HOKKAIDO UNIVERSITY

A new index representative of seismic cracks to assess post-seismic landslide susceptibility

Mio Kasai and Shui Yamaguchi

November 5, 2021

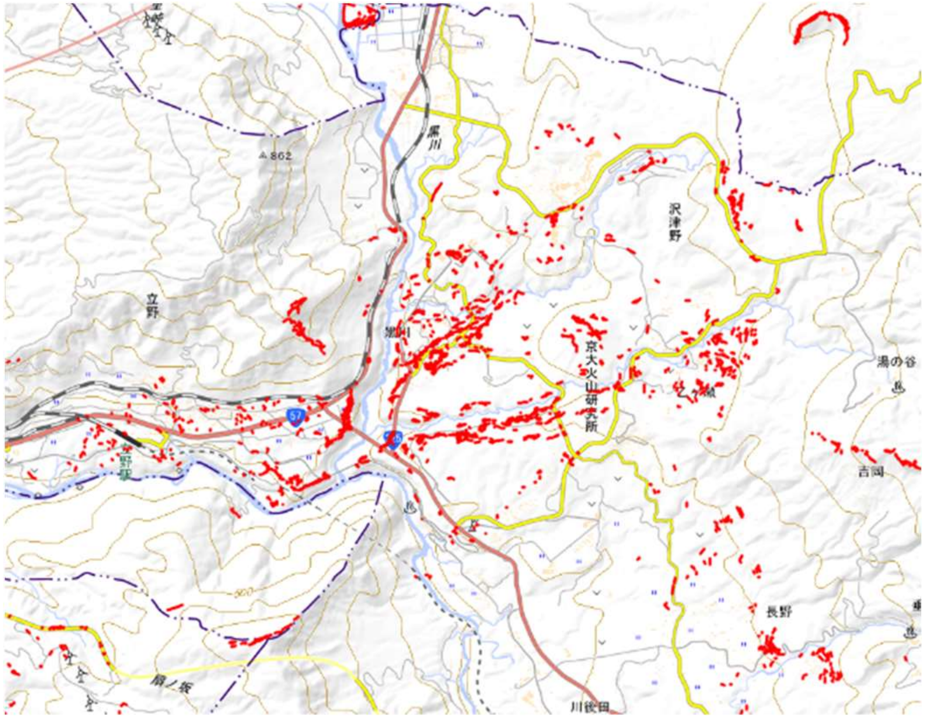
Introduction

- An intense earthquake can trigger numerous landslides over a wide area, causing damage to human lives, property, and infrastructure.
- Following an earthquake, an area will remain prone to landslides because the ground that is affected by strong tremors is still weak.
- Therefore, although co-seismic slides are usually a major concern from the perspective of disaster mitigation and management, the susceptibility of post-seismic slides is also to be appraised immediately after an earthquake.

Aso region after the 2016 Kumamoto earthquake, Japan

Tateno, Aso after the 2016 Kumamoto earthquake

- The susceptibility to post-seismic slides is considered to be related to formation and dilation of open cracks.
- Hence, the distribution of seismic cracks is urgently mapped immediately after a major earthquake.



Crack distribution identified by GSI after the Kumamoto earthquake

- However, not all seismic cracks represent local slope instability. Some are formed only as a result of ground displacement

  → Is it really necessary to concern about seismic cracks?

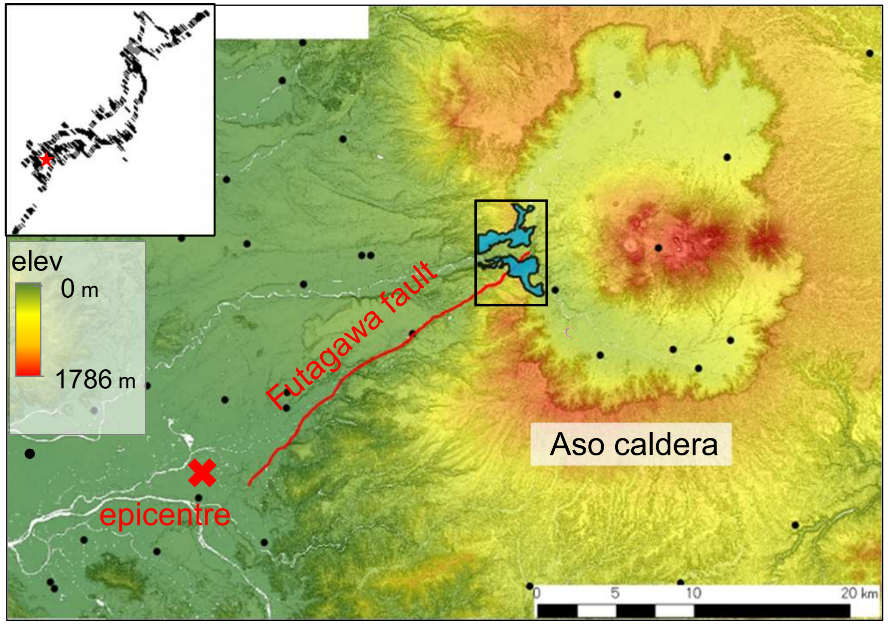
At least

- Crack distribution should be considered together with other conditioning factors (e.g. tectonics, lithology, climate, hydrology, topography, vegetation, etc.) in the context of slope strength

An open crack remained 3 years after the Kumamoto earthquake

This study

1. proposes a new index, DCI (dense crack index), which represents the spatial density of seismic cracks. A reliable digital index should help to quickly and objectively locate slopes susceptible to further landslides in emergency after a major earthquake.
2. examines association of the DCI index with post-seismic landslide occurrences, along with other relevant factors, using Weight of Evidence and Random Forest methods.
3. assesses whether the inclusion of the DCI index improves the performance of the model for evaluating the susceptibility to landslides after an earthquake. The models applied are WoE, RF, and Logistic Regression (LR)

