



XVIII
World Water Congress
International Water Resources Association (IWRA)
Beijing, China | September 11-15, 2023



Water Security in Guangdong-Hong Kong-Macao Greater Bay Area 粤港澳大湾区水安全保障 专场

Urban hazards under extreme rainstorms 极端暴雨下城市复合型地质灾害

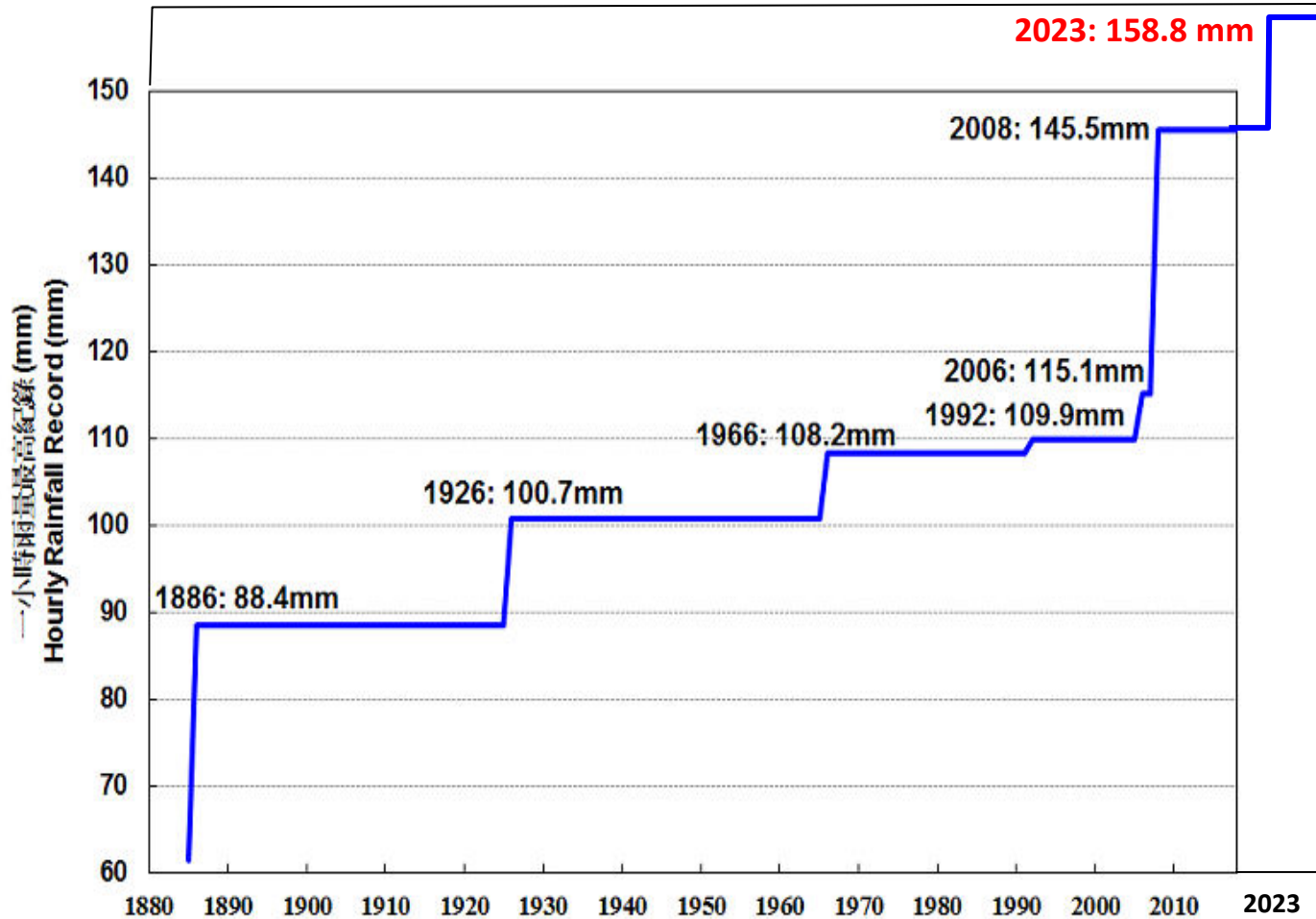
Limin Zhang, Hong Kong Univ. of Science and Technology
张利民, 香港科技大学

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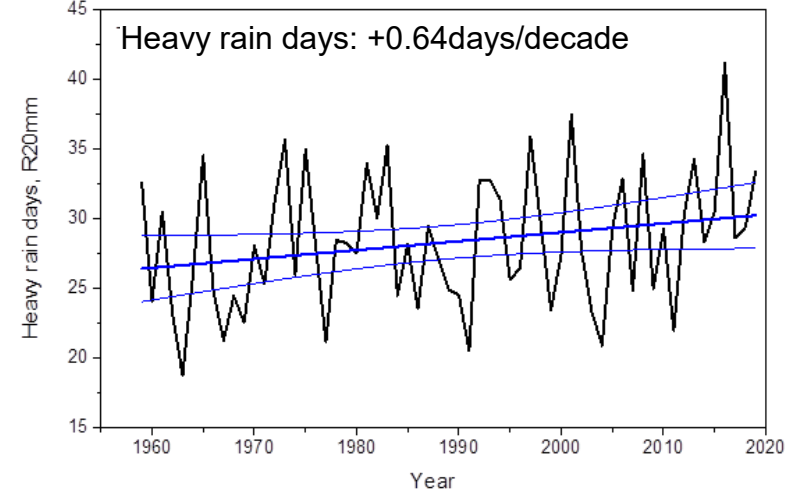
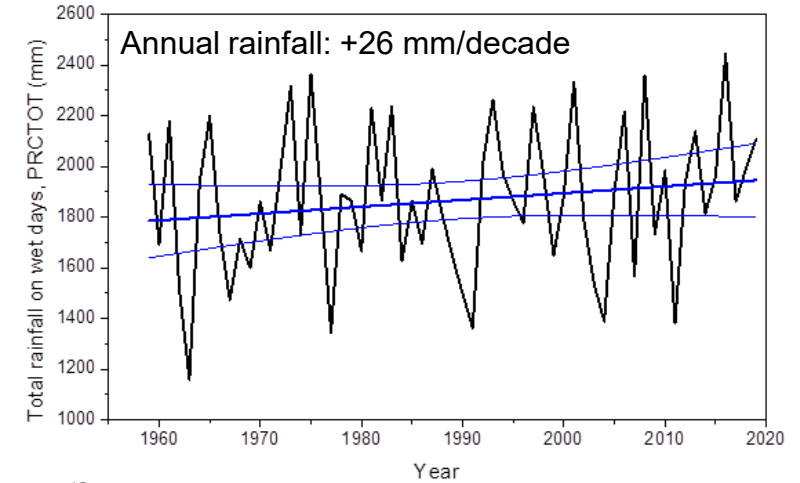
- **Climate change and urban hazards in GD-HK-MC Greater Bay Area**
- **The 1 Sept 2023 Typhoon Saola and its impact**
- **The 7 Sept 2023 extreme storm and its impact**
- **Prompt landslide risk assessment**
- **Stress testing for future extremes**



Impact of climate change: Extreme rainfall in Hong Kong



Hourly rainfall records in Hong Kong
(Courtesy: Dr CT Lee)

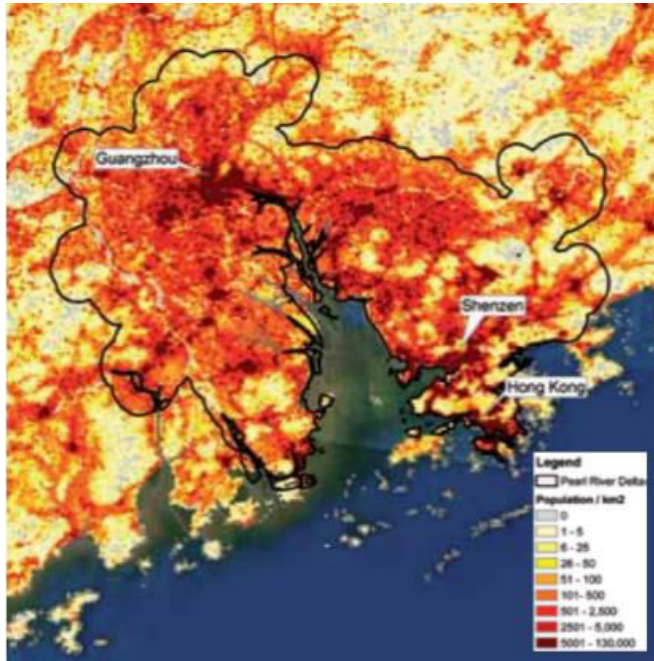


Rainfall trends in GBA
(Qiang, 2021)

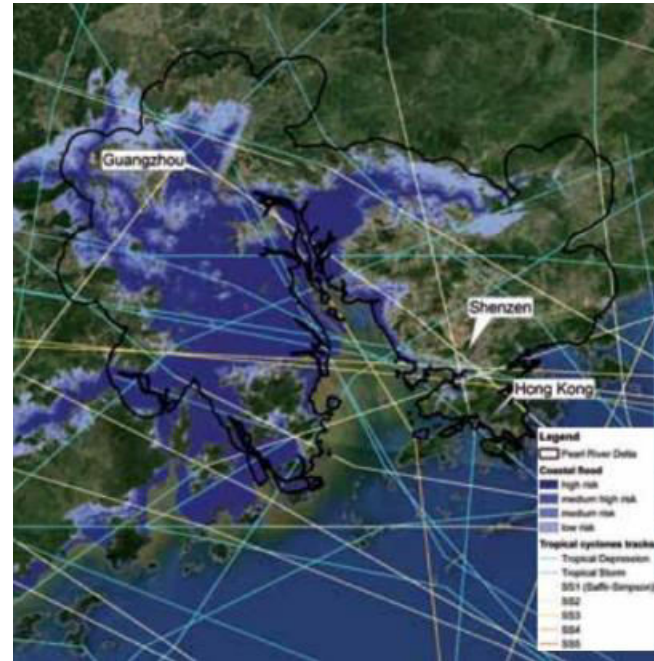
Increasing intensity and frequency of extreme rainfall



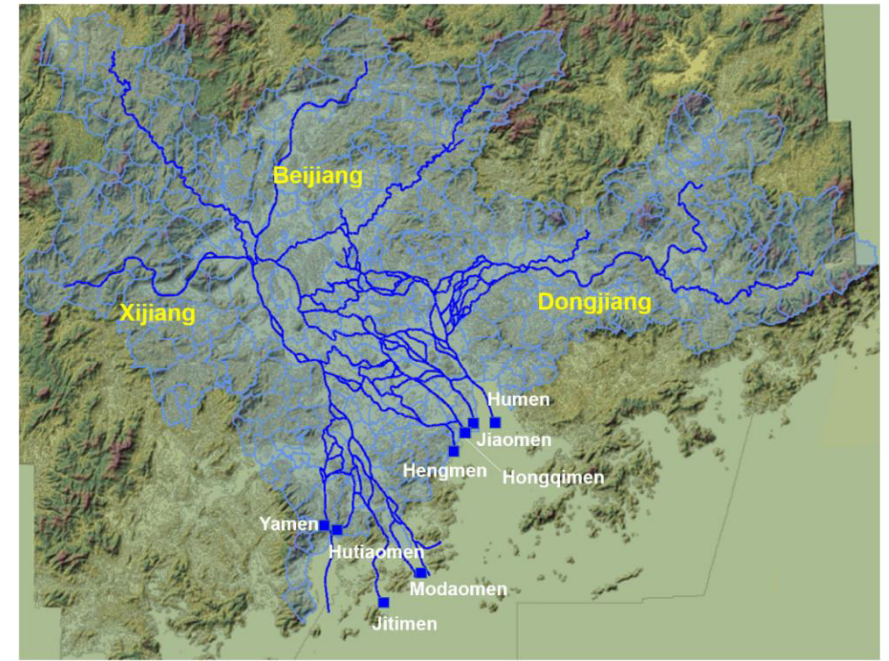
Guangdong-Hong Kong-Macao Greater Bay Area (GBA)



