Geomorphic evolution by endogenic and exogenic processes in mountainous area of Taiwan

台灣山區內外營力作用下之地形變遷

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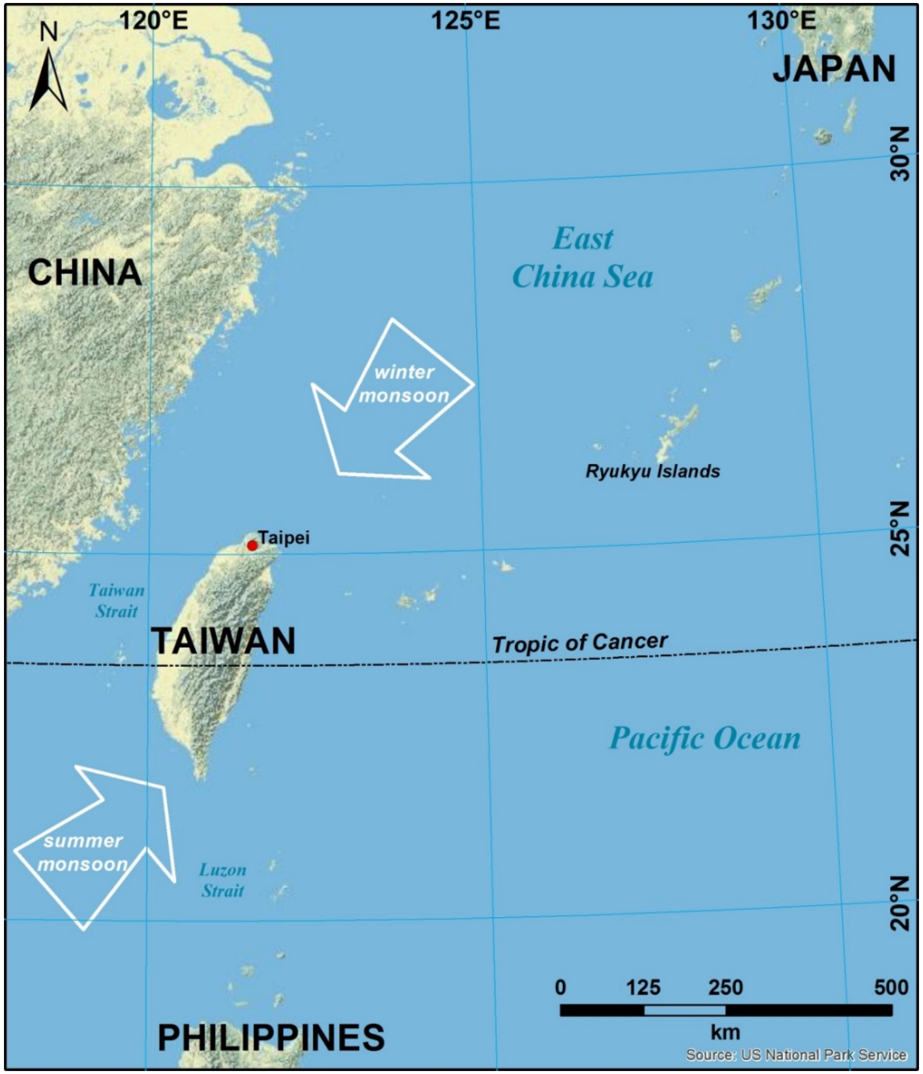
Content

- **Research interests**
- **On-going projects**
  - Landslide monitoring & simulation
  - Landslide and fault behavior by GPS
- **Future work**
- **Teaching plan**

Environment of Taiwan

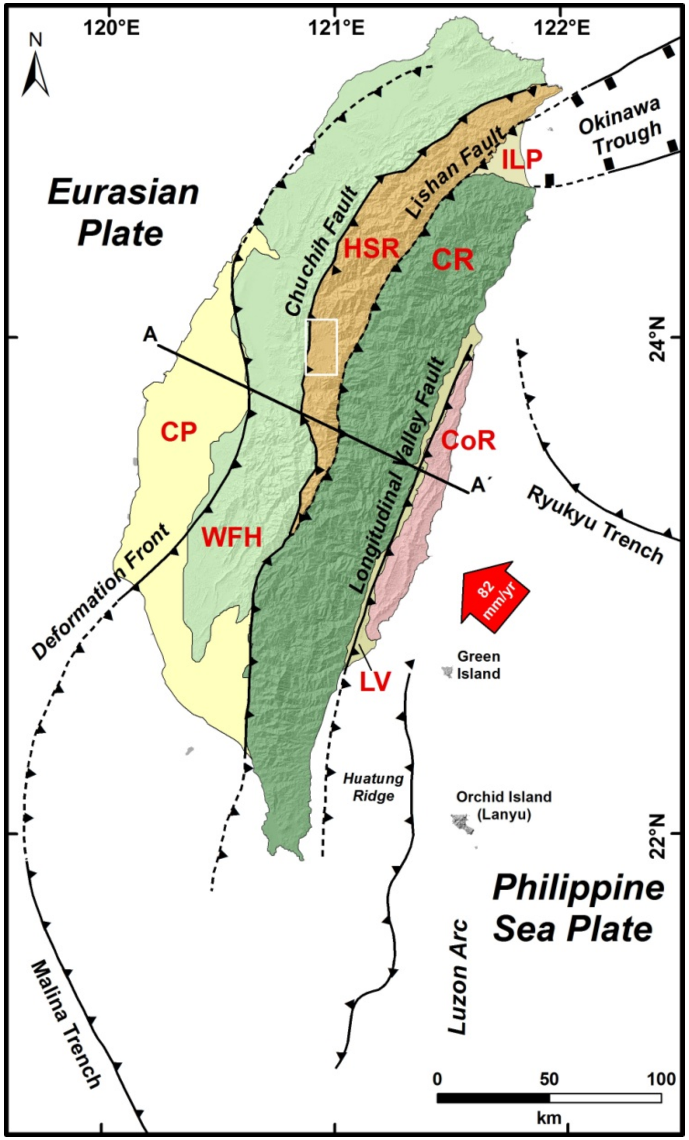
Geography and climate

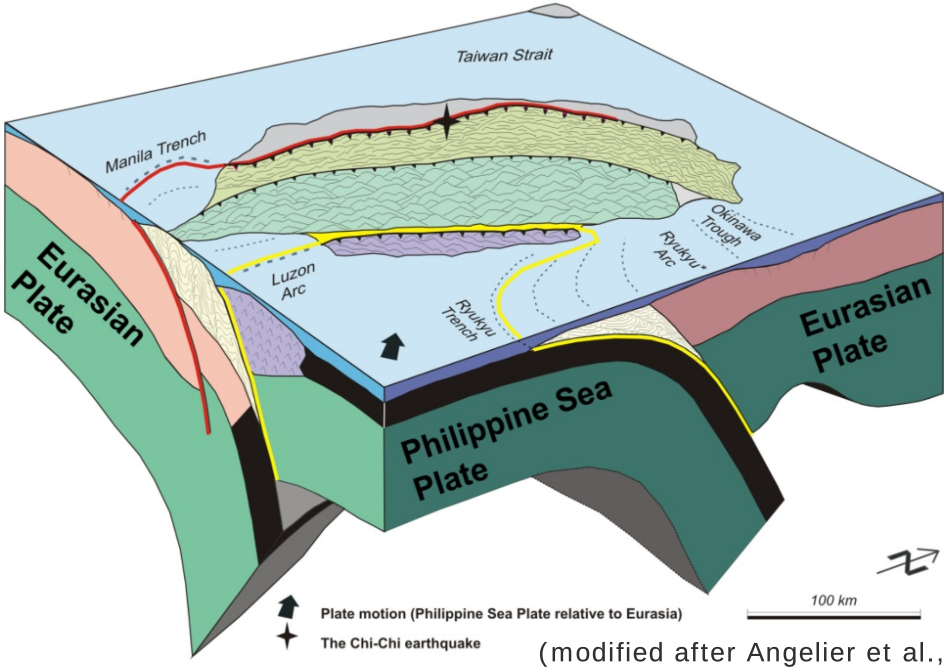


<u>Position:</u>
Tropic of Cancer (23.5° N), margin of the Pacific Ocean
<u>Climate:</u>
subtropical and tropical, Eastern Asian monsoons
<u>Typhoon:</u>
3 to 4 typhoons between July and September
<u>Precipitation:</u>
~2500 mm/yr on average (mainly from typhoons)
(***Puli Basin: 2120 mm/yr**)

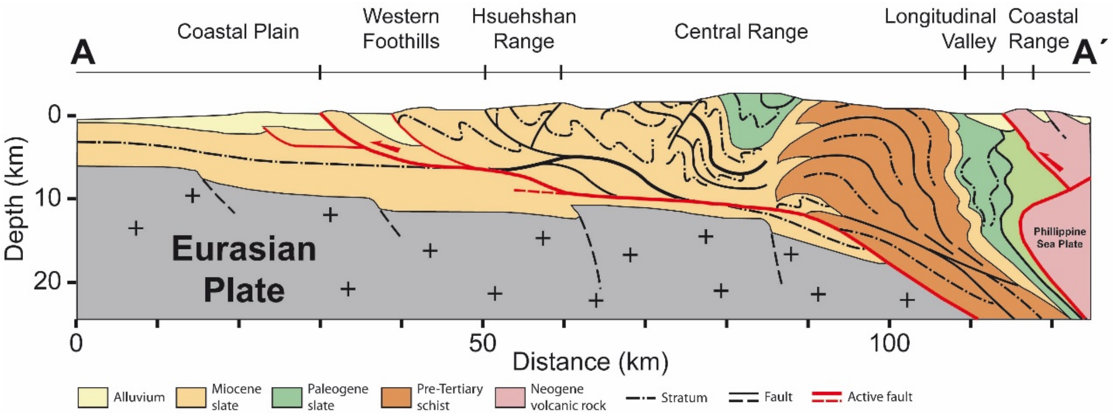
→ ***Strong weathering and erosion***

Ongoing mountain building





(modified after Angelier et al., 2001)



(modified after Malavieille et al., 2010)

Landform evolution in Taiwan

Processes of rivers

River incision
Da-an Gorge in Miaoli

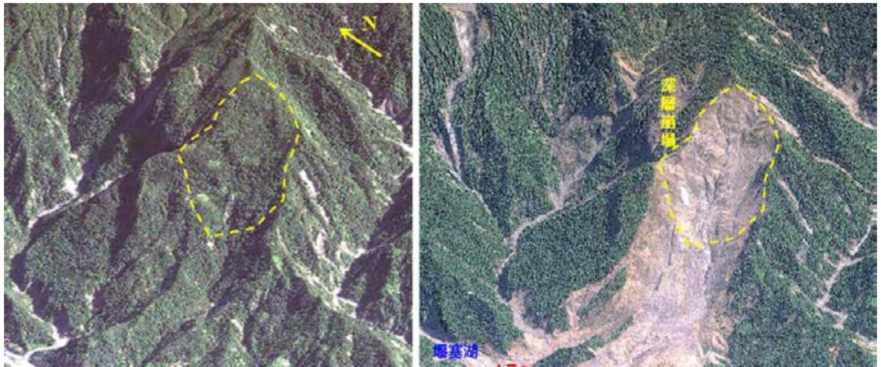
River deposition
Alluvial fan in Taichung

Processes of erosion by rain

Rain washing mudstone
Moon world in Kaohsiung

Rain washing gravel
Huoyan Mountain in Miaoli

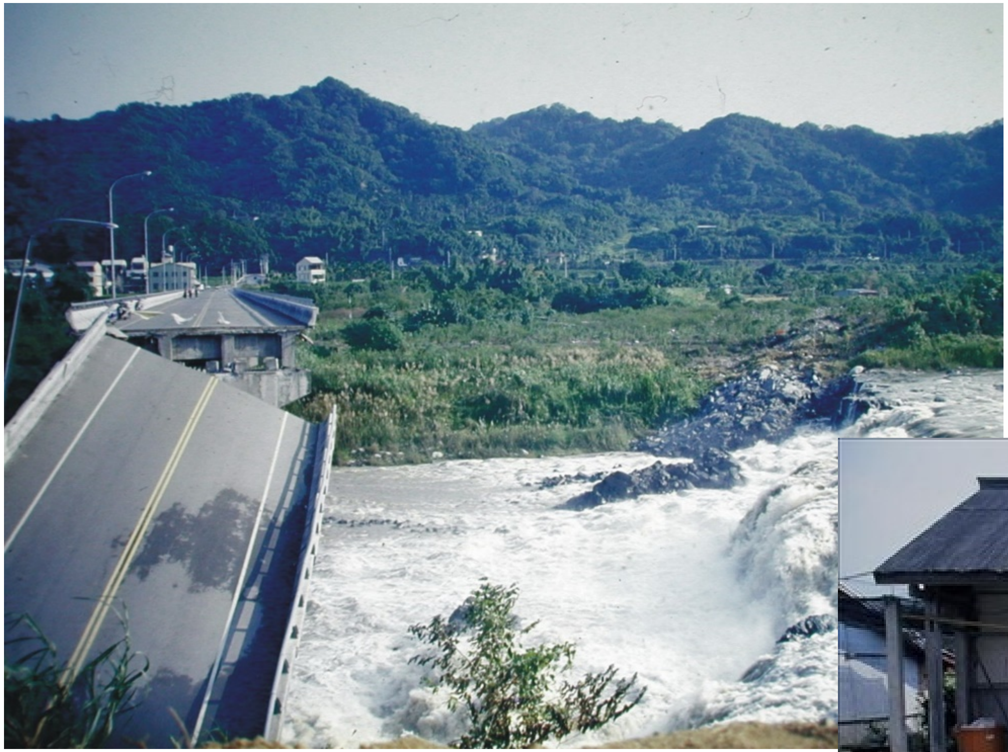
Processes of gravity



Slope failure due to rain
Shiaolin Village in Kaohsiung

Slope failure without rain
Highway No. 3 in Keelung

Processes of tectonics



Faulting in bedrock
Dachia River in Taichung

Fault creeping
Chihshang in Taitung

Processes of seismicity

Landslide in bedrock
Jiufenershan in Nantou

Landslide in gravel
99 Peaks in Nantou

Endogenic and Exogenic processes

- **Endogenic processes (deep in the Earth)**
  - Metamorphism
  - Magmatism → volcano
  - Tectonic movement → orogeny, earthquake, fault

