14th South East Asia Survey Congress

Future and Prospect for Monitoring Deep-Seated Landslide Activity over Extensive Area

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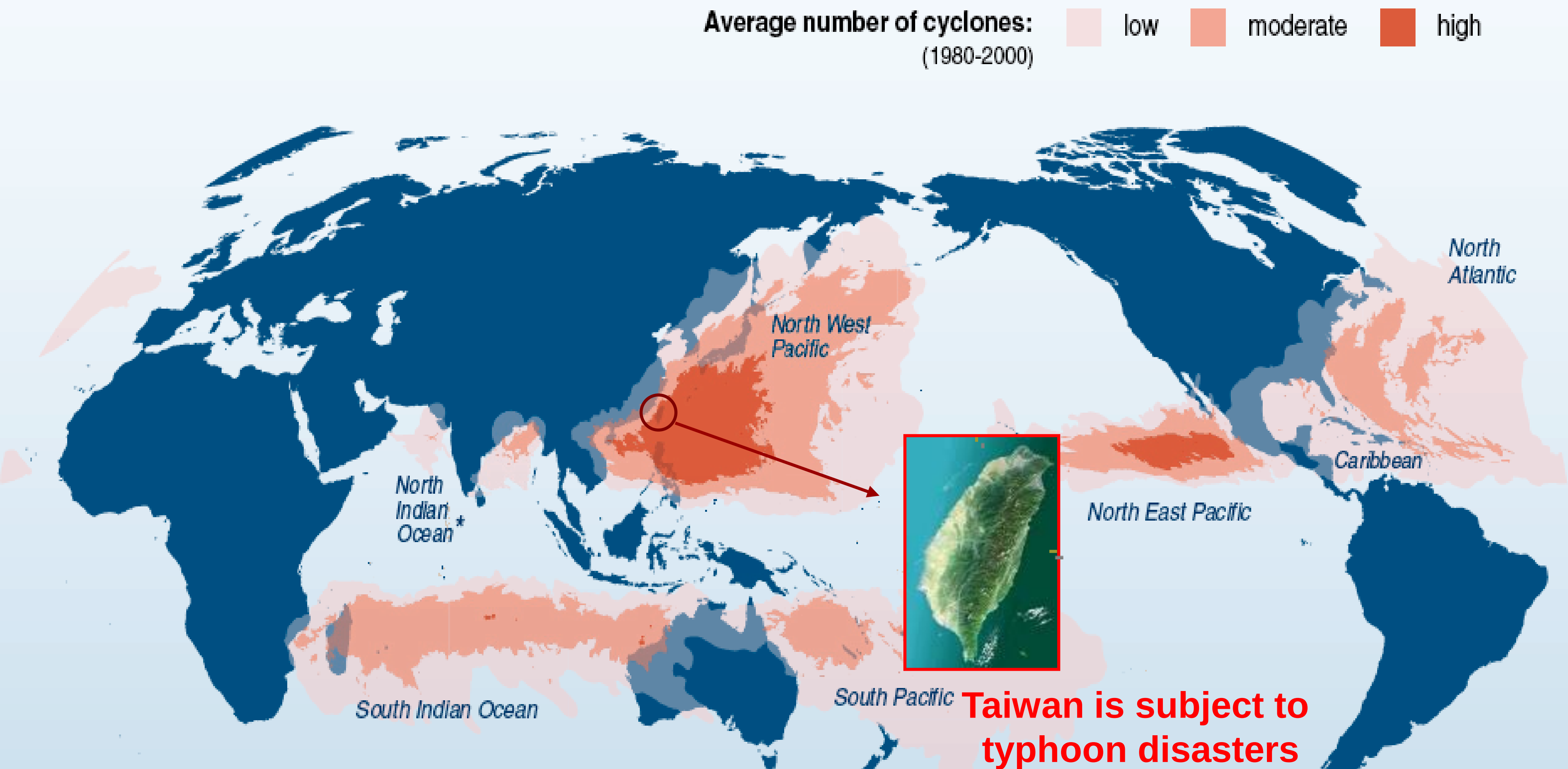
Outline

1. ***Challenges of Typhoon Morakot***
2. ***Comprehensive Plan of Large-scale Landslide Hazard Mitigation***

   Risk Assessment of Potential Landslides
   Multi-scale Monitoring Techniques

3. ***Future Development and Conclusions***

Tropical cyclone frequency



'Low' refers to less than one cyclone every three years per 0.002 dd², 'moderate' between one every three years to one every year per 0.002 dd² and 'high' to one to three cyclones per year per 0.002 dd². The unit '0.002 square decimal degree (dd²)' is equivalent to 25 km² on the equator, diminishing as latitude gets higher.

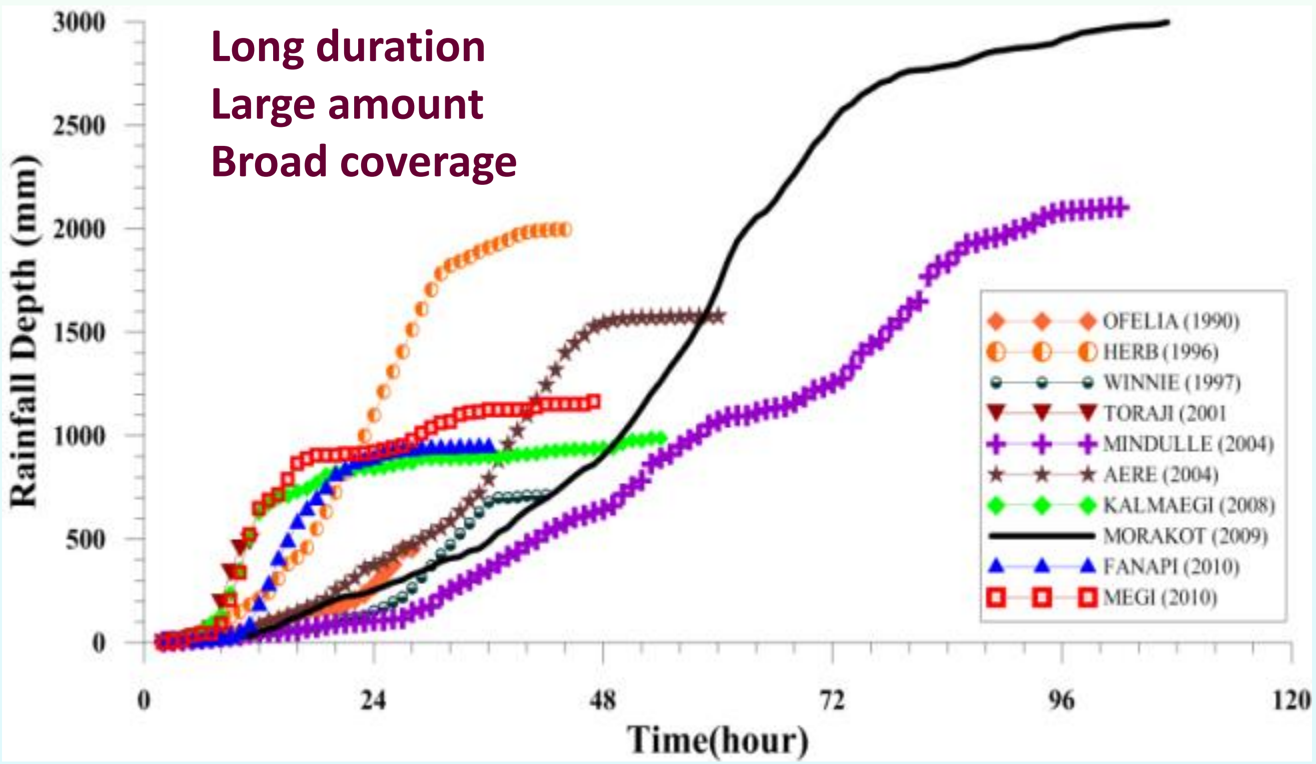
* *average based on eight years only.*

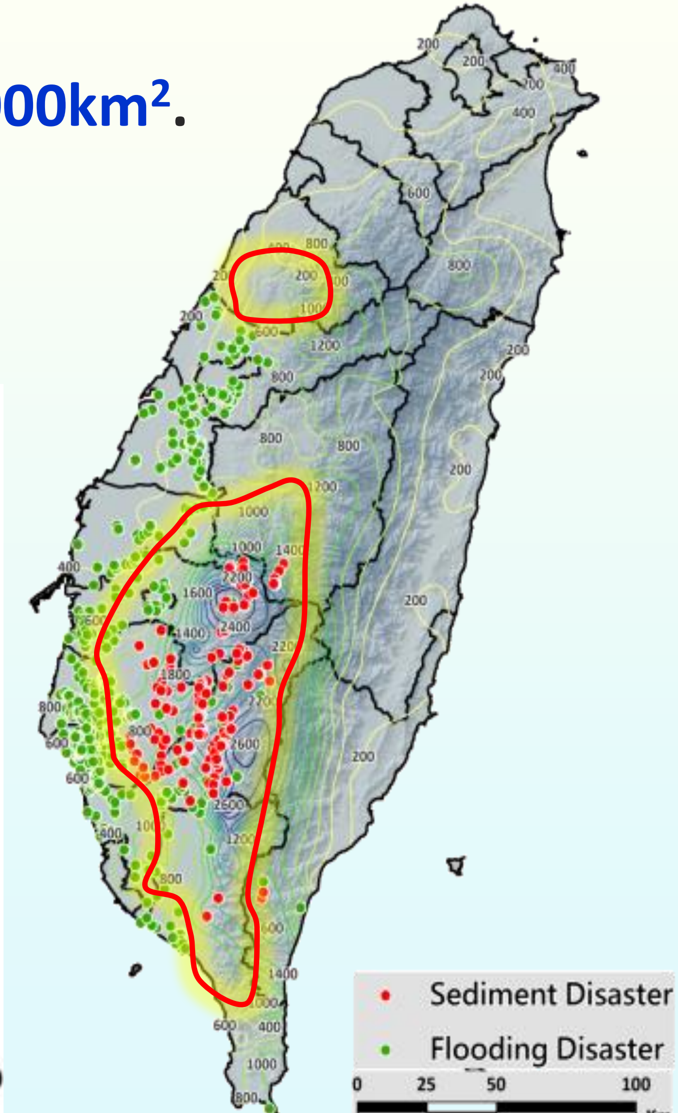
Sources: PREVIEW Global Cyclone Asymmetric Windspeed Profile, UNEP/GRID-Europe.

Challenges of Typhoon Morakot, 2009

(Aug 6-10, 2009)

- Max. accumulated rainfall: 3059.5mm.
- Coverage area of total rainfall ≧2000mm: 320,000km^2.
- Total new landslides: 39,492 ha.
- Casualty and missing: 699 people.
- Total damage: 6.7 billion USD(1.6% GDP)





Debris Flow Warning and Evacuation

- ***During typhoon Morakot, the SWCB issued 21 debris flow warnings to local governments for evacuation activities based on real-time weather information.***

Debris flow warning	*Warning ravines*	*County (City)*	*Town*	*Village*
Red alarm	***519***	***12***	***61***	***230***
Yellow alarm	***338***	***14***	***58***	***163***

9,100 people were evacuated by local governments according to the warning. Among them, 1,046 people escaped from the possible casualties.

onservation Bureau (SWCB)

Deep-Seated Landslide in Hsiaolin Village

Landslide occurred at am 6:16, Aug 9, with R=1676.5 mm
Average slope: 22 degrees; Landslide area: 202 ha;
Depth: 82 meters ; Volume: 25 million m3
Dead and missing: 457 casualties

