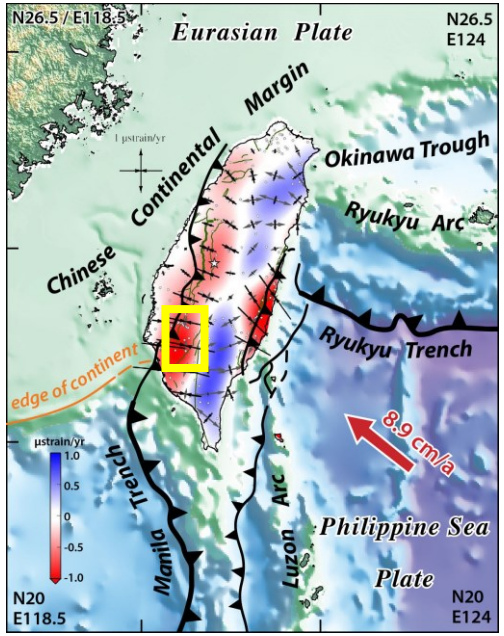
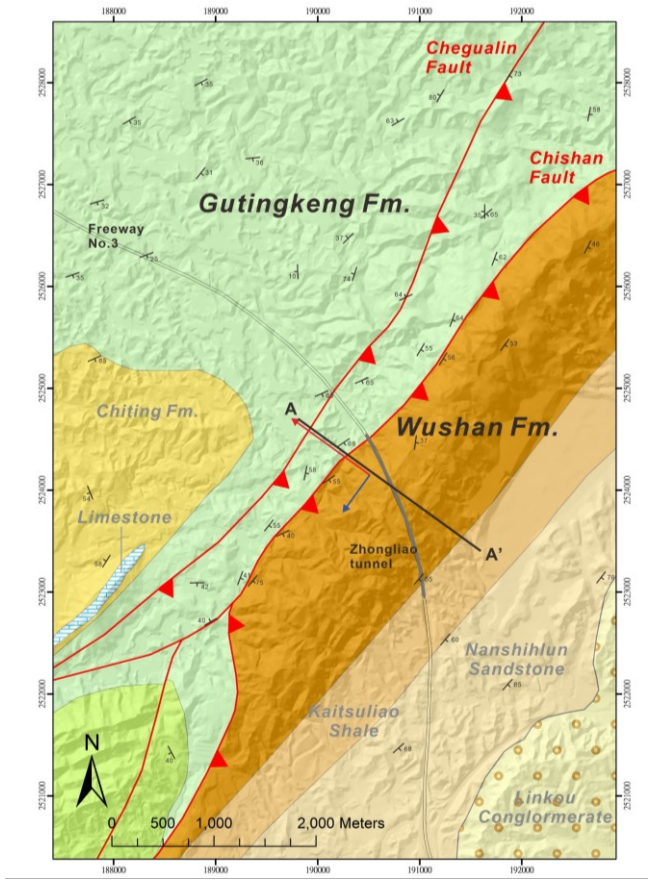
Measuring ground deformation across creeping faults through aerial image correlation: a case study of southwestern Taiwan

Presenter: **Chen Kai-Feng**
Advisor: **Prof. Maryline Le Béon**
Date: **2023/10/6**

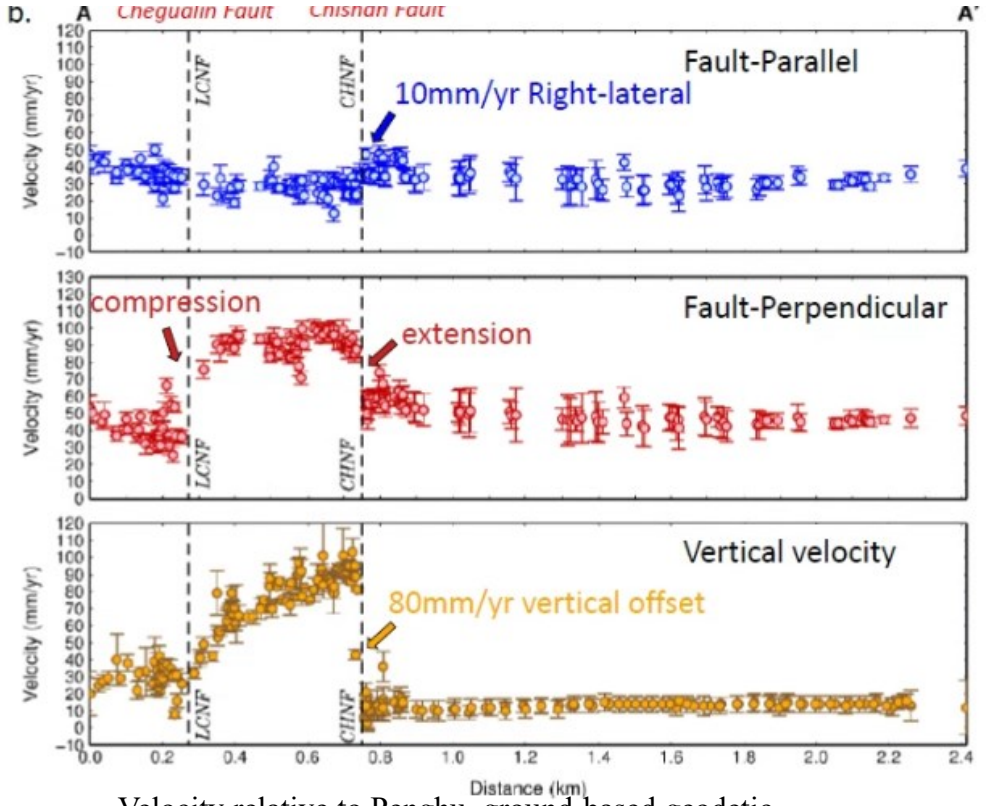
Introduction



Tectonic setting of Taiwan (Strain rate map from Hsu et al., 2009)



Geological map (Lin CW, 2013, complemented with our observations along the Chishan fault).



Velocity relative to Penghu, ground-based geodetic measurements, projected on AA' line (Chang-Lee, 2014).

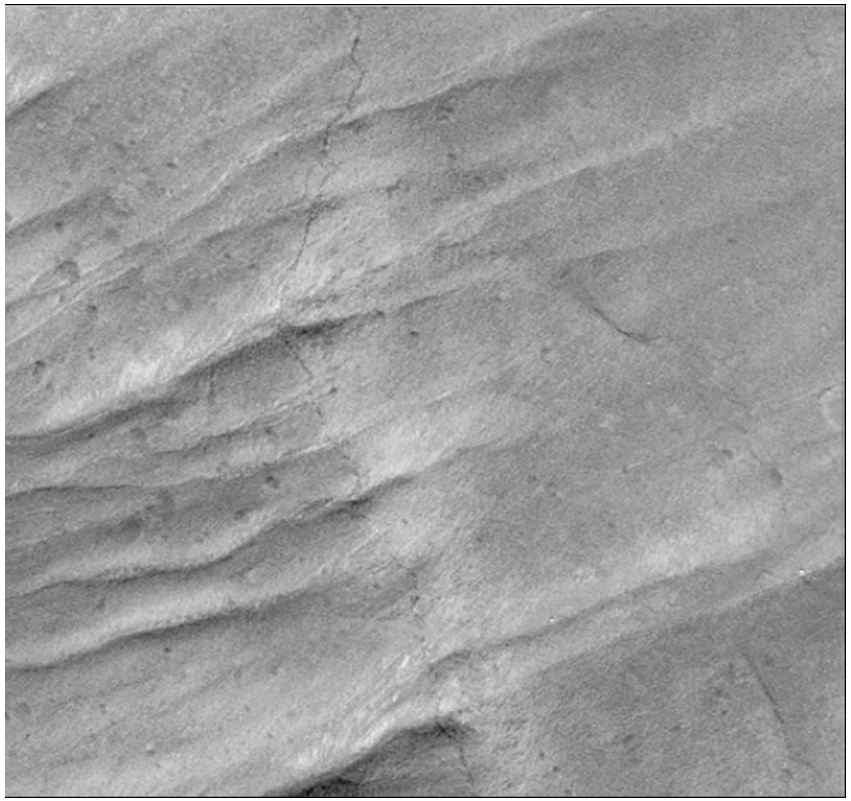
- 30 mm/yr extension and 50 mm/yr compression at Chishan fault and Chegualin fault, respectively, together with 80 mm/yr of while across the Chishan fault.
- To find out the mechanism behind such a rapid surface deformation.

Principle of image correlation

How to measure the surface deformation that results from tectonics?

GPS, leveling, InSAR … **Satellite/Aerial Image correlation!**

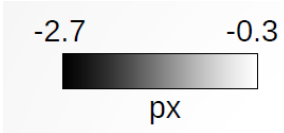
To detect the displacement of pixels in the images shot before and after tectonic activity.

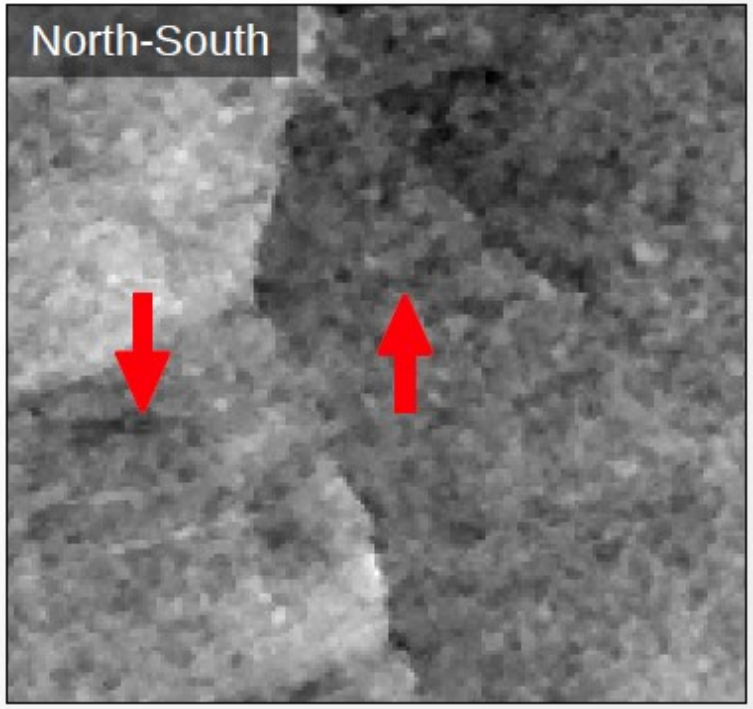


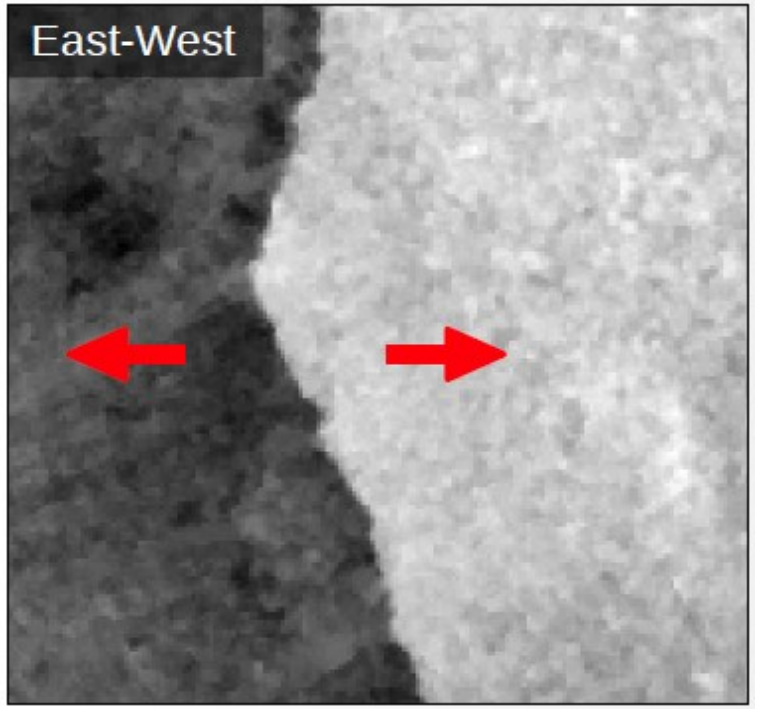
Pleiades satellite image

~2 px (1 m) of relative horizontal displacement between the two blocks

Images are provided by Arthur Delorme (Norcia earthquake, Italy, 2016)