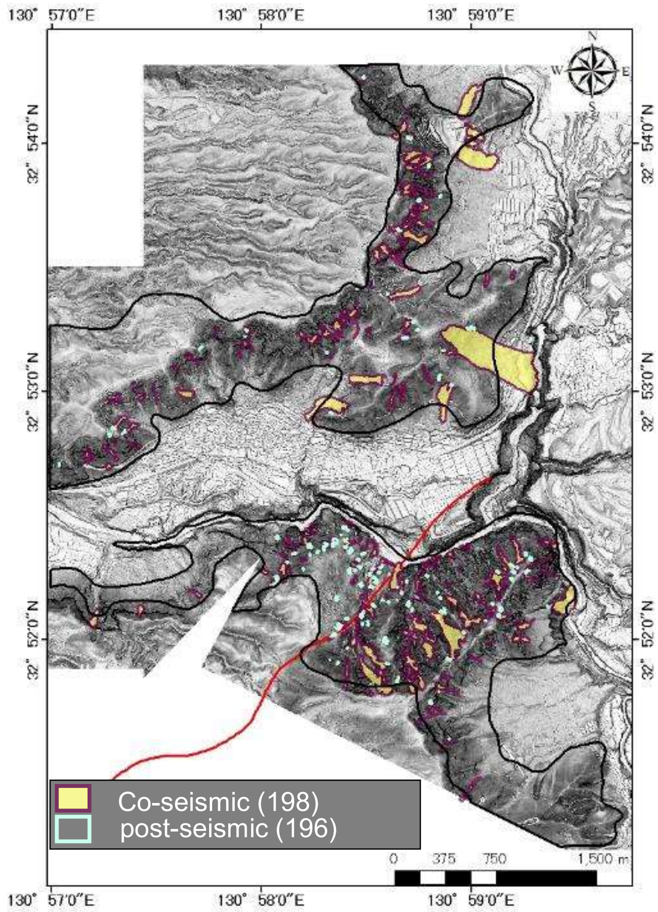


Dec 2017

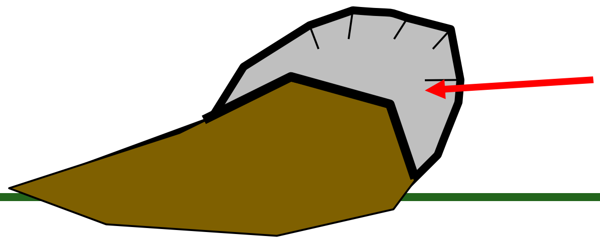
- 6 km²（181 - 853 m a.s.l）
- located on the flank of the caldera wall of the Aso volcano
- covered with pyroxene andesite lava (hard with joints)
- covered with aged *Cryptomeria japonica*
- the Kumamoto earthquake (Mw 7.0) struck the area in April 2016
- Max PGA recorded in the area: 1270 cm/s^2

- 196 (2.6 ha) in total
- Identified with aerial photographs and LiDAR survey data acquired simultaneously in January 2013 and in April and August 2016
- Mostly caused by rainfall from June 19 to 29 : 946 mm in total, max 247 mm (Ishikawa et al., 2016)
- Few landslides were observed after the event
- Mostly shallow translational type
- They tended to appear on slopes:
  - ✓ 40-50 degrees
  - ✓ along a longitudinally convex feature, such as nick lines
  - ✓ horizontally concave
  - ✓ with clusters of seismic cracks

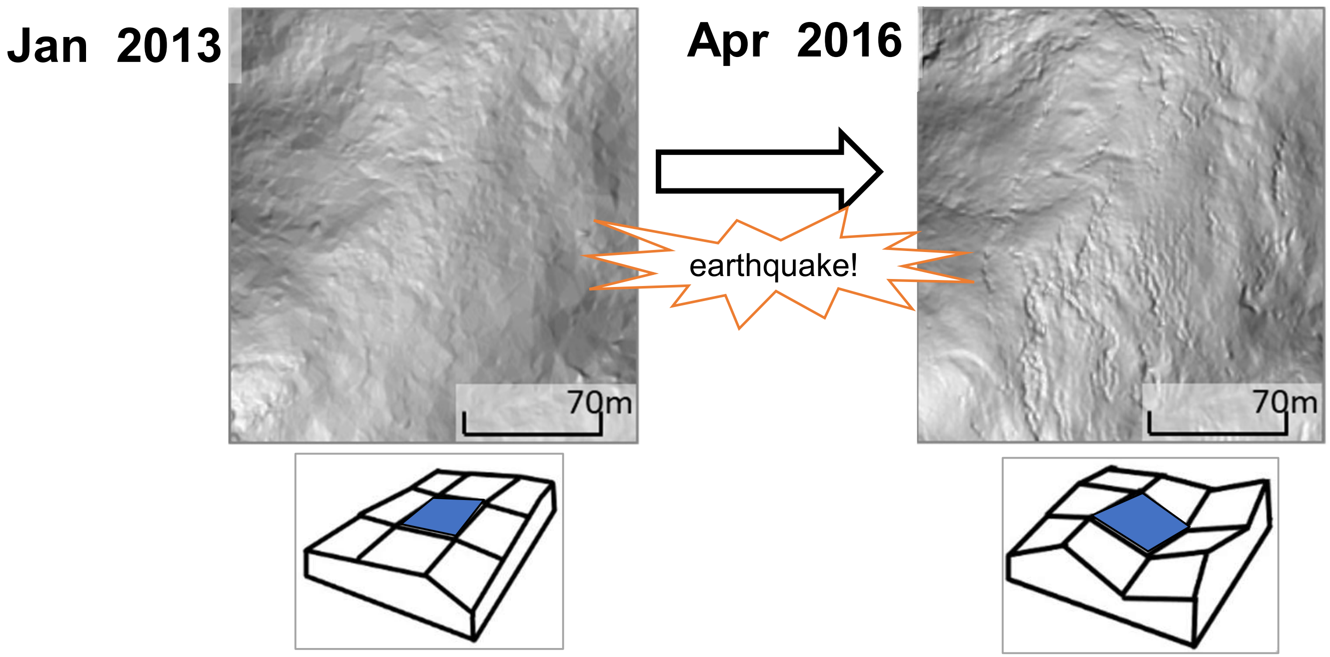
  (Seismic Crack Counterplan in the Tateno District, 2019).



Landslides by the Kumamoto earthquake



Since this study investigates the effect of seismic cracks on post-seismic slides, the areas where they were initiated were targeted for analysis.