Formosat-2

2. Comprehensive Plan of Large-scale (Deep-Seated) Landslide Hazard Mitigation

Risk Assessment of Potential Landslides

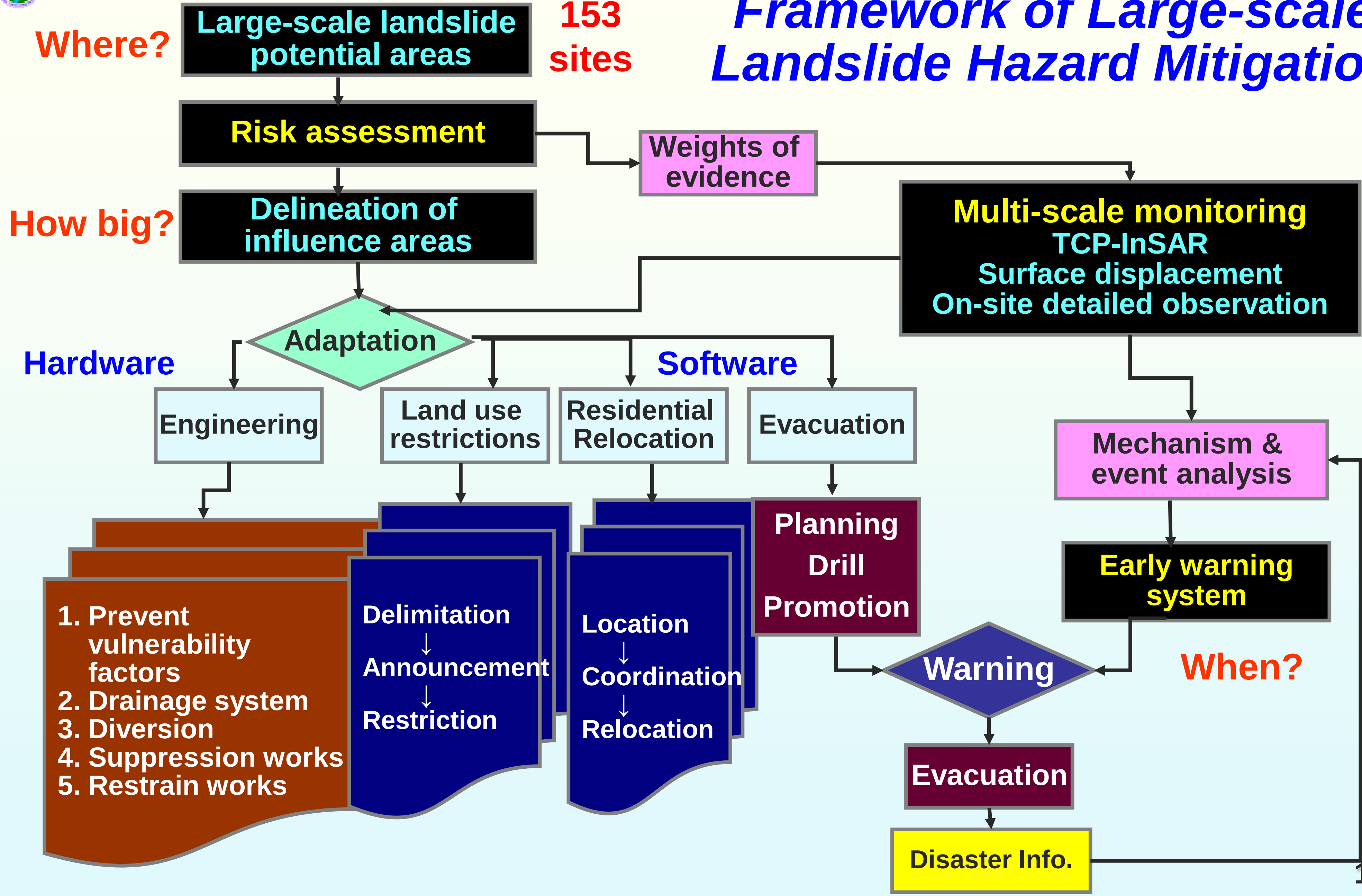
Multi-scale Monitoring Techniques

Comprehensive Plan of Large-scale Landslide Hazard Mitigation under Climate Change Impact

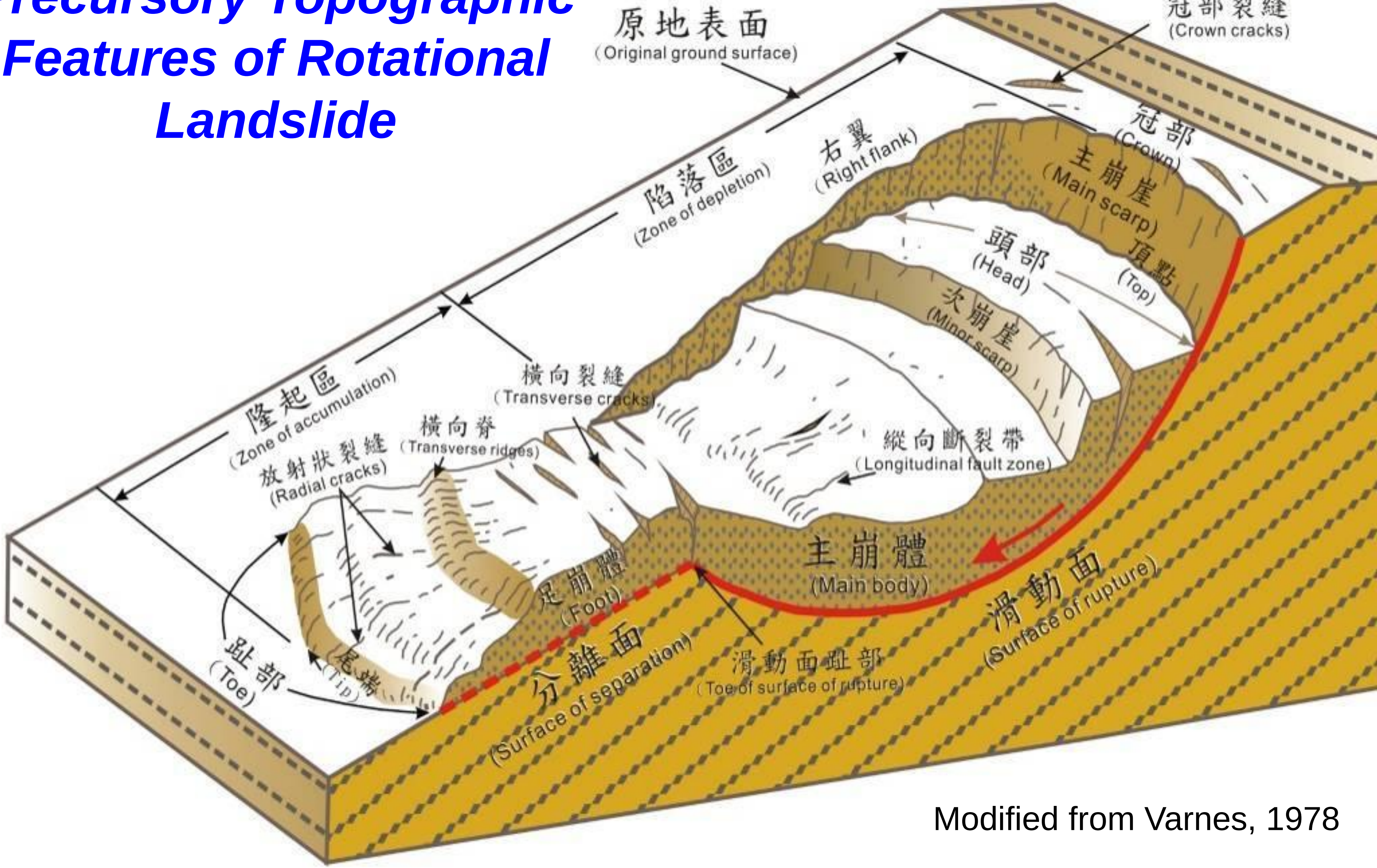
(2017-2020, Budget: 110 million USD)