Population density



Tropical cyclone tracks and coastal flood zones



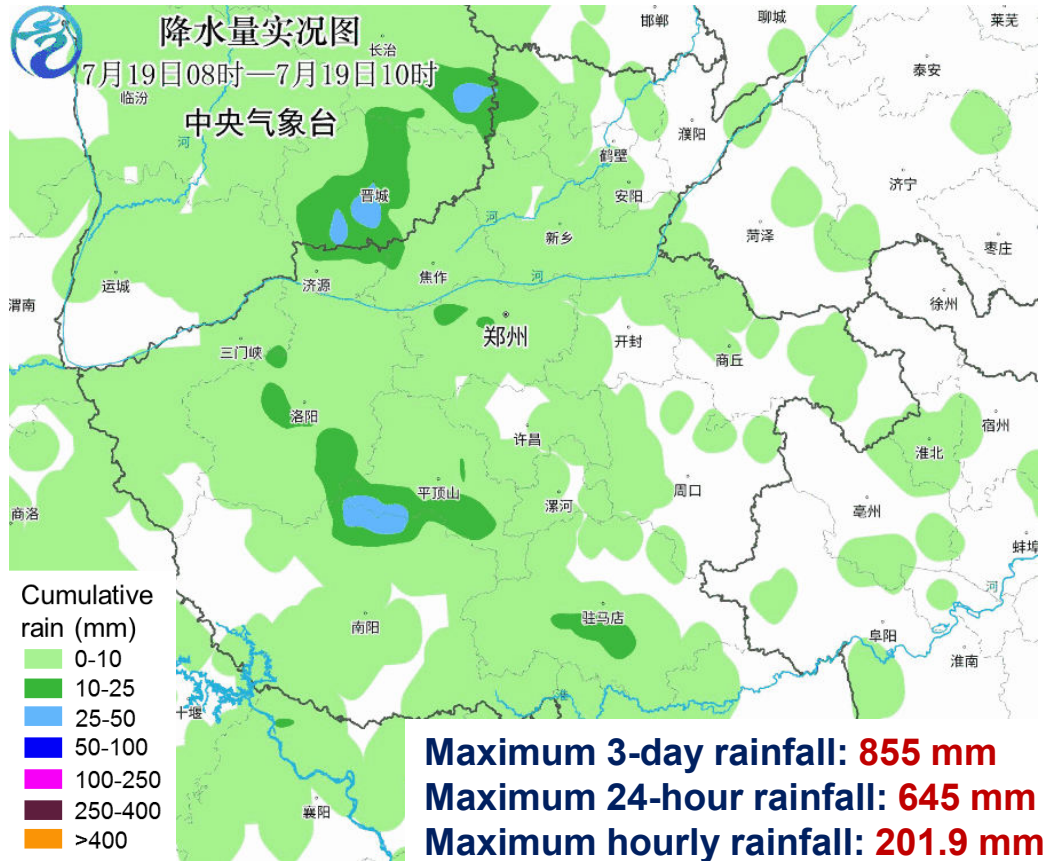
River network

Global ranking for GBA for hazards (Swiss Re, 2013)

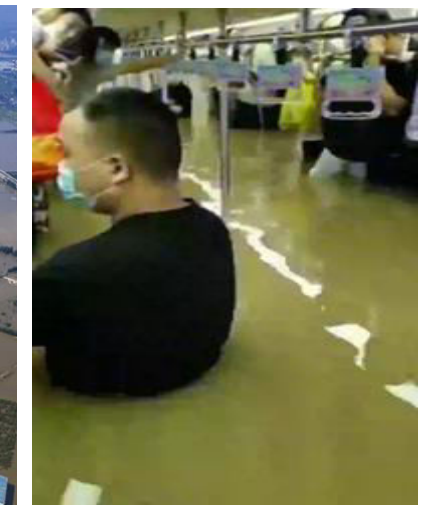
Peril scenario	Population potentially affected in million	Rank of population potentially affected	Population potentially affected in % of metro area population
Storm	17.2	1	41
Storm surge	5.3	1	12
River flood	12.0	1	28

Climate change and intensified urban natural hazards

Extreme rainstorm in Henan, July 2021



- Tunnels and subways inundated
- More than **300 deaths**



Climate change and intensified urban natural hazards

□ Typhoon Hato, 23 Aug 2017 & Typhoon Mangkhut, 16 Sept 2018: Storm surge and wave overtopping



Rise of Pearl River water level due to storm surge during Hato (Guangzhou)



Damage of waterfront promenade by wave overtopping during Mangkhut



Storm surge and wave overtopping during Hato (Hong Kong)

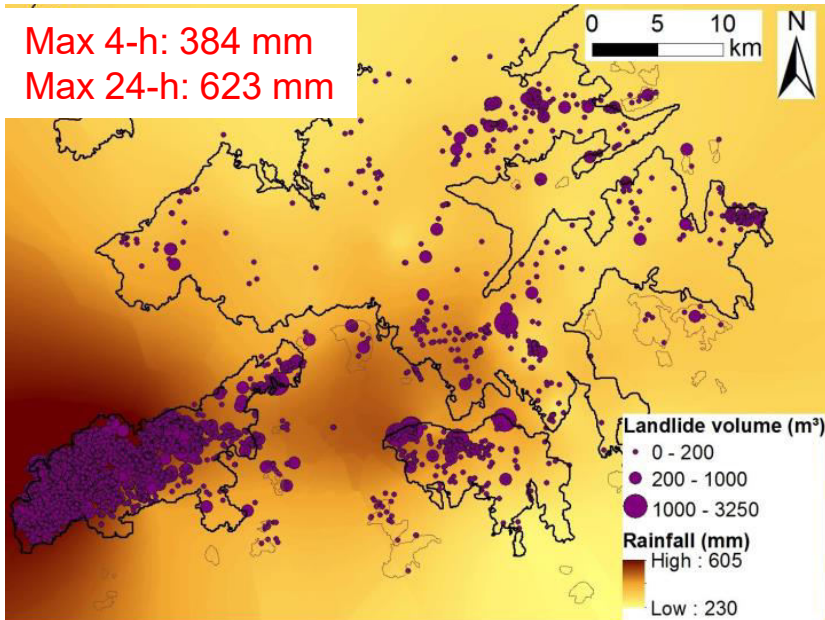
- Maximum storm surge in Hong Kong: **2.42 m** (Hato) and **3.4 m** (Mangkhut)
- Maximum sea level in Hong Kong: **4.09 m** (Hato) and **4.71 m** (Mangkhut)
- Typhoon Hato: **32 fatalities**; damage up to USD **4.34 billion**
- Typhoon Mangkhut: **3.29 million** people affected; damage up to USD **7.62 billion**



Climate change and intensified urban natural hazards



Multi-hazard processes in Hong Kong during the extreme rainstorm on 7 June 2008



Total rain amount on 7 June, 2008 and locations of landslides (Gao, 2016)



North Lantau Highway flood due to drainage blockage by landslide debris

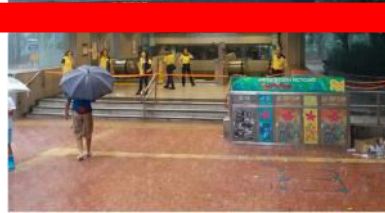
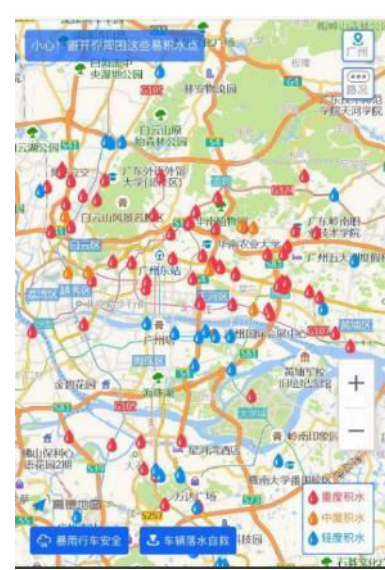


Sheung Wan Wing Lok Street Floods

- **1,900** natural terrain landslides, **900** debris flows, **622** flood spots
- North Lantau Highway was blocked for **16 hours**.



Hazard cascades



重点研究计划：“多碰头”与地质灾害的复合灾害

首席科学家：陈晓宏 教授

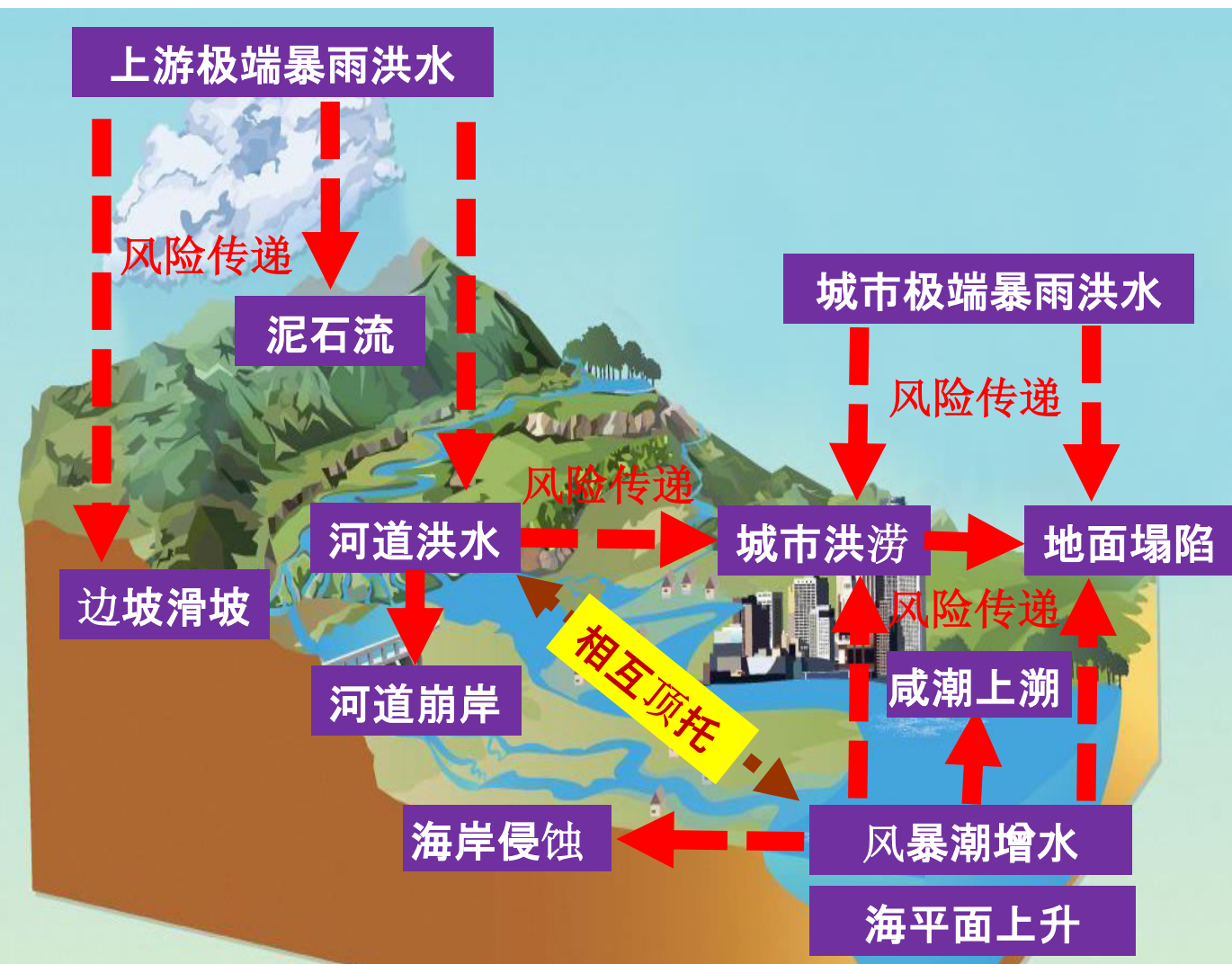
复合灾害	“多碰头” - 风暴潮-咸潮-洪水-内涝
	衍生地质灾害-河岸崩塌-地面塌陷-滑坡