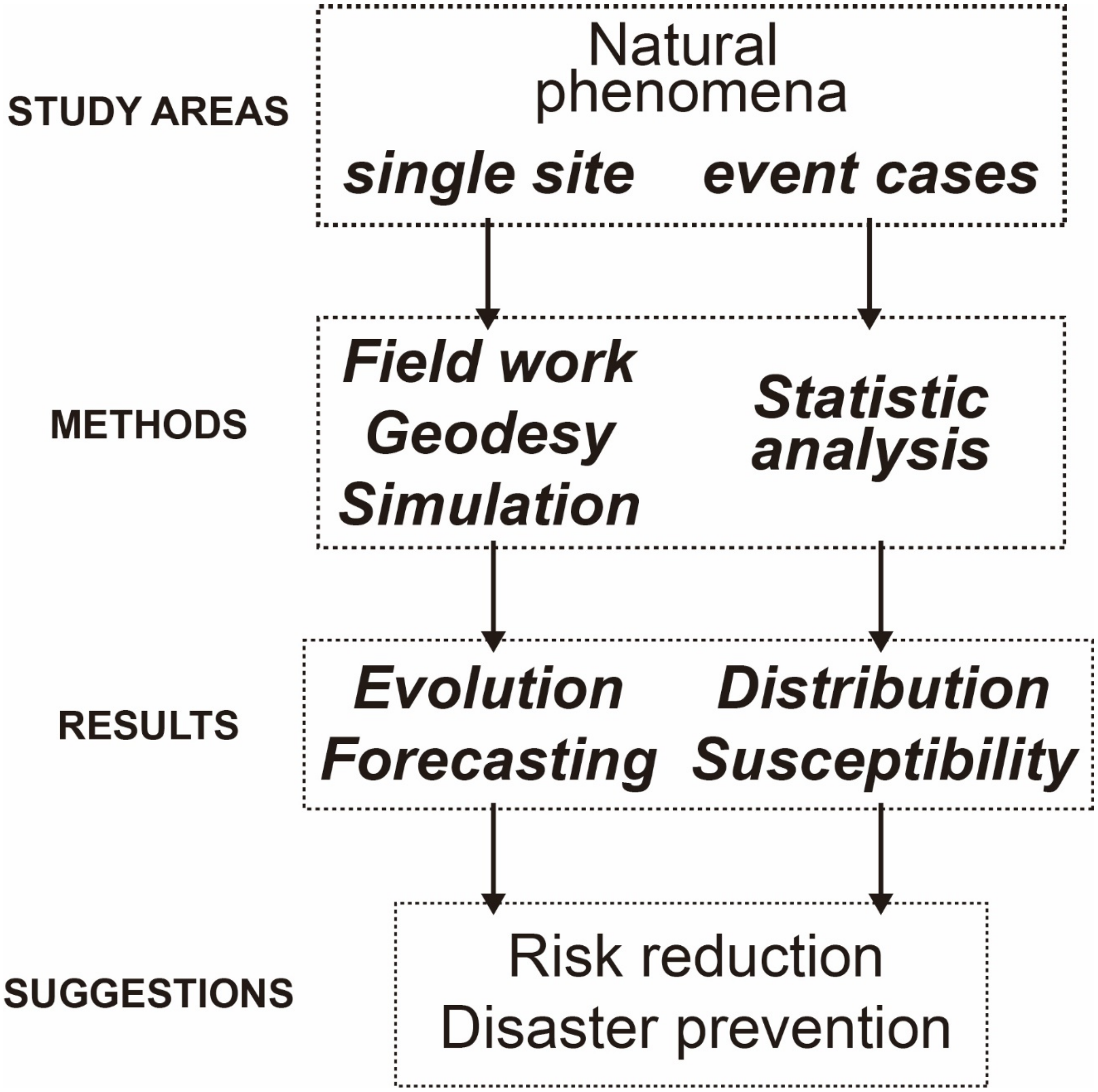
- **Exogenic processes (on the Earth surface)**
  - Deposition → alluvial fan, delta
  - Denudation → weathering, erosion, transportation

Questions

- **How did / will natural phenomena develop?**
  - Survey → *field work, remote sensing*
  - Monitoring → *geodesy, geotechnics*
  - Forecasting → *numerical simulation*

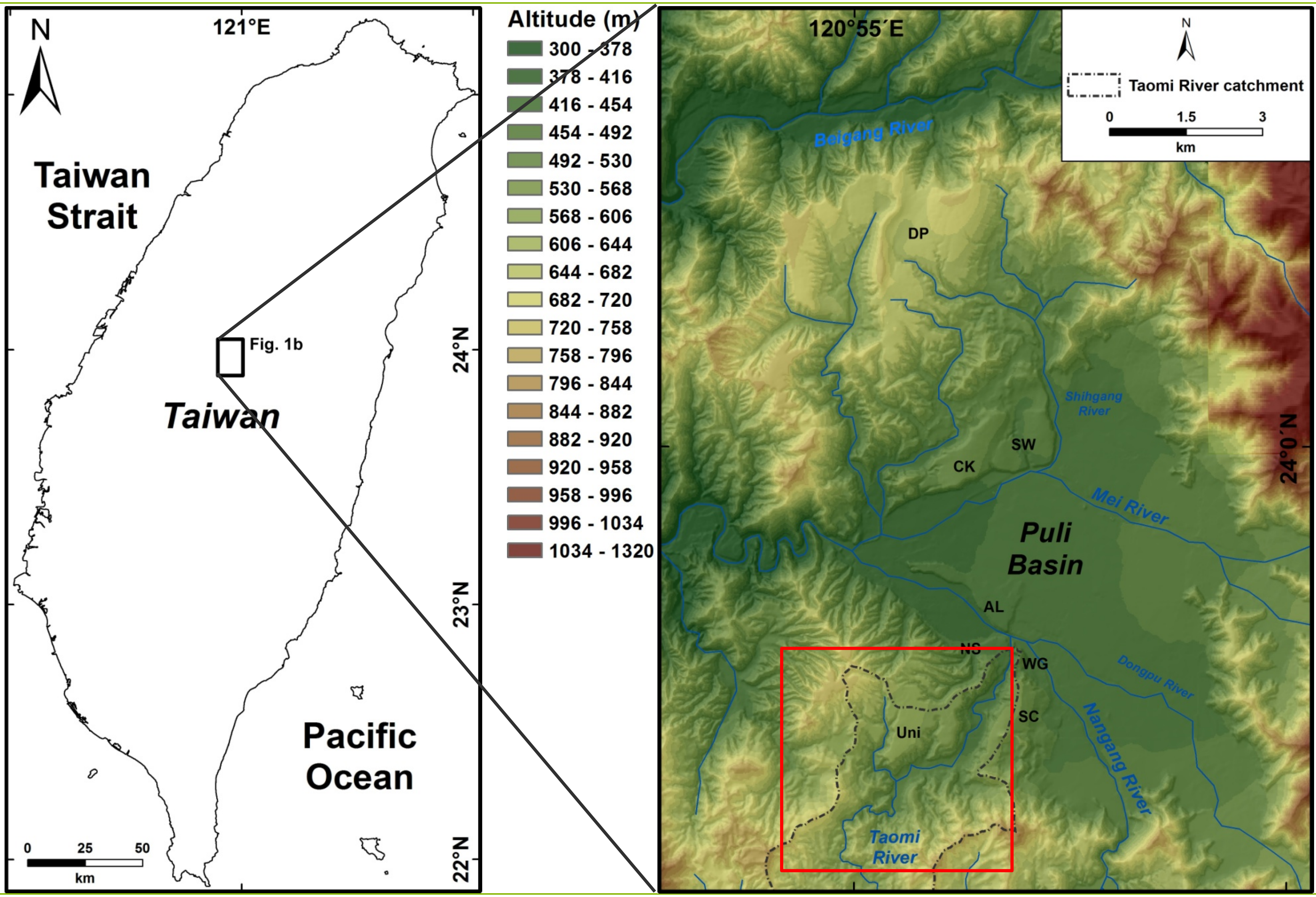
- **Will natural phenomena turn to be natural hazards?**
  - Evolution → distribution, susceptibility
  - Hazards → reduction, prevention

Procedure of research

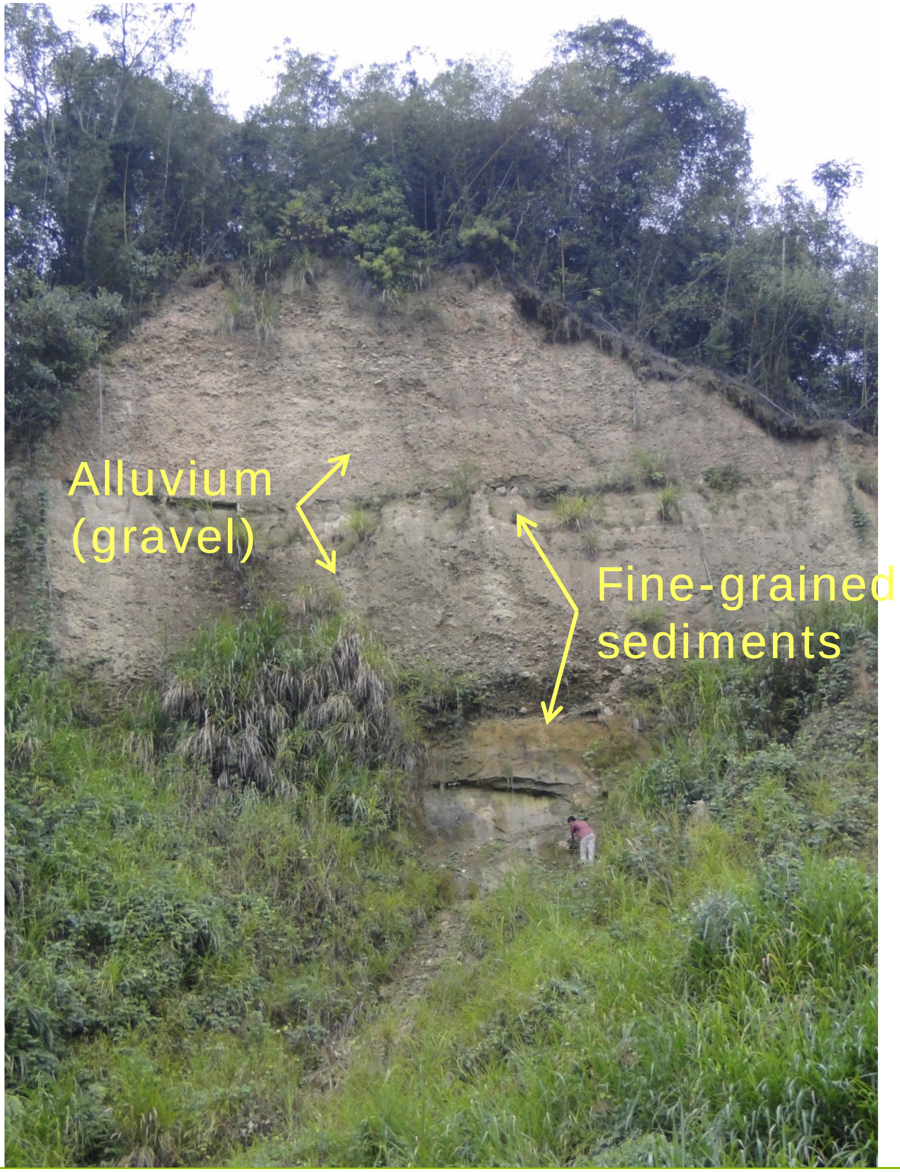


STUDY CASE – PULI BASIN

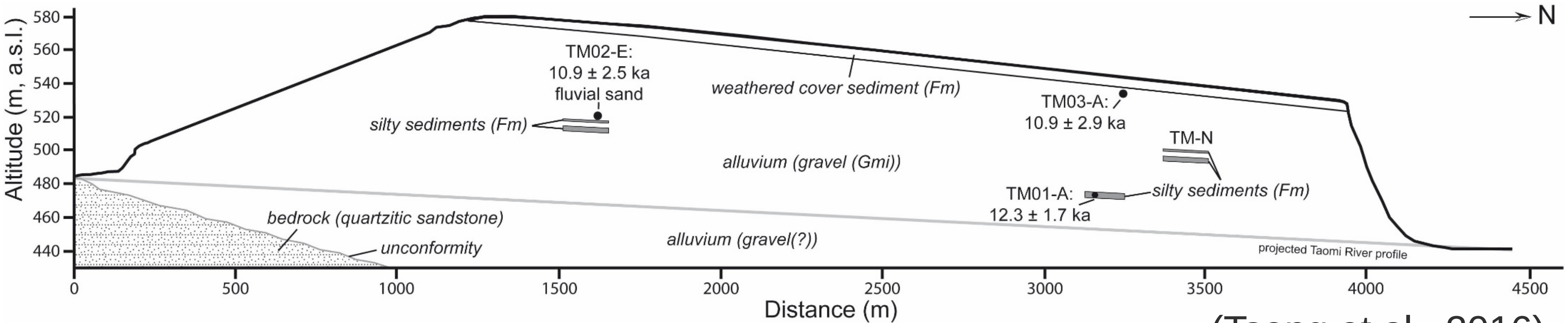
Puli basin in central Taiwan



Alluvial fan deposits



Formation age of the tableland



(Tseng et al., 2016)

Characteristics:

clast-support;

maximal size of gravel: ≤ 20 cm;

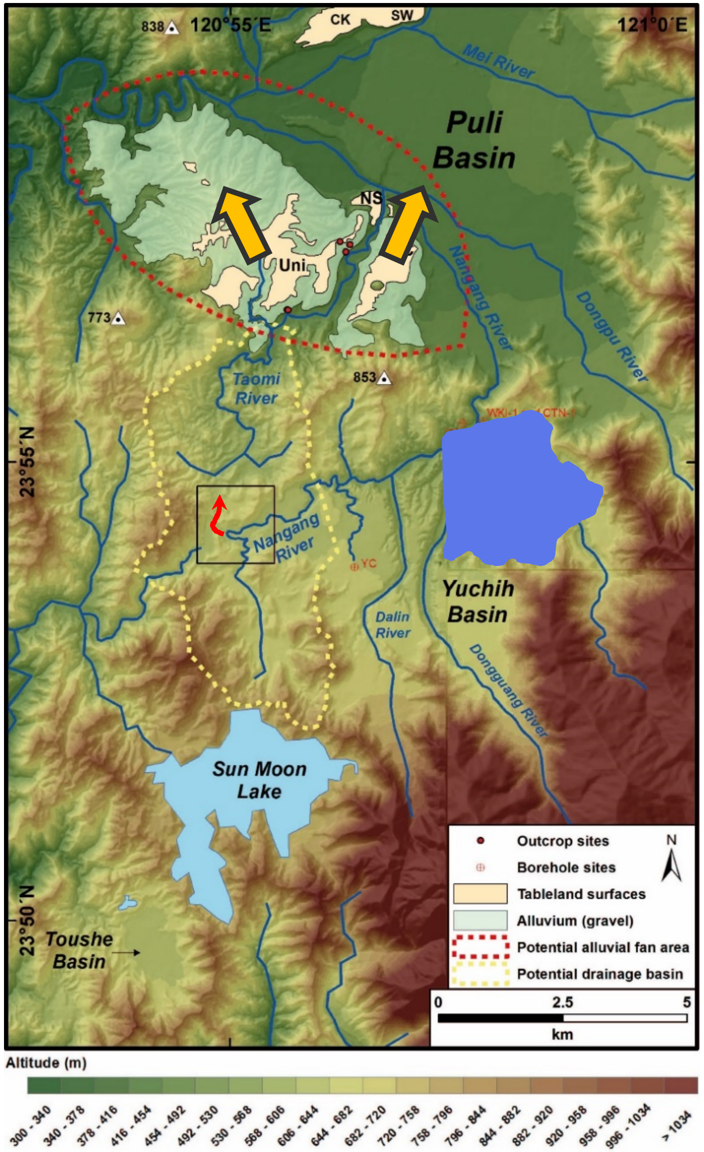
moderate to poorly sorted;

Imbrication and stratification;

locally including stratified fluvial gravels.

