國立中央大學
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National Central University

Determination of Chi-Chi Coseismic Activation of the Chusiang Active Fault Using Aerial Image Correlation and Coulomb Stress Transfer

Presenter : Chung-Wei Chang Advisor : Wen-Jeng Owen Huang

OUTLINE

- Introduction
  - Geological setting
  - Motivation & Purpose
- Methodology
- Results
- Discussion
- Conclusions
- Future work

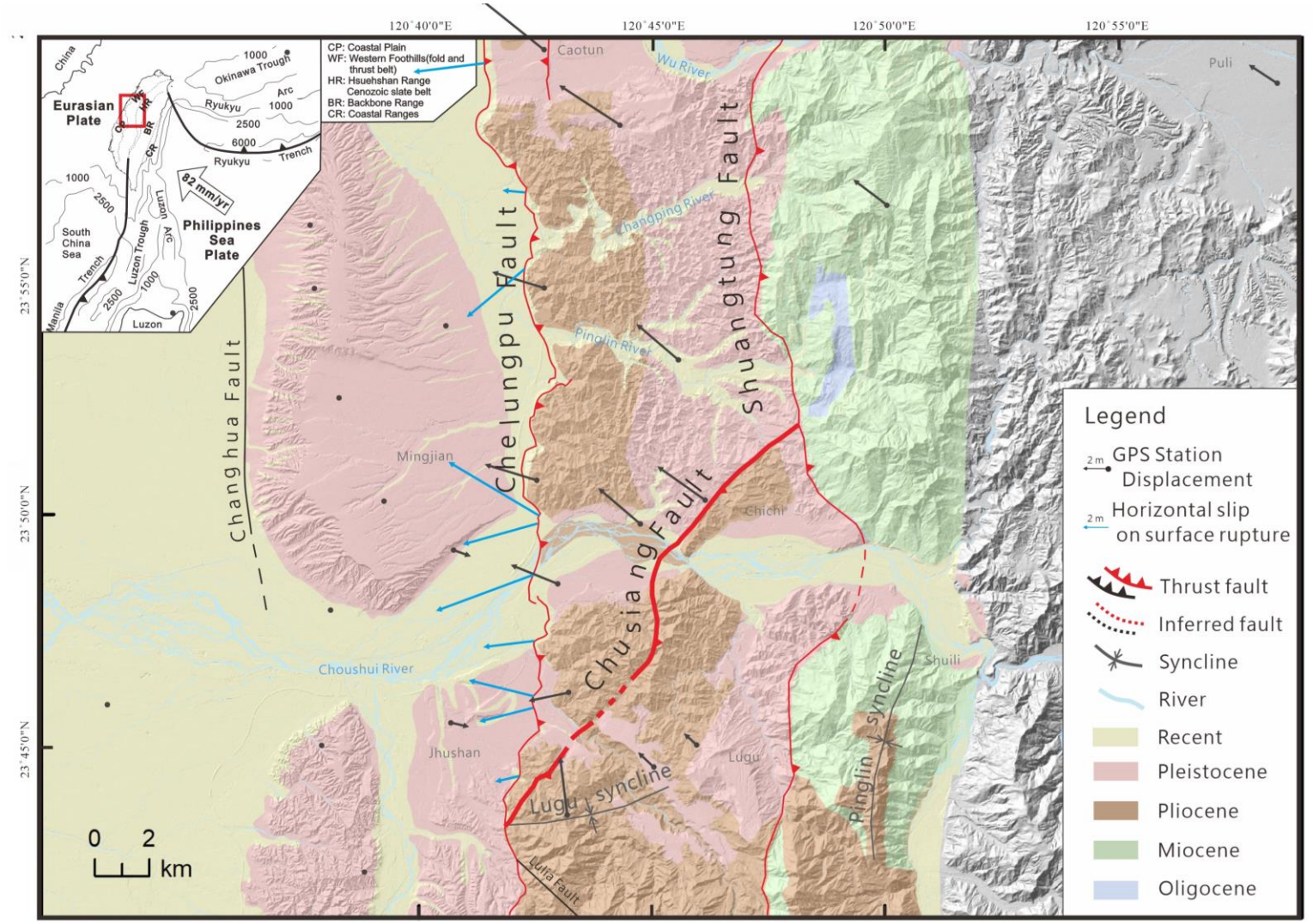
INTRODUCTION

Geological setting

- Chelungpu fault
- Chusiang fault
- Shuangtung fault

1999 Chi-Chi earthquake

- The block between the Shuangtung fault and the Chelungpu fault has the largest displacement. (CGS, 1999)
- There was no obvious uplift of the Chusiang fault. (Lin et al., 2000)
- The coseismic GPS data and the cadastral data show that the horizontal displacement direction has changed significantly after passing through the Chusiang fault. (Lee et al., 2003; Shih, 2005)



(Modify from CPC geomap; Chen et al.,2013; Huang, 2022; GPS data from Yu et al., 2001 & Yang et al., 2000; Horizontal slip on surface rupture from Lee et al., 2003)

INTRODUCTION

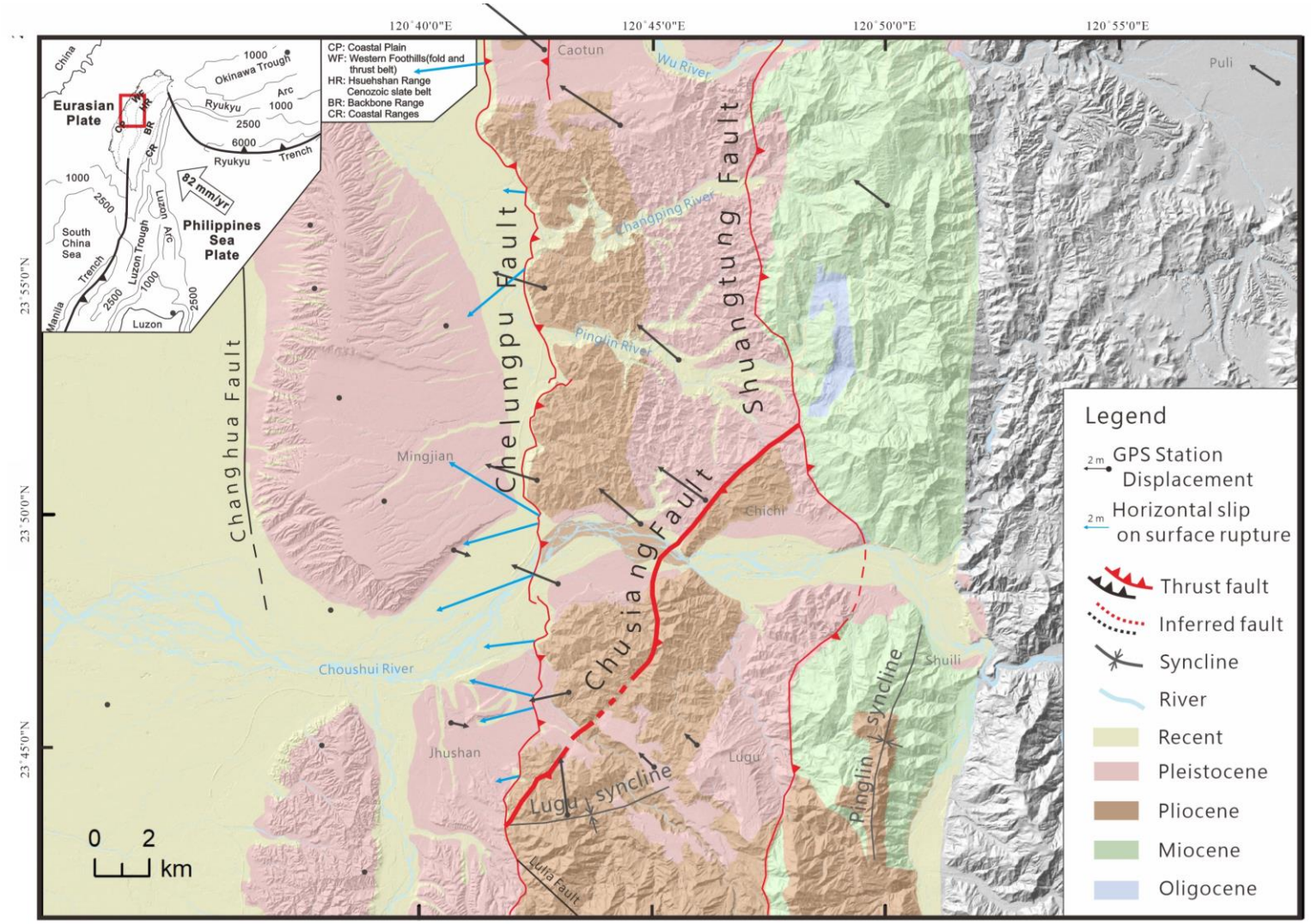
Motivation

- Based on the surface fault length, the possible max seismic moment scale is Mw6.6. (Lin et al., 2021)
- In the next 50 years, the Chusiang fault has a 37% chance of causing a magnitude 6.0 earthquake. (TEM, 2022)

Purpose

To understand

- Is there coseismic activation of the Chusiang fault while 1999 Chi-Chi earthquake?
- How active is the Chusiang fault?



