Off-fault damage of the 2023 Kahramanmaraş earthquakes estimated from 3D displacements of satellite radar images

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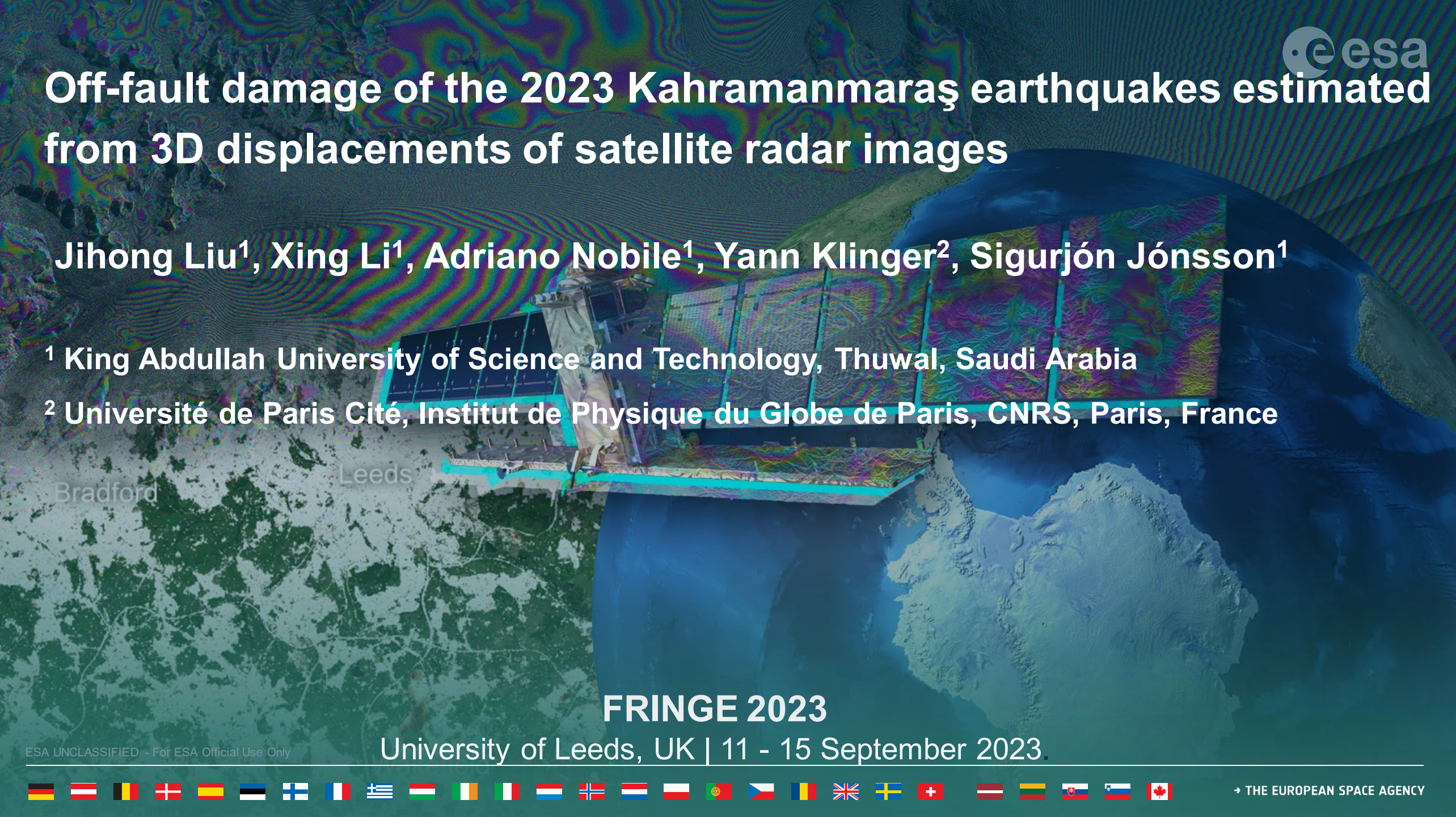

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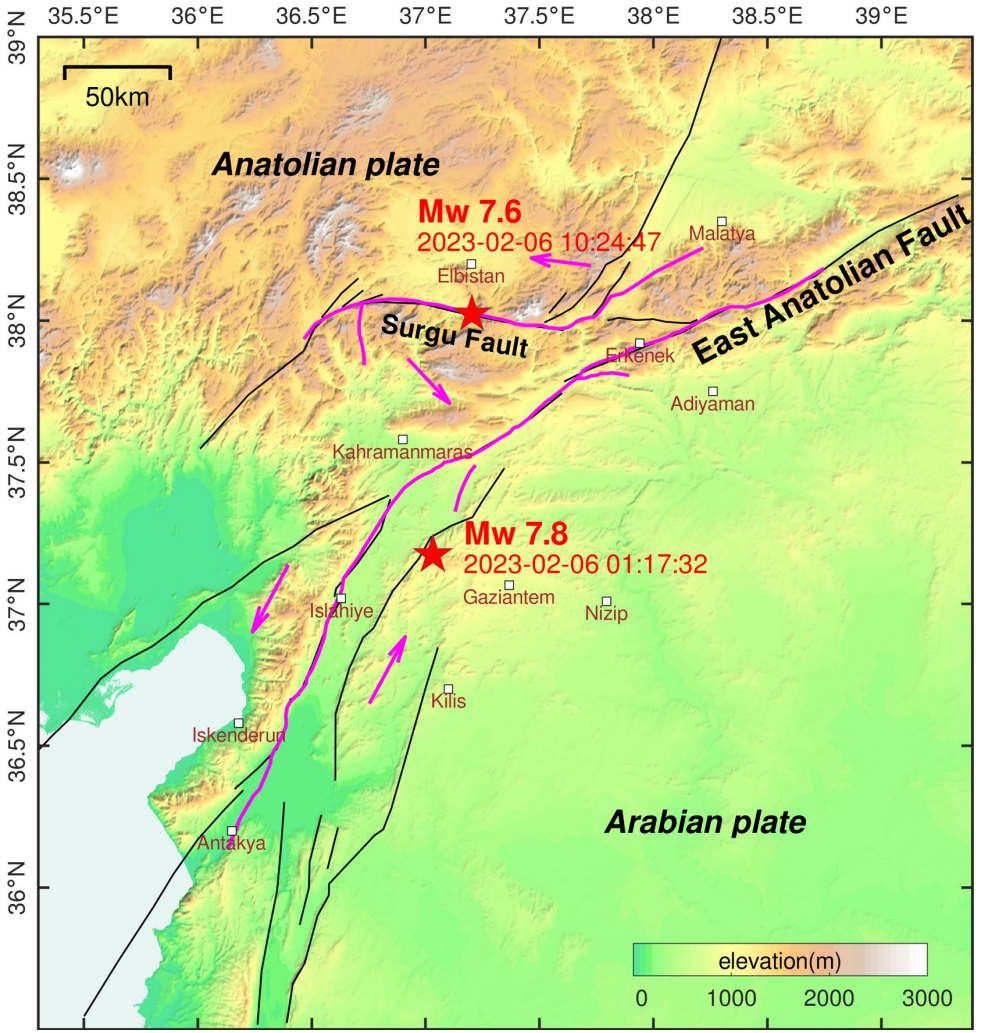
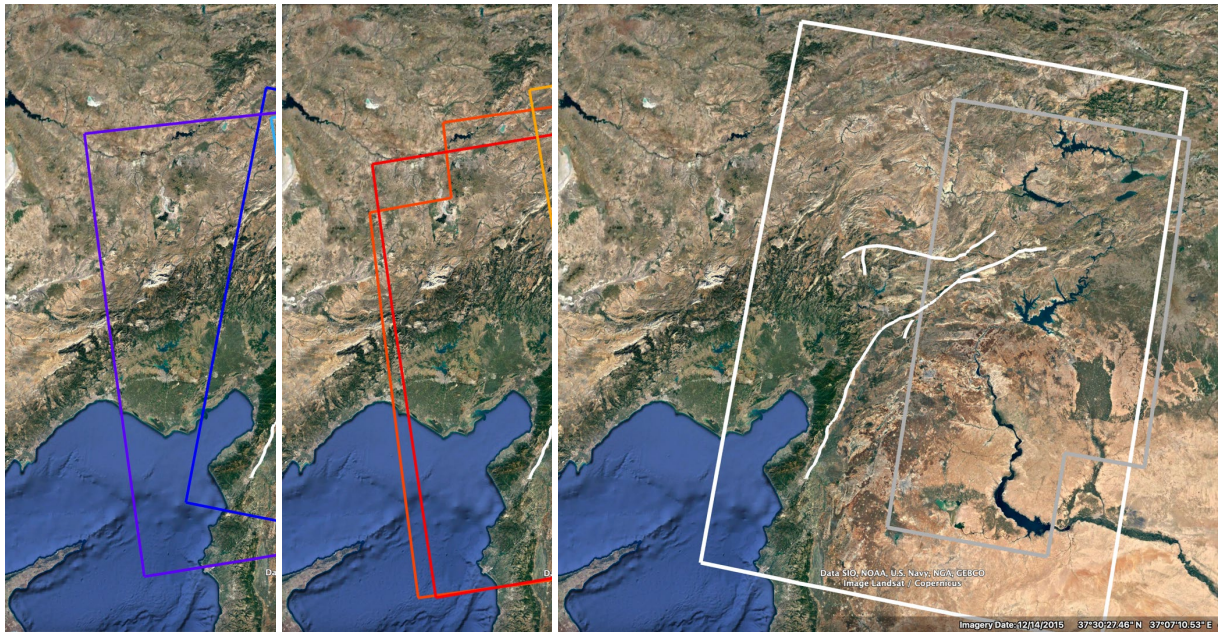
Outlines

- **Coseismic 3D displacements from radar images**
  - Surface displacements
  - Fault slips
- **Off-fault damage analysis**
  - How to estimate
  - Off-fault damage distribution
  - Is the displacement underestimated