→ A type of alluvial fans: Transitional-flow deposits (T1)(Wells and Harvey, 1987).

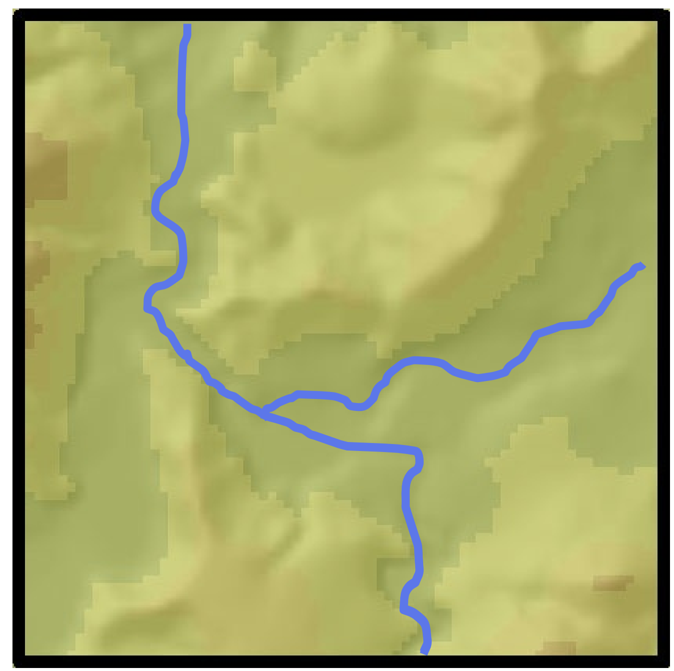
Source of the alluvium



Different imbrication directions of gravel, being consistent with a pattern of alluvial fans

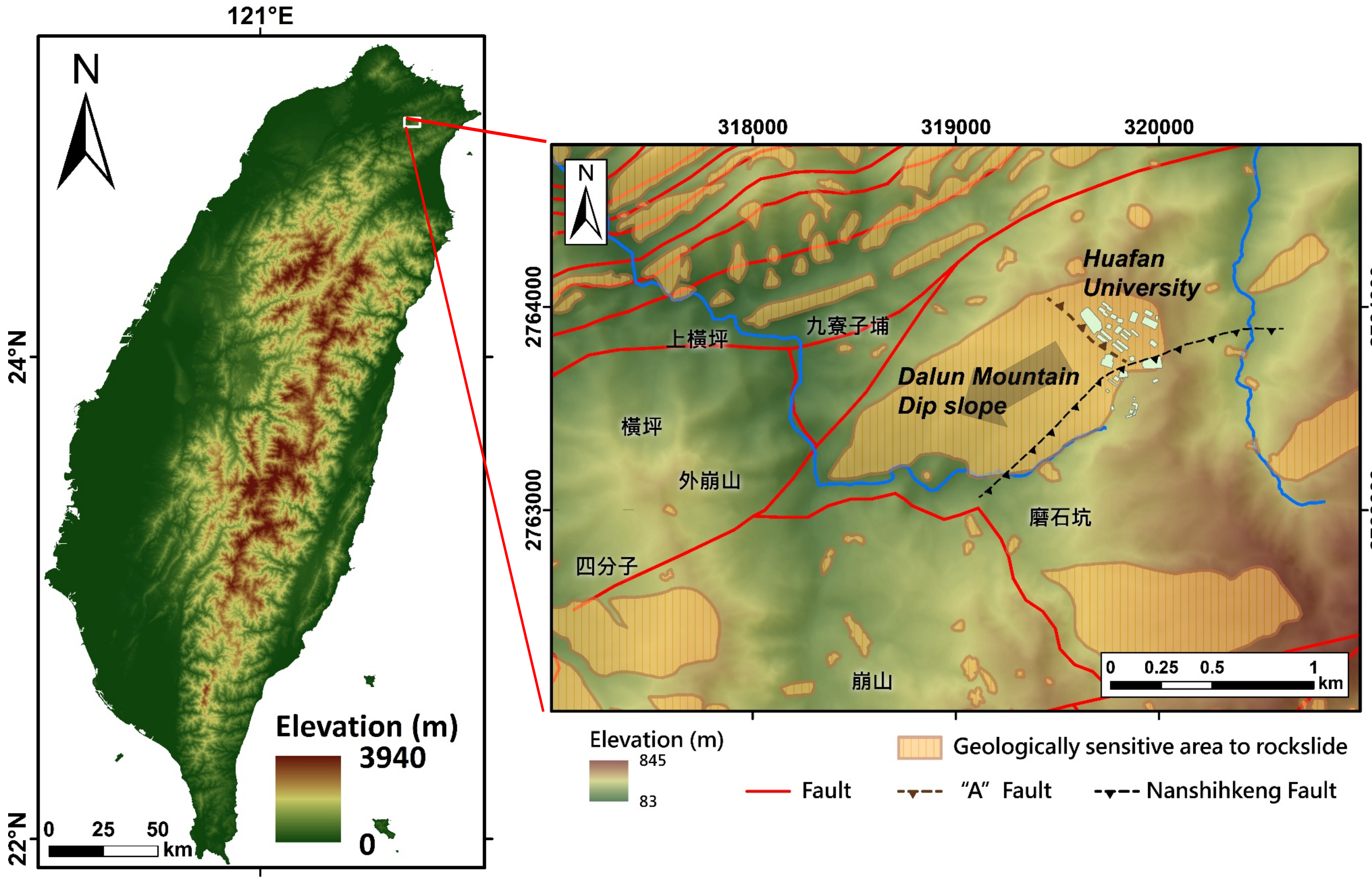
River capture of the Nangang River, leading to shortening of the Taomi River

An old Yuchih Basin lake, which was drained about 6 ka (Chen, 2003)



STUDY CASE – DIP SLOPE

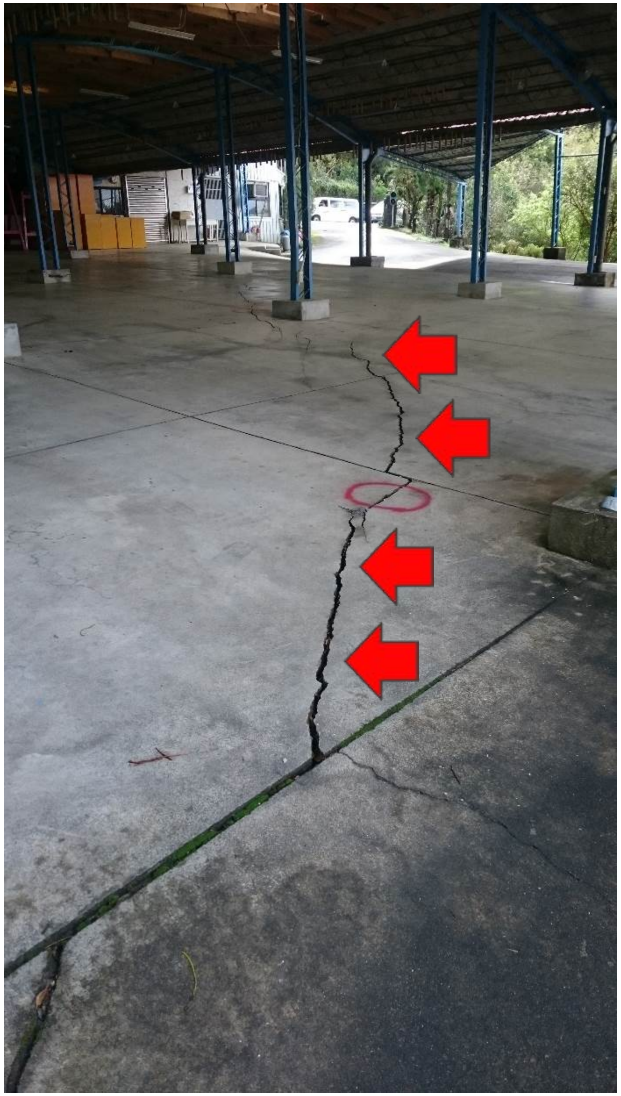
Dip slope failure (新北石碇大崙山)

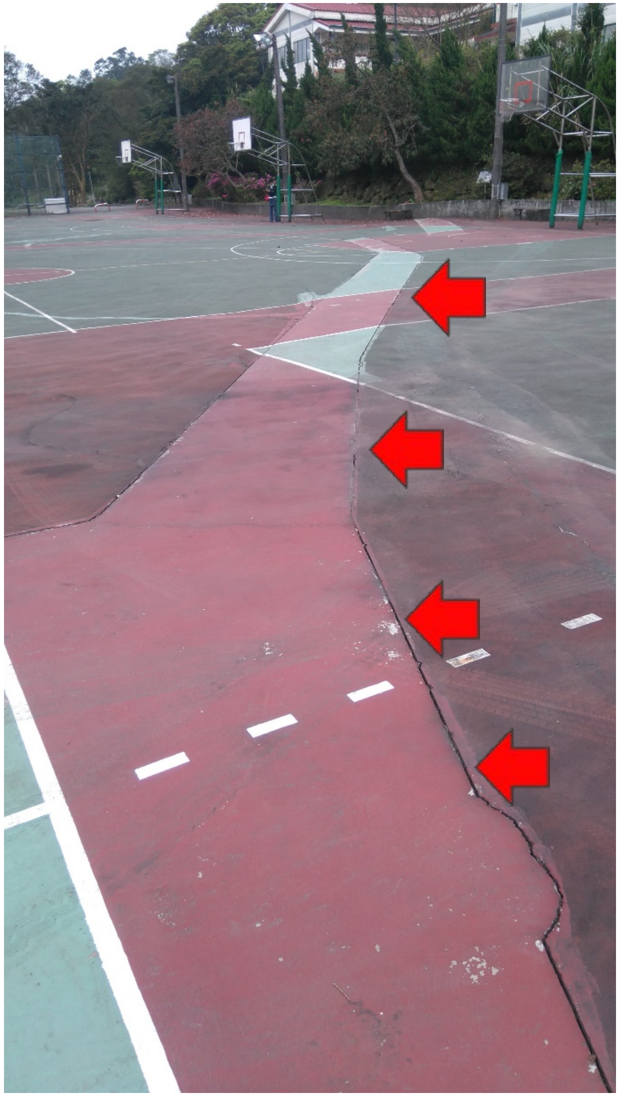


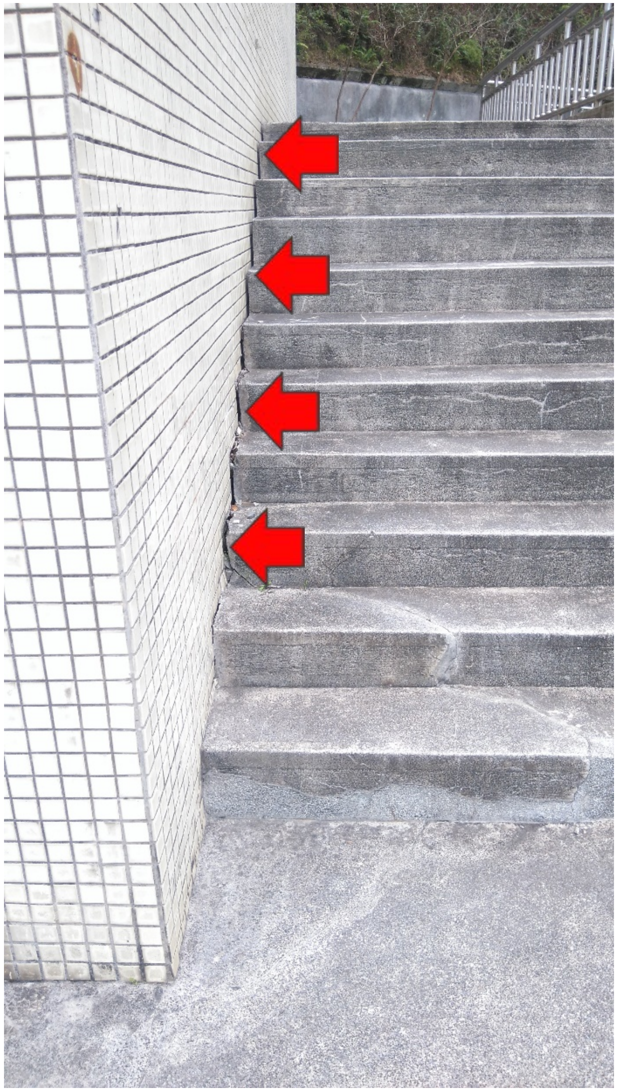
Dip slope in Dalun Mountain

(SWCB project, 2018)