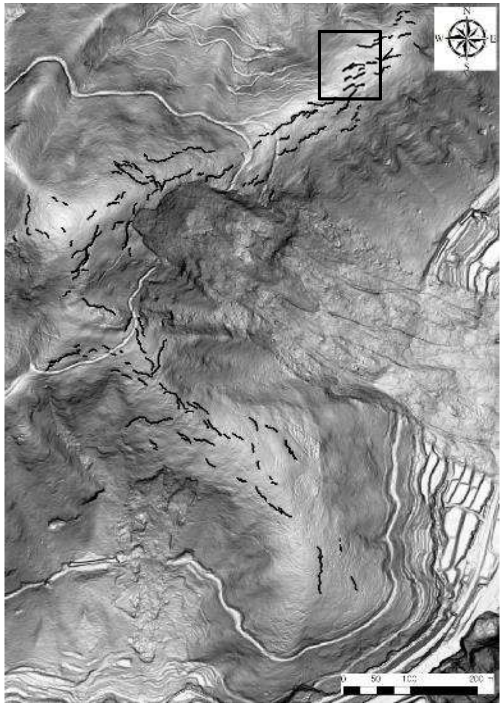


Change in surface roughness: $\sigma_{s\ chg} = \sigma_{s\ post} - \sigma_{s\ pre}$

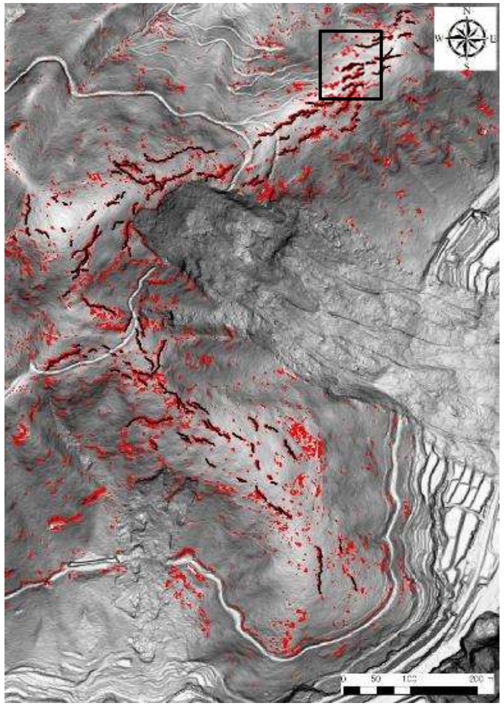
$\sigma_{s\ pre}$ and $\sigma_{s\ post}$: the standard deviation of the slope angle (3 × 3) in January and in April 2016,

1. Calculate $\sigma_{s\ chg}$ for 1 m cells
2. Select the cells with $\sigma_{s\ chg}$ was ≥ 2°
3. Convert the cells into points to calculate the point density using a kernel density function with the bandwidth of 10 m.