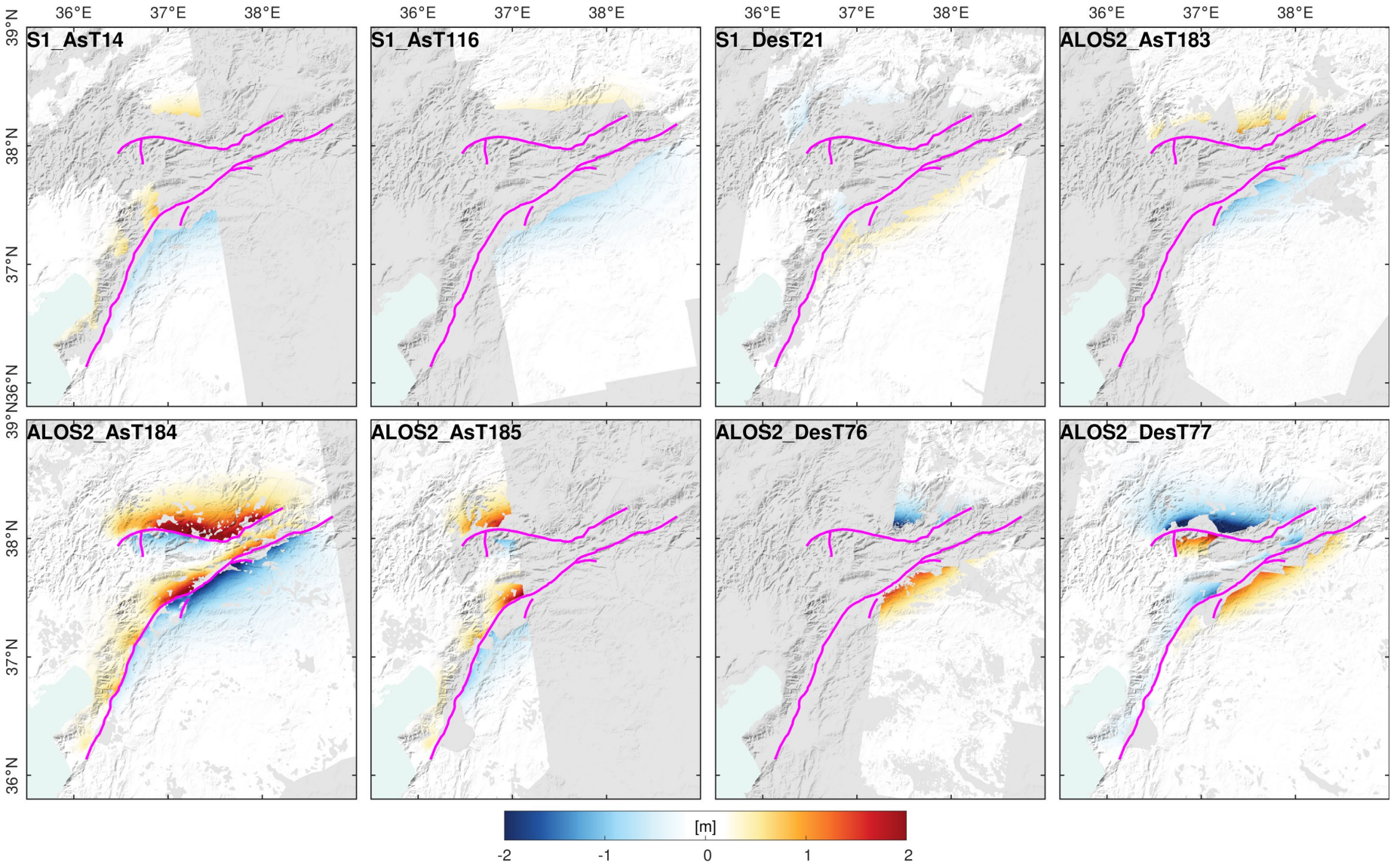
Study area and SAR data



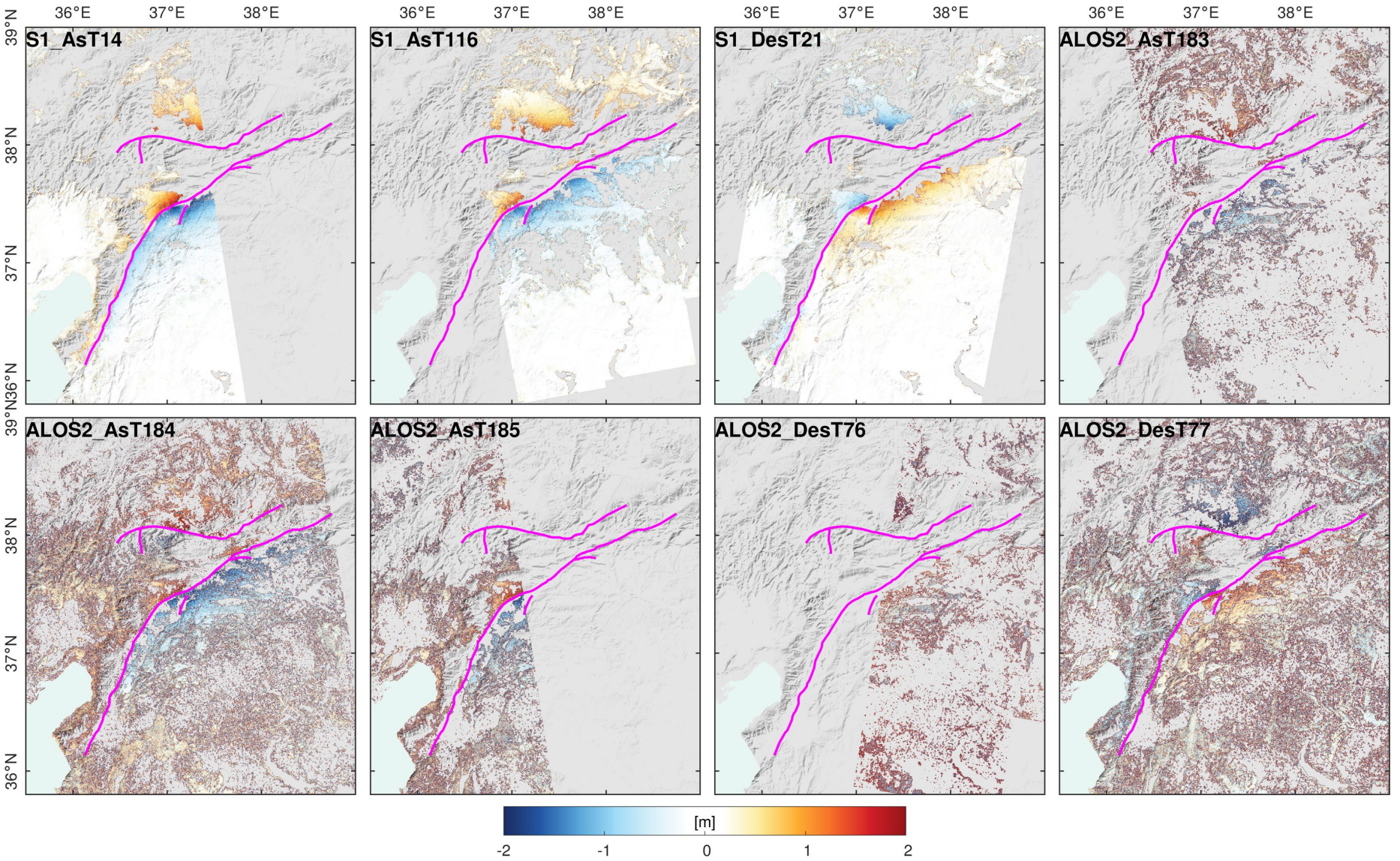
	Ascending	Descending
Sentinel-1	T14, T116	T21
ALOS-2	T183, T184, T185	T76, T77
Method	**DInSAR, RSSI, POT, MAI**	



