

# **Escalating Tropical Cyclone Precipitation Extremes and Landslide Hazards in South China under Global Warming**

**Xiaoming Shi**

Division Of Environment And Sustainability  
Hong Kong University Of Science And Technology

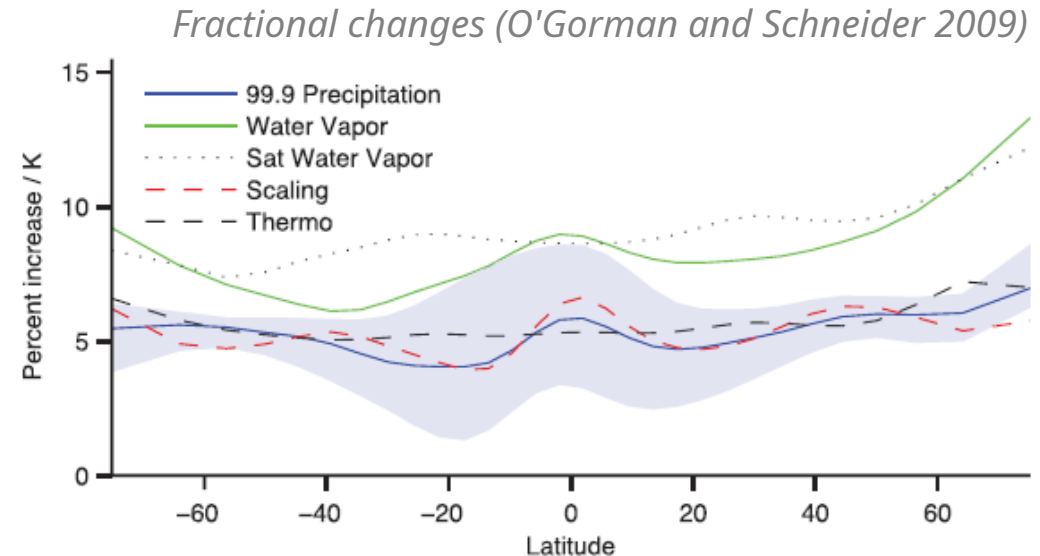
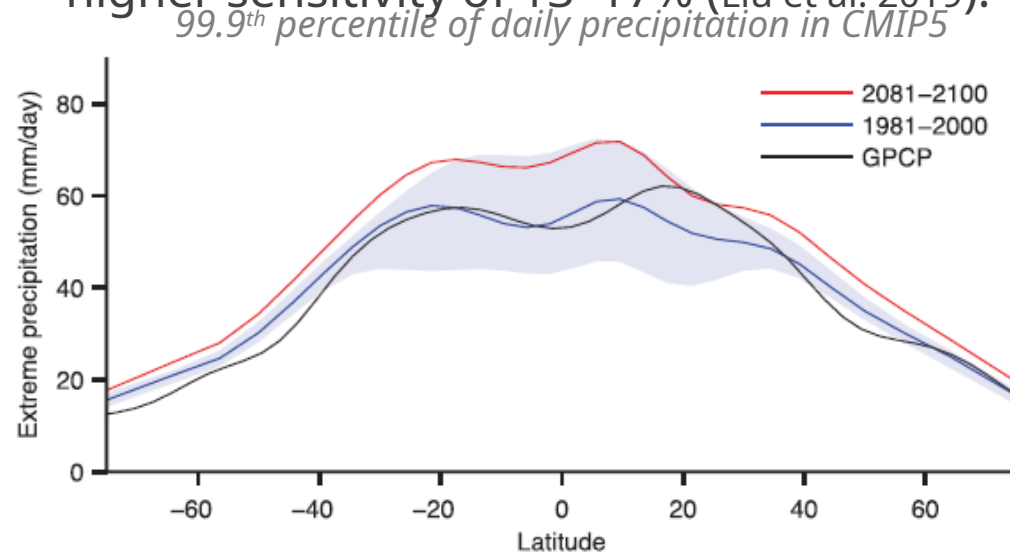
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March 10, 2026

**The 58<sup>th</sup> Session of ESCAP/WMO Typhoon Committee  
Jeju Island, Republic of Korea**

# Current Predictions and Uncertainties

- Previous studies found more confidence in predicting extratropical extreme precipitation under global warming, mostly due to thermodynamical reasons.
- Tropical convection exhibits large uncertainties: 2 – 9 %/K of warming.
- For tropical cyclones' precipitation, experts' estimation is 1.5 – 11 %/K of warming (Knutson et al. 2020).
- Some high-resolution (~25km) global models, despite their outliers status, suggest an even higher sensitivity of 13–17% (Liu et al. 2019).



# Convection Permitting Simulations

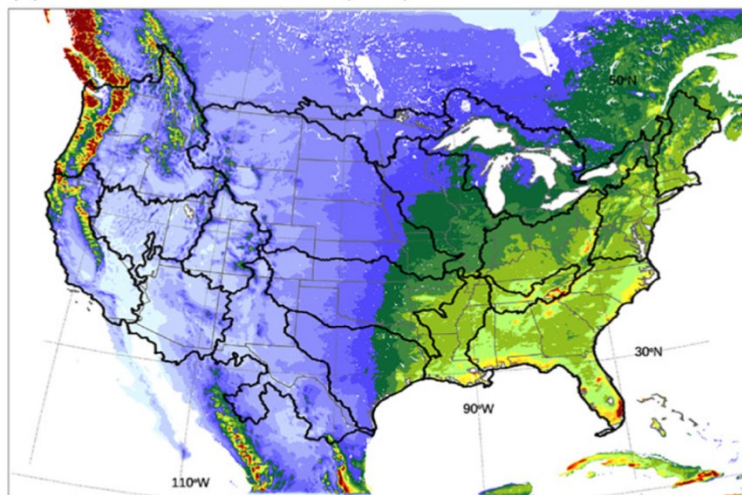
- Convection permitting simulations ( $\Delta x \sim 1$  km) have become popular in climate studies.

**BAMS**  
Article

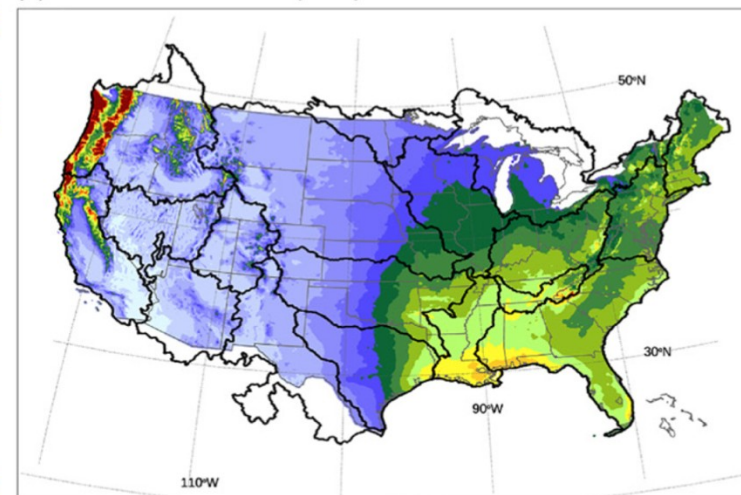
**CONUS404**  
The NCAR-USGS 4-km Long-Term Regional Hydroclimate Reanalysis over the CONUS

R. M. Rasmussen, F. Chen, C.H. Liu, K. Ikeda, A. Prein, J. Kim, T. Schneider, A. Dai, D. Gochis, A. Dugger, Y. Zhang, A. Jaye, J. Dudhia, C. He, M. Harrold, L. Xue, S. Chen, A. Newman, E. Dougherty, R. Abolafia-Rosenzweig, N. D. Lybarger, R. Viger, D. Lesmes, K. Skalak, J. Brakebill, D. Cline, K. Dunne, K. Rasmussen, and G. Miguez-Macho

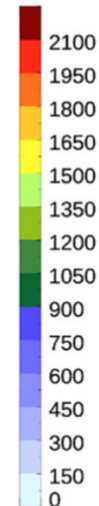
(a) CONUS404 Mean annual precipitation: WY1986-WY2020



(b) PRISM Mean annual precipitation: WY1986-WY2020



mm



# km-Scale

## GLOBAL MODELLING SUMMIT 2026

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## Overview

Welcome to the km-scale Global Modelling Summit 2026!

## Enabling Smart Dynamical Downscaling of Extreme Precipitation Events With Machine Learning

Xiaoming Shi<sup>1,2</sup> 

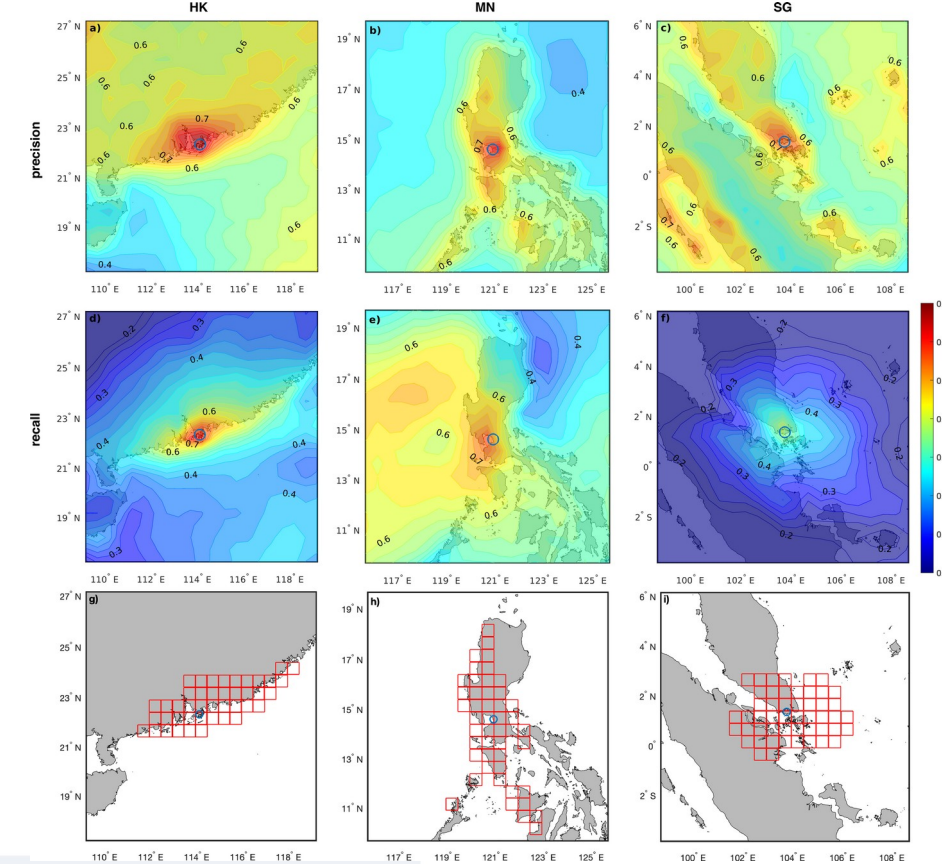
<sup>1</sup>Division of Environment and Sustainability, Hong Kong University of Science and Technology, Hong Kong.

