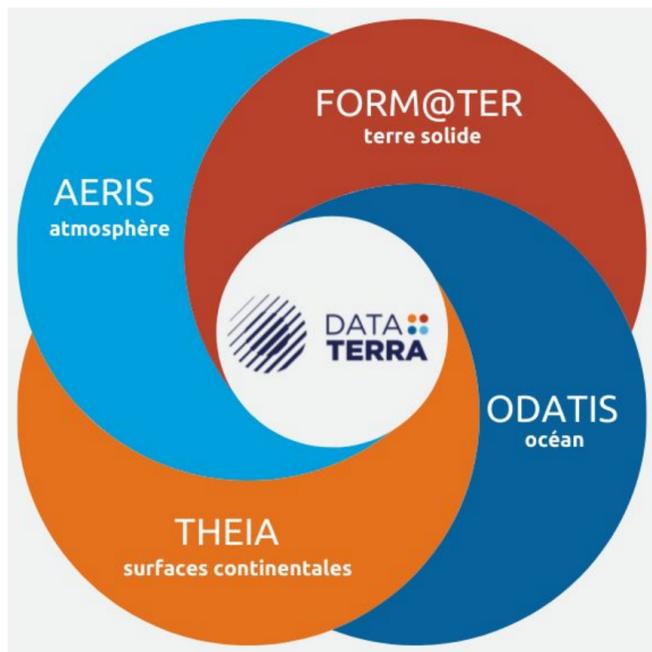


# Les produits Data-Terra / ForM@Ter GDM-OPT de mouvement du sol : cartographies des ruptures de surface des séismes de Turquie-Syrie (2023) par mesures des décalages d'images optiques satellitaires

Floriane Provost, Jean-Philippe Malet, Frédéric Masson, Volkan Karabacak, David Michéa, Jérôme van der Woerd, Mustapha Meghraoui, Mathieu Ferry, Elisabeth Pointal



Données et services pour la Terre solide  
[www.poleterresolide.fr](http://www.poleterresolide.fr)



# Data-Terra / ForM@Ter - Pôle Terre Solide

## Service d'accès aux données (entrepôt, données satellitaires)

## Services de calcul

**APPLICATIONS**

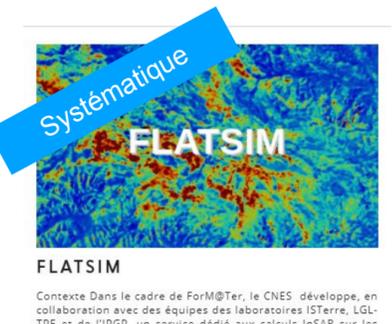
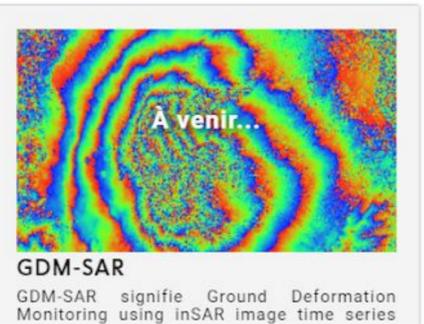
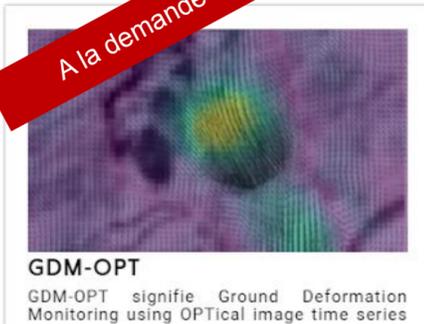
Zones de failles actives et systèmes magmatiques, glissements de terrain et déformations lithosphériques à l'échelle des grands massifs.

**SUIVI SPATIAL ET TEMPOREL DE RÉGIONS CRITIQUES**

**CALCUL DE LA DEFORMATION DU SOL PAR IMAGERIE SPATIALE**

A la demande

Systématique



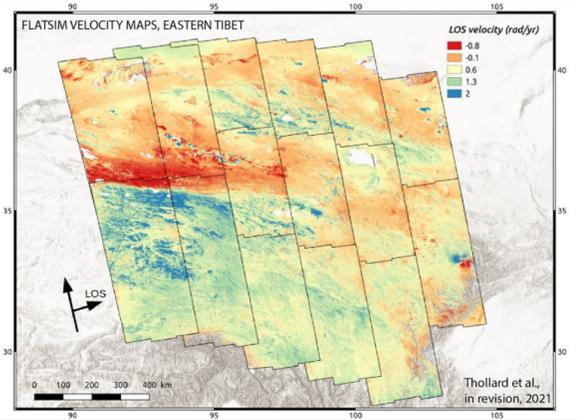
Activation de l'initiative **CIEST<sup>2</sup>**

**ERUPTION DE LA SOUFRIÈRE SAINT-VINCENT: EVALUER LES ALÉAS VOLCANIQUES EN TEMPS RÉEL GRÂCE À L'IMAGERIE OPTIQUE HAUTE-RÉSOLUTION**

**Données : missions satellitaires, instruments in-situ, résultats d'expériences, de modélisation et de simulations.**

**Services de calcul intensif (à la demande, systématique)**

**Service d'accès aux données spatiales (CIEST2)**



# l'exemple de la crise sismique de Turquie

## 6 février 2023

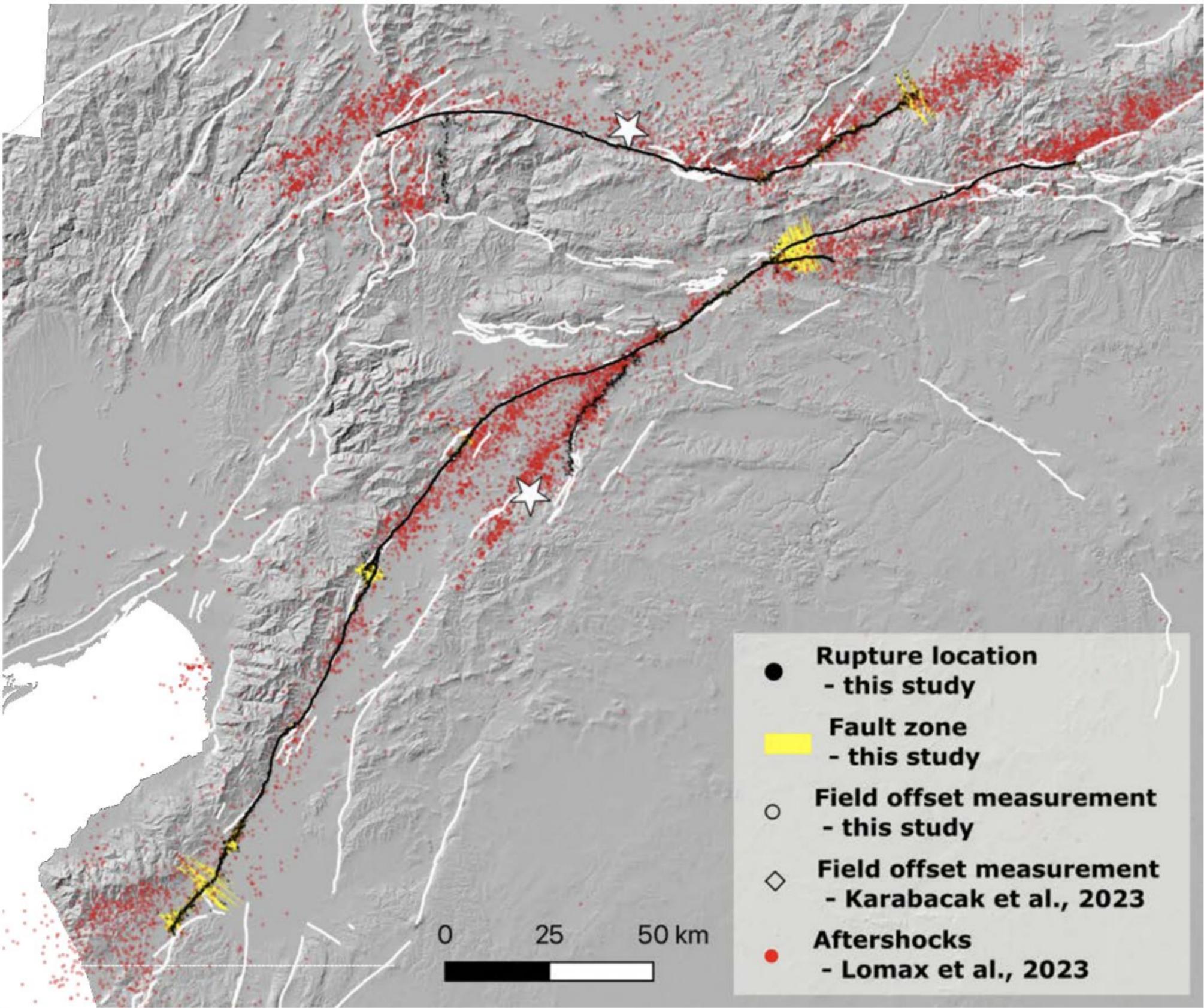
### Contexte géodynamique



Séquence de séismes de 2023 :

2 événements en décrochement sénestre sur la faille Est-Anatolienne et la faille de Cardak ★

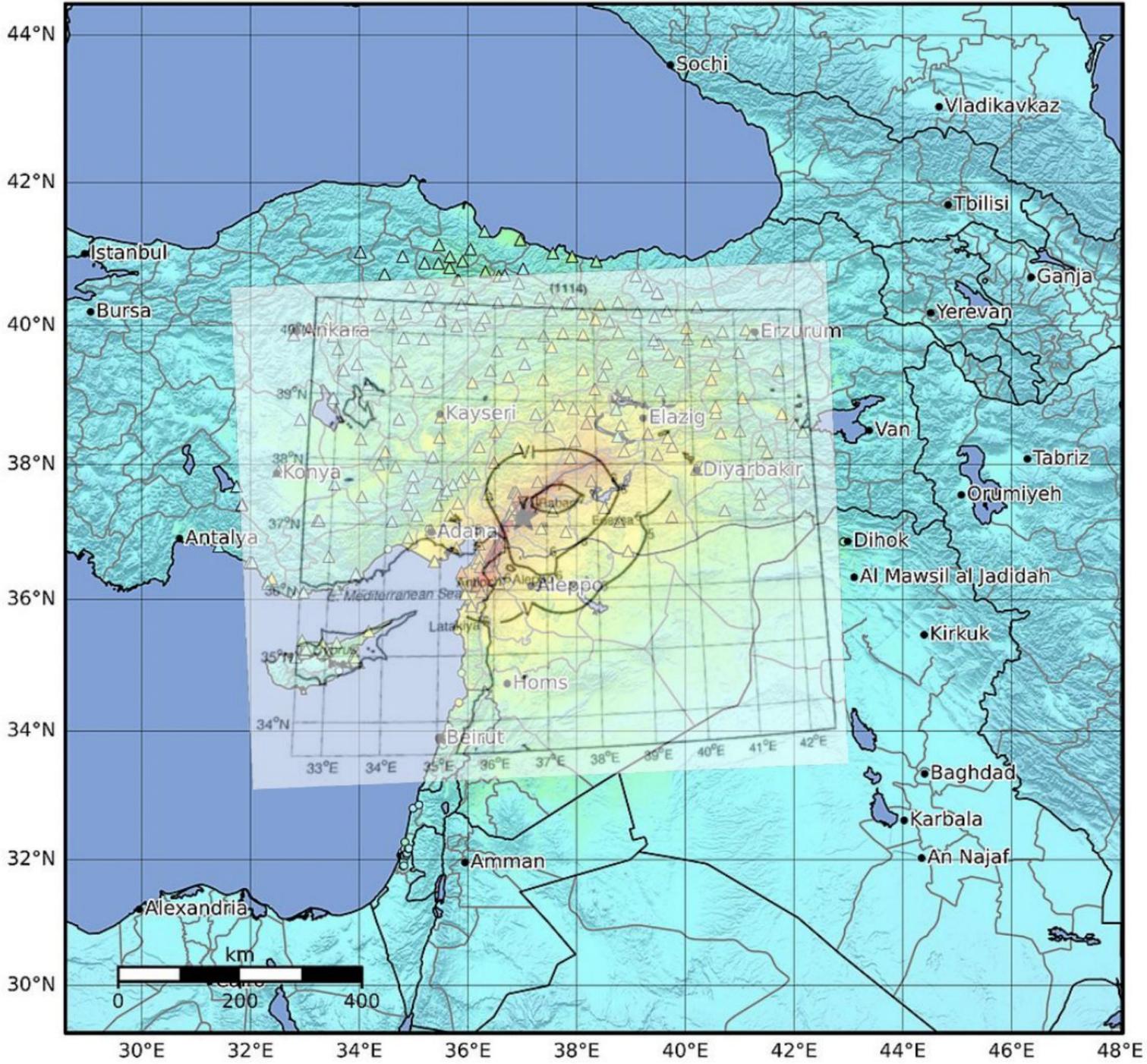
# La rupture et la sismicité



Provost et al. (2023)