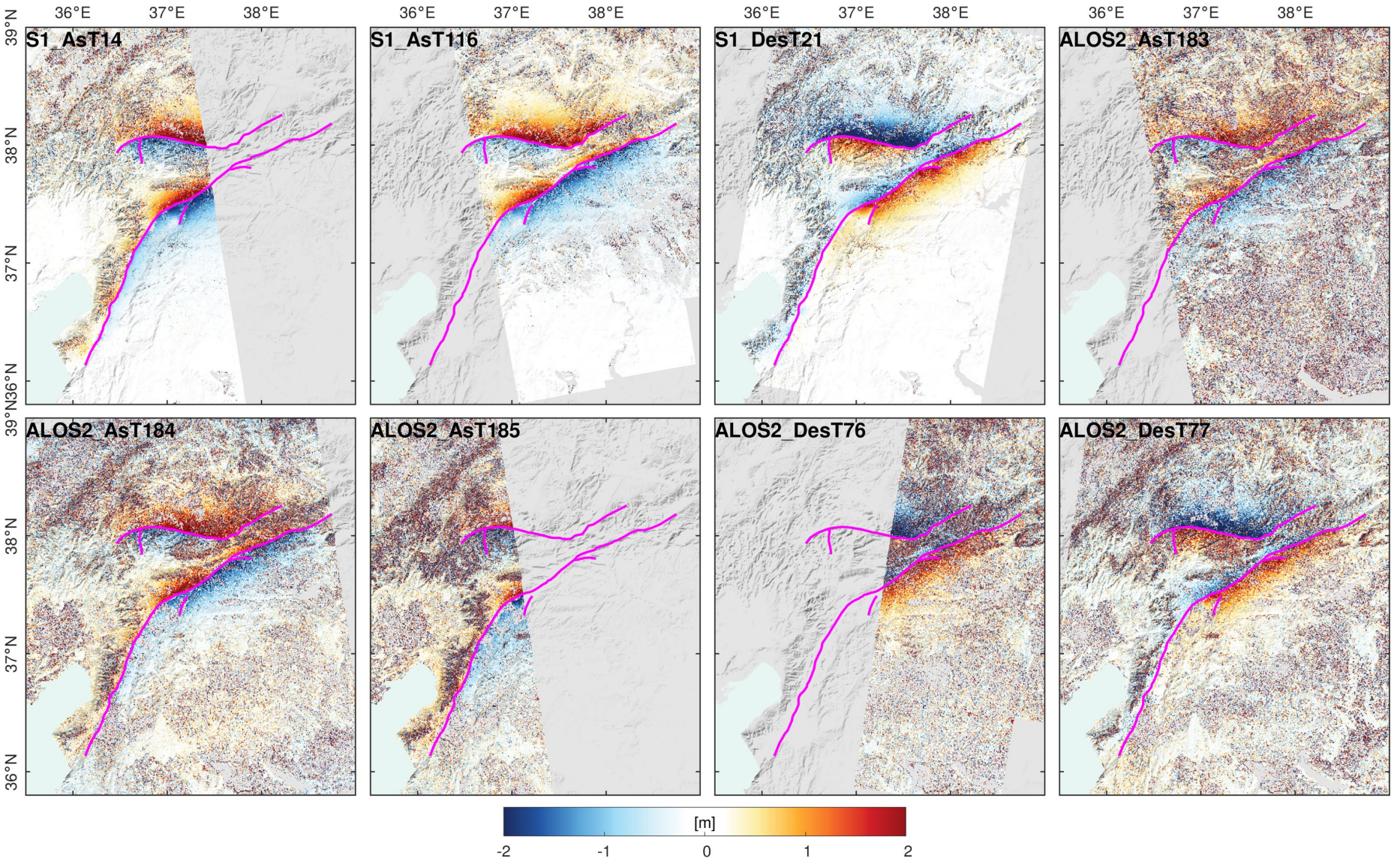
DInSAR


S1_AsT14
S1_AsT116
S1_DesT21
ALOS2_AsT183
ALOS2_AsT184
ALOS2_AsT185
ALOS2_DesT76
ALOS2_DesT77
36°E
37°E
38°E
39°N
38°N
37°N
36°N
[m]
-2
-1
0
1
2

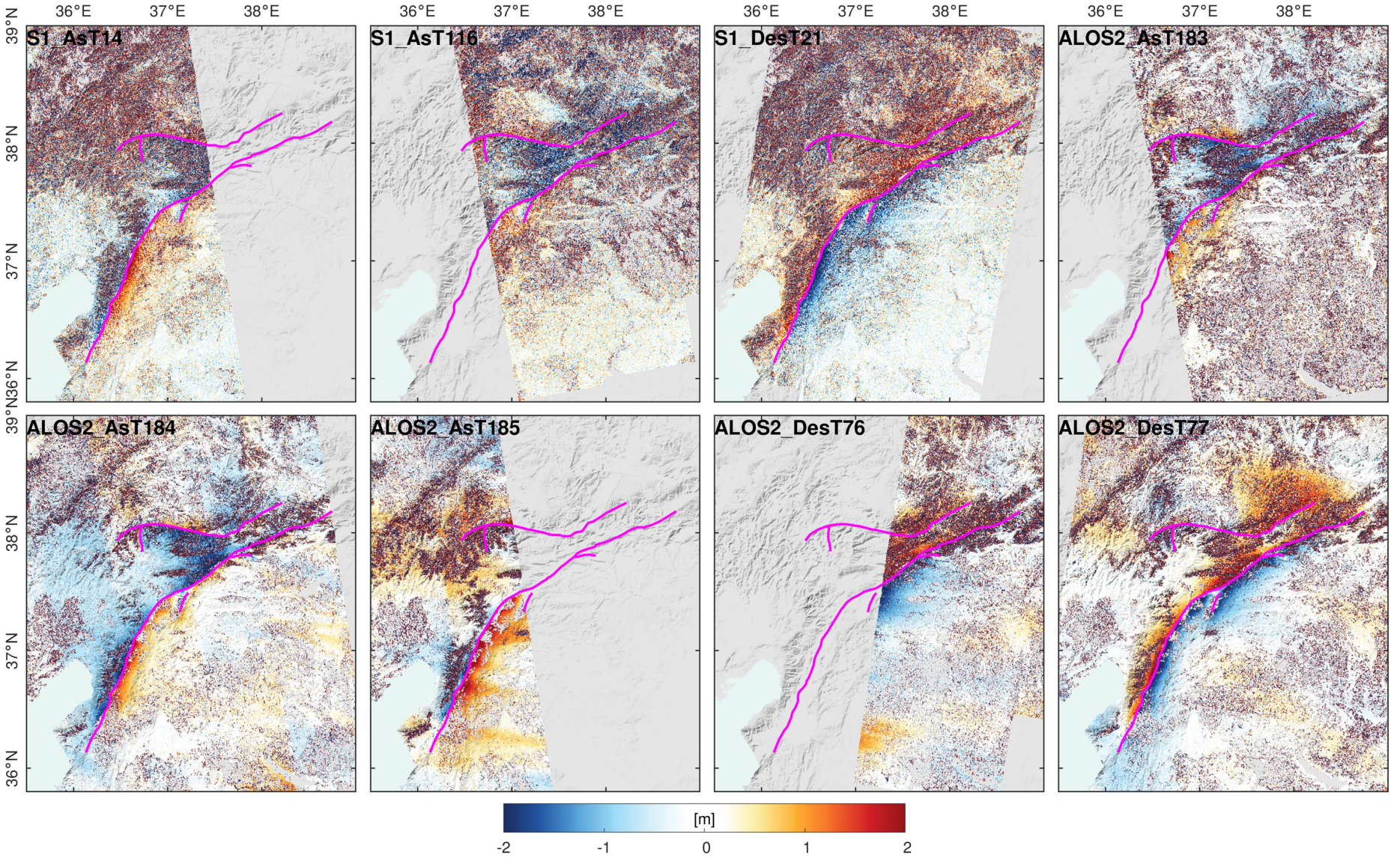
Range Spectrum Split Interferometry (RSSI)



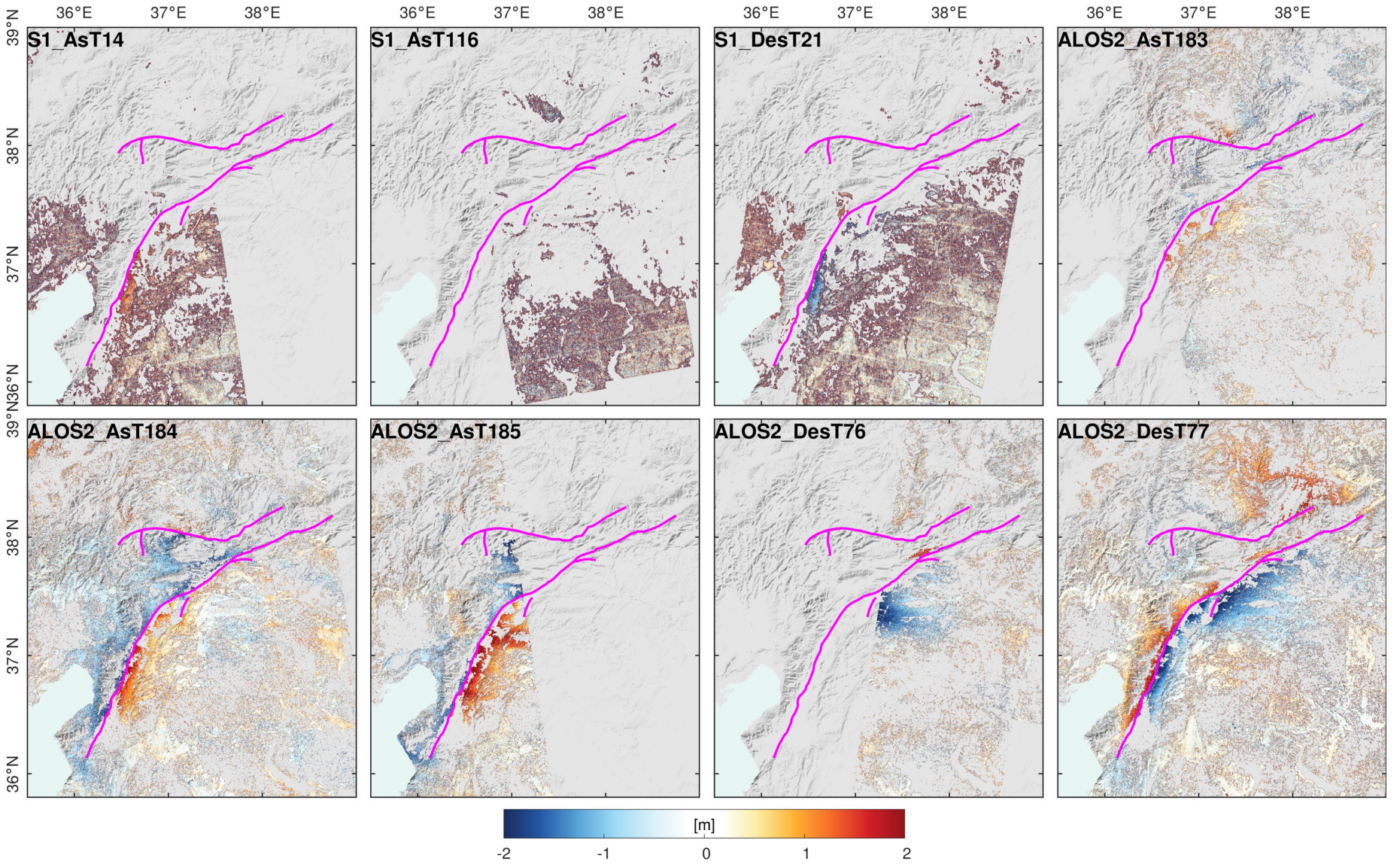
Range of Pixel Offset Tracking (POT)



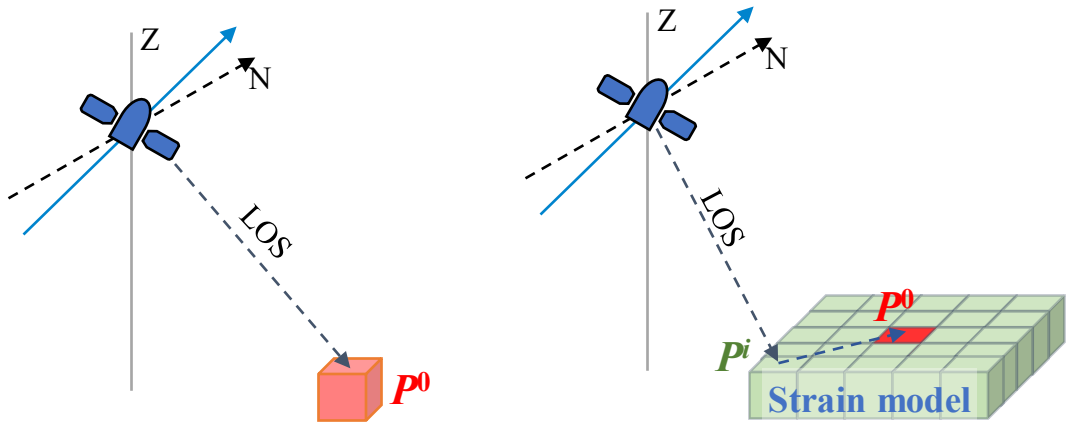
Azimuth of Pixel Offset Tracking (POT)



