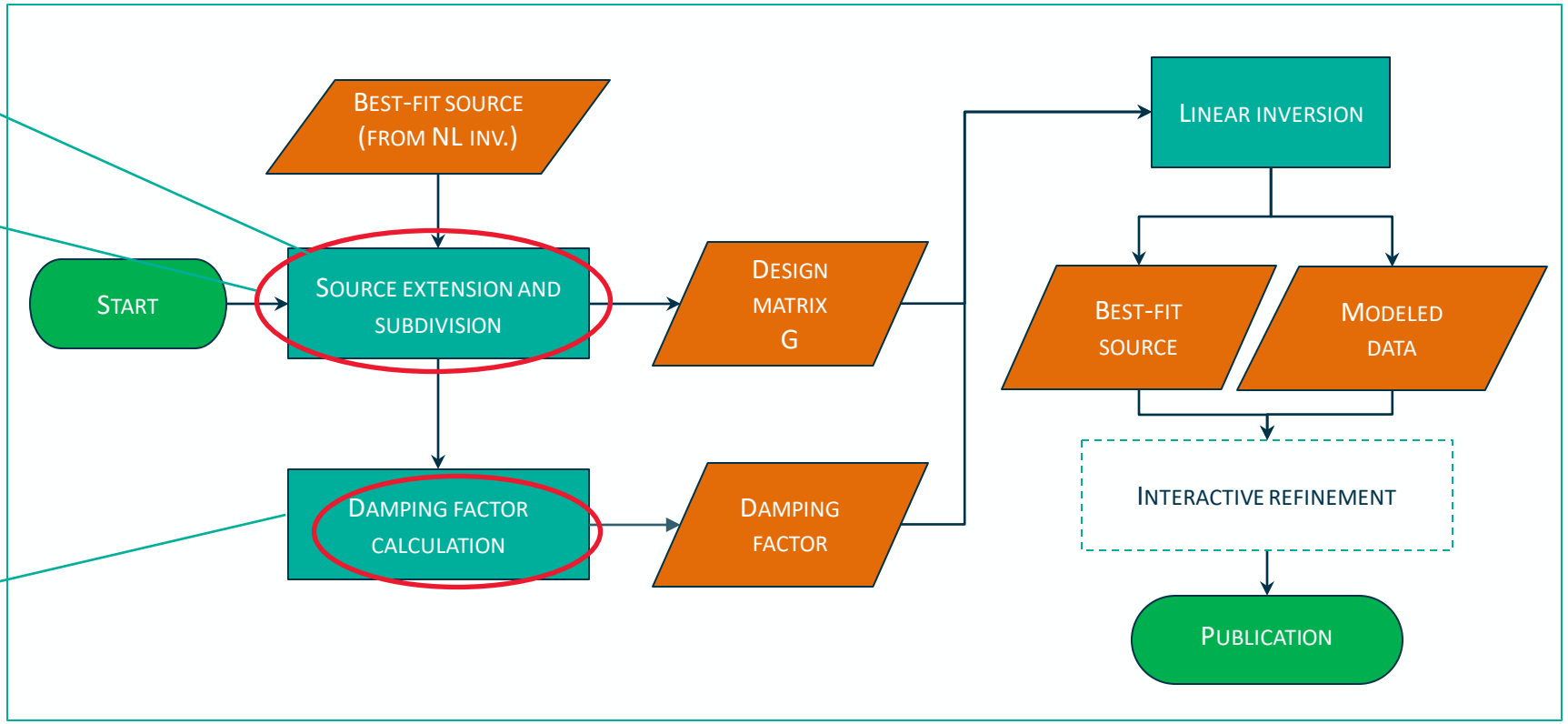


Automatic Linear Inversion

Goal of the linear inversion is to retrieve the distribution of the shear dislocation over the fault plane identified by non-linear inversion.

The extension (length and width) NL source.

The fault plane subdivision into a number of patches (own slip value after the linear inversion).



$\mathbf{d} = \mathbf{Gm}$ linear system

$\mathbf{m}^{est} = [\mathbf{G}^T\mathbf{G} + \varepsilon^2\mathbf{W}_m]^{-1}\,\mathbf{G}^T\mathbf{d} = \mathbf{G}^{-g}\mathbf{d}$

ε strength of the smoothing

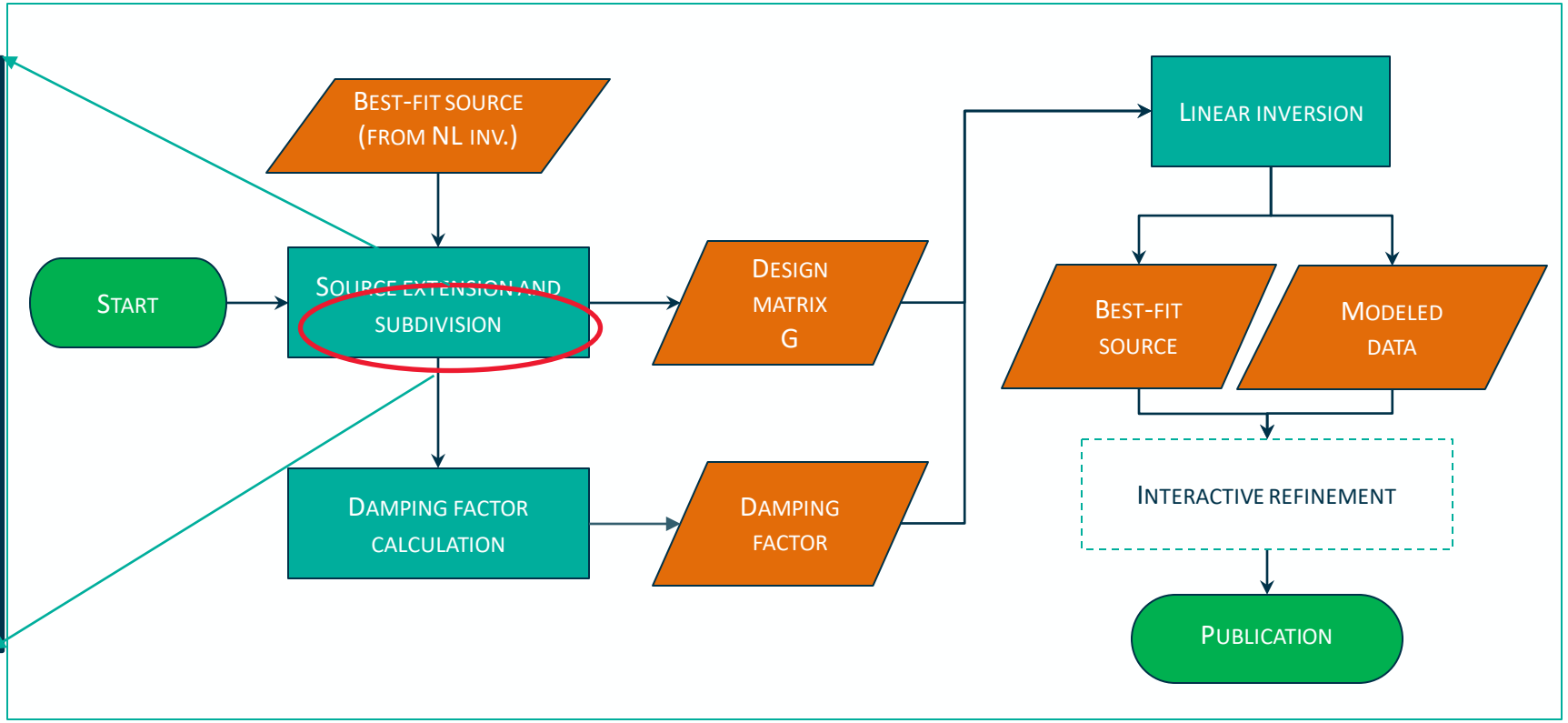
(automatic algorithm developed)

