大規模與大範圍之崩塌監測警戒技術研發與對應警戒值建置

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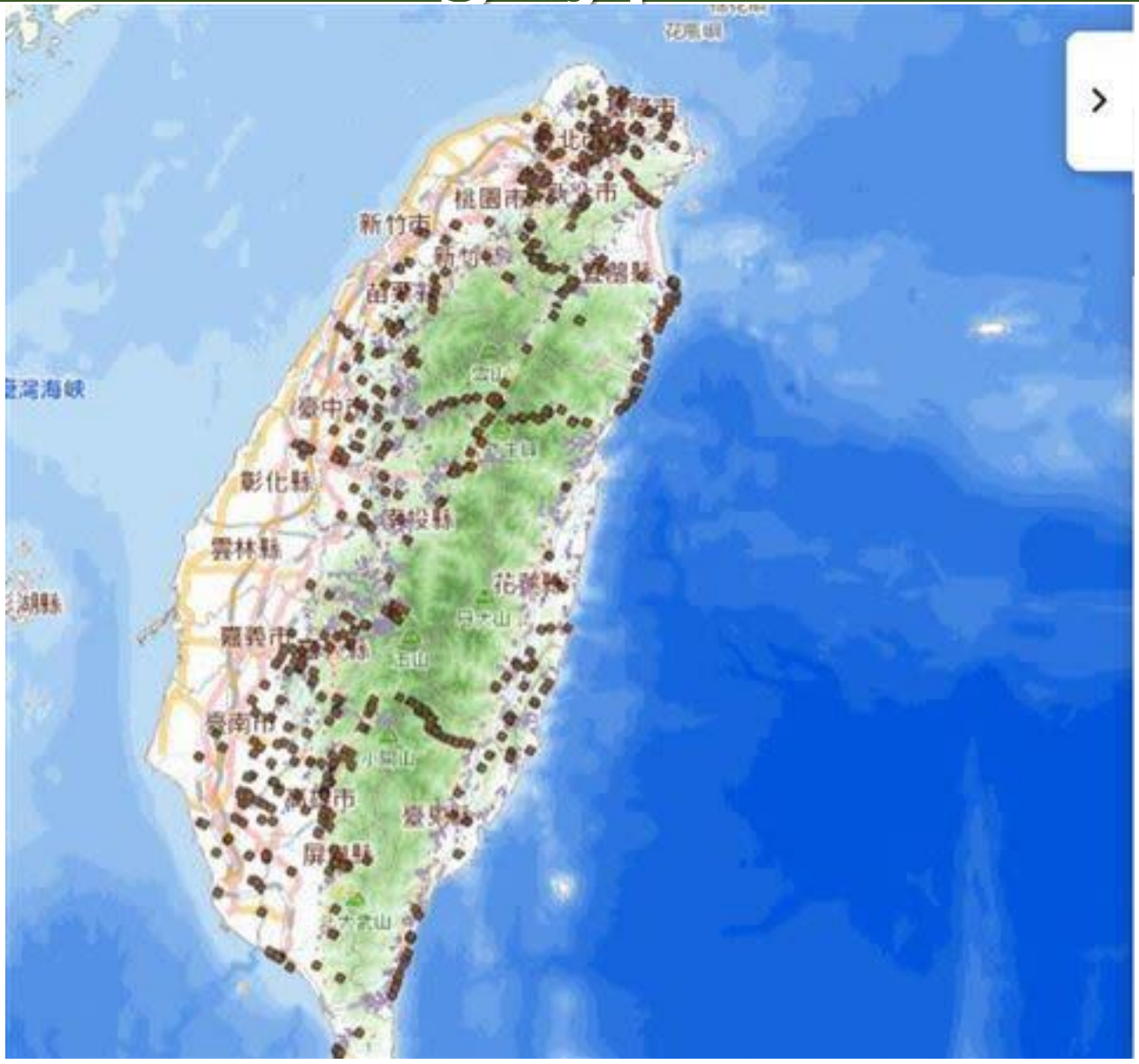
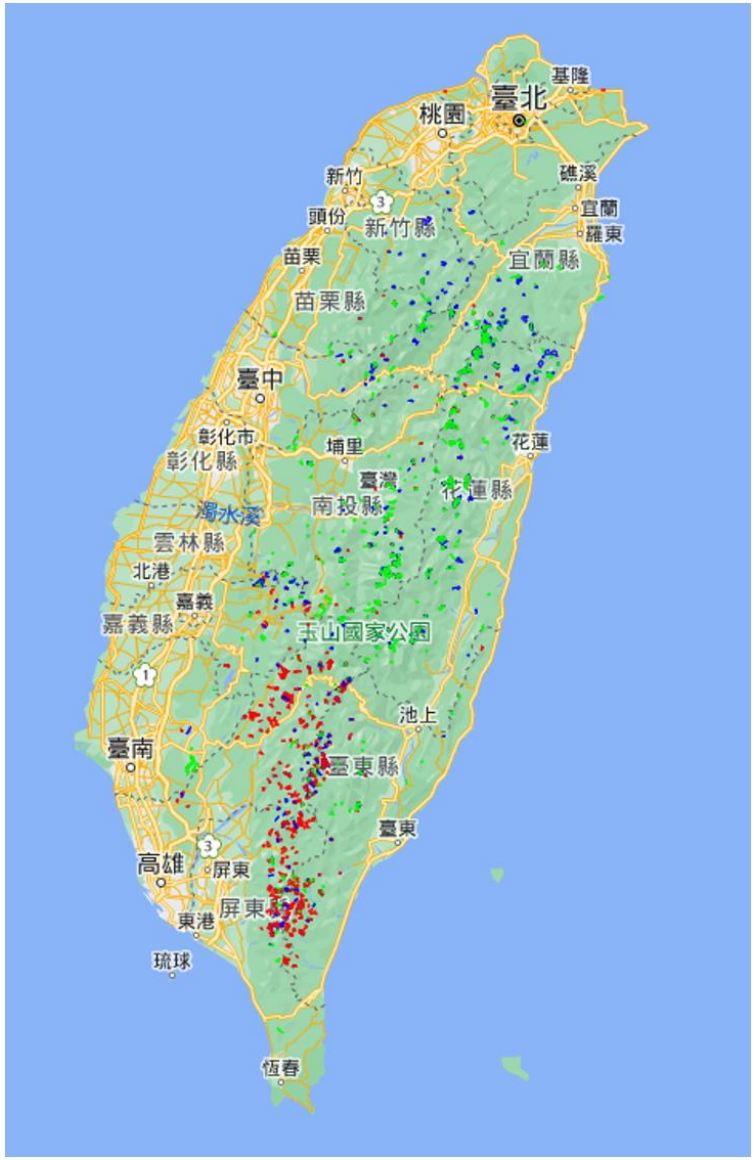
資源工程系 教授

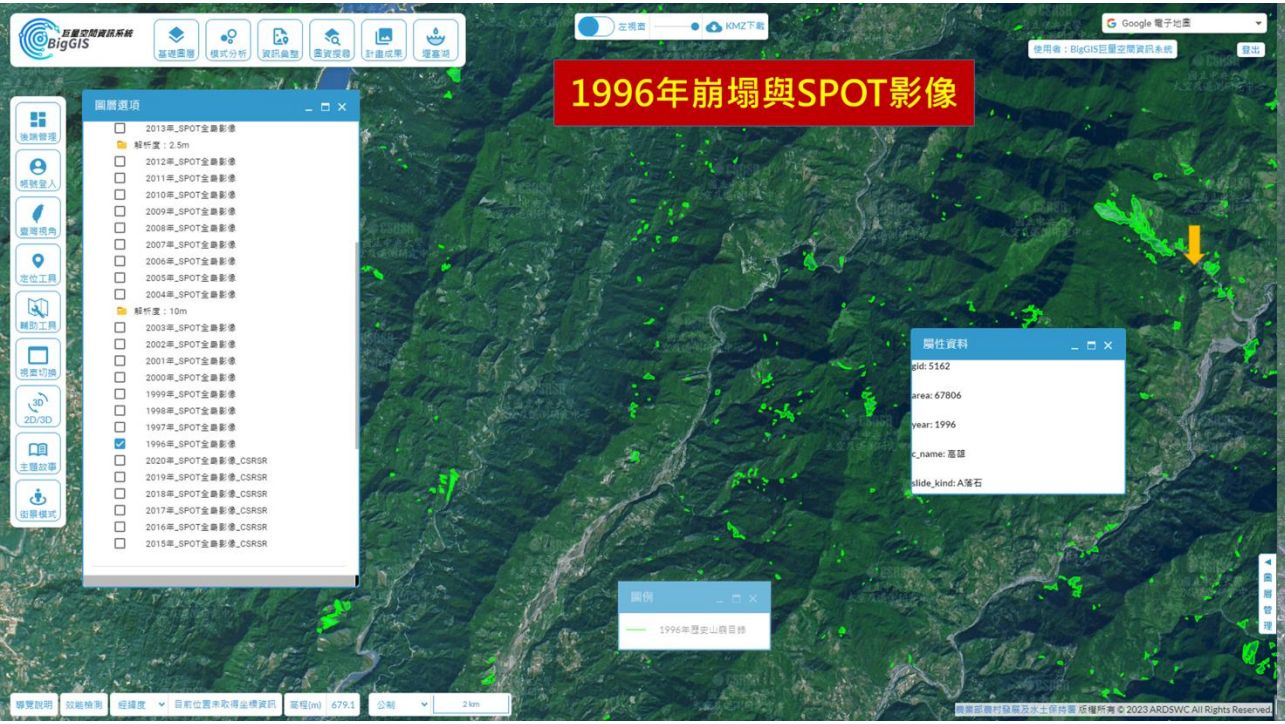
671 Possible Landslide sites alarmed for an incoming typhoon in Taiwan