Definition: Area 10 ha; Depth 10 meters ; Volume 100,000 m3

Framework of Large-scale Landslide Hazard Mitigation



Precursory Topographic Features of Rotational Landslide

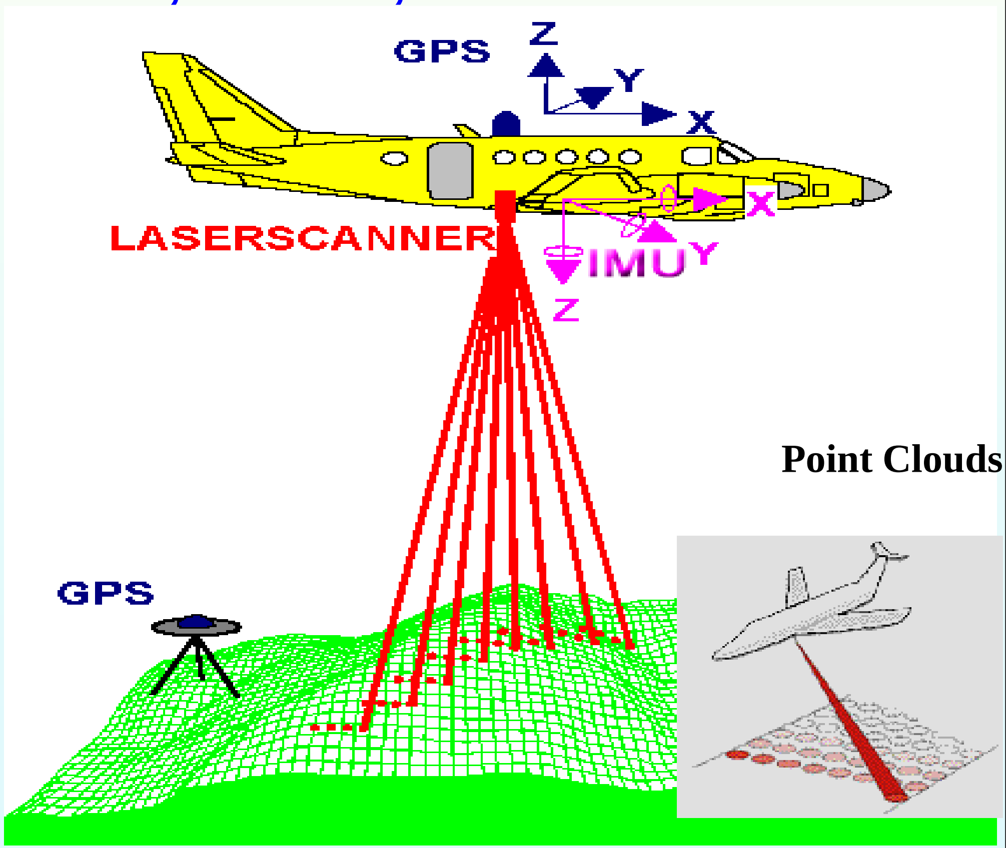


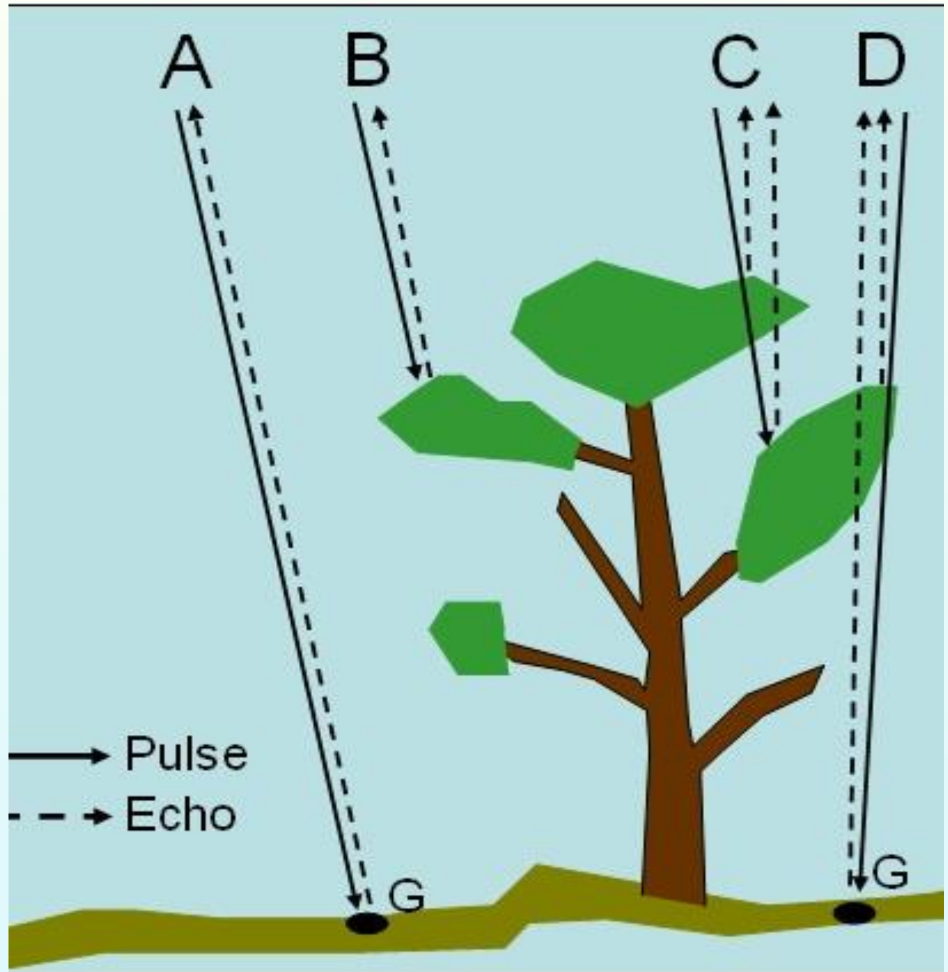
Modified from Varnes, 1978

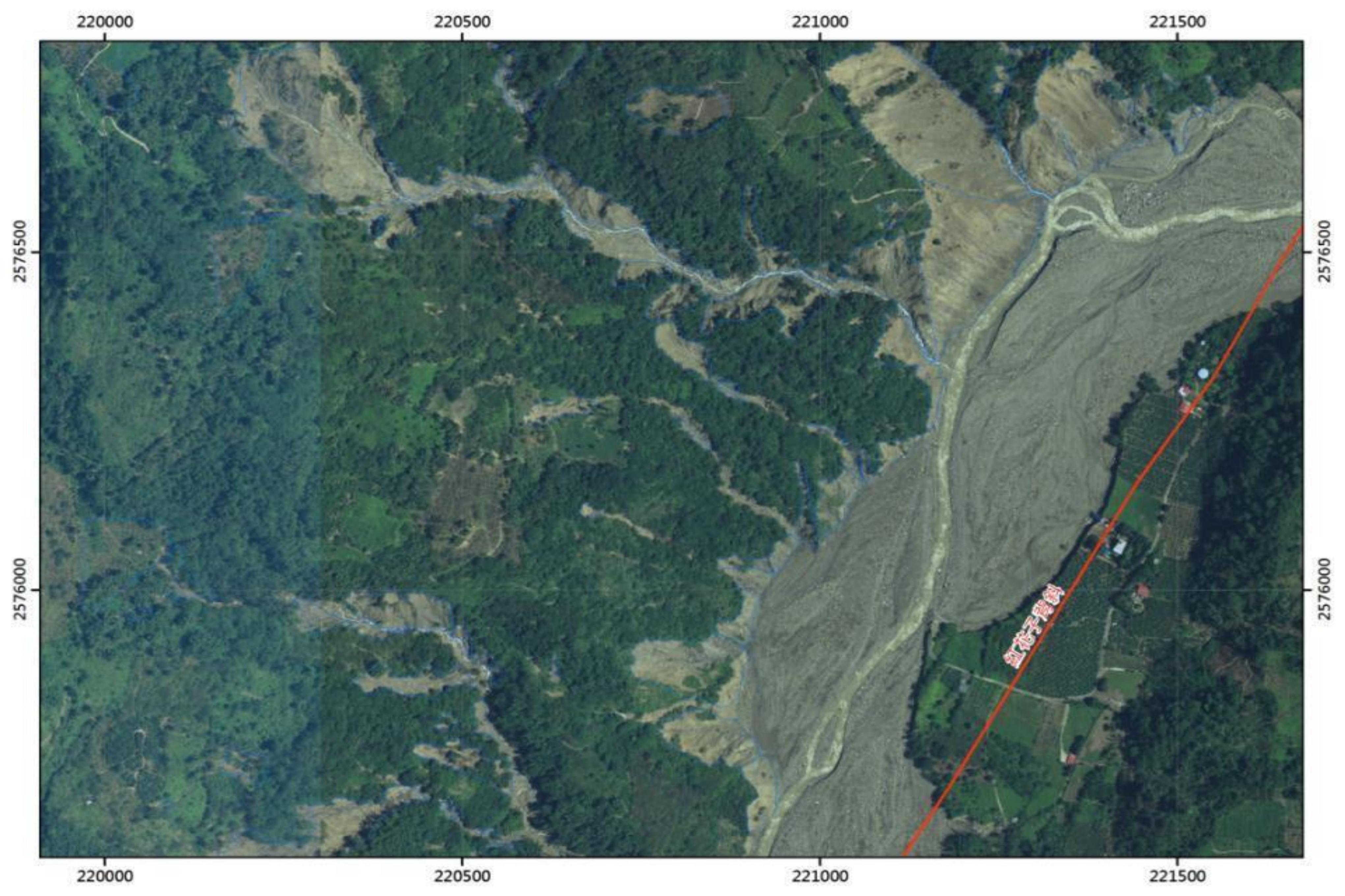
LiDAR : Light Detection And Ranging

Only ground points are selected to construct high resolution DEM

Frequency of laser pulse
50,000~200,000Hz



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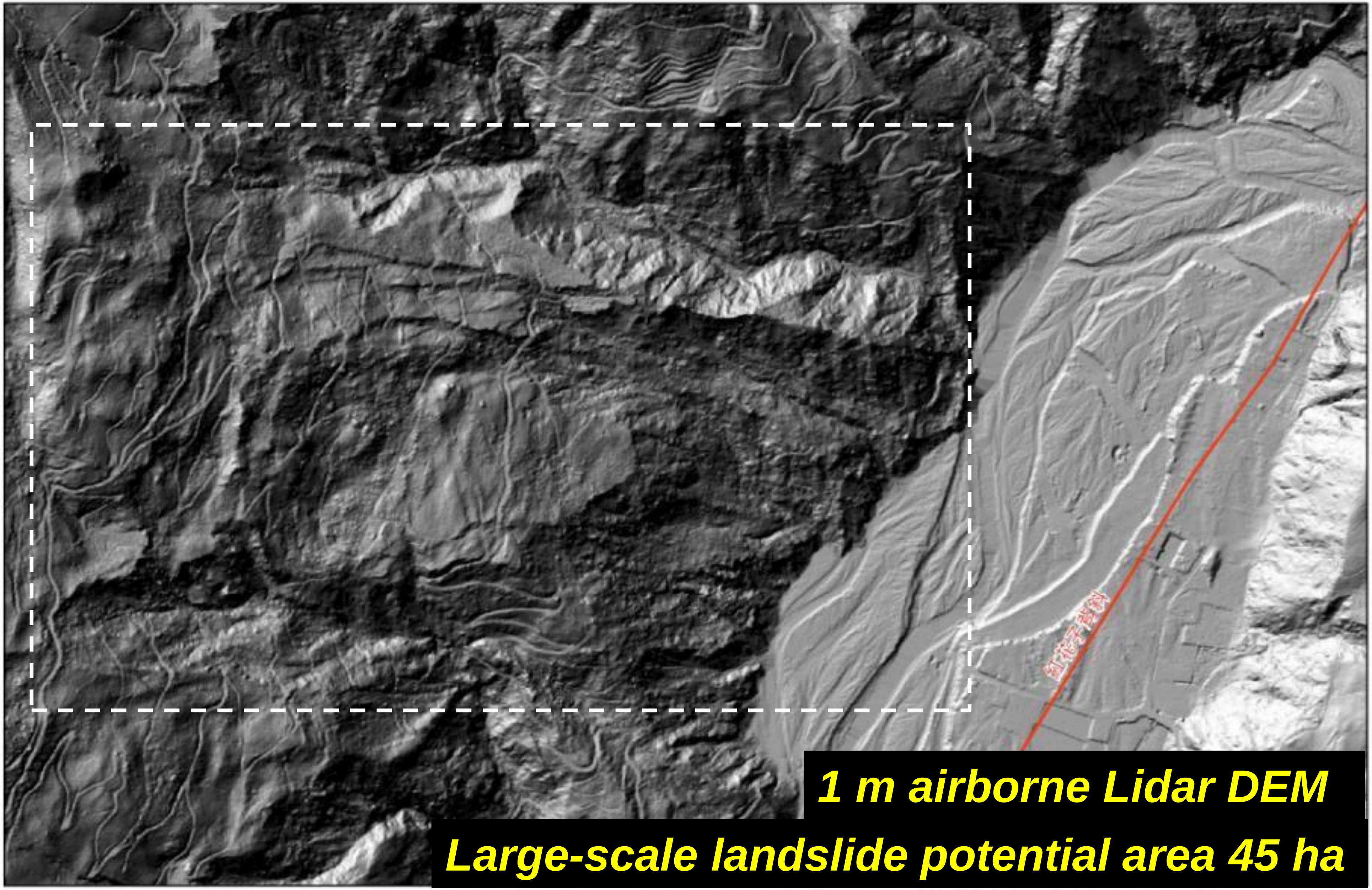
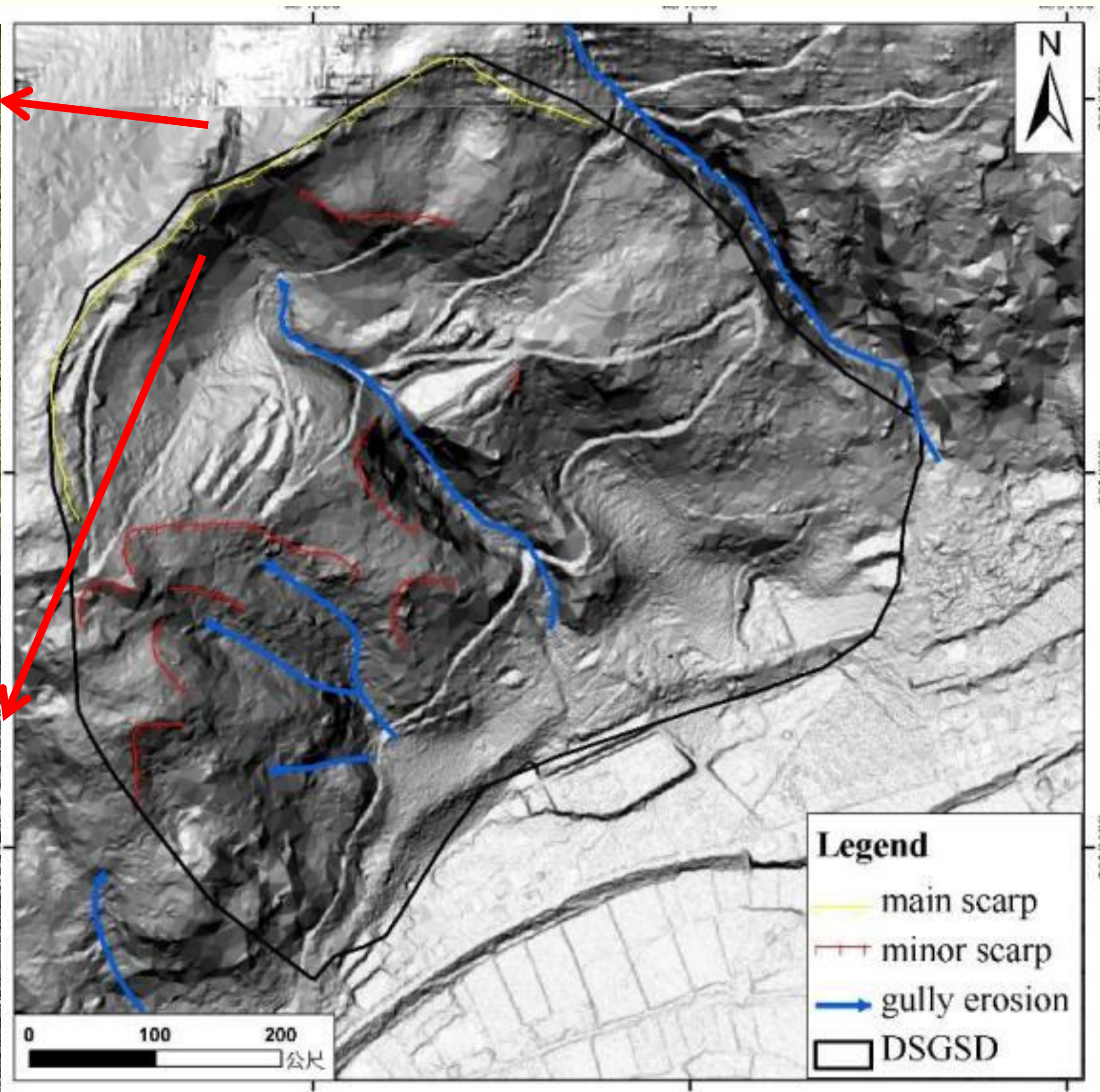

