MOEA

Central Geological Survey

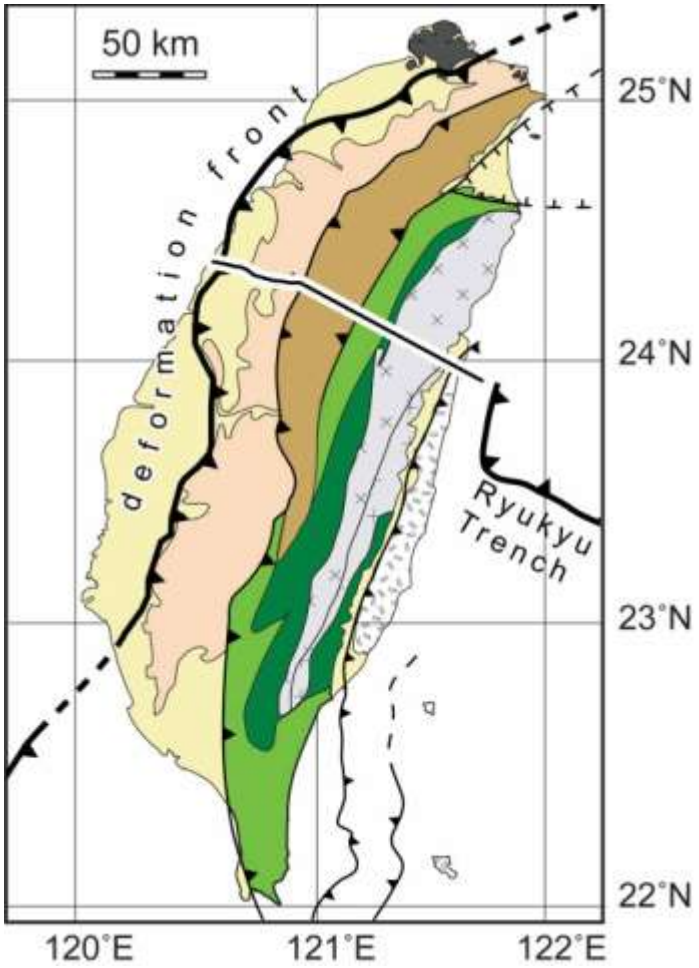
14th South East Asia Survey Congress (SEASC)
Brunei Darussalam in 2017

The Road from National LiDAR mapping program to Zonation of the Geologically Sensitive Areas in Taiwan

Li-Yuan FEI
feily@moeacgs.gov.tw

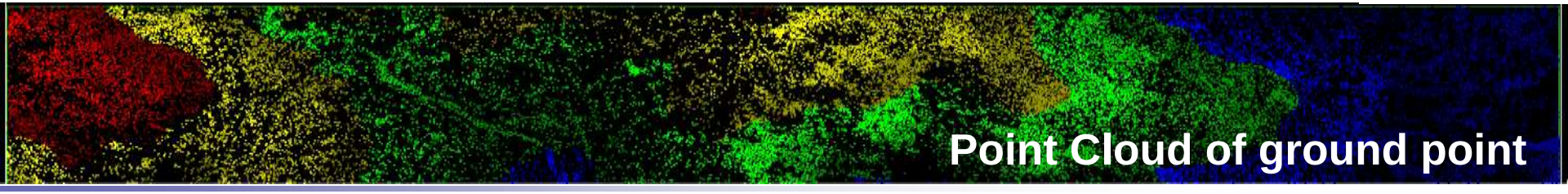
OUTLINE

1. Geography & Geology of Taiwan
2. Airborne LiDAR & Aerial photograph under the Program of National Land Preservation (2010- 2016)
3. DEM Data Applied in Zonation of the Geologically Sensitive Areas
4. Conclusion



orthoimage(2,503×485m)

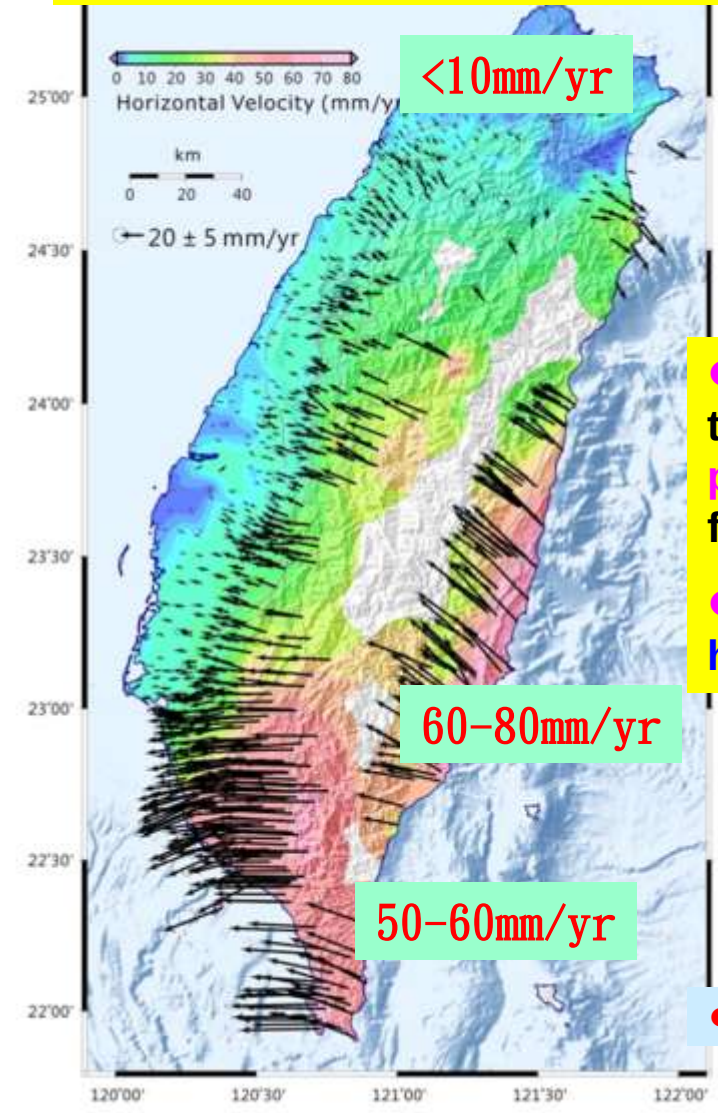
Geography & Geology of Taiwan



Point Cloud of ground point

Horizontal Displacement analyzed by GPS Data, from 2002 to 2011

＞33 Active Faults located in Taiwan



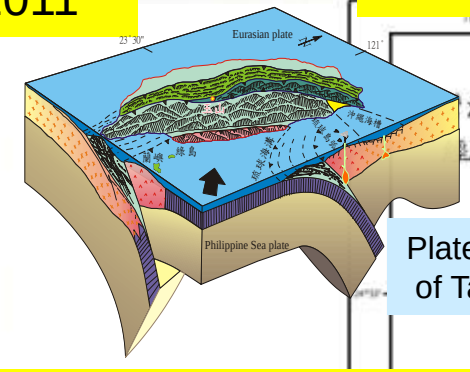
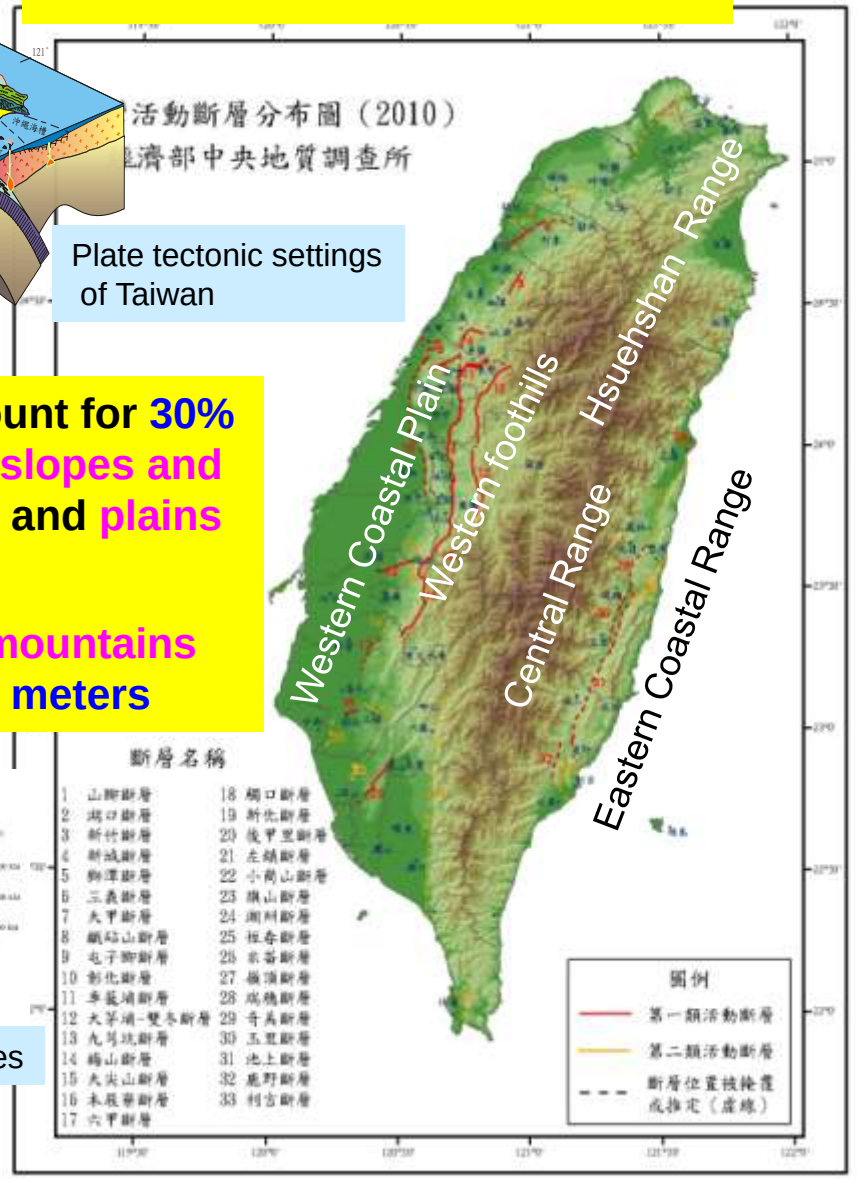
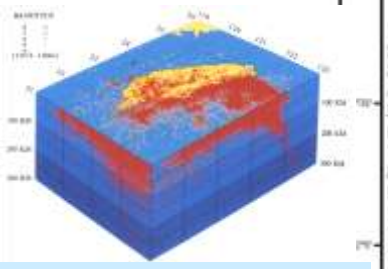


Plate tectonic settings of Taiwan

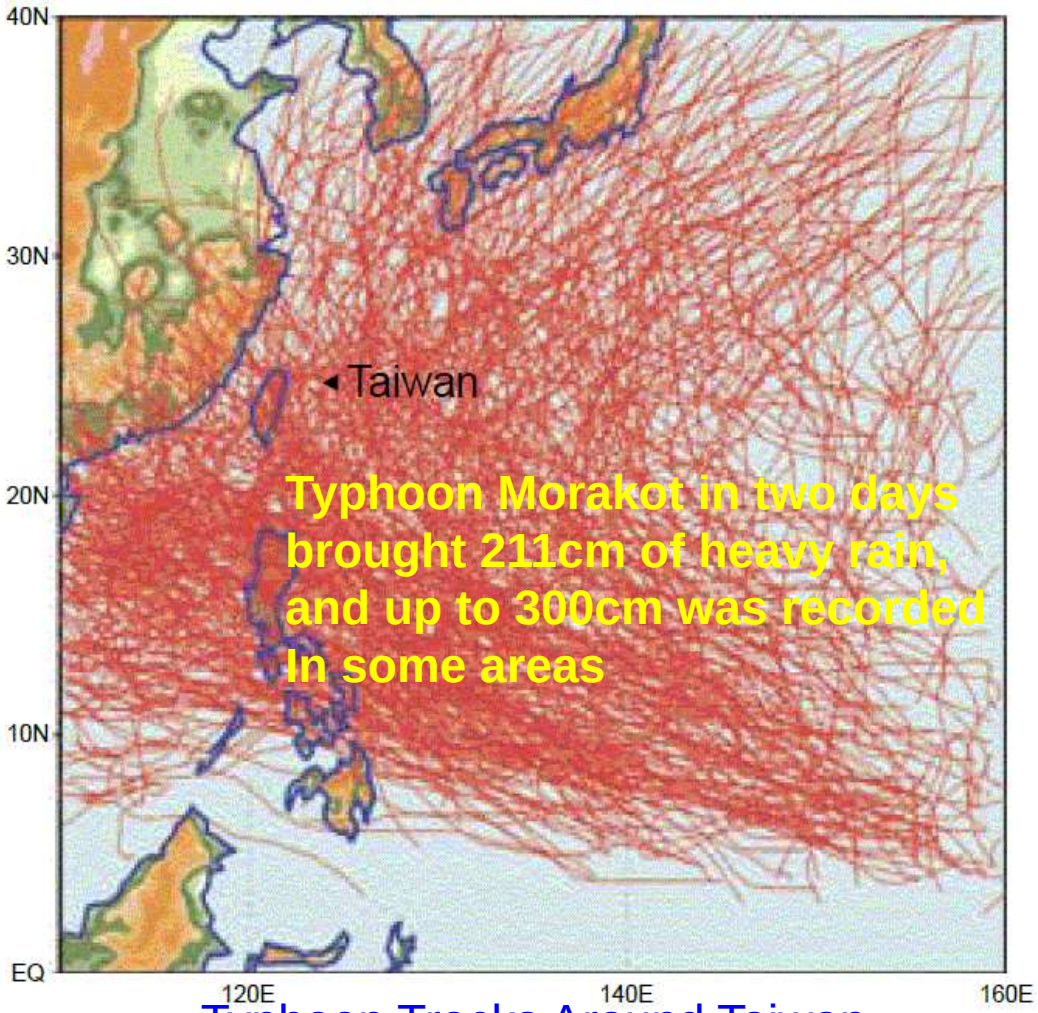


- **Mountains account for 30% the total area, hillslopes and plateaus for 40%, and plains for 30%**
- **more than 100 mountains higher than 3,000 meters**



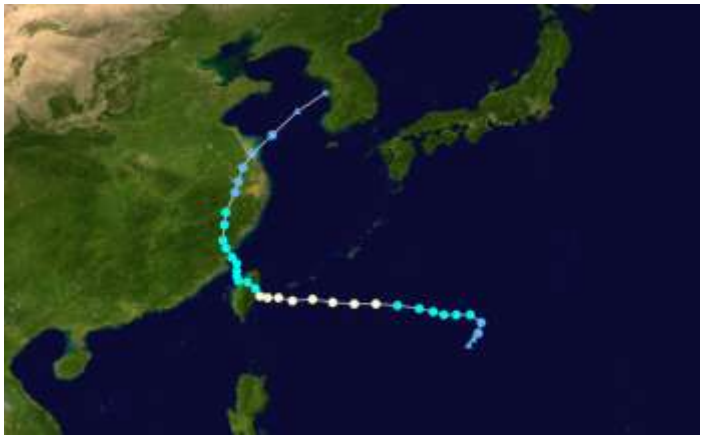
- focus of the earthquakes

Taiwan is located on the tracks of typhoons in northwest Pacific area

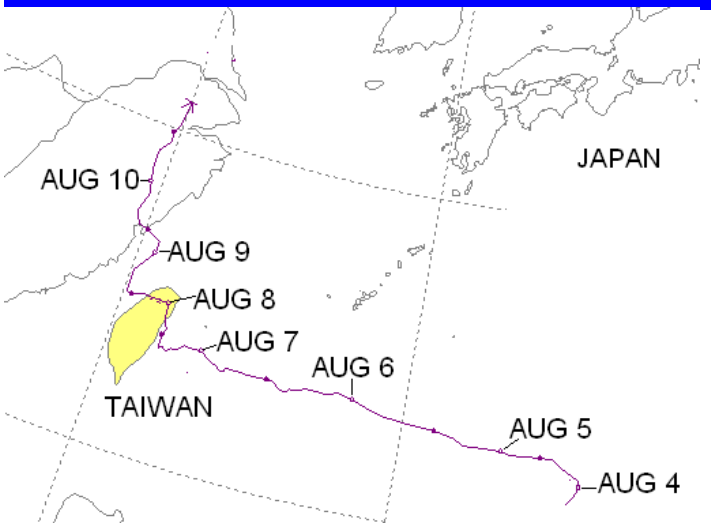


Typhoon Tracks Around Taiwan

(3.6 typhoons touched down in Taiwan every year)

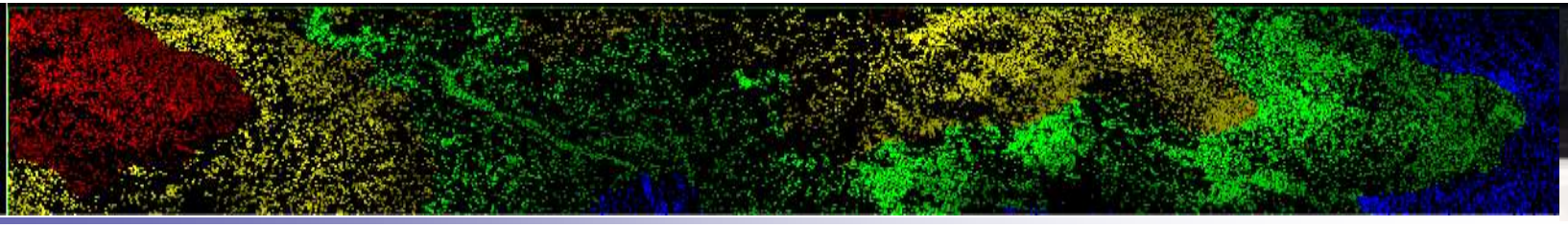


Track map of Typhoon Morakot



good lucks, good fortune and long life

Airborne LiDAR & Aerial photograph under the Program of National Land Preservation (2010- 2016)



Shiaolin Village suffered with 681 casualties, 18 people still unaccounted for, and the destruction of over 100 houses.