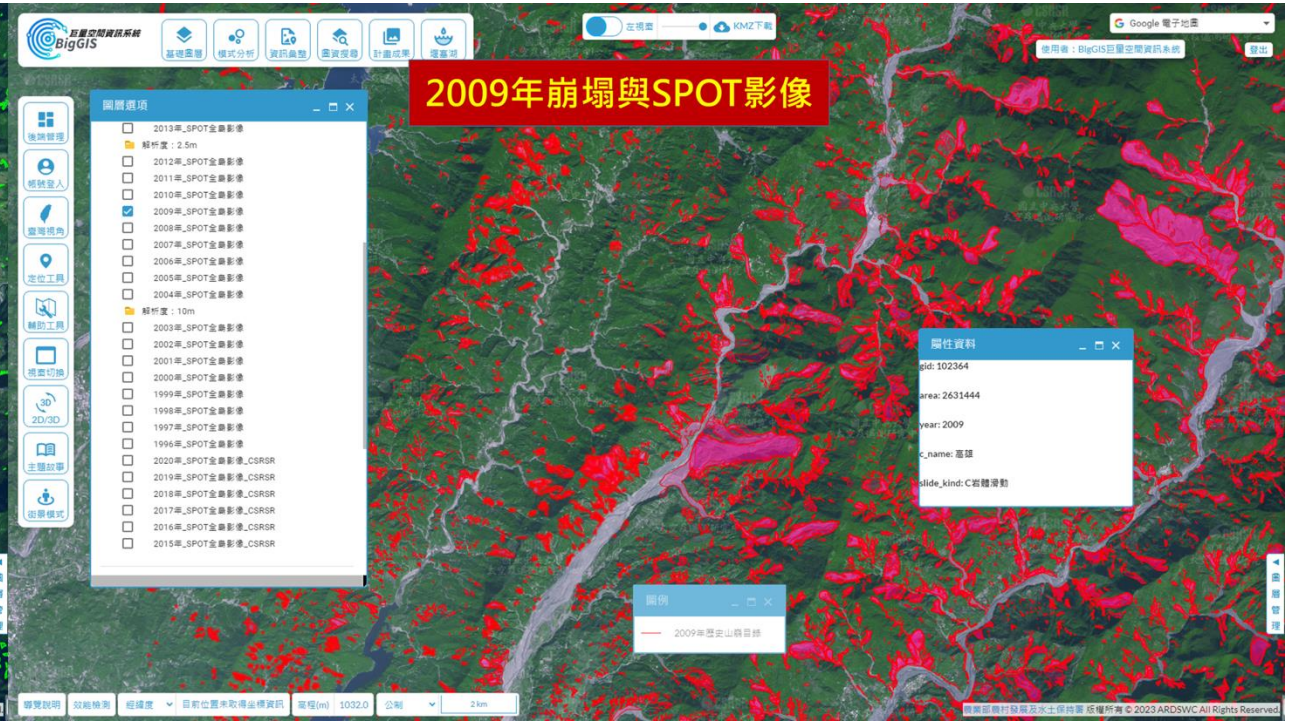


1980-2015 Historical landslide in Taiwan

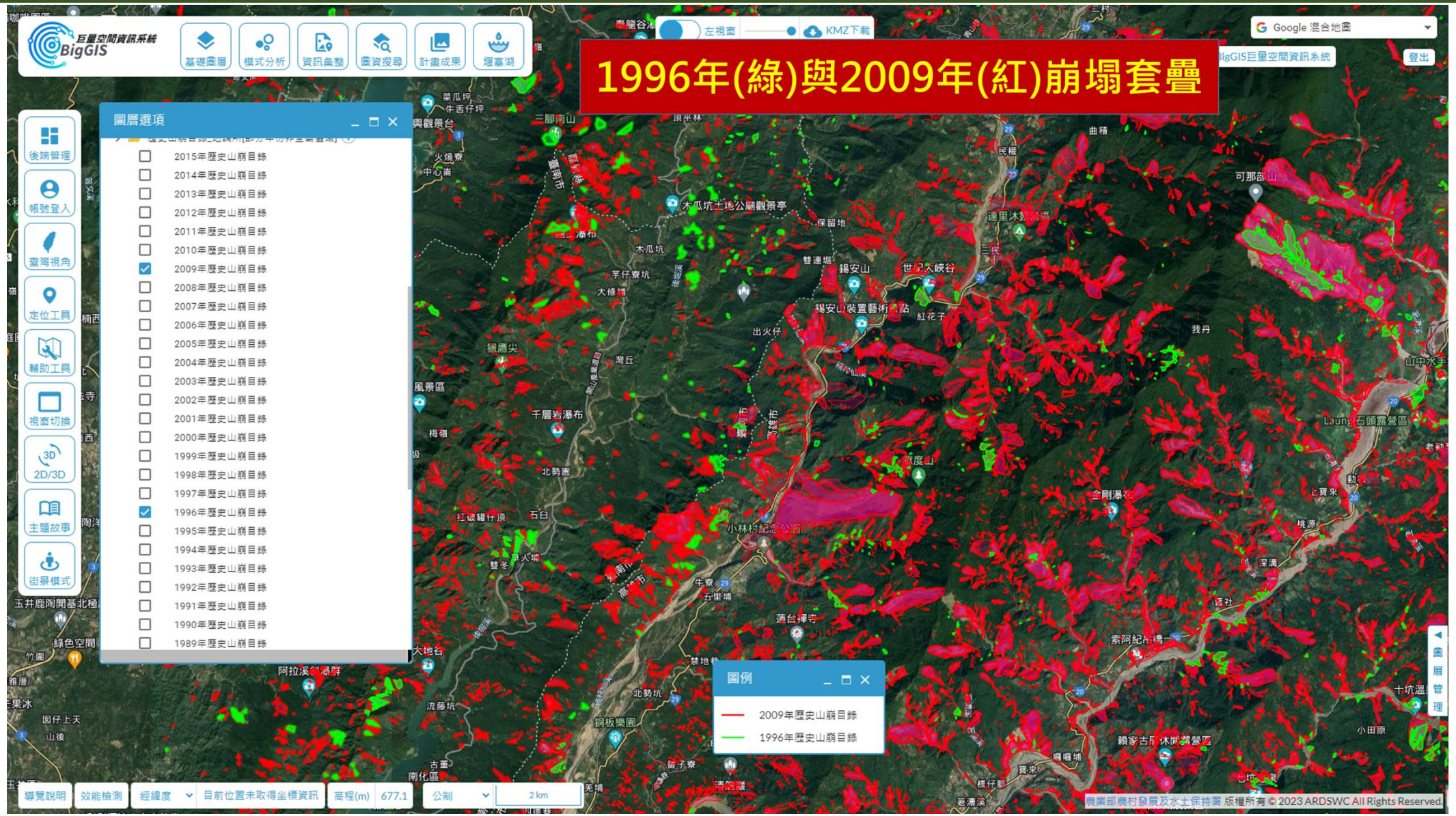


SPOT image of 1996 and 2009 Landslide

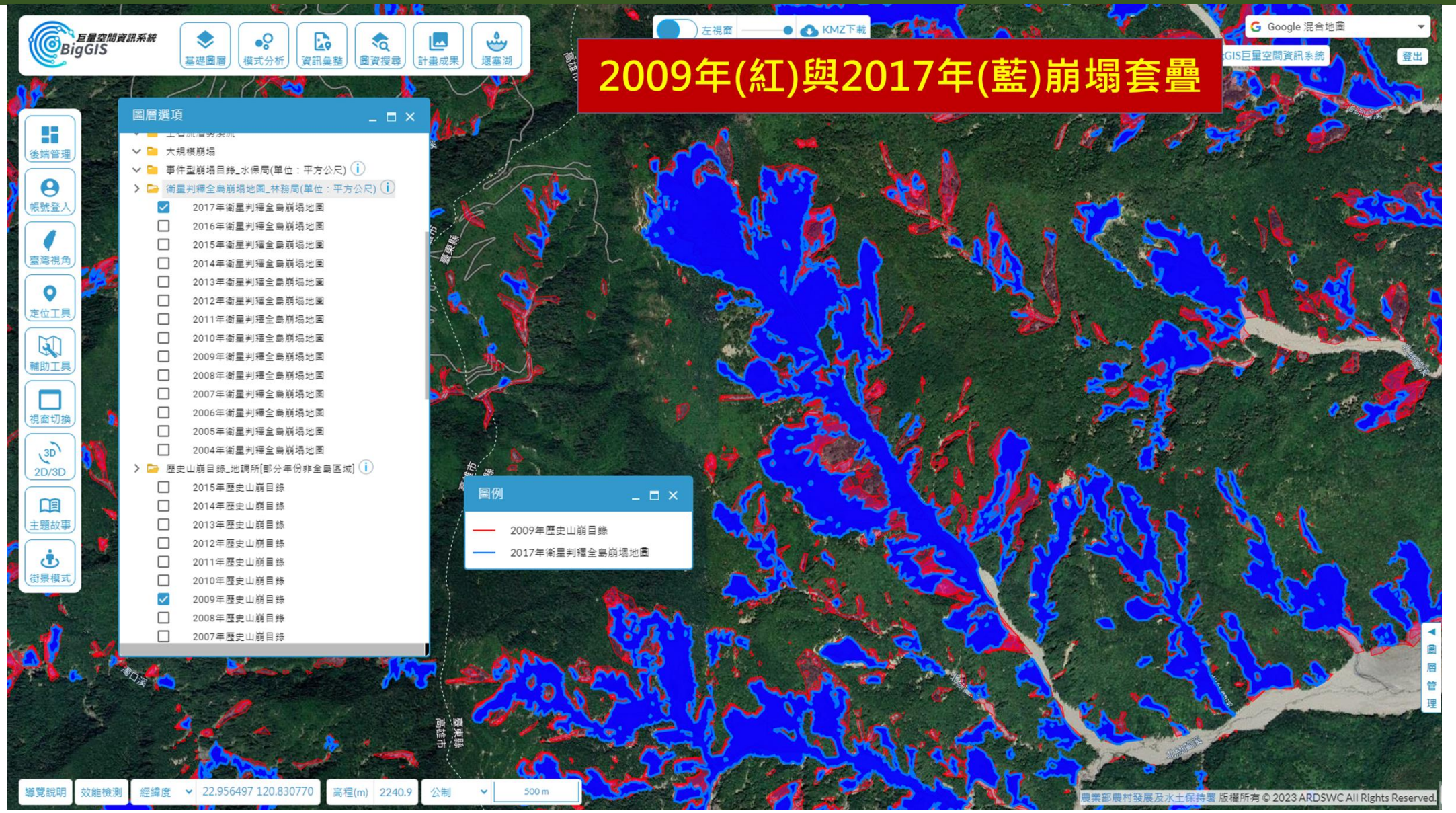




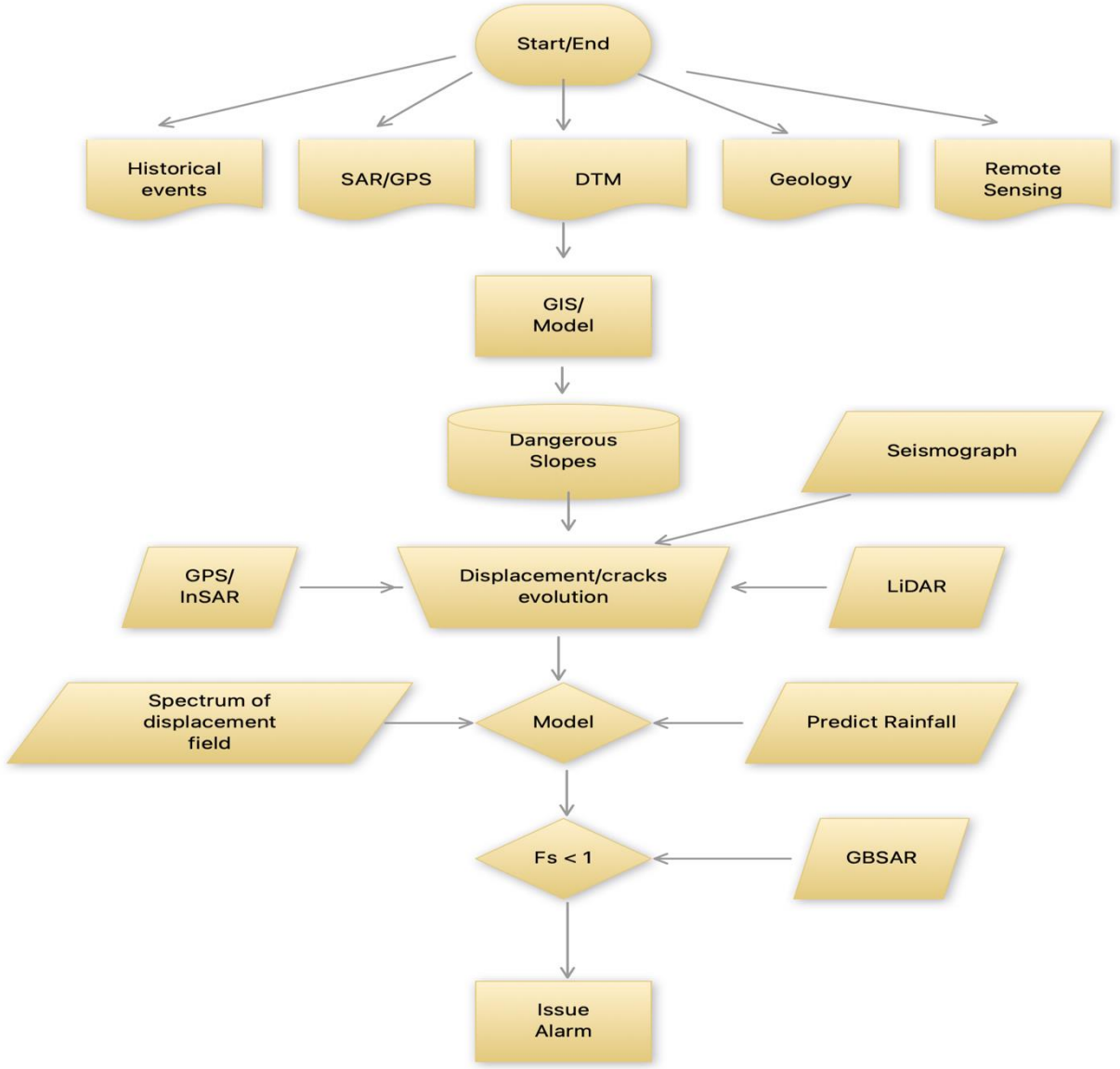
1996 (Green) vs. 2009 (Red) Southern Taiwan



2009 (Red) vs. 2017(blue) Southern Taiwan

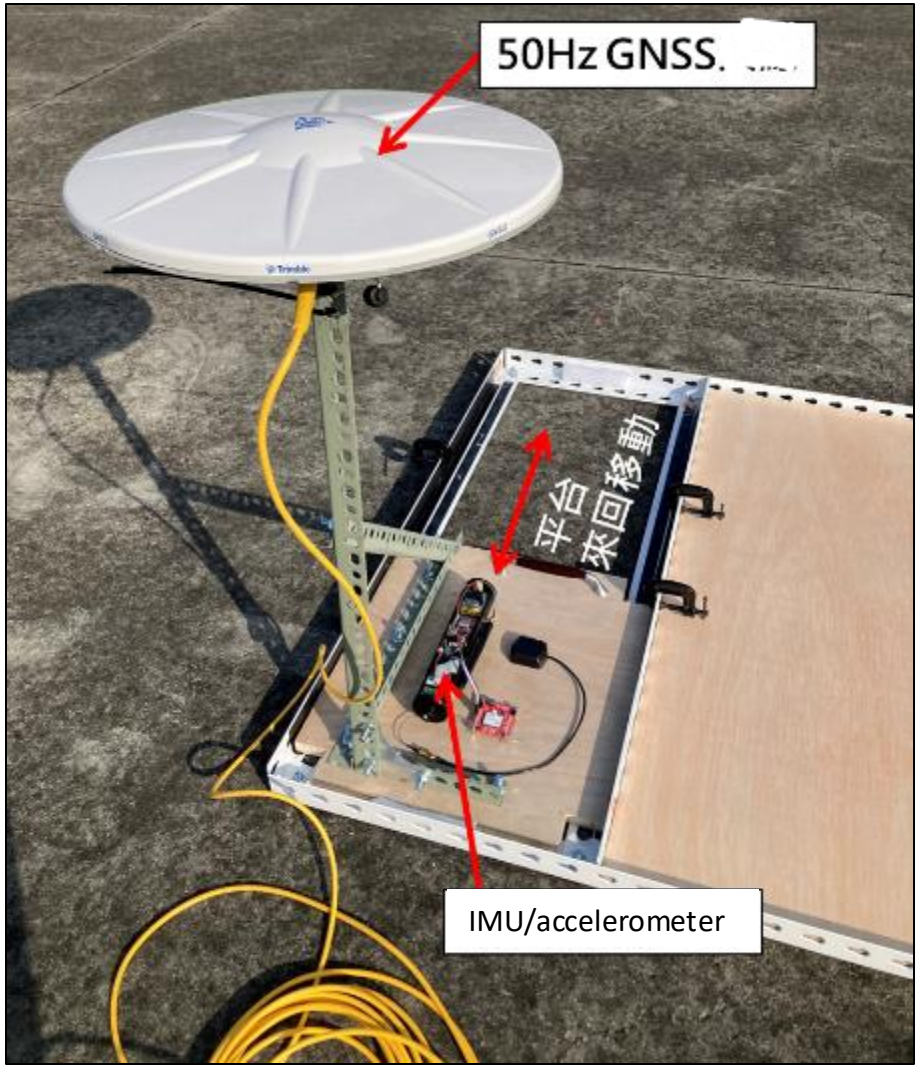


Flow chart of data & method

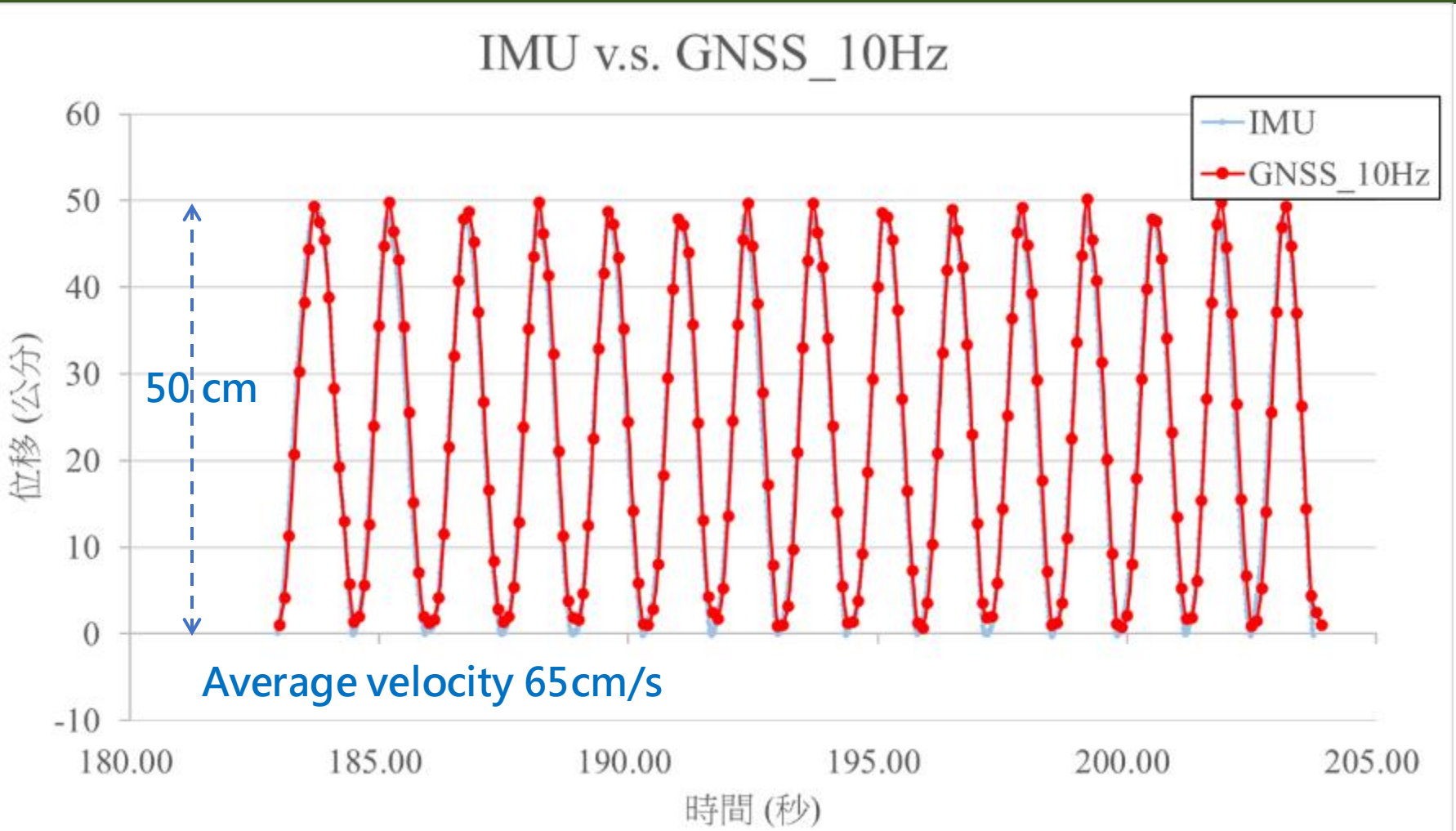


50Hz HR GNSS test and validation for displacement field

- Shaking table with GNSS antenna
  - Displacement: 48 cm
  - Frequency: 0.8Hz (significant fre. Of magnitude 7 earthquake)。
  - IMU integrated into Displacement field，baseline correction。
- GNSS Positioning
  - With TBC to calculate relative baseline change。
  - With dynamic mode to process 1Hz、5Hz、10Hz data。



