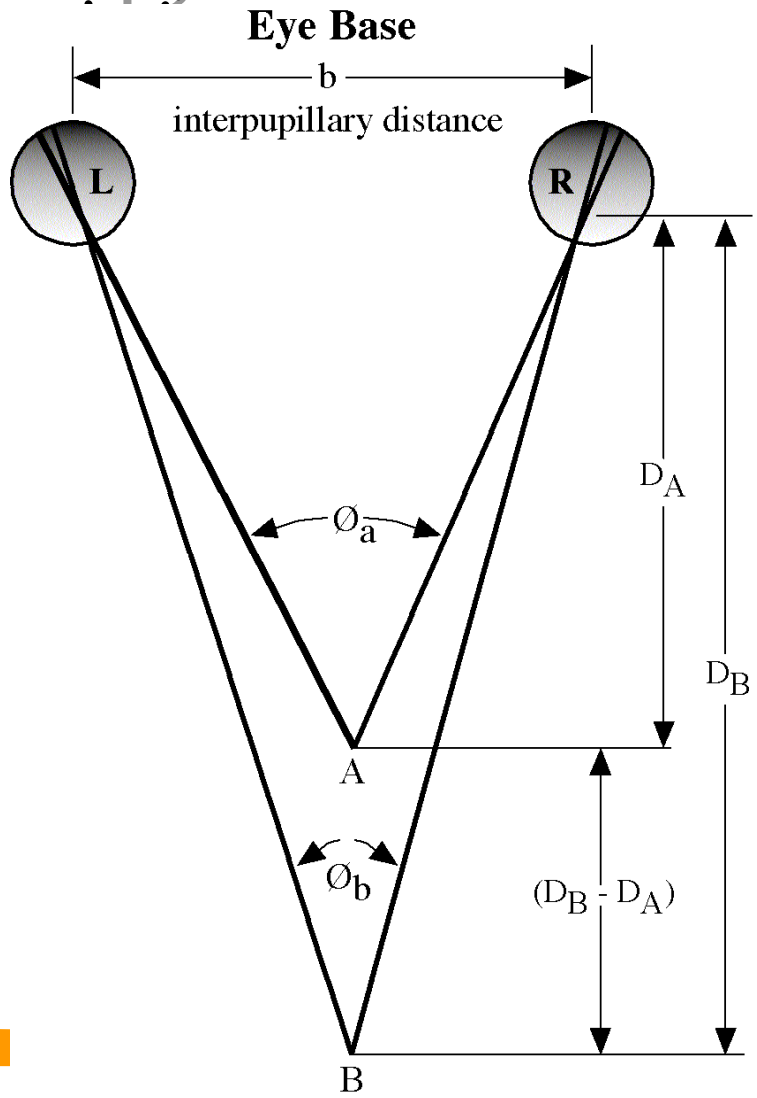
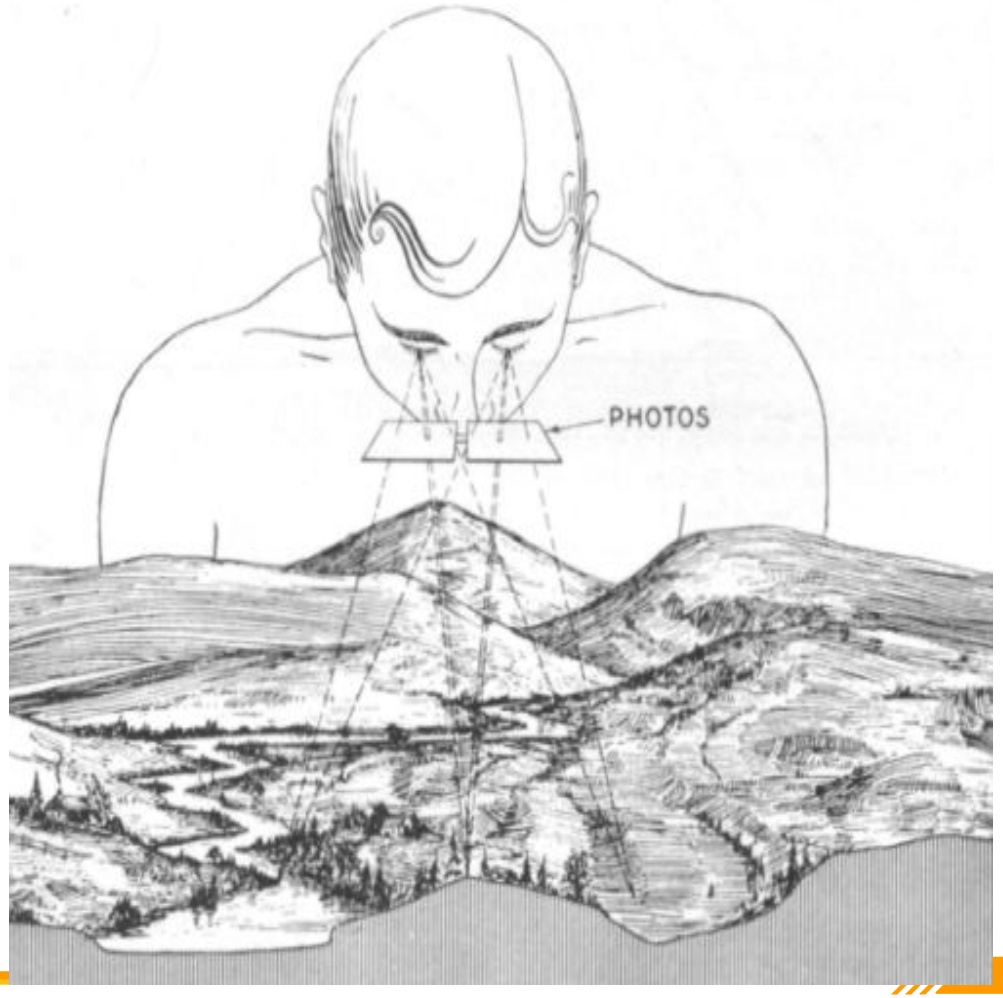
無人載具多時序高解析空間資訊擷取技術整合、精度評估及應用

張國楨

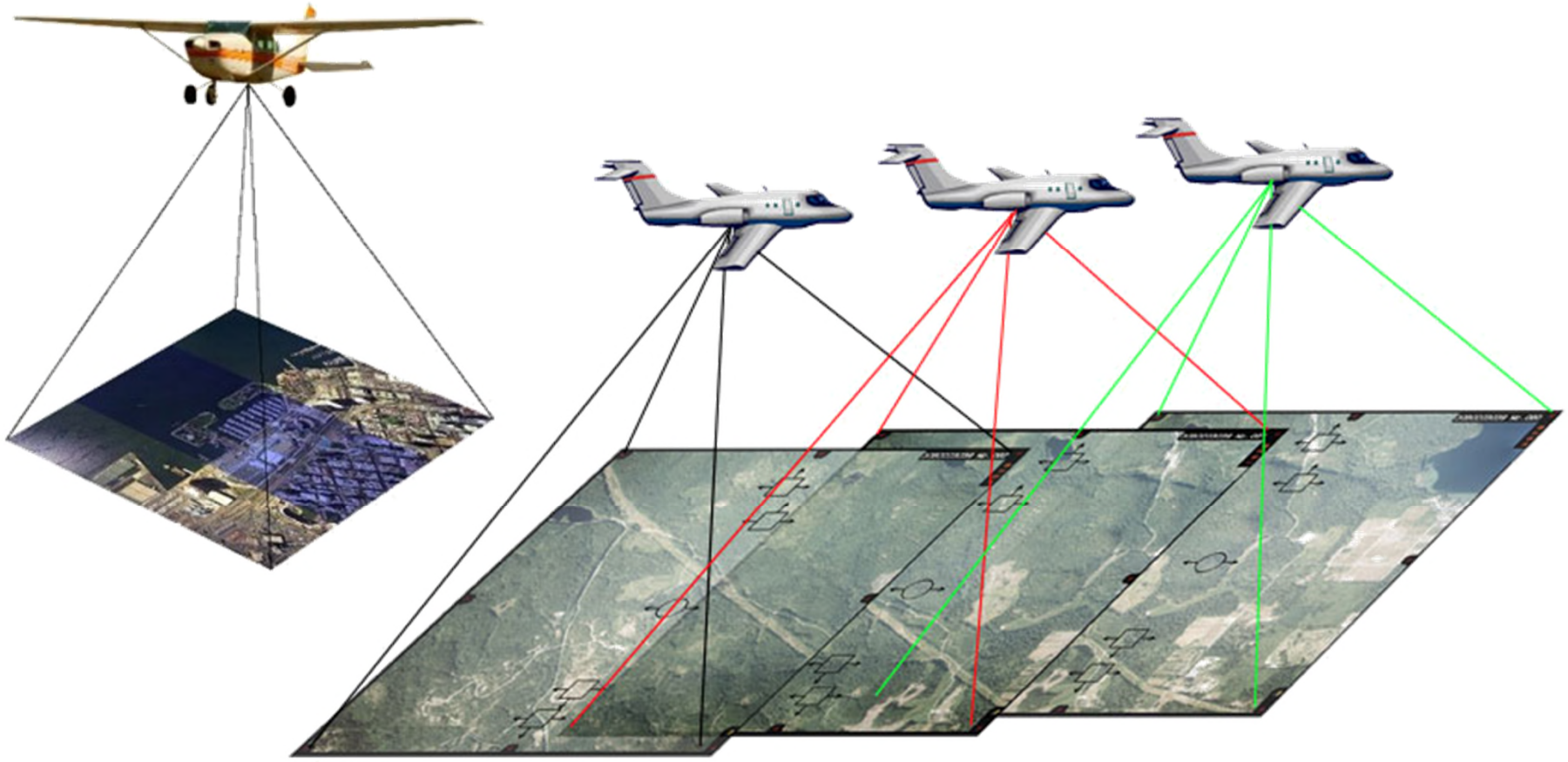
台北科技大學土木系

Parallactic Angles Used During Depth Perception

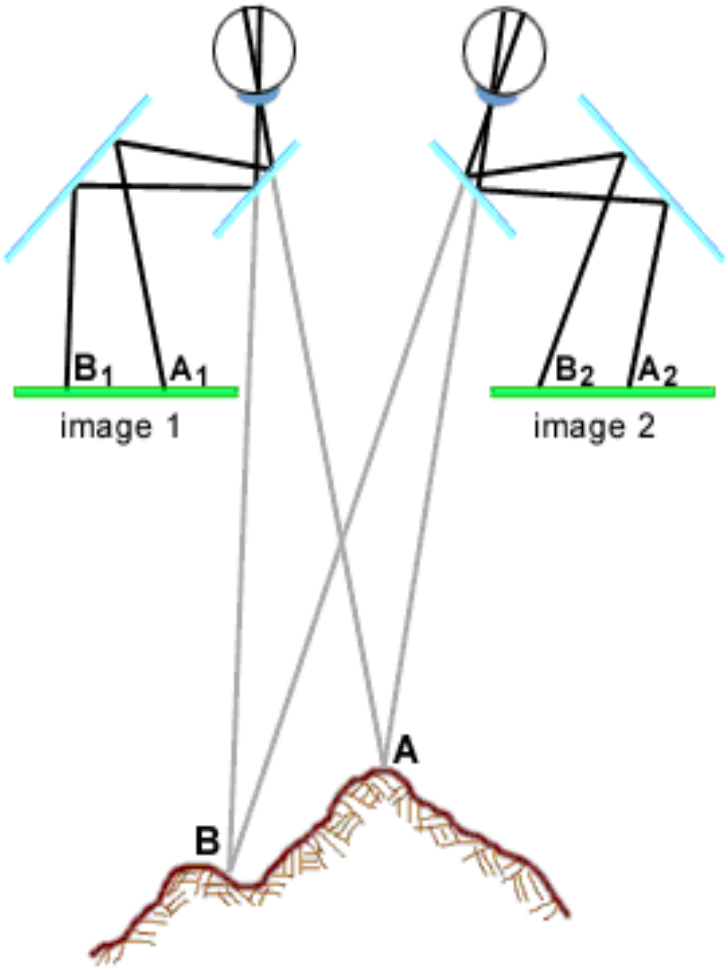




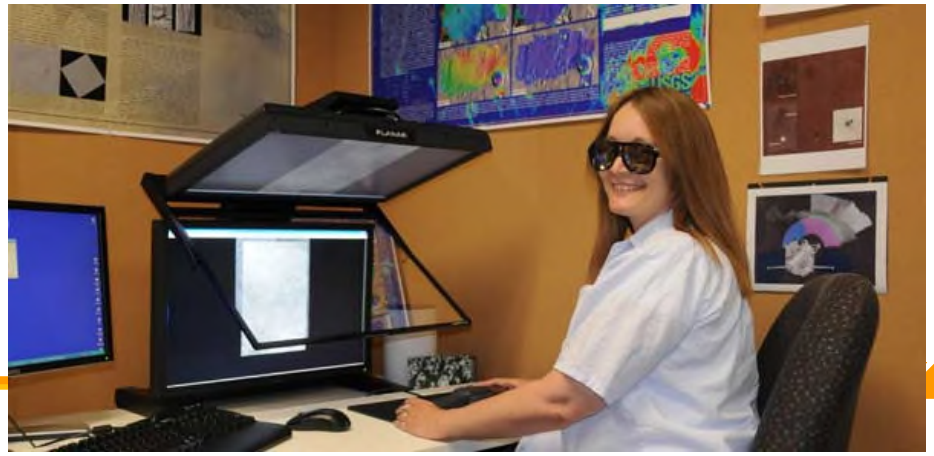
Aerial Photography



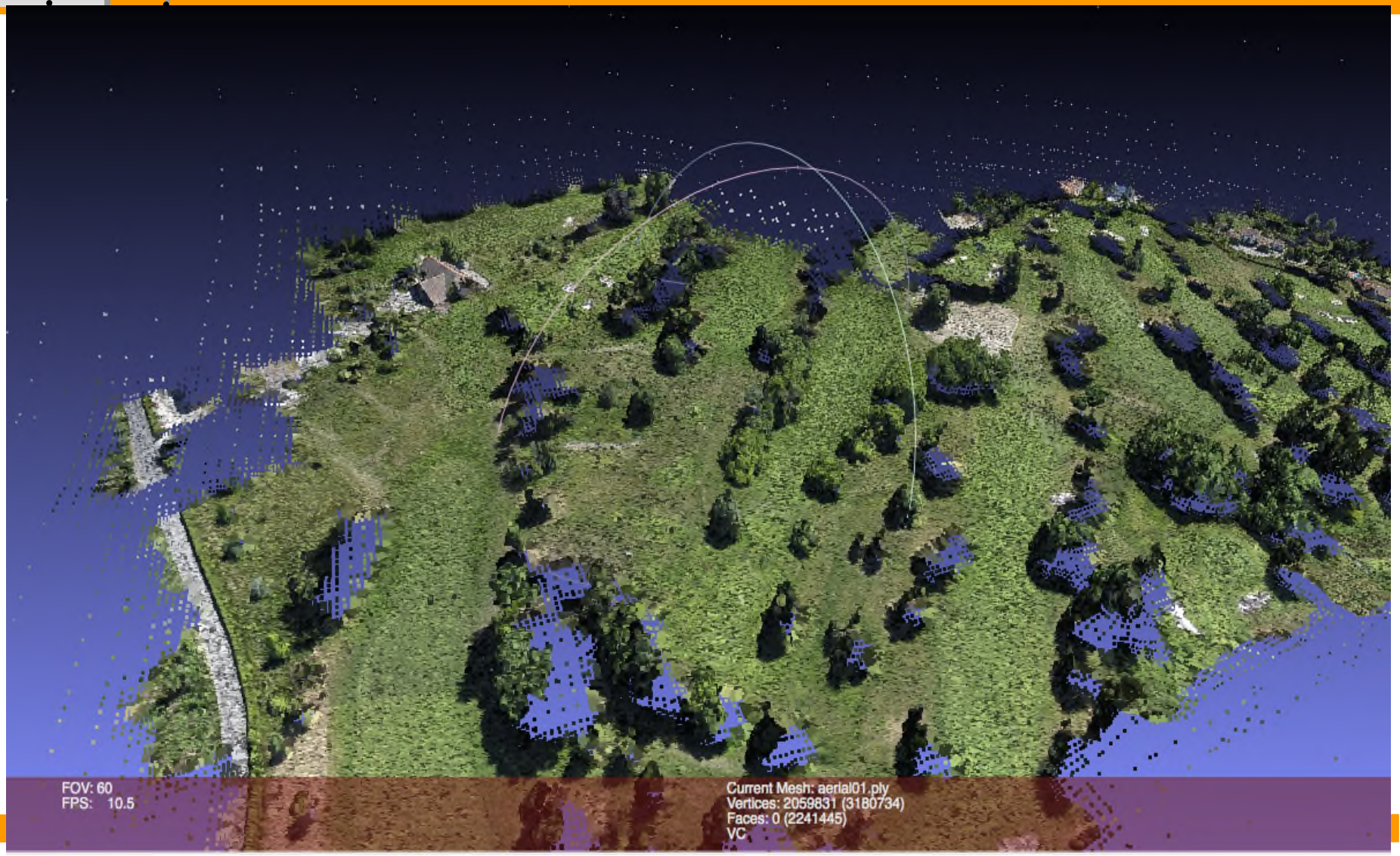
Aerial Photographs





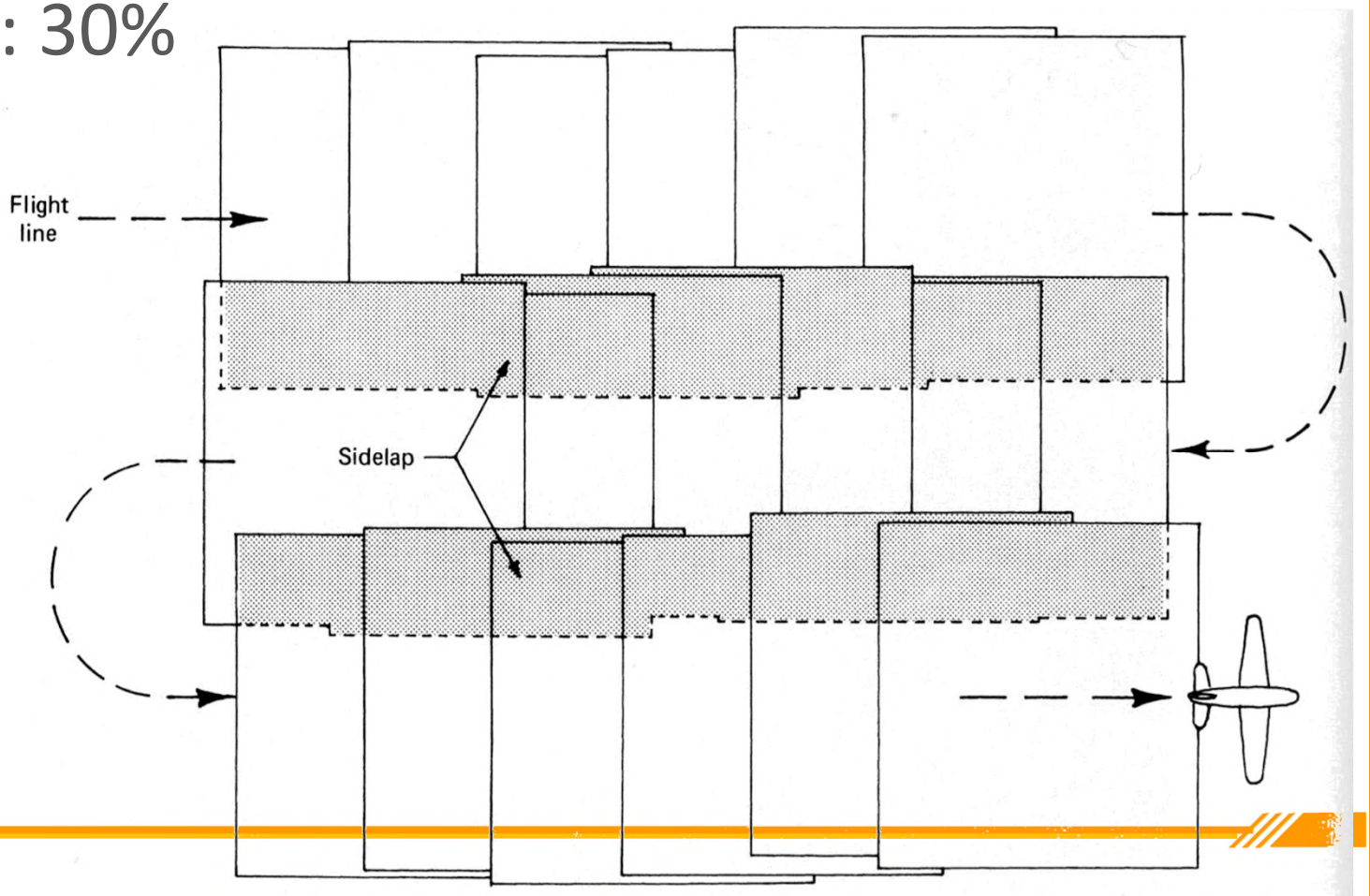


Digital photogrammetry



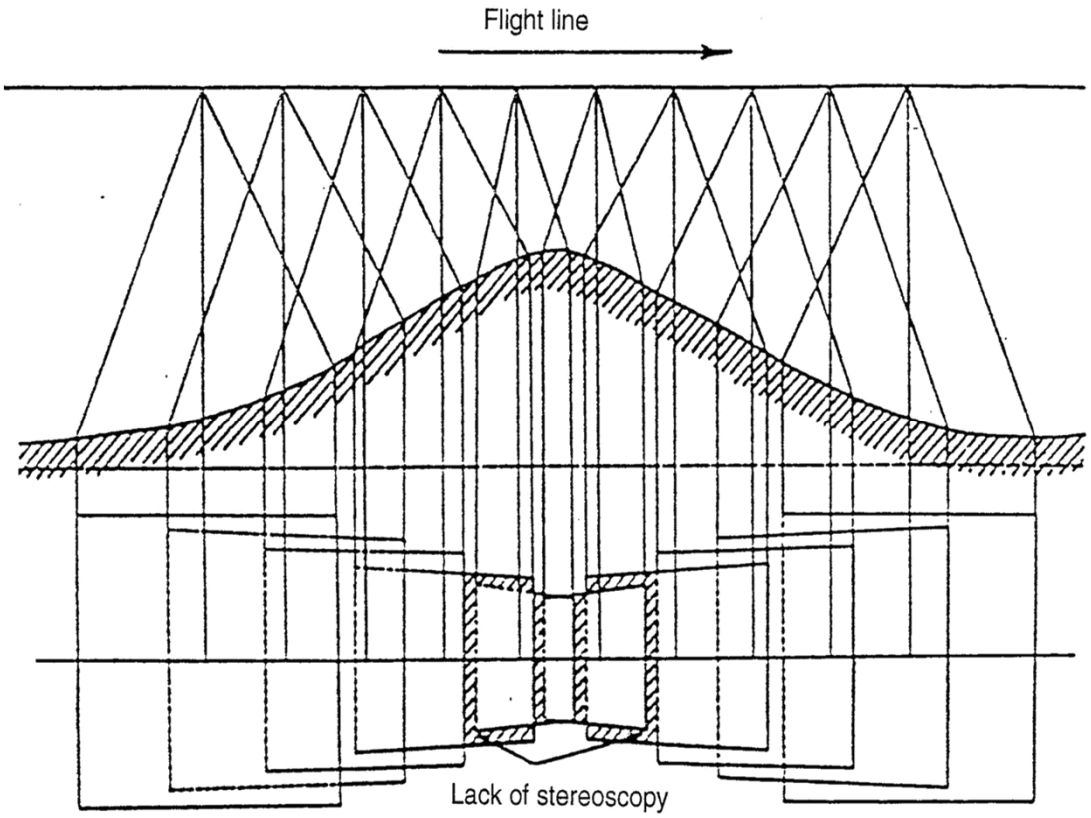
Multiple Photographs

- Forward overlap(endlap): 60% along flight line
- sidelap: 30%



Aerial Photographs

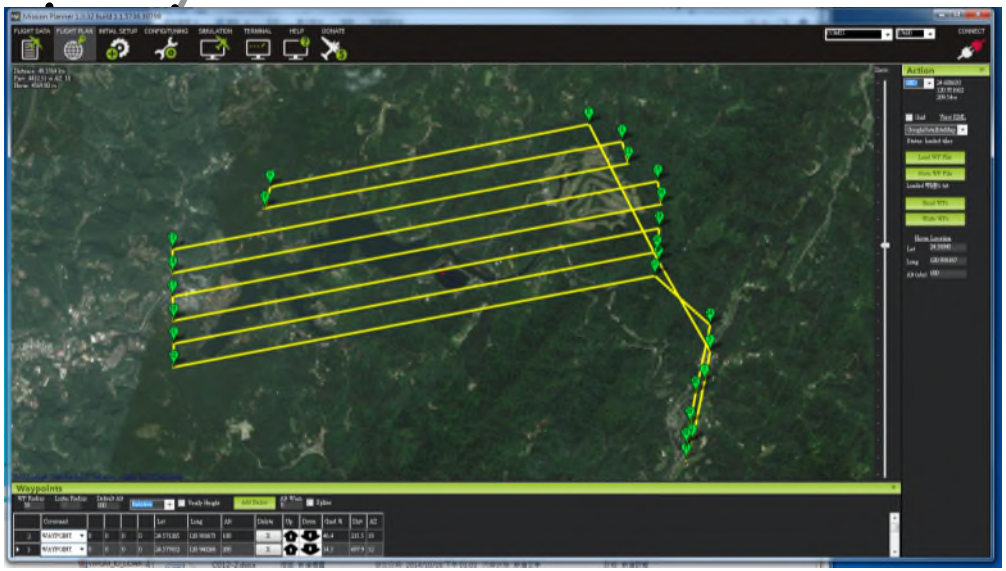
- **Effect of Relief on Scale**

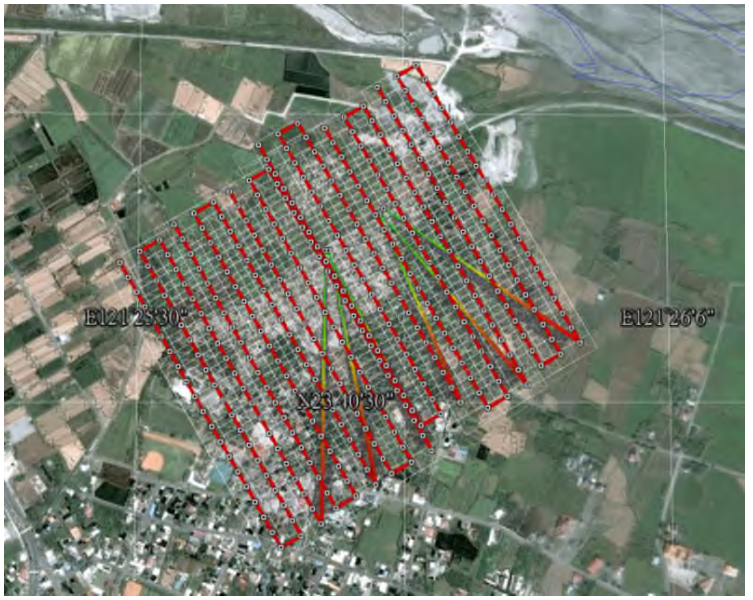


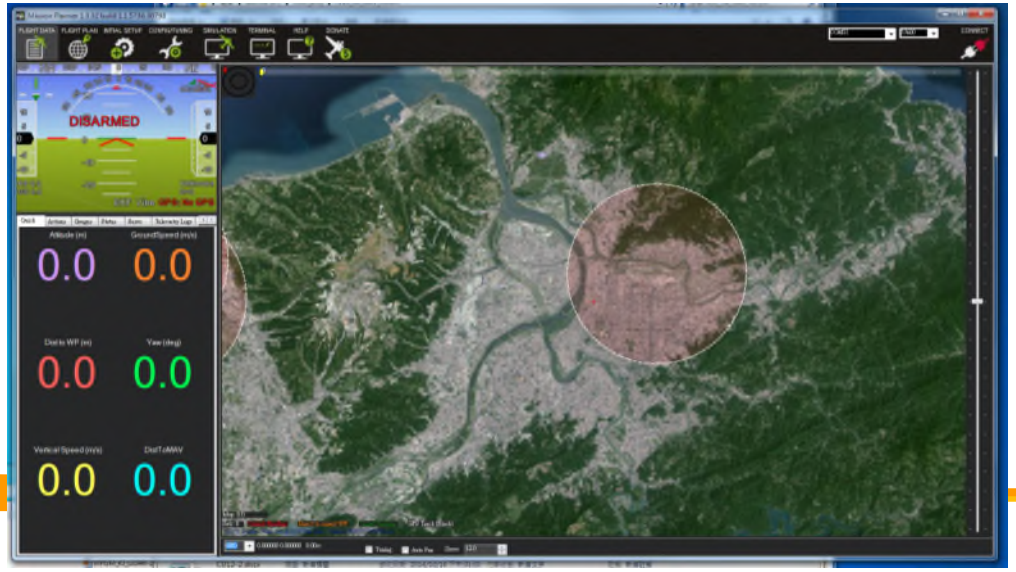
Photogrammetric Drones @ NTUT, 2017



航線、航點規劃及拍照點檢核



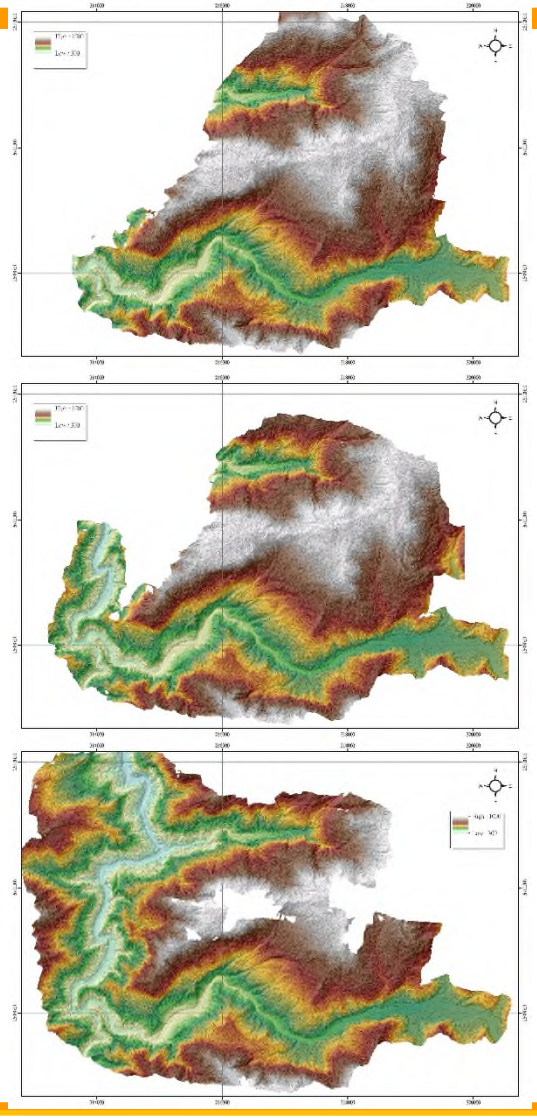


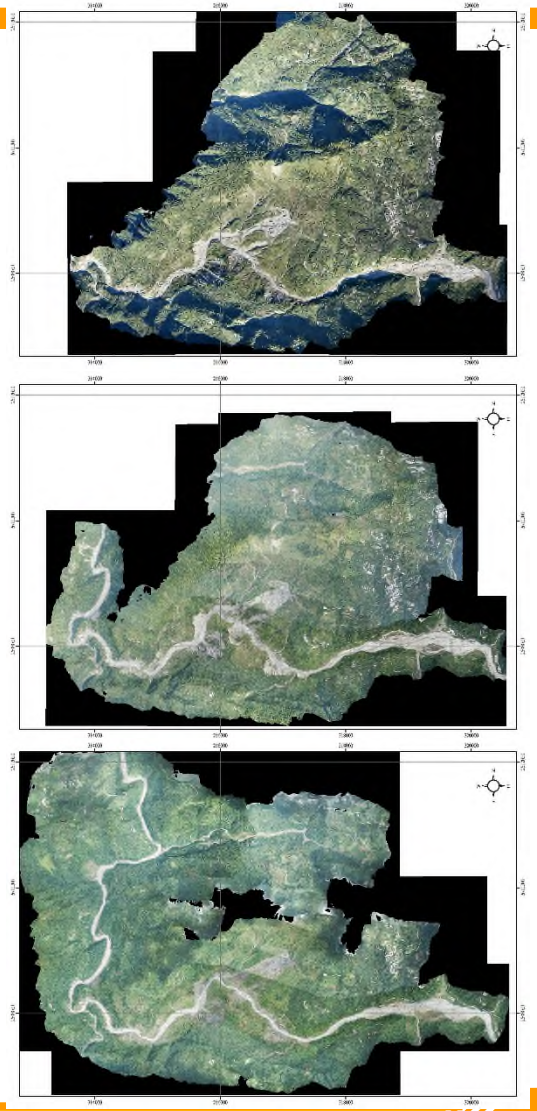




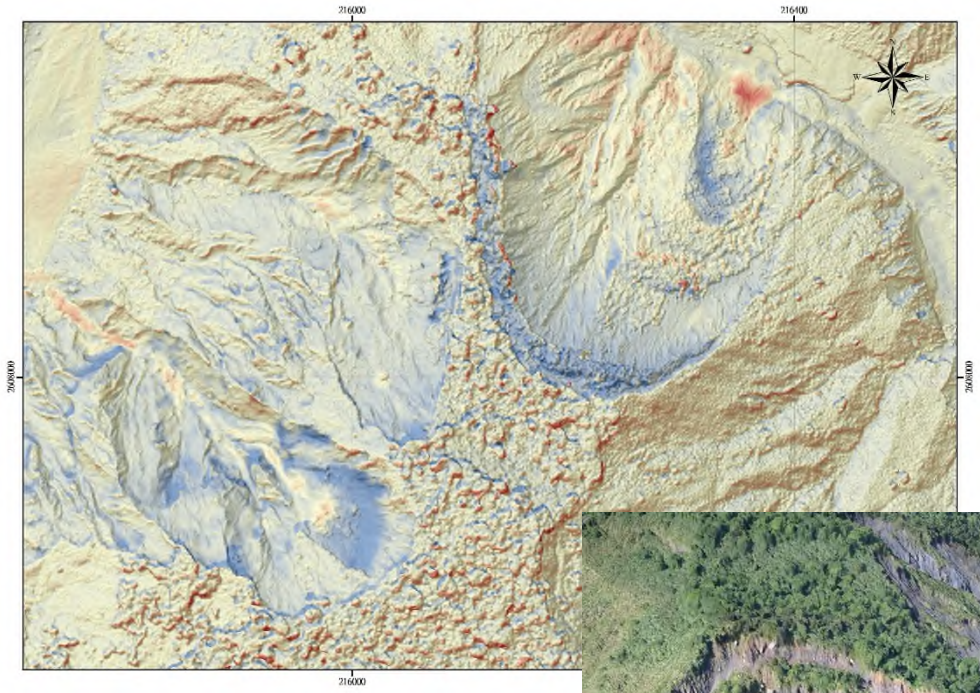
草嶺地區航拍建模成果

- 日期:
  - 2016/08/19
  - 2017/07/09
  - 2017/11/11
  - 2017/12/04
  - 2018/04/22
  - 2018/09/01
  - 2019/10/13
  - **2020/07/19**
- GSD: 10-15cm
- 面積: > 20km^2
- 產出:
  - 正射影像鑲嵌
  - 數值地表模型 (DSM)
  - 三維模型