SINLAKU, JANGMI-(20080916-)
20081112-MS-1
20081220-MS-2
20081201-MS-3
20090114-MS-4
20081221-MS-5
20081203-MS-6
20081207-MS-6
20081204-MS-7
圖例 LEGEND
裸露區域
行政區界

N

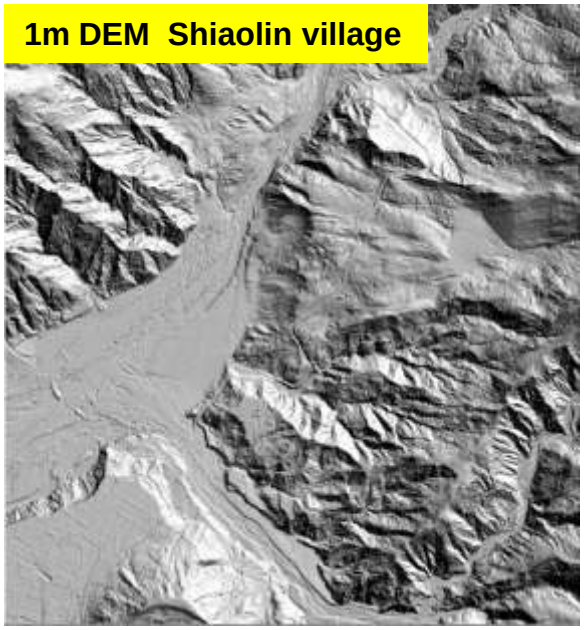
FORMOSAT-II IMAGE
LEVEL 4 MS
RGB BANDS: 4-1-2

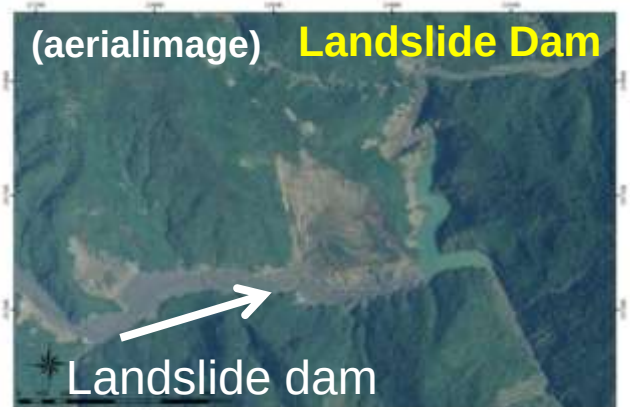
Landslides estimatd：
40,594 in the southern Taiwan
Bare surface area ＞ 30,000 ha

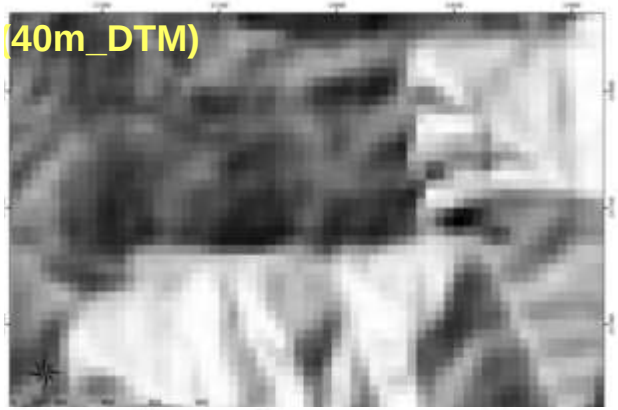
Bare surface (before & after) Typhoon Morakot

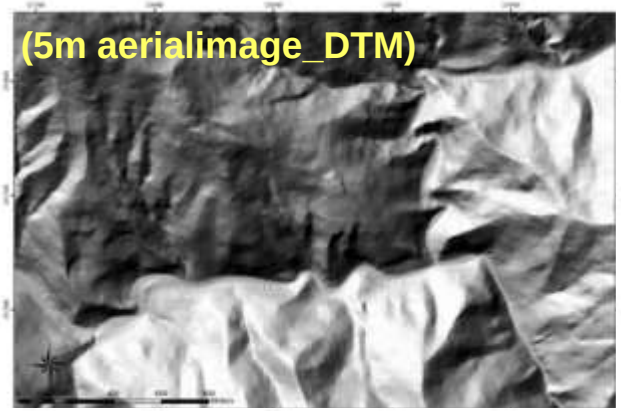
5m DEM Shiaolin village

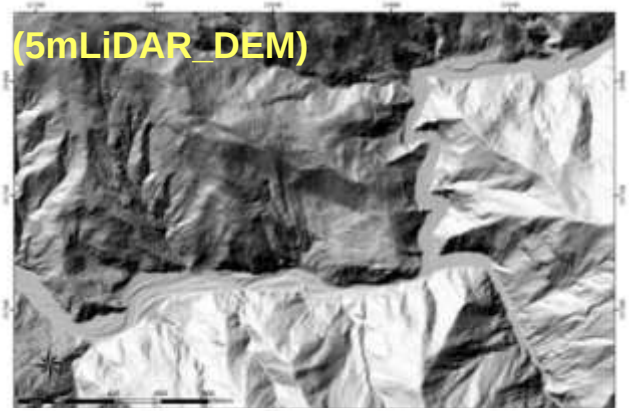
1m DEM Shiaolin village

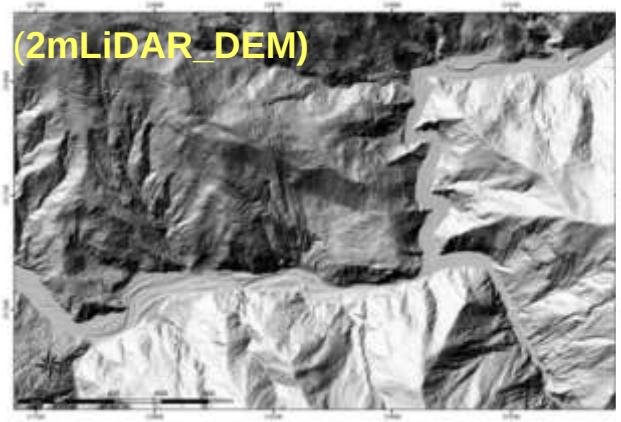


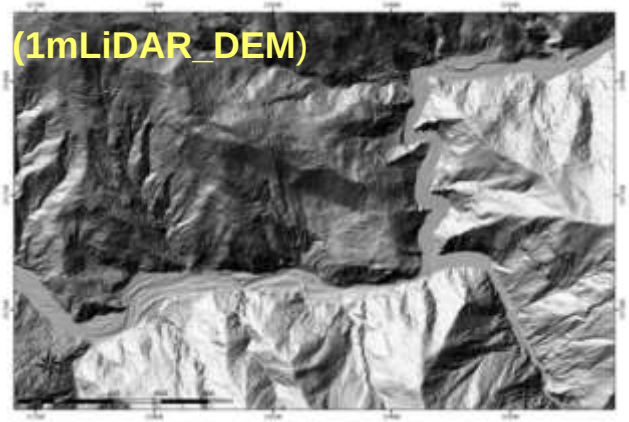




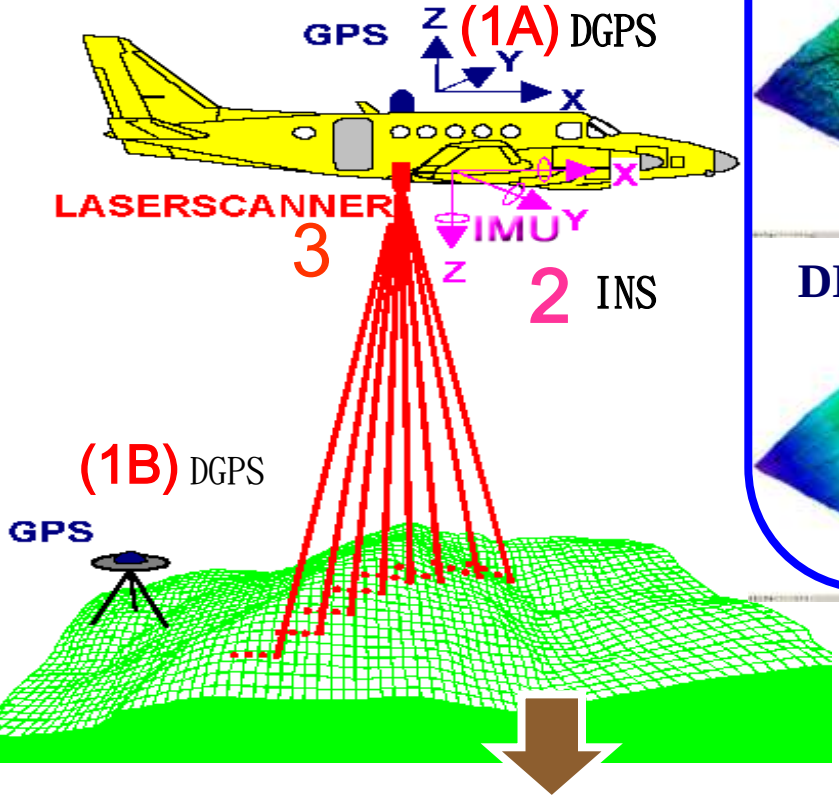


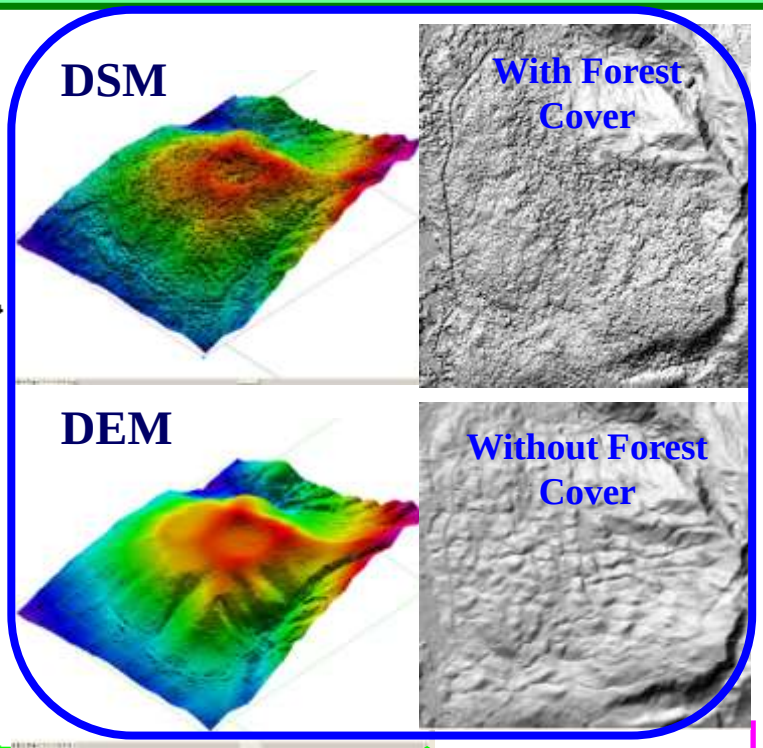


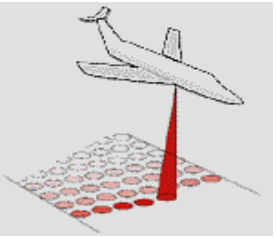




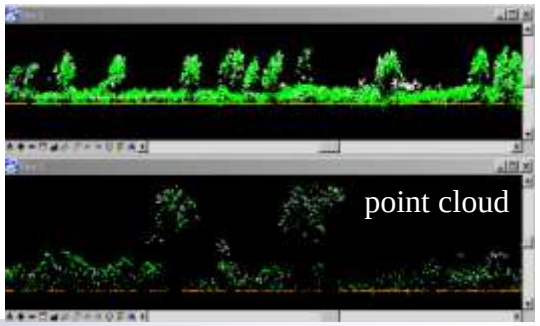
Airborne LiDAR(Airborne Light Detection And Ranging)

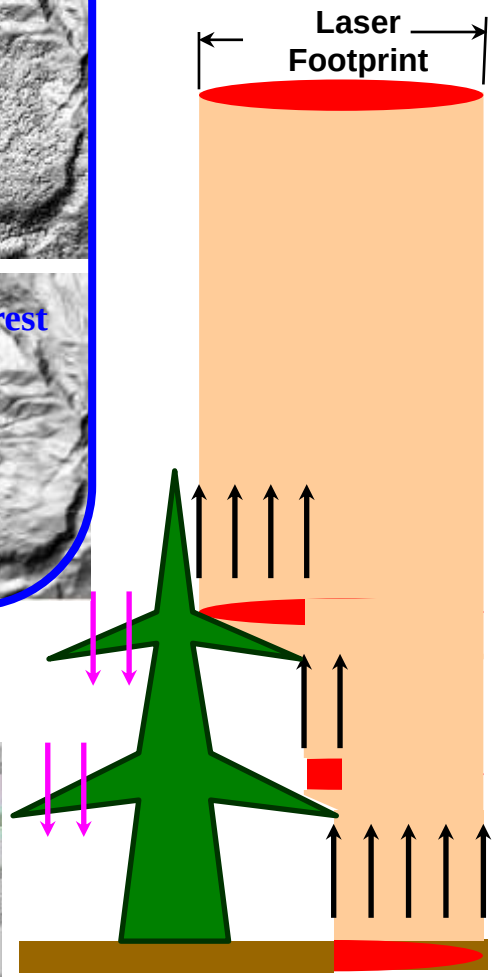






1. GPS(on plane & ground)
2. Inertial Navigation System
3. Laserscanner
4. Digital Camera





Penetration & Reflection

Project of Investigation and Analysis for Geologically Sensitive Areas under the Program of National Land Preservation (2010- 2016)

The High Resolution LiDAR DEM & DSM of 1 m grid and digital aerial photograph of 50cm grid Generation

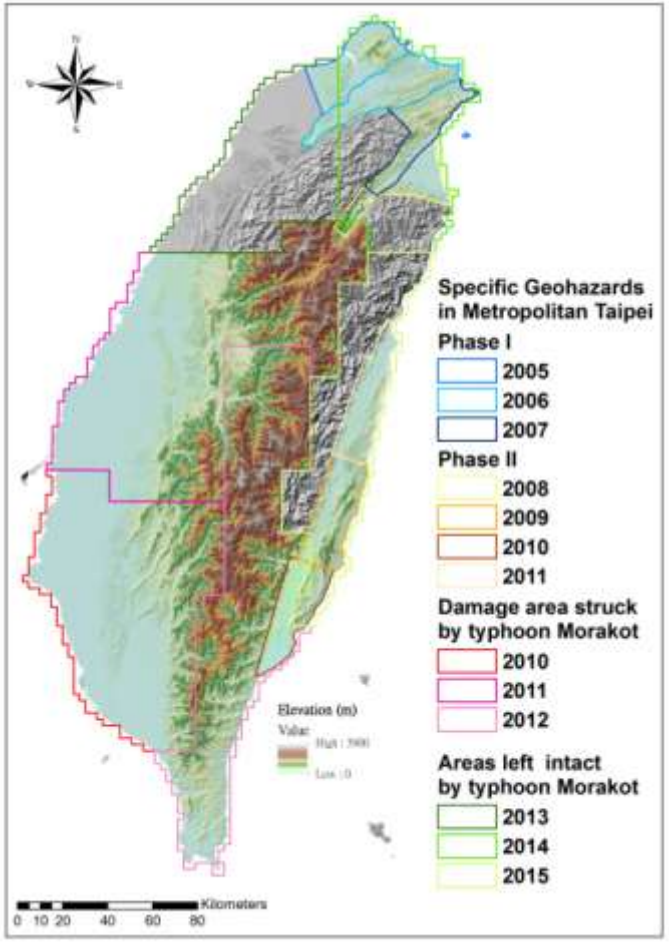
The High Resolution LiDAR DEM & DSM Data QA/QC by quality assurance team

Result : (1)DEM , (2)DSM and (3)Orthoimage

(1) Geological sensitive areas
(2) Potential geohazard analysis

With Airborne-LiDAR data and orthoimage, to investigate and analyze geologically sensitive areas, geological and topographical characteristics, river system analysis etc.

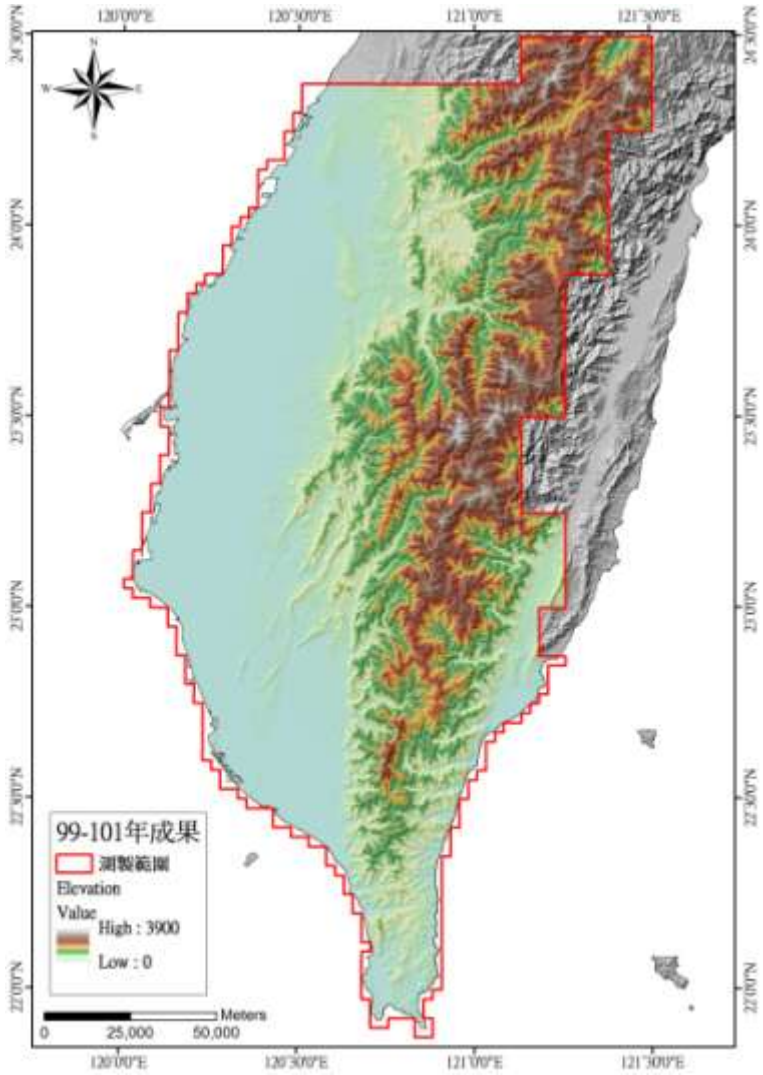
Project of Investigation and Analysis for Geologically Sensitive Areas under the Program of National Land Preservation



