



# 台湾と日本の斜面崩壊発生に関する比較

防災科学技術研究所マルチハザード評価研究部門  
陳 麒文

# 斜面崩壊とは

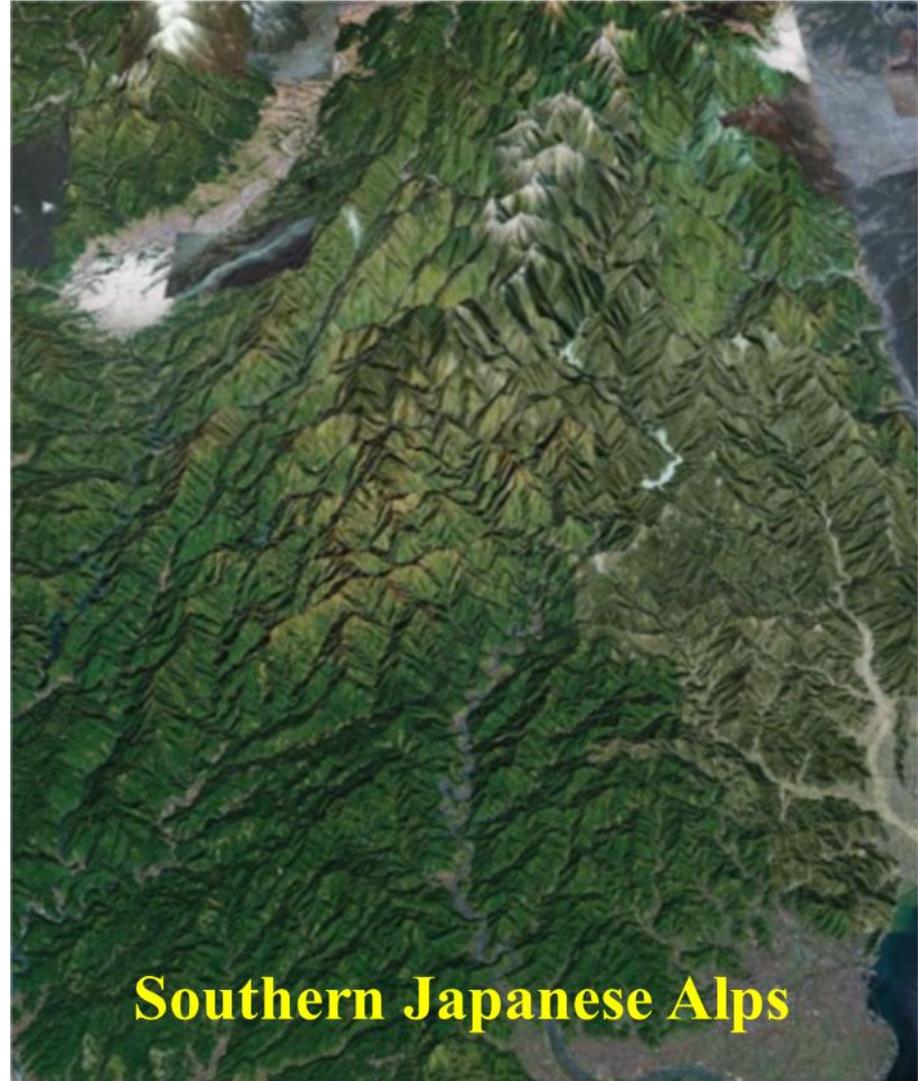
- 斜面を構成する土層もしくは岩盤までが、おもに重力により斜面下方に移動する現象