Tension cracks at campus

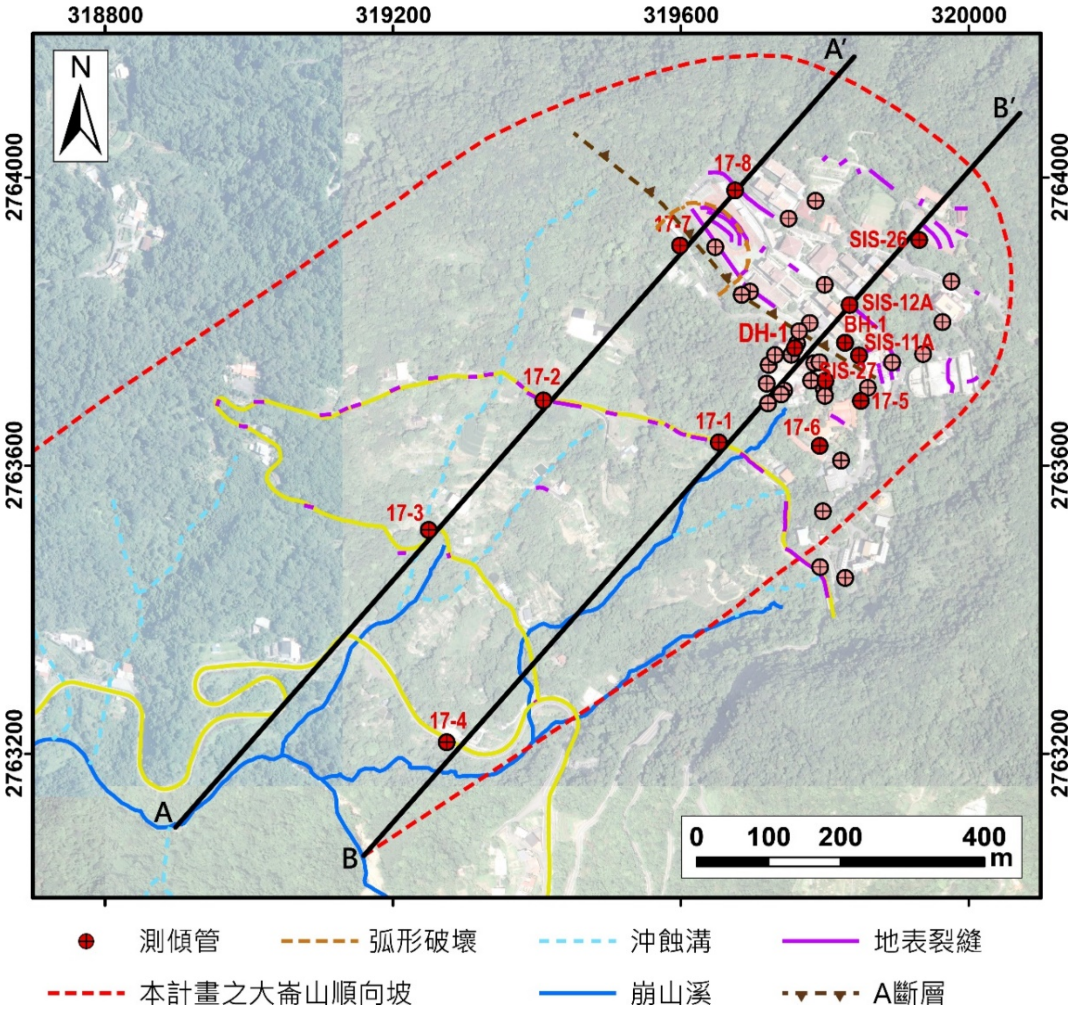






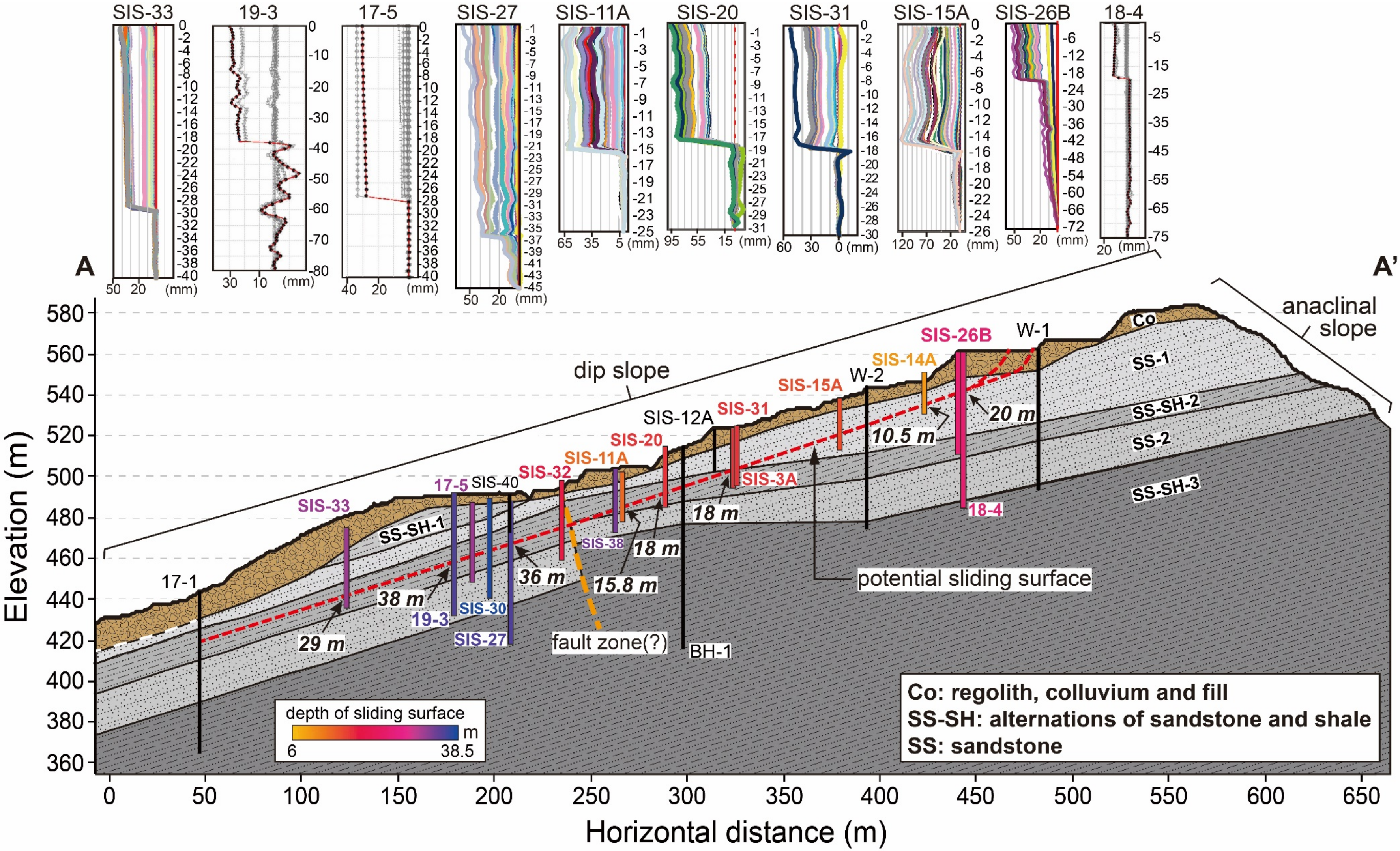
Tension cracks outside campus

Monitoring systems



1. Inclinometer
   SAA : 2
   Manual : 26
2. GPS
   Dual : 2(L1+L2)
   Single : 13(L1)
3. Groundwater
   4 at campus
4. Rain gauge
   1 at campus

Geology context



(Tseng et al., 2021)

UAV images for landform evolution

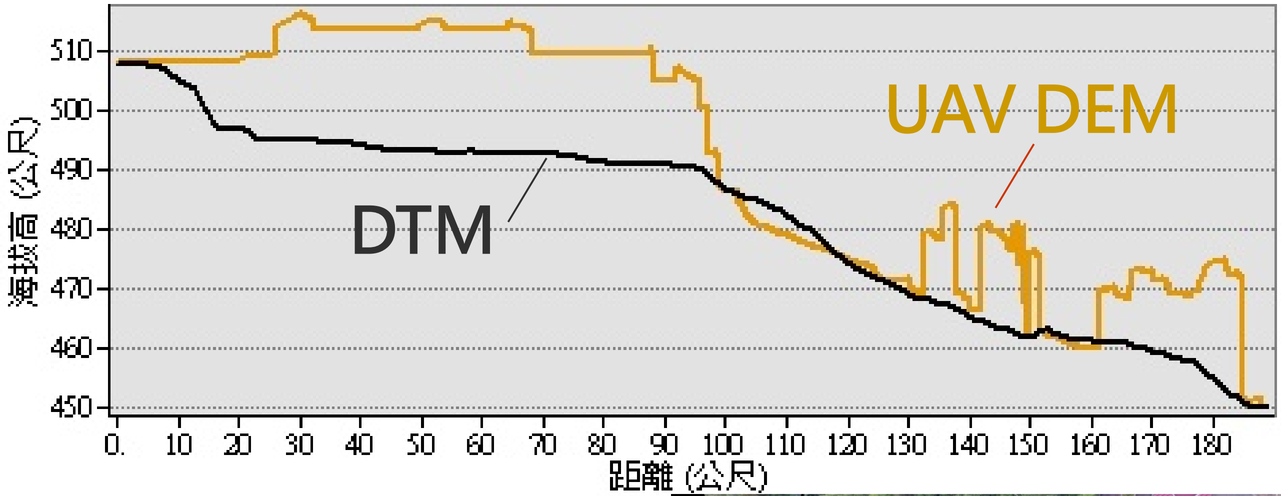
(2014.08.24)

(1.87 cm/pixel, 2017.01.05)

Orthorectified images analyses by GIS (**UAV影像正射處理**)

(MOST project, 2017)

Landform evolution

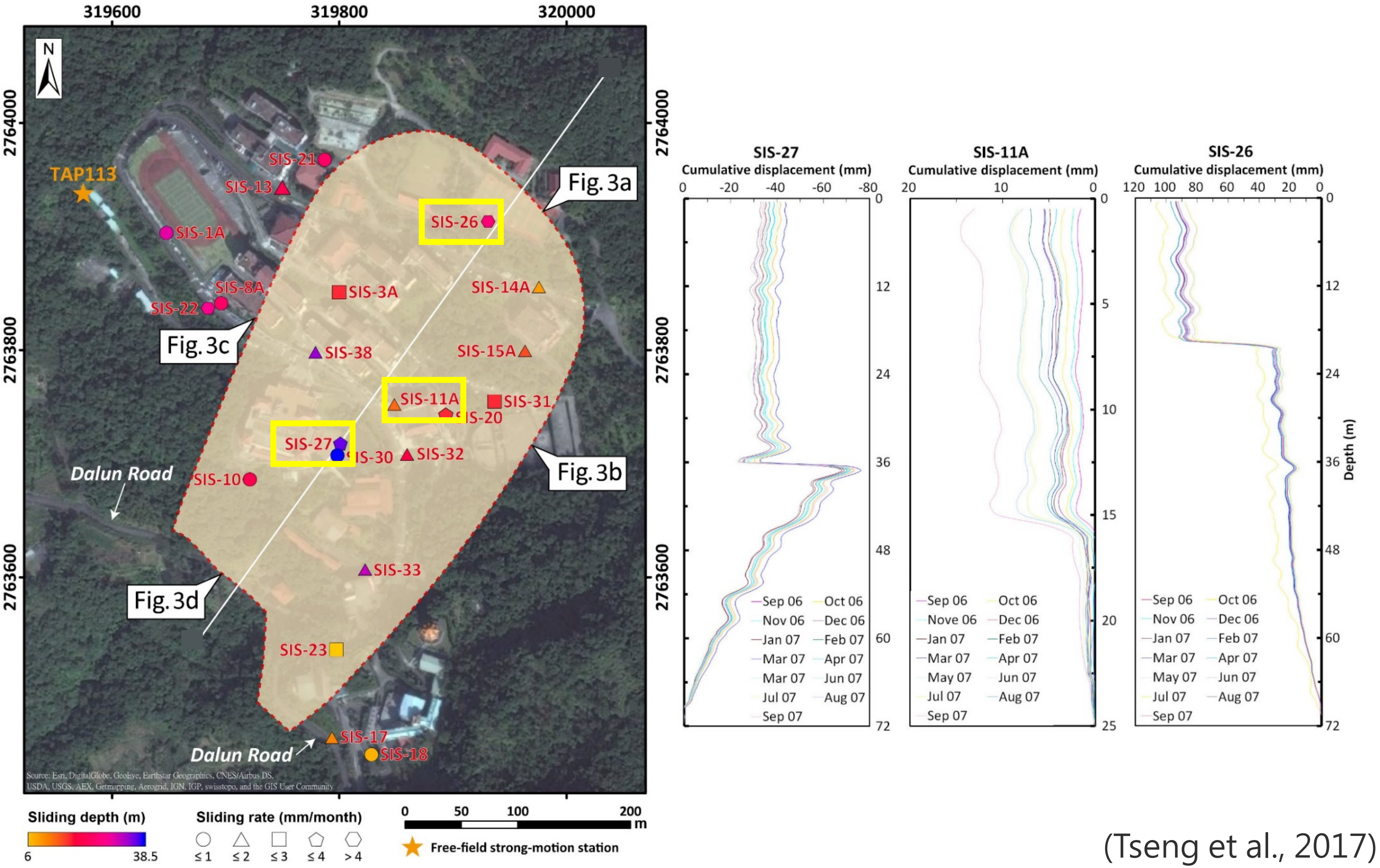


(MOST project, 2017)

DTM analyses by GIS (高程變化分析)