50Hz HR GNSS Positioning Result



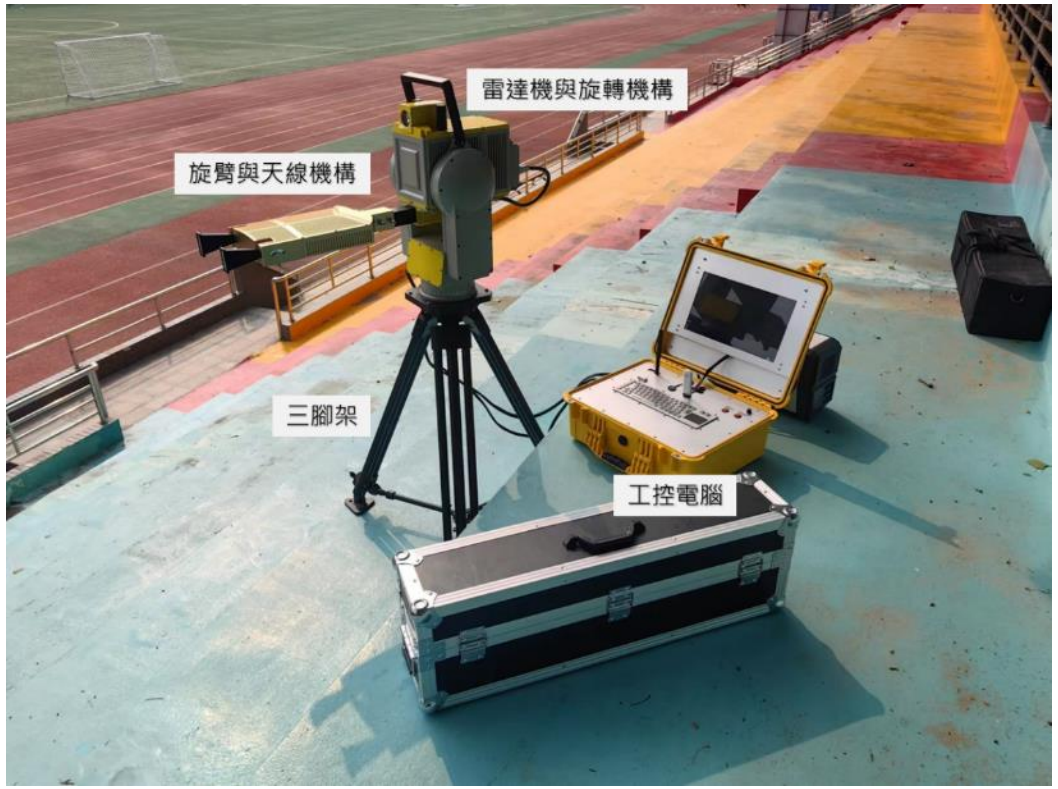
IMU displacement Vs GNSS dynamic solution at various frequency, error is around 3 cm。

Frequency	1 Hz	5 Hz	10 Hz
RMS (cm)	3.07	3.06	3.01

Linear GBSAR

Operating Frequency	17000-18000MHz (17.0 GHz-18.0 GHz)
Bandwidth (Bw)	0 ~ 1000 (MHz)
Pulse-width (Pw)	1 - 1000 (ms)
Waveform	FMCW
Radar Rotation Angle	108°
Polarization	None
Transmit Power	2 mW ~ 1 W
Antenna Gain	0 - 30 dB
Antenna Scanning Angle	18°(azimuth), 40°(elevation) 28°(azimuth), 18°(elevation)
Radar Scanning Angle	-30° ~ 30°
Synthetic Length	1.6 m
Scanning Distance	70 m - 4000 m
Range Resolution	0.75 m - 0.15 m
Cross Range Resolution	5.36 mrad

Arc GBSAR



1.Rotate 360 degree, length 0.65 m，resolution 0.9~5 m (Range 70~400 m)。

2.Ku band (1.75cm) 。

GB-SAR: Comparisons

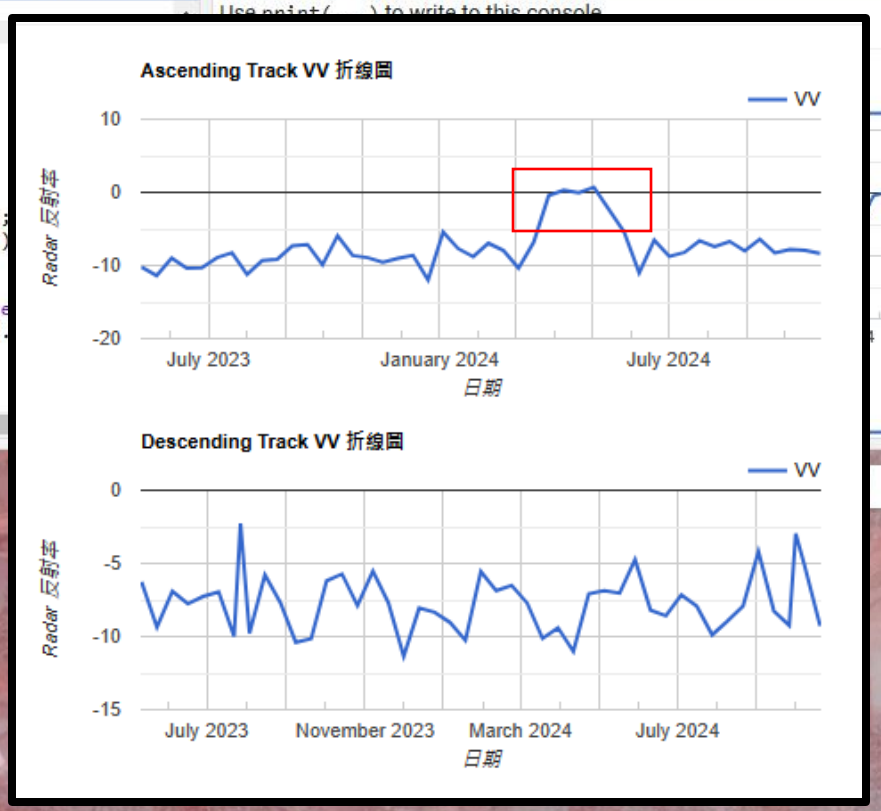
	Gen 1 (Linear GBSAR)	Gen 2 (ArcSAR)
Waveform	FMCW	FMCW
Operating Frequency	17000-18000MHz (17.0 GHz-18.0 GHz)	17000-18000MHz (17.0 GHz-18.0 GHz)
Bandwidth (Bw)	0 ~ 1000 (MHz)	0 ~ 1000 (MHz)
Pulse-width (Pw)	1 - 1000 (ms)	1 - 300 (μs)
Max Radar Rotation Angle	108° (additional 18° from antenna)	360° (Can select specific angle)
Polarization	None	None
Transmit Power (ATT)	2 mW ~ 1 W	2 mW ~4 W
Antenna Gain (GN)	0 - 30 dB	0 - 30 dB
Antenna Scanning Angle	18°(azimuth), 40°(elevation)	60°(azi) , 18° (ele)
	28°(azimuth), 18°(elevation)	60°(azi) , 30° (ele) or 60° (ele)
Radar Scanning Angle	-30° ~ 45°	0-360°
Synthetic Length	1.6 m	Up to the length of arm (0.65m)
Scanning Distance	70 m - 4000 m	10 m - 5000m
Range Resolution	0.75 m - 0.15 m	0.75 m - 0.15 m
Cross Range Resolution	5.36 mrad	~ 6 mard
Weight of Equipments	> 100 Kg	< 50 Kg (4 items)
Acquisition time (min/image)	~ 1 min	3°/s (20s/60°)

*can operated at raining, night

Use reflector cone to improve SAR signal

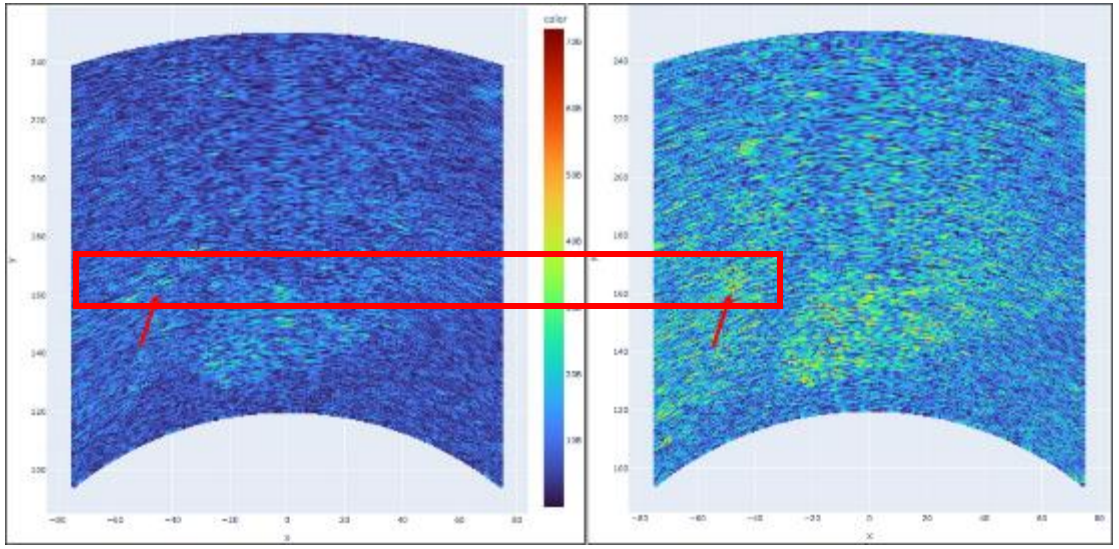
Sentinel 1 image

```
// 選擇 Sentinel-1 影像集
var collection = ee.ImageCollection('COPERNICUS/S1_GRD')
  .filterBounds(location)
  .filterDate(startDate, endDate);

// 選擇升降軌
var ascending = collection.filter(ee.Filter.eq('orbitProperties_pass', 'ASCENDING'));
var descending = collection.filter(ee.Filter.eq('orbitProperties_pass', 'DESCENDING'));

// 選擇最新的影像
var latestAscending = ee.Image(ascending.sort('system:time_start', false).first()).se
var latestDescending = ee.Image(descending.sort('system:time_start', false).first()).

// 繪製折線圖
var chartVVAscending = ui.Chart.image.series({
```

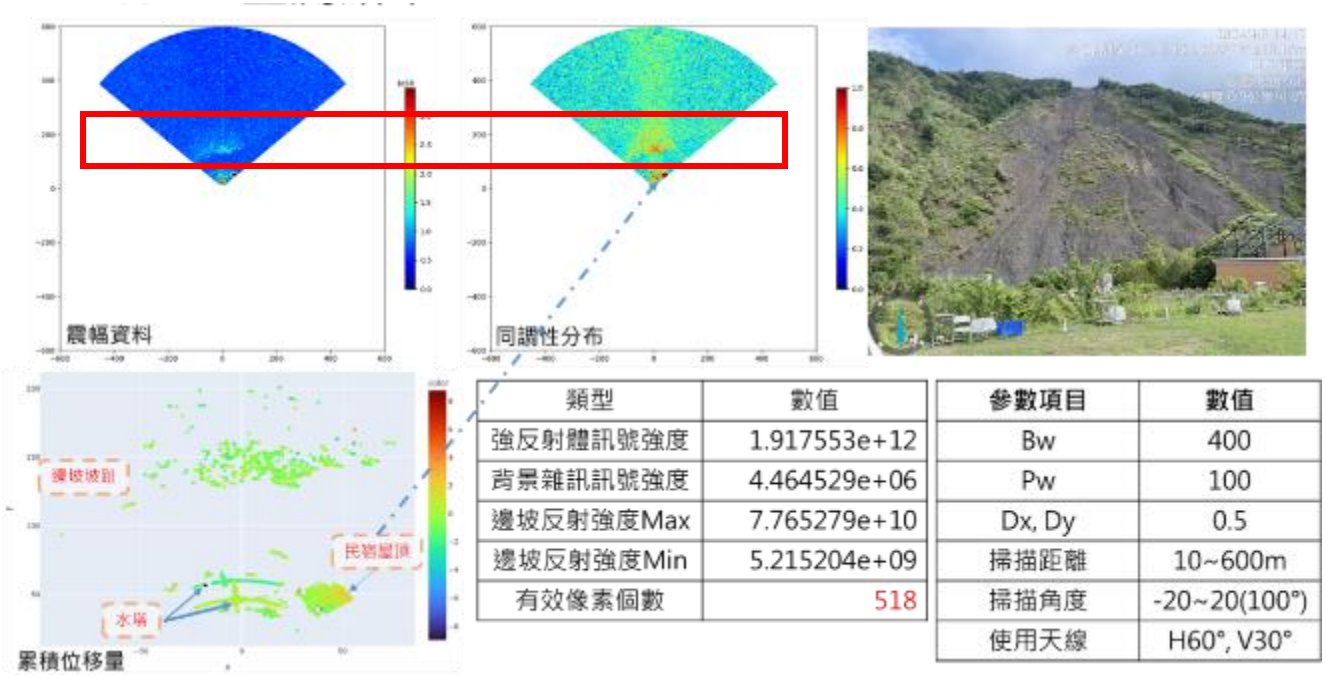


50 cm cone could enhance signal at 30*30 m region

2024 GBSAR during typhoon Krathon

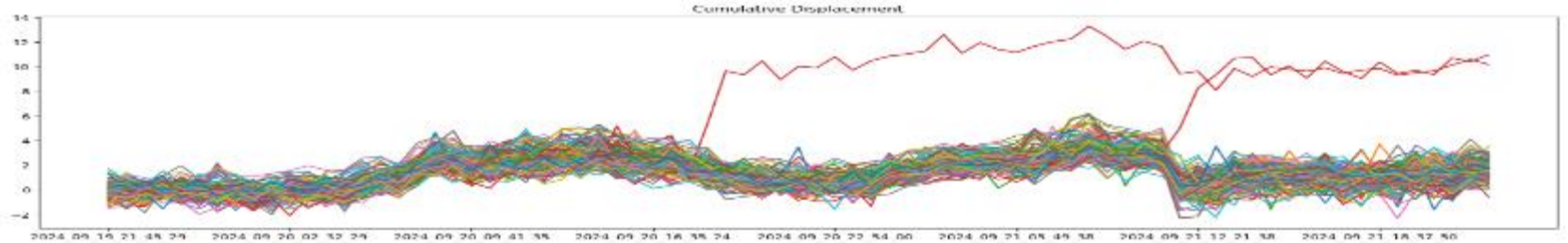


Locations of cone



類型	數值
強反射體訊號強度	1.917553e+12
背景雜訊訊號強度	4.464529e+06
邊坡反射強度Max	7.765279e+10
邊坡反射強度Min	5.215204e+09
有效像素個數	518