(Modify from CPC geomaps; Chen et al.,2013; Huang, 2022; GPS data from Yu et al., 2001 & Yang et al., 2000; Horizontal slip on surface rupture from Lee et al., 2003)

METHODOLOGY

Images correlation

Aerial images
- Chi-Chi weir
- South part of the Chelungpu fault

Metashape

Orthophotography
- Aerial images before and after the earthquake

MicMac

Images correlation
- NS Horizontal Displacement
- WE Horizontal Displacement

Coulomb failure stress change

Surface displacement
- Coseismic GPS displacement (Yu et al., 2001)
- Fault slip of the surface rupture (Lee et al., 2003)

+

Chelungpu fault geometry
- Fault trace (Chen et al., 2013)
- Cross sections (Yue et al., 2005)
- Simplify and Create the mesh (Acknowledge CAMRDA)

Slip distribution on fault plane
- Coseismic slip distribution on the fault surface

Outputs
- Coulomb failure stress change (ΔCFS)

Assess reactivity of the Chusiang faults

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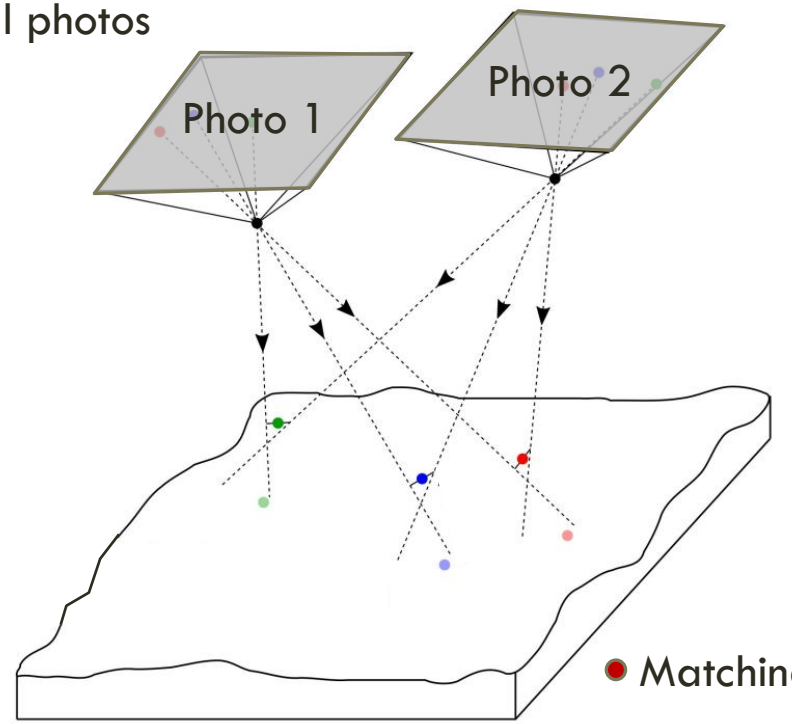
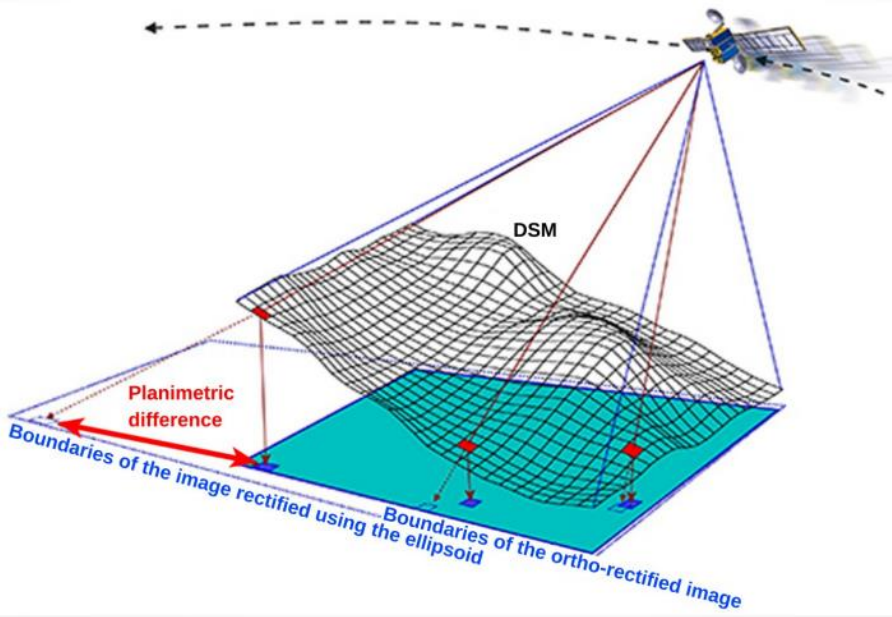
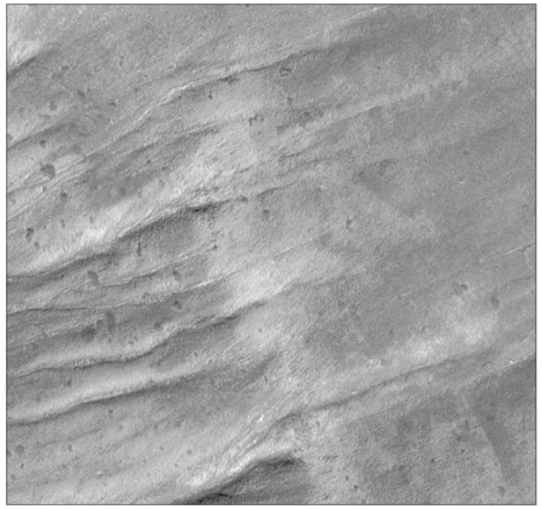
Aerial photos





Example

Orthophotography



Norcia earthquake, Italy, 2016
From IPGP, 2019

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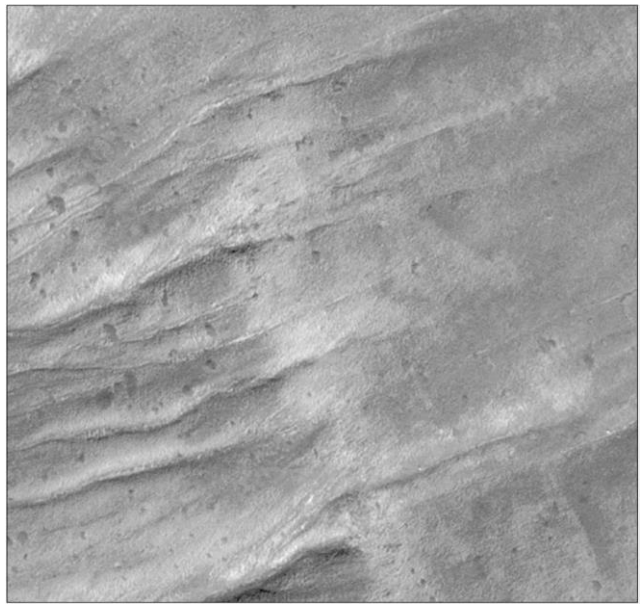
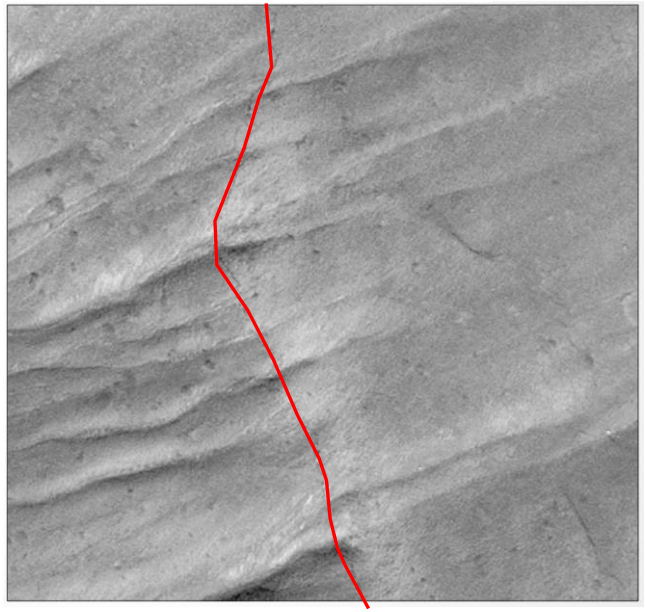
Orthophotography