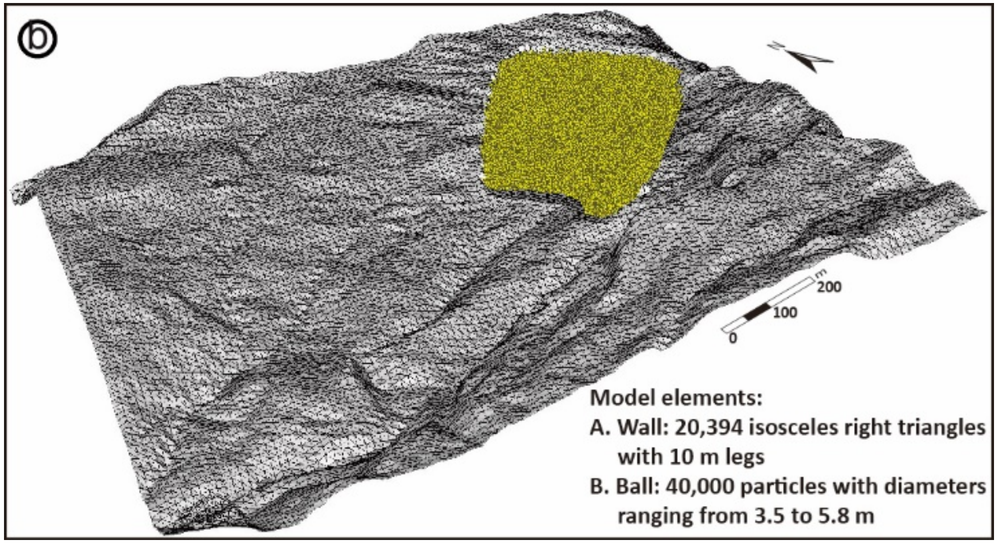
Deepest: 8.96 m
Area: 247.28 m^2

Sliding surface from inclinometers

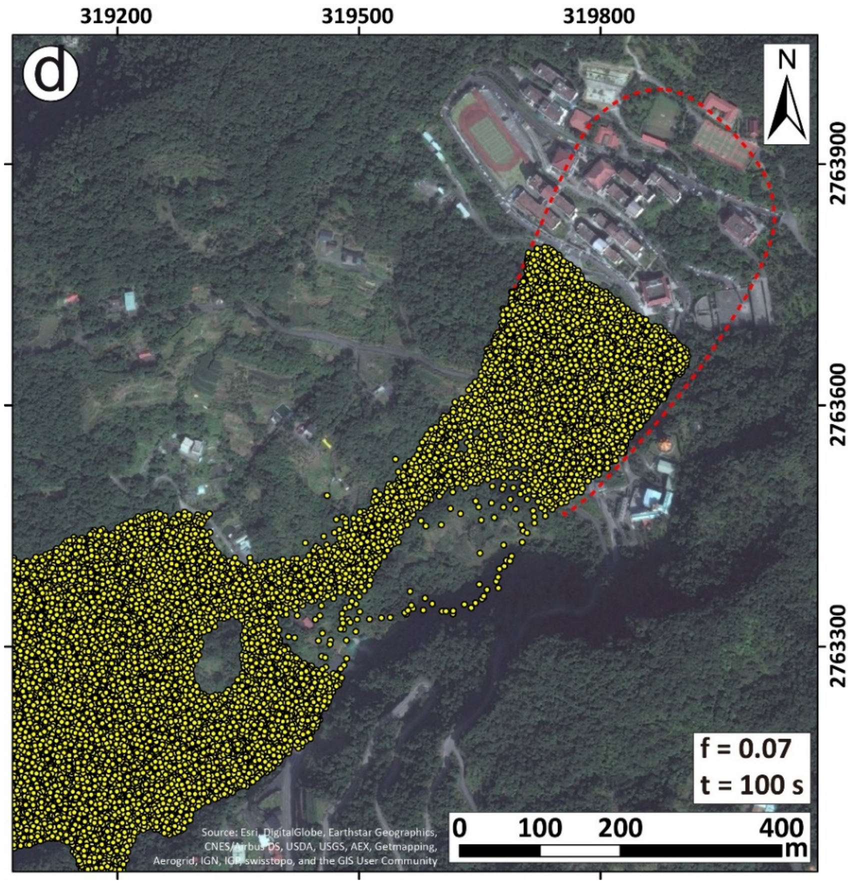


(Tseng et al., 2017)

Slope runout simulation



(PFC3D simulations)

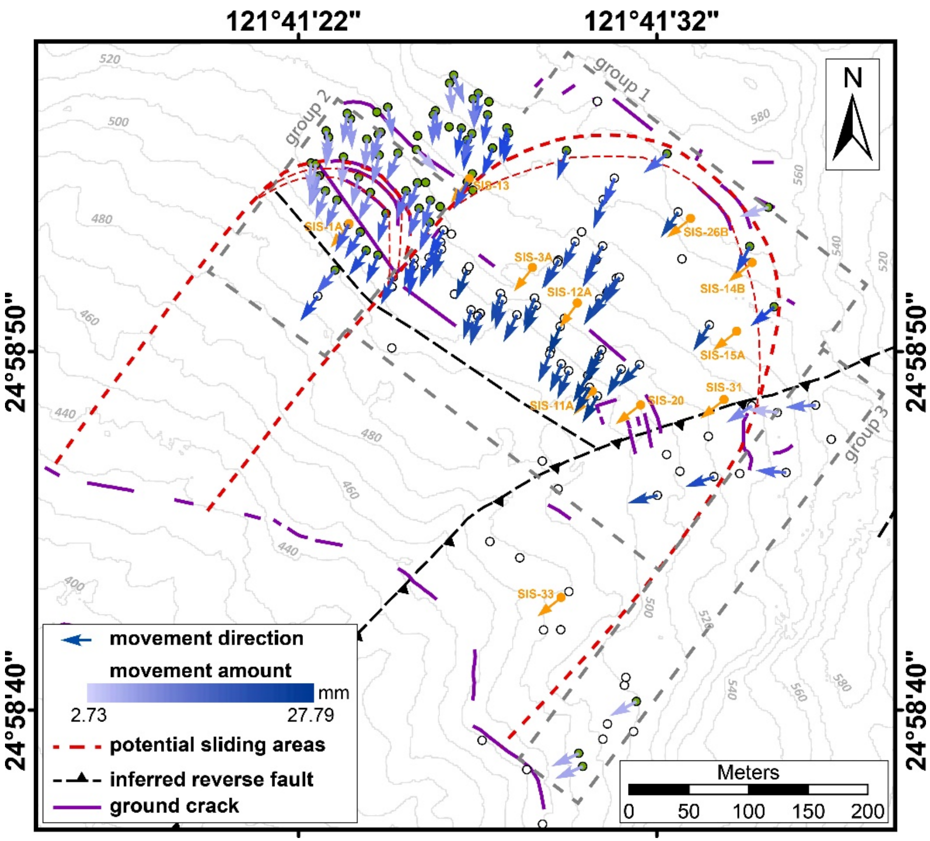


- Failure takes place when μ = 0.13.
- The campus with the sliding block may slide down in 100 seconds.

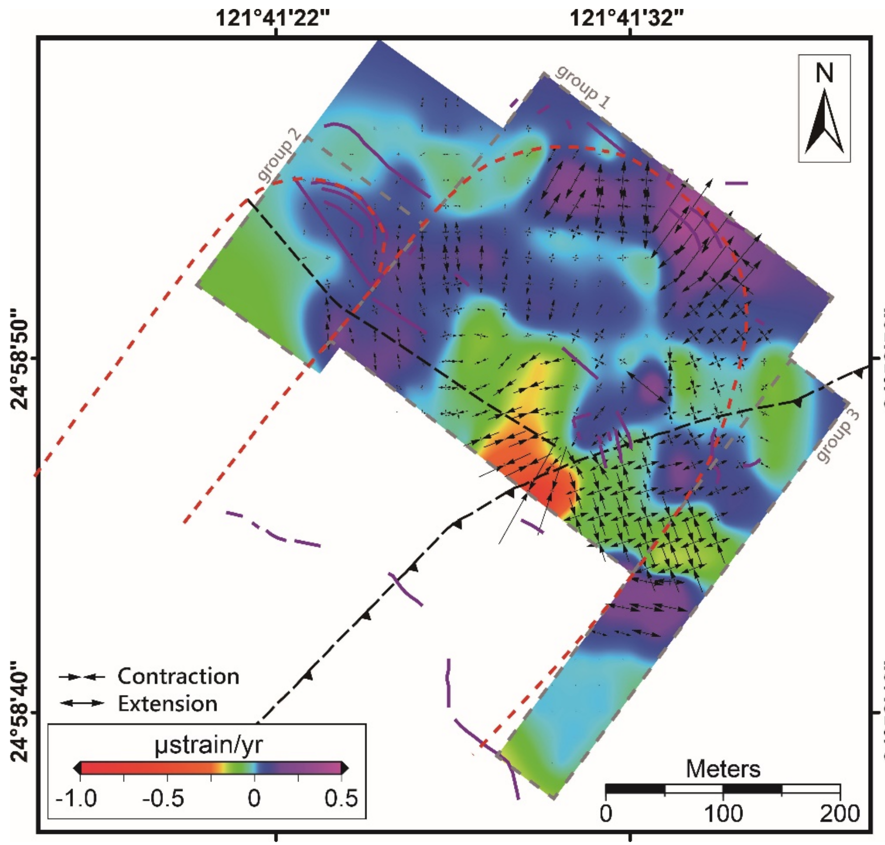
(Tseng et al., 2017)

Long-term monitoring

Velocity field of the slope(速度場)

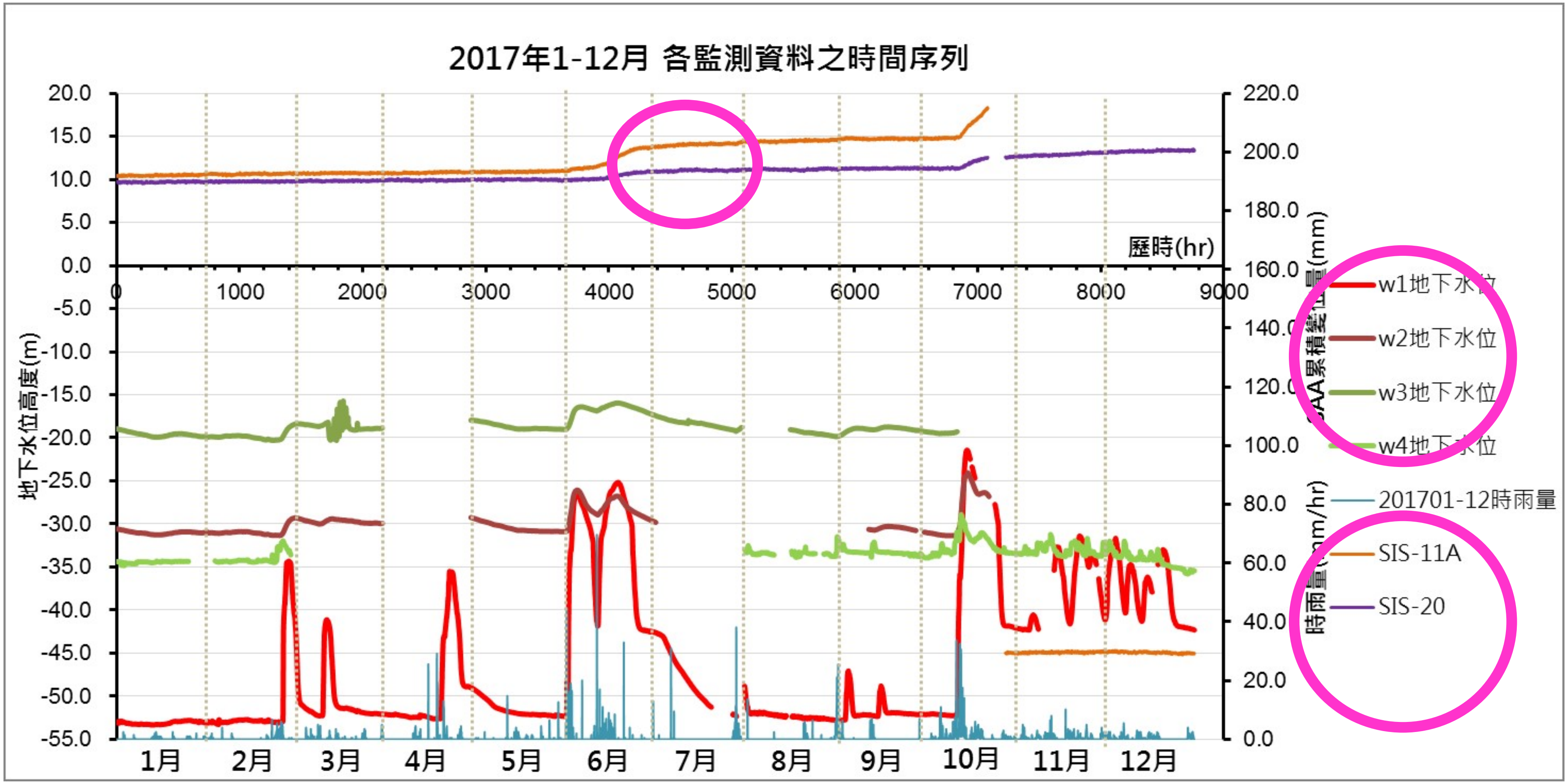


Strain of the slope(應變場)