1 m airborne Lidar DEM
Large-scale landslide potential area 45 ha

On-site Investigation of Landslide Features

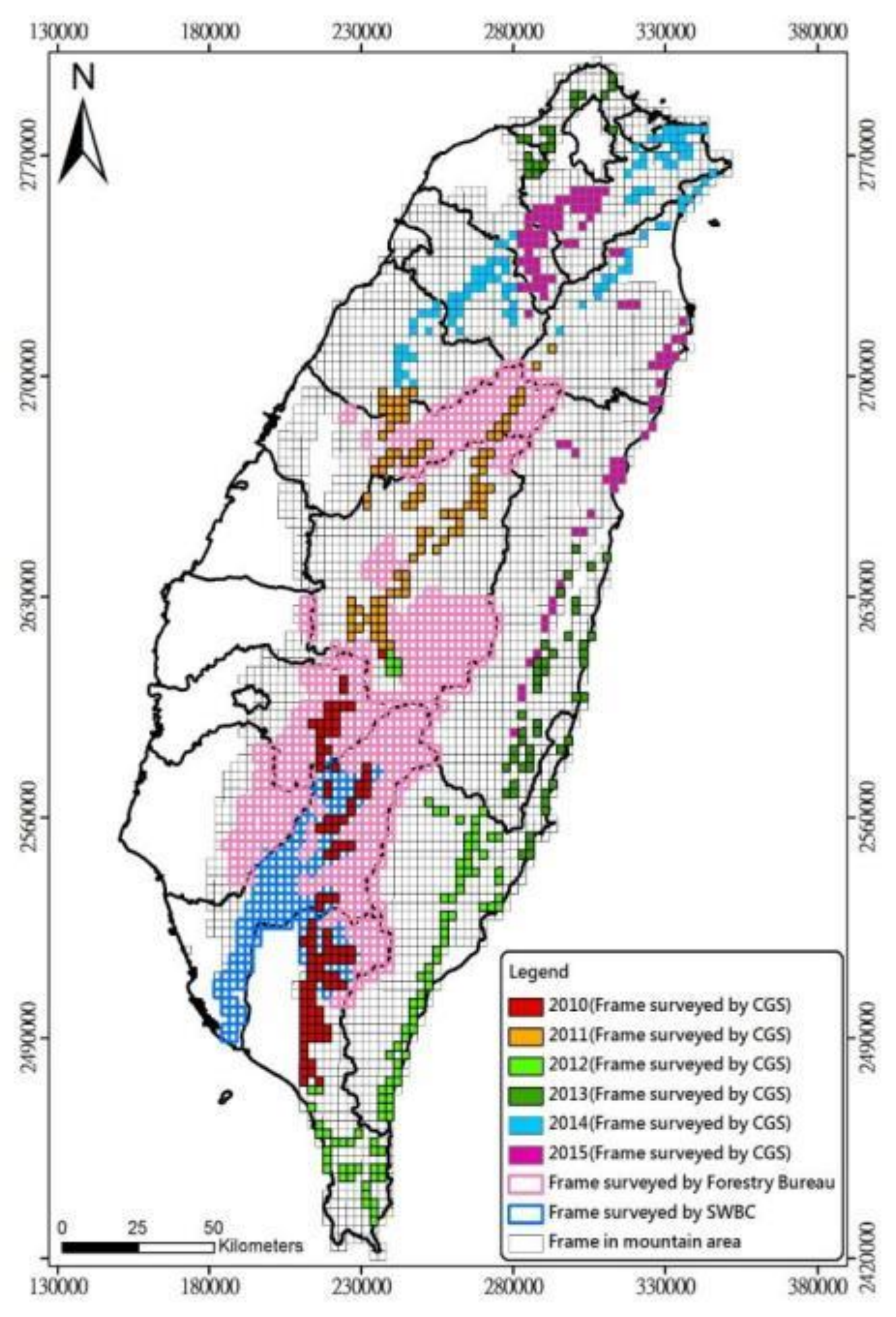


Identification of Large-scale Landslide Potential Areas

- **153 large-scale landslides** are selected from **3,763 sites** surveyed by CGS, Forestry Bureau, and SWBC.

(2010~2015)

Large Scale Landslide	Central Geological Survey	Forestry Bureau	SWCB	SUM
Analysis Frame	571	763	251	1,482
Sites	1,125	2,523	125	3,763
Potential areas (km^2)	413.86	789.30	49.62	1,178.01



Risk Assessment of 153 Large-scale Potential Landslide

Risk ＝ Hazard X Vulnerability

Risk degree ＝ Occurrence degree X Protected targets

Occurrence Degree (Weights of evidence)

- **8 Factors**: Aspect, Slope, Vegetation(NDVI), Rock mass strength, Dip slope degree, Elevation, Distance of river, Distance of geological structure

Protected Targets

- Buildings
- Transportation facilities
- Important infrastructures
- Water storage range of reservoir

Risk Degree (153 sites)		Occurrence degree: Low	Occurrence degree: Mid	Occurrence degree: High
Protected Targets	Low	Low	Low	Mid
	Mid	Low	Mid	High
	High	Mid	High	High

Multi-scale Monitoring of Large-scale Potential Landslide Areas

Risk Degree

Risk Degree	Observation	Methods
High Risk	On-site Detailed Observation	• Geophysical exploration • Geological survey • Geological boring • Ground water • Surface and Underground displacement
Middle Risk	Surface Displacement Observation	• Single frequency GPS • Extensometer • Rain gauge
Low Risk	Long-term extensive Observation	• TCP-InSAR Techniques Extensive Observation

TCP InSAR for Large-scale Potential Landslide Monitoring

Temporarily Coherence Point(TCP) Interferometric Synthetic Aperture Radar(InSAR)

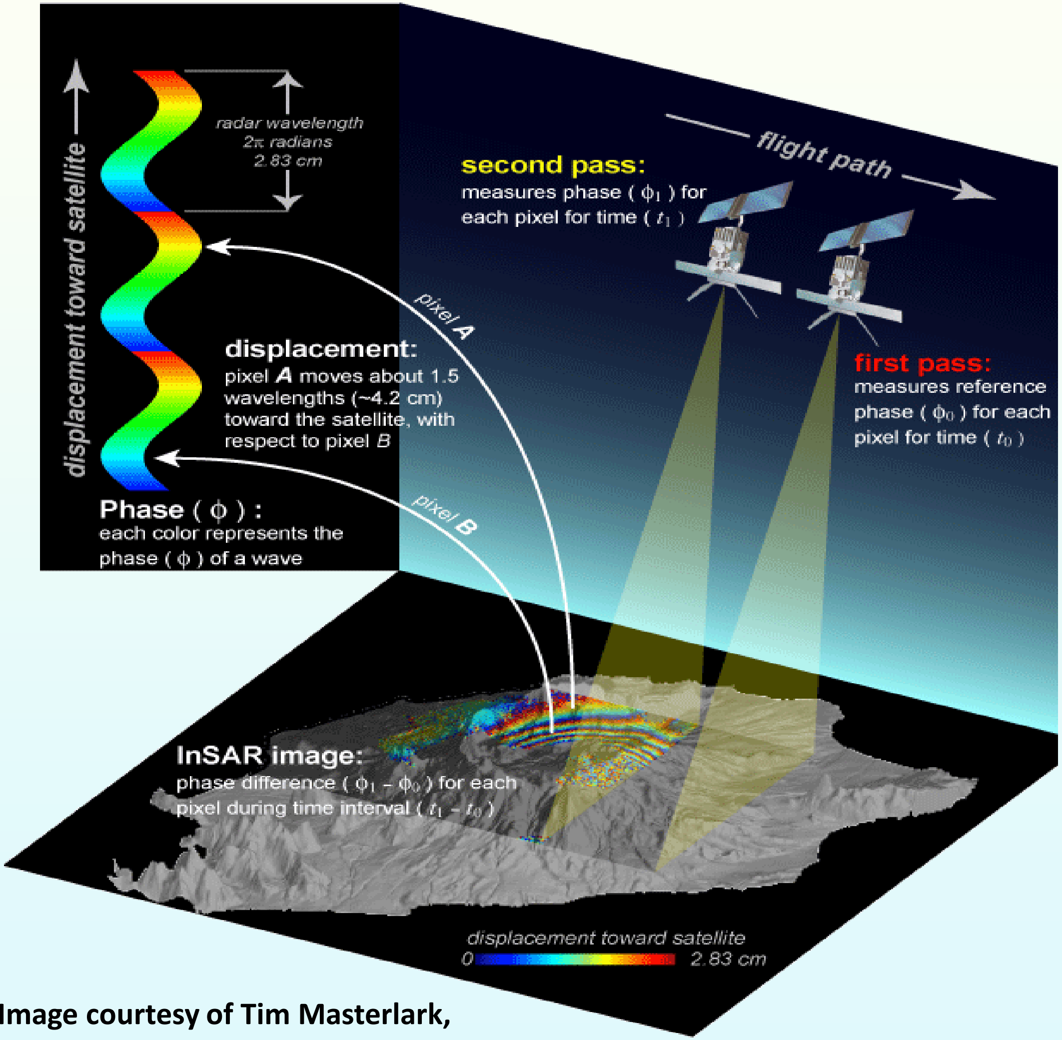


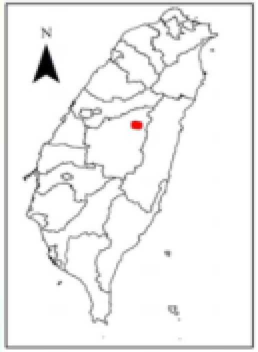
Image courtesy of Tim Masterlark, UW-Madison Ph.D. almunus

TCP InSAR technology has been proven very useful in assessing remotely ground displacements.
It is a fast and economic approach to evaluate the activity of large-scale potential landslide.

Advantages

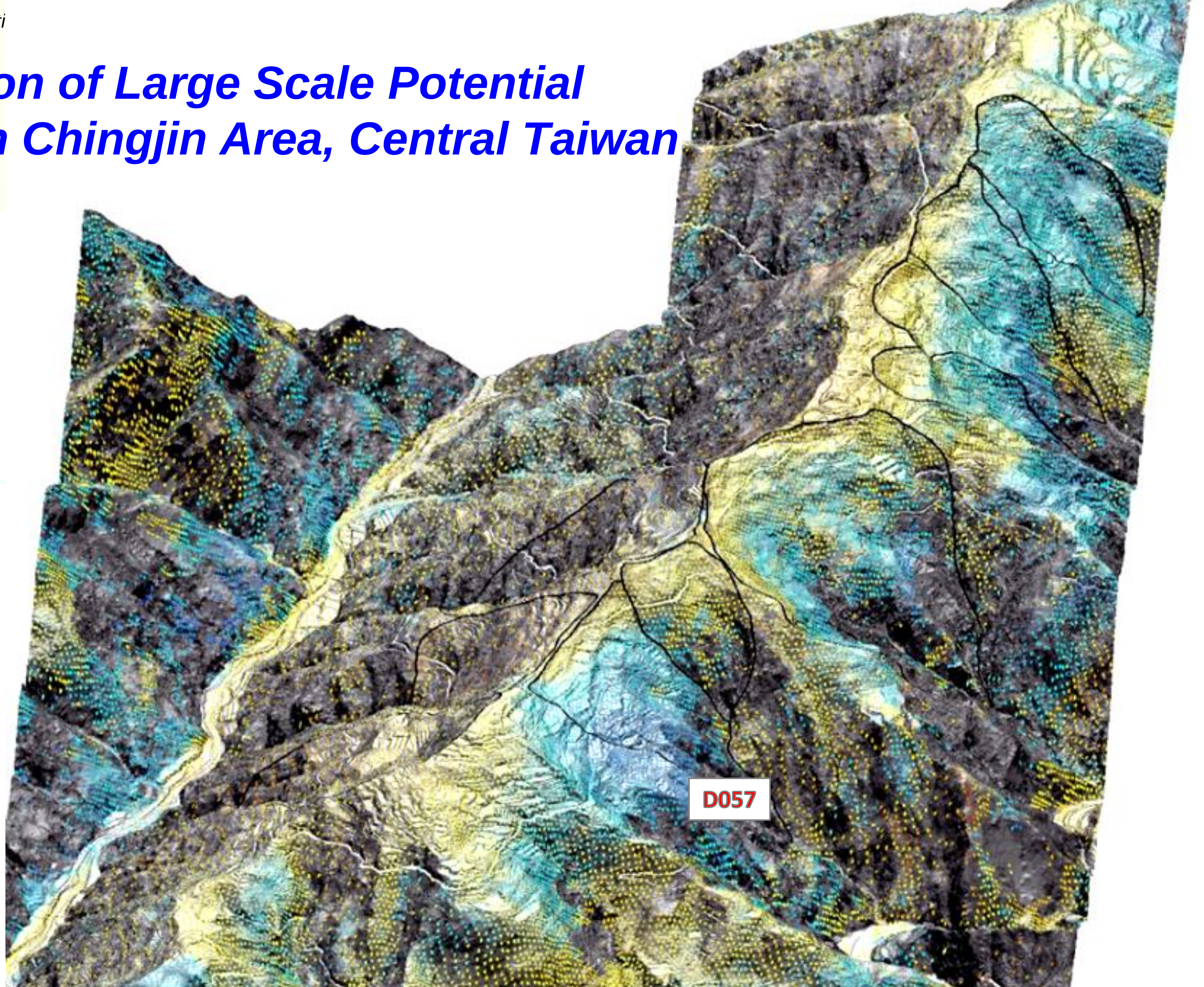
- ✓ ***All-day, all-weather***
- ✓ ***Wide range, spatial continuity***
- ✓ ***High precision surface deformation without ground instruments***