# Sismicité historique

Macroseismic Intensity Map USGS  
 ShakeMap: 25 km ENE of Nurdağı, Gaziantep, TR  
 Feb 06, 2023 01:17:34 UTC M7.8 N37.22 E37.02 Depth: 10.0km ID:us6000jllz



Comparaison des champs macrosismiques du séisme de Karamanmaras et de 1114 (carte de N. Ambraseys)

SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0464	0.297	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

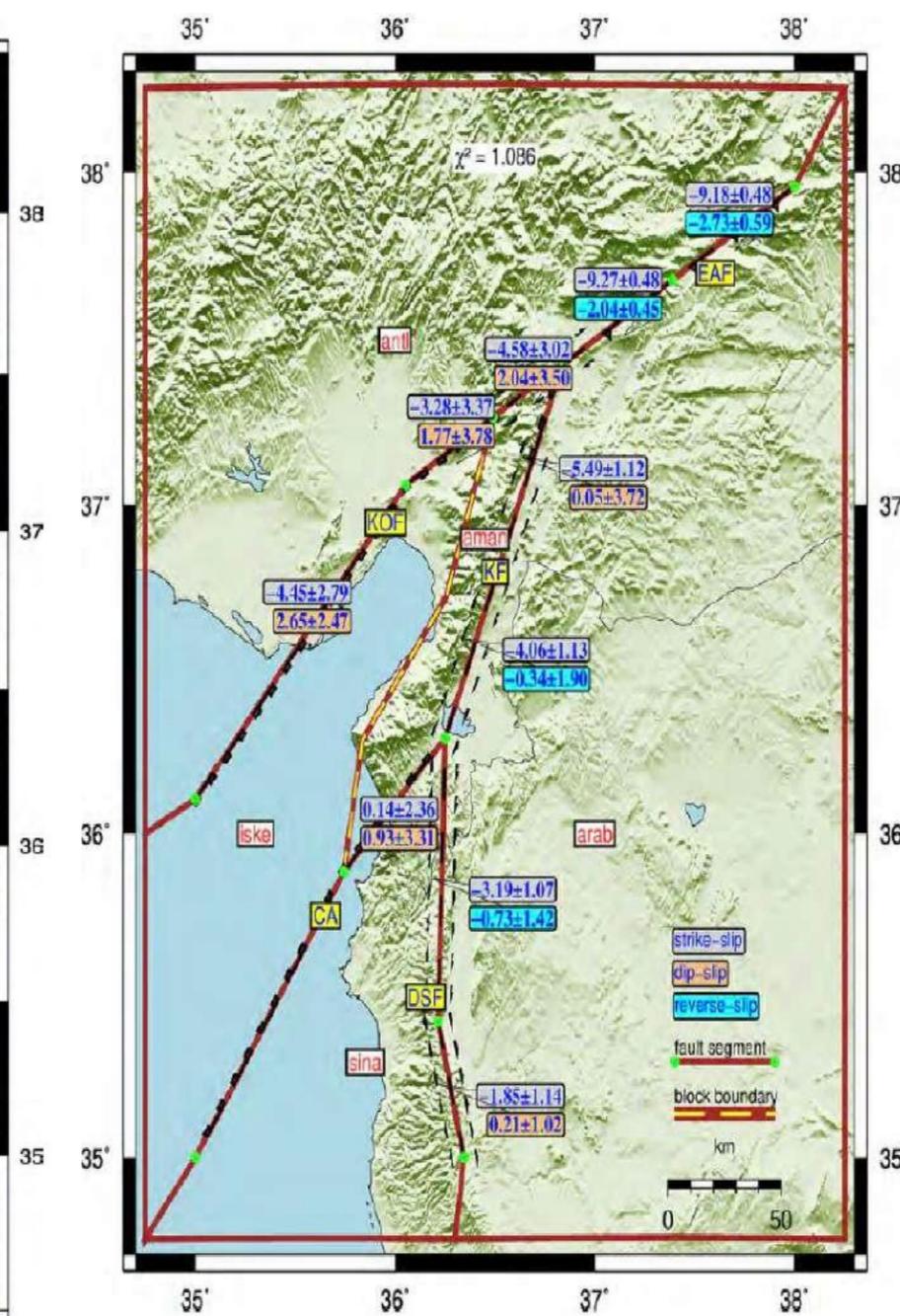
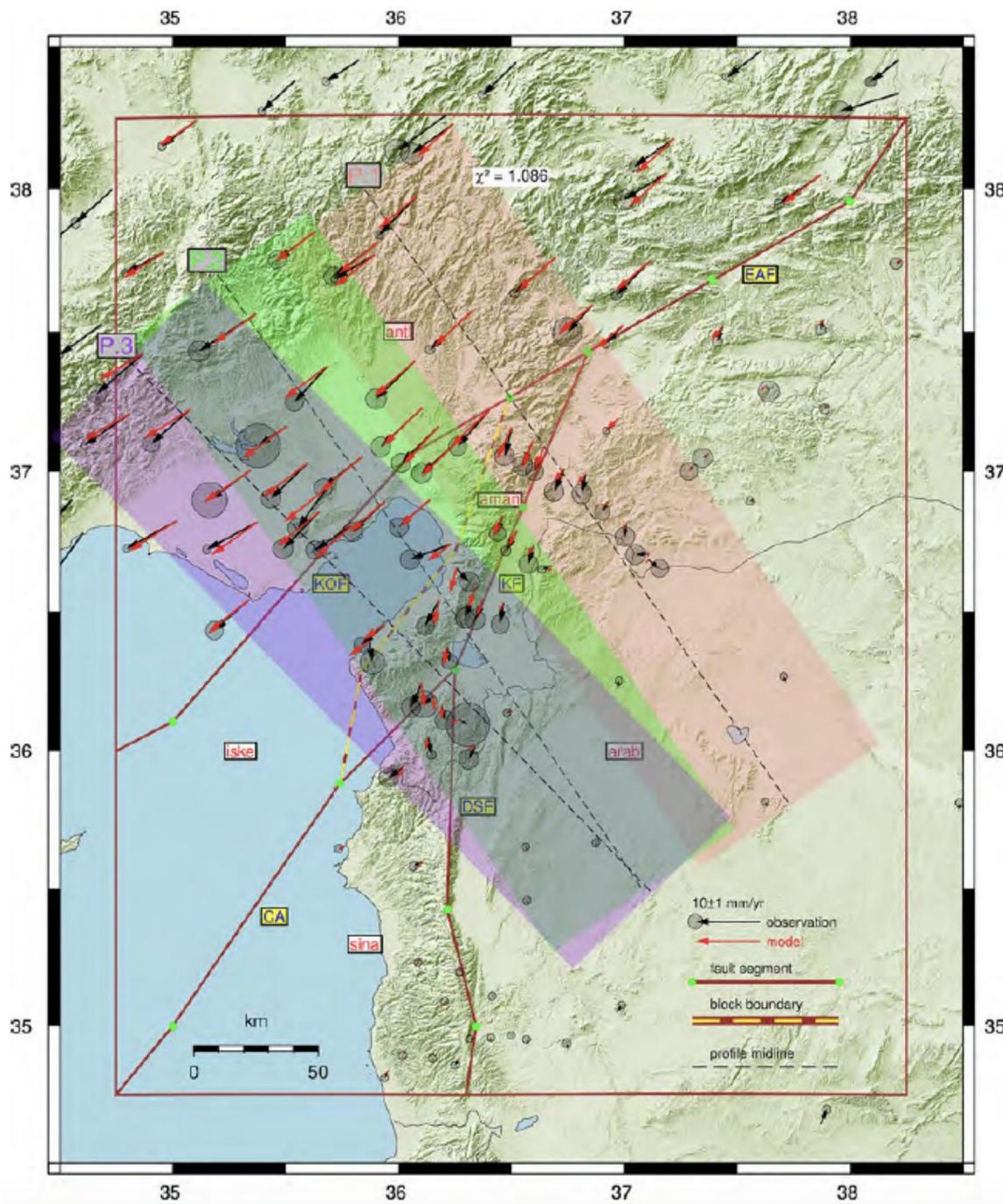
Scale based on Worden et al. (2012) Version 15: Processed 2023-03-09T21:13:16Z  
 Δ Seismic Instrument ○ Reported Intensity ★ Epicenter □ Rupture



# Cinématique des failles de la jonction triple (campagnes GNSS)

Present-day strain accumulations and fault kinematics at the Hatay Triple Junction using new geodetic constraints

