HOKKAIDO UNIVERSITY

Incorporating ground cracks in the estimation of post-seismic landslide susceptibility

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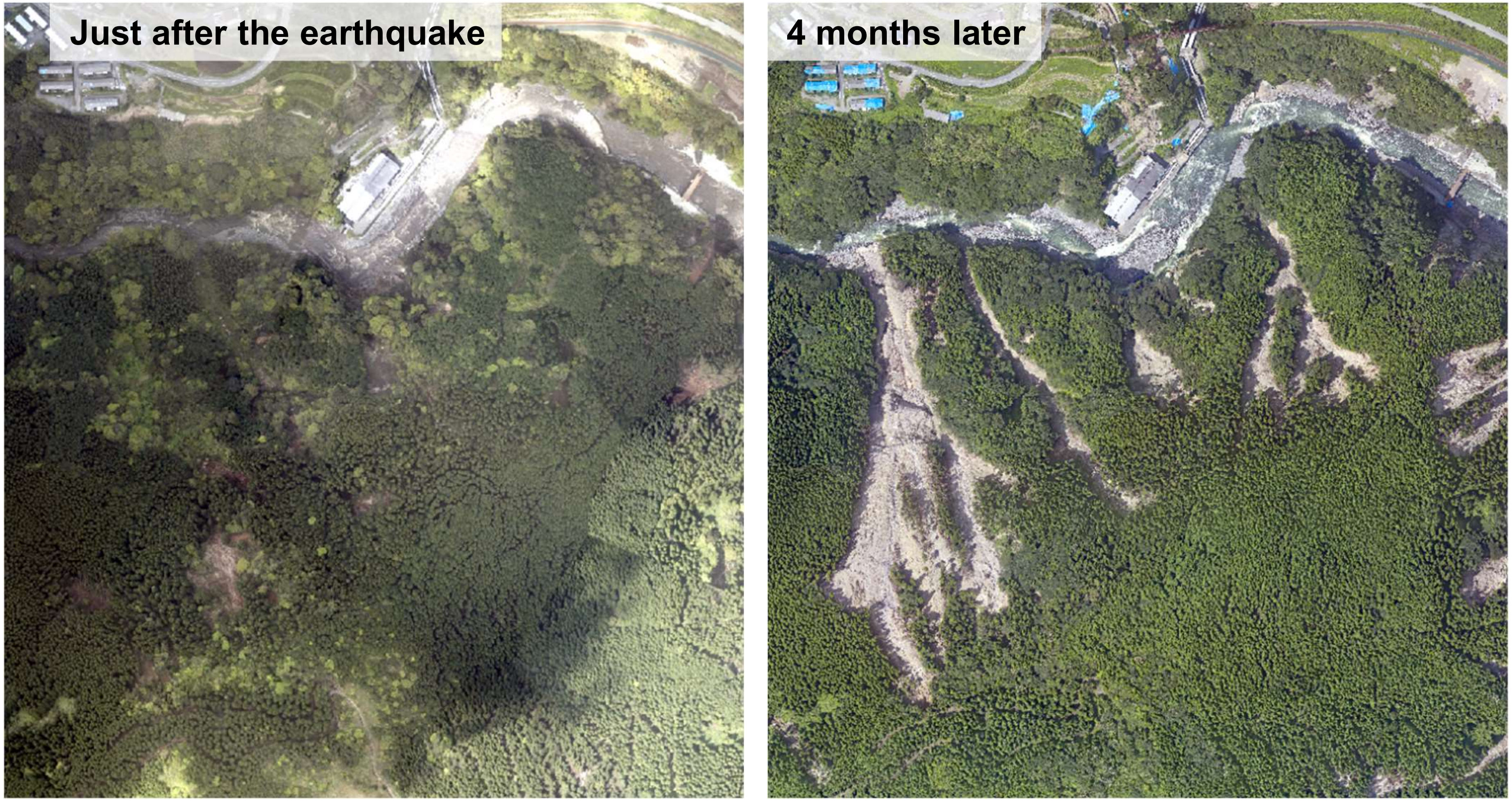
September 15, 2021

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.

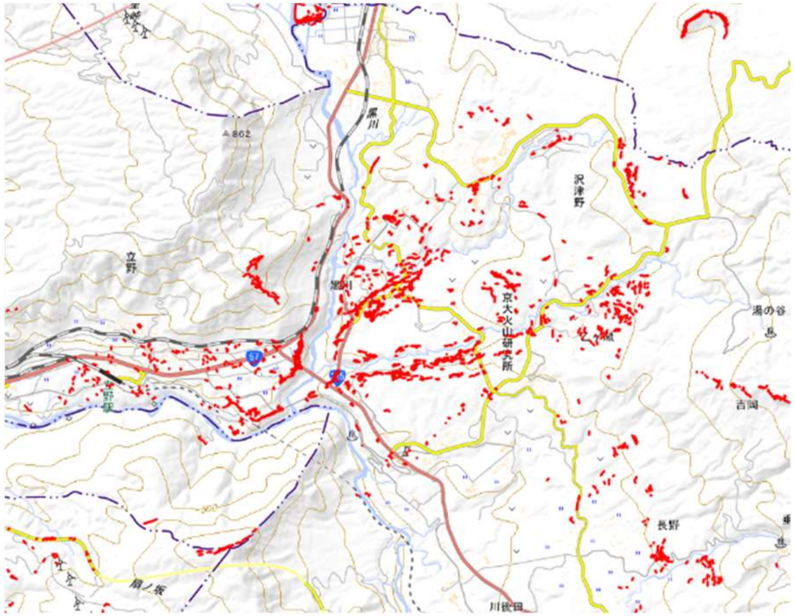
Aso region after the 2016 Kumamoto earthquake, Japan



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.
- Proposing a reliable index that can digitally represent the distribution of seismic cracks should help to quickly and objectively locate slopes susceptible to further landslides in emergency after a major earthquake.