Multiple Aperture Interferometry (MAI)



Three-dimensional surface displacements — SM-VCE method



$$\begin{bmatrix} d_e^k \\ d_n^k \\ d_u^k \end{bmatrix} = \begin{bmatrix} \partial d_e/\partial x_e & \partial d_e/\partial x_n & \partial d_e/\partial x_u \\ \partial d_n/\partial x_e & \partial d_n/\partial x_n & \partial d_n/\partial x_u \\ \partial d_u/\partial x_e & \partial d_u/\partial x_n & \partial d_u/\partial x_u \end{bmatrix} \cdot \begin{bmatrix} \Delta x_e^k \\ \Delta x_n^k \\ \Delta x_u^k \end{bmatrix} + \begin{bmatrix} d_e^0 \\ d_n^0 \\ d_u^0 \end{bmatrix}$$

SM-VCE (opened) : InSAR 3D displacement calculation based on strain model and variance component estimation

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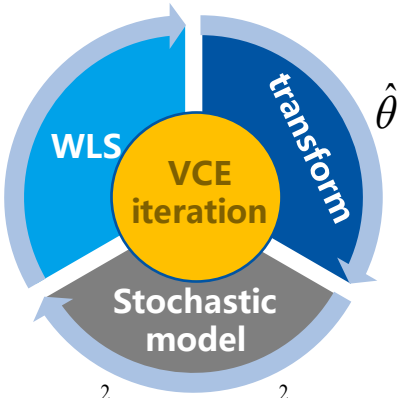
$$\hat{X} = N^{-1}W$$

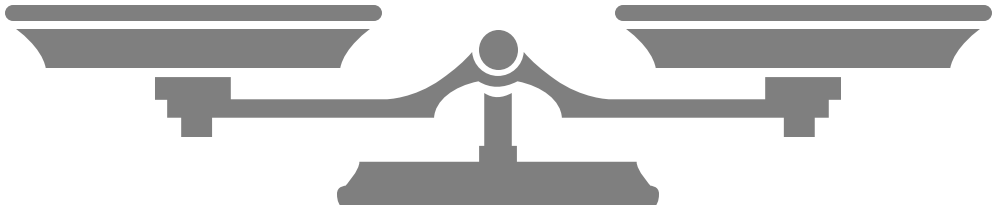
$$\begin{cases} V_1 = B_1\hat{X} - L_1 \\ V_2 = B_2\hat{X} - L_2 \\ V_3 = B_3\hat{X} - L_3 \\ V_4 = B_4\hat{X} - L_4 \end{cases}$$



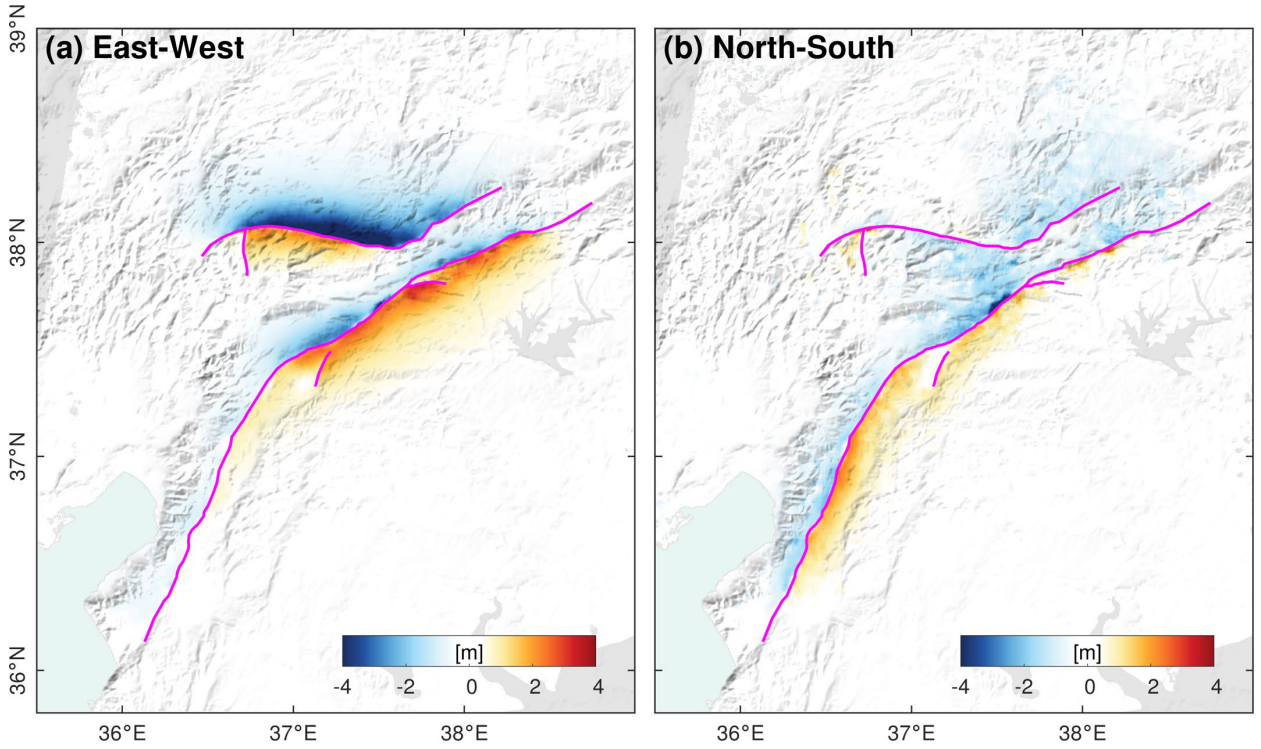
$$\hat{\theta} = \Gamma^{-1}W_\theta$$

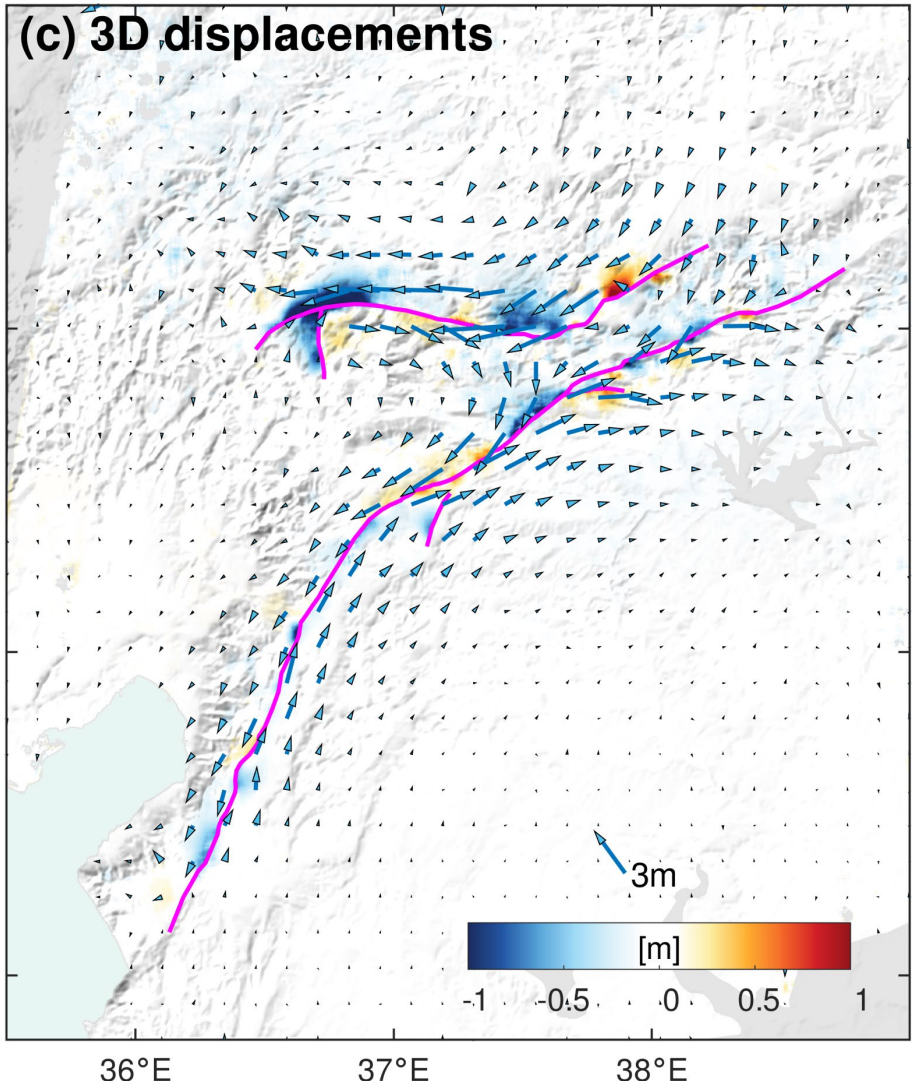
$$\hat{P}_1 = P_1, \hat{P}_2 = \frac{\sigma_{0_1}^2}{\sigma_{0_2}^2 P_2^{-1}}, \hat{P}_3 = \frac{\sigma_{0_1}^2}{\sigma_{0_3}^2 P_3^{-1}}, \hat{P}_4 = \frac{\sigma_{0_1}^2}{\sigma_{0_4}^2 P_4^{-1}}$$

Weight of Obs_1 **Weight of Obs_n**



Three-dimensional surface displacements — SM-VCE method





SM-VCE (opened) : InSAR 3D displacement calculation based on strain model and variance component estimation