草嶺山崩堆積區崩崖後退

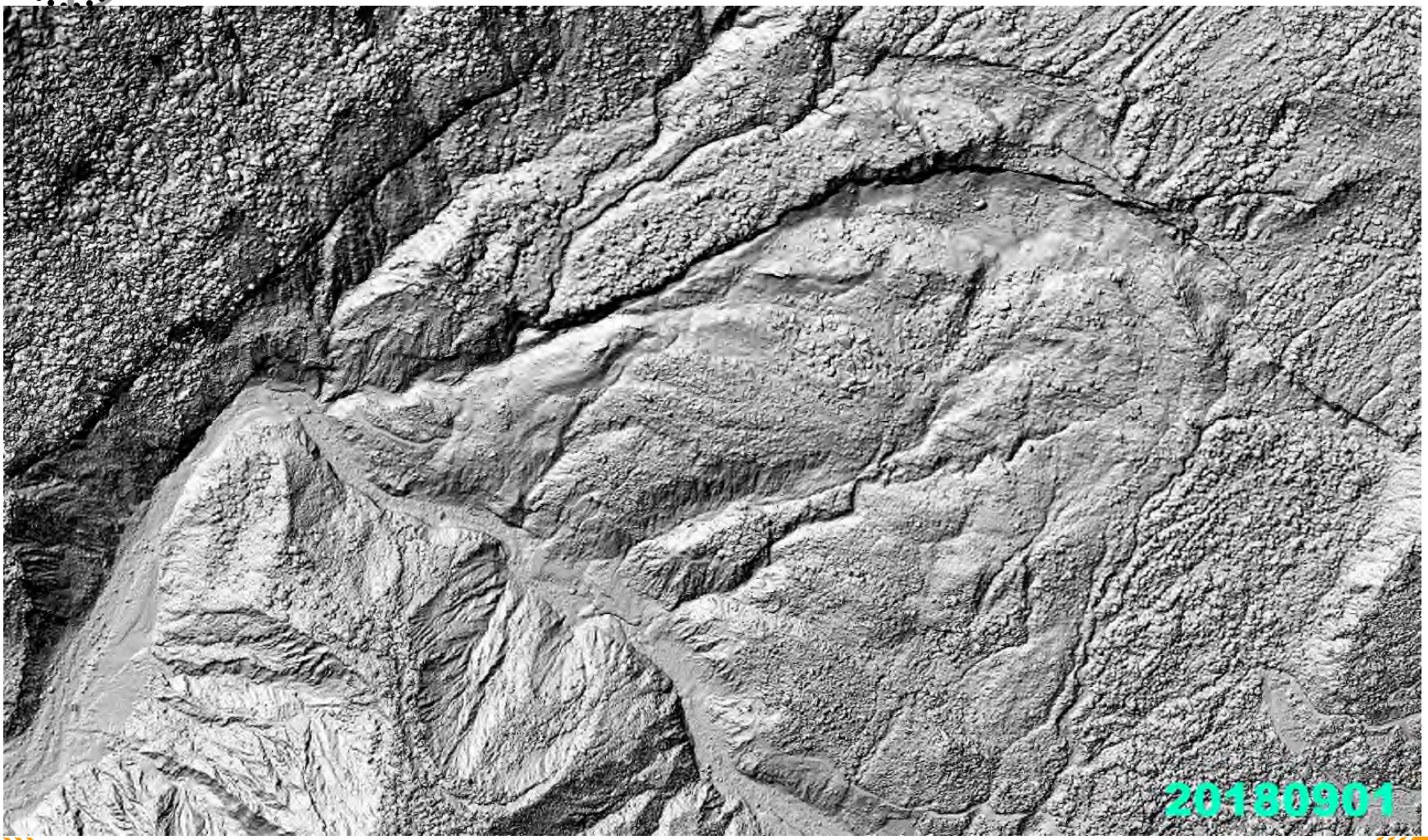




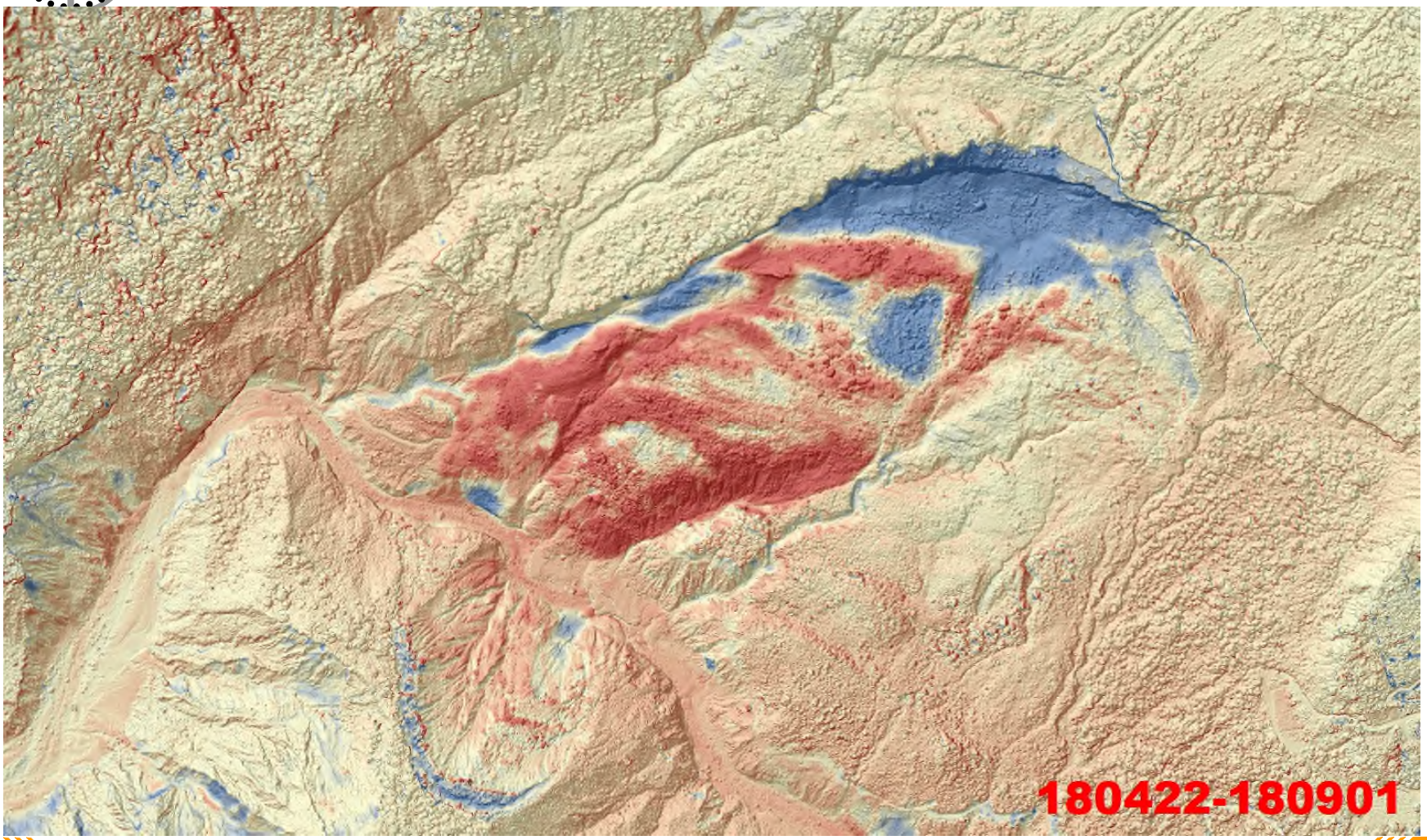



Tsaoling_2017Jul_3mx
Cliff retreat:
133-167m
Slid mass:
1.6 Mm3

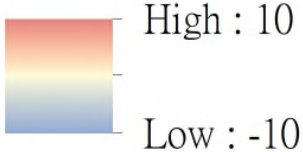
草嶺山崩區地形變動分析

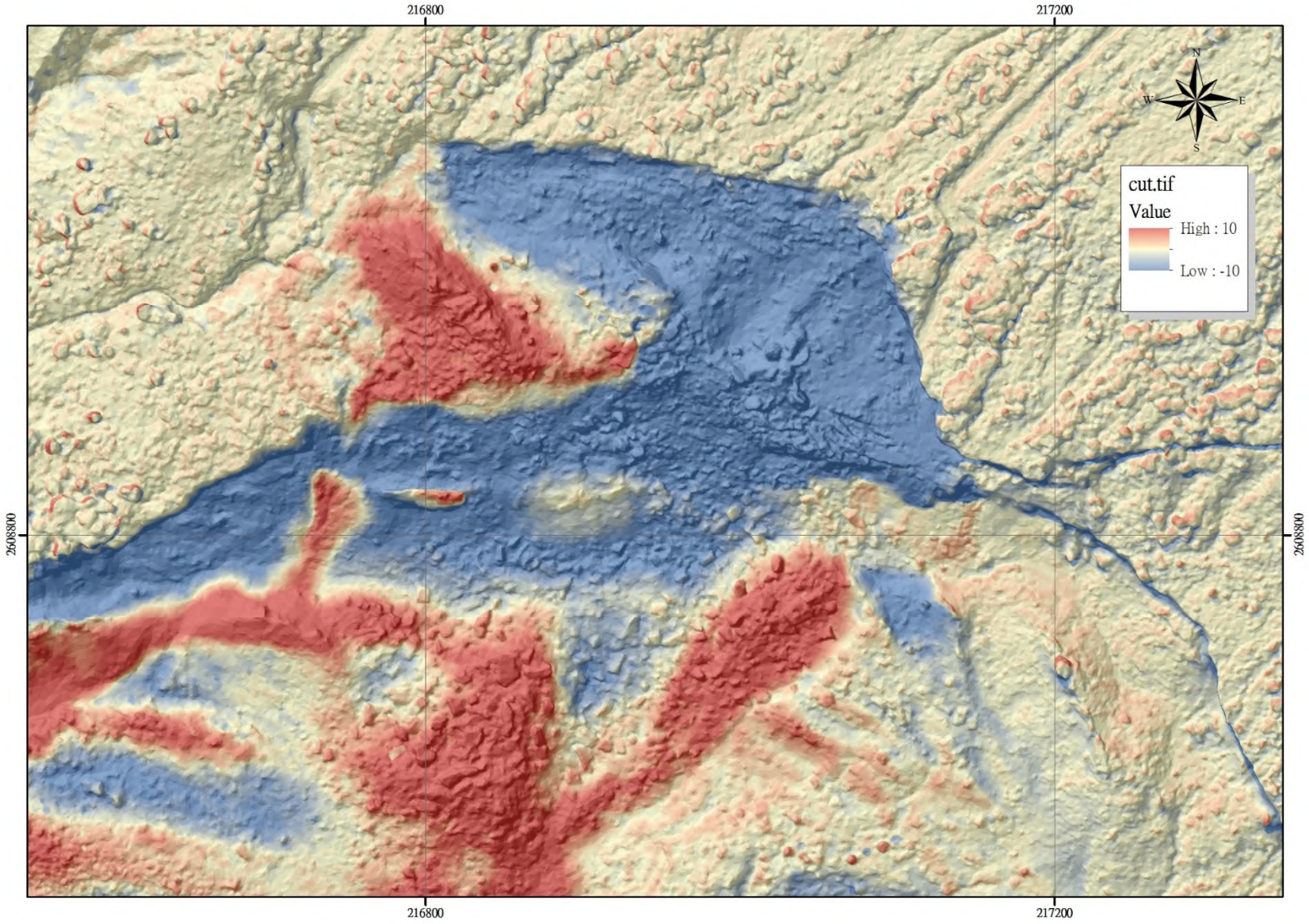


草嶺山崩區地形變動分析

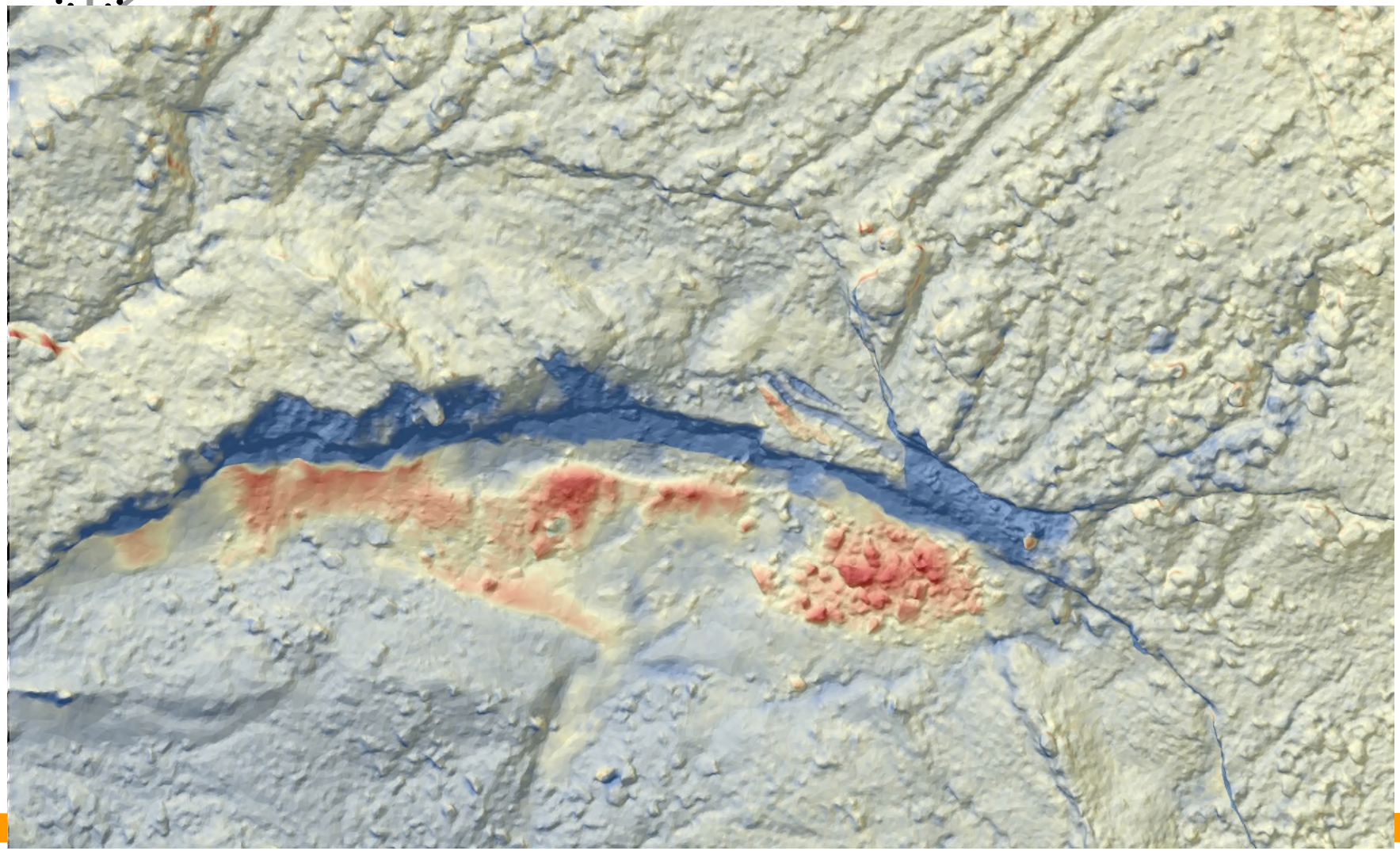


地形變異量體計算

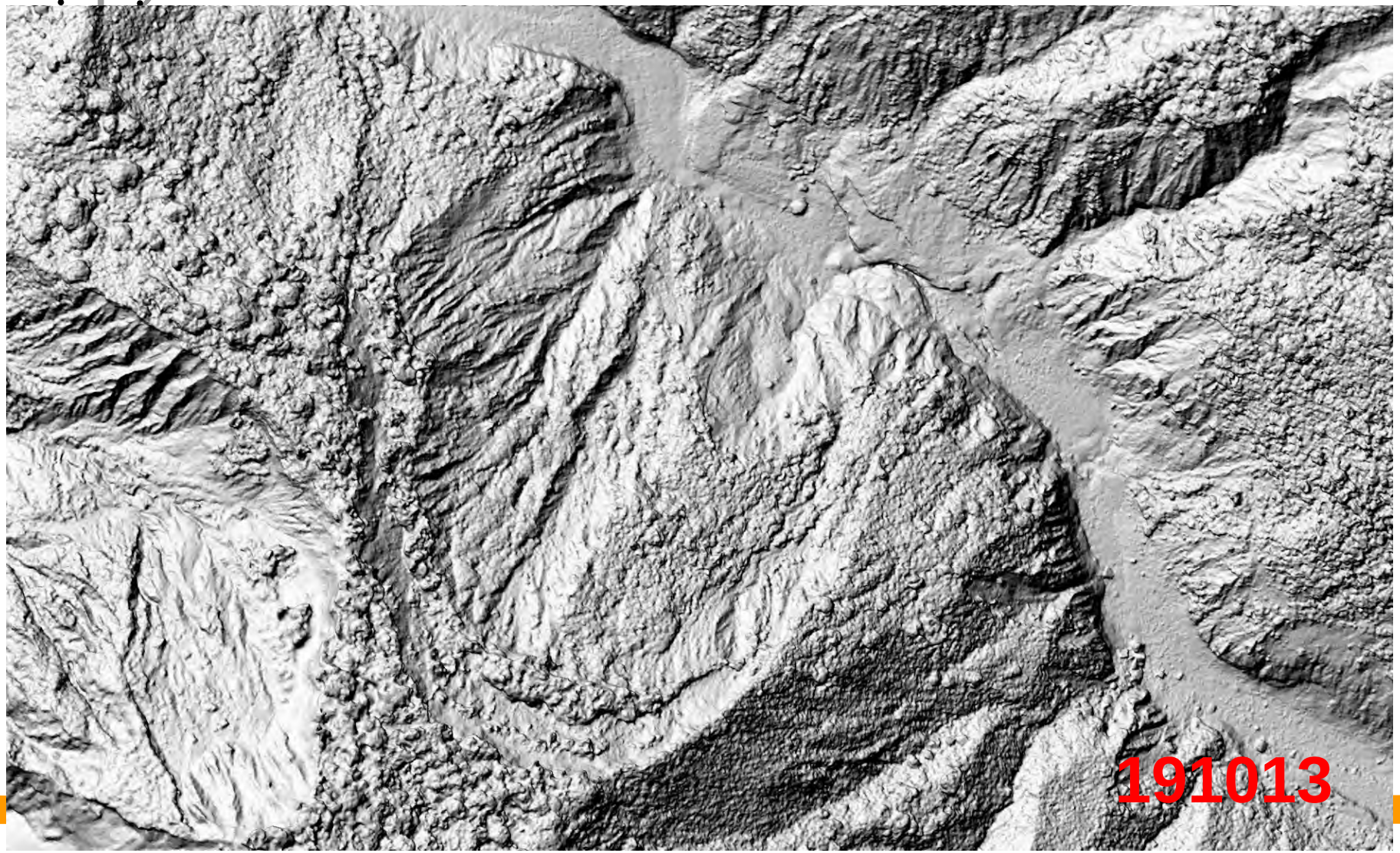

High : 10
Low : -10


216800
217200
2608800
N
W
E
S
cut.tif
Value
High : 10
Low : -10

Scarp Line Retreat



Activate Landslide in Zone of Accumulation

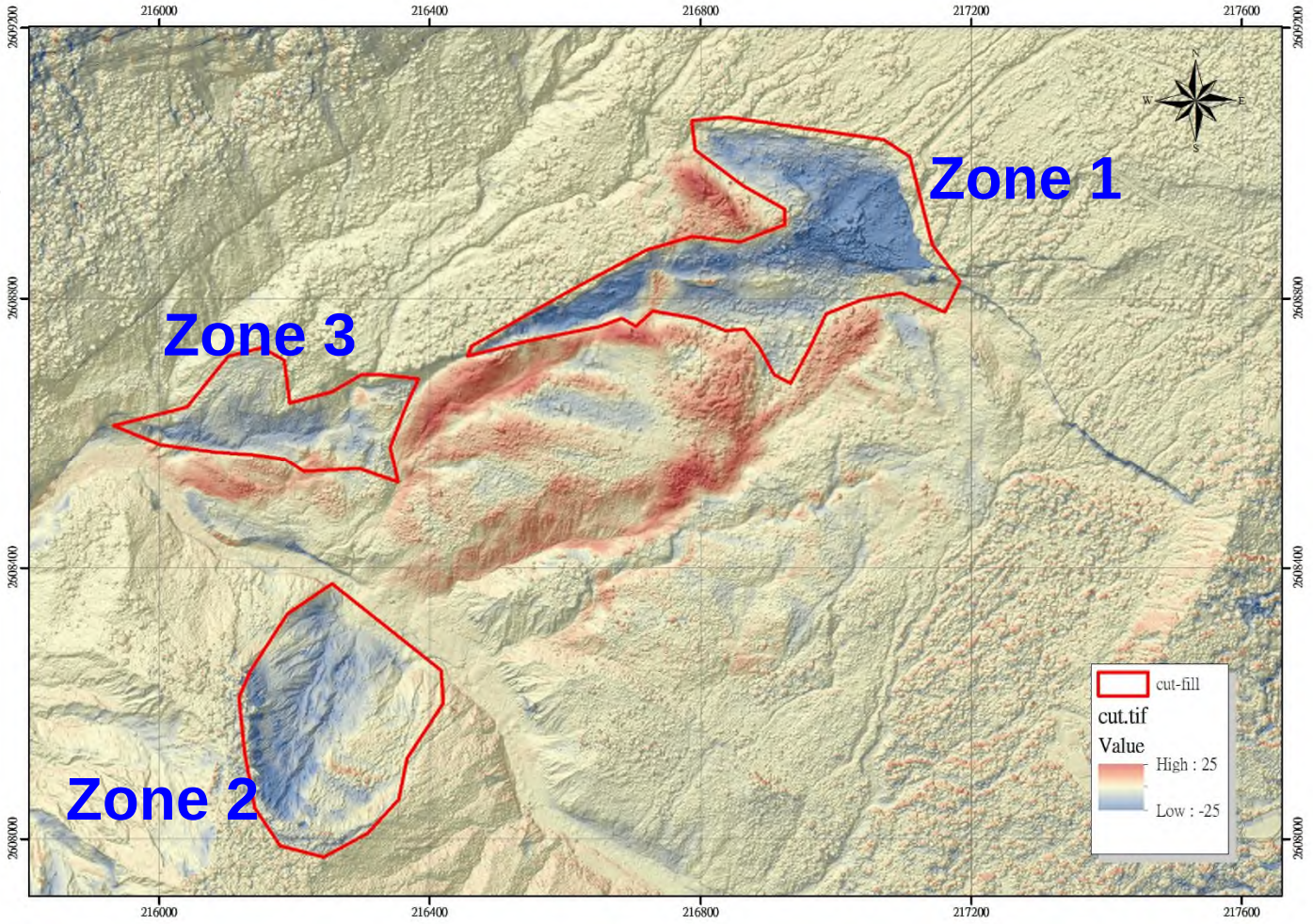


地形變異量體計算

Zone 1
- 1.54 Mm^3
- >150m
- Fault

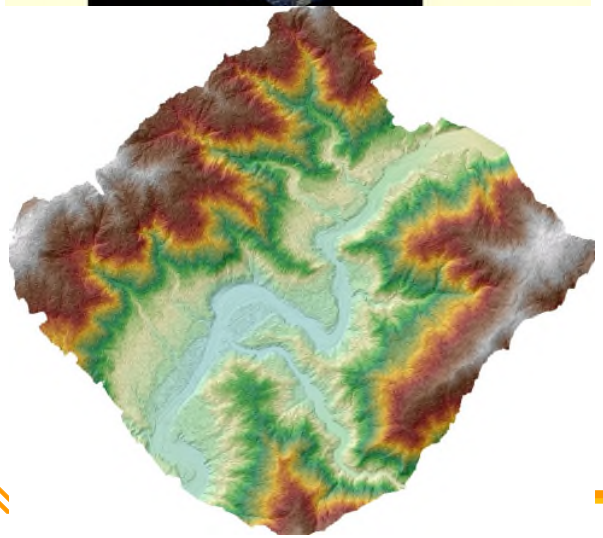
Zone 2
- 0.69Mm^3

Zone 3
- 0.25Mm^3



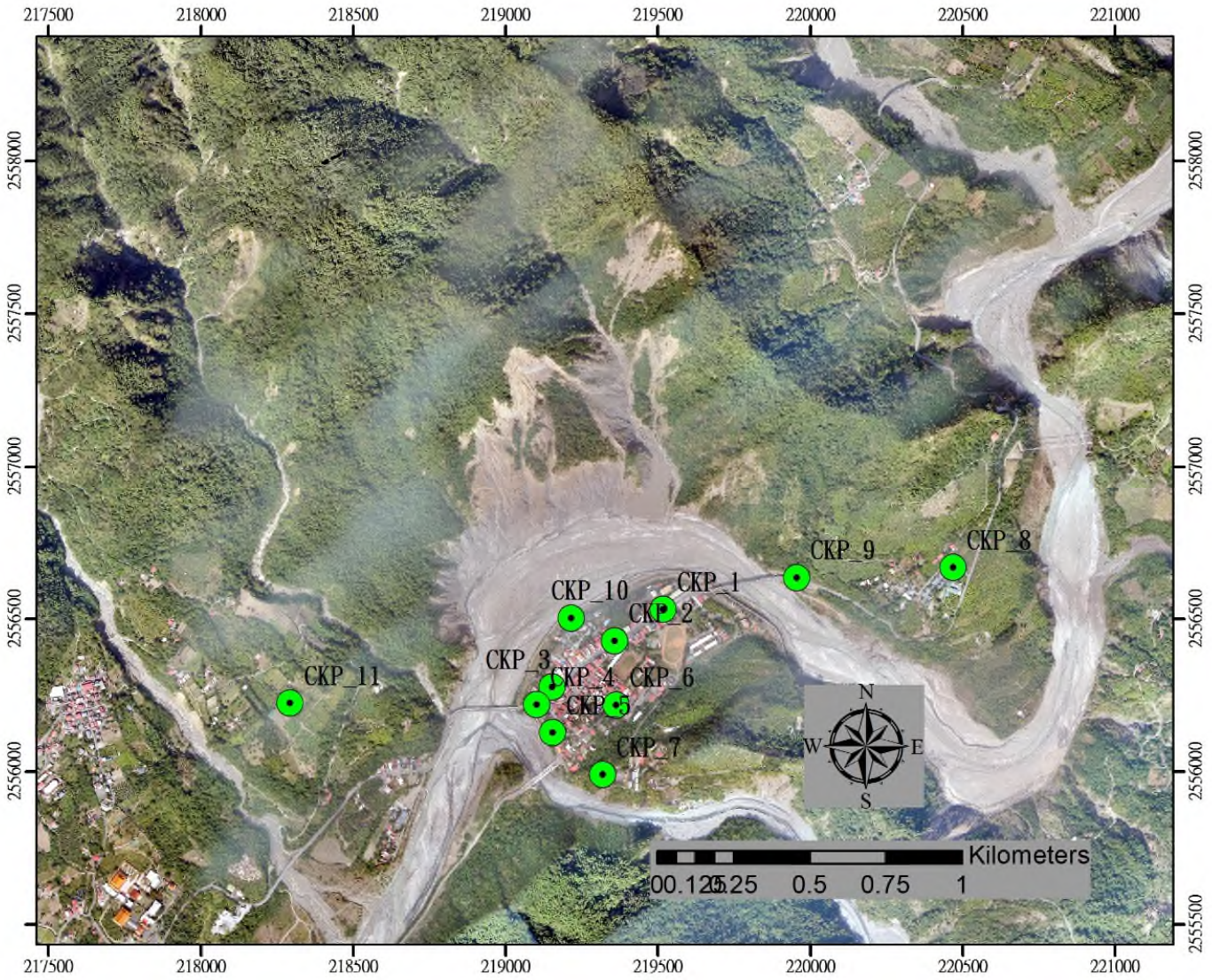
多時期影像及空間資料庫建置





日期	點位數量		照片數量
	控制點	檢核點	
2015/02/01	12	9	1454
2015/11/09	11	8	2398
2016/06/06	13	11	390
2016/11/18	13	11	2556
2017/07/08	15	11	746
2017/09/24	15	10	752
2017/11/15	12	10	1182
2017/11/17	15	11	683
2018/01/18	15	11	941
2018/07/20	19	11	1393
2018/12/22	19	11	964
2019/06/09	19	11	1922
2019/0717	19	11	1924
2019/11/24	19	11	1678
2020/03/08	19	11	1956
2020/09/19	19	11	3120

Ground Control and Check Points



Topographic Changes in Baolai

Base model：2017/11/17



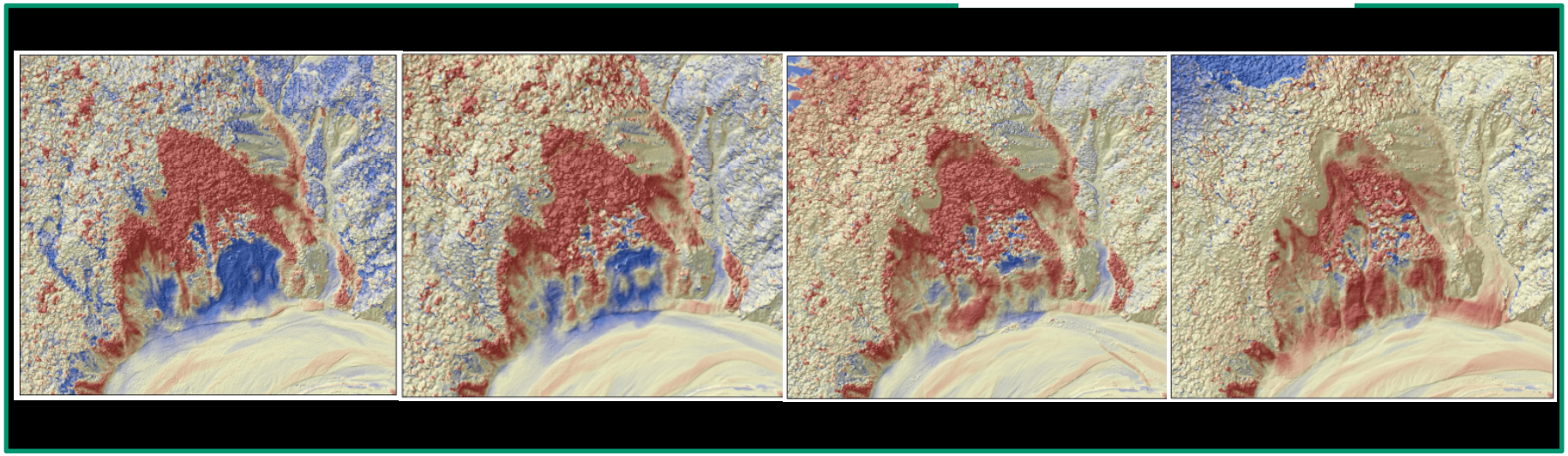


High： 10

Low：-10

0 0.5 1 KM

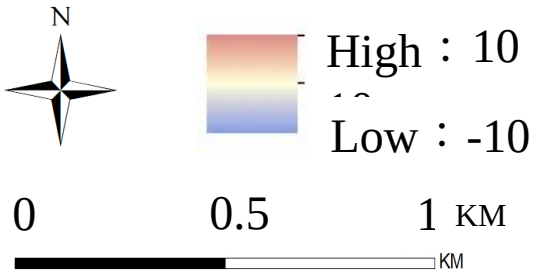
KM

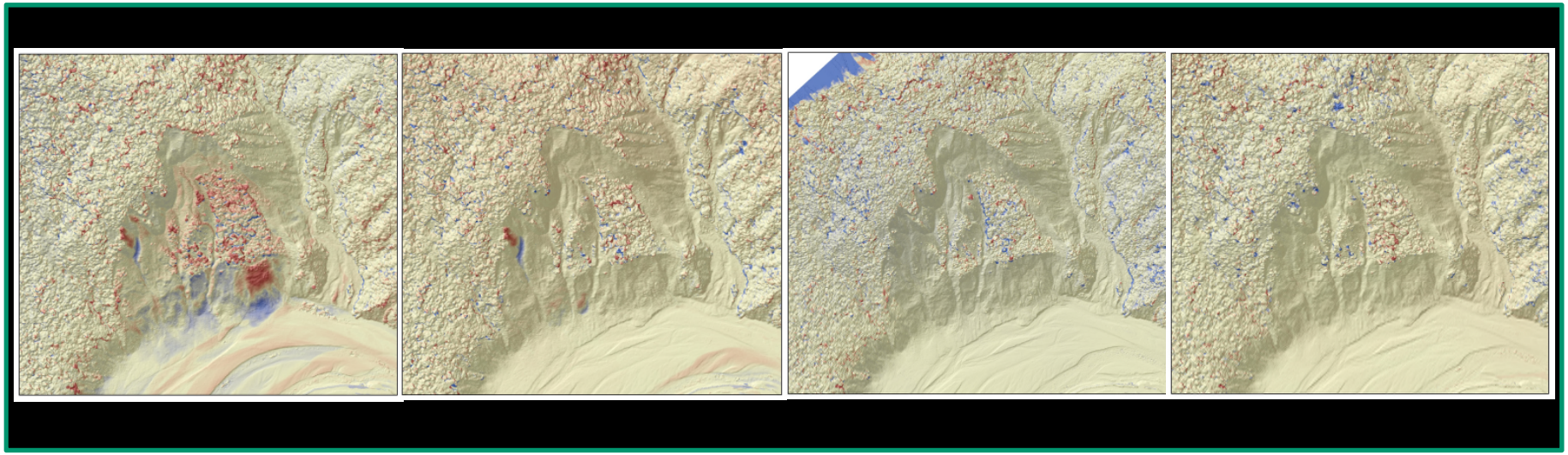


2015/02/01 2015/11/09 2016/06/06 2016/11/18

Topographic Changes in Baolai (cont.)

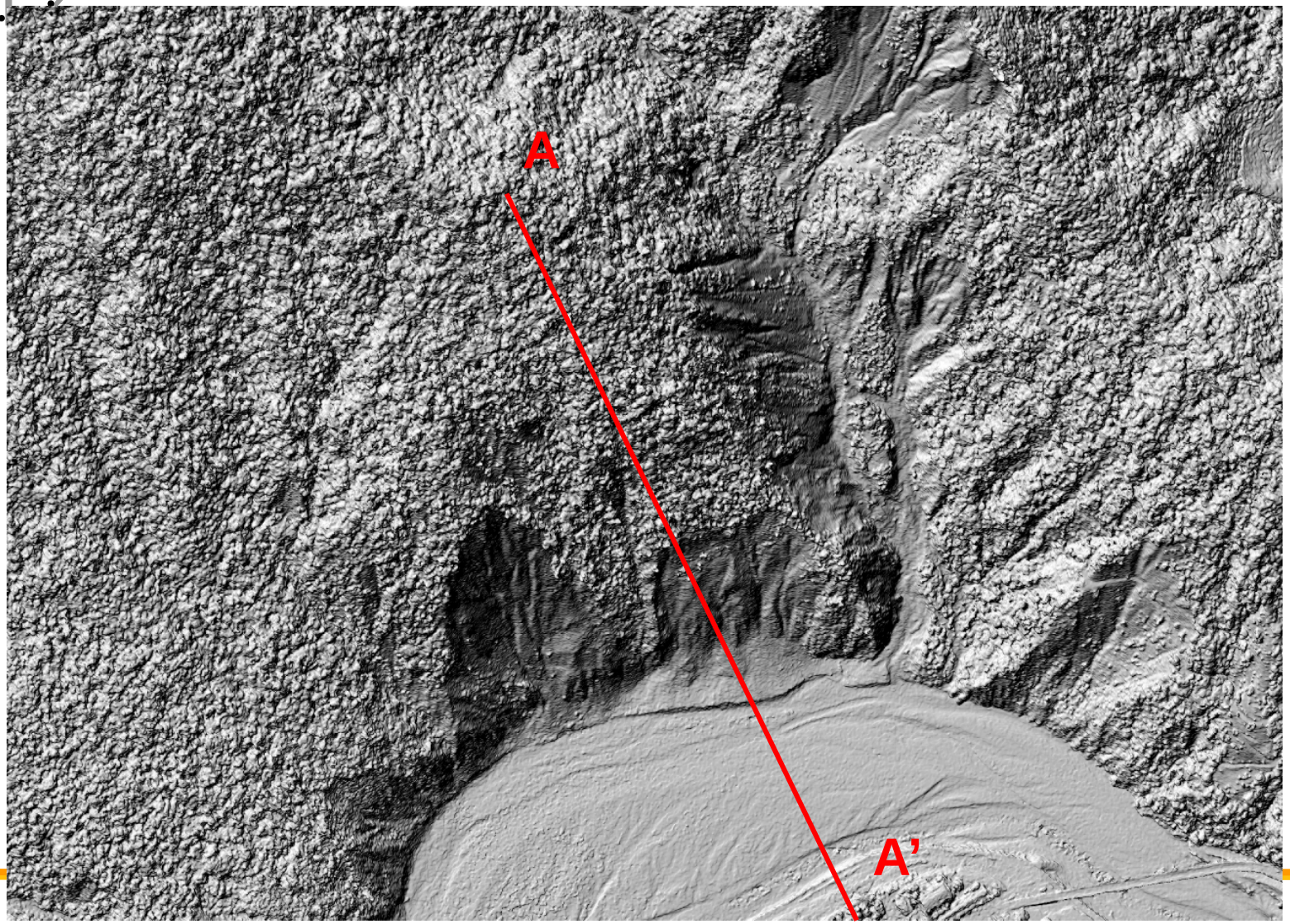
Base model：2017/11/17



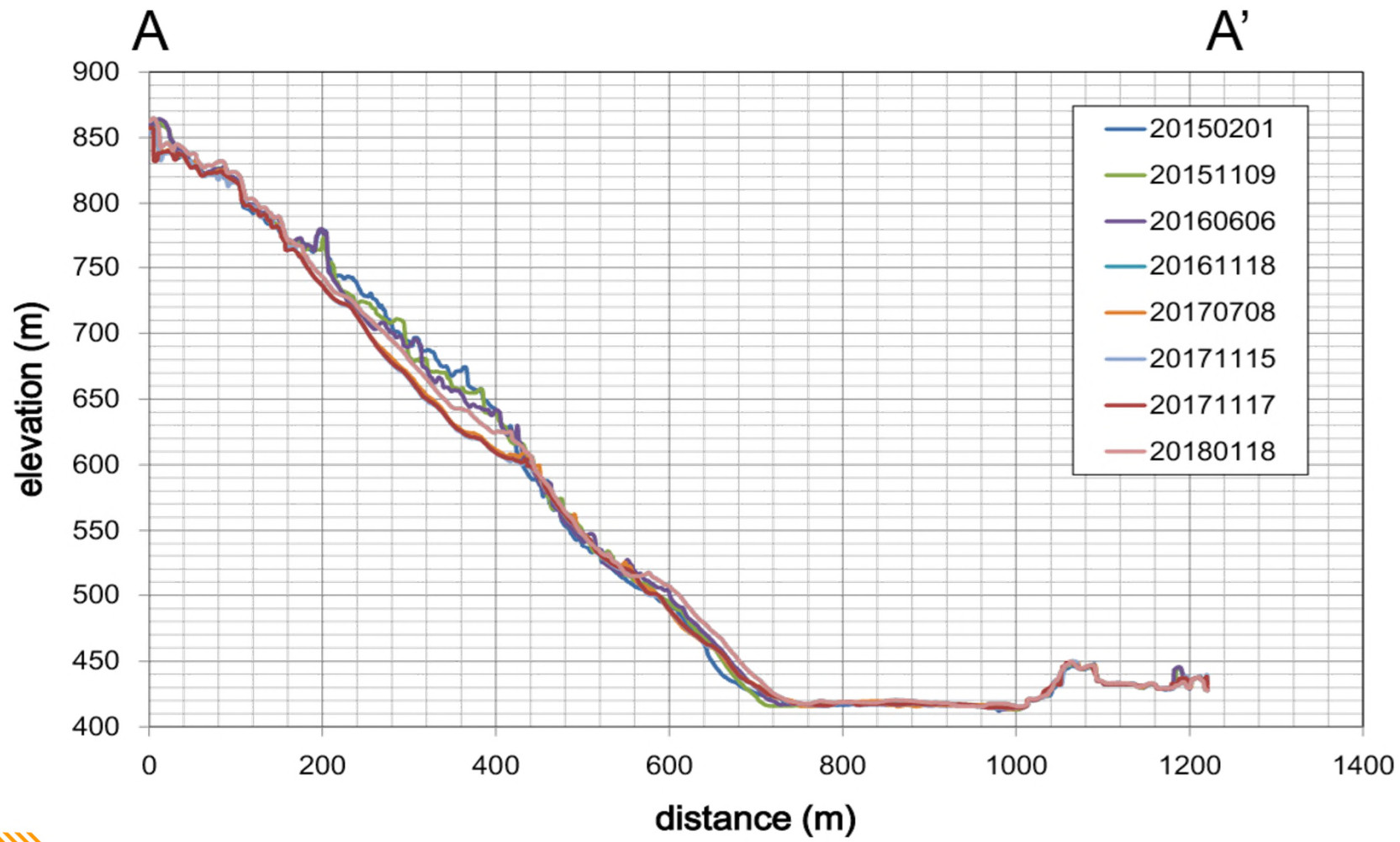


2017/07/08 **2017/09/24** **2017/11/15** **2018/01/18**

Landslide Monitoring in Baolai



Topographic Changes



塊體崩塌位移量



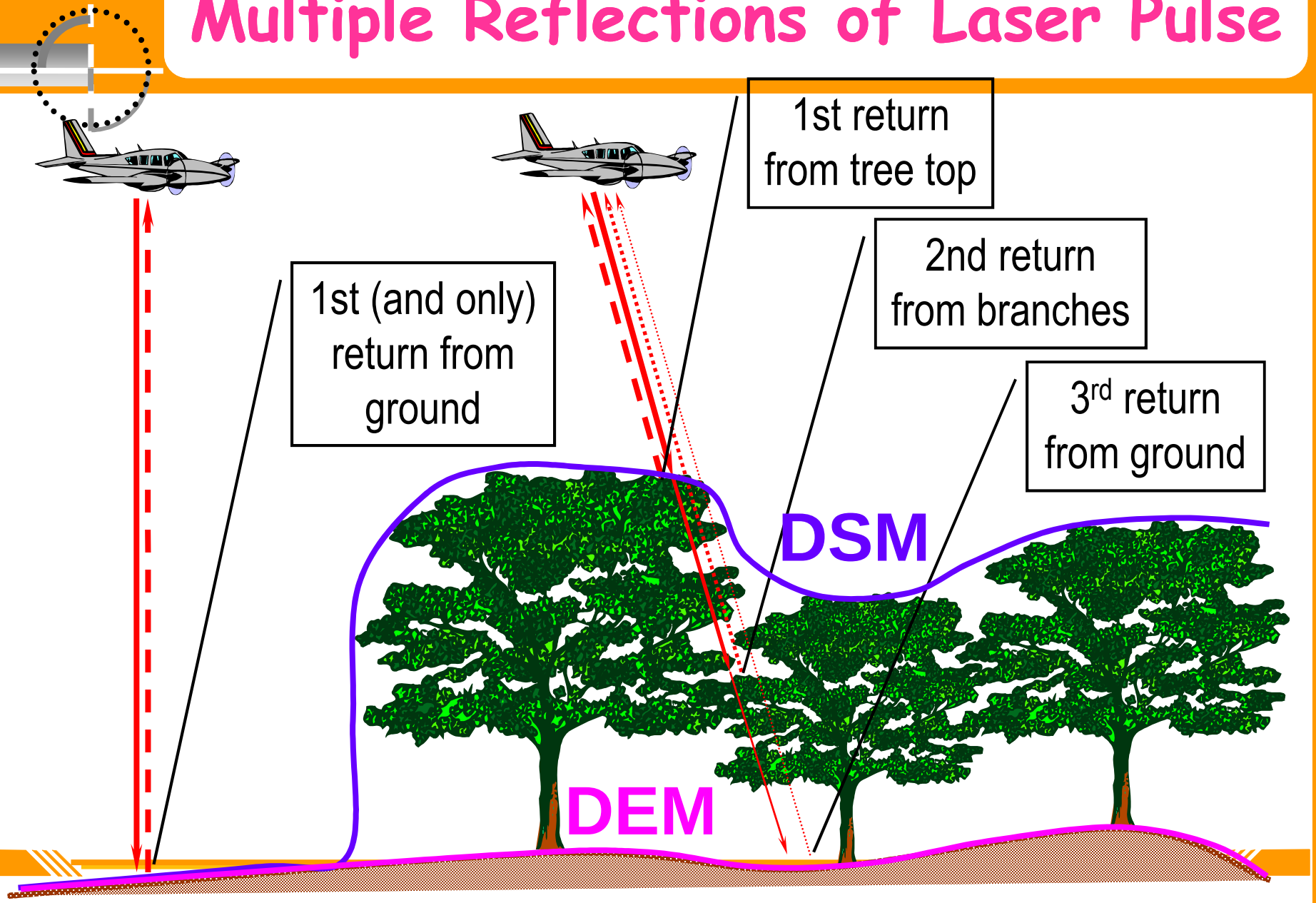
平面位移量
3.460
4.177
1.941
2.557
1.426
3.533
3.182
4.174
4.864
4.508