Pre-earthquake



1 px = 0.5 m

Post-earthquake



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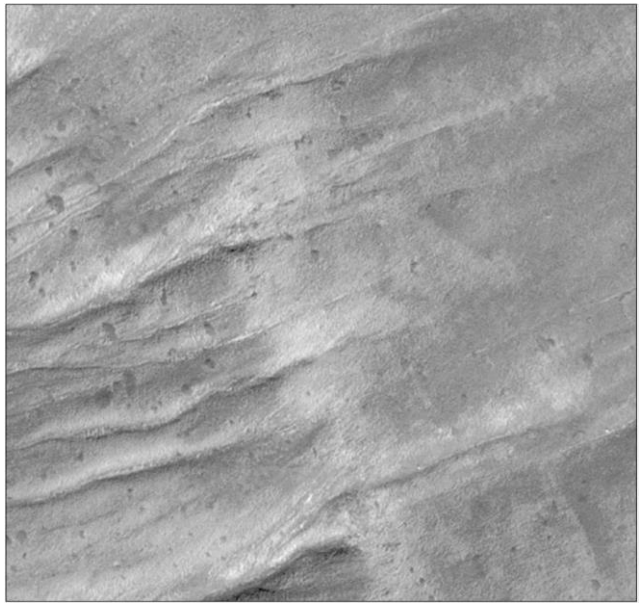
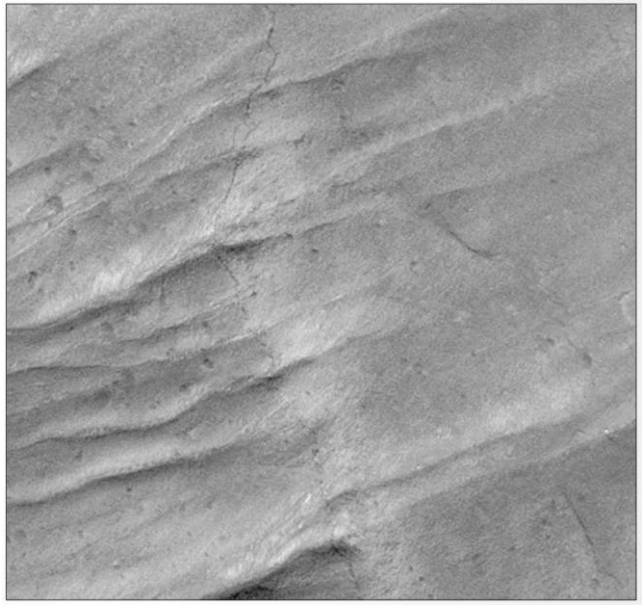


Norcia earthquake, Italy, 2016

100 m

Post-earthquake



From IPGP, 2019

Photo 1 - Before

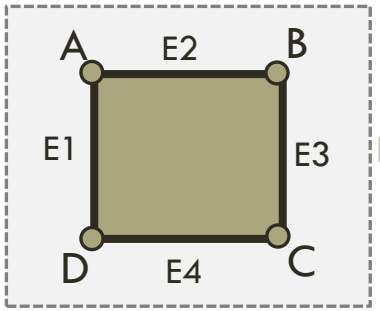
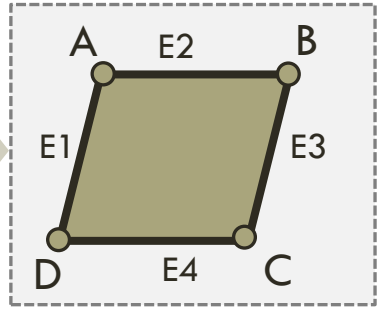
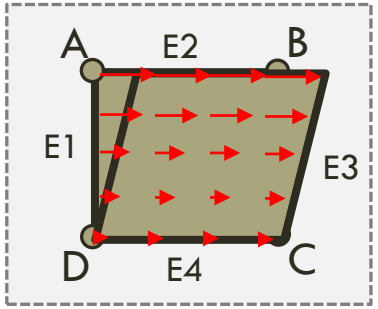


Photo 2 - After



Images correlation



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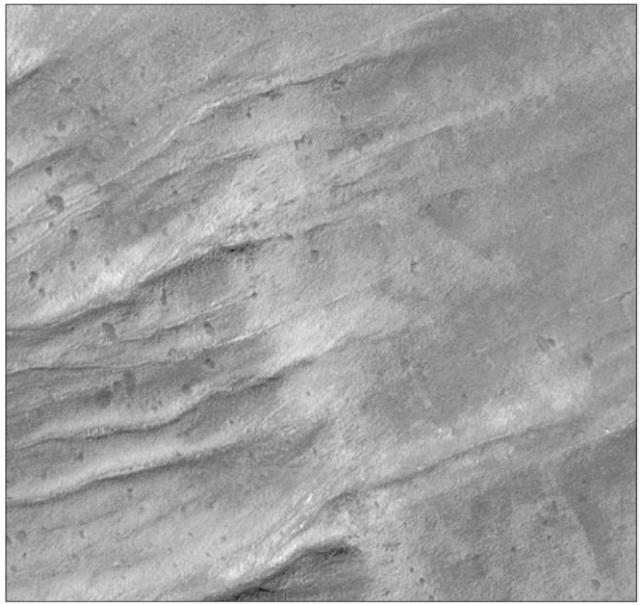
Orthophotography

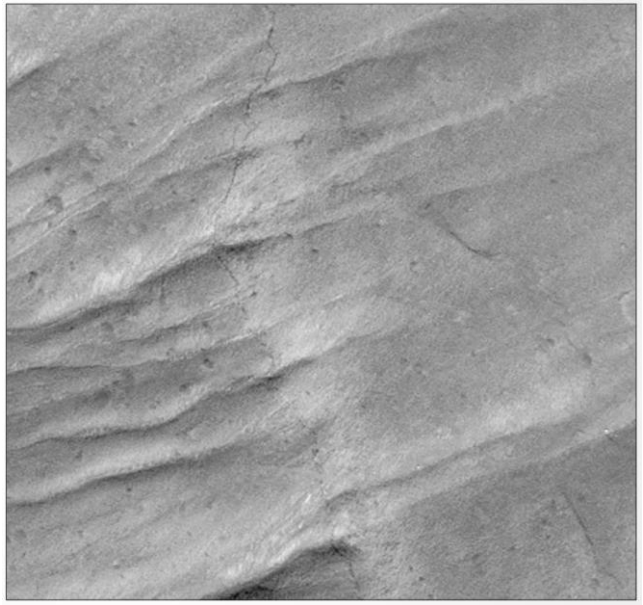
Pre-earthquake



Norcia earthquake, Italy, 2016

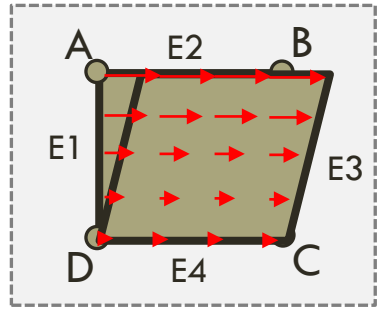
100 m

Post-earthquake

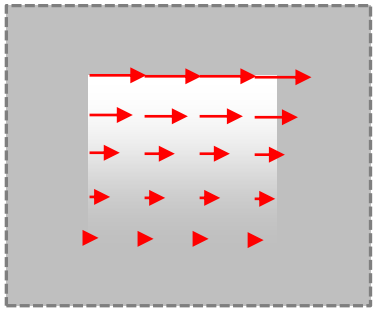


From IPGP, 2019

Images correlation



WE Horizontal Displacement



NS Horizontal Displacement

West — East North — South

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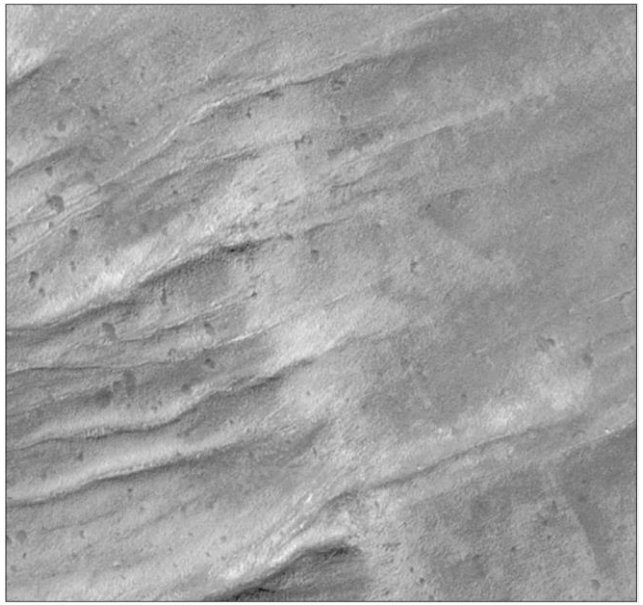
Images correlation
- NS Horizontal Displacement
- WE Horizontal Displacement