<sup>2</sup>Department of Civil and Environmental Engineering, Hong Kong University of Science and Technology, Hong Kong

**Key Points:**

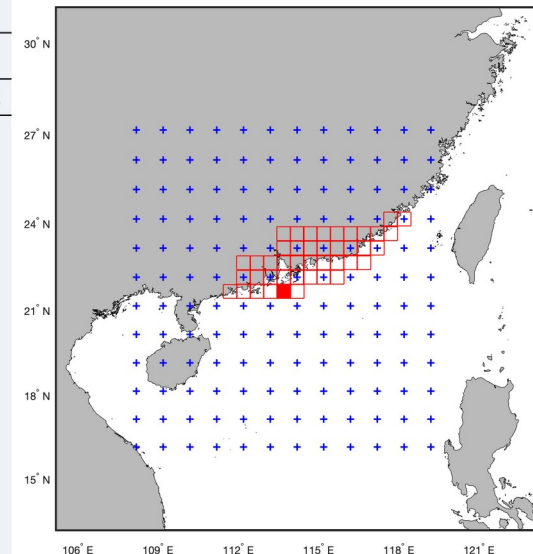
- Dynamical downscaling at ~1-km resolution produces reliable estimations of extreme rainfall but is computationally expensive
- Machine learning (ML) makes smart dynamical downscaling (SDD) possible, where ML

- We started the idea of Smart Dynamical Downscaling (SDD) in 2020.
- The validity of this idea was tested for Hong Kong, Manila, and Singapore
- The deep learning model takes in large-scale circulation patterns and predict rain intensity at the domain center
- Generalizability is **good for subtropical** region but limited for deep tropics



**Table 1**  
Performance Metrics of RaNet and RxNet

		HK Region		MN Region		SG Region	
		RaNet	RxNet	RaNet	RxNet	RaNet	RxNet
accuracy	FNL	0.936	0.961	0.897	0.933	0.900	0.920
	ERA5	0.948	0.964	0.904	0.938	0.905	0.931
	JRA-55	0.950	0.957	0.907	0.931	0.883	0.926
precision	FNL	0.238	0.331	0.229	0.307	0.230	0.274
	ERA5	0.257	0.326	0.224	0.292	0.201	0.238
	JRA-55	0.259	0.276	0.217	0.241	0.148	0.180
recall	FNL	0.921	0.858	0.832	0.748	0.770	0.749
	ERA5	0.777	0.663	0.725	0.553	0.557	0.428
	JRA-55	0.738	0.645	0.650	0.462	0.475	0.299
recall (99%)	FNL	0.985	0.983	0.955	0.935	0.927	0.936
	ERA5	0.927	0.843	0.904	0.800	0.742	0.643
	JRA-55	0.901	0.798	0.864	0.695	0.622	0.465



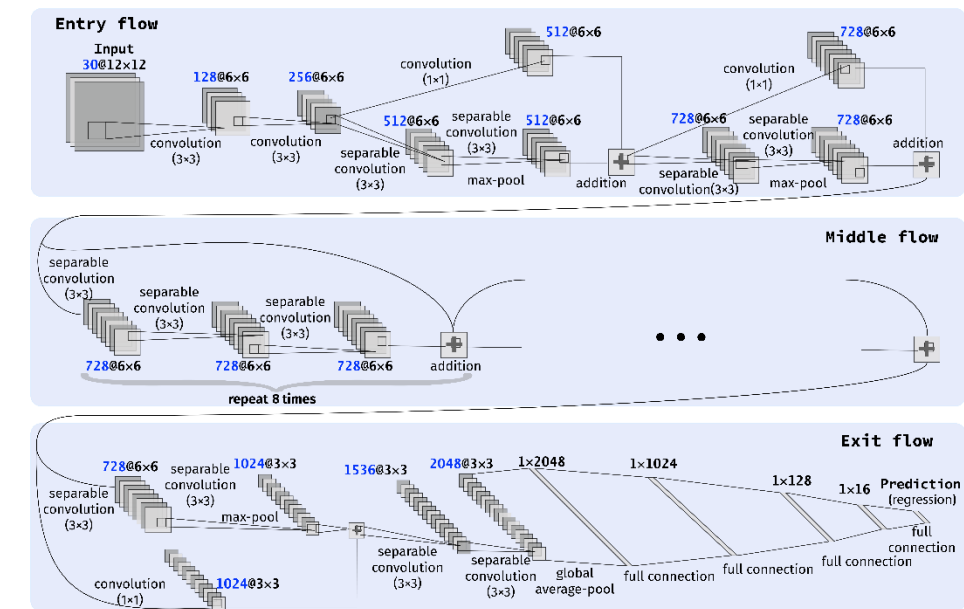
**Escalating tropical cyclone precipitation extremes and landslide hazards in South China under global warming**

[Xiaoming Shi](#), [Yang Liu](#), [Jianan Chen](#), [Haoming Chen](#), [Yueya Wang](#), [Zhongming Lu](#), [Ruo-Qian Wang](#), [Jimmy C.-H. Fung](#) & [Charles W. W. Ng](#) 

*npj Climate and Atmospheric Science* 7, Article number: 107 (2024) | [Cite this article](#)

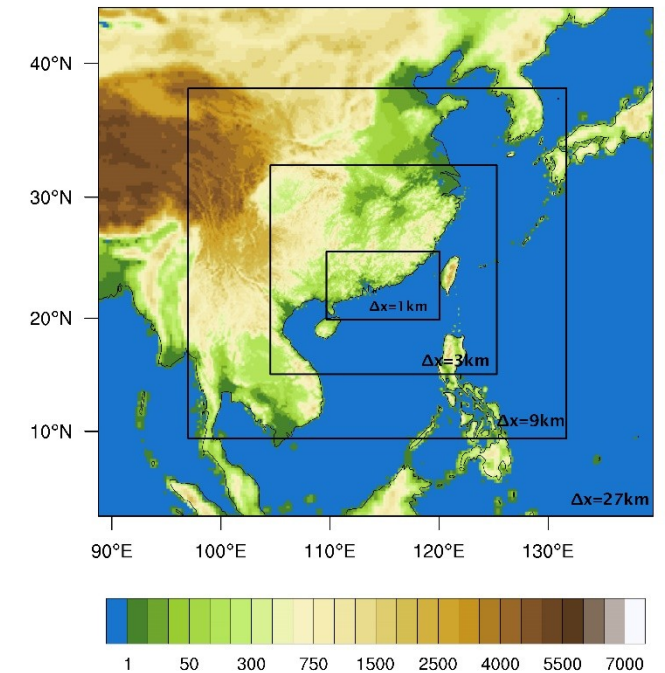
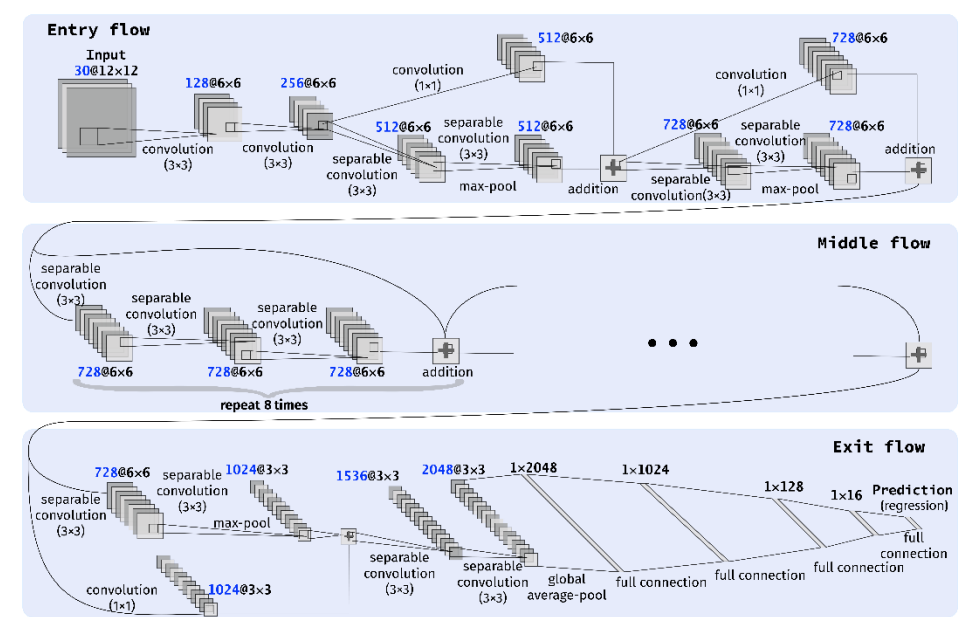
# More Confident Estimation of Precipitation Extremes

