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Internal structure and present-day activity of deep-seated gravitational slope deformation (Chingjing, Taiwan)

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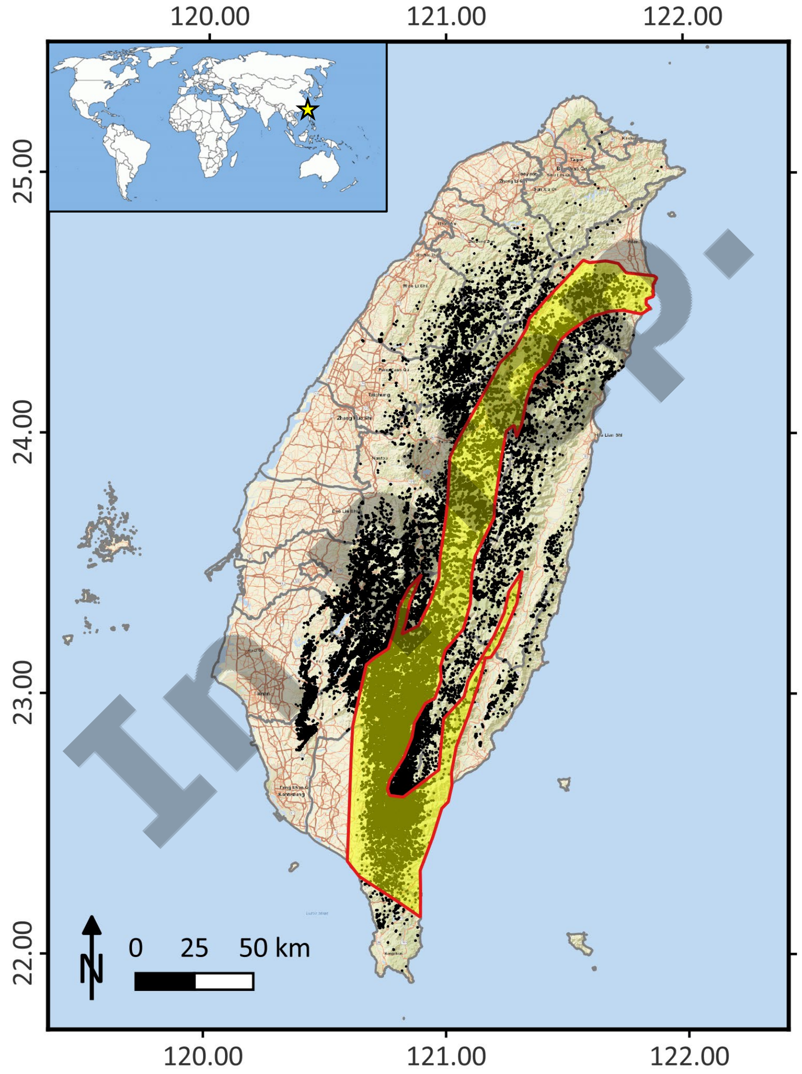
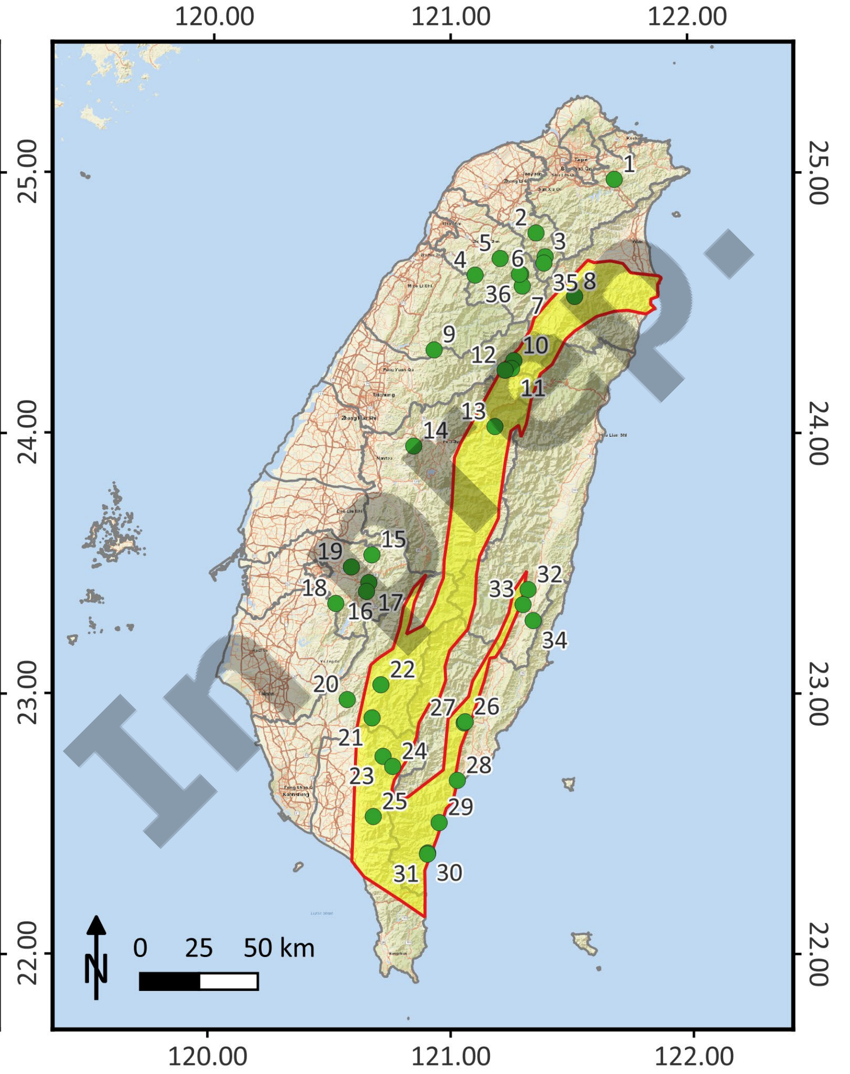
Introduction, *slate belt of Taiwan*

- Deep-seated gravitational slope deformation (DSGSD) dominated by cleavage is widely distributed.
- Landslide prone area from disaster history.
- Contain half of key large landslides of Taiwan.