參數項目	數值
Bw	400
Pw	100
Dx, Dy	0.5
掃描距離	10~600m
掃描角度	-20~20(100°)
使用天線	H60°, V30°



2024/09/19

2024/09/21

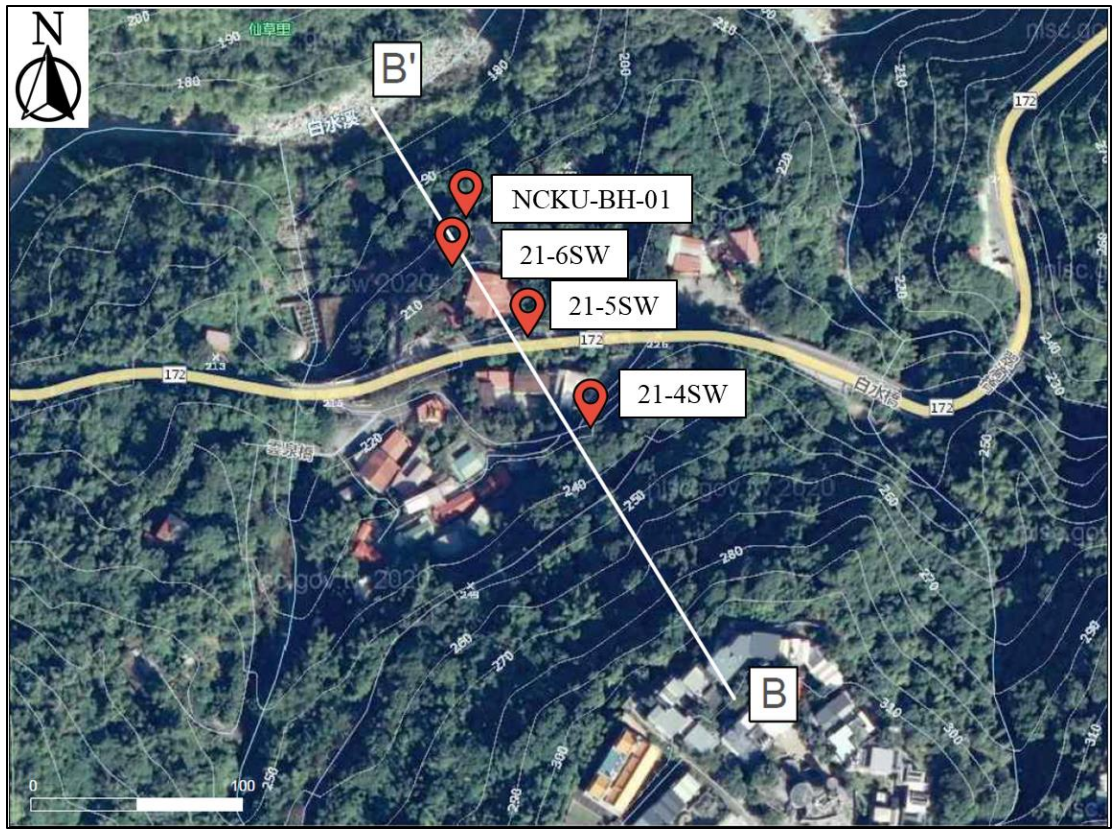
No significant movement in 3 days

Numerical model of Landslide

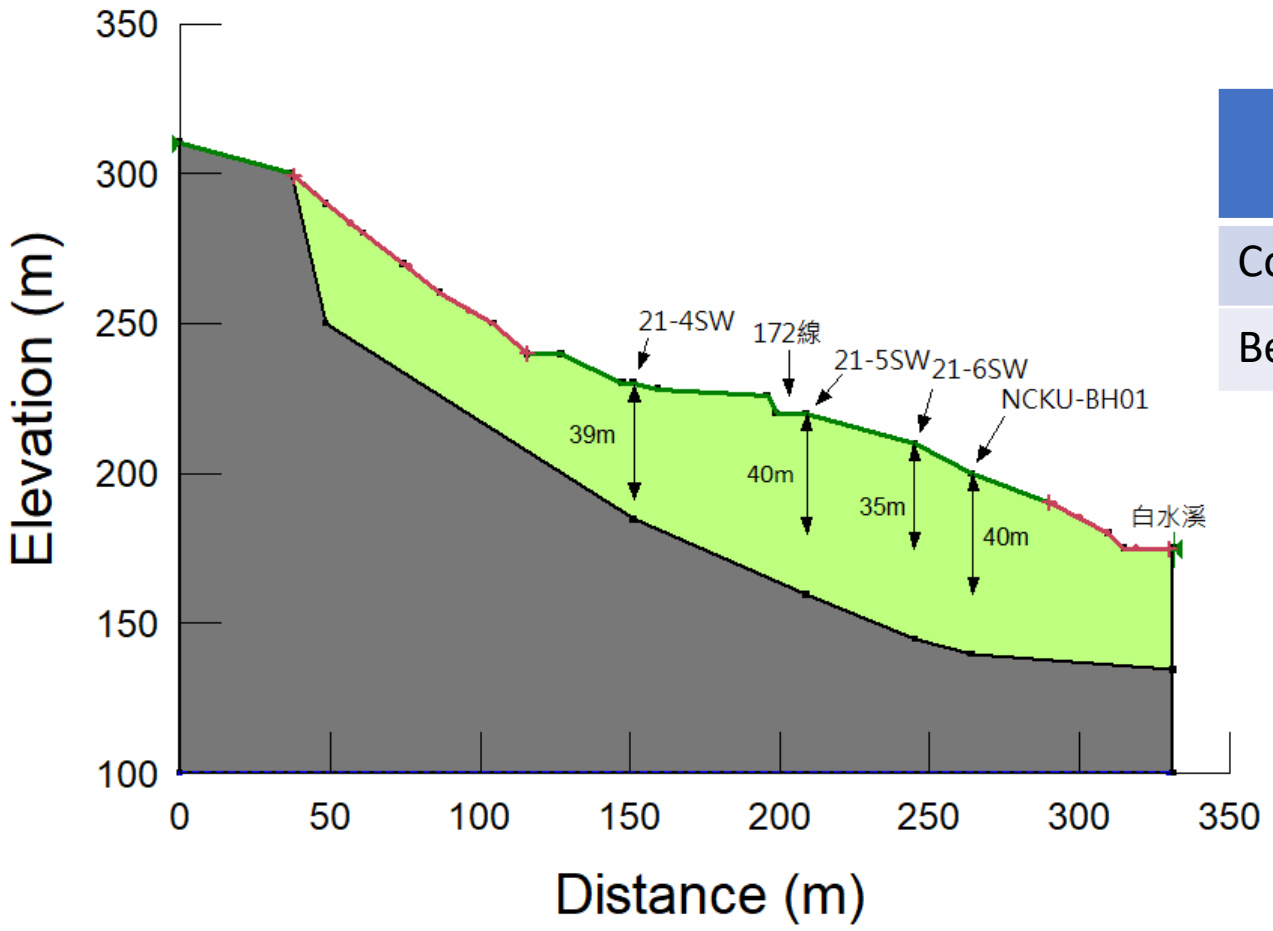
With GeoStudio
For 2D
simulation

GeoStudio®

- SLOPE/W™
- SEEP/W™
- SIGMA/W™
- QUAKE/W™
- TEMP/W™
- CTRAN/W™
- AIR/W™
- VADOSE/W™



Model parameters

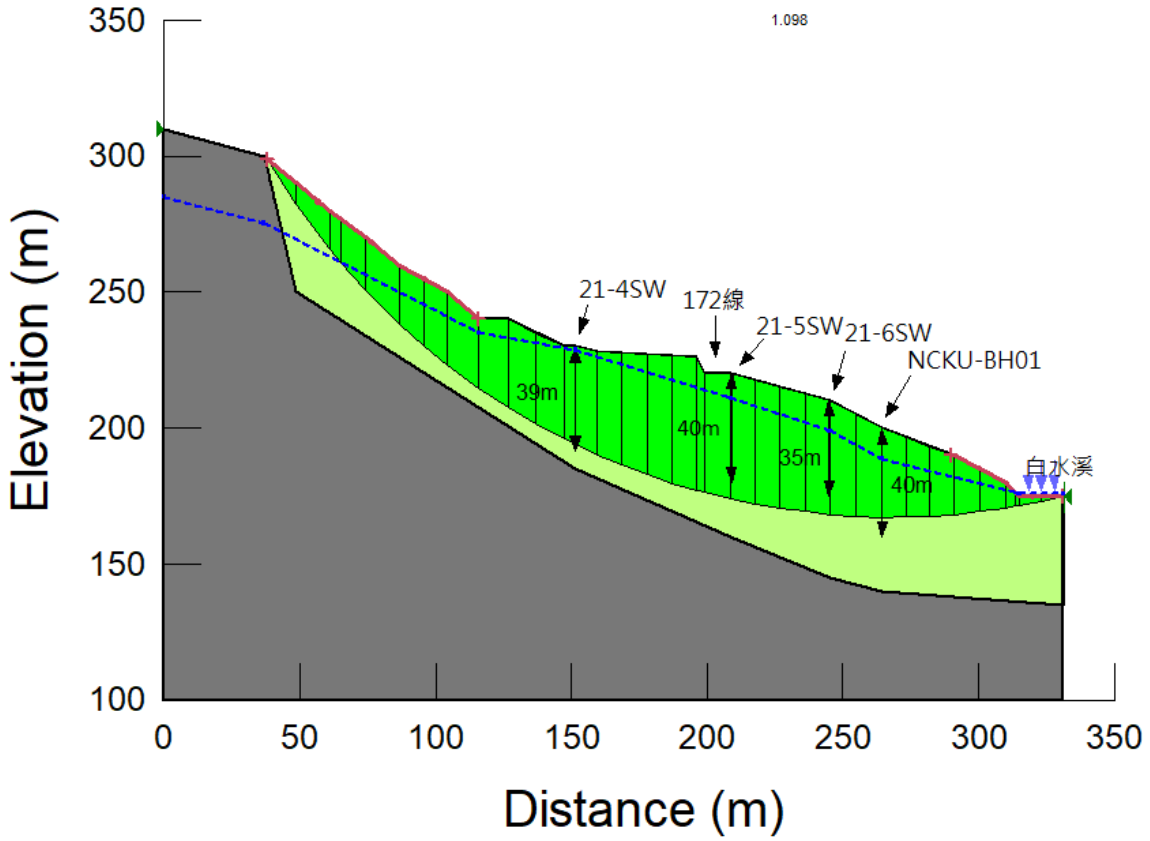


layer	Color	(kN/m³)	(kPa)	coherence (º)
Colluvium		20.95	15.967	26
Bed rock		X	X	X

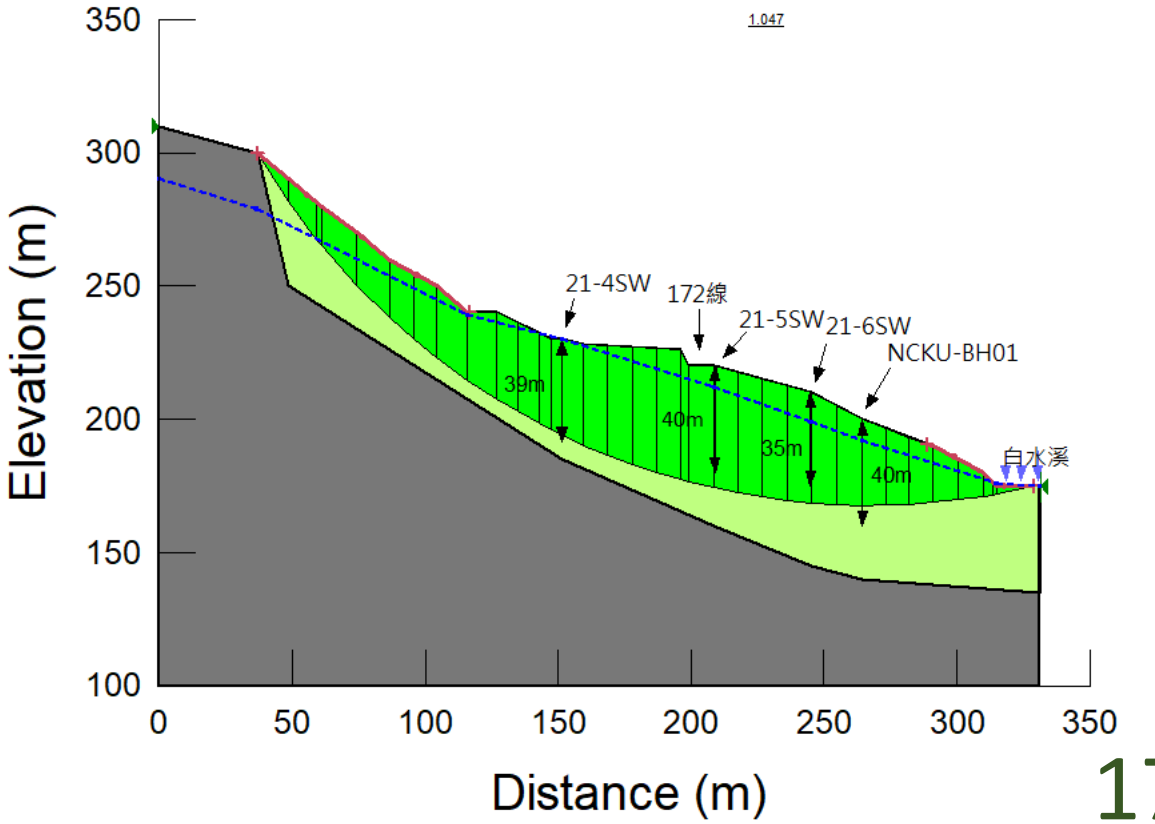
From shear test of in-situ samples at 20 m depth

Model Result

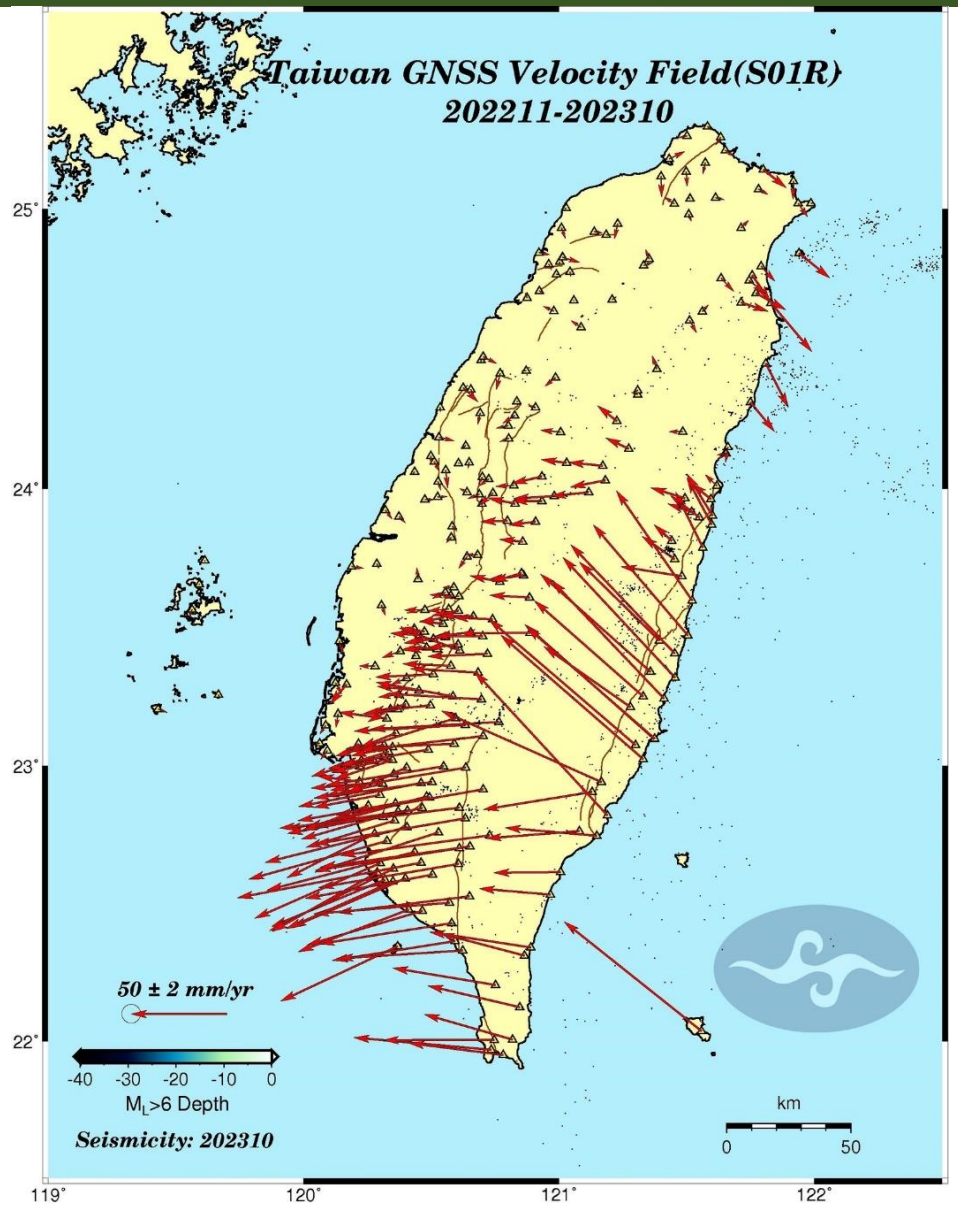
Regular ground water level ，safety factor1.098