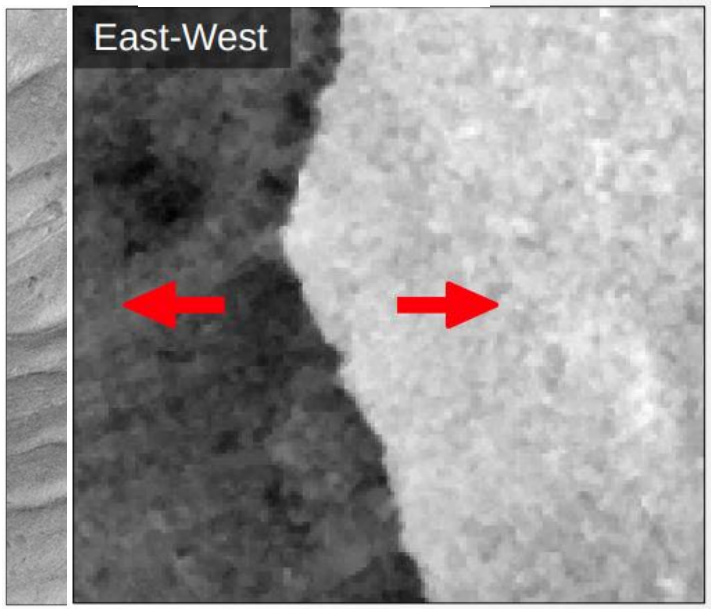
Orthophotography

Pre-earthquake



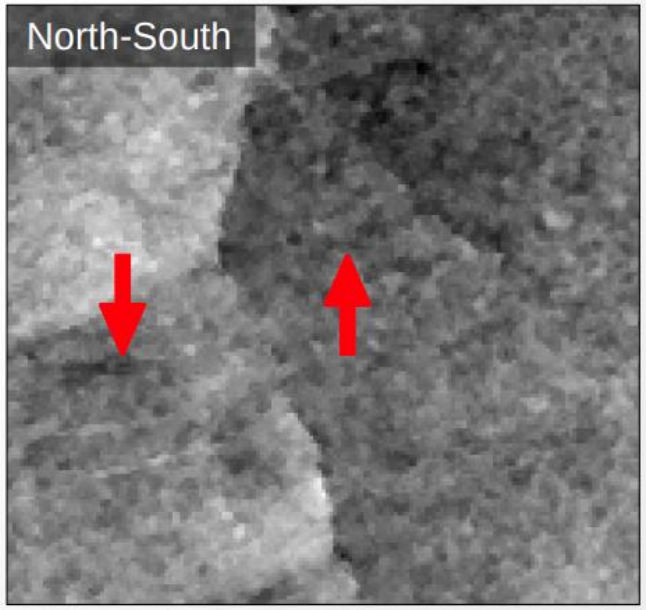
Norcia earthquake, Italy, 2016 — 100 m

Post-earthquake



West — px — East

2 px = 1m



North — px — South

2 px = 1m

METHODOLOGY

Coulomb failure stress change

Chelungpu fault geometry

- Fault trace (Chen et al., 2013)
- Cross sections (Yue et al., 2005)
- Simplify and Create the mesh (Acknowledge CAMRDA)

Surface displacement

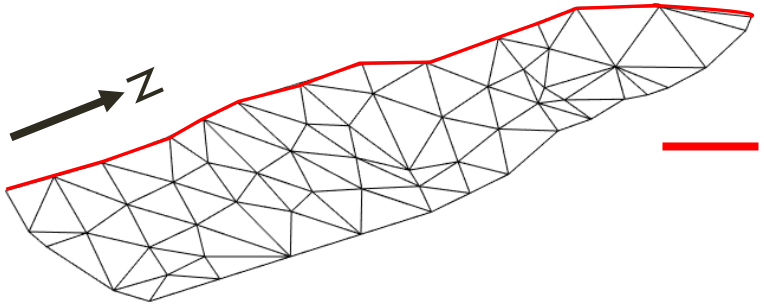
- Coseismic GPS displacement (Yu et al., 2001)
- Fault slip of the surface rupture (Lee et al., 2001)

Slip distribution on fault plane

- Coseismic slip distribution on the fault surface

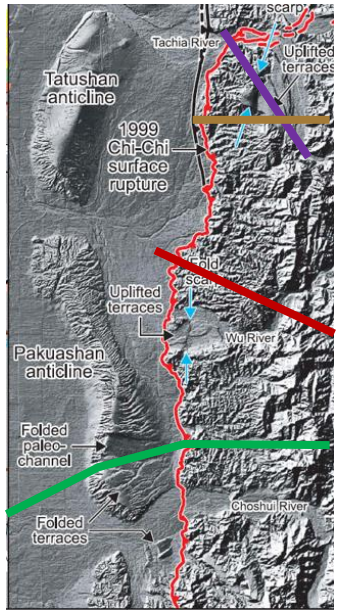
ailure stress change

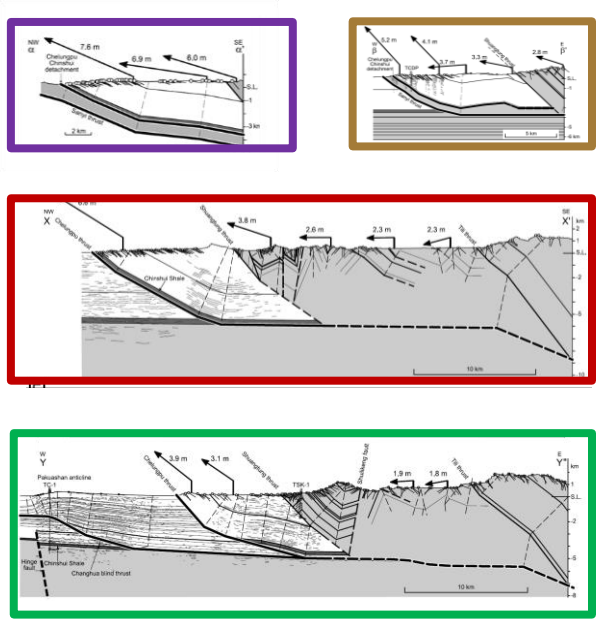
Triangular mesh of the Chelungpu fault



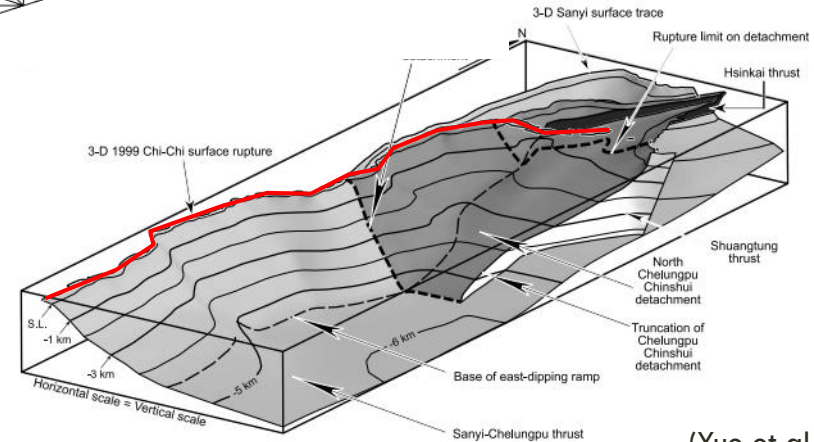
Simplified Fault Trace

1999 Chi-Chi earthquake surface rupture & Cross sections





(Yue et al., 2011)



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METHODOLOGY

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Slip distribution on fault plane