（單位：公尺）

Horizontal Displacement

canopy number	170708-170924	171117-180118	total disp. (m)
1	0.647	0.325	26.243
2	0.858	1.022	24.123
3	1.098	0.217	9.431
4	0.469	0.582	35.145
5	0.368	0.636	38.767
6	0.541	0.958	70.567
7	0.651	0.998	34.578
8	0.404	0.917	59.401
9	0.469	0.328	57.543
10	0.711	0.000	11.775
11	0.421	0.000	31.935
12	0.782	0.593	8.332
13	0.660	0.687	4.931
14	0.556	0.402	20.035
15	0.496	0.000	4.595
16	0.405	0.000	4.620
17	0.505	0.284	2.868
18	0.455	0.096	3.507

Multiple Reflections of Laser Pulse



UAS LiDAR System, 2017

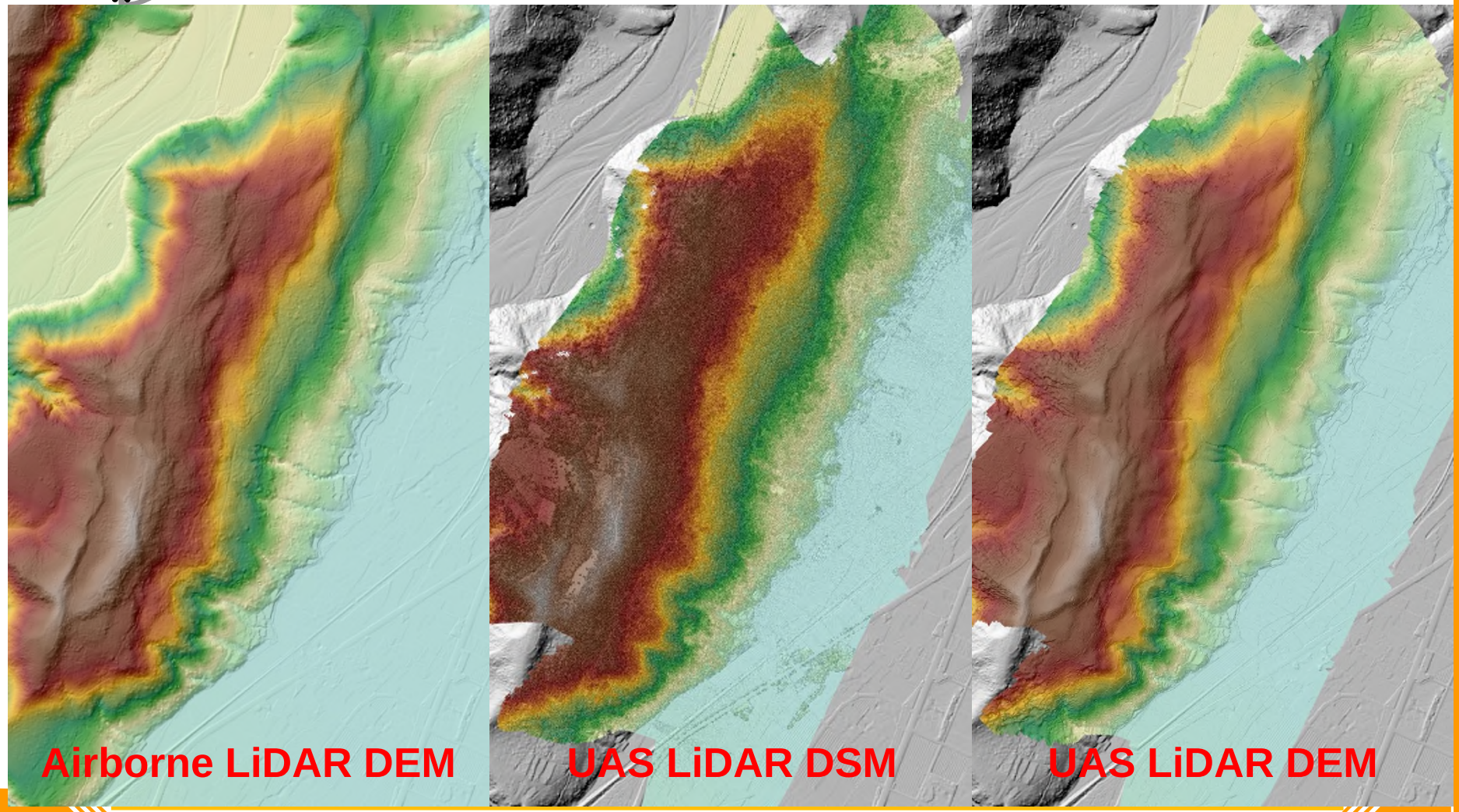


UAS LiDAR System

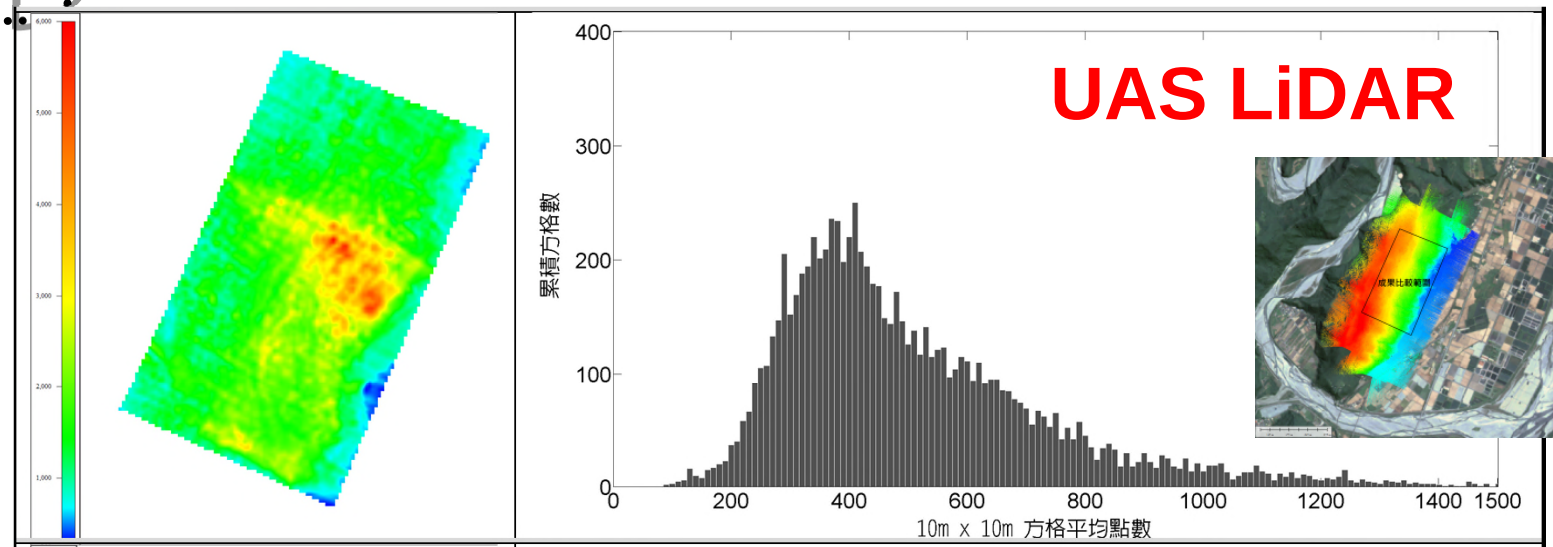
Riegl VUX-1 UAV + Trimble Applanix AP20

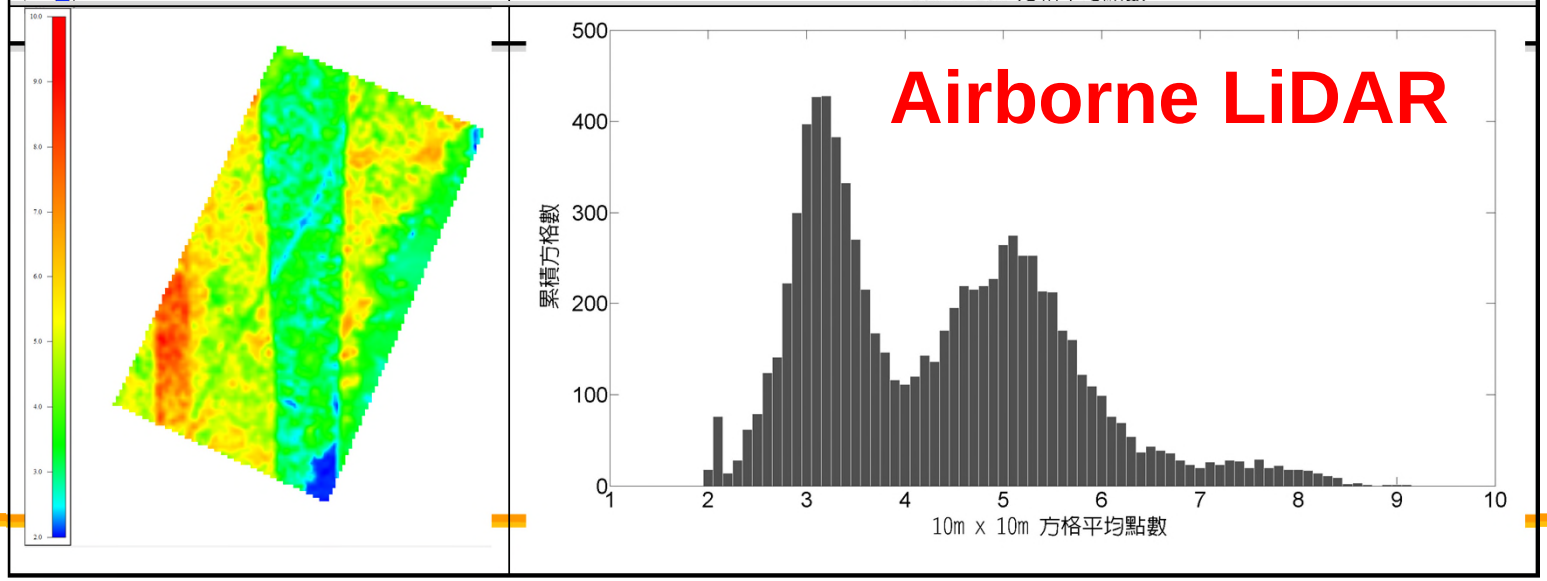
Lightweight	3.75Kg	VUX-1 + AP20
Dimension	227x209x129 mm	
Accuracy	10mm	
Precision	5mm	
Data rate	550kHz	
FOV	330°	
Max Range	920m(Reflectivity 60%) 550m(Reflectivity 20%)	
Max Meas. Rate	550000 points/s	
Operation High	5500m	
Storage	240G SSD	
OP Temperature	-20℃~50℃	