# 斜面崩壊発生の要因

- **素因**
  - 地形（例：勾配）
  - 地質
  - 植生
- **誘因**
  - 降雨
  - 地震

# どちらも険しい山地地形である





## **Shallow slides: Central Japanese Alps**



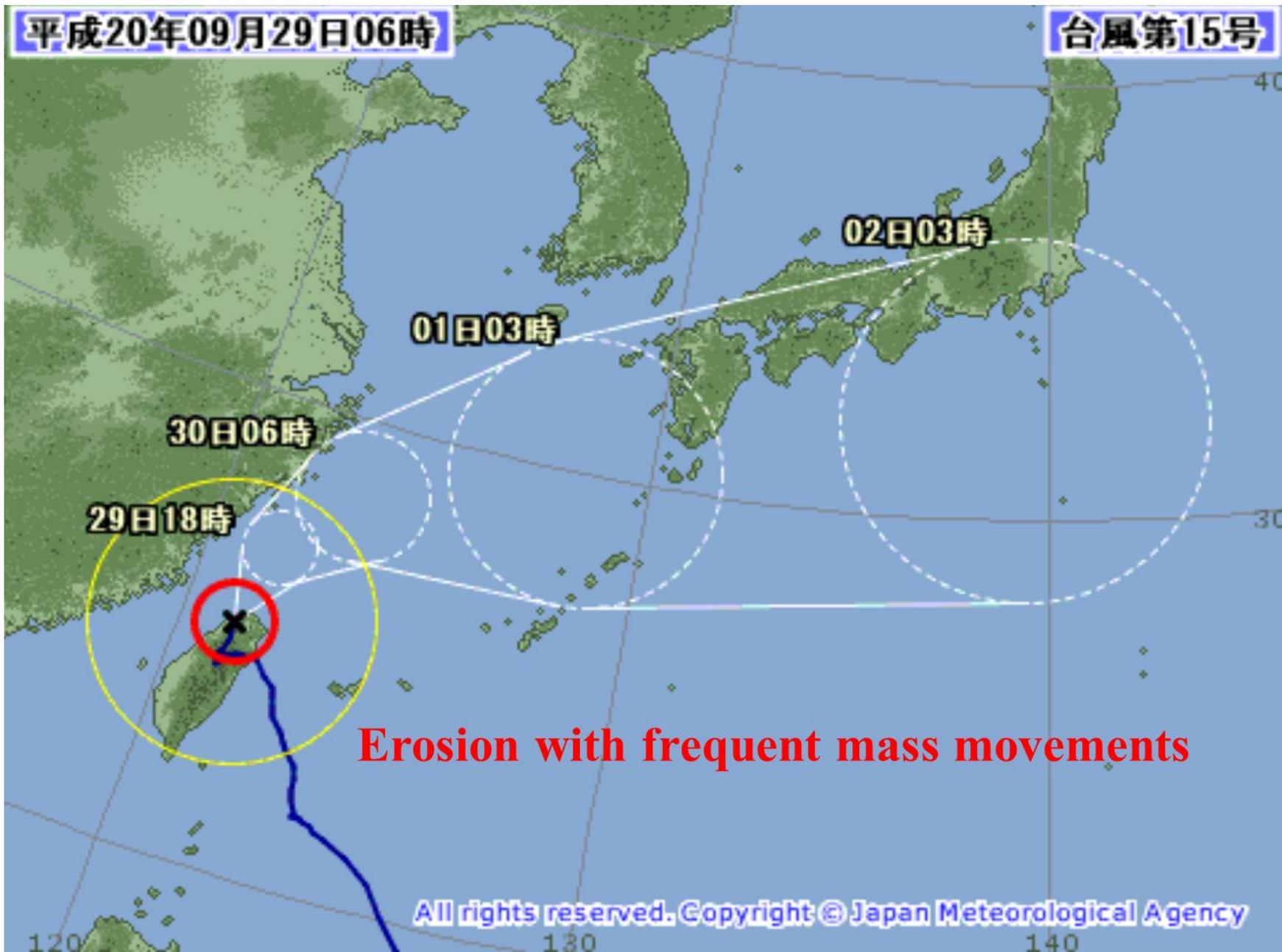


**2011年8月台湾屏東县**

# 降雨による斜面崩壊

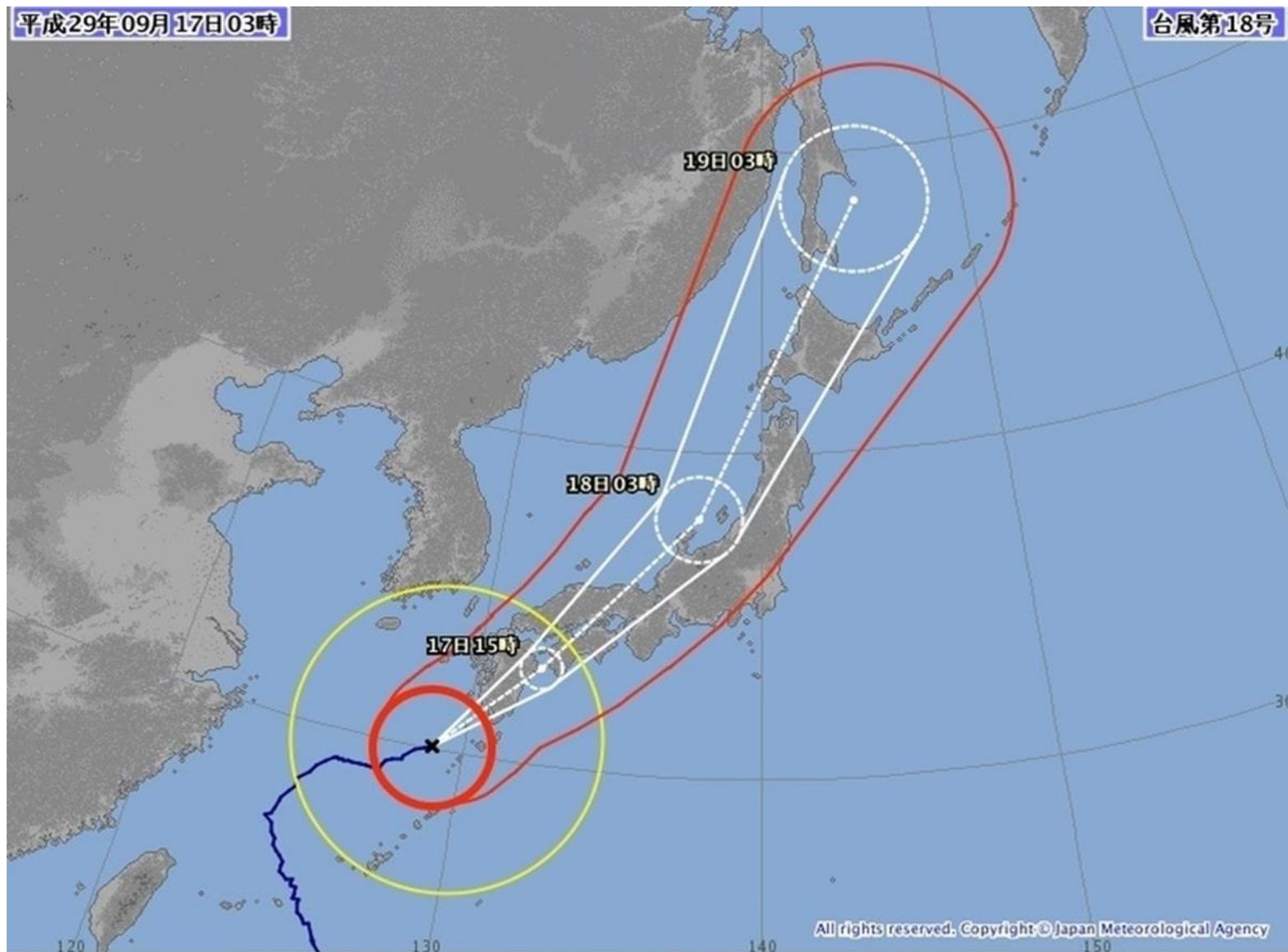
Landslide





平成29年09月17日03時

台風第18号



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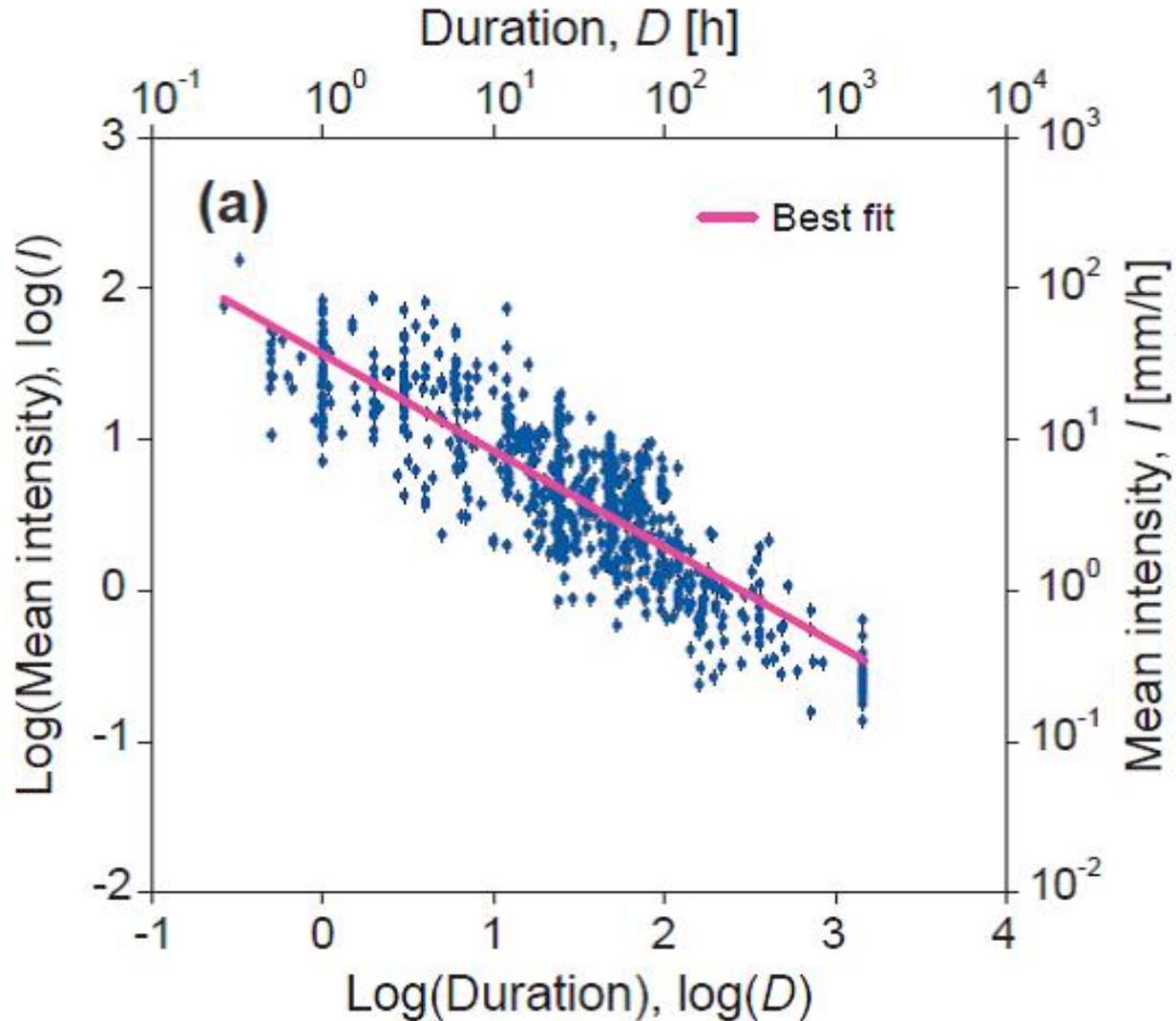
25m/s以上の暴風域

15m/s以上の強風域

暴風警戒域

予報円

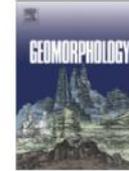
# $I$ - $D$ relationship





Contents lists available at ScienceDirect

# Geomorphology

journal homepage: [www.elsevier.com/locate/geomorph](http://www.elsevier.com/locate/geomorph)

## Relationship between the initiation of a shallow landslide and rainfall intensity–duration thresholds in Japan

Hitoshi Saito<sup>a,b,\*</sup>, Daichi Nakayama<sup>a</sup>, Hiroshi Mat<sup>a</sup> Department of Geography, Graduate School of Urban Environmental Sciences, Tokyo<sup>b</sup> Research Fellow of the Japan Society for the Promotion of Science, Japan

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*I*–*D* threshold

Rescaling

Quantile regression

East Asian summer monsoon

### ABSTRACT

The empirical rainfall in defined for Japan where rainfall causes sediment induced shallow landslides from rainfall data (Rada regression method:  $I =$  measured from the beginning of rainfall for 2 years the mean annual precipitation rainfall intensity. These The new thresholds are regions, the Asian monsoon induced shallow landslides and rainfall characteristics

Chen et al. *Progress in Earth and Planetary Science* (2015) 2:14  
DOI 10.1186/s40645-015-0049-2

 Progress in Earth  
and Planetary Science  
a SpringerOpen Journal

### RESEARCH ARTICLE

Open Access



## Rainfall intensity–duration conditions for mass movements in Taiwan

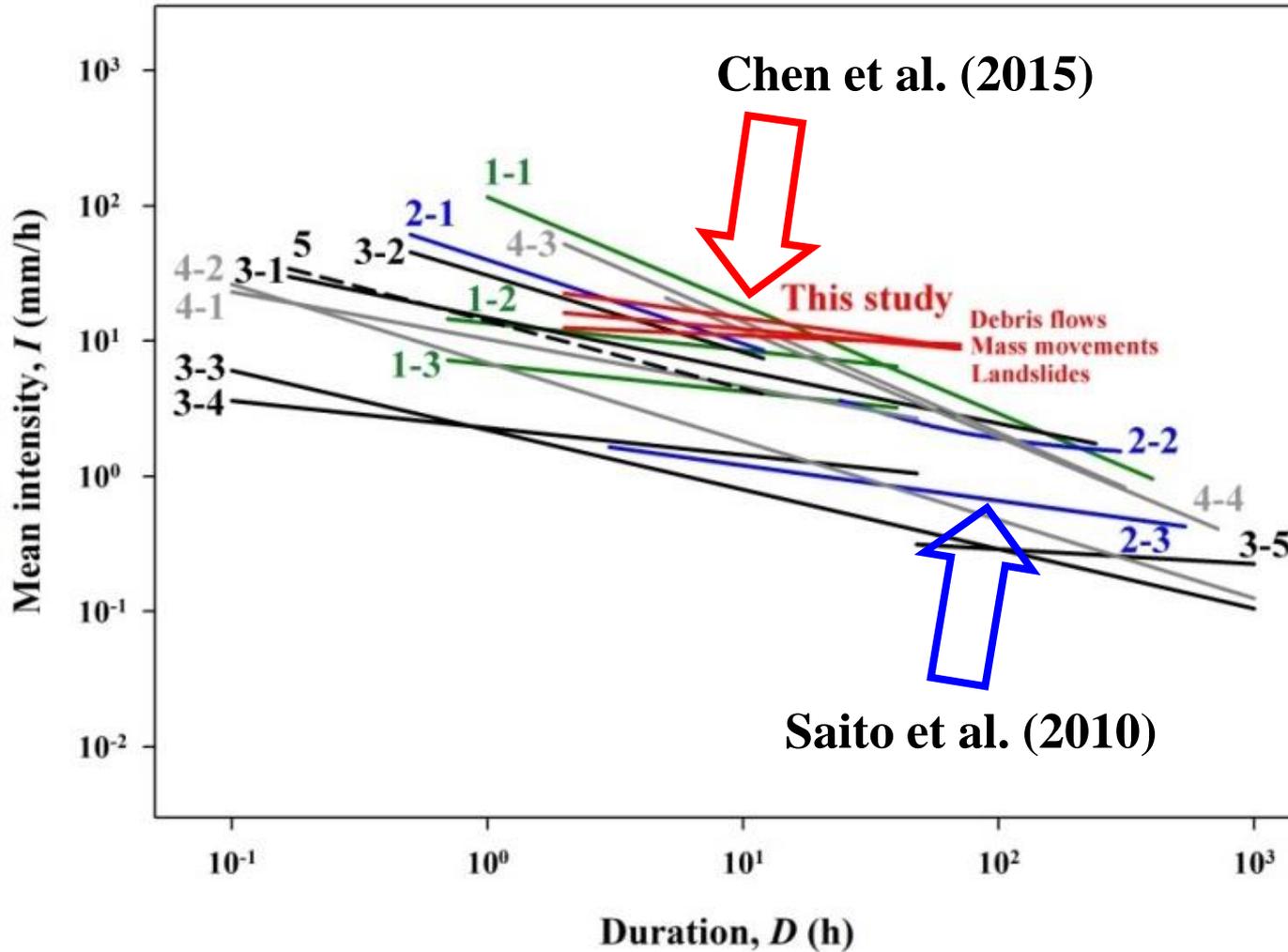
Chi-Wen Chen<sup>1\*</sup>, Hitoshi Saito<sup>2,3</sup> and Takashi Oguchi<sup>1,3</sup>

### Abstract

Mass movements caused by rainfall events in Taiwan are analyzed during a 7-year period from 2006 to 2012. Data from the Taiwan Soil and Water Conservation Bureau reports were compiled for 263 mass movement events, including 156 landslides, 91 debris flows, and 16 events with both landslides and debris flows. Rainfall totals for each site location were obtained from interpolated rain gauge data. The rainfall intensity–duration (*I*–*D*) relationship was examined to establish a rainfall threshold for mass movements using random sampling:  $I = 18.10(\pm 2.67)D^{-0.17(\pm 0.04)}$ , where *I* is mean rainfall intensity (mm/h) and *D* is the time (h) between the beginning of a rainfall event and the resulting mass movement. Significant differences were found between rainfall intensities and thresholds for landslides and debris flows. For short-duration rainfall events, higher mean rainfall intensities were required to trigger debris flows. In contrast, for long-duration rainfall events, similar mean rainfall intensities triggered both landslides and debris flows. Mean rainfall intensity was rescaled by mean annual precipitation (MAP) to define a new threshold:  $I_{MAP} = 0.0060(\pm 0.0009)D^{-0.17(\pm 0.04)}$ , where  $I_{MAP}$  is rescaled rainfall intensity and MAP is the minimum for mountainous areas in Taiwan (3000 mm). Although the *I*–*D* threshold for Taiwan is high, the  $I_{MAP}$ –*D* threshold for Taiwan tends to be low relative to other areas around the world. Our results indicate that Taiwan is highly prone to rainfall-induced mass movements. This study also shows that most mass movements occur in high rainfall-intensity periods, but some events occur before or after the rainfall peak. Both antecedent and peak rainfall play important roles in triggering landslides, whereas debris flow occurrence is more related to peak rainfall than antecedent rainfall.