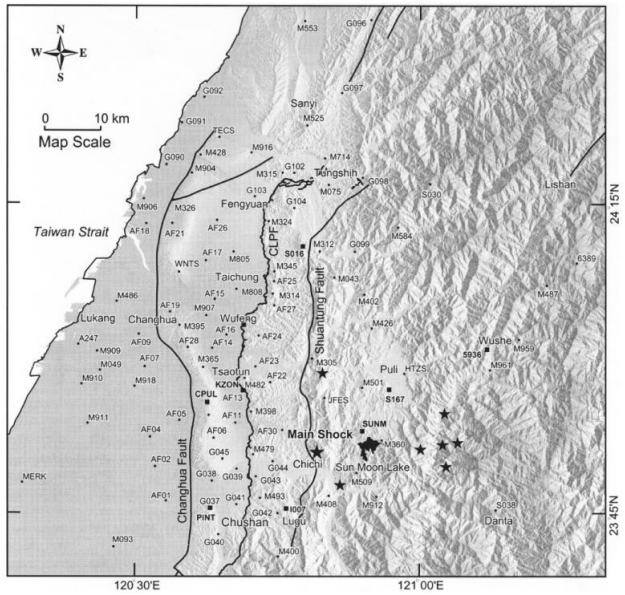
- Coseismic slip distribution on the fault surface

Outputs

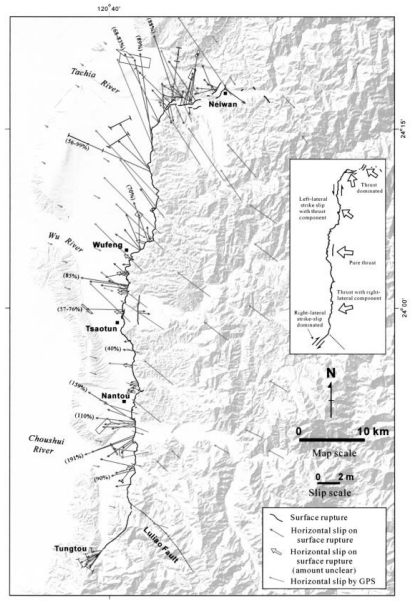
- Coulomb failure stress change (ΔCFS)

Assess reactivity of Chusiang faults

GPS stations (Yu et al., 2001)



Surface rupture (Lee et al., 2003)



METHODOLOGY

Coulomb failure stress change

Chelungpu fault geometry
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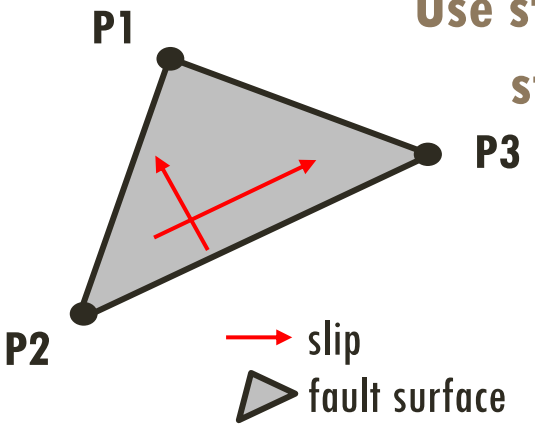
Forward model : Fault geometry + Slip distribution → Surface displacement

(Meade, 2007; Comninou and Dunders, 1975) aults



Use strike-slip and dip-slip to calculate displacements, strains, and stresses:

Displacements $\mathbf{u}(\mathbf{r}) = \int_S b_i C_{ijkl} n_j \partial_l \mathbf{u}_k(\mathbf{r}' - \mathbf{r})\, \mathrm{d}S$

Strain $\varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$ **Stress** $\sigma_{ij} = \lambda\, \varepsilon_{kk}\, \delta_{ij} + 2\mu\, \varepsilon_{ij}$

Meade's (2006) MATLAB code

Inversion function

Assumptions :

Linear elastic half-space, Homogeneities, No topographic effects

METHODOLOGY

Coulomb failure stress change

Chelungpu fault geometry
- Fault trace (Chen et al., 2013)
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Surface displacement
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- Fault slip of the surface rupture (Lee et al., 2003)

→

Slip distribution on fault plane
- Coseismic slip distribution on the fault surface

Outputs
- Coulomb failure stress change (ΔCFS)

Assess reactivity of Chusiang faults

Meade's (2006) MATLAB code

[Meade's (2006) MATLAB code] × [Slip distribution] = [Displacement (Surface)(**GPS**)]

Inverse function of Meade's

[**Inverse function of Meade's**] × [Displacement (Surface)(**GPS**)] = [Slip distribution]

METHODOLOGY

Coulomb failure stress change

Chelungpu fault geometry
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→

Slip distribution
- Coseismic slip distribution on the fault surface

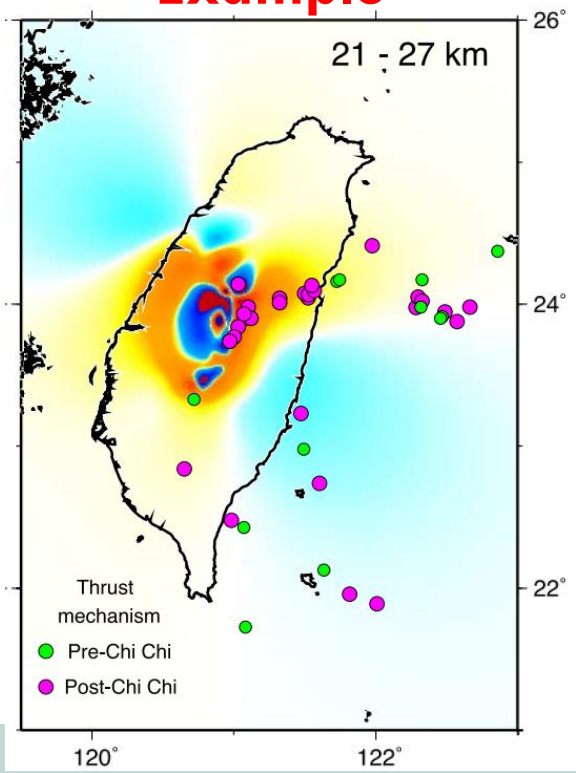
↓

Outputs
- Coulomb failure stress change (ΔCFS)

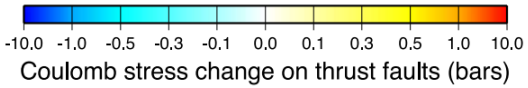
- ΔCFS on the other fault plane (Chusiang fault):
  - Increase: The fault plane more prone to have dislocation and trigger aftershocks. → Higher activity
  - Decrease: The fault plane more difficult to induce aftershocks. → Lower activity

(King et al., 1994; Toda and Stein, 2003)

Example



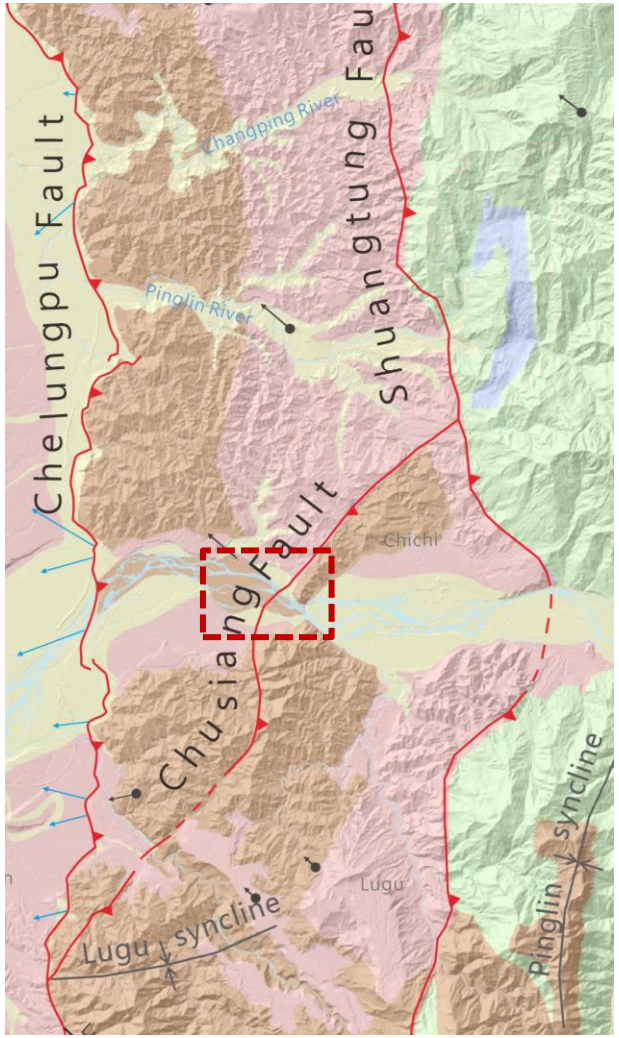
decrease increase



(Ma et al., 2005)