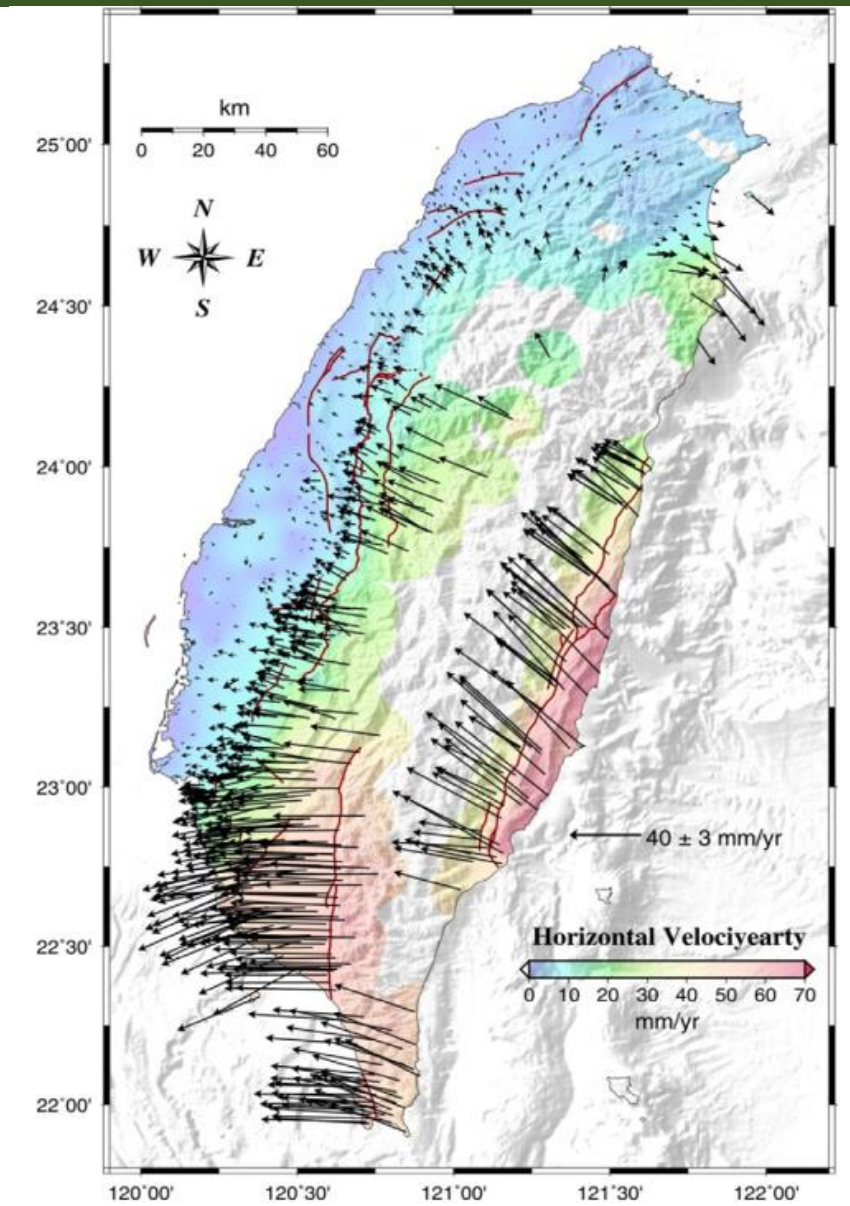


Ground water level during typhoon Gaemi 2024 ，safety factor 1.047

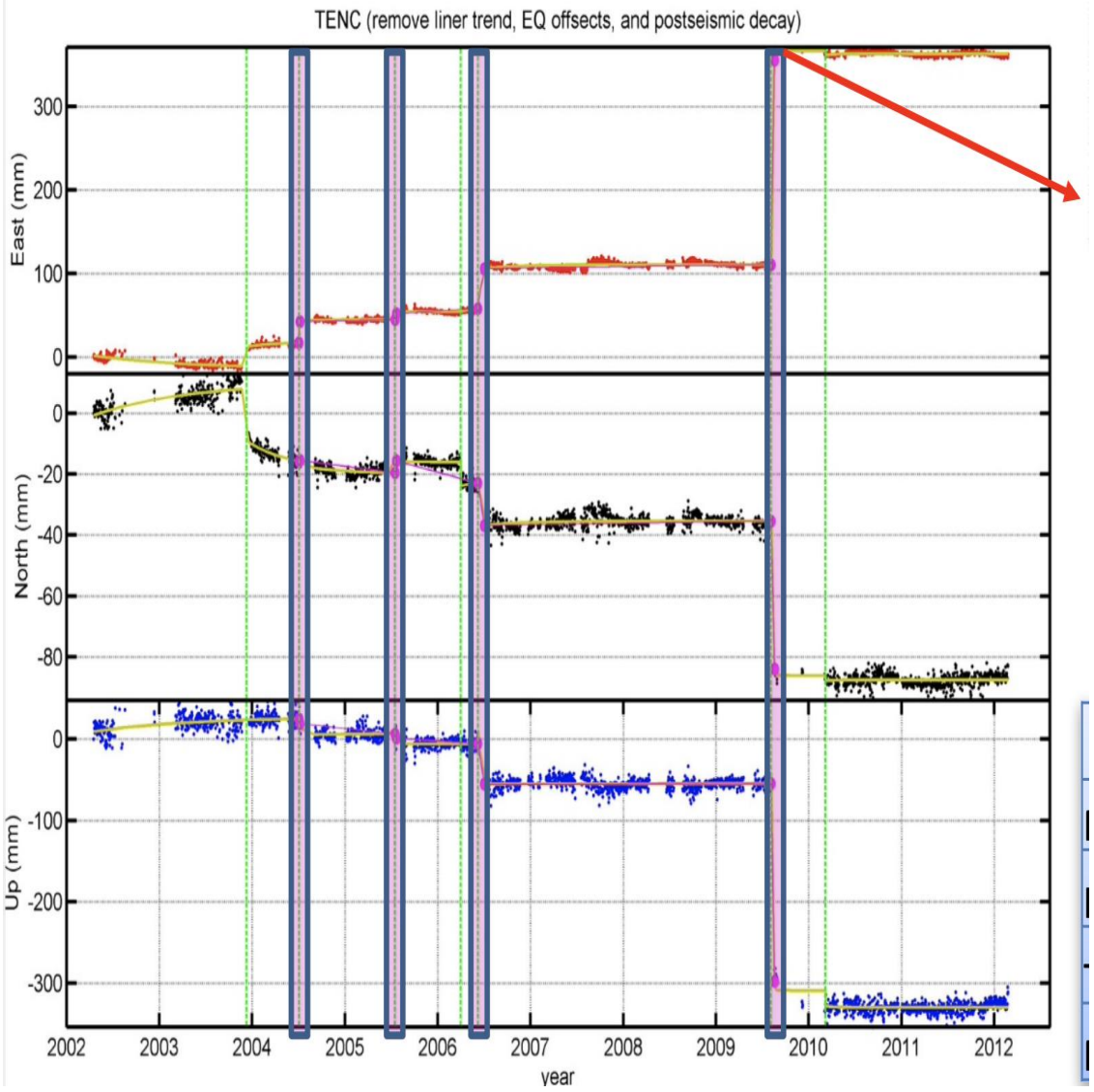


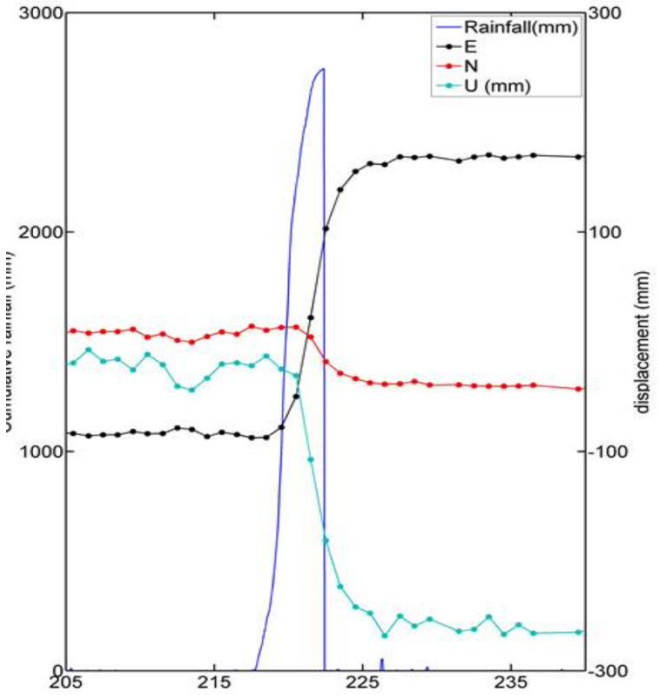
1 & 10 years GNSS velocity field of Taiwan

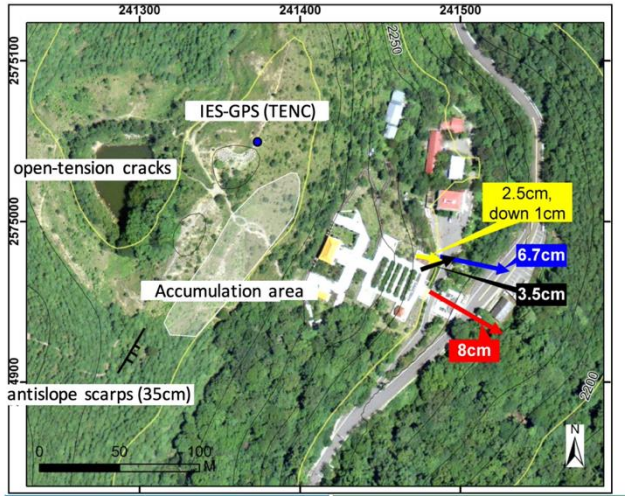




For landslide movement

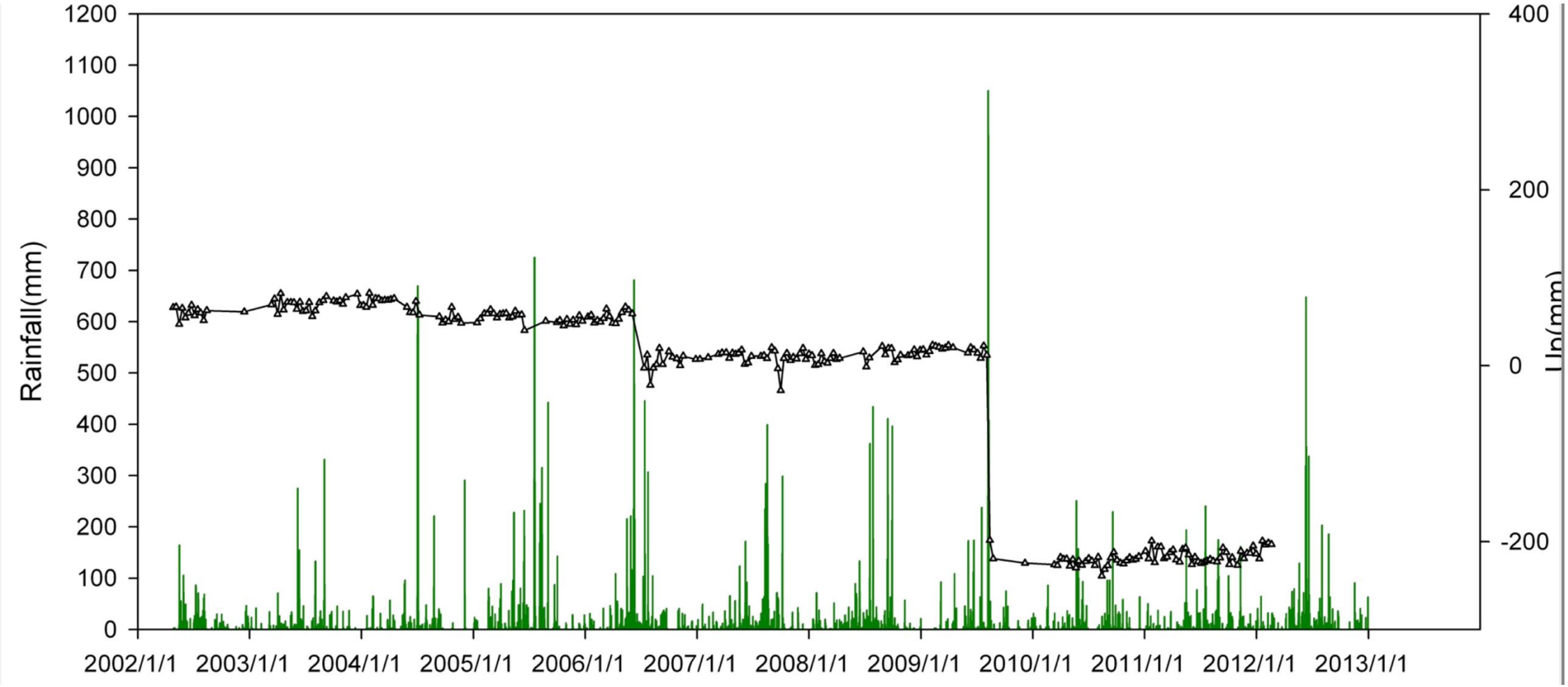




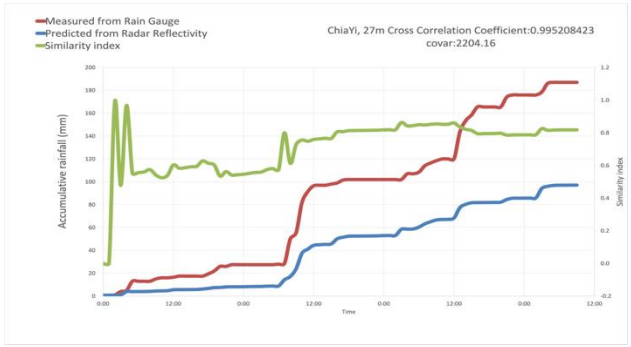


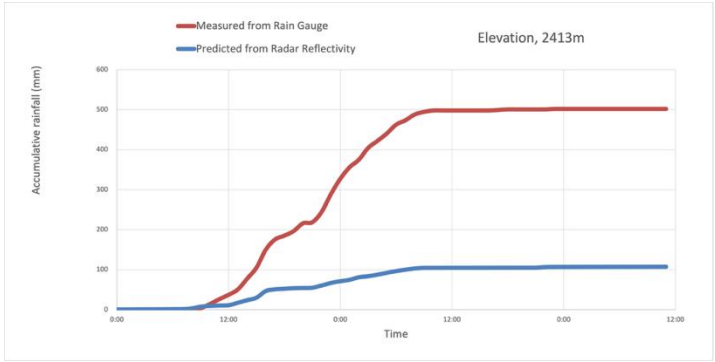
Event	East (mm)	North (mm)	Up (mm)
Mindulle/2004.5	25.74	0.27	-5.69
Haitang/2005.5	7.35	3.9	-5.20
Torrential rain/2006.4	47.92	-13.90	-49.64
Morakot/2009.6	245.15	-48.63	-243.01