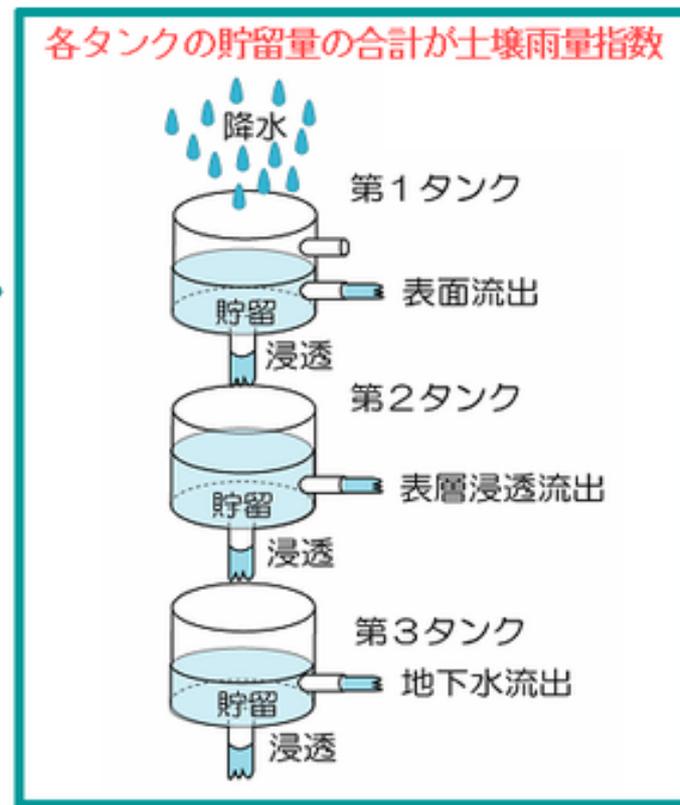
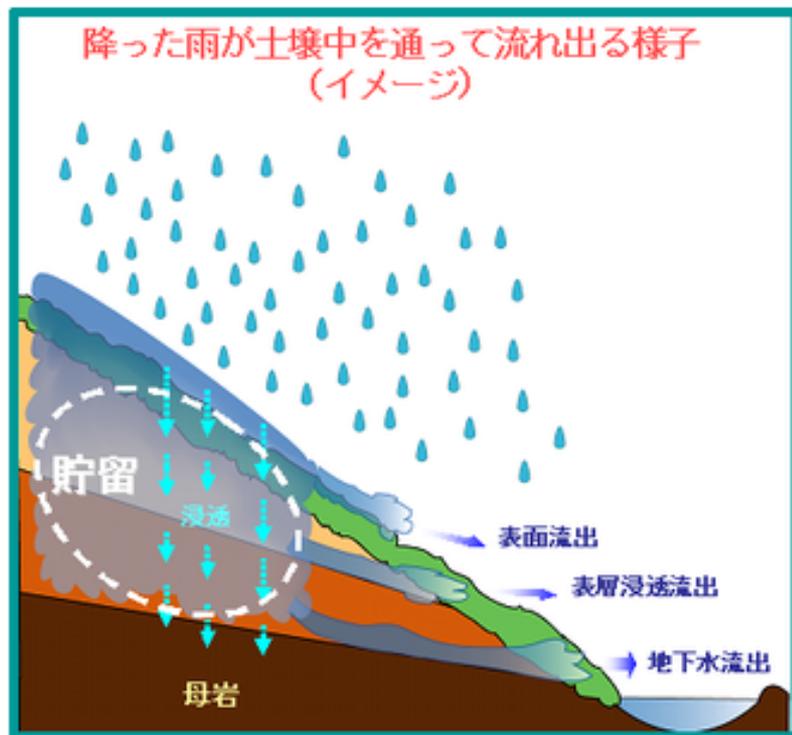
**Keywords:** Mass movements; Landslides; Debris flows; *I*–*D* thresholds; Rainfall; Typhoons

# 地域間の比較



# 土壌雨量指数

- 2008年から気象庁は、土壌雨量指数を用いて、土砂災害警戒を発信している。



ホーム

防災情報

各種データ・資料

[ホーム](#) > [防災情報](#) > 土砂災害警戒判定メッシュ情報



高解像度  
降水ナウキャスト



土砂災害警戒  
判定メッシュ情報



大雨警報(浸水害)の  
危険度分布



洪水警報の  
危険度分布



## 土砂災害警戒判定メッシュ情報

表示時間



10/02 17:20 ▾



最新

画像保存

印刷

動画方法 6時間前から最新まで 動画表示

動画開始

動画停止

動画速度

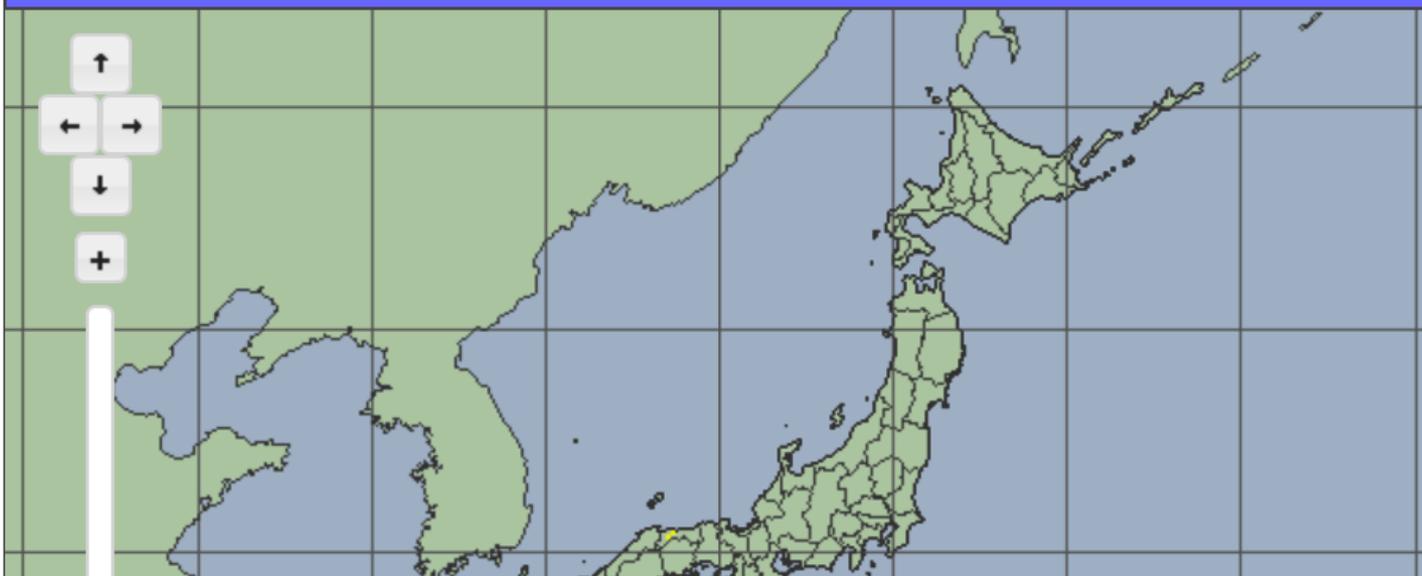
遅く



速く

使い方

2017年10月02日17時20分





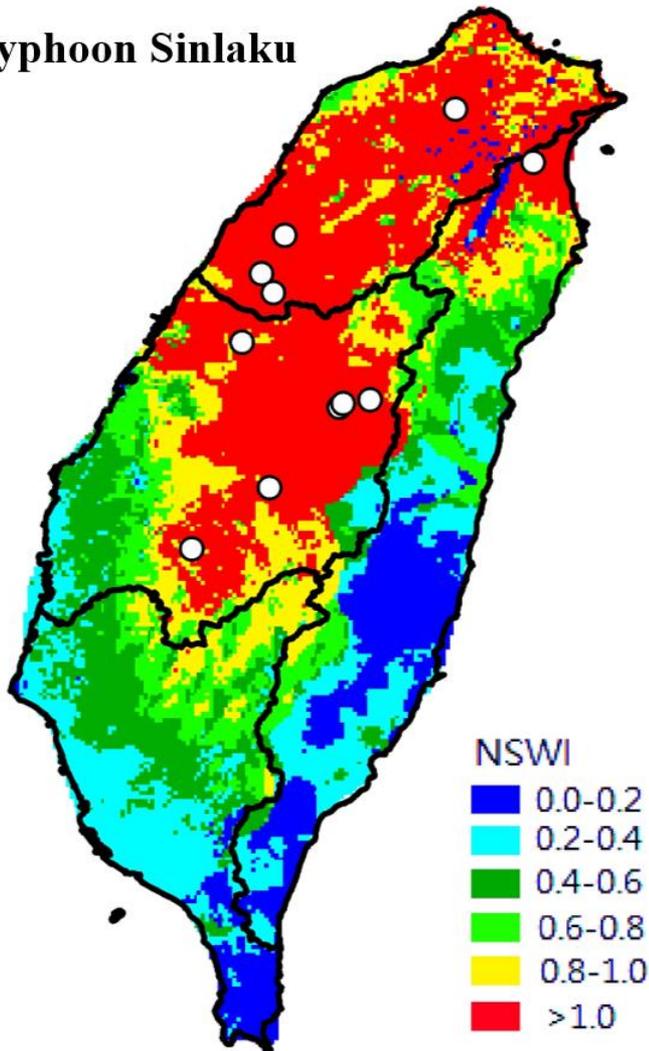
色	説明	内閣府のガイドラインで土砂災害警戒区域等を対象に発令が必要とされている避難情報
紫	<実況で土砂災害警戒情報の基準※に到達> 過去の土砂災害発生時に匹敵する <b>極めて危険</b> な状況。既に土砂災害が発生しているおそれもあり。この状況になる前に避難を完了する。まだ避難していない場合は直ちに身の安全を確保する。	避難指示(緊急)
紫	<予想で土砂災害警戒情報の基準※に到達> 土砂災害がいつ発生してもおかしくない <b>非常に危険</b> な状況。速やかに土砂災害危険箇所・土砂災害警戒区域等の外の少しでも安全な場所へ避難する。	避難勧告
赤	<実況または予想で大雨警報の基準に到達> 土砂災害への <b>警戒</b> が必要。避難準備をし、早めの避難を心がける。	避難準備・高齢者等避難開始
黄	<実況または予想で大雨注意報の基準に到達> 土砂災害への <b>注意</b> が必要。今後の情報や周囲の状況、雨の降り方に留意する。	-
白	<実況及び予想で大雨注意報の基準未達> 今後の情報や周囲の状況、雨の降り方に留意する。	-