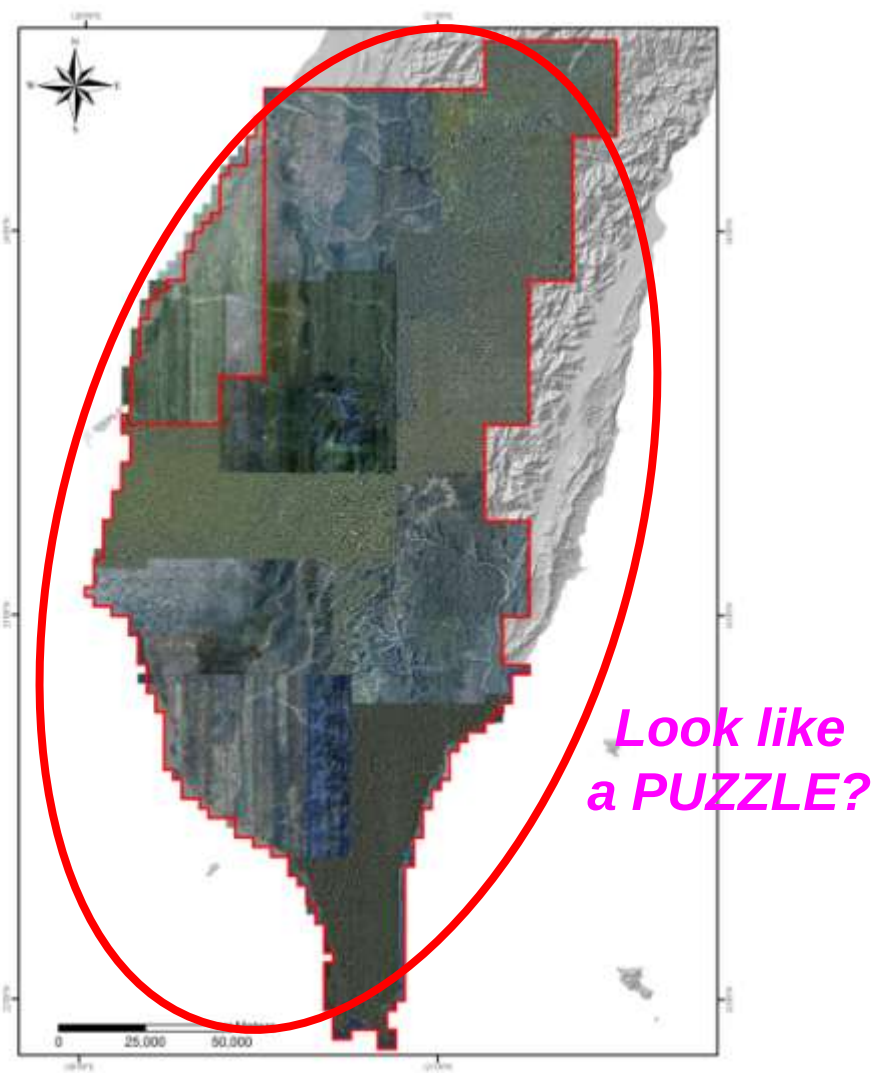
Year	Area(km^2)	Mapsheet (1/5,000)	
2013	3,663	527 maps	4-1 : 117
			4-2 : 137
			4-3 : 136
			4-4 : 137
2014	4,778	680 maps	5-1 : 170
			5-2 : 170
			5-3 : 170
			5-4 : 170
2015 (2016)	4,778	680 maps	6-1 : 170
			6-2 : 170
			6-3 : 170
			6-4 : 170
Total	13,219	1,887 maps	
2010-2016	38,115	5,517 maps	

Budget :
Total : US$ 30 millions
Ave: US$ 840 dollars/km^2

Results of 2010 - 2012

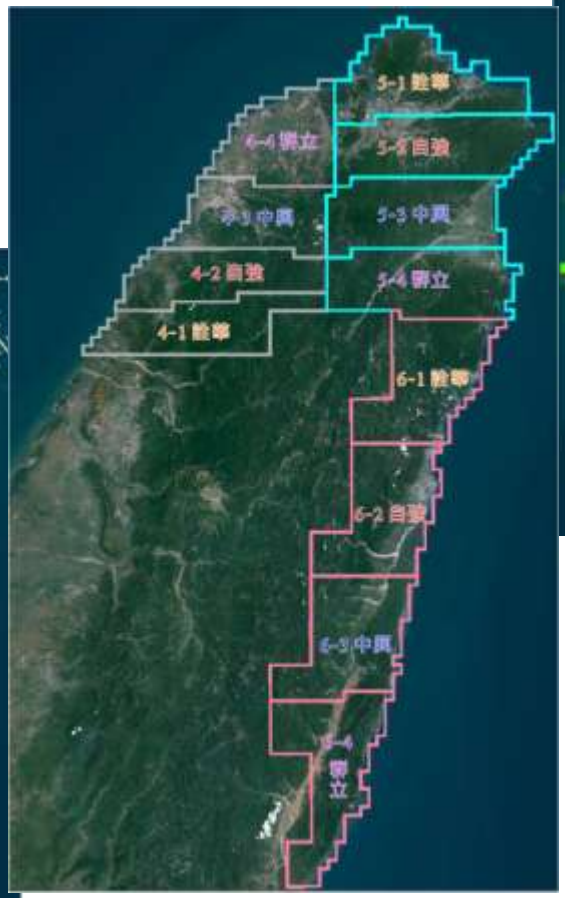


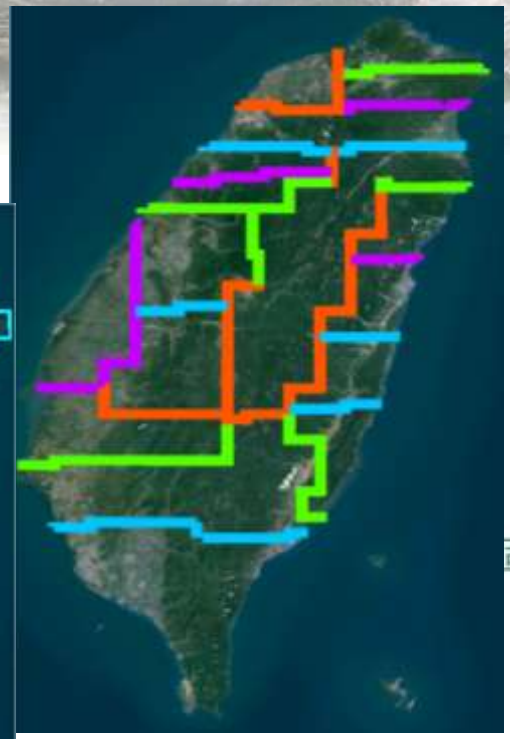
DEM

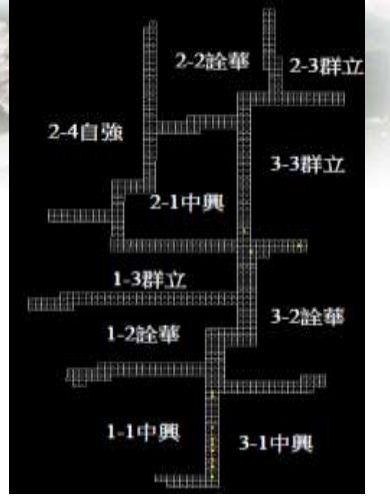


Look like a PUZZLE?

Orthoimage







Totally divided into
52 subareas in Taiwan

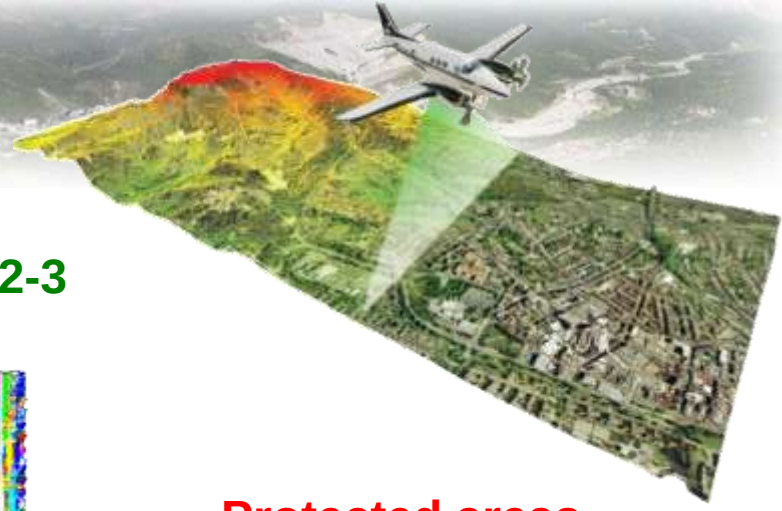
Variety of **LiDAR & Aerial Photograph** equipments from different contractors

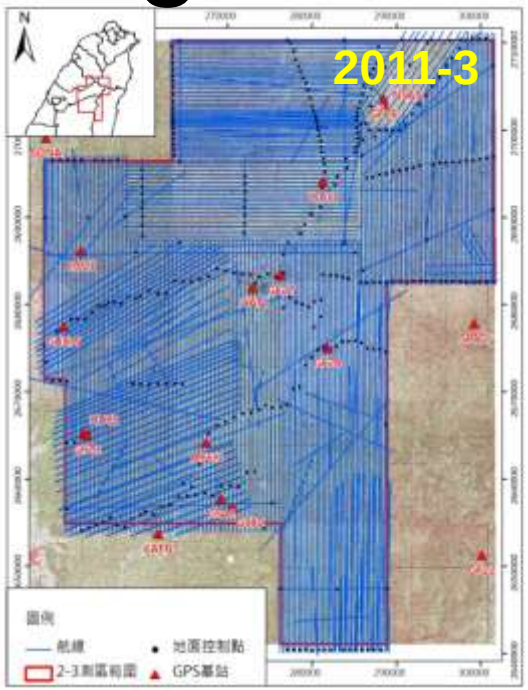
Different software and hardware equipment
(with different advantages and know how)

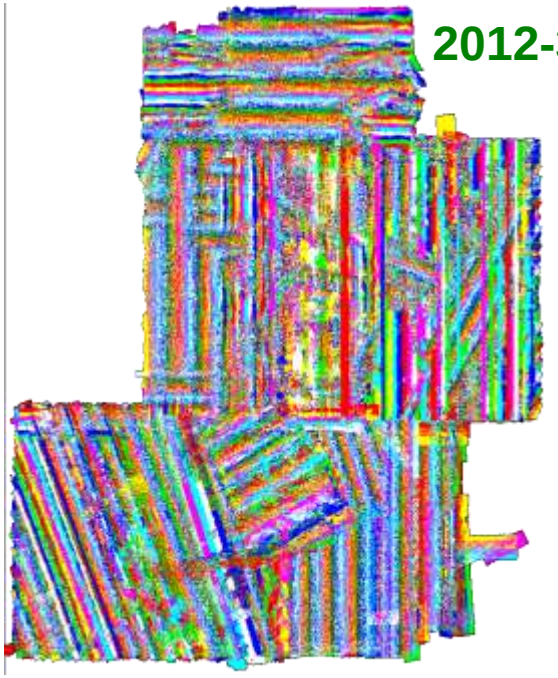
Company	Equipment	Model
ST (Strong Engineering Consulting Co., Ltd.)	Airborne-LiDAR Scanning	Riegl LMS-Q680i
	Digital camera	IGI DigiCAM、P65+
	POS System	Trimble 4700、Trimble 5700 Leica SR530
RW (Real World Engineering Consultants Inc.)	Airborne-LiDAR Scanning	Leica ALS70-HP
	Digital camera	DMC、AIC pro P65+
	POS System	Trimble POS610(200Hz)
CH (Chung Hsing Surveying Co., Ltd.)	Airborne-LiDAR Scanning	ALTM Pegasus
	Digital camera	Dimac Ultralight + 60MP
	POS System	Trimble 4000SSI/ 4700/5700
GF (GeoForce Technologies Co., Ltd.)	Airborne-LiDAR Scanning	Leica ALS60
	Digital camera	Trimble Aerial Camera P65+
	POS System	Leica SR530

CHECK PROJECT → **EDUCATION AND TRAINING** → **Good Staff**

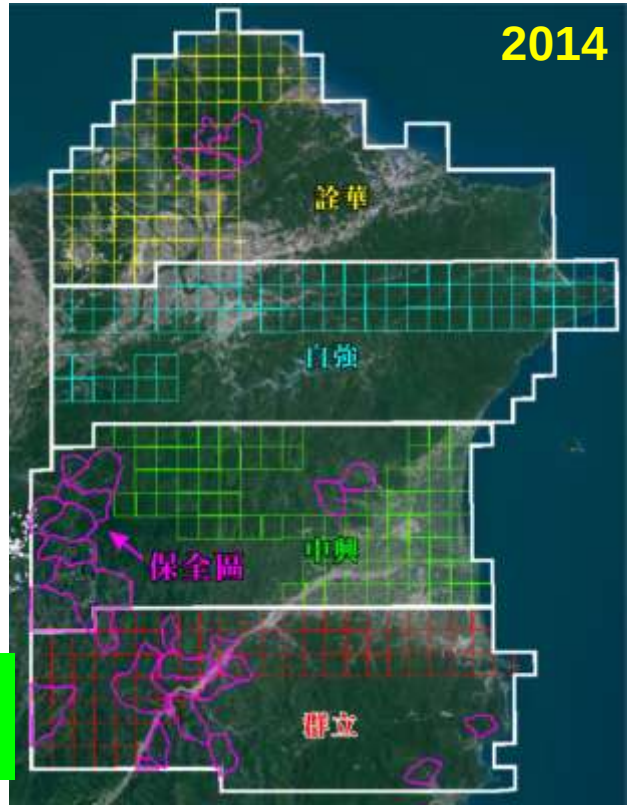
Flight Plan & Strip



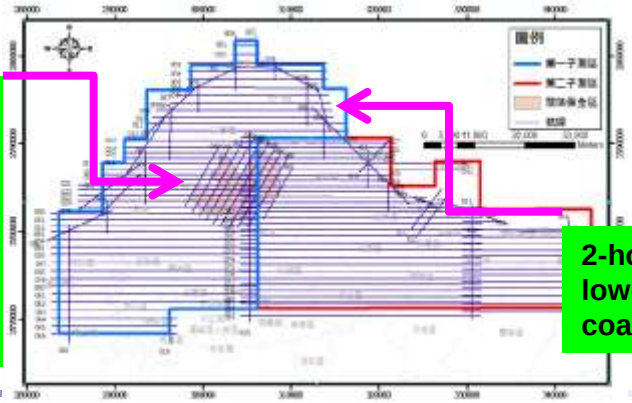




Protected areas



Protected areas(selected areas near mountainous settlements),need more denser flight strips, acquire more point cloud in the ground

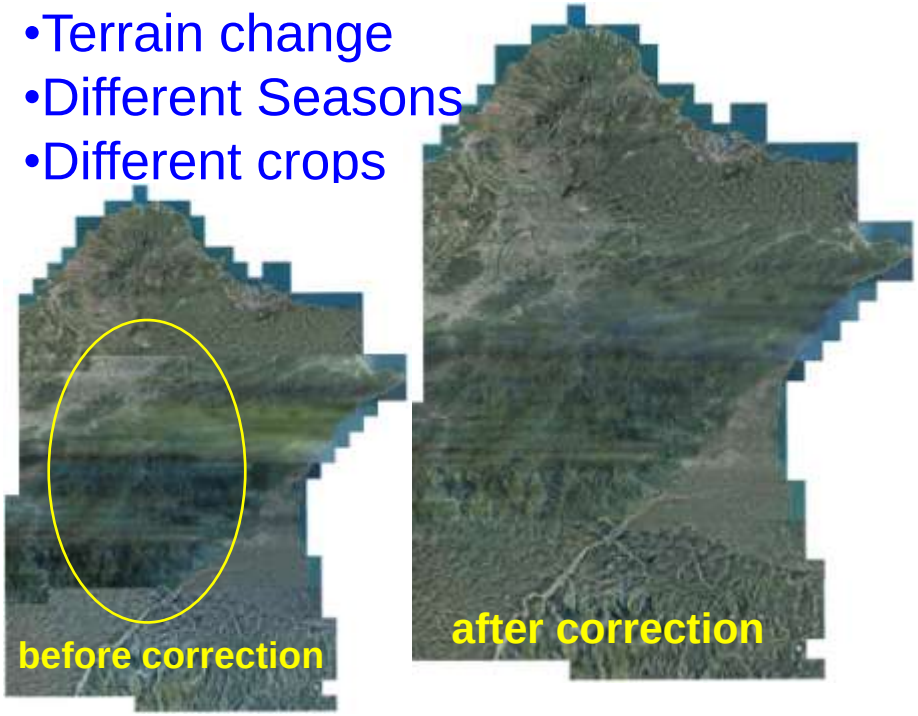


2-hour window for low-tide survey in coastal area

LiDAR data and aerial photographs image quality assurance project(6 items, 22 tables) NCKU RESEARCH & DEVELOPMENT FOUNDATION (Department of Geoinformatics & Satellite Geoinformatics Research Center)	
1. **Flight plan check**	Check Flight plan
	Check LIDAR system calibration (including calibration field)
	Check preliminary results check and flight scan report
2. **Control measurements check**	Check control and measuring results
	Check new GPS base station
	Check elevation control points and horizontal control point
3. **Point cloud heading adjustment check**	Check point cloud format
	Complete coverage of the survey area and adjacent heading overlapping rate checking
	Check point cloud density
	Heading Adjustment written information
	Heading relative error (internal precision)
4. **Point cloud filtering results check**	DEM and DSM data in ASCII format check
	DEM and DSM data in other formats and contour map format checks
	Check point cloud filtering and DEM results
5. **Aerial photography check**	Check aerial images covering integrity
	Aerial camera
	Aerial image quality
6. **orthoimage check**	Check the format and quality of the orthoimage
	Check the feature continuous and rationality

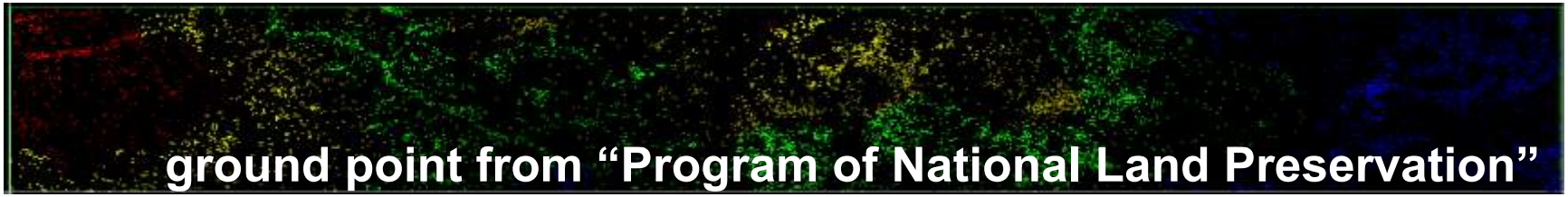
Edge discrepancies reasons：

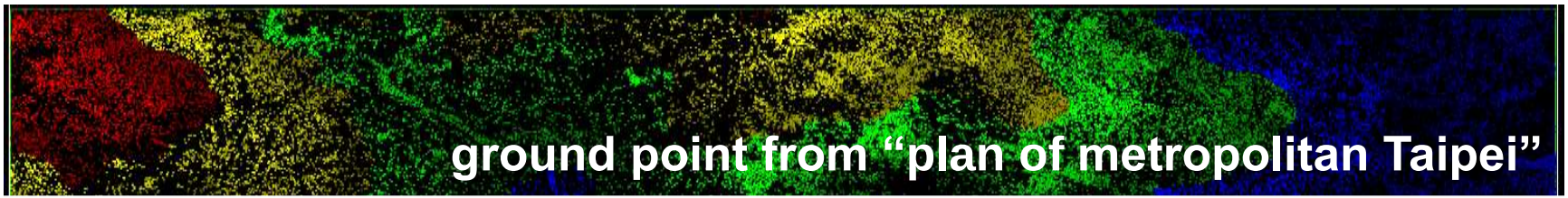
- Different instruments
- Different measurement results
- Surveying at different times
- Terrain change
- Different Seasons
- Different crops