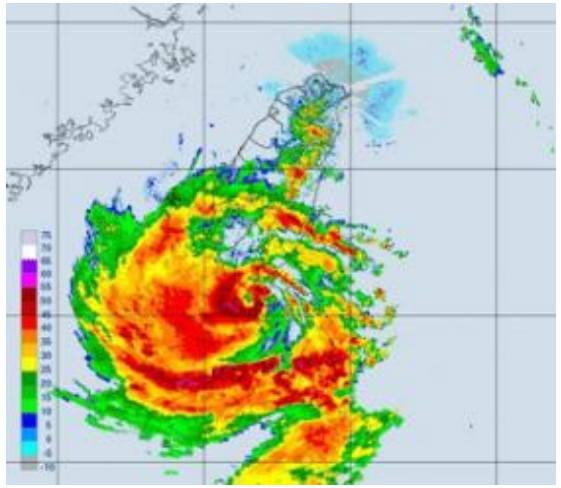
Slope movement vs rainfall

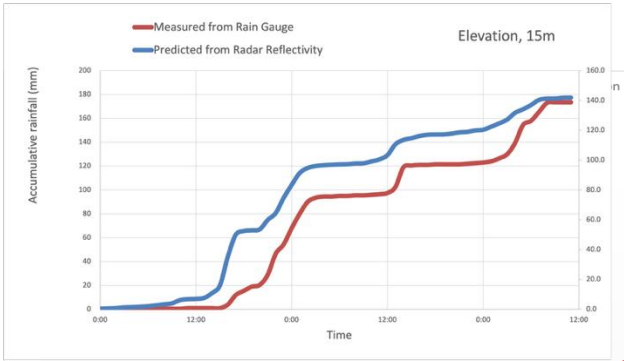


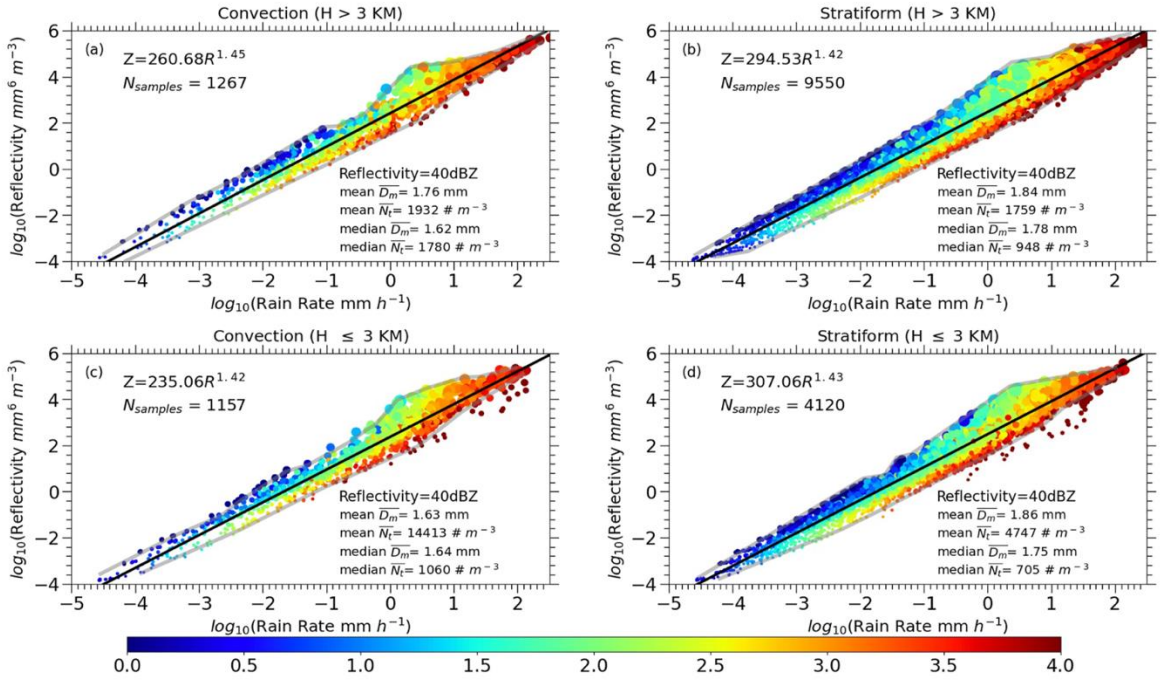
GNSS data as early warming of landslide



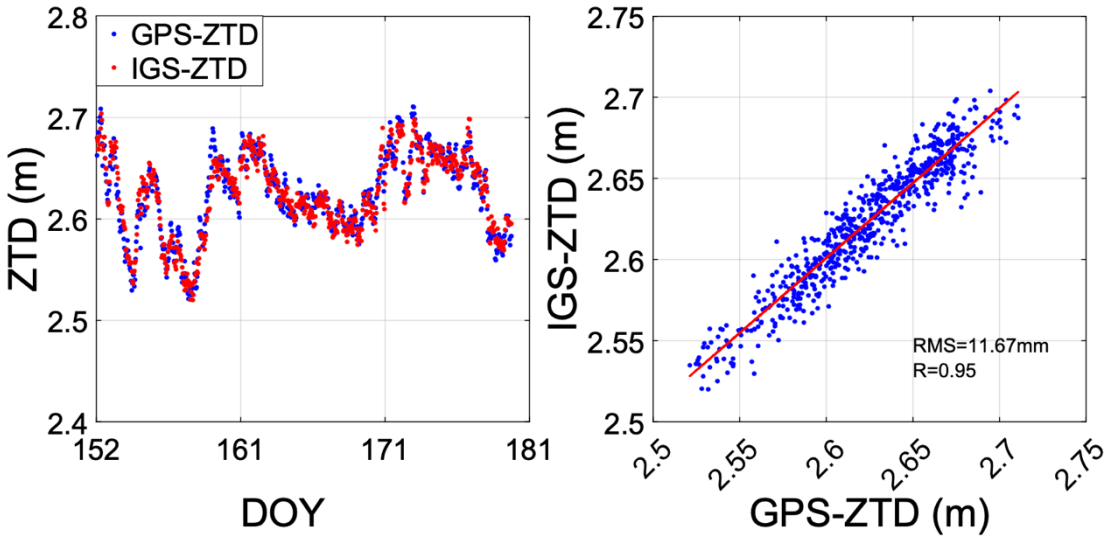








High Rate GPS to predict rainfall 20 min. ahead



From Wu et al., 2023 (Earth Science Informatics)

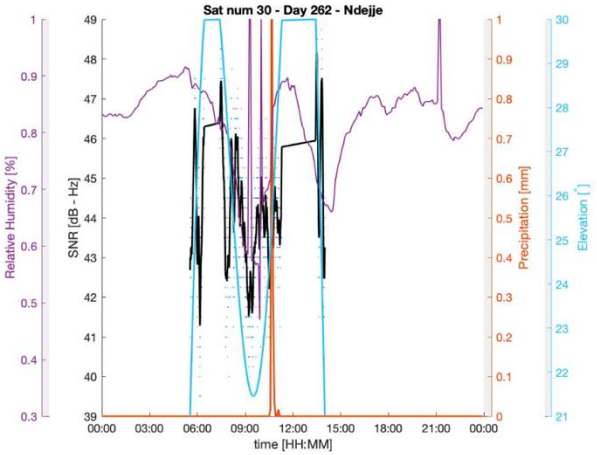


Figure 5.2: GPS and precipitation graph, day 262, Ndejje, sat. 30

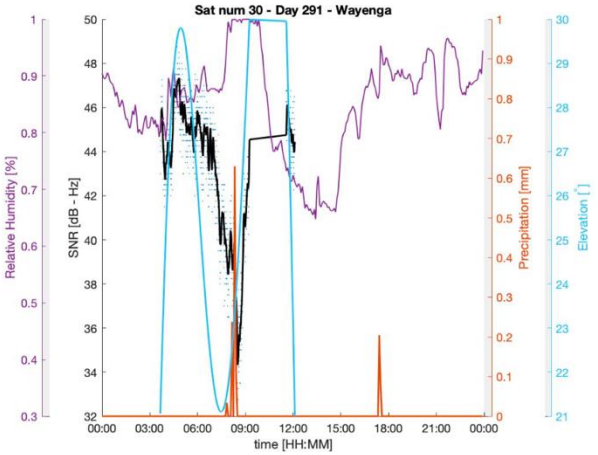


Figure 5.3: GPS and precipitation graph, day 291, Wayenga, sat. 30

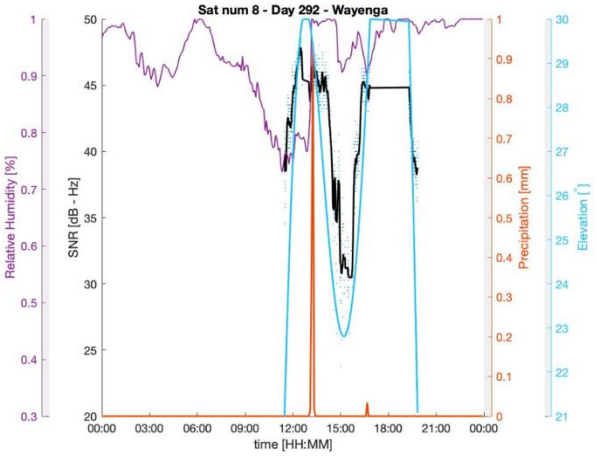


Figure 5.4: GPS and precipitation graph, day 266, Ndejje, sat. 4

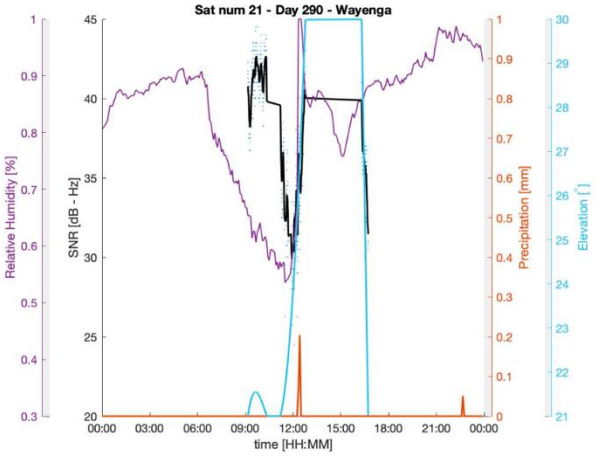
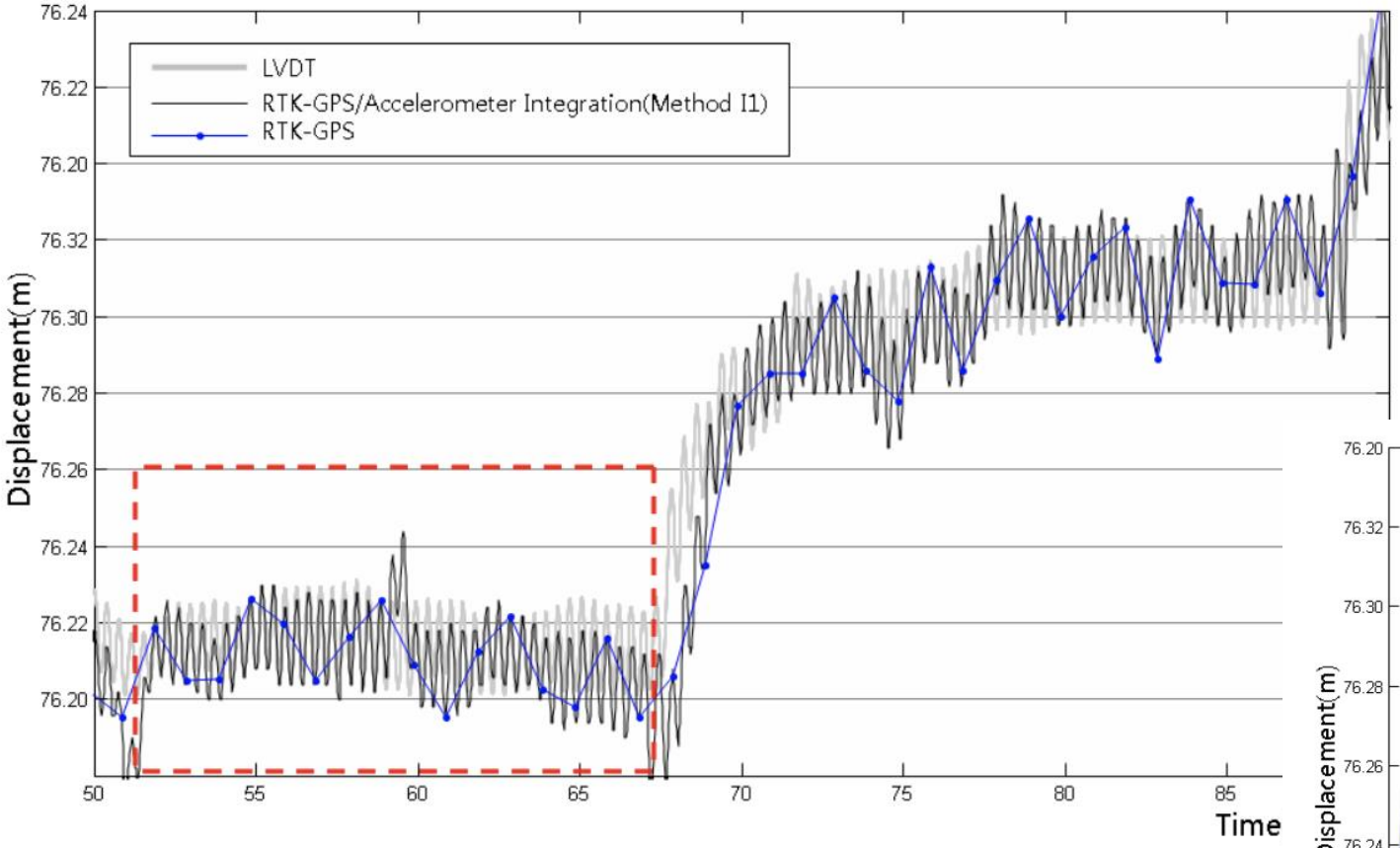
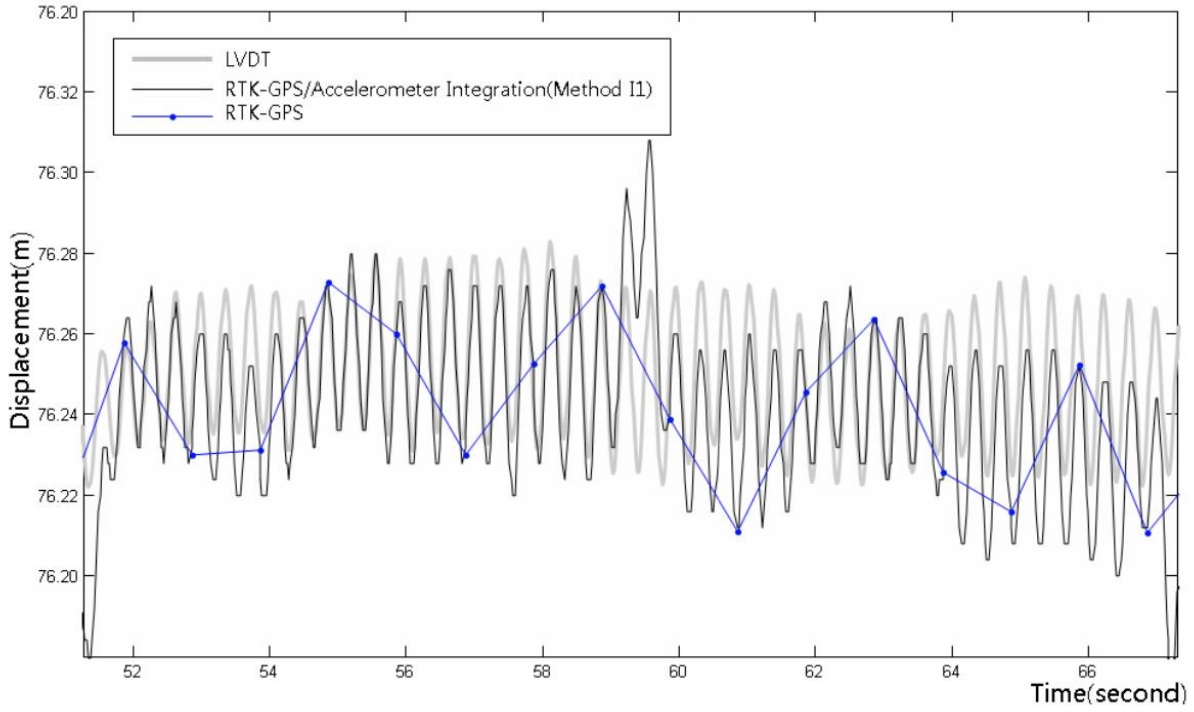