Landslide Mapping ~ 3Km^2

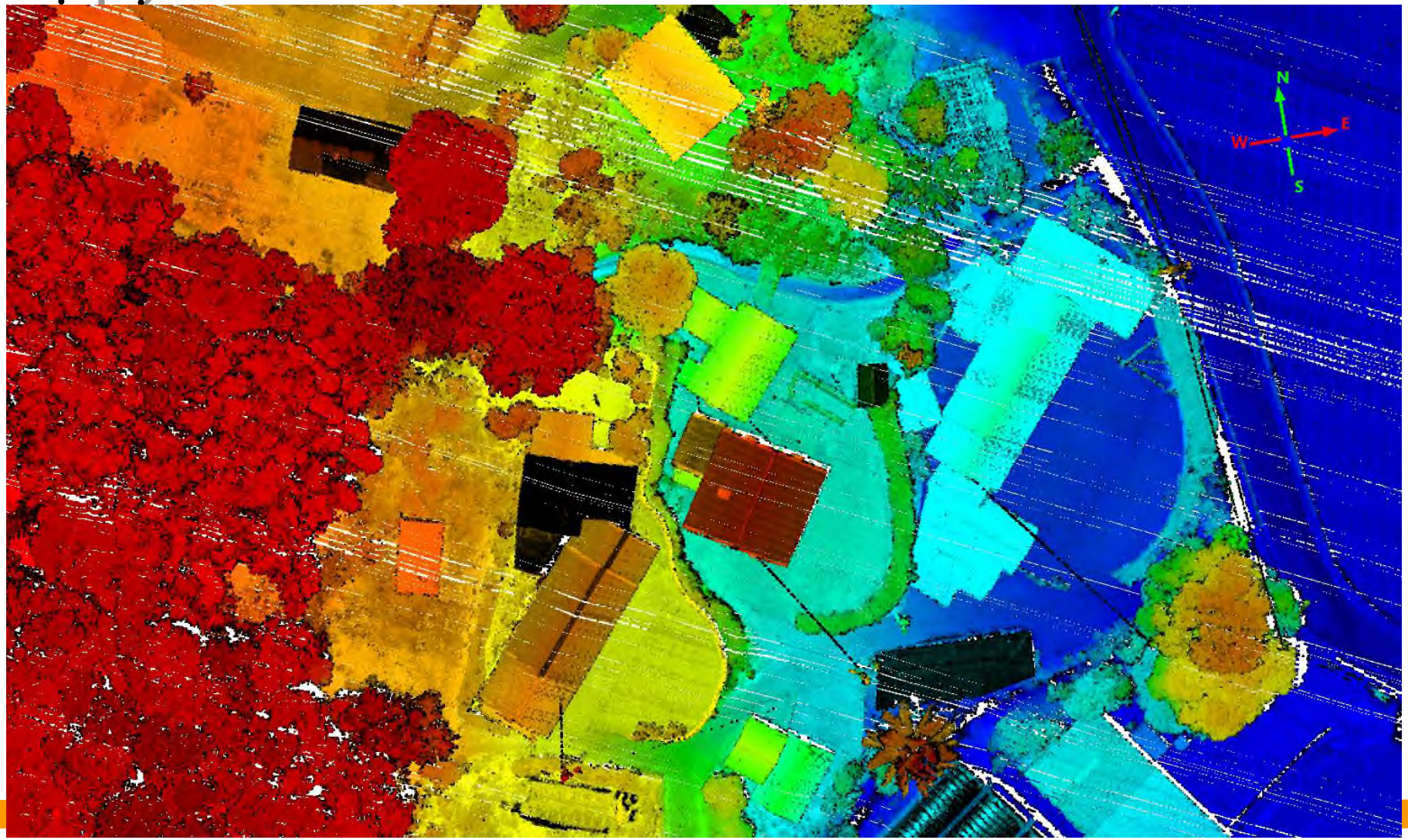


Density of Point Cloud

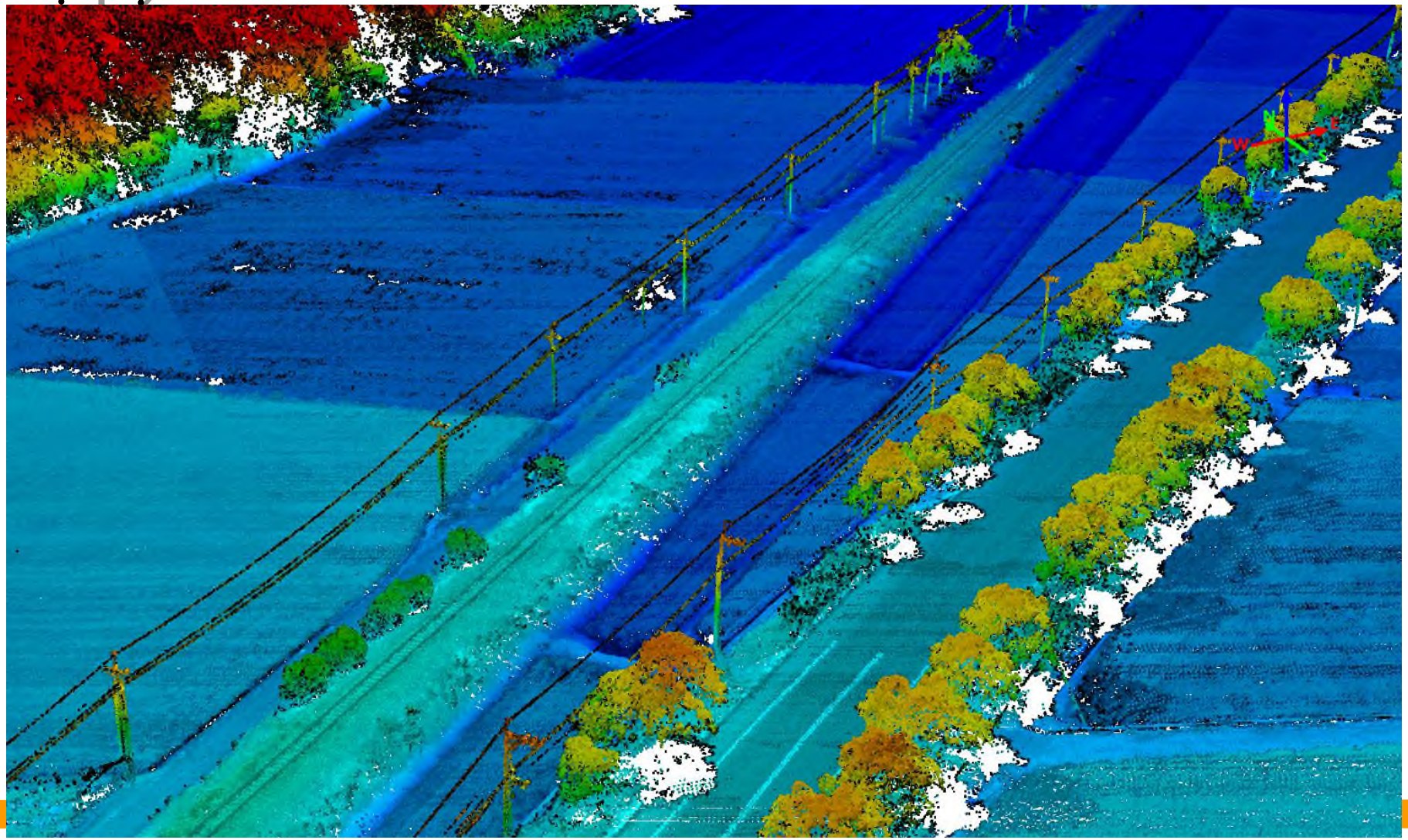




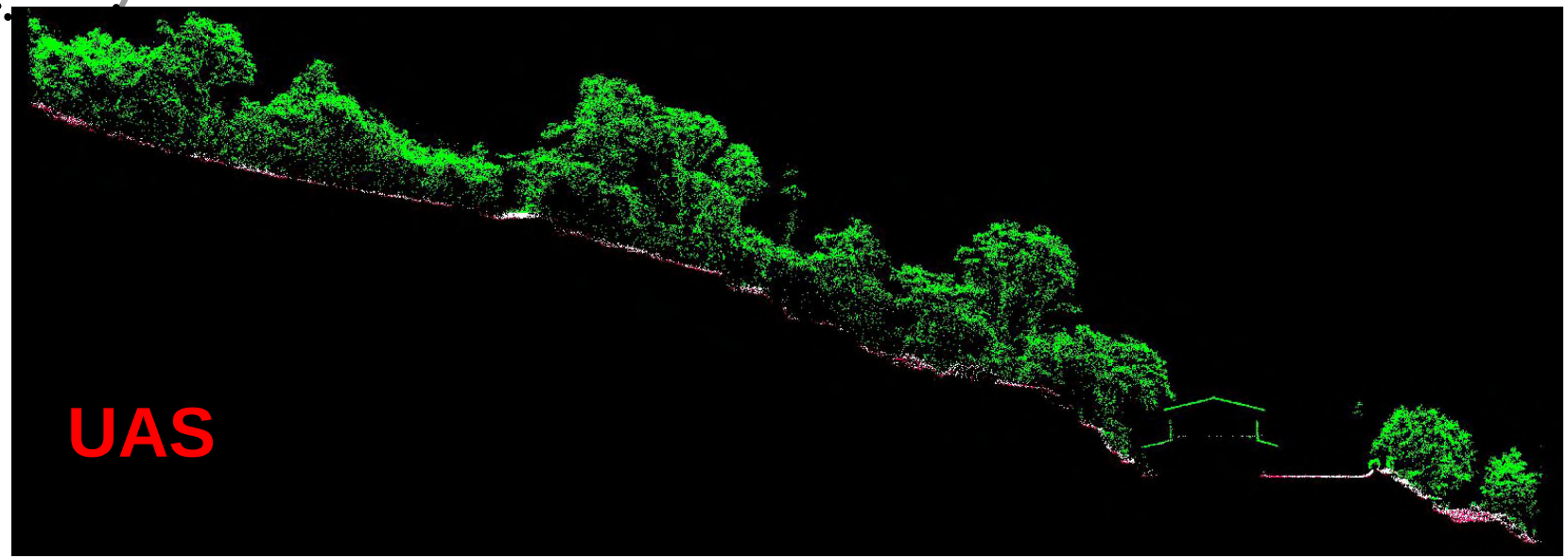
Point Cloud: UAS vs. Airborne

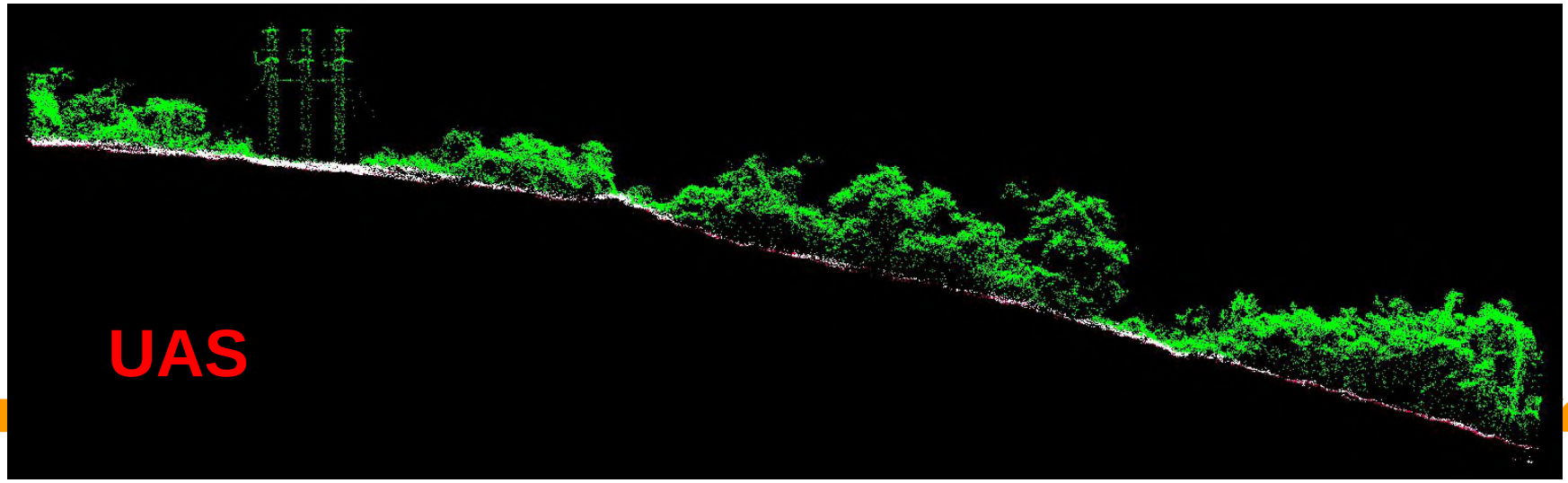


Point Cloud: UAS vs. Airborne

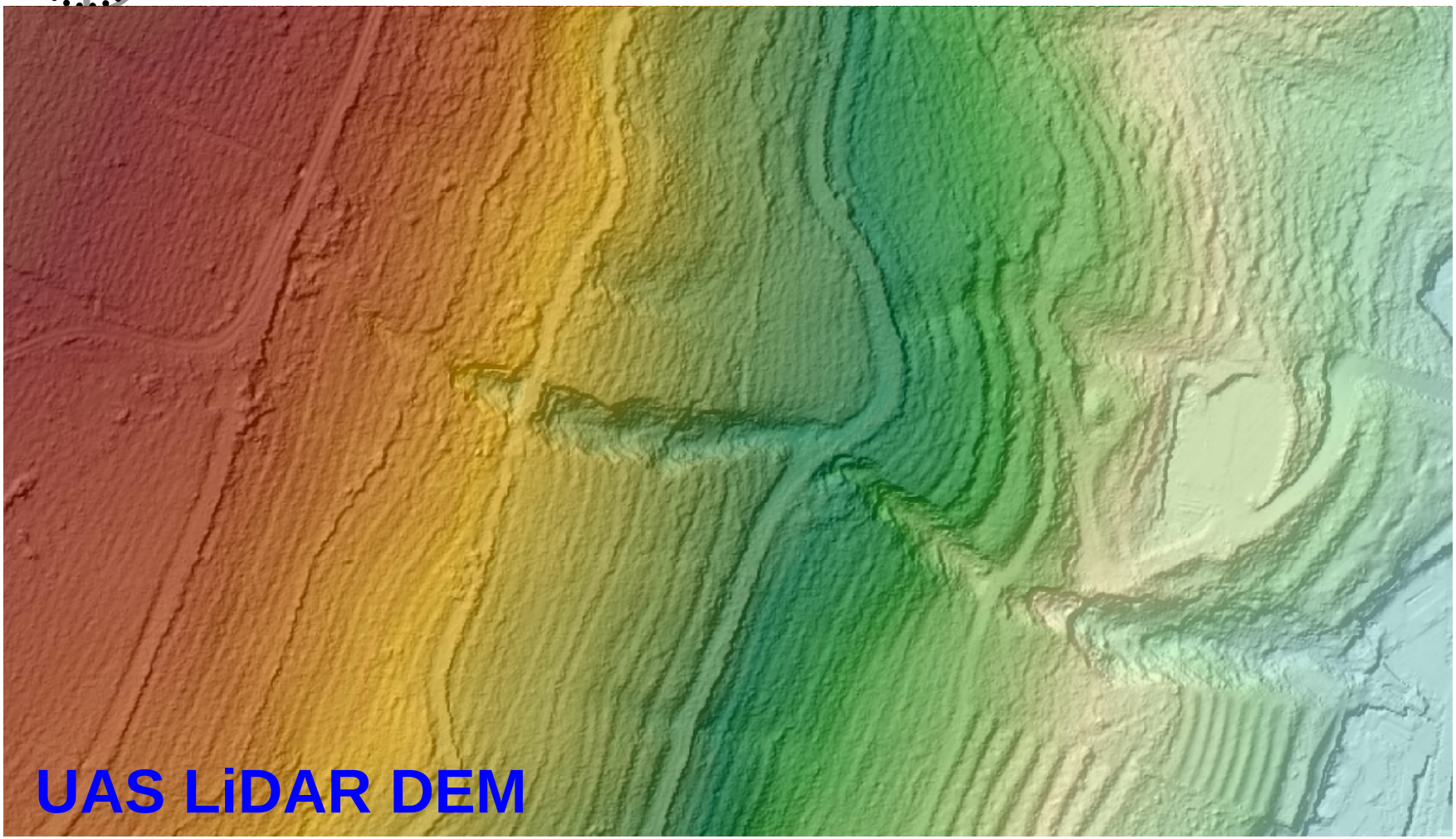


Profiles of Point Cloud





UAS LiDAR DEM vs. DSM



DSM: Single Return vs. Multiple Returns

All Returns



Single + First Return

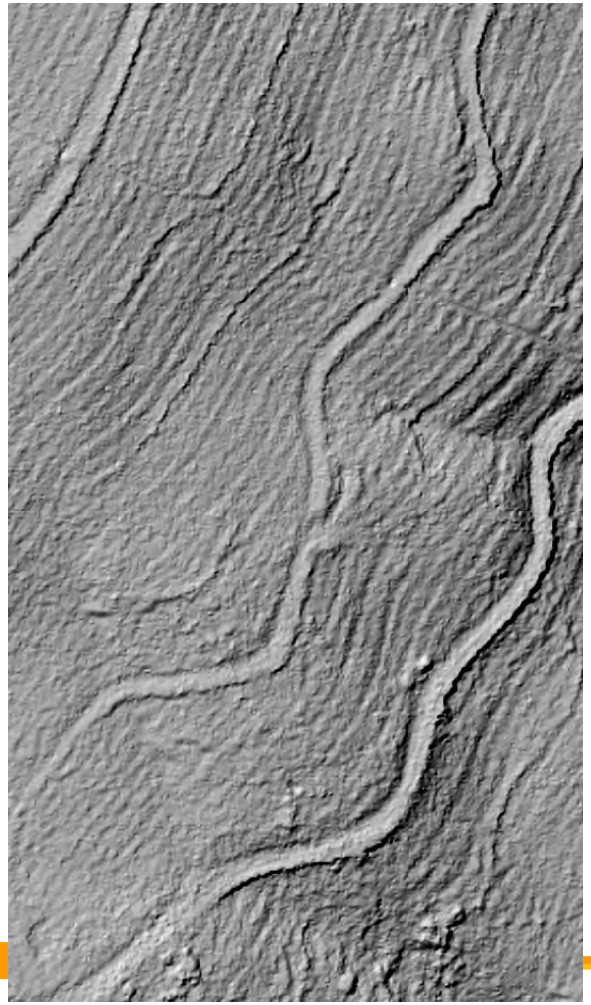


Orthophoto

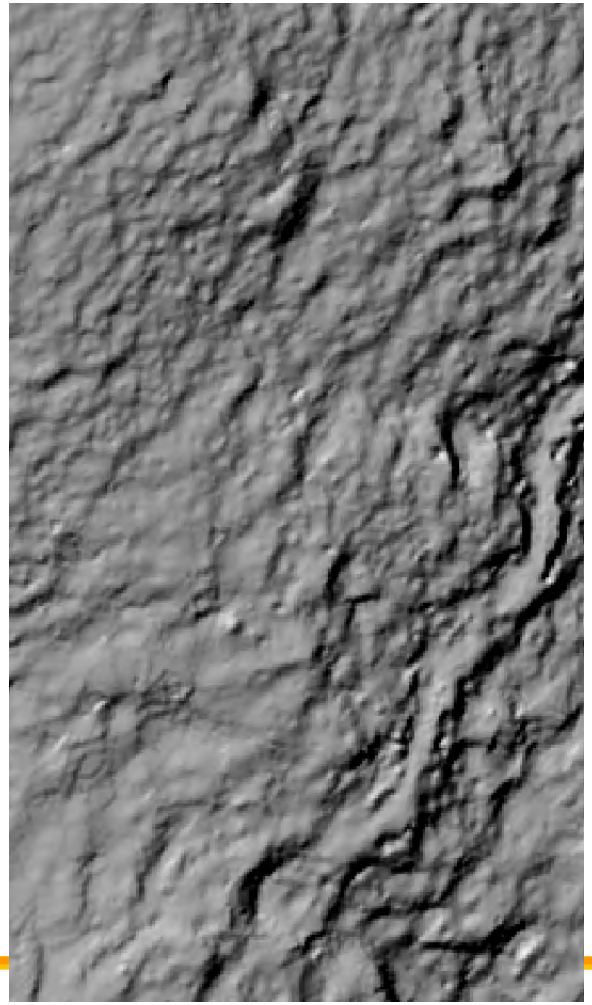


DEM: Single Return vs. Multiple Returns

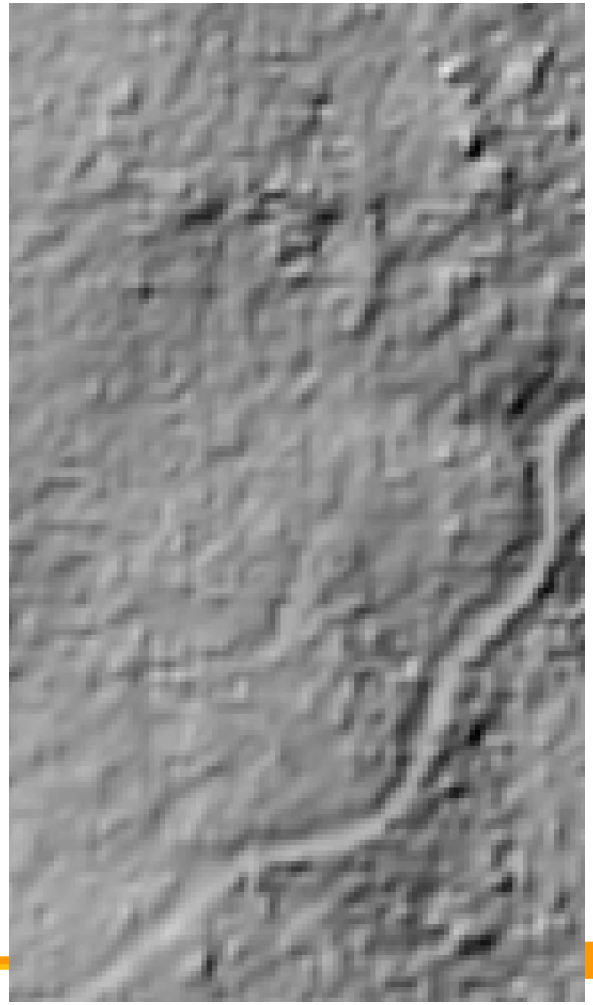
All Returns



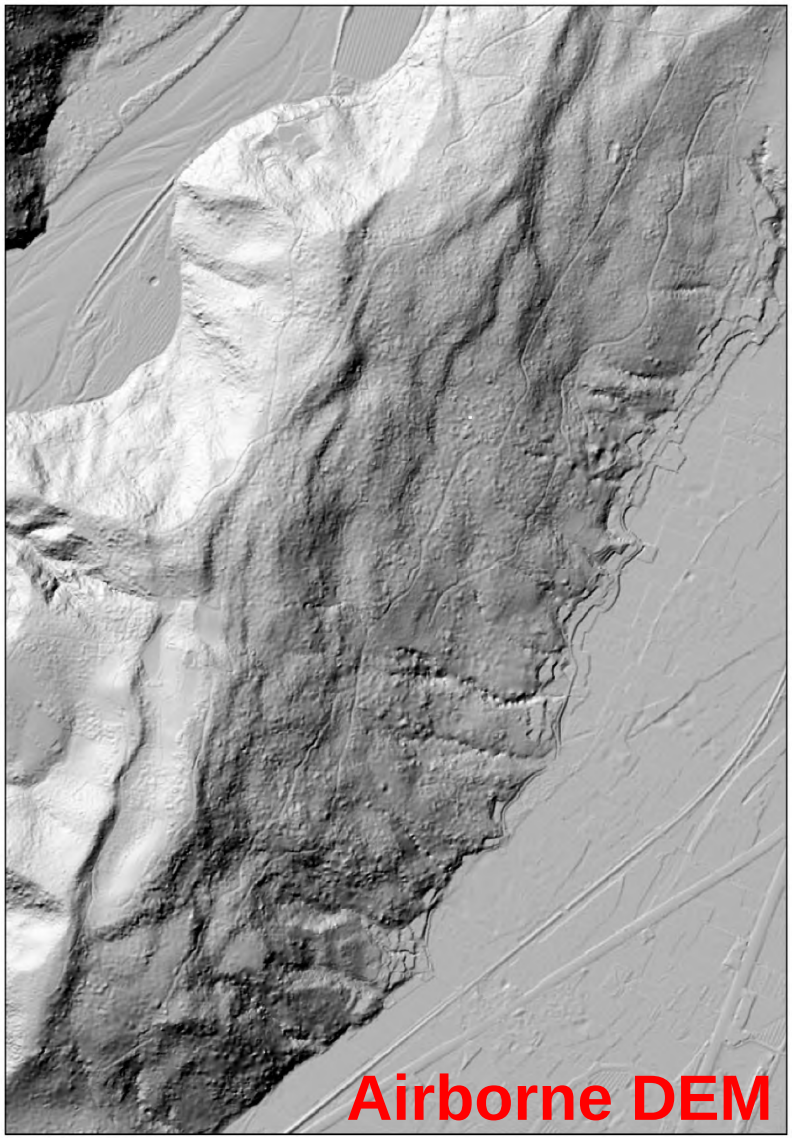
Single + First Return

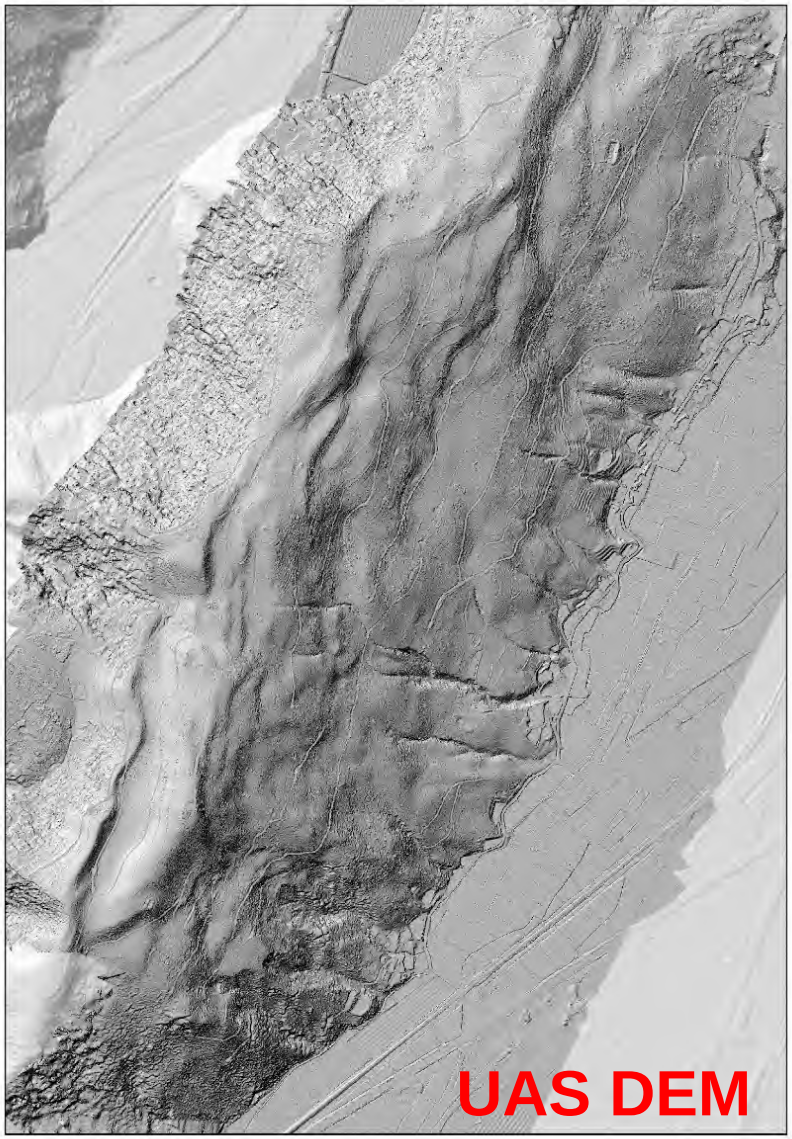


Airborne DEM 2015

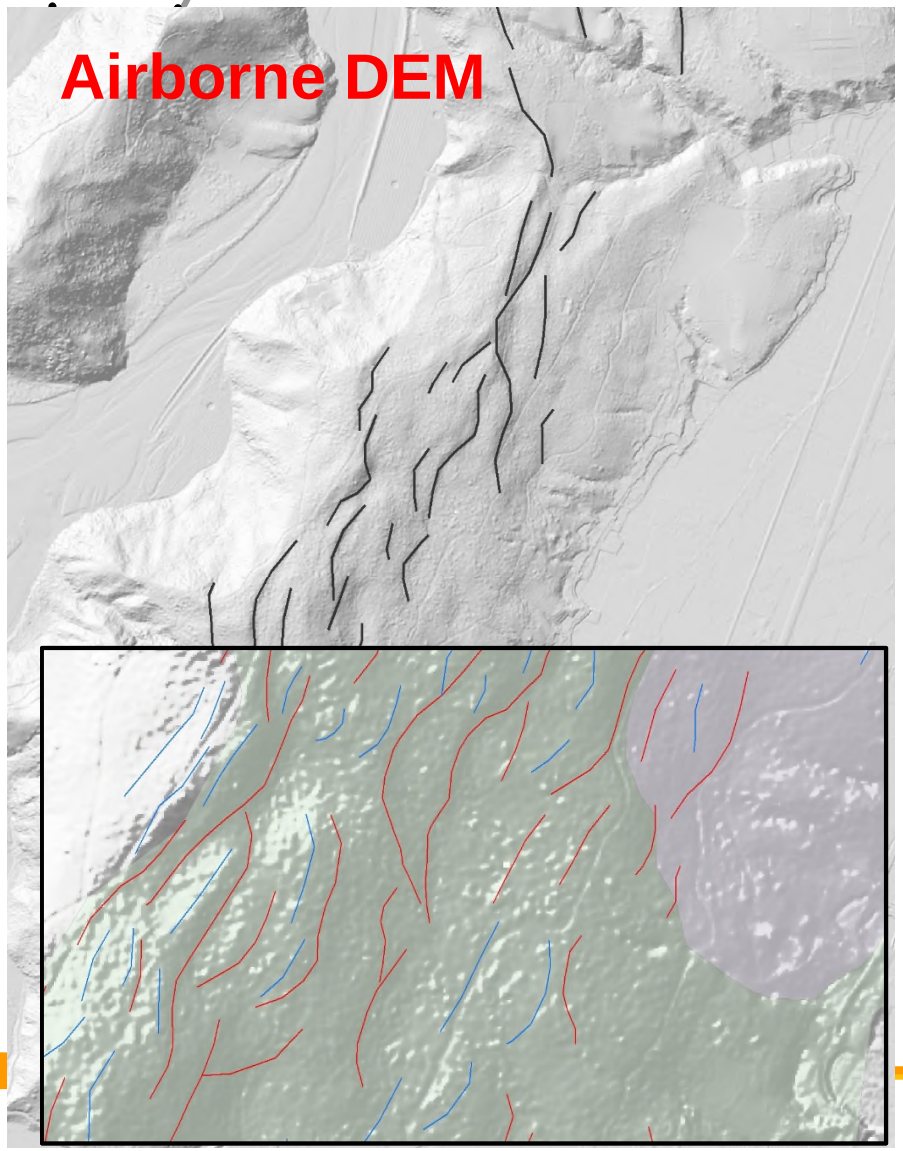


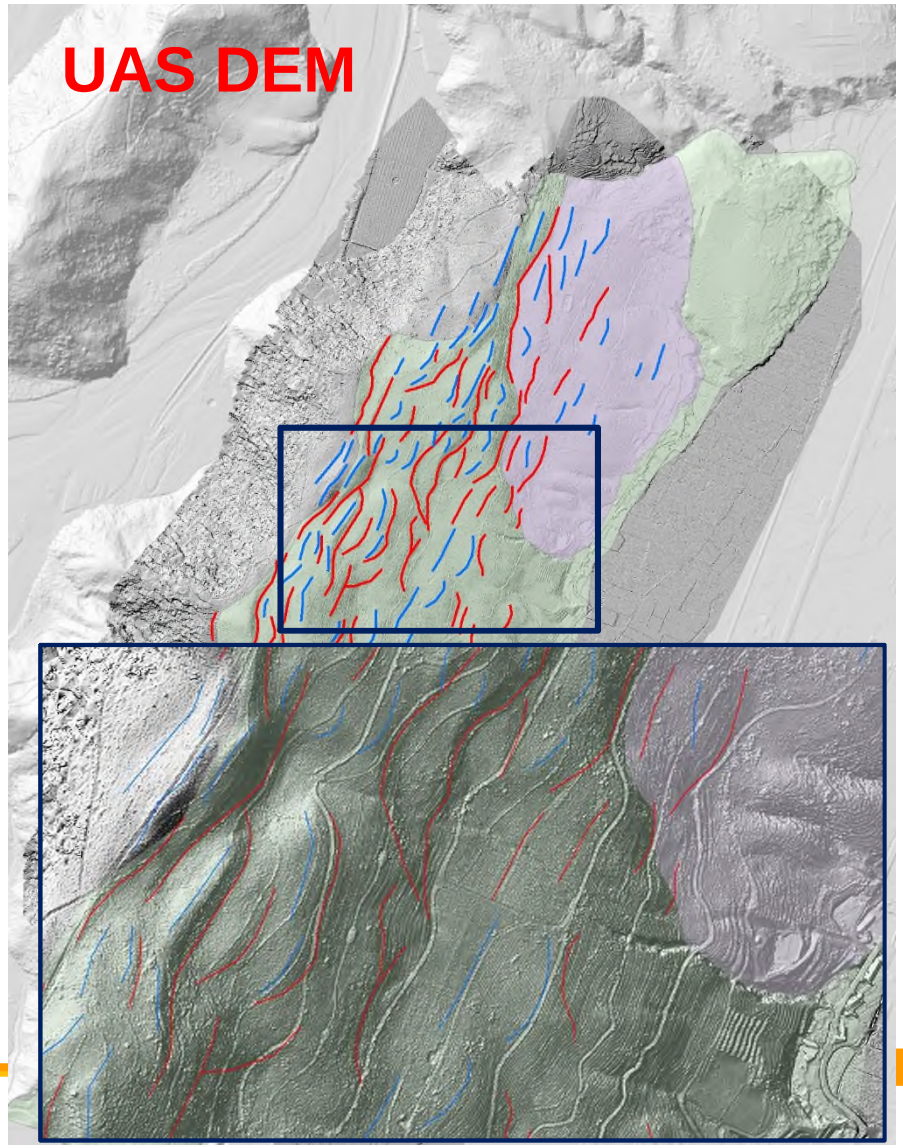
Potential Large-scale Landslide ?!



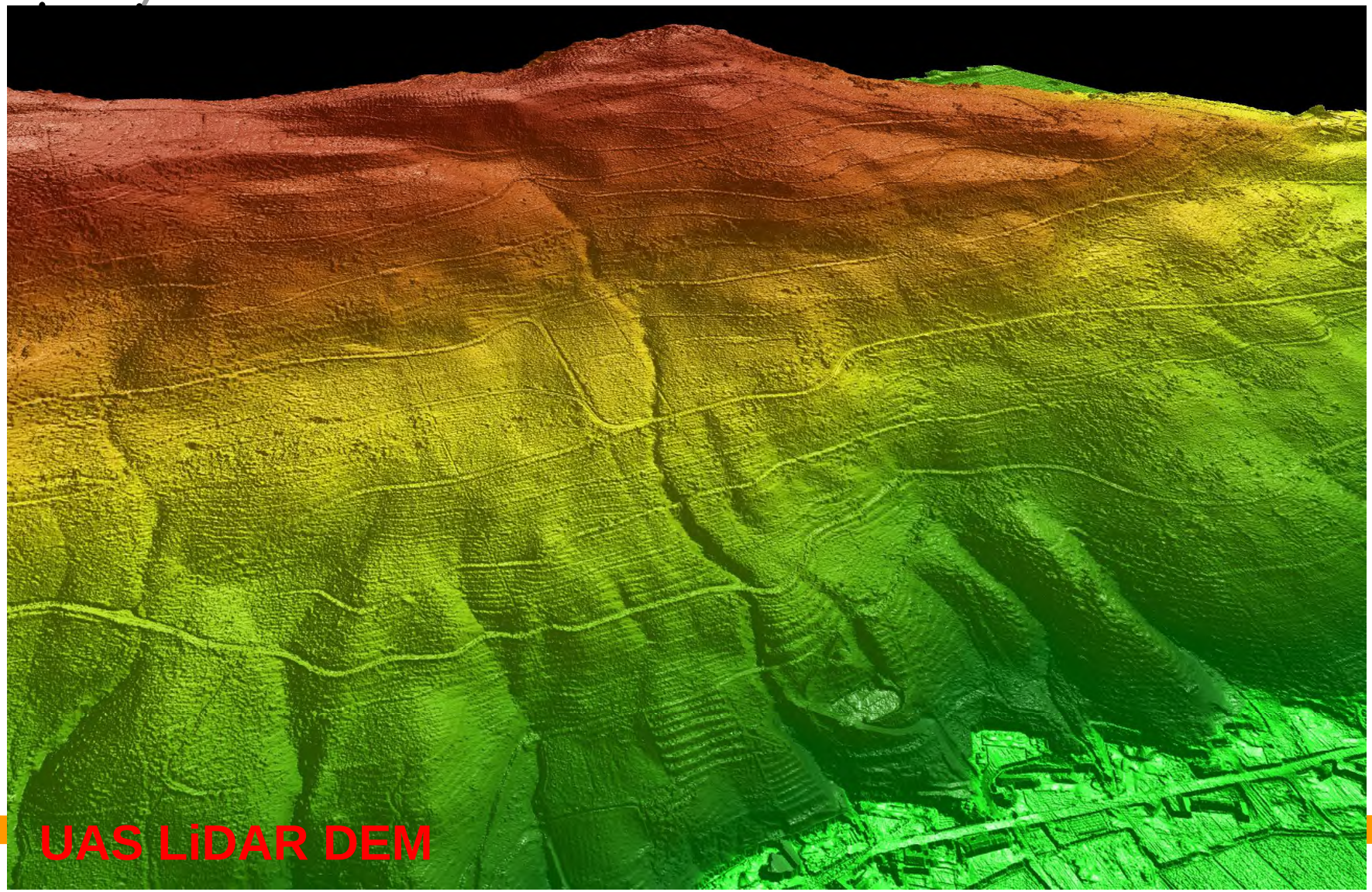


Landslide Micro-morphotectonic Analysis

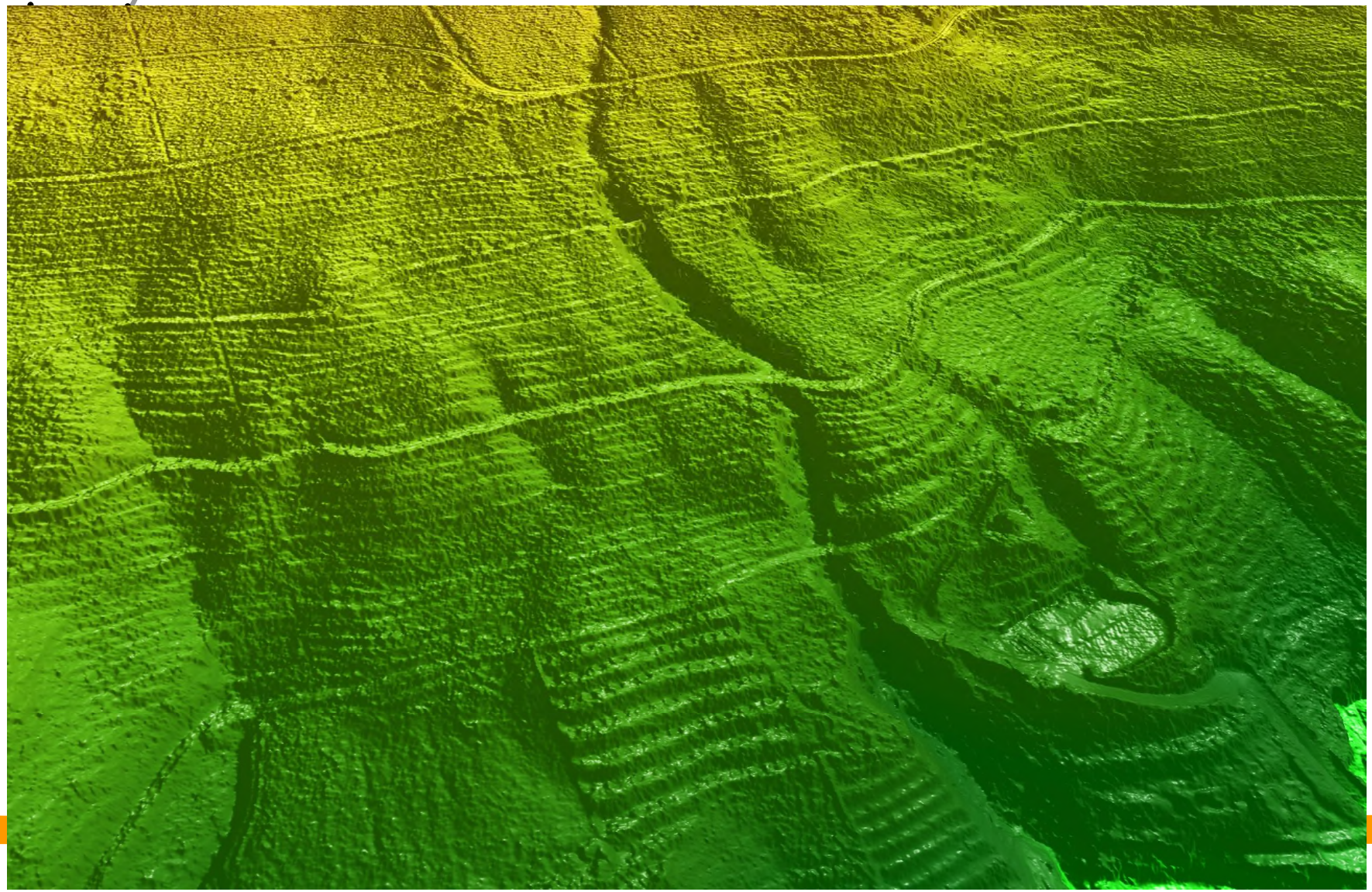




3D Side View of Study Area



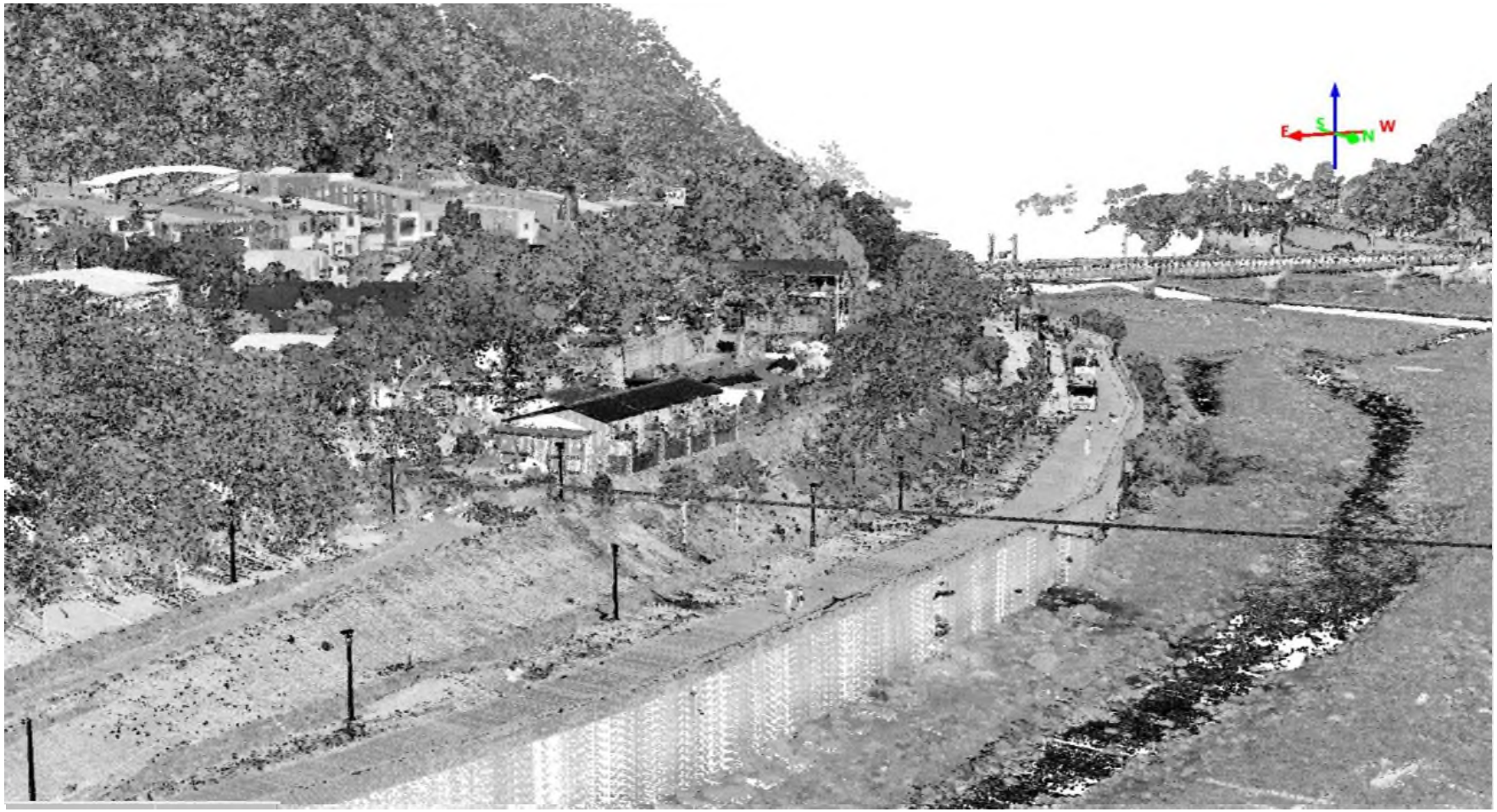
Artificial Slope Modification?!



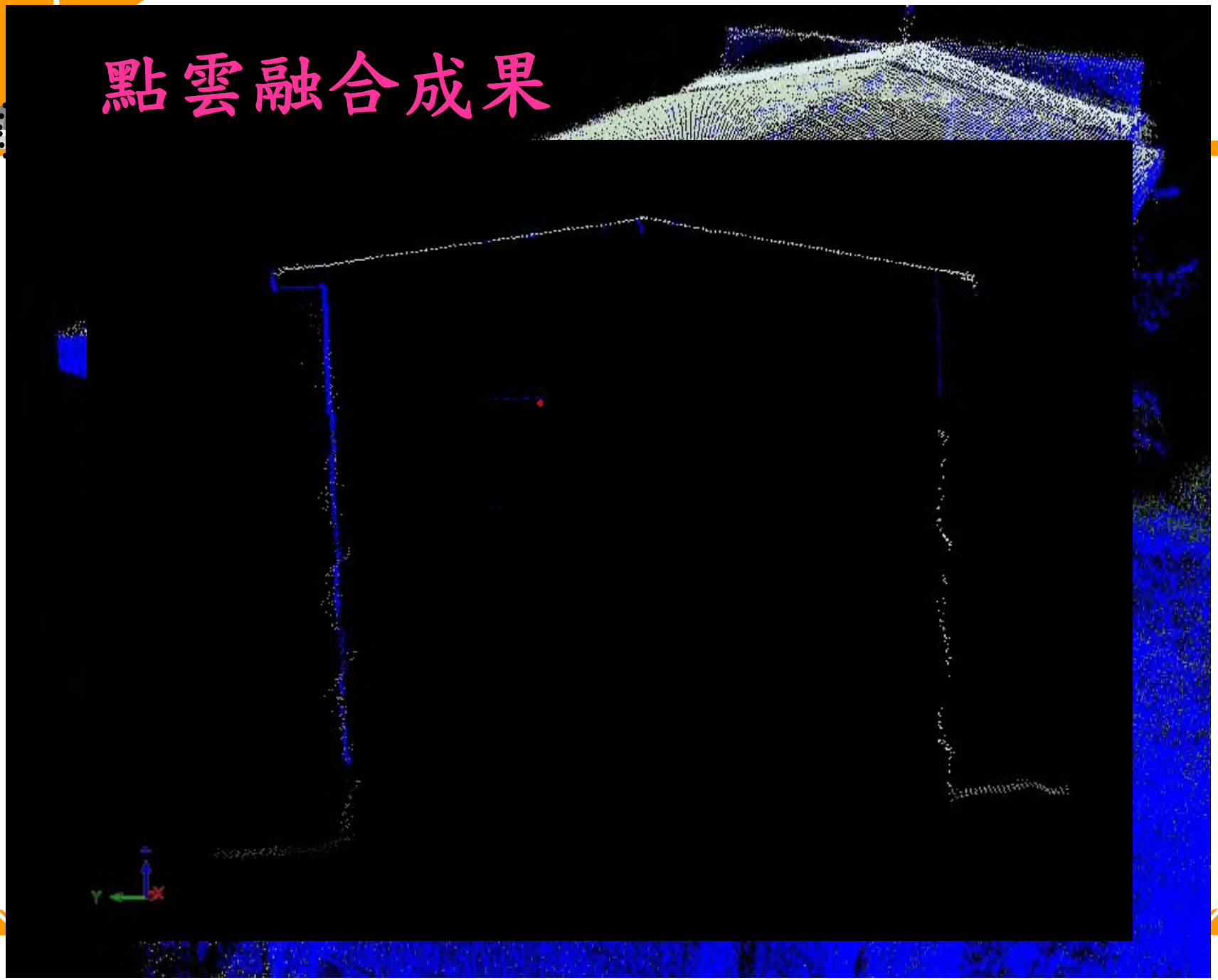
光達系統類型及比較

掃描器	VUX-1 UAV + Applanix AP20	VZ-2000i			
主要尺寸（寬x高）/重量	227x209x129mm/3.75Kg	206x308mm/9.7 kg			
雷射脈衝重複率 PRR	550k	100k	300k	600k	1200k
最大測量距離	920m	800m	480m	350m	250m
準確度/精度度	5mm/10mm	3mm/5mm			
最高雷射發射頻率	0.55M points/s	1.2M points/s			

Terrestrial LiDAR + UAS LiDAR



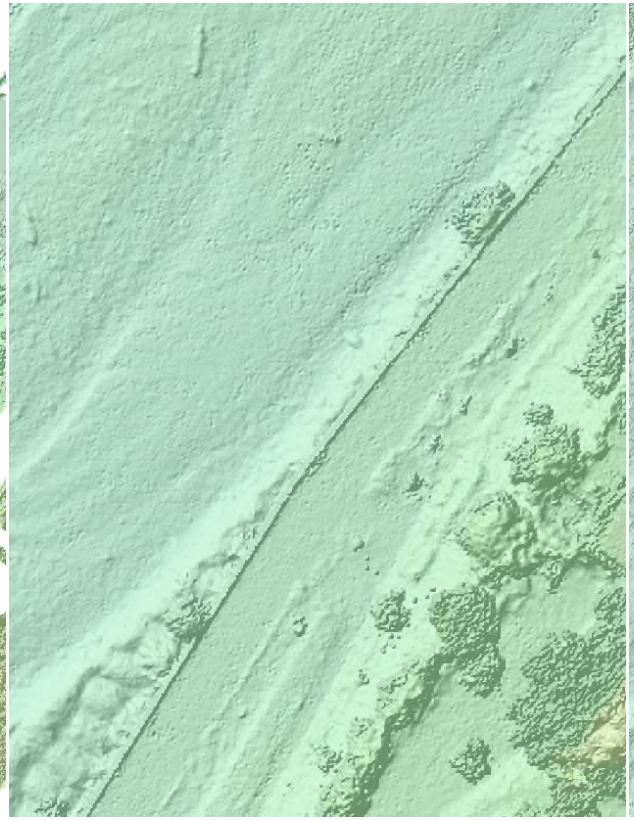
點雲融合成果



DSM



地面光達系統

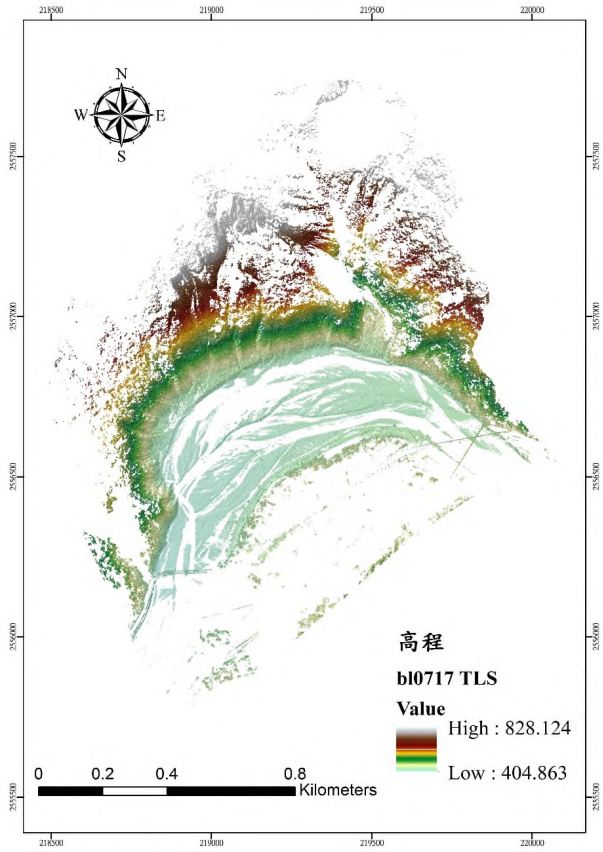


無人機影像系統

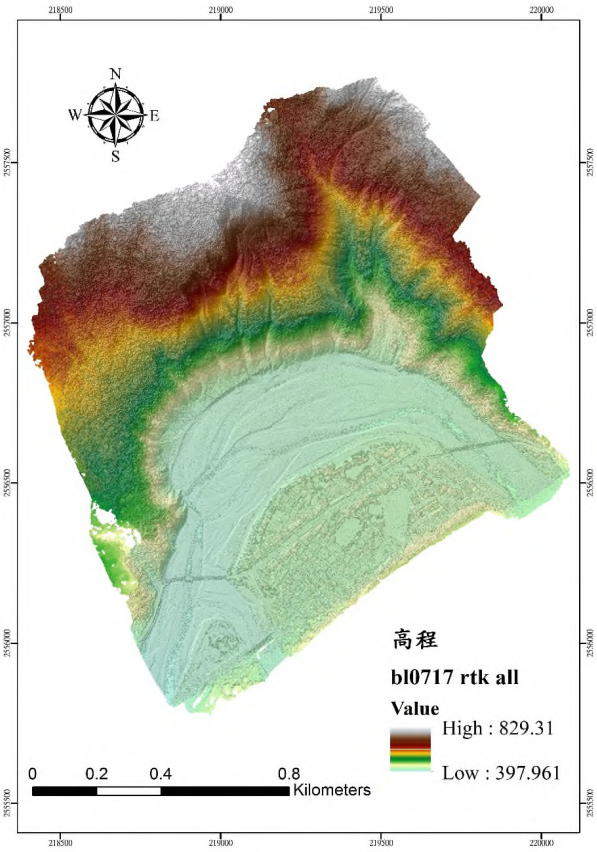


兩系統融合

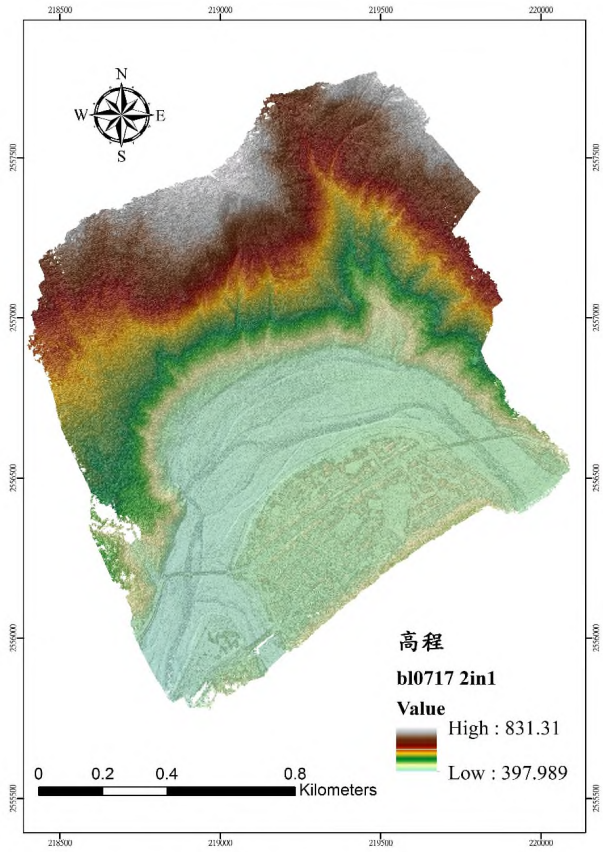
DSM



地面光達系統

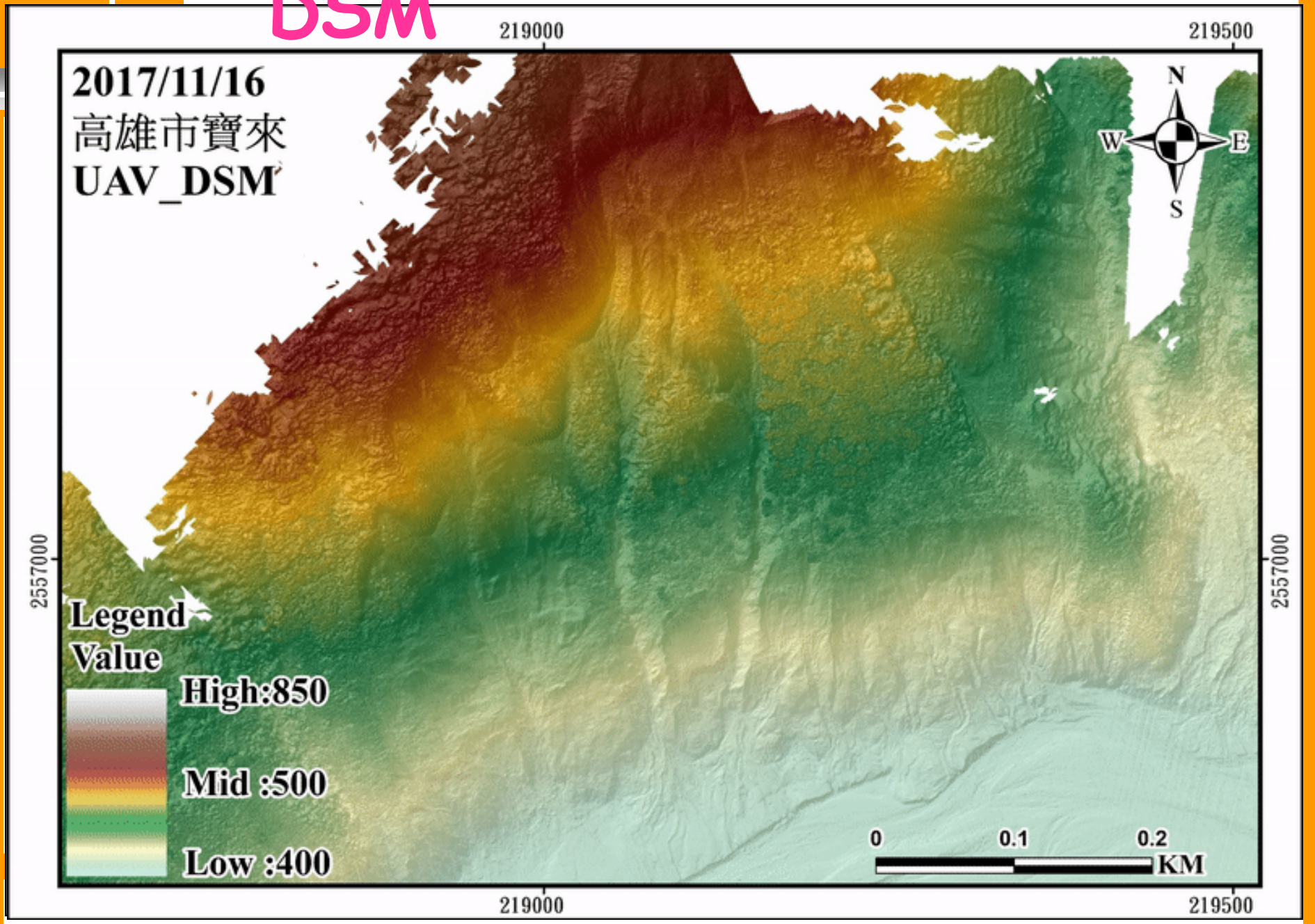


無人機影像系統

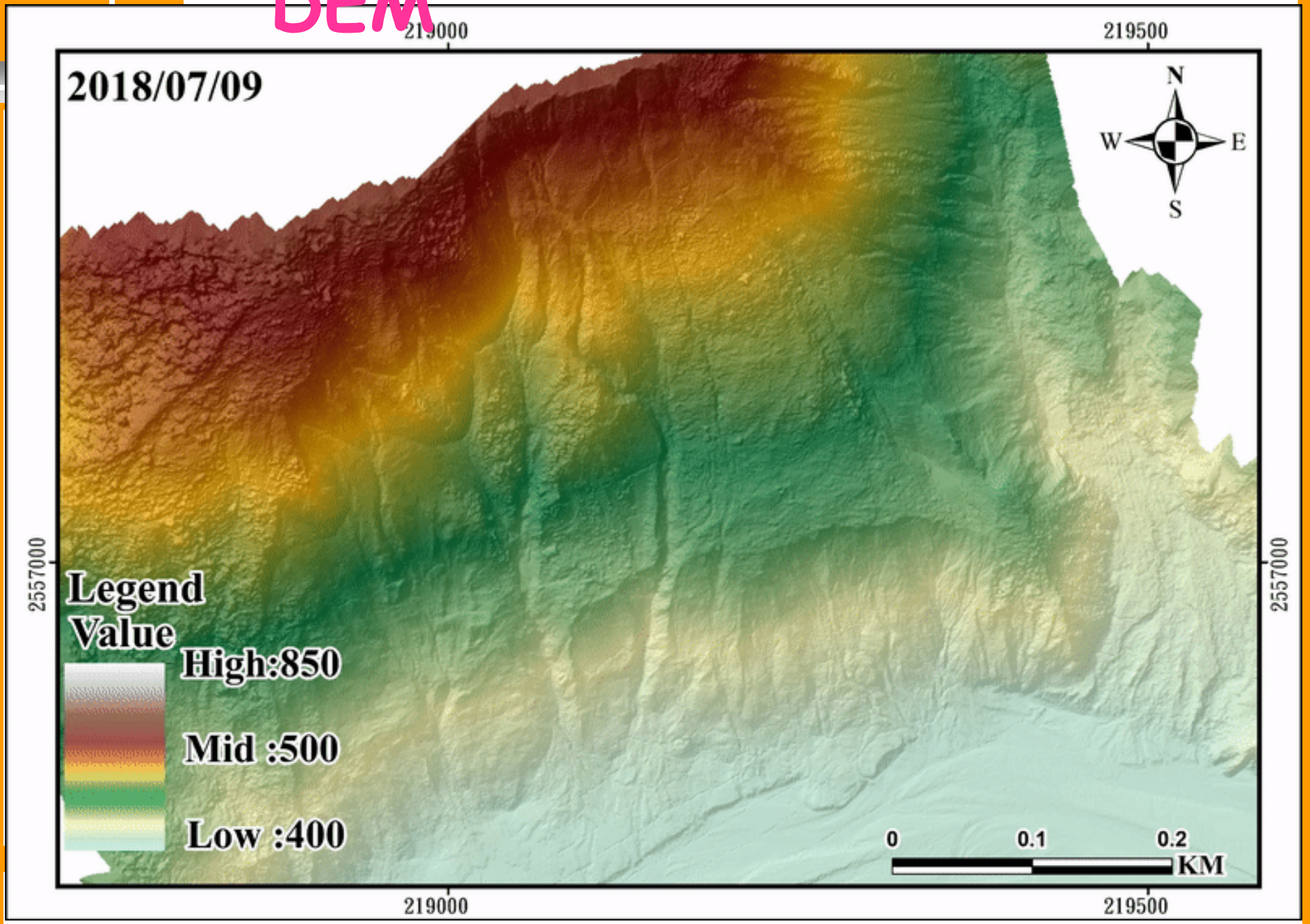


兩系統融合

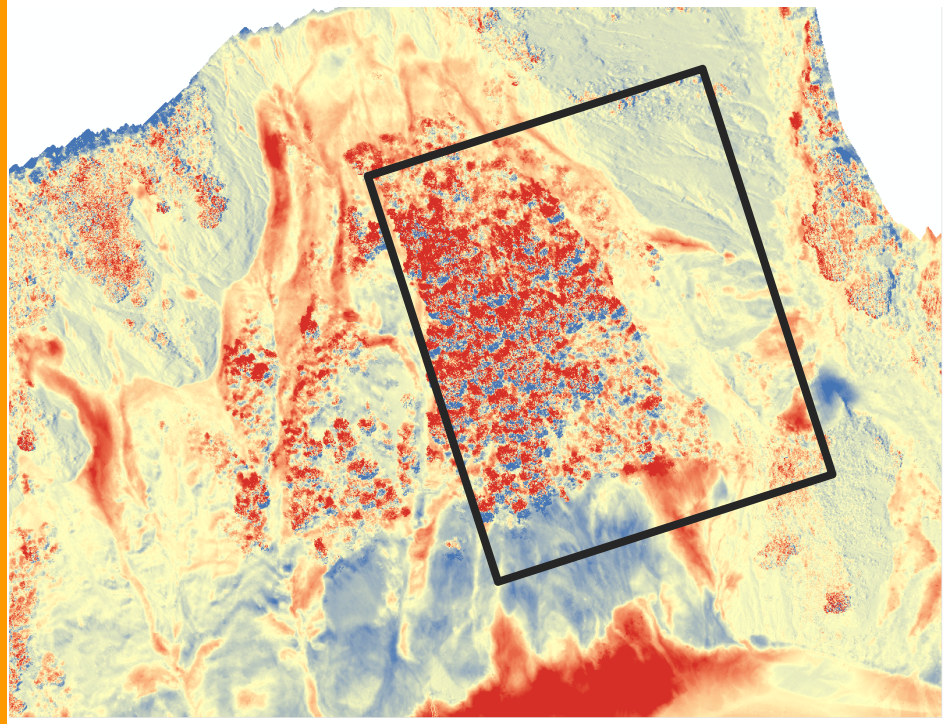
DSM


2017/11/16
高雄市寶來
UAV_DSM
219000
219500
2557000
N
W
E
S
Legend
Value
High:850
Mid :500
Low :400
0
0.1
0.2
KM

