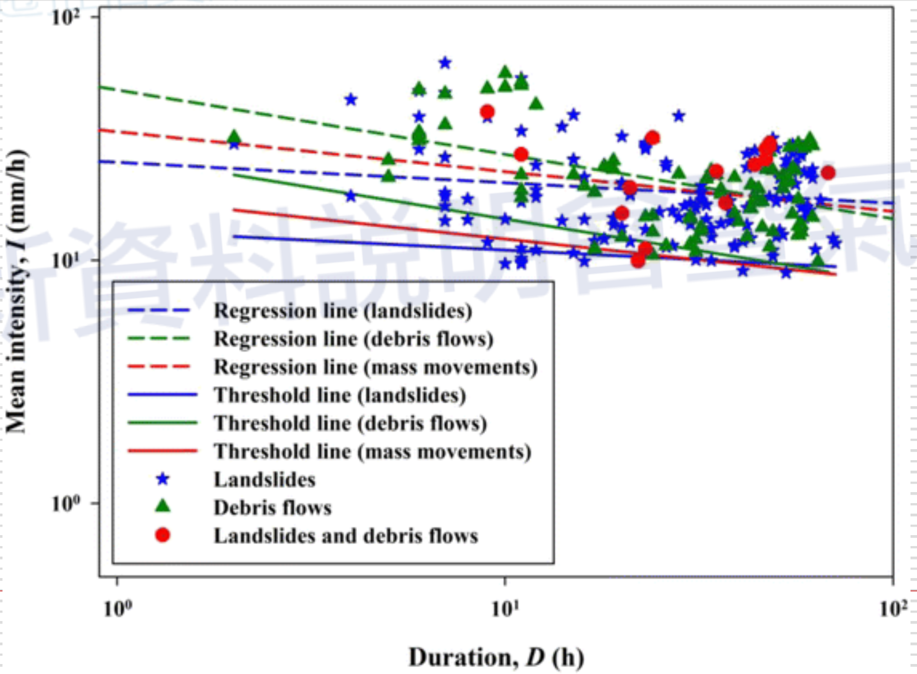
動力降尺度資料於坡地崩塌之評估

台灣大學地質科學系
陳麒文

2023.5.9

坡地崩塌發生的雨量基準值（閾值）

- 氣候變遷下坡地崩塌是否會增加？
- 統計方法（雖然忽略了坡地作用的基礎原理）對於區域特性的理解很重要 (Caine, 1980; Guzzetti et al., 2007)
- 崩塌會發生的最小雨量（雨量基準值）

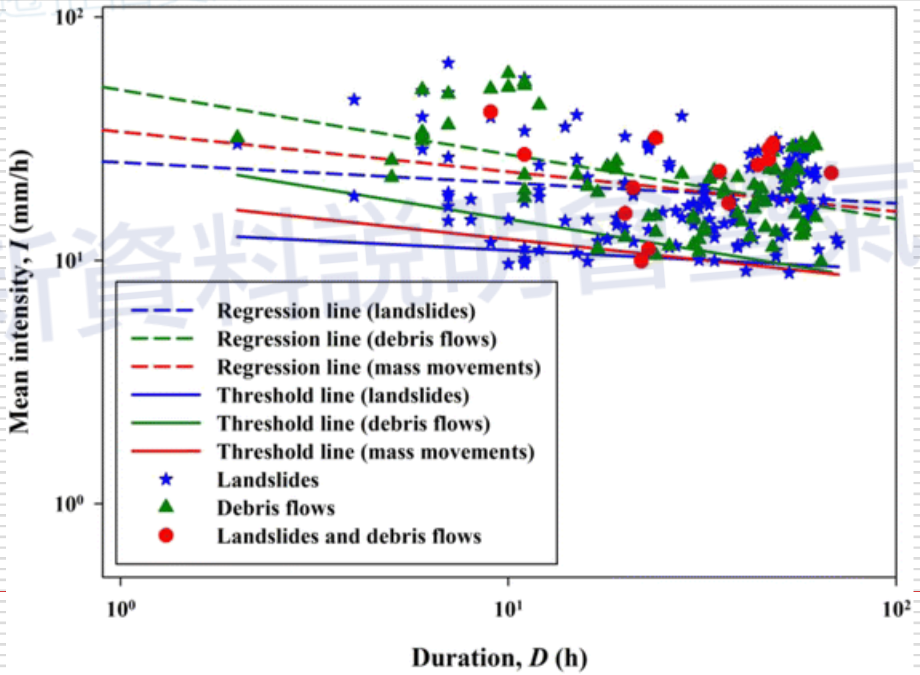


崩塌發生的降雨ID關係

台灣崩塌發生之降雨強度–降雨延時下限值（雨量基準值）的探討 (Chen et al., 2015)

坡地崩塌發生的雨量基準值（絕對值）

- 無法得知崩塌的數量及規模
  超過後的數量、規模是否增加？
- 由於氣候、地形、及地質的差異，不同地區的雨量基準值無法進行比較 (Guzzetti et al., 2008)



台灣崩塌發生之降雨強度–降雨延時下限值（雨量基準值）的探討 (Chen et al., 2015)

崩塌發生的降雨量因地而異

- 坡地崩塌對降雨的適應性（雨水適應性）

  「多雨地區比非多雨地區有更高的坡地崩塌臨界降雨量。當相當規模的豪雨發生時，坡地崩塌發生的數量較少」

  (Omura, 1982; Hayashi, 1985; Iida, 2012)

- 以氣候值和降雨機率來探討

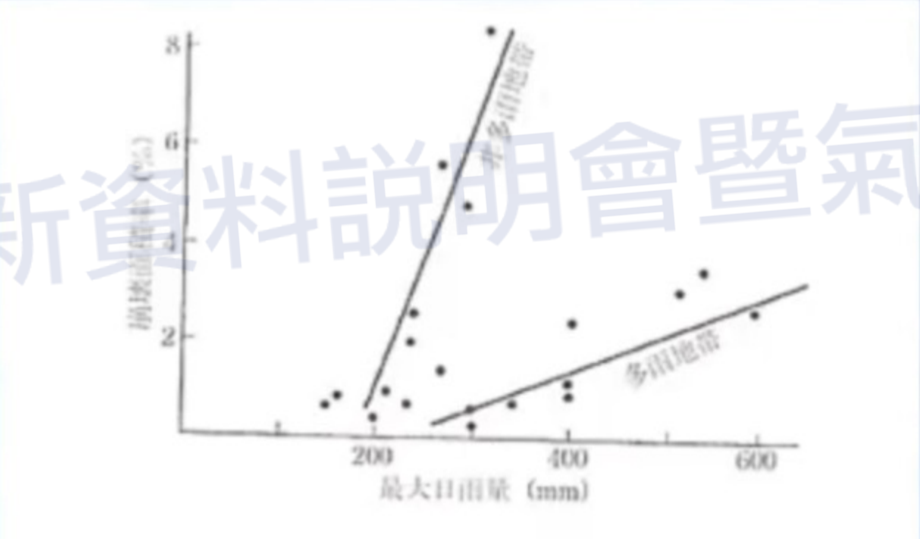


図 1. 10　最大日雨量と崩壊面積率の関係(難波・秋谷，1970)