Figure 5.5: GPS and precipitation graph, day 290, Makerere, sat. 4

High sampling data makes difference

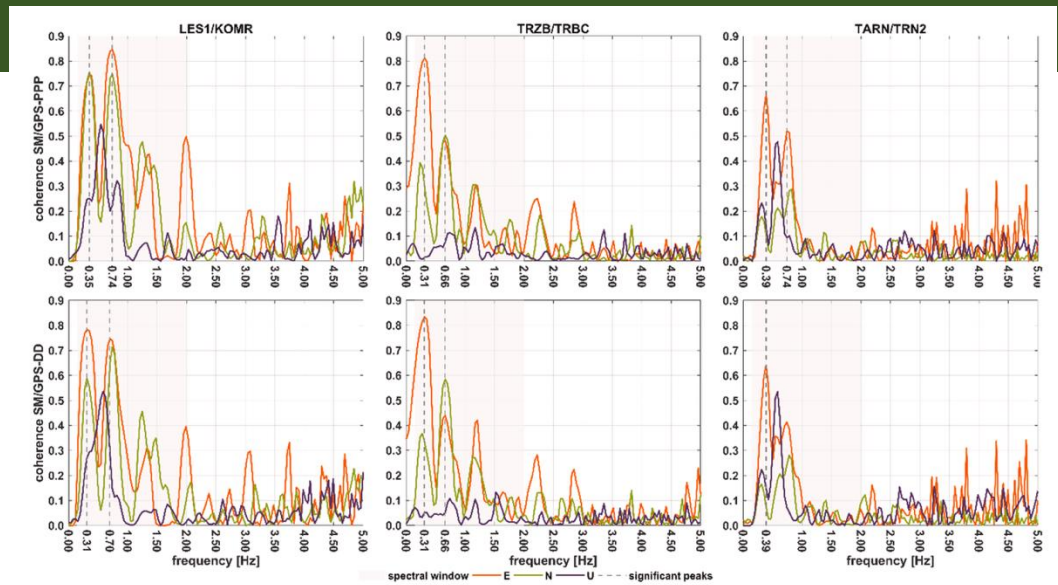


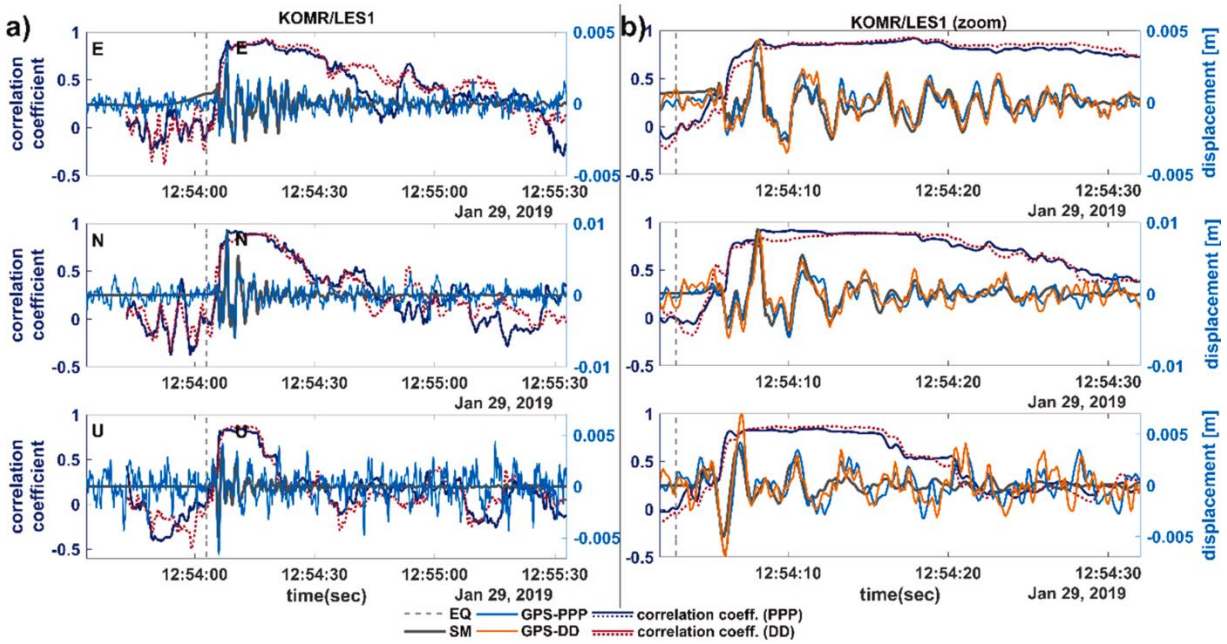
After Hwang et al., Sensor 2012

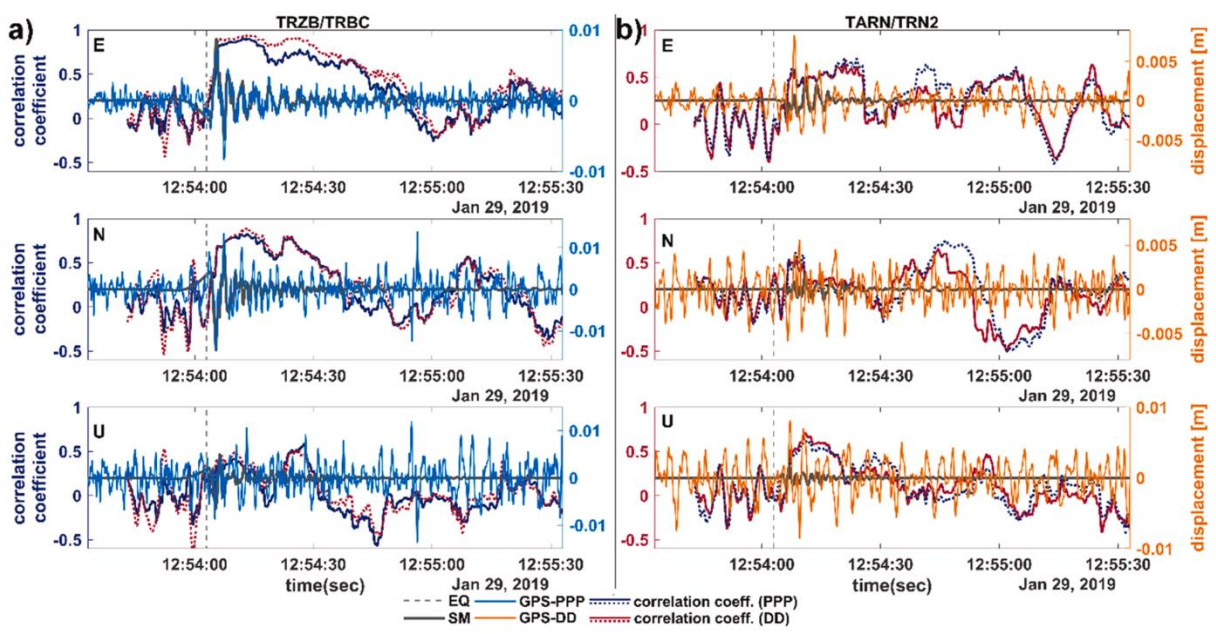


HR GPS derived displacement of earthquake

By I. Kudtacik et al. Measurement 2021.

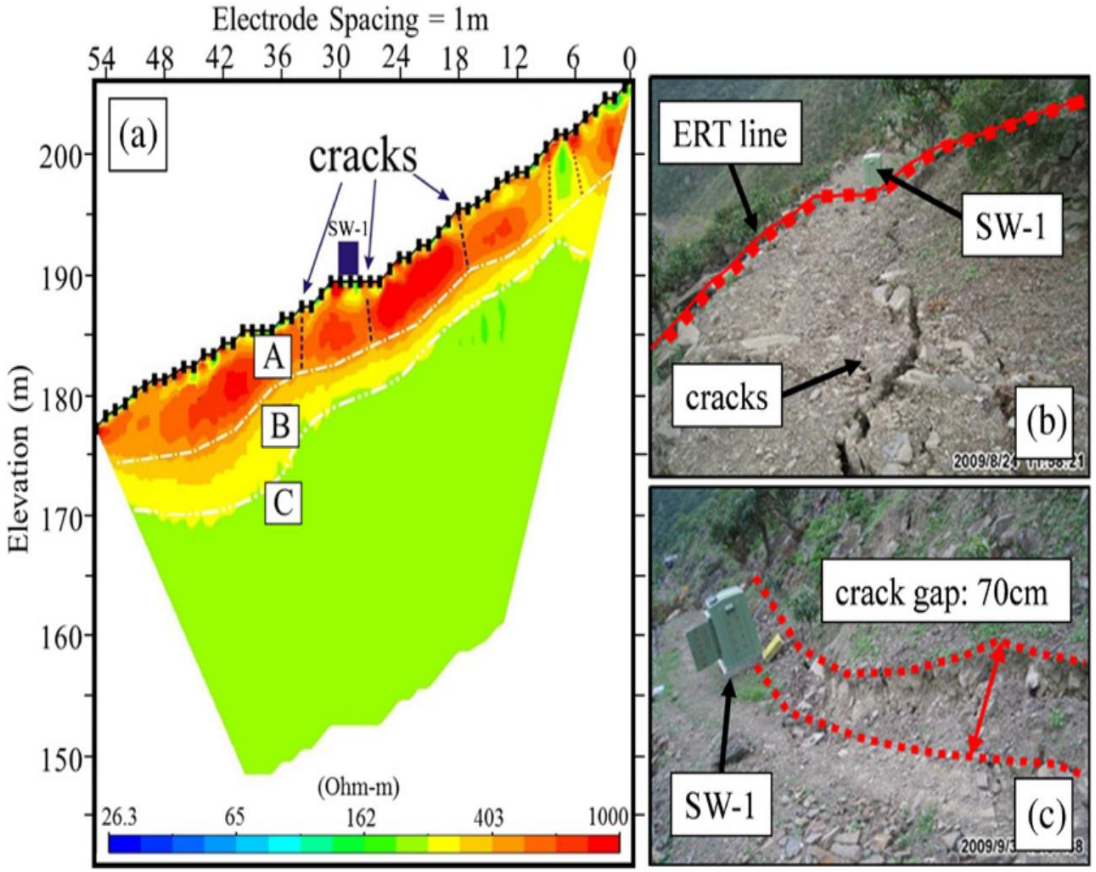


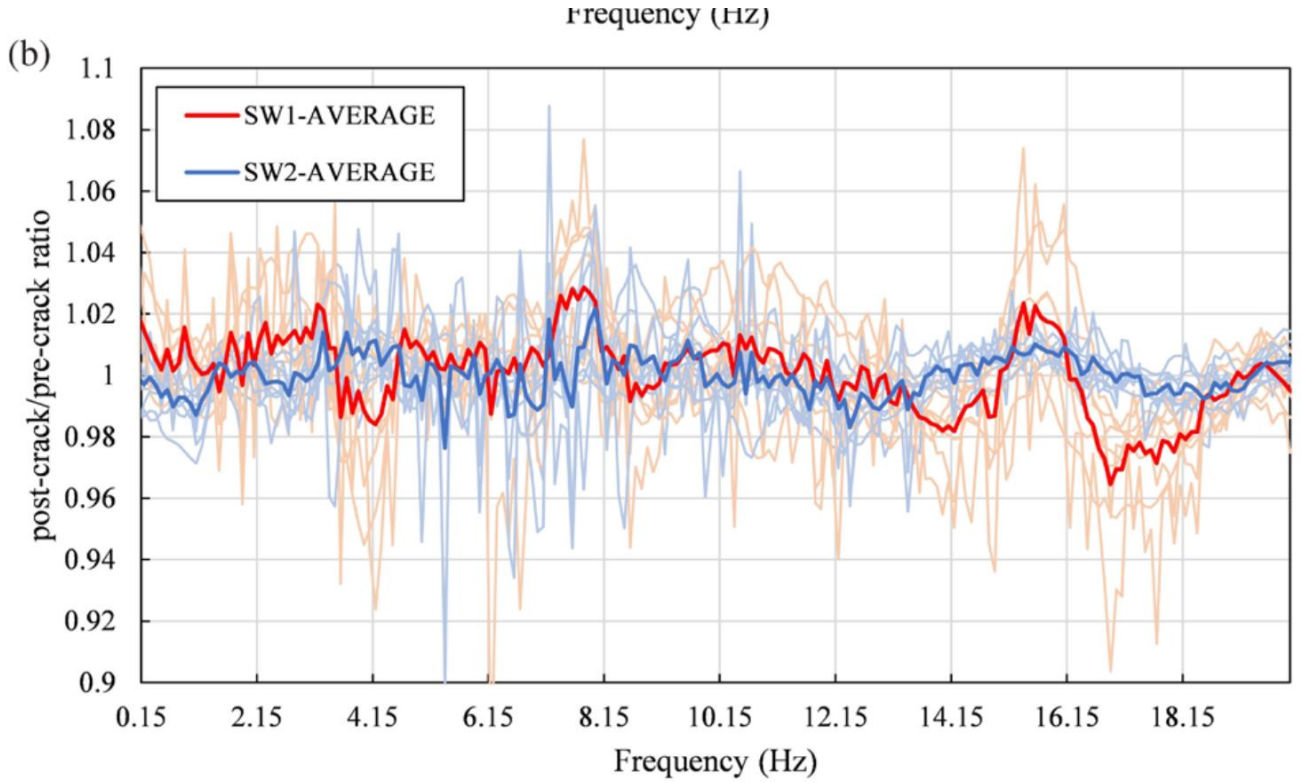




Low frequency coseismic displacement field altered by the existence of local cracks

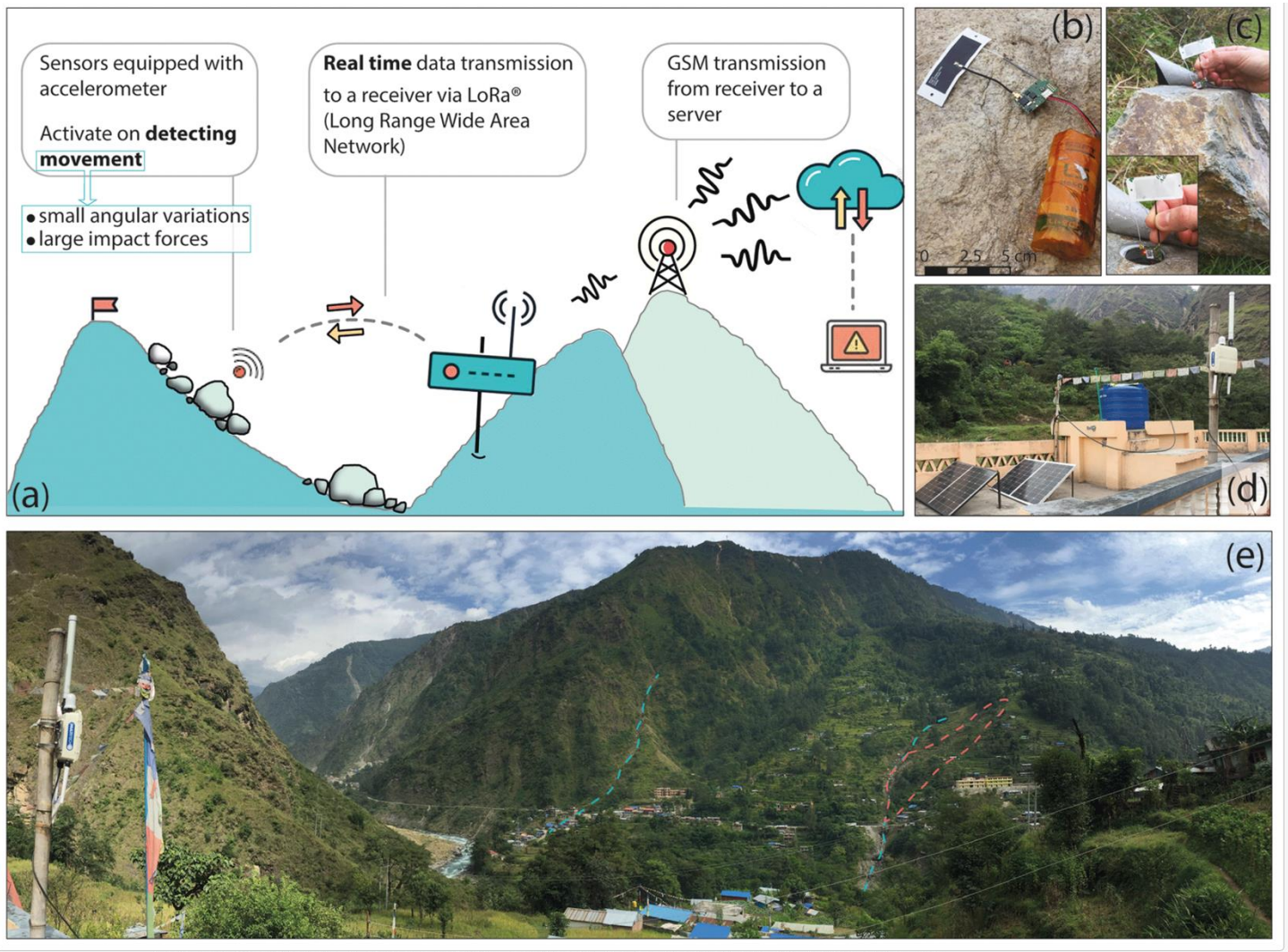
After Wu et al., J. Geophys. Eng. 2014





HR GPS in mountain region

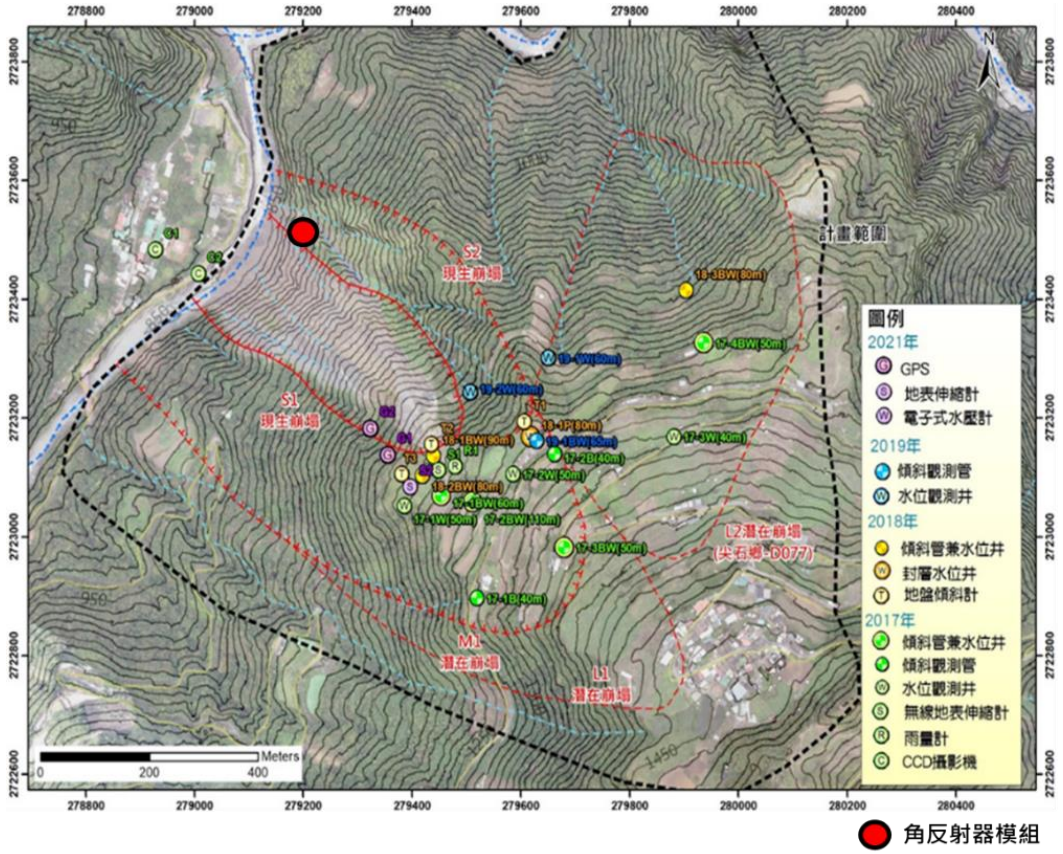
After Din et al., https://doi.org/10.5194/esurf-9-295-2021



1. Offer real-time movement of stations.
2. Derived wet-delay for all stations, estimate participation 20 min. ahead of the storm.
3. Gathered temporal low frequency coseismic ground displacement information to invert the status of underground cracks.