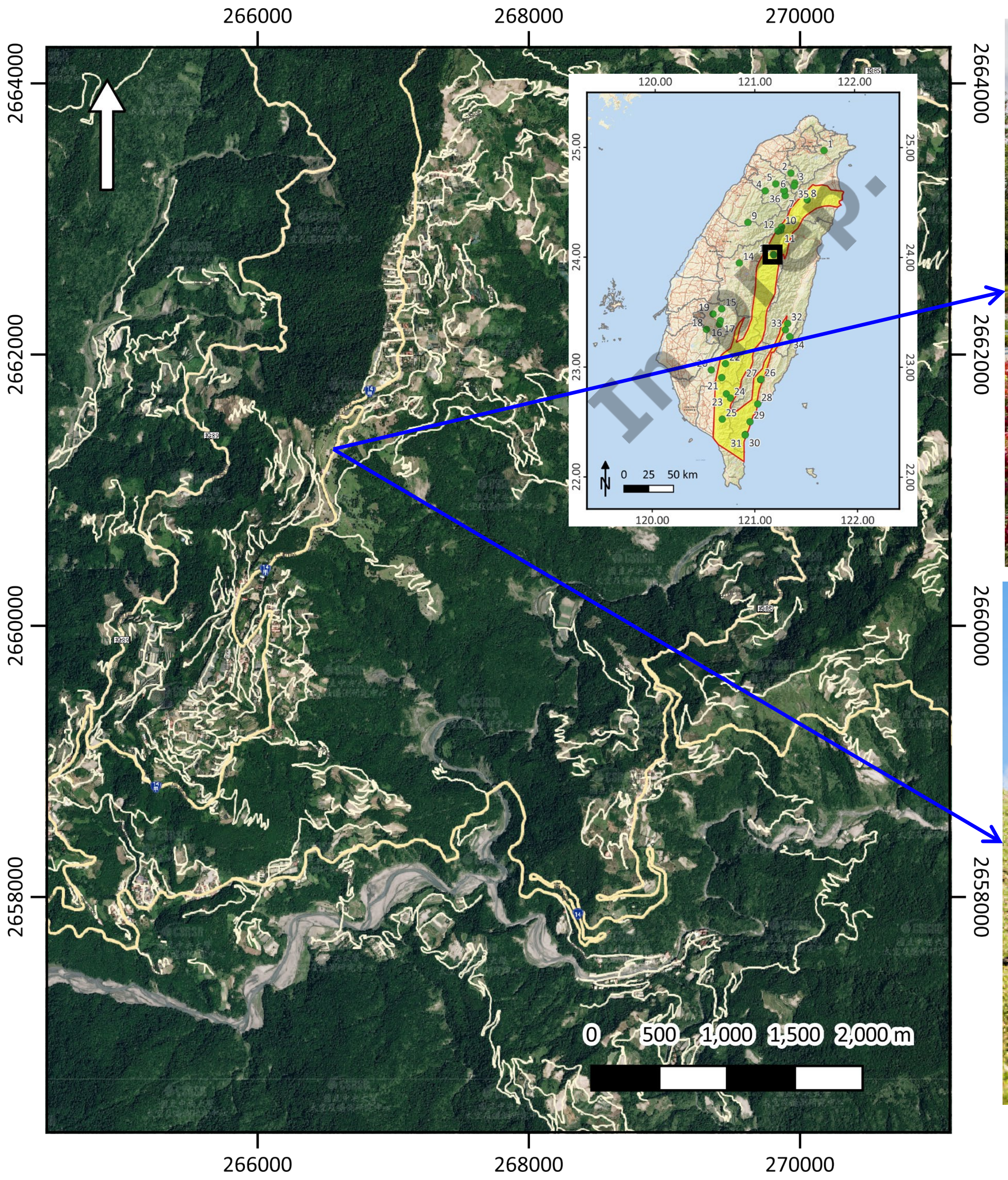


Landslides during 2009 Typhoon Morakot



Key large landslides announced in 2022

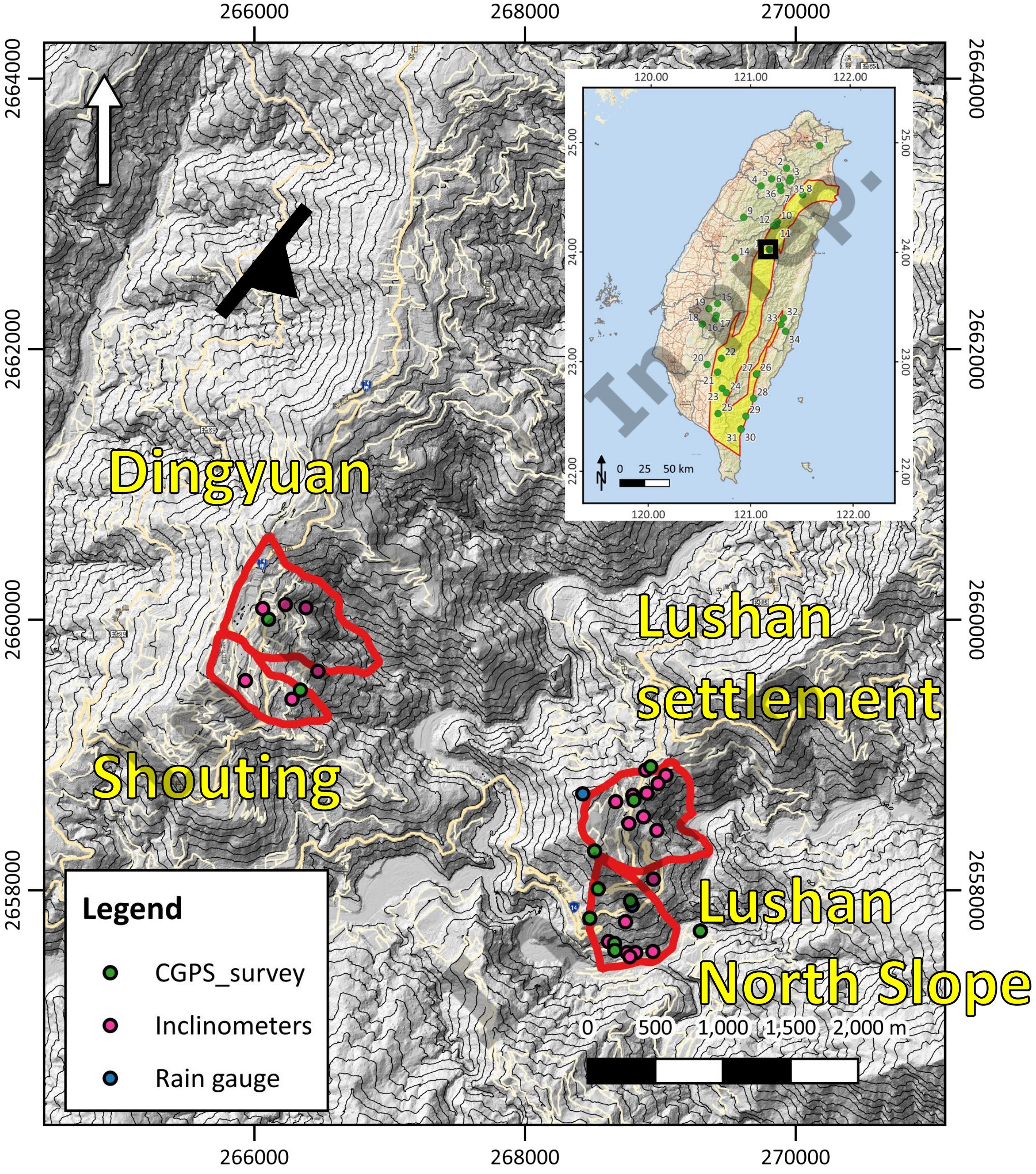
Introduction, *study area: Chingjing region, Taiwan*



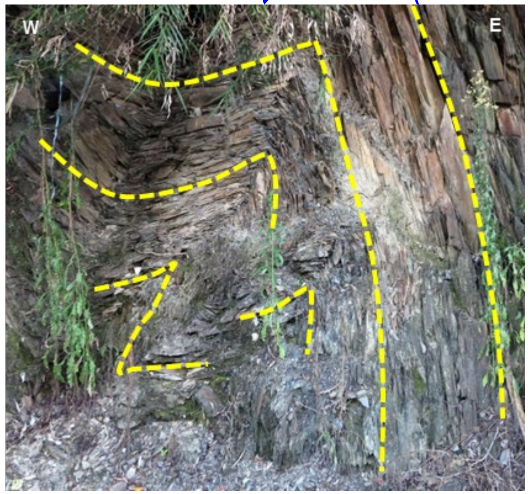
- Hot spot (Protected objects)

(Photos credits: https://www.cingjing.gov.tw/eng/)

Introduction, *why is the Chingjing region*



(After Lin et al., 2020)



- Hot spot (Protected objects)
- Large landslides have been identified from morphology.
- Relative long-period and complete previous surveys.

Introduction, *motivations & objectives*

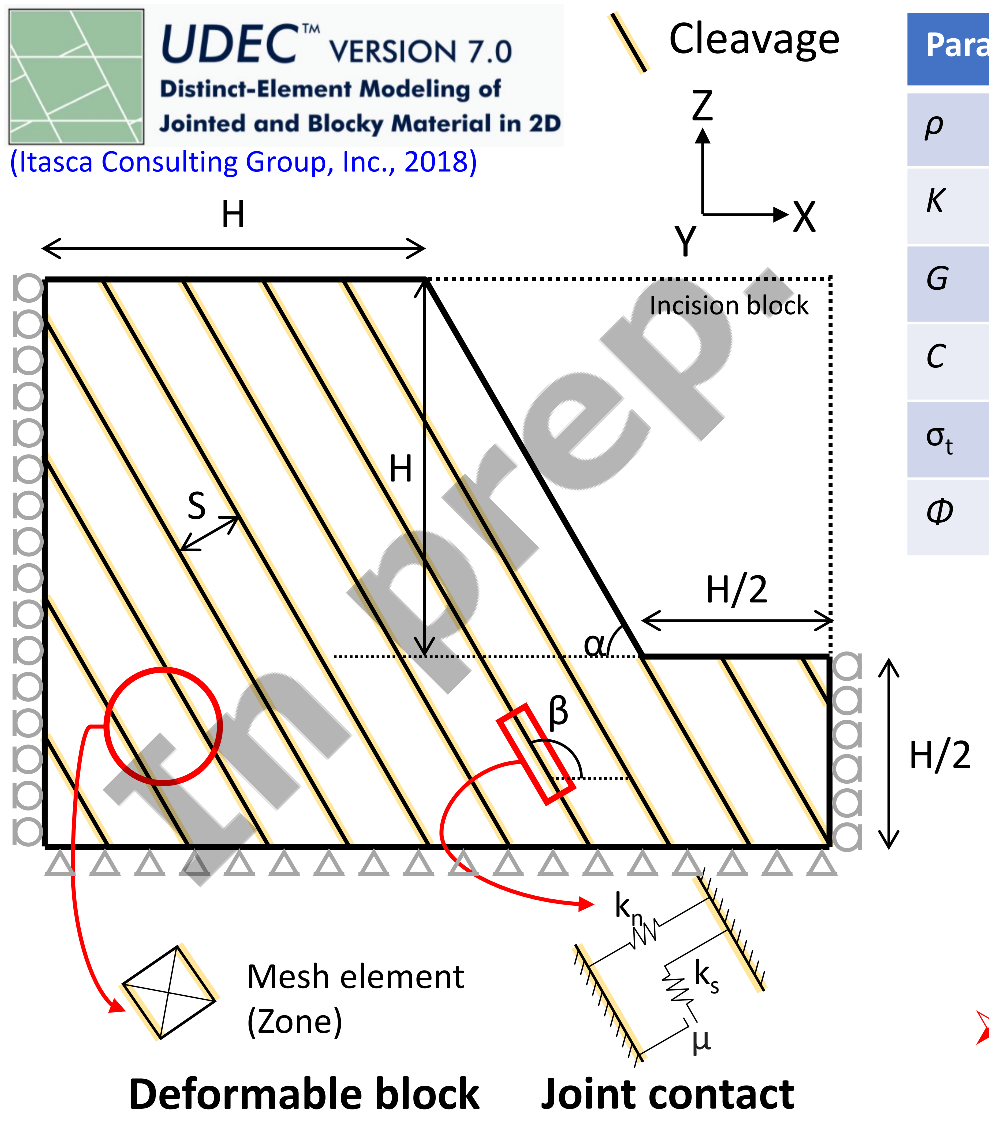
Motivation:

- DSGSDs originate from deep structure regulation, then manifest slope morphology changing, and could transfer into rockslides.
- In the study area, large landslides recognized previously seem to be at different stages in the DSGSD process.