An open crack formed in the Kumamoto earthquake

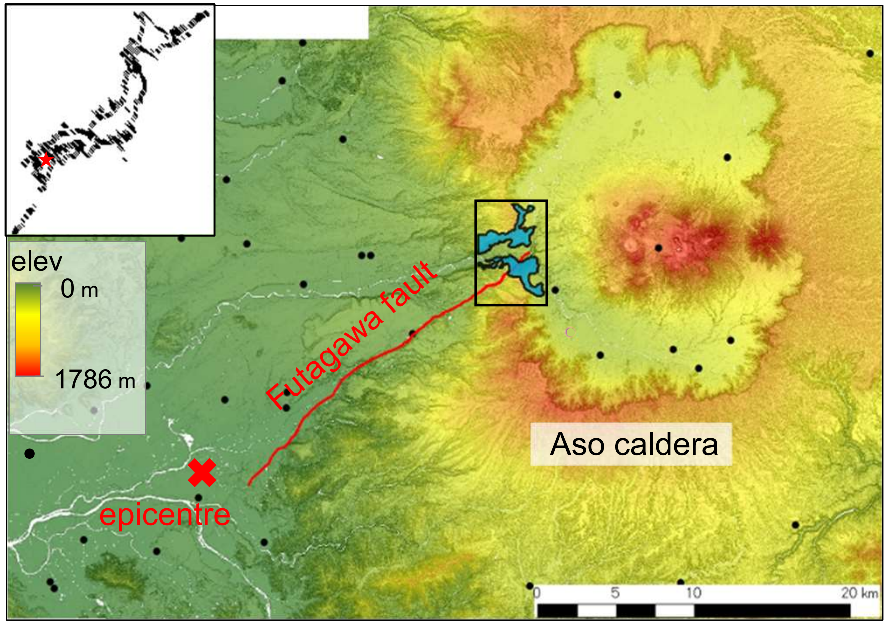


Crack distribution identified by GSI after the Kumamoto earthquake

This study proposes a new index, DCI (dense crack index), which represents the spatial density of seismic cracks, to help identify slopes vulnerable to landslides after a major earthquake.

We examine:

1. Association of the DCI index with post-seismic landslide occurences, along with other relevant factors, using Weight of Evidence and Random Forest methods.
2. 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)

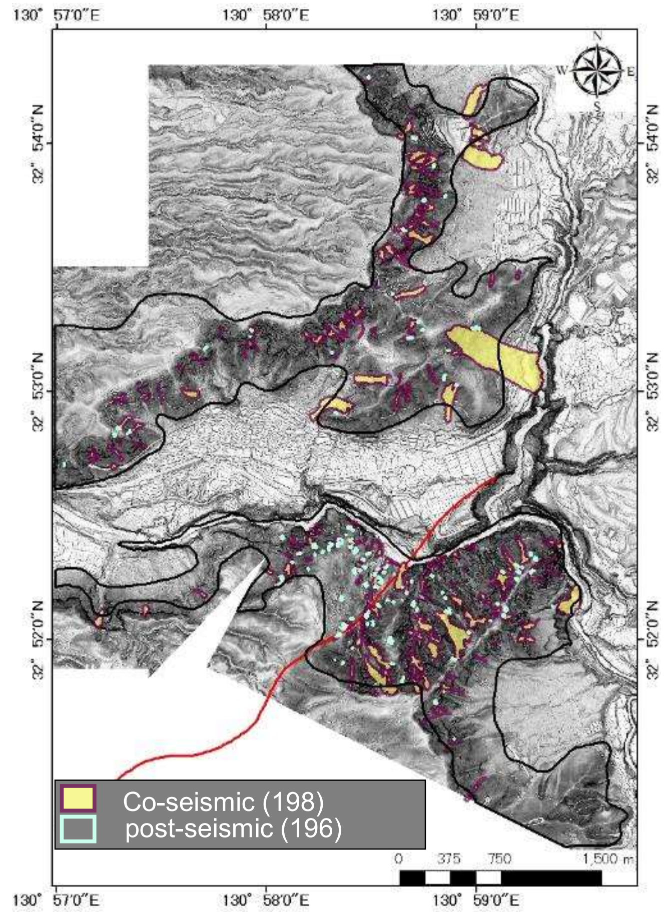


Dec 2017

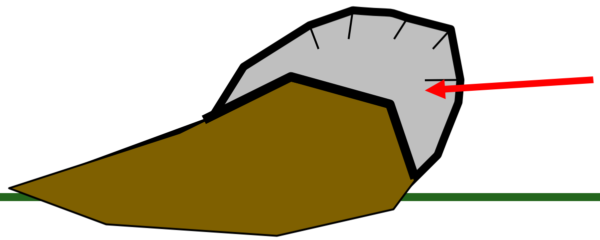
- 6 km^2（181 - 853 m a.s.l）
- located on the flank of the caldera wall of the Aso volcano
- covered with pyroxene andesite lava
- covered with aged *Cryptomeria japonica*
- the Kumamoto earthquake (Mw 7.0) struck the area in April 2016
- Max PGA recorded in the area: 1270 cm/s^2

- 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).