风暴潮-咸潮-洪水-内涝-崩岸-塌陷-滑坡

它们哪些会遭遇组合形成复合灾害？概率？

复合灾害中各灾种风险如何传递叠加？

如何准确预报复合灾害进而有效应急避险？

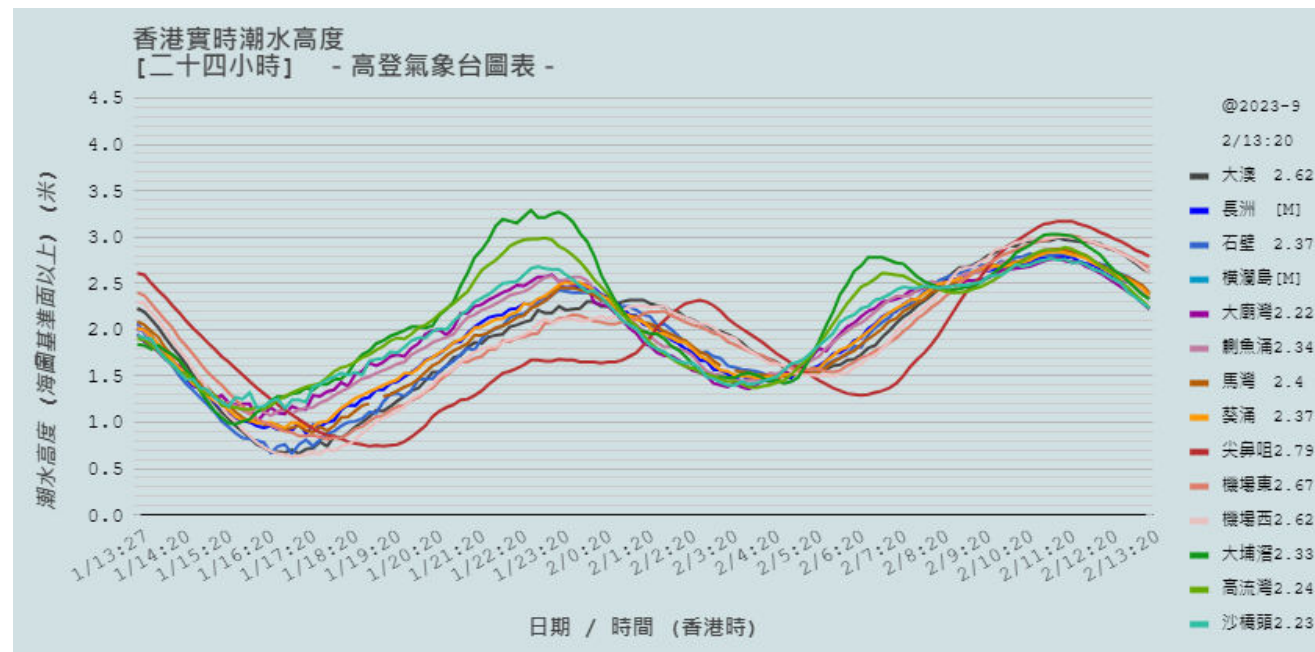
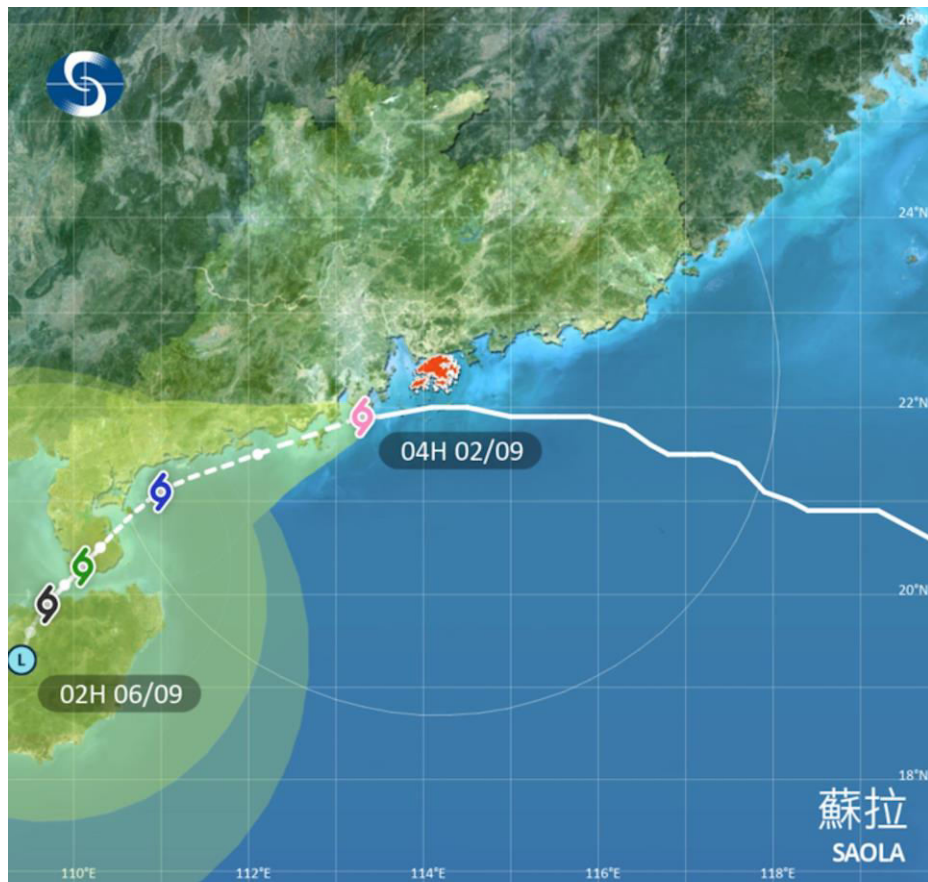


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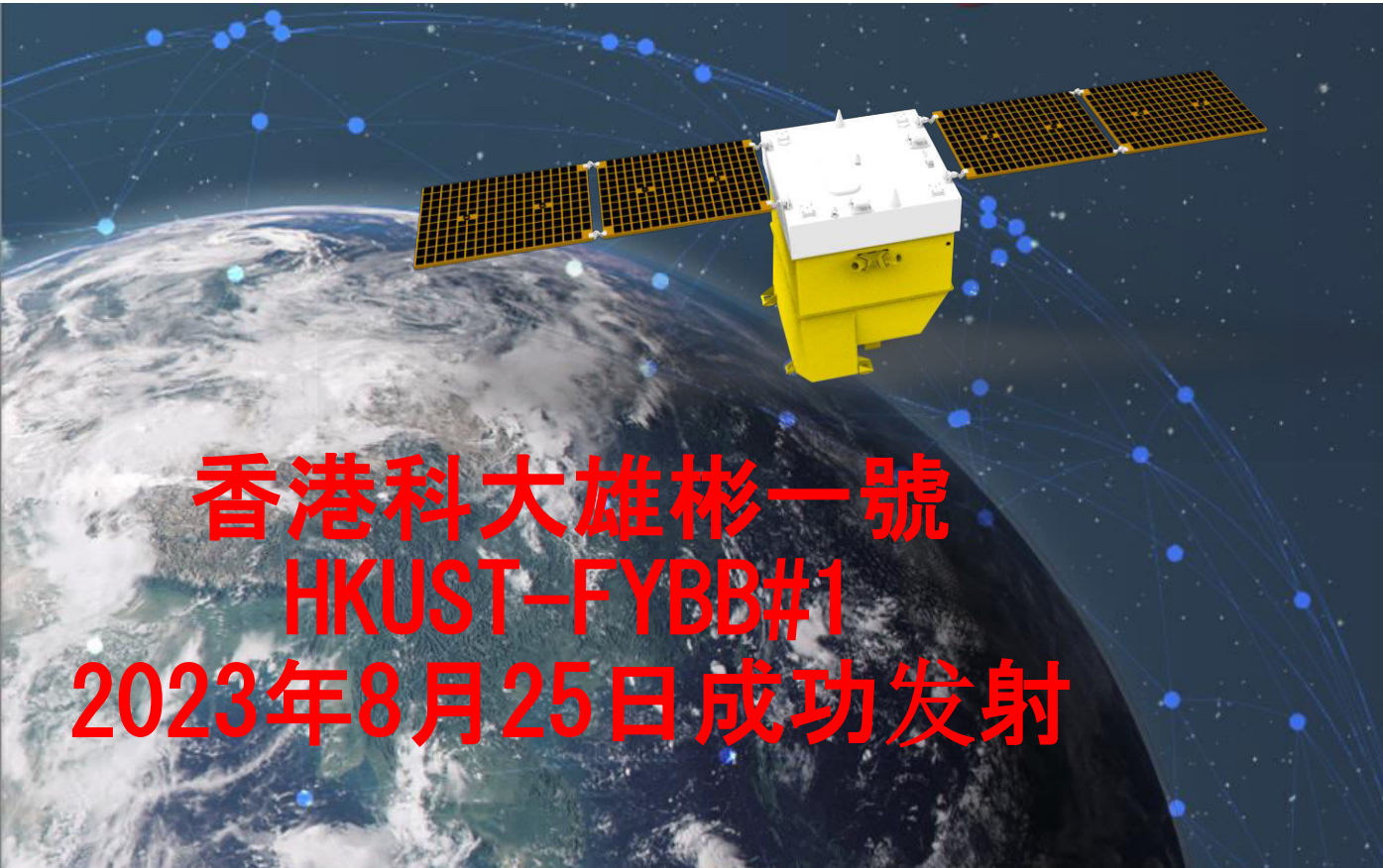


Typhoon Saola, 1 Sept 2023



- 10min gust: 111.9 km/h (Mangkhut 141.1 km/h)
- Maximum storm surge: 1.4 m
- **Maximum sea level: about 3.3 m**
- **86 injuries**
- 1500 fallen tree reports
- 21 flooding cases
- 2 landslide incidents