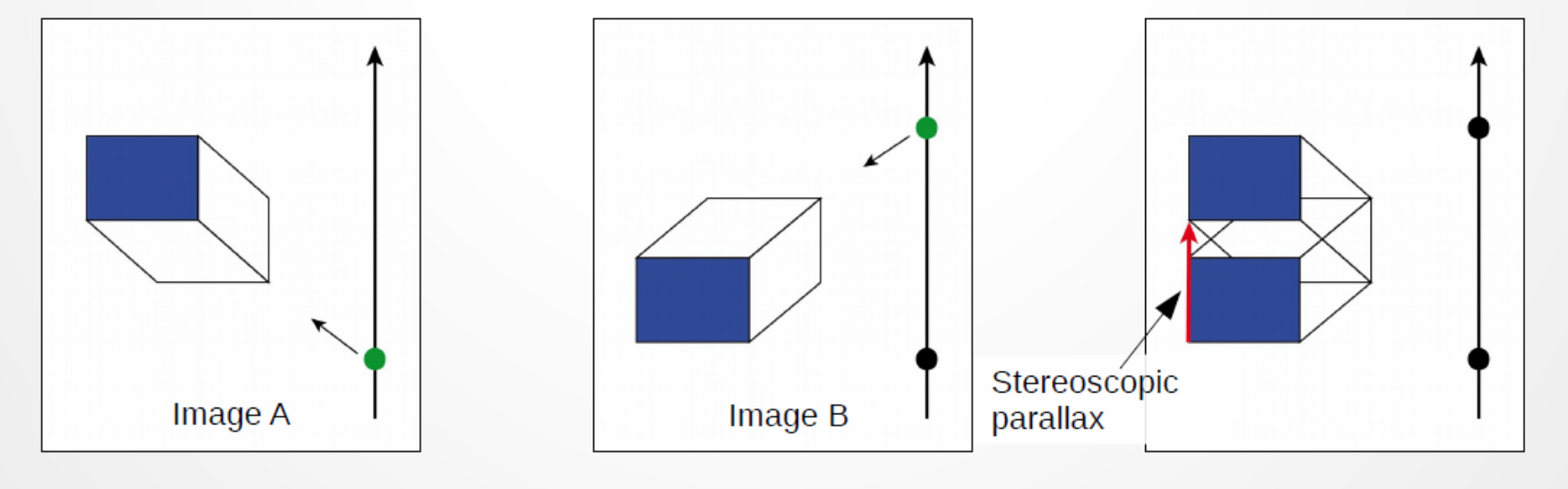




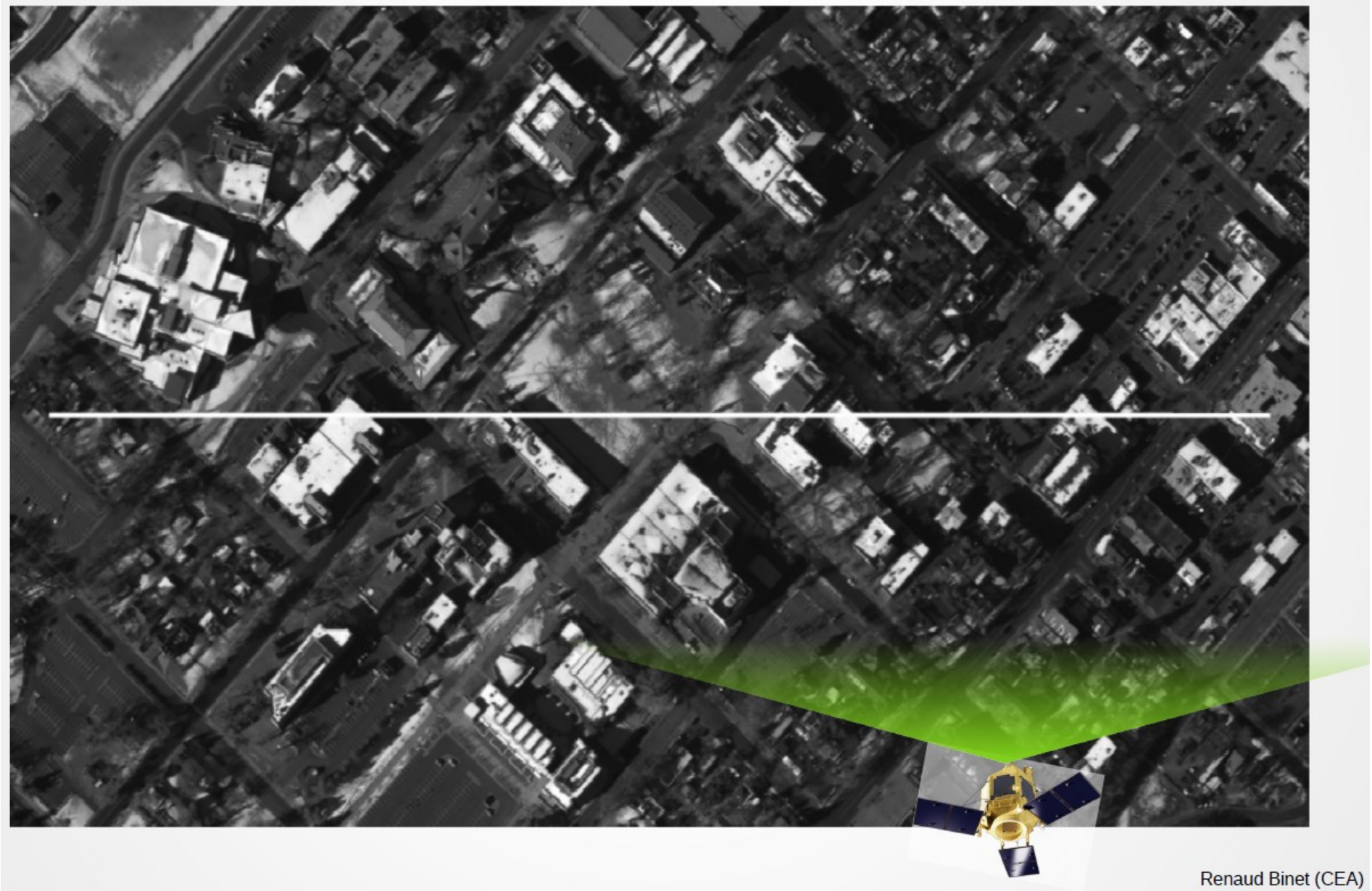
Principle of image correlation

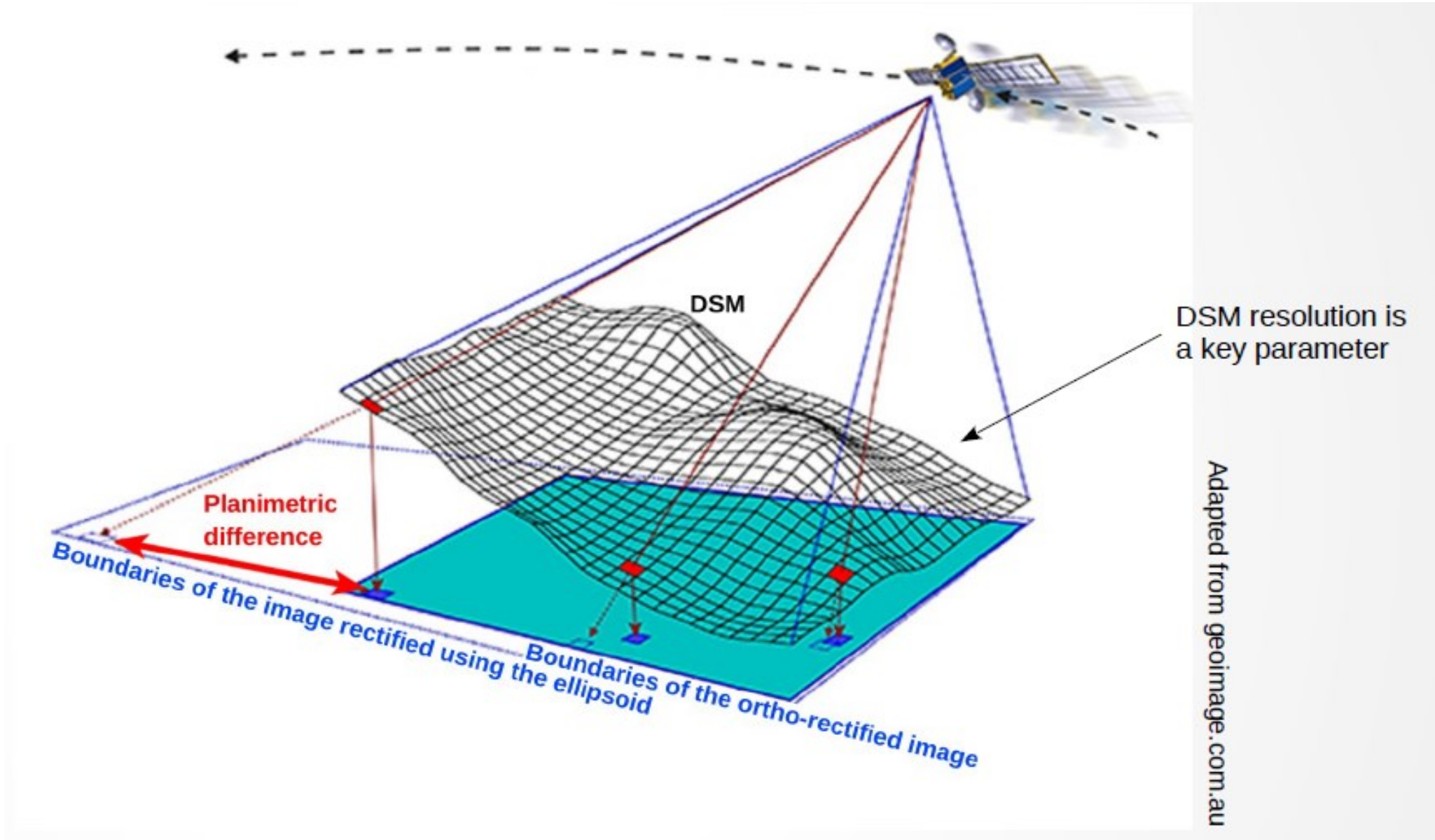
- However, the displacement of original image pair will include not only tectonic signals but also stereoscopic parallax.

- Therefore, **performing the orthorectification with Digital Surface Models (DSM) is necessary.**

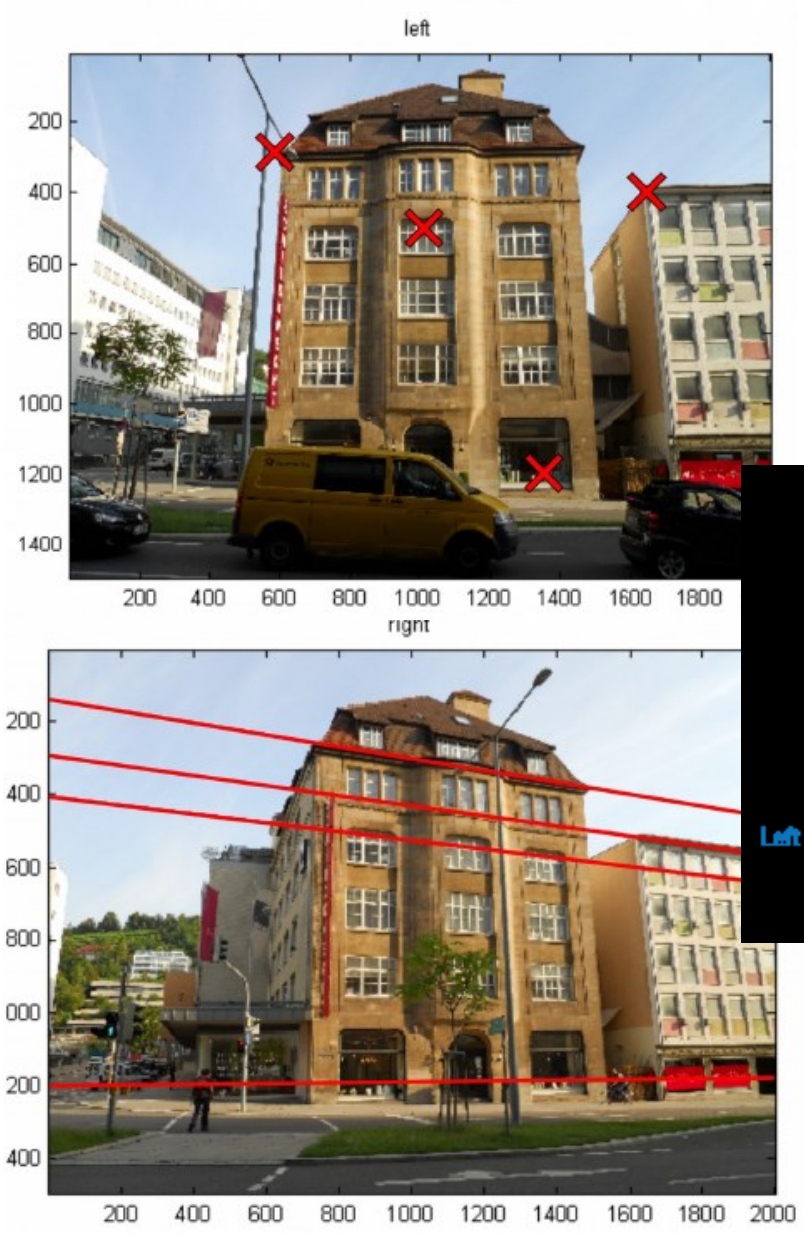


Stereoscopic Parallax




DSM
DSM resolution is
a key parameter
Planimetric
difference
Boundaries of the image rectified using the ellipsoid
Boundaries of the ortho-rectified image
Adapted from geoimage.com.au

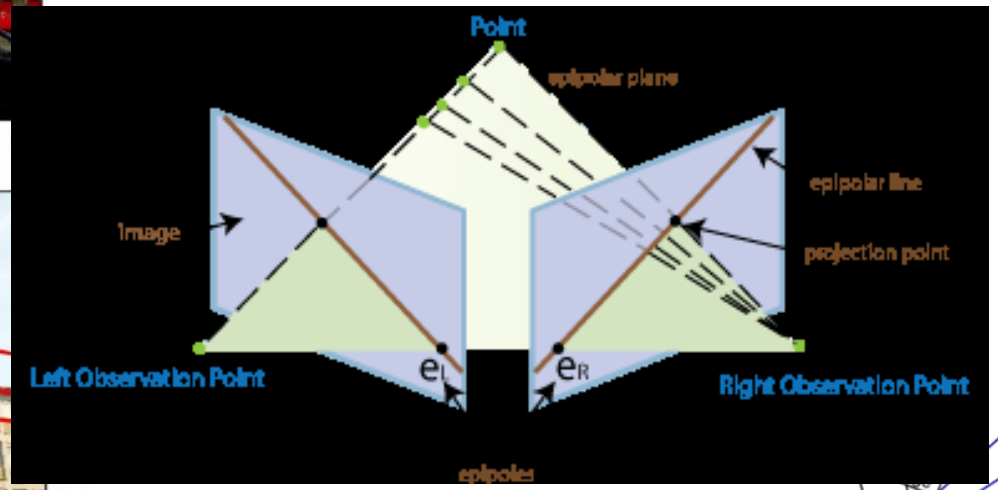
Structure from Motion (SfM)



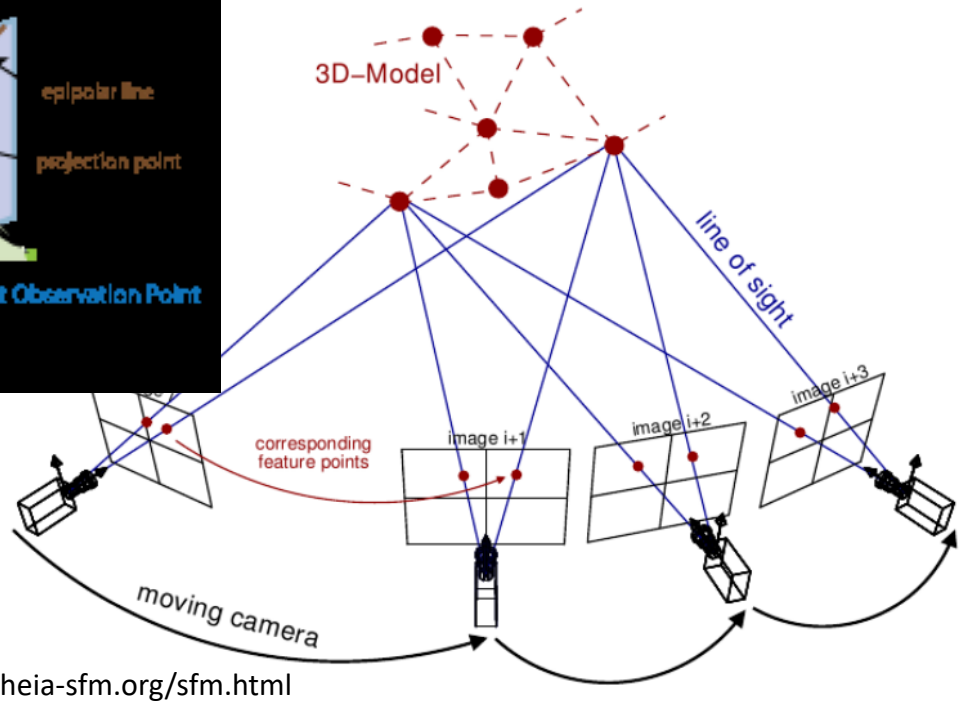
Structure from motion (SfM): the process to estimate the 3-D structure from a set of 2-D images

Structures: Topography, buildings, any 3D objects

Software for SfM processing : Pix4D, MetaShape, MicMac, etc.