m is the vector of slip values,
d is the vector of observations
G the design matrix based on the same dislocation model in an elastic half-space (Okada, 1985) used in the non-linear optimization.

Automatic Linear Inversion

Goal of the linear inversion is to retrieve the distribution of the shear dislocation over the fault plane identified by non-linear inversion.

1. the longest between length and width is subdivided number of patches (30, by default)
2. the patch dimension is rounded to a multiple of hundreds/thousands of meters
3. the number of patches in the other dimension is calculated
4. final width and length are adjusted to be multiple of the patch size.



Automatic Linear Inversion

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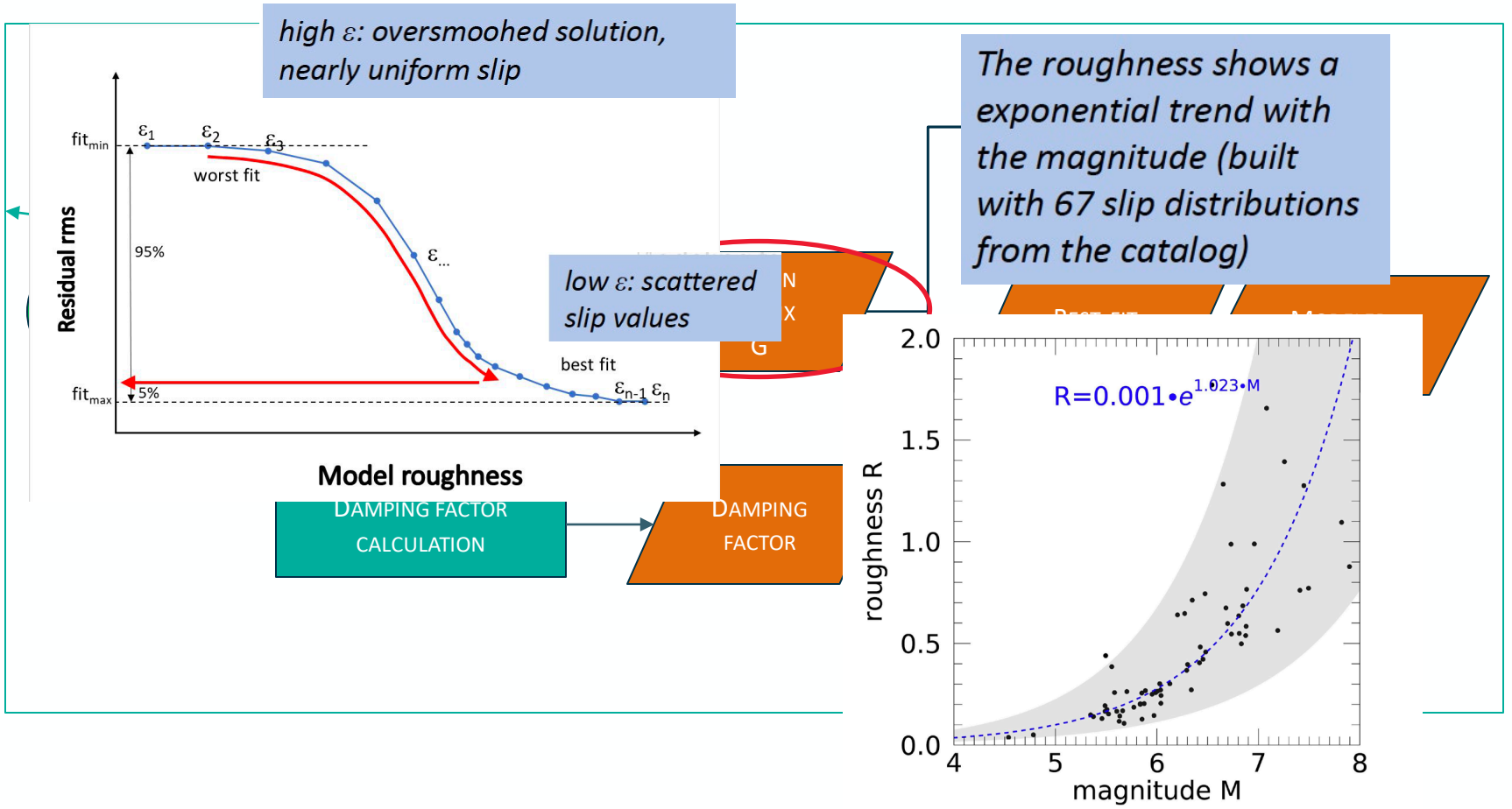
$$\mathbf{m}^{est} = [\mathbf{G}^T\mathbf{G} + \varepsilon^2\mathbf{W}_m]^{-1}\,\mathbf{G}^T\mathbf{d} = \mathbf{G}^{-g}\mathbf{d}$$