- Instead of classification, the new (2024) deep learning model directly predicts rain intensity
- It features regular and channel-wise separable convolution layers and residual layers
- The model inputs were fundamental variables ( $u$ ,  $v$ ,  $T$ ,  $\Phi$ ,  $q$ ) at 6 pressure levels and trained with ERA5 reanalysis and APHRODITE precipitation, **predicting the maximum subgrid rainfall from low-resolution circulation**



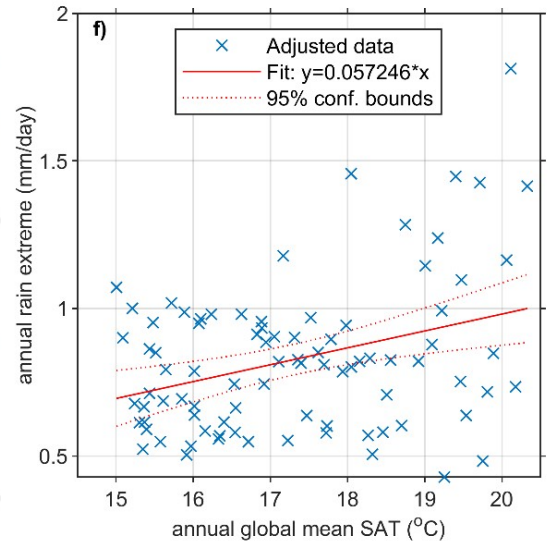
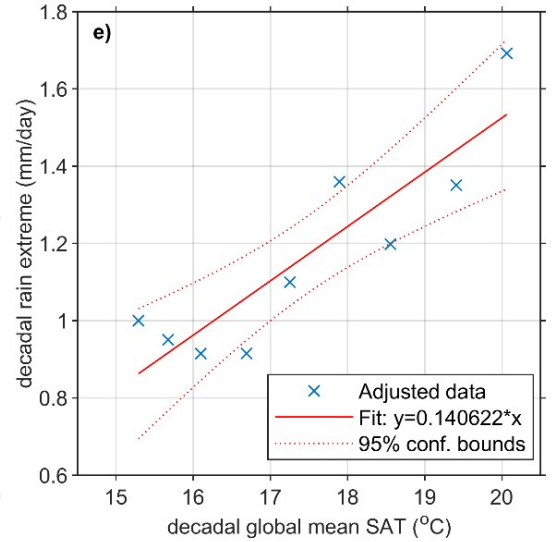
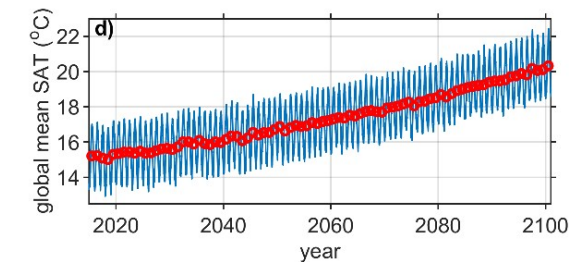
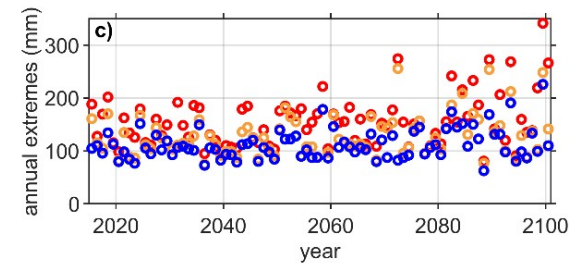
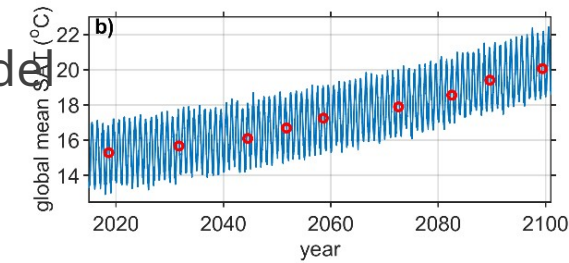
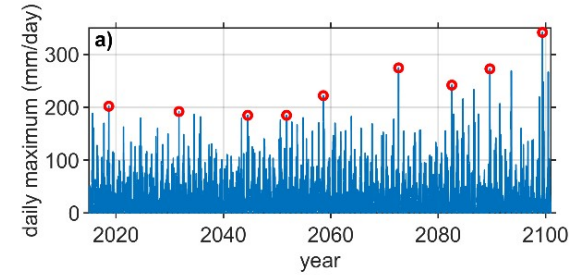
# More Confident Estimation of Precipitation Extremes

- The deep learning model identifies potentially extreme cases from a global climate model (CESM2 under SSP5-8.5) simulation for 2015 – 2034 (*present*) and 2081 – 2100 (*future*).
- Then we used 3- and 1-km resolution WRF to resolve storms in the South China region in the **dynamical downscaling**
- We select 32 cases for WRF simulations of *present* extreme precipitation events and 32 cases for *future* extremes.
- Finally, we re-rank those simulations and retain the top 16 + 16 for analysis.



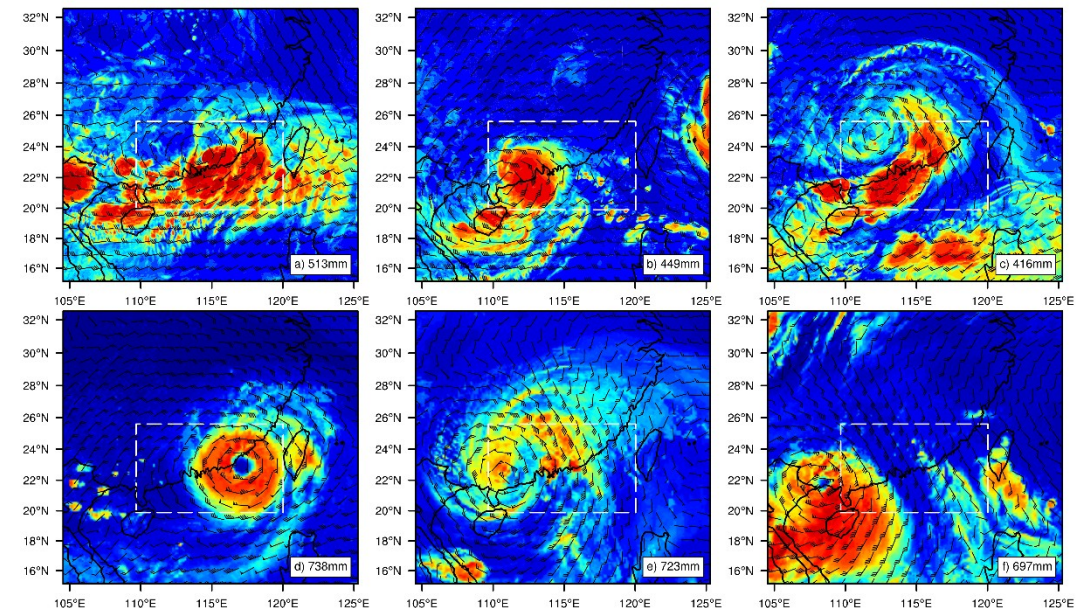
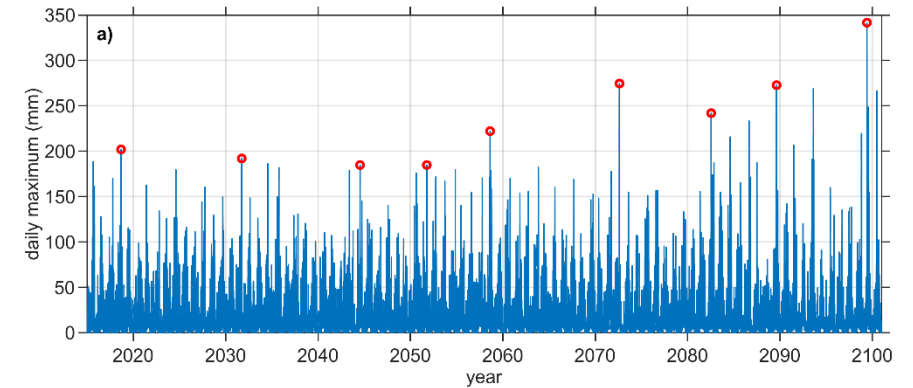
# Timescale of Extremes Response Signal

- Decadal rainfall extremes in deep learning model prediction exhibit a significant sensitivity to global temperature change
- However, if we focus on annual extremes, the relation to temperature is not statistically significant