Detection of Large Scale Potential Landslide in Chingjin Area, Central Taiwan

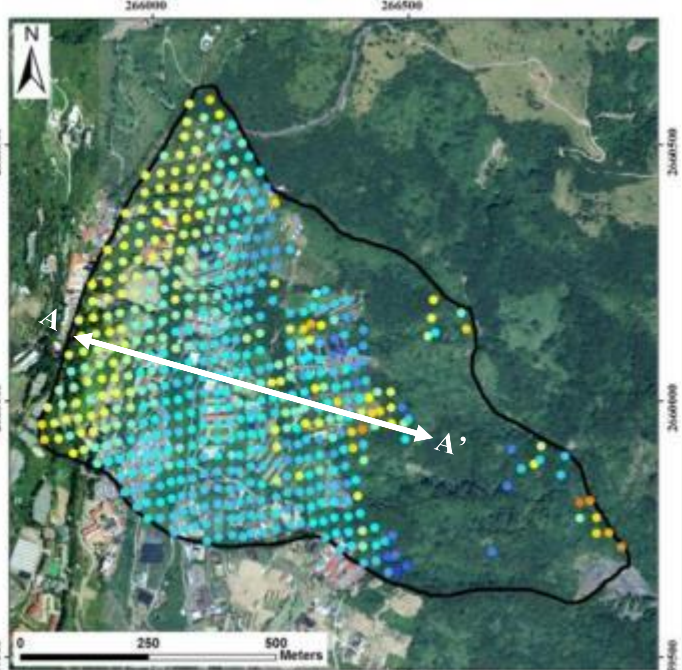


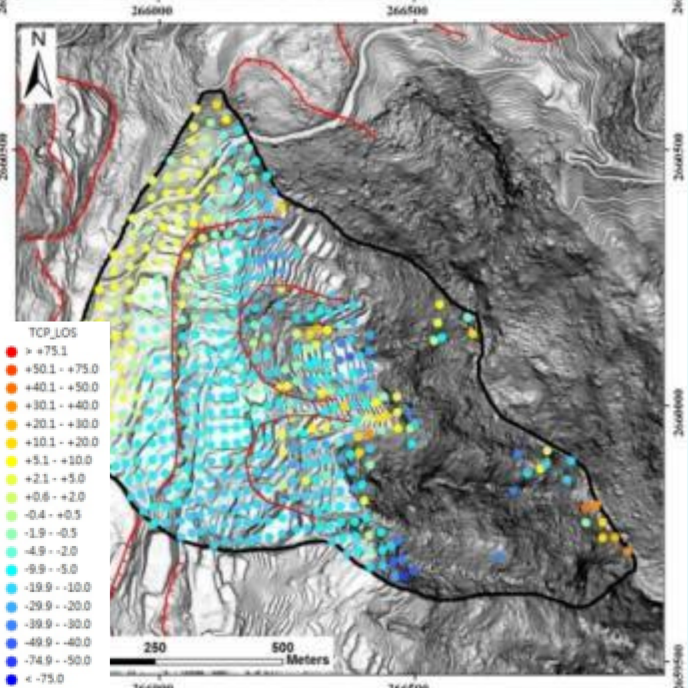
TCP_LOS (mm/yr)

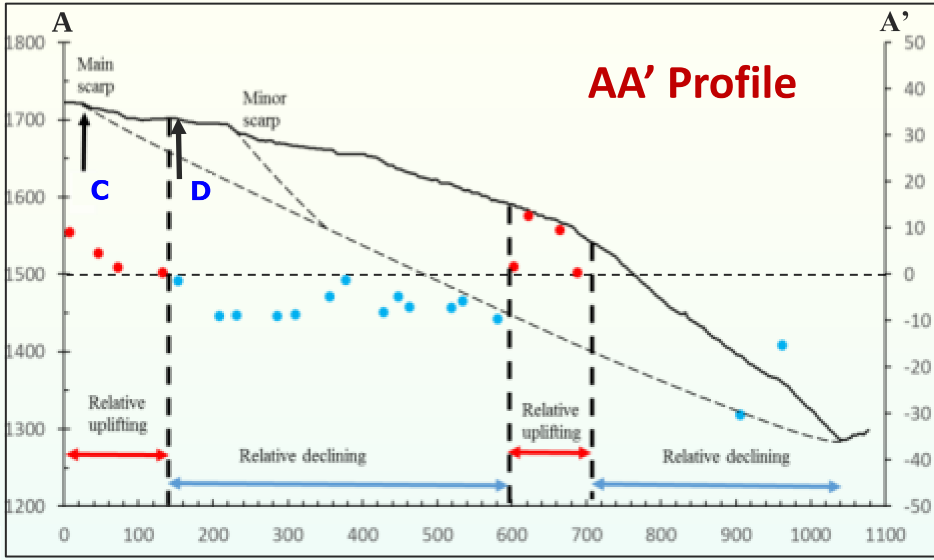
- > +75.1
- +50.1 - +75.0
- +40.1 - +50.0
- +30.1 - +40.0
- +20.1 - +30.0
- +10.1 - +20.0
- +5.1 - +10.0
- +2.1 - +5.0
- +0.6 - +2.0
- -0.4 - +0.5
- -1.9 - -0.5
- -4.9 - -2.0
- -9.9 - -5.0
- -19.9 - -10.0
- -29.9 - -20.0
- -39.9 - -30.0
- -49.9 - -40.0
- -74.9 - -50.0
- < -75.0



D057 (Rotational Sliding)







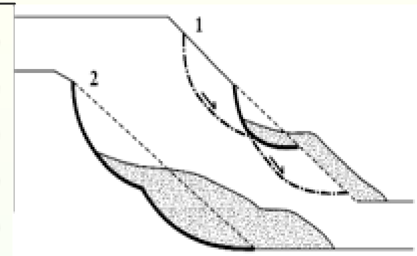


Image Source: Cooper, R.G. (2007)