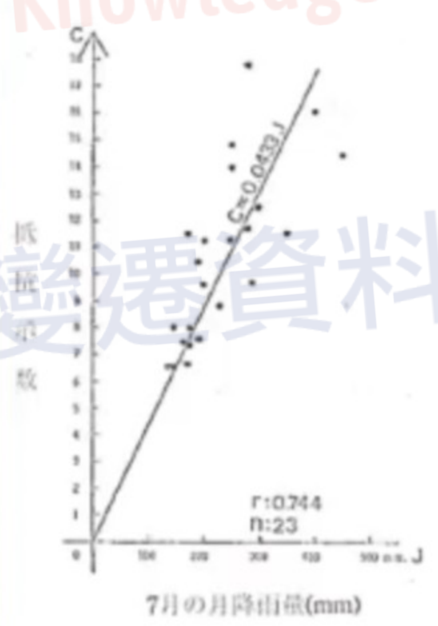


図 1. 11　7 月の平均月雨量と抵抗示数の関係 (大村，1982)

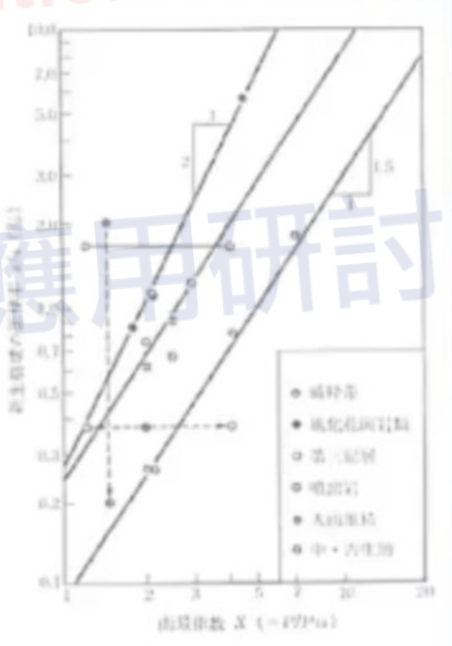


図 1. 12　雨量指数と新生崩壊の面積率 (林，1985)

廣域的崩塌目錄製作、崩塌發生的區域氣候學研究

- 斜坡單元的崩塌發生時間間隔：~1000年規模 (Dietrich et al., 1984; Iida, 1999)
- 在空間和時間範圍上對強降雨頻率的依賴性？

Kirschbaum et al., 2020

Geophysical Research Letters
RESEARCH LETTER
10.1029/2019GL085347

Key Points:
- We present the first quantitative view of how landslide activity may change within High Mountain Asia resulting from changes in extreme precipitation
- We find that the rate of increase in landslide activity at the end of the century is expected to be greatest over areas covered by current glaciers and glacial lakes
- We show how Global Climate Models and satellite observations can be used to model landslide impacts at time scales affected by climate change

Changes in Extreme Precipitation and Landslides Over High Mountain Asia

D. Kirschbaum[1], S. B. Kapnick[2], T. Stanley[1,3], and S. Pascale[4]

[1]Hydrological Sciences Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD, USA, [2]NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA, [3]Universities Space Research Association, Columbia, MD, USA, [4]Department of Earth System Science, Stanford University, Stanford, CA, USA

Abstract High Mountain Asia is impacted by extreme monsoonal rainfall that triggers landslides in large proportions relative to global distributions, resulting in substantial human impacts and damage to infrastructure each year. Previous landslide research has qualitatively estimated how patterns in landslide activity may change based on climate change scenarios. We present the first quantitative view of potential

Handwerger et al., 2022

Geophysical Research Letters
RESEARCH LETTER
10.1029/2022GL099499

Key Points:
- Open-access standardized products can be used to identify and monitor landslides over large regions
- Slow-moving landslides occur in both dry and wet environments with mean annual rainfall ranging from ~200 to ~2000 mm/yr
- Landslides are sensitive to seasonal, annual, and multi-year changes in rainfall in both dry and wet environments

Landslide Sensitivity and Response to Precipitation Changes in Wet and Dry Climates

Alexander L. Handwerger[1,2], Eric J. Fielding[1], Simran S. Sangha[1,3], and David P. S. Bekaert[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [2]Joint Institute for Regional Earth System Science and Engineering, University of California, Los Angeles, Los Angeles, CA, USA, [3]Earth, Planetary, and Space Sciences, University of California, Los Angeles, Los Angeles, CA, USA

Abstract Slow-moving landslides are hydrologically driven. Yet, landslide sensitivity to precipitation, and in particular, precipitation extremes, is difficult to constrain because landslides occur under diverse hydroclimatological conditions. Here we use standardized open-access satellite radar interferometry data to quantify the sensitivity of 38 landslides to both a record drought and extreme rainfall that occurred in California

Johnston et al., 2021

Geophysical Research Letters
RESEARCH LETTER
10.1029/2021GL094038

Key Points:
- We quantify the effect of precipitation on landslide concentration within distinct land use types across the US Pacific Coast
- Landslide hazard is most sensitive to precipitation variations in urbanized areas
- Results highlight the importance of considering interactions with urbanization when predicting landslide response to climate

Supporting Information:
Supporting Information may be found in the online version of this article.

Quantifying the Effect of Precipitation on Landslide Hazard in Urbanized and Non-Urbanized Areas

Elizabeth C. Johnston[1], Frances V. Davenport[1], Lijing Wang[2], Jef K. Caers[2,3], Suresh Muthukrishnan[4,5], Marshall Burke[1,6,7], and Noah S. Diffenbaugh[1,8]

[1]Department of Earth System Science, Stanford University, Stanford, CA, USA, [2]Department of Geological Sciences, Stanford University, Stanford, CA, USA, [3]Institute for Human-Centered Artificial Intelligence, Stanford University, Stanford, CA, USA, [4]Department of Earth, Environmental, and Sustainability Sciences, Furman University, Greenville, SC, USA, [5]GIS and Remote Sensing Center, Furman University, Greenville, SC, USA, [6]Center on Food Security and the Environment, Stanford University, Stanford, CA, USA, [7]Environment and Energy Economics, National Bureau of Economic Research, Cambridge, MA, USA, [8]Woods Institute for the Environment, Stanford University, Stanford, CA, USA

Abstract Although most landslides are precipitation-triggered, a number of other complex conditions simultaneously predispose any given slope to failure, with the impact of urbanization posing particular scientific challenges. We use panel regression with fixed effects—which controls for observed

Luna and Korup, 2021

Geophysical Research Letters
RESEARCH LETTER
10.1029/2022GL098506

Key Points:
- Bayesian inference learns the seasonal pattern of landslide activity in the Pacific Northwest from five combined heterogeneous inventories
- Landsliding is distinctly seasonal with highest probability (intensity) in January (February), lagging the annual precipitation peak
- Landslide intensity for a given monthly rainfall during peak season in February is up to 10 times higher than at the onset in November

Supporting Information:
Supporting Information may be found in the online version of this article.