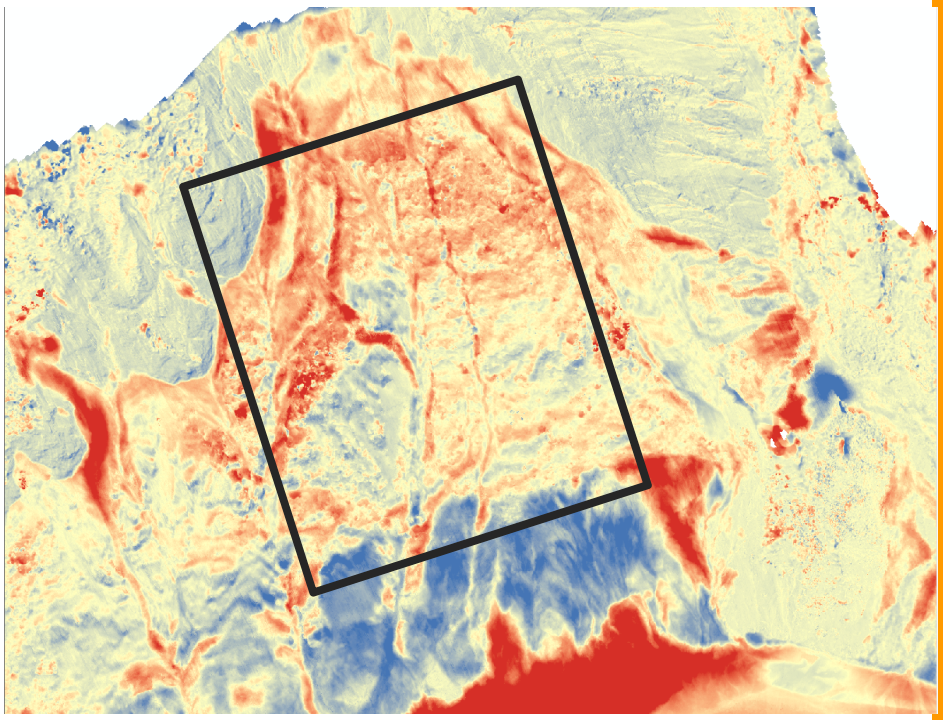
DEM


2018/07/09
219000
219500
2557000
N
W
E
S
Legend
Value
High:850
Mid :500
Low :400
0
0.1
0.2
KM

寶來地區DOD成果

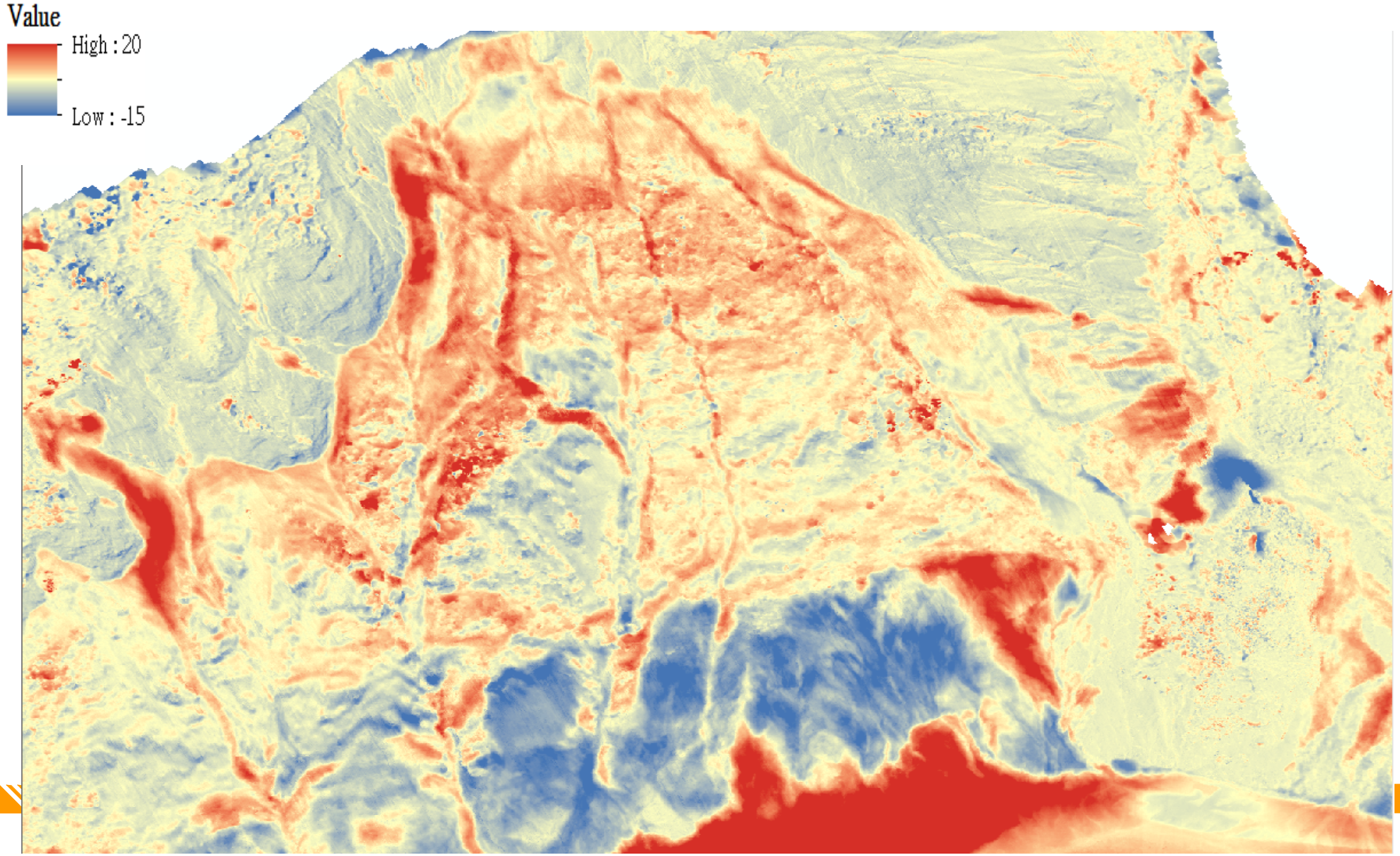


DSM



DEM

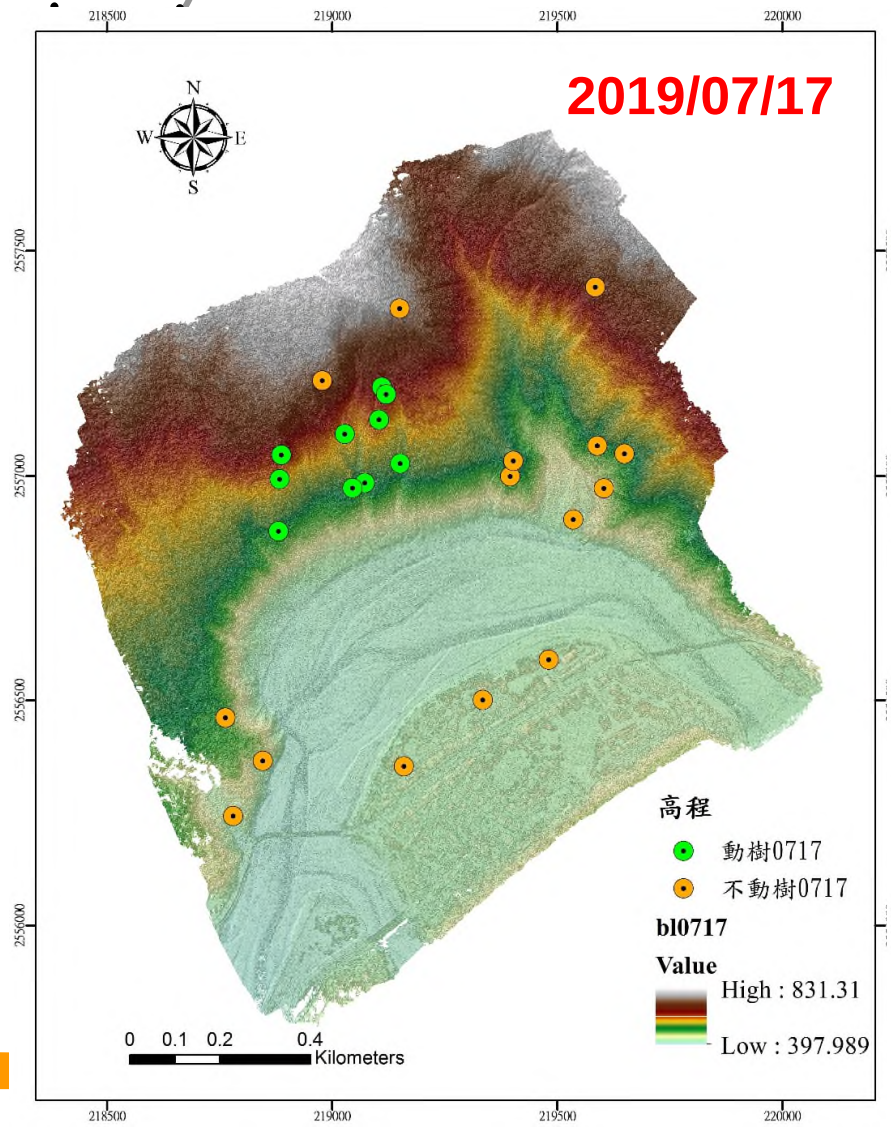
Topographic Change: Aug-Dec 2018

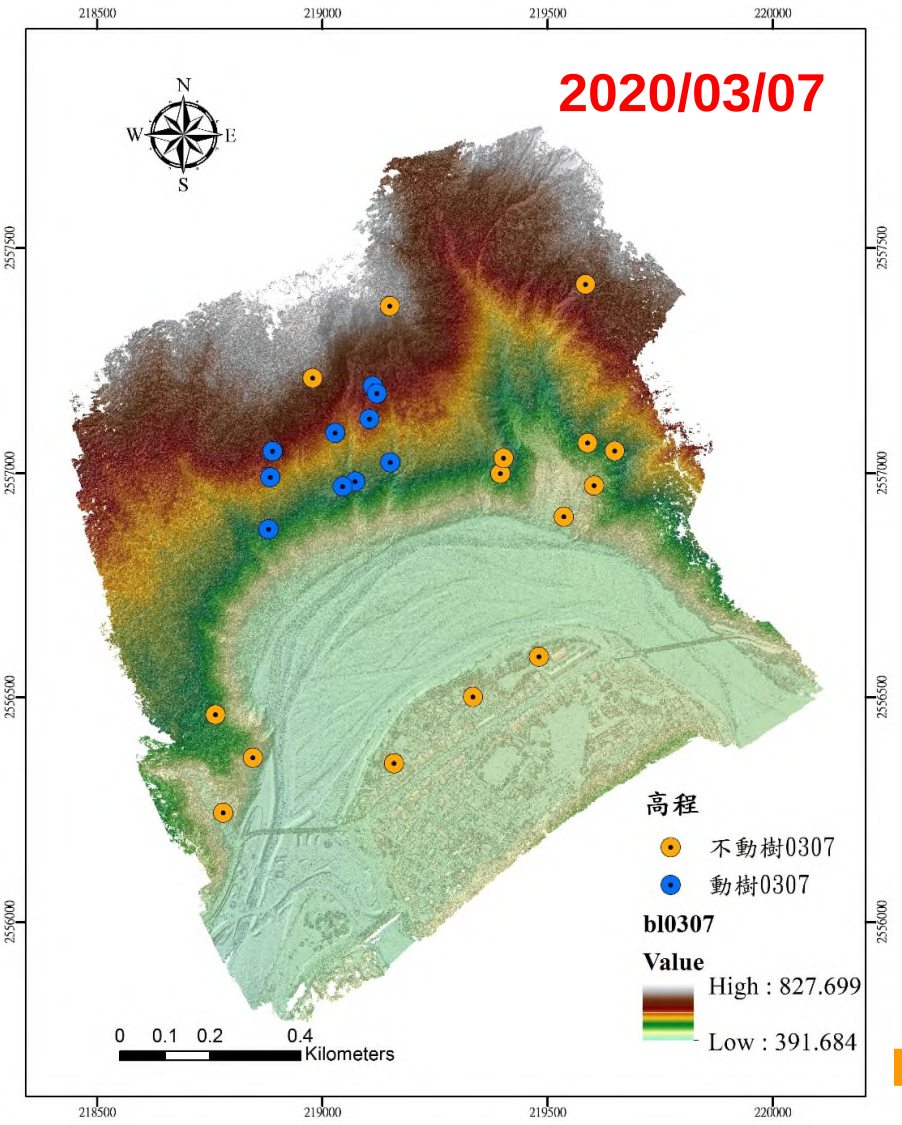


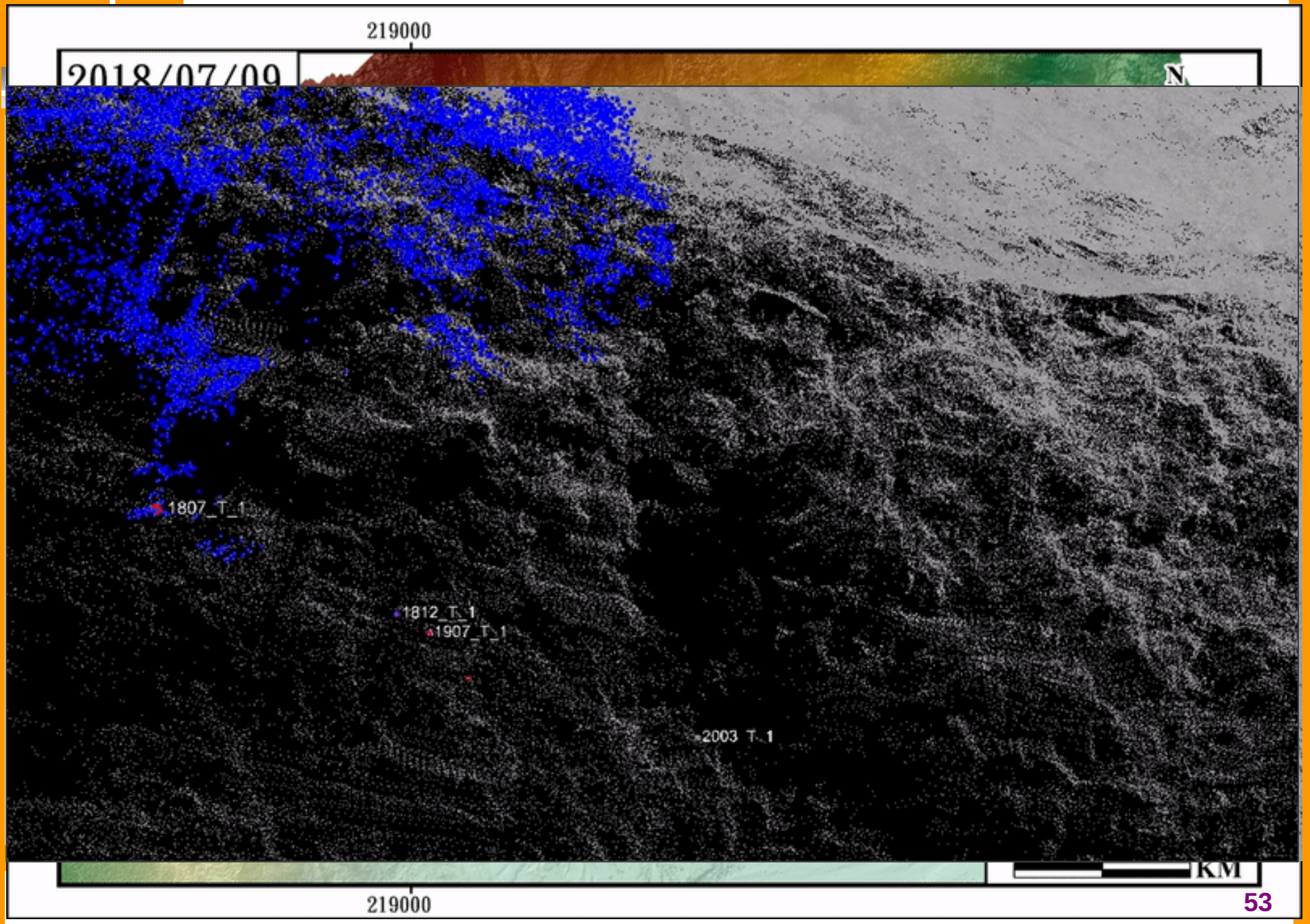
山崩量體計算

日期	系統	虧損面積 (ha)	虧損量 (Mm^3)	虧損率	加積面積 (ha)	加積量 (Mm^3)	加積率
2018 /12/24	UAV	43.8	0.68	67%	24.7	0.34	24%
	UAV&TLS	46.1	0.7	66%	24.3	0.36	23%
2019 /07/17	UAV&TLS	32.7	0.42	26%	53.9	1.18	74%
2020 /03/07	UAV&TLS	29.6	0.32	20%	55.9	1.27	80%

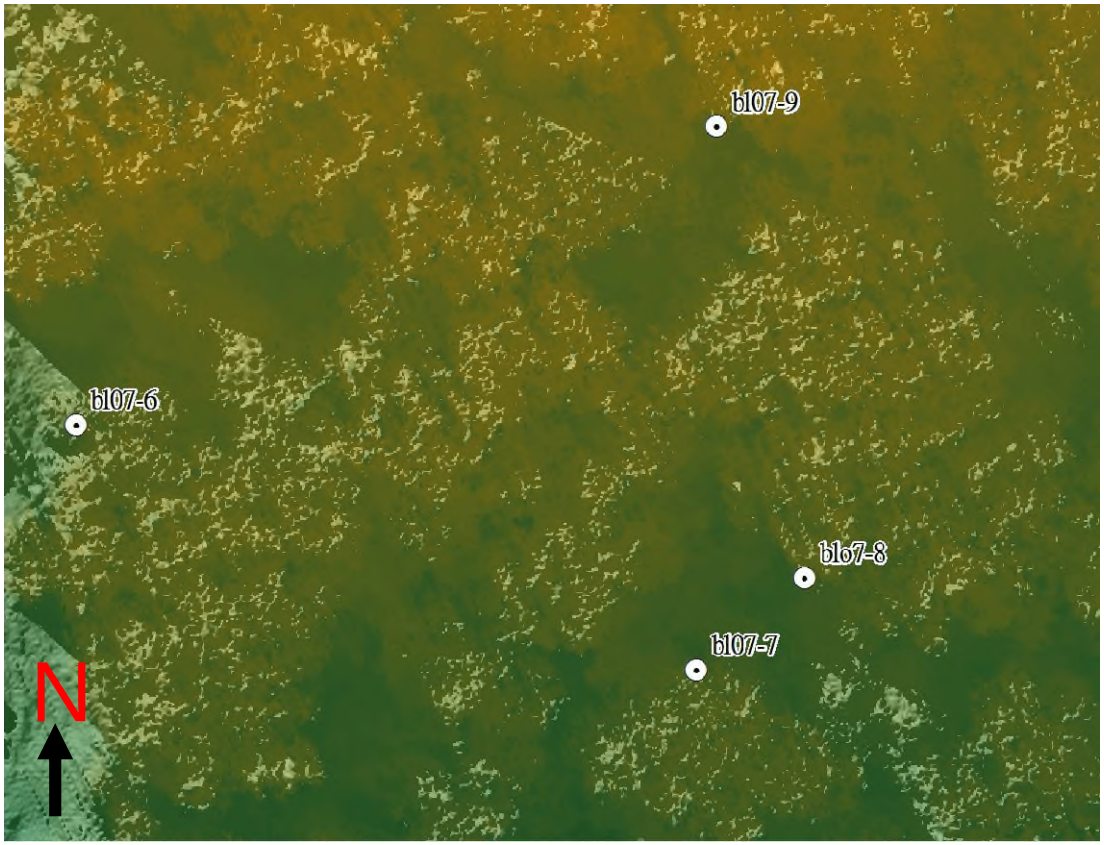
塊體崩塌位移量


2019/07/17
N
W
E
S
218500
219000
219500
220000
2557500
2557000
2556500
2556000
高程
動樹0717
不動樹0717
bl0717
Value
High : 831.31
Low : 397.989
0 0.1 0.2 0.4
Kilometers


2020/03/07
N
W
E
S
218500
219000
219500
220000
2557500
2557000
2556500
2556000
高程
不動樹0307
動樹0307
bl0307
Value
High : 827.699
Low : 391.684
0 0.1 0.2 0.4
Kilometers


219000
2018/07/09
N
1807_T_1
1812_T_1
1907_T_1
2003_T_1
KM
219000

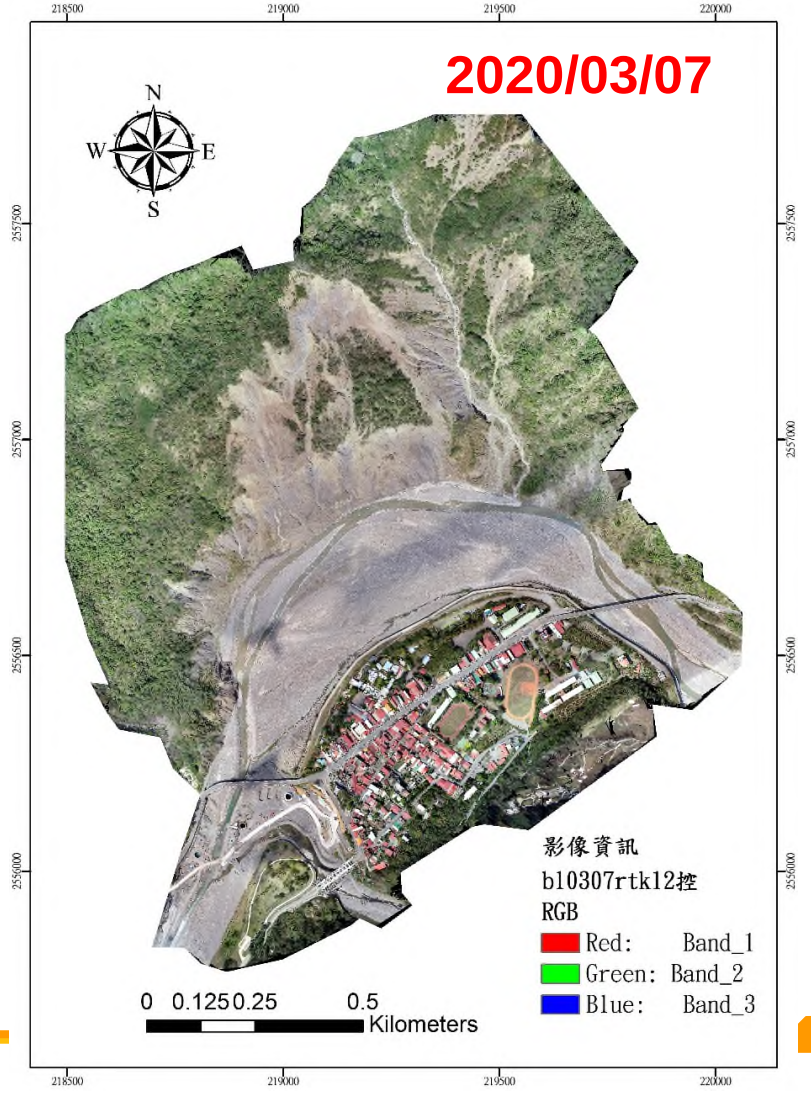
Disp. by means of Tree Canopy



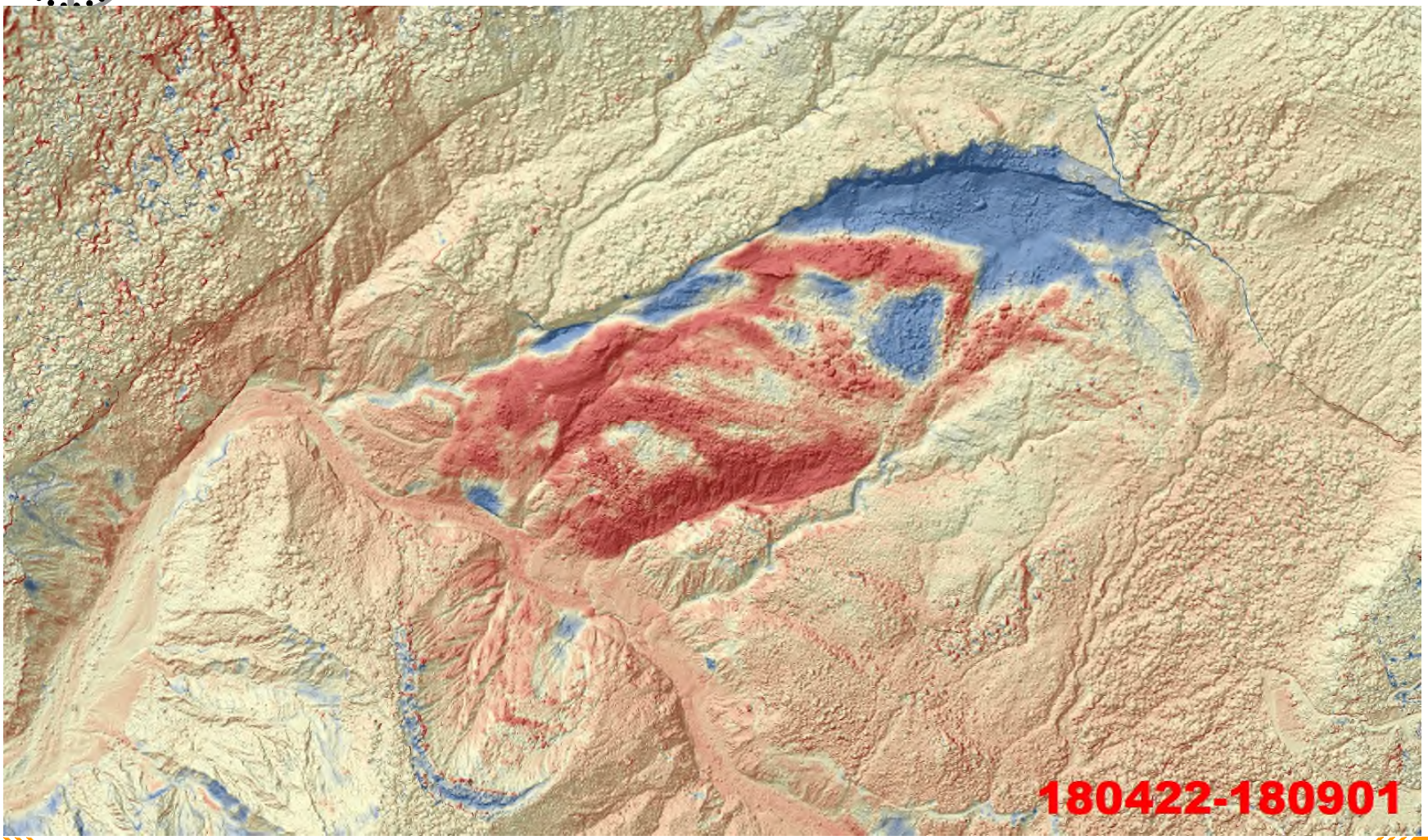
Tree	X Disp	Y Disp	H Disp (m)
1	0.76	-1.48	1.66
2	0.47	-0.87	0.99
3	0.66	-1.09	1.27
4	0.15	-0.11	0.18
5	1.25	-2.58	2.87
6	1.32	-2.88	3.17
7	1.66	-5.68	5.92
8	1.59	-4.18	4.48
9	2.42	-4.60	5.20
10	1.11	-2.34	2.59

攝影測量極限 ?!

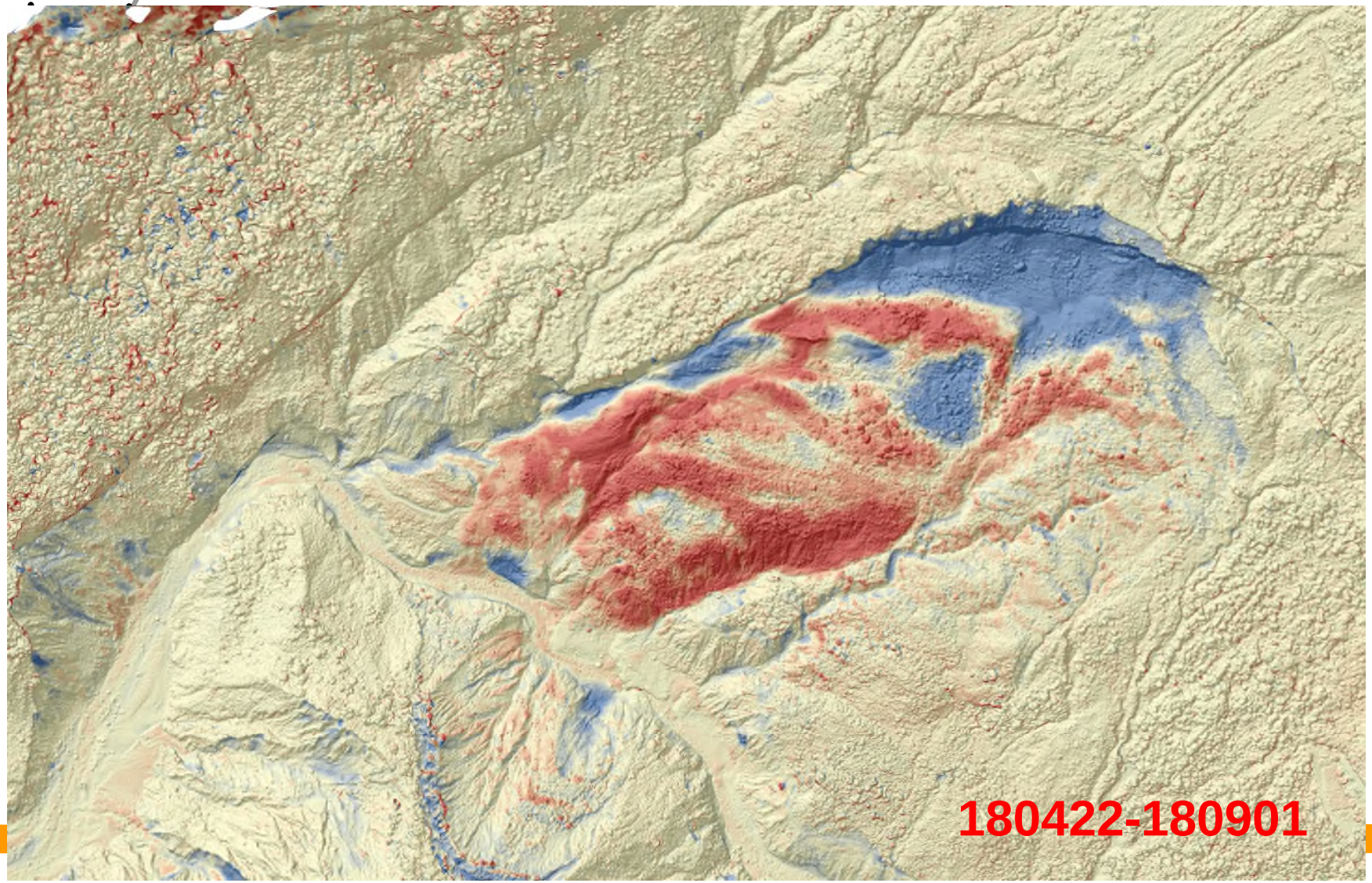

2019/07/17
N
W
E
S
218500
219000
219500
220000
2557500
2557000
2556500
2556000
影像資訊
bl0717 8控
RGB
Red: Band_1
Green: Band_2
Blue: Band_3
0 0.1250.25 0.5
Kilometers


2020/03/07
N
W
E
S
218500
219000
219500
220000
2557500
2557000
2556500
2556000
影像資訊
bl0307rtk12控
RGB
Red: Band_1
Green: Band_2
Blue: Band_3
0 0.1250.25 0.5
Kilometers