- 🌀 熱帶低氣壓
Tropical Depression
- 🌀 熱帶風暴
Tropical Storm
- 🌀 強烈熱帶風暴
Severe Tropical Storm
- 🌀 颱風
Typhoon
- 🌀 強颱風
Severe Typhoon
- 🌀 超強颱風
Super Typhoon
- Ⓕ 低壓區 / 溫帶氣旋
Low Pressure Area / Extratropical Low



香港科大雄彬一號 HKUST-FYBB#1 2023年8月25日成功发射



整星质量	215kg		
轨道	高度	535km	
	类型	太阳同步轨道	
相机	成像方式	推扫	
	成像谱段	全色	450nm~700nm
		蓝色	450nm~510nm
		绿色	510nm~580nm
		红色	630nm~690nm
近红外	770nm~895nm		
分辨率	0.5米 (民用卫星最高级别)		
成像幅宽	≥150km		
侧摆能力	±45°		



香港科大
雄彬一號
2023年9
月3日发
回影像



2023年9月
3日影像





2023年9月
3日影像



2023.9.2 Typhoon Saola



2018.9.16 Typhoon Mangkhut



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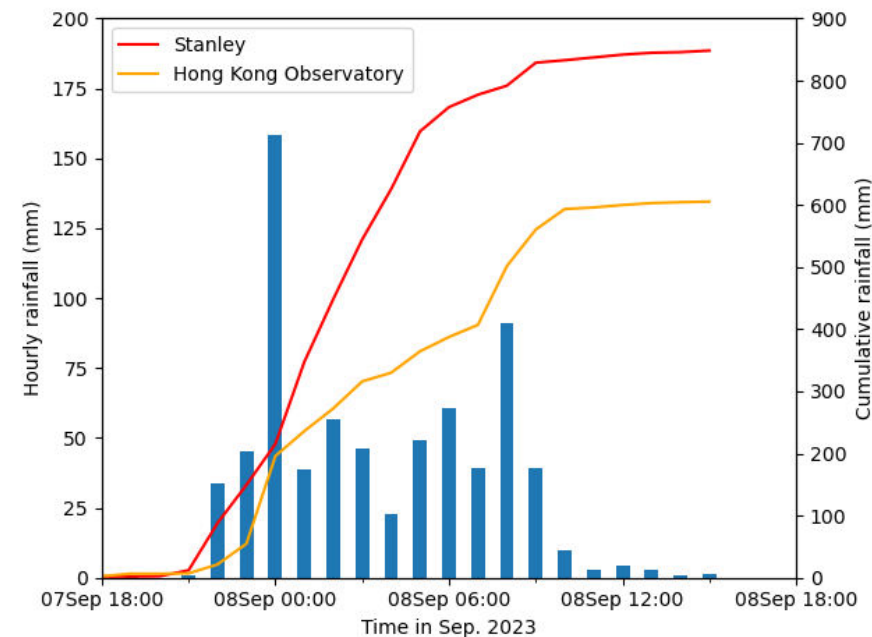
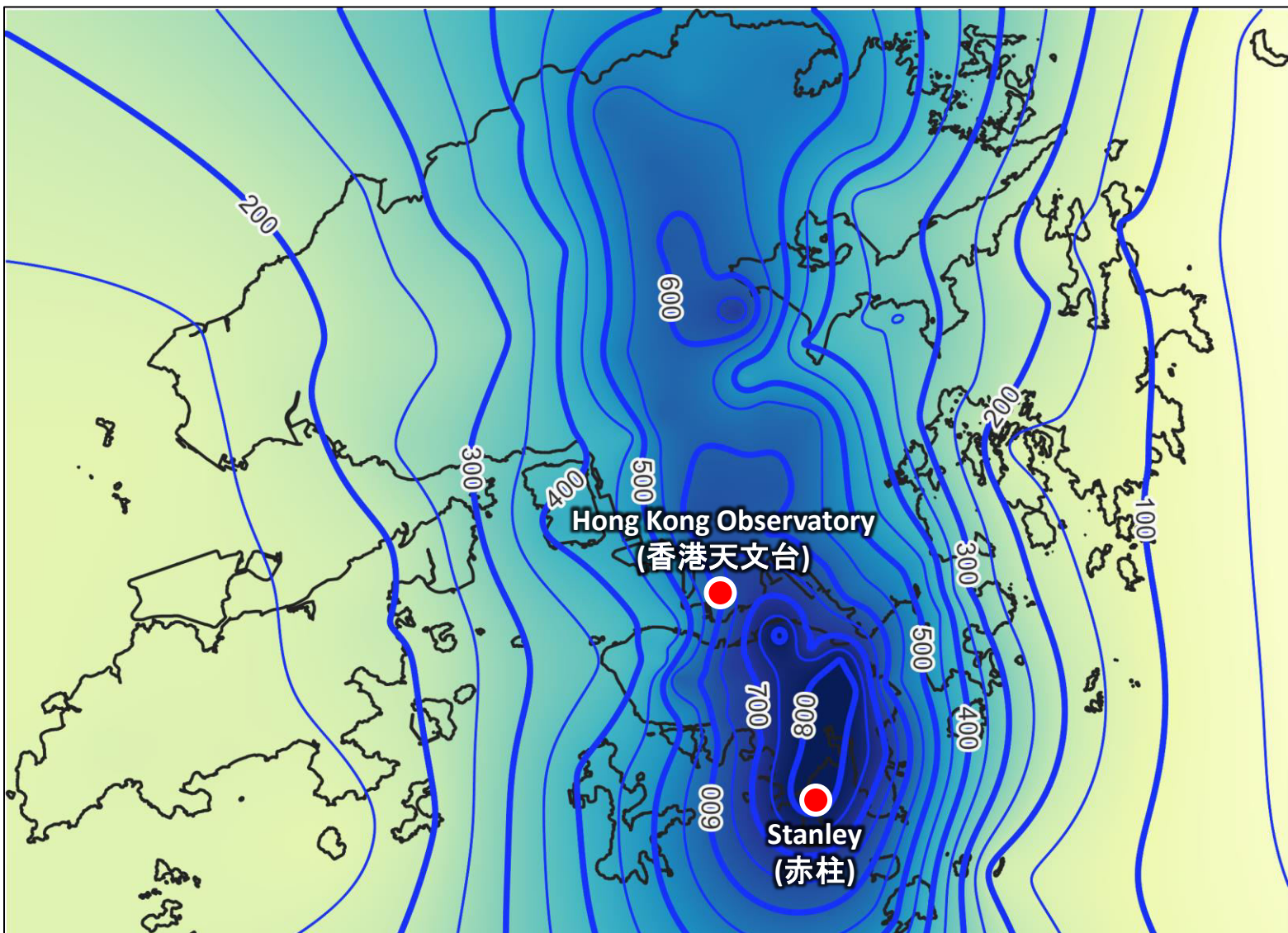


Hilly landscape of Hong Kong



- ❖ Over **60%** land area is **natural terrain**.
- ❖ **~30%** terrain steeper than **30°**.
- ❖ **Annual precipitation 2300 mm**
- ❖ Population located **on or close to steep hillsides**.

The 7 Sept 2023 extreme storm



158.1 mm

New record of hourly rainfall at HKO

846 mm

Max. 24-h rainfall in Hong Kong

817 mm

New record of 12-h rainfall at Stanley

645.0 mm

Max. 24-h rainfall at Zhengzhou (720 rainstorm)

Number of landslides in Hong Kong and triggering rainfall amounts in the past 30 years

Year	Open hillslope landslides	Channelized debris flows	Total number	Max rolling 4-h rainfall (mm)	Max rolling 24-h rainfall (mm)
1989	384	285	669	224.0	552.0
1993	928	775	1703	350.0	742.0
1994	563	243	806	394.5	954.0
1997	256	105	361	296.0	799.0
1998	308	78	386	223.0	562.0
1999	517	418	935	230.0	551.0
2000	706	204	910	340.0	526.0
2003	214	93	307	322.0	505.0
2005	136	108	244	208.5	570.0
2008	1596	1407	3003	384.0	622.5
2016	398	234	632	280.0	409.0
2023	Unknown	Unknown	Unknown	410.0	846.0

Hong Kong 907 records:

1-h: 158.8 mm
4-h: 410 mm
12-h: 817 mm

Zhengzhou 720:

1-h: 201.9 mm
24-h: 645 mm
3-day: 855 mm

The 7 Sept 2023 extreme storm



Flooded MTR station at Wong Tai Sin, Kowloon



Flash flood at Chai Wan, Hong Kong Island



Landslide at Shau Kei Wan, Hong Kong Island

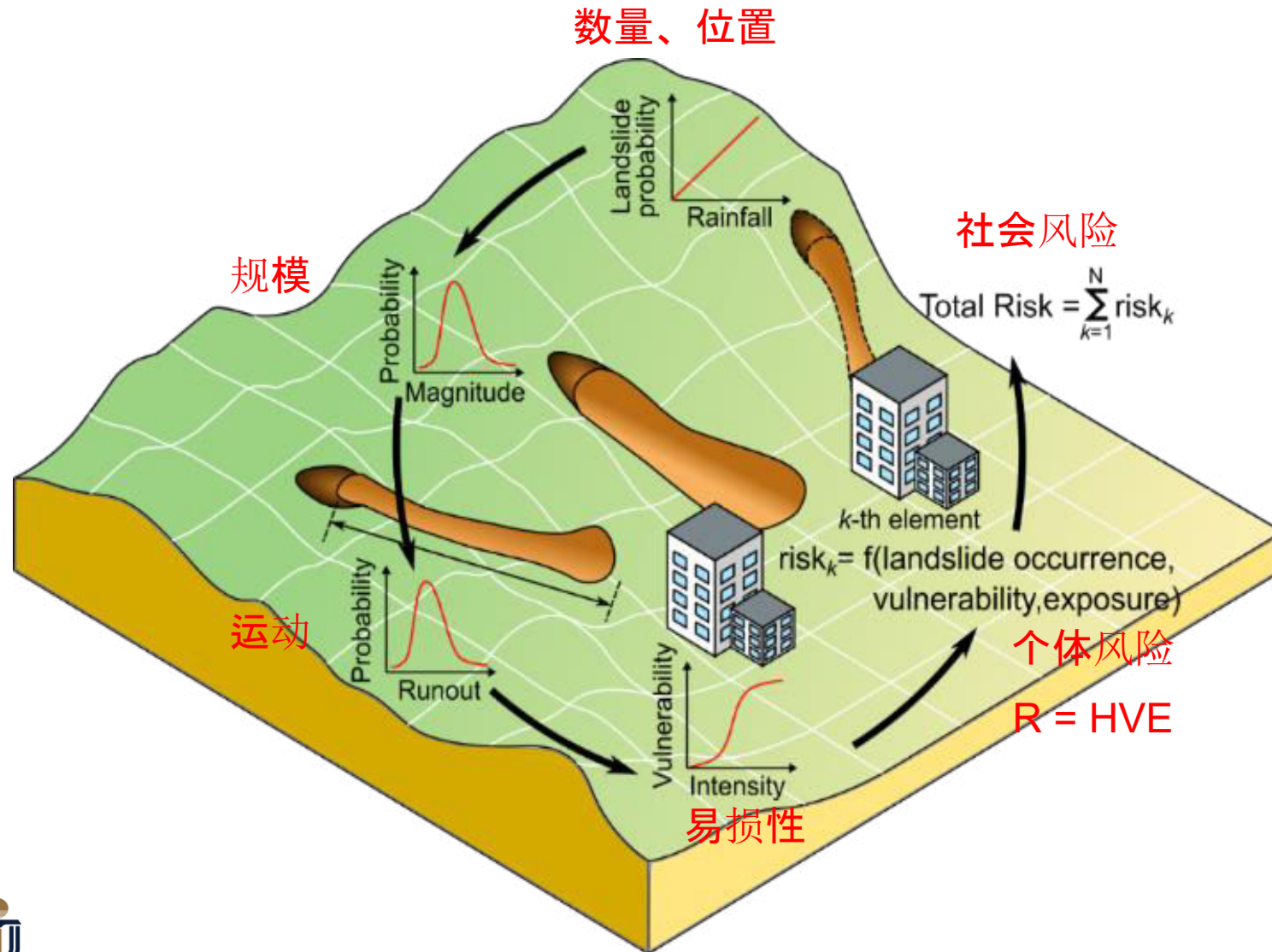
As of 10 Sep. 2023:

- **144 injuries**
- **1 missing, 2 deaths**
- **60 flooding cases**
- **83 landslide incidents**

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Prompt landslide risk assessment for real-time warning and rescue 快速风险评估



降雨

- 降雨强度
- 降雨时长
- 降雨分布

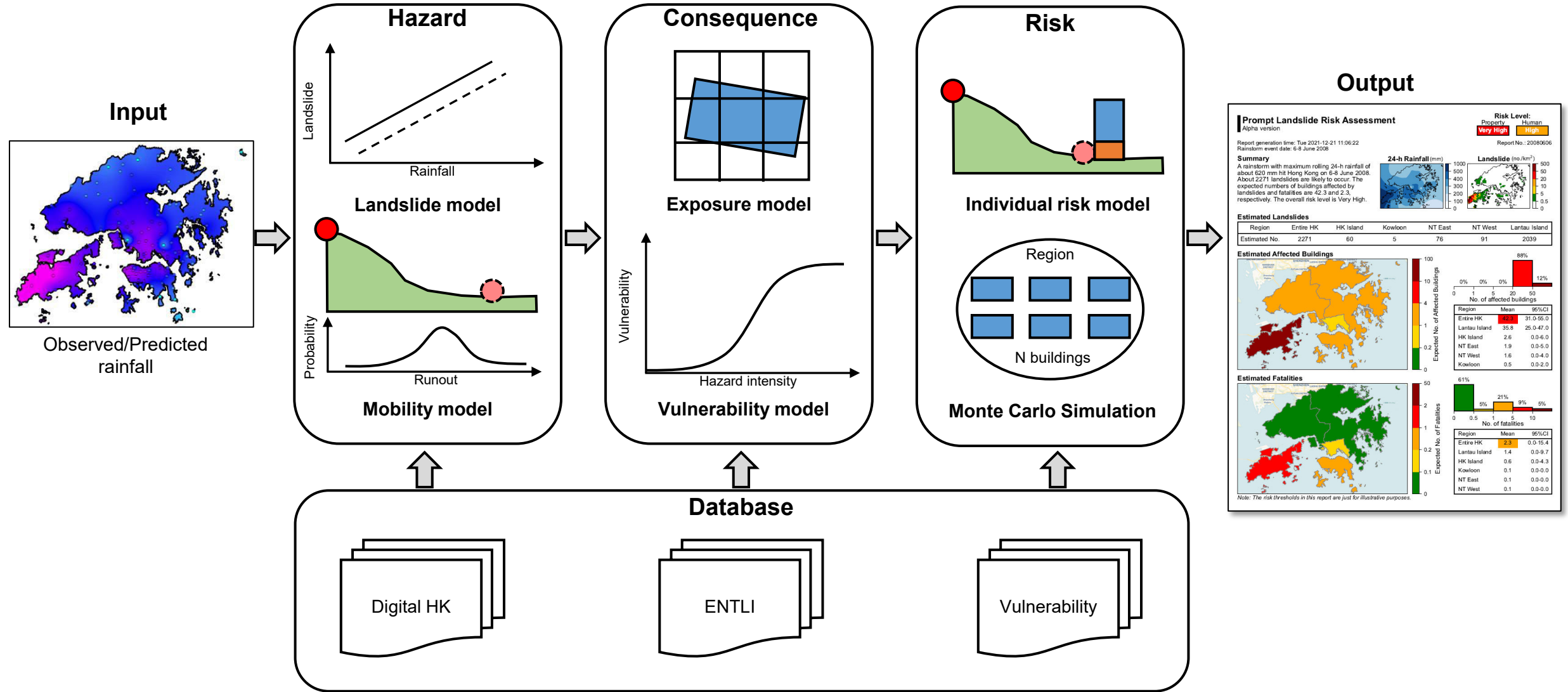
滑坡

- 滑坡时间？
- 滑坡位置？
- 滑坡数量？
- 滑坡规模？
- 移动距离？

后果

- 受影响房屋？
- 受影响交通？
- 人员伤亡？

Prompt Landslide risk Assessment (PoLA) 城市级降雨—滑坡链式风险快速评估



Landslide risk by the 7 Sept 2023 storm

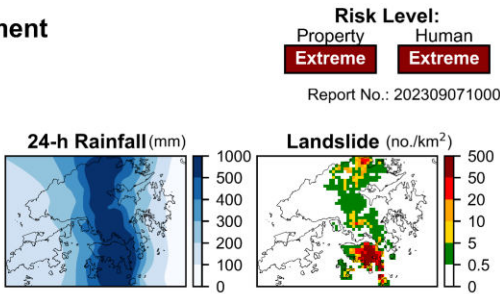
Prompt Landslide Risk Assessment

Alpha version

Report generation time: Fri 2023-09-08 17:00:00
Rainstorm event date: 7-8 Sep, 2023

Summary

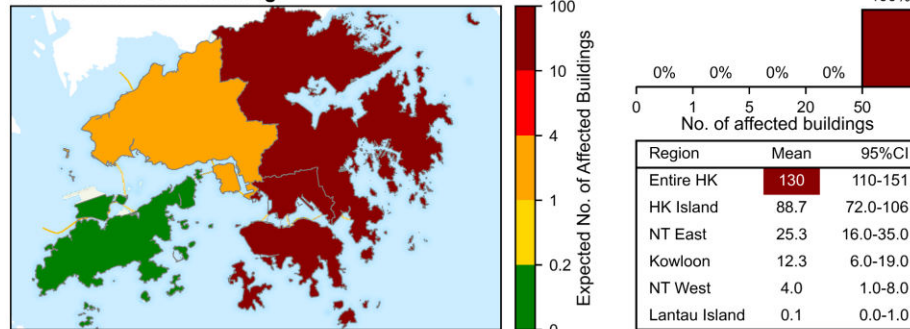
A rainstorm with maximum rolling 24-h rainfall of about 846 mm hit Hong Kong on 7-8 Sep, 2023. About 4888 landslides are likely to occur. The expected numbers of buildings affected by landslides and fatalities are 130 and 12.7, respectively. The overall risk level is Extreme.



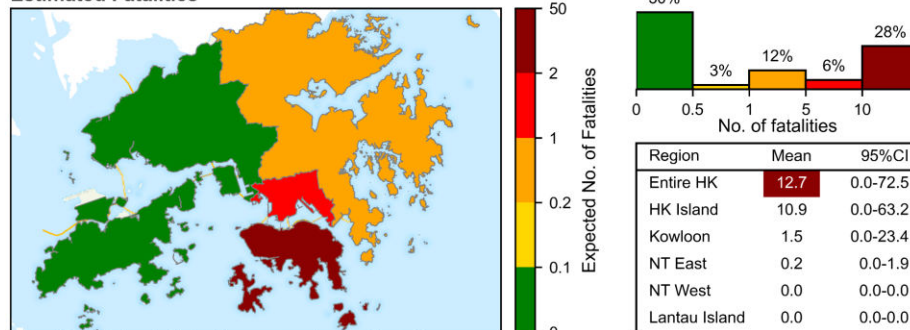
Estimated Landslides

Region	Entire HK	HK Island	Kowloon	NT East	NT West	Lantau Island
Estimated No.	4888	3503	94	1190	97	4

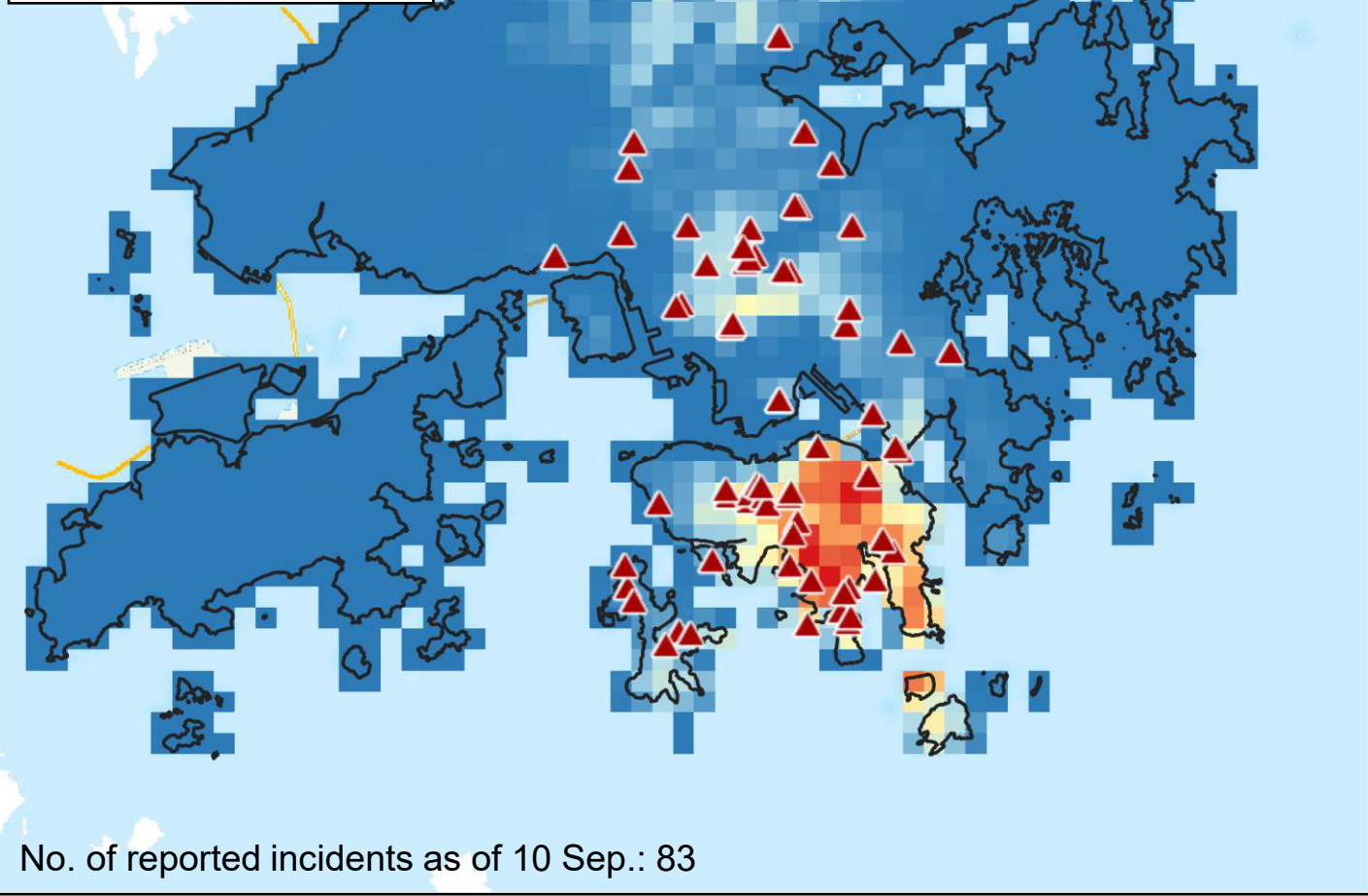
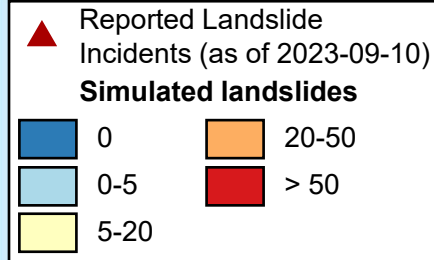
Estimated Affected Buildings