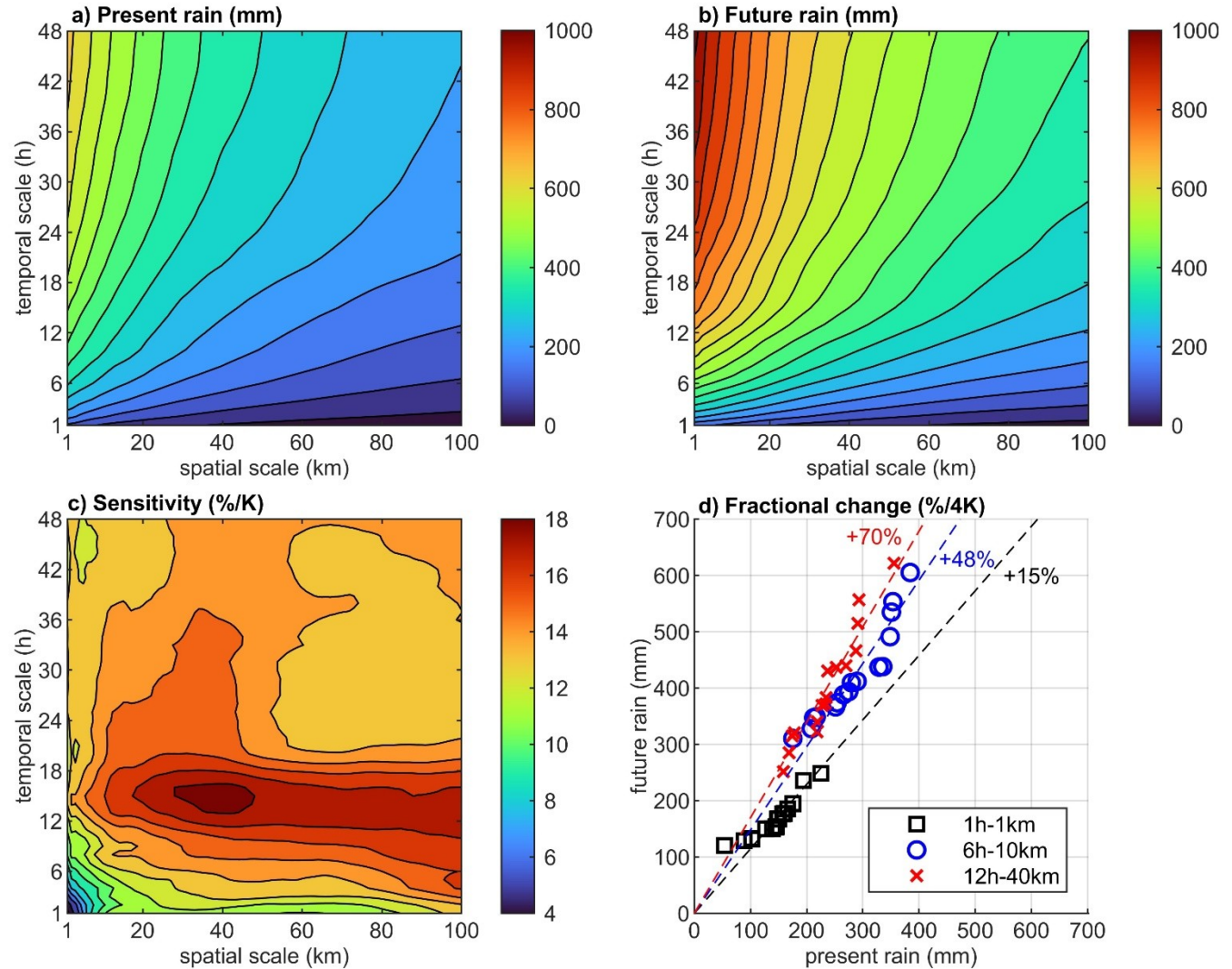
# Cases of Extreme Precipitation

- The AI model can reliably estimate rainfall intensity, though **underestimation** exists due to training data limitation ( $0.25^\circ \times 0.25^\circ$ ).
- AI prediction for the *present* period extremum is 202 mm and *future* period extremum 342 mm, implying a +17%/K sensitivity.
- WRF downscaling found top cases are all tropical cyclones.
  - 6/16 are typhoons for the *present* period and 9/16 for the *future* period.
  - 2/16 are **super** typhoons for the *present* period and 3/16 for the *future*.



# Sensitivity at Different Scales

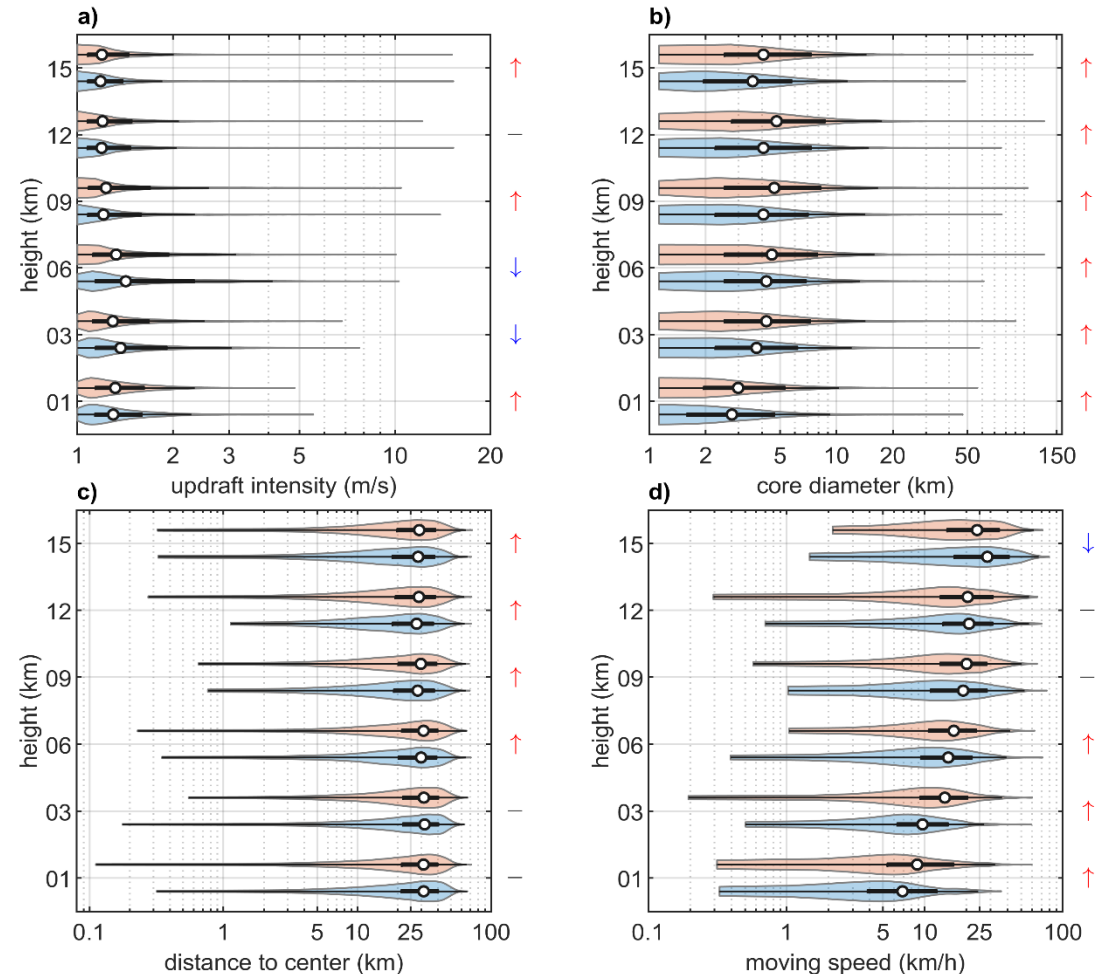
- Clausius-Clapeyron (CC) equation suggests a 7%/K increase in water vapor; Does the ~1-km WRF simulation suggest sub- or super-CC scaling or precipitation extremes? *Yes and No.*
- When focusing on a small scale (1 km) and short duration (1 hour), the sensitivity is **~4 %/K**.
- However, the sensitivity reaches **~18 %/K** for 30 – 50 km and half-day accumulation.
- *Hong Kong's scale is ~ 30 km; Shenzhen is ~ 50 km; Guangzhou is ~ 80 km*



# Weaker Convection?

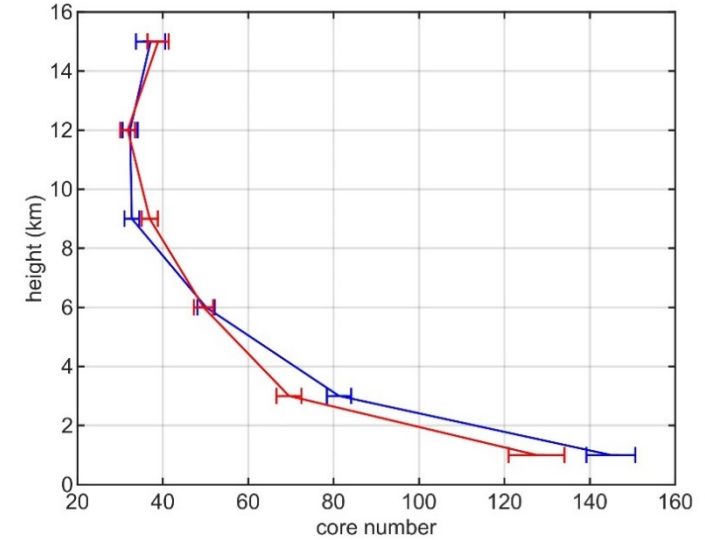
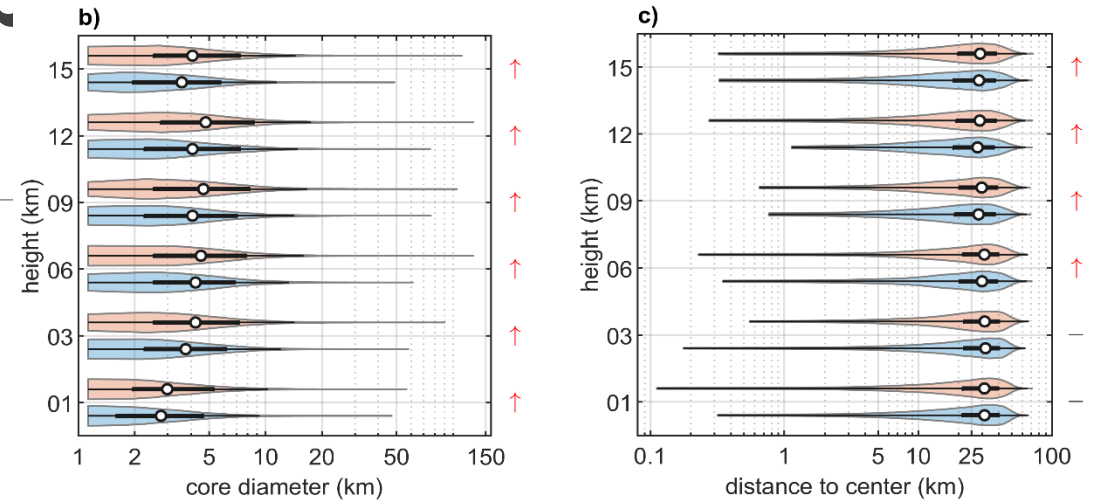
We analyzed the characteristics of convective cores.