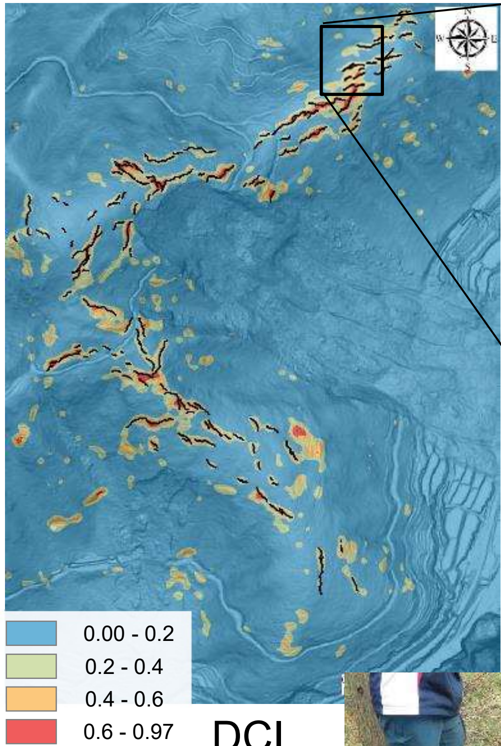
DCI



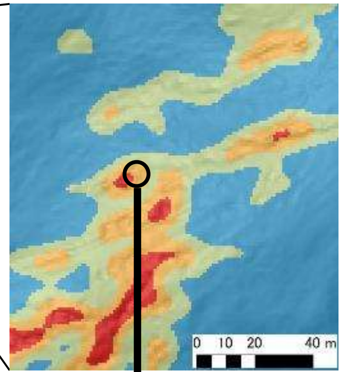
Seismic cracks identified



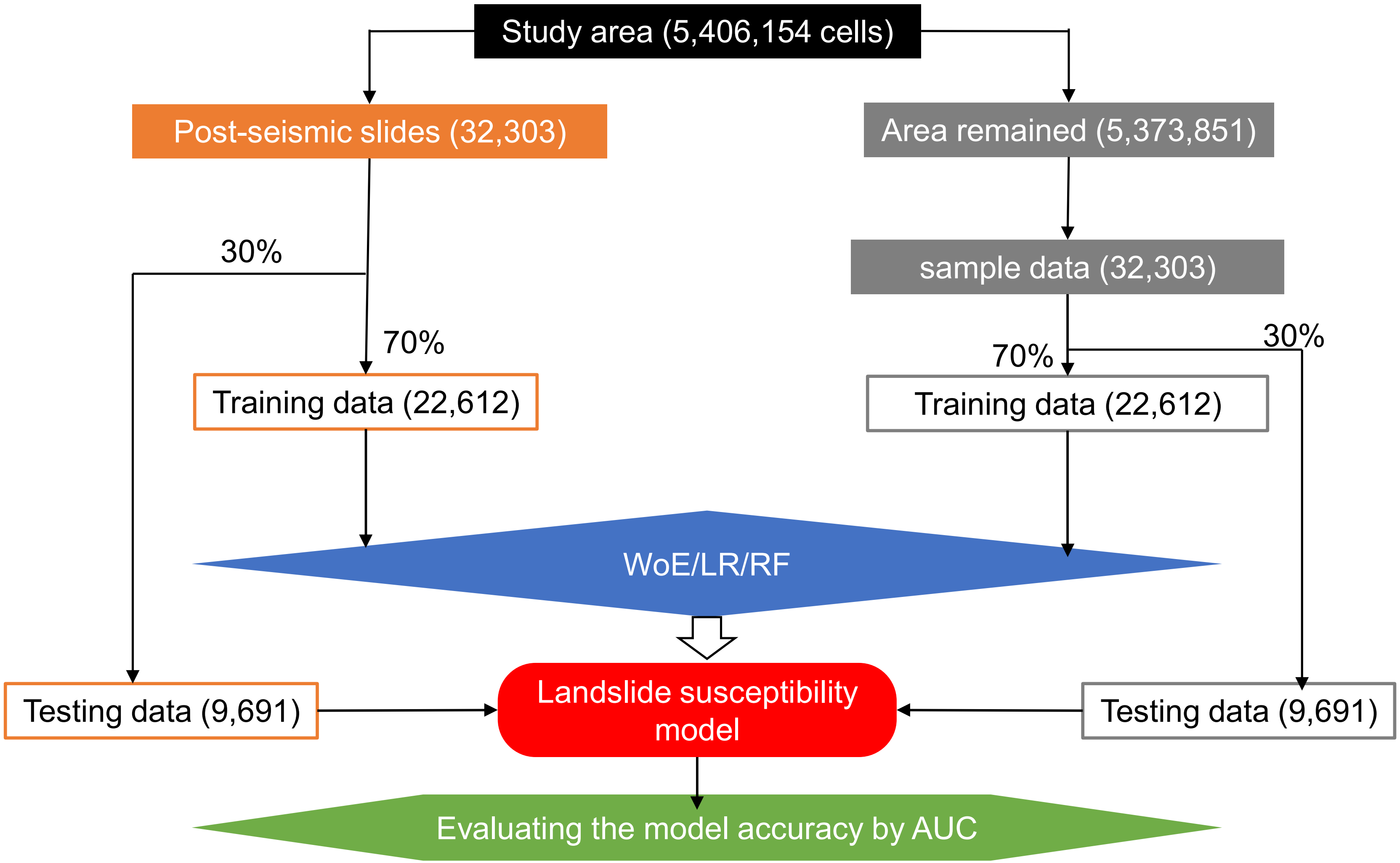
$\sigma_{s\ chg} \geq 2°$



DCI



w:60cm d:85cm



- 10 datasets were created

Topographic

- **DCI**
- Slope angle
- Plan curvature
- Profile curvature
- Aspect

values were averaged in an area of 10 m^2 for each 1m cell

- CTI (Compound Topographic Index) $CTI = \ln\left(\frac{A}{\tan(\theta)}\right)$ A:catchment area, θ:slope angle

Seismic

- Distance to Futagawa fault, DtF
- PGA (peak ground acceleration)

estimated by interpolating three-dimensional synthetic PGA, recorded at 98 surrounding stations

Meteorological

- Total rainfall (19-29 June 2016)

estimated by interpolating the observations at 35 surrounding stations

Geology

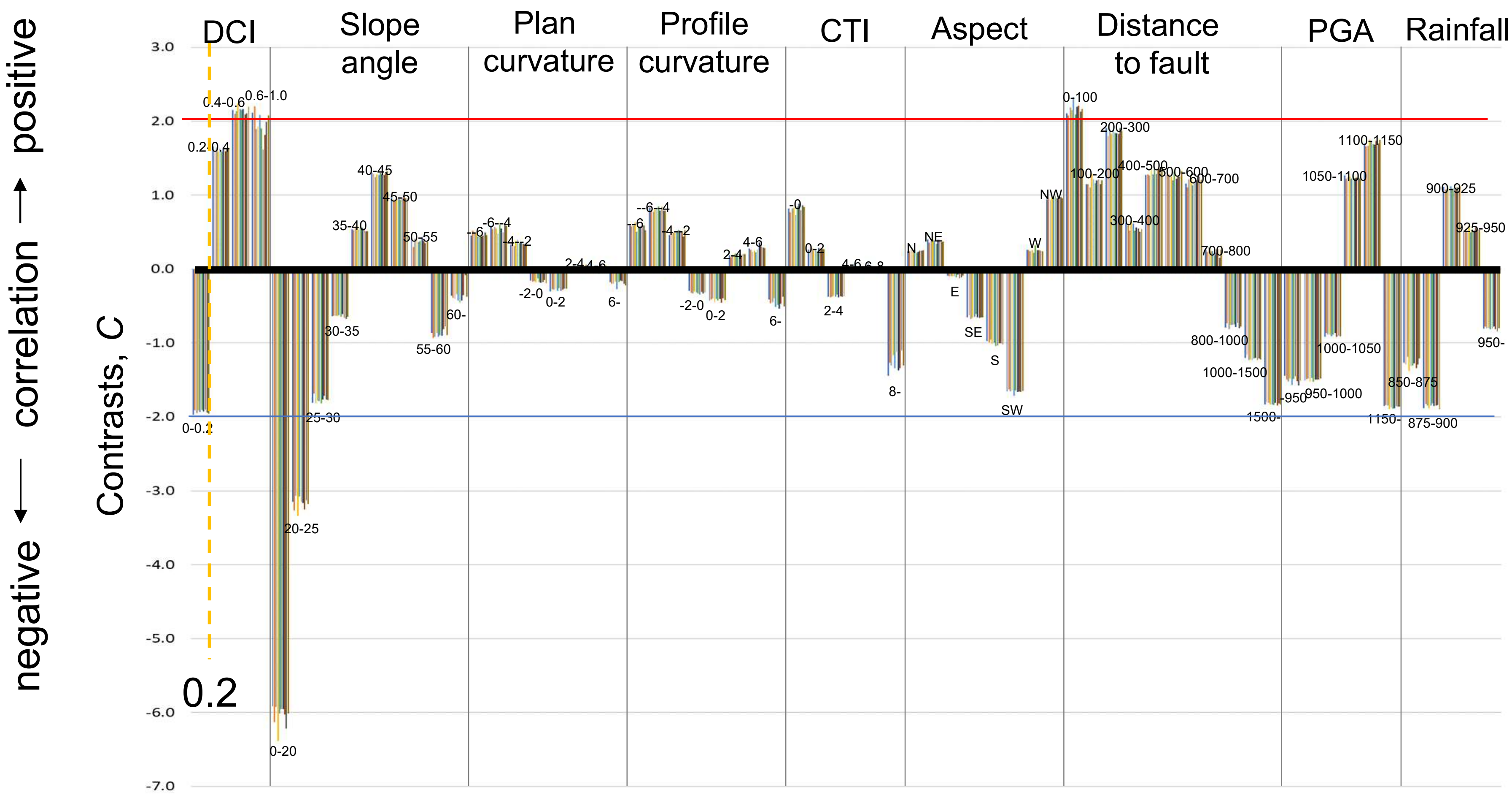
Vegetation

Not considered (regarded as the same)