G = num of inversion points / patch subdivision

ε strength of the smoothing

(automatic algorithm developed)

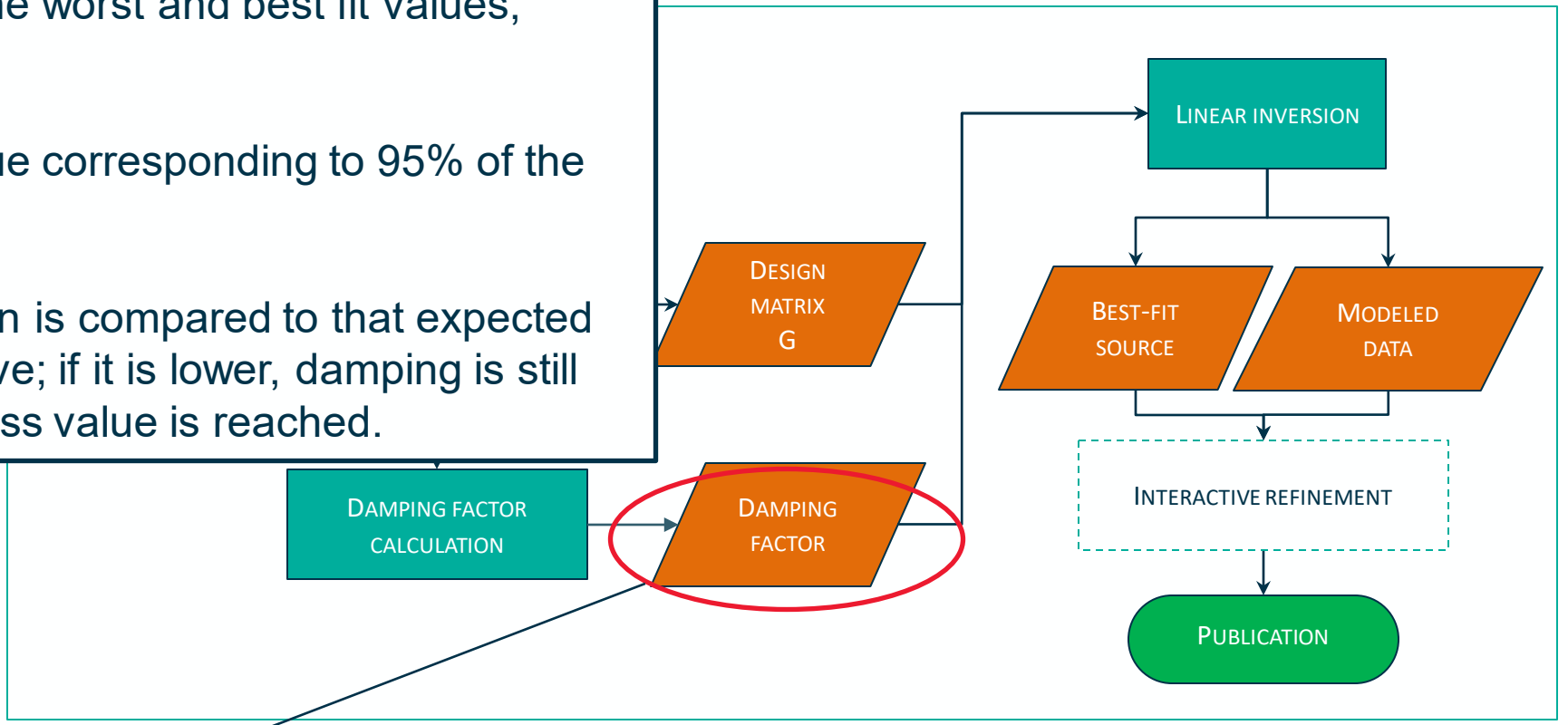


Automatic Linear Inversion

1. a data fit vs. model roughness curve is calculated to define, for the specific event, fitmin and fitmax, i.e. the worst and best fit values, respectively.

2. the damping factor is set to the value corresponding to 95% of the fitmin-fitmax interval

3. the roughness of this slip distribution is compared to that expected from the roughness vs magnitude curve; if it is lower, damping is still decreased until the expected roughness value is reached.



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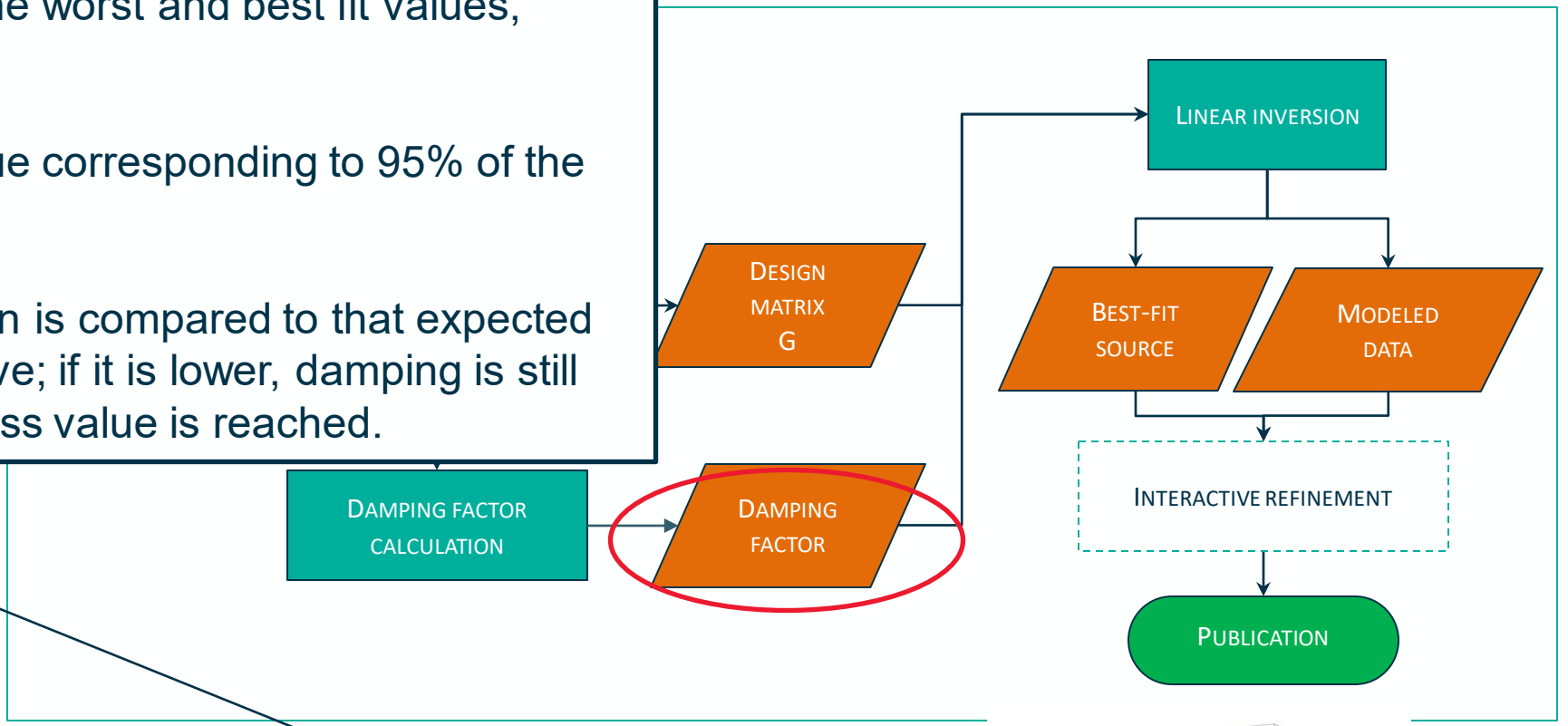