- Updraft cores' mean intensity has a slight decrease in the mid-troposphere.
- **The size of updraft cores increases due to warming.**
- **The distance of cores to the cluster center has no change at lower levels and increases at upper levels**
- The convective cores move faster in the lower troposphere in response to warming.



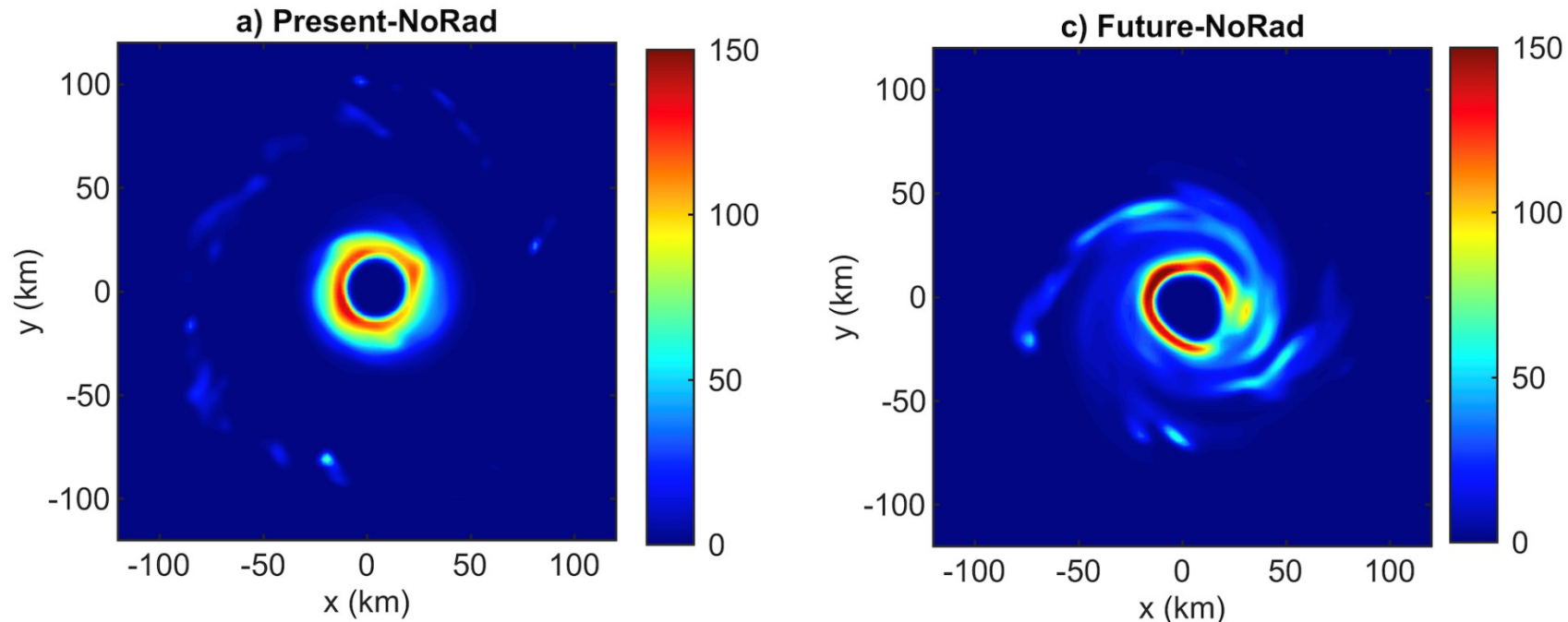
# Strengthening of Deep Convection

- The number of convective cores decreases at lower levels but does not have a significant change at upper levels.
- Thus, **deep convective cores expand at the price of disappearing shallow cumulus and congestus clouds at lower levels**



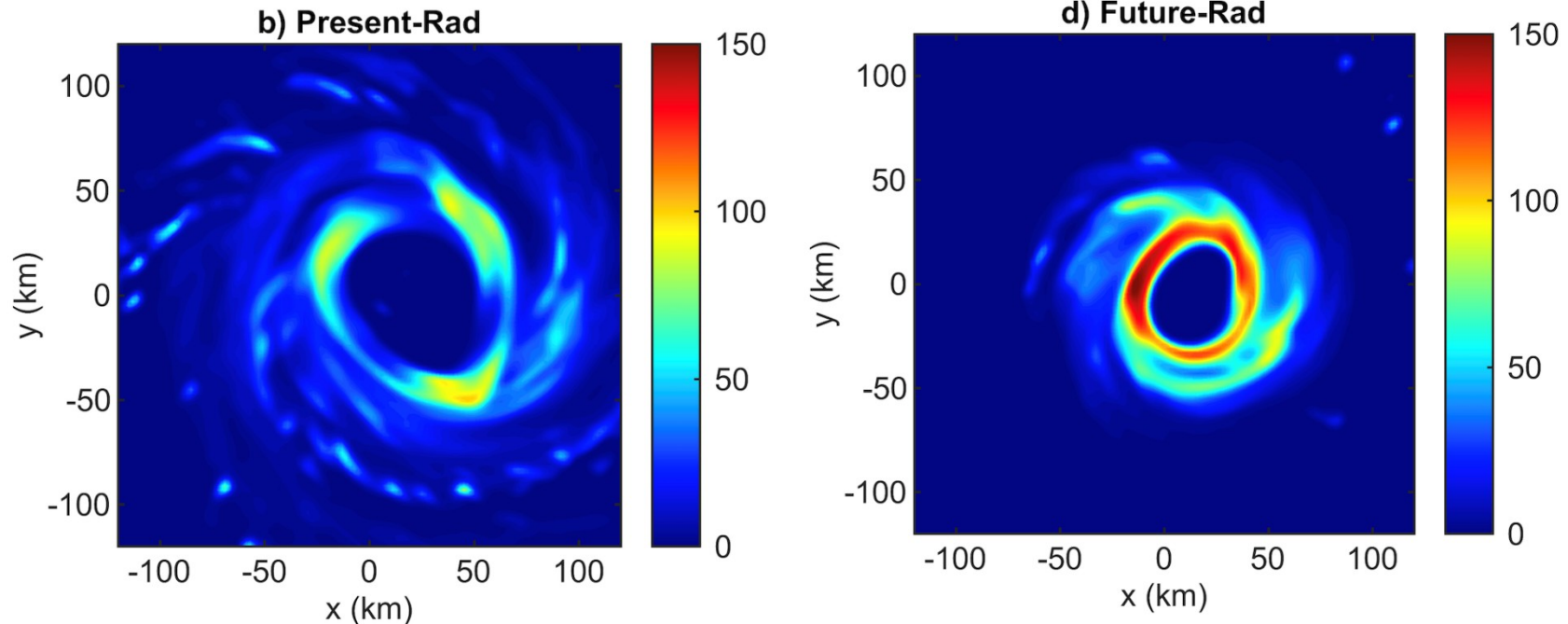
# Idealized Cloud Model 1 (CM1) Simulations

- Previous idealized simulations suggest TCs weaken under global warming due to the stabilization of the atmosphere under global warming.
- In the “standard” setup of CM1 idealized TC simulations, warming causes rainbands to become stronger and but have a larger radius, resulting no change in total precipitation.