土砂災害警戒判定メッシュ情報



# 警戒システムの構築

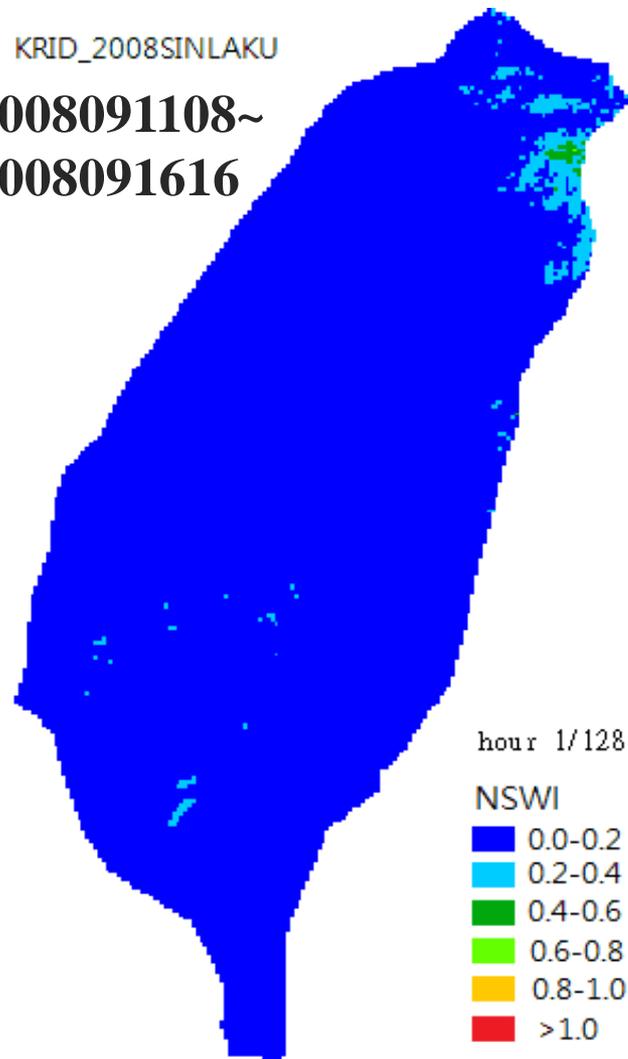
2008 Typhoon Sinlaku



Maximum NSWI

KRID\_2008SINLAKU

2008091108~  
2008091616



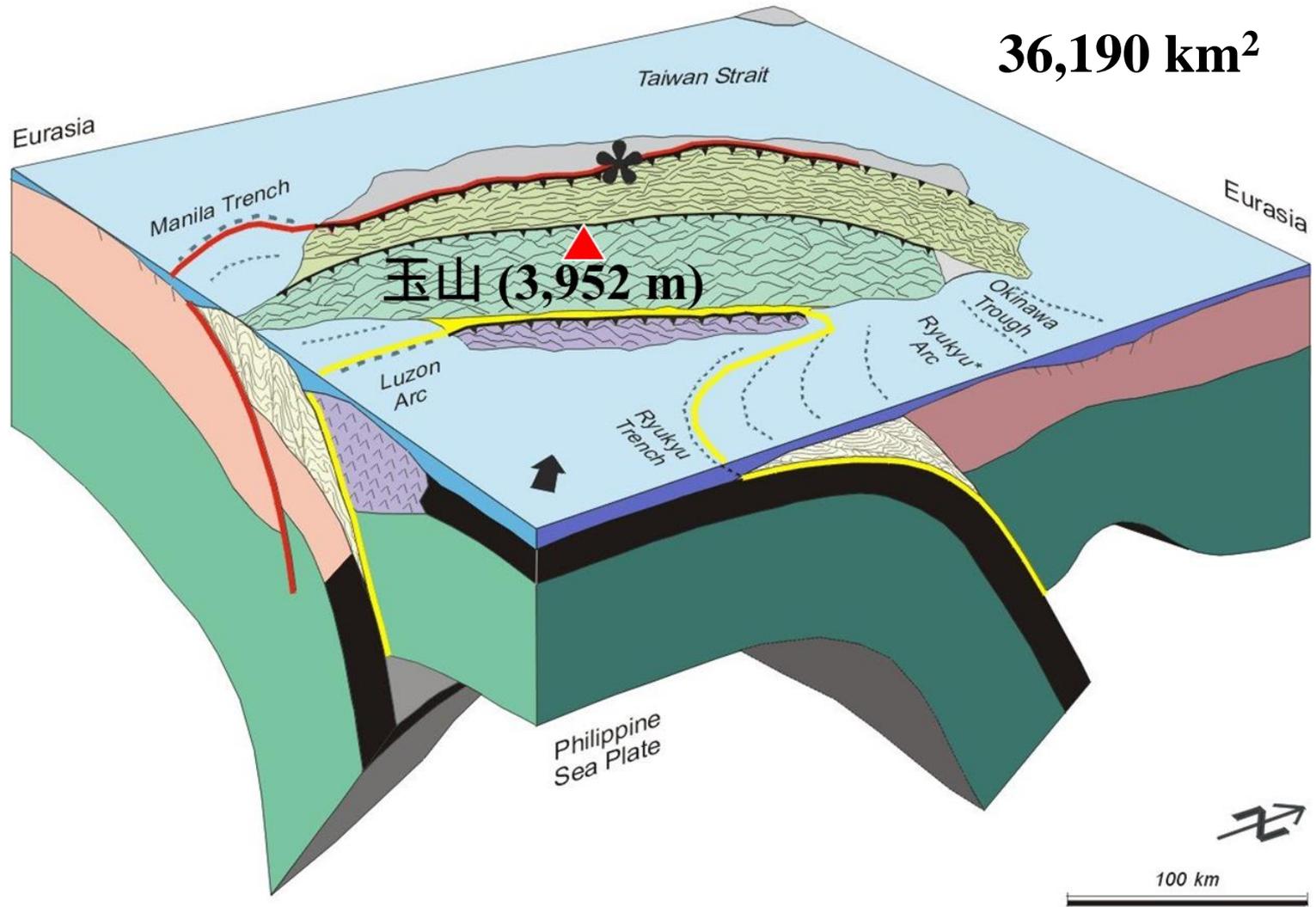
Time series changes

# 地震による斜面崩壊

Landslide

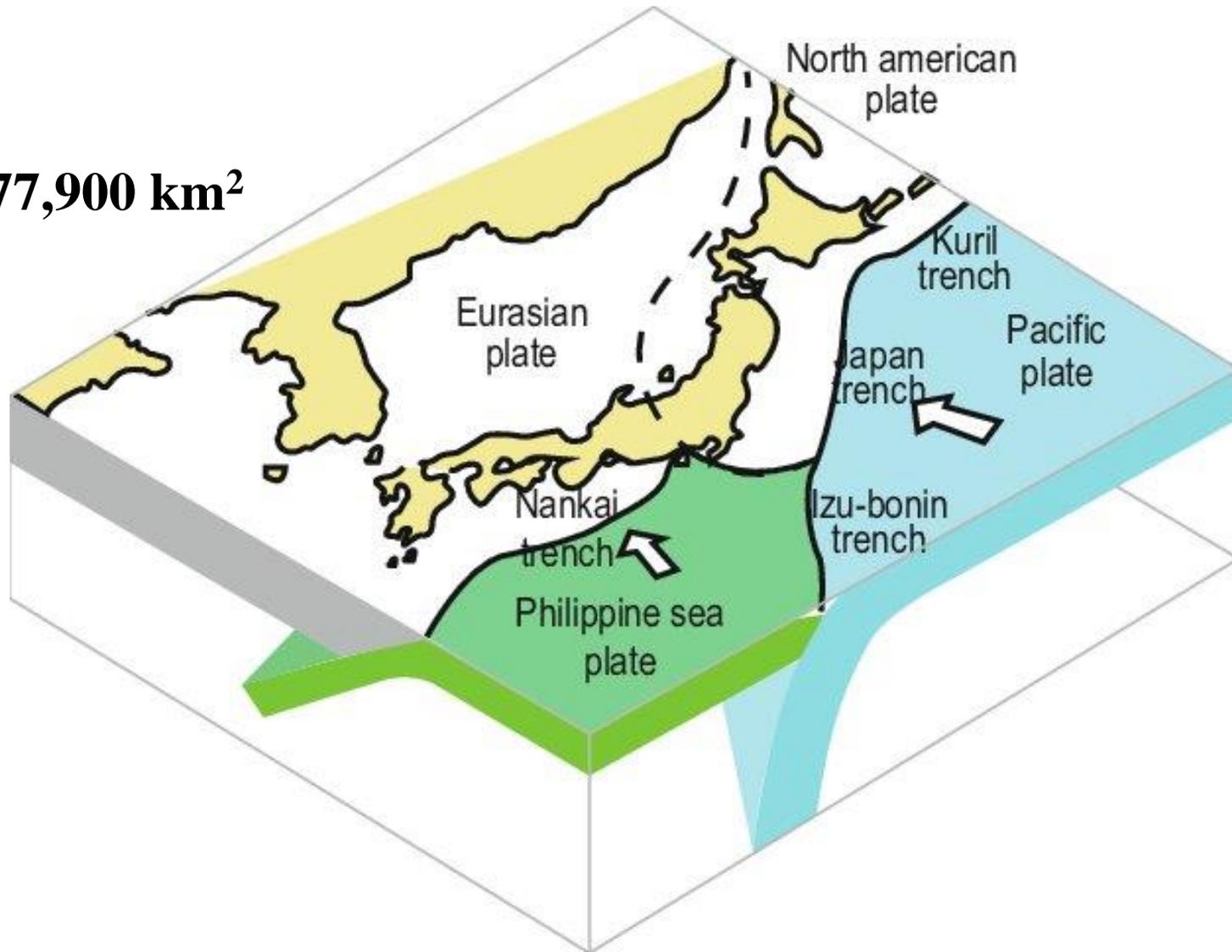


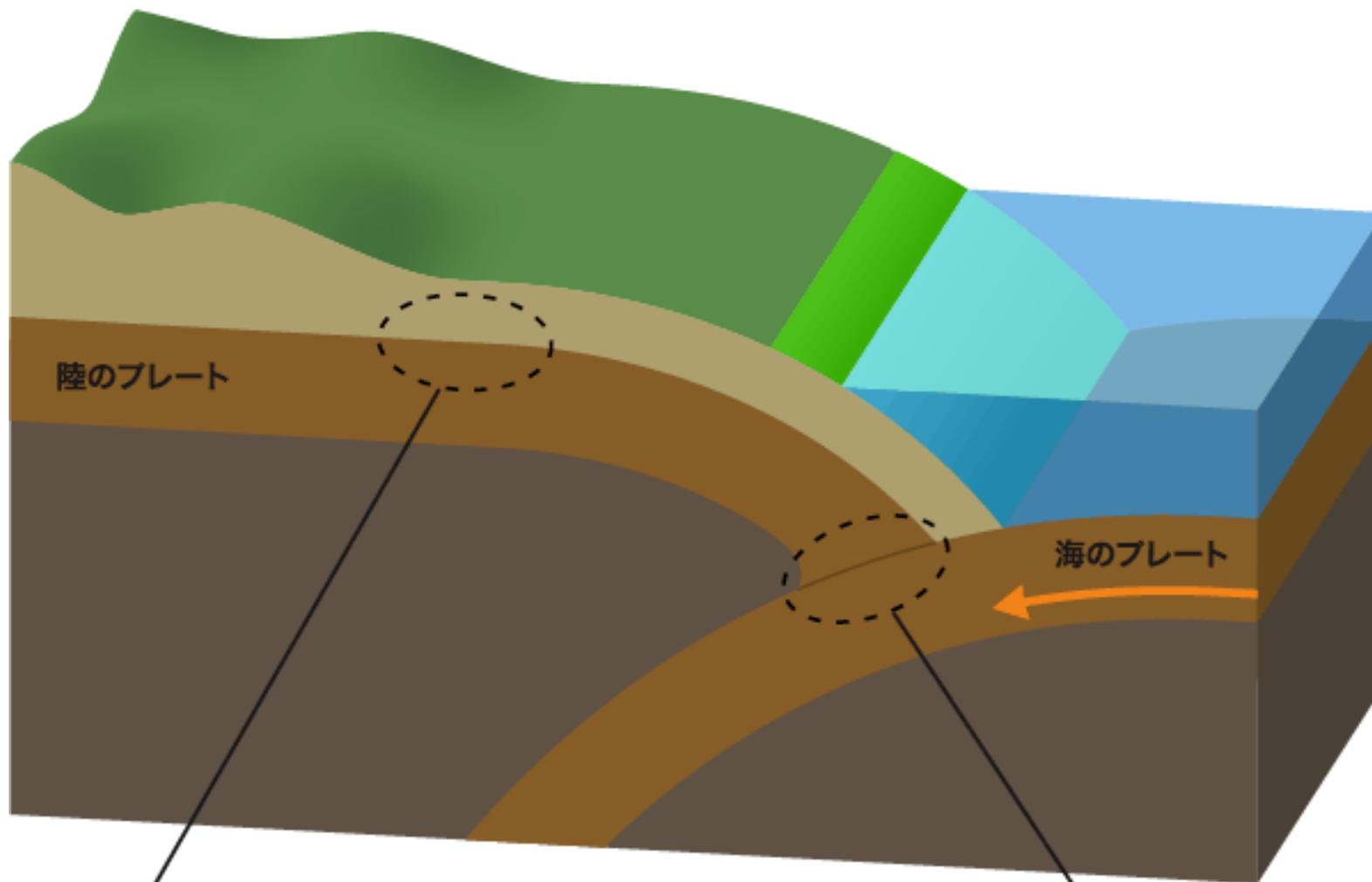
# プレート境界



# プレート境界

377,900 km<sup>2</sup>

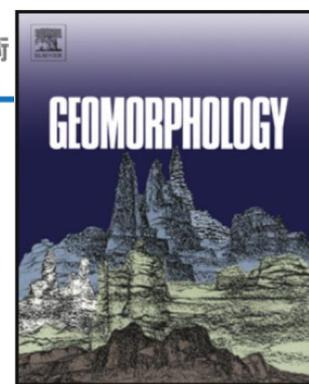




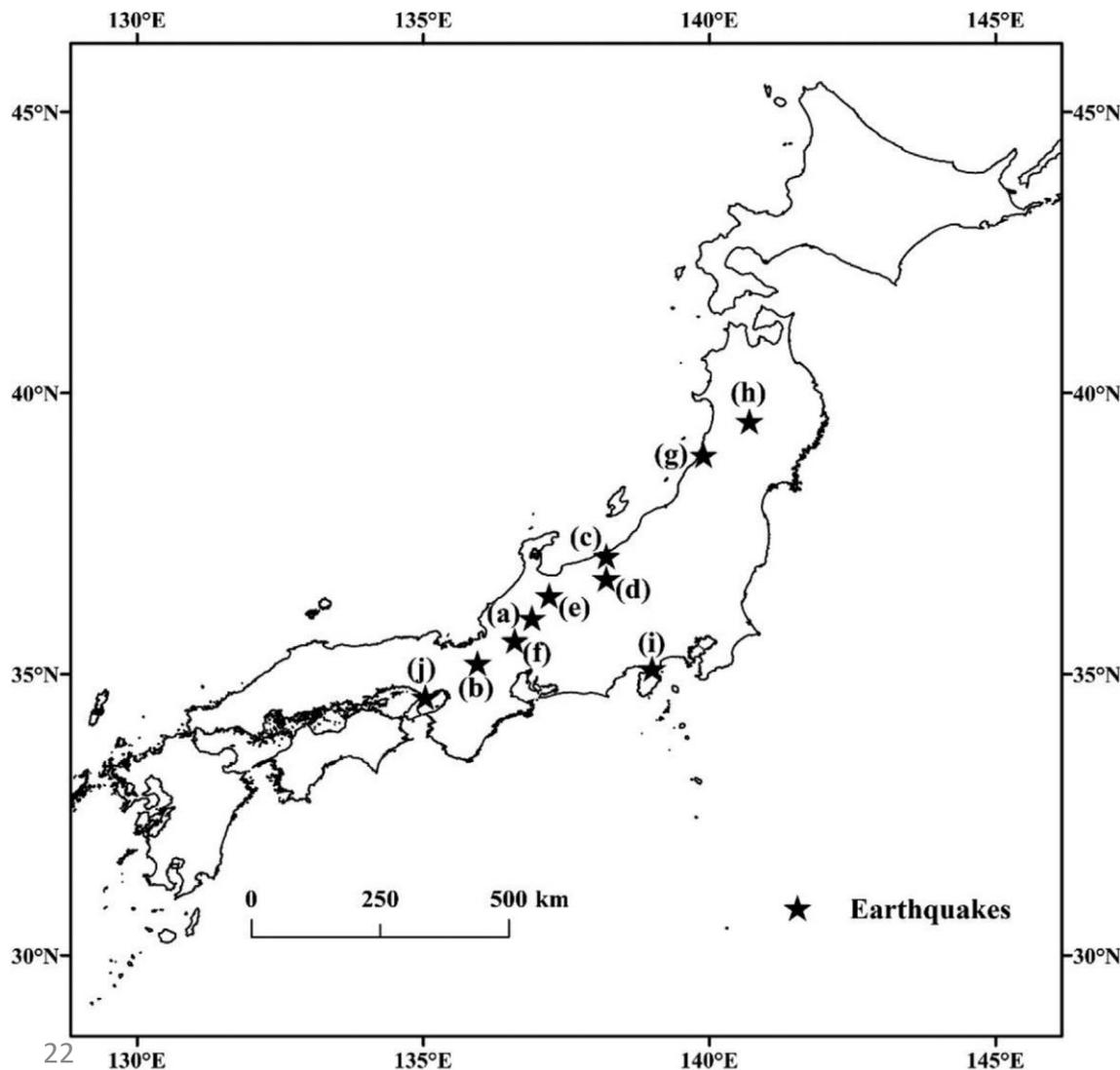