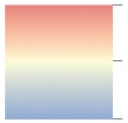
一般演算法 DoD

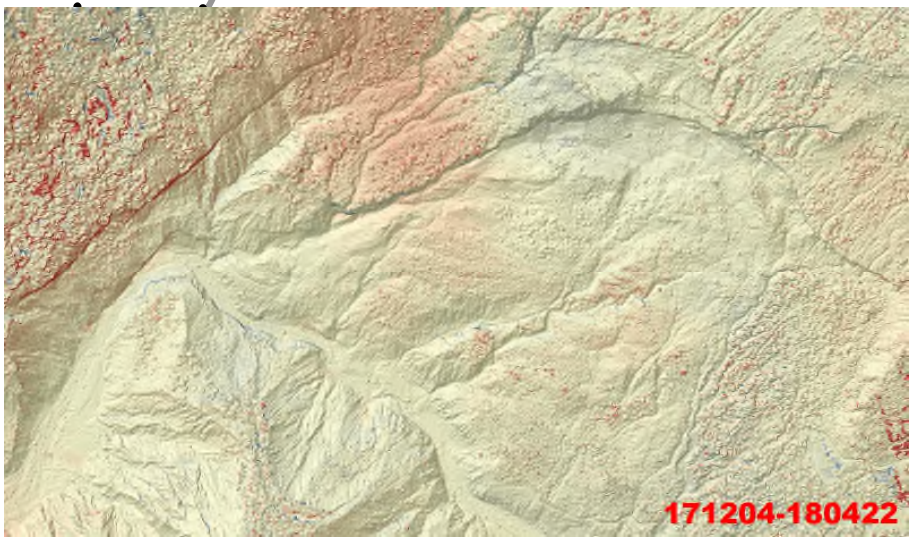


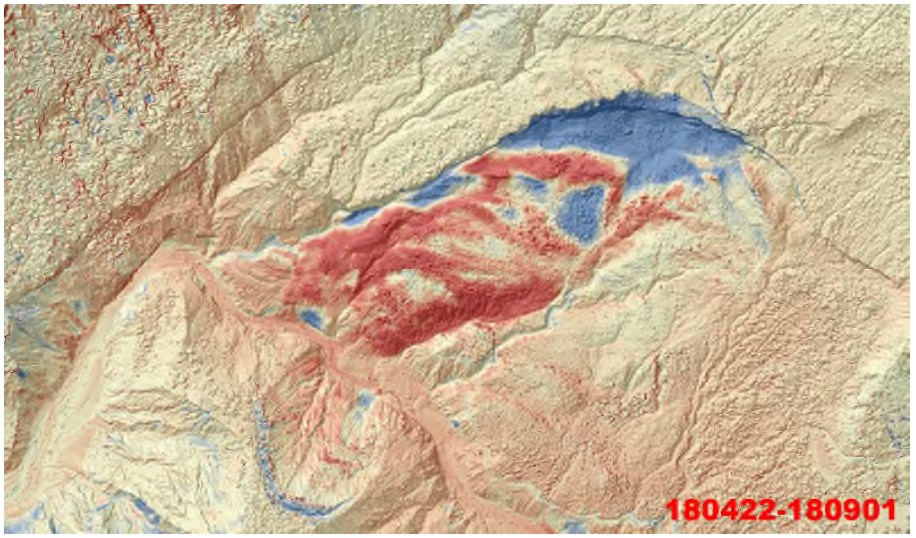
新演算法 DoD

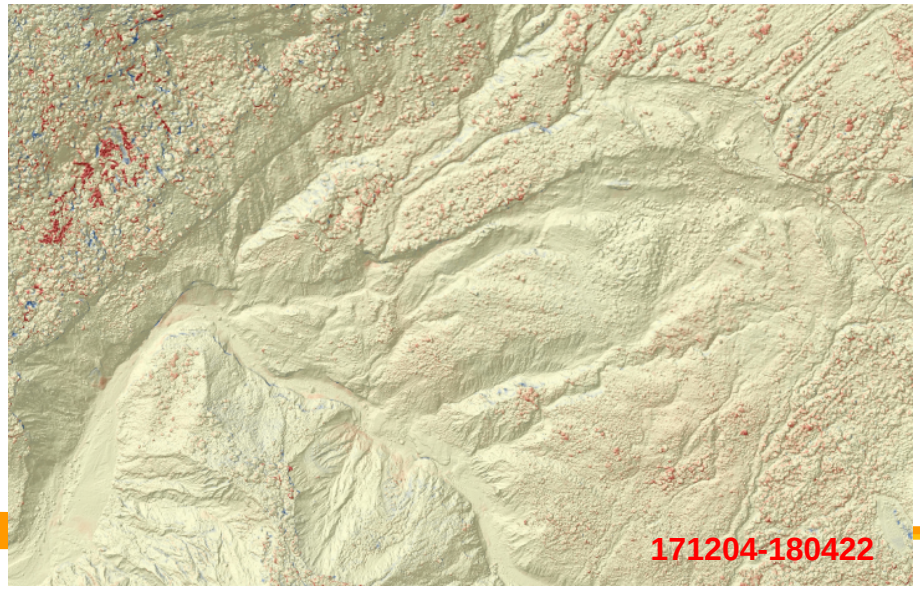


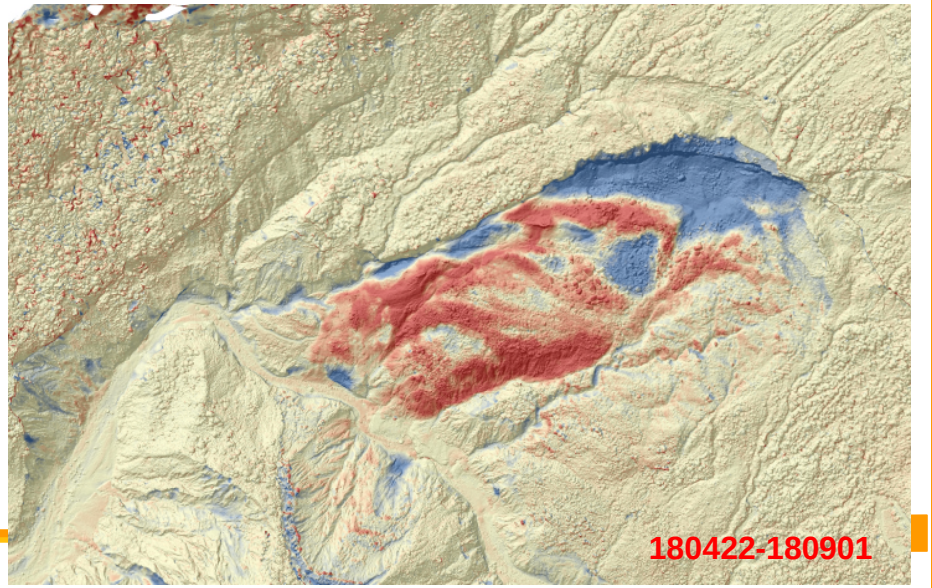
方法學成果比較


High : 10
Low : -10

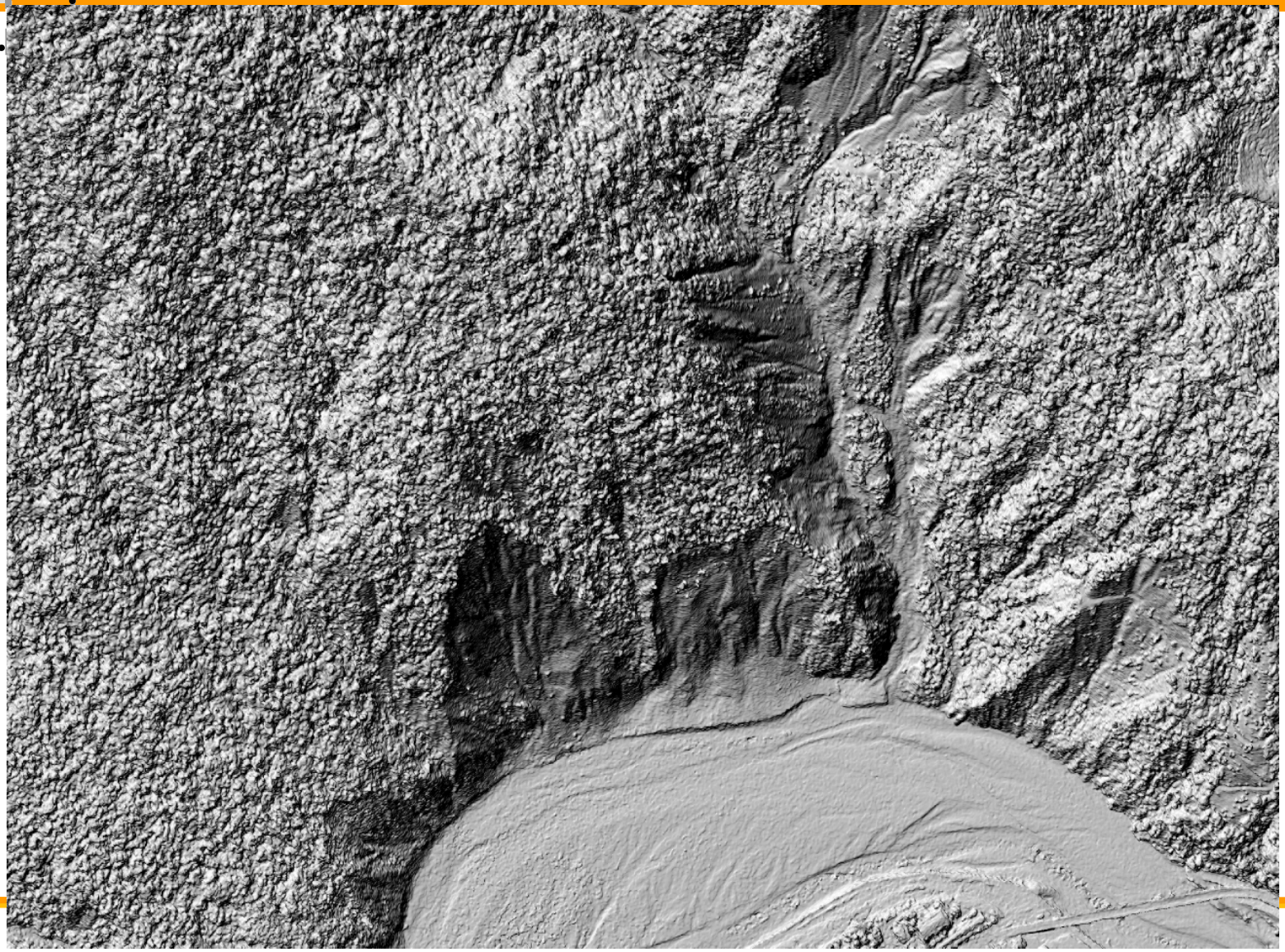

171204-180422


180422-180901

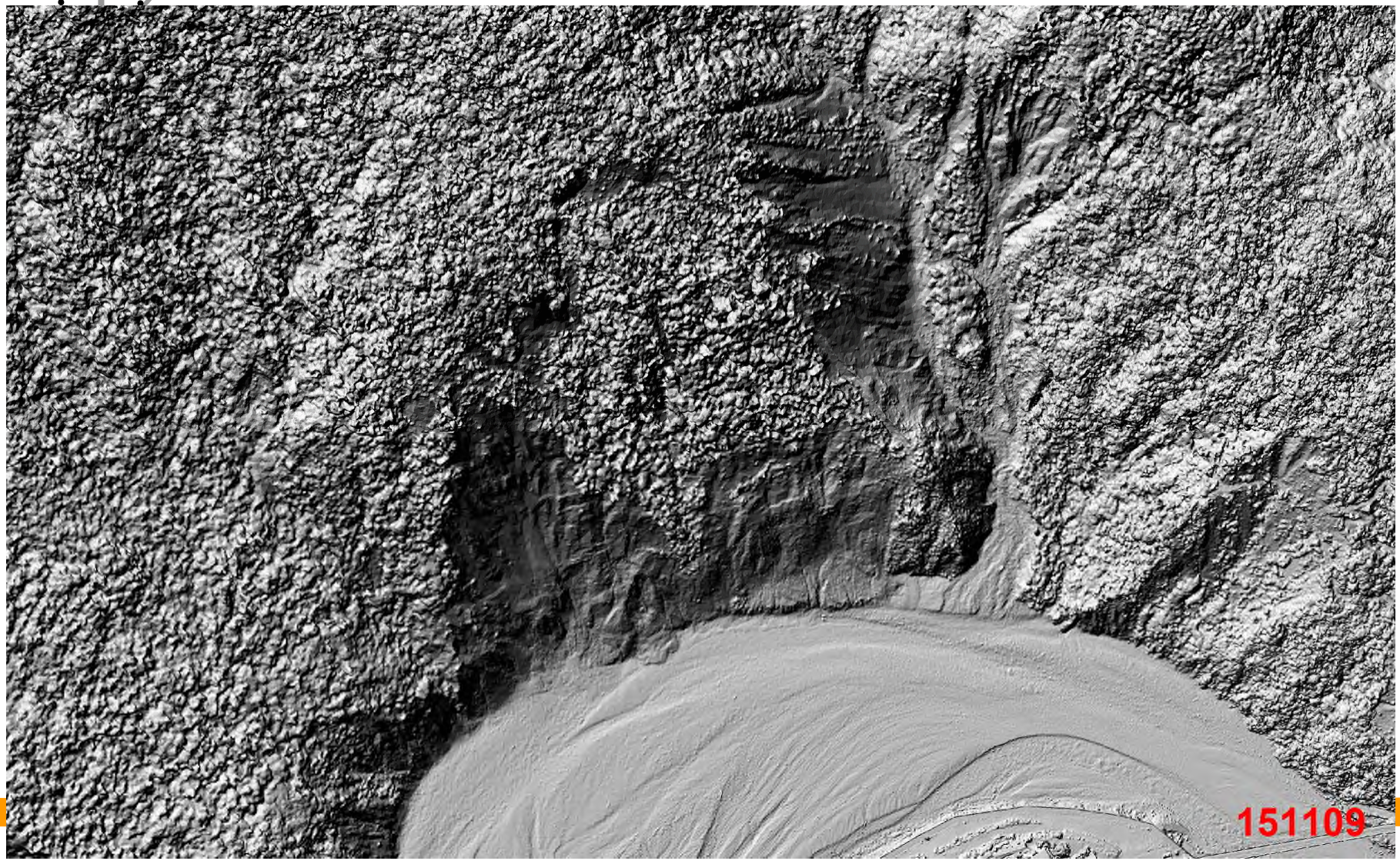

171204-180422


180422-180901

Landslide Monitoring - Old Algorism



Landslide Monitoring - New Algorism



Landslide Monitoring - New Algorism

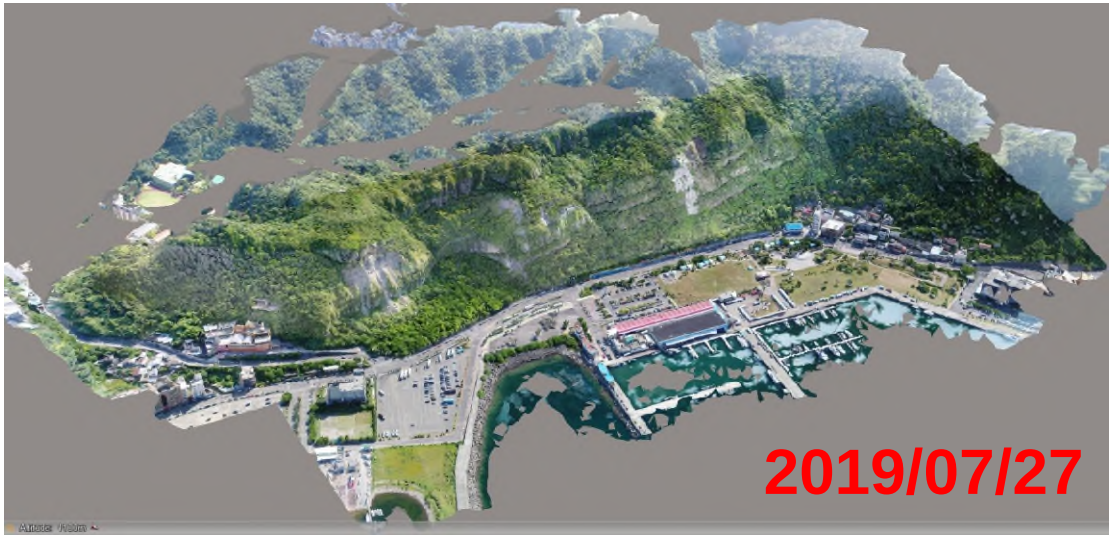


Landslide Monitoring - New Algorism

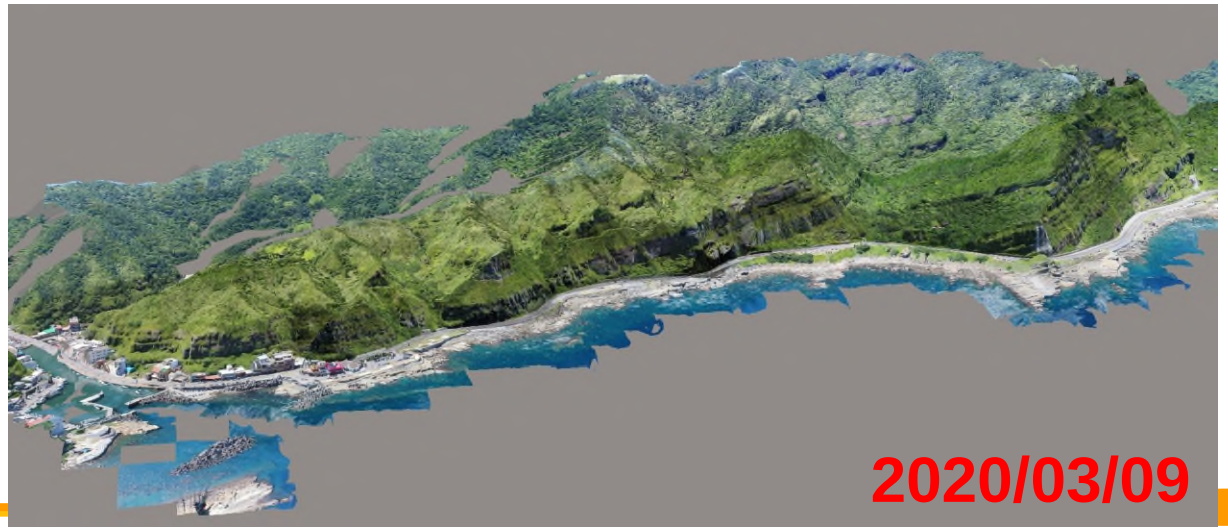


3D models: 2019 vs. 2020

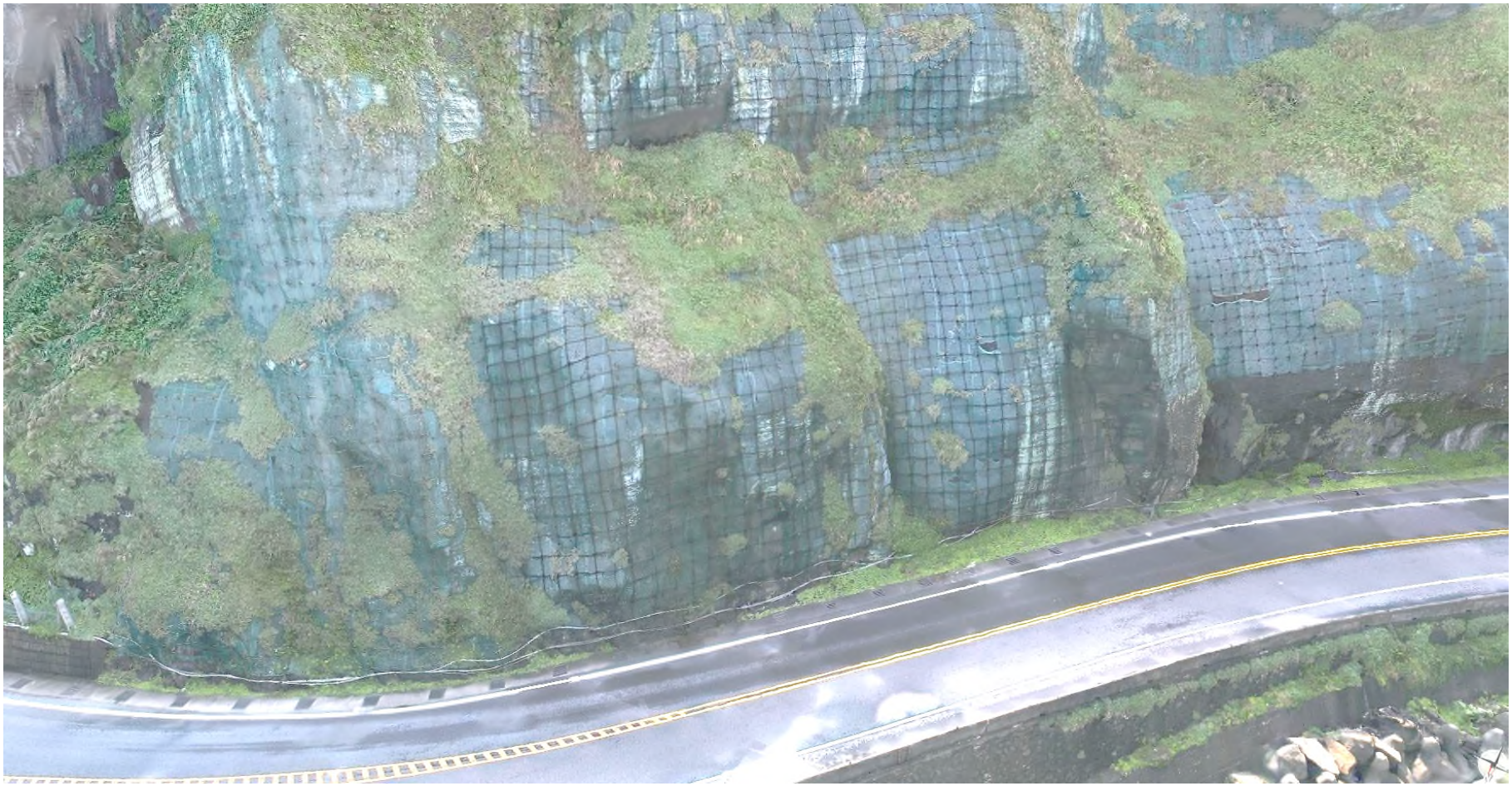
- 108/07/27
- 109/03/09
- 範圍：80公頃
- GSD : 3.3 cm



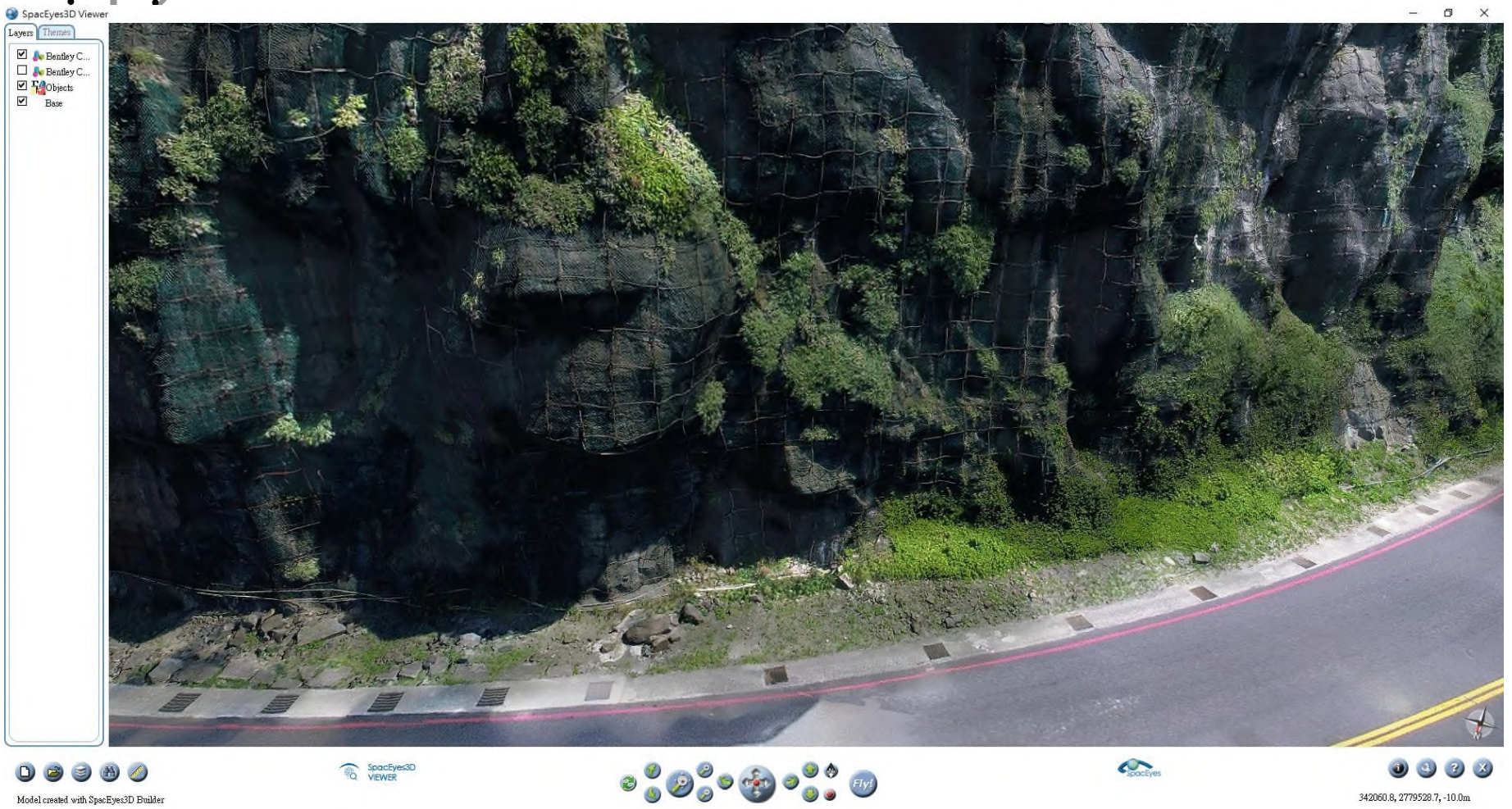
- 108/07/27
- 109/03/09
- 範圍：140公頃
- GSD : 3.1 cm



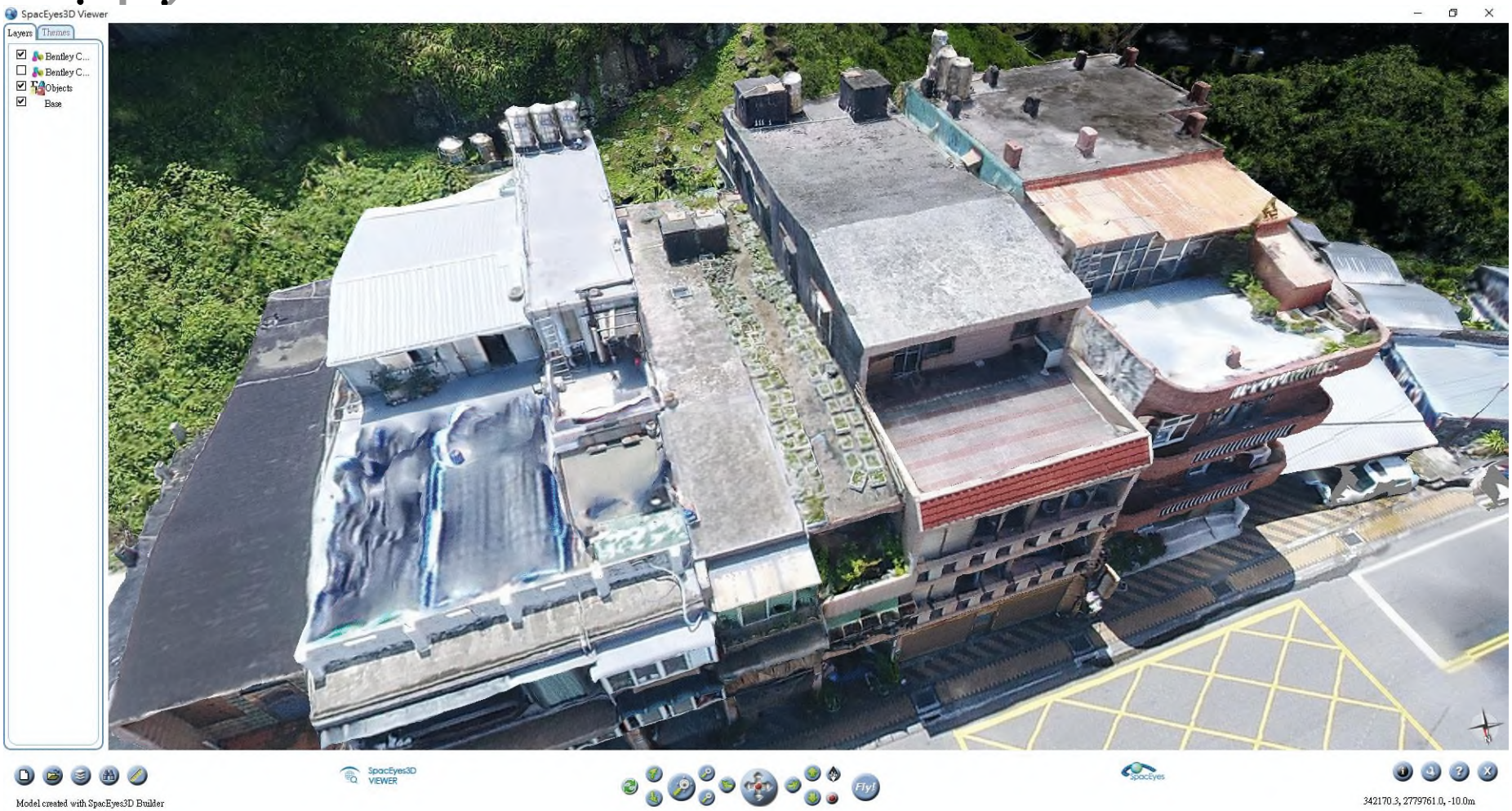
Change Detection ?!



Change Detection ?!



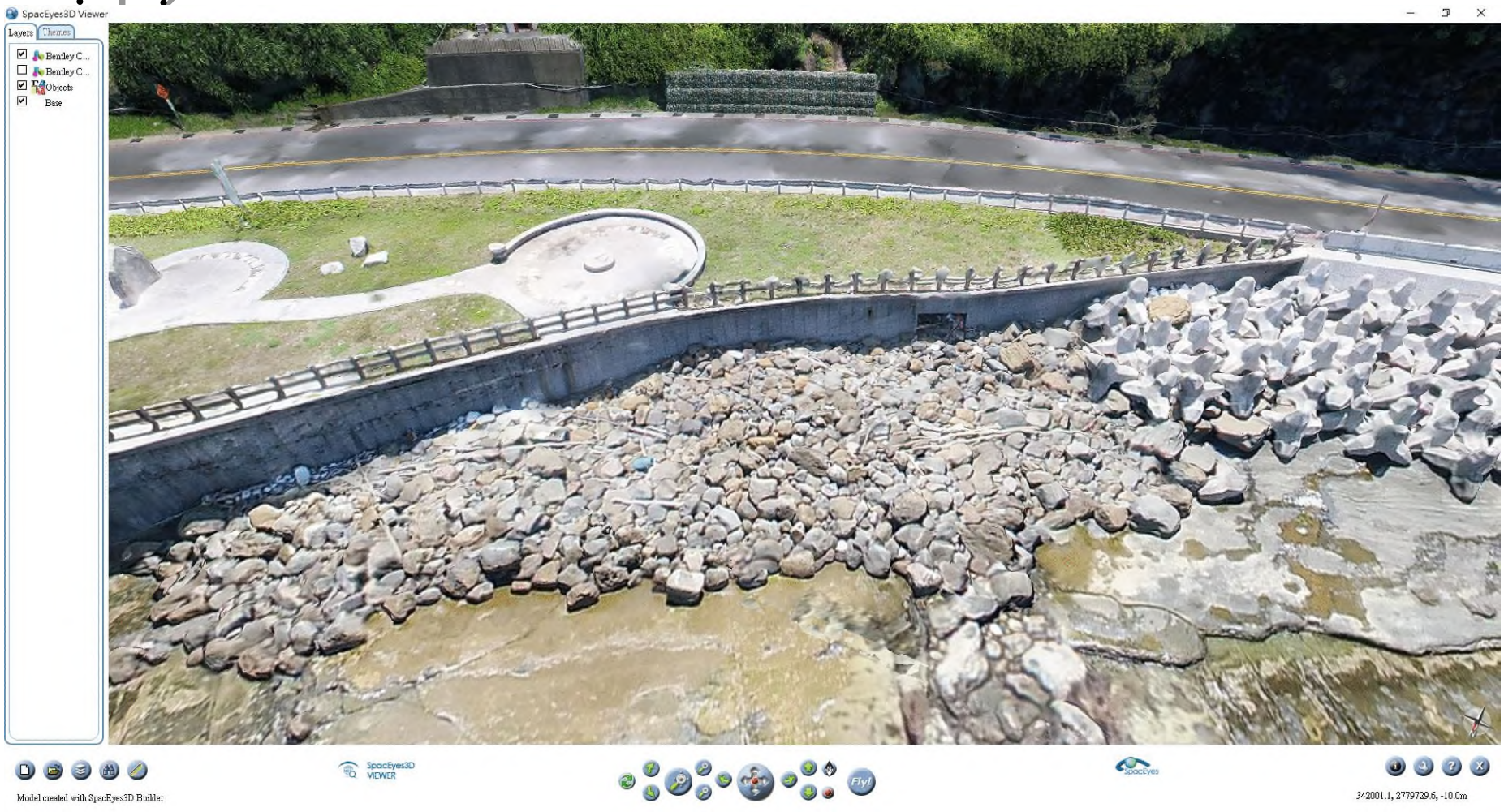
Change Detection 2



Change Detection 3



Change Detection 4



Topographic Change Detection



Rock Fall Detection

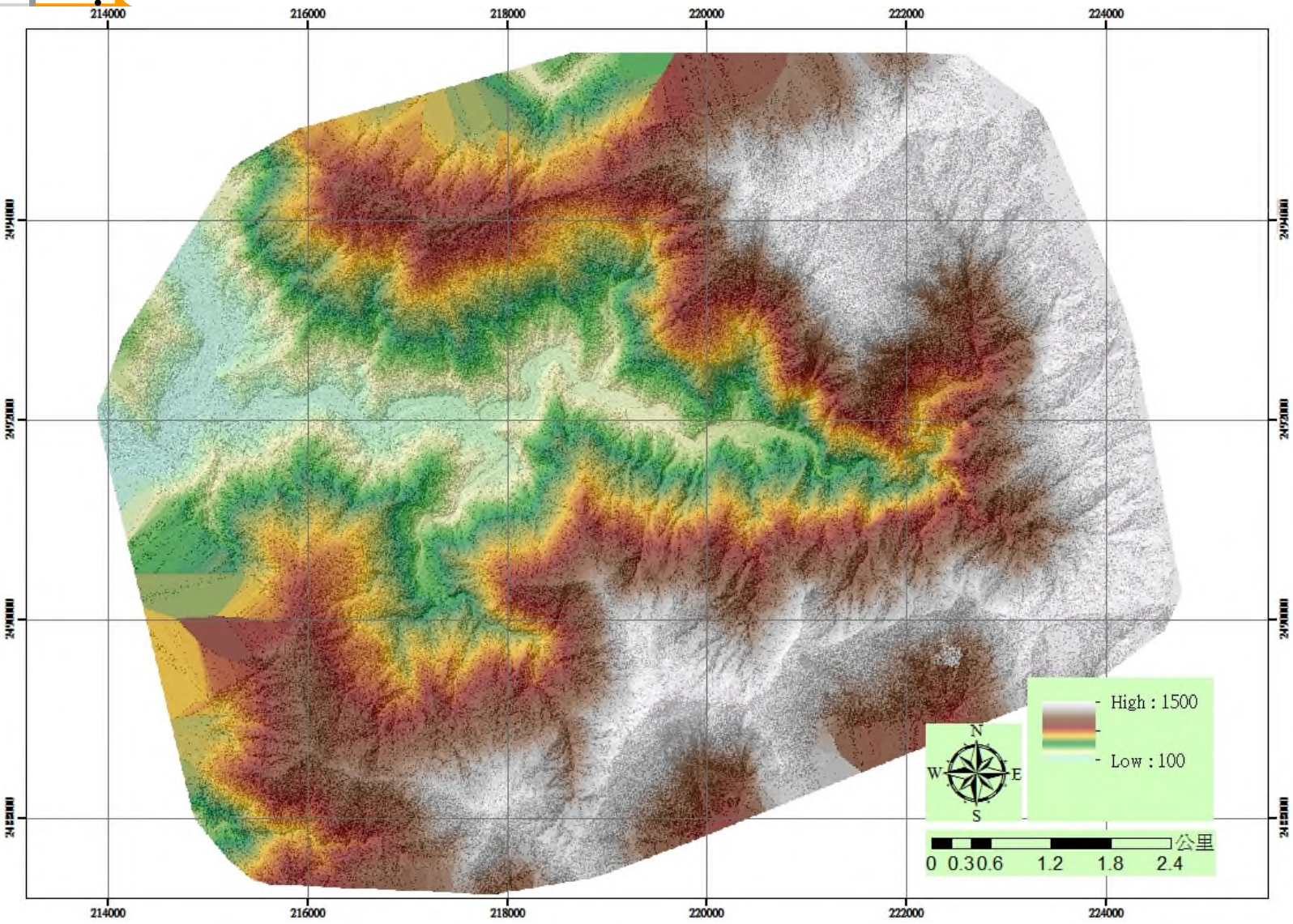



Thanks for Your Attention

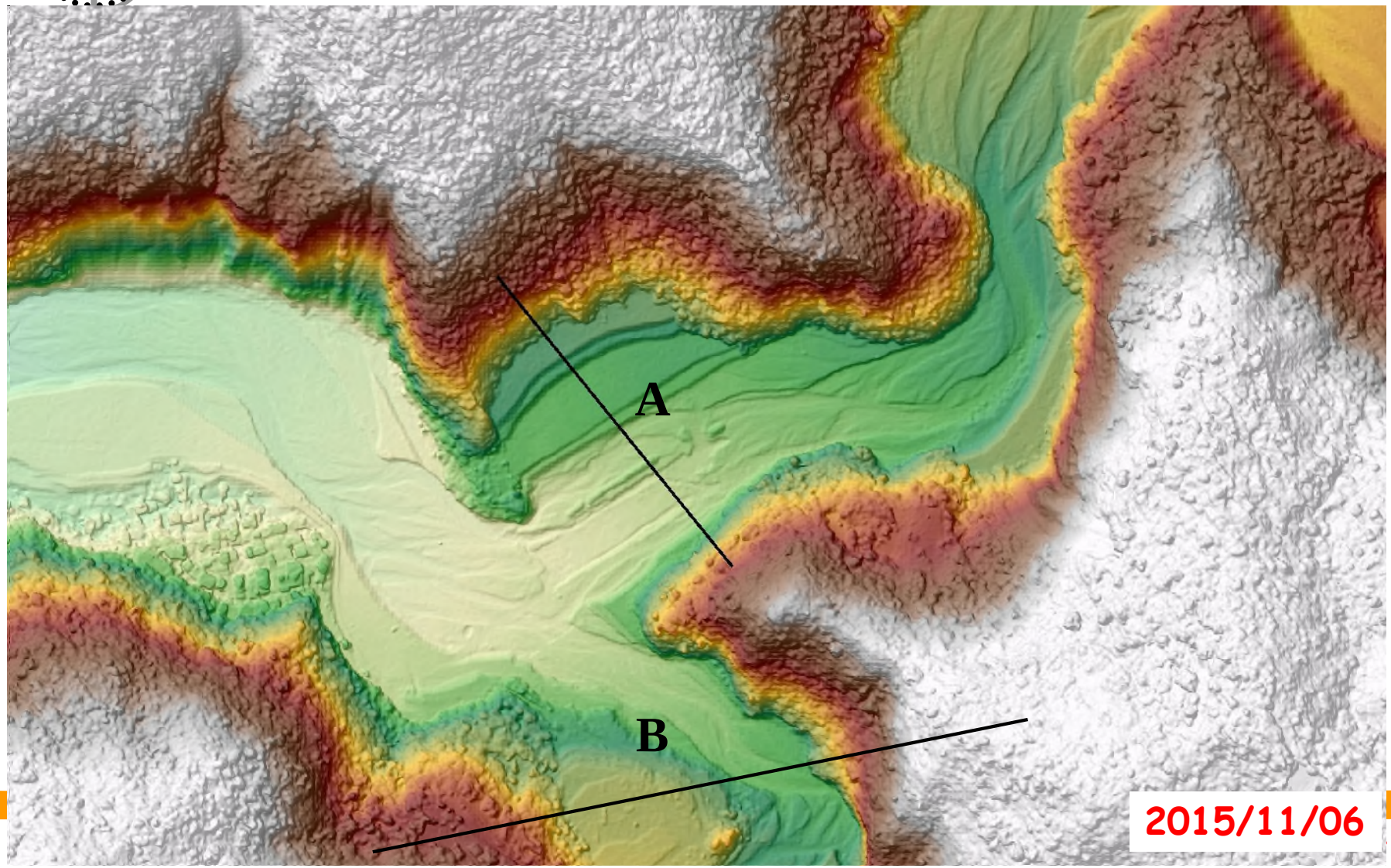
來義地區多期影像數據資料

Date	2009 04/10	2009 08/28	2010	2011	2013/ 03	2013 07/30	2014 05/17	2015 01/23	2015 05/21	2015 11/06
Source	Air photo	ADS 40	LiDAR	LiDAR	DMC	UAV	UAV	UAV	UAV	UAV
Area (km^2)	80	32	>150	30	120	1.5	2.2	67.5	22.5	69.8
Image res.	30cm	15cm	--	--	20cm	8cm	10cm	15cm	12cm	15cm
DTM res.	2m	2m	1m	2m	2m	8cm	12cm	17cm	15cm	20cm