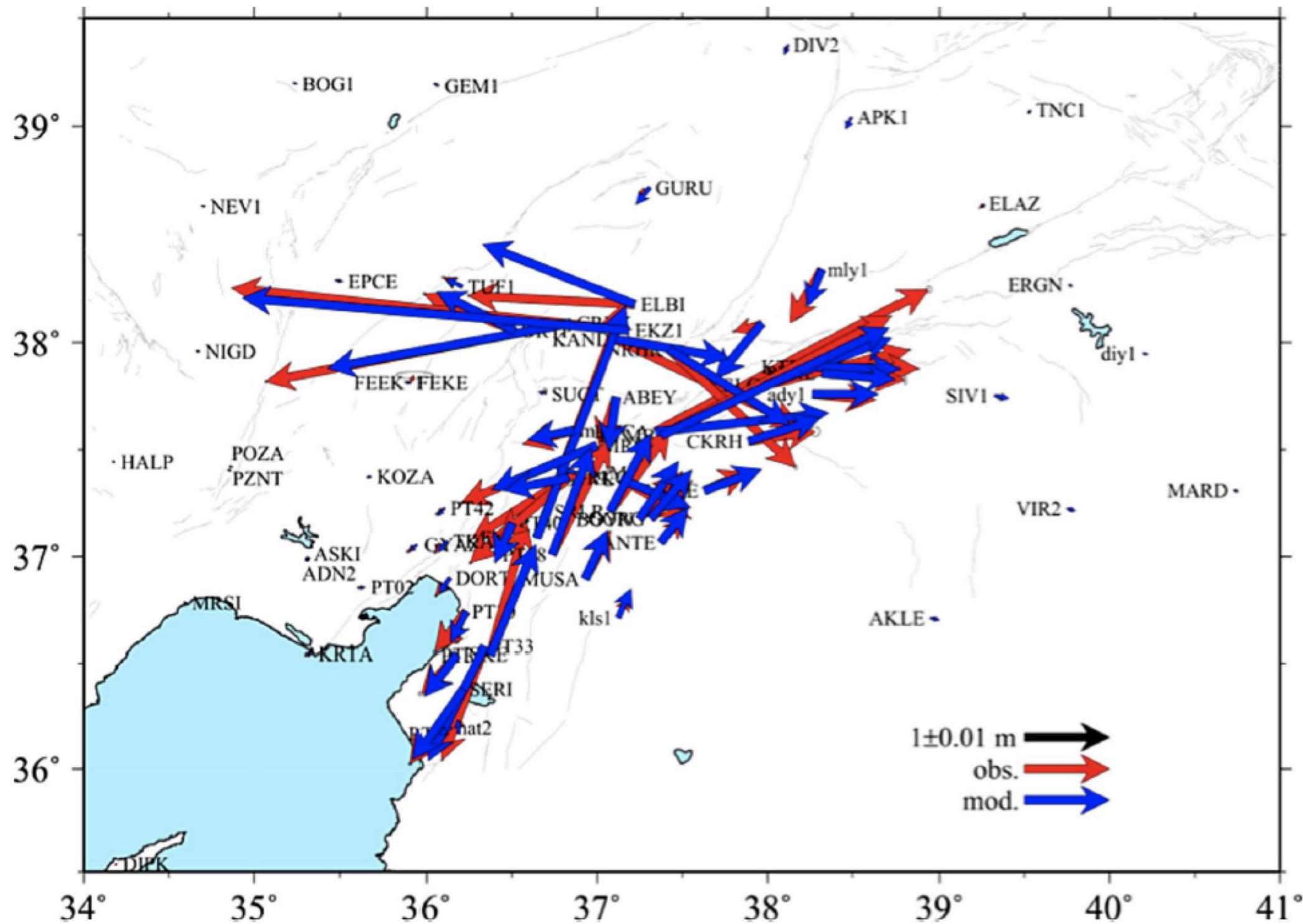
Ali Özkan <sup>a,\*</sup>, Hasan Hakan Yavaşoğlu <sup>b</sup>, Frédéric Masson <sup>c</sup>



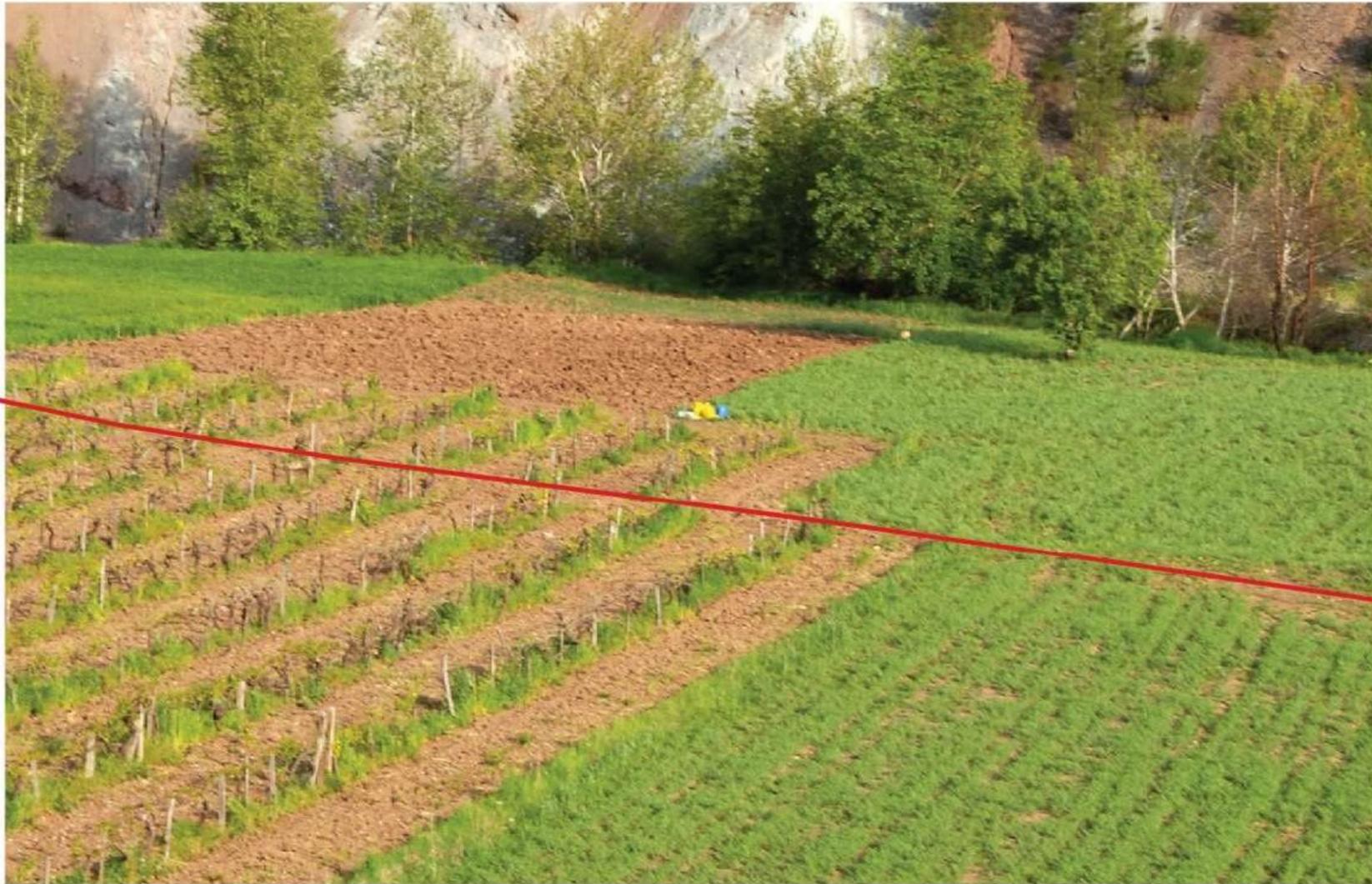
# Mouvement co-sismique (campagnes GNSS)

Characterization of the co-seismic pattern and slip distribution of the February 06, 2023, Kahramanmaraş (Turkey) earthquakes ( $M_w$  7.7 and  $M_w$  7.6) with a dense GNSS network

Ali Özkan<sup>a</sup>, Halil İbrahim Solak<sup>b,d</sup>, İbrahim Tiryakioğlu<sup>c,d</sup>, Murat Doruk Şentürk<sup>e</sup>, Bahadır Aktuğ<sup>e</sup>, Cemil Gezgin<sup>f</sup>, Fatih Poyraz<sup>g</sup>, Hüseyin Duman<sup>g</sup>, Frédéric Masson<sup>h</sup>, Göksu Uslular<sup>i</sup>, Cemal Özer Yiğit<sup>i</sup>, Hasan Hakan Yavaşoğlu<sup>i,k,\*</sup>



# Déformations du sol par observation in-situ (mai 2023)



# Déformations du sol par observation in-situ (mai 2023)



# Déformations du sol par observation in-situ (mai 2023)



# Déformations du sol par observation in-situ (mai 2023)



Déplacement de 7 m

# Le service en ligne de calcul GDM-OPT

- corrélation de séries temporelles d'images satellites optique
- service numérique opéré par ForM@Ter pour l'usage de communautés de recherche qui exploitent le service (ISDeform, OMIV, GlacioClim, etc ...)

ON DEMAND PROCESSING | GDM-OPT

SELECT A SERVICE RESULTS OF PROCESSING

Log as jeanphilippe.malet@unistra.fr

GDM-OPT-ETQ

Reset

Collection: SENTINEL-2ST

Temporal Extent: Define the period of analysis for the image selection. From: 01/11/2015, To: 16/11/2021

Region of Interest: Draw bounding box on map or select a S2 tile. Tile: MGRS identifier like 30U

Filters: Processing parameters

- Job name: [input field]
- Correlation Module:
  - Images input:  $2 \leq N \leq 4$
  - Use Region of Interest:
  - DEM: Copernicus
  - Image band: B04
  - Matching mode: Acquisitions
  - Maximum matching range: 2
  - Minimum matching range: 2
  - Matching direction: Forward
  - Split date: dd/mm/yyyy
- MicMac parameters:
- Mask:
- Correction Module:

About: GDM-OPT stands for Ground Deformation Monitoring with OPTical image time series. The service is developed and maintained by CNRS/EOST (Strasbourg) with contribution of IGN/Matis (M. CNRS/IPGP (Paris)). The service allows the processing of optical image pairs for the monitoring of Earth surface deformation.

The service version GDM-OPT-ETQ stands for Earthquake-triggered crustal deformation. It is designed for quantifying co-seismic deformation along faults triggered by large magnitude earthquakes. It provides:

- a component for the measurement of sub-pixel displacement among one or multiple optical image pairs (sub-pixel image correlation),
- a component for the correction of outliers and geometric residuals.