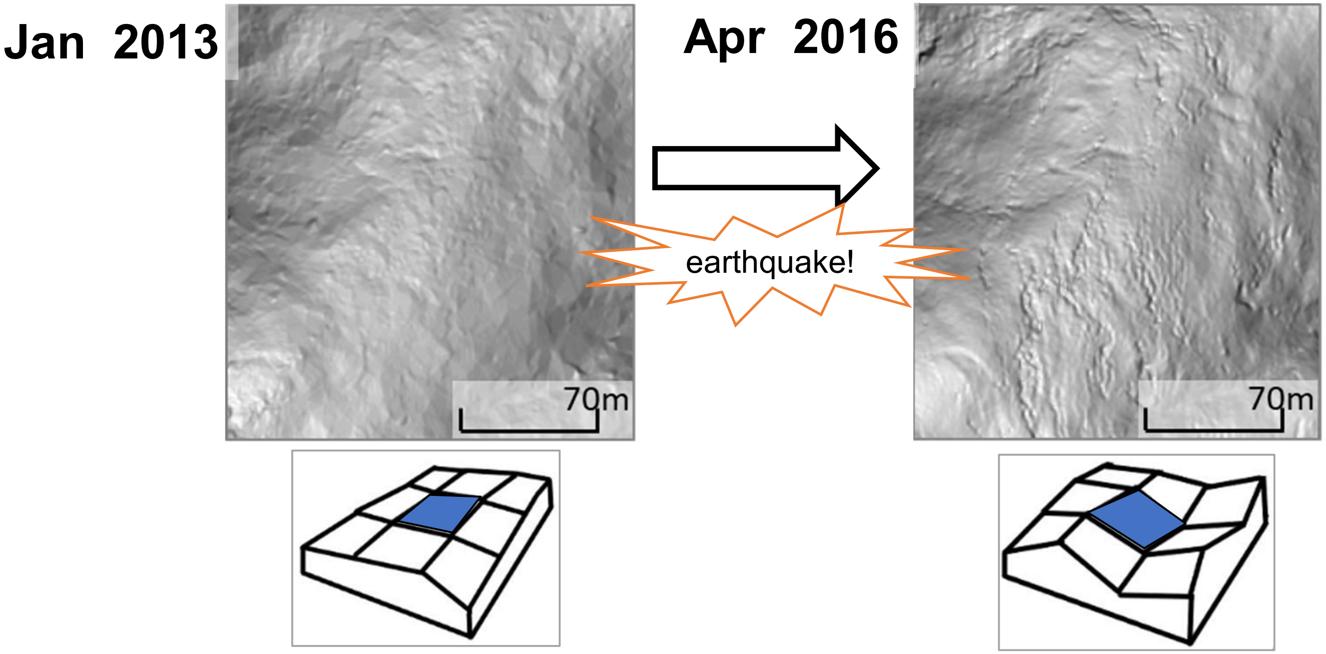


Landslides by the Kumamoto earthquake



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

DCI（Dense Crack Index）

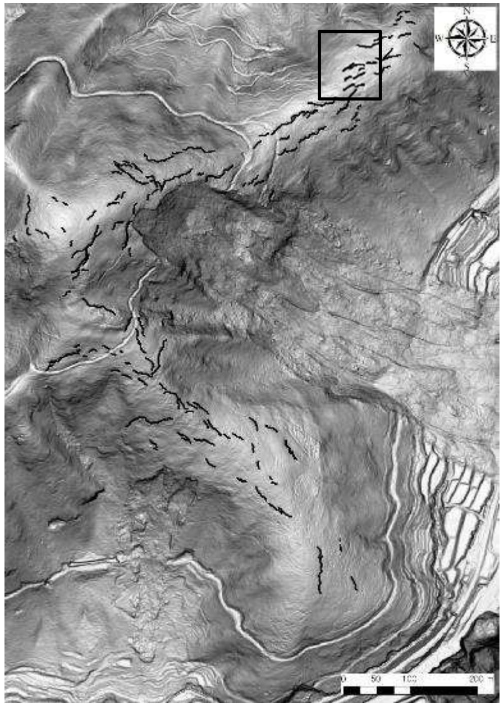


Change in surface roughness: $\sigma_{s\ chg} = \sigma_{s\ post} - \sigma_{s\ pre}$

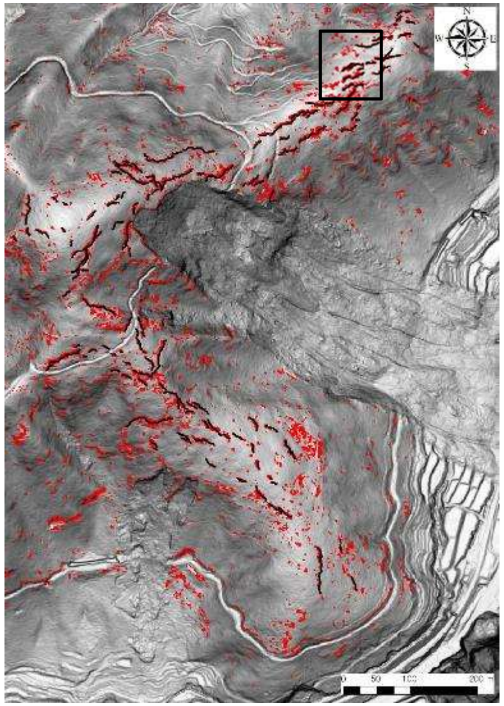
$\sigma_{s\ pre}$ and $\sigma_{s\ post}$: the standard deviation of the slope angle (3 × 3) in January and in April 2016,

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.