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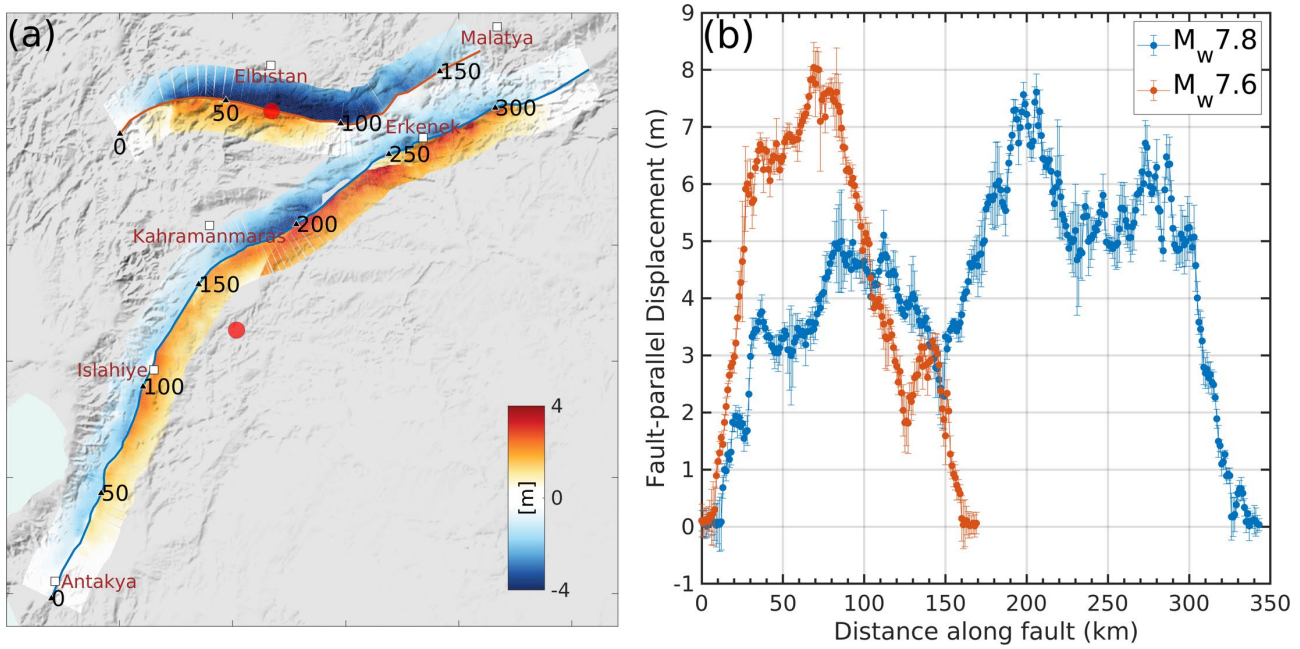
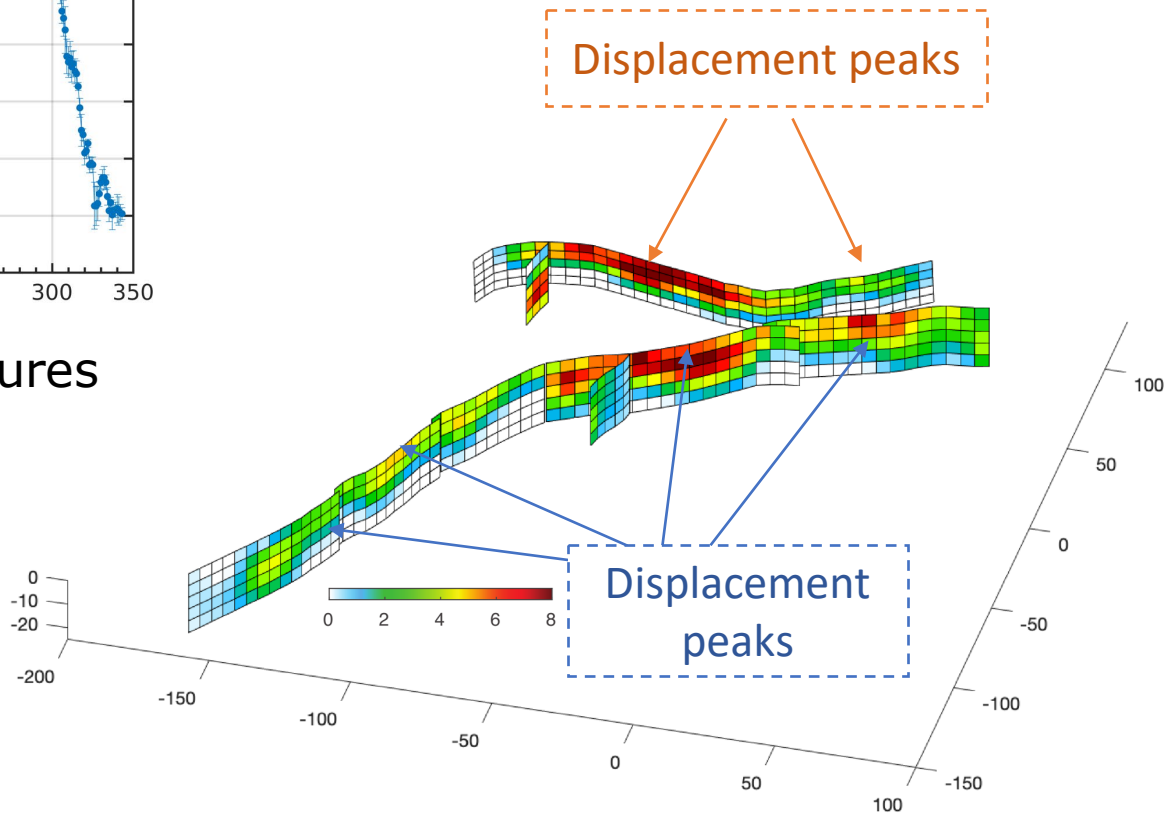
On-fault slips



Fault-parallel displacements along main ruptures



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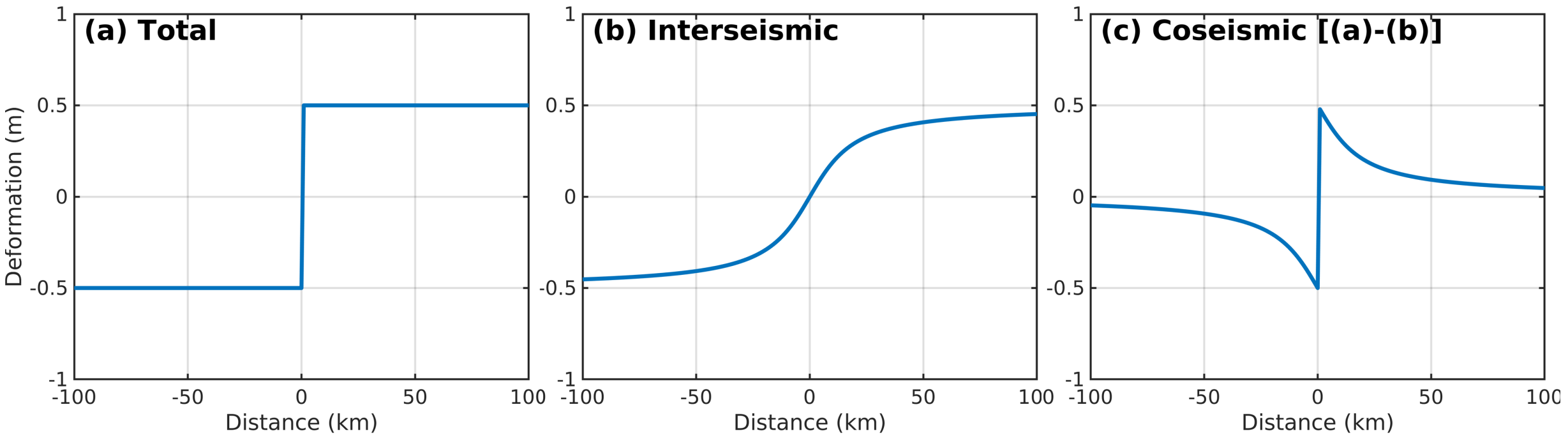
Elastic case



$$H(x) = \begin{cases} -0.5s_0 & x < 0 \\ 0.5s_0 & x > 0 \end{cases}$$

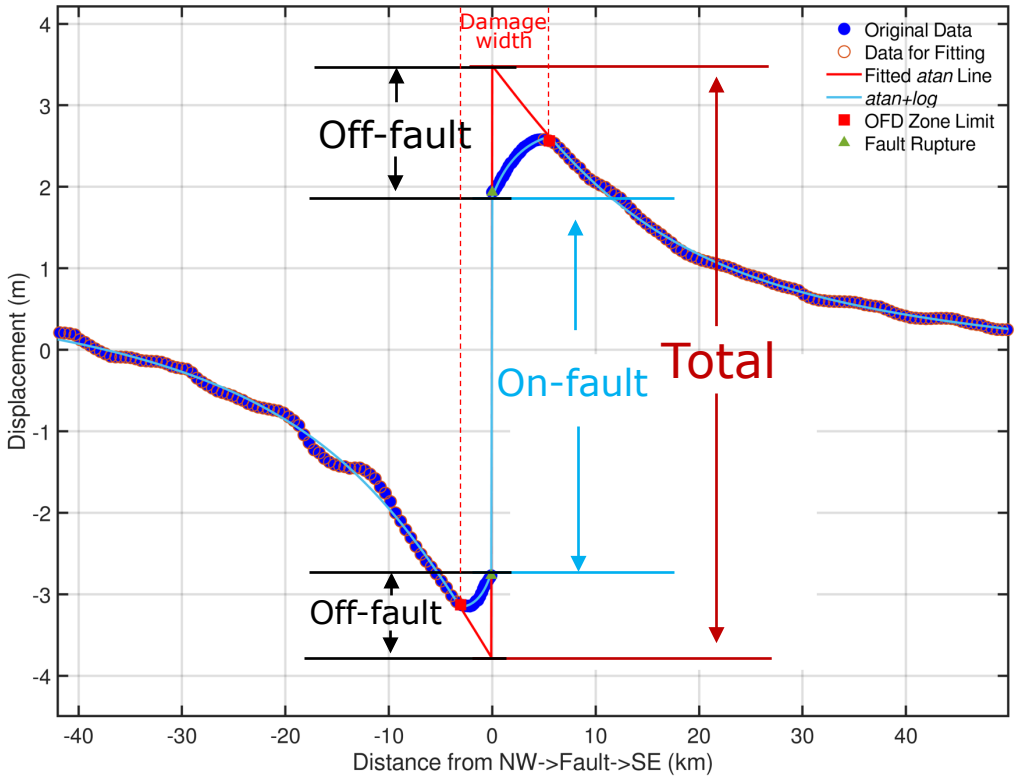
$$d(x) = \frac{s_0}{\pi} \cdot atan\left(\frac{x}{D}\right)$$