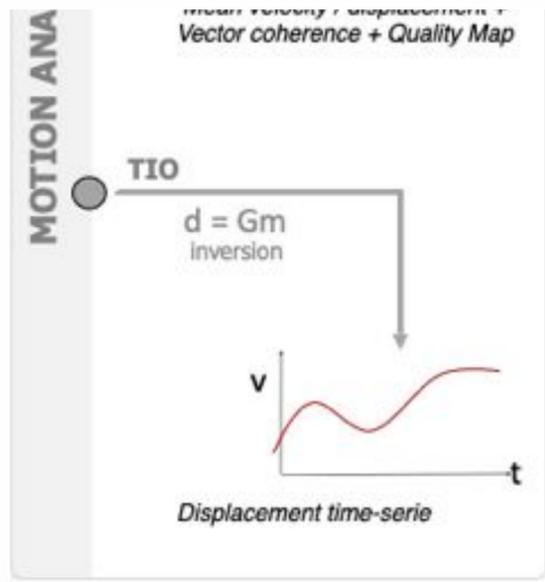
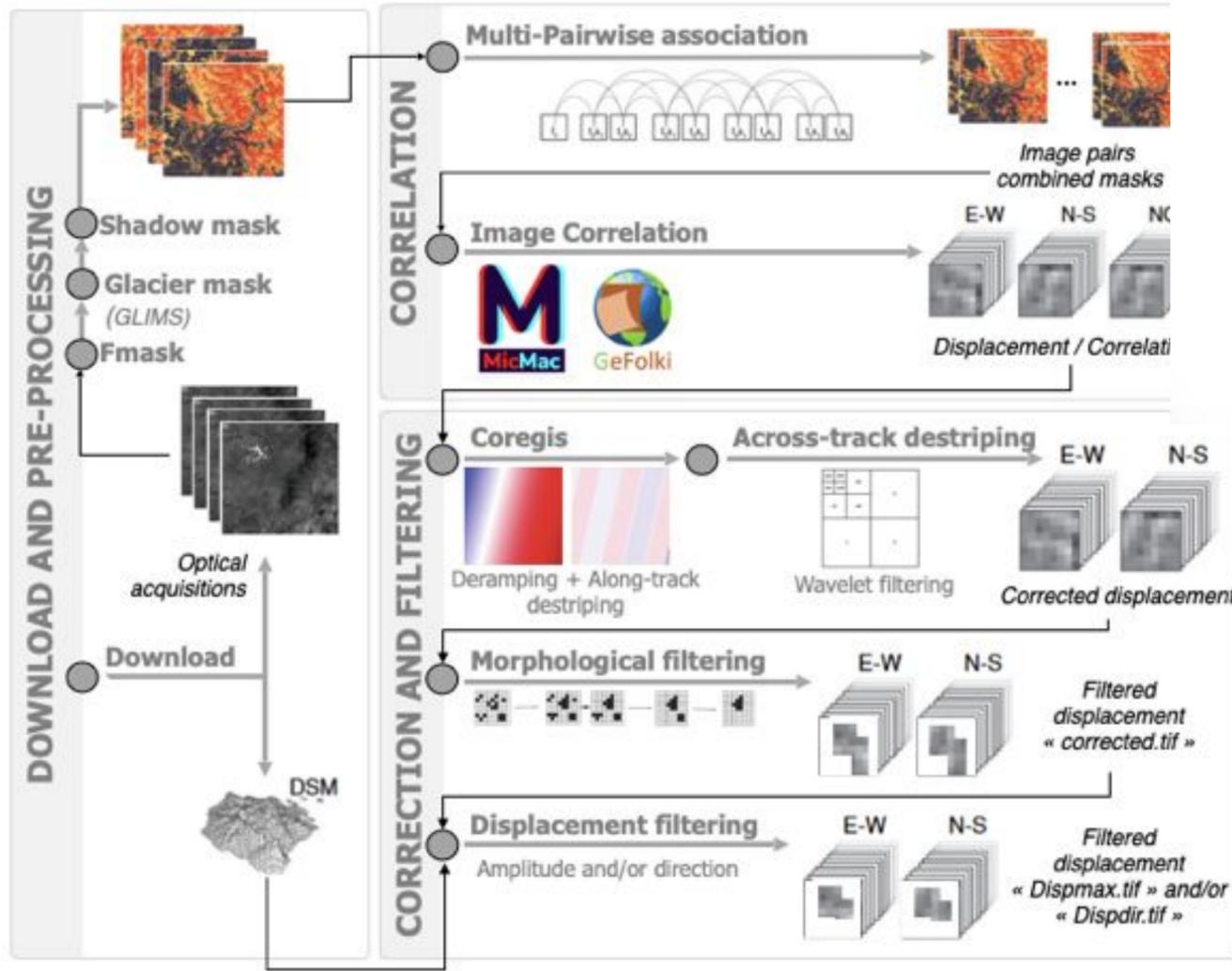
It builds on the MicMac (IGN/Matis; Rosu et al., 2015), CO-REGIS (CNRS/EOST; Stumpf et al., 2018) and FMask (Texas Tech University; Qiu et al., 2019) algorithms. The service is designed for the processing of a maximum of 4 Sentinel-2 images with 2 images before the earthquake (pre-event) and 2 images after the event (post-event). The service is available.

**GDM-OPT-ETQ**

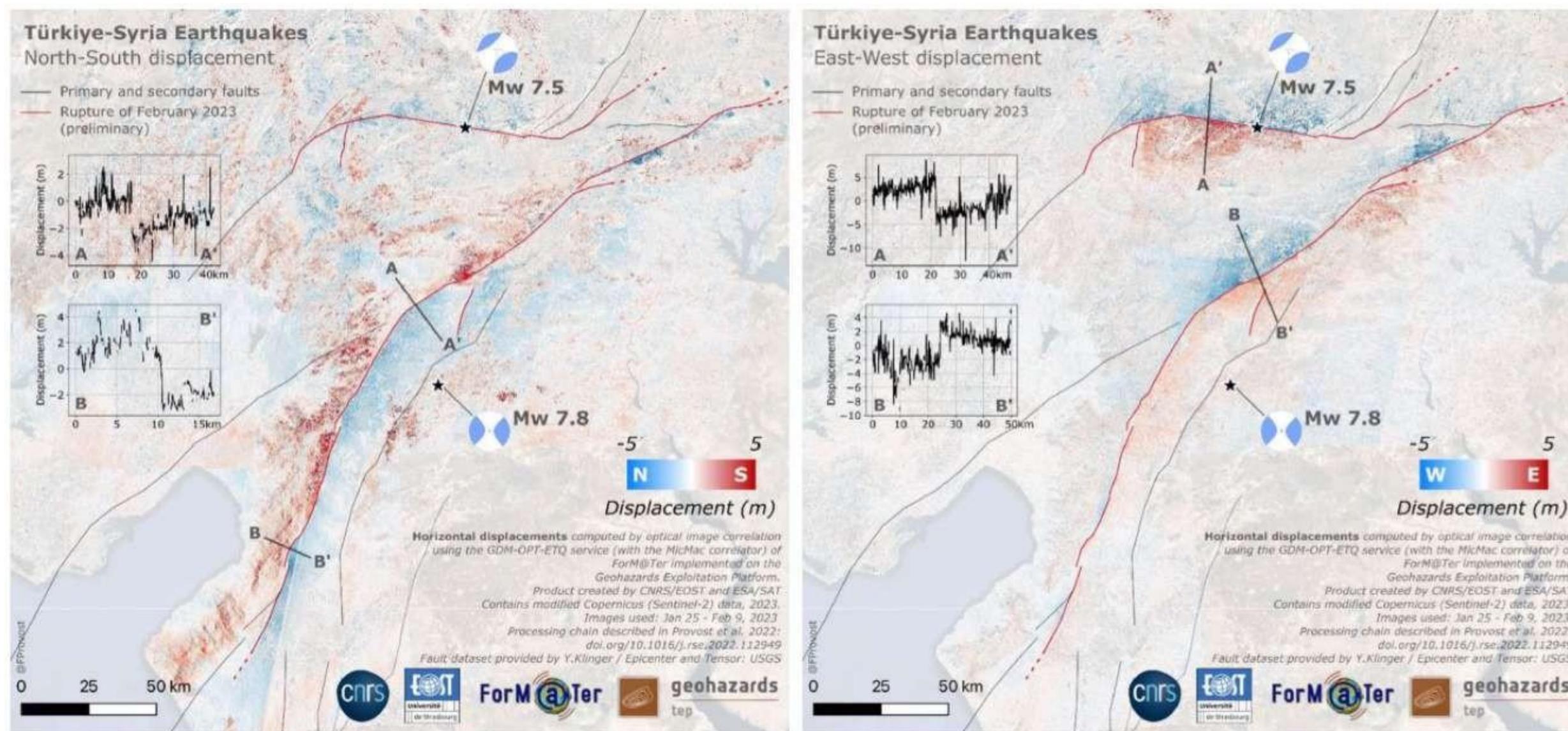
GDM-OPT stands for Ground Deformation Monitoring with OPTical image time series.

The service version GDM-OPT-ETQ stands for Earthquake-triggered crustal deformation. It is designed for quantifying co-seismic deformation along faults triggered by large magnitude earthquakes. It enables the on-demand processing of Sentinel-2 images.

Accessible to the French Solid Earth science community  
 Accessible (to be discussed) to EPOS



# Déformations du sol vues par le service optique GDM-OPT



Provost et al. (2023)

## Le service ForM@Ter GDM-OPT-ETQ

### Produit rapide :

Cartes de déplacement produites et publiées 24h après la première acquisition post-séisme (Sentinel-2, 9/02/2023)

Méthode : corrélation d'image (pre/post), approche hiérarchique sous-pixel,

Produit : 10 m de résolution spatiale, composante NS et EW du déplacement

Emprise : 9 tuiles Sentinel-2 sur une zone de 300 x 300 km → traitement intensif (HPC / EOST)

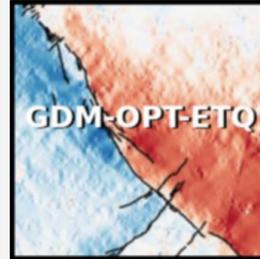
### Produit amélioré :

Pour améliorer la corrélation et pertes d'information (neige), 2 paires d'images Sentinel-2 à des périodes différentes sont combinées (25/01/23 – 9/02/23 et 20/05/22 – 5/05/23)

# Déformations du sol vues par le service optique GDM-OPT



Identifier DOI [10.25577/EWT8-KY06](https://doi.org/10.25577/EWT8-KY06)  
DataCite Metadata [HTML](#) [XML](#)  
License 



**How to cite :**  
**ForM@Ter - EOST (2023): Terrain displacement from the Turkiye-Syria earthquakes of February 6,2023 obtained with the GDM-OPT-ETQ service applied on Sentinel-2 optical imagery**

[doi:10.25577/EWT8-KY06](https://doi.org/10.25577/EWT8-KY06)

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### Description

The region along the East Anatolian Fault (EAF) has a well-known history of seismic activity. On February 6, 2023, two earthquakes of Mw 7.8 and 7.5 had devastating effects on the ground by opening large ruptures and by displacing the earth crust of 5 to 10 m locally. The longer of the two ruptures stretches nearly 300 km in the northeastern direction from the northeastern part of the Mediterranean Sea. The surface rupture was created by the first and most powerful 7.8-magnitude earthquake that triggered at 4:17 am local time; the second surface rupture of 125 km long opened during the second 7.5-magnitude earthquake about nine hours later.

By comparing several optical satellite imagery before and after the earthquake, the horizontal displacements of the ground can be calculated using image correlation (also known as offset tracking) techniques. This data release contains co-seismic horizontal displacements obtained from the analysis of Copernicus Sentinel-2 satellite imagery at 10 m spatial resolution. The dataset has been created with the GDM-OPT-ETQ service (Provost & al., 2022<sup>[1]</sup>) of the ForM@Ter solid Earth data hub using the open source photogrammetry library MicMac (Rosu & al., 2015<sup>[2]</sup>, Rupnik & al., 2018<sup>[3]</sup>). The massive processing was performed on the Geohazard Exploitation Platform (GEP).