Different color or tone of the aerial photographs

Compare the results of different equipments, different projects





LiDAR point cloud filtering list of obvious errors (common mistakes)

1	**Building is not filtered**	**7**	**Non-permanent mound not filtered**
2	**The dike or solid road was filtered (including embankment, ridge)**	8	**Not filtered out unreasonable point cloud (high or low)**
3	**Bridge (including viaducts), culverts not filtered**	9	**Strips with obvious deviation (adjustment problem)**
4	**The waters of the point cloud is not filtered**	10	**Sidelin of DEM**
5	**Ground point excessively filtered**	11	**Insufficient ground point**
6	**The vegetation is not filtered out**		

LiDAR point cloud density checking(example)

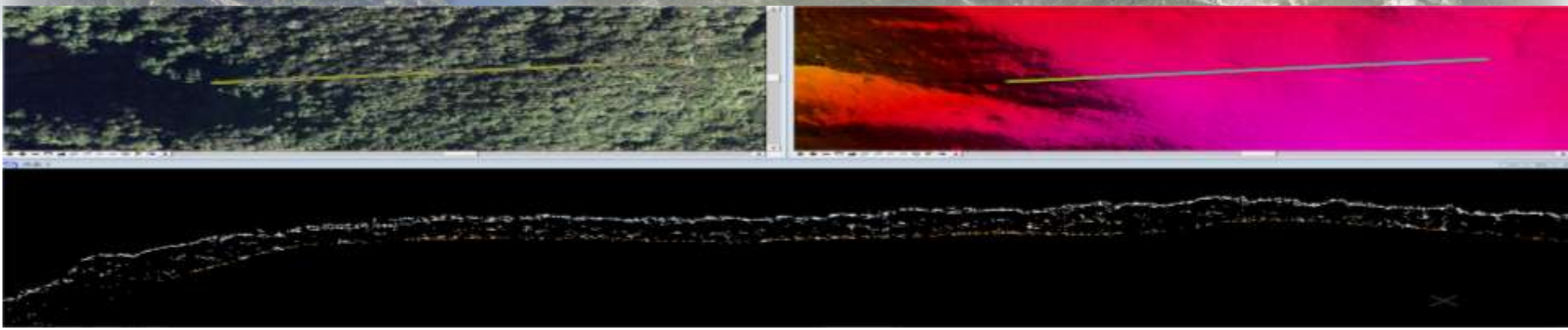
Area(2013)	average point density at Low Area(Ele.< 800m)	average point density at mountain area(Ele.> 800m)
4-1	2.1 Points / m^2	1.6~1.8 Points / m^2
4-2	2.6 Points / m^2	1.72~3.92 Points / m^2
4-3	2.2 Points / m^2	2.2 Points / m^2
4-4	2.2~2.5 Points / m^2	2.2~2.5 Points / m^2

Standard for checking：

- **at least 2 points per square meter, elevation is lower than 800 m;**
- **at least 1.5 points per square meter, elevation is higher than 800 m.**
- **Protected area** (slopeland settlement area) is 95% of the average density of the area required more than 2 points, 99% of the average density of the area required more than 1 point.

Point Cloud Filtering

code	Class description	Level
2	Ground	2
9	Water	9
30	Outlier	30
31	Others	31



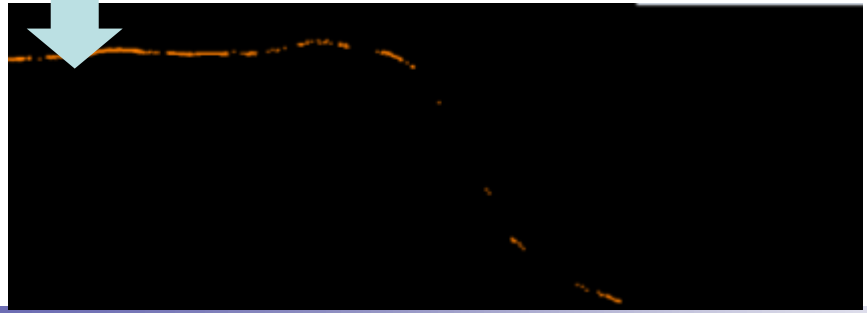
Improvement the point cloud density

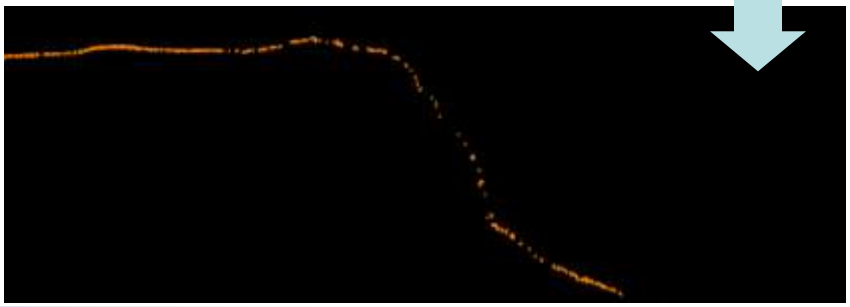
- Equipment: using Multi-channel /Multi-pulse equi.
- Flight: increasing flight lines; choosing different flying directions
- Using full-waveform LiDAR extraction techniques

Penetration rate increased, less flights required

System (ALTM)	Altitude(m)	FOV	PRF (kHz)	Swath Width (m)	Point density (pts/m^2)	Flight line
30/70 Single-channel	2,600	20	50	783	1.23	**8**
Pegasus Double-channel	2,600	40	100(50*2)	1,601	1.21	**4**

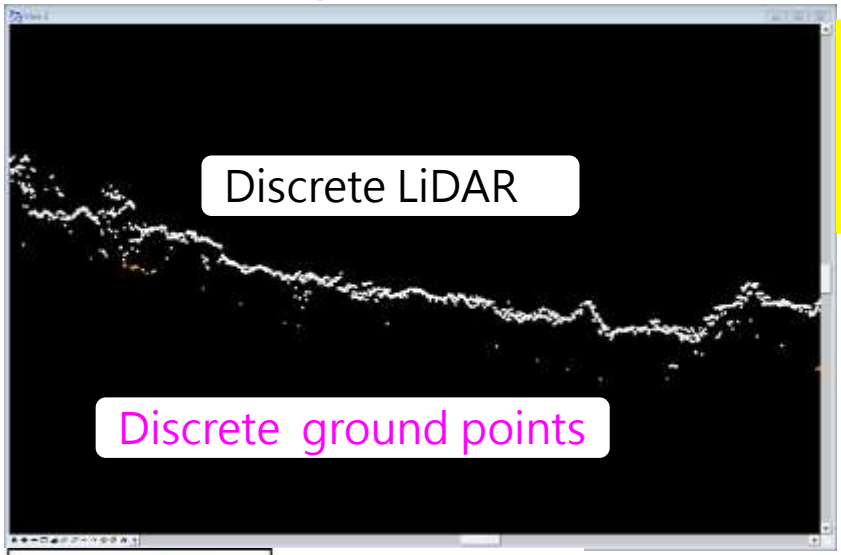
Dense vegetation with steep slope area



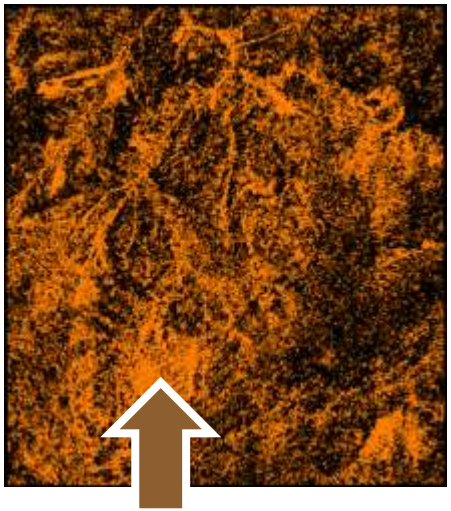


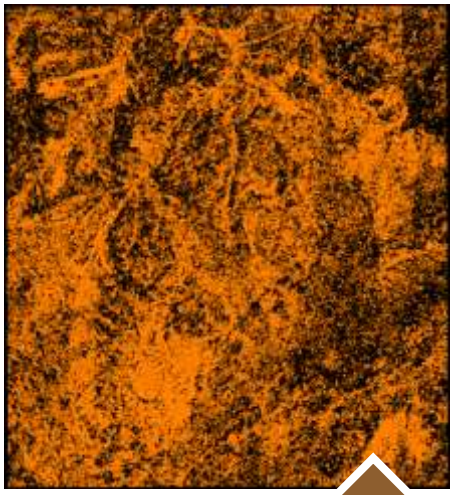
Improve the ground points under dense vegetation

Using full-waveform LiDAR extraction technique



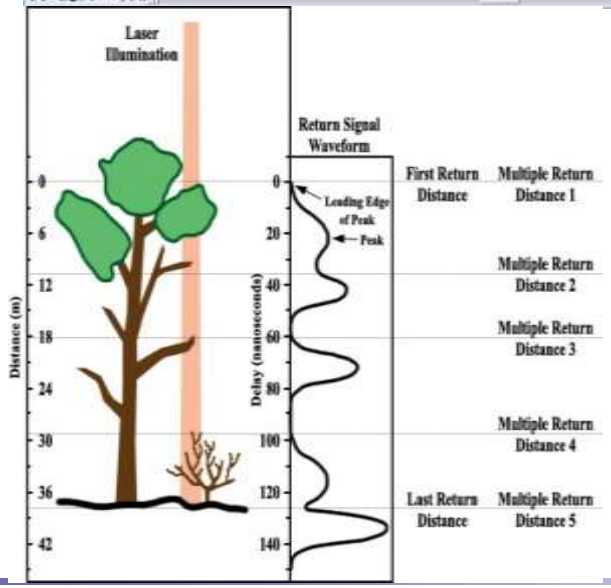
Discrete LiDAR's penetration was 9.98%. After the full-waveform extraction, the penetration increased by 3.55%.





Discrete LiDAR
574,198 ground points

Discrete + full-waveform
778,297 ground points

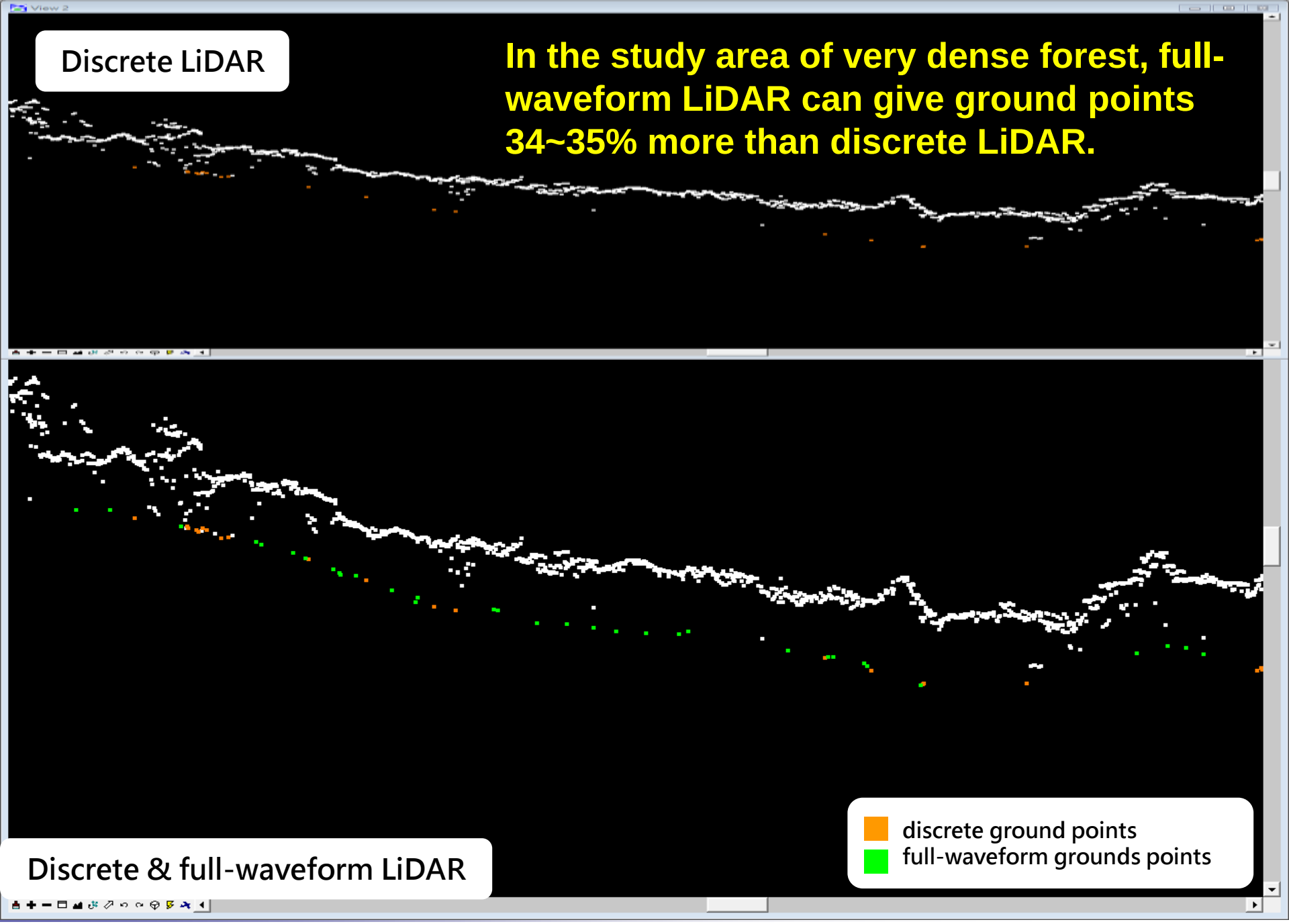


Discrete echo:

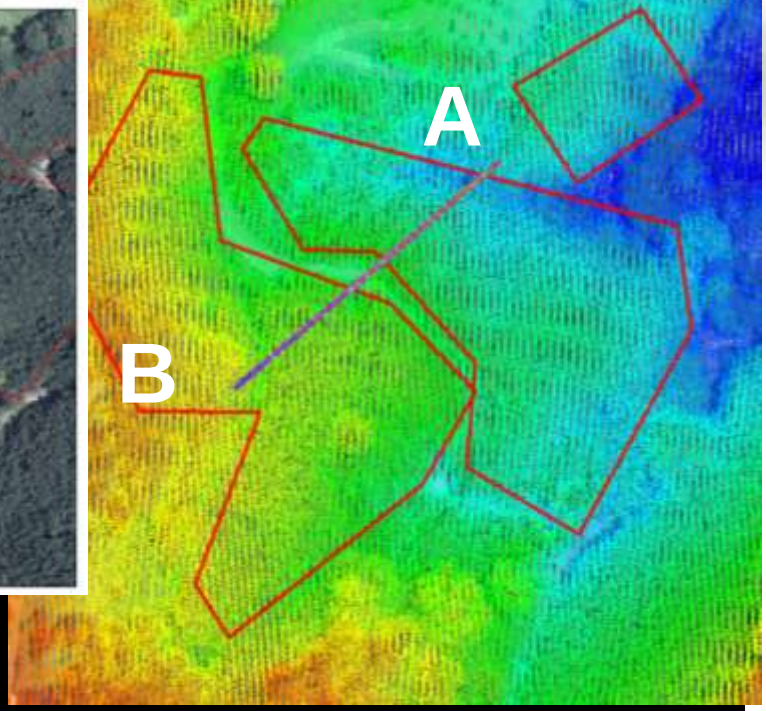
- amplitude
- 4 echoes

Full-waveform echo:

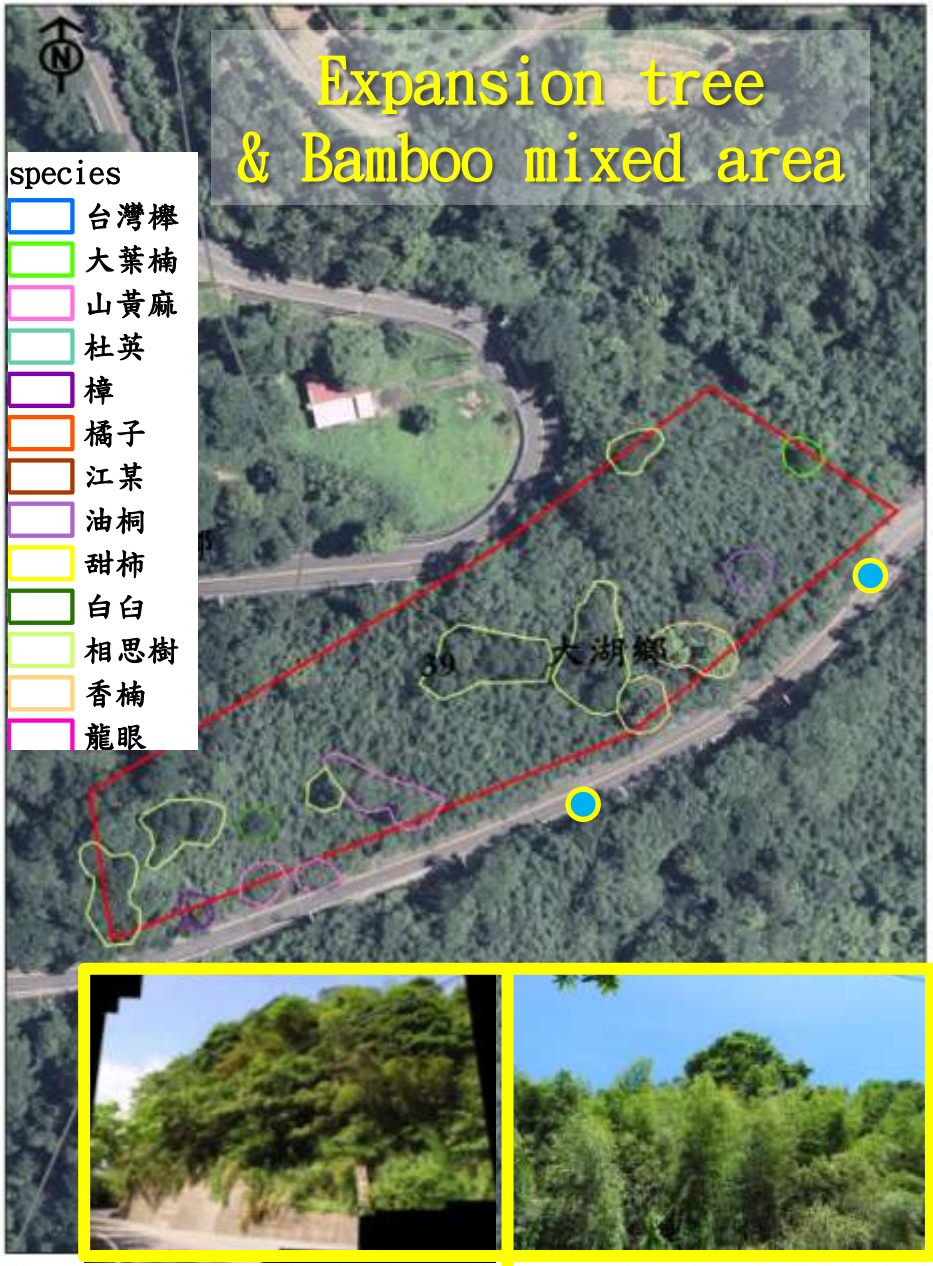
- maximum 256 echoes

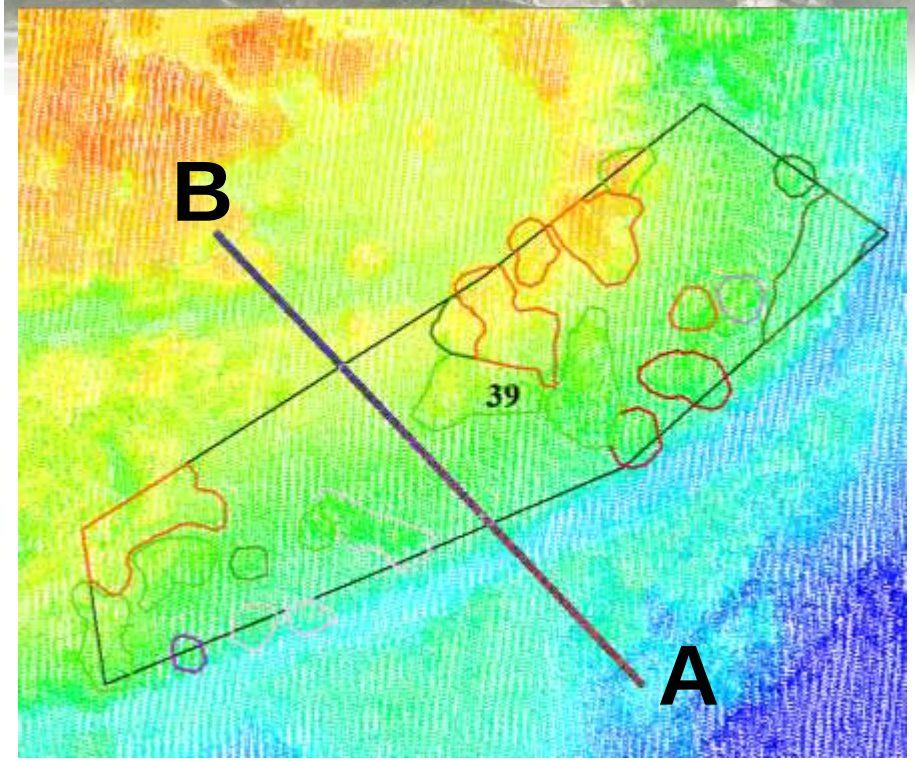

Discrete LiDAR
In the study area of very dense forest, full-waveform LiDAR can give ground points 34~35% more than discrete LiDAR.
Discrete & full-waveform LiDAR
discrete ground points
full-waveform grounds points

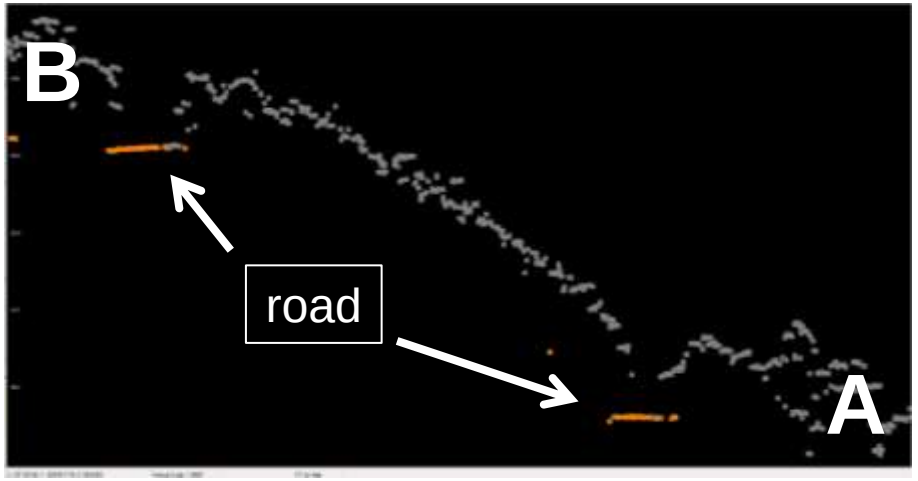

Bamboo tree


A
B

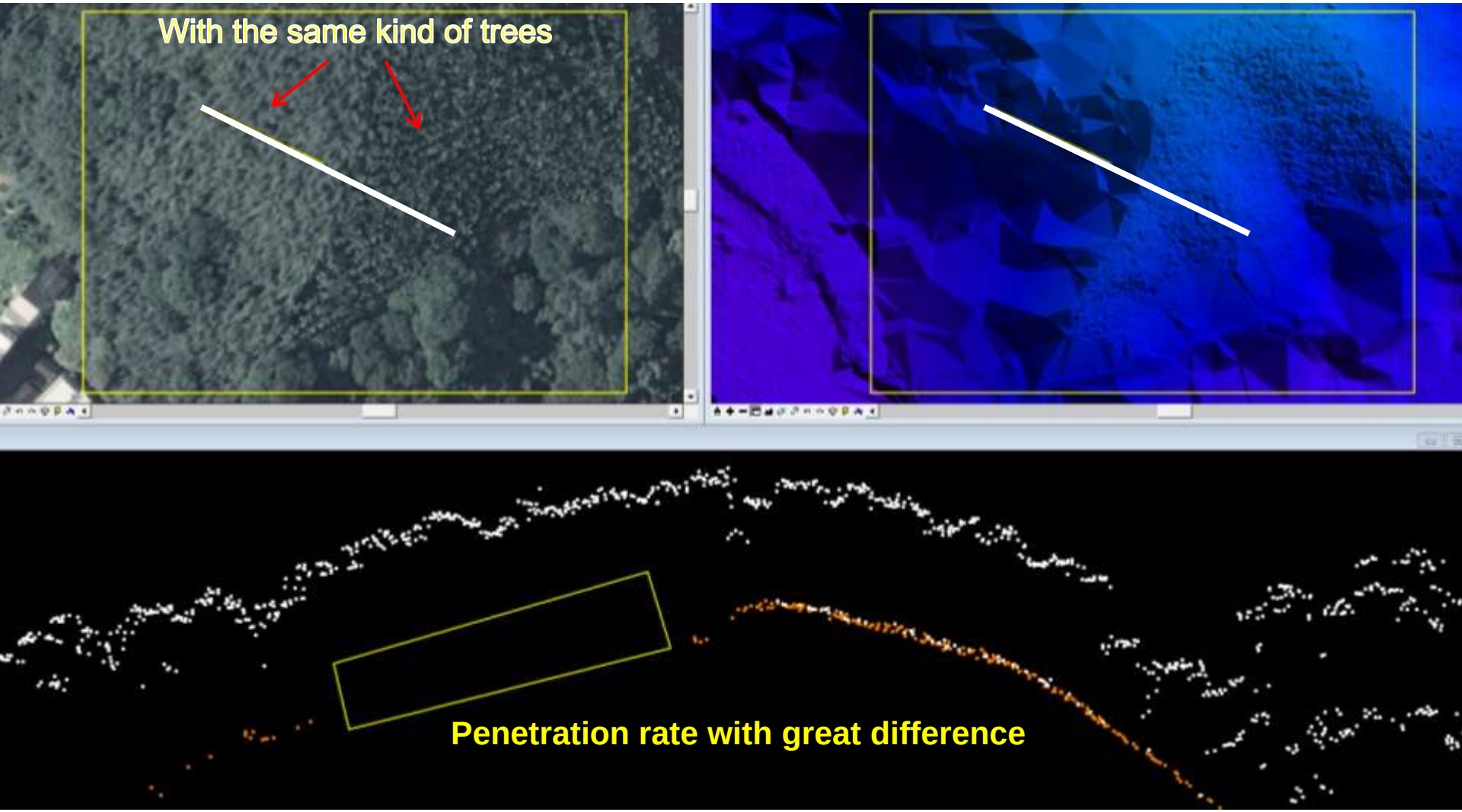

A
all the ground points only in the road
B


Expansion tree
& Bamboo mixed area
species
台灣櫸
大葉楠
山黃麻
杜英
樟
橘子
江某
油桐
甜柿
白臼
相思樹
香楠
龍眼
39
大湖鄉


B
39
A

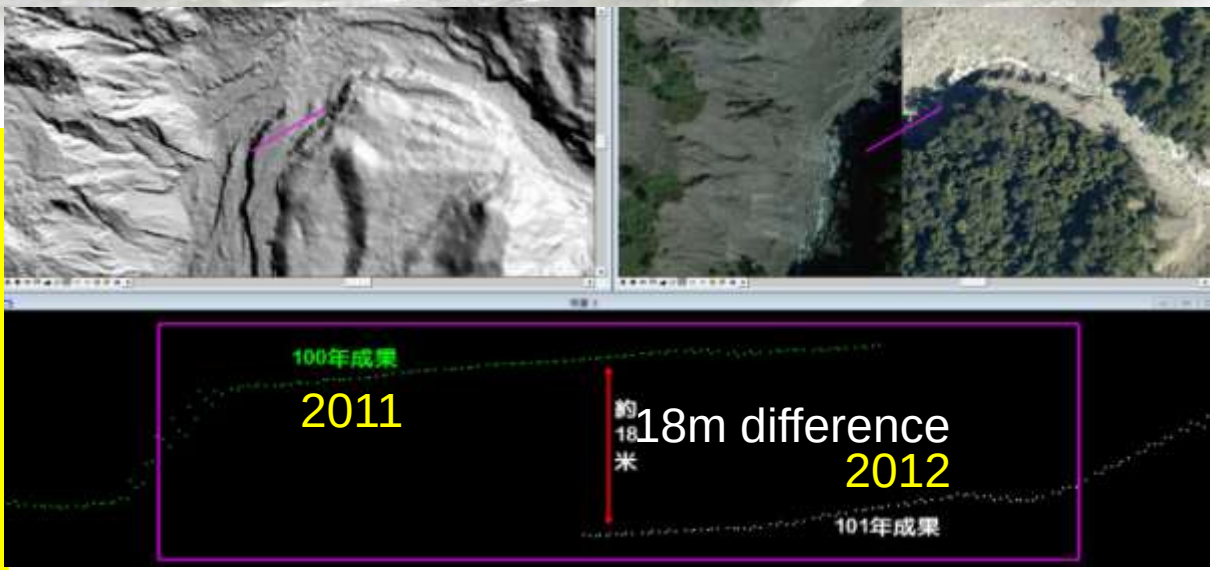

B
road
A

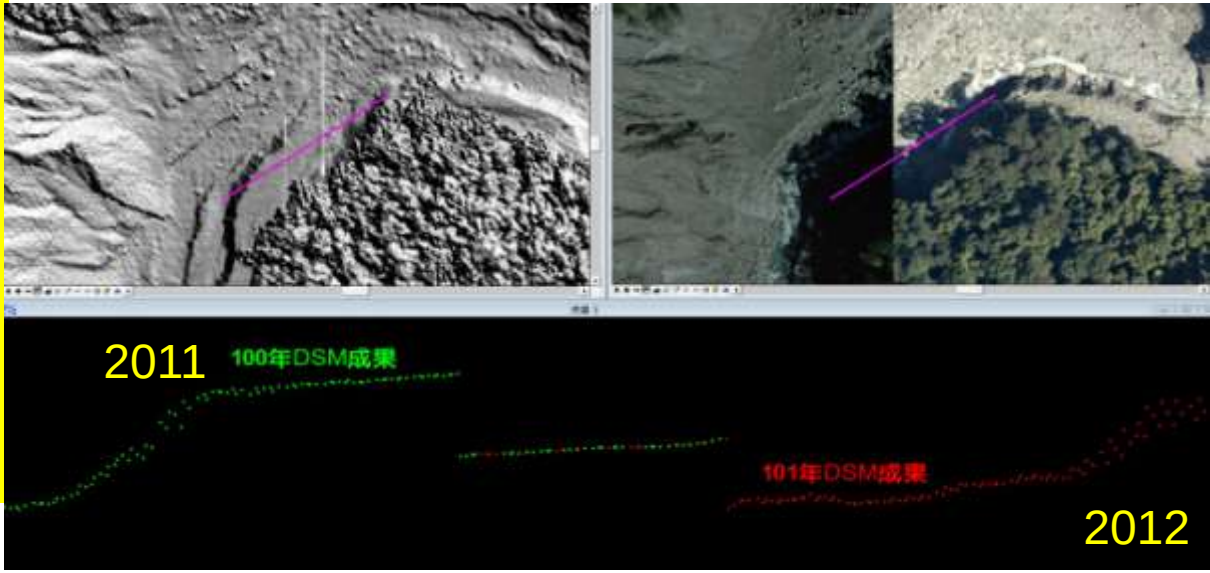
■Different slope direction with different cloud density



Boundary can't adjust owing to:

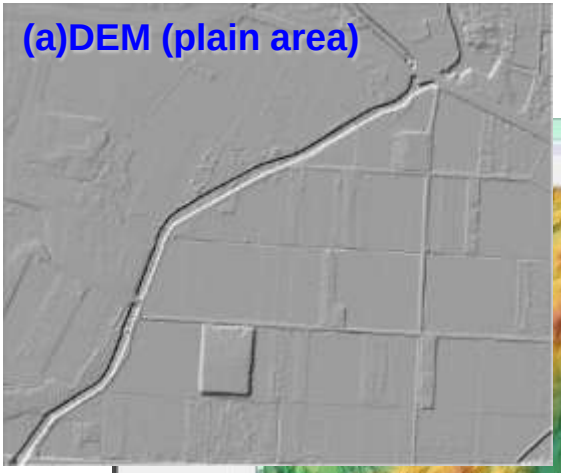
Topographic features changed by natural or man-induced activities from different year's surveying

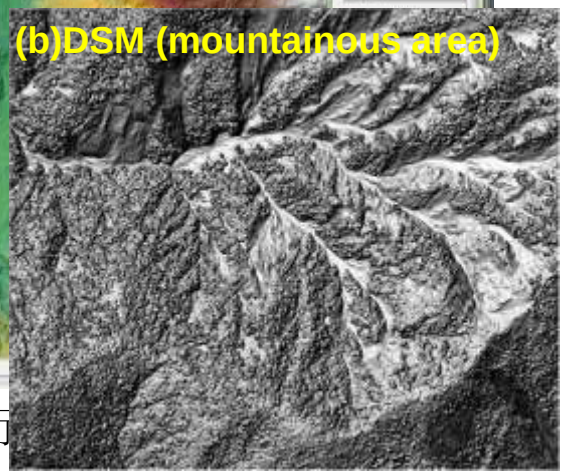


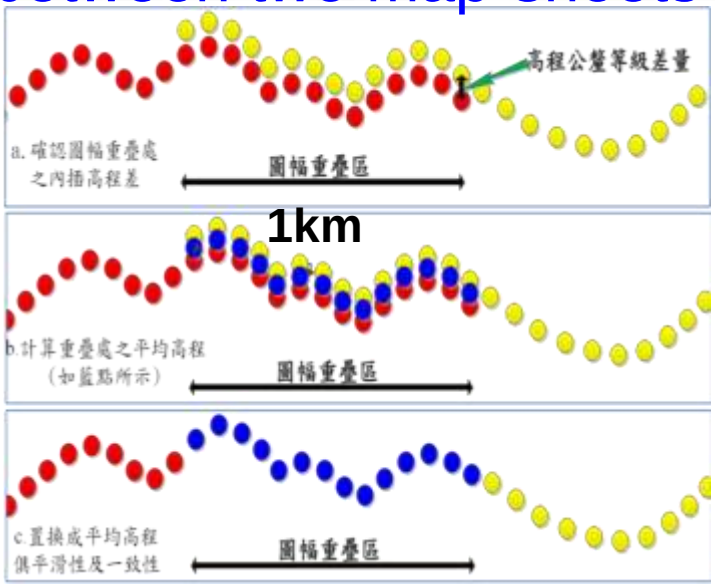


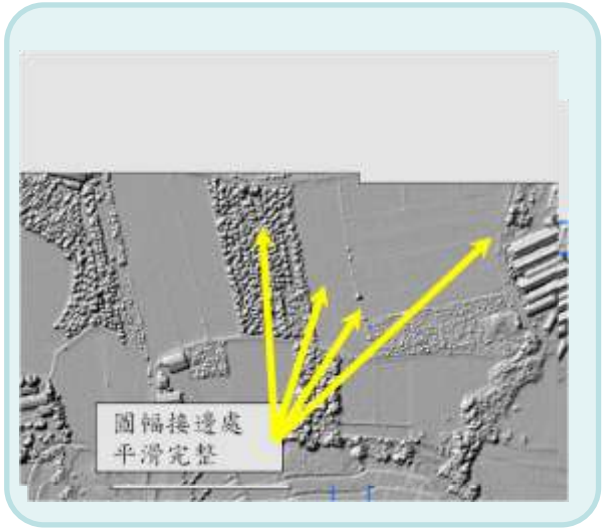
Adjust the boundary between two map-sheets