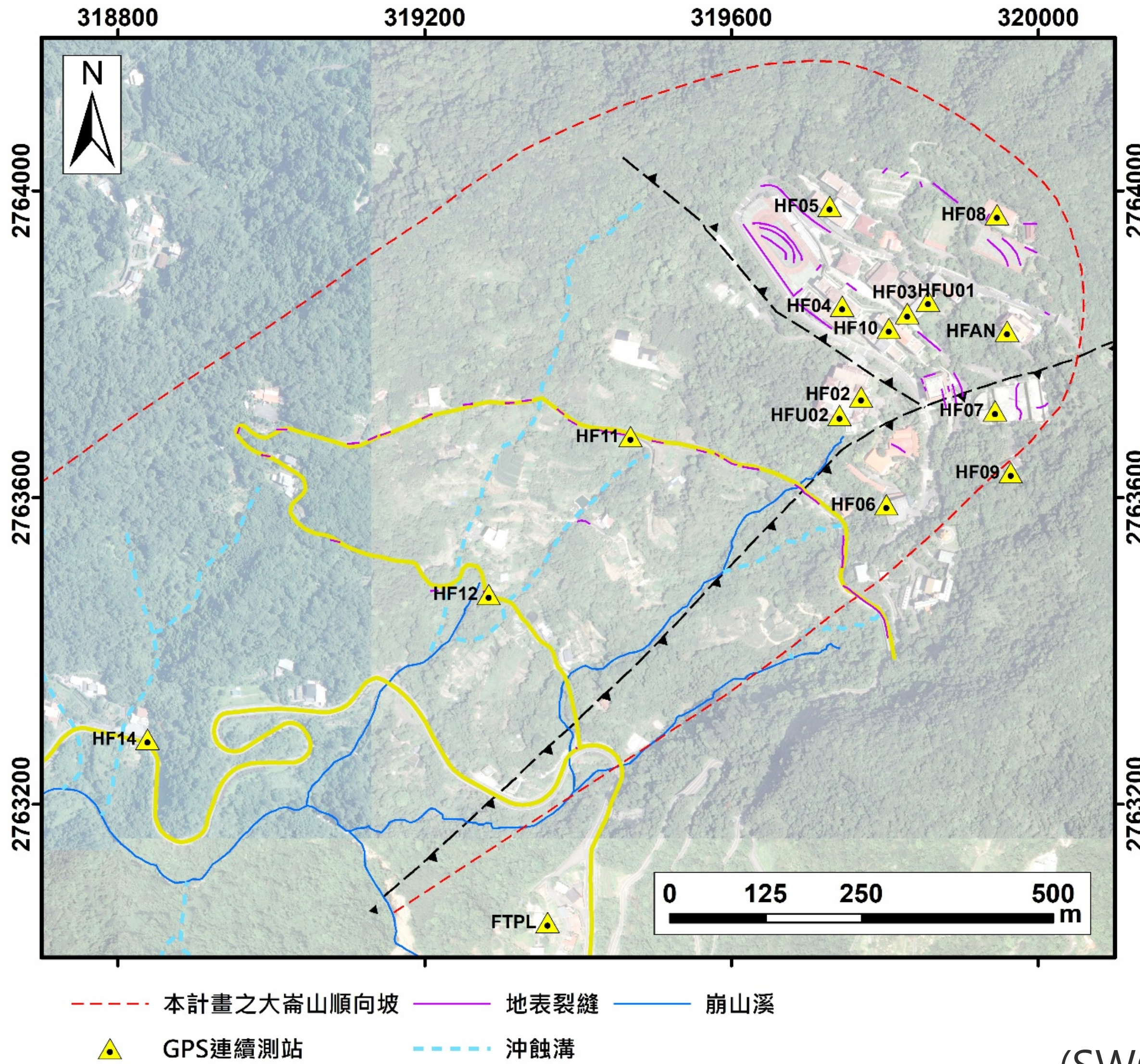
(Tseng et al., 2021)

Movement behavior in 2017



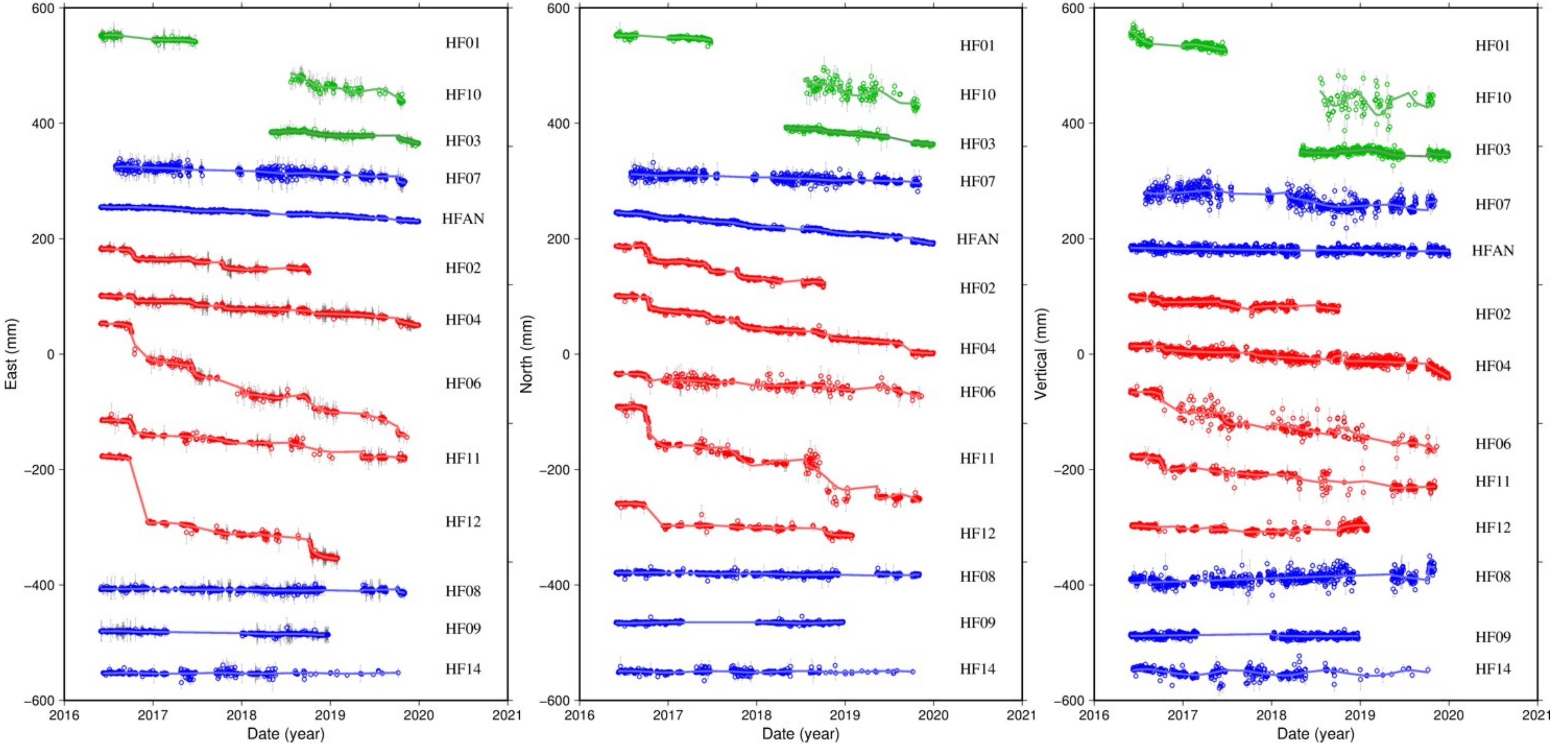
(SWCB project, 2018)

GPS stations in Dalun Mountain



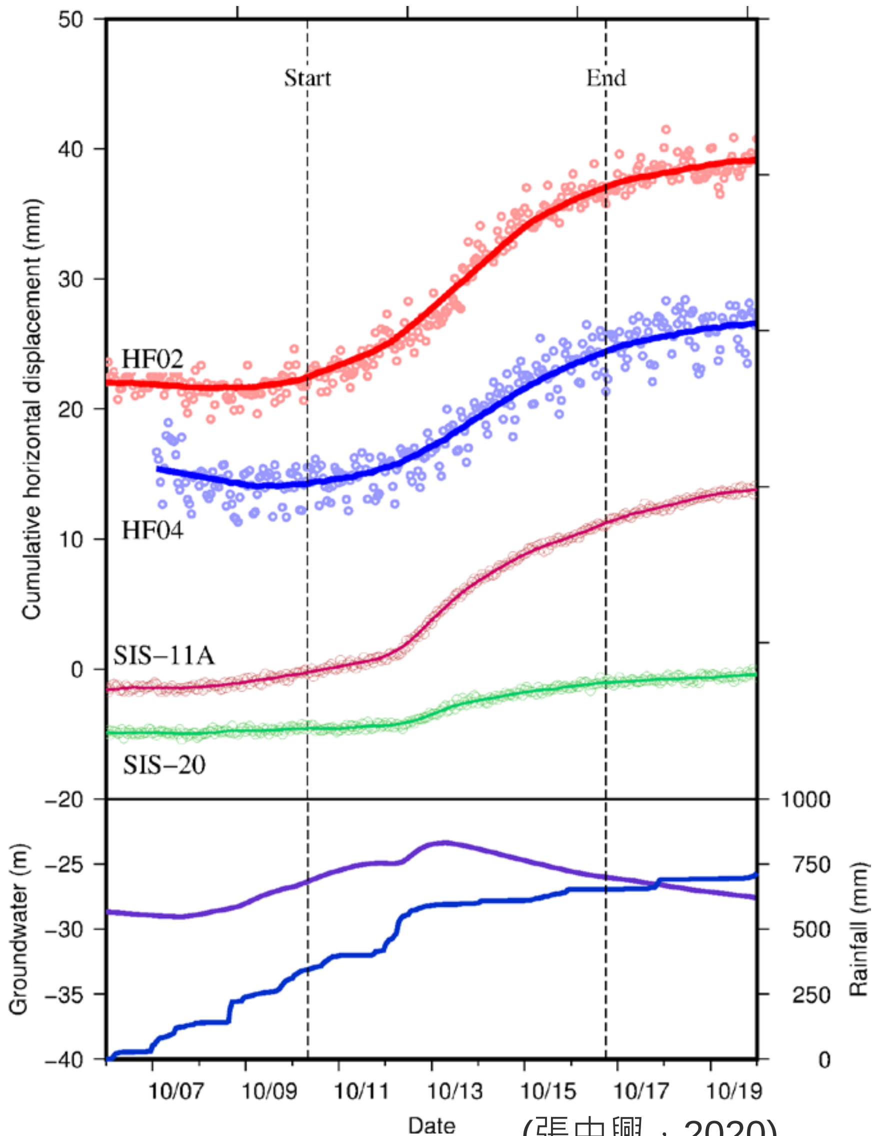
(SWCB project, 2020)

GPS time series during 2016-2019



(SWCB project, 2020)

Movement by continuous GPS

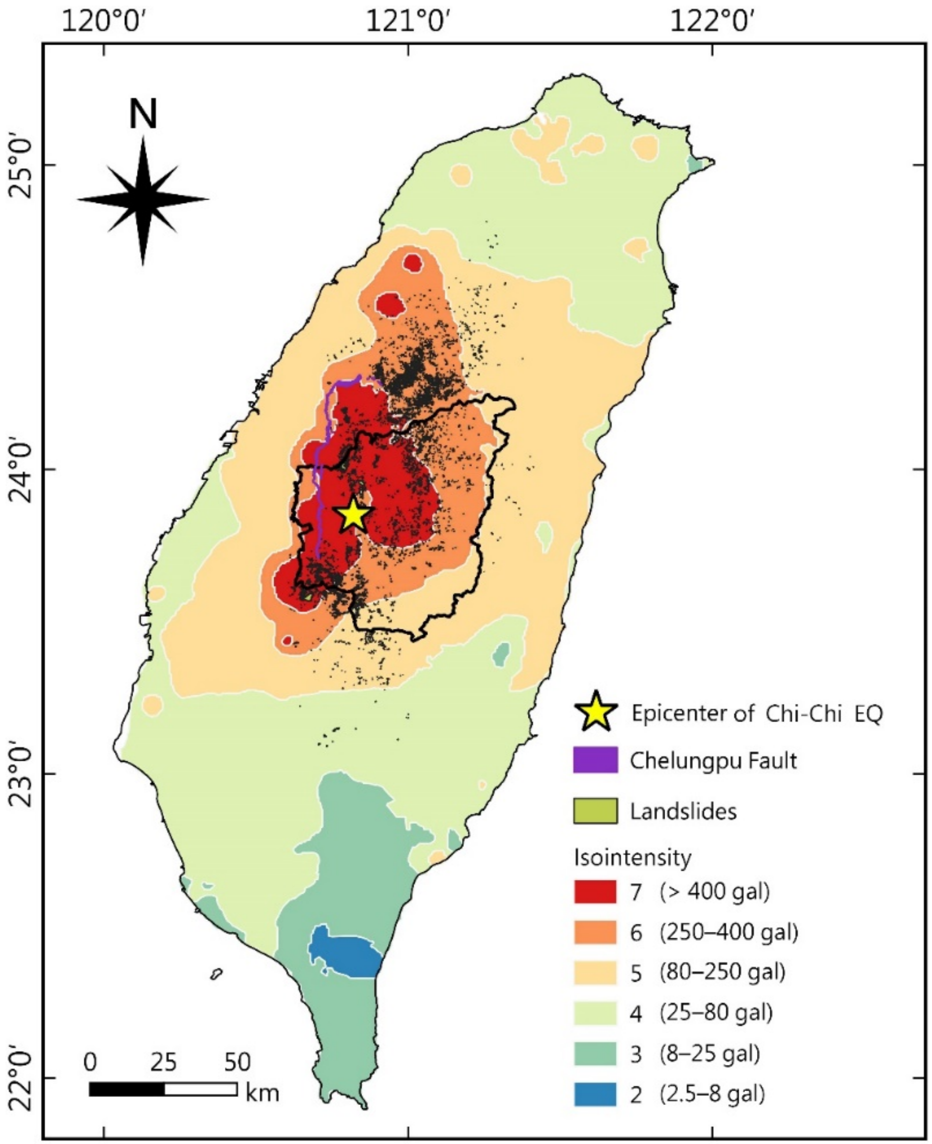


(張中興，2020)

ID	Location	Geology	Trend
HF08	Crown	Fill	Non
HFAN	Upper	Fill	SW
HF03	Upper	Fill	SW
HF07	Upper	Boundary	SW
HF10	Upper	Fill	SW
HF01	Upper	Fill	SW
HF04	Upper	Boundary	SW
HF09	Outside	Bedrock	Non
HF02	Upper	Fill	SW
HF06	Upper	Fill	SW
HF11	Middle	Fill	SW
HF13	Middle	Fill	-
HF12	Middle	Fill	SW
FTPL	Outside	Bedrock	Non
HF14	Toe	Fill	Non