$$C(x) = H(x) - d(x)$$

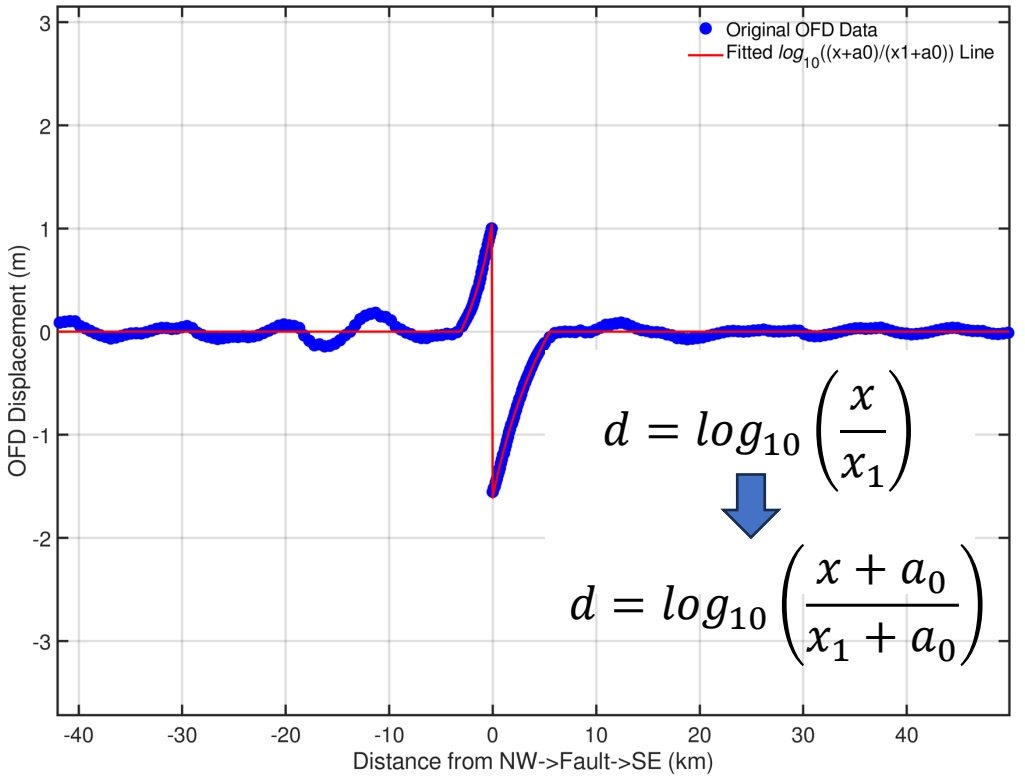
$$= \begin{cases} -0.5s_0 - \frac{s_0}{\pi} \cdot atan\left(\frac{x}{D}\right) & x < 0 \\ 0.5s_0 - \frac{s_0}{\pi} \cdot atan\left(\frac{x}{D}\right) & x > 0 \end{cases}$$

Real case

$$R = \frac{\text{off-fault damage deformation}}{\text{total deformation}}$$



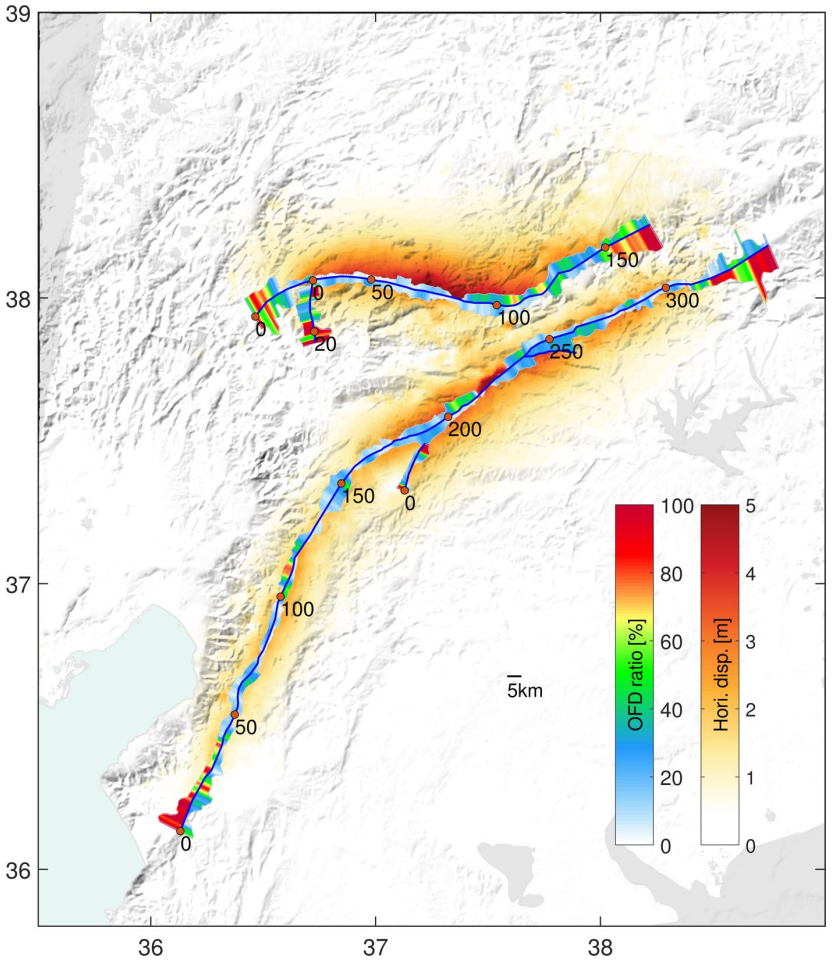
Fault-parallel displacement across the fault