The dataset contains the 2-dimensionsal (2D) surface displacements for the East-West (EW) and North-South (N-S) components. It has been created with the following pairs of Sentinel-2 images:

S2A\_MSIL1C\_20230209T082111\_N0509\_R121\_T36SYF\_20230209T091429.SAFE  
S2A\_MSIL1C\_20230209T082111\_N0509\_R121\_T36SYG\_20230209T091429.SAFE  
S2A\_MSIL1C\_20230209T082111\_N0509\_R121\_T37SBA\_20230209T091429.SAFE  
S2A\_MSIL1C\_20230209T082111\_N0509\_R121\_T37SBB\_20230209T091429.SAFE  
S2A\_MSIL1C\_20230209T082111\_N0509\_R121\_T37SBC\_20230209T091429.SAFE  
S2A\_MSIL1C\_20230209T082111\_N0509\_R121\_T37SBV\_20230209T091429.SAFE  
S2A\_MSIL1C\_20230209T082111\_N0509\_R121\_T37SCB\_20230209T091429.SAFE  
S2A\_MSIL1C\_20230209T082111\_N0509\_R121\_T37SCC\_20230209T091429.SAFE  
S2A\_MSIL1C\_20230209T082111\_N0509\_R121\_T37SDB\_20230209T091429.SAFE  
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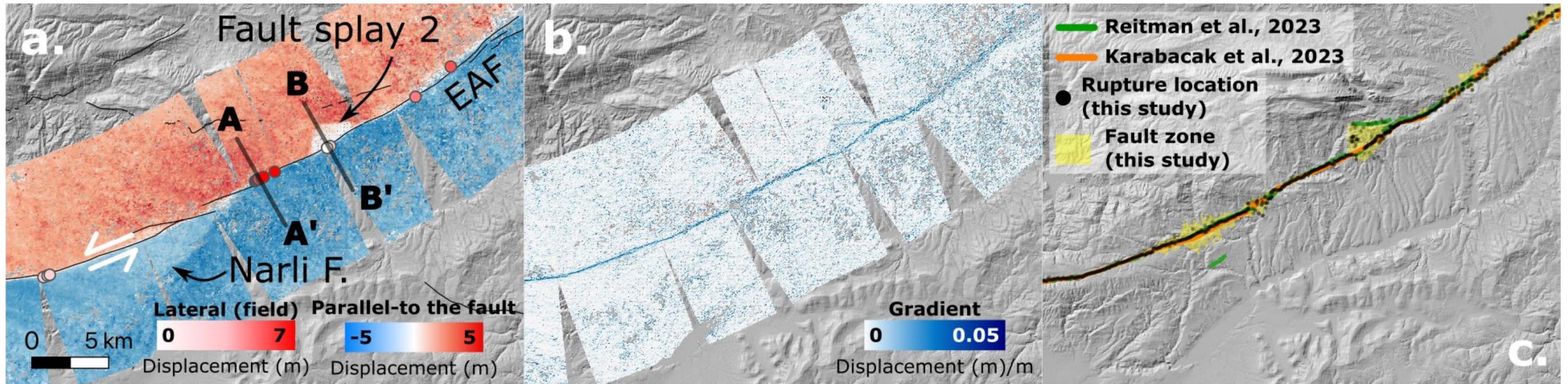
S2B\_MSIL1C\_20230125T082129\_N0509\_R121\_T36SYF\_20230125T090640.SAFE  
S2B\_MSIL1C\_20230125T082129\_N0509\_R121\_T36SYG\_20230125T090640.SAFE  
S2B\_MSIL1C\_20230125T082129\_N0509\_R121\_T37SBA\_20230125T090640.SAFE  
S2B\_MSIL1C\_20230125T082129\_N0509\_R121\_T37SBB\_20230125T090640.SAFE  
S2B\_MSIL1C\_20230125T082129\_N0509\_R121\_T37SBC\_20230125T090640.SAFE

## Produits FAIRisés :

- aux normes EPOS / TCS satellite data
- téléchargeables sur l'entrepôt ForM@Ter / CDOS "déformation"
- métacatalogue interopérable