DEM/DSM with 1m＊1m resolution







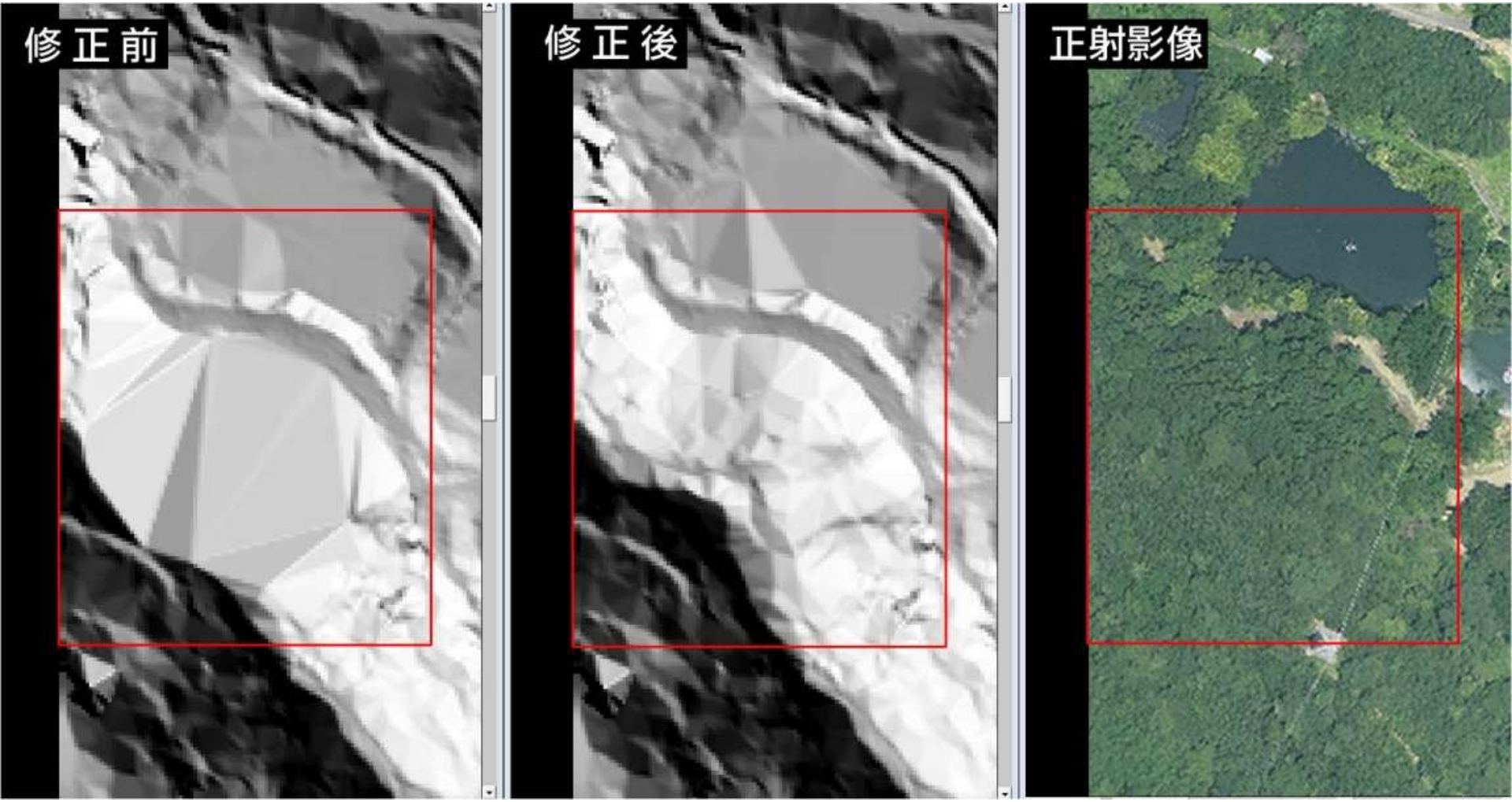


Error check - point cloud filtering

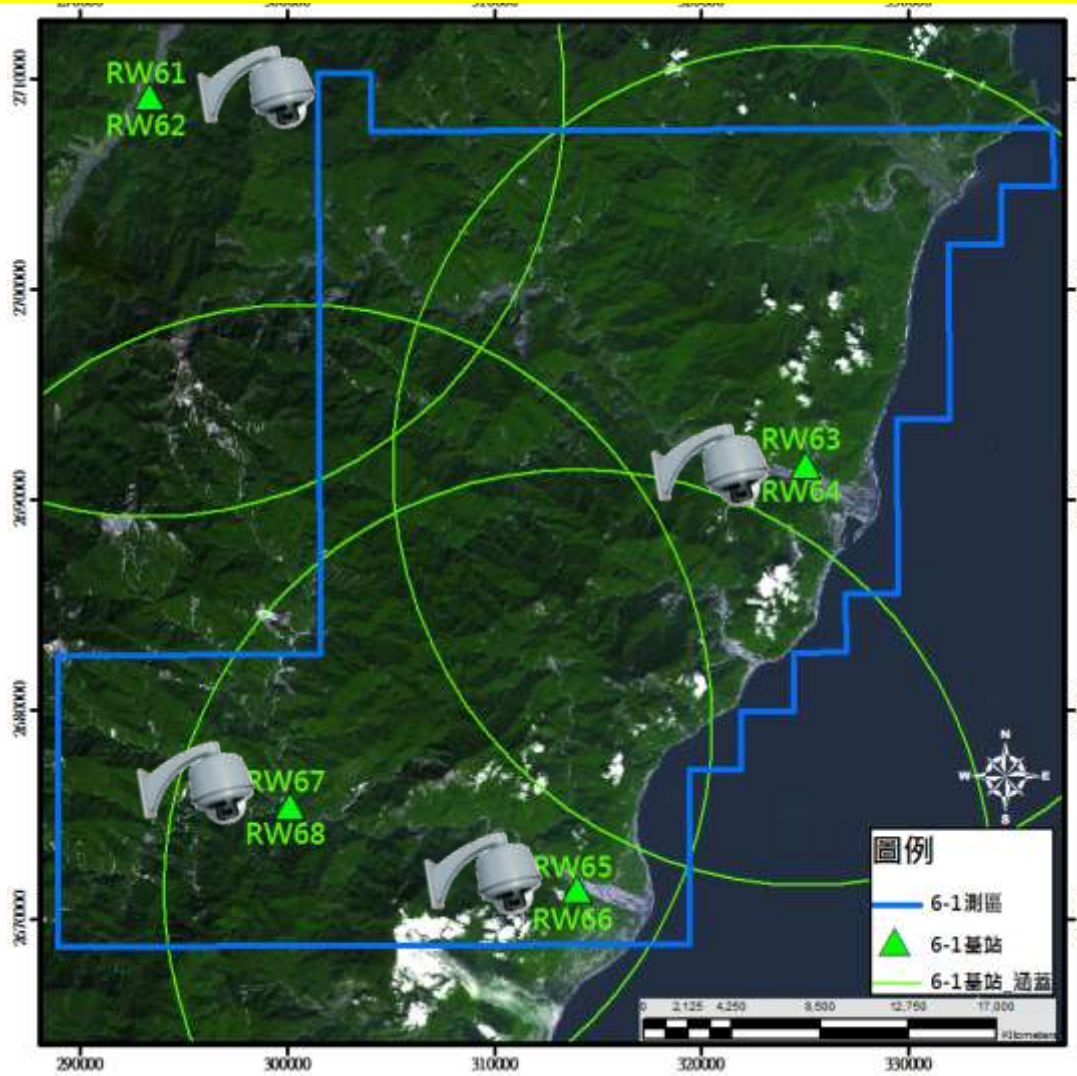
Before correction

After correction

Orthoimage

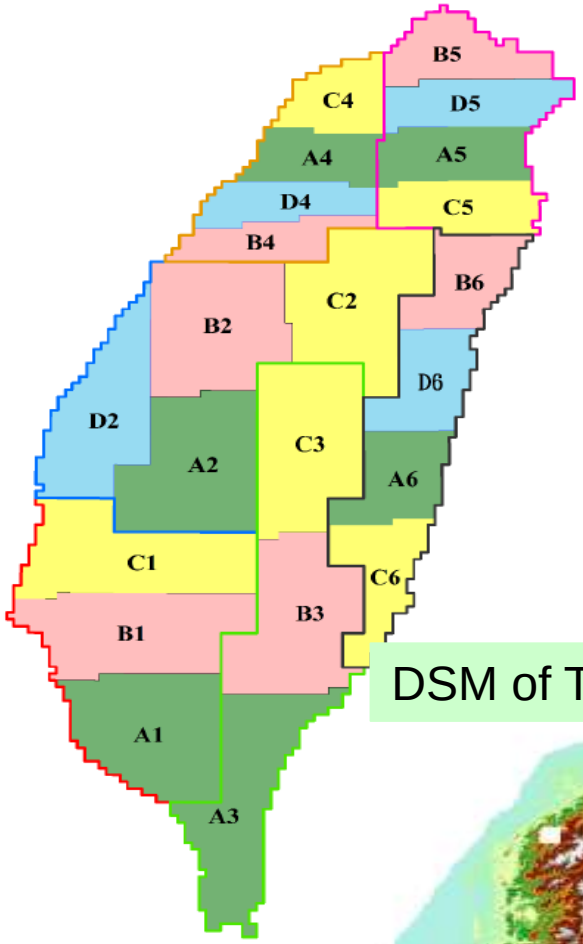


Only 30 hours of flight for a month, and 200 hours for a year in Taiwan



Monitoring the local weather with CCTV

Density of point clouds in each subarea



52 subareas in Taiwan

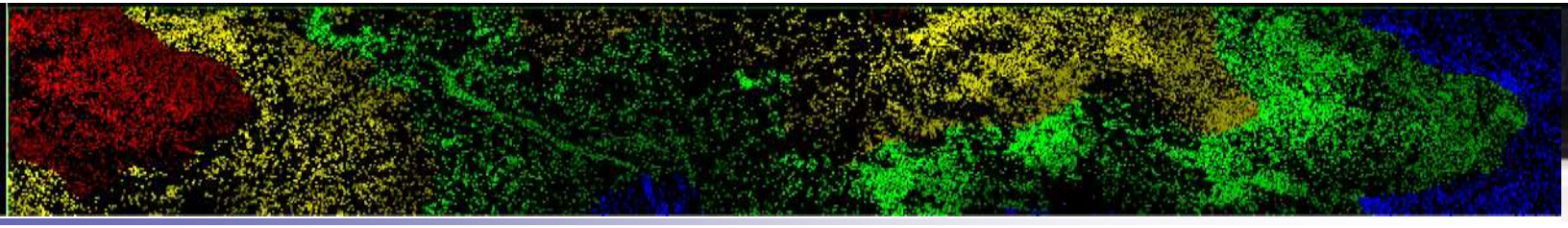
DSM of Taiwan

代碼	Scanning system	Density of points(point/m^2)	Year
A1	Optech ALTM 30/70、Optech ALTM Gemini、Optech ALTM Pegasus	5.06	2010
B1	ORION M200、Leica ALS60	4.55	2010
C1	Leica ALS60	5.02	2010
A2	Optech ALTM Pegasus	4.84	2011
B2	Leica ALS60	3.75	2011
C2	Leica ALS60	3.07	2011
D2	Riegl LMS-Q680i	5.45	2011
A3	Optech ALTM Pegasus	4.21	2012
B3	Leica ALS60	4.00	2012
C3	Leica ALS60	3.07	2012
B4	Leica ALS70-HP	4.48	2013
D4	Riegl LMS-Q680i	4.98	2013
A4	Optech ALTM Pegasus	4.59	2013
C4	Leica ALS60	3.62	2013
B5	Leica ALS70-HP	5.07	2014
D5	Riegl LMS-Q680i	5.32	2014
A5	Optech ALTM Pegasus	4.66	2014
C5	Leica ALS60	4.82	2014
B6	Leica ALS70-HP	4.00	2015
D6	Riegl LMS-Q680i	4.55	2015
A6	Optech ALTM Pegasus	6.00	2015
C6	Leica ALS60	5.05	2015

DSM of Taiwan by reprocessing LiDAR data using pit-free algorithm (Lin,2017)

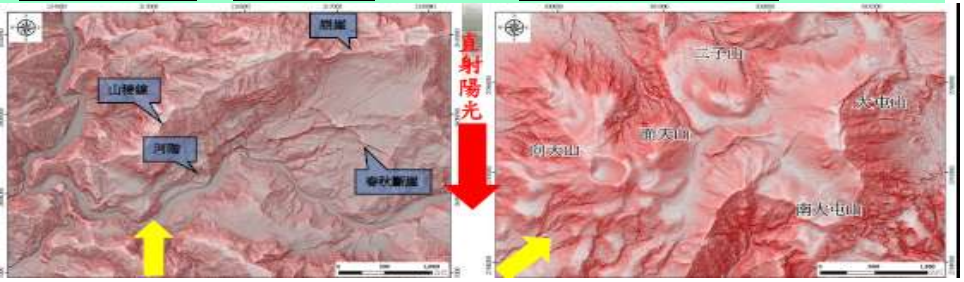
good lucks, good fortune and long life

DEM Data Applied in Zonation of the Geologically Sensitive Areas



■ RRIM (Red Relief Image Map) can easily identify fine-scale geomorphic change, it combines the **positive openness** (**Red**) and **negative openness** (**Grey**) values.

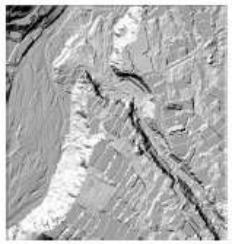
■ **Positive openness** shows convex, ridge, scarp and terrace, whereas **negative openness** describe concave, valley, river and gully etc.

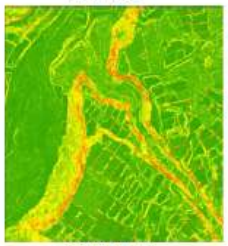


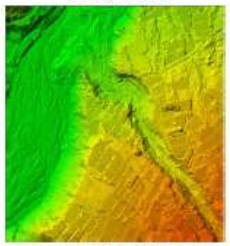
NewLand Mapping & Surveying Co.,Ltd

赤色立體地圖是一種嶄新的地形渲染技術，為日本 千葉達郎博士於 2002 年發明。本公司透過與現有各類地形表現方式進行比較，可突顯赤色立體地圖的優點。


等高線圖


地形陰影圖


地形斜度圖


地形彩色圖


96 年正射影像圖


98 年正射影像圖


100 年正射影像圖

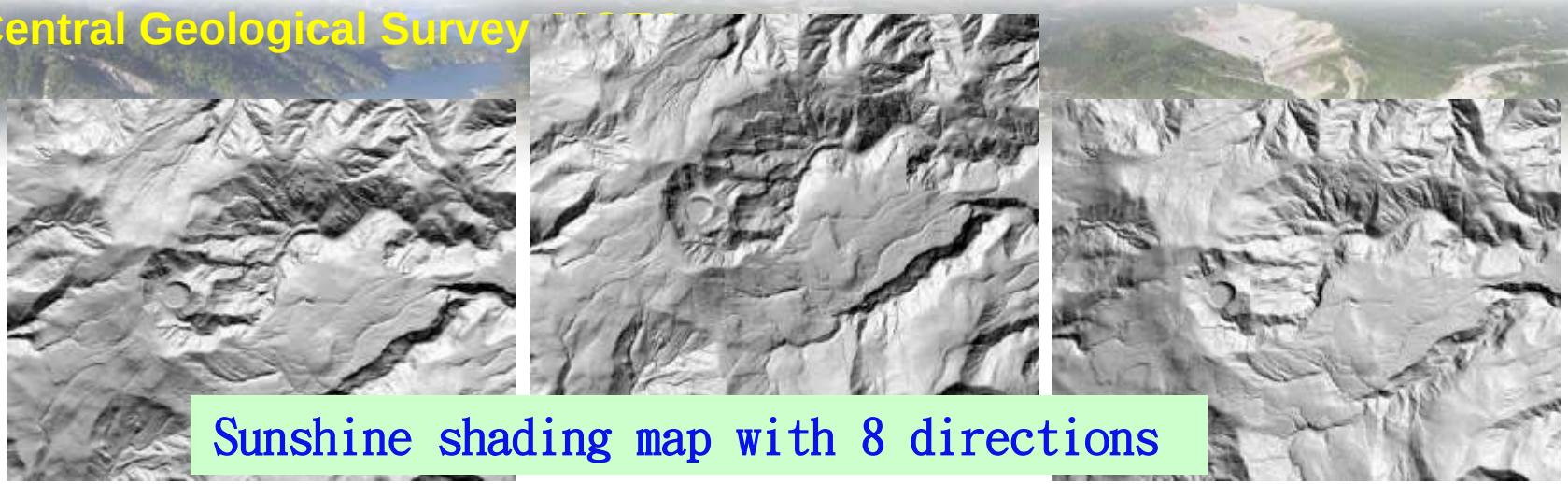

100 年赤色立體地圖


地面全景影像

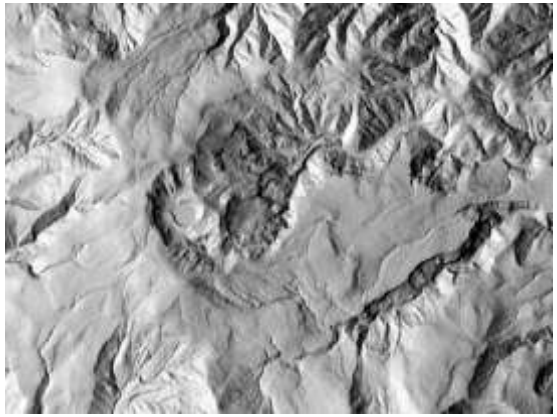
★赤色立體地圖較正射影像圖更能看出隱藏在植被下的細微地形，容易判讀出地質斷層帶及土石流潛勢區域。

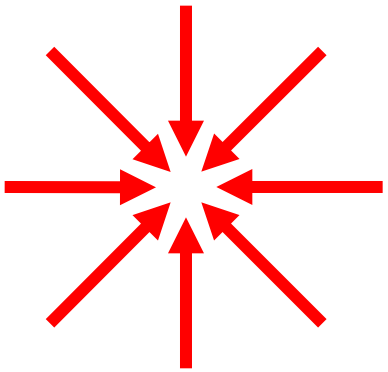
資料來源:日本亞洲航測株式会社　台灣代理:新陸國土測繪有限公司

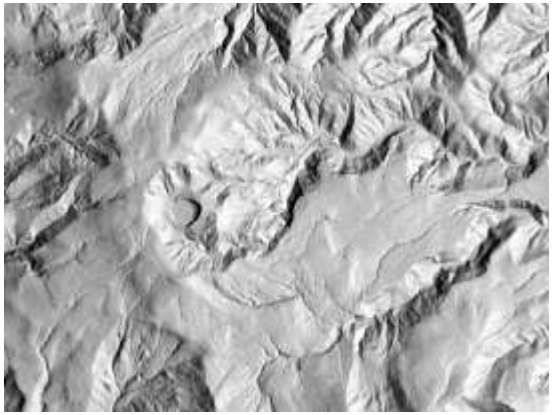
Large-scale landslide area; volcanic area