Objective:

- The geological models of the large landslides in the study area were inferred mainly based on borehole data and inclinometers. Can the geological model be supported by mechanical modeling and provide more information on the DSGSD process?
- Large landslides in the study area have been monitored mainly based on GNSS. A survey approach with higher spatial coverage is necessary to assist the identification/characterization of the DSGSD's activity.

Methodology, *distinct element modeling*



Rock mass properties described by Mohr-Coulomb constitutive model (Weng et al., 2017, 2022)

Parameter	Definition	Value	Unit
ρ	Density	2,700	kg/m^3
K	Bulk modulus	5.00	GPa
G	Shear modulus	3.75	GPa
C	Cohesion	132.43	kPa
σ_t	Tension	131.90	kPa
Φ	Friction angle	34	°

Discontinuity properties for the Mohr-Coulomb constitutive law

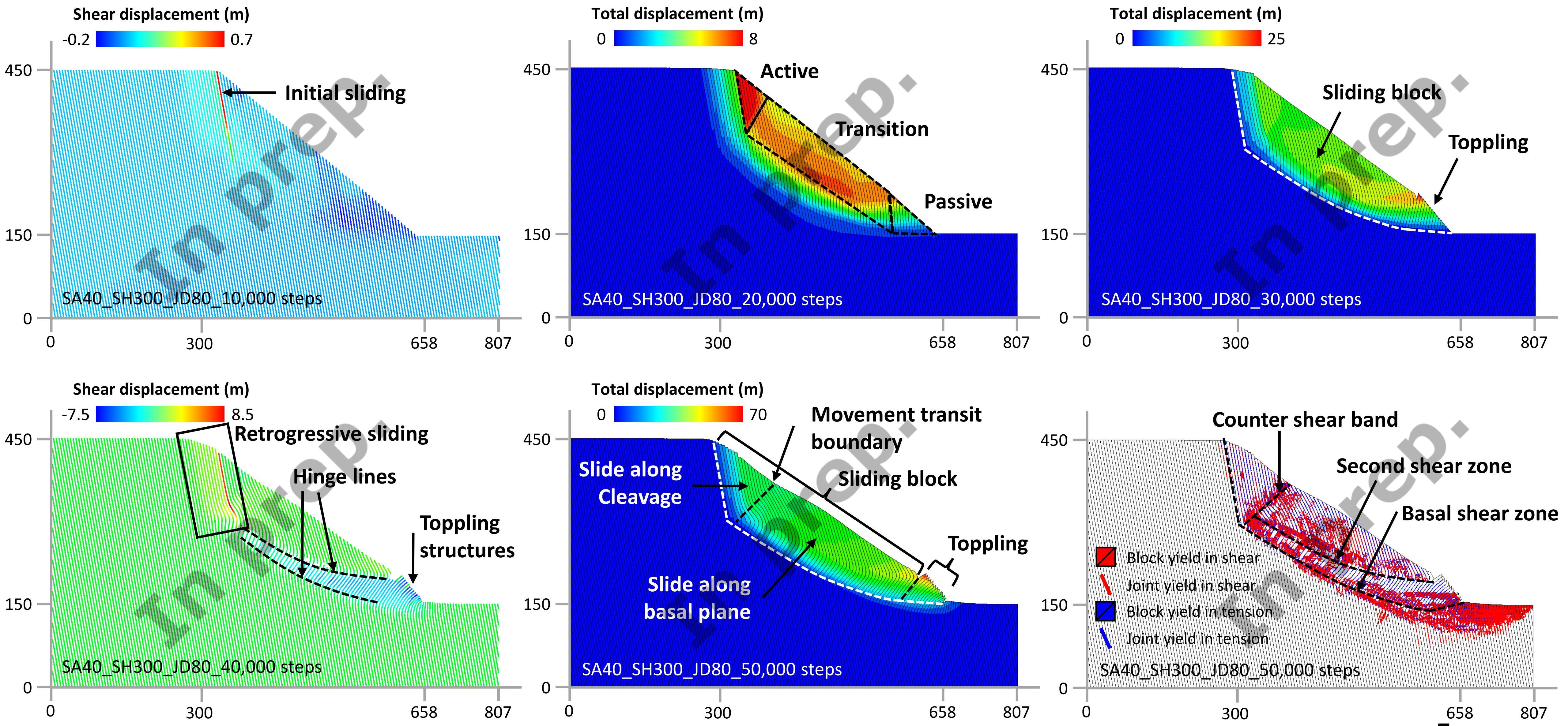
Parameter	Definition	Value	Unit
k_n	Normal stiffness	5.00	GPa
k_s	Shear stiffness	5.00	GPa
C_j	Cohesion	0	MPa
σ_j^t	Tension	0	MPa
Φ_j	Friction angle	10	°

Set-up for the parametric study

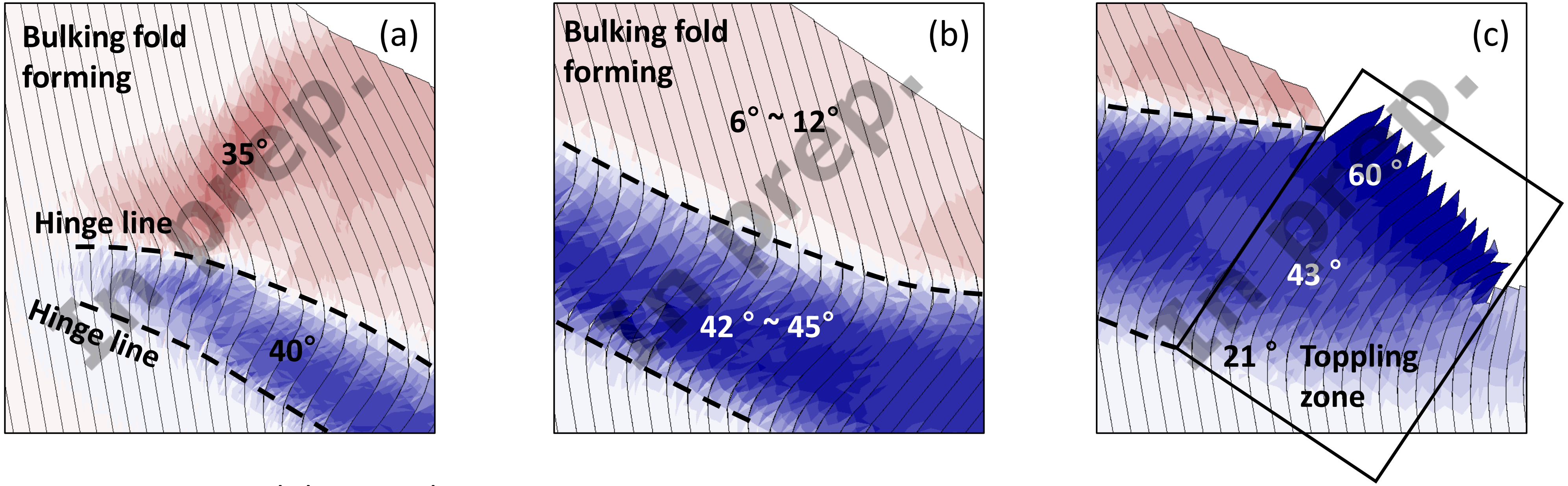
Parameter	Definition	Min. value	Max. value	Steps	Unit
α	Slope angle	25	50	5	°
β	Joint dip angle	60	80	10	°
H	Slope height	200	400	100	m