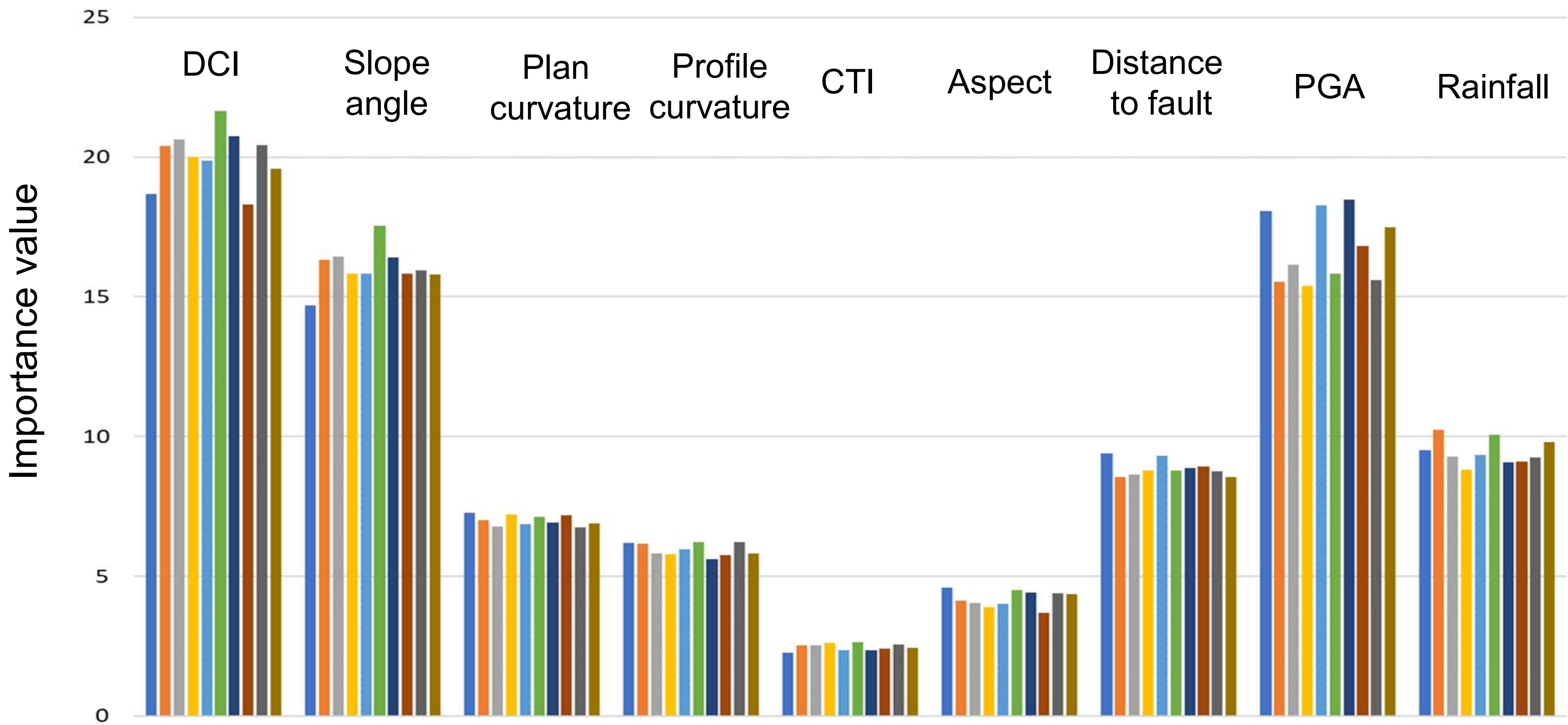
Models are built with factors with and without DCI, and their accuracy is compared using AUC.

VIF: 1.088 – 1.652

Association of conditioning factors with post-seismic slide occurrence (WoE)



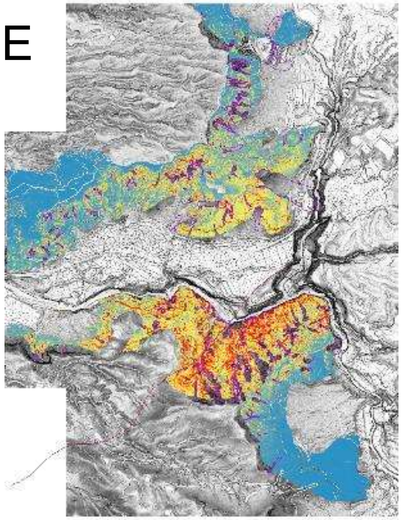
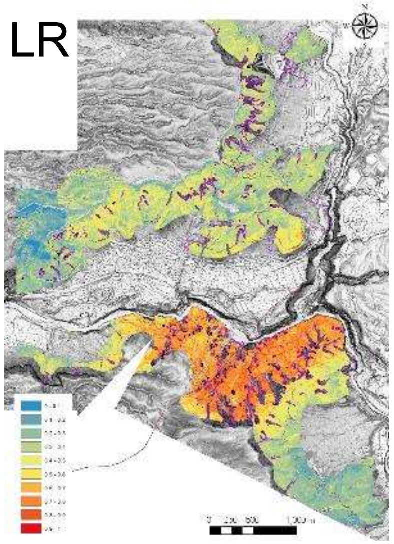
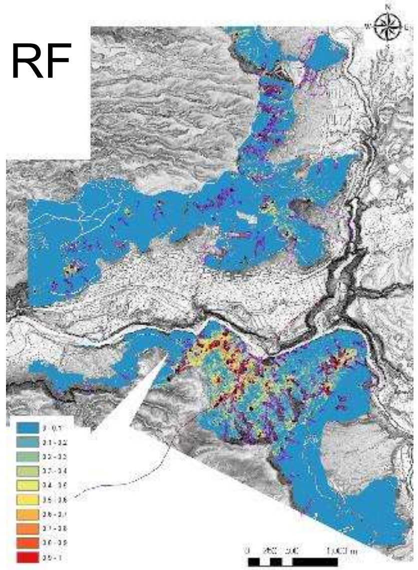
- agreed with the topographic characteristics associated with post-seismic slide occurrence reported by SCCTD
- Contrasts of DCI classes suggest that the formation of seismic cracks is closely related to subsequent landslides: denser → more slides, sparse → less slides



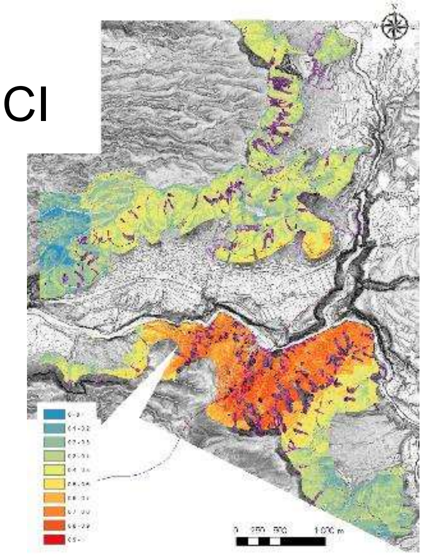
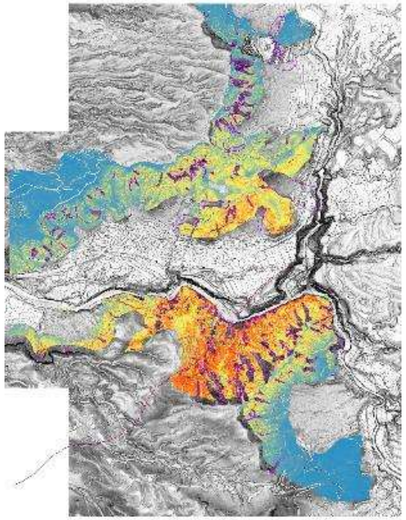
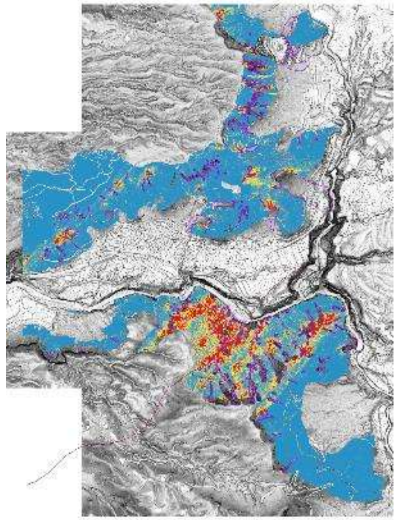
- DCI is the most influential factor, followed by slope angle and PGA
- This is consistent with strong likelihood or unlikelihood presented by the contrasts for these factors
- Rainfall and DtF were ranked as less important than those factors, even though the positive and negative contrasts were as large as them, probably due to their lower involvement in seismic crack formation