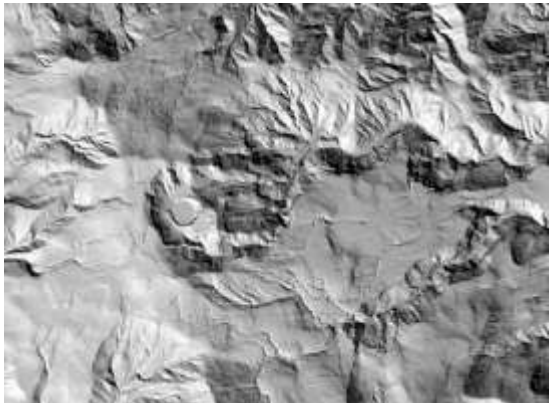


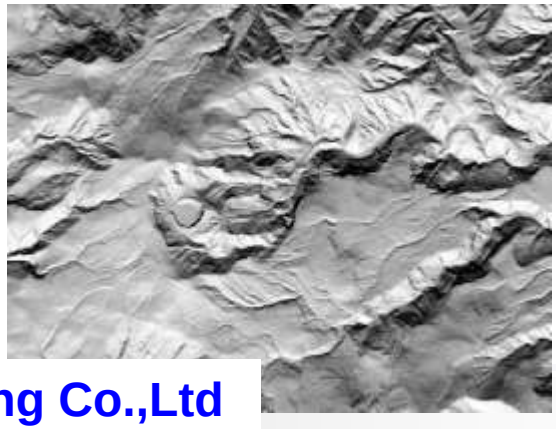
Sunshine shading map with 8 directions

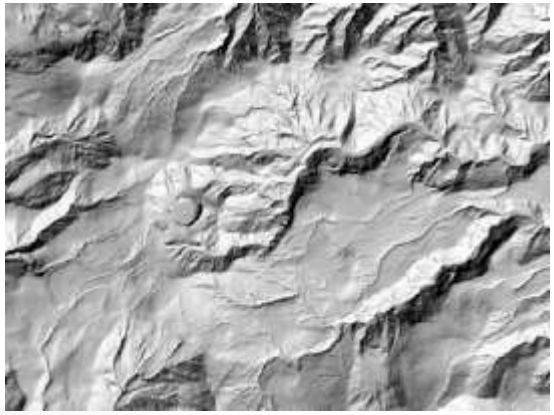












(Geology map of Taipei)

The term "**geological hazard**" means a natural or human-induced

- earthquake(1),
- tsunami(2),
- volcanic eruption(3),
- fault activity(4),
- landslides(5),
- landslip(6),
- debris flow(7),
- land subsidence(8),
- coastal change(9),

or other disasters induced by geological processes

Topographic features of the Large-scale Landslide

- ✓ Ridge with a gentle slope
- ✓ Scarp、reverse slope、fissures and tension cracks
- ✓ Double ridge
- ✓ Linear depression
- ✓ Slide-body
- ✓ The bulge at the toe
- ✓ Gully sidewall and gully headwall failures
- ✓ Bedrock creep
- ✓ Older landslides

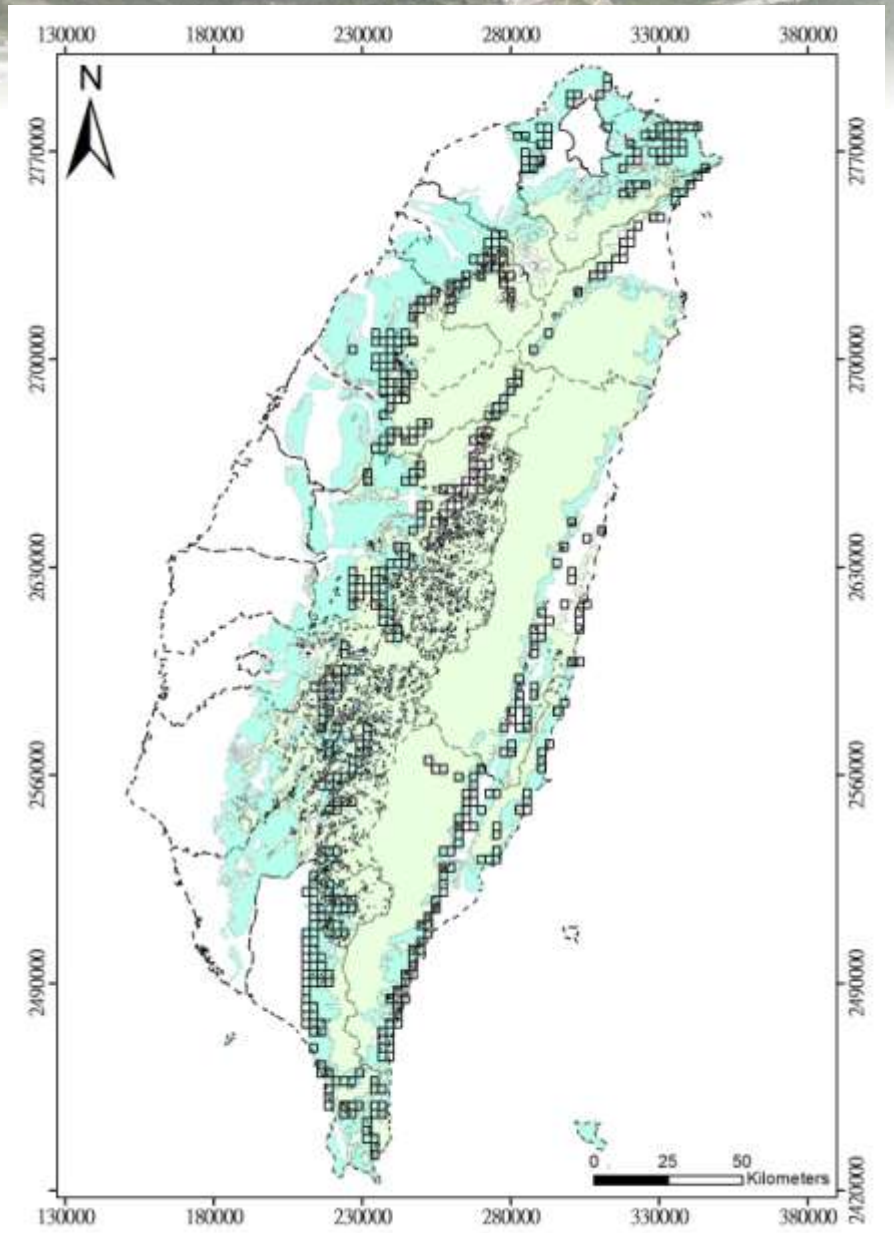
(Lin modified from WP/WLI,1993)

The Results of large-scale landslide identification from 2010~2015

In 4,200km^2, 1,207 potential sites were identified, with total area of 411km^2 ,about 9.8%. Among them, 113 sites located nearby 103 Villages

TAIWAN (Total area:36,000km^2)

- Roughly estimated about：5,000~6,000 sites
- With high susceptibility (about 15%)：750 sites(area:5,400km^2)
- Located nearby villages(about 3%)：150 sites(1,080km^2)

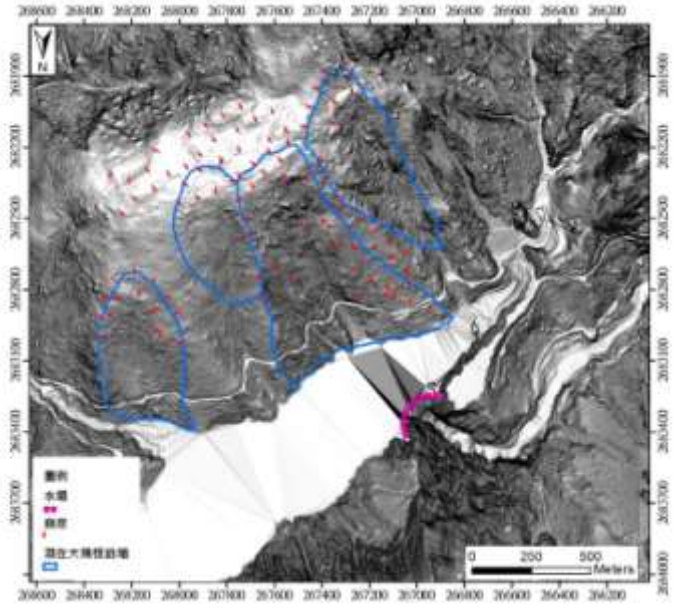


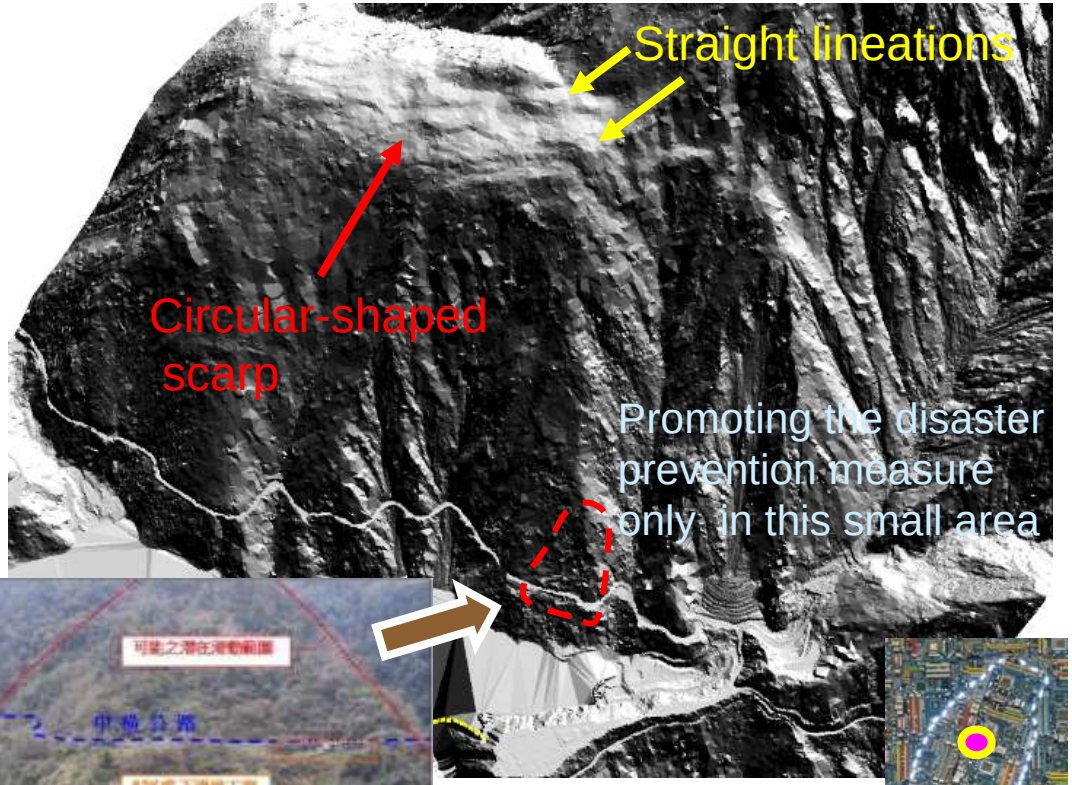
Geohazard zone may be very close to you ！

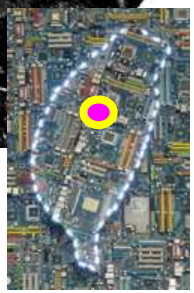
Site threaten by potential large-scale landslide

Techi Dam(completed in 1974)

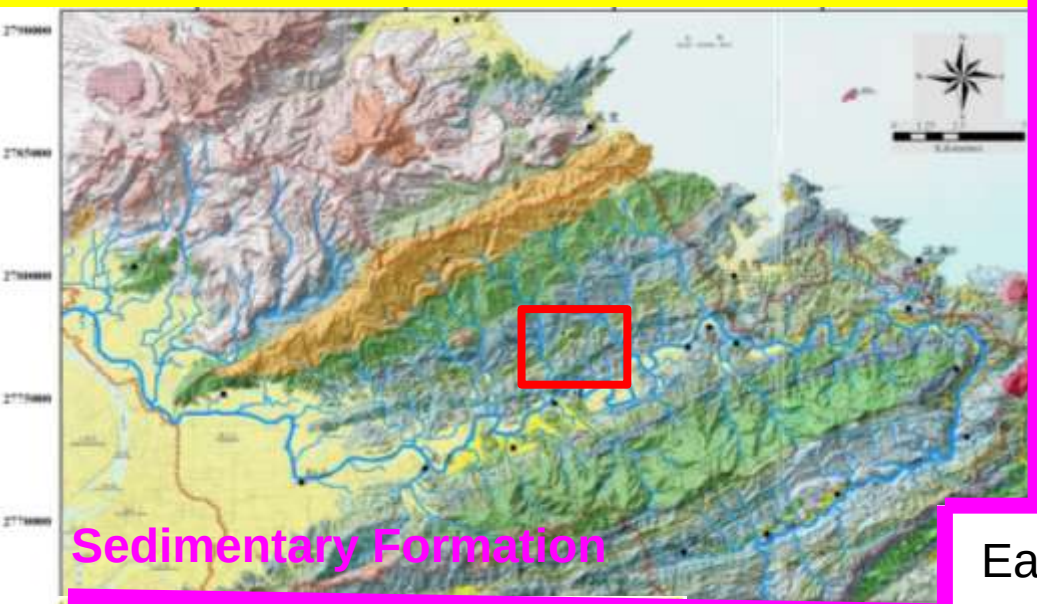
- Forming the 454 ha Reservoir
- The highest dam(at 180 m) in Taiwan
- One of the tallest dam in the world



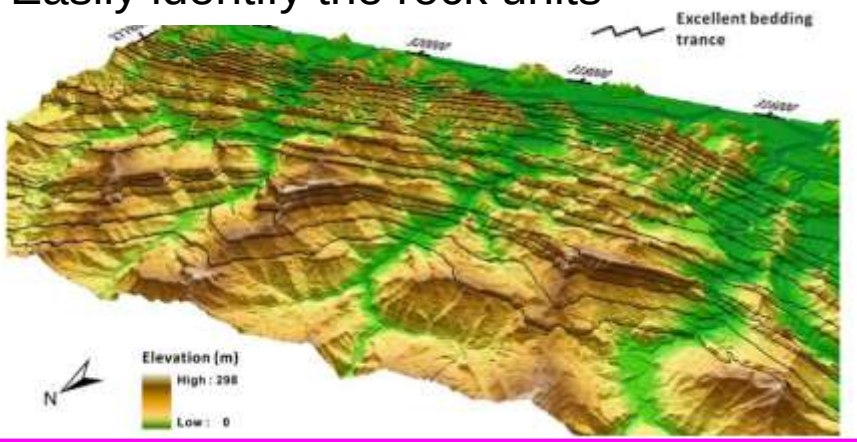


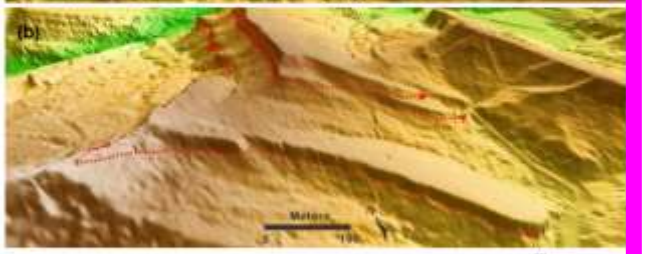


Detailed geological mapping – The rock units & bedding plane analyzed on the northern bank of Keelung River

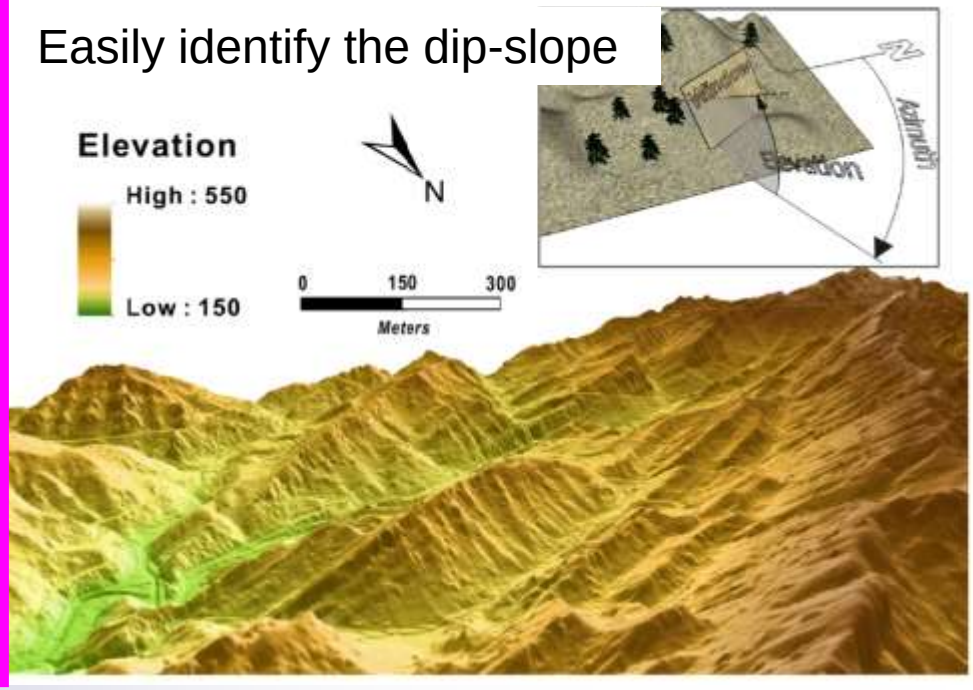


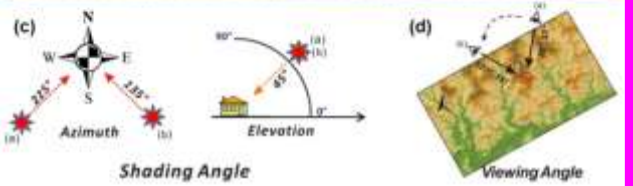
Easily identify the rock units





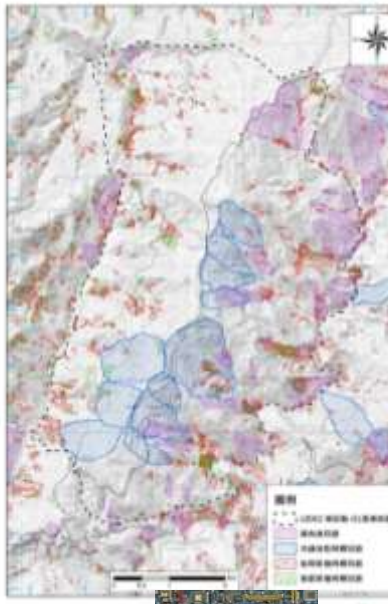
Easily identify the dip-slope

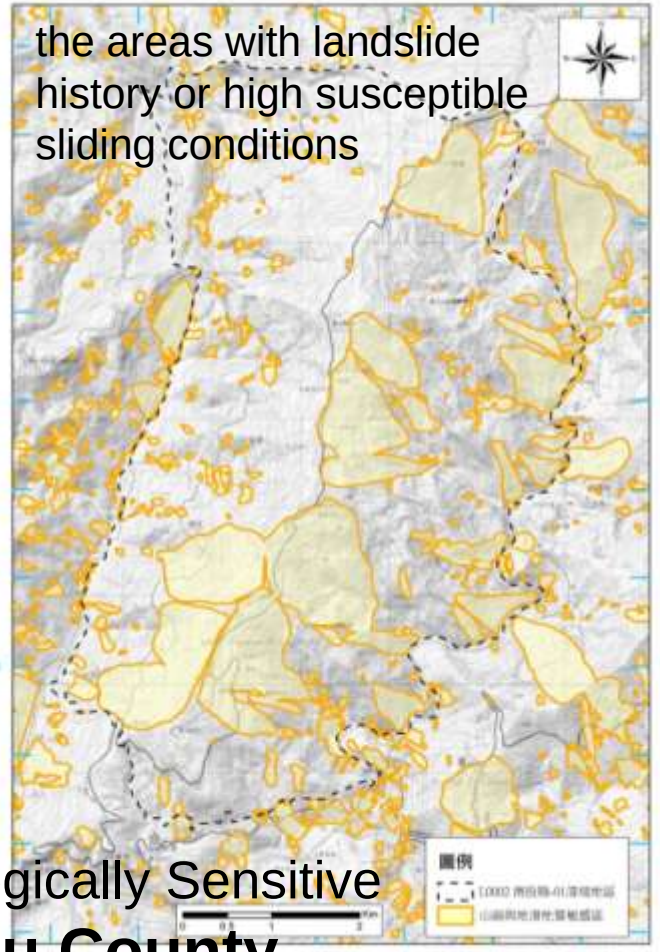


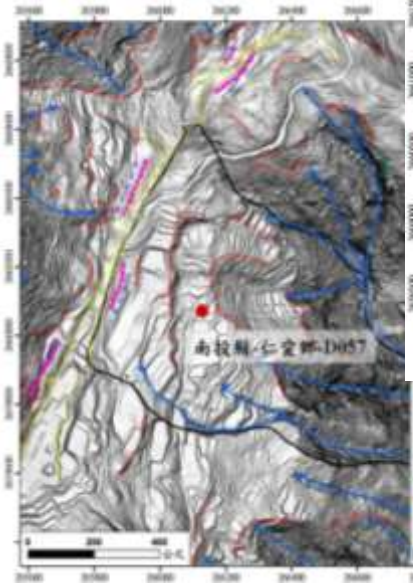


Geology Act (Dec.1, 2011) Article 5

The central competent authority shall publicly announce areas with special geologic scenery, special geological environments, **or potential geological hazards** to be geologically sensitive areas.