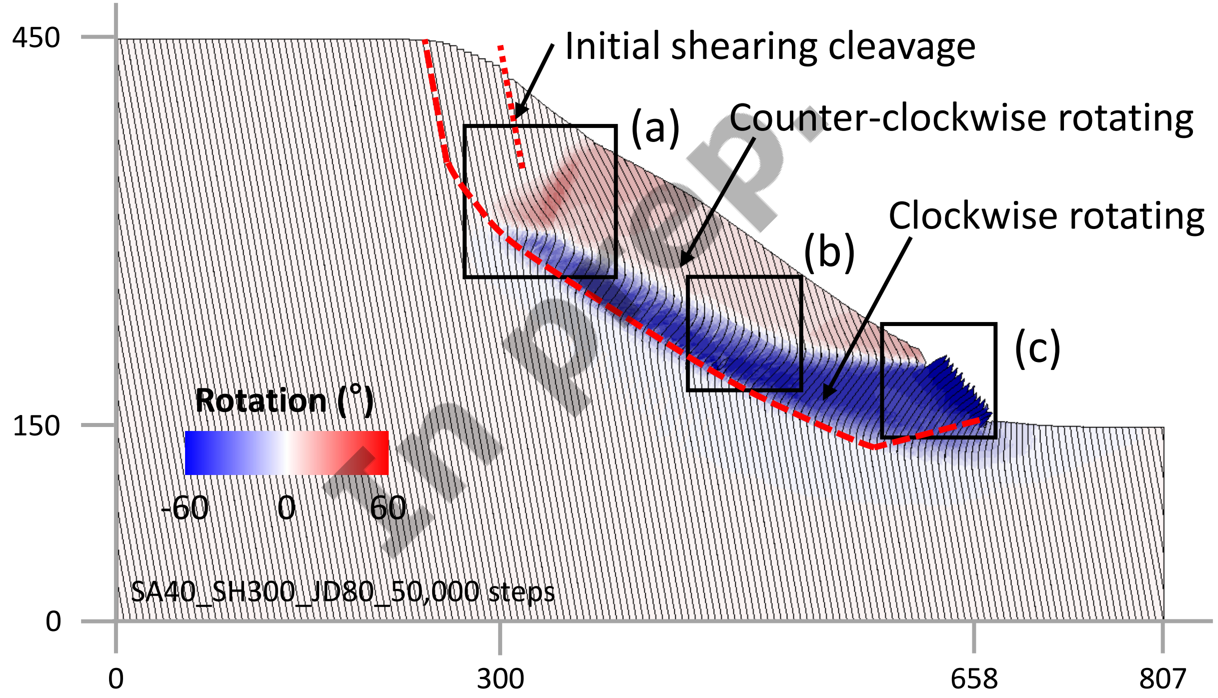
- Focus on the models with 35° and 40° slope angles, 80° cleavage dip angle and 300-m slope height in the following.

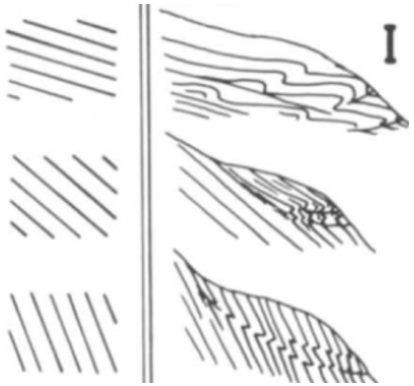
Results, *DSGSD process*



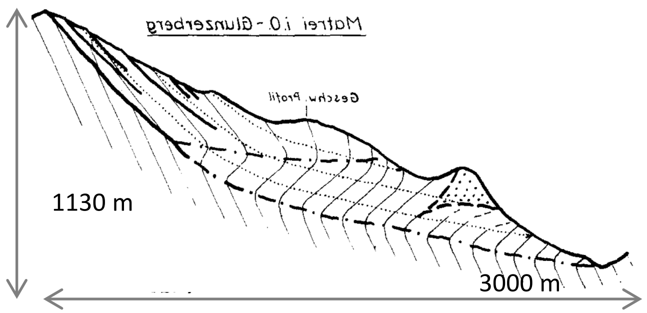
Results, *internal structures of the DSGSD*





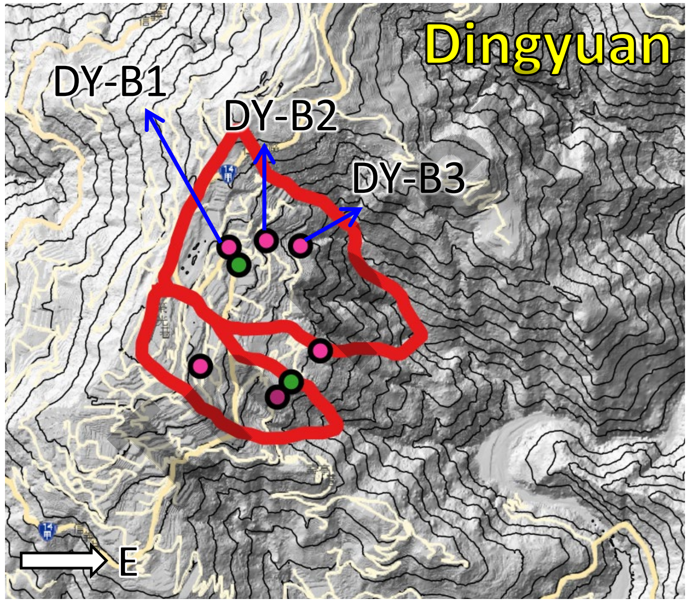


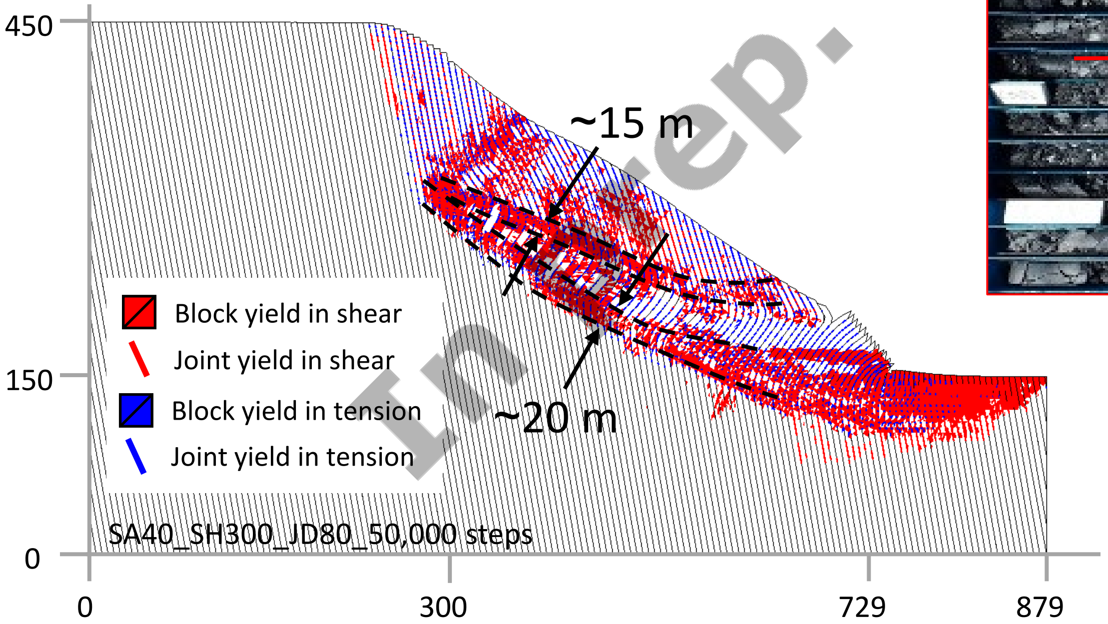
Buckling folds formed in consequent slopes
(After Chigira, 1992)



(After Zischinsky, 1969)

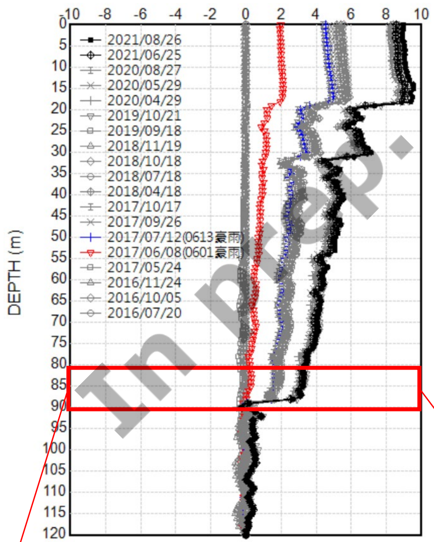
Results, *evidences from the boreholes*



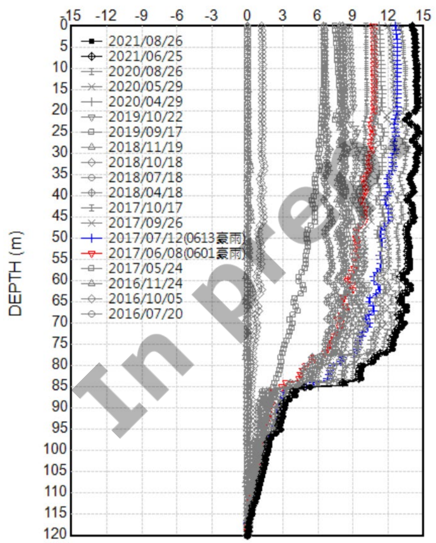


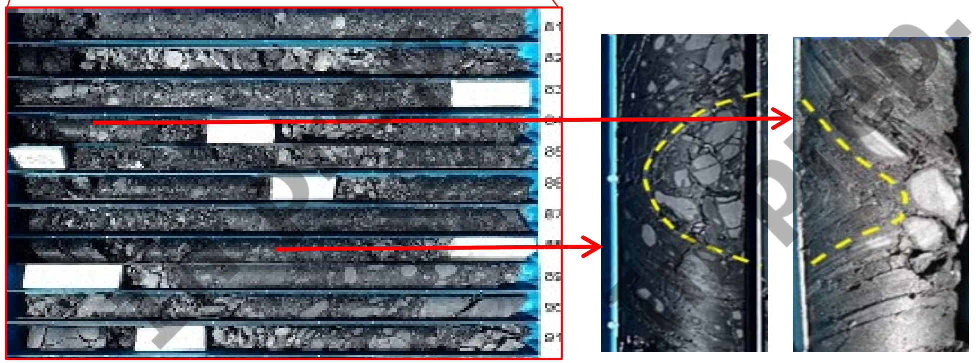
Basal shear zone

DY-B1 (A)