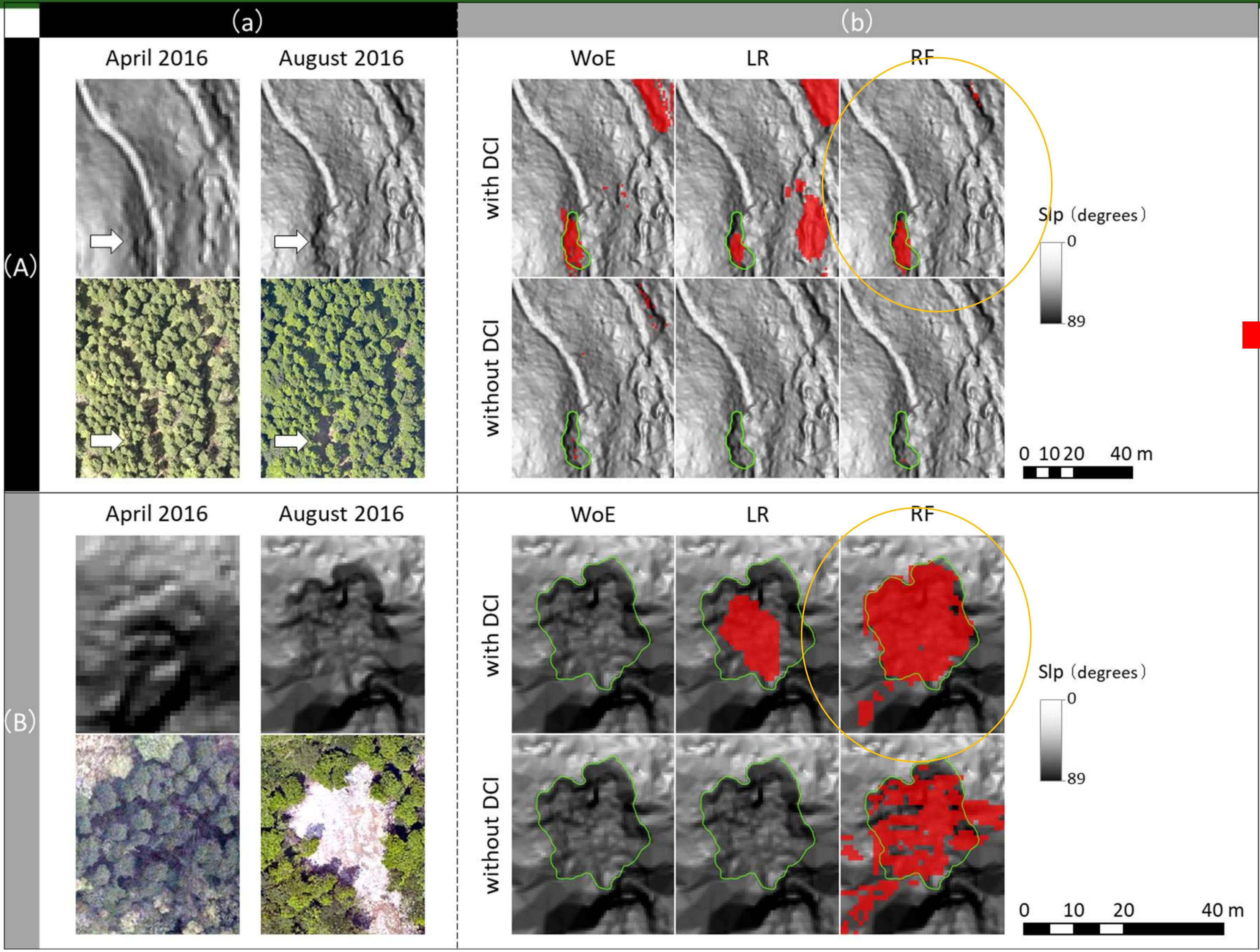
WoE | LR | RF

with DCI

without DCI



very high
(upper 0.06%)

AUC values (averaged for 10 datasets)

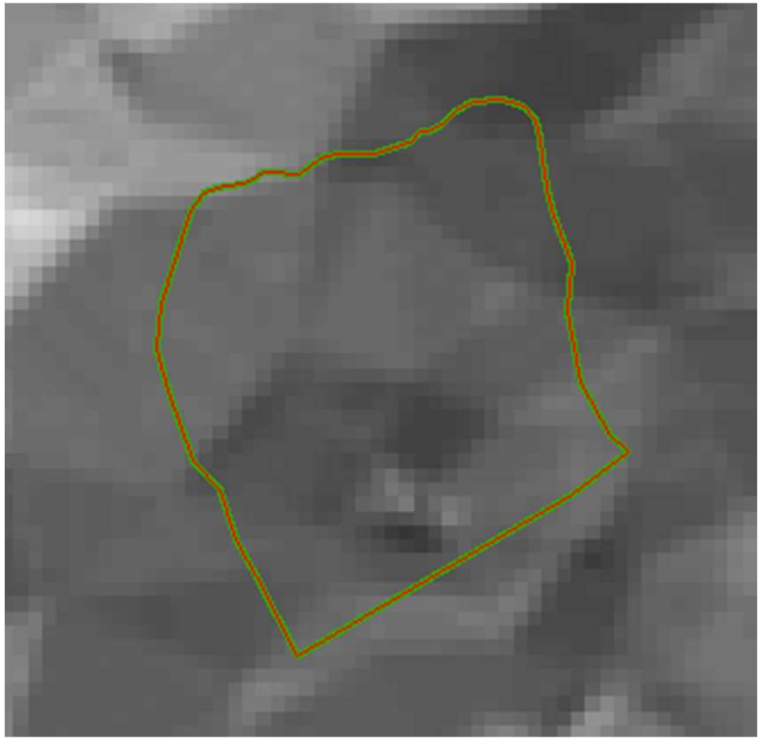
	Training data		Testing data	
	DCI incl.	DCI excl.	DCI incl.	DCI excl.
WoE	0.891	0.868	0.890	0.867
LR	0.896	0.859	0.895	0.857
RF	0.999	0.999	0.997	0.997

- All the AUC values indicated excellent/outstanding performance of the models
- However, the improvement of the performance by including DCI was marginal or negligible

Possibly because..