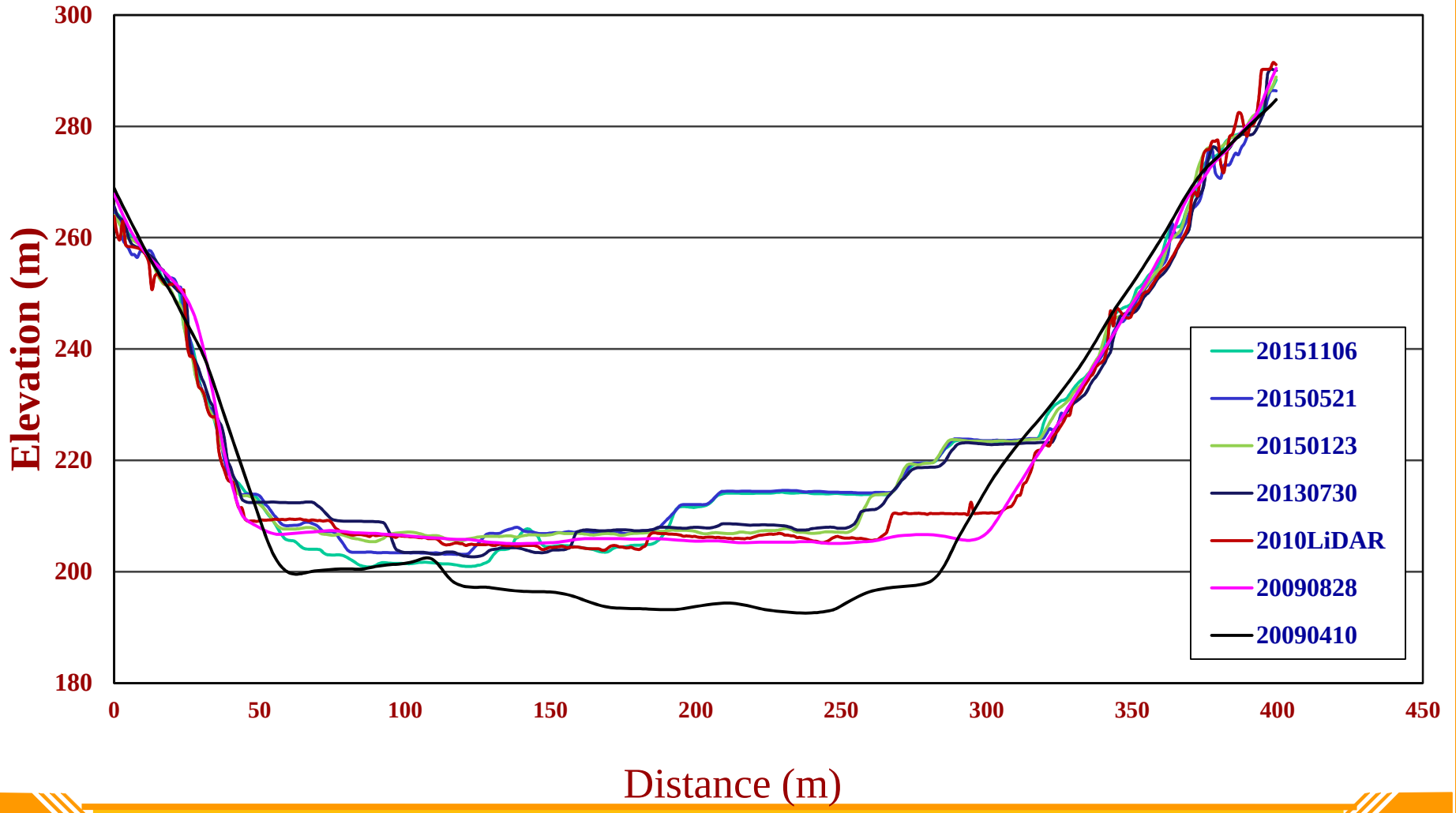
Orthomosaic & DSM 2015/01/23



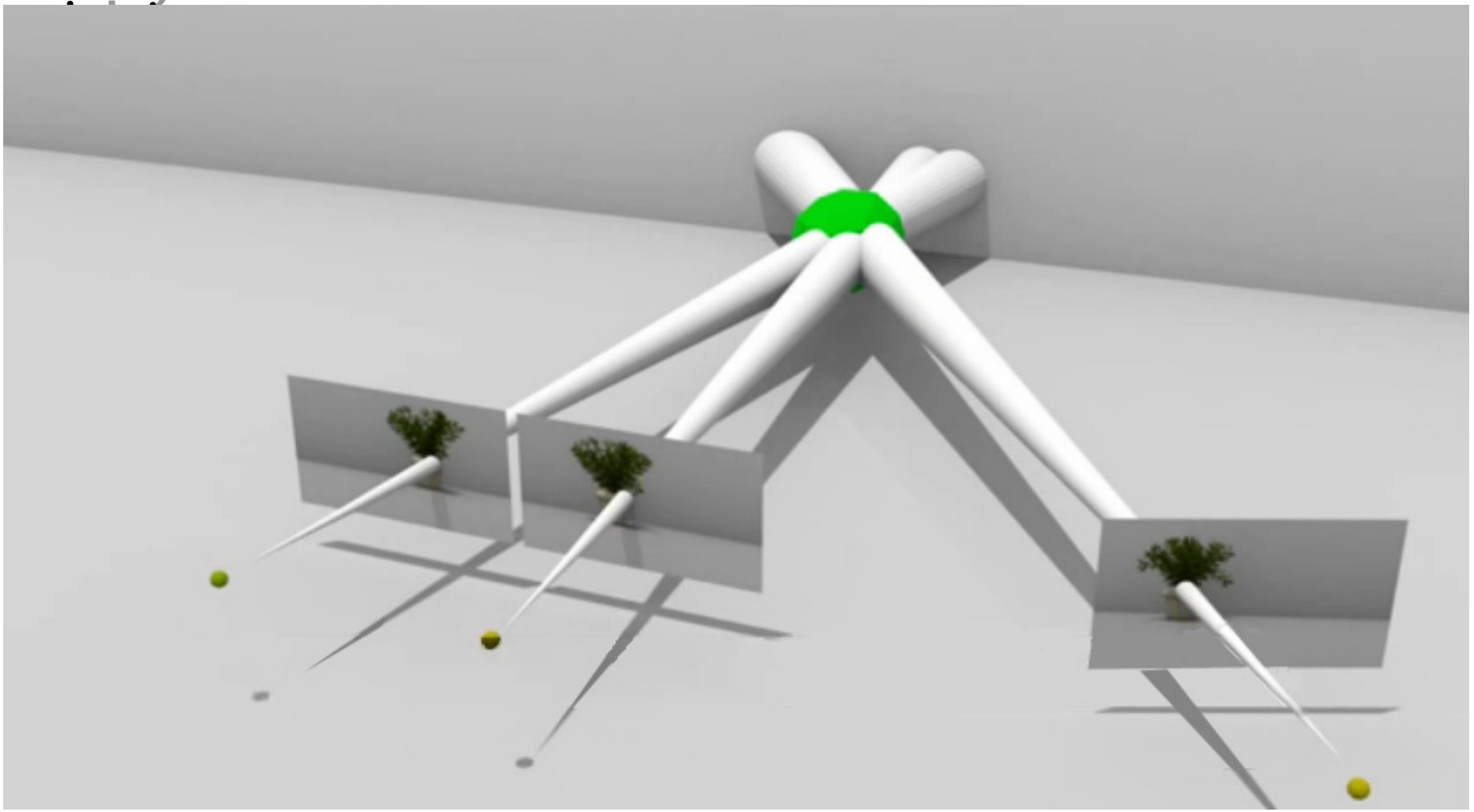
DSM Data Quality Evaluation



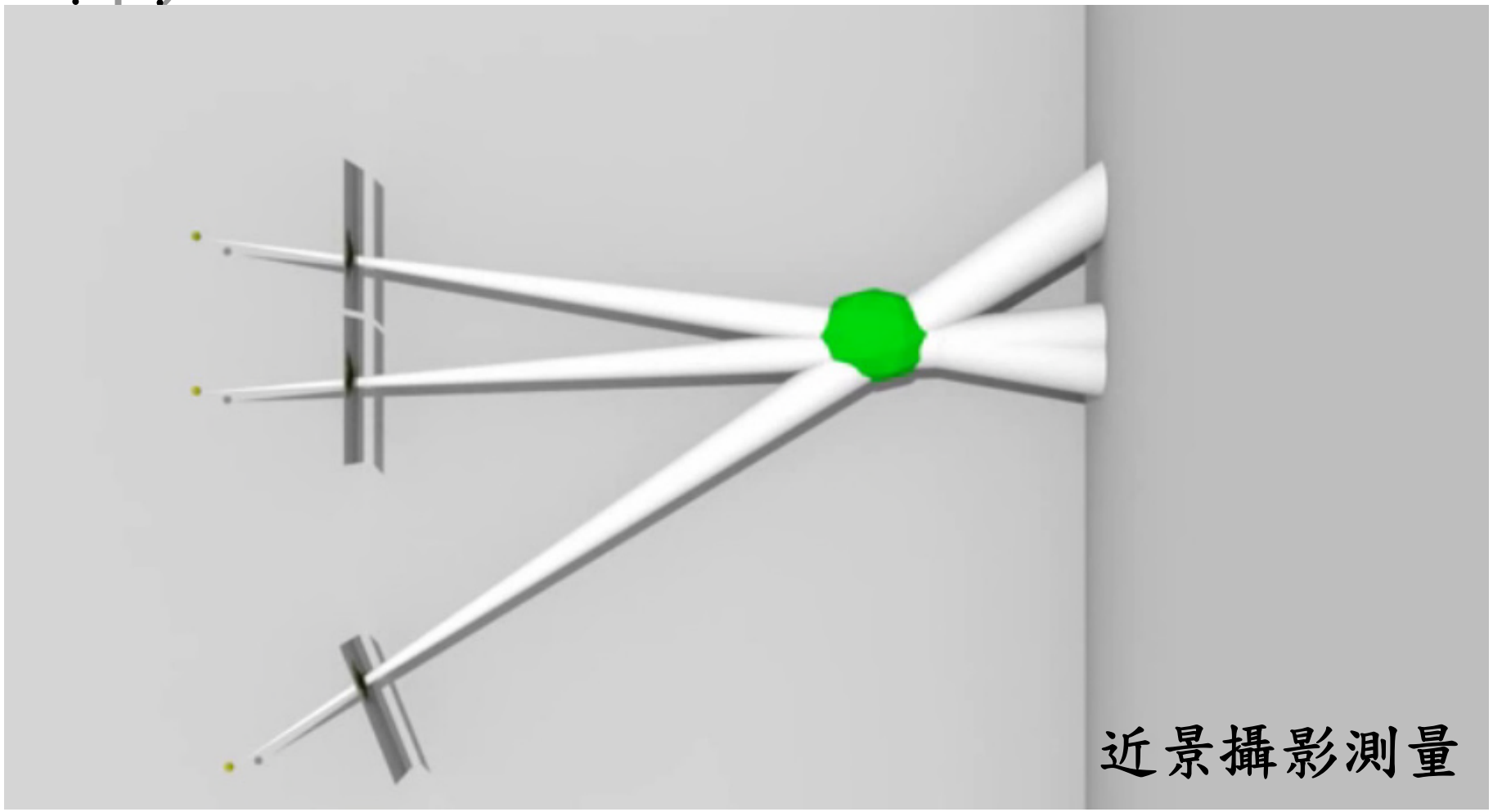
DSM Quality Evaluation– Profile A



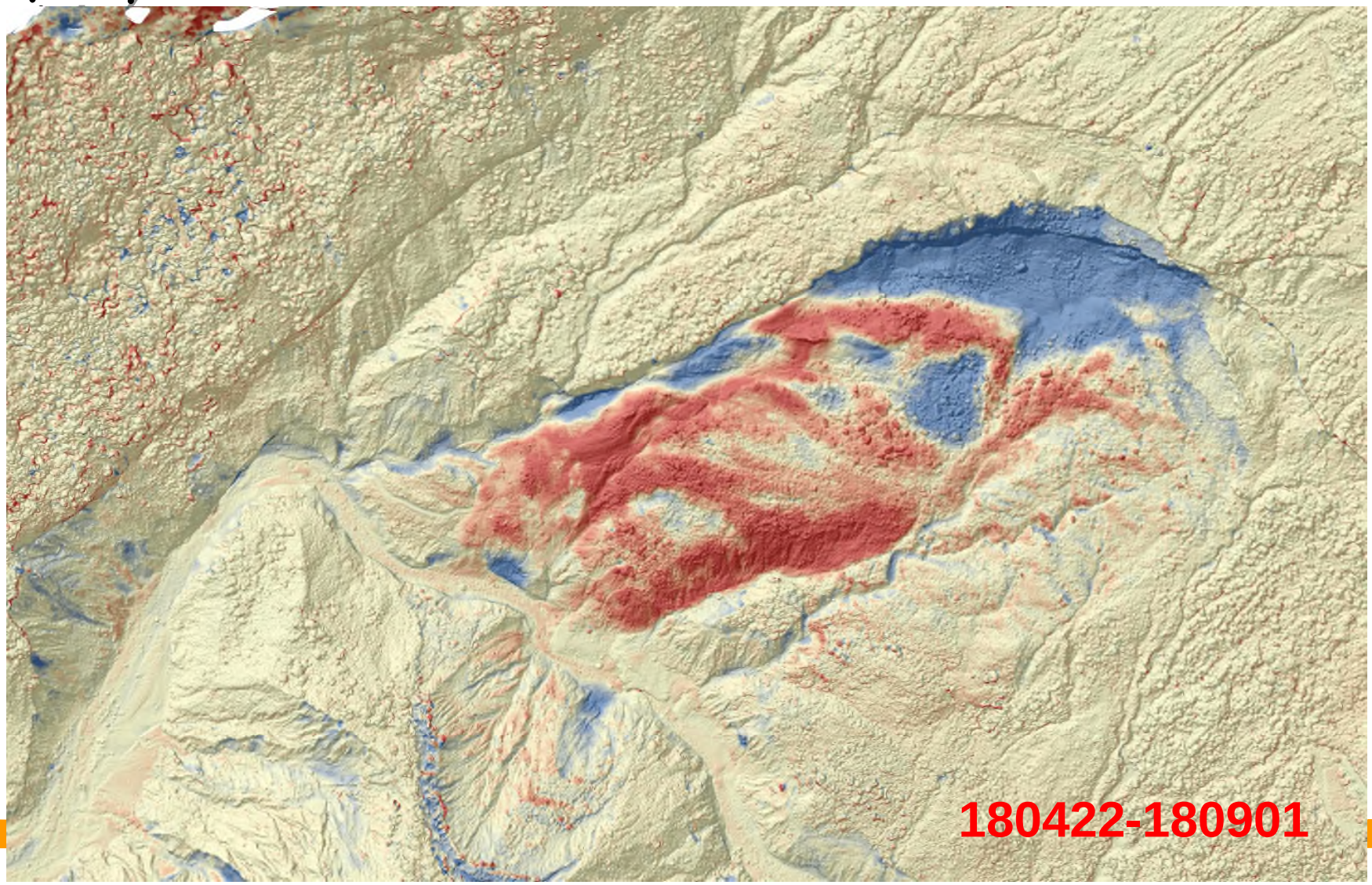
近景攝影於UAV應用之優勢



近景攝影於UAV應用之優勢

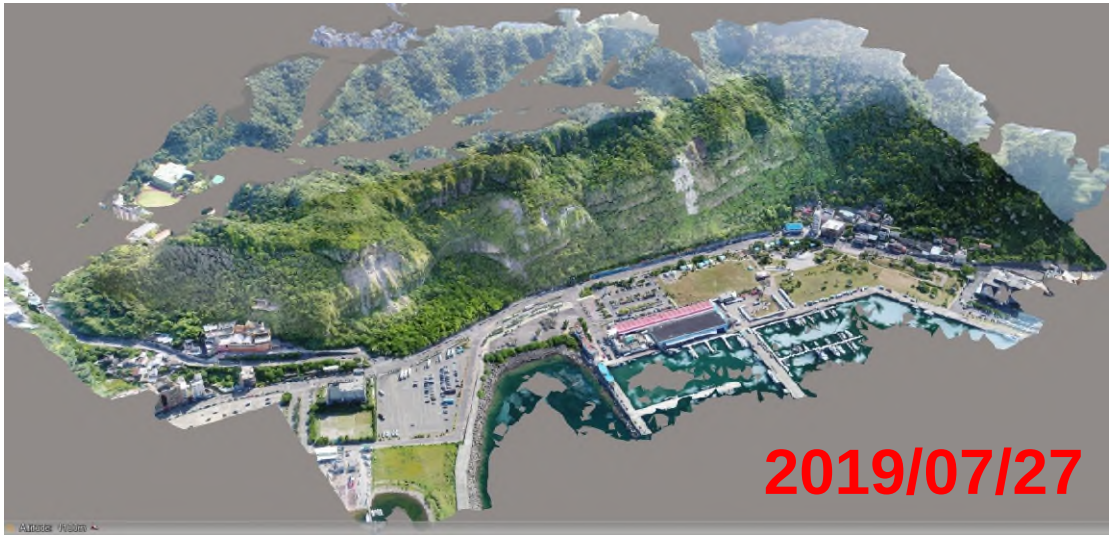


新演算法成果

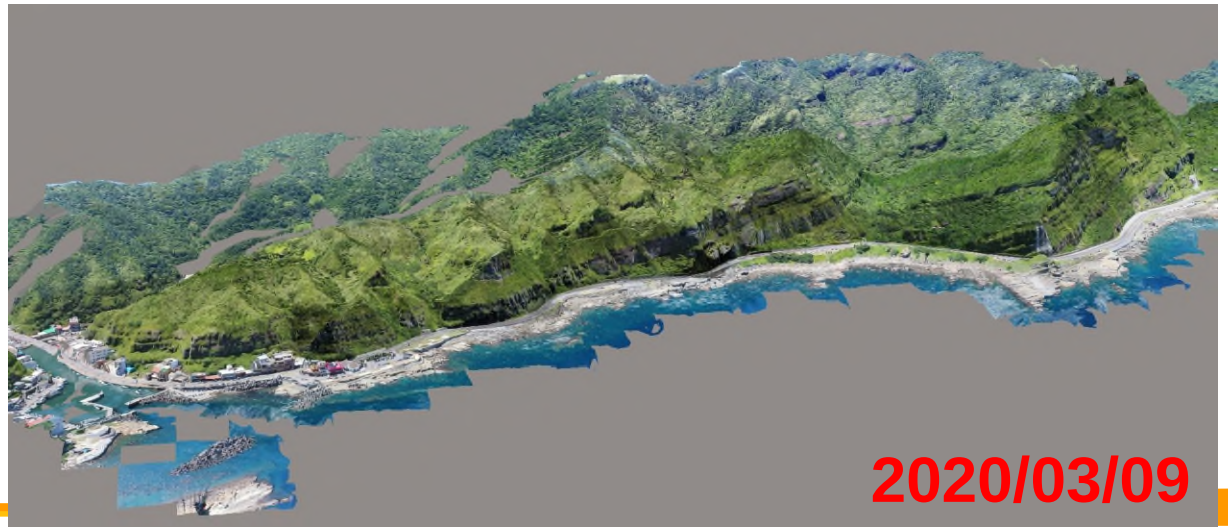


3D models: 2019 vs. 2020

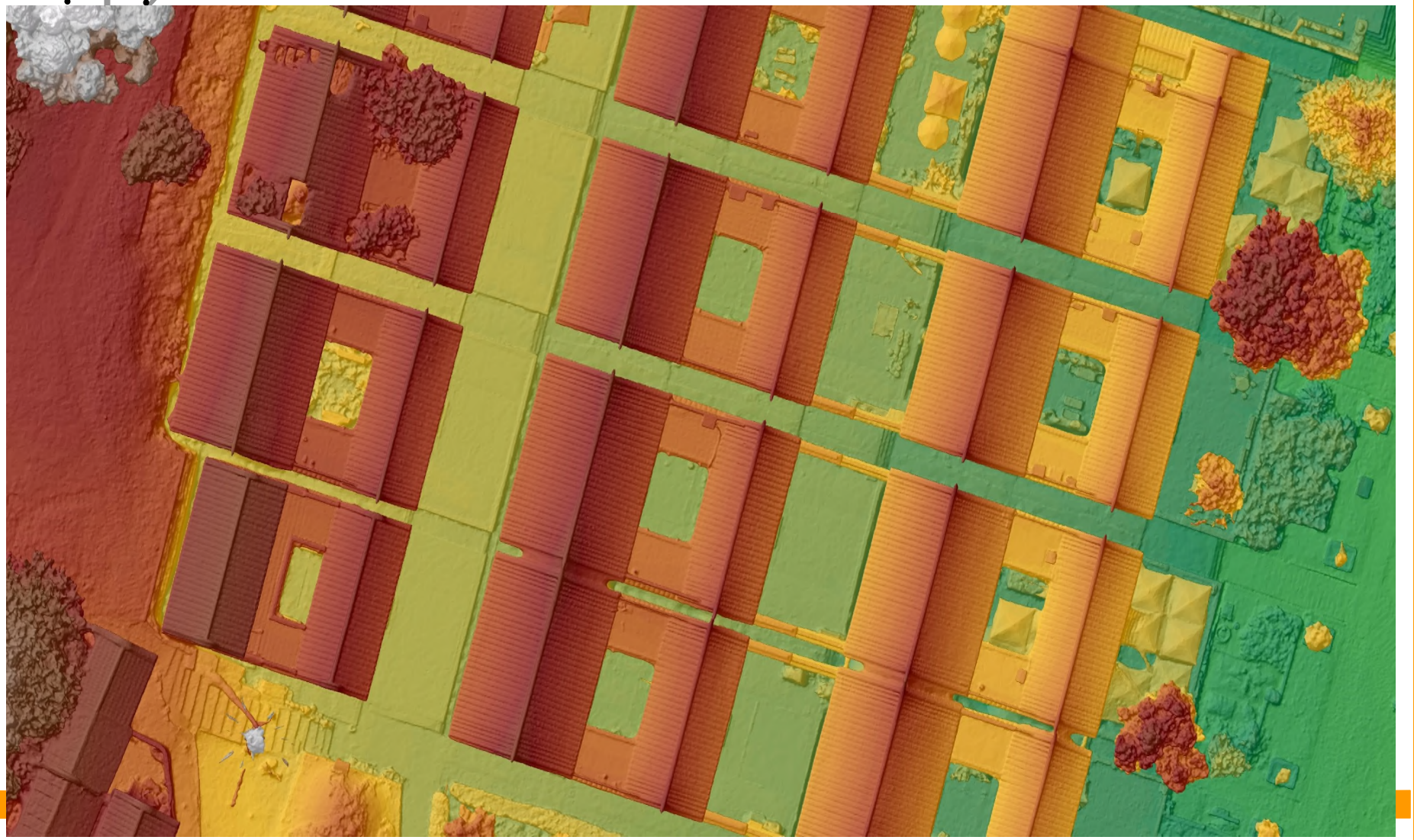
- 108/07/27
- 109/03/09
- 範圍：80公頃
- GSD : 3.3 cm



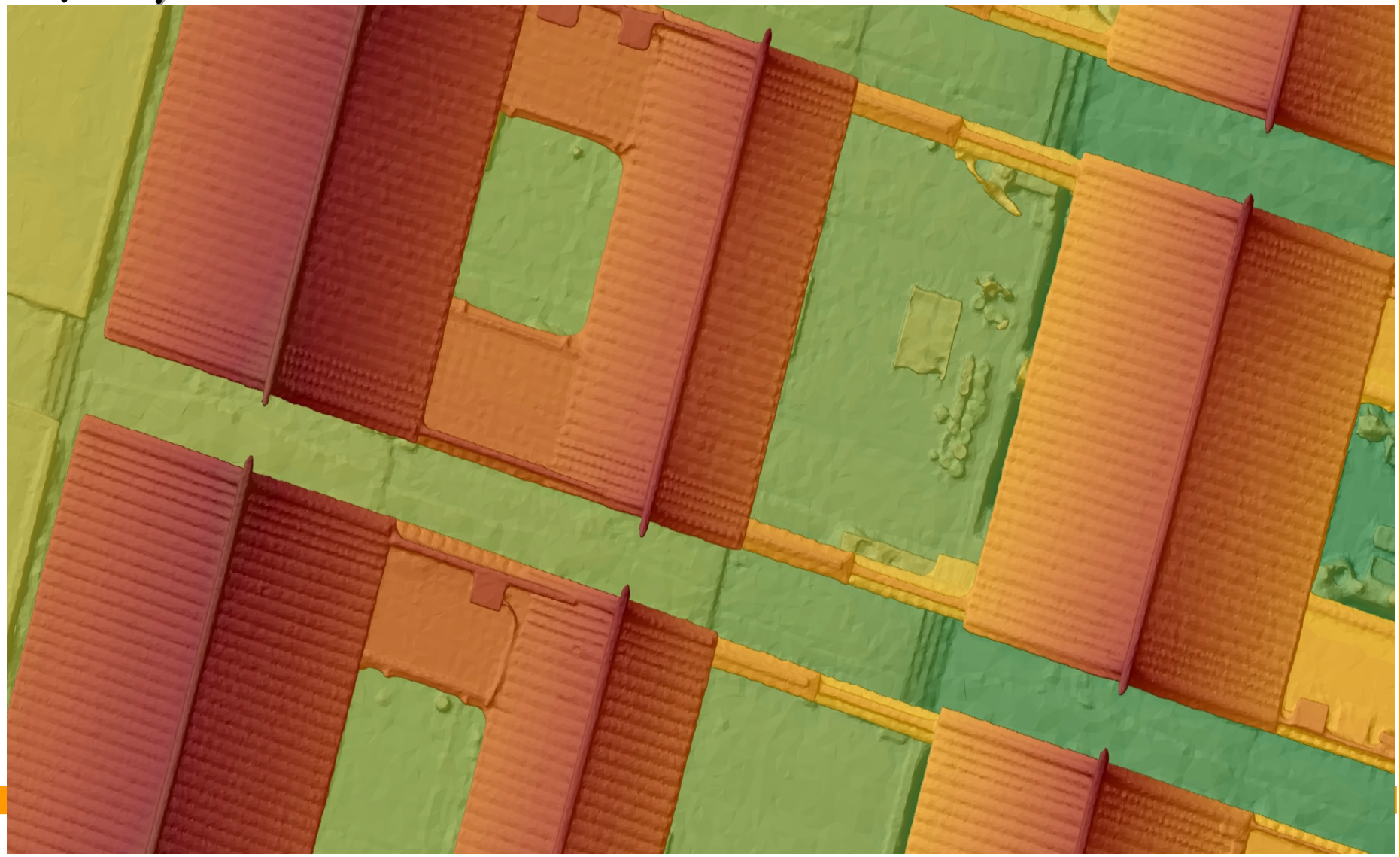
- 108/07/27
- 109/03/09
- 範圍：140公頃
- GSD : 3.1 cm



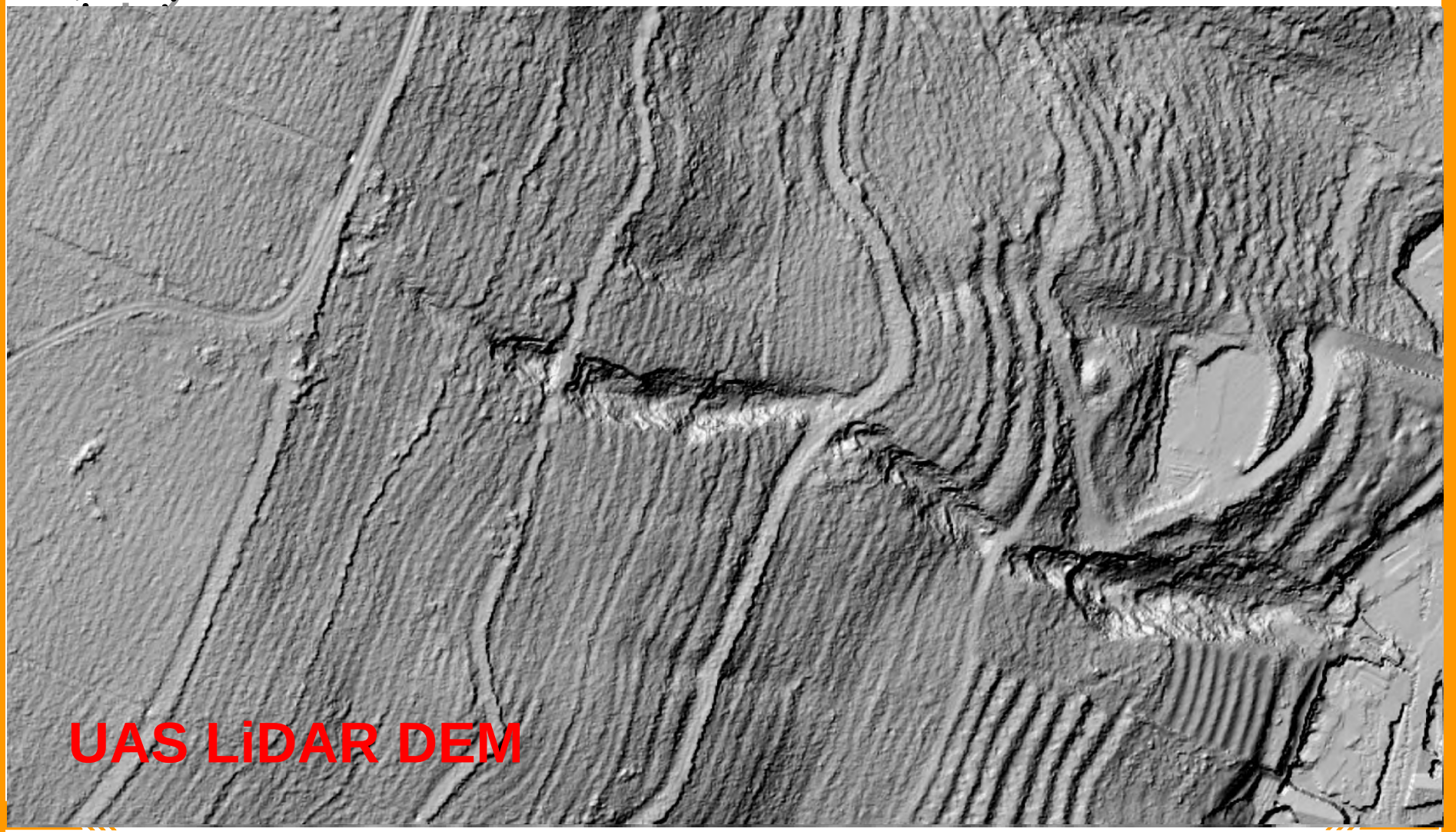
Data Comparison



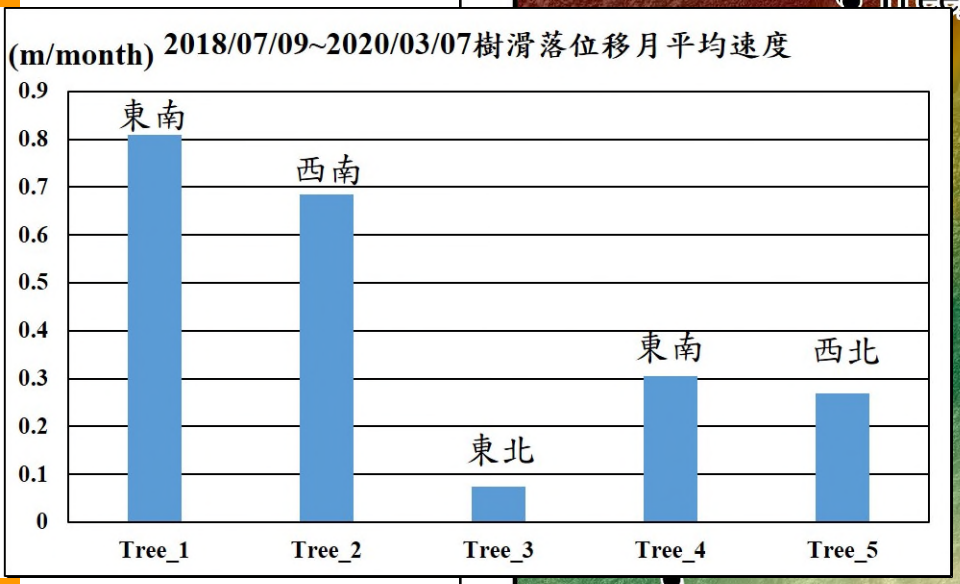
Data Comparison



Evolution of LiDAR Systems

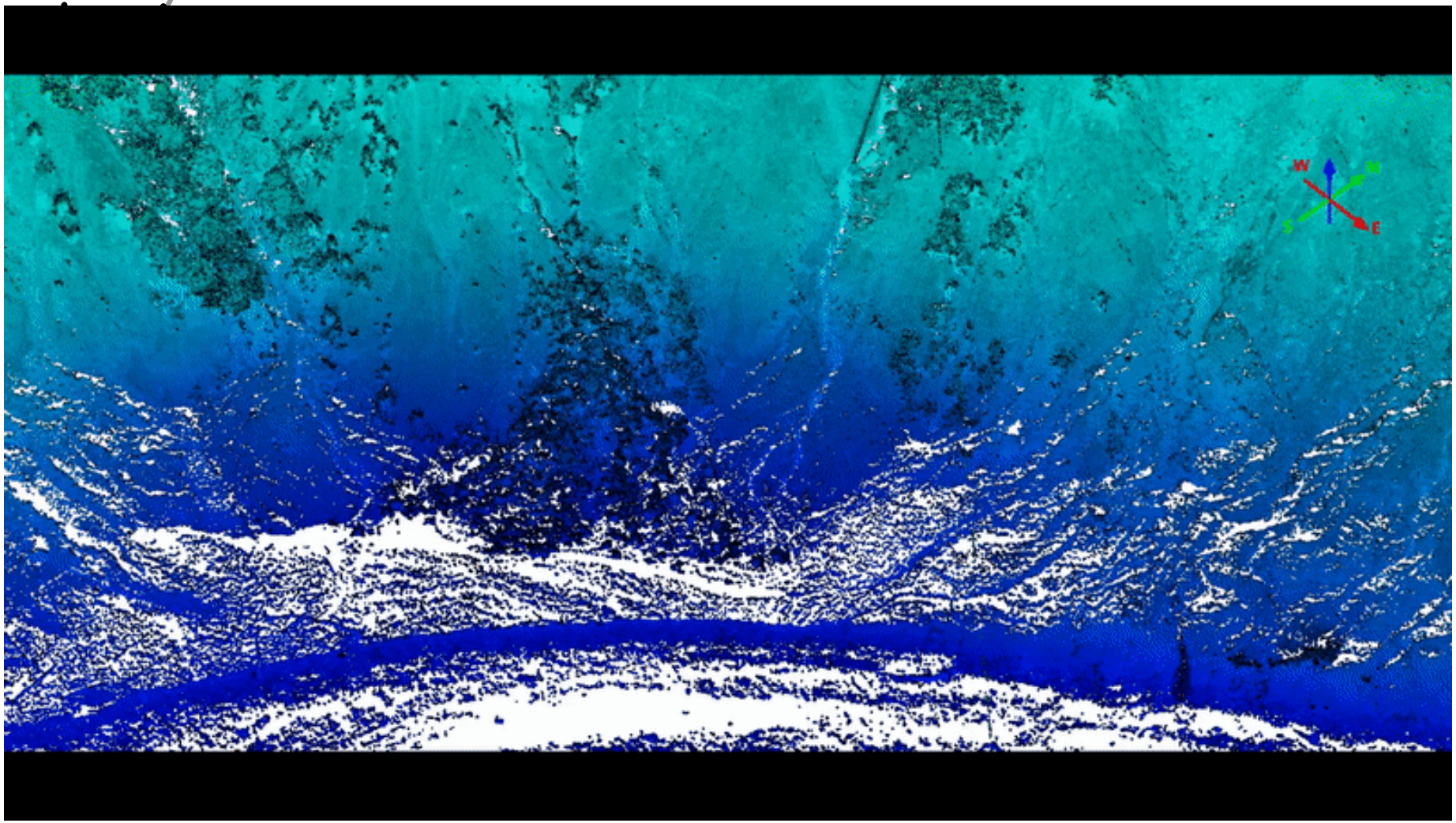


滑落位移量


(m/month) 2018/07/09~2020/03/07樹滑落位移月平均速度
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
東南
西南
東北
東南
西北
Tree_1
Tree_2
Tree_3
Tree_4
Tree_5

219000
2018/07/09~2020/03/07
滑落位移量
Tree_5
Tree_2
N
W
E
S
Tree_1
Tree_3
Tree_4
2557000
0
0.05
0.1
KM
219000

掃描儀空間資料差異

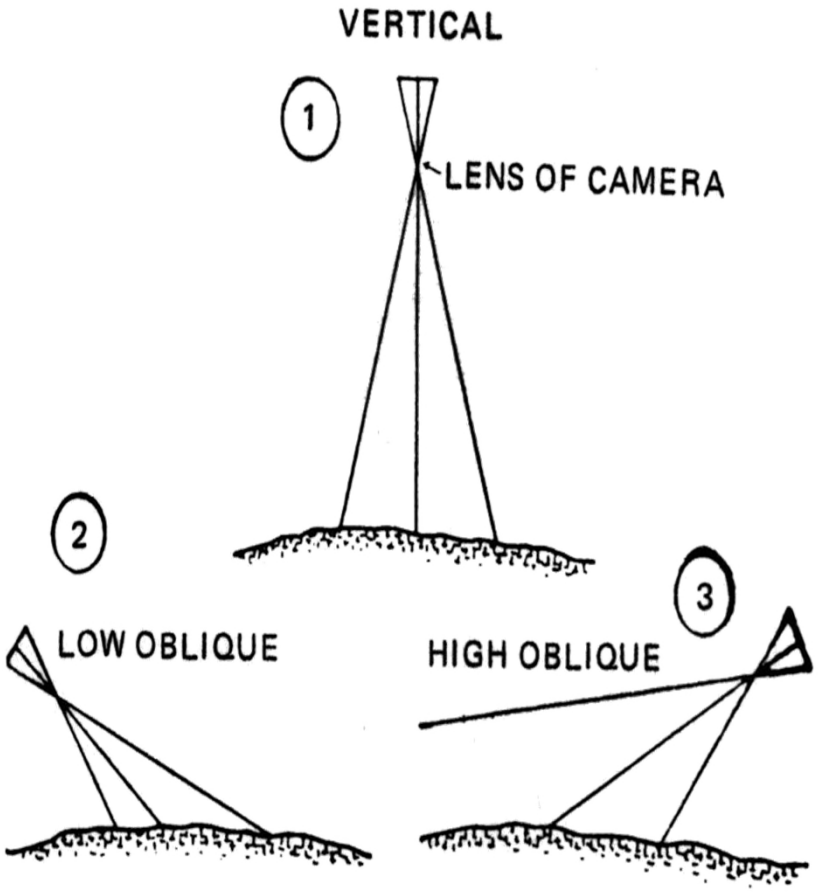


2.5D vs. True 3D Model

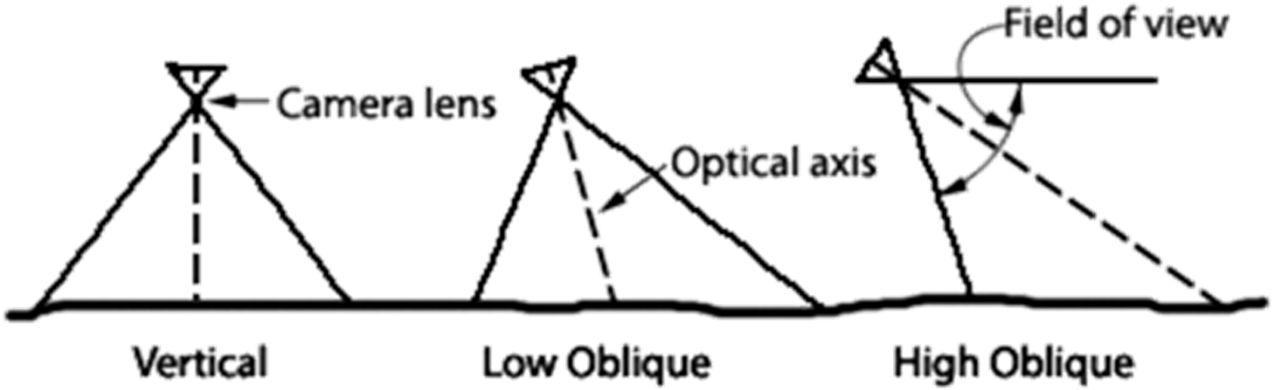


Geometry of Vertical Aerial Photo

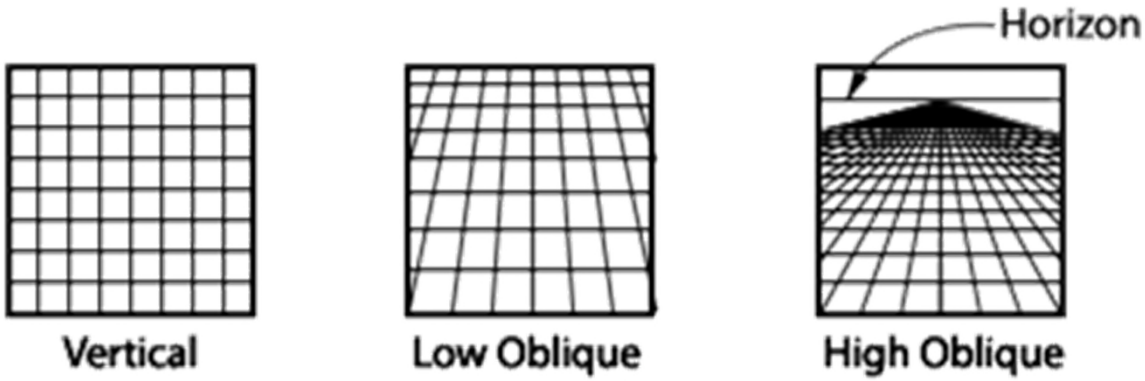
- Vertical photographs
  - camera aimed directly at the ground surface from above
- Oblique photographs
  - Cameras oriented toward the side of the aircraft
    - high oblique (includes horizon)
    - low oblique (no horizon)



Geometry of Aerial Photo



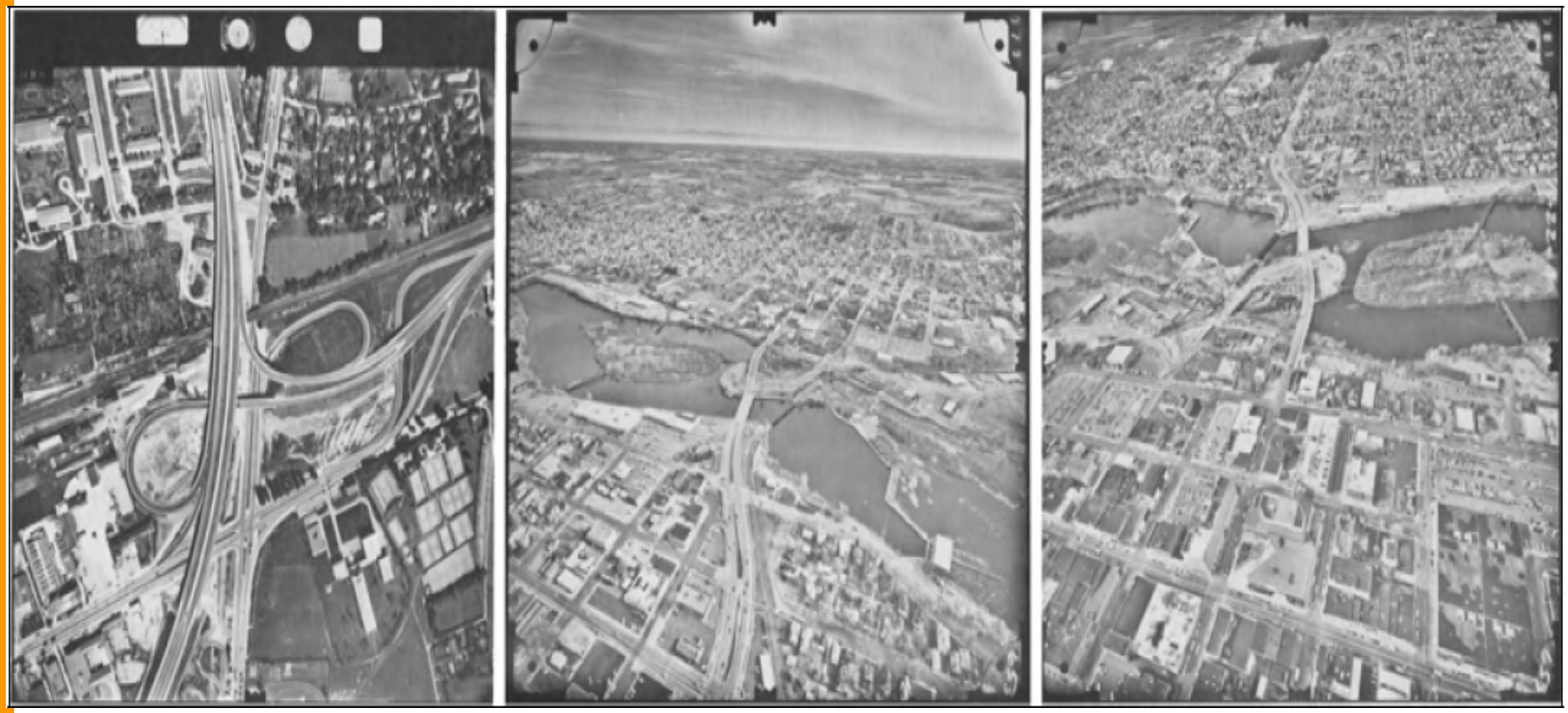
Camera orientation for various types of aerial photographs



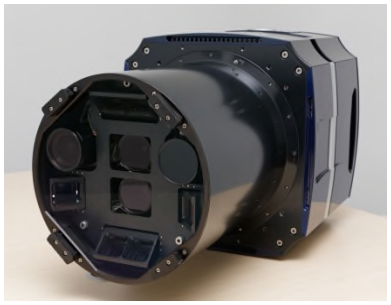
How a grid of section lines appears on various types of photos.