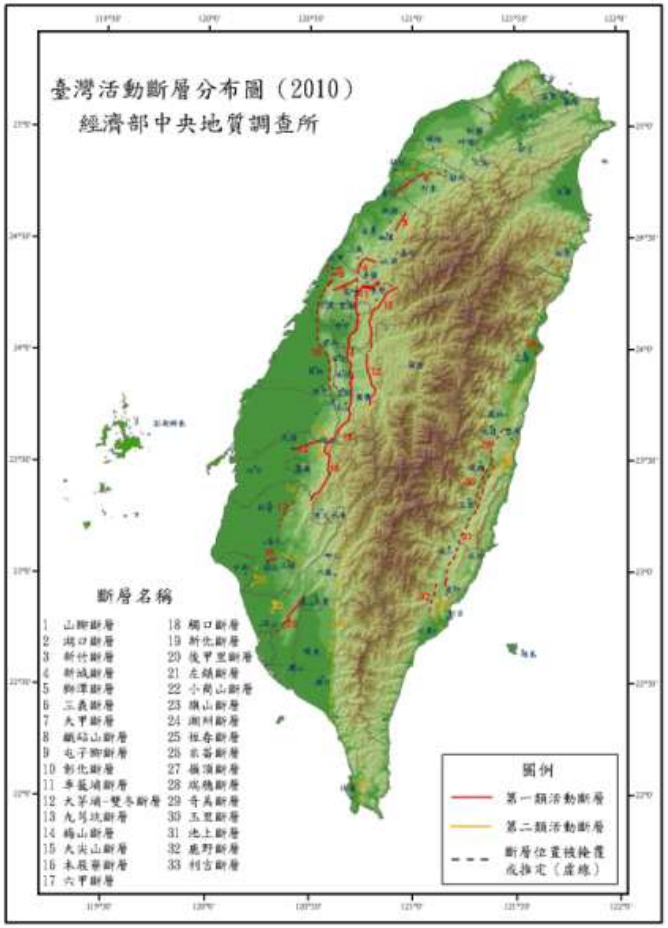


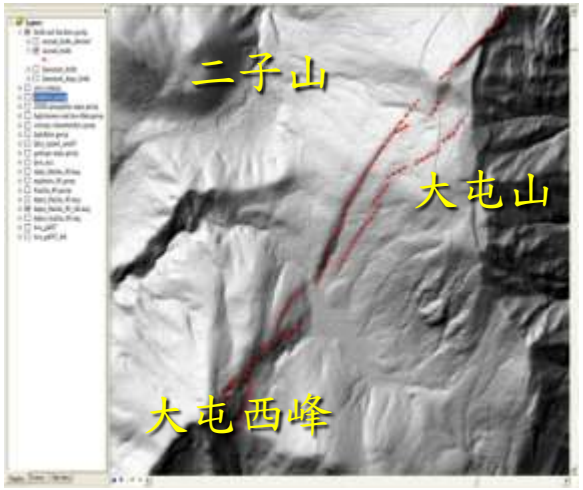


Landslide-Landslip Geologically Sensitive Area **of Chinjing, Nantou County**

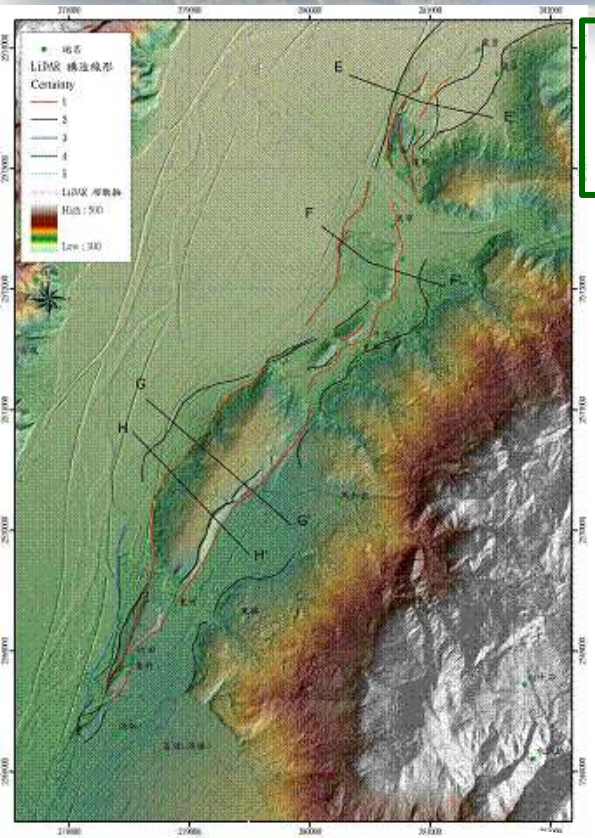
More than 33 Active Faults locating in Taiwan

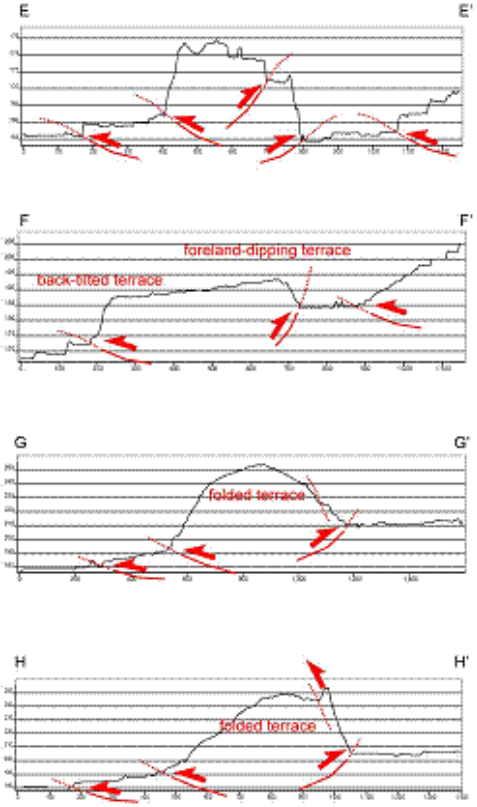
(1999 Chelungpu Fault)

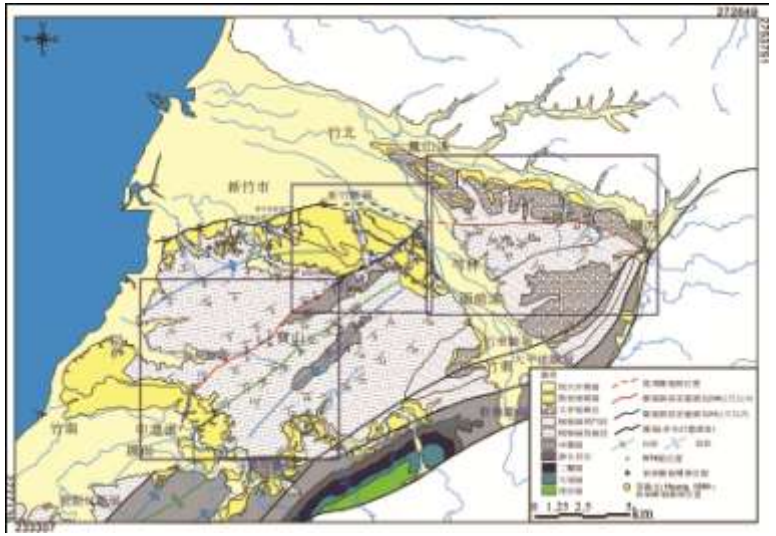




Locating the accurate position of active faults
Investigating the activities of active faults



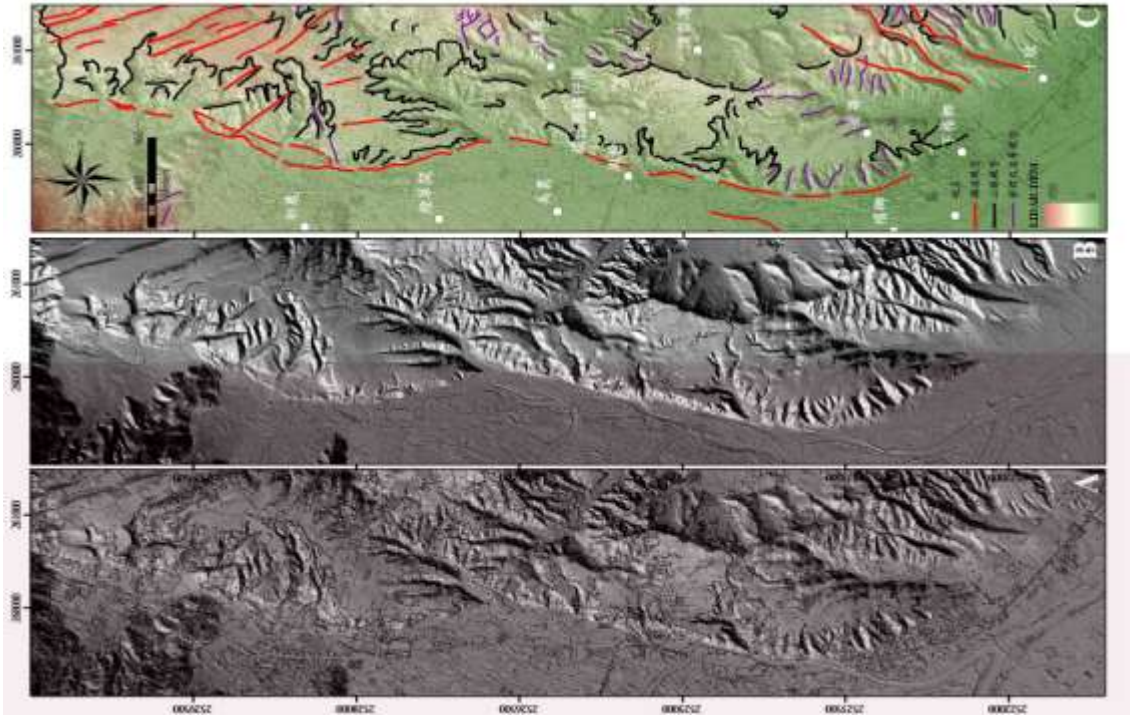


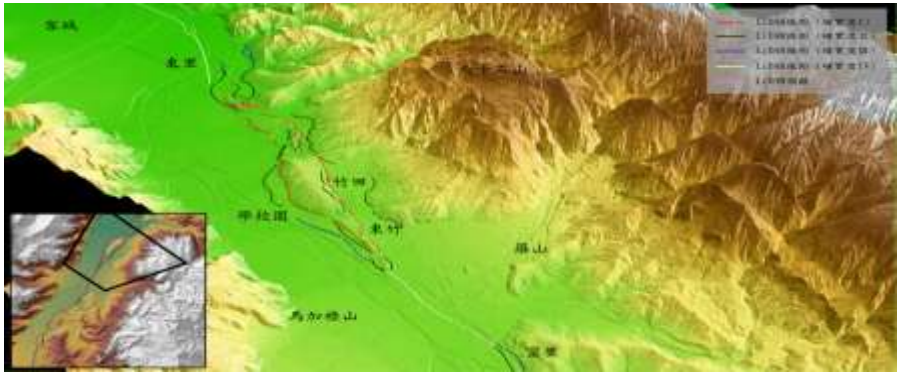


Identifying the geomorphologic evidences of faults by using 1m × 1m DEM

The morphotectonic analysis of the active faults based on LiDAR data

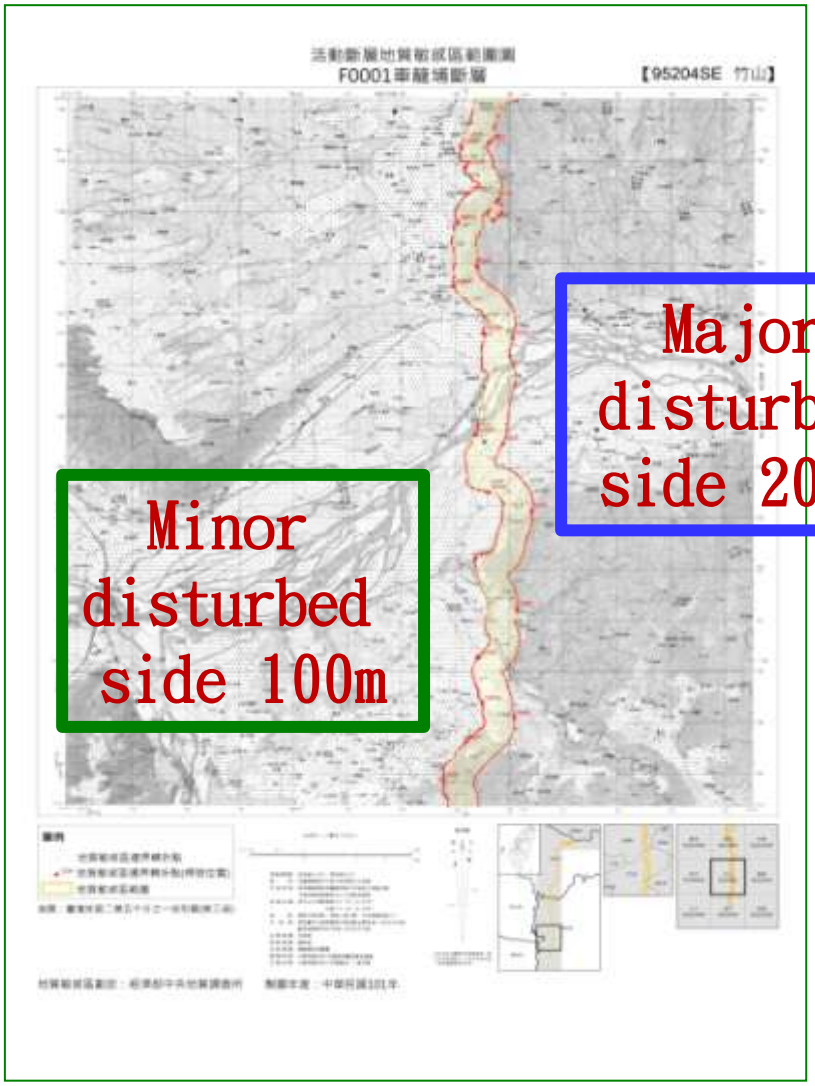
33 active faults in Taiwan

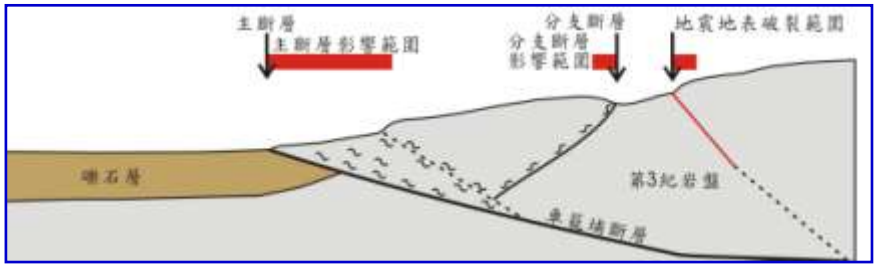




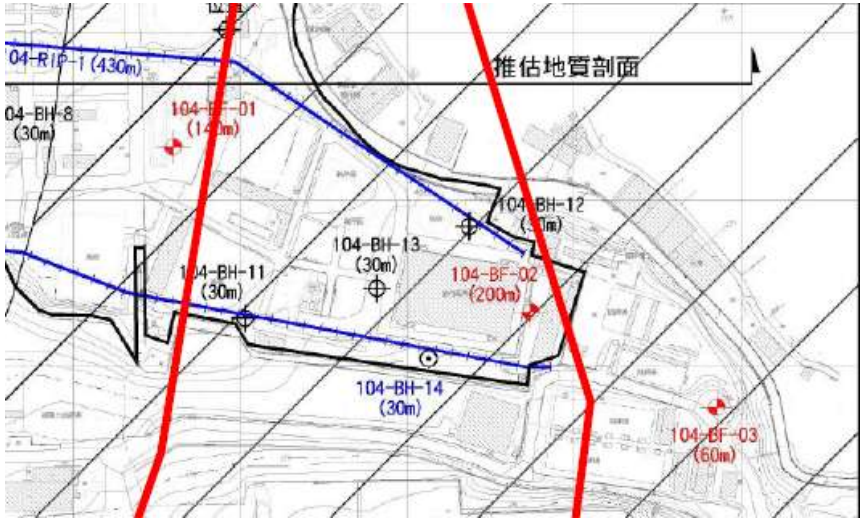
The detail structural characteristics of a fault analyzed by 3D anaglyph images

Geologically Sensitive Area **of Chelunpu Active Fault**





Disturbed area along both sides of active fault



Active fault may located in a site, make geological investigation to confirm the exact location of it

Conclusion

High resolution DEM data ⇨ geological hazard

Having：new tool, new technique, new idea
Facing：new issues, new disasters
new challenges, new missions

Paolo Tarolli (2014) pointed out, our mission is: (1) to "*help in scheduling appropriate environmental planning for sustainable development*"; (2) to "*mitigate the consequences of anthropogenic alteration*"; (3) to "*better understand the evolution of our Planet*".