地震で地表に現れる活断層 (タイプ 2)

海溝型地震が起こるしくみ (タイプ 1)

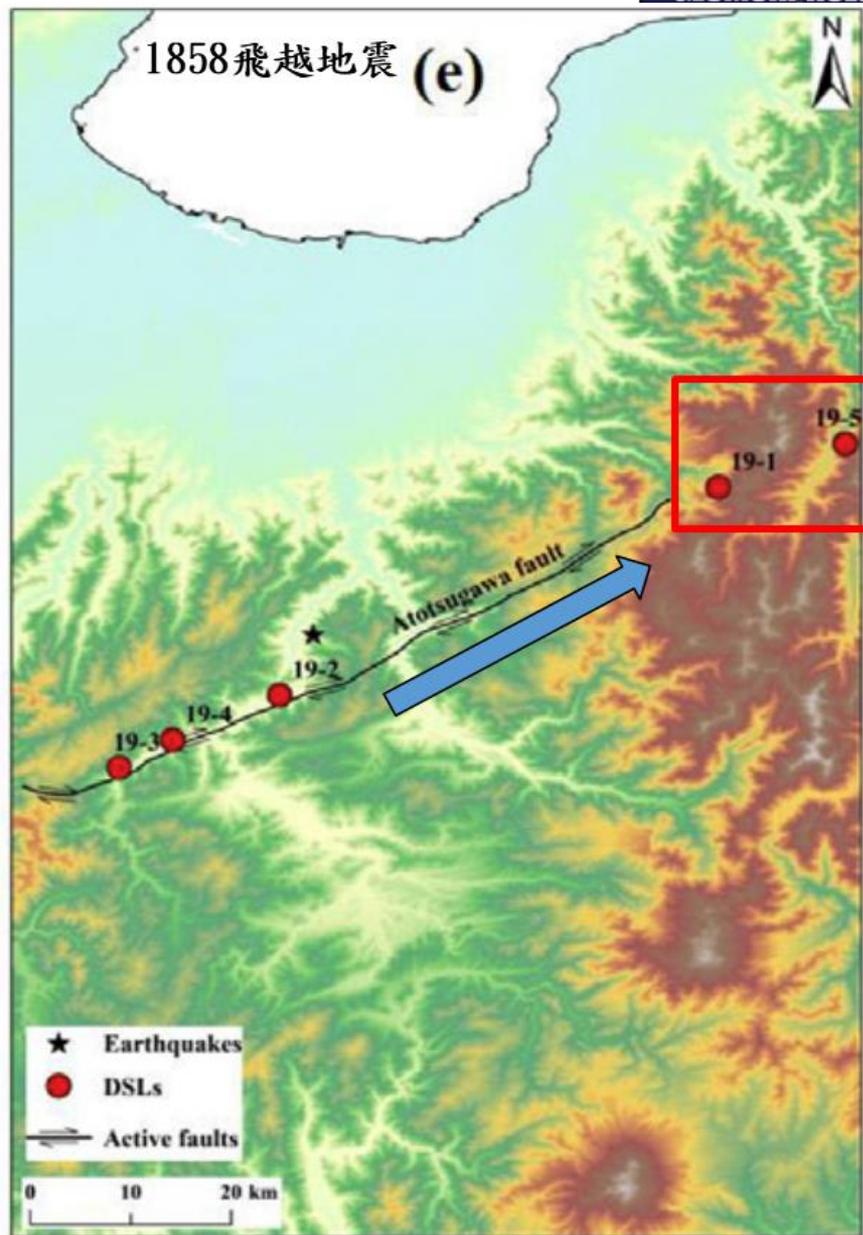
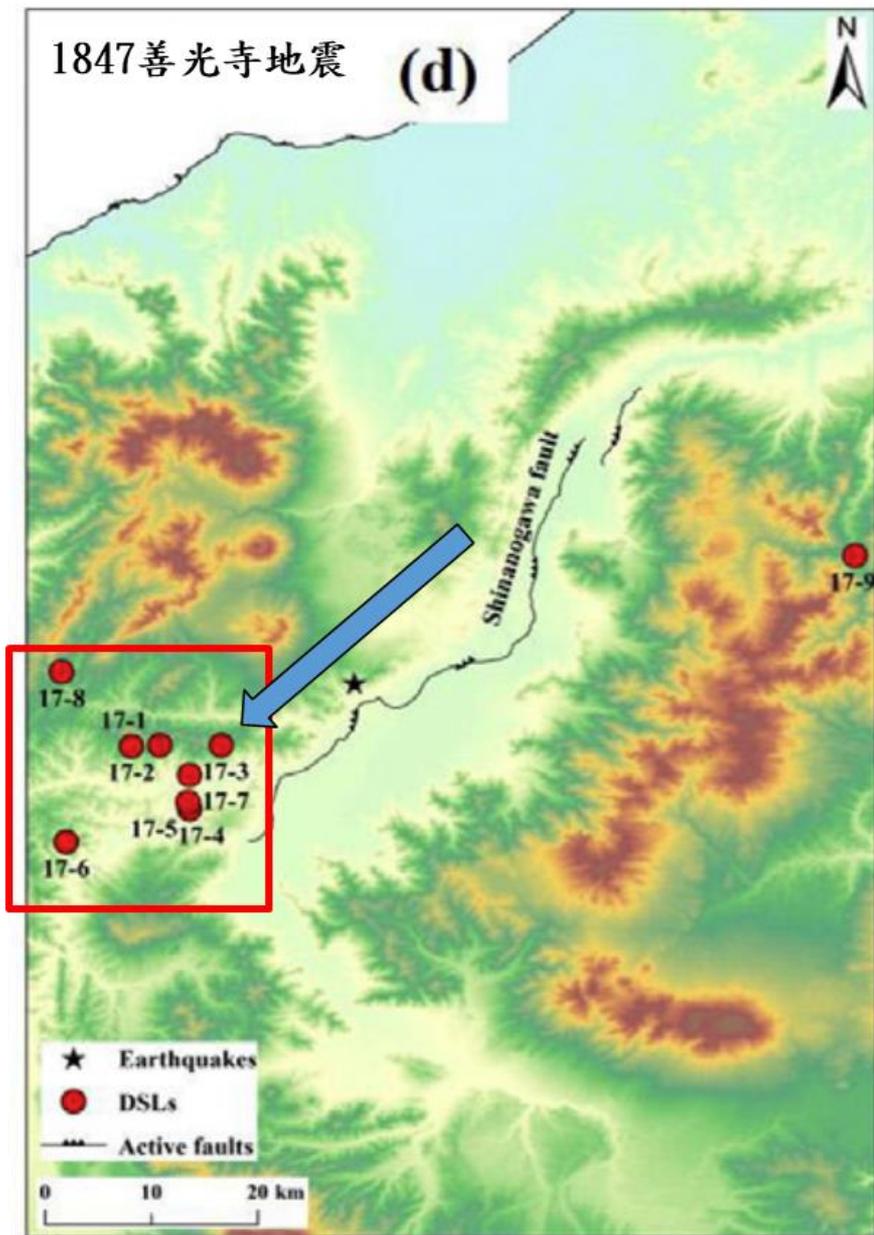
(内閣府HP)

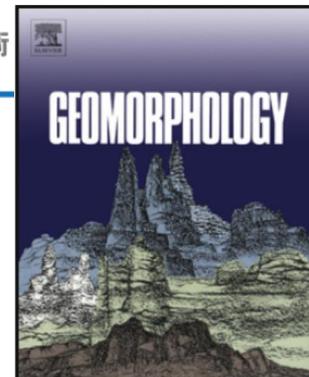


# 大地震と深層崩壊 (1586 - 1995)

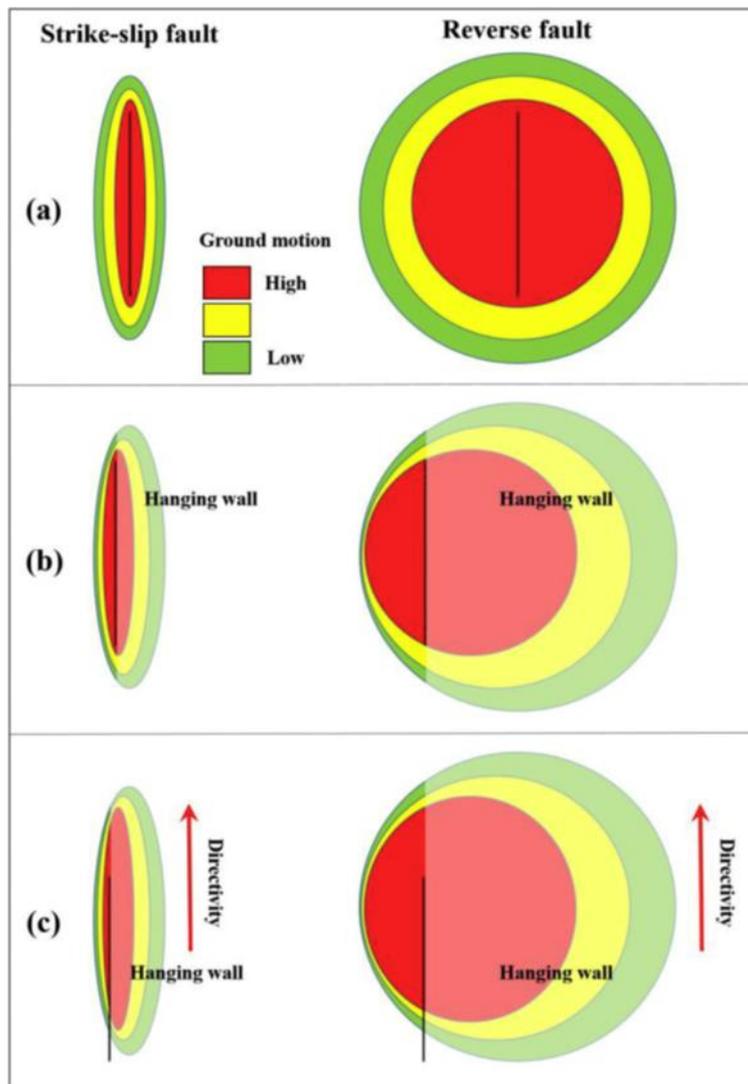


- (a) 1586 天正地震
- (b) 1662 近江若狭地震
- (c) 1751 高田地震
- (d) 1874 善光寺地震
- (e) 1858 飛越地震
- (f) 1891 濃尾地震
- (g) 1894 庄内地震
- (h) 1896 陸羽地震
- (i) 1930 北伊豆地震
- (j) 1995 兵庫県南部地震