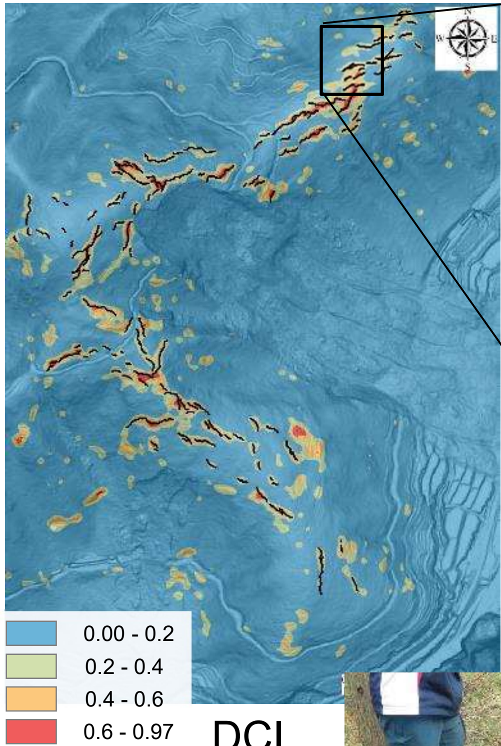
DCI

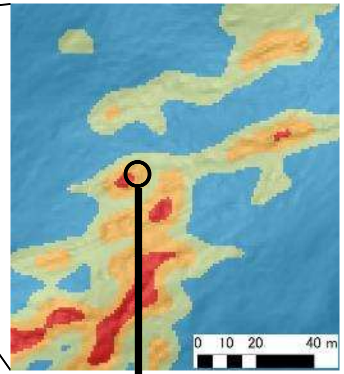


Seismic cracks identified



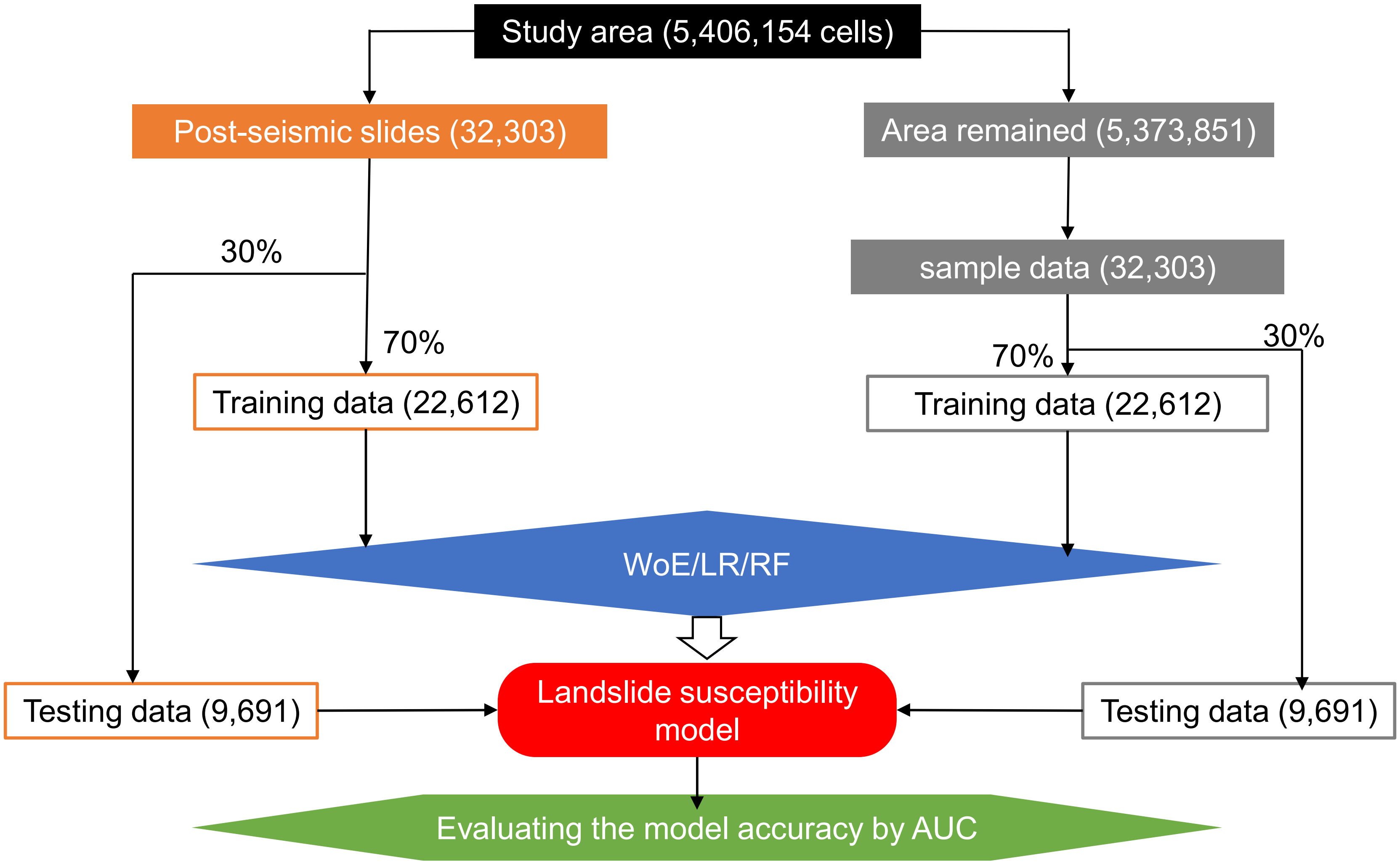
$\sigma_{s\ chg} \geq 2°$