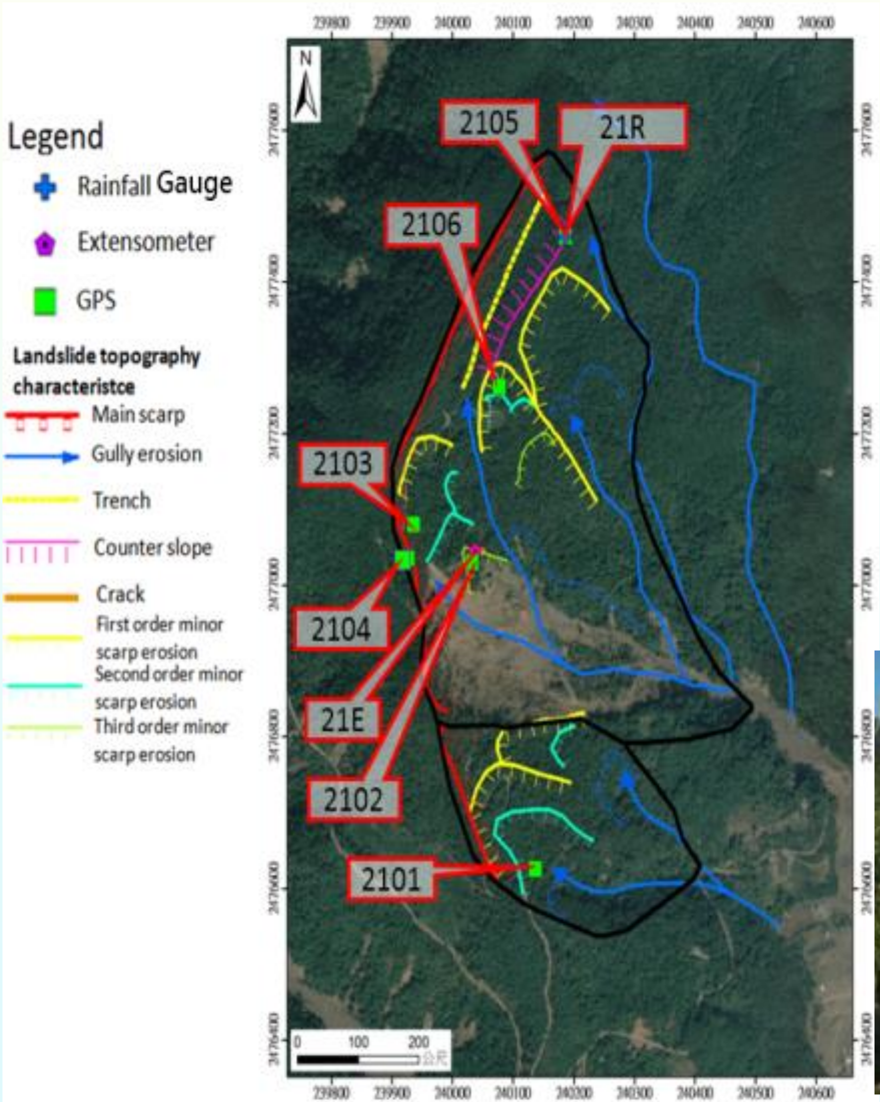
C: Main scarp

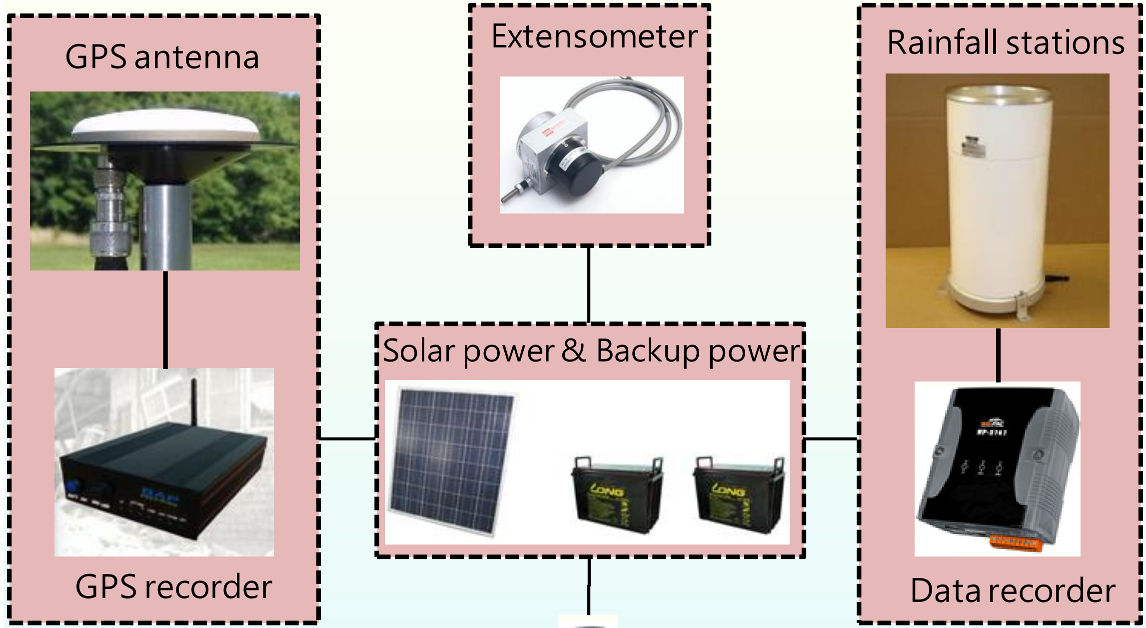
D: Extension crack

Middle Risk

Surface Displacement Monitoring System

6 single frequency GPS stations, 1 rain gauge, and 1 extensometer





GPS Monitoring Example in Sulin, New Taipei City

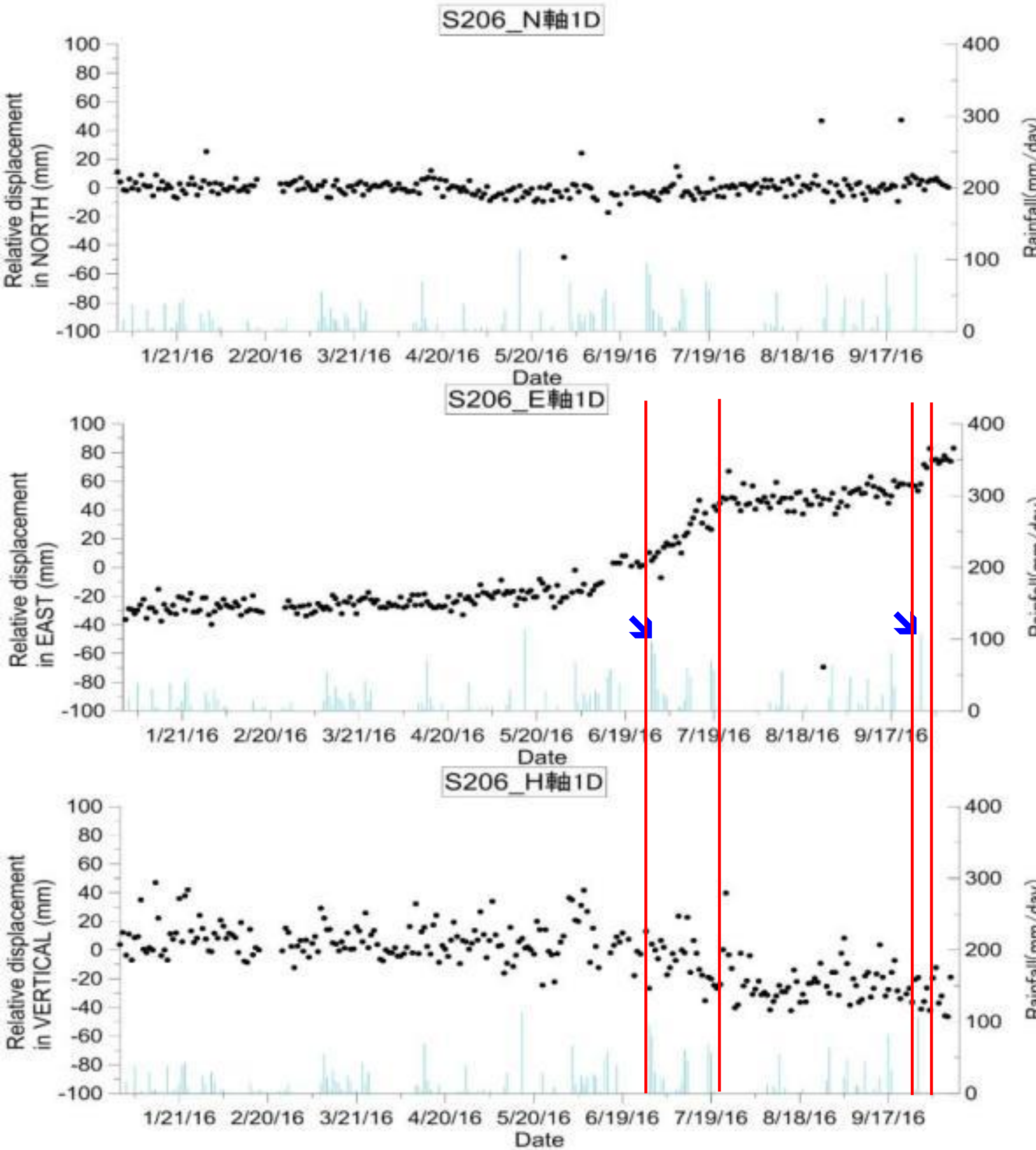
The figures show a very good correlation between landslide displacement and heavy rainfall.

June 19 - July 19, 2016, torrential rain

Eastward:70 mm, Downward:40 mm

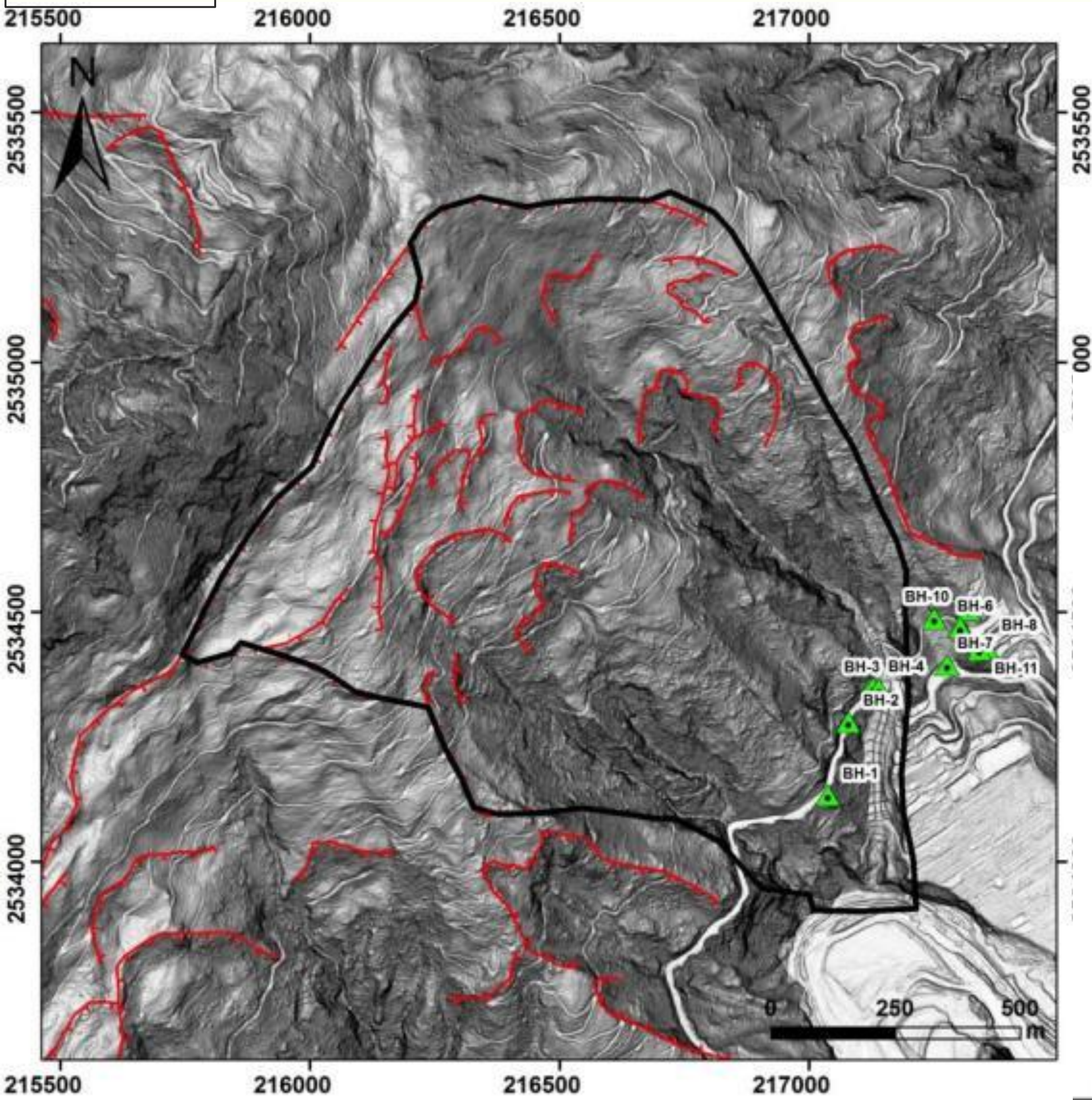
Sep. 25 - 28, 2016, typhoon Megi

Eastward:20 mm, Downward:15 mm



High Risk

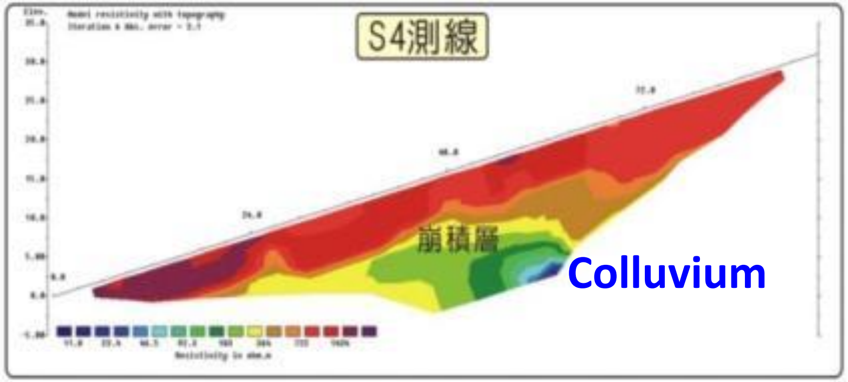
On-site Detailed Observation in Wanshan, Kaohsiung City

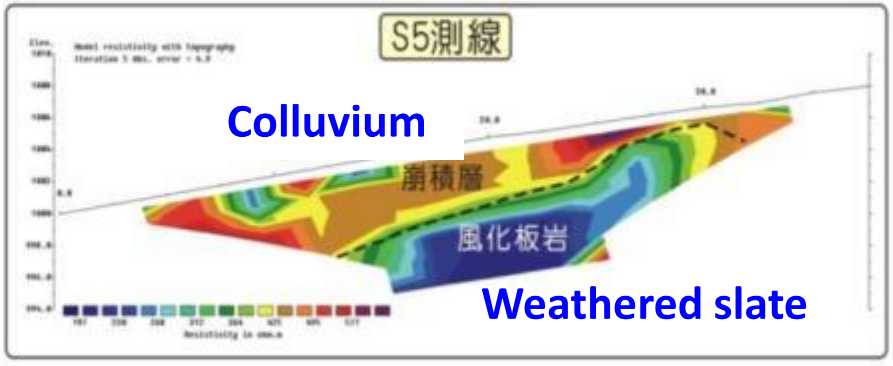


Geophysical exploration-

Electrical Resistivity Survey

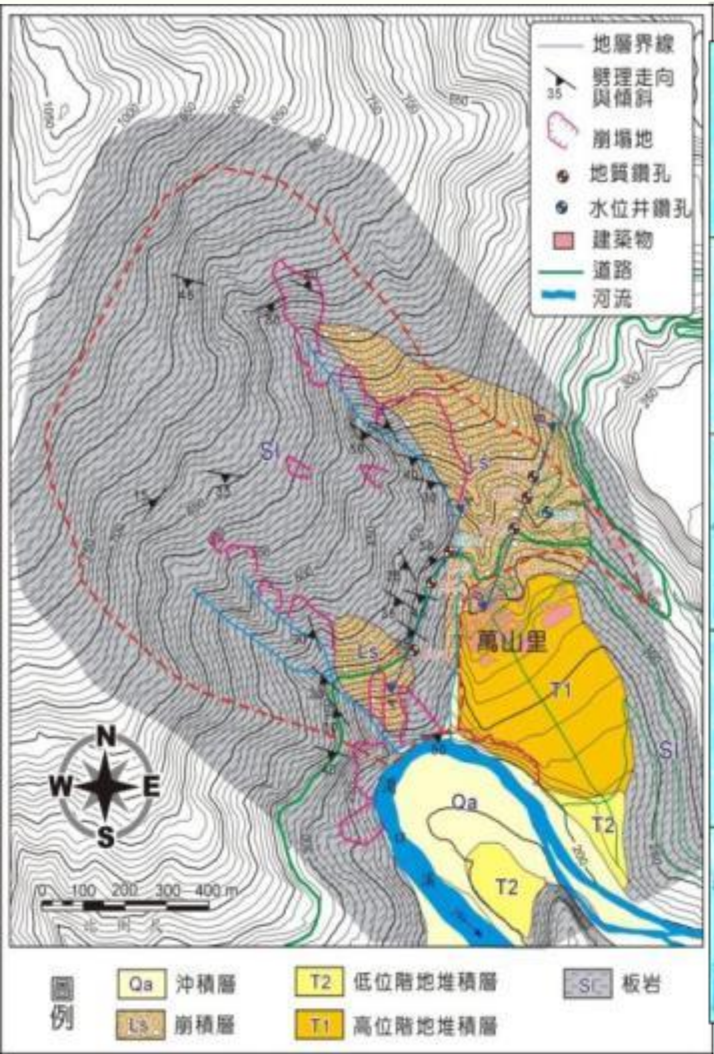
Comparing the resistivity profile with geo-drilling data for stratum cross section.