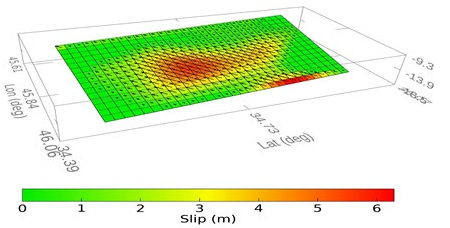
$$\mathbf{m}^{est} = [\mathbf{G}^T\mathbf{G} + \varepsilon^2\mathbf{W}_m]^{-1}\,\mathbf{G}^T\mathbf{d} = \mathbf{G}^{-g}\mathbf{d}$$

G = num of inversion points / petch subdivision

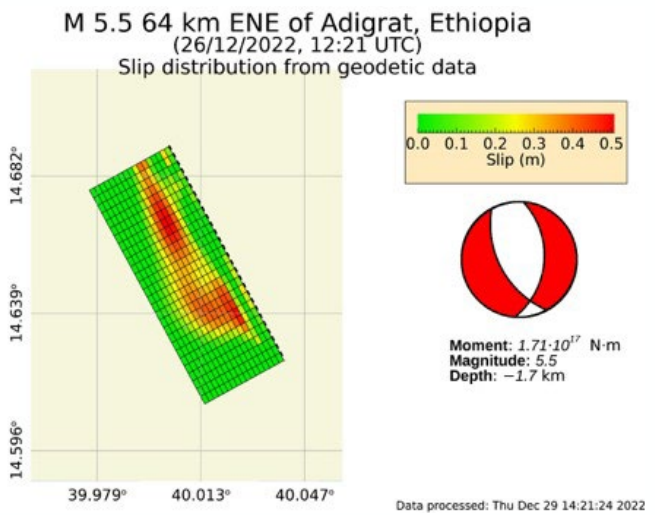
ε strength of the smoothing

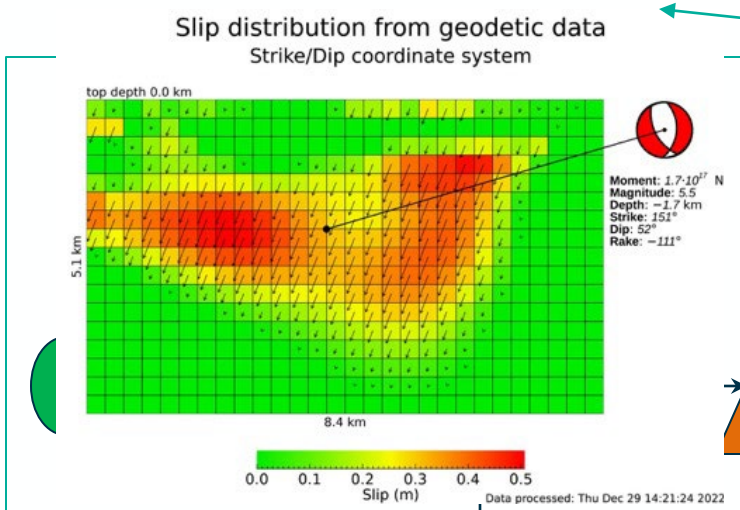
(automatic algorithm developed)