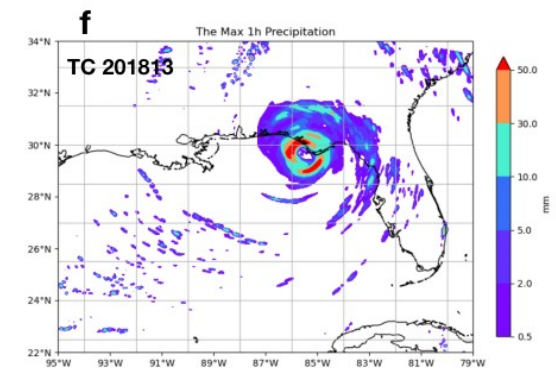
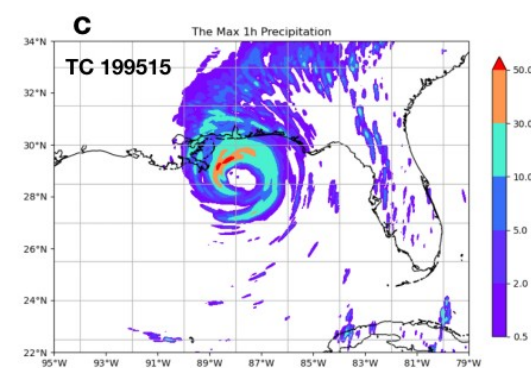
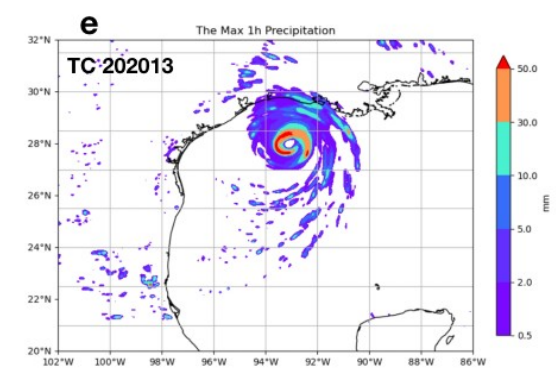
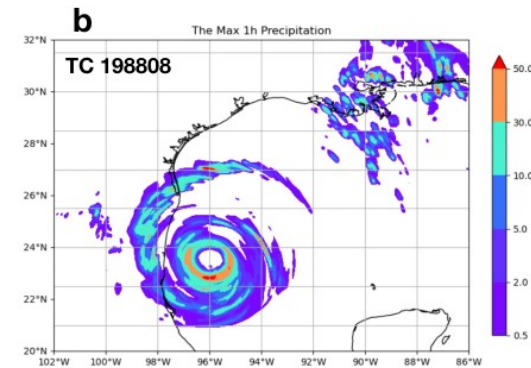
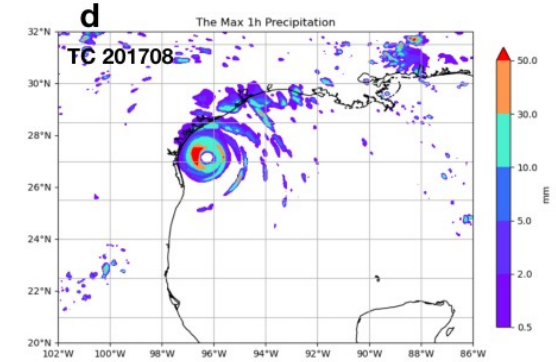
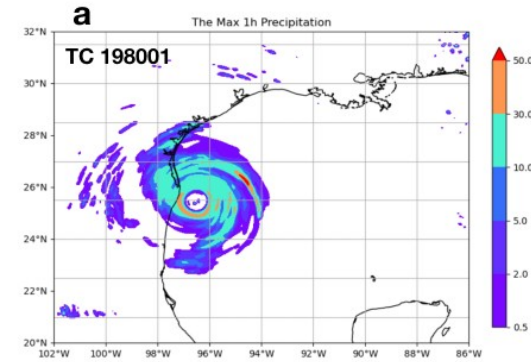
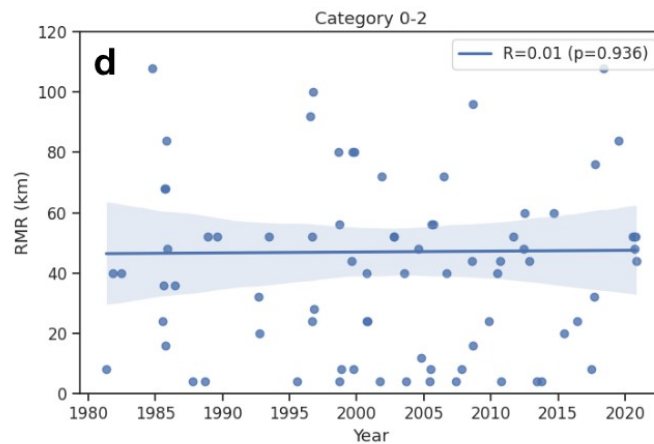
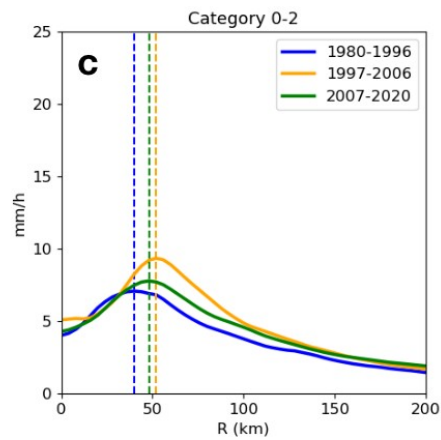
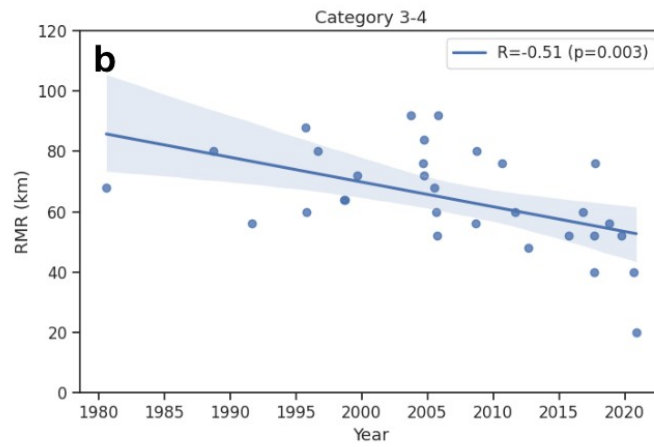
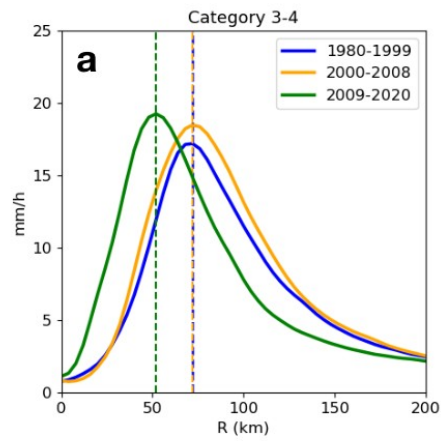
# Change Driven by Radiative Effect

- However, the “standard” setup uses a Newtonian relaxation of temperature to replace active radiation code.
- With radiation code (RRTMG) on, TC rainbands become not only stronger but also more continuous; **the smoother TC rainbands’ rainfall accumulation may exhibit higher sensitivity than instantaneous precipitation.**



# Similar Trends in the Atlantic

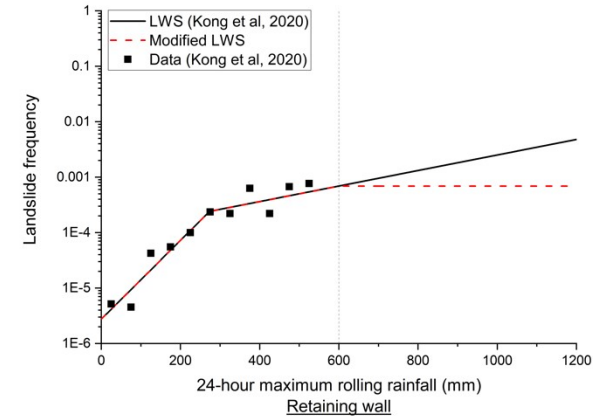
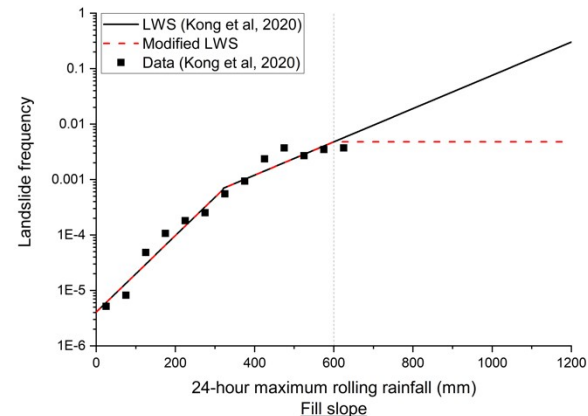
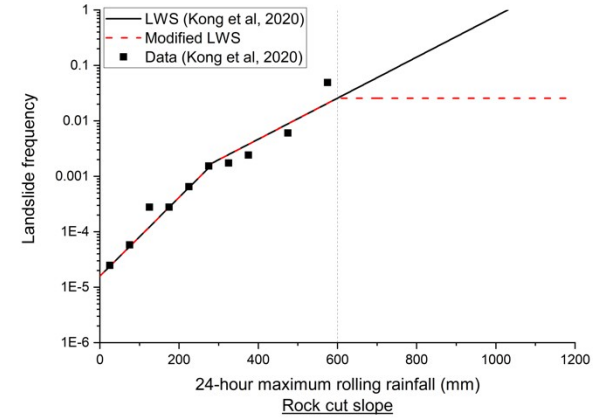
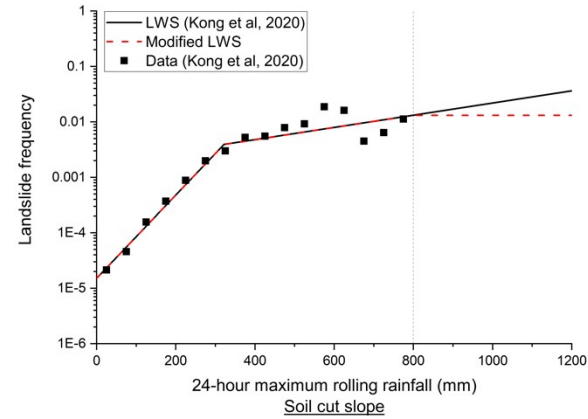
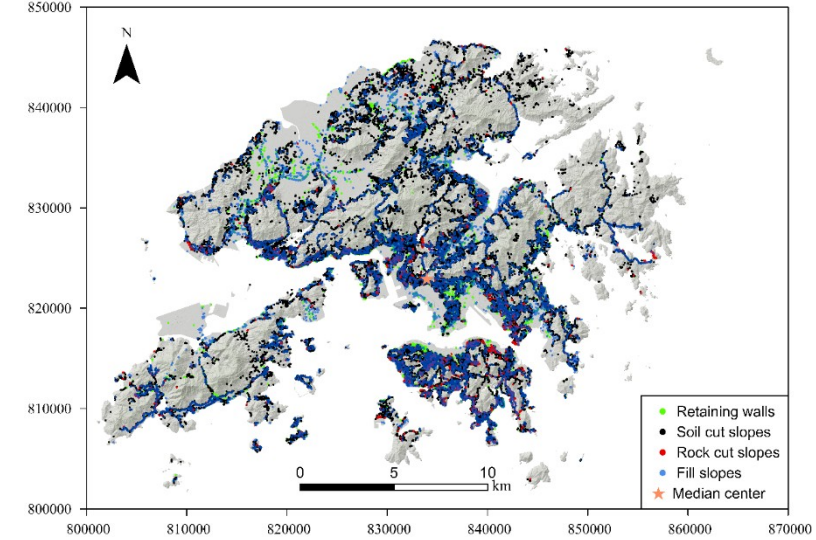
- Analysis of CONUS404 suggests that the radius of maximum rainfall in intense hurricanes decreased in the last four decades (manuscript submitted to JGR)