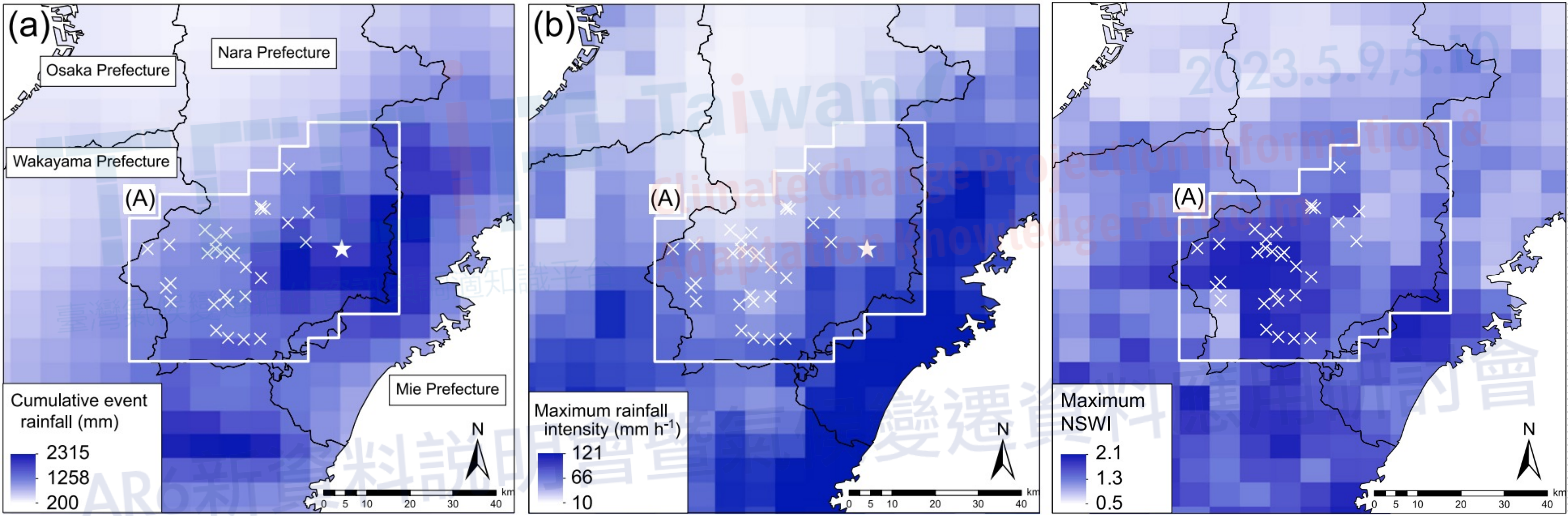
Seasonal Landslide Activity Lags Annual Precipitation Pattern in the Pacific Northwest

L. V. Luna[1,2,3] and O. Korup[1,2]

[1]Institute of Environmental Science and Geography, University of Potsdam, Potsdam, Germany, [2]Institute of Geosciences, University of Potsdam, Potsdam, Germany, [3]Potsdam Institute for Climate Impact Research, Potsdam, Germany

Abstract Seasonal variations in landslide activity remain understudied compared to recent advances in landslide early warning at hourly to daily timescales. Here, we learn the seasonal pattern of monthly landslide activity in the Pacific Northwest from five heterogeneous landslide inventories with differing spatial and temporal coverage and reporting protocols combined in a Bayesian multi-level model. We find that landslide activity is distinctly seasonal, with credible increases in landslide intensity, inter-annual variability, and probability marking the onset of the landslide season in November. Peaks in landslide probability in January and intensity in February lag the annual peak in mean monthly precipitation and landslide activity is more variable in winter than in summer, when landslides are rare. For a given monthly rainfall, landslide intensity at the season peak in February is up to 10 times higher than at the onset in November, underlining the importance

雨量絕對值和崩塌分布無法對應的案例
（2011年塔拉斯颱風；日本紀伊半島）



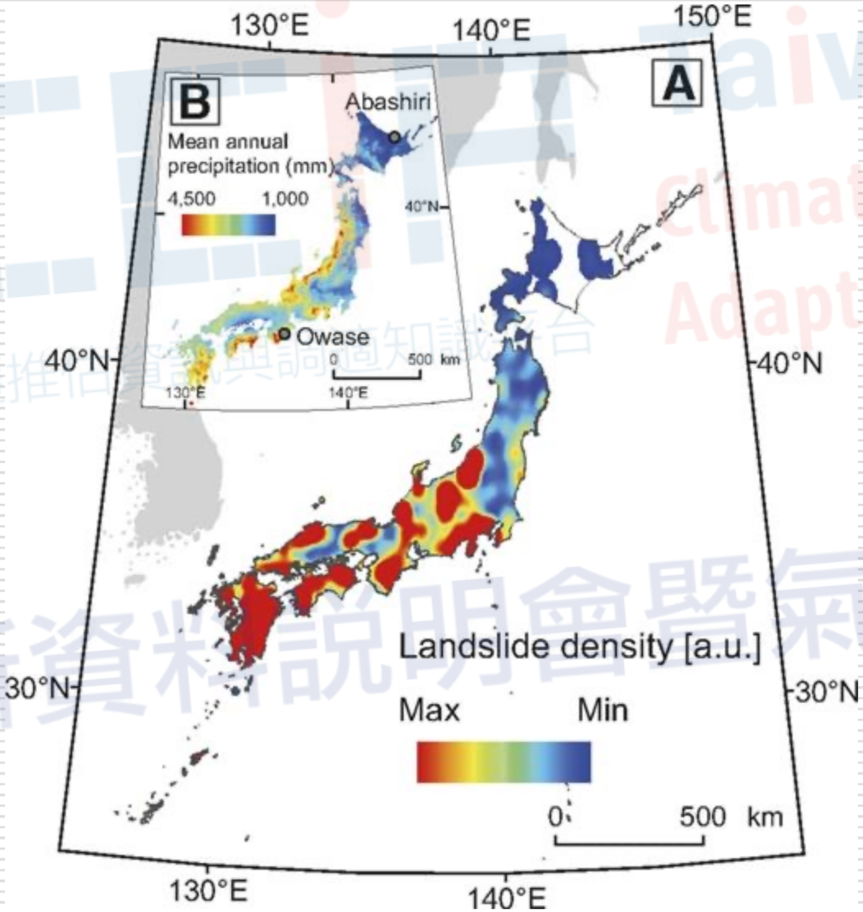
累積雨量　　最大1小時雨量　　土壤雨量指數/10年最大值

- ➢ 該區域的豪雨歷史及機率評估的重要性

(Saito and Matsuyama, 2012; Marc et al., 2019)

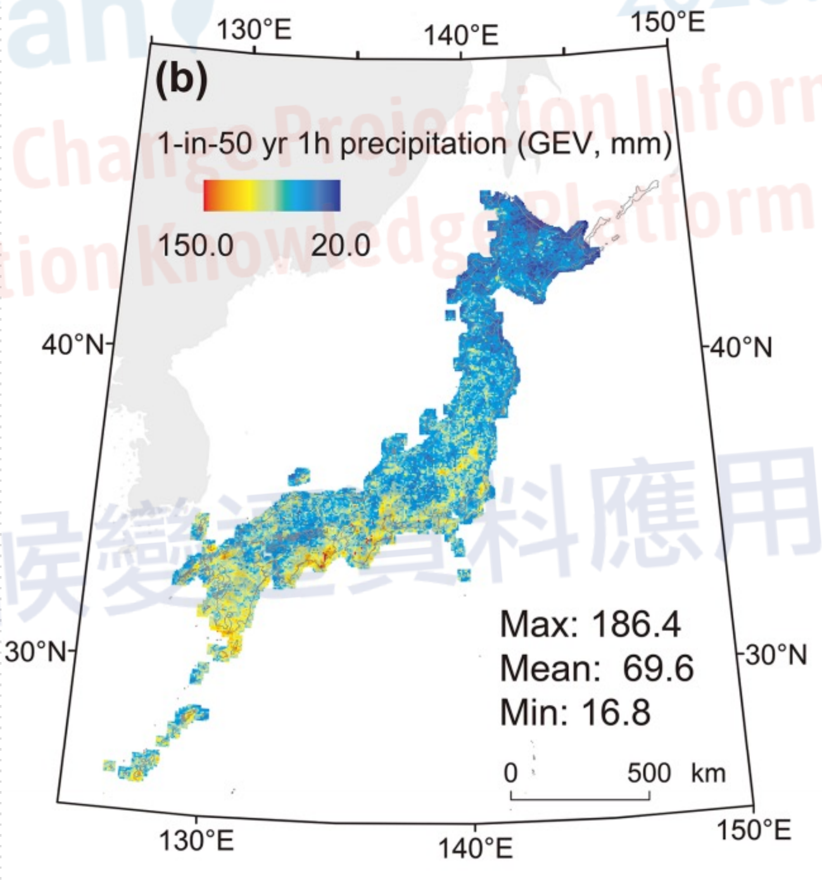
崩塌分佈（密度）有區域偏差（集中在日本西南部）

➢ 不能僅僅用「雨水適應性」來解釋 (Iida and Yamada, 2018)