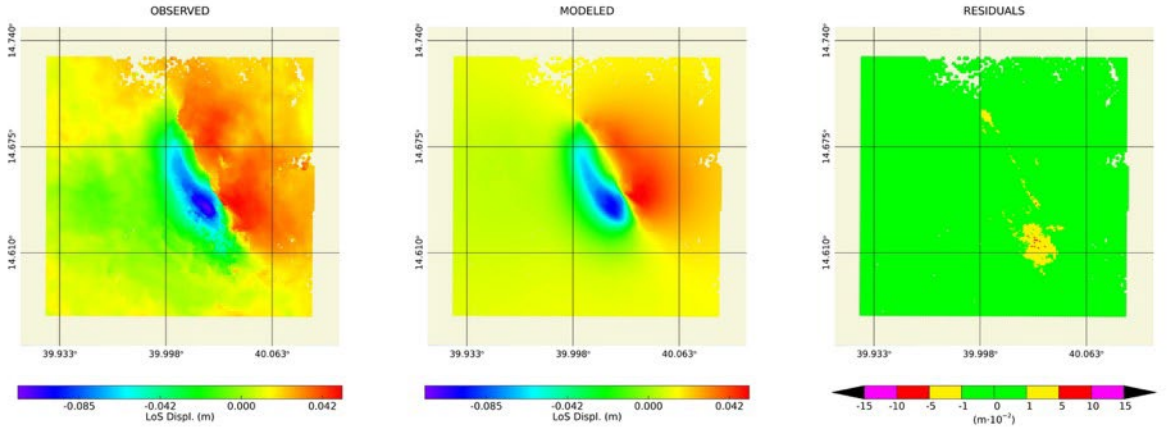
Array of slip vector

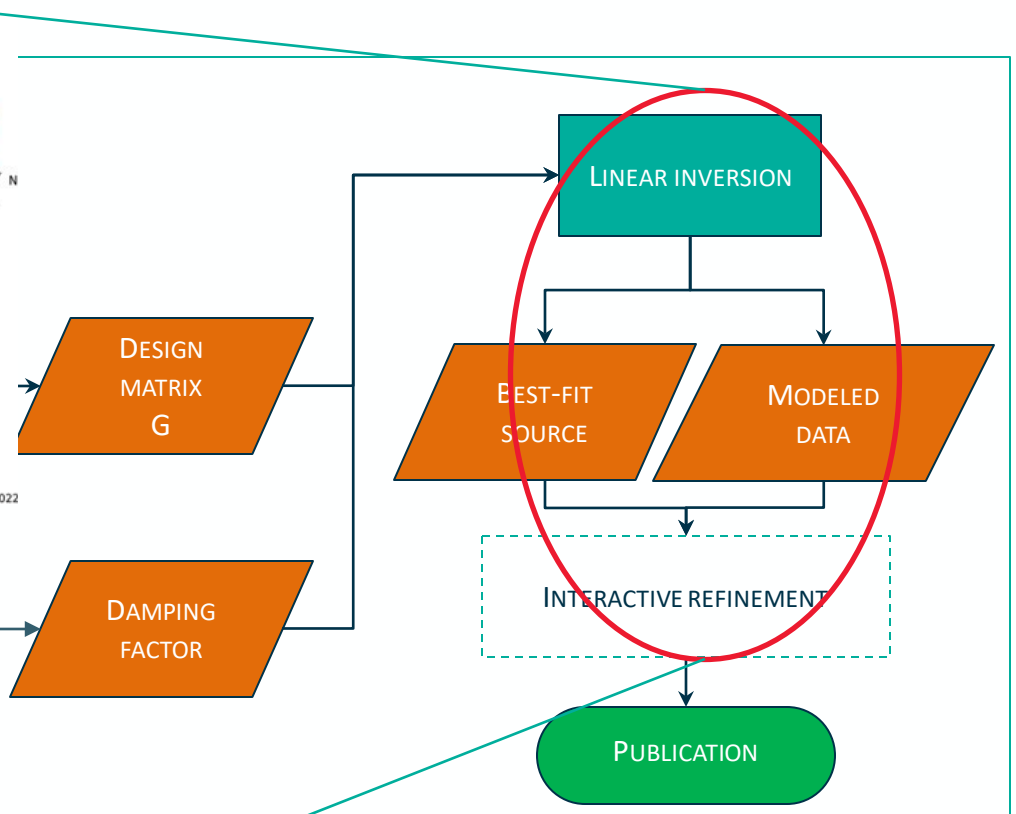


Automatic Linear Inversion



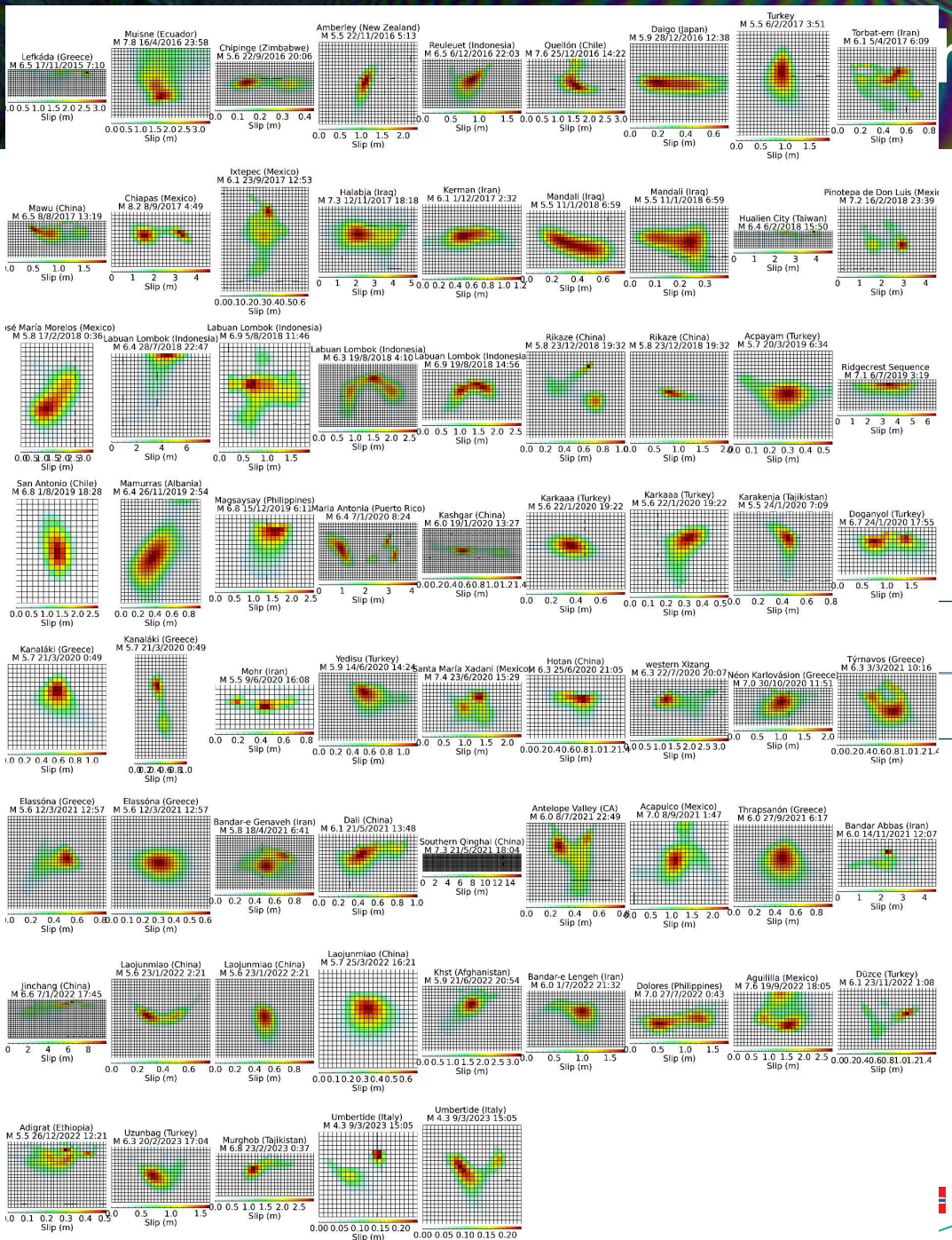






a completely automatic and unsupervised result can not be shared with the scientific community without any validation