RESULTS

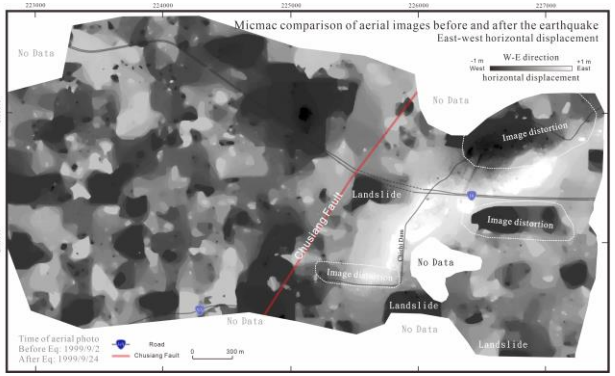
Images correlation – Chi-Chi weir



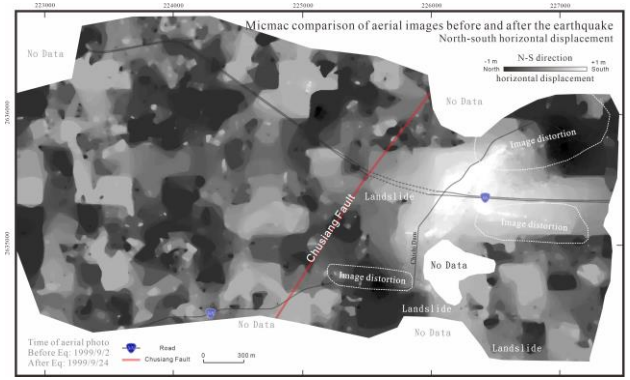
Before 921 (1999/9/2)

After 921 (1999/9/24)

WE horizontal displacement

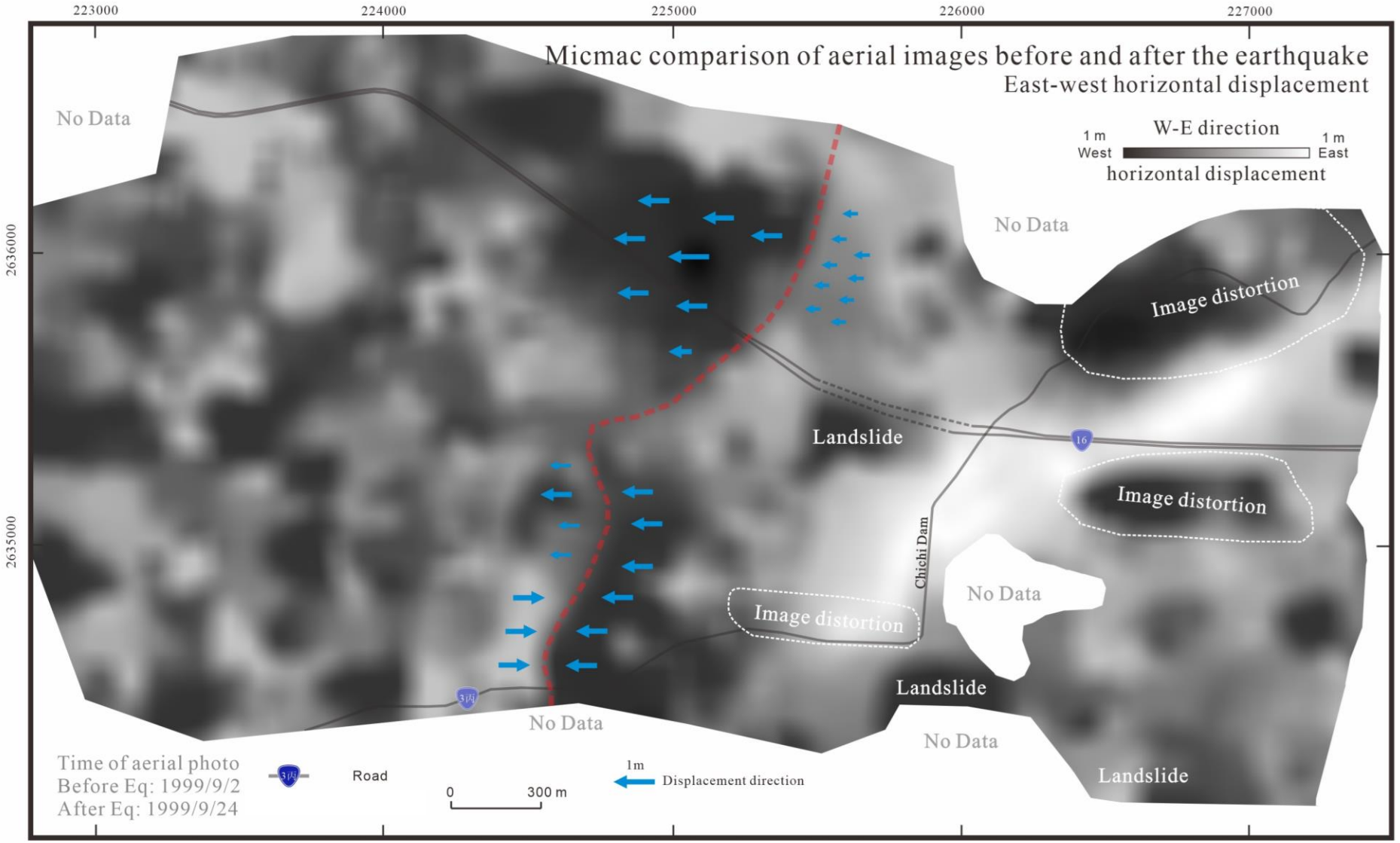


NS horizontal displacement



RESULTS

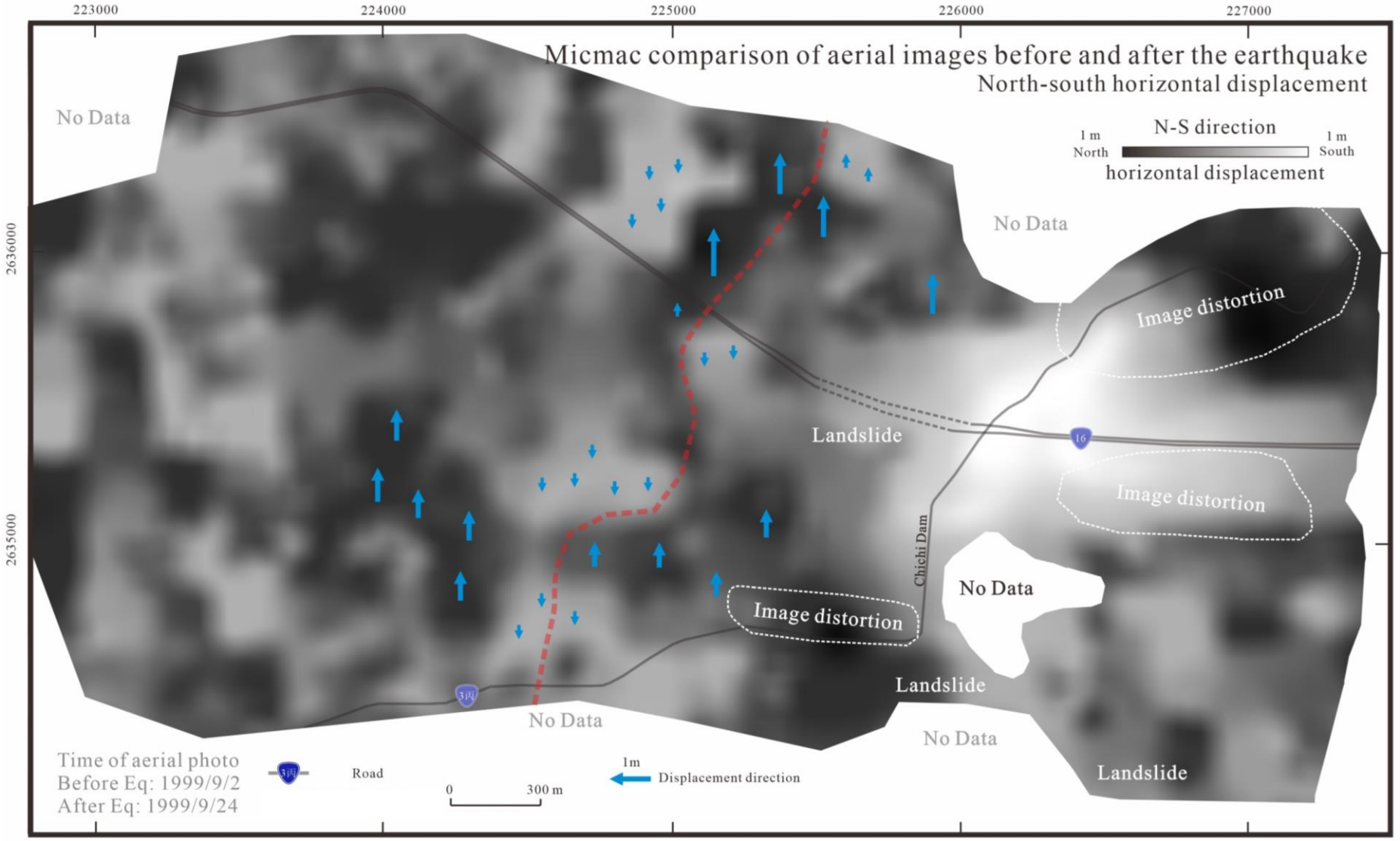
Images correlation – WE horizontal displacement