# Future Landslides

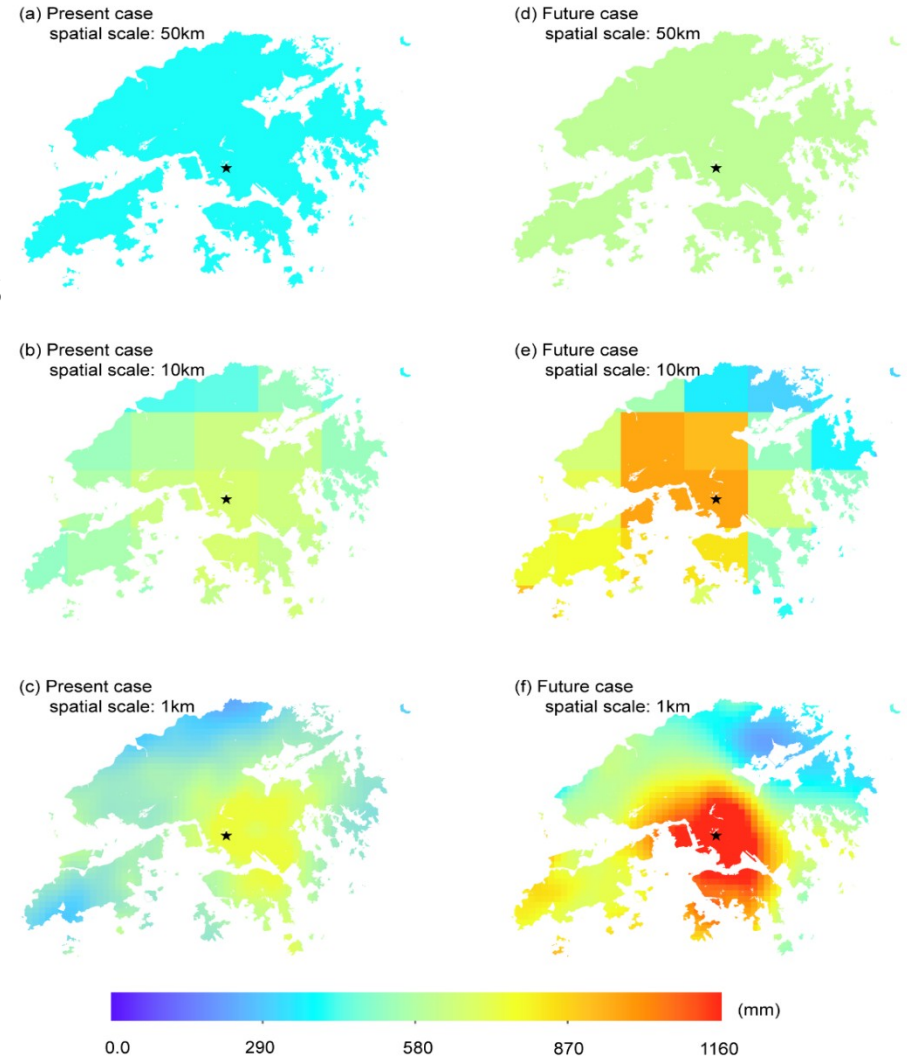
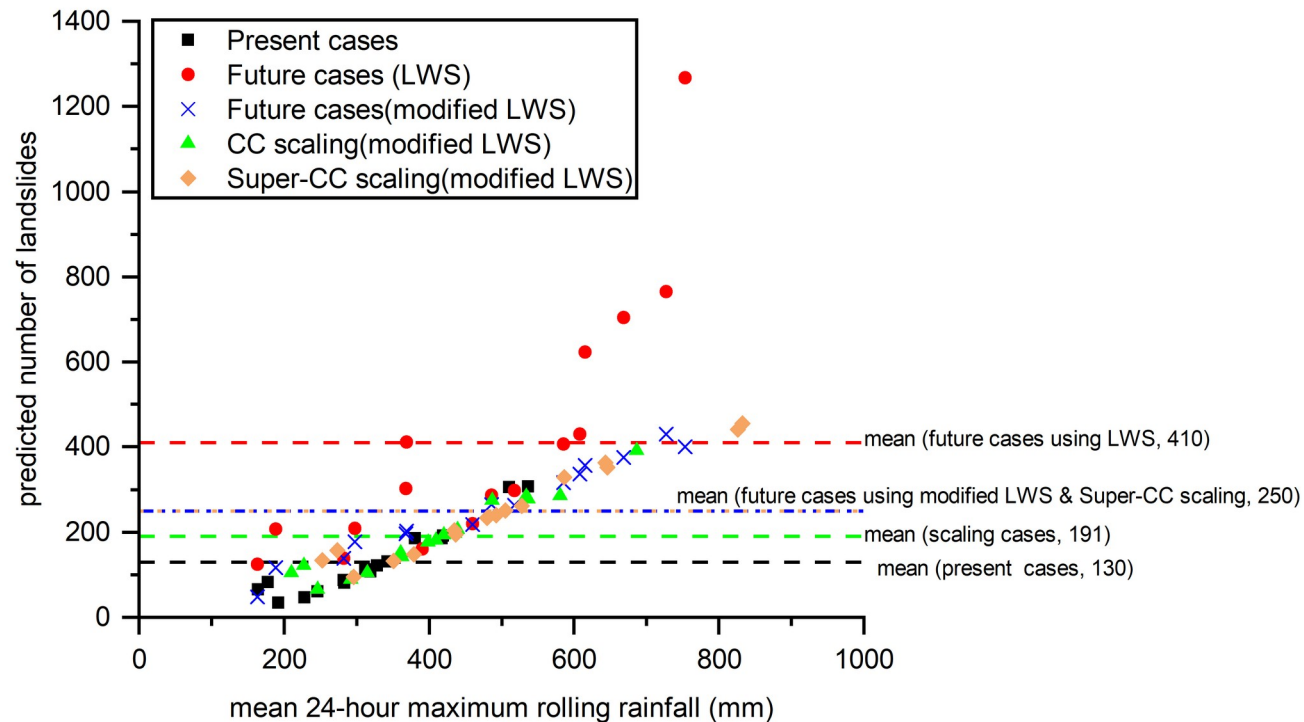
- Previous GCM predicts that extreme rain rate will increase by  $5\%/^{\circ}\text{C}$  warming.
- Our high-resolution simulations found extreme rain rate increases by  $18\%/^{\circ}\text{C}$ . (i.e., 72% total increase in rain rate by 2100 under RCP8.5 scenario)

**We assessed the future landslide risks using Hong Kong's slope data.**



# Future Landslides

**Conservative** estimation assumes current relation applies to future, and **optimistic** view assumes no further increases above current maximum



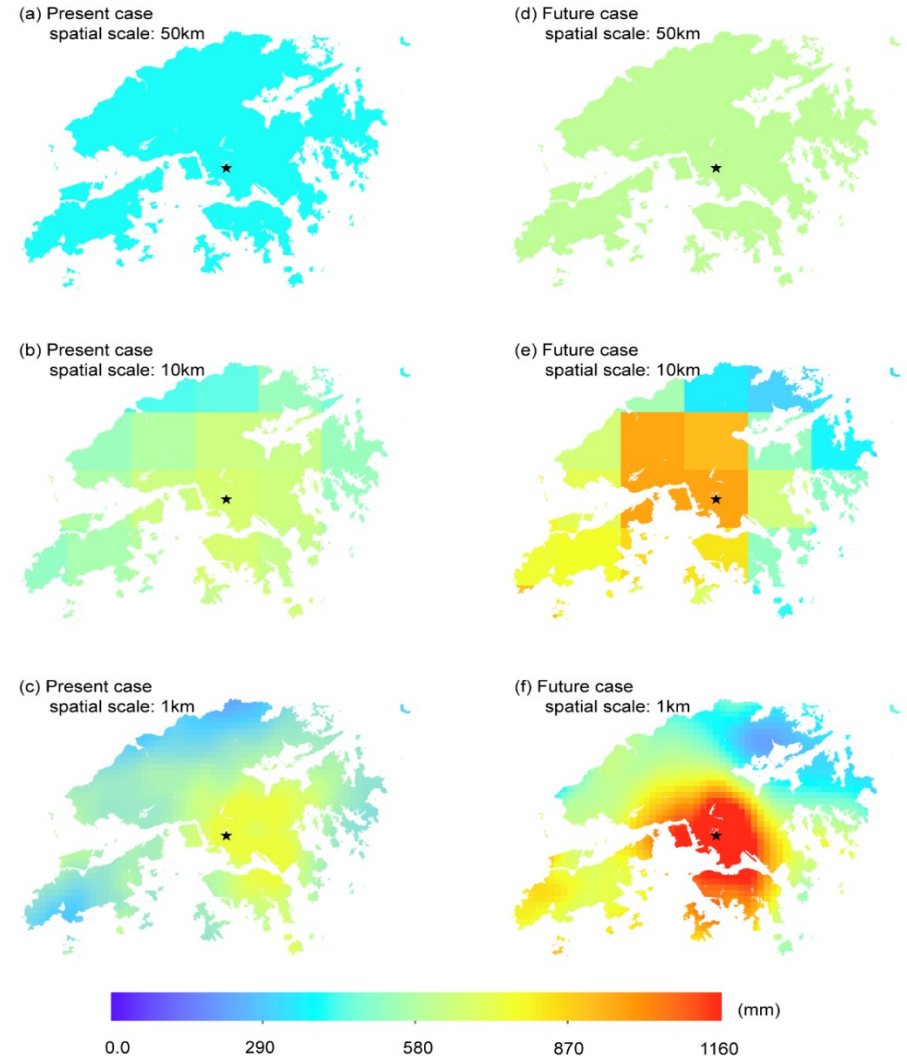
# Future Landslides

- Assuming super-CC scaling and apply 1-km resolution reanalysis data yield more accurate projection of future risks
- Landslide risks exhibit **additional** exponential amplification