DY-B2 (A)

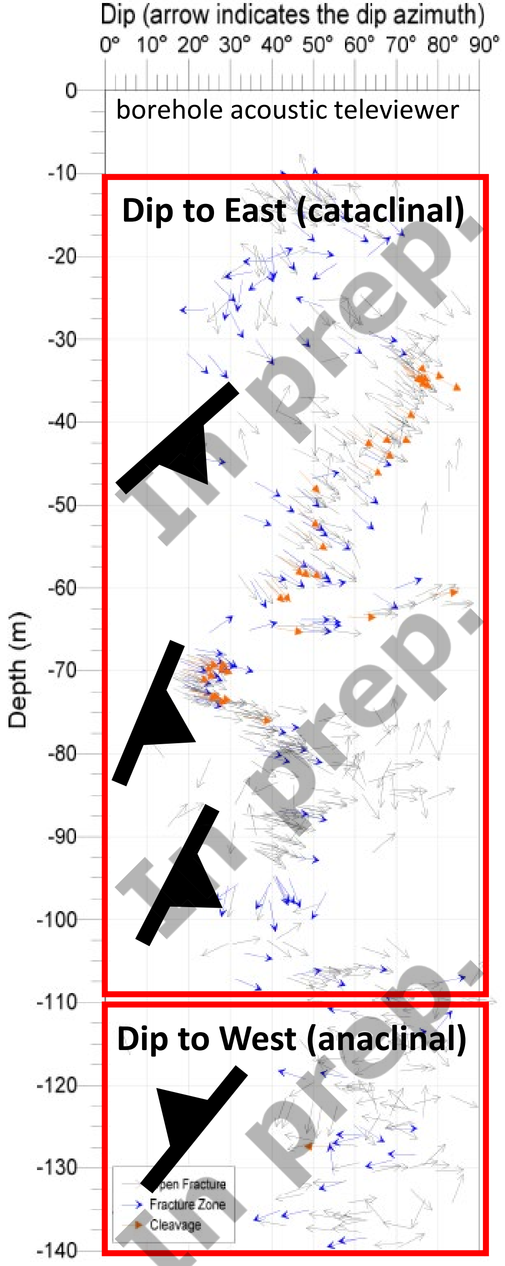




(borehole data are obtained from the CGS of Taiwan)

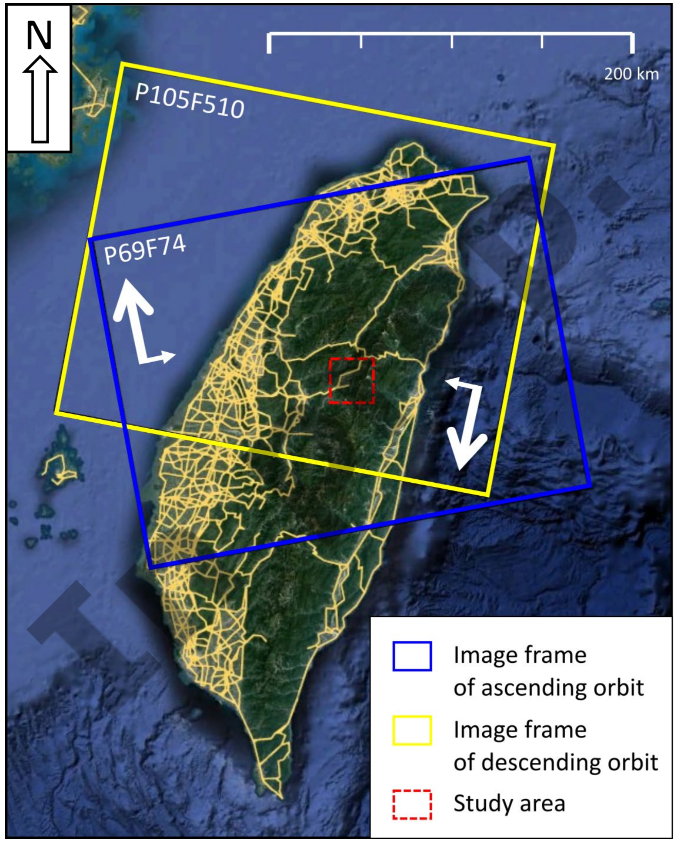
Structure variation

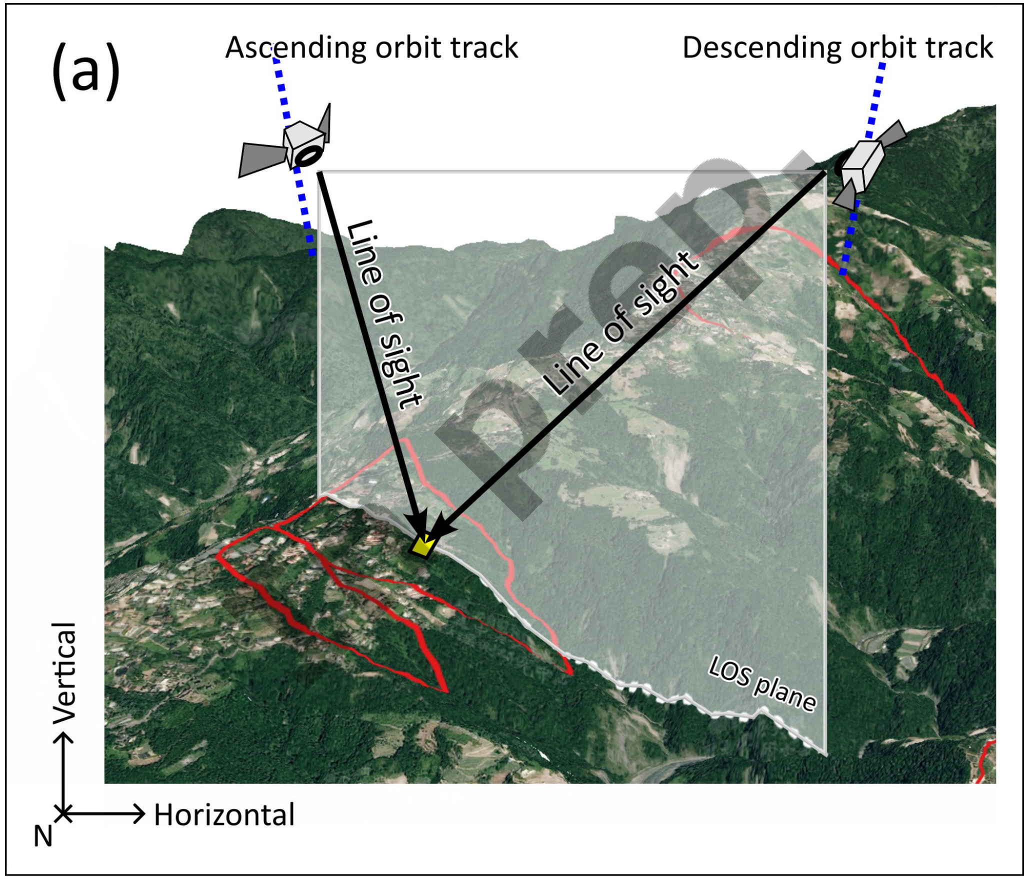
DY-B3 (A)

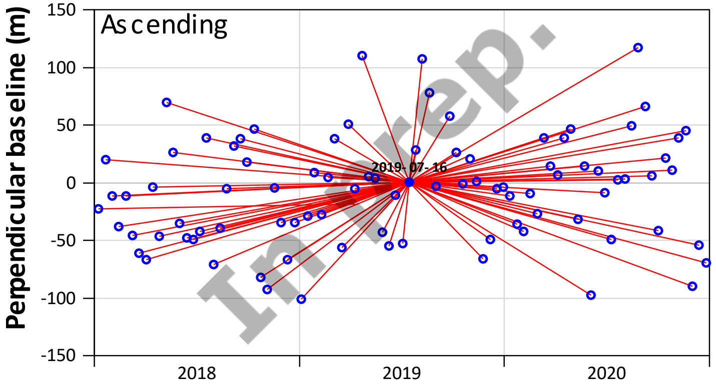


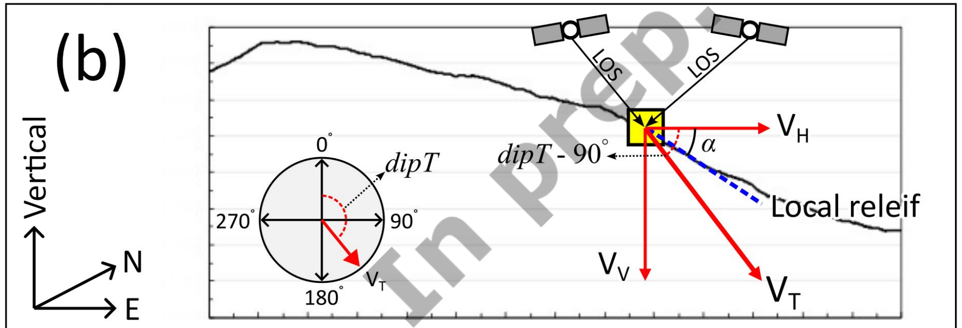
Methodology, *PSInSAR analysis*

- Sentinel-1 A
- Time interval:
  2018 – 2020 (3 years)
- Number of images:
  - 90 for ascending track
  - 87 for descending track
- Processors:
  - stacking of coregistered:
    ISCE2 (Fattahi et al., 2017; Rosen et al., 2012)
  - time-series analysis:
    StaMPS (Hooper et al., 2004