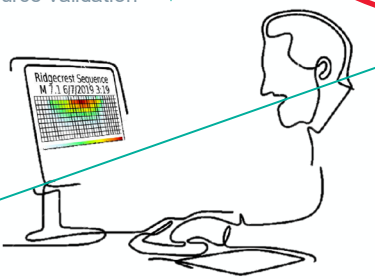
hain Implementation



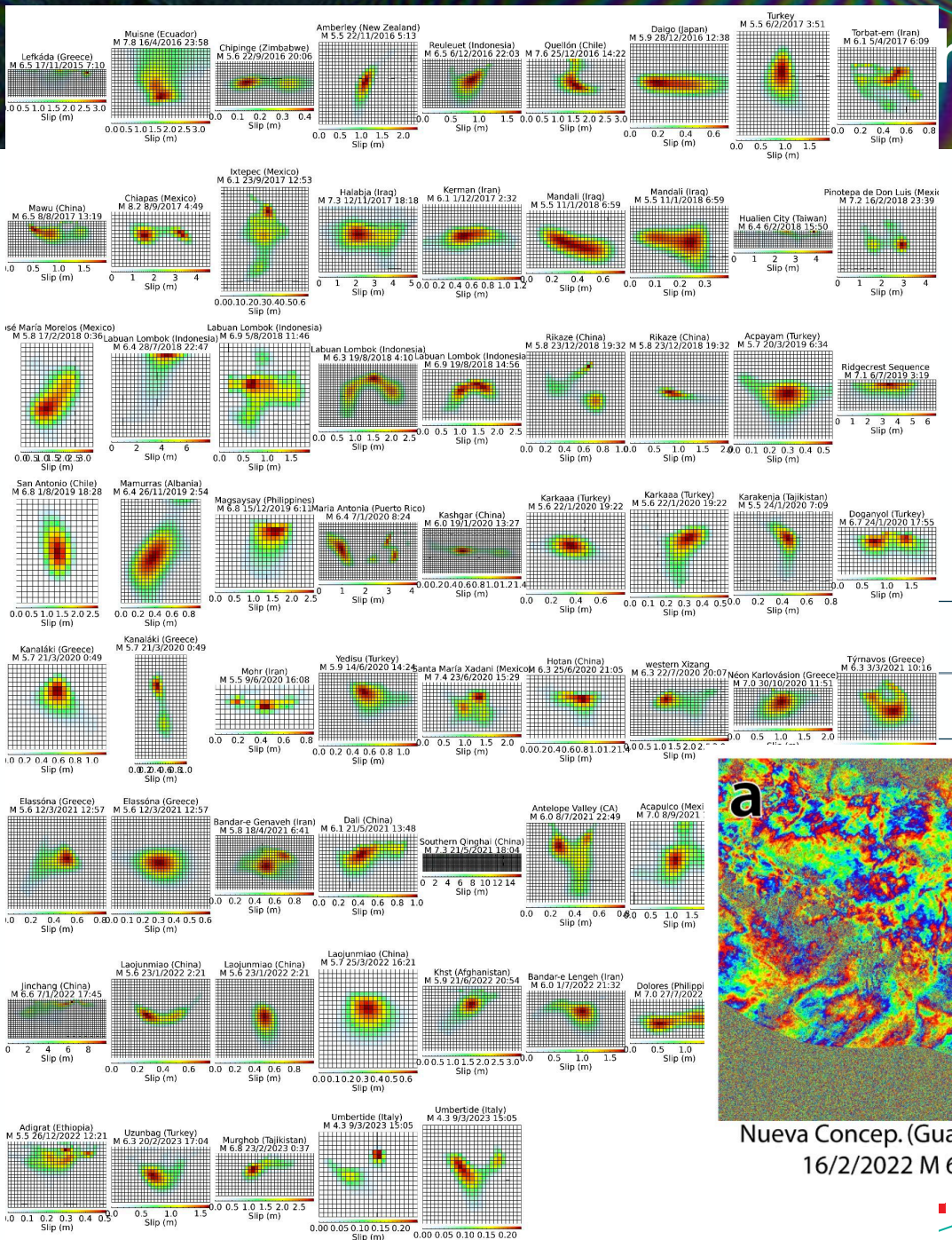
99 Earthquakes tested (5.5 – 8.2 mw) and small magnitude 4.5 earthquake occurred near Umbertide (Italy).

– Linear Inversion → Linear Inversion → Public Repository

source validation



hain Implementation



a). 16 earthquakes failed (not visible coseismic pattern).

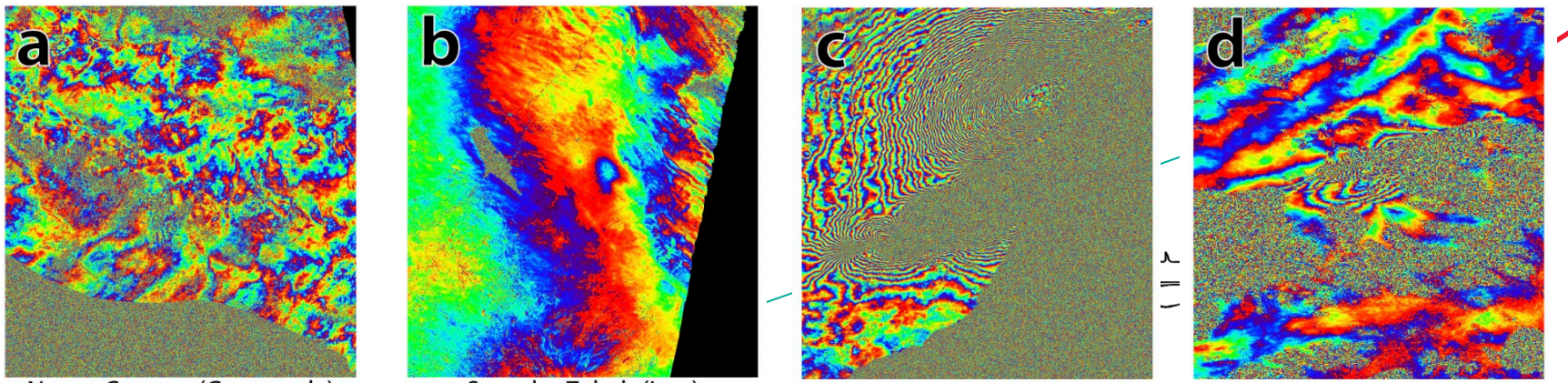
b). 6 cases with coseismic signal was very small.