Horizontal displacement field boundary

RESULTS

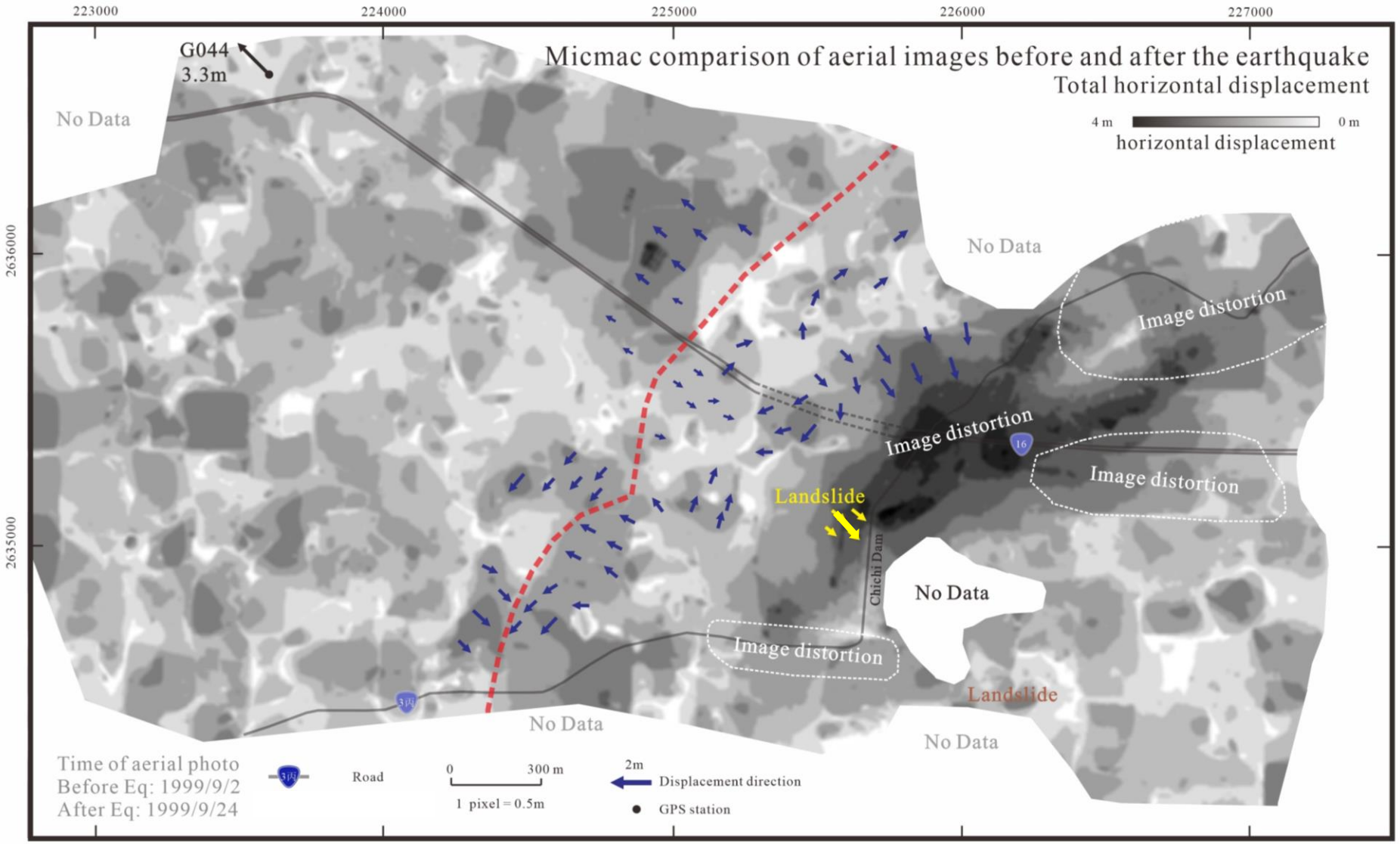
Images correlation – NS horizontal displacement