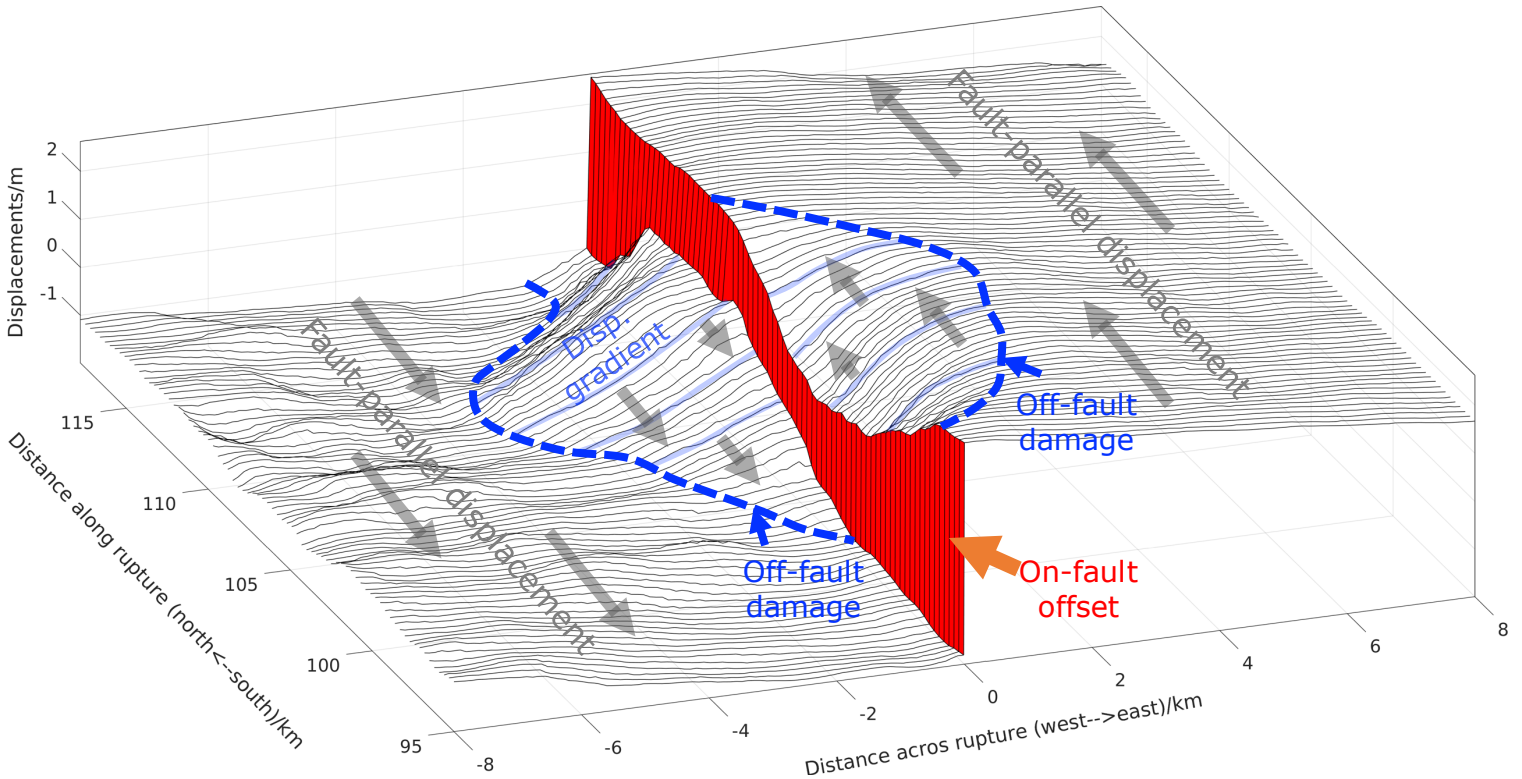


Residuals between observation and elastic model

The ratio of off-fault damage deformation total deformation

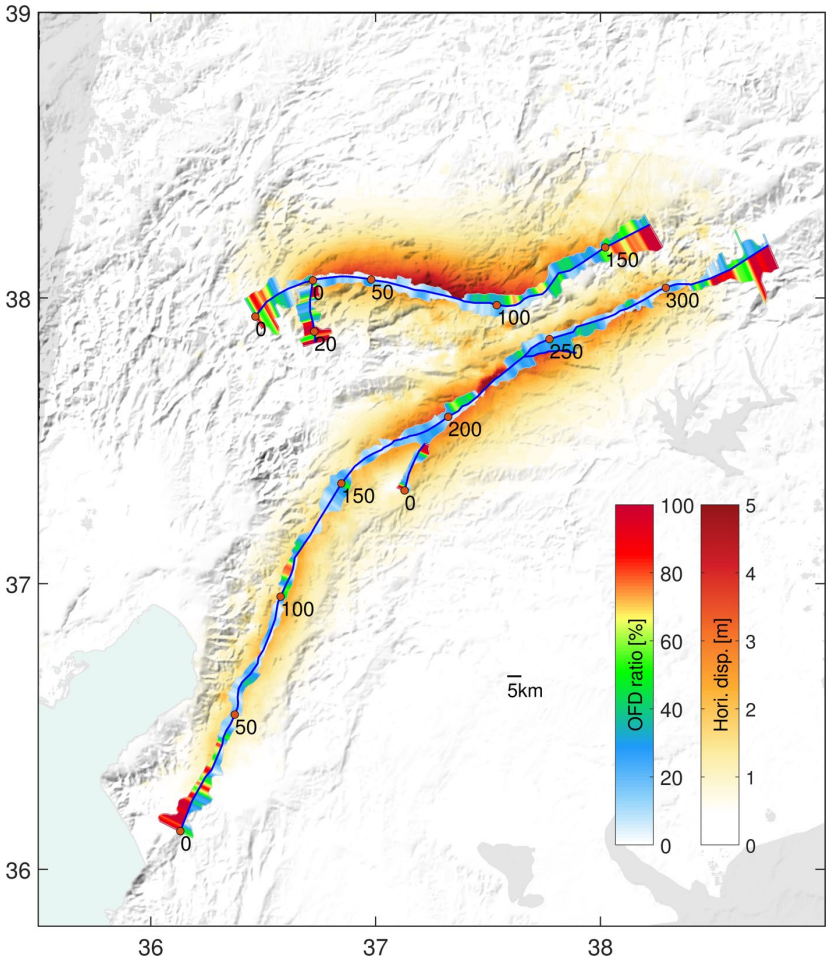
$$R = \frac{\text{off-fault damage deformation}}{\text{total deformation}}$$