https://www.mathworks.com/help/vision/ug/structure-from-motion.html



http://www.theia-sfm.org/sfm.html

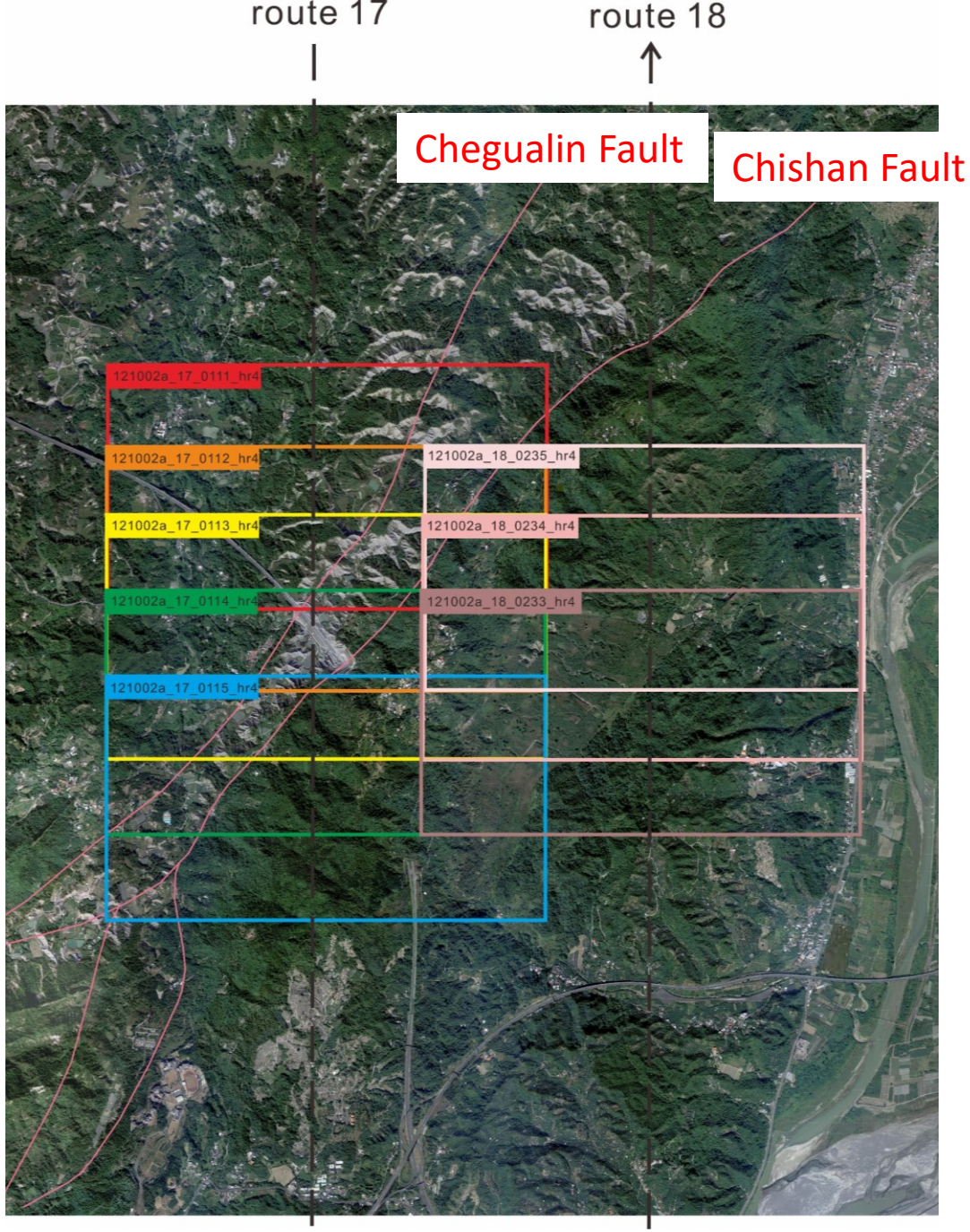


Image acquisition

Aerial images are acquired from Aerial Survey and Remote Sensing Branch, Forestry and Nature Conservation Agency.

We acquired 8 images for 8 epochs, from 2008-09-07 to 2015-09-23: total of 64 images.

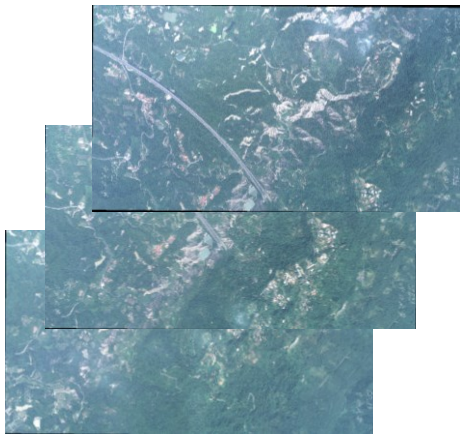
The image correlation is processed mainly on 2008-2015, other intermediate epochs will be assistive to the processing.