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

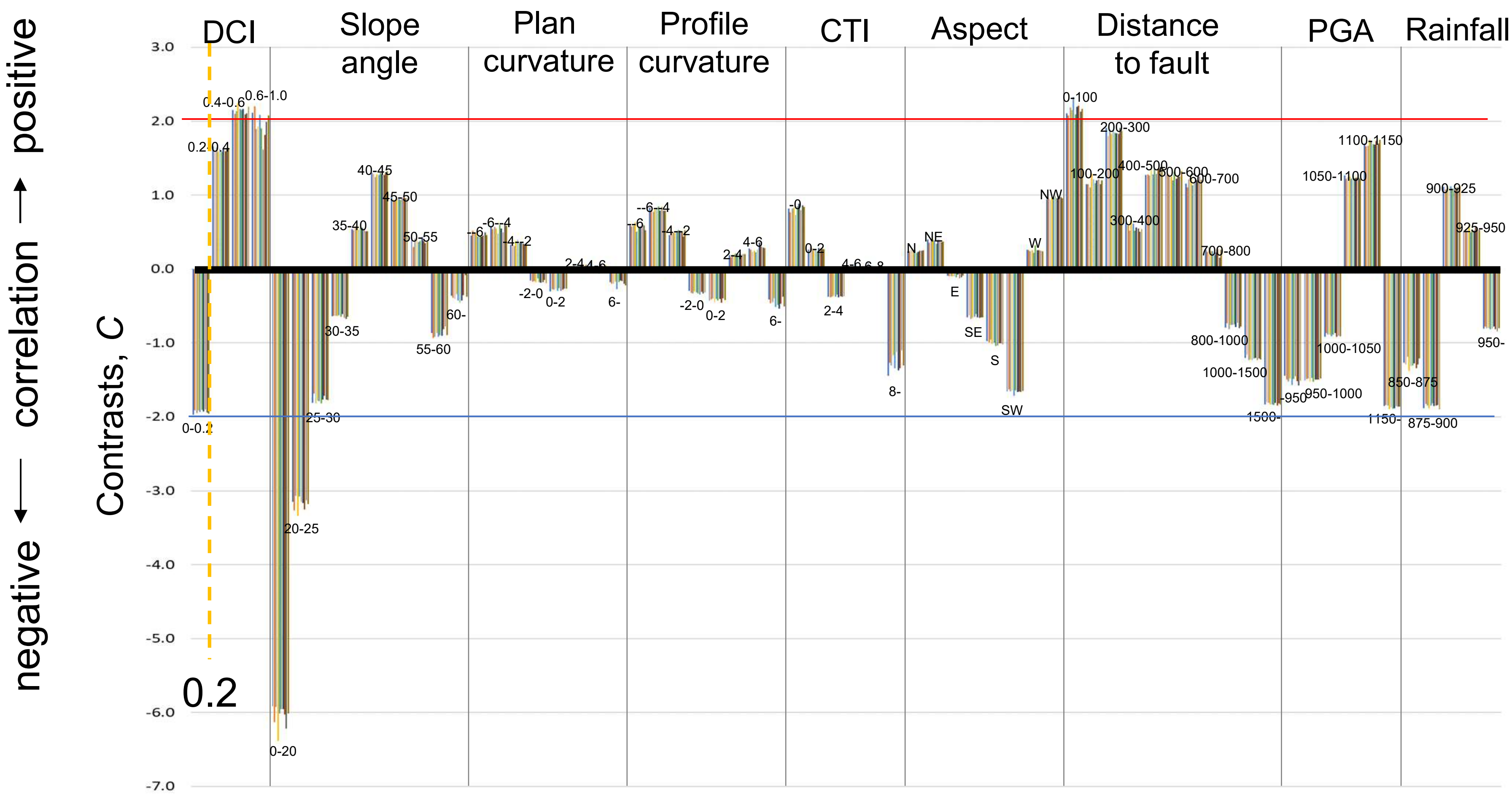
Geology

Vegetation

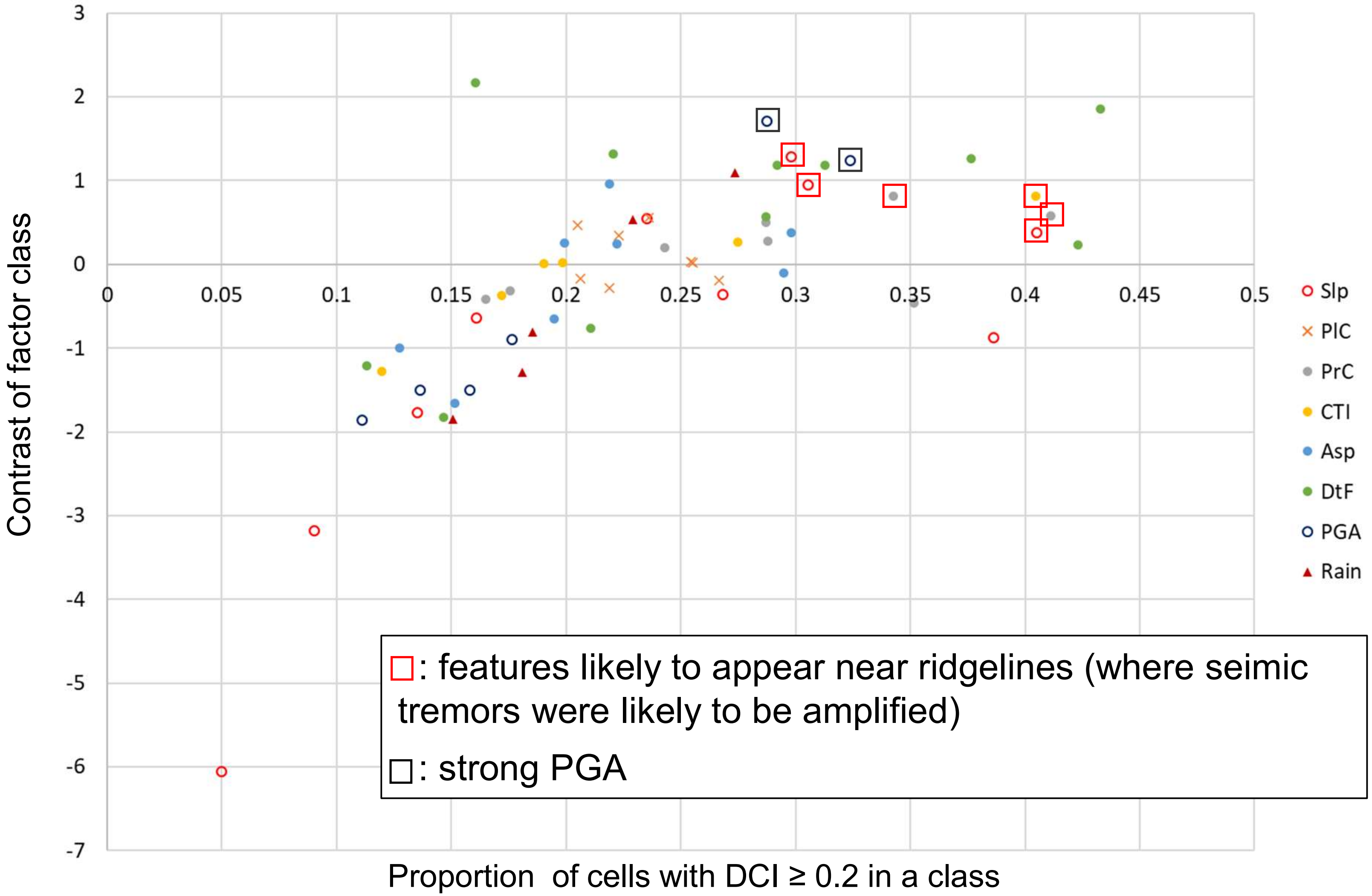
Not considered (regarded as the same)