崩塌發生密度 (2001~2011)

(Saito et al., 2014)

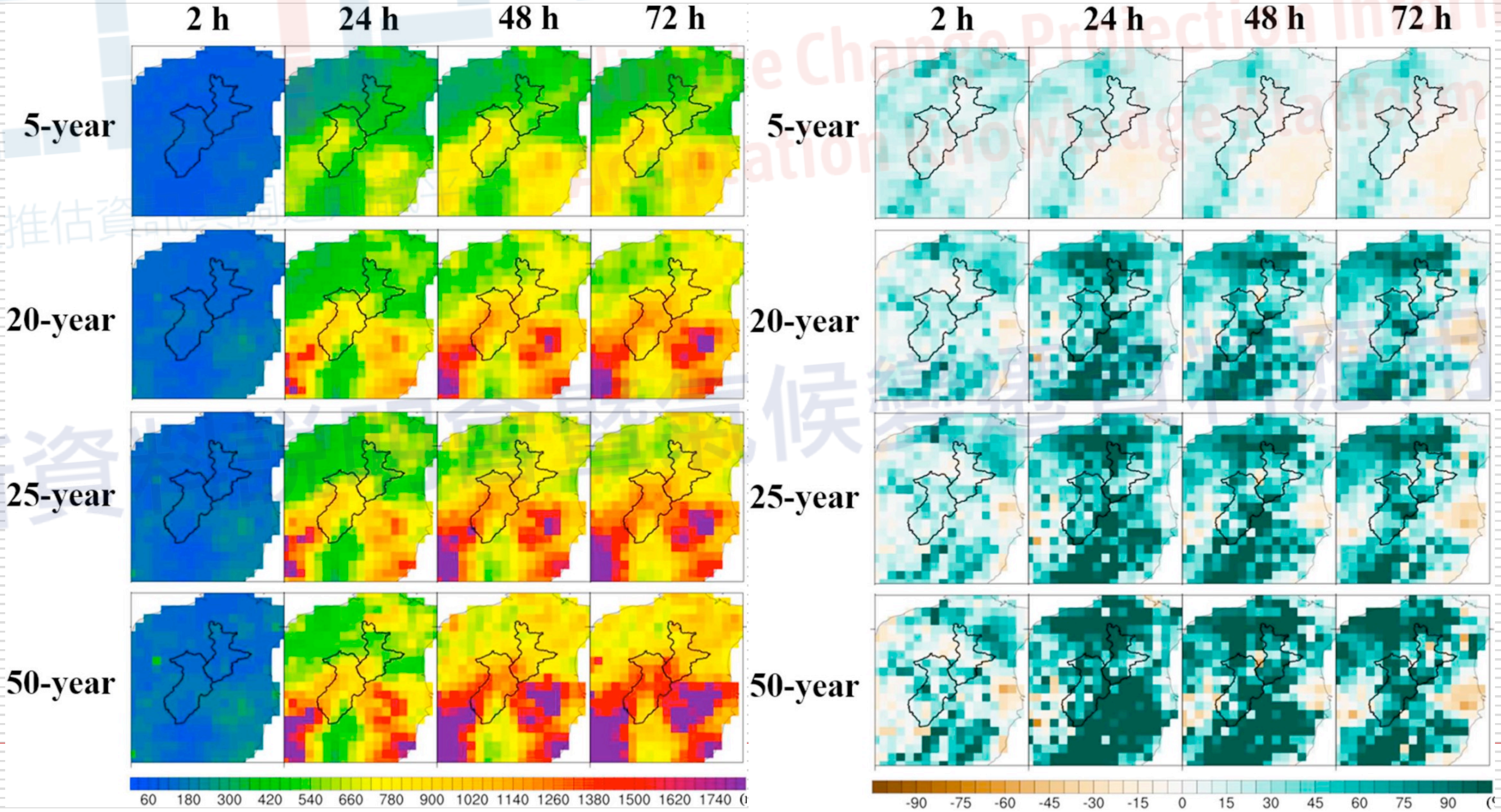


50年1次的1小時雨量

(Saito and Matsuyama, 2015)

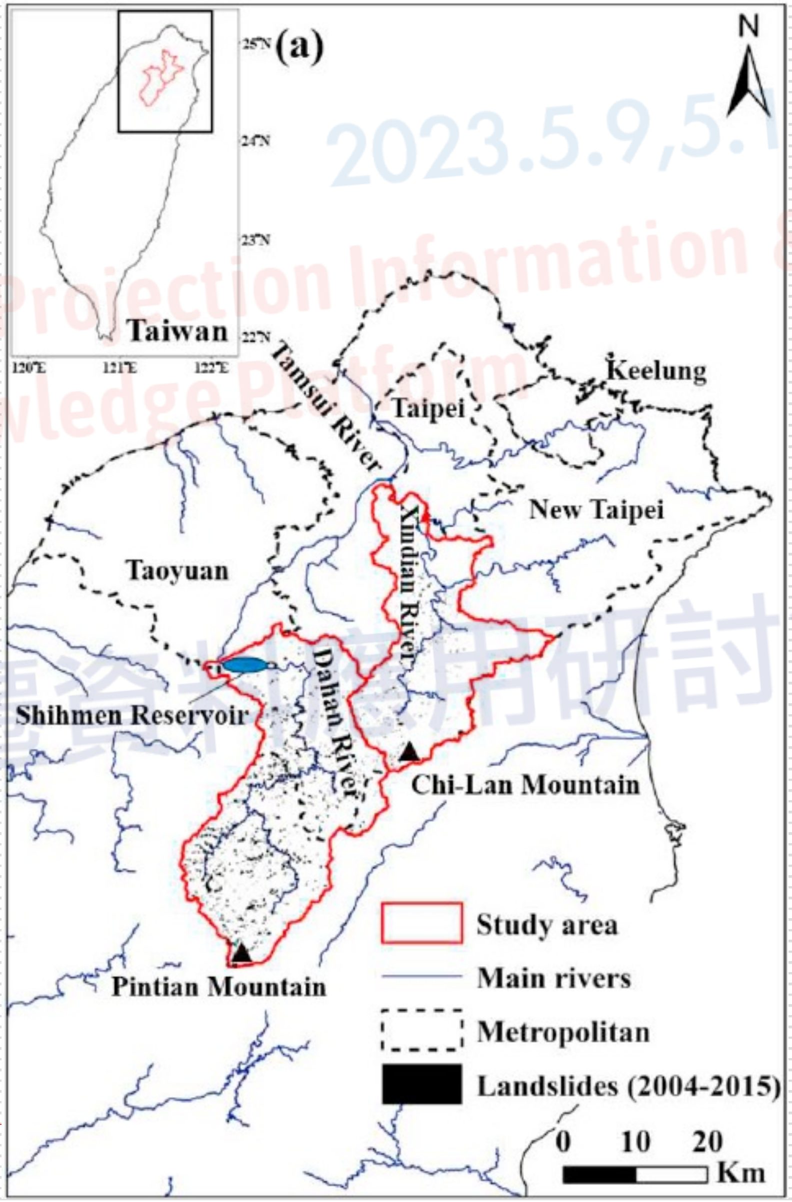
研究目的

- 以崩塌發生的降雨及其重現期（機率年）探討氣候變遷影響下的崩塌特性及其空間分布



研究區域

- ➢ 淡水河流域
  - ✓ 石門水庫集水區
  - ✓ 新店溪（南勢溪）集水區
- ➢ 林務局判釋全島崩塌地圖(2004–2015)
  - ✓ 8場颱風事件