# Déformations du sol vues par le service optique GDM-OPT

## Des produits pour cartographier la rupture - méthodologie

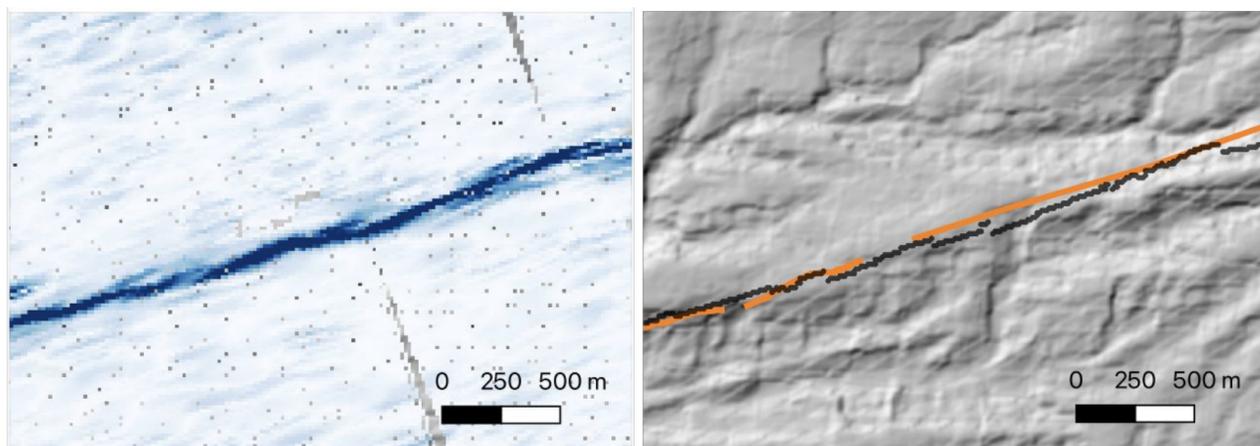


1. Compute parallel to the fault and normal to the fault displacement field

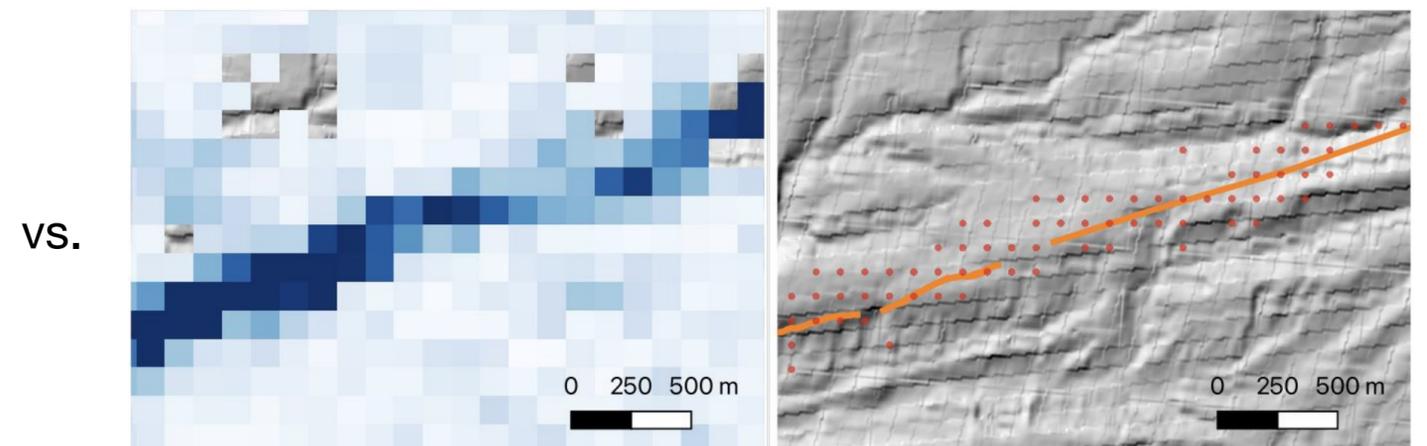
2. Compute the gradient

3. Gradient > 0.02 (m/m)

### GDM-OPT (FR) @10 m x 10 m

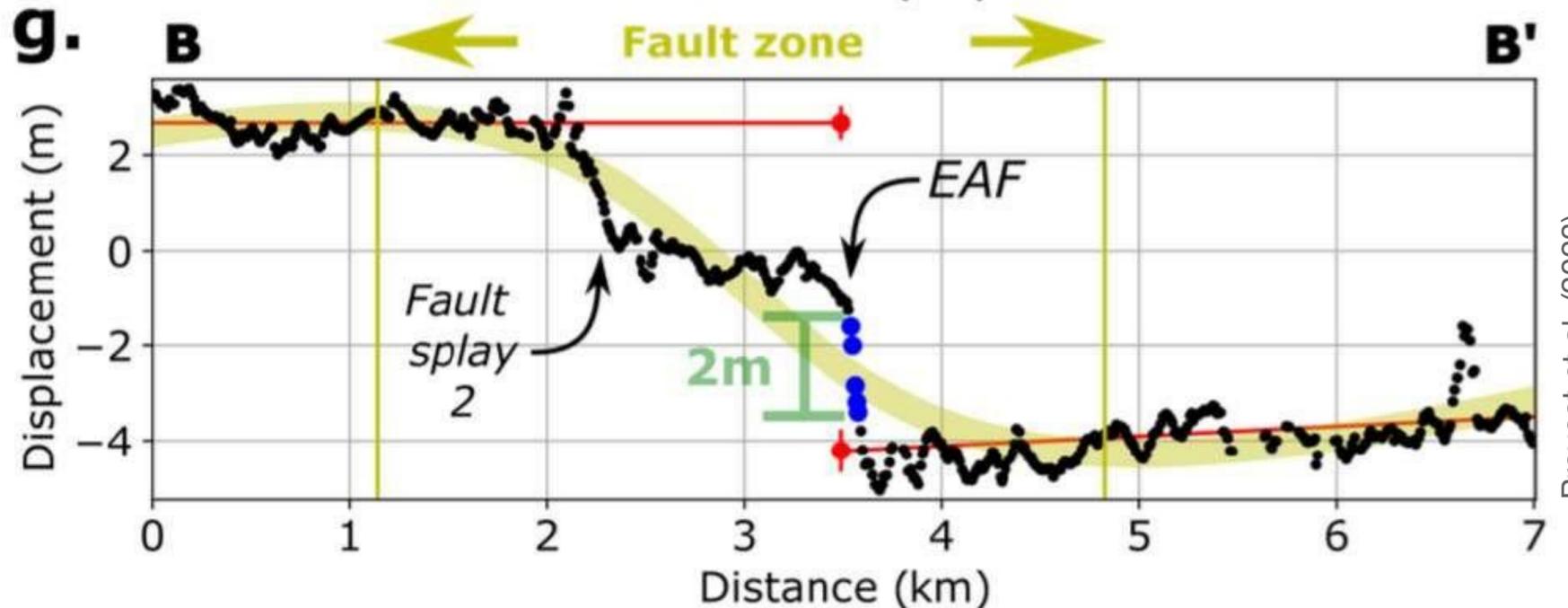
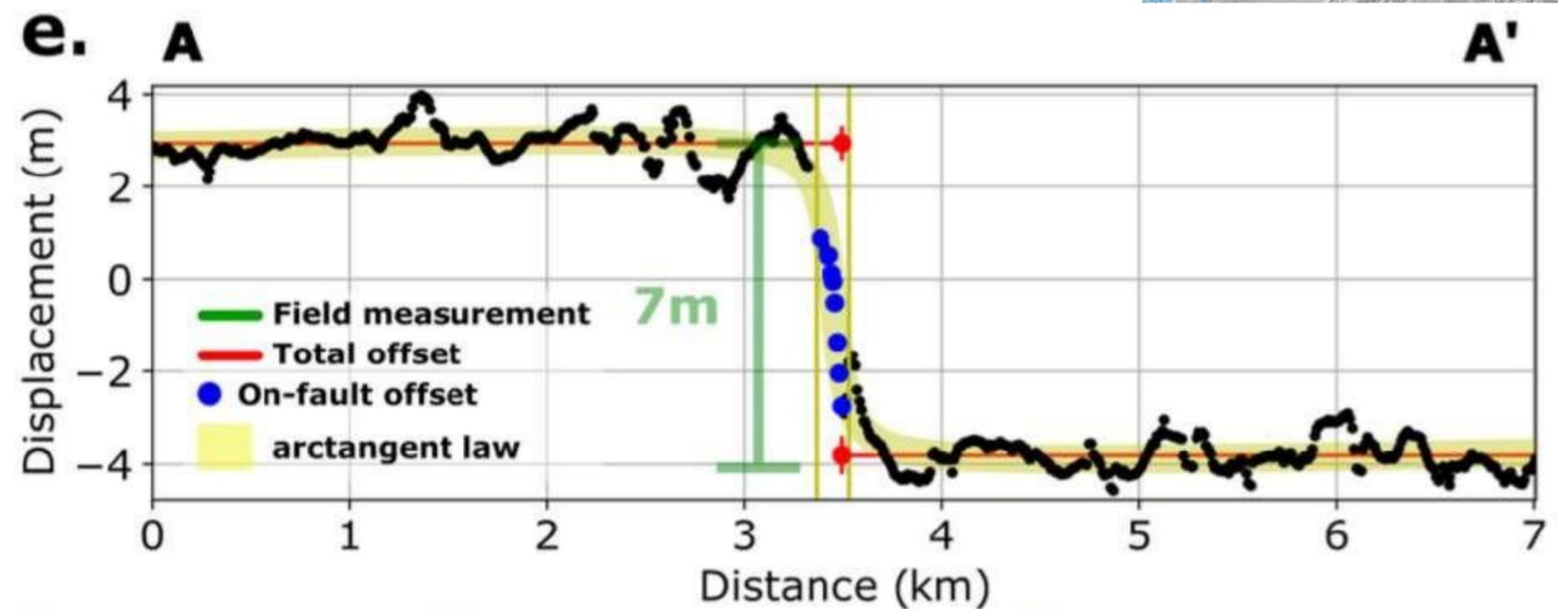
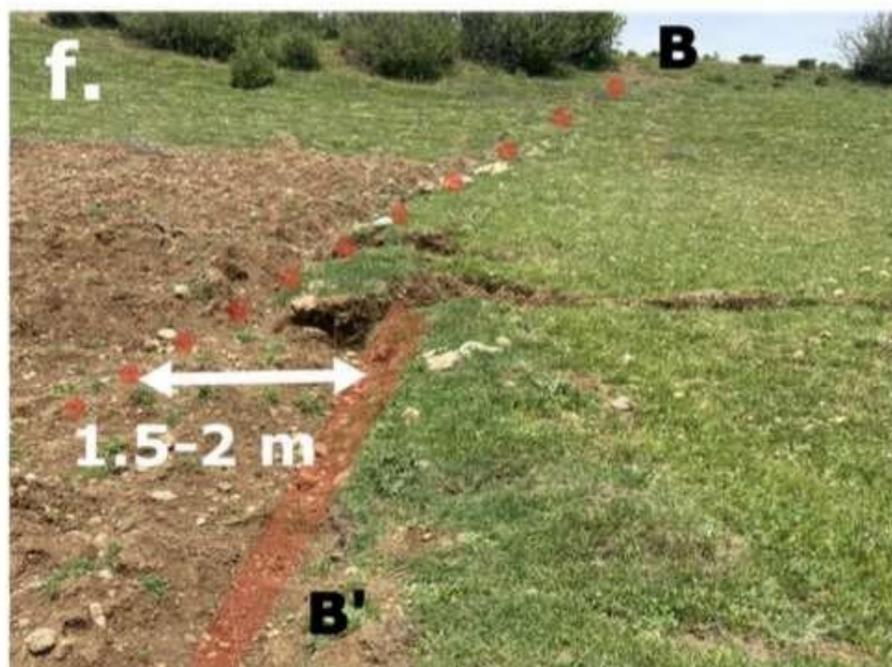
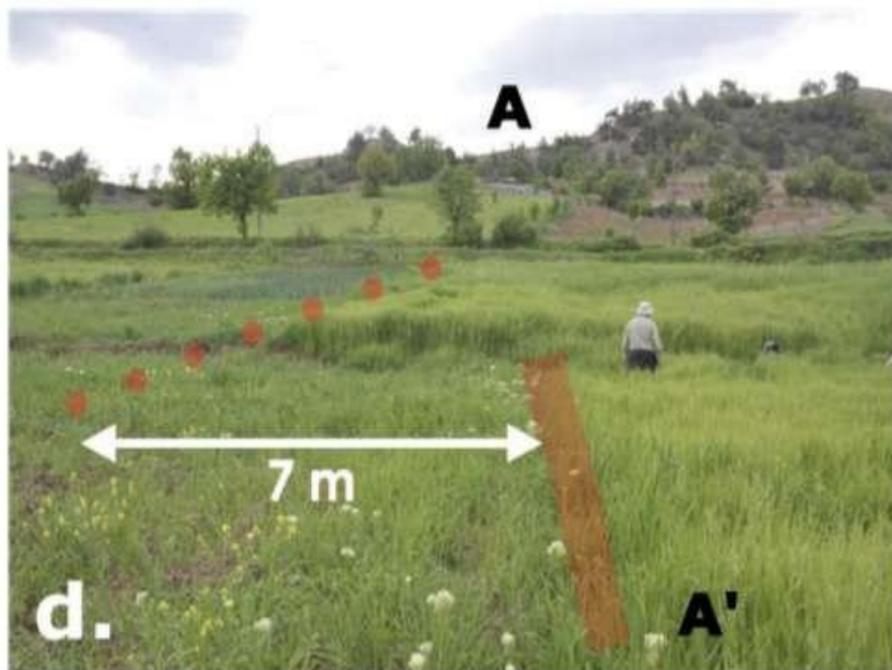
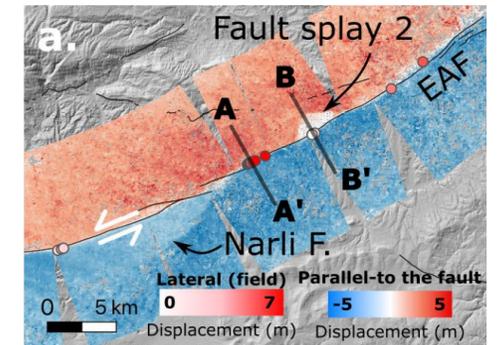