# 斜面崩壊分布を影響する要素



• 活断層のタイプ

• 上盤/下盤

• 地震波の指向性

# 近年の事例



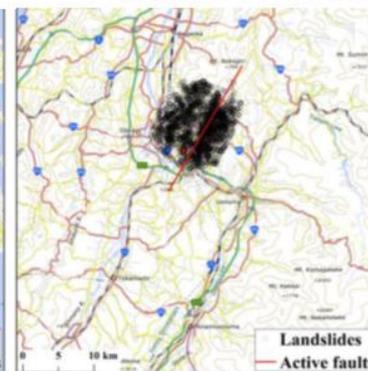
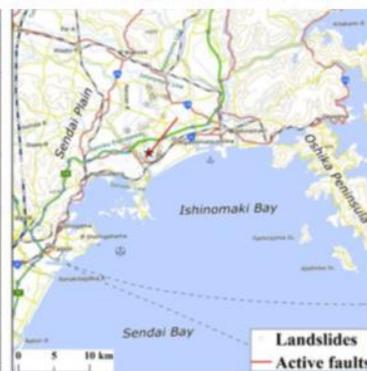
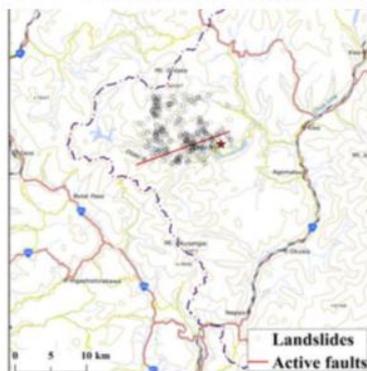
1984 長野県西部地震



2003 宮城県北部地震



2004 新潟県中越地震



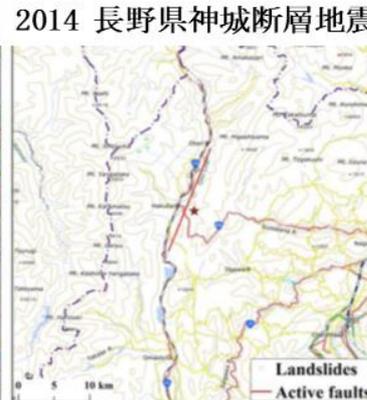
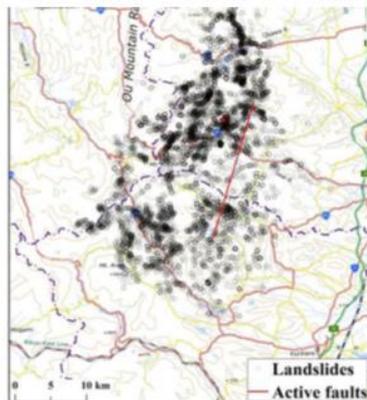
2008 岩手・宮城内陸地震