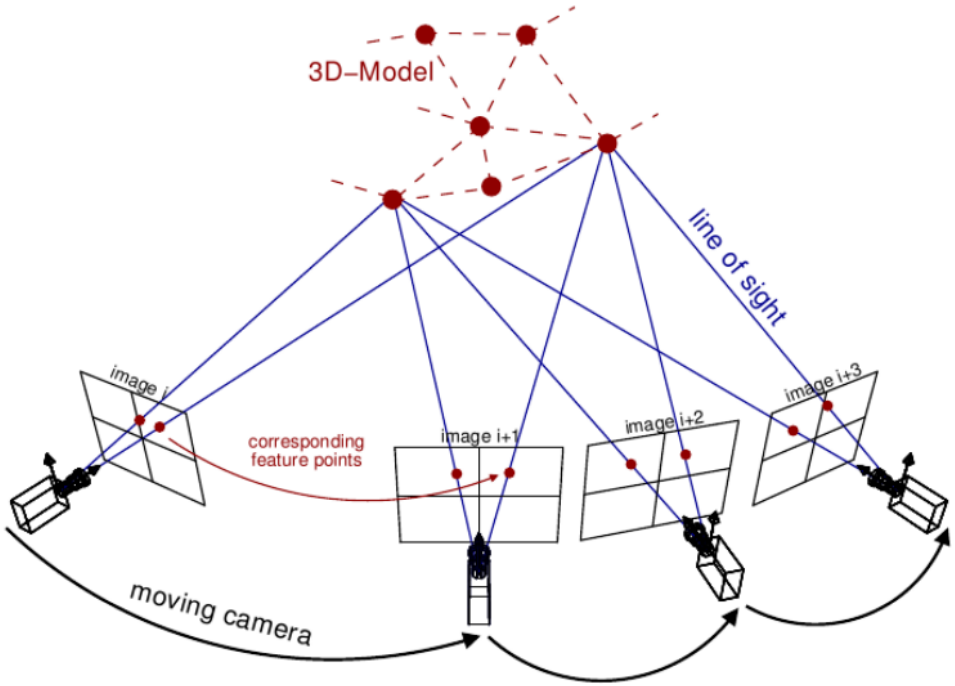
Processing steps

1.Image collection

2008-09

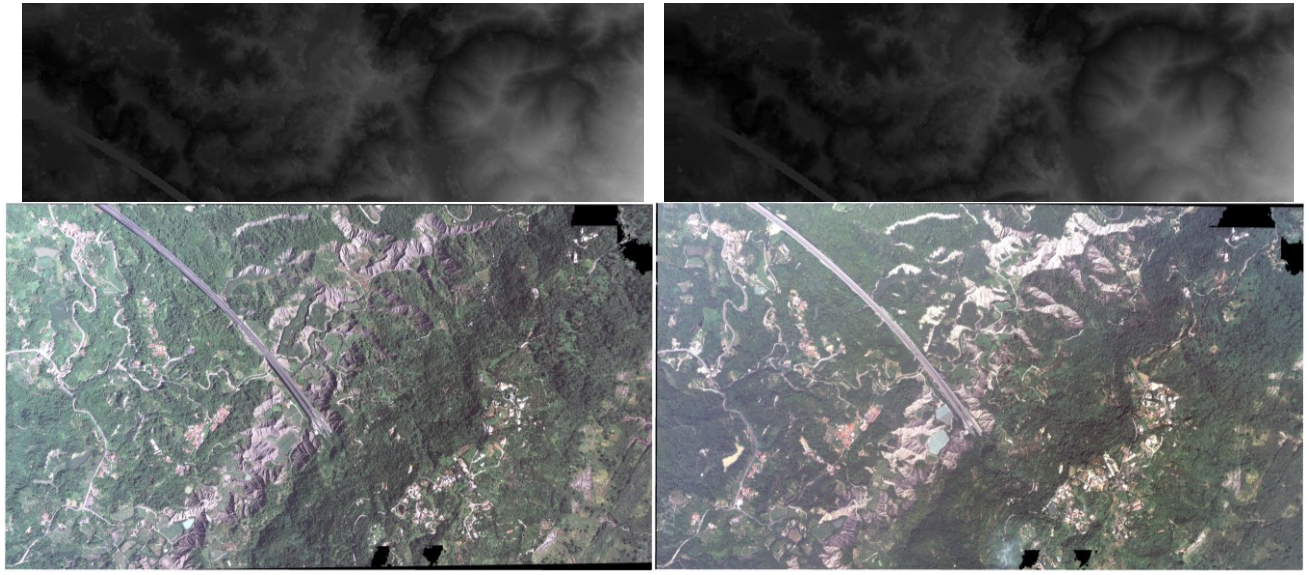
2015-09

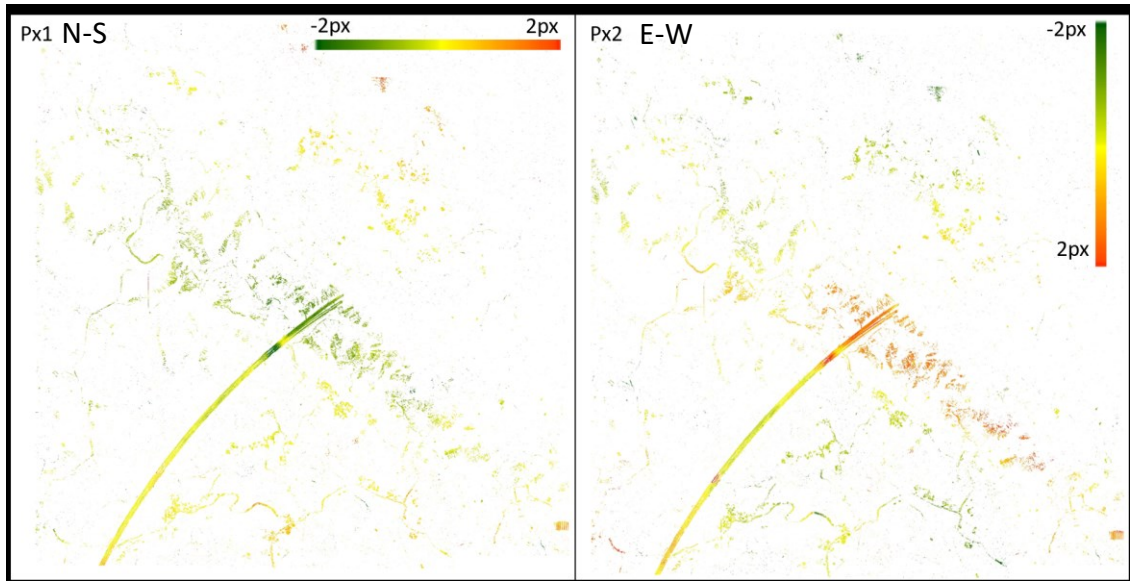




2. 3D Reconstruction by SfM

3. Extract DSM and orthorectify the aerial images

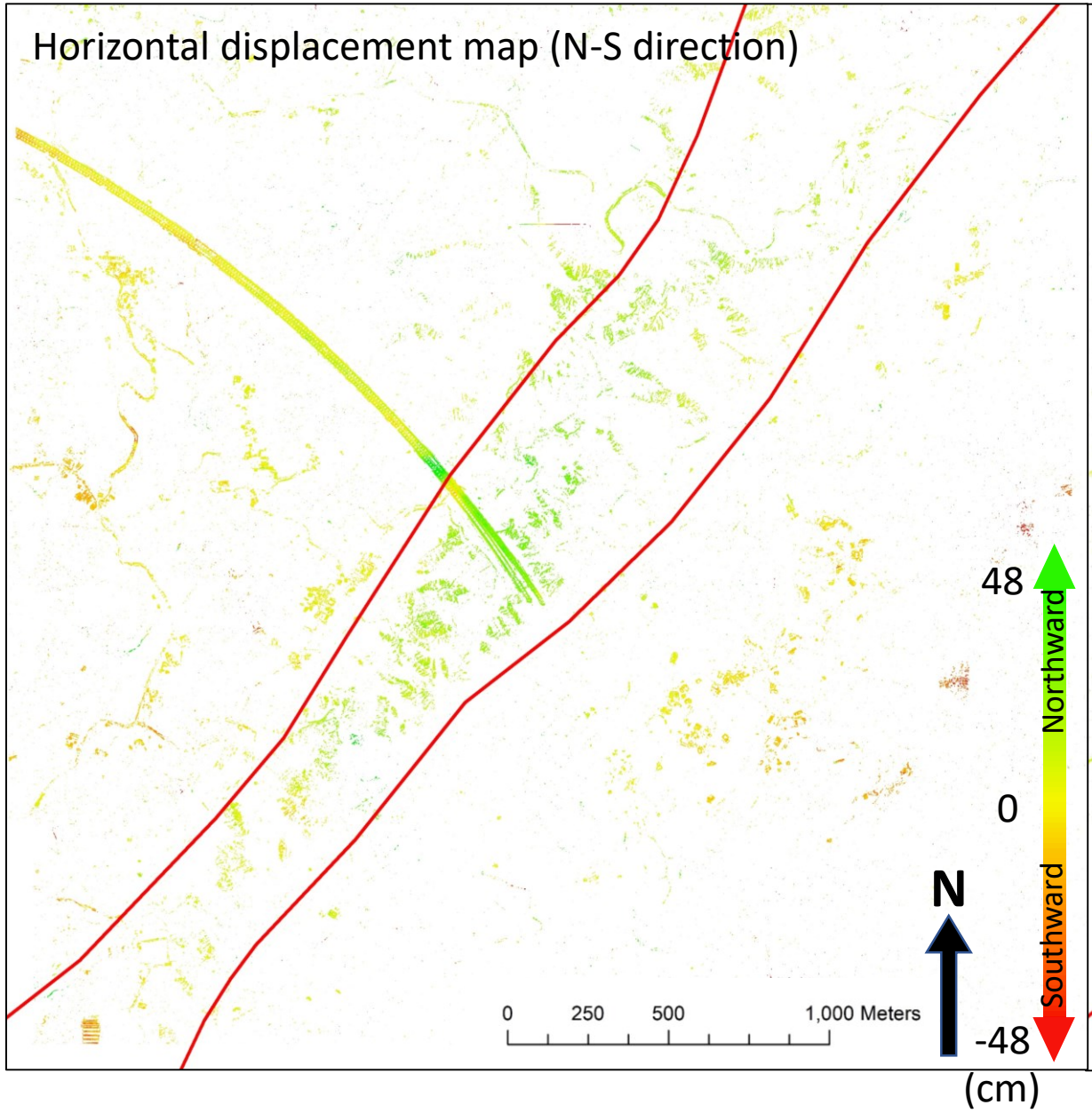




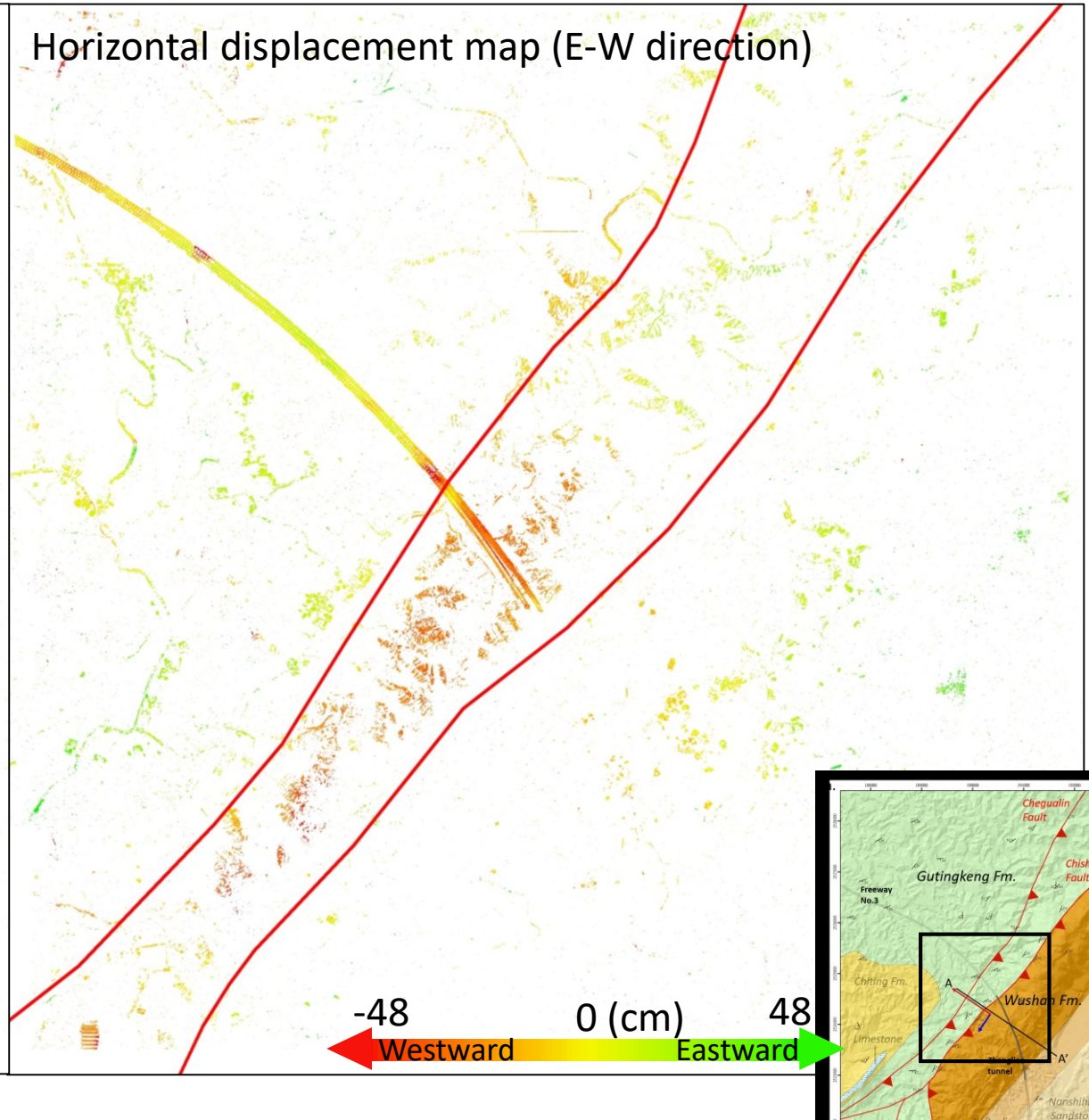
4. Measure 2D horizontal displacement

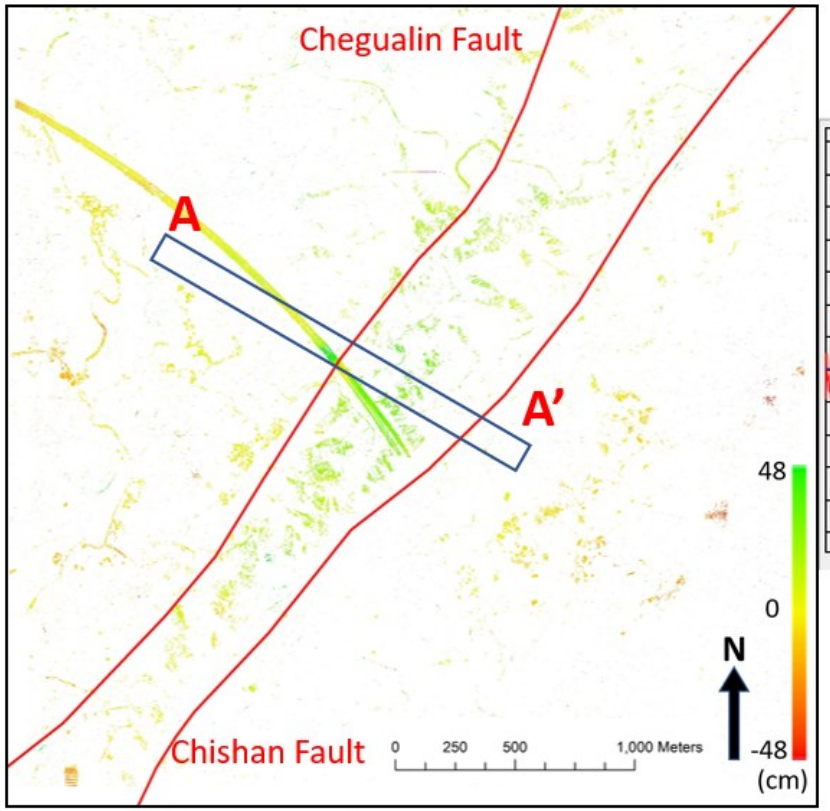
Chegualin Fault Chishan Fault

Horizontal displacement map (N-S direction)

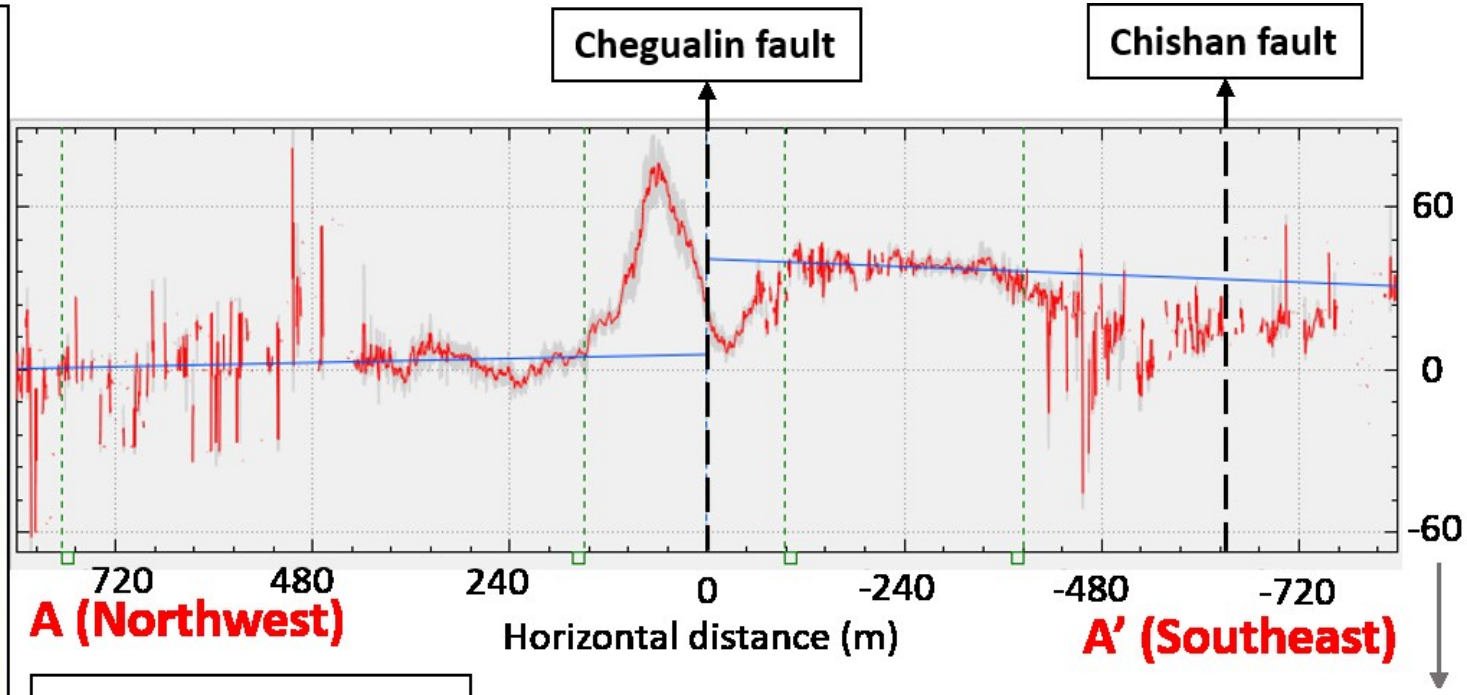


Horizontal displacement map (E-W direction)



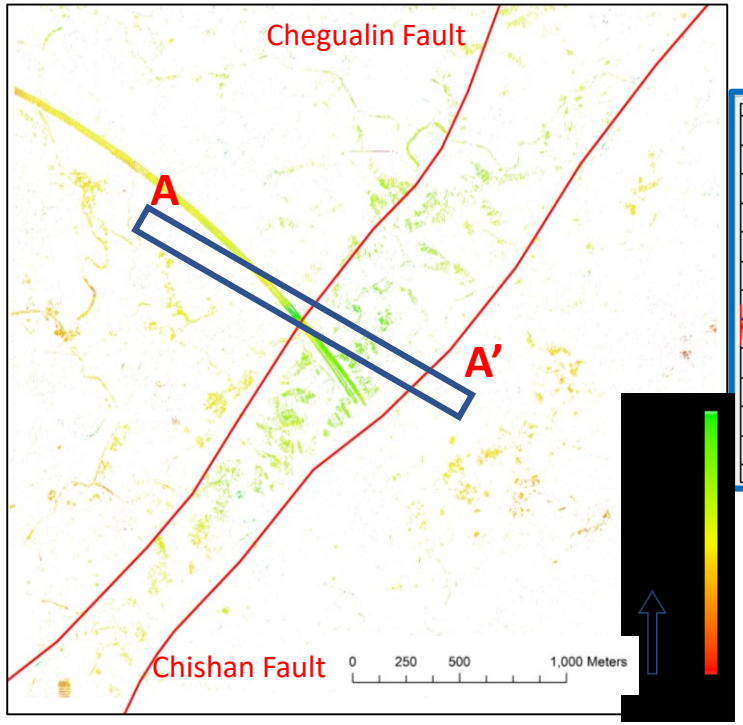


Horizontal displacement map
(N-S direction)

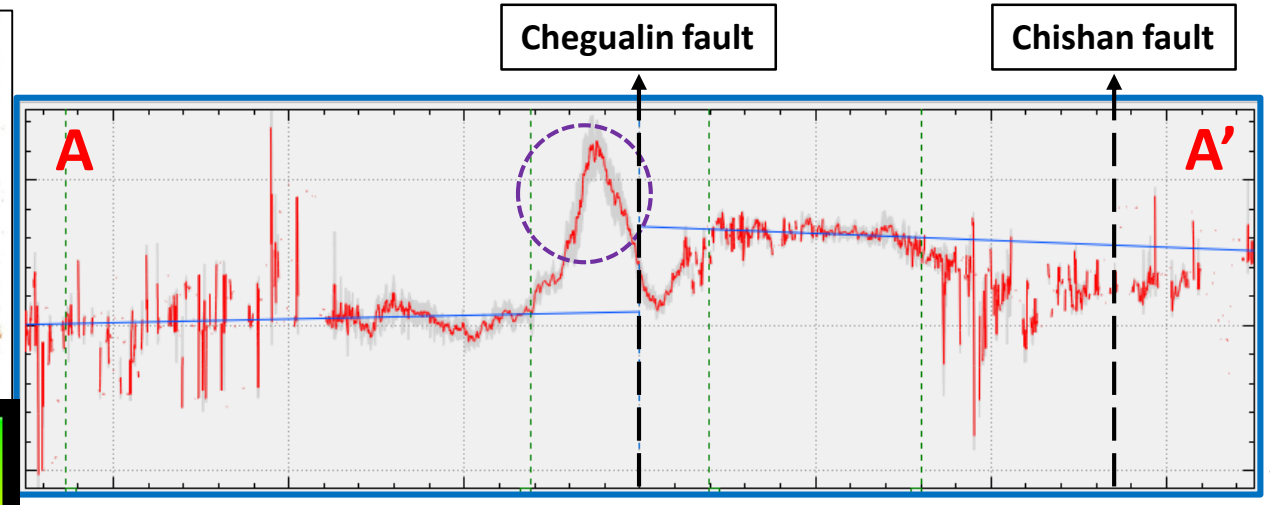


Projected horizontal displacement along A-A' direction (cm, positive to the northwest)

X axis: horizontal distance.
Y axis: displacement along A-A' direction (positive to the northwest).
Blue lines: the regression line between two green dashed lines.
Offset: the gap of two blue lines in Y axis.



Horizontal displacement map (N-S direction)

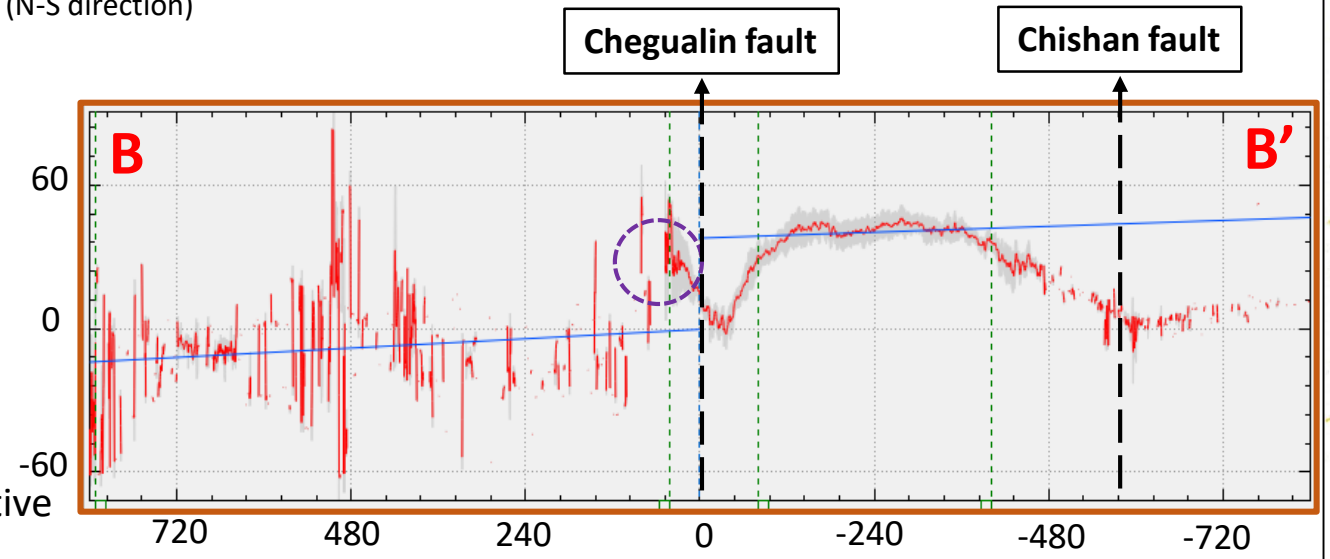


Horizontal distance (m)

displacement (cm, positive to the northwest)

Marks the artifact due to repavement of the highway (non-tectonic related signal)