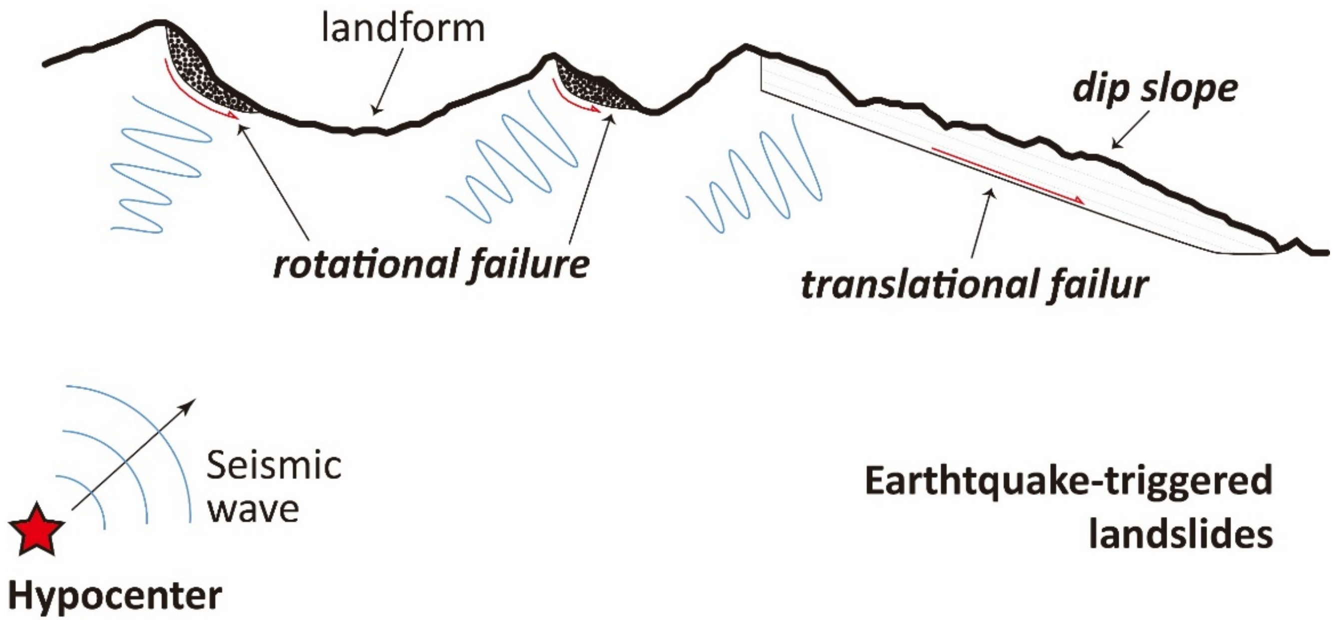
STUDY CASE- EARTHQUAKE INDUCED LANDSLIDES

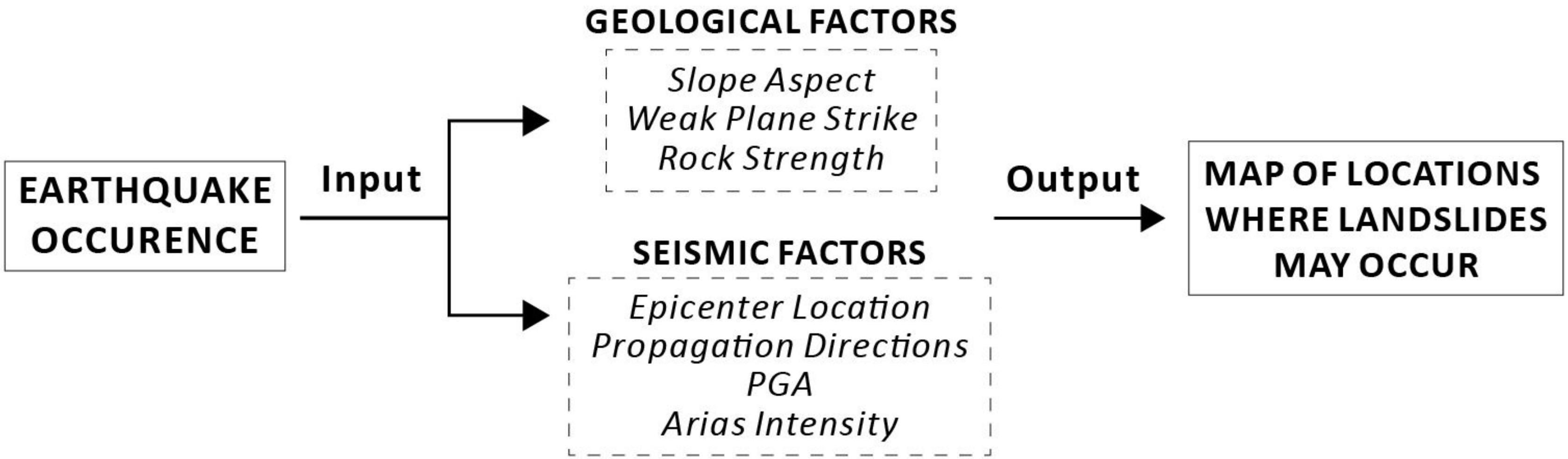
1999 Chi-Chi EQ-landslides



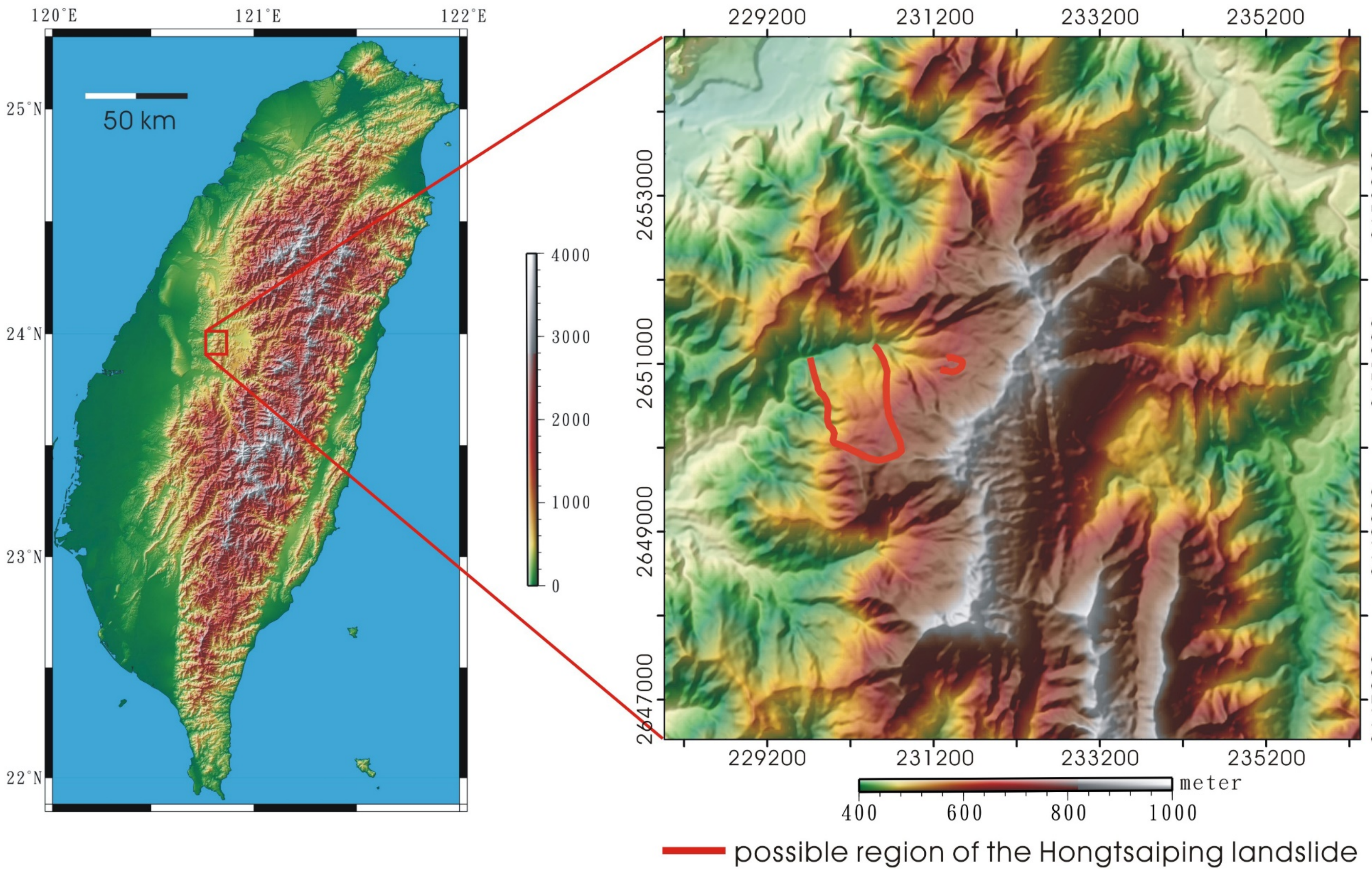
- More than 9000 catastrophic landslides triggered by the 921 EQ.
- Most of the landslides occurred within the region of intensity > 5.
- Landslide inventory made based on SPOT images before and after the EQ (Prof. Chyi-Tyi Lee).
- Also non-catastrophic landslides occurred.

Factors controlling landsliding



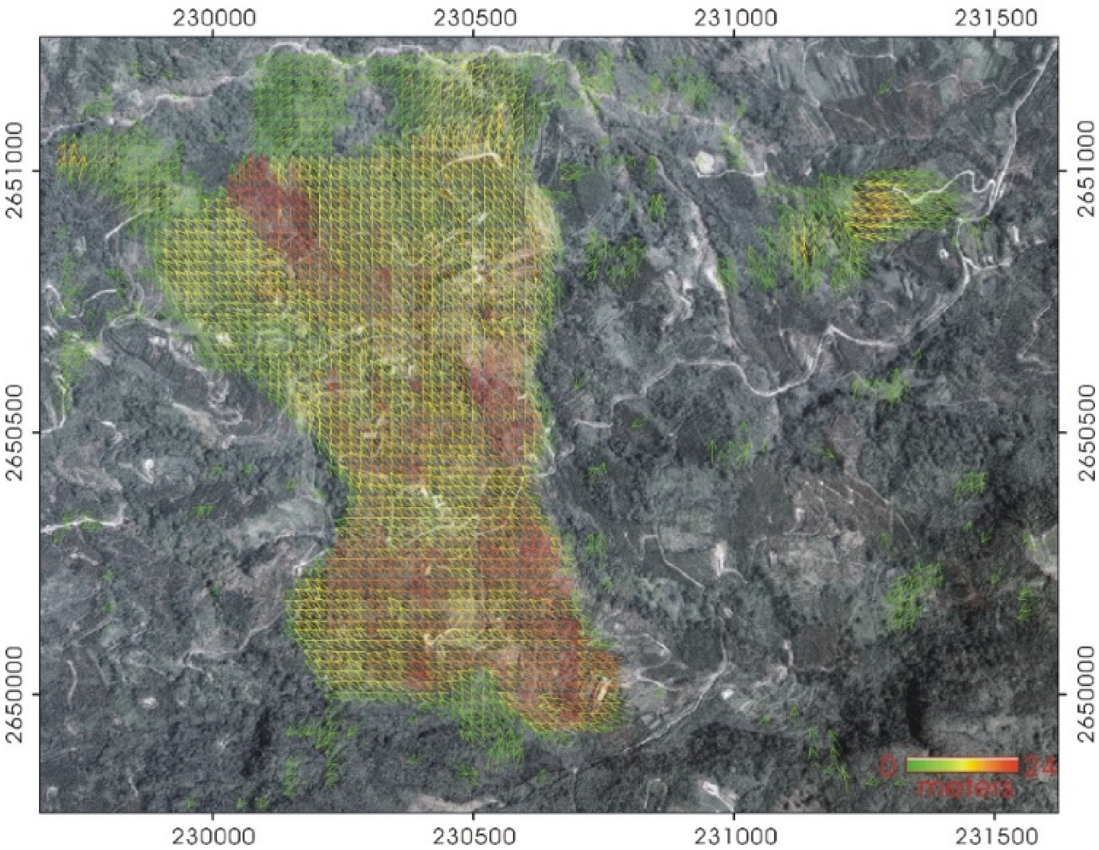


Hongtsaiping landslide



(Tseng et al., 2009)

Remote sensing method



- Aerial images before and after the 921 EQ.
- Compare displacement of ground features in each pixel.
- Displacement amount (24 m), directions, sliding blocks can be revealed.
- Non-catastrophic landslide.