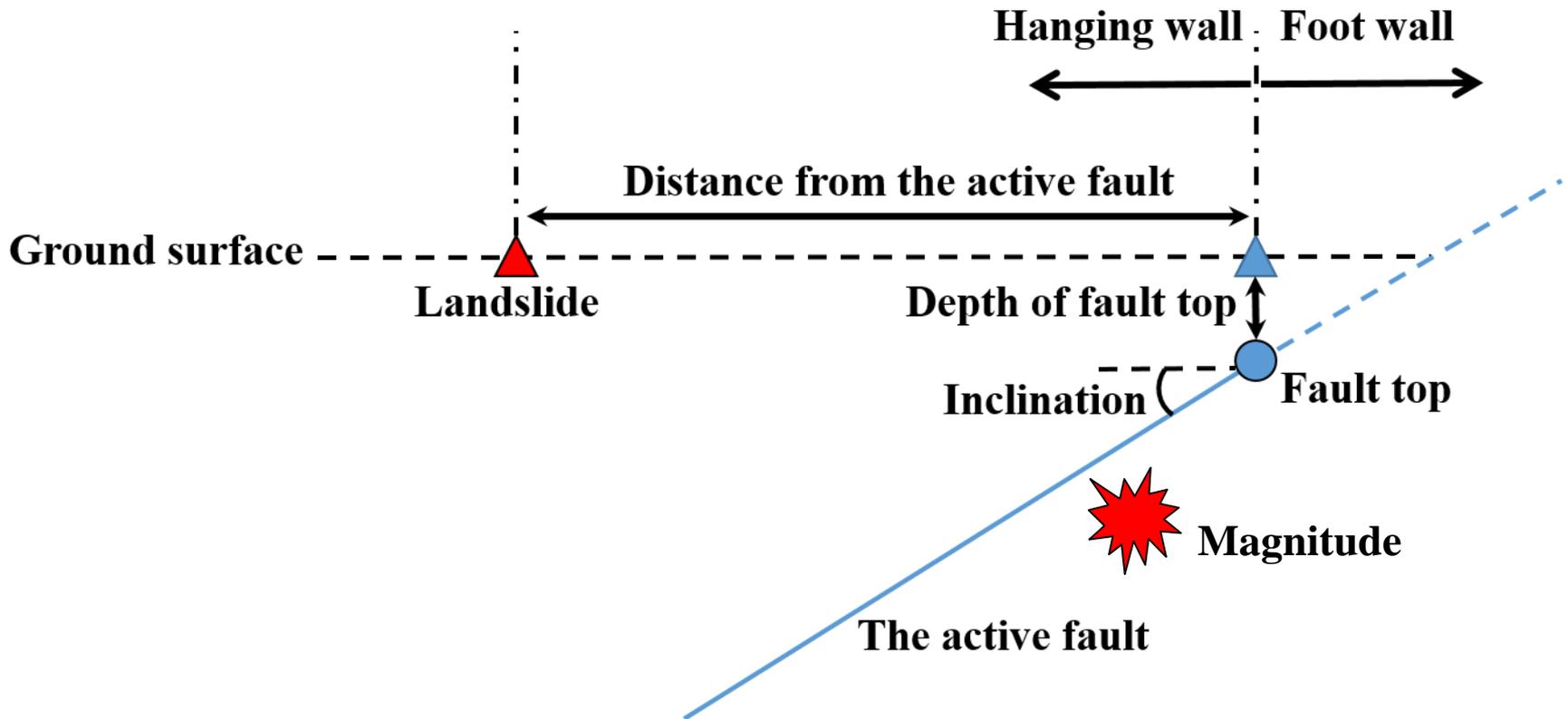
2014 長野県神城断層地震



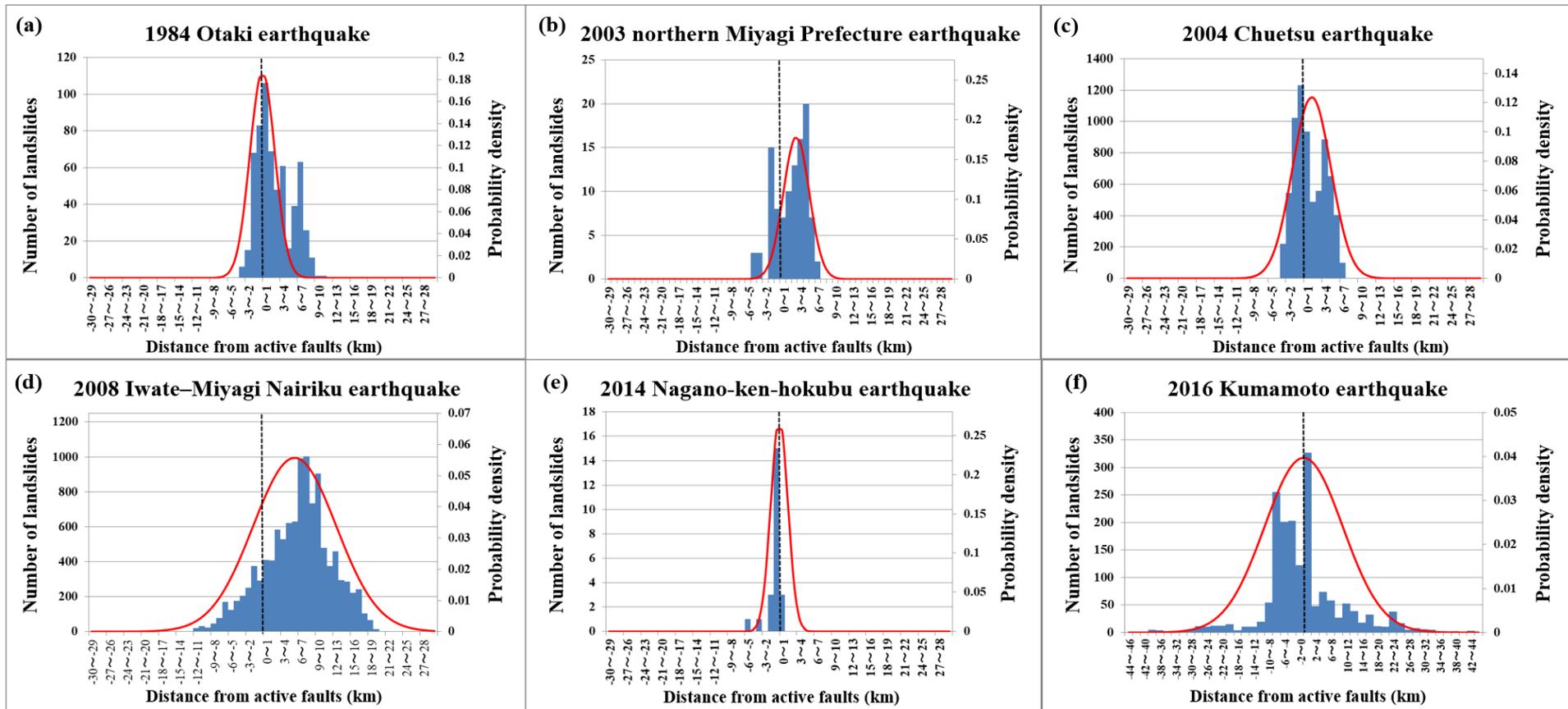
2016 熊本地震



# 地震と活断層のパラメータ



# 斜面崩壊分布 (正規分布)



Normal distribution

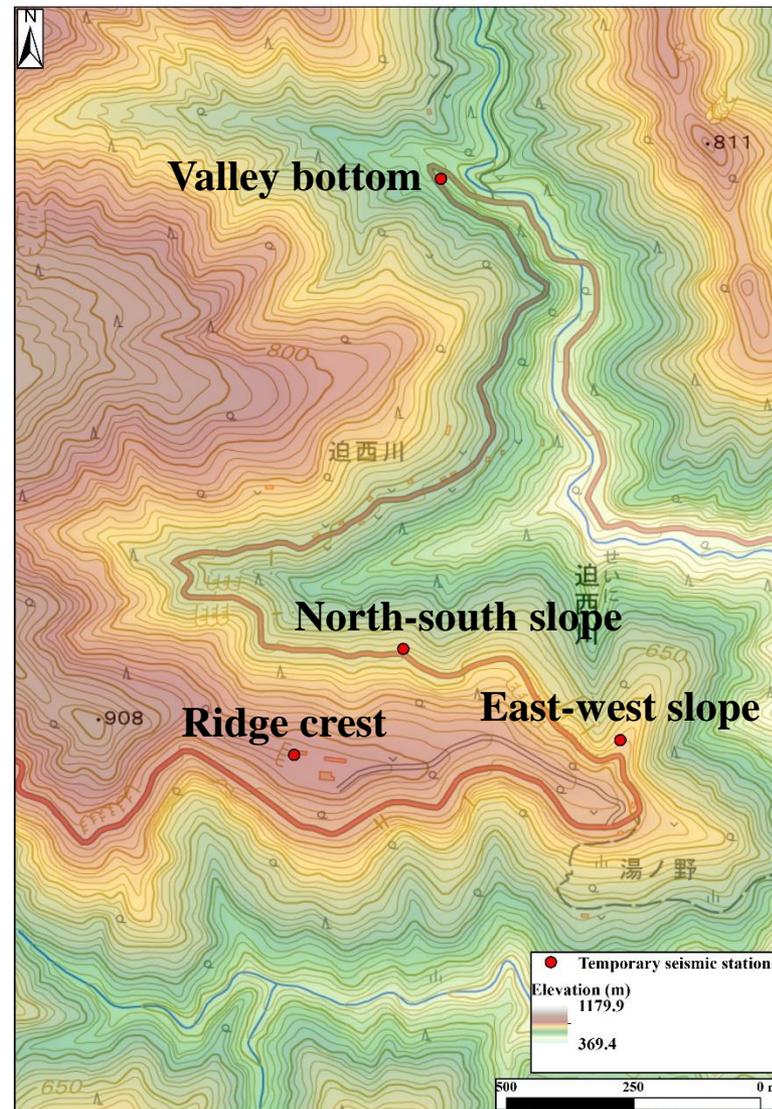
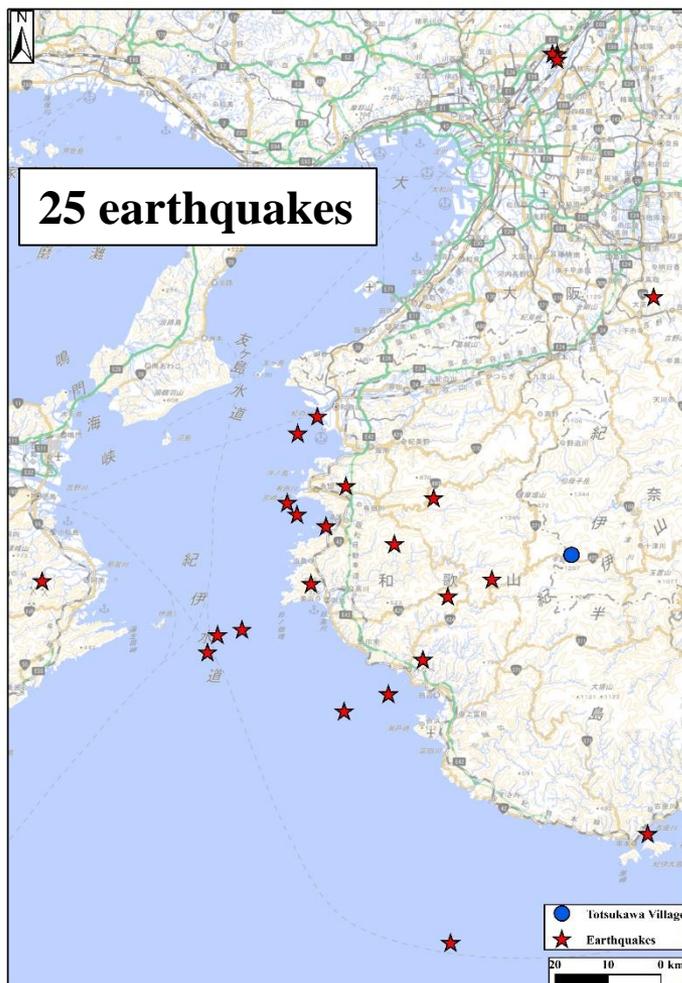
$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(x - \mu)^2}{2\sigma^2}\right)$$

$$\begin{cases} \mu = -0.188 \times I + 11.280 & (I \leq 60^\circ) \\ \mu = 0 & (I > 60^\circ) \end{cases}$$

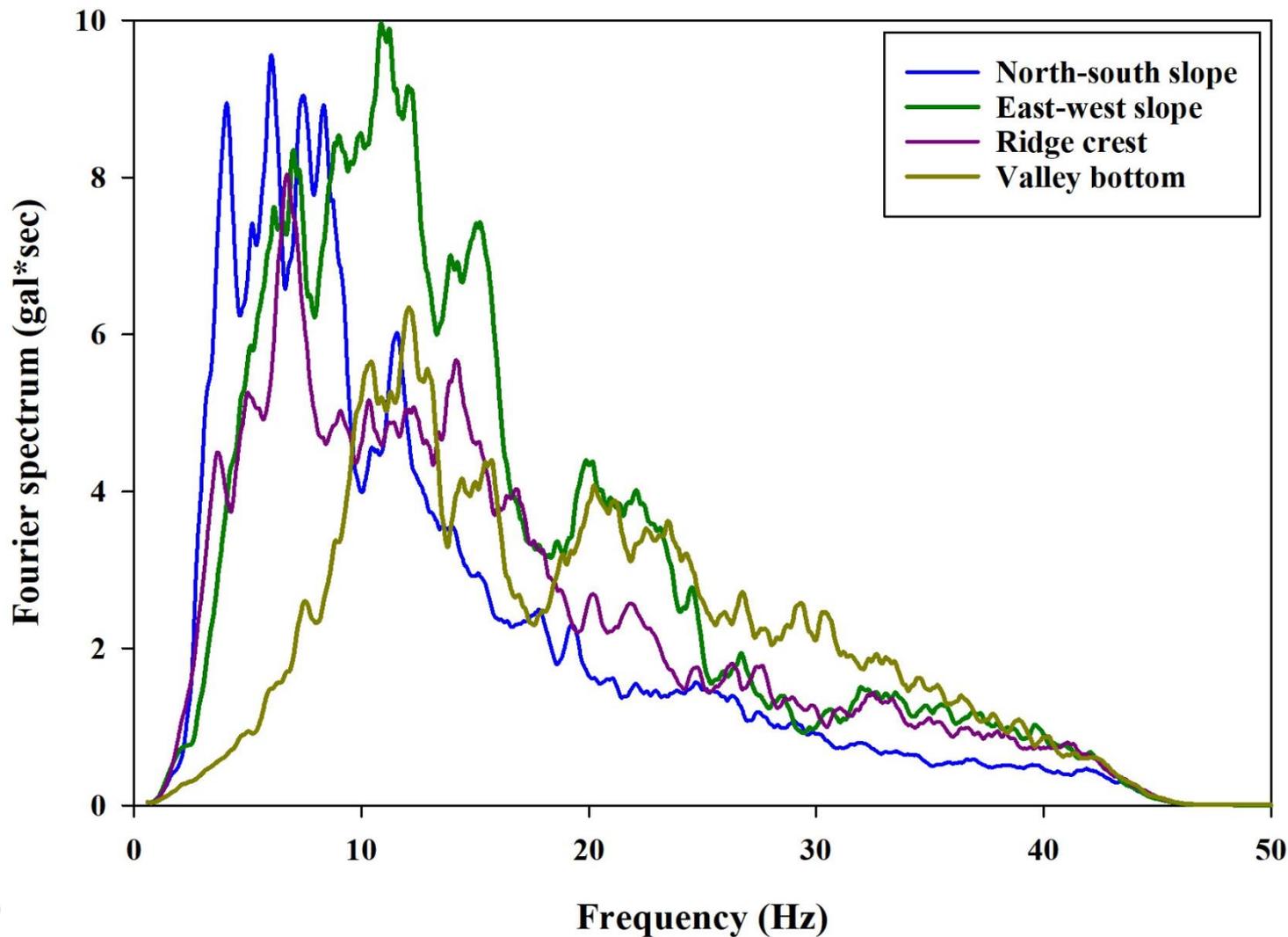
$$\sigma = 0.472 \times D + 1.701 \times 10^{-15} \times E + 0.202$$

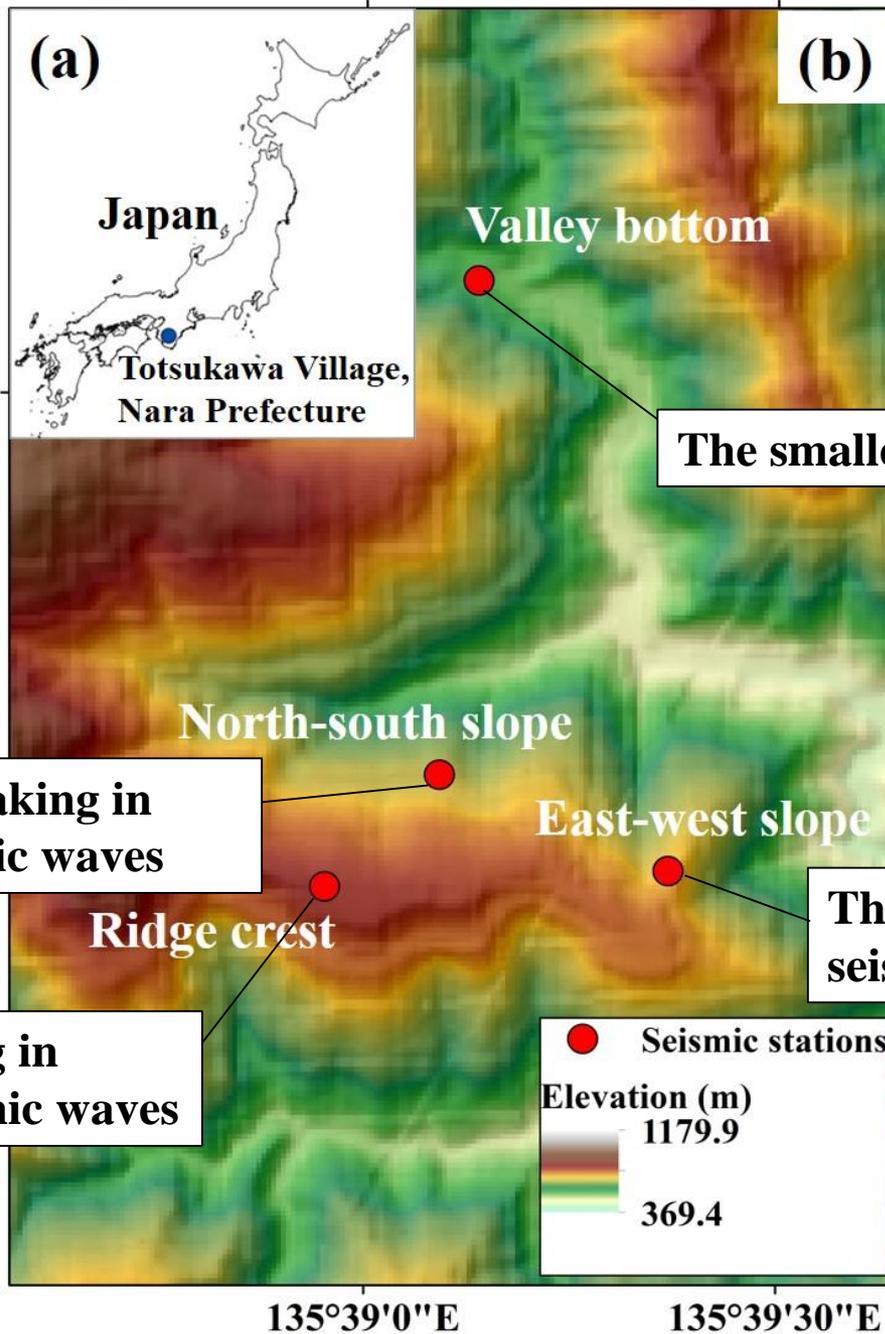
# 地震動臨時観測

November 15, 2017 — December 10, 2019



# 各地点における振幅の中央値





**The smallest ground shaking**

**The largest ground shaking in lower-frequency seismic waves**

**The largest ground shaking in seismic waves with >10 Hz**

**Large ground shaking in lower-frequency seismic waves**

# 台湾の地震による斜面崩壊の分布・確率の要因に関する研究

## 2019 Japan-New Zealand-Taiwan Seismic Hazard Workshop @ 洞爺湖

2019 G-SHA\_P-25

### Study of factors in distribution and probability of landslides triggered by earthquakes in Taiwan

Chia-Han Tseng<sup>1</sup> and Ruey-Juin Rau<sup>2</sup>

<sup>1</sup> Graduated Institute of Applied Geology, National Central University, Taoyuan, Taiwan  
<sup>2</sup> Department of Earth Sciences, National Cheng-Kung University, Tainan, Taiwan

#### Introduction

Landslides are prone to occur in orogenic and humid mountain belts in the world, and often become serious natural hazards for the cause of huge loss of human lives and properties.