c). 6 cases with rupture of different fault segments (Hawaiian events or Amberley earthquake New Zealand).

d). 11 cases, modelling failed because the displacement maps were affected by strong decorrelation.

In 60 cases the modeling process successfully ended with the retrieval of a reliable slip distribution.

– Linear Inversion → Linear Inversion → Public Repository



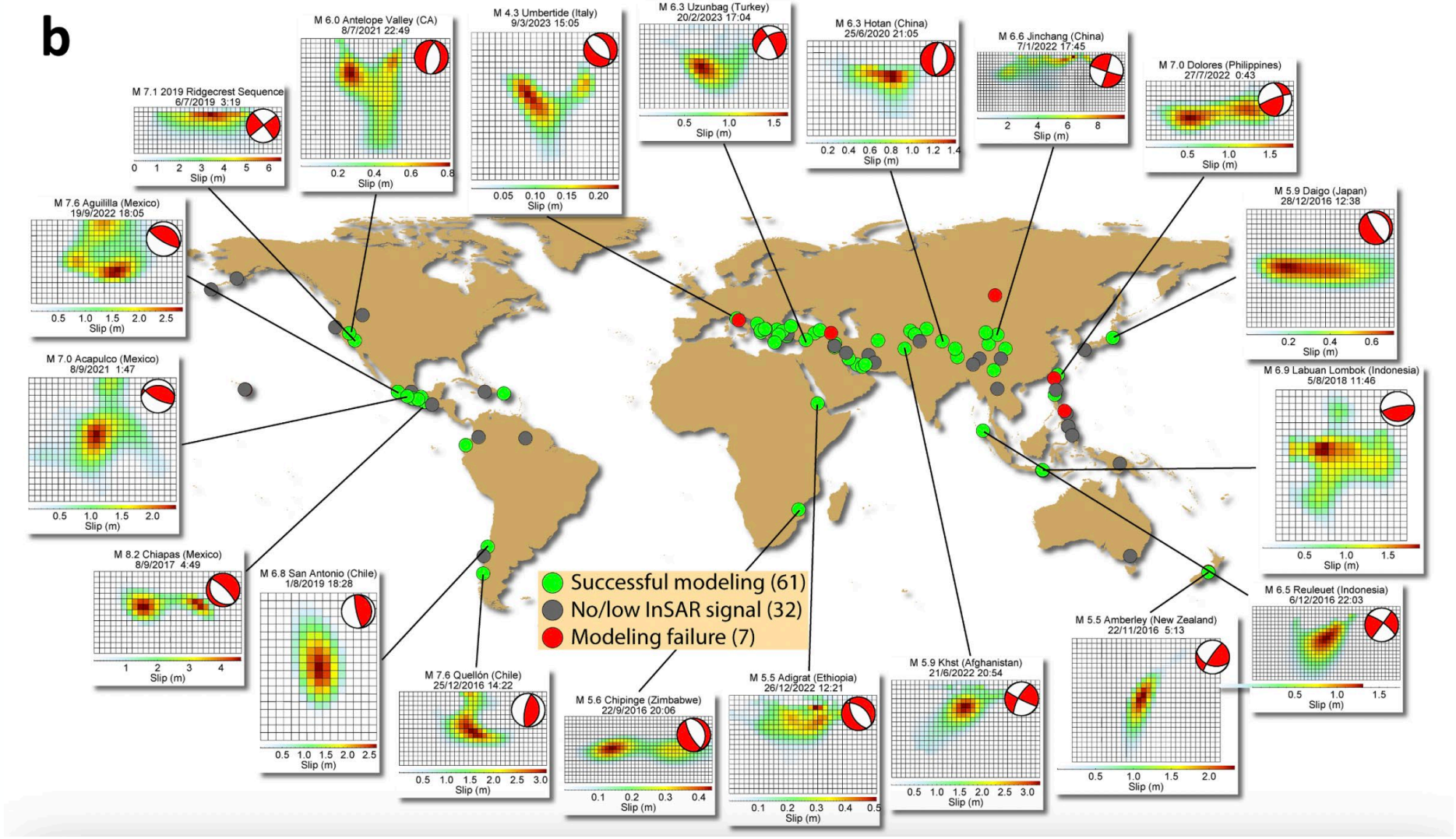
Nueva Concep. (Guatemala)
16/2/2022 M 6.2

Sarpol-e Zahab (Iran)
6/1/2019 M 5.6

Amberley (New Zealand)
13/11/2016 M 7.8

Unalaska (Alaska)
22/1/2022 M 6.2

Experimental Results (100 Earthquakes)