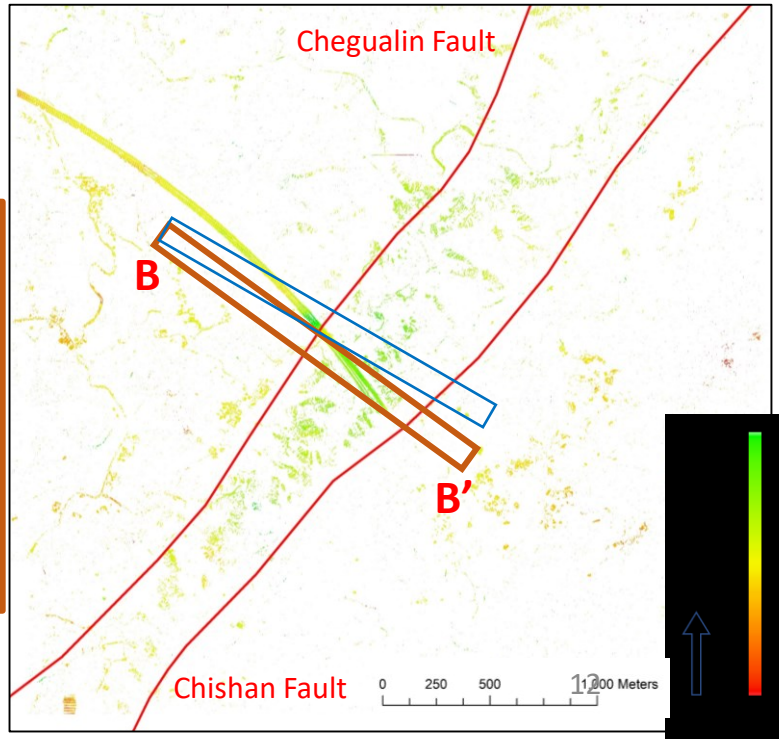
Offset = 35.2cm



Horizontal distance (m)

displacement (cm, positive to the northwest)

Offset = 38.2cm

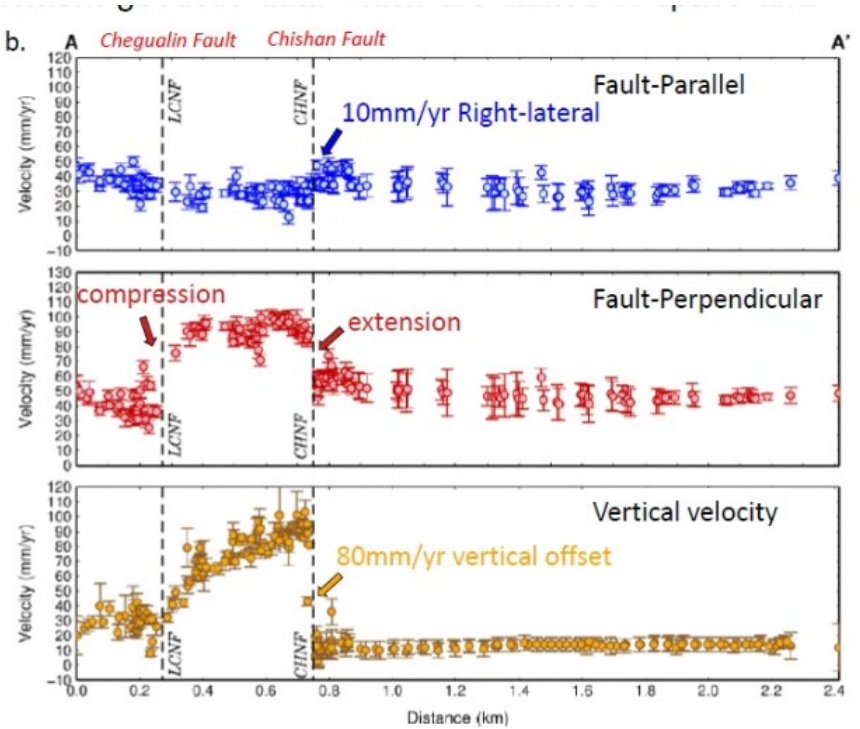


Horizontal displacement map (N-S direction)

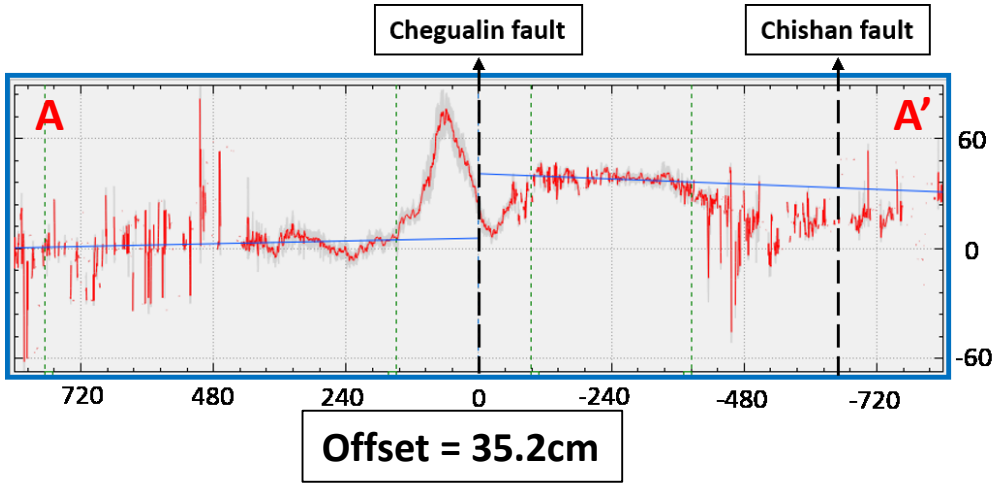
Ground displacement nearby Zhongliao tunnel

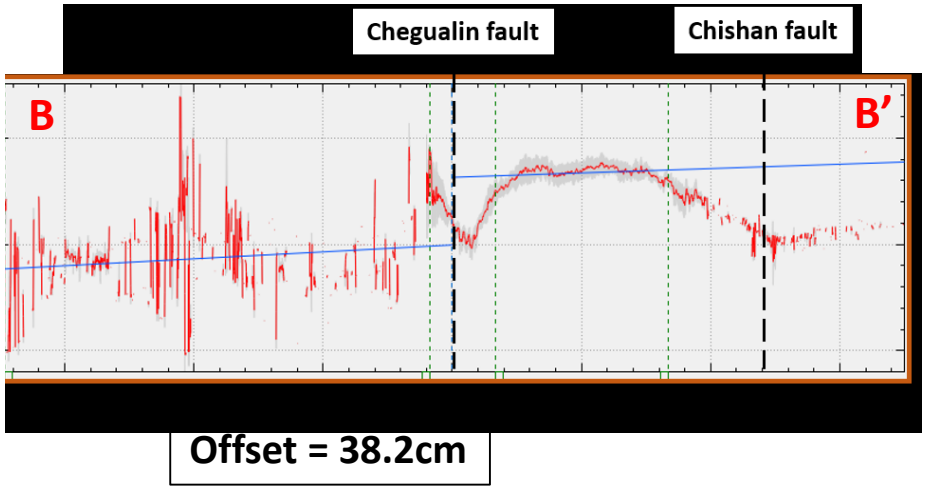
- Ground-based geodetic measurements along the freeway, the displacement at fault-perpendicular direction: **50 mm/yr compression across the Chegualin fault**.
- We expect a **total displacement of 35 cm during 2008-2015**.

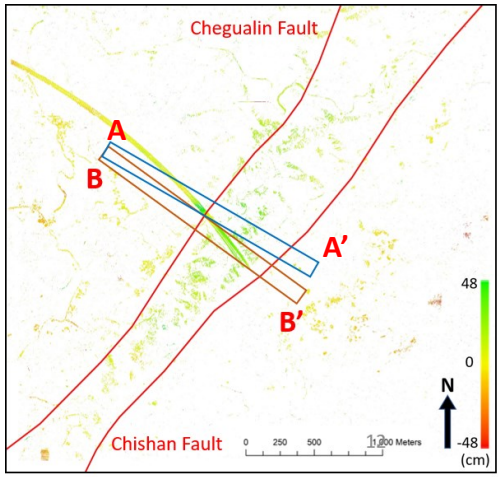
- The displacement measured from the **aerial images (2008-2015) correlation** is about **36.7 cm,** which is quite consistent with previous observation.



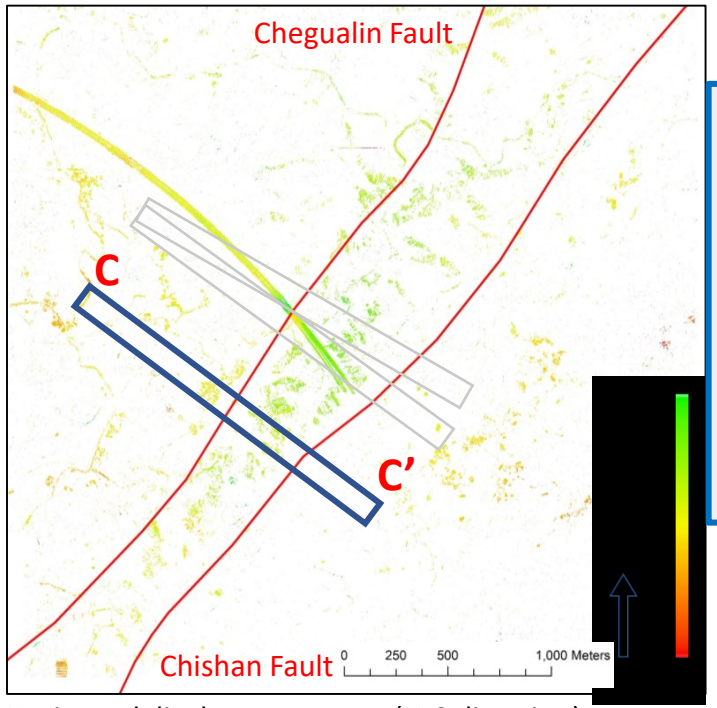
Velocity relative to Penghu, ground-based geodetic measurements, projected on AA' line (Chang-Lee, 2014).



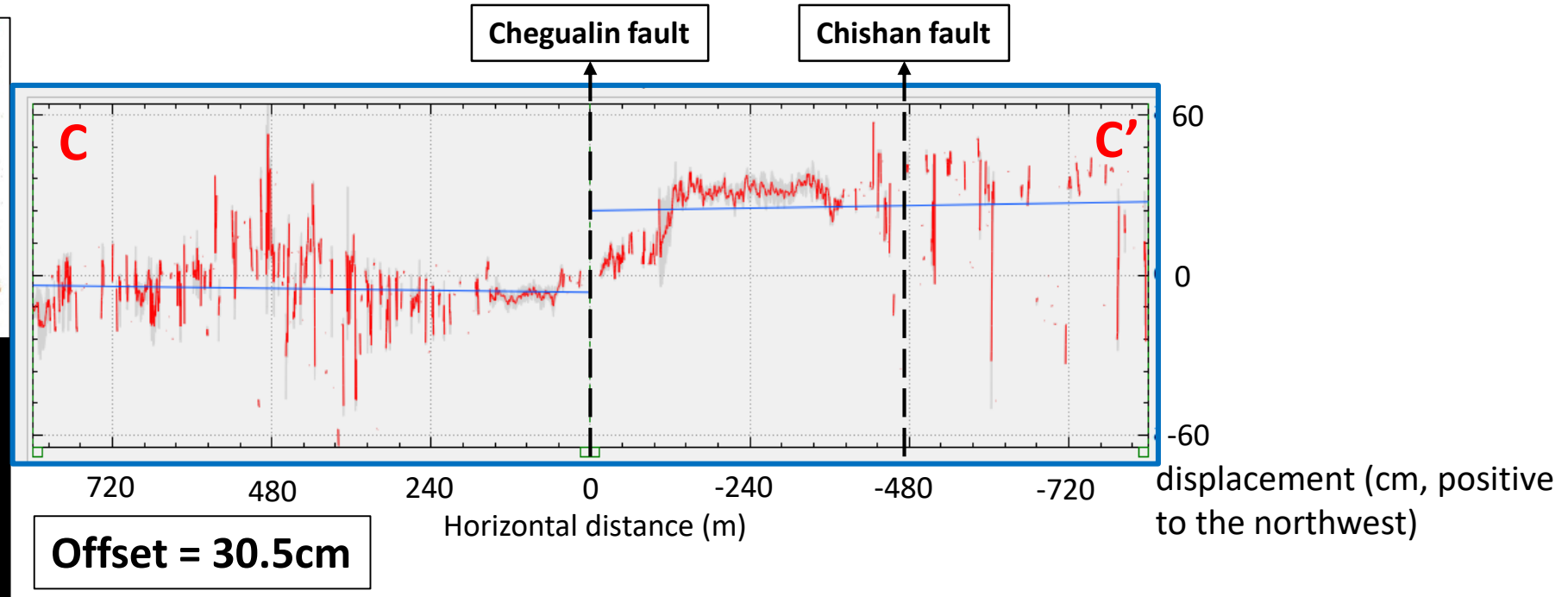




Horizontal displacement map (N-S direction)

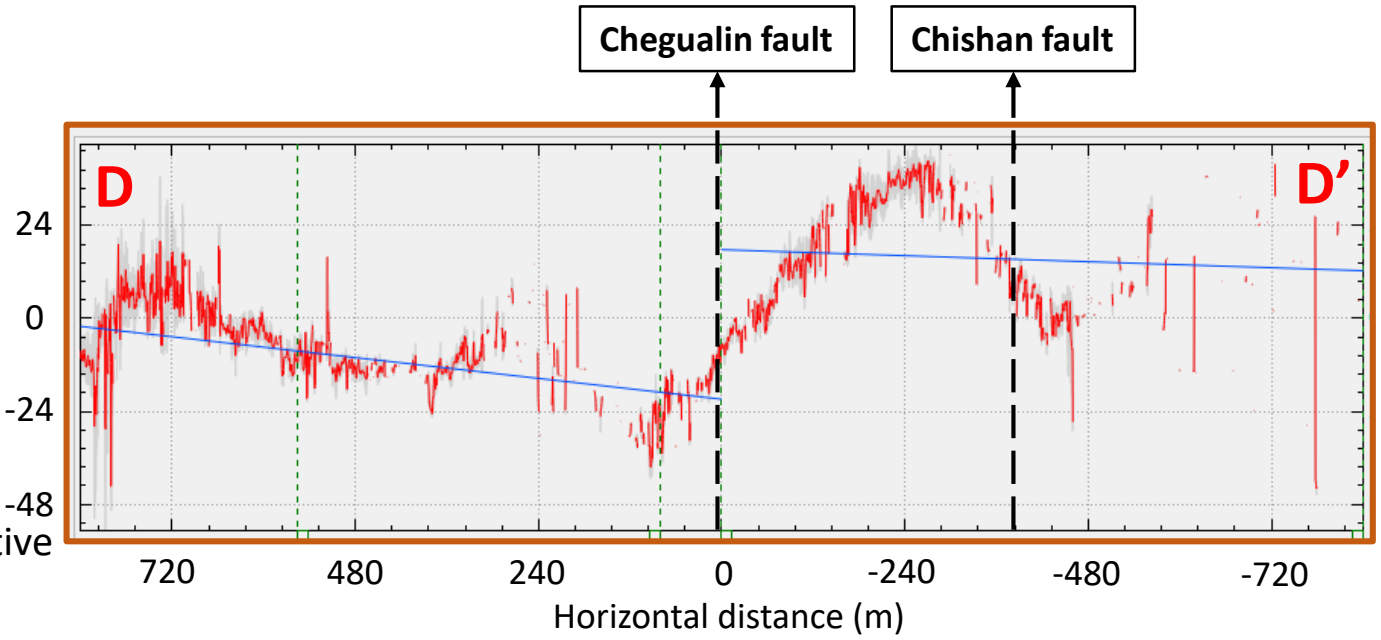


Horizontal displacement map (N-S direction)