Model	Number of Landslides in Extreme Events (2015-2035 vs. 2080-2100)		Fractional Change
100-km resolution GCM	Model	Number of Landslides in Extreme Events (2015-2035 vs. 2080-2100)	Fractional Change
	100-km resolution GCM	130 → 178	+36%
1-km Cloud-Resolving model	Model	Number of Landslides in Extreme Events (2015-2035 vs. 2080-2100)	Fractional Change
	1-km Cloud-Resolving model	130 → 410	+215%

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# Compound Risks



A search for survivors after Typhoon Mangkhut triggered a landslide last week in Itogon, the Philippines. Credit: Jes Aznar/NYT/Redux/eyevine

Other examples of cascading hazards:

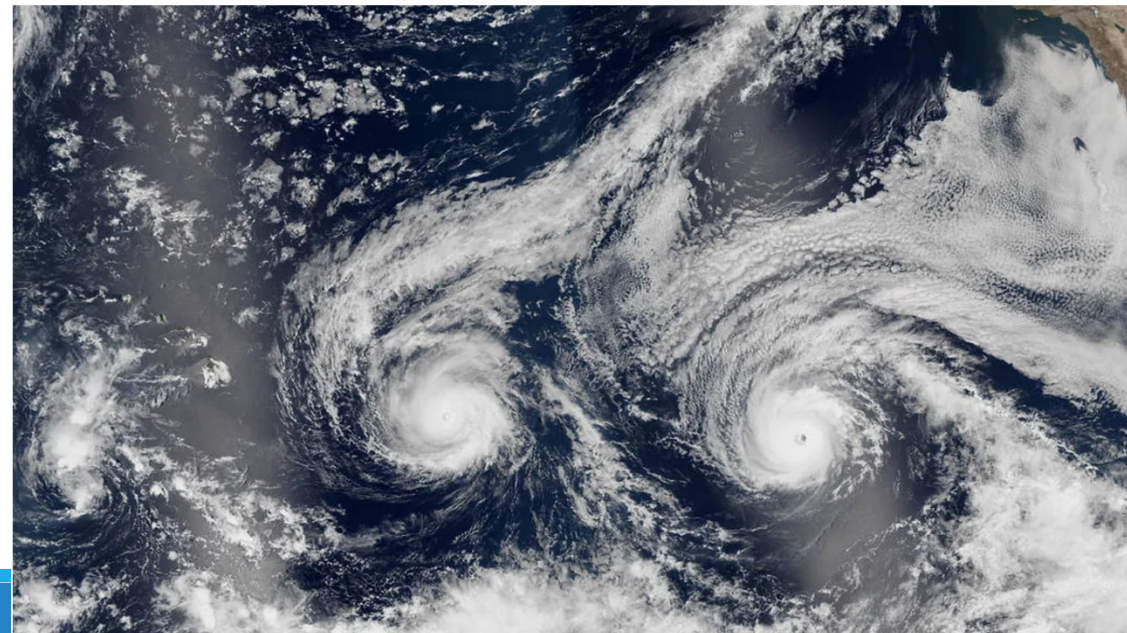
- Wildfires leading to mudslides and flooding
- Droughts and heatwaves coinciding
- Extended fire seasons due to snow and ice melt

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**COMMENT** | 24 September 2018

## How do natural hazards cascade to cause disasters?

Track connections between hurricanes, wildfires, climate change and other risks, urge Amir AghaKouchak and colleagues.

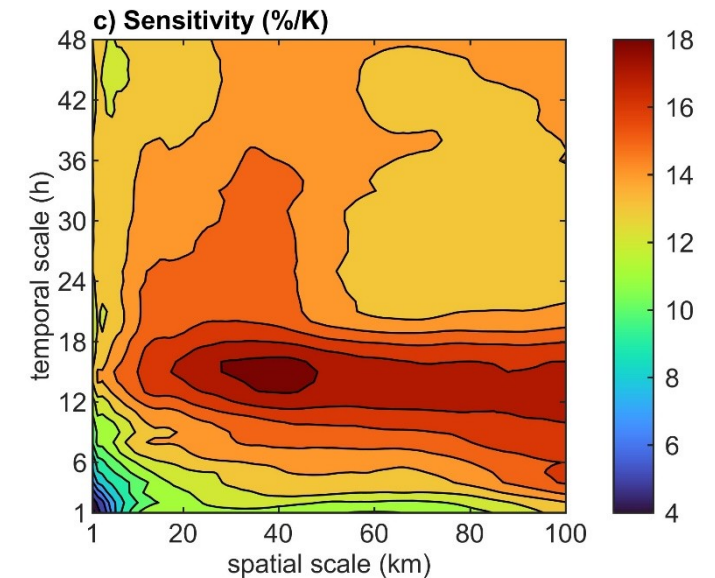


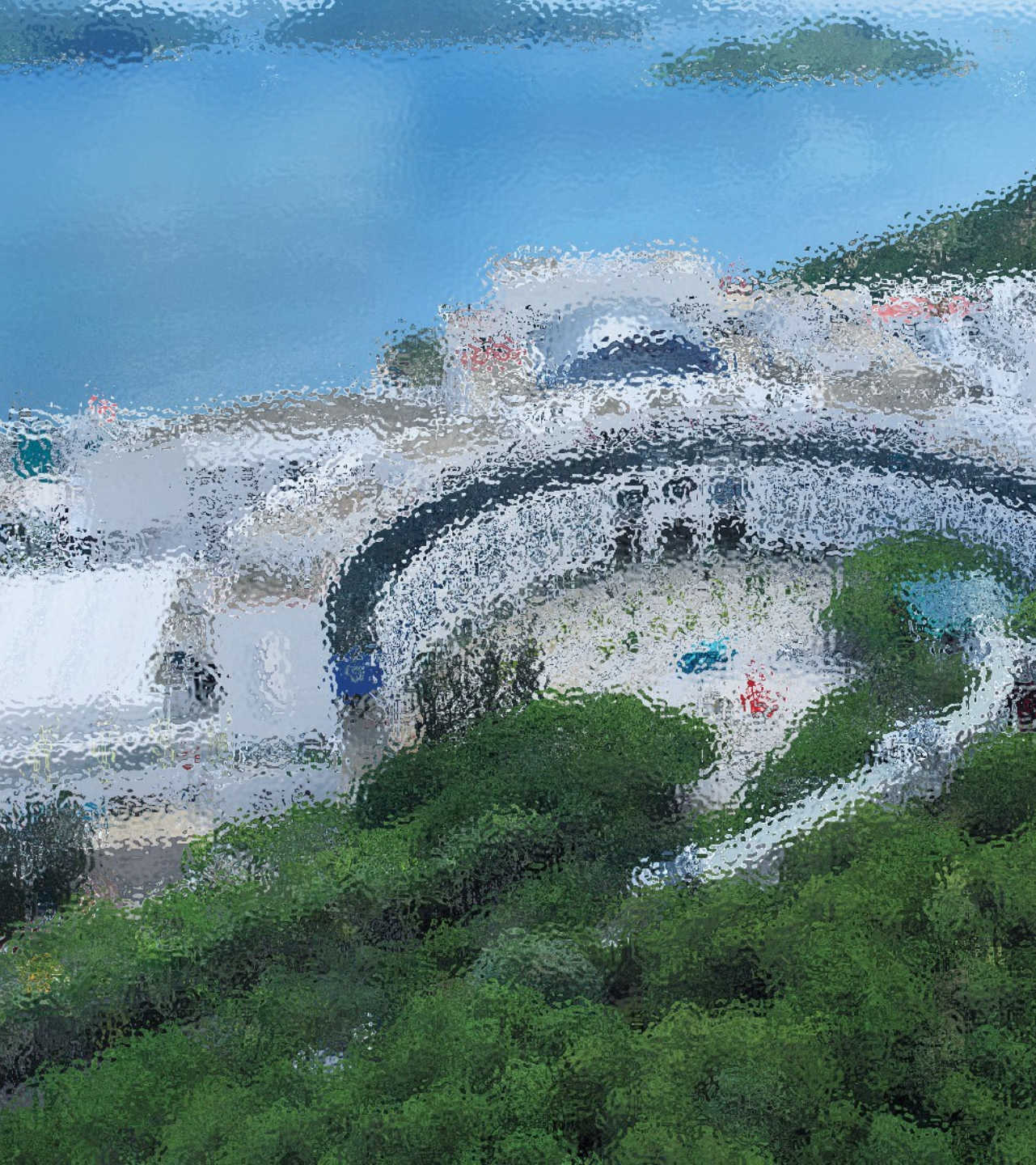
Hurricanes Madeline and Lester move toward Hawaii in late August 2016. Credit: NASA Earth Observatory

# Summary

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- **Deep learning** is a useful tool to enable selective (targeted) cloud-resolving climate downscaling (**SDD**).
- High-resolution simulations of extreme events suggest that the sensitivity of extreme precipitation cannot be quantified as a single value.
- Instead, the sensitivity is **sub-CC at small-scale**, short durations but becomes **amplified for larger spatial and temporal scales and is more than 2 × CC**.
- The **amplified strengthening of urban-scale** extreme precipitation has important implications for **flooding and landslide risks** under climate change
- Ongoing work to generate large-ensemble projection with SDD





***Thanks!***

**Xiaoming Shi**  
**Hong Kong University of**  
**Science and Technology**  
**(HKUST)**  
**shixm@ust.hk**

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