Like many other places, the Taiwan Island is located on an active orogenic belt and in a subtropical monsoon climatic zone, so it is subject to earthquakes and highly cumulative rainfall. Hence, landslides often occur due to ground shaking caused by earthquakes and rock or soil weakening by heavy rainfall.

To minimize the losses of lives and properties resulting from landslides, understanding and predicting the distribution and probability of landslides triggered by either earthquakes or rainfall are a substantial issue.

#### Idea

The focus of this study is on studying factors of earthquake-triggered landslides. After an earthquake occurs, both seismic and geological factors which may influence distribution and probability of landslides should be taken into consideration. The idea of the analysis procedure is as follows (Fig. 1):

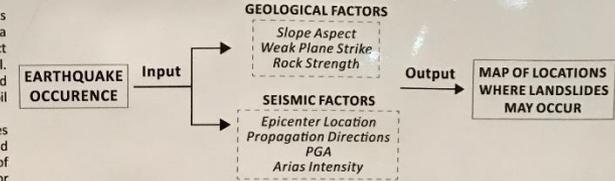


Figure 1: Analysis procedure for distribution and probability of earthquake-triggered landslides.

#### Earthquake-triggered landslides by the 1999 Chi-Chi earthquake in Taiwan

9272 large landslides (> 625 m<sup>2</sup>) occurred during the earthquake shaking (Liao and Lee, 2000). The total area of the landslides is 127.8 km<sup>2</sup>, and 8843 of the landslides are located within the region of PGA value ≥ 250 gal (Fig. 2).

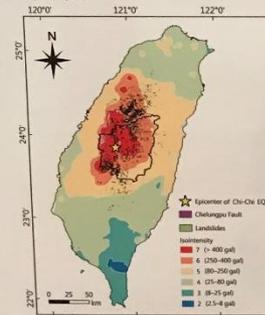


Figure 2: Locations of the landslides triggered by the 1999 Chi-Chi earthquake in Taiwan.

#### Earthquake-triggered landslides by the 1999 Chi-Chi earthquake in Nantou County

More than 1/3 (3222) of the Chi-Chi landslides occurred in Nantou County, where the hanging wall of the Chelungpu Fault is located (Fig. 3). Aspect of each landslide triggered can be correlated to the propagation direction of the seismic waves.

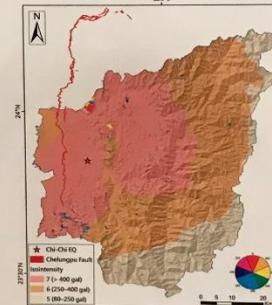


Figure 3: Landslides triggered by the 1999 Chi-Chi earthquake in Nantou County of Taiwan.

#### Dominant aspect of the dip slopes in Nantou County of Taiwan

According to the distribution of the dip slopes (from CGS, MOEA), provinces with the dominant aspect can be defined. The landslides triggered by the earthquake are not necessarily dip slopes, but are more related to the aspect of hillslopes.

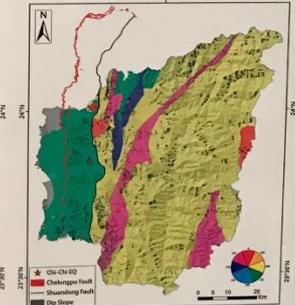


Figure 4: Provinces of the dominant dip slope aspect in Nantou County. The DEM has a resolution of 20 m/pixel.

#### Relationship between the landslide aspects and the propagation directions of seismic waves

About 52.6% of the landslides have the angles of smaller than 90° between their hillslope aspects and the propagation directions of the seismic waves of the 1999 Chi-Chi earthquake. Each of the angle groups have similar numbers of the landslides.

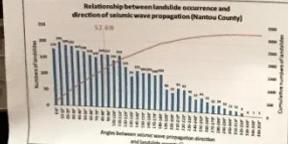


Figure 5: Numbers of the landslides vs. angles between seismic wave propagation direction and landslide aspects.

#### Amplification effect of seismic waves at the rear of hillslopes

When seismic waves coming from a hypocenter reach the hillslopes whose aspects are parallel to the propagation direction, the wave amplitude can be amplified probably owing to unconsolidated material near the ground surface, or due to wave oscillation parallel to the hillslope surfaces or weak planes, so that destabilize the slope material.

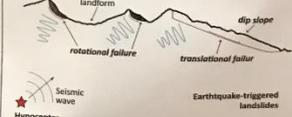


Figure 6: Slope failures, including rotational and translational failures triggered by amplification of seismic waves coming from the rear of the hillslopes.

#### Conclusions and future work

Earthquake-triggered landslides can be attributed both to geological and seismic conditions. In the case of the 1999 Chi-Chi earthquake, hillslope aspects can be one of the geological factors, and the propagation directions of the seismic waves correlate the hillslope aspects of the landslides triggered. Therefore, translational failures are not necessarily the majority of the landslides that are triggered by earthquakes.

The future work will be to create synthetical seismic waves coming from the hypocenters within and outside the Taiwan Island. Underground geological structures will also be taken into consideration in order to understand that if the path effect would also control the distribution of occurrence of earthquake-triggered landslides.

Contact information:  
E-mail: b89204007@ntu.edu.tw

Chen, Yi-Chin, et al., 2019. Controls of preferential orientation of earthquake- and rainfall-triggered landslides in Taiwan's orogenic mountain belt. *ESPL*, 44, 1661-1674.  
Liao and Lee, 2000. Landslides triggered by the Chi-Chi earthquake. *Proceedings of the 21st Asian Conference on Remote Sensing*, Taipei, Volume 1&2, 383-388.

# 地震波方向と斜面方位の夾角

- 半数以上の崩壊は斜面方位と地震波方向の夾角  $< 90^\circ$

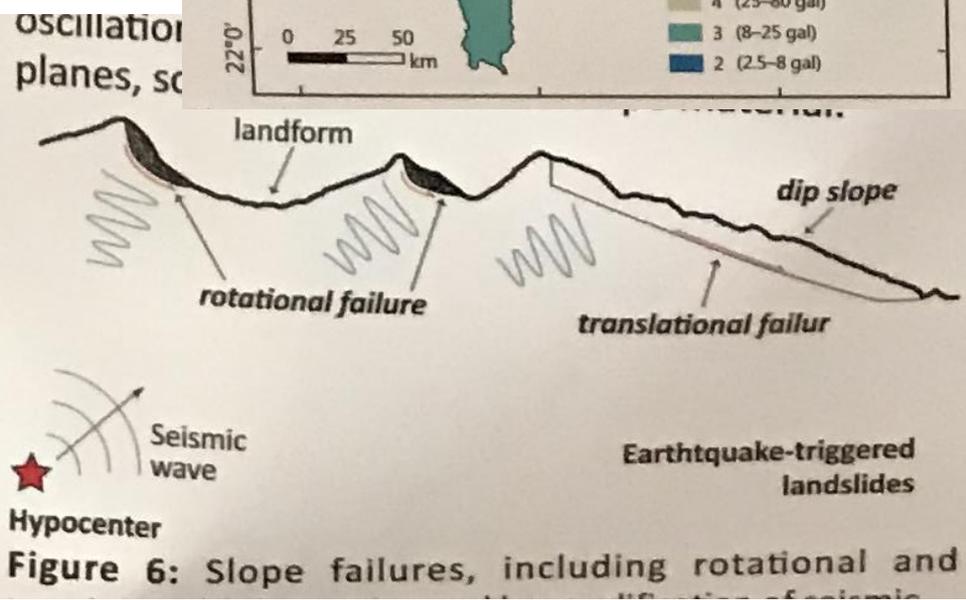
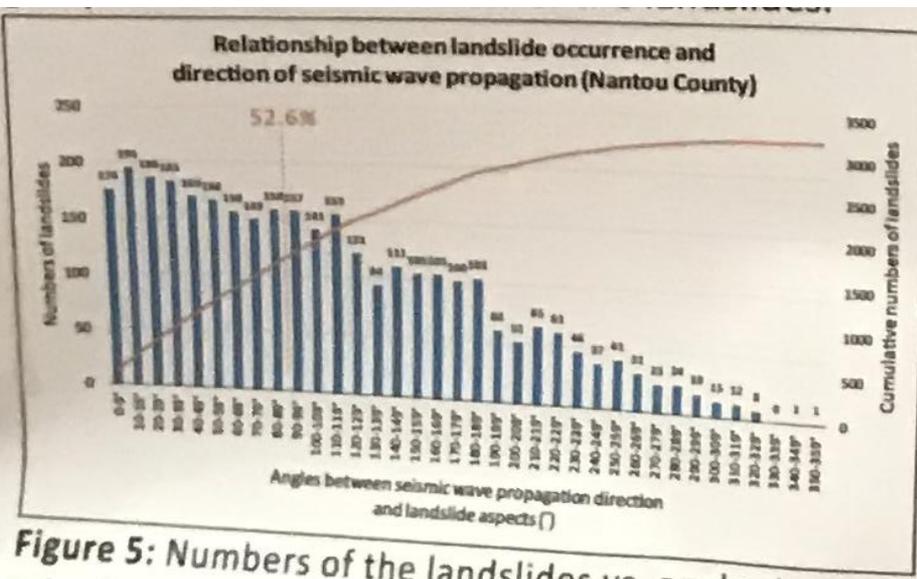
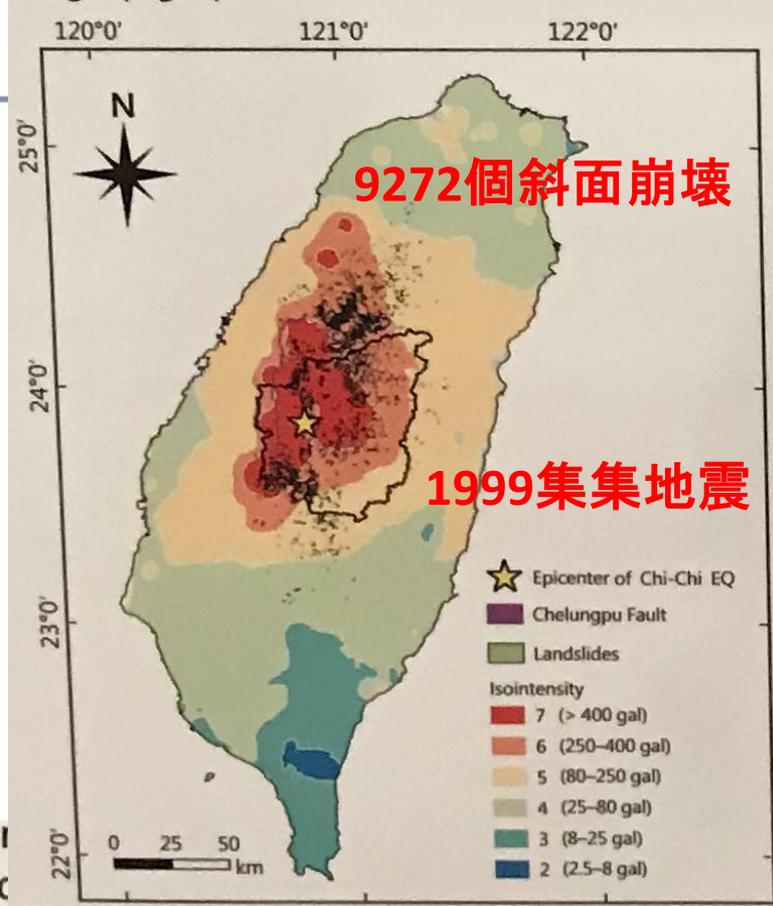


Figure 5: Numbers of the landslides vs. angles between seismic wave propagation direction and landslide aspects

Figure 6: Slope failures, including rotational and translational failures, triggered by seismic waves

# まとめ

## • 素因

- 地形 – 険しい山地地形
- 地質 – 脆弱な地質、  
テフラは台湾にほぼ分布していない

## • 誘因

- 降雨 – 台湾：2009年台風8号3000mm  
– 日本：2012年台風12号2000mm
- 地震 – 日本がより頻繁