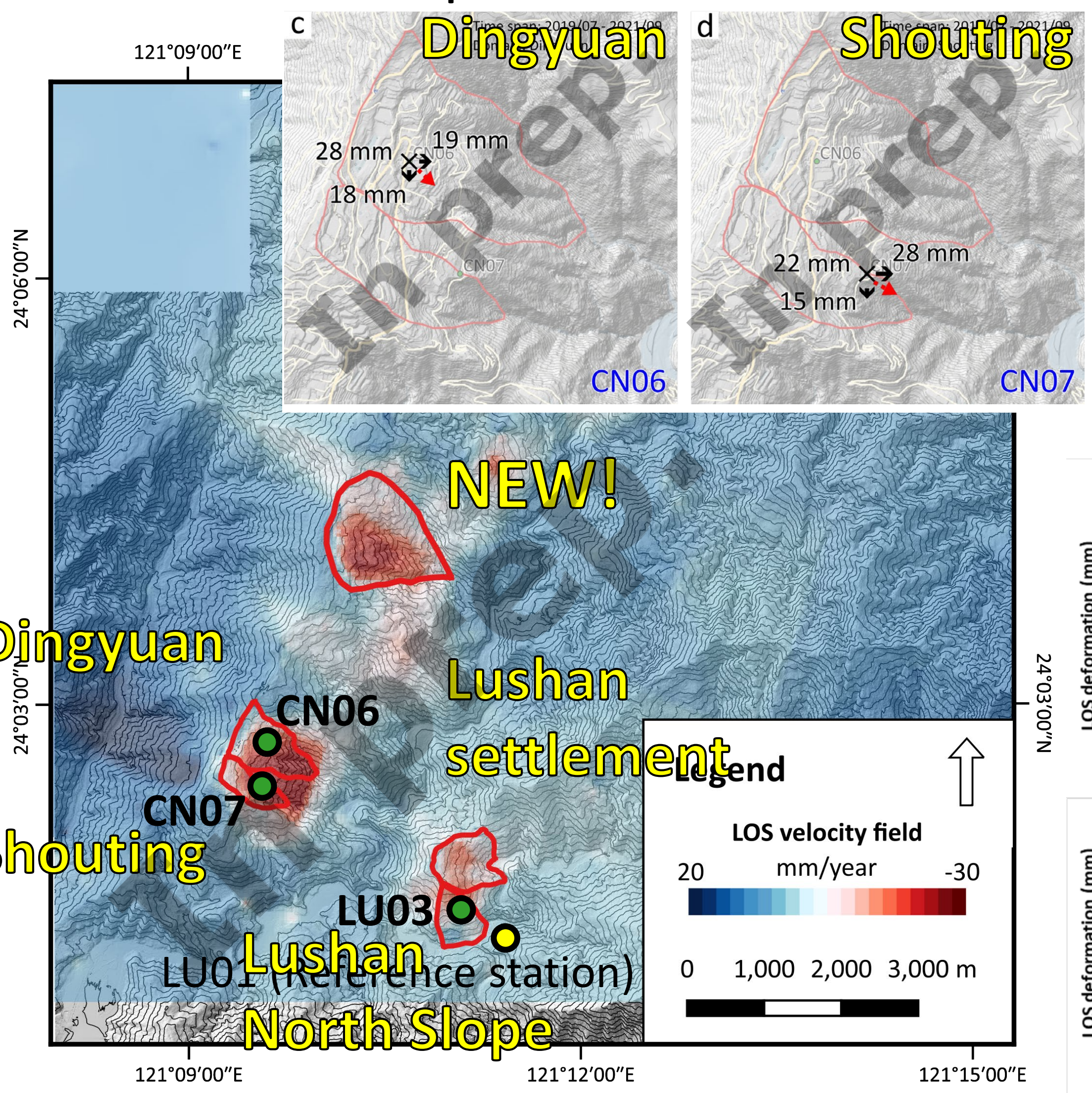


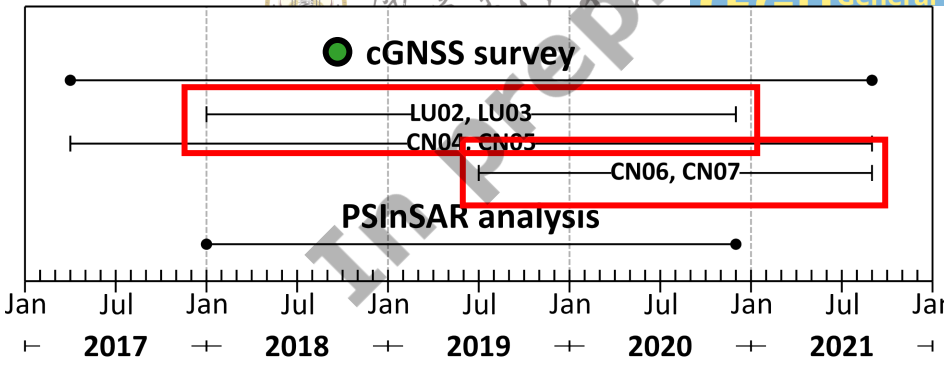




Results, *validation of the PSInSAR products*

Total displacement from GNSS in 2018-2020

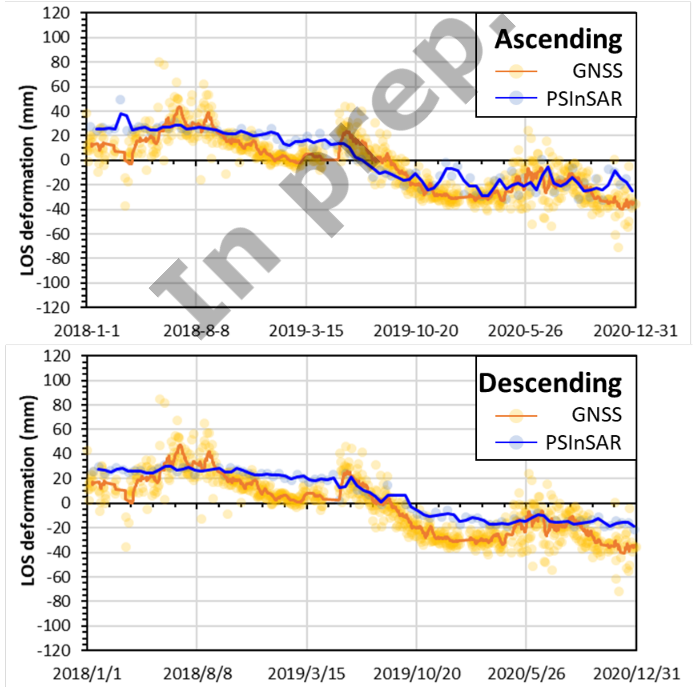




(GNSS is maintained by Prof. Kuo-Lung Wang at the National Chi Nan University)

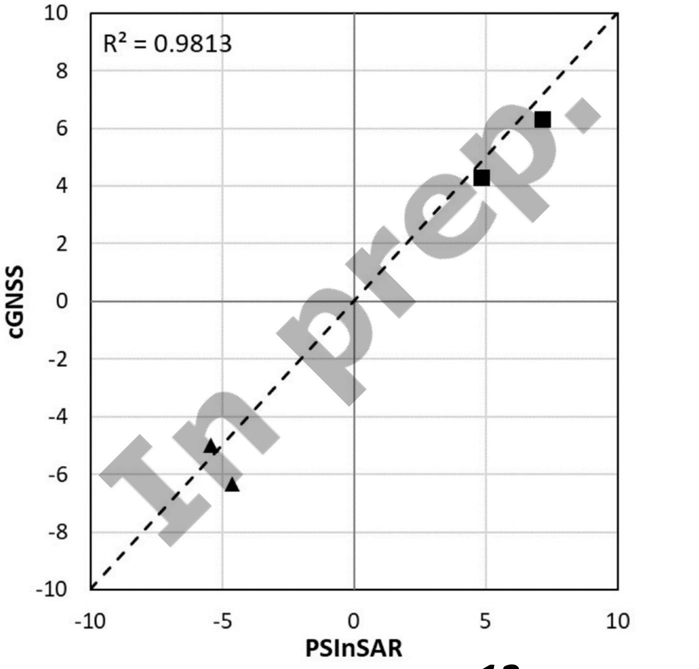
LOS time-series validation

(project GNSS to LOS direction)