### COMET (UK) @100 m x 100 m

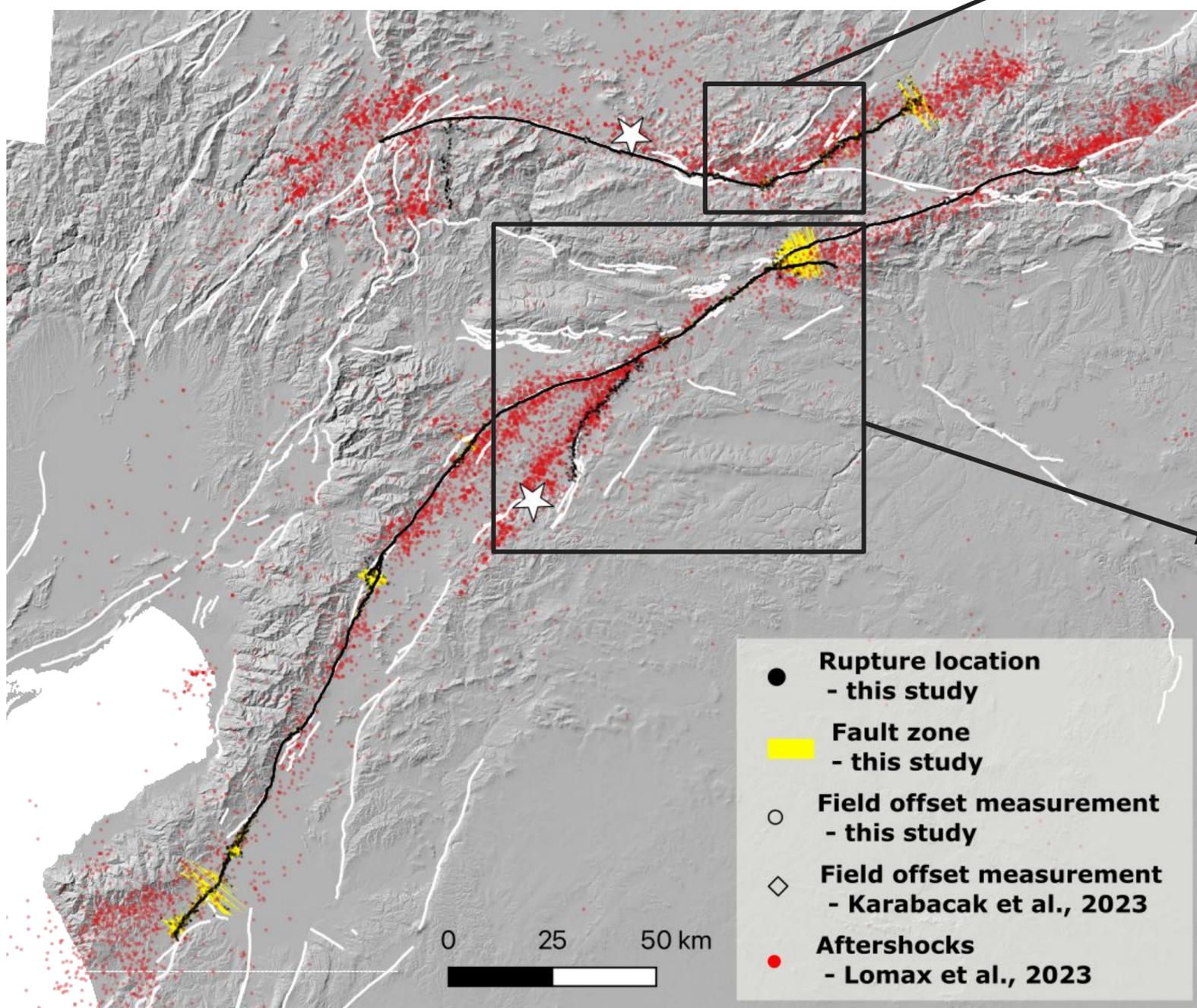


# Déformations du sol vues par le service optique GDM-OPT

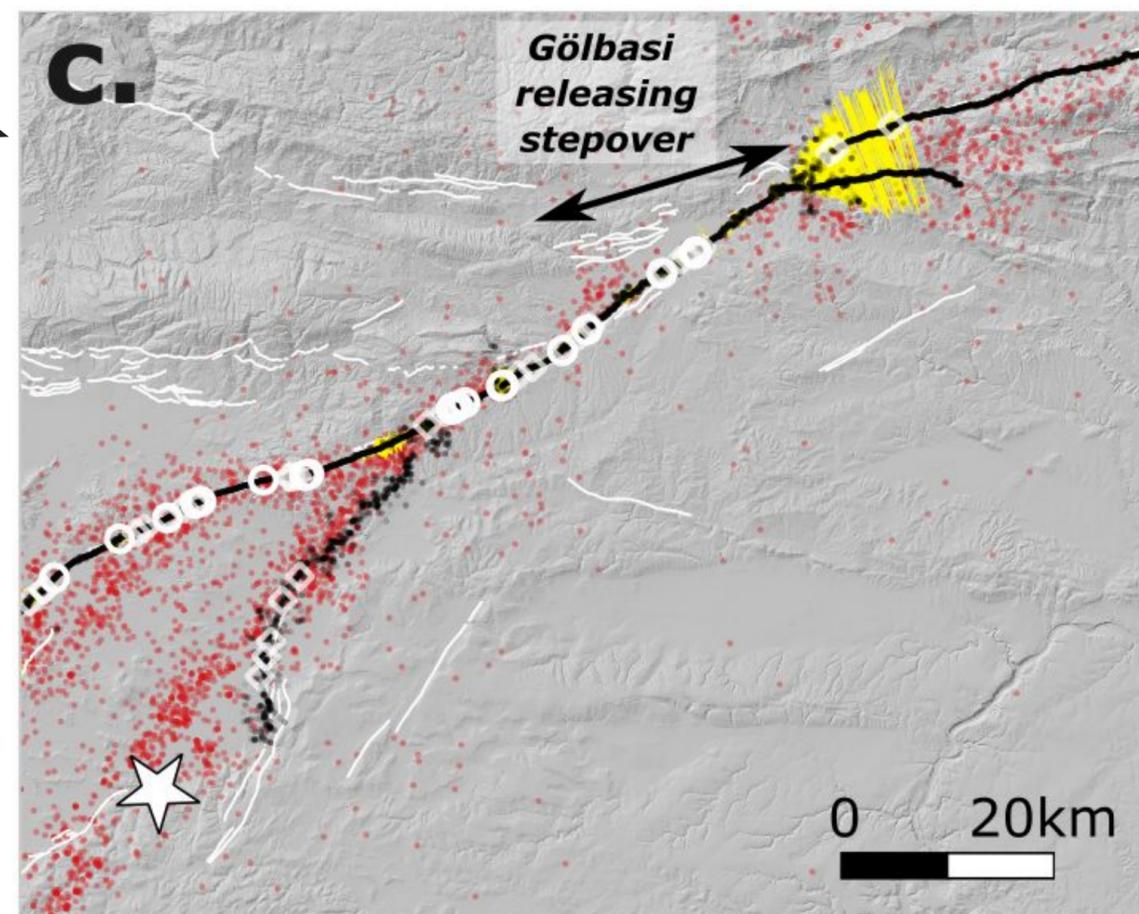
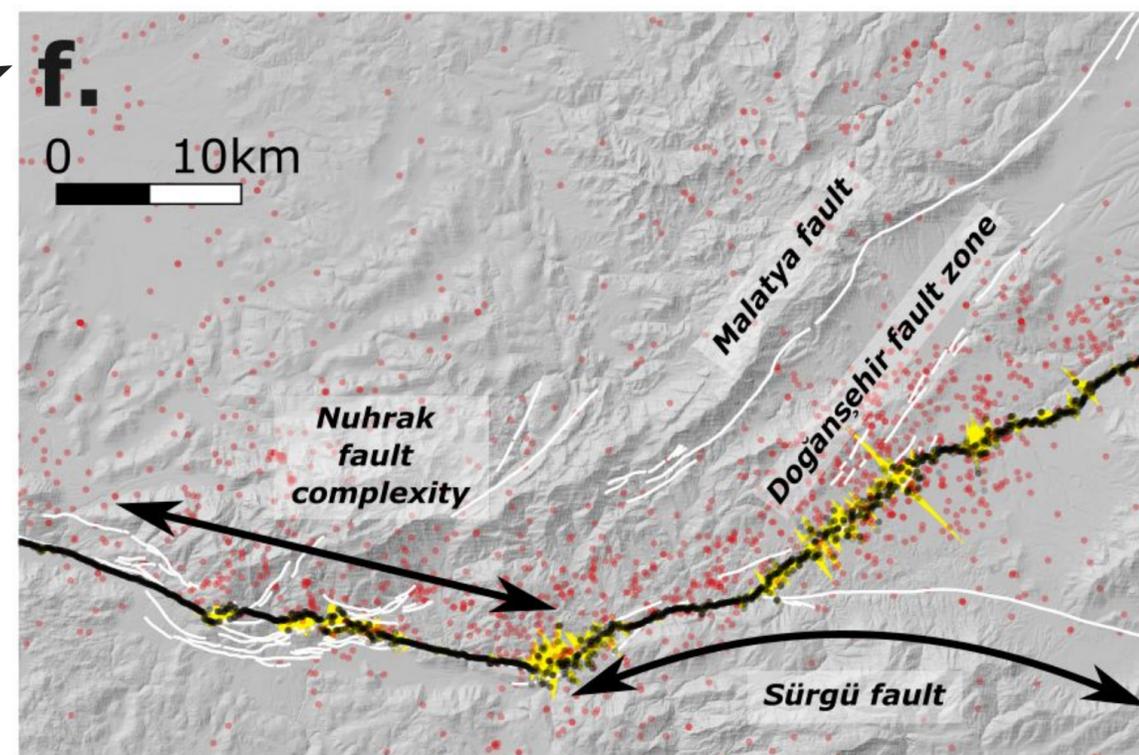
Identification de la largeur et de la géométrie de la rupture et l'amplitude du décalage à partir des données Sentinel-2



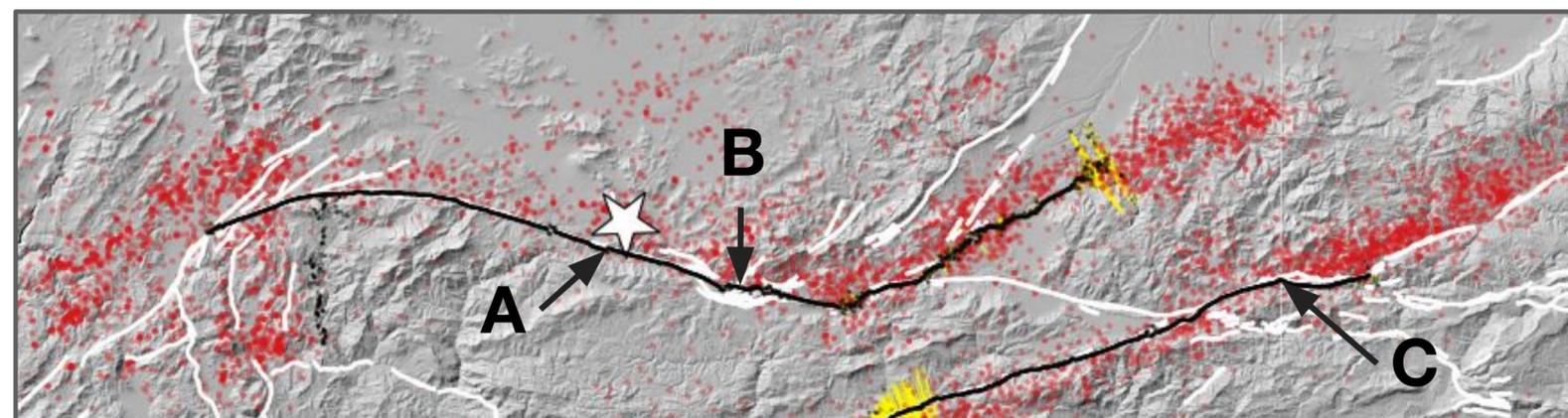
# Déformations du sol vues par le service optique GDM-OPT



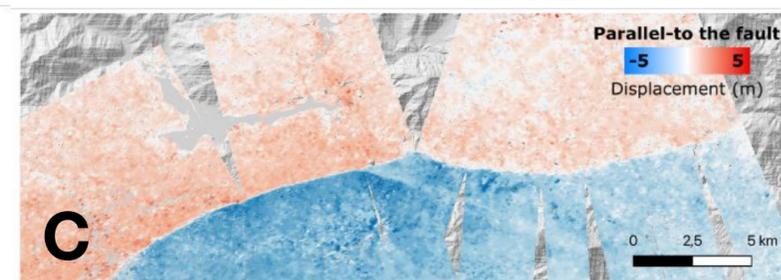
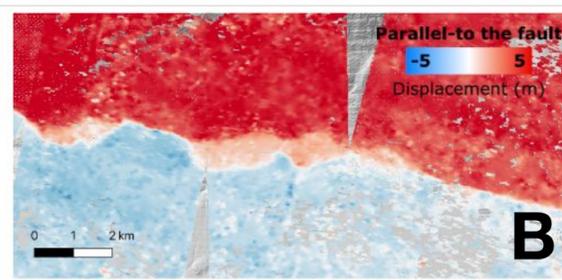
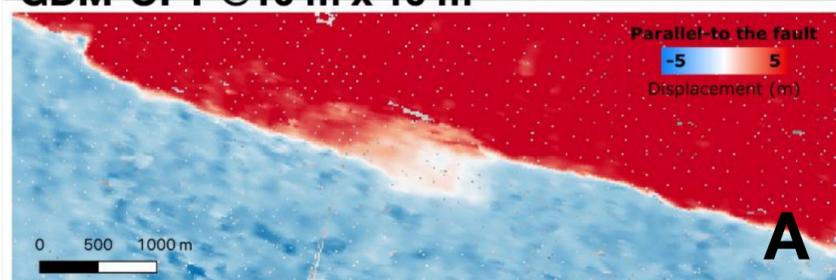
Provost et al. (2023)



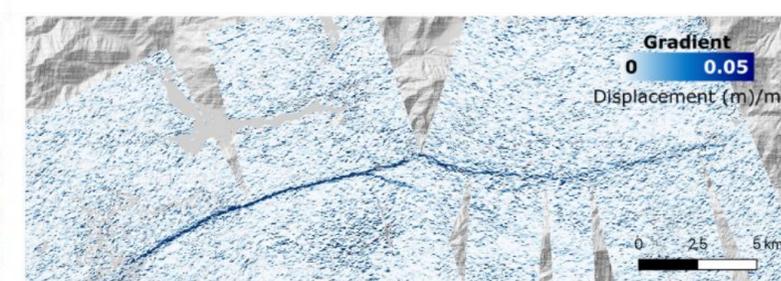
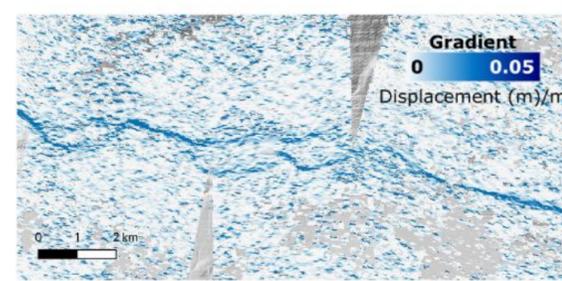
# Déformations du sol vues par le service optique GDM-OPT



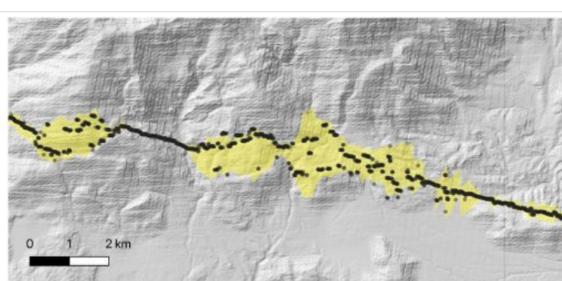
GDM-OPT @10 m x 10 m



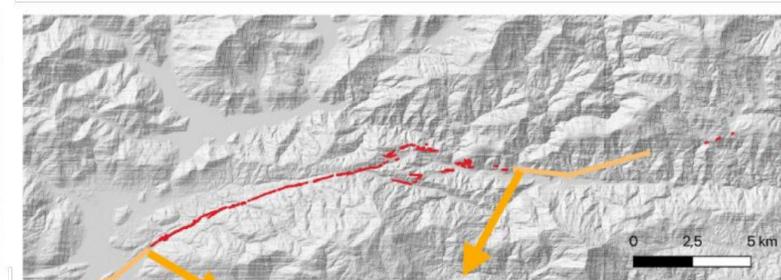
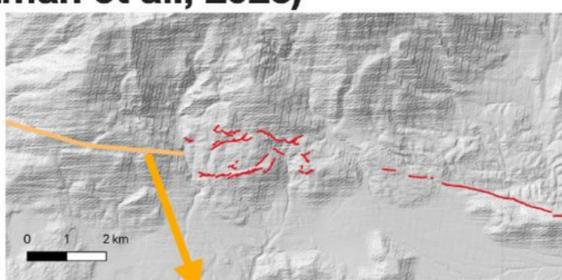
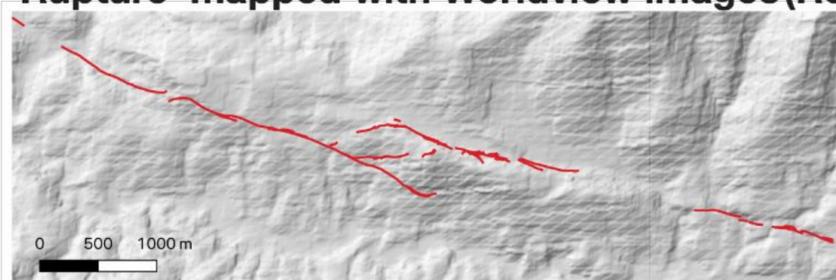
Gradient (GDM-OPT)