Estimated Fatalities



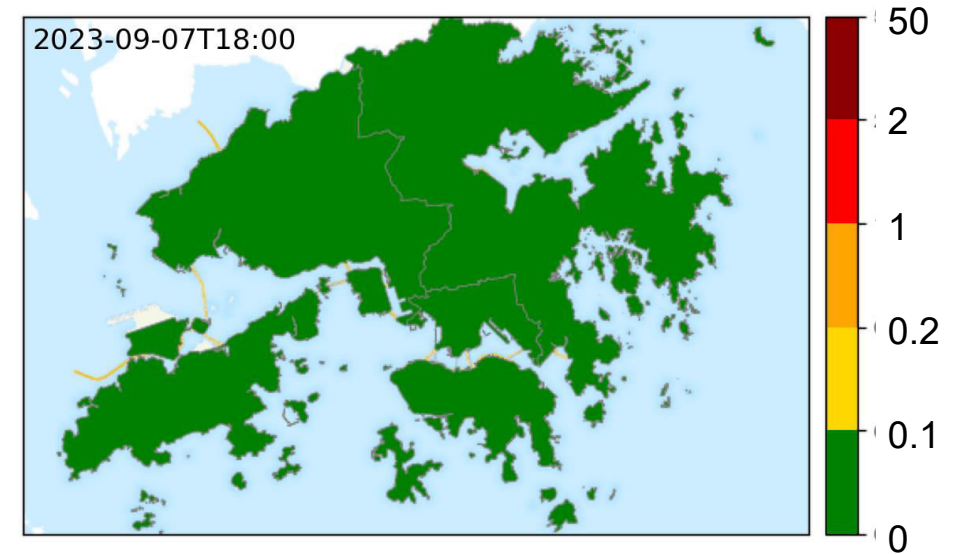
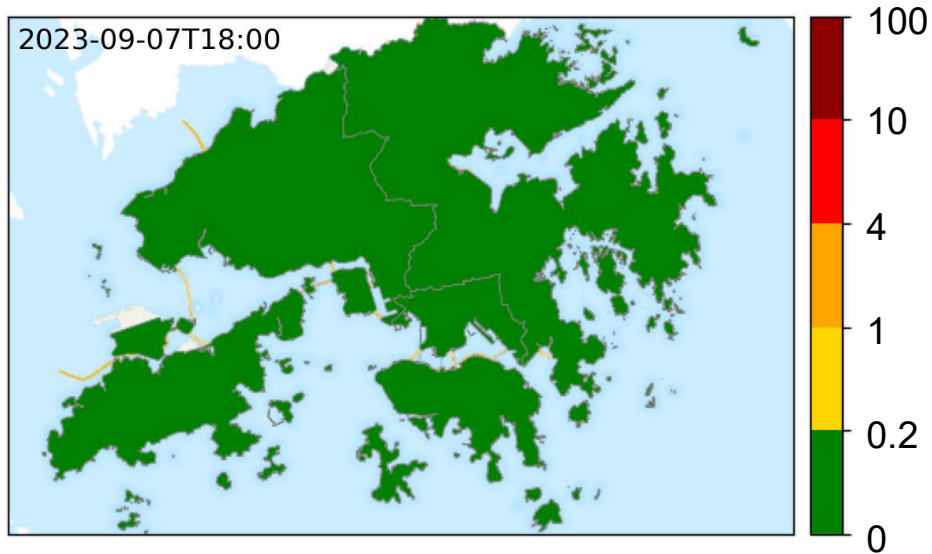
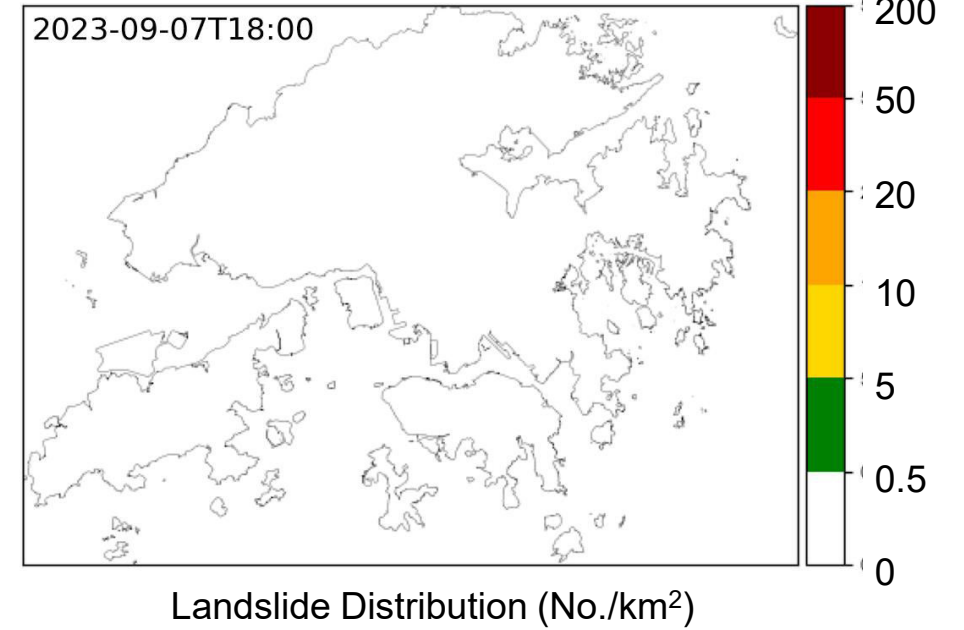
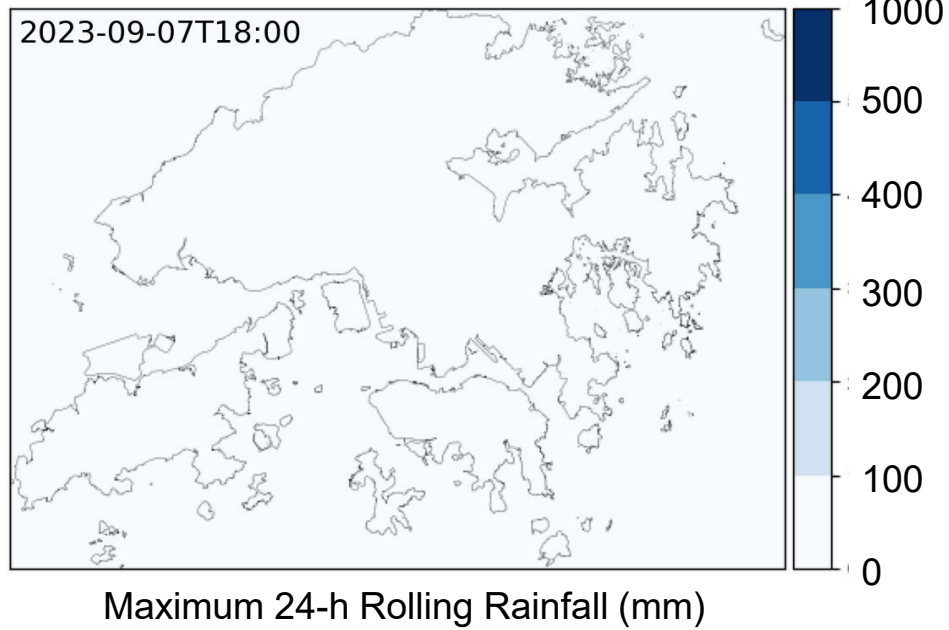
Note: The risk thresholds in this report are just for illustrative purposes.



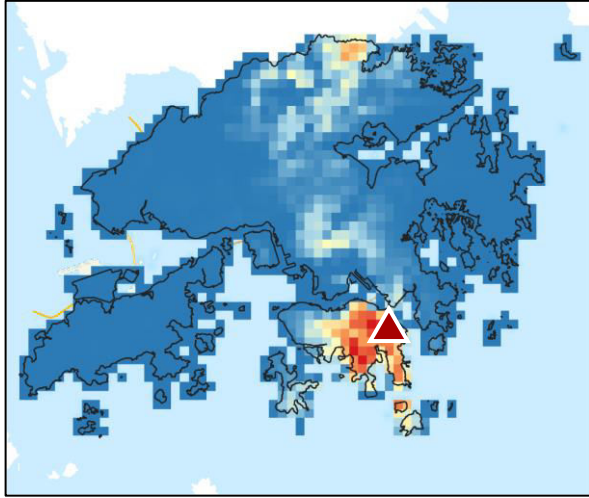
No. of reported incidents as of 10 Sep.: 83