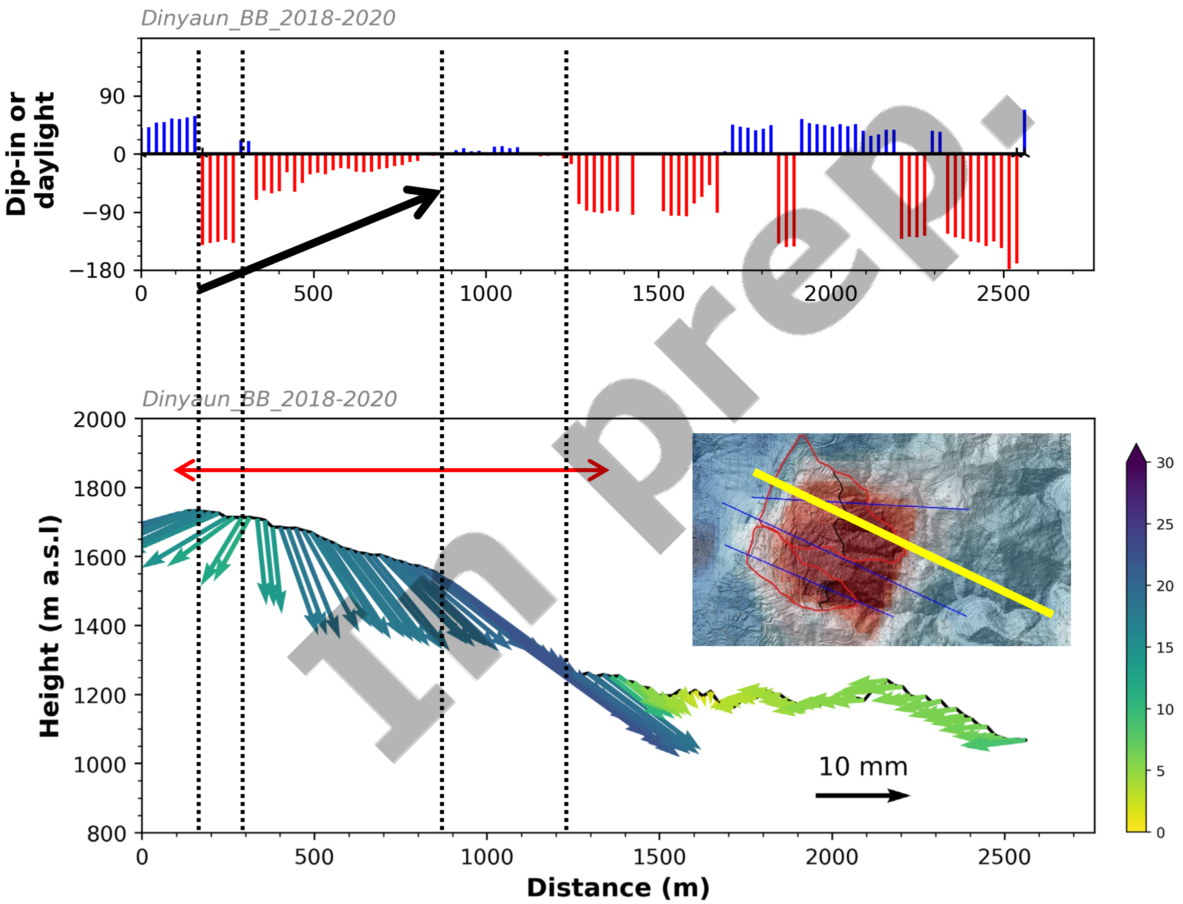


Decomposed V_H & V_V validation

(compare with total displ. From GNSS)