研究方法（觀測雨量）

- 雷達降雨（1.25 km；小時）
  - →建立崩塌發生的降雨ID關係
  - →建立崩塌特性和降雨的經驗關係

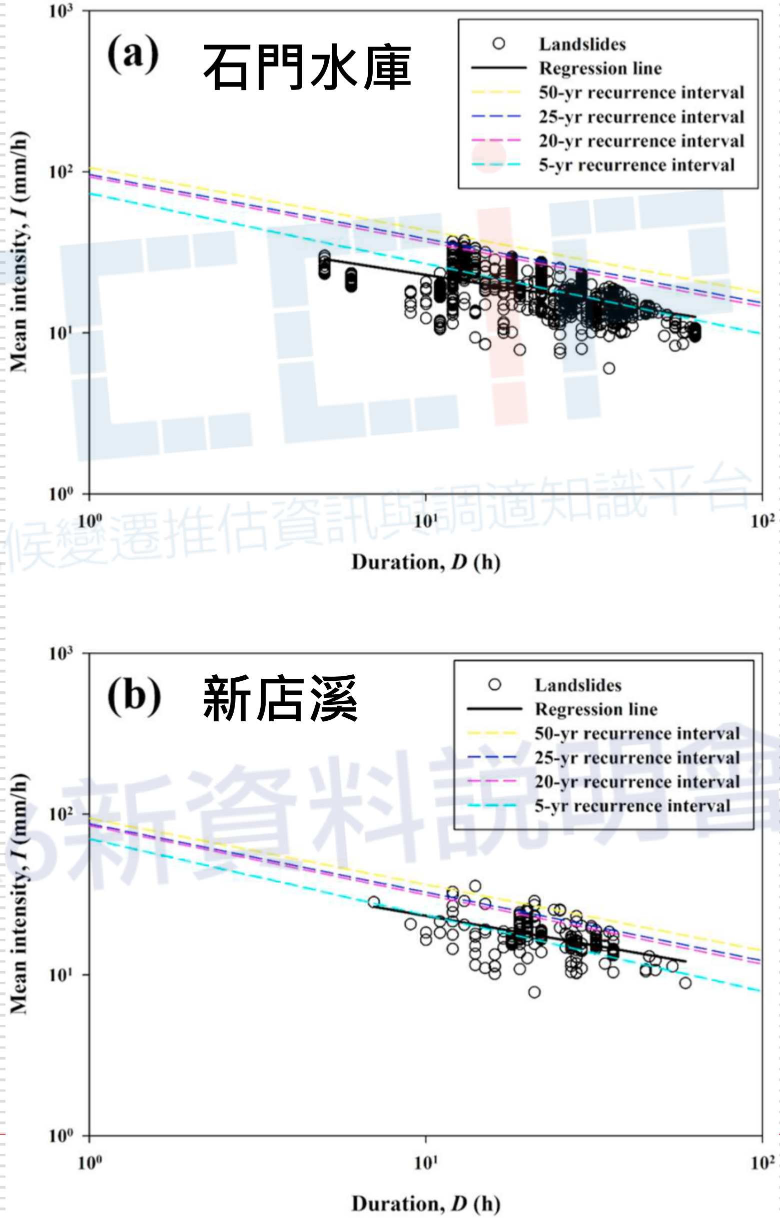
- 雨量站 （1991–2013；5 km；小時）
  - →計算水文統計重現期（一般化極值分配：GEV）