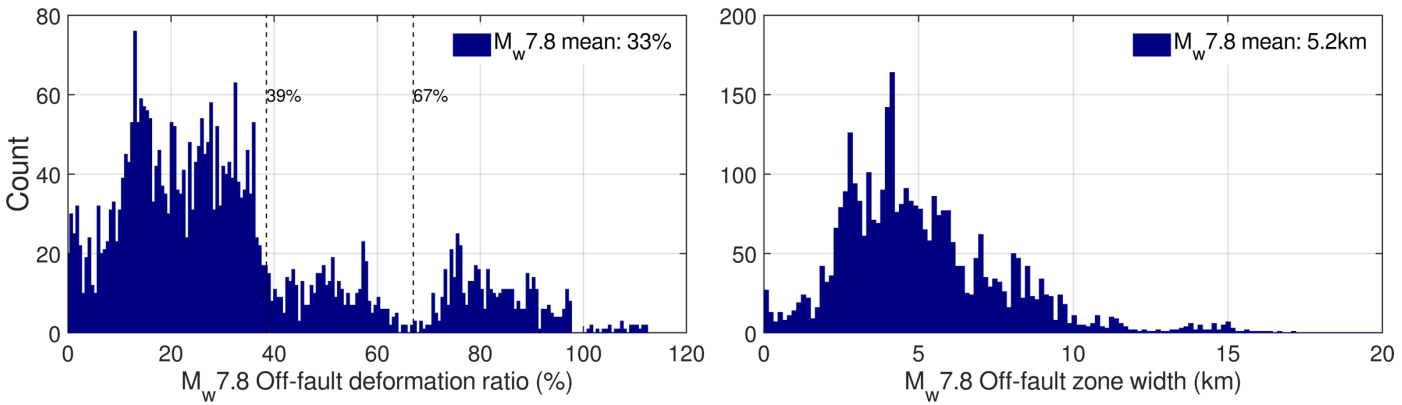


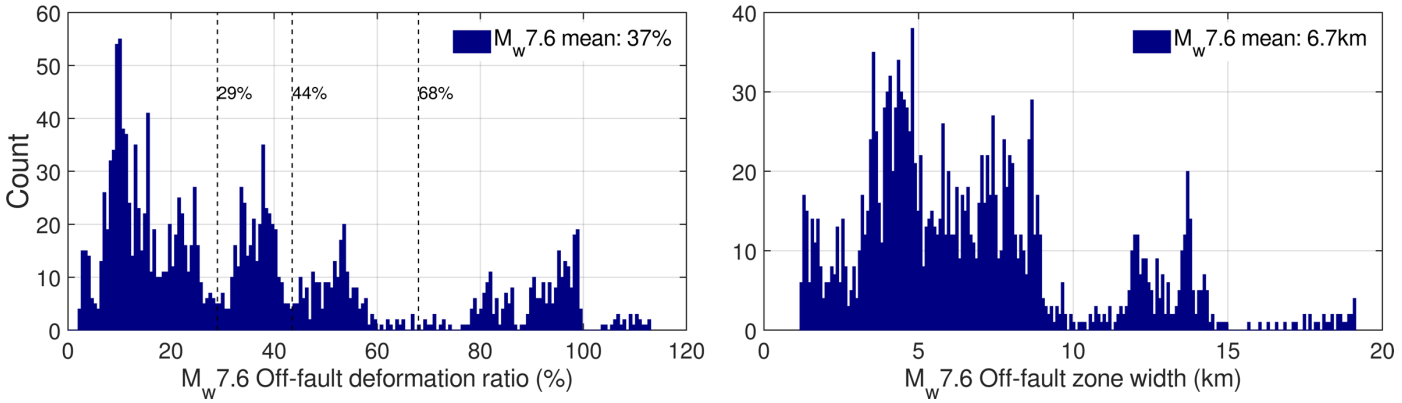


The ratio of off-fault damage deformation total deformation

$$R = \frac{\text{off-fault damage deformation}}{\text{total deformation}}$$

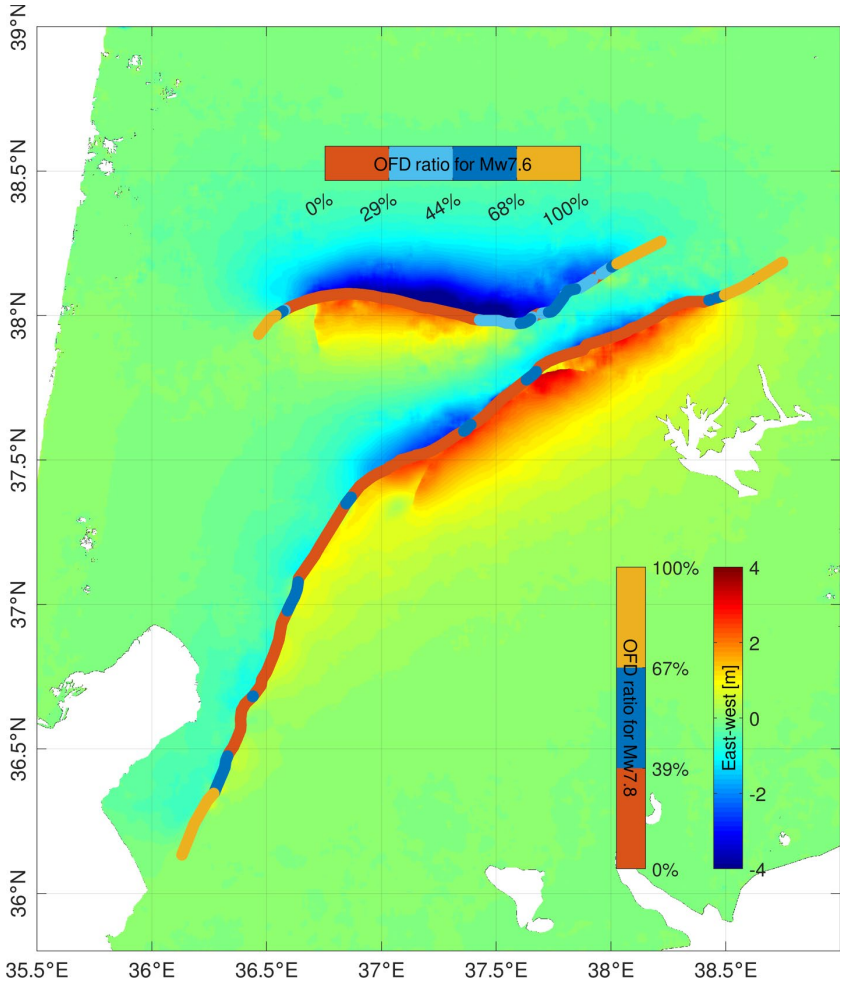


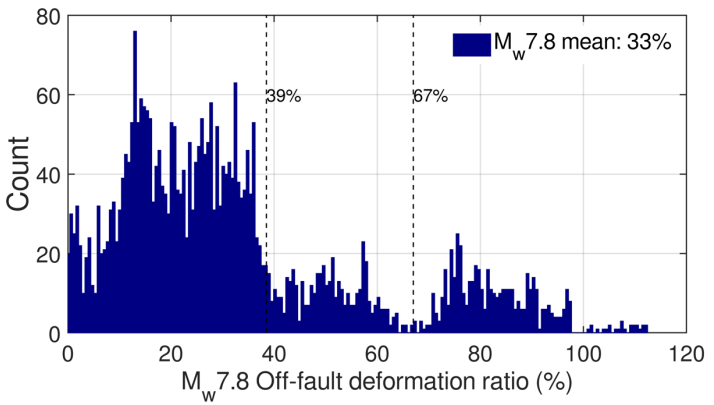


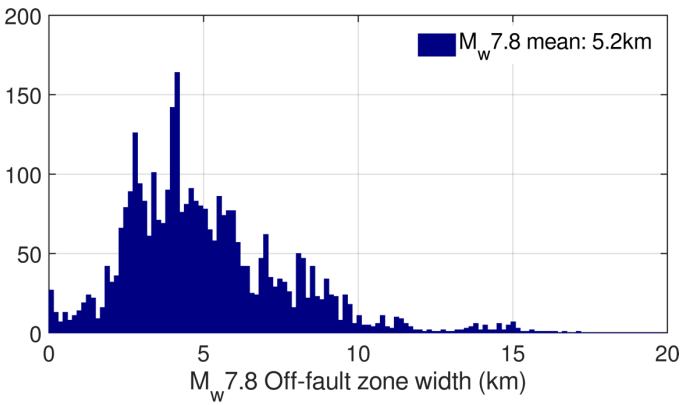


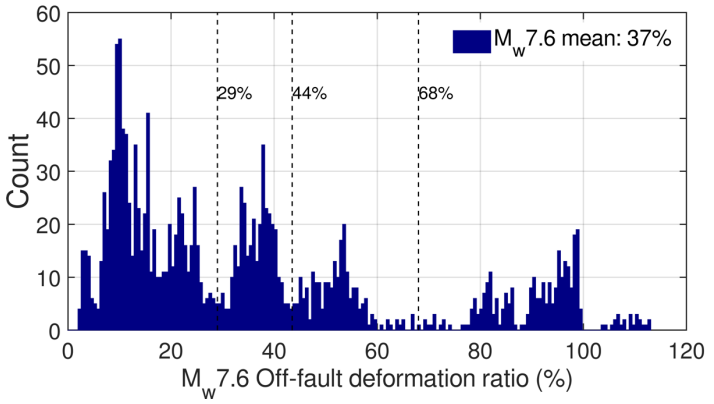
The ratio of off-fault damage deformation total deformation

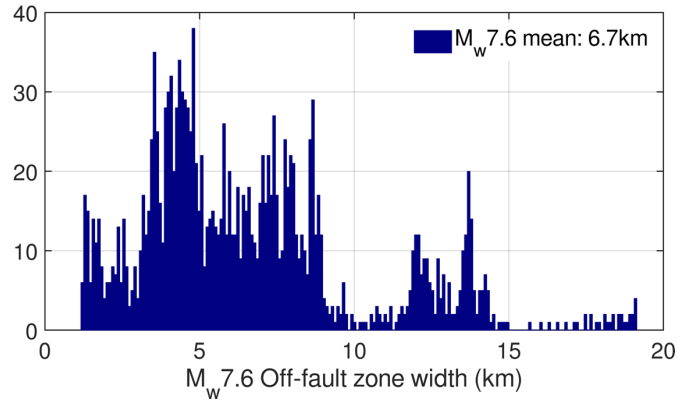
$$R = \frac{\text{off-fault damage deformation}}{\text{total deformation}}$$











Conclusions

- We obtained 3D coseismic displacement of the 2023 Kahramanmaraş earthquakes;
- Off-fault damages are analyzed based on the 3D displacement field;
- SM-VCE open code for calculating 3D displacements (earthquakes, volcanos, landslides, etc.)

SM-VCE (opened) : InSAR 3D displacement calculation based on strain model and variance component estimation

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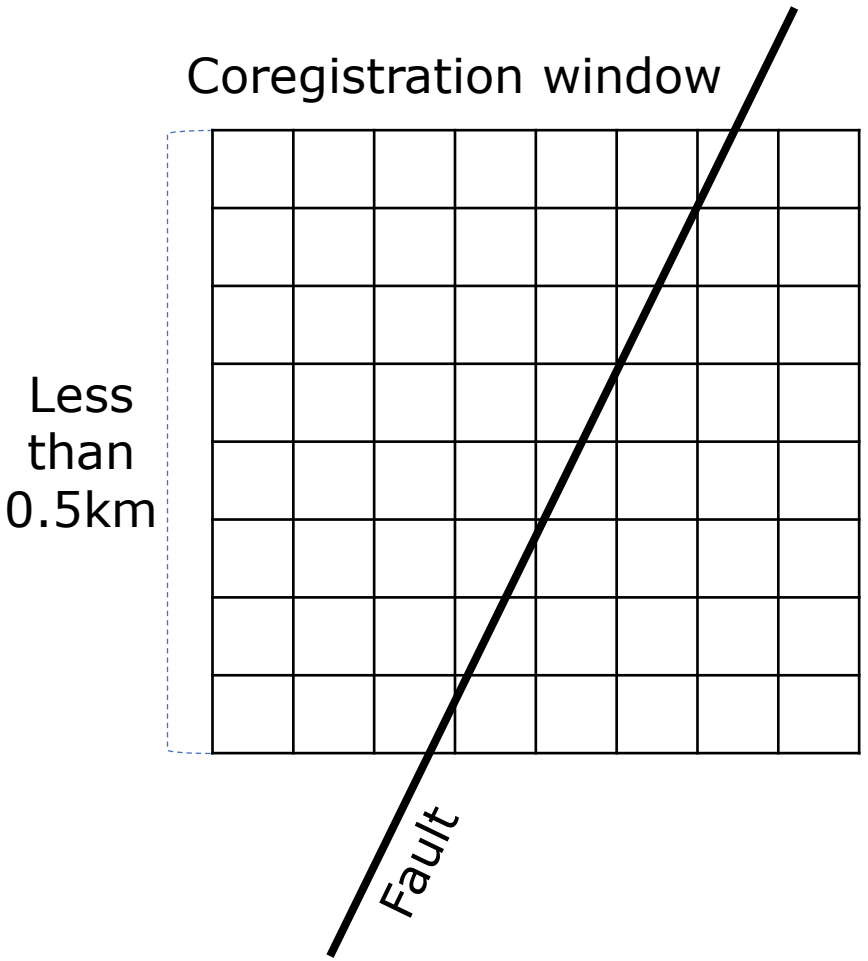
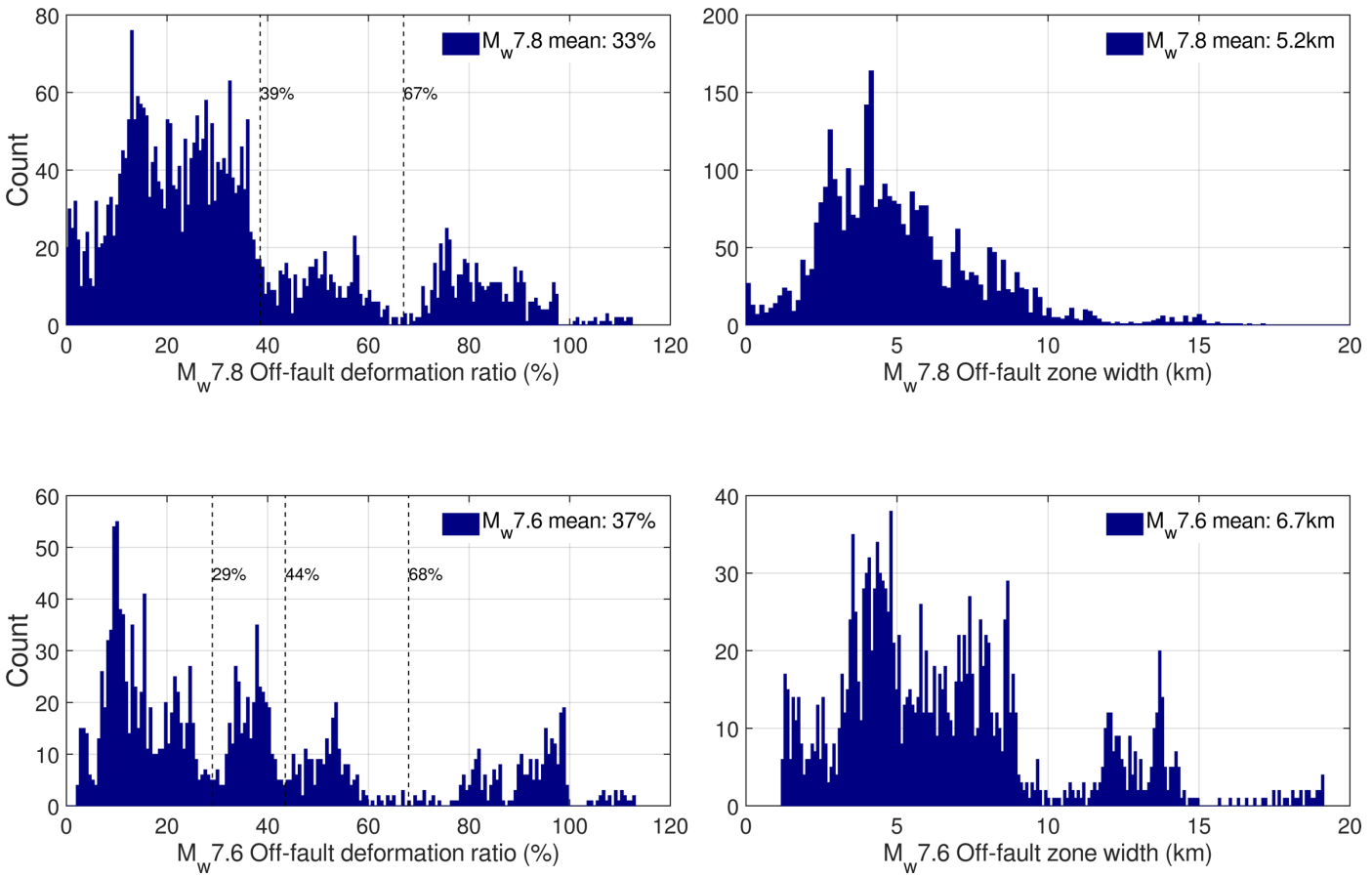
Thanks for your attention!
Welcome comments and suggestions……

If the displacement underestimated?

Near-field observations from pixel-offset of a window across the fault, is the off-fault damage a fake signal?





The off-fault damage behavior