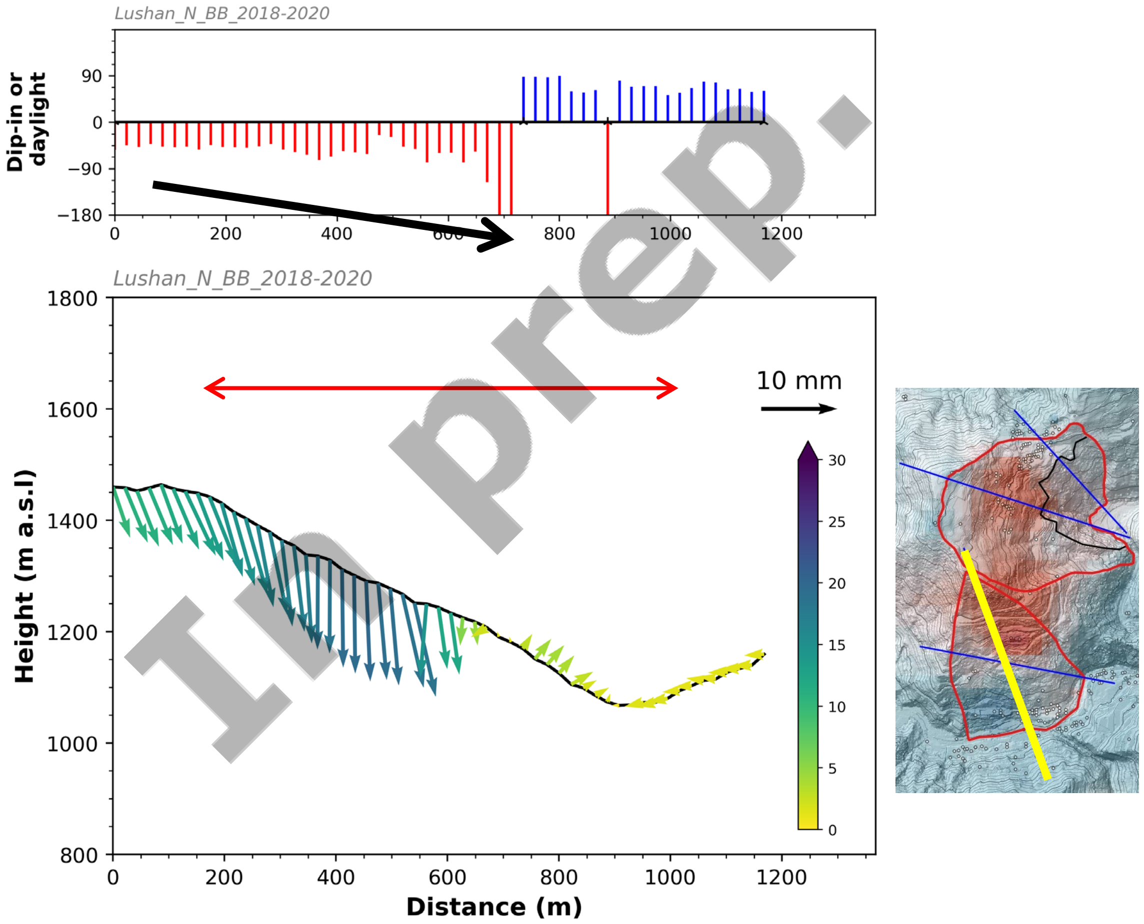


Results, *kinematic movement & present-day activity*



DSGSD

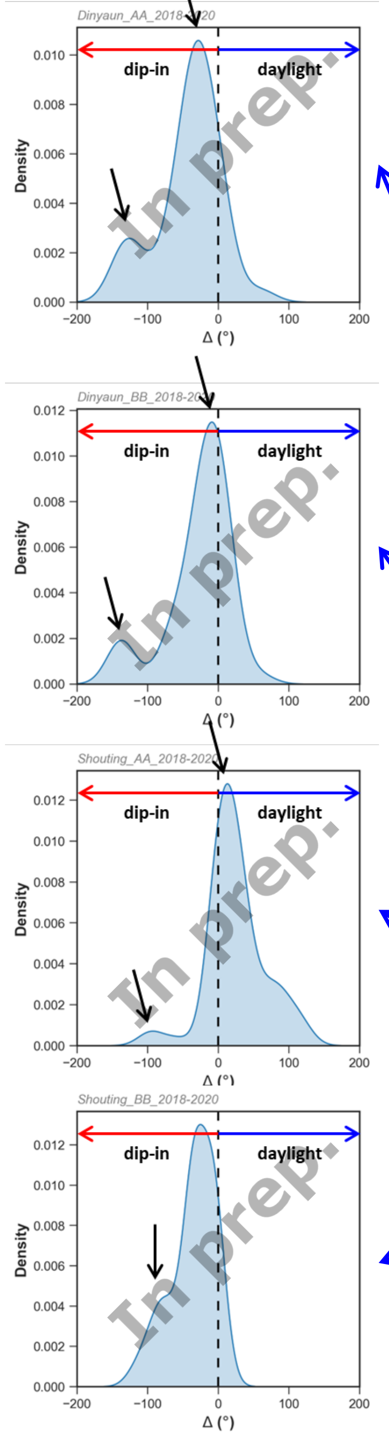
Dingyuan domain



Rockslide

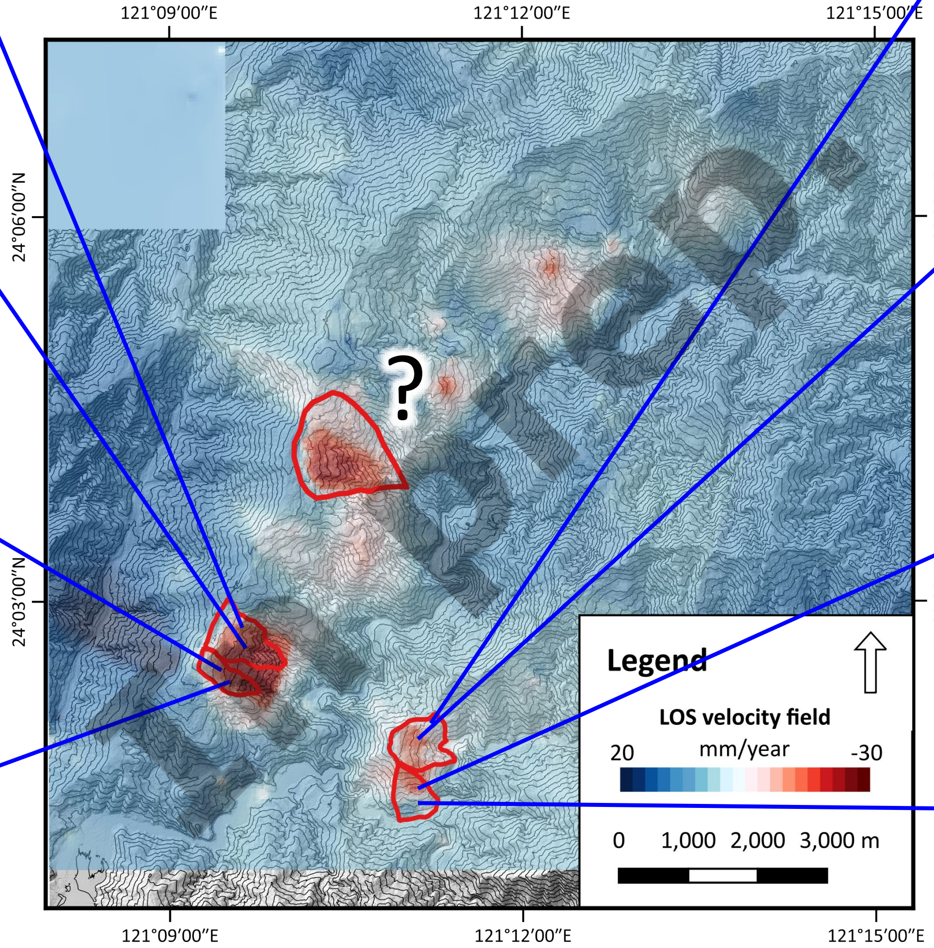
Lushan North Slope domain

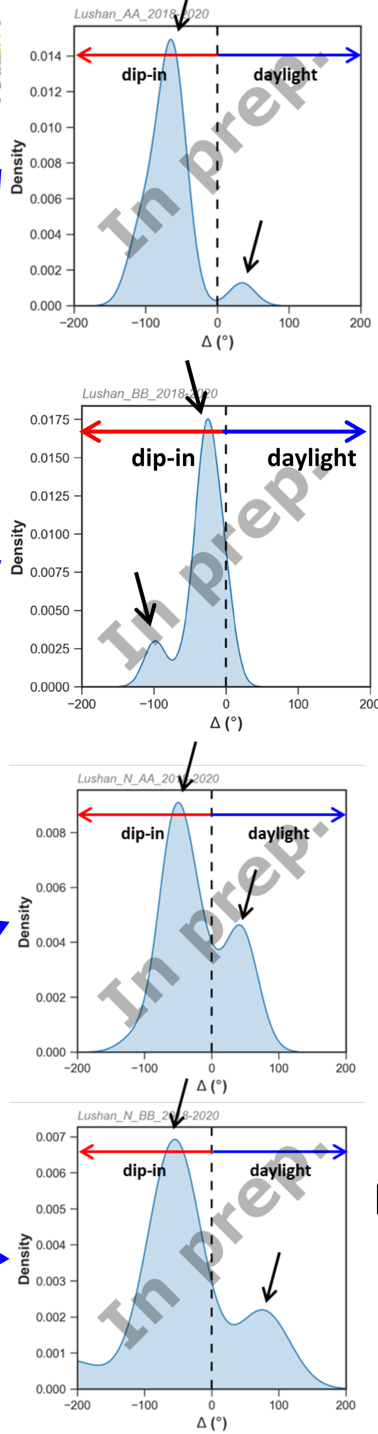
Results, *DSGSD characterization from PSInSAR products*



DSGSD
Dingyuan

DSGSD
Shouting





Transition?
Lushan settlement

Rockslide
Lushan North Slope

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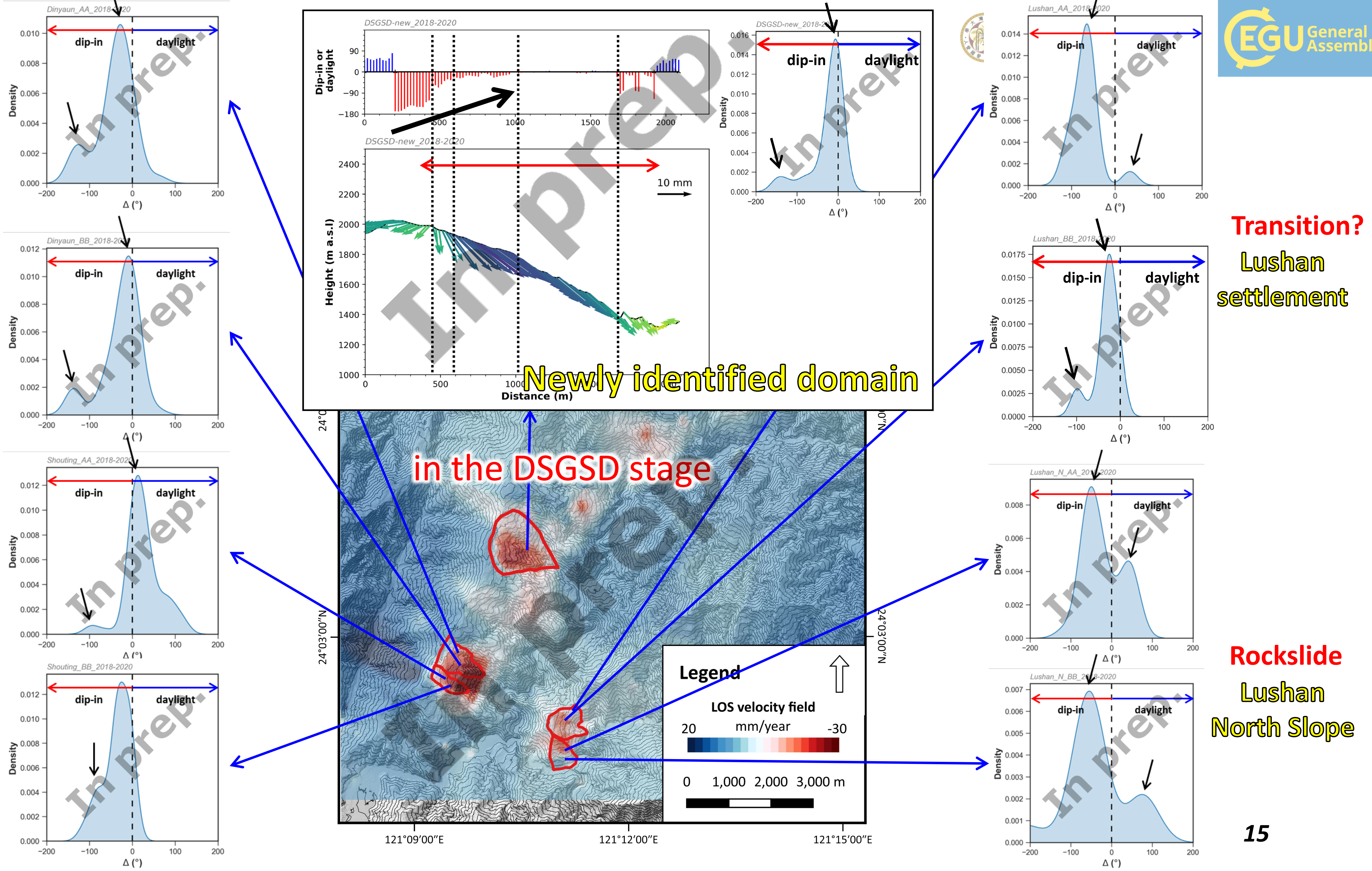

DSGSD
Dingyuan
DSGSD
Shouting
Transition?
Lushan
settlement
Rockslide
Lushan
North Slope
Dinyaun_AA_2018-2020
Dinyaun_BB_2018-2020
Shouting_AA_2018-2020
Shouting_BB_2018-2020
Lushan_AA_2018-2020
Lushan_BB_2018-2020
Lushan_N_AA_2018-2020
Lushan_N_BB_2018-2020
dip-in
daylight
Density
Δ (°)
In prep.
DSGSD-new_2018-2020
Dip-in or daylight
Height (m a.s.l)
Distance (m)
10 mm
Newly identified domain
in the DSGSD stage
Legend
LOS velocity field
20 mm/year -30
0 1,000 2,000 3,000 m
24°03′00″N
121°09′00″E
121°12′00″E
121°15′00″E

Concluding remarks

Distinct element modeling:

- ✓ captures the full process of DSGSD in the cataclinal slopes (cleavage dip direction parallels to the topographic downslope direction)
- ✓ reproduces the features of deep structures and basal shear zone observed in the borehole data
- ✓ recognizes the kinematic movement of DSGSD process at any location in a slope

PSInSAR analysis:

- ✓ provides high spatial coverage velocity data to improve delineation
- ✓ demonstrates the characterization of DSGSD stage based on kinematic movement (decomposed displacement vectors)
- ✓ sheds light on future monitoring strategy for DSGSDs in the slate belt of Taiwan

References

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Thanks for listening!

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