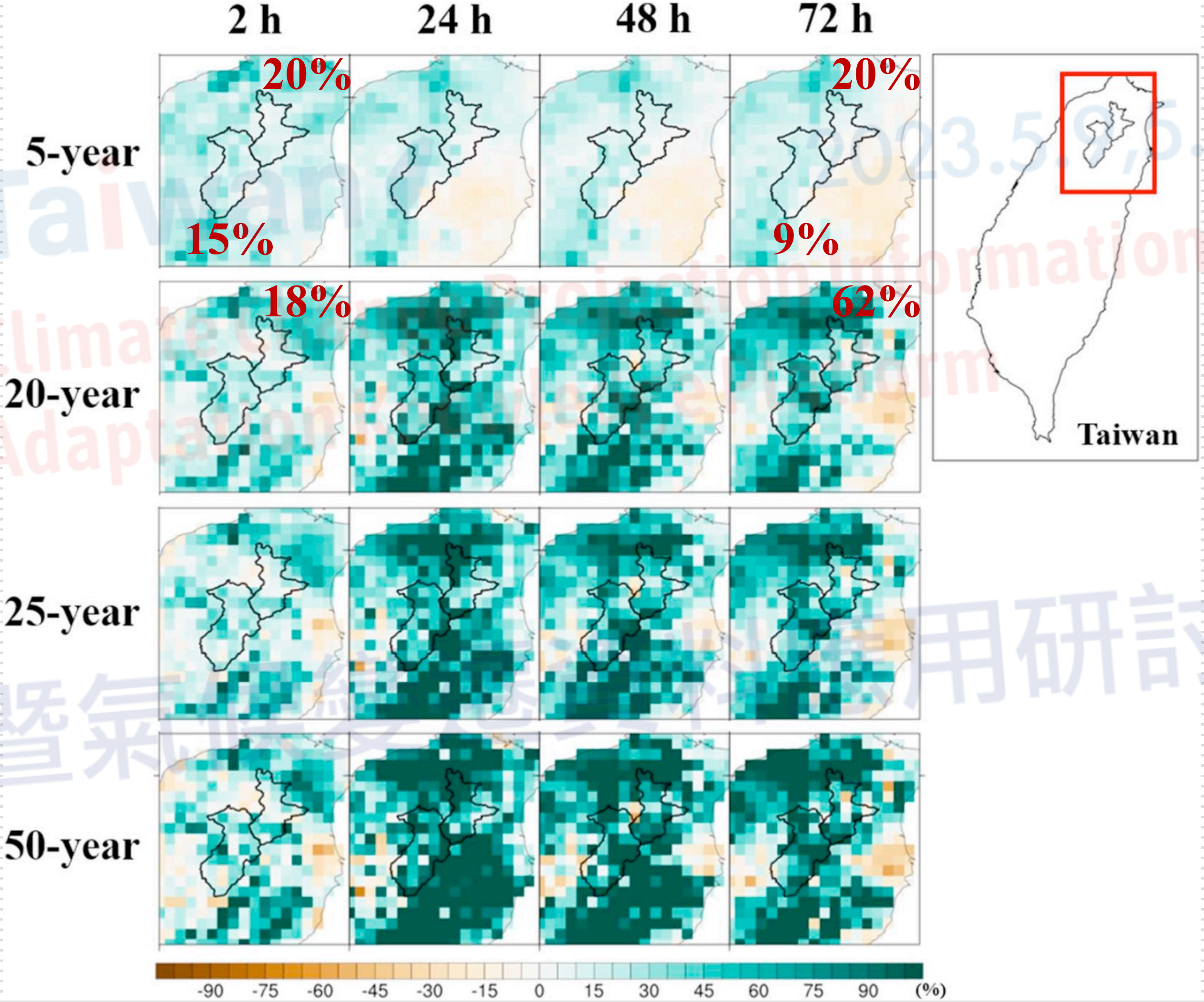
✓ 降雨延時2、24、48、72小時的5、20、25、50年重現期

研究方法（模式雨量）

- AR5 WRF-MRI動力降尺度（5 km；小時）
  - ✓ MRI-AGCM （20 km）
  - ✓ RCP8.5系集平均海水面溫度
- 基期 (1979–2003)
  - ✓ 計算水文統計重現期
  - ✓ 84場颱風
- 21世紀末 (2075–2099)
  - ✓ 計算水文統計重現期
  - ✓ 45場颱風

降雨ID關係與降雨重現期





石門水庫：以小規模崩塌增加為主

新店溪：崩塌將明顯增加（特別是大規模）

崩塌特性和降雨的經驗關係

石門水庫

	D	E	I	I_p	A_M	L	N	A_T
D	1.00							
E	0.65	1.00						
I	-0.40	0.44	1.00					
I_p	-0.91	-0.43	0.57	1.00				
A_M	0.57	0.97	0.50	-0.42	1.00			
L	0.86	0.91	0.07	-0.63	0.81	1.00		
N	0.43	0.82	0.45	-0.17	0.74	0.79	1.00	
A_T	0.86	0.91	0.07	-0.63	0.81	1.00	0.79	1.00

D: Duration
E: Cumulative rainfall
I: Mean rainfall intensity
I_p: Peak rainfall intensity
A_M: Maximum landslide area
L: Landslide ratio
N: Number of landslides
A_T: Total landslide area

$$A_T = 4697.3 \times E + 737287$$

$$L = 0.0006 \times E + 0.0974$$

$$A_M = 921.69 \times E - 141948$$

$$N = 0.6969 \times E + 71.532$$

新店溪

	D	E	I	I_p	A_M	L	N	A_T
D	1.00							
E	0.70	1.00						
I	-0.36	0.40	1.00					
I_p	0.07	0.52	0.69	1.00				
A_M	-0.35	0.18	0.79	0.87	1.00			
L	0.00	0.54	0.79	0.89	0.91	1.00		
N	0.06	0.57	0.75	0.84	0.86	0.99	1.00	
A_T	0.00	0.54	0.79	0.89	0.91	1.00	0.99	1.00

D: Duration
E: Cumulative rainfall
I: Mean rainfall intensity
I_p: Peak rainfall intensity
A_M: Maximum landslide area
L: Landslide ratio
N: Number of landslides
A_T: Total landslide area