Landslide risk by the 7 Sept 2023 storm

1000km²
区域风
险评估
耗时少
于3分钟

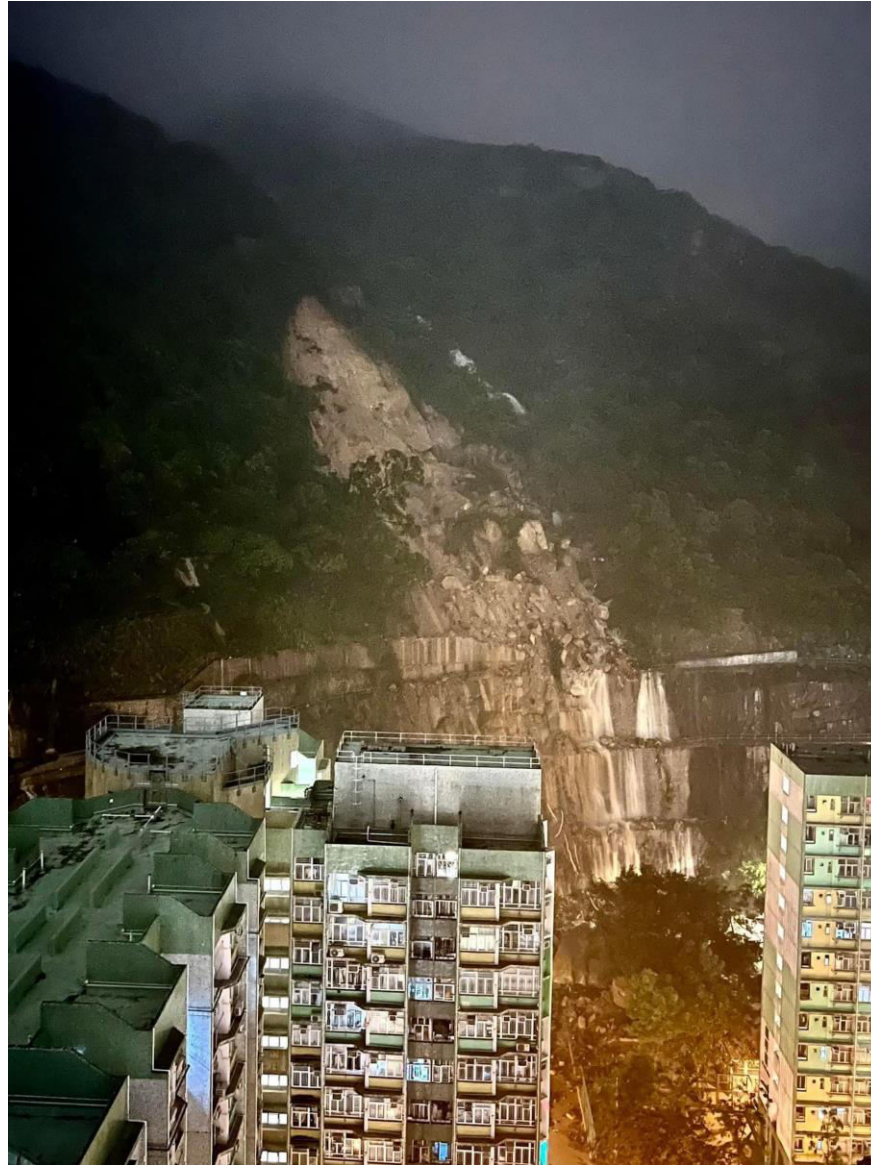


Landslide incidents



Shau Kei Wan, Hong Kong Island

- Boulders 4-5 in diameter
- Roads blocked
- Affected area: 500 m²



Landslide incidents

Shek O Road, Hong Kong Island



Tai Wai, New Territories



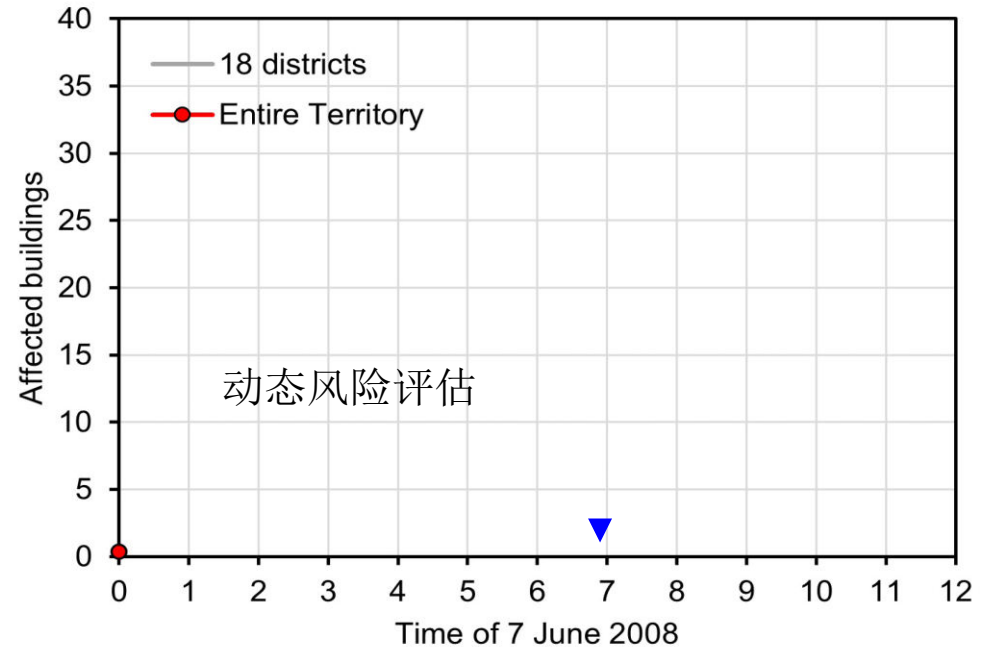
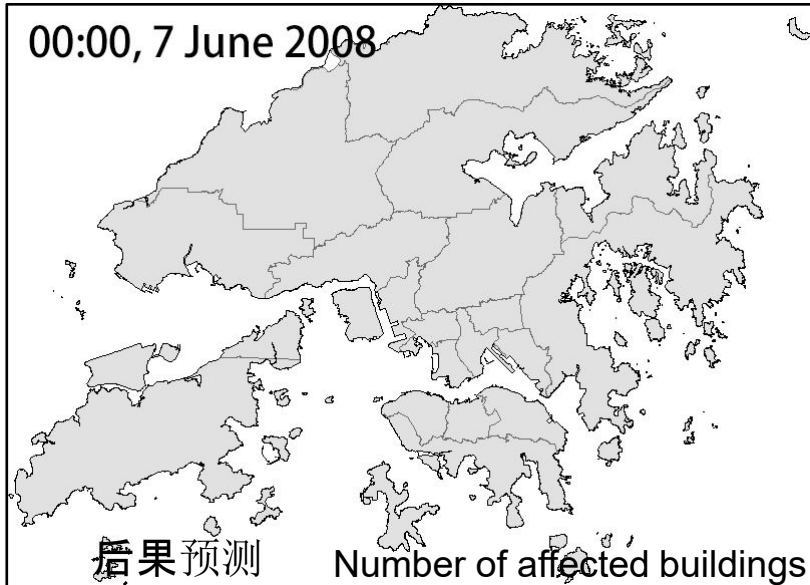
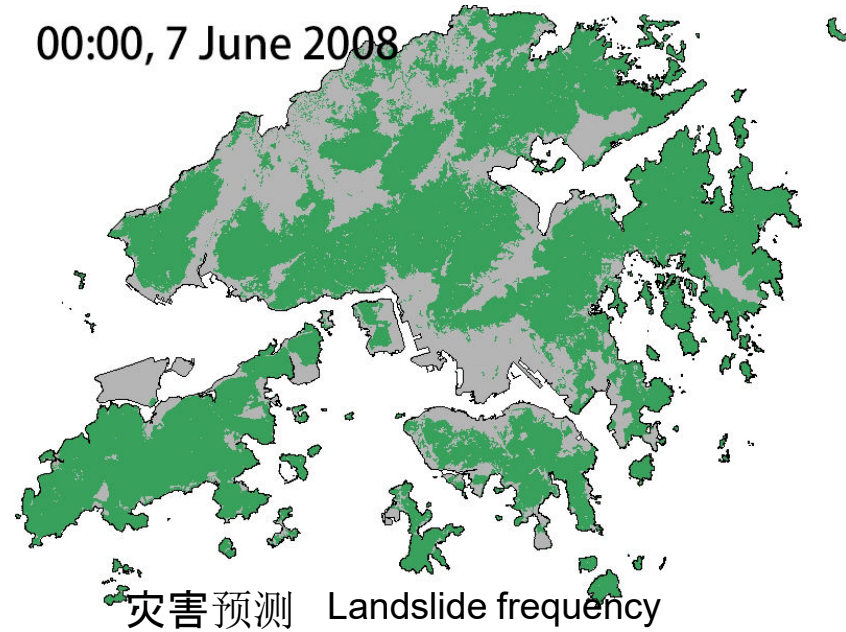
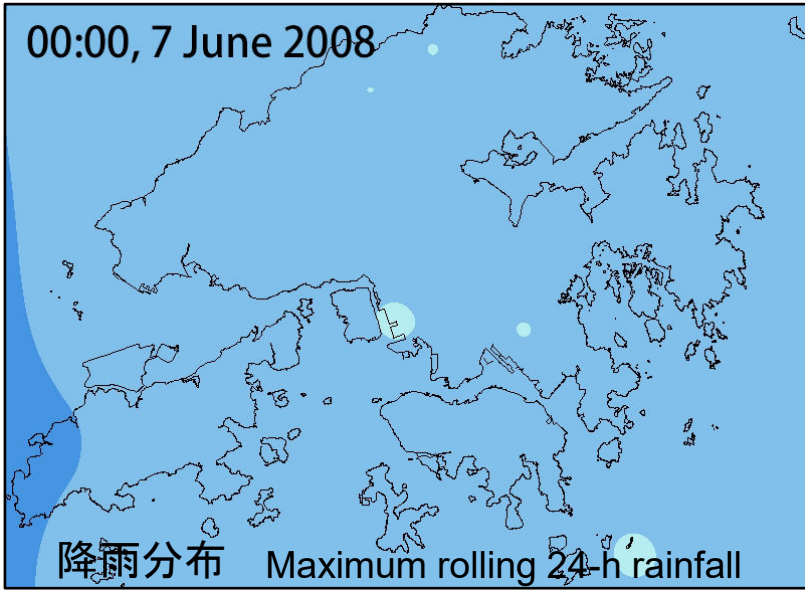
Redhill Peninsula, Hong Kong Island