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

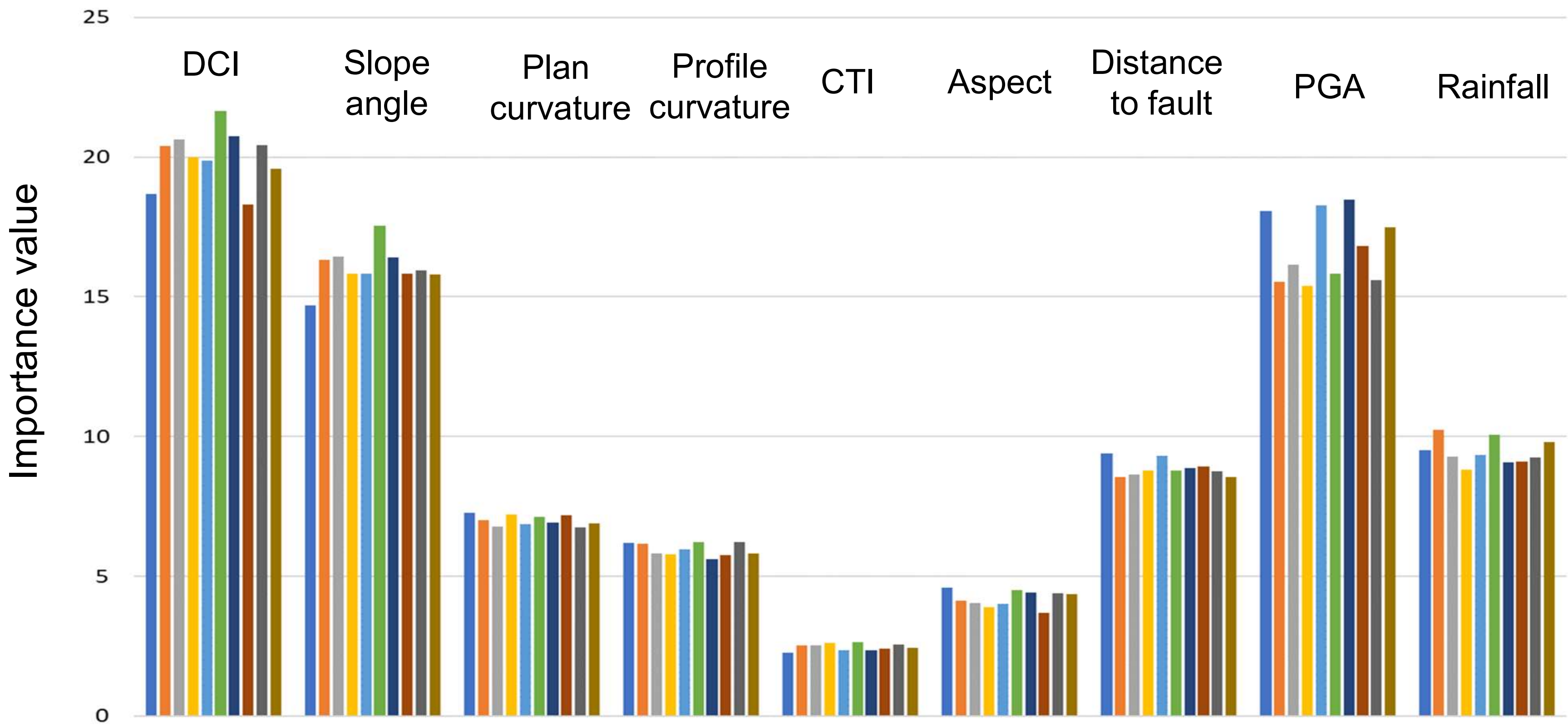
VIF: 1.088 – 1.652



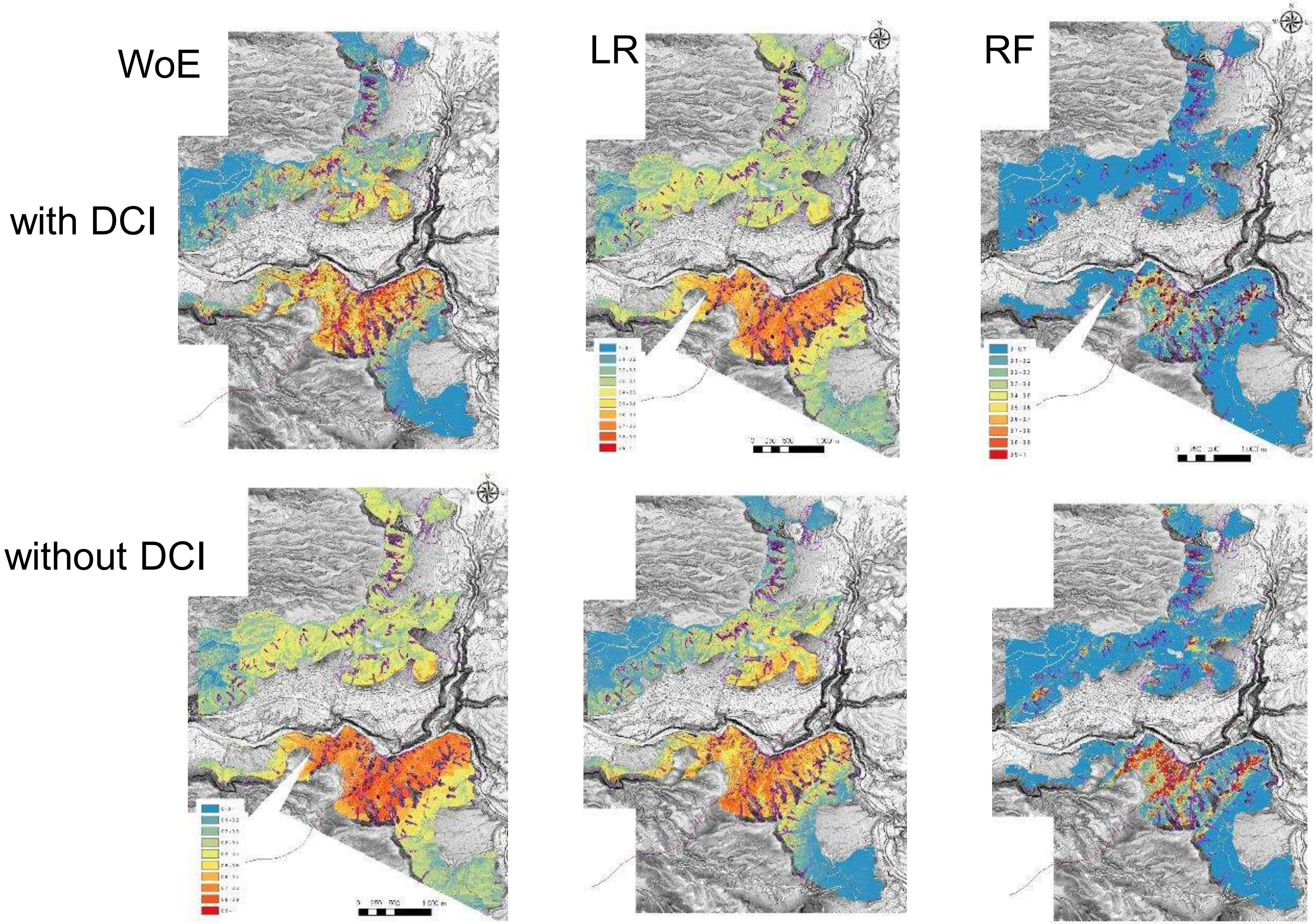
- agreed with the topographic characteristics associated with post-seismic slide occurrence reported by SCCTD
- Contrasts of DCI classes suggest that the formation of seismic cracks is closely related to subsequent landslides