(Tseng et al., 2009)

Statistic analysis of EQ landslides

Factors applied:

1. Slope
2. Aspect
3. Elevation
4. Arias intensity
5. Openness
6. Curvature
7. Lithology

Data analyzed:

- 20 m DEM:

Ministry of the Interior

- Landslide inventory of 921 EQ (provided by Prof. Chyi-Tyi Lee)

- Seismic stations :

Central Weather Bureau

(沈楷庭、曾佳漢)

Logistic regression

Logistic regression run in SPSS

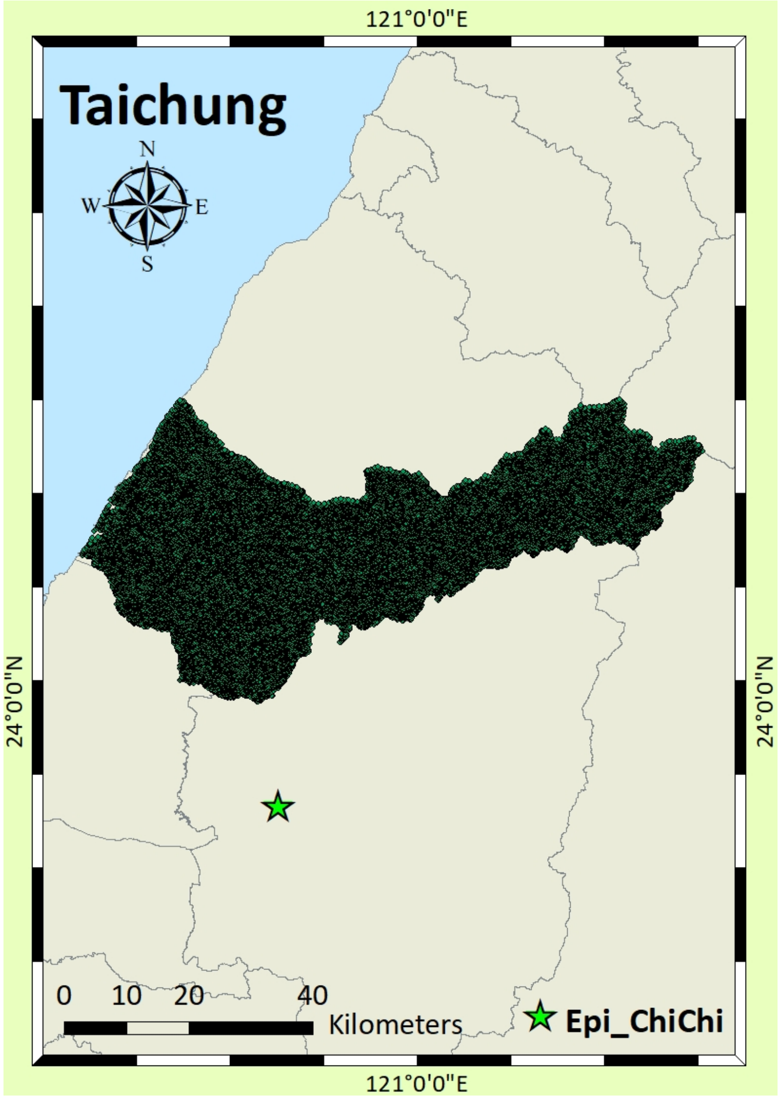
$$Y = -3.350 + 0.217x_1 + 2.136x_2 + 0.104x_3 + 0.476x_4 - 0.905x_5 + 0.032x_6 - 0.001x_7$$

分類誤差矩陣 (Confusion matrix of classification)				
observe		predict		
		landslide		Percent %
		0	1	
Land slide	0	5666	1302	81.3
	1	979	5989	86.0
Accuracy				83.6

x_1 to x_7	β value
Curvature	0.217
Openness	2.136
Slope	0.104
Aspect (SIN)	0.476
Aspect (COS)	-0.905
Arias intensity	0.032
Elevation	-0.001
Coefficient	-3.350

(沈楷庭、曾佳漢)

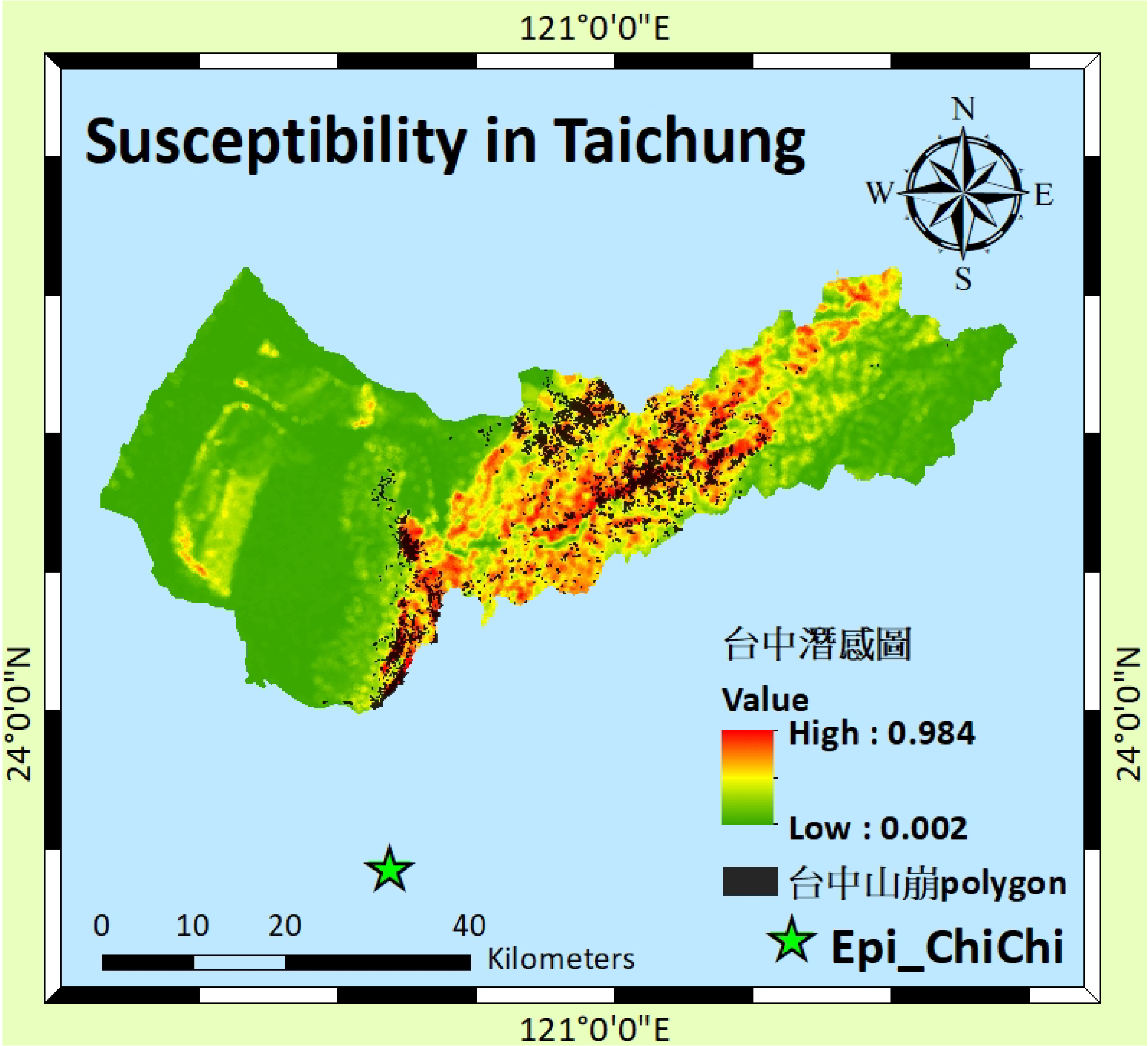
Susceptibility of landslides in Taichung



- Choose 50000 points
- Input the values of factors of each point into Logistic regression equation and it can get probability
- Plot on the ArcMap and use Kriging Interpolation to draw susceptibility map of landslides

(沈楷庭、曾佳漢)

Susceptibility in Taichung



- Most of the landslides are the red area

In the landslide events：
15472 grids < 0.5
51593 grids > 0.5

Accuracy:
15472/51539=76.9%

(沈楷庭、曾佳漢)

Conclusions

- Topography in Taiwan is dynamics, being controlled by endogenic and exogenic processes.
- Understanding geological context is essential for monitoring and analyzing movement progress.
- Case studies and statistic analyses of a certain event are complementary to each other.
- Risk assessment and hazards reduction can be achieved by the study of geomorphic evolution.

Research projects organizing:

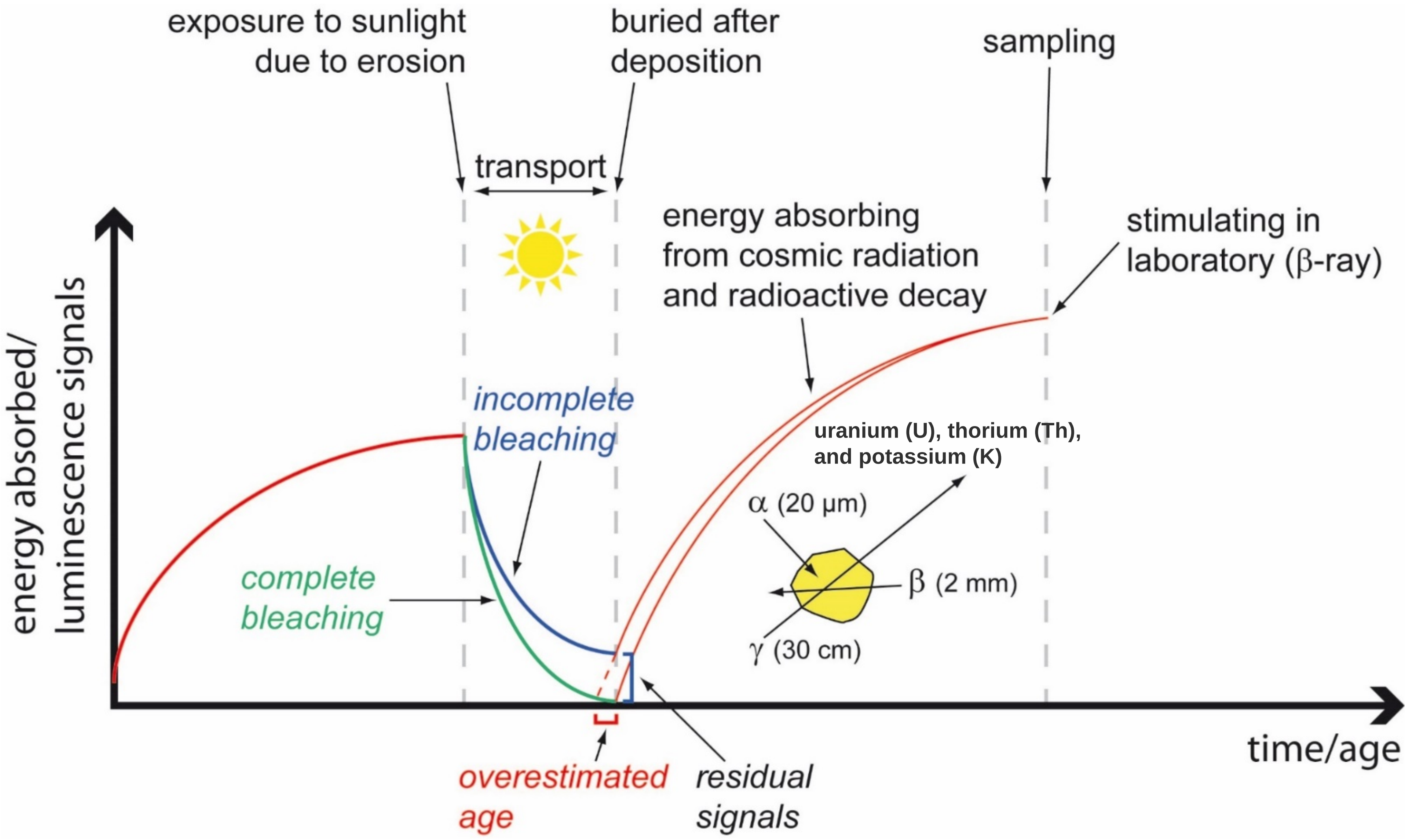
- **MOST,** 2016-2019
- **SWCB,** 2018-2020
- **MOST,** 2021-2022
- **MOST Taiwan-Czech bi-lateral project (台灣-捷克雙邊計畫),** 2022-2024 (in preparation)

Thank you for your attention!

Perspective of continuous GPS monitoring

- Single-frequency (L1 (19 cm))：**13 stations of 1Hz** sample rate
- Dual-frequency (L1+L2 (24 cm))： **2 stations of 1Hz、20Hz**
- Calculation software：
  Dual-frequency and Single-frequency：
  RTKLIB v.2.4.3 and **Bernese v.5.0**
- **Long-term movement trend**：
  A. daily average (daily solution)
  B. with rainfall, groundwater and inclinometer data
- **Short-term/event movement behavior**：
  A. deformation of sliding mass derived from 20Hz data during speeding-up sliding
  B. sliding behavior when cumulative rainfall exceeding threshold amount

Basic concepts of luminescence dating



Principles of GPS technique

- 3D spatial positioning by measuring distance between GPS satellites and receivers with 4 GPS satellites (1 for correcting time error)
- Errors of GPS data:
  - satellite orbits (衛星軌道誤差)
  - time delay in receivers and satellites (時錶誤差)
  - ionosphere delay (電離層延遲)
  - troposphere delay (對流層延遲)
  - multi-passes of GPS signals (多路徑效應)
  - receiver positions
  - phase center within antenna
  - cycle slips (週波脫落)
  - cycle ambiguity (週波脫落未定值)
  - coordinates of constraint stations

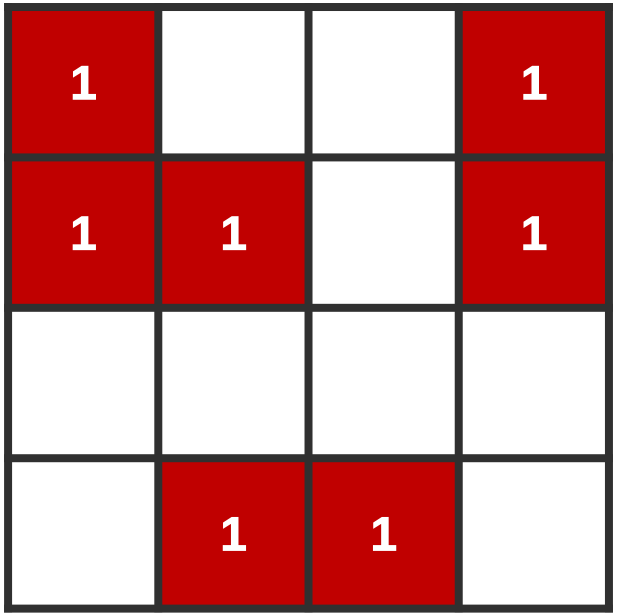
Factor select | Logistic regression | Calculate susceptibility | Draw susceptibility

Landslide Ratio from DEM grid

$$= \frac{the\ grid\ of\ landslide}{total\ grid\ in\ area}$$

Assume 1 for landslide, 0 for non-landslide

Ex.: Landslide Ratio $= \frac{7}{16} = 43.75\%$



Calculation Area

(沈楷庭、曾佳漢)

Factor select | **Logistic regression** | Calculate susceptibility | Draw susceptibility

Logistic regression

$$\ln\left(\frac{P_i}{1-P_i}\right) = \beta_c + \sum_{i=1}^{k} \beta_k x_i = Y$$

$$\Rightarrow e^Y = \frac{P_i}{1-P_i}$$

P_i *is probability of event occurrence*

$$\Rightarrow e^Y - e^Y \cdot P_i = P_i$$

β_c *is coefficient*

x_i *is value of factor*

$$\Rightarrow P_i = \frac{e^Y}{1+e^Y}$$

β_k *is weight of factor*

(沈楷庭、曾佳漢)