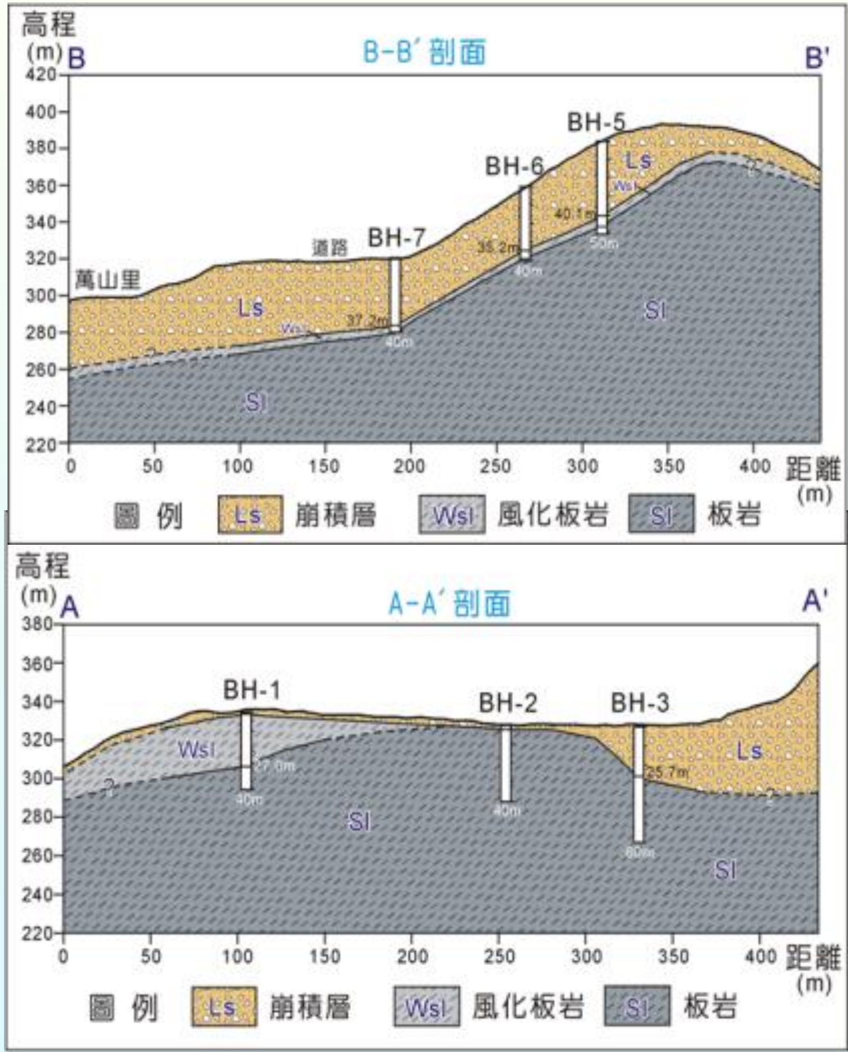
Different On-site Detailed Observation Techniques

Geological Investigation

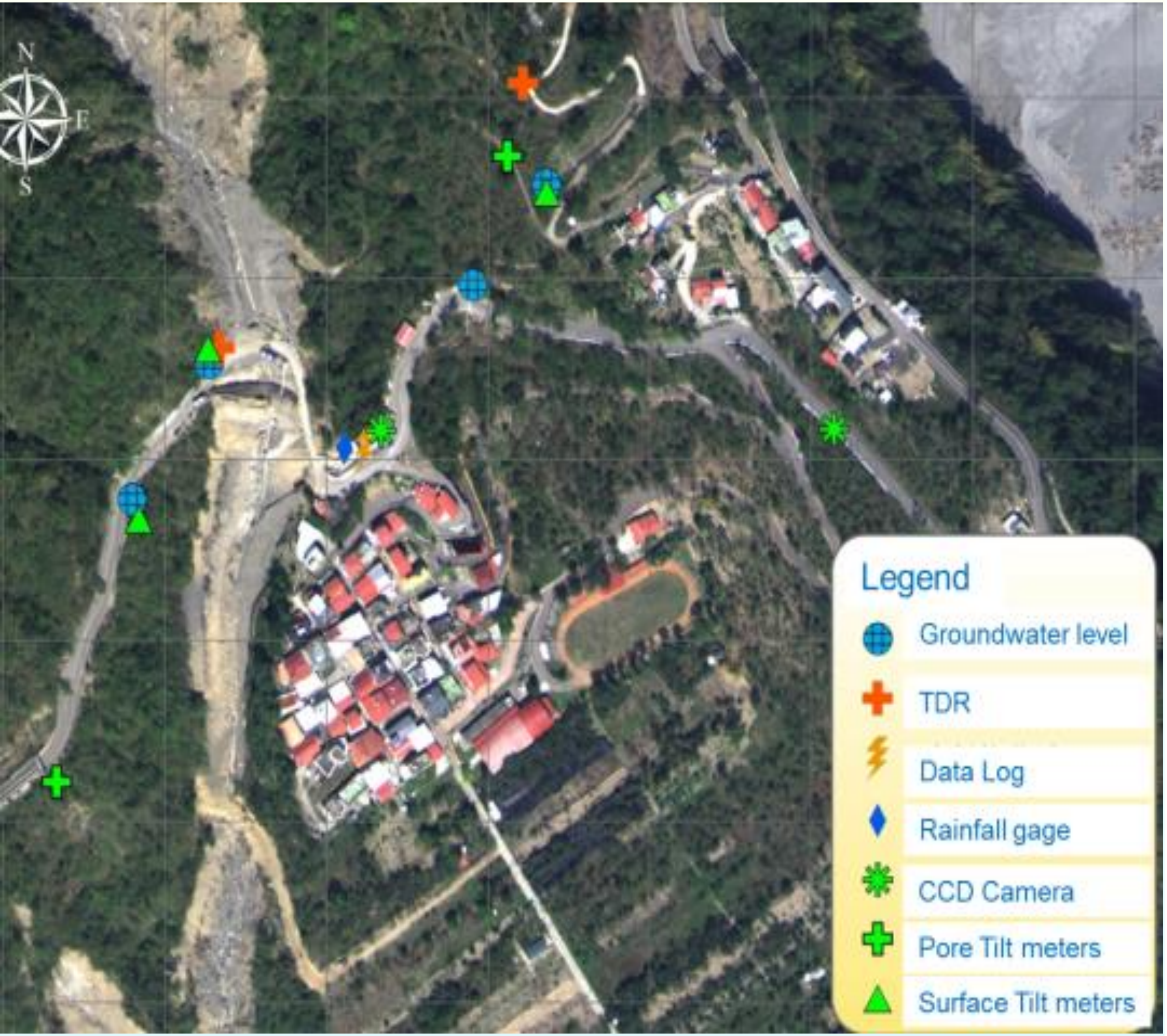


Boring core

Geological profile



Deployment of On-site Monitoring Sensors



Monitoring Items	*Number Frequency*
1. Rainfall	1 point Every 5 minutes
2. Groundwater level	3 points Every 5 minutes
3. Surface tilt	3 points Every 5 minutes
4. TDR	1 point Every 5 minutes
5. CCD camera	2 points Every 1 minutes
6. Water inrush	1 point Every 5 minutes
7. Inclinometer	5 points, manual Every month
8. Surface displacement	10 points, manual Every month

3. Future Development and Conclusions

Influence Area of Large-Scale Landslide

Runout distance L_{max} can be derived from equivalent friction coefficient

$$f = \log\left(\frac{H}{L_{Max}}\right) = 0.624 - 0.157 \log V$$

(Scheidegger, 1973)

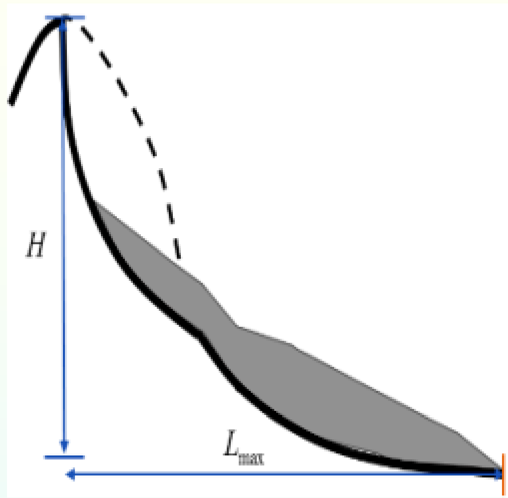
$$V = 0.1025 \times A_L^{\,1.401}$$

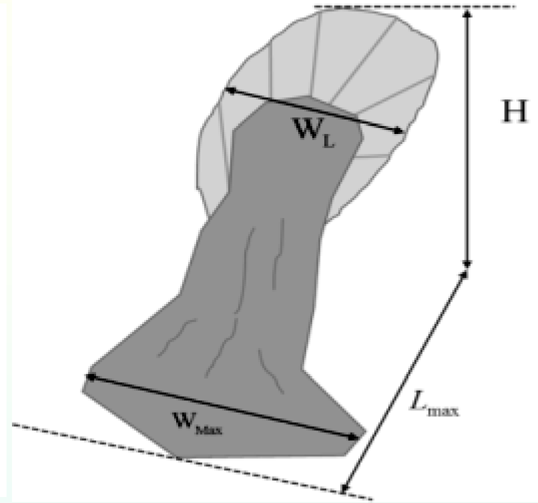
(Shieh et al, 2015)

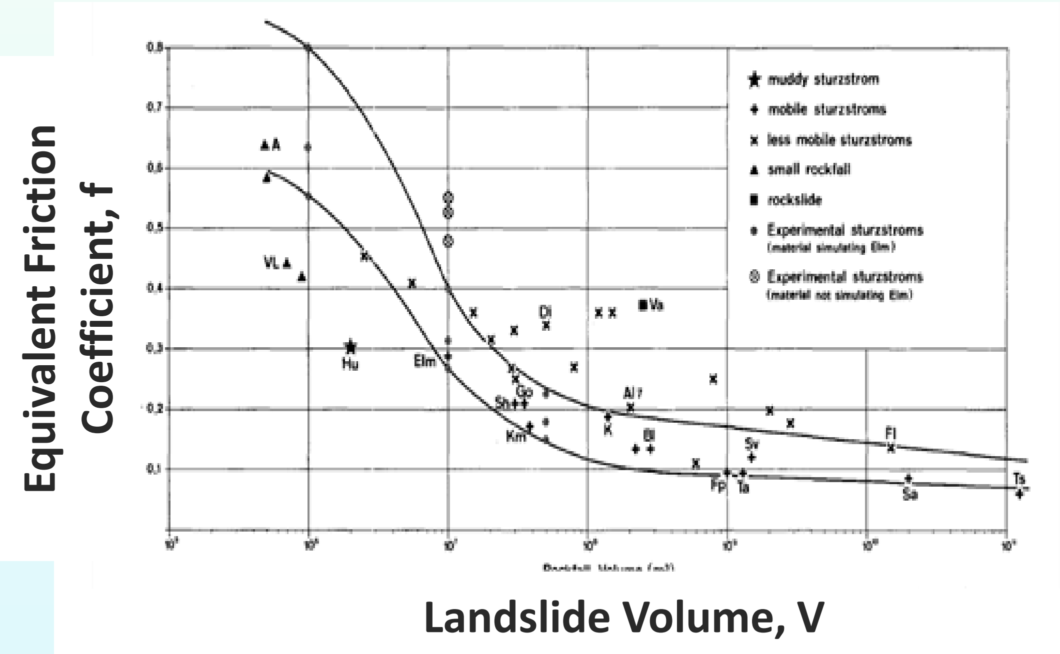
Deposit width W_{MAX} is about 1.5-2 times than that of landslide width