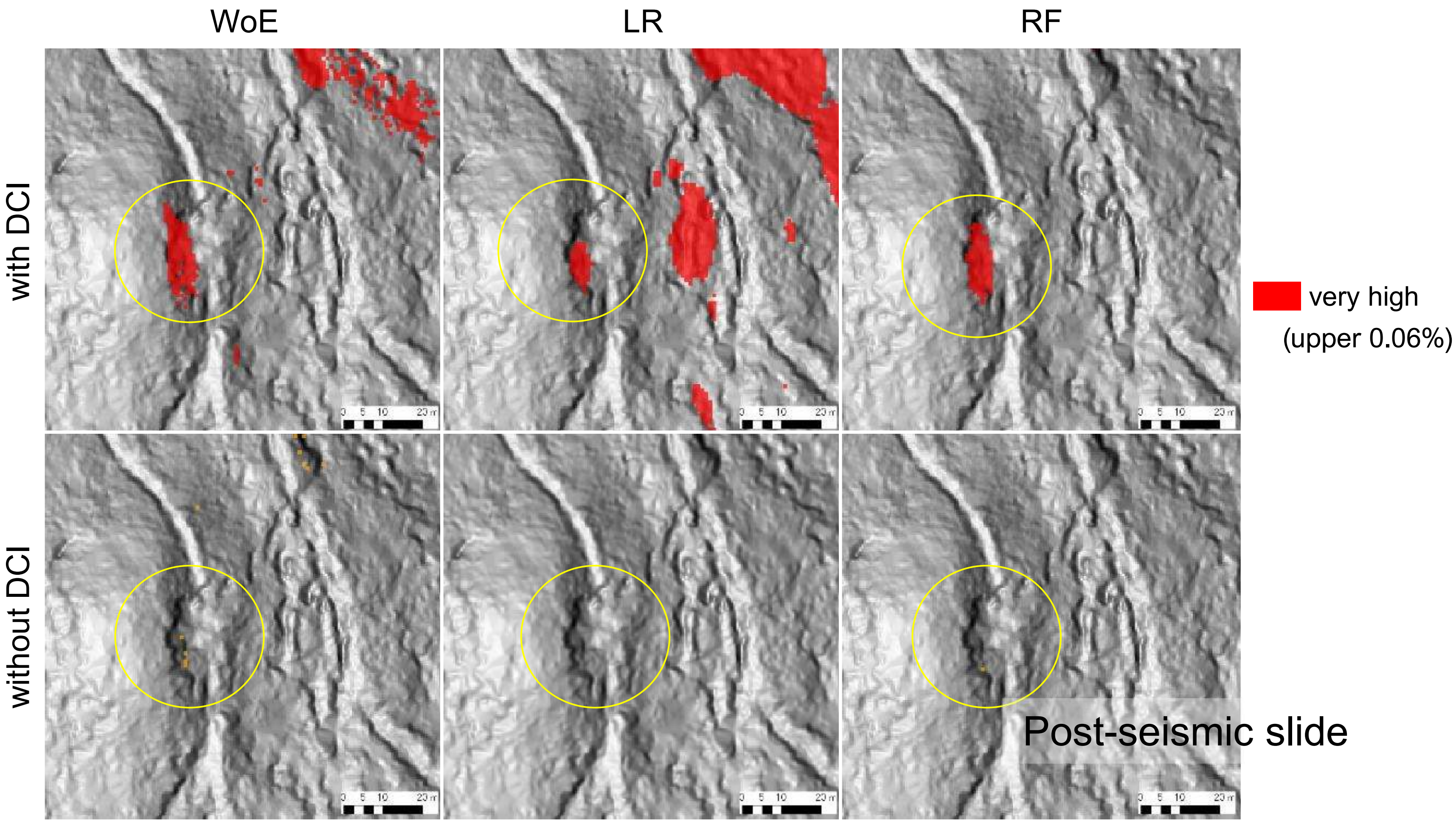


More cracks in a class → more susceptible to post-seismic slides



- 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


WoE
LR
RF
with DCI
without DCI
very high
(upper 0.06%)
Post-seismic slide

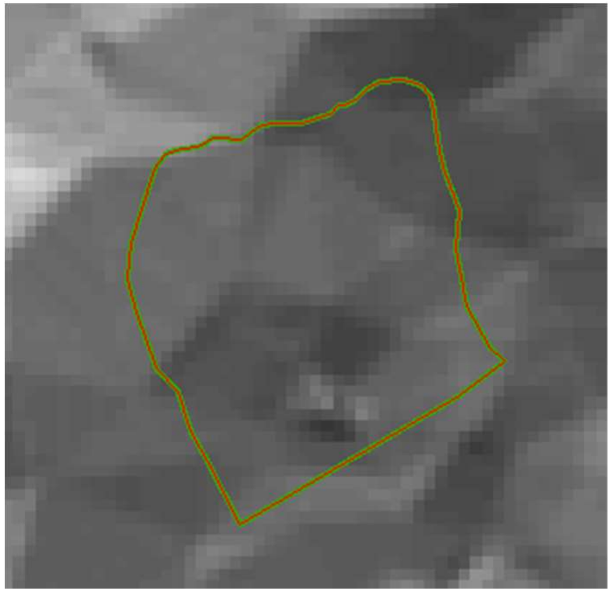
HOWEVER

AUC values (averaged for 10 datasets)

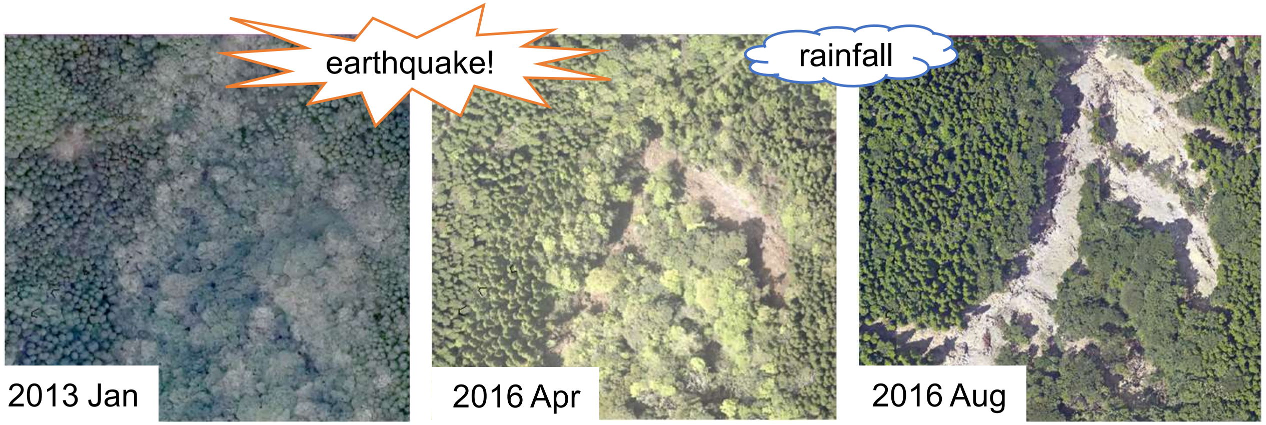
	Training data		Testing data	
	DCI incl.	DCI excl.	DCI incl.	DCI excl.
WoE	0.891	0.868	0.890	0.867
LR	0.896	0.859	0.895	0.857
RF	0.999	0.999	0.997	0.997

- All the AUC values indicated excellent/outstanding performance of the models
- However, the improvement of the performance by including DCI was marginal or negligible
- This was probably because the combination of other factors enabling to express locations where strong seismic wave was locally hit could compensate for the absence of the index.
- The contribution of DCI could be evaluated higher with better accuracy of LiDAR data used in the analysis.

- 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.
- The presence of landslides, especially slow-moving slides with shallow depths, was difficult to be confirmed on such images (2016), even though the models suggested it.



- This study proposed a new index, DCI, which represents the spatial density of seismic cracks, to assess their association with post-seismic slides.
- By introducing it into the WoE and RF models along with other topographic, seismic, and meteorological conditioning factors, we found that this index was the most important factor determining the occurrence of post-seismic slides in the 6 km^2 area struck by the 2016 Kumamoto earthquake.
- However, the performance of the WoE, LR, and RF 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 that prevented proper calculation of DCI values in some locations, including a quarter of the post-earthquake slides, and the failure to confirm the presence of landslides. Therefore, their contribution to post-seismic slides could have been underestimated in this case.



- In addition, the combination of features that indicated where open cracks were likely to occur, or ridgelines where strong PGA was likely to be amplified, could also compensate for the absence of the DCI index in the models.
- This 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, where water is supplied through cracks and accumulates to raise the groundwater table.
- The index itself also needs to be more refined. The future development of the index will require the collection and analysis of a wide range of field data. These efforts are expected to contribute to future disaster prevention programs in tectonically active regions.

In this study the high potential of the DCI for evaluating the susceptibility of slides after a major earthquake could be presented, although there is still room for further research and development before the index can be practically applied.

Thank you for listening