Horizontal displacement field boundary

RESULTS

Images correlation - Total horizontal displacement

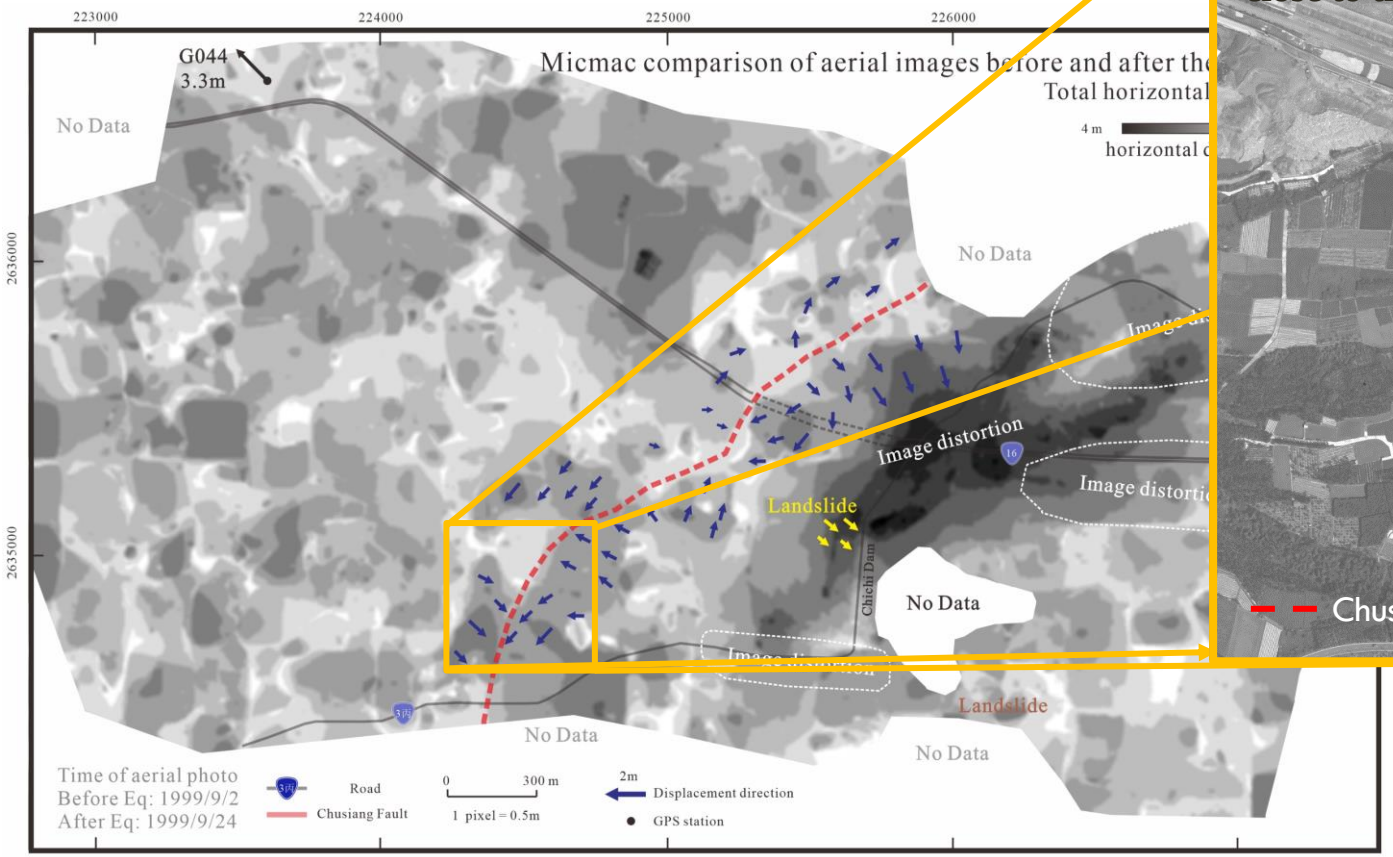


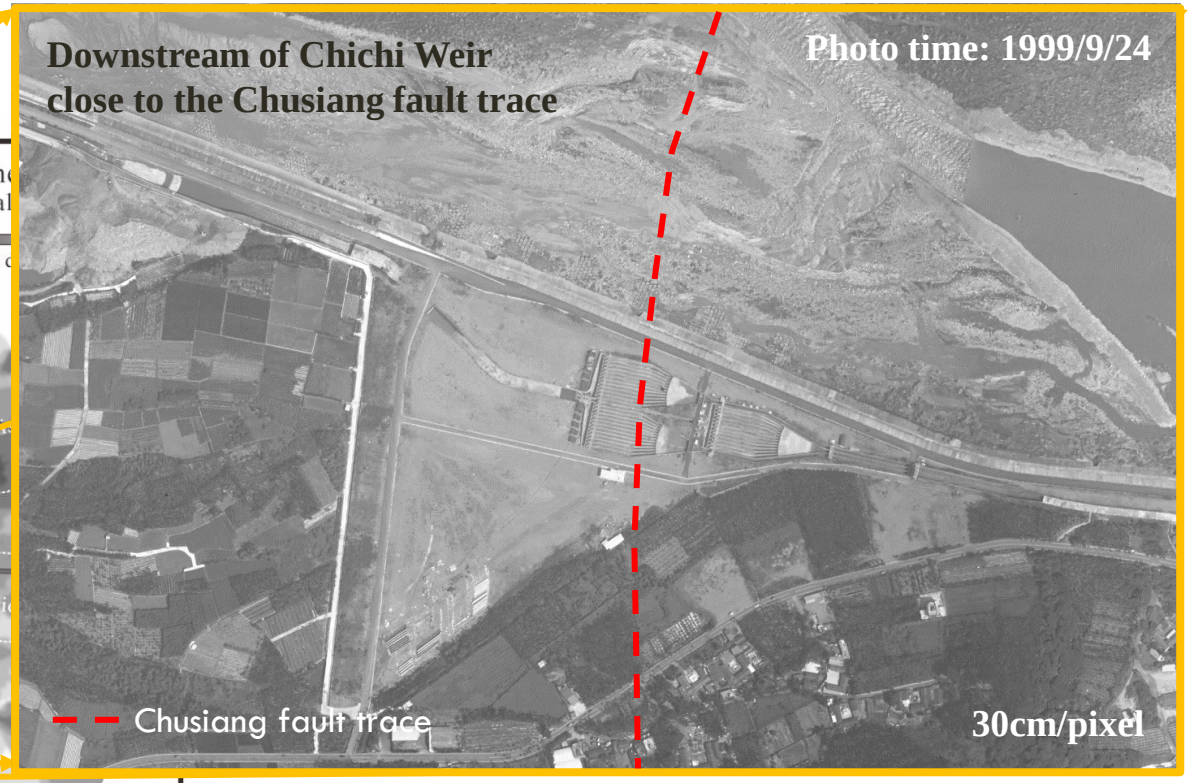
Horizontal displacement field boundary

- The results in the landslide area are consistent well with the orthophoto.

DISCUSS

Images correlation - Total horizontal displacement





- The magnitude difference passing through the Chusiang fault is more than 1 meter.

Without the surface rupture or breaking man-made buildings ? or insufficient image resolution ?

CONCLUSIONS

Images correlation

- The results in the landslide area are consistent well with the orthophoto.
- The horizontal displacement field (direction and magnitude) has changed close to the Chusiang fault.
- Some parts of the composite orthophoto are distorted, which seriously affect the result.

FUTURE WORK

Inverse function

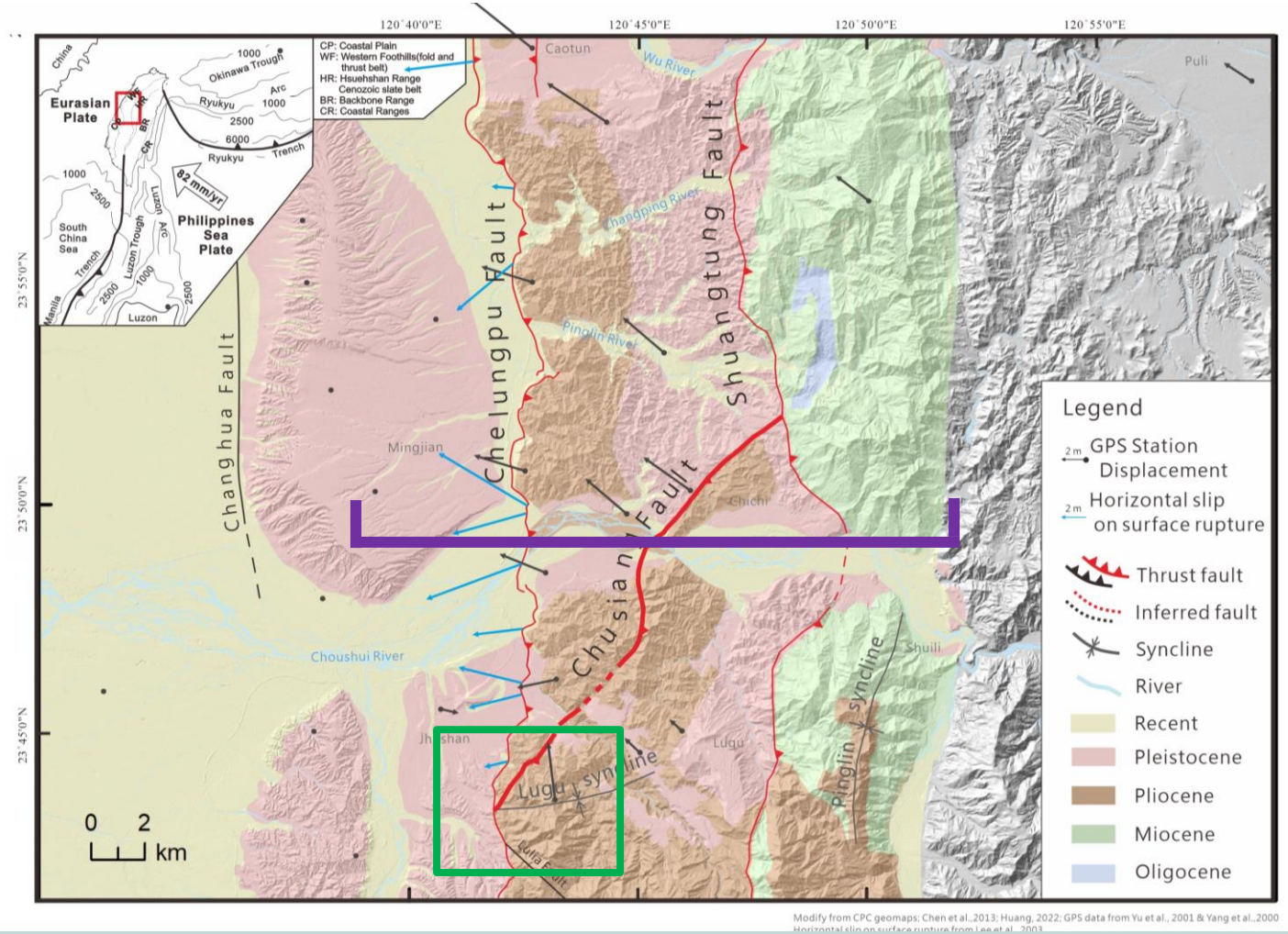
- How to compare the data → slip distribution on the Chelungpu fault → Coulomb failure stress change

Images correlation

- South part of the Chelungpu fault

Structural profiles

- Along the Choushui River



Acknowledgements

- CAMRDA (Center for Advanced Model Research and Applications)

Thanks for your attention