$$A_T = 23764 \times I_p - 547585$$

$$L = 0.0049 \times I_p - 0.1119$$

$$A_M = 3924.4 \times I_p - 89062$$

$$N = 6.0251 \times I_p - 137.23$$

氣候變遷下崩塌特性變化

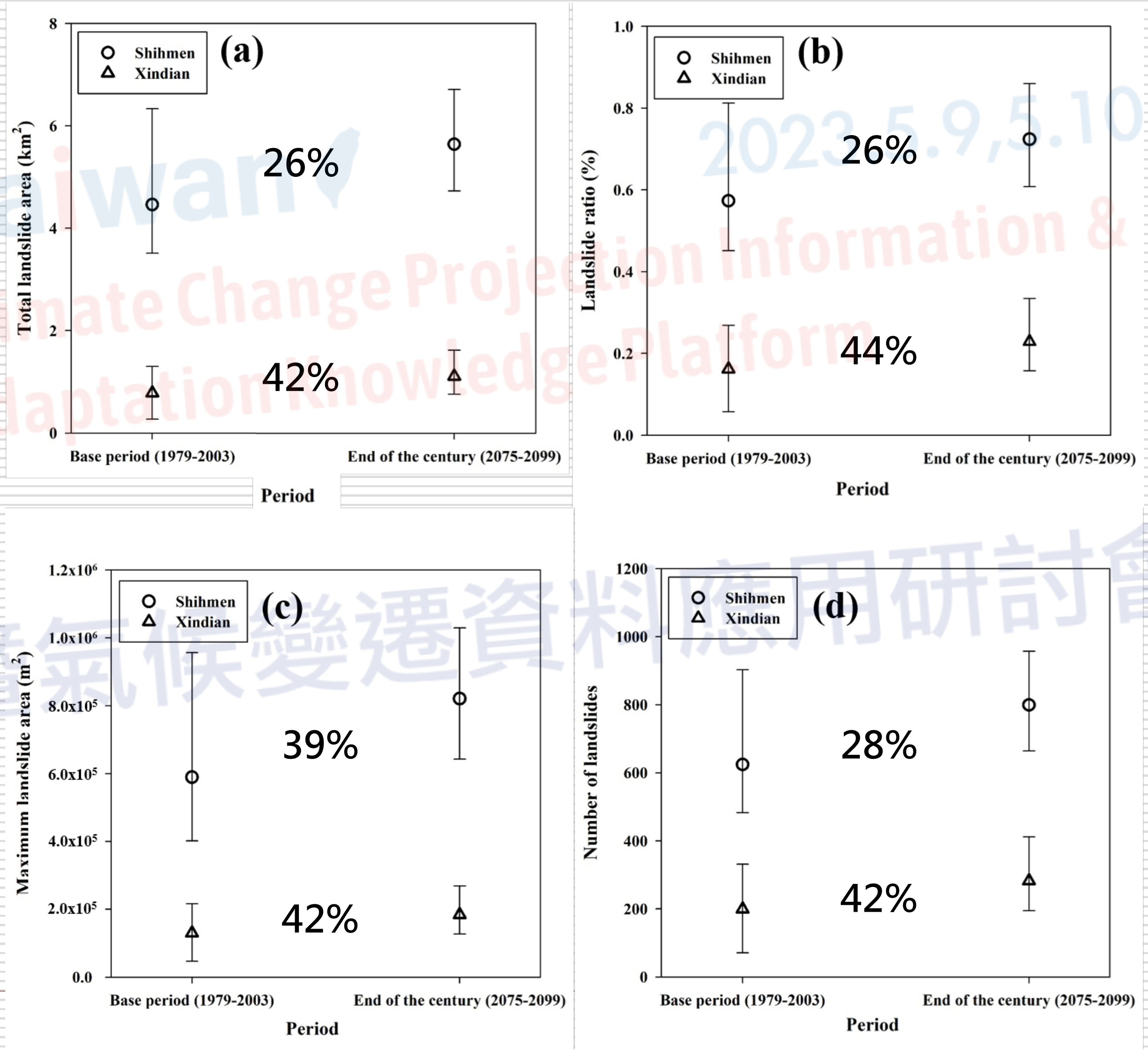
- 基期和21世紀末各依照總雨量選取**前10%**的颱風事件（8場及4場）

應該選取到前百分之多少的颱風事件？

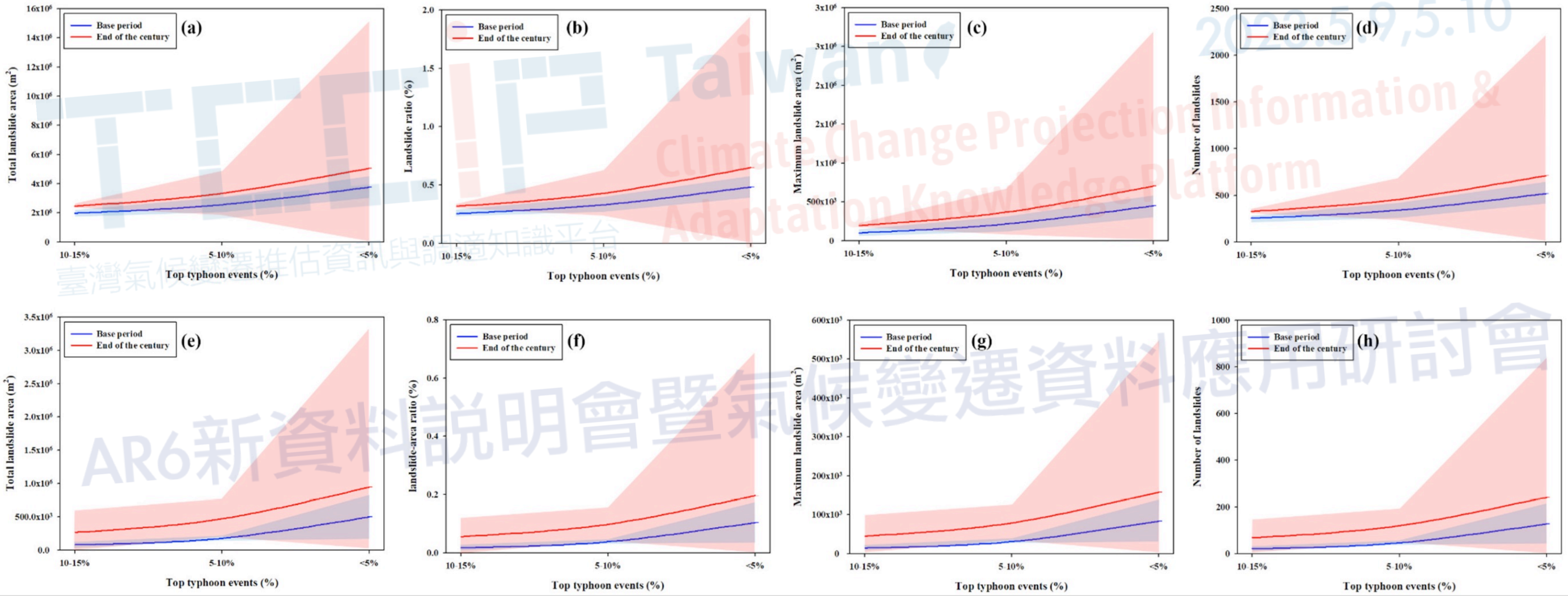
崩塌規模

崩塌大小

崩塌個數



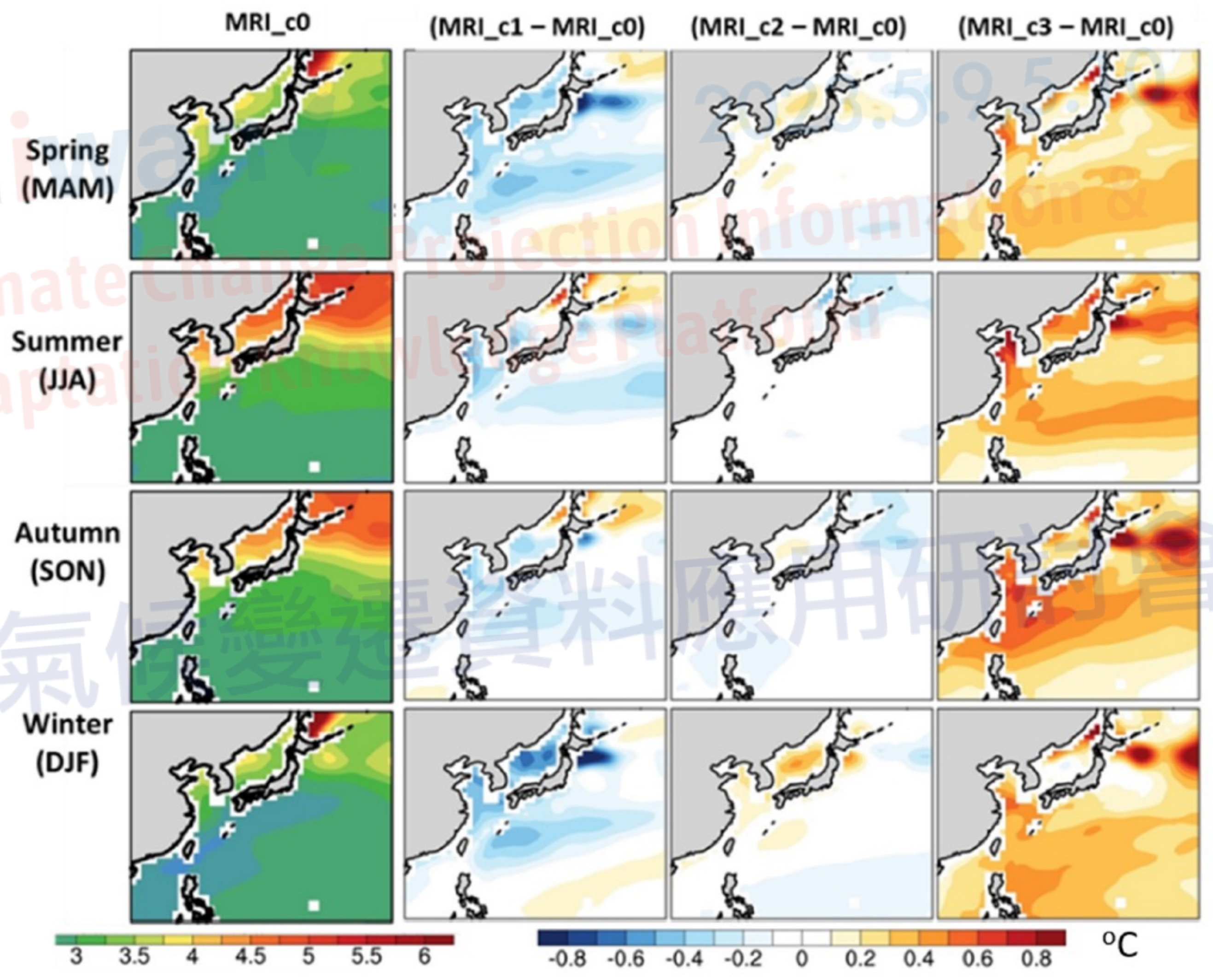
氣候變遷的不確定性


Base period
End of the century
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
Total landslide area (m^2)
Landslide ratio (%)
Maximum landslide area (m^2)
Number of landslides
landslide-area ratio (%)
Top typhoon events (%)
10-15%
5-10%
<5%