Types of Photographs

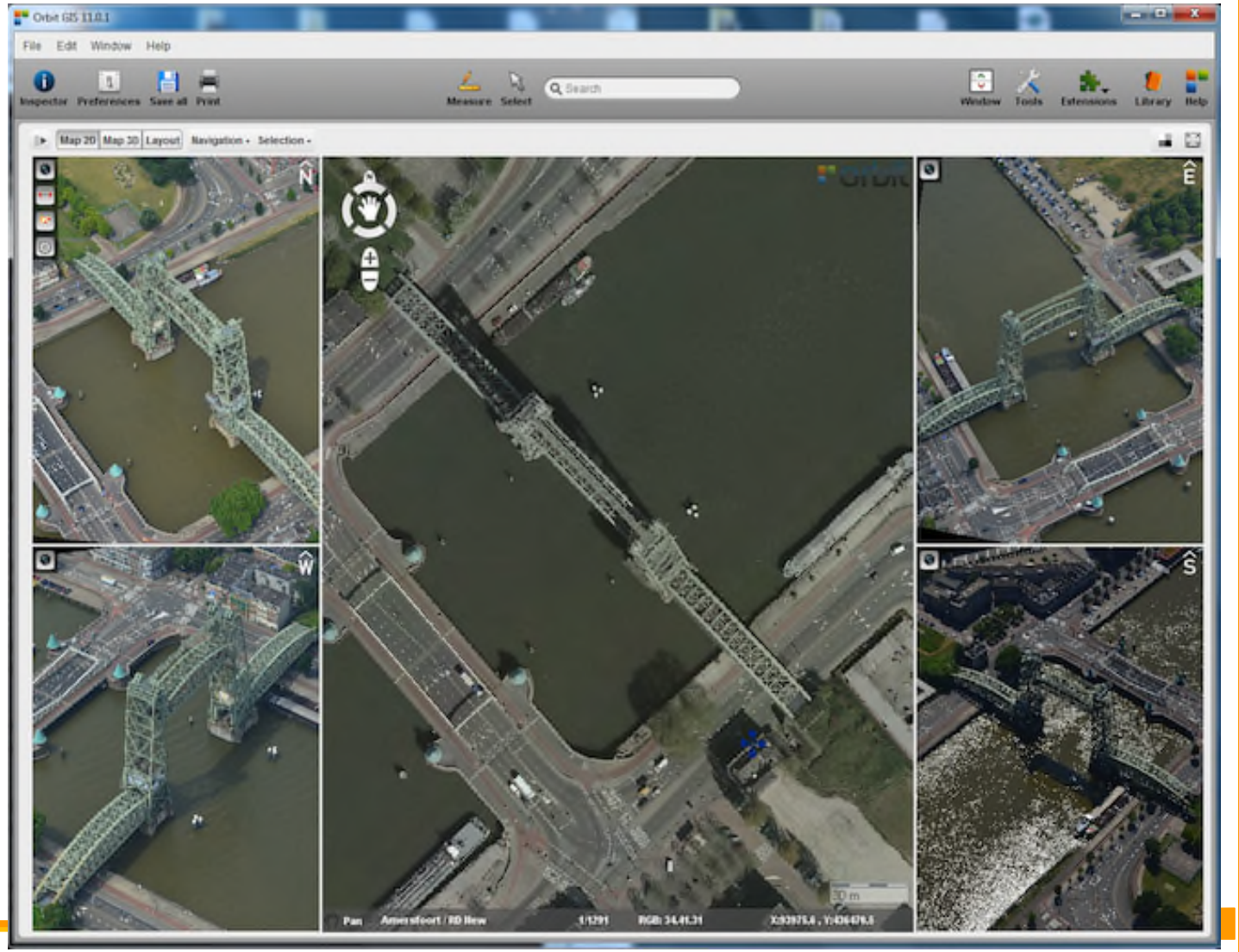
Example of vertical, high, and low oblique photos



Oblique Photogrammetry







多相機傾斜攝影





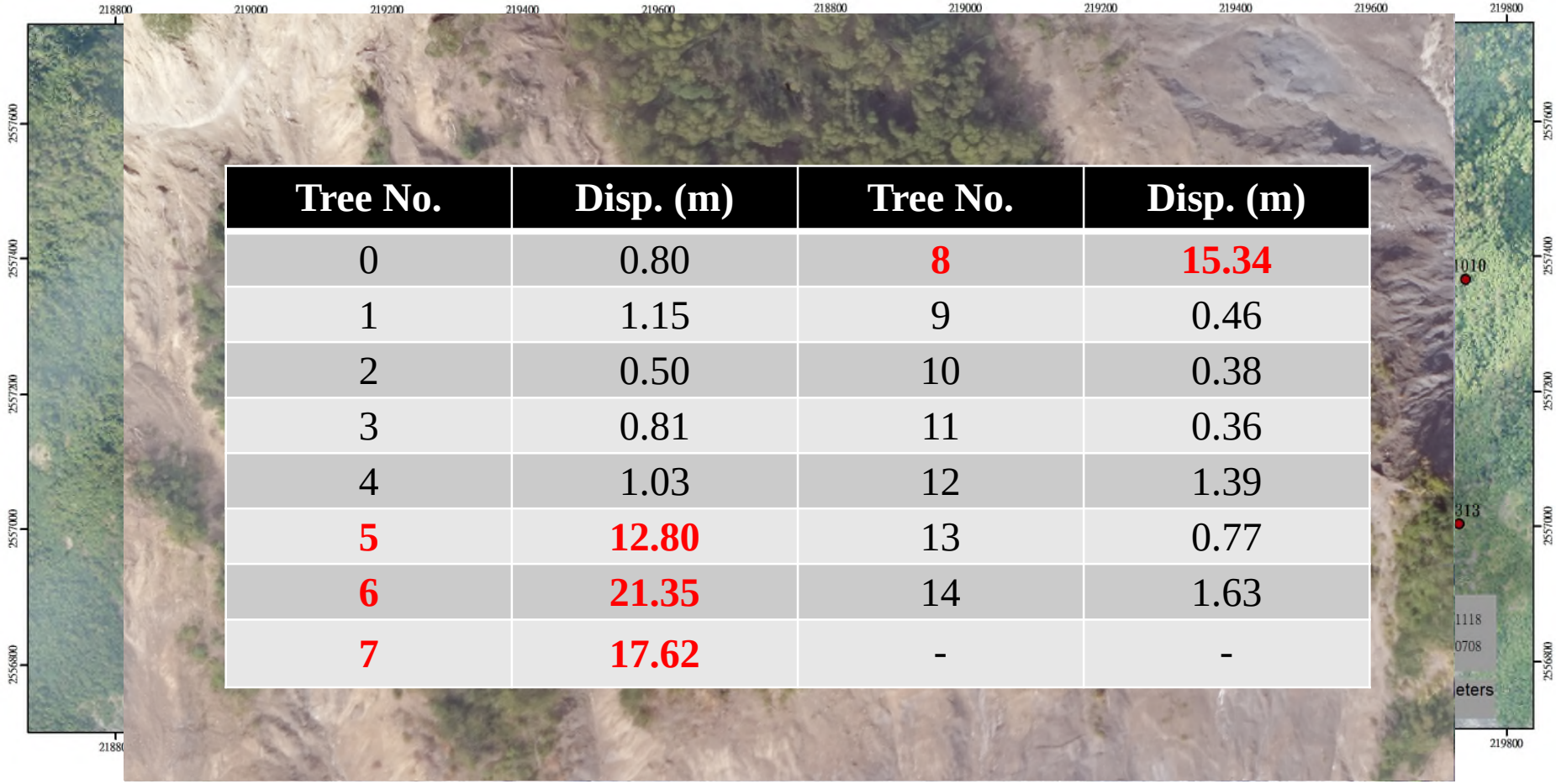






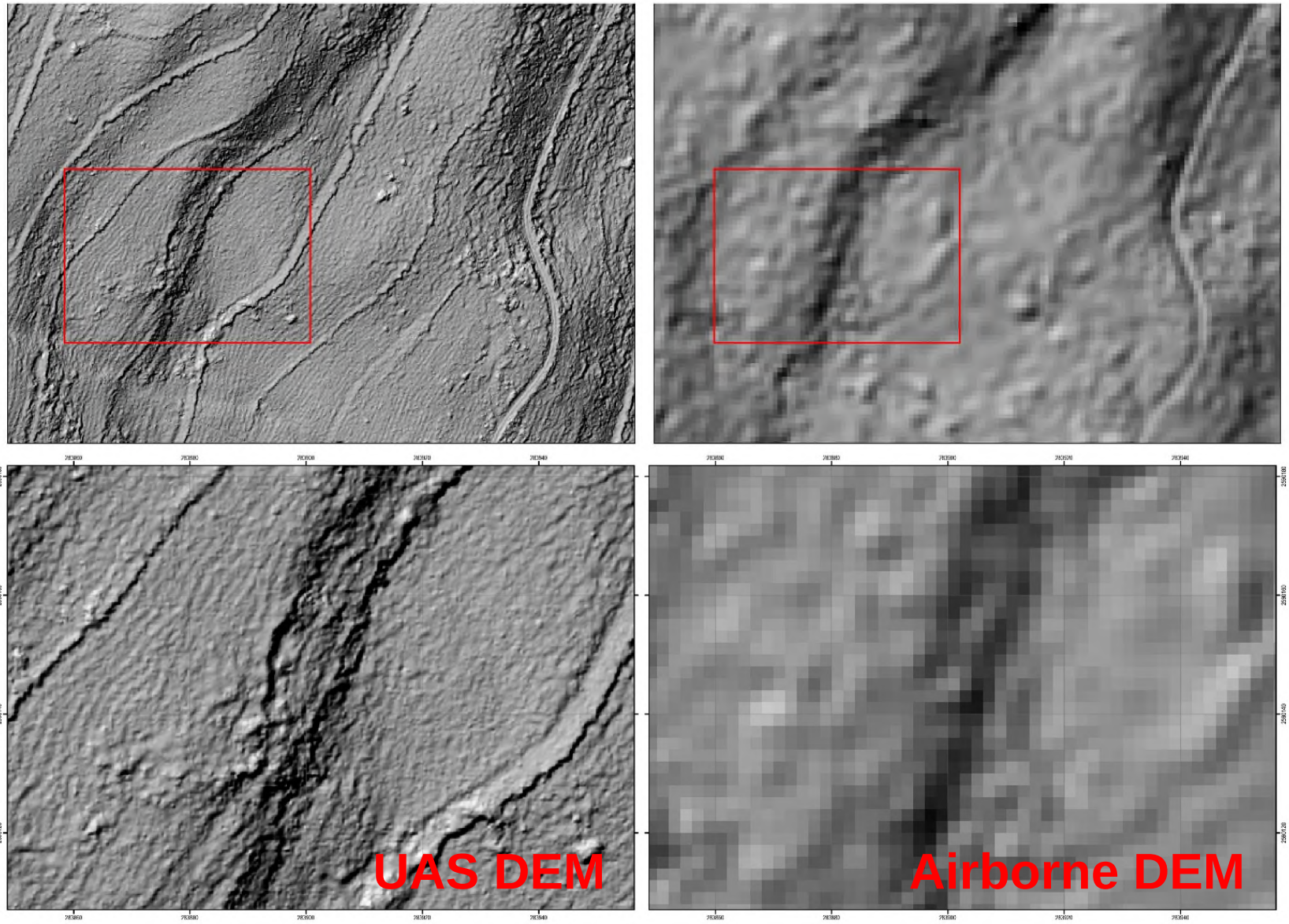


Horizontal Displacement



Tree No.	Disp. (m)	Tree No.	Disp. (m)
0	0.80	8	15.34
1	1.15	9	0.46
2	0.50	10	0.38
3	0.81	11	0.36
4	1.03	12	1.39
5	12.80	13	0.77
6	21.35	14	1.63
7	17.62	-	-

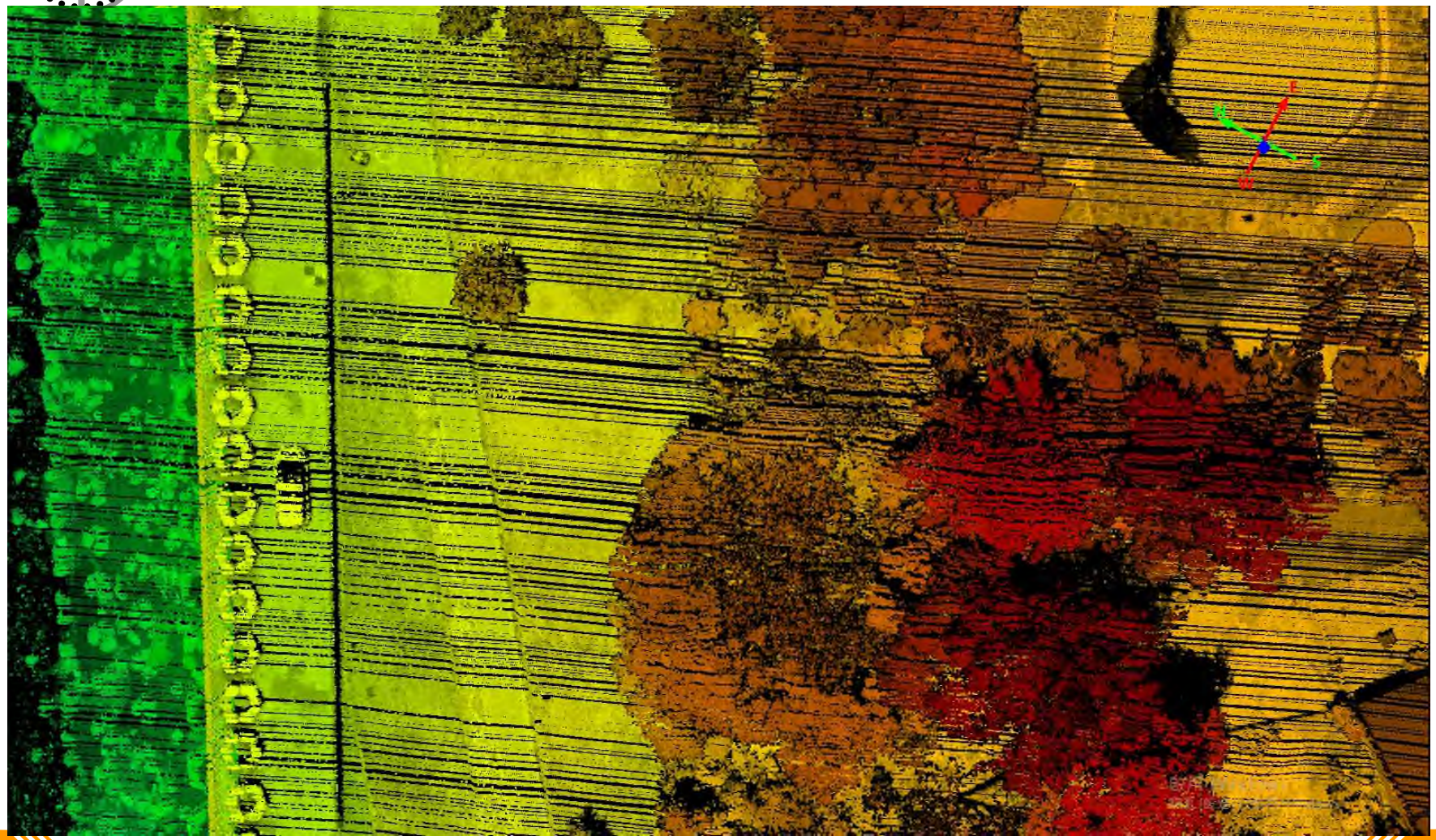
Potential Large-scale Landslide ?!



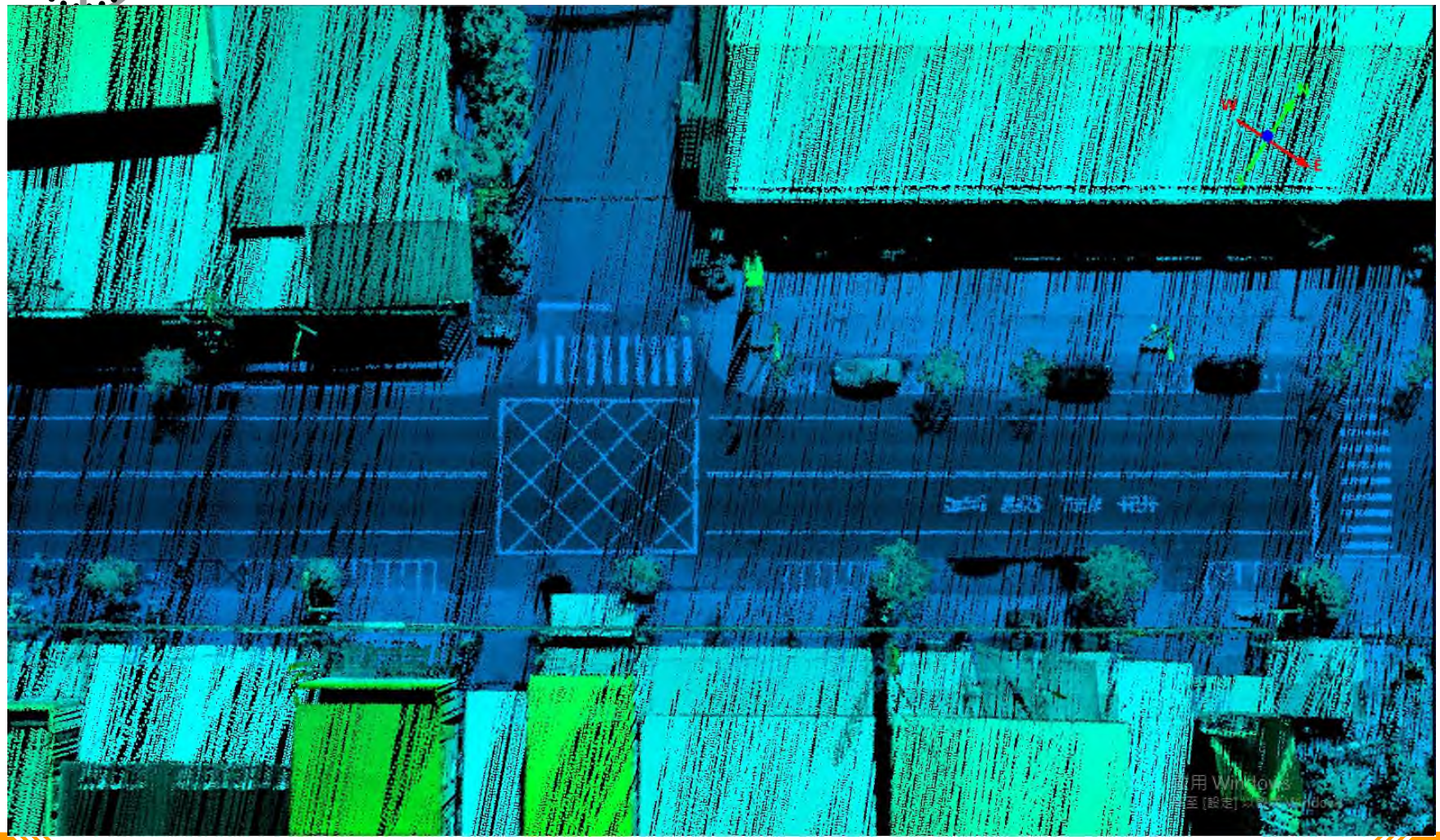
資料收集

日期	類別	點雲數	航帶/站數
2017/11/16	無人機光達	83 M	2航次
2018/07/09	無人機光達	108 M	3航次
2018/12/24	無人機光達	141 M	4航次
2018/12/24	地面光達	101 M	11站
2019/07/17	無人機光達	186 M	4航次
2019/07/17	地面光達	141 M	14站
2020/03/07	無人機光達	165 M	3航次
2020/03/04	地面光達	356 M	33站

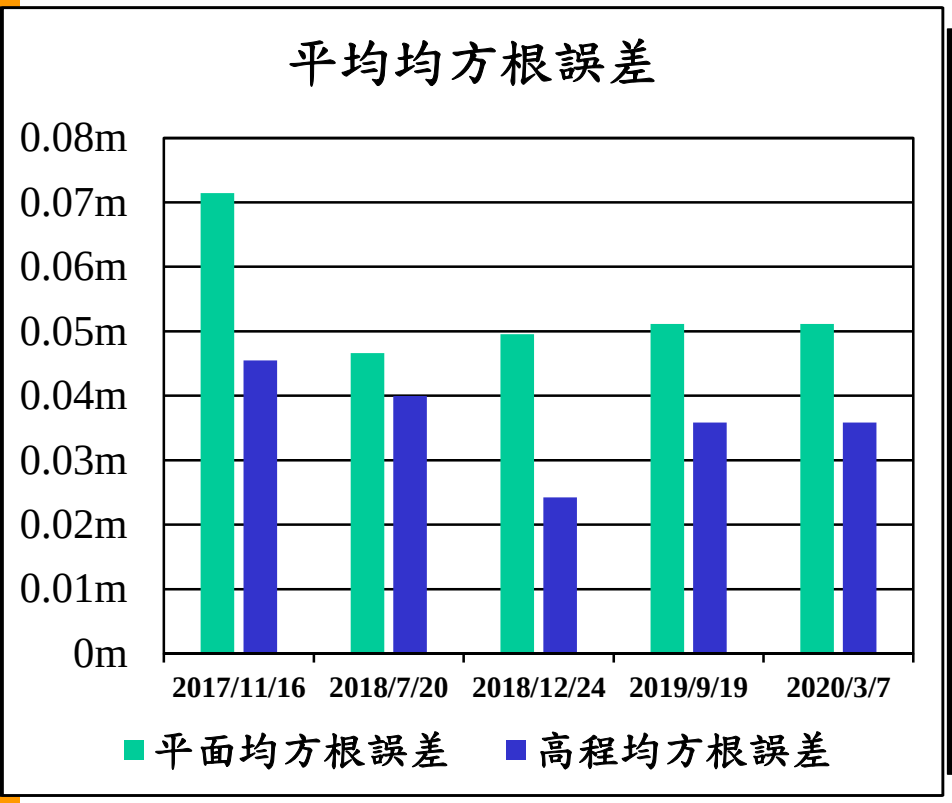
點雲資料航帶平差

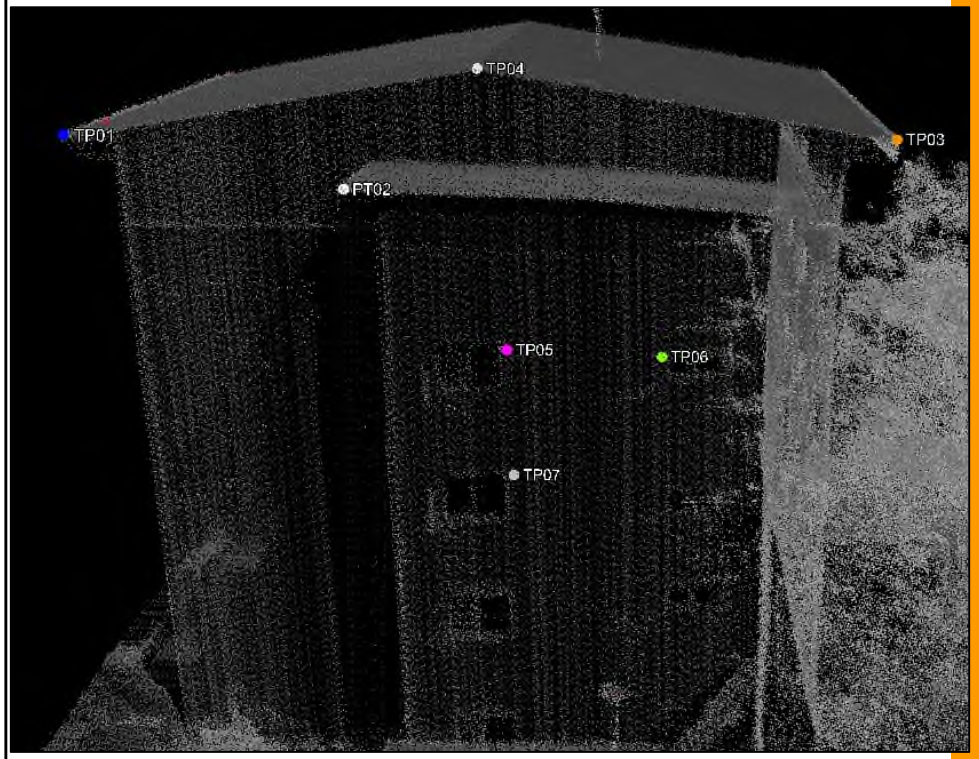


點雲資料航帶平差

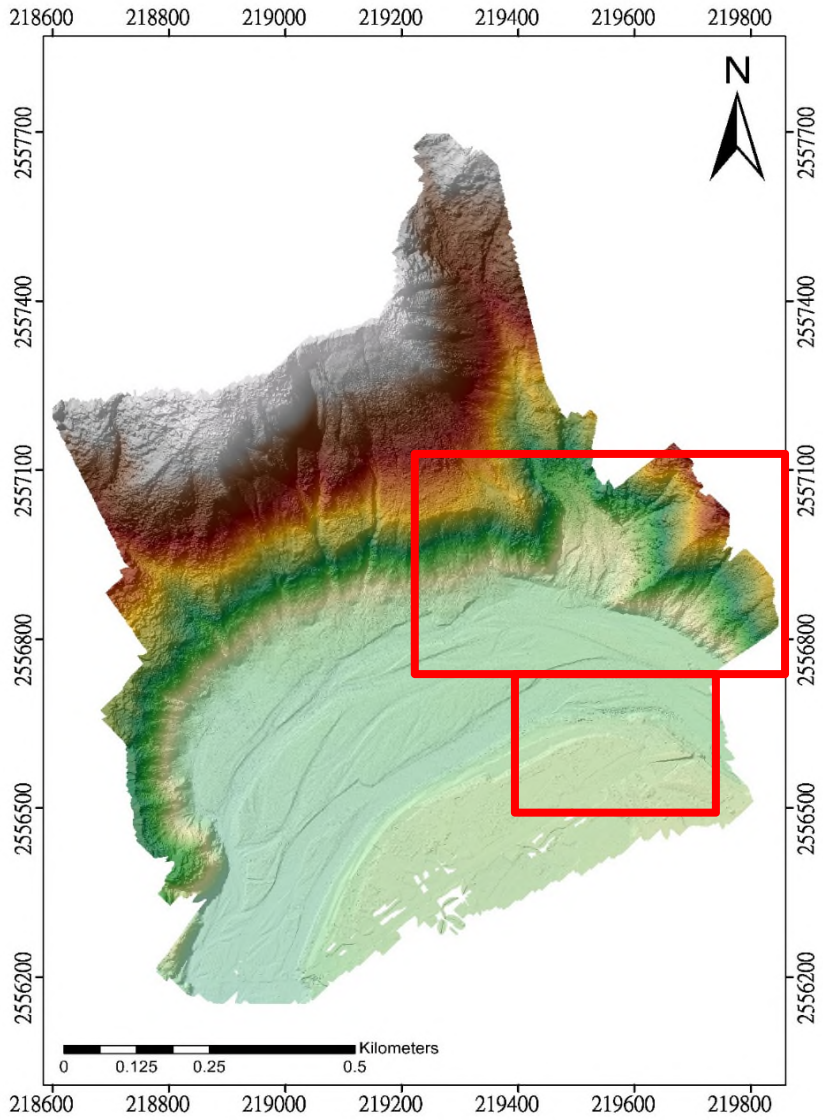


光達系統平差精度

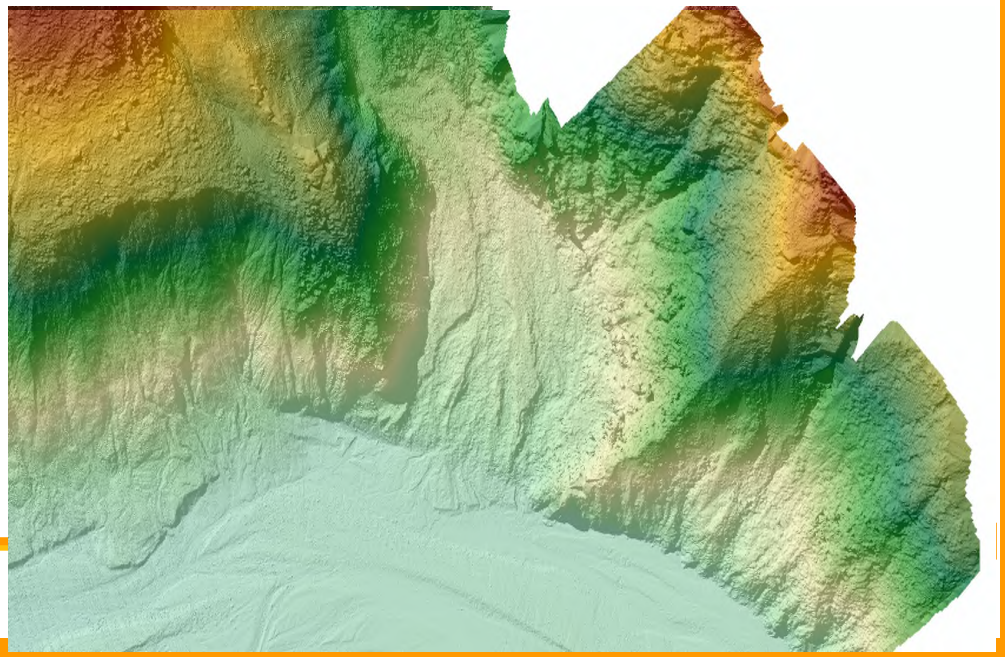

平均均方根誤差
0.08m
0.07m
0.06m
0.05m
0.04m
0.03m
0.02m
0.01m
0m
2017/11/16
2018/7/20
2018/12/24
2019/9/19
2020/3/7
平面均方根誤差
高程均方根誤差


TP01
TP02
TP03
TP04
TP05
TP06
TP07

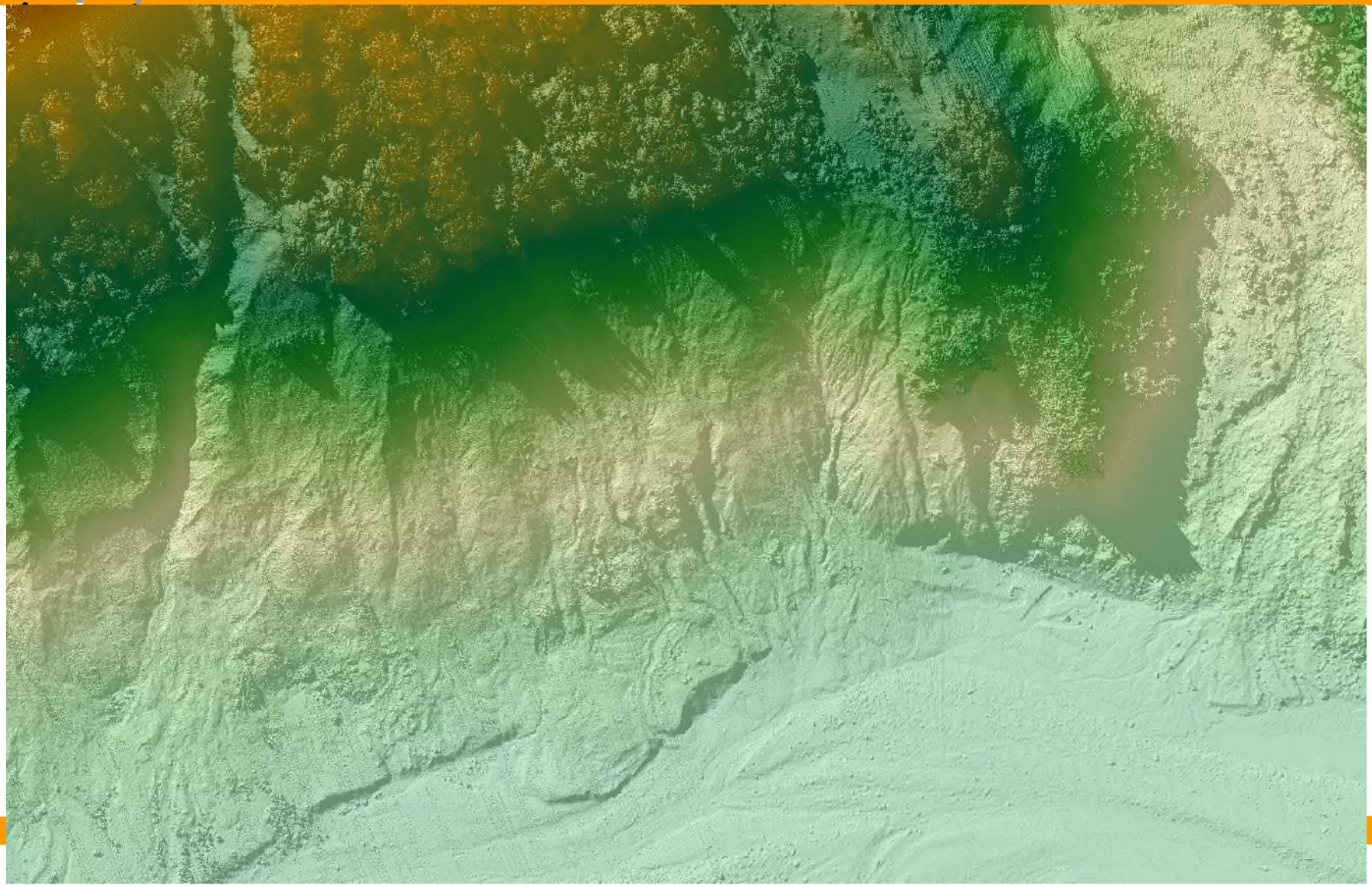
Landslide Monitoring Baolai







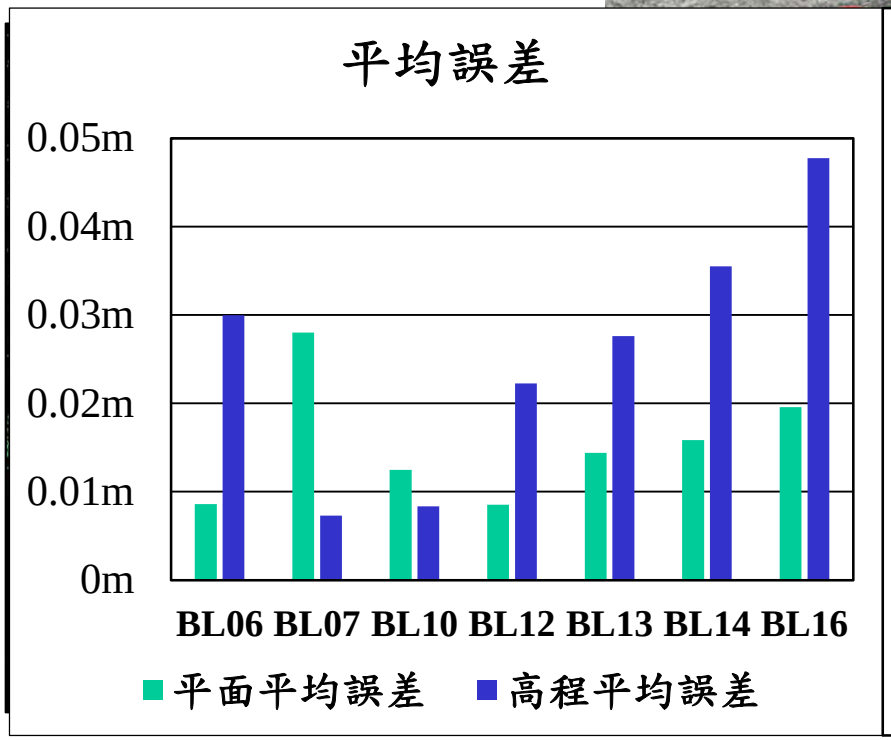
Landslide Disp.: Dec 18-Jul 19



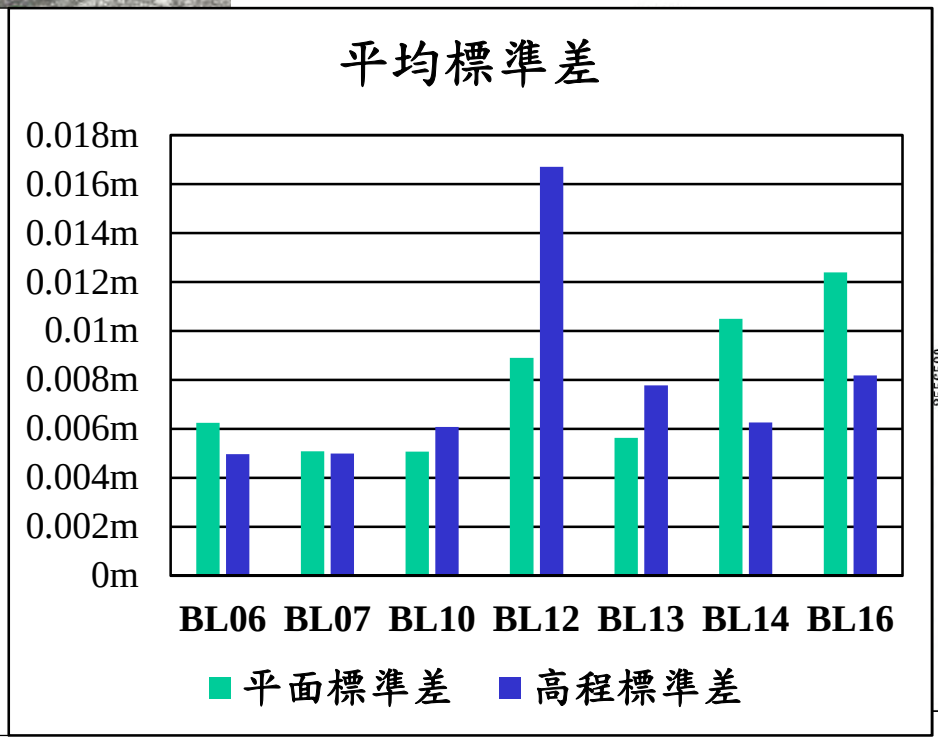
Terrestrial LiDAR + UAS LiDAR



測量精度



反光標點與檢核點示意圖



控制點與檢核點分布圖