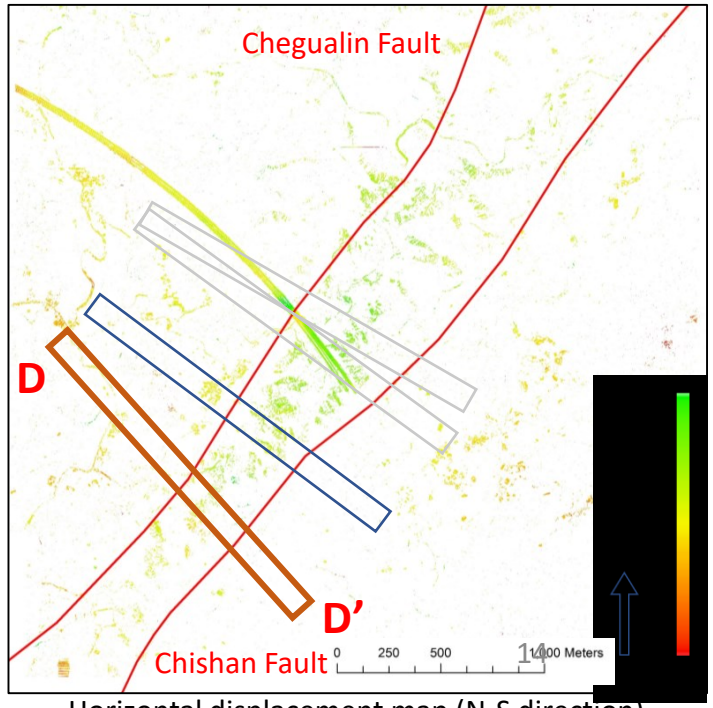


displacement (cm, positive to the northwest)

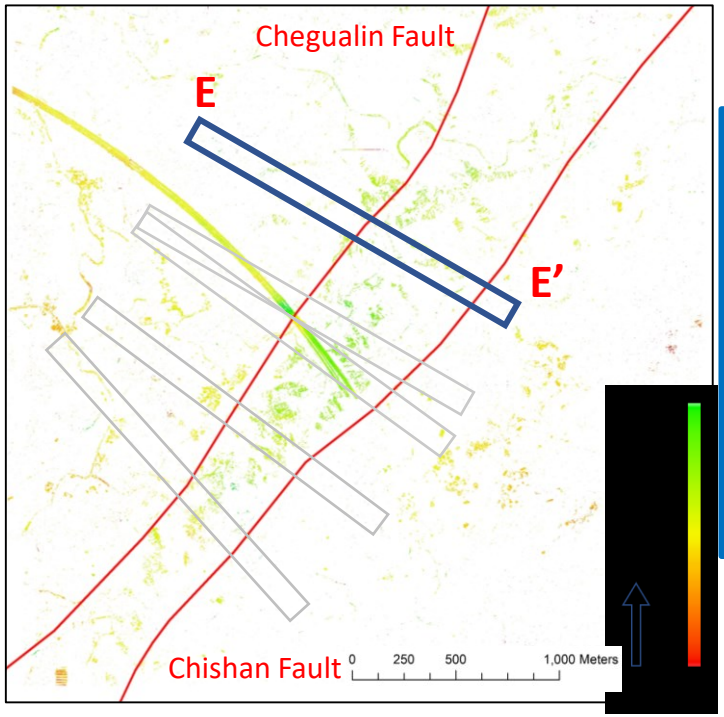
Offset = 30.5cm



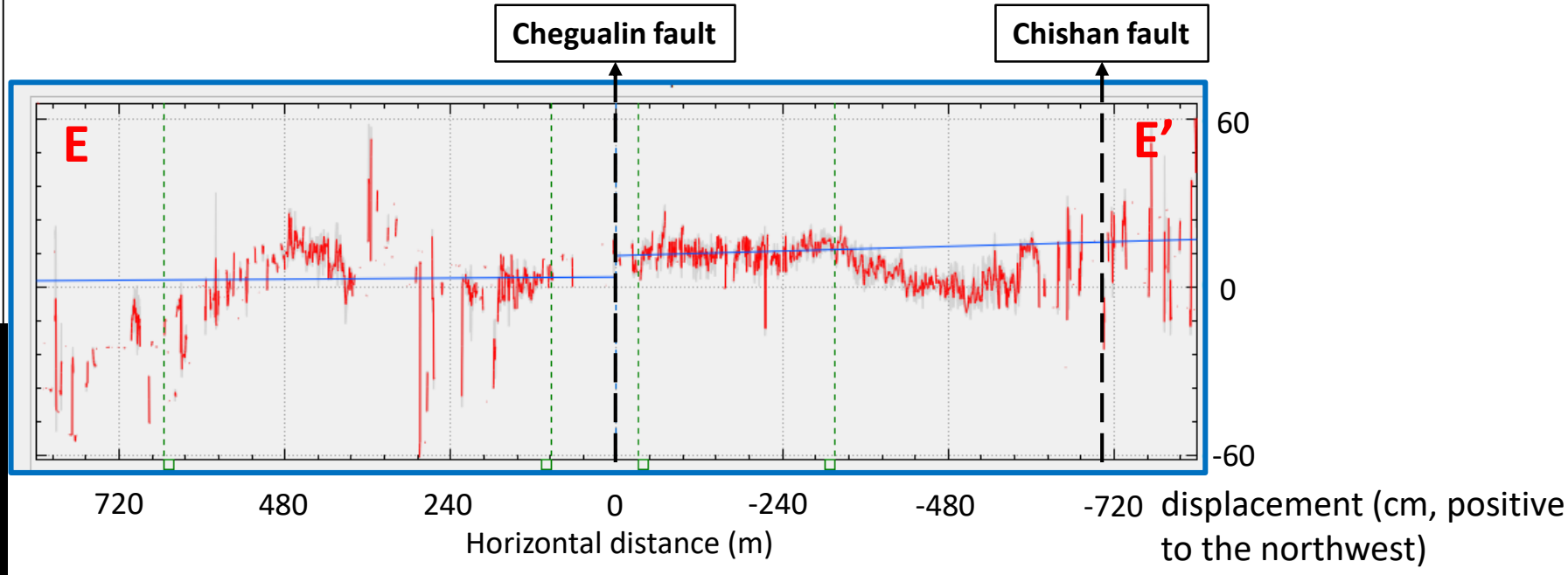
displacement (cm, positive to the northwest)



Horizontal displacement map (N-S direction)



Horizontal displacement map (N-S direction)



- The tectonic signal of Chegualin fault can be observed southward for 500 meters, but poorly extended northward.
- The signal across the Chishan fault is noisy, due to lack of stable target (roads, houses, etc.) for correlation.

Summary

- We can measure the horizontal displacement through aerial image correlation. The amount of compression across Chegualin fault is about 37 cm over 7 years (2008-2015), which is consistent with geodetic measurements.

- However, it remain challenging to estimate the displacement at Chishan fault, due to the lack of stable targets (roads, houses, etc.).

- The tectonic signal of Chegualin fault is significant at the freeway No.3, and at least 500 meters further to the south.

Future work

- Ground-based measurements showed very high uplift ➔ Use DSMs to quantify the vertical displacement component.

- Deeper analysis on the displacement map: We will build the displacement profile with higher density and different transect direction, in order to understand the pattern of displacement better.

- Long-term goal: Combine our research with previous studies about this area to constrain the mechanism of these significant tectonic activities.

Thank you :)

Image geometry and bundle adjustment

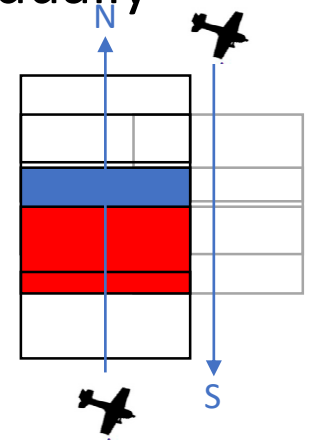
The position and orientation of the sensor (Ex. The camera of UAV)

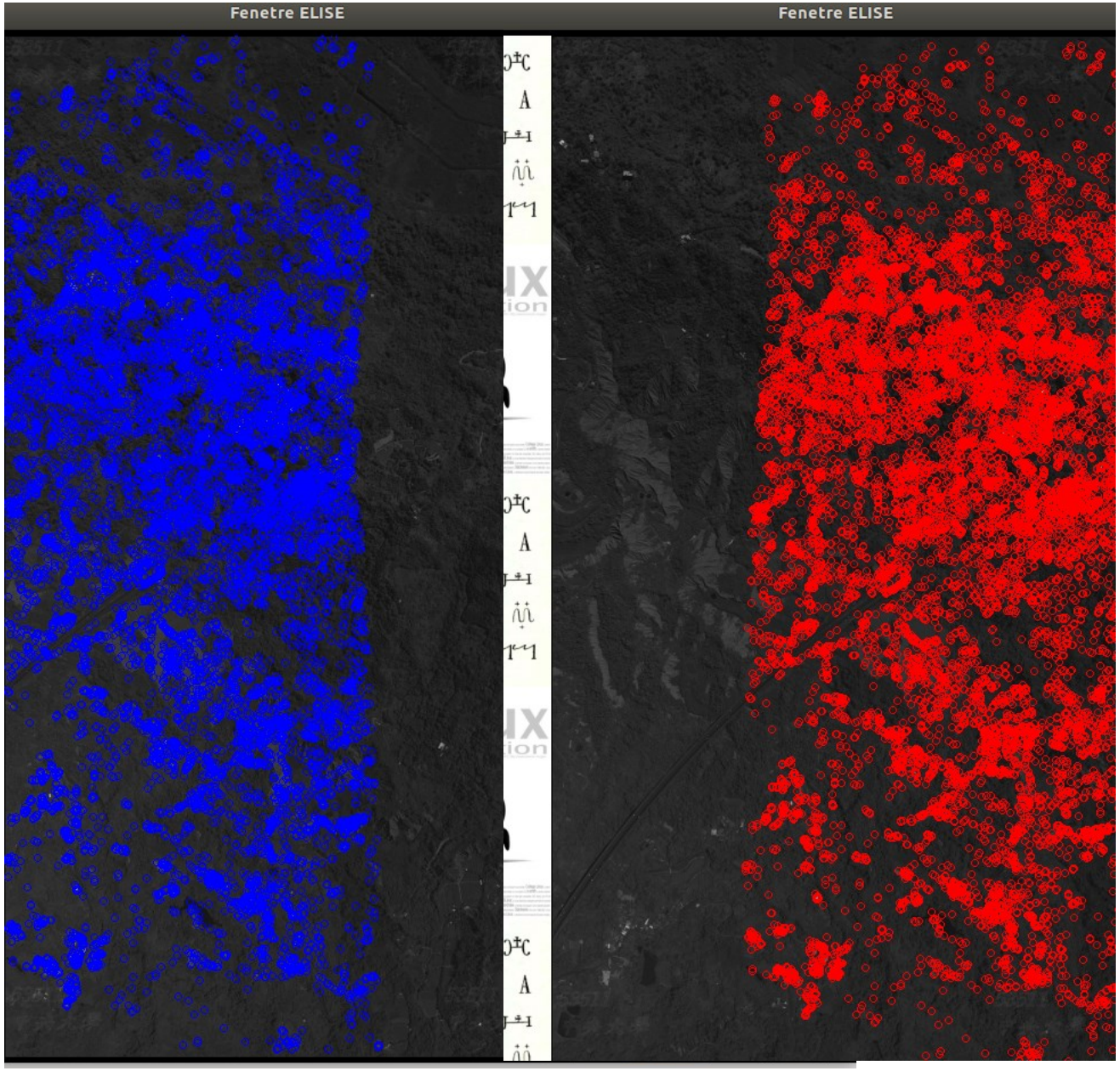
The physical parameters are divided into two categories:

- The **internal parameters**
  - Camera : focal length, principal point, size of the sensor, distortions of the lens
  - Satellite : geometry of the focal plane (line of sight of the detector for each pixel)
- The **external parameters**
  - Camera : position (X, Y, Z) and attitude (R, T, L)
  - Satellite : time of acquisition, position (X, Y, Z), attitude (R, T, L) and their derivatives (∂ *X*/ ∂ *t*, ∂ *Y*/ ∂ *t*, …)

Processing steps

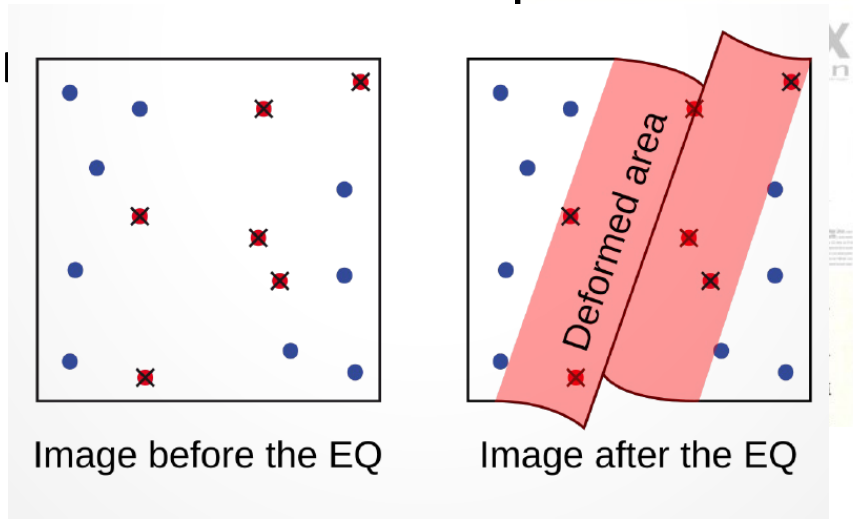
- Tapioca for both epochs individually --- result-A
- Tapioca for inter-epoch tie points
- Mask the inter-epoch tie points that are inside of the deformation zone --- result-B
- Tapas with the merged result of A and B
- Malt both epoch individually
- MM2DPosSism





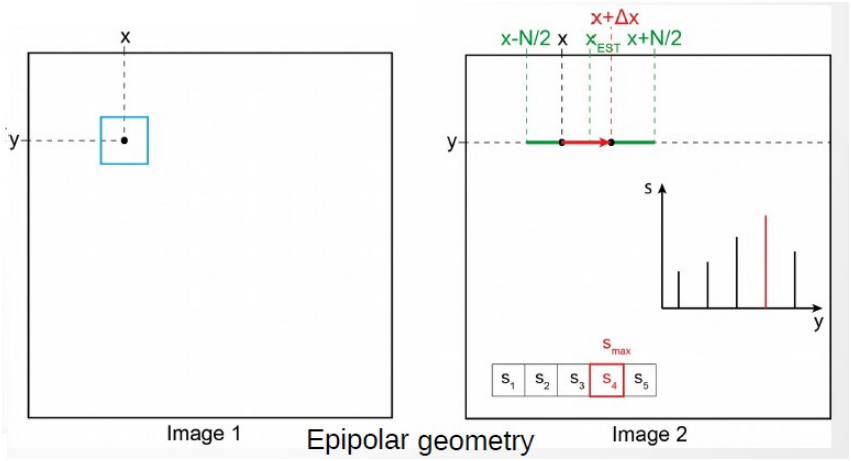
Processing steps

- Tapioca for both epochs individually --- result-A
- Tapioca for inter-epoch tie points
- Mask the inter-epoch tie points that are inside of the deformation zone --- result-B
- Tapas with the merged result of A and B
- Malt both epoch i
- MM2DPosSism

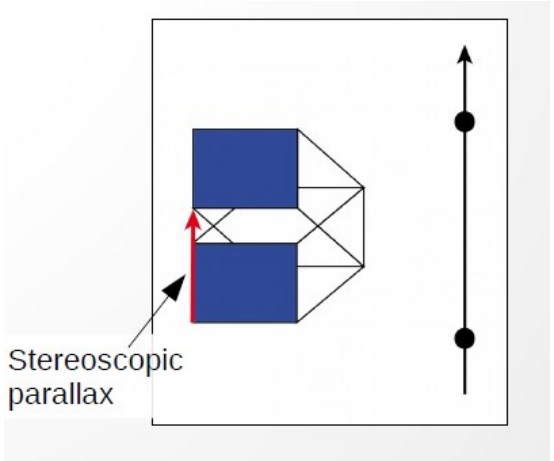


For each pixel in image 1, we want to estimate the position of the homologous pixel in image 2, to measure the parallax.
Consider the images resampled in **epipolar geometry**. Consider a pixel (x, y) in image 1. In image 2, we define a search space of size N on the epipolar line, centered on the estimated position of the homologous pixel, to save computation time and reduce the risks of confusion.