$$W_{Max} = 2W_L$$

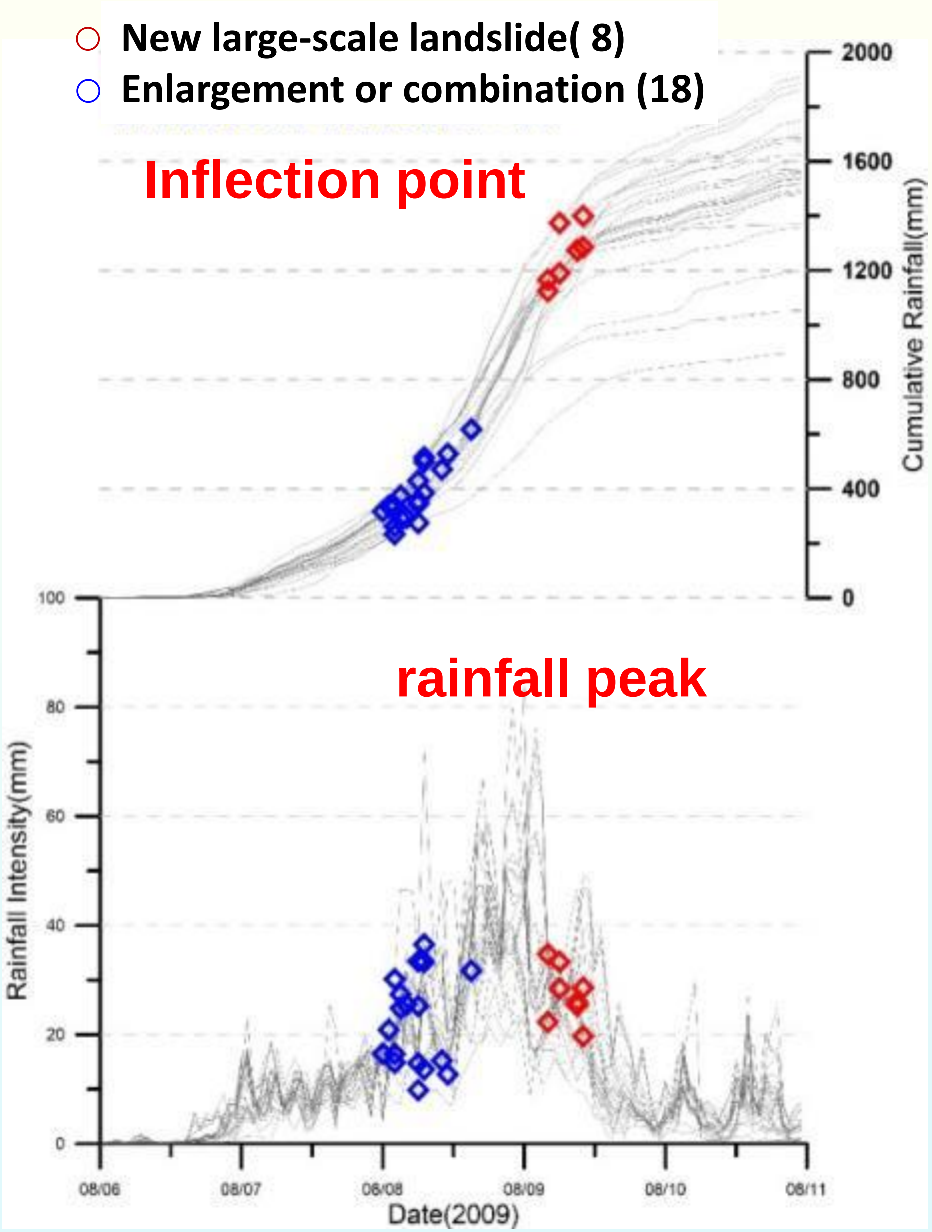
(Shieh et al, 2015)







Rainfall analysis of historic landslides events

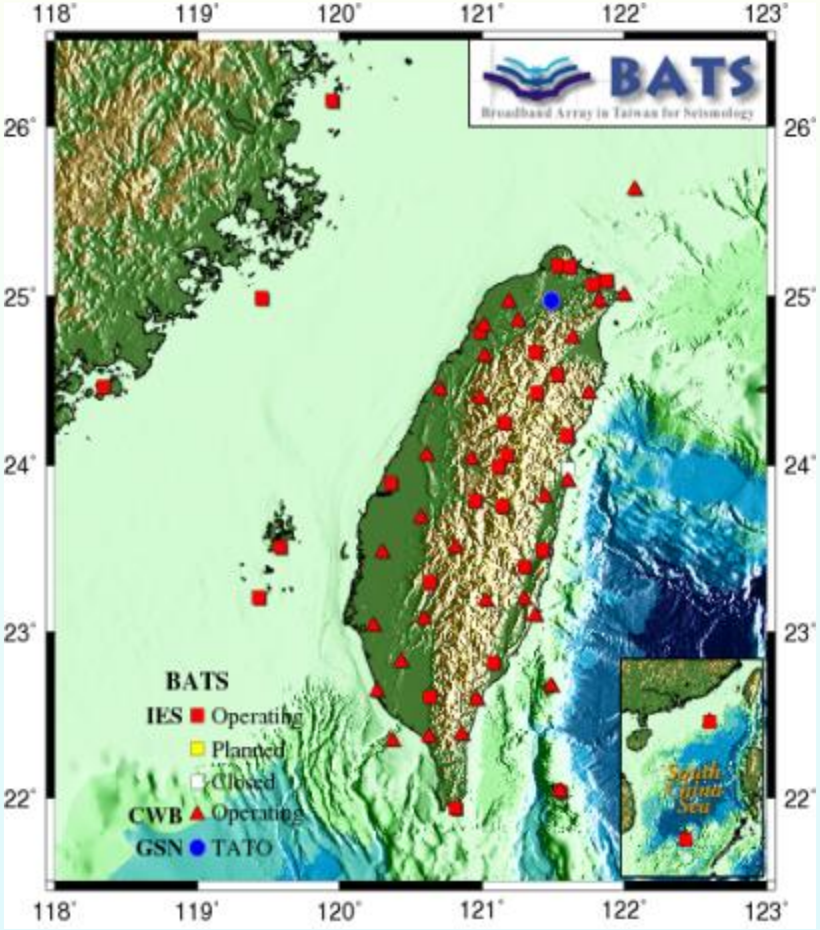


◆ **New large-scale landslide**
- **Accumulated rainfall ＞ 1000 mm**
- **From accumulated rainfall FIG Occurring times are near inflection point**
- **From rainfall hydrograph Landslides occurred after the peak**

◆ **Enlargement or combination**
- **Accumulated rainfall 200-600 mm**
- **From accumulated rainfall FIG Occurring times lie among the rising period**
- **From rainfall hydrograph Landslides occurred before or near the peak**

Application of Seismic Network on Landslide Detection

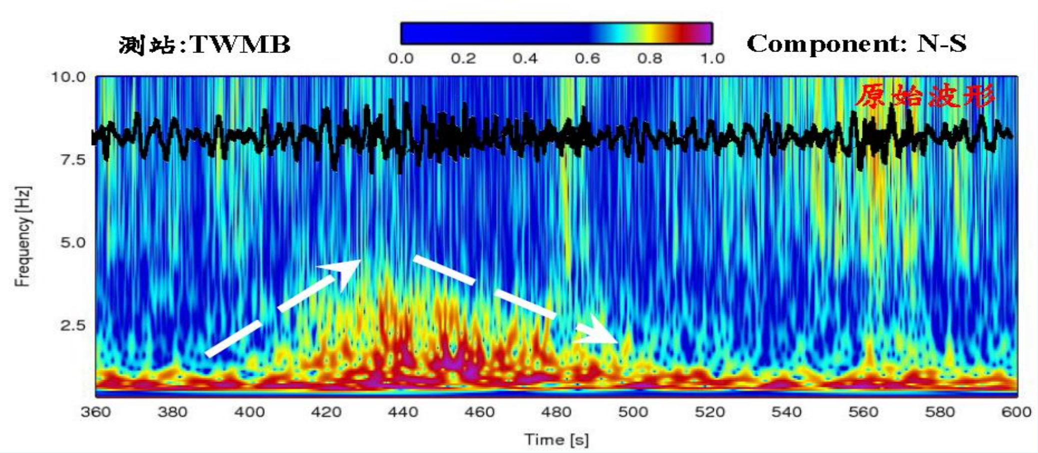
Broadband Array in Taiwan for Seismology, BATS



42 stations around Taiwan

Ground vibrations generated by landslide can be detected by seismometer.

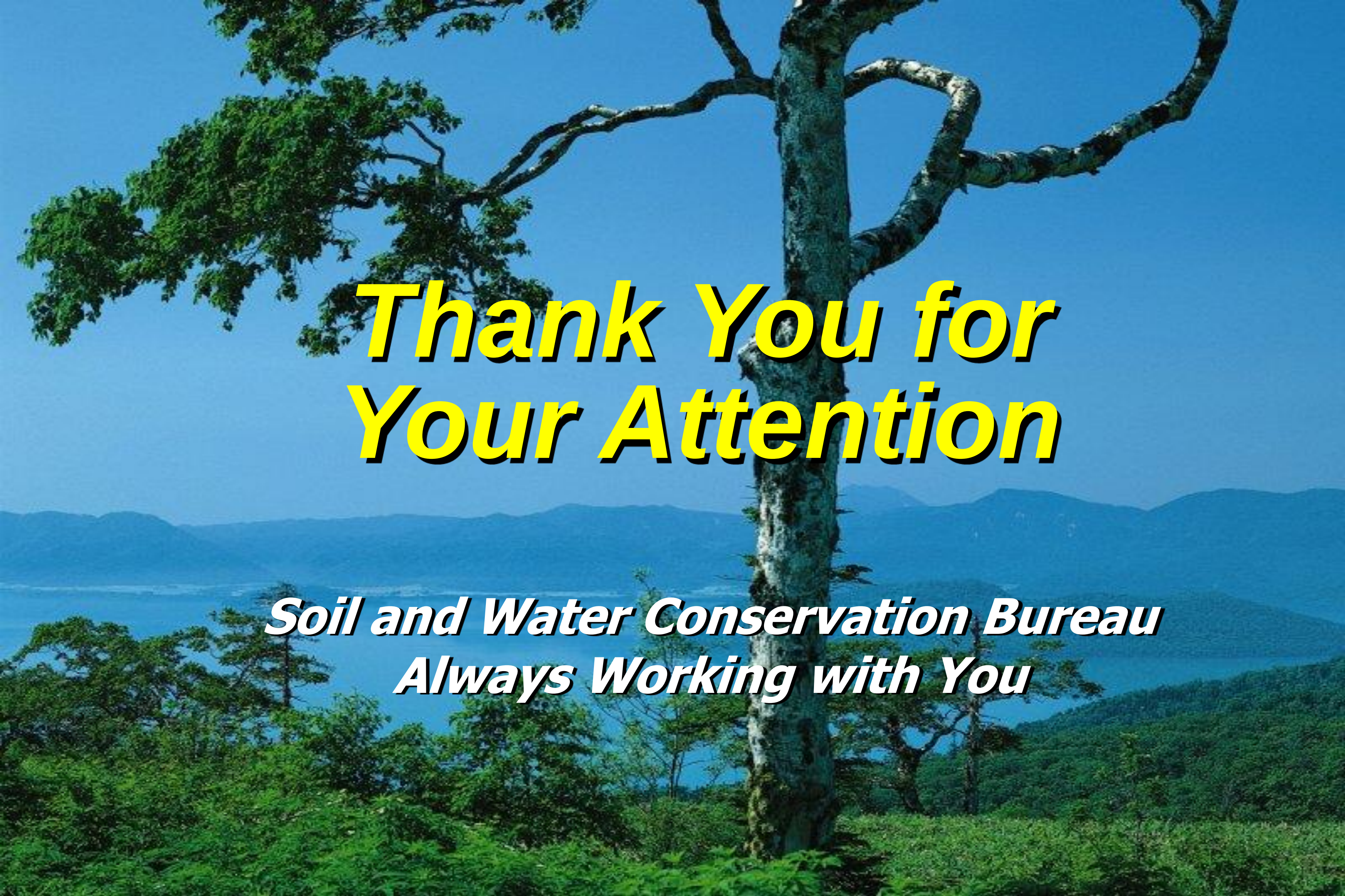
We try to acquire the initiation time of large-scale landslide through BATS.



Vibrations of Hsiaolin large-scale landslide

Conclusions

1. The prevention measures for debris flows disasters have been developed more than 15 years. The experiences could be the basis of developing a new mitigation strategy for large-scale landslide.
2. From the lessons of Hsiaolin village, the large-scale landslide has become a new challenge in the coming future of Taiwan which results in the brand new project-the comprehensive plan of large-scale landslide hazard mitigation under climate change impact. It might take another 10 years to fulfill all those tasks.
3. Different up-to-date techniques such as Lidar DEM, TCP InSAR, single frequency GPS system, traditional on-site detailed observation skills and BATS system should be integrated in order to mitigation the possible hazards of large scale landslides in the future.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