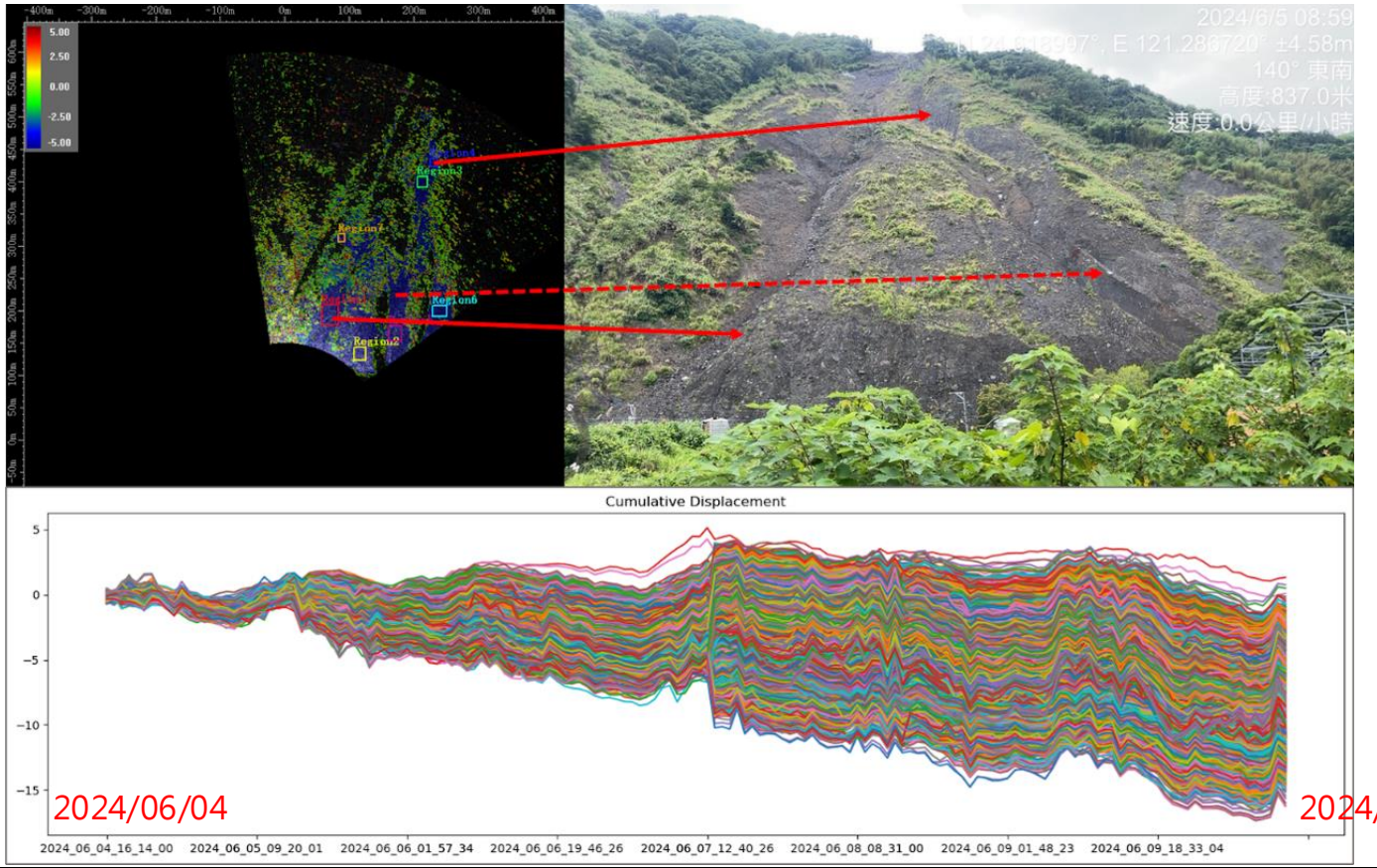
Try to alarm the occurrence of landslide 10-20 minutes before the rupture.

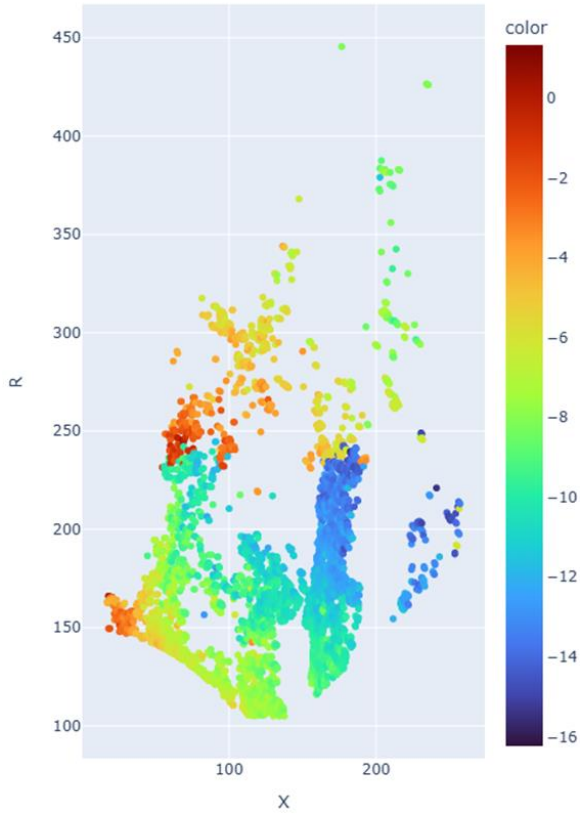
3.地基合成孔徑雷達於坡地監測應用



秀巒(DS194崩塌地)監測

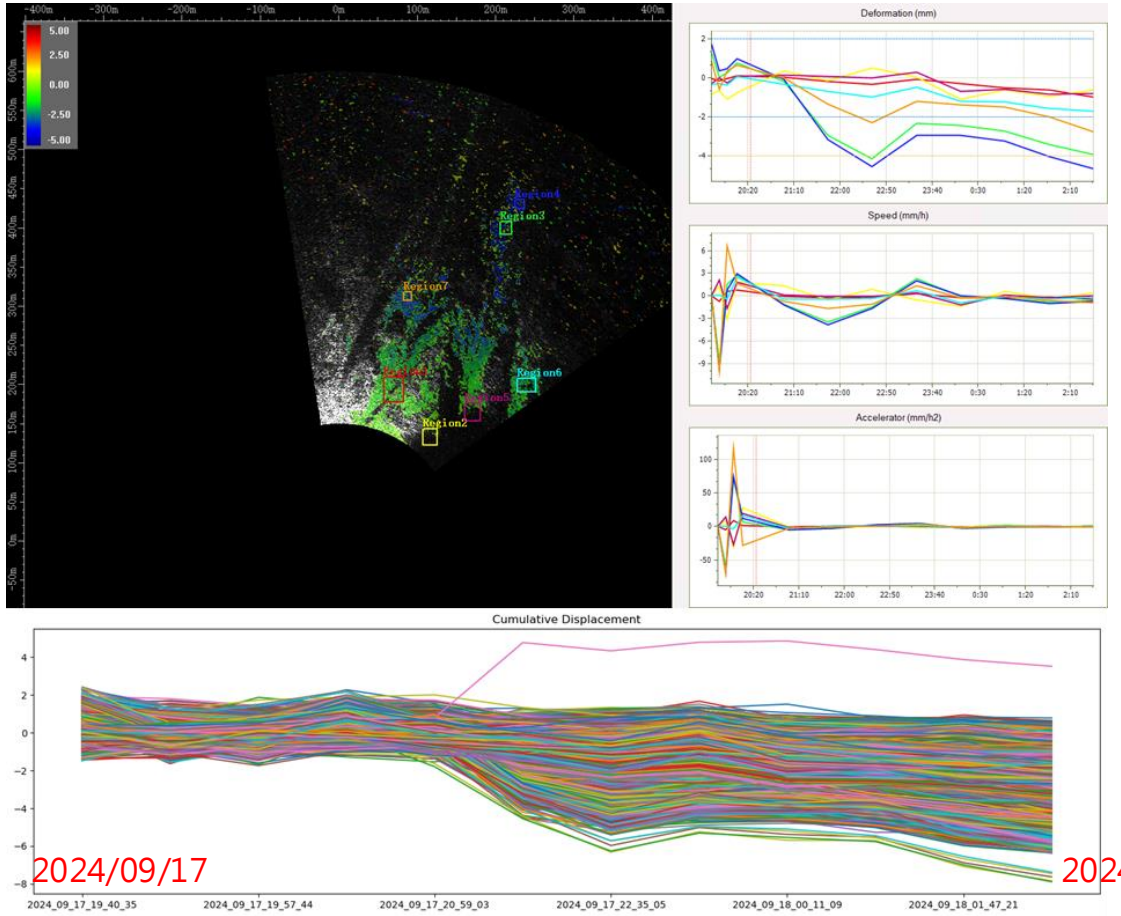
2024 monitoring during rain season

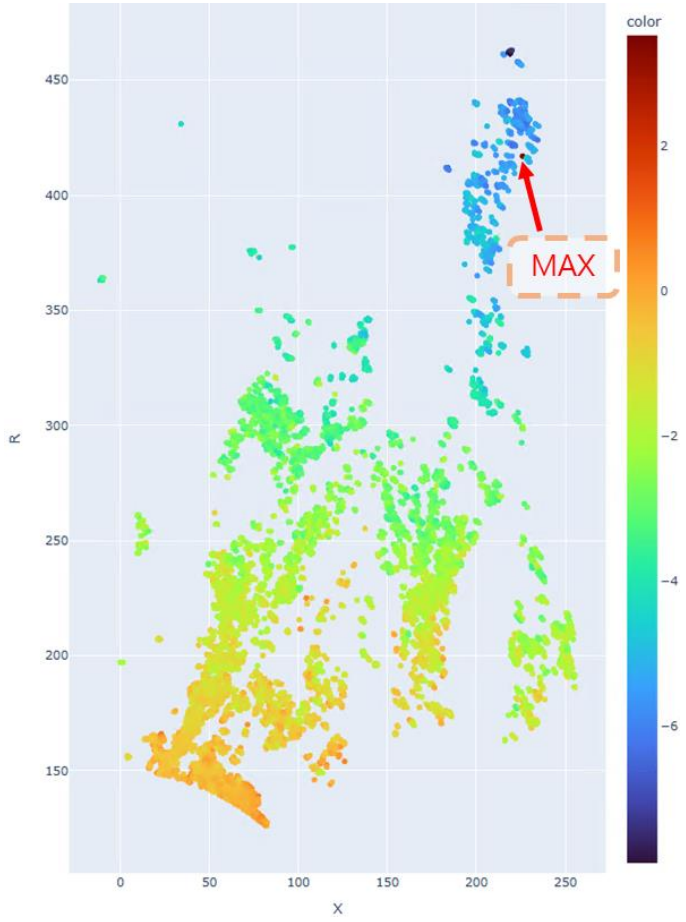




Local creeping is observed, no alarm issued.

2024 monitoring after rain season

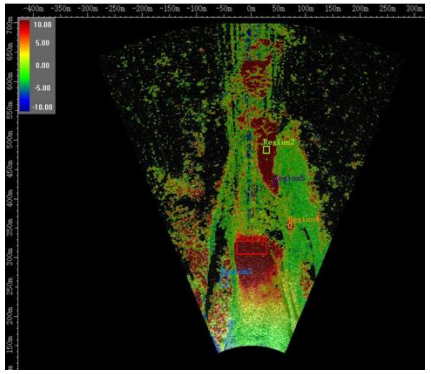




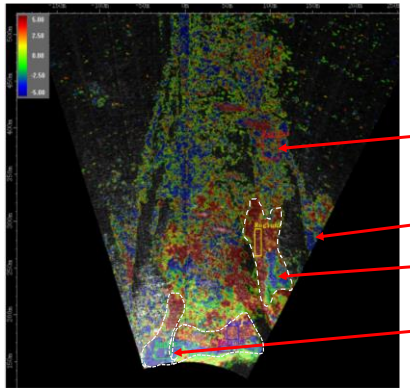
displacement +4~-8mm/day in average

2021-2024 monitoring status

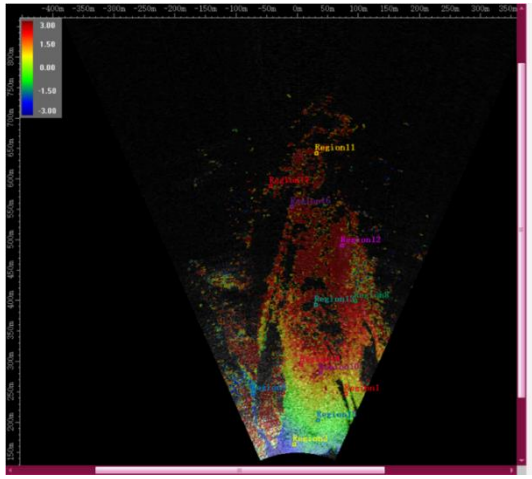
2021

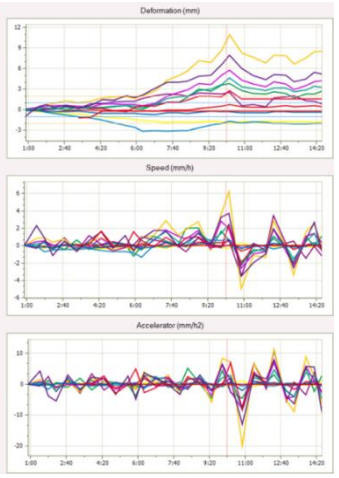


2023 (2.5cm/2weeks)

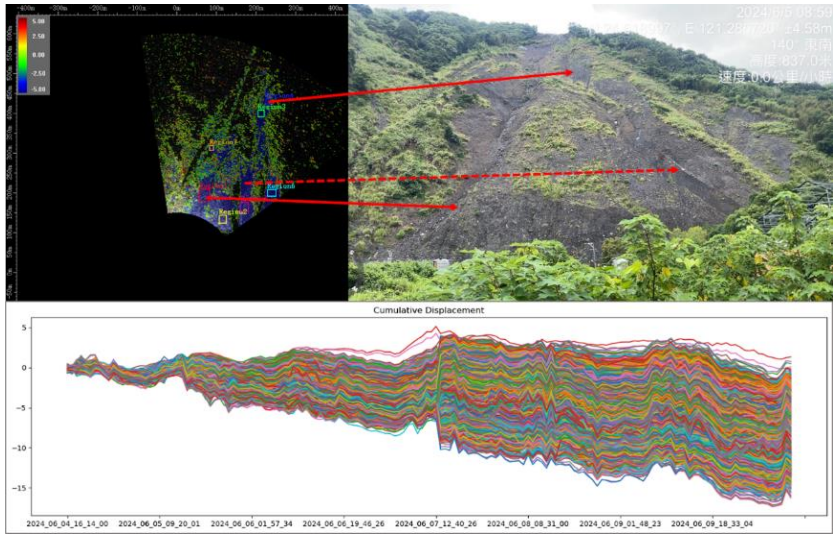


2022





2024



Conclusions:

- HR-GNSS receiver offer better information in detecting wet-delay to predict amount of rainfall better than weather radar (QPSUM).
- Low-frequency Displacement field via 50 Hz GPS offer degree of evolution for underground slip boundary.
- Numerical model offer the current threshold of rainfall at particular landslide zone.
- Ku Band GB-SAR obtain 2D mm level deformation in real time.
- Joint above measurements, early warming of landslide become possible.

I hope there is no need for issuing this alarm, any where, any time.

Thanks for listening.