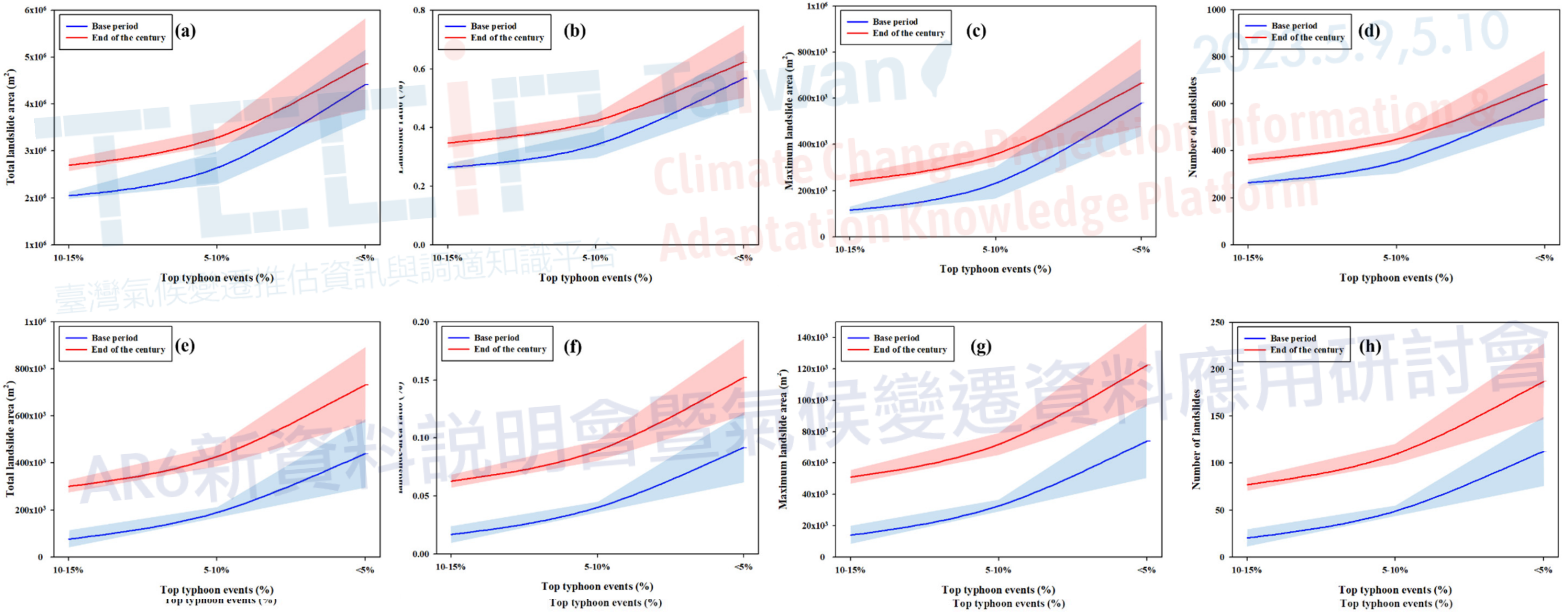
可用之氣候變遷情境

基期
(1979–2003)
84+82=166場颱風
m01+m00 (AR4 A1B情境)

21世紀末
(2075–2099)
45+23+55+46=169場颱風
c0+c1+c2+c3
（群集分析）



降低不確定性

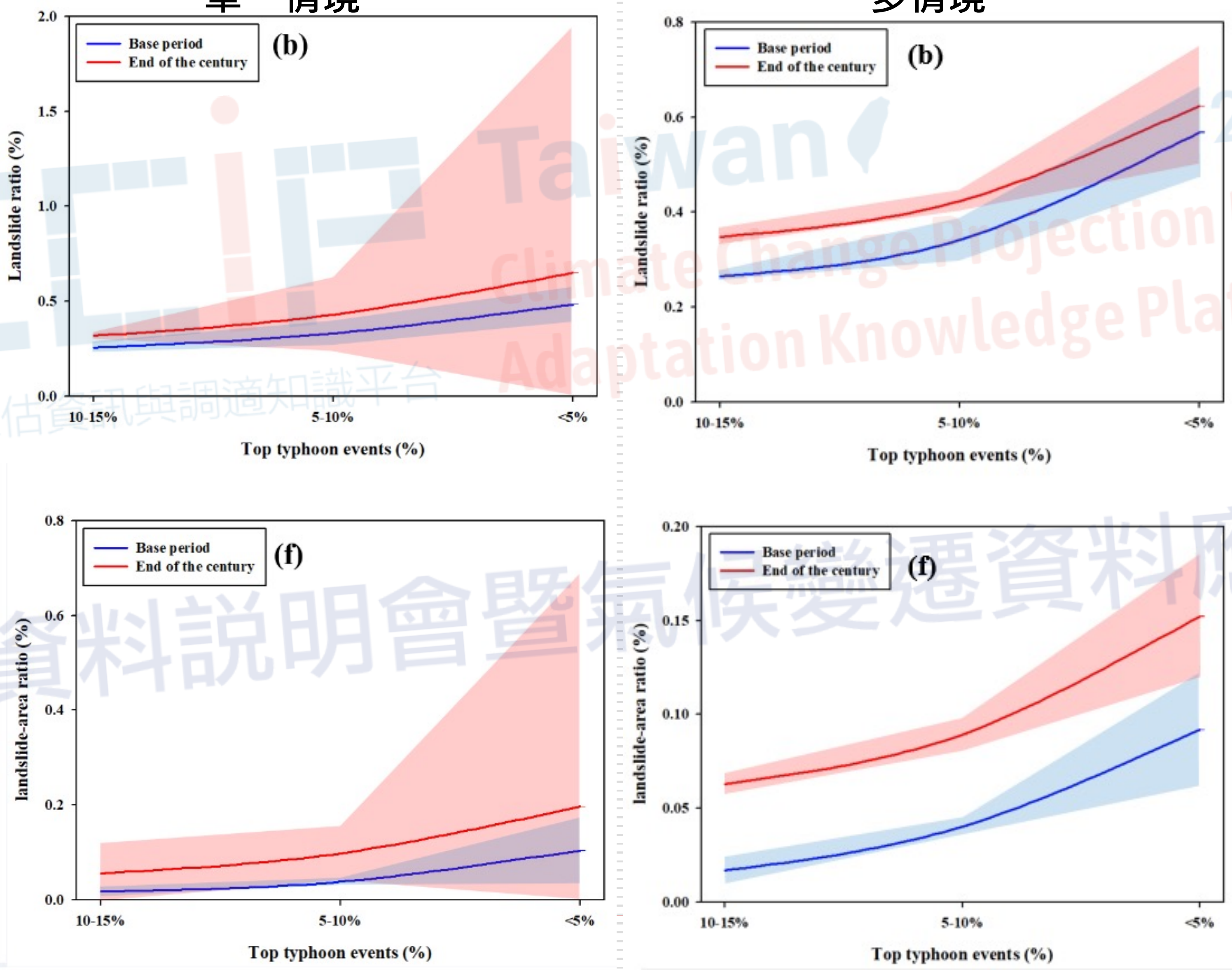

(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
Base period
End of the century
Total landslide area (m^2)
Maximum landslide area (m^2)
Number of landslides
Top typhoon events (%)
10-15%
5-10%
<5%

兩集水區之崩塌率變化

單一情境　　多情境

石門水庫

新店溪



多情境系集模擬
① 更可靠的預測
② 極端現象預測

結論

- 動力降尺度資料，適合以氣候學觀點分析崩塌發生的特性及其空間分布
  - ✓ 多雨地區與非多雨地區的比較
  - ✓ 乾濕季或季節性對崩塌發生的影響

- 動力降尺度的颱風資料需依照區域特性（崩塌特性、氣候特性），選取適當的颱風數量

謝謝聆聽　敬請指教