Kwun Tong, Kowloon

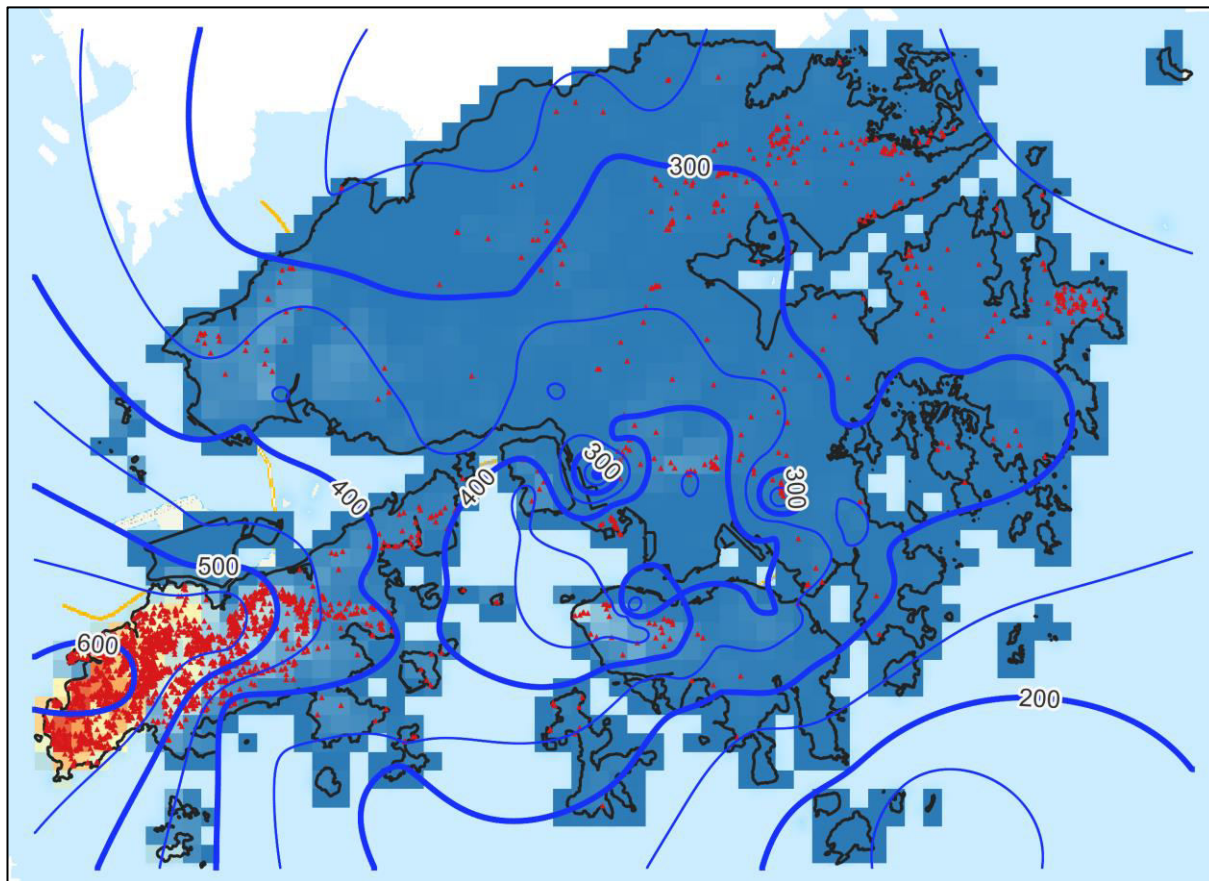


2008 vs 2023 rainstorms



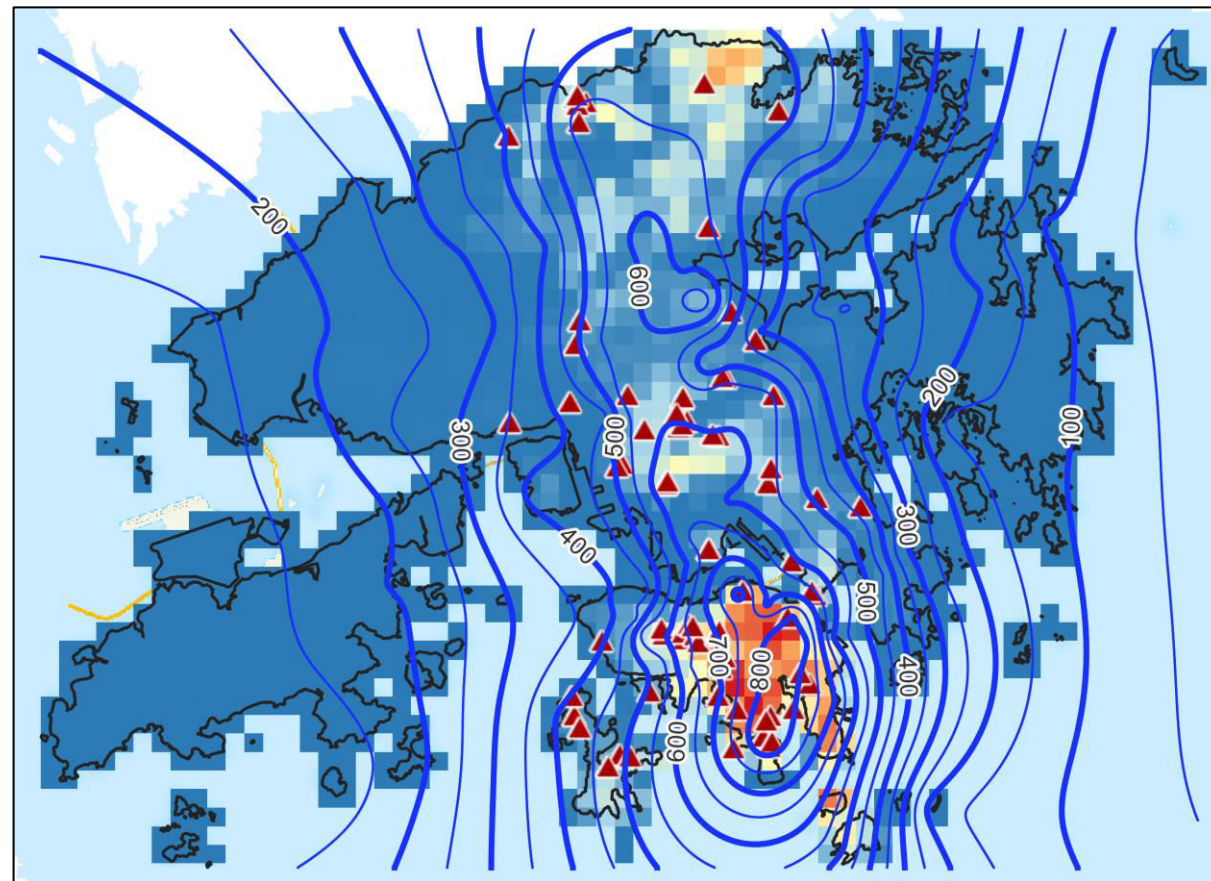
2008 vs 2023 rainstorms

Rainstorm on 6-8 Jun. 2008



- Max. 24-h rolling rainfall: **622 mm**
- Actual no. of landslides: **about 2400**
- Simulated no. of landslides: **2271**
- Estimated no. of affected buildings: **42.2**
- Estimated no. of fatalities: **2.2**

Rainstorm on 7-8 Sep. 2008



- Max. 24-h rolling rainfall: **846 mm**
- Actual no. of landslides: unknown
- Simulated no. of landslides: **4888**
- Estimated no. of affected buildings: **130**
- Estimated no. of fatalities: **12.7**

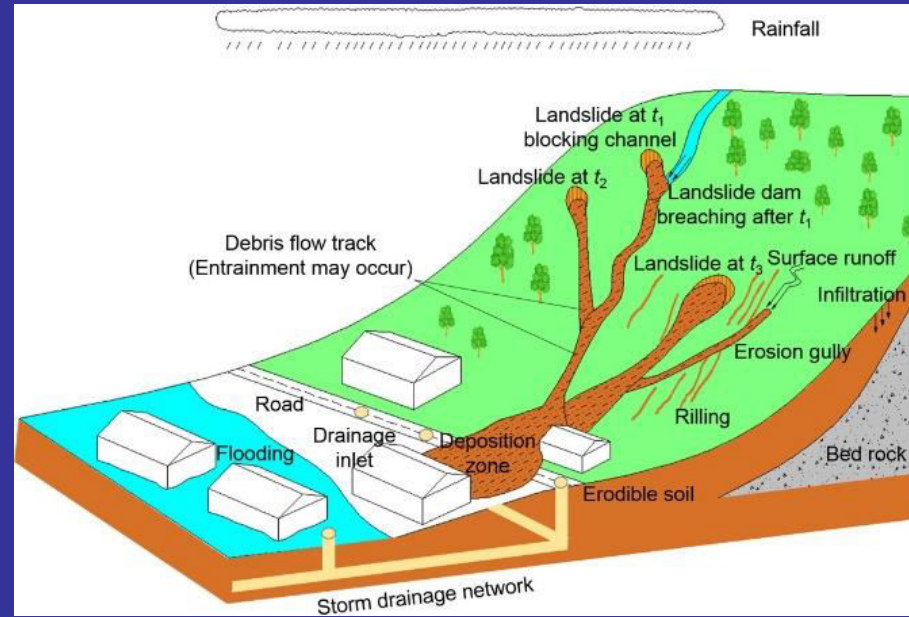
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Distributed, cell-based analysis 复合灾害数值模拟平台： 分布式滑坡、泥石流、冲刷数值模拟，EDDA3.0

- Rainfall-induced multi-hazard processes
- Two mechanisms of debris flow initiation: **erosion and transformation from landslides**
- Saint-Venant equation considering erosion and deposition process, depth-averaged

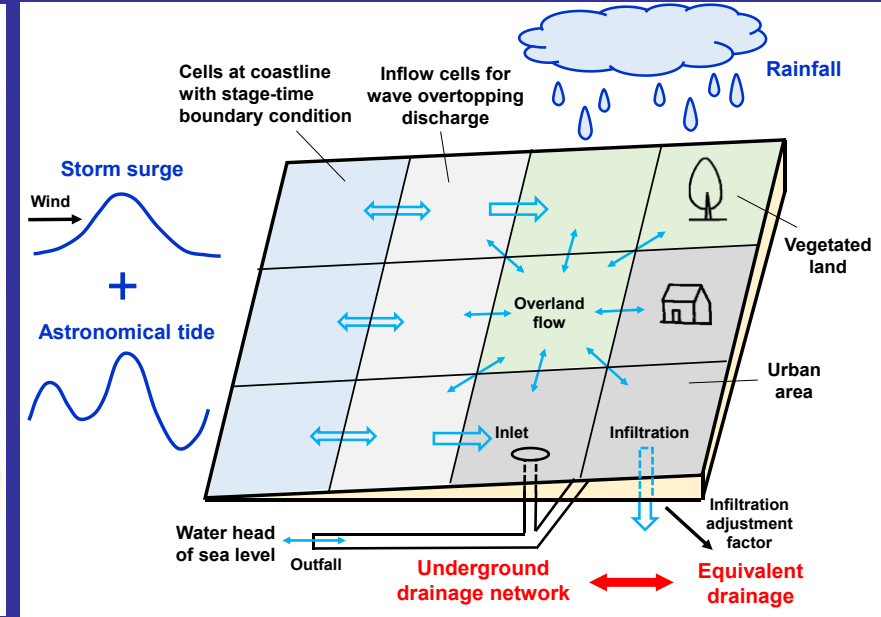


$$\frac{\partial h}{\partial t} + \frac{\partial(hv)}{\partial x} = i[C_{v*} + (1 - C_{v*})s_b] + A[C_{vA} + (1 - C_{vA})s_A]$$

$$\frac{\partial(C_v h)}{\partial t} + \frac{\partial(C_v h v)}{\partial x} + = i C_{v*} + A C_{vA}$$

$$\frac{\partial v}{\partial t} + v \frac{\partial v}{\partial x} = g \left[-\text{sgn}(v) S_f - \frac{\partial(z_b + h)}{\partial x} \right]$$

$$- \frac{v \{ i [C_{v*} + (1 - C_{v*})s_b] + A [C_{vA} + (1 - C_{vA})s_A] \}}{h}$$

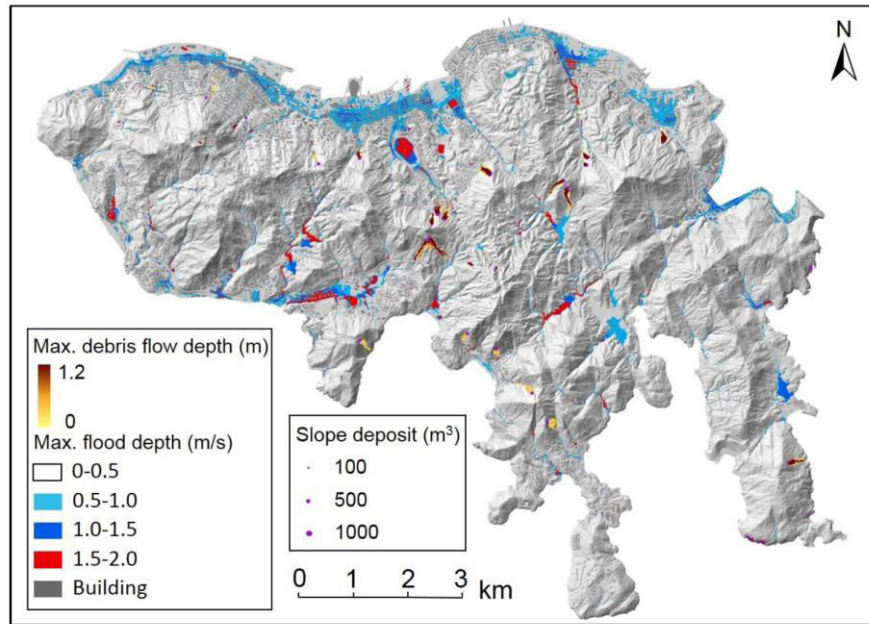


Chen, H.X., Zhang, L.M. (2015). EDDA 1.0: integrated simulation of debris flow erosion, deposition and property changes. *Geoscientific Model Development*, 8, 829–844.