We define a window of size n*n, centered on the pixel in image 1 and a "sliding" window of the same size in image 2, which is moved step by step (step = p) inside the search space. For each position, we estimate the **similarity** between the two windows. The similarity criteria can be radiometrical, statistical or mathematical. We can use for instance the **normalized cross-correlation coefficient**.
We obtain a **similarity score** for each position of the window in the search space.



Epipolar geometry

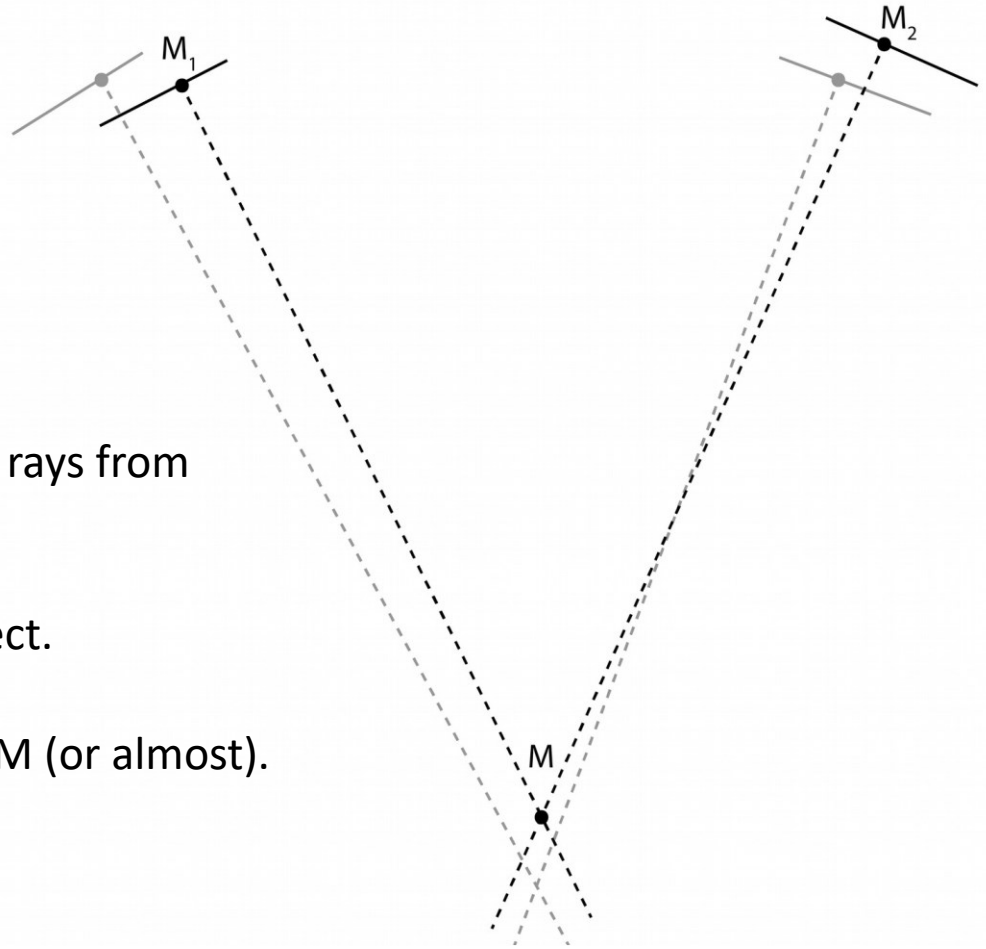


We measure Δx, the parallax at (x, y).
If p < 1 px, the measurement resolution is **sub-pixel**. The detection threshold can reach ~0.05 px in the most favorable cases.

Processing Pipeline:

1. Tapioca for the **intra-epoch** tie points (2008-2015)
2. SuperGlue for **inter-epoch** tie points (2008-2015)
3. Merge all the tie points and perform **bundle adjustment** (Tapas)
4. Select **manual tie points** on designated epochs for Campari (2008 and 2015)
5. Malt with the Image geometry given by Campari
6. Use the orthoimage for **pixal correlation** (MM2DPosSism)

Image geometry and bundle adjustment



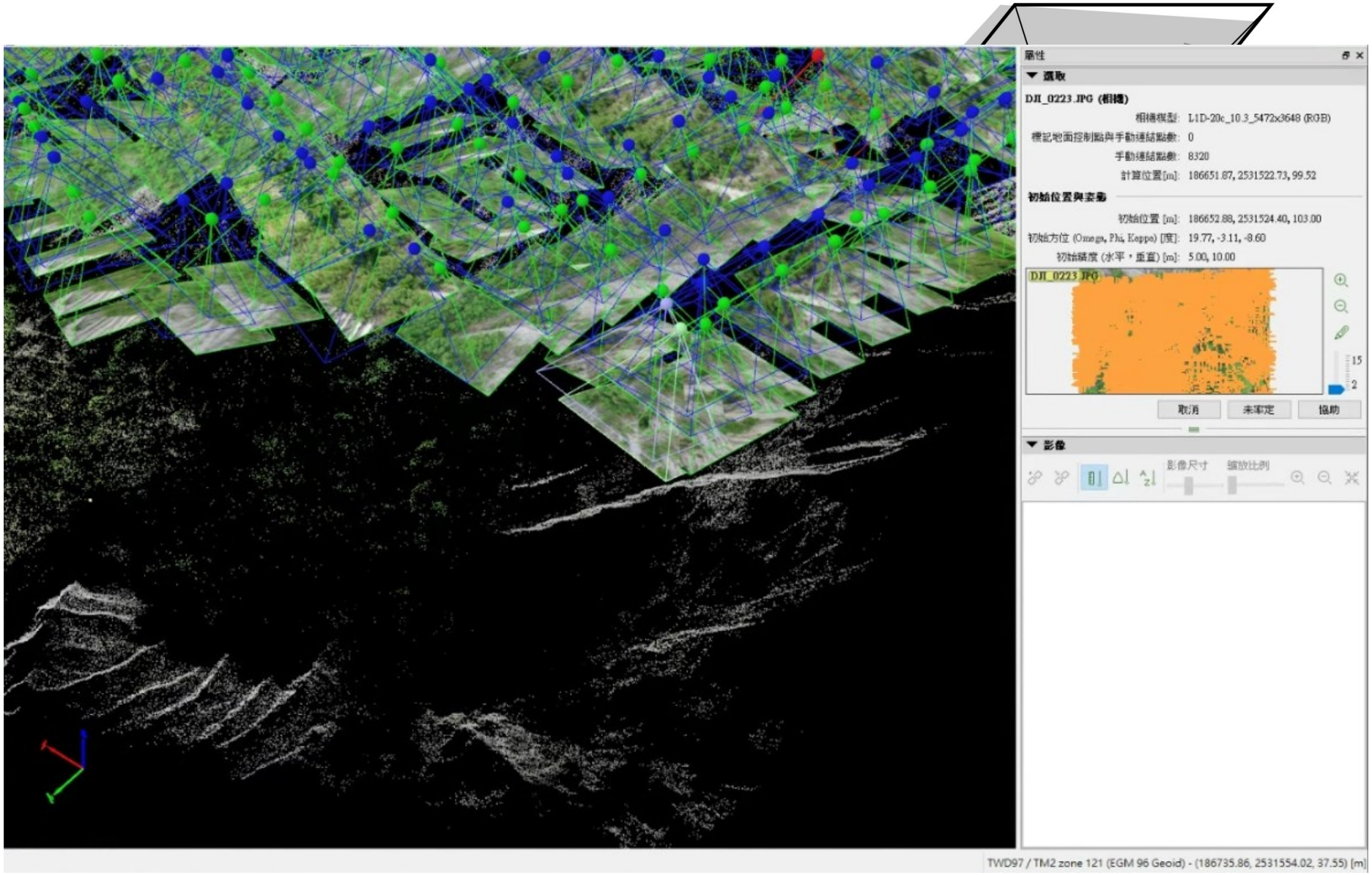
If the geometry were perfectly known, the rays from M1 and M2 should intersect in 3D in M.

Before the refining: the rays do not intersect.

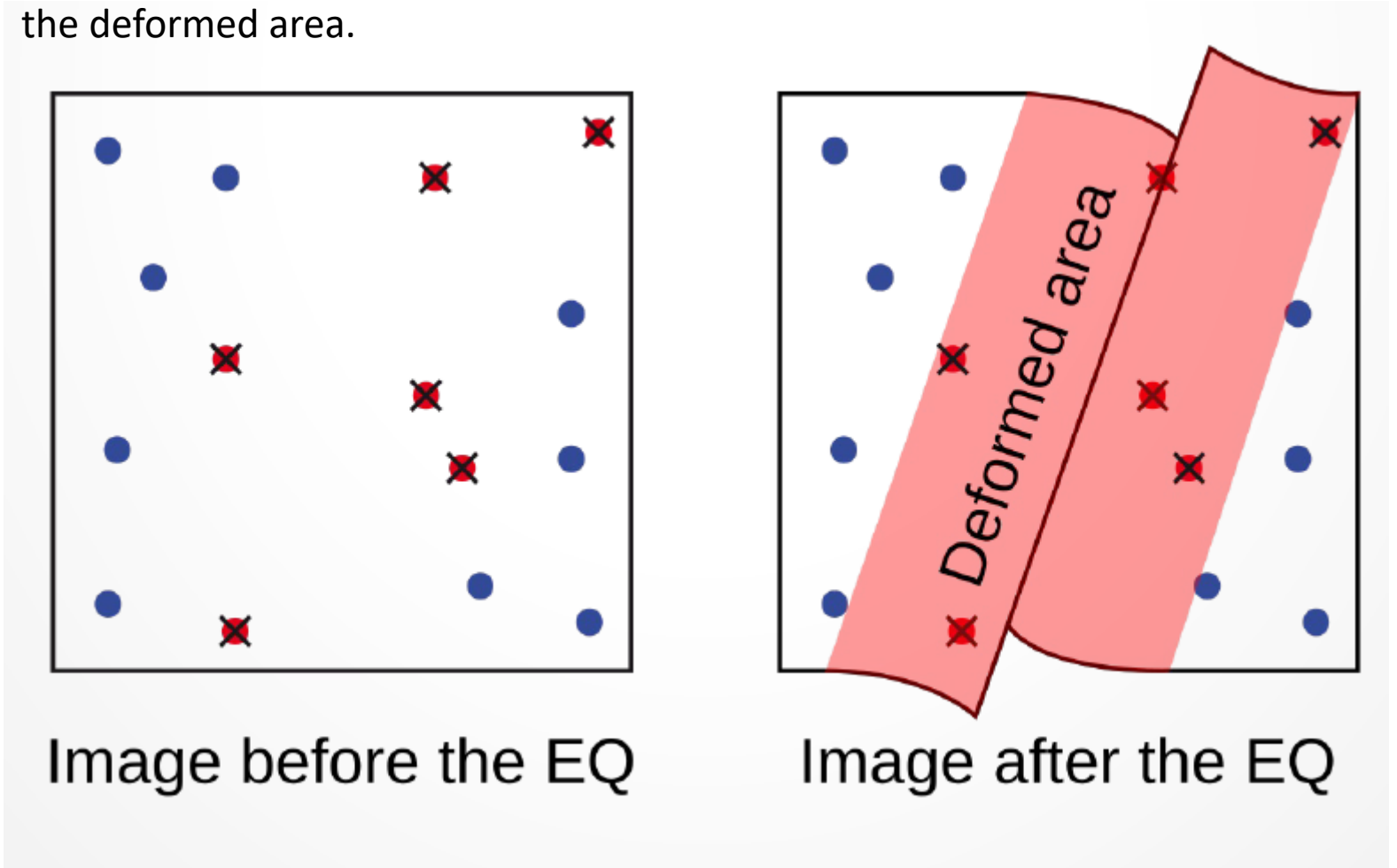
After the refining: the rays do intersect in M (or almost).

The method that consists in refining simultaneously the models of geometry of two or more images is called **bundle block adjustment**.