Rupture and fault zone width (GDM-OPT)



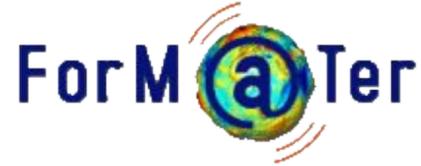
Rupture mapped with Worldview images (Reitman et al., 2023)



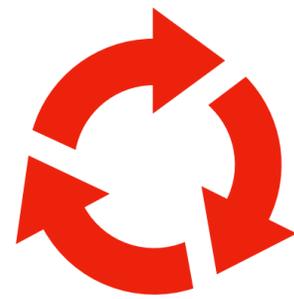
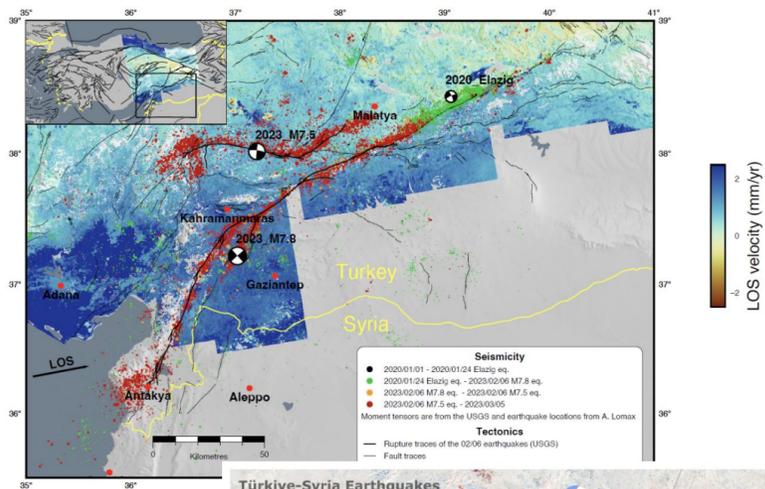
No image or clouds

No image or clouds

# Complémentarité des services, synergie à construire avec d'autres structures



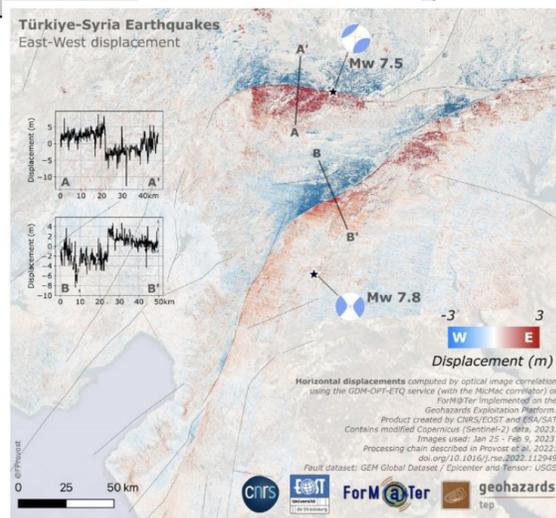
FLATSIM



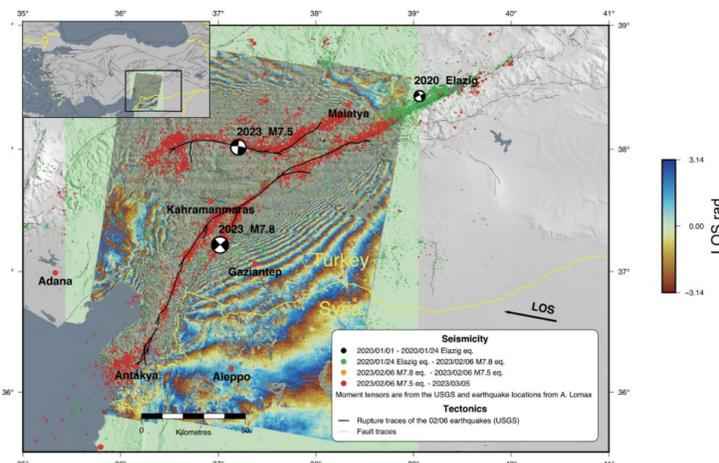
CIEST2



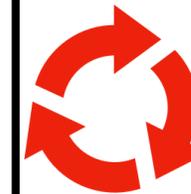
CELLULE D'INTERVENTION ET D'EXPERTISE SCIENTIFIQUE ET TECHNIQUE NOUVELLE...



GDM-SAR



GDM-OPT



Cellule post-sismique INSU

cellule post-sismique

▼ Accueil

Mars 8 septembre 2023 Mw 9

Nov 16 juin 2023 Mw 5.8

Turquie 06 février 2023 Mw 7.8

Turquie 06 février 2023 Mw 7.7 - 10h24 UTC

Habé 14 août 2021 Mw 7.2

Grèce 03 mars 2021, Mw 6.5

## Turquie 06 février 2023

### Mw 7.8 - 01H17 UTC

Le séisme s'est produit dans le Centre - Sud de la Turquie, proche de la frontière avec la Syrie. L'épicentre est proche de la faille Est Anatolienne (senestre), dans sa partie Sud-Ouest, là où elle fait la jonction avec la faille du levant (faille de la mer morte, Dead Sea Fault, senestre). La magnitude de moment (Mw) varie entre 7.7 et 8.0 selon les organismes. La profondeur est donnée superficielle, entre 10 et 18 km (sauf USGS 33 km) par les inversions des formes d'ondes. Ces mêmes inversions donnent toutes un mécanisme essentiellement décrochant, avec un plan NE-SW à ENE - WSW proche de la vertical à jeu senestre qui serait le plan de rupture (d'après les premières inversions du glissement et les répliques). Dès les premières heures, plusieurs centaines de victimes et des destructions importantes sont reportées en Turquie et en Syrie.

Autres observations et mesures de différents SNO, IR d'Observations, Projets, missions de terrains.....

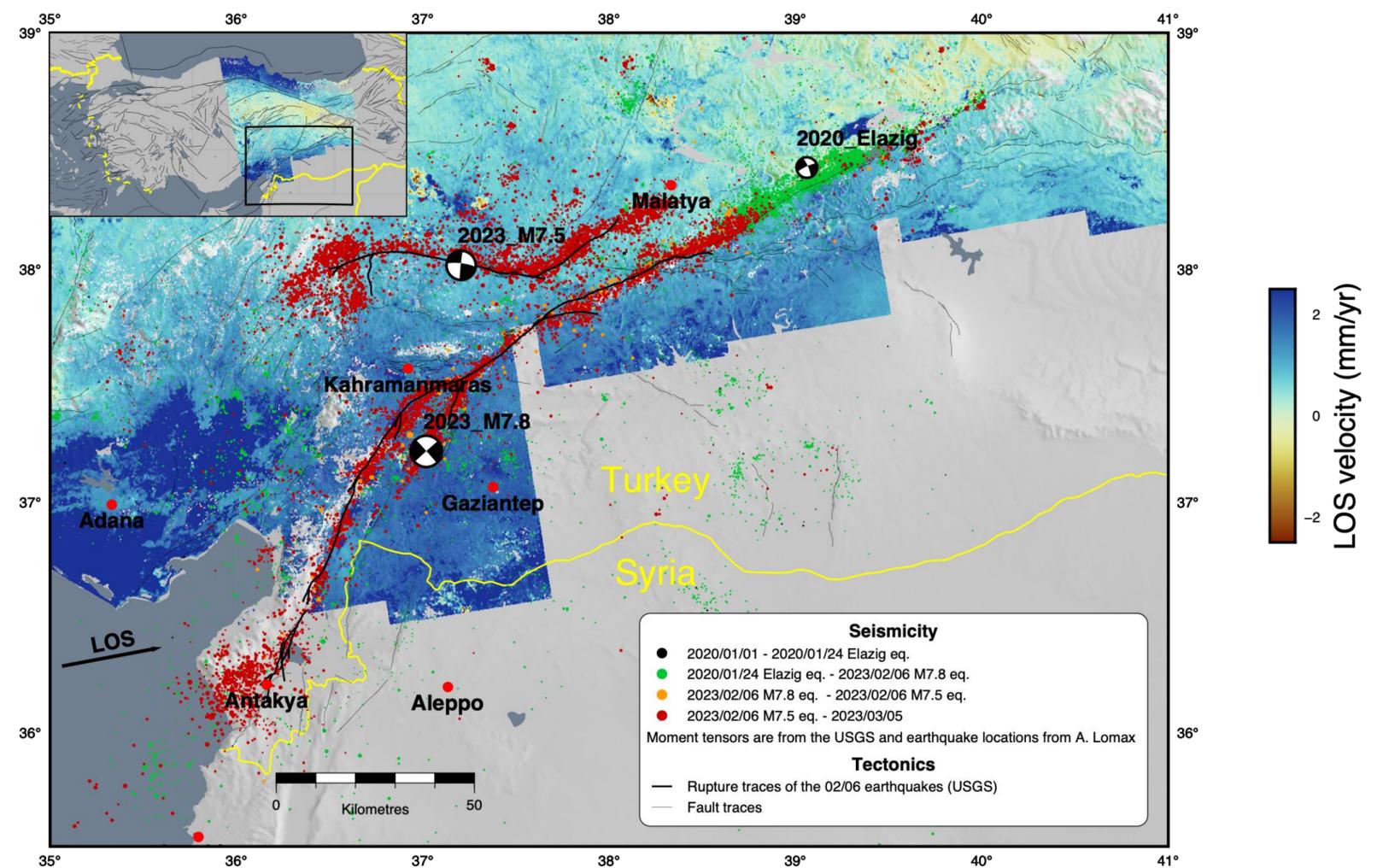
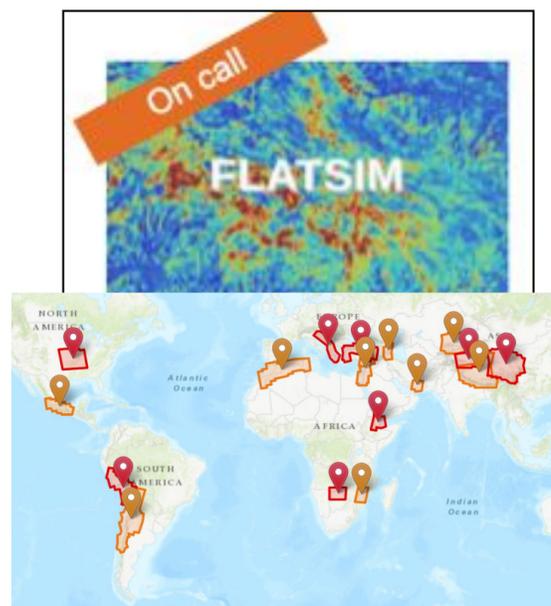




# Les séismes de 2023 vus par les services radar

« Turquie » parmi les chantiers FLATSIM de l'Appel à Idées 2020

Séries temporelles et **carte de vitesse moyenne pour la période 2014-2021** (pré-séismes 2023) : mouvement relatif des plaques tectoniques et chargement élastique au travers des failles dans la période pré-séismes



Disponible également : solution incrémentale 2020-2023 produite juste après les séismes