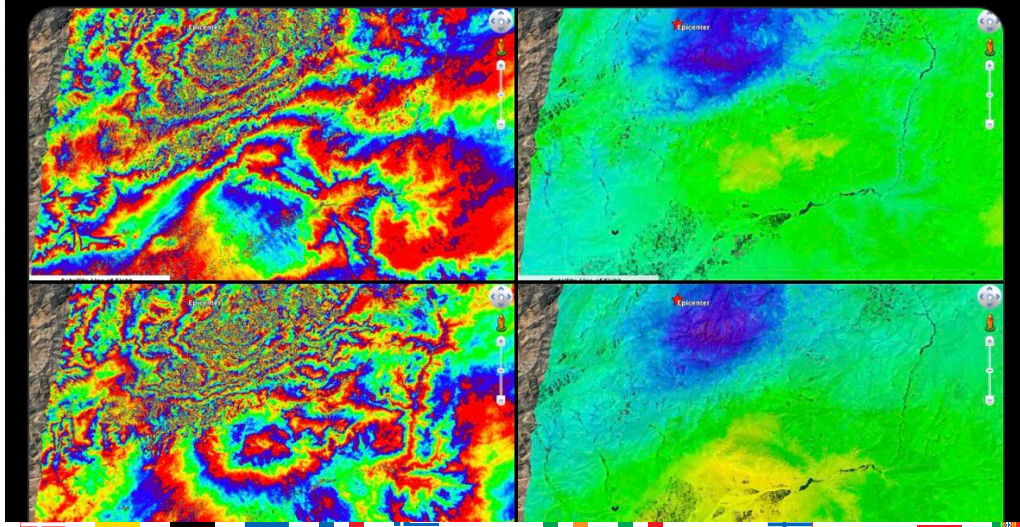


Operational services
EPOSAR: Automatic generation of co-seismic displacement maps

Coseismic interferograms for Morocco Earthquake Descending Orbit 154

Fernando Monterroso
@maferp_13

The #Sentinel1 co-seismic interferogram and LOS Displacement map of the recent #MoroccoEarthquake (Mw 6.8), You can find this and other DInSAR co-seismic products on the
@EPOSeu geoportal
@CnrIrea
@FraxInSAR
@claudiodeluca
@SimoneAtzori73
@dott109
Traducir post

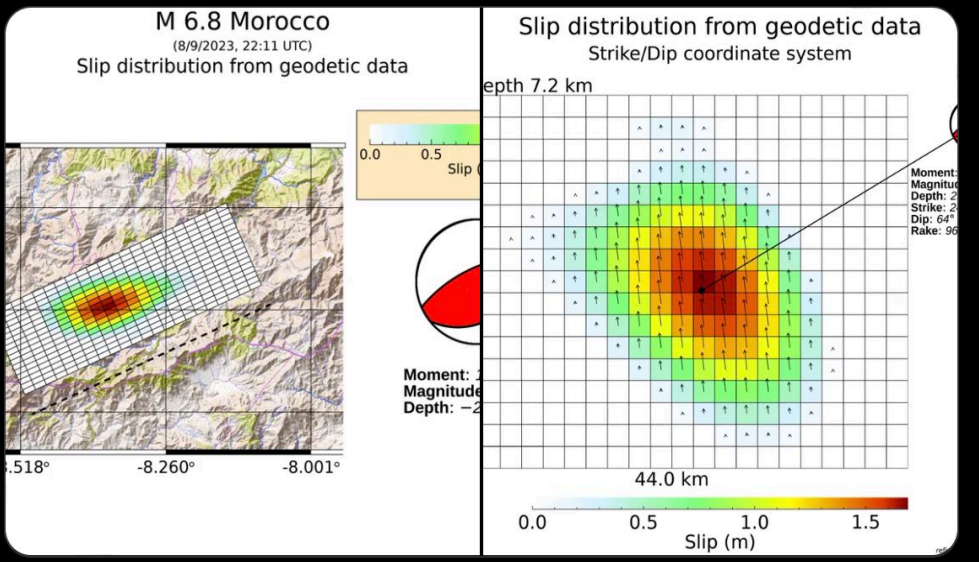


Simone Atzori
@SimoneAtzori73

Source model of the M 6.7 #moroccoearthquake derived from inversion of #InSAR data (see cited tweet).

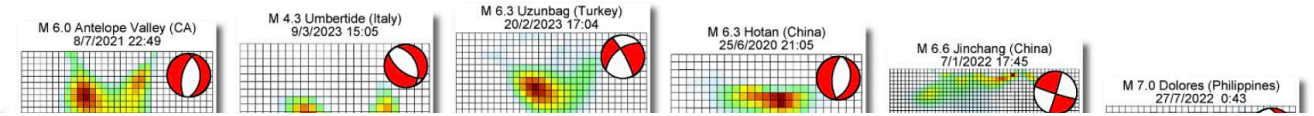
More info, model and sampled InSAR data for download (shapefile) here: terremoti.ingv.it/en/finitesourc.. ("finite source" tab)

With @antandre71 @maferp_13 @FraxInSAR @dott109
Traducir post



Experimental Results (100 Earthquakes)

b



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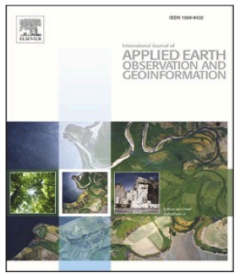
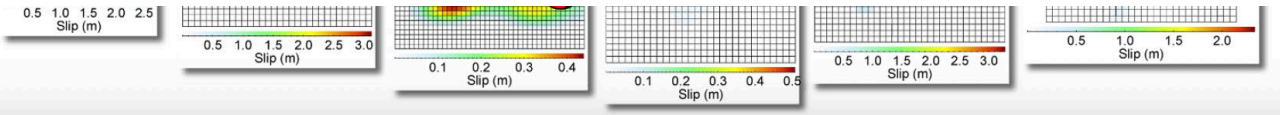


Automatic seismic source modeling of InSAR displacements

Simone Atzori [a,*], Fernando Monterroso [b], Andrea Antonioli [a], Claudio De Luca [b], Nikos Svigkas [a], Francesco Casu [b], Michele Manunta [b], Matteo Quintiliani [a], Riccardo Lanari [b]

[a] *Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy*
[b] *Istituto per il Rilevamento Elettromagnetico dell'Ambiente, Naples, Italy*



Conclusions and Future Advances

- We create a instrument for a quick and robust identification of the source parameters after an earthquake
- We developed an active service with future M > 5.5 events at global scale
- Extension of the catalog to all the sources detected with InSAR since 2015 (Sentinel-1)
- Consolidation of formats and metadata within EPOS, TCS-SATD to be published available for the scientific community
- System preparation for incoming SAR missions (NISAR, NASA-ISRO)
- Extension to multiple source modeling with AI

Thank you!

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@maferp_13
@SimoneAtzori73

Paper published 18 August 2023

https://www.sciencedirect.com/science/article/pii/S1569843223002698

The catalog of sources

http://terremoti.ingv.it/finitesource

The catalog EPOSAR service

https://www.ics-c.epos-eu.org/