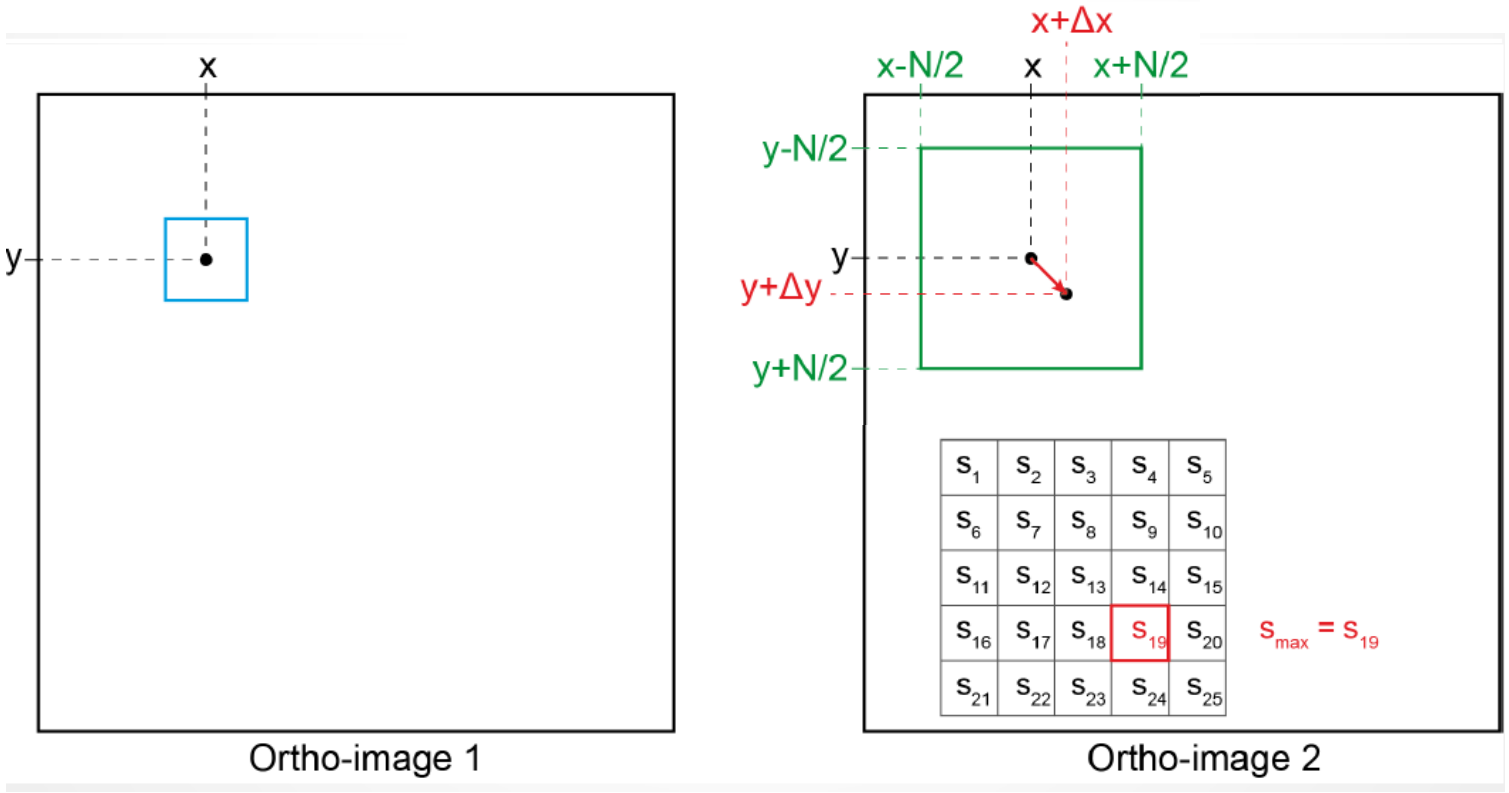
Image geometry and bundle adjustment

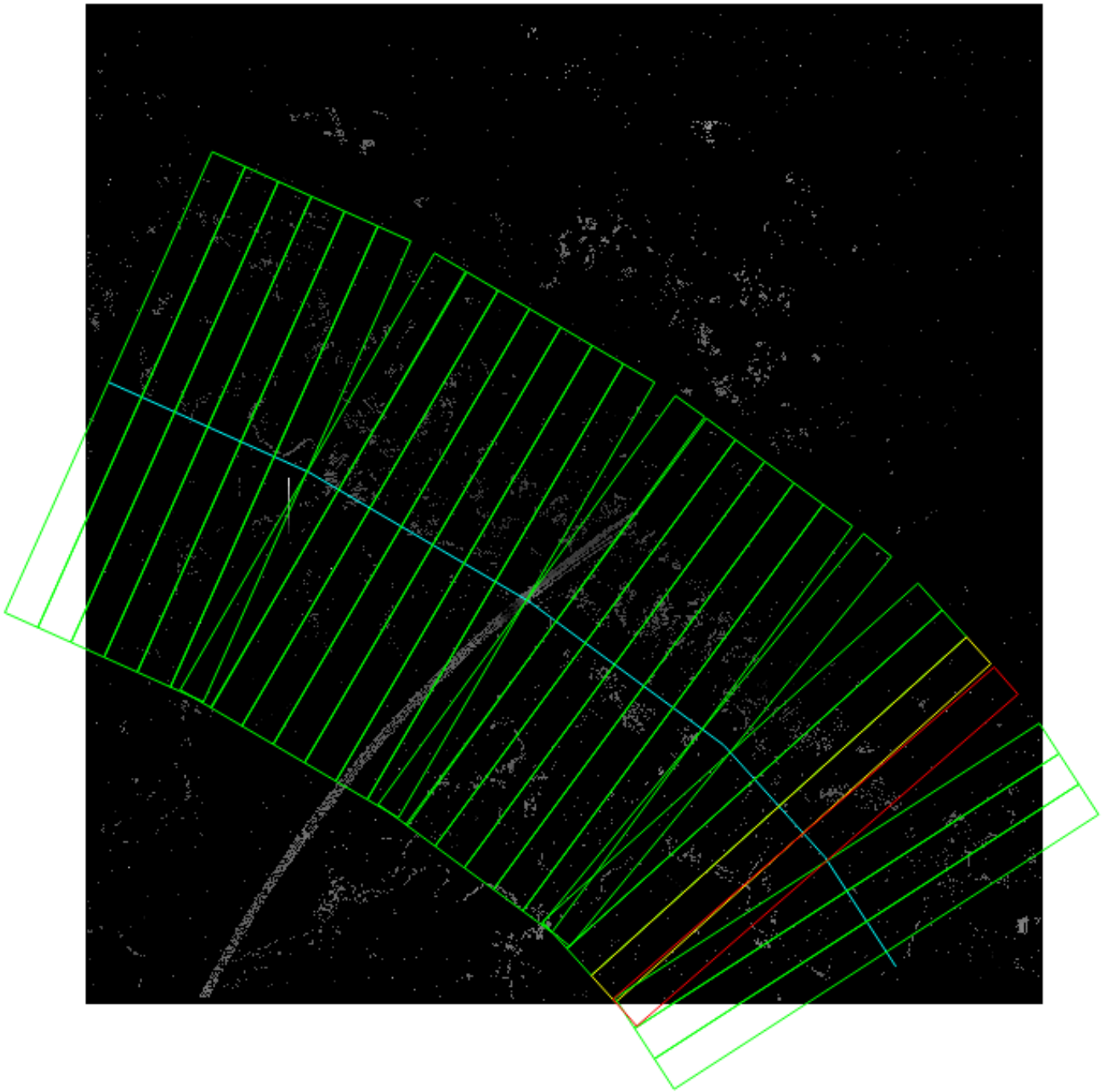


As for 3D restitution, a **bundle block adjustment** is performed to refine the models of geometry.
However, we must be careful not to include the deformation caused by the studied event in this refining. The tie points must therefore be selected **outside** the deformed area.



In the case of the **deformation measurement**, from one ortho-image to the other, the pixel may have moved as well according to the columns as according to the lines.
The search for the homologous pixel must therefore be carried out in these **two dimensions**.

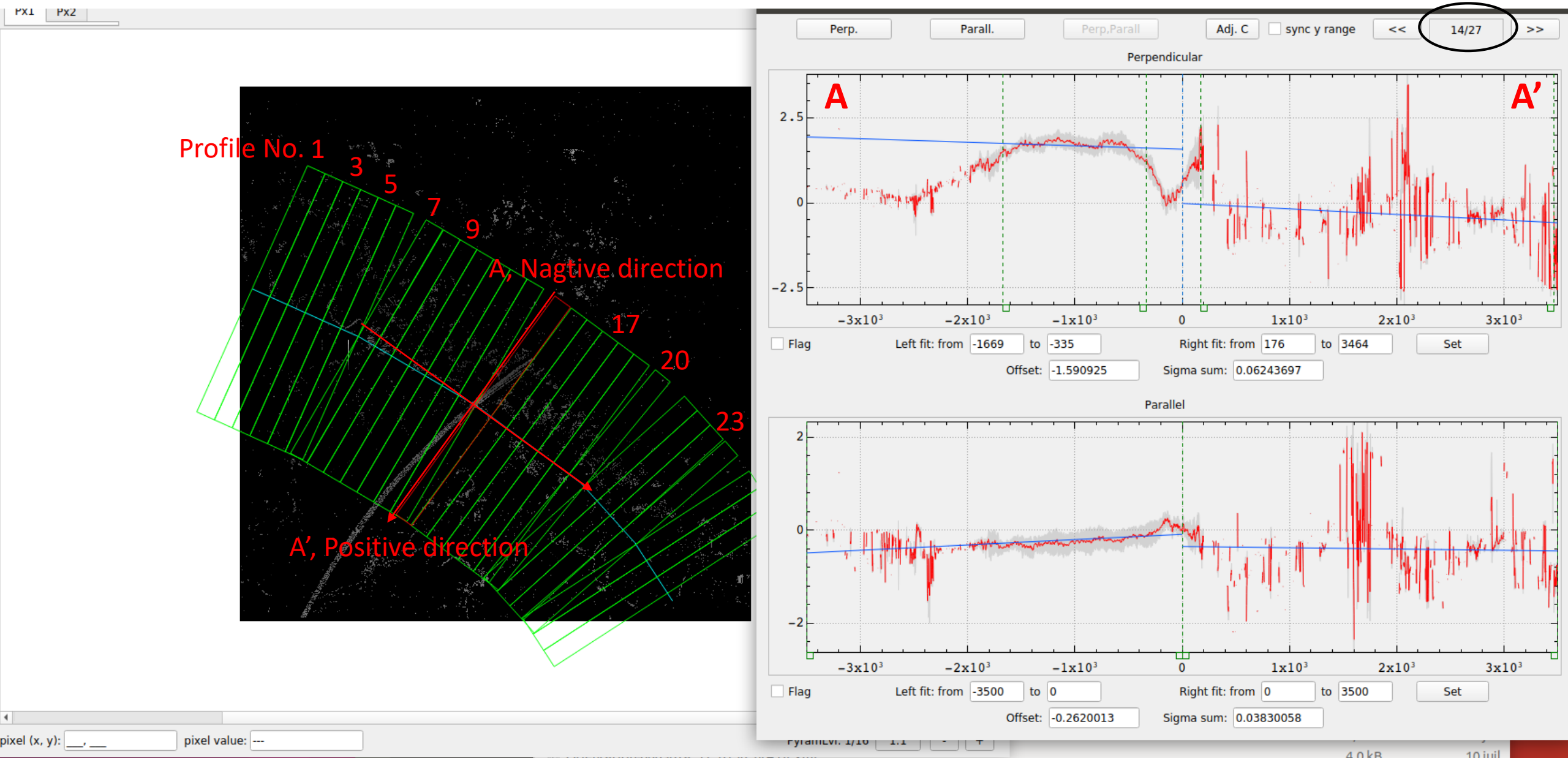




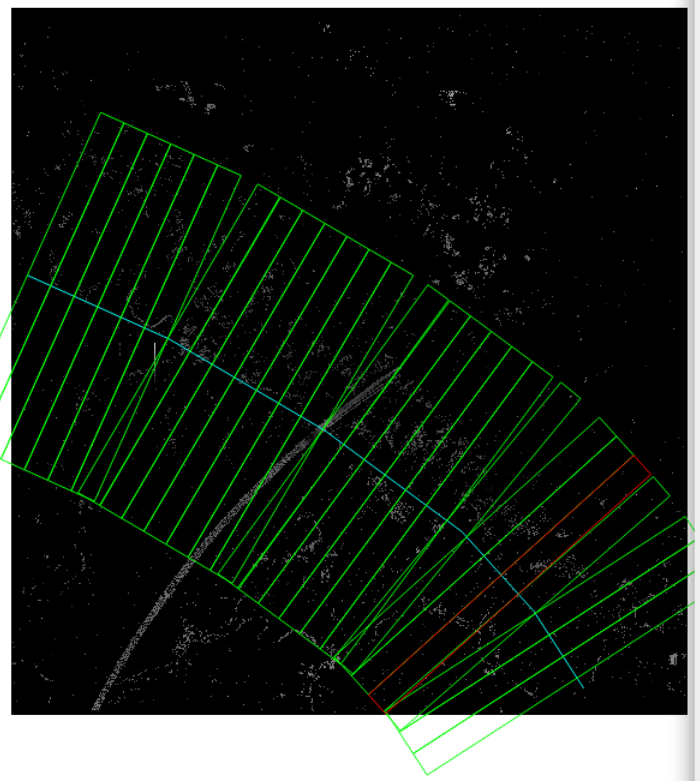
Displacement profiles

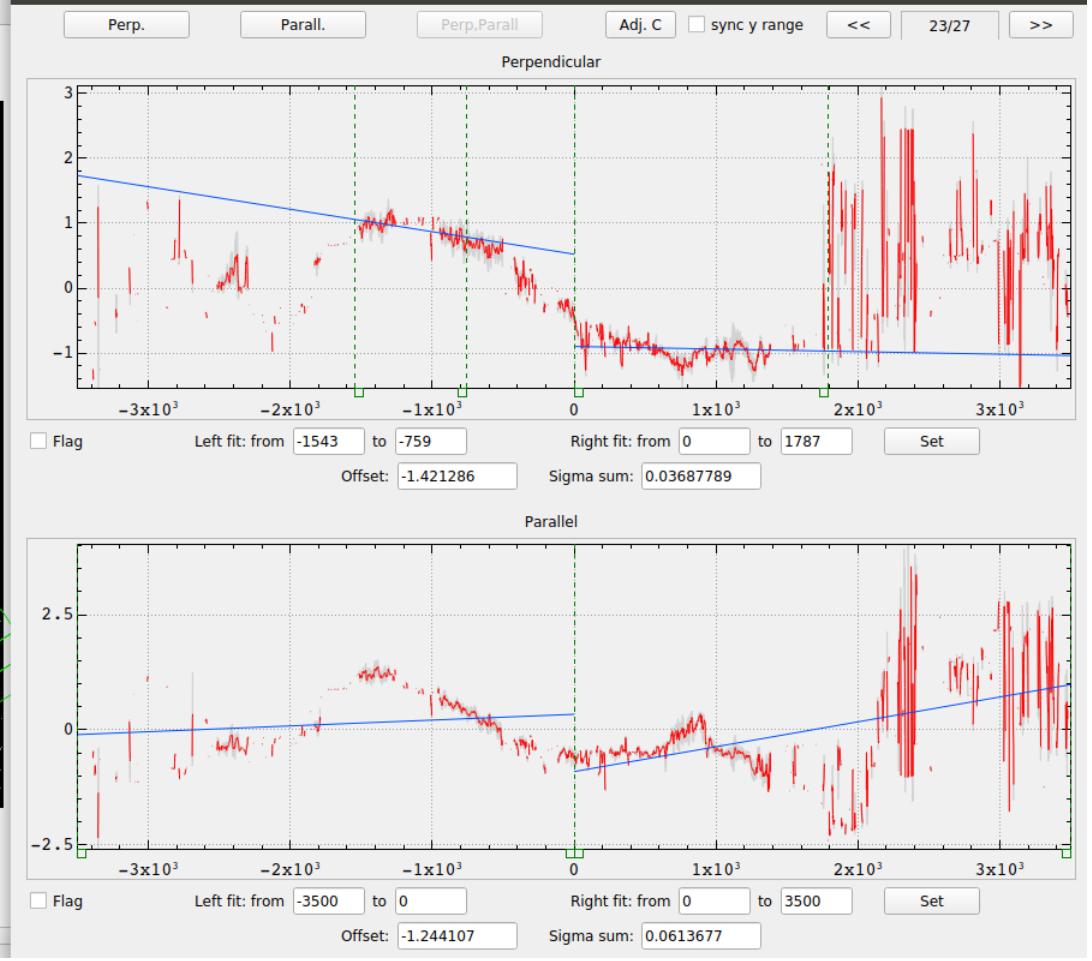
Light Blue: Trace of Chegualin fault

Profile No.


Px1
Px2
Profile No. 1
3
5
7
9
A, Nagtive direction
17
20
23
A', Positive direction
Perp.
Parall.
Perp,Parall
Adj. C
sync y range
<<
14/27
>>
Perpendicular
A
A'
2.5
0
-2.5
-3x10³
-2x10³
-1x10³
0
1x10³
2x10³
3x10³
Flag
Left fit: from -1669 to -335
Right fit: from 176 to 3464
Set
Offset: -1.590925
Sigma sum: 0.06243697
Parallel
2
0
-2
-3x10³
-2x10³
-1x10³
0
1x10³
2x10³
3x10³
Flag
Left fit: from -3500 to 0
Right fit: from 0 to 3500
Set
Offset: -0.2620013
Sigma sum: 0.03830058
pixel (x, y): ___, ___
pixel value: ---

Profile No.23





Elevation changes