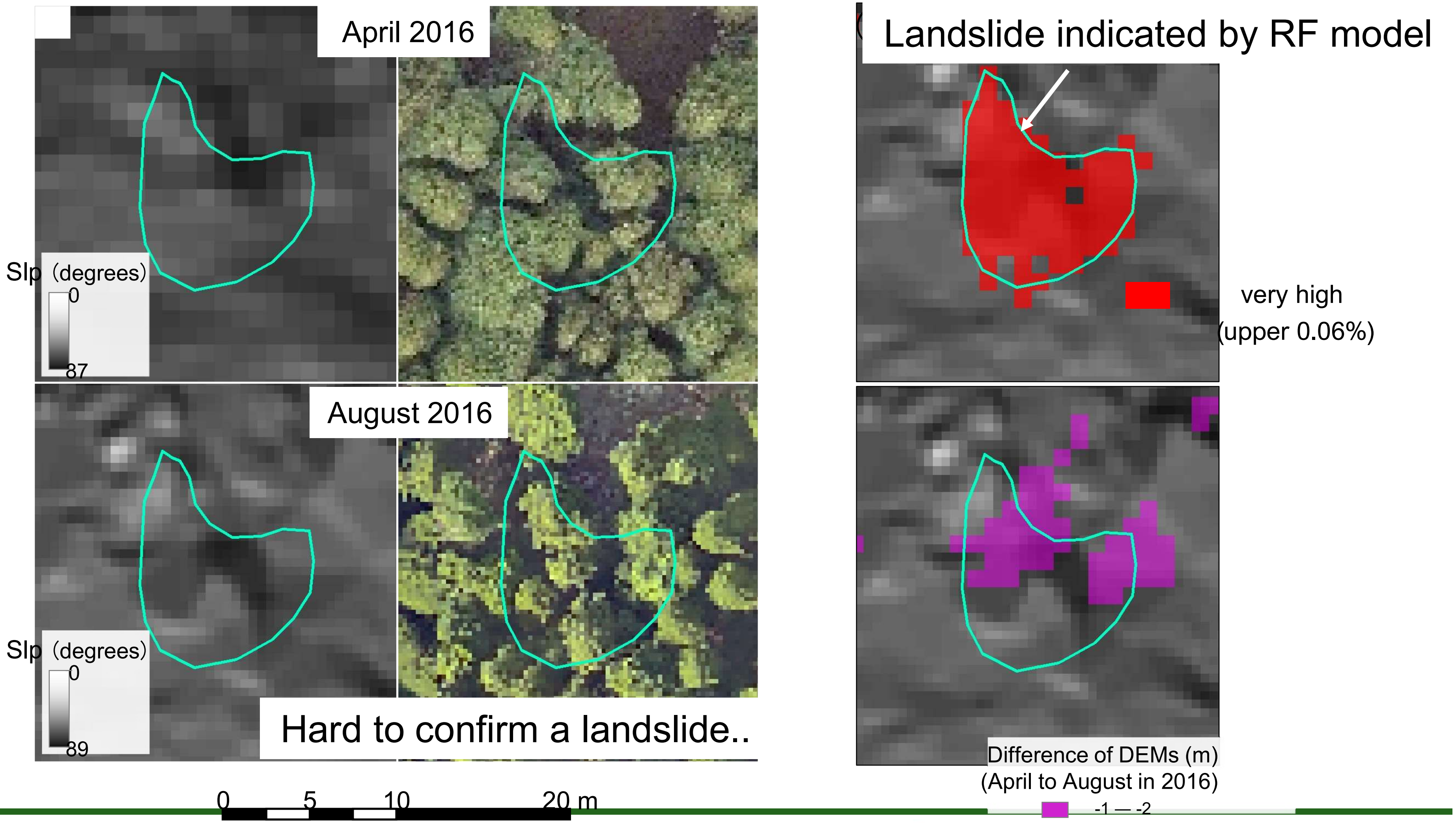
- The contribution of DCI could not be evaluated properly with LiDAR data used in the analysis.
- Landslide inventory we created was not entirely correct.
- The combination of features that indicated where open cracks were likely to occur could compensate for the absence of the DCI in the models.

- The reliability of the DCI value depends on the accuracy of the DEMs used for the calculation.
- A quarter (48/196) of the post-seismic landslides were located on slopes with sparse ground points in the 2013 LiDAR survey. This limited the feasibility of properly assessing the relationship between seismically induced cracks and the slides.

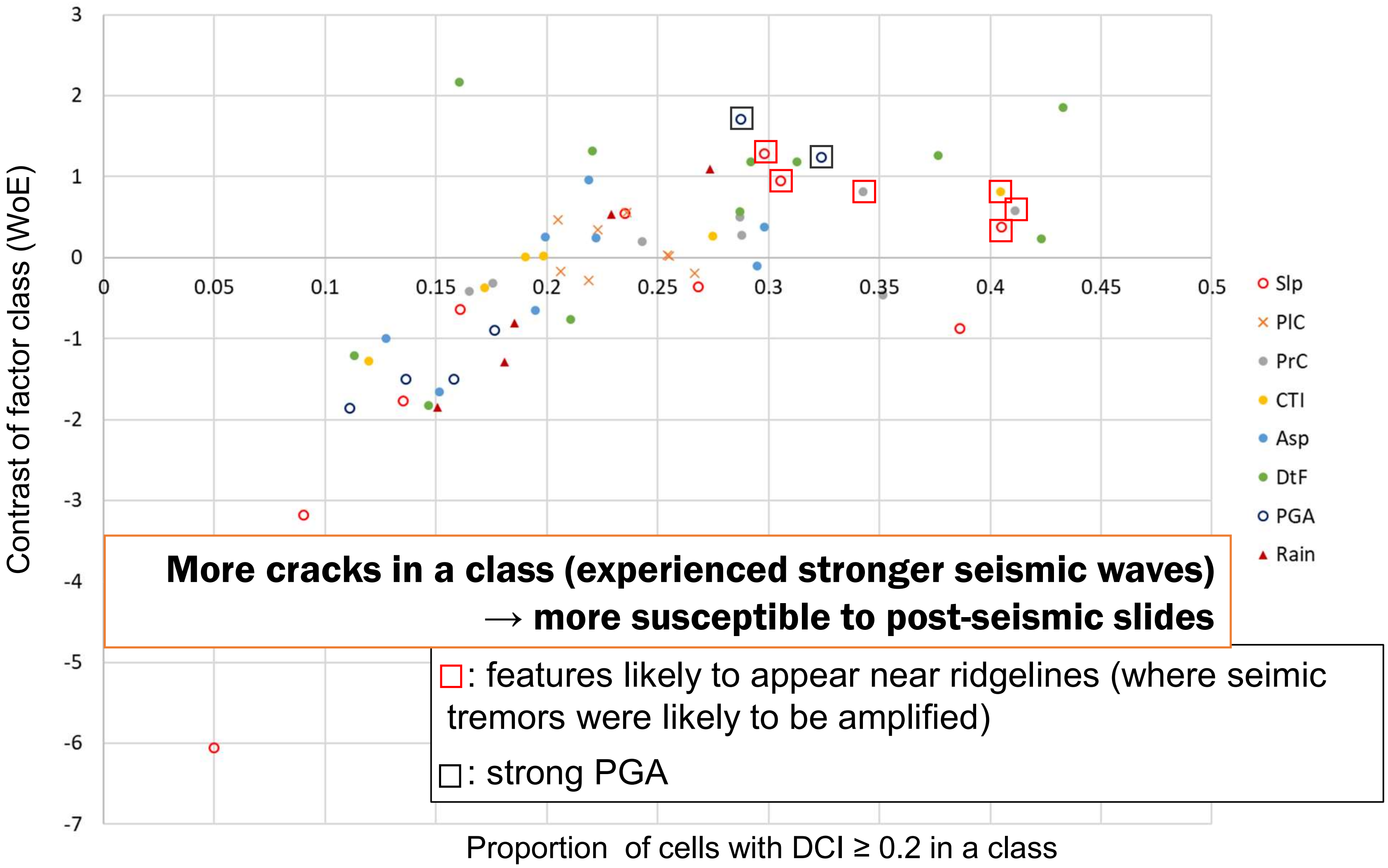


Contribution of seismic cracks to landslide occurrences could be underestimated?

- The presence of landslides, especially slow-moving slides with shallow depths, was difficult to be confirmed on the images, even though the models suggested it.



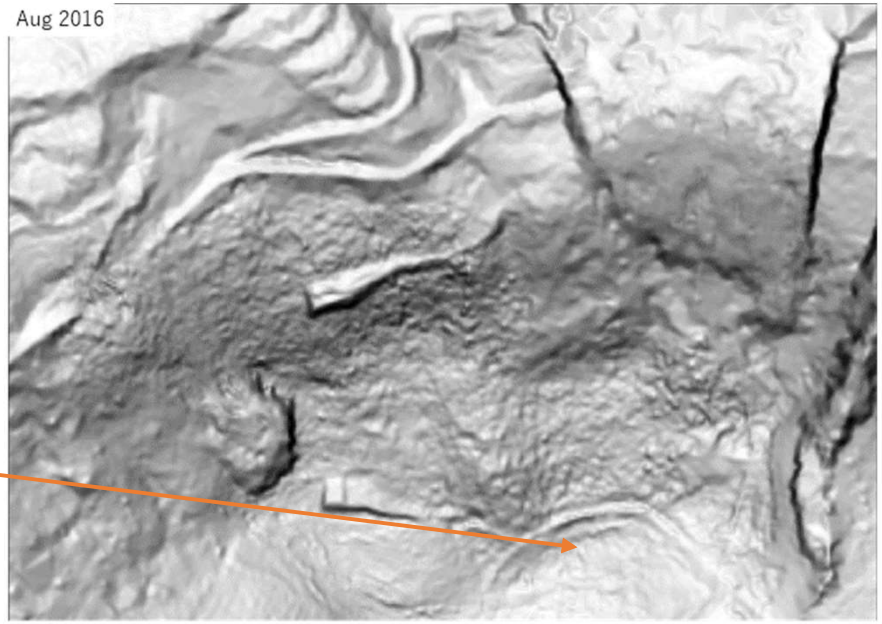
<u>Uncertainty in response variable for modelling</u>



◆ the combination of features that indicated where open cracks were likely to occur, or ridgelines where seismic waves were prone to be amplified, could compensate for the absence of the DCI.

- The compensation was probably possible because of the lithology consisted mainly of clastic volcanic rocks with joints, which did not retain water from cracks to cause further landslides.
- Contribution of the index to the susceptibility to post-seismic slides is expected to be different in an area with subsurface layers of low permeability (below), where water is supplied through cracks and accumulates to raise the groundwater table.

Dec 2017



Change after the earthquake (until October 2016)

This study

(1) proposed a new index, DCI (dense crack index), which represents the spatial density of seismic cracks

DCI would help save time and labor to identify slopes with a high risk of sliding by objectively limiting the areas that should be considered immediately after a major earthquake.

For instance, in the study area..

- cells with DCI > 0.2 covered only 7 % of the entire study area (0.44 km^2)
- By excluding gentle slopes < 25° (probably related to the angle of repose), and steep slopes > 55° (mainly cliffs), the area of concern was then reduced to 5.5% of the entire study area (0.33 km^2), which included 71 % of the post-seismic slides
- This proportion should improve as the error in the data decreases.

In an emergency, this simple approach could be used if LiDAR survey data are available for the periods before and immediately after the earthquake.

(2) This study examined association of the DCI index with post-seismic landslide occurrences, along with other relevant factors, using Weight of Evidence and Random Forest methods.

- Contrasts from the WoE analysis and the importance value from the RF model indicated a close association of DCI values with the occurrence of landslides.

It is necessary to concern about seismic cracks after a major earthquake

(3) This study assessed whether the inclusion of the DCI index improves the performance of the model for evaluating the susceptibility to landslides after an earthquake. The models applied are WoE, RF, and Logistic Regression (LR)

- the performance of the models with the index was only slightly improved over them without it, according to the AUC values.
- This could be due to errors in the LiDAR survey data, the failure to confirm the presence of landslides, and the combination of features that could compensate for the absence of the DCI.

The contribution of the index to post-seismic slides could be estimated better with more accurate LiDAR data and in the area underlain by different type of rocks (e.g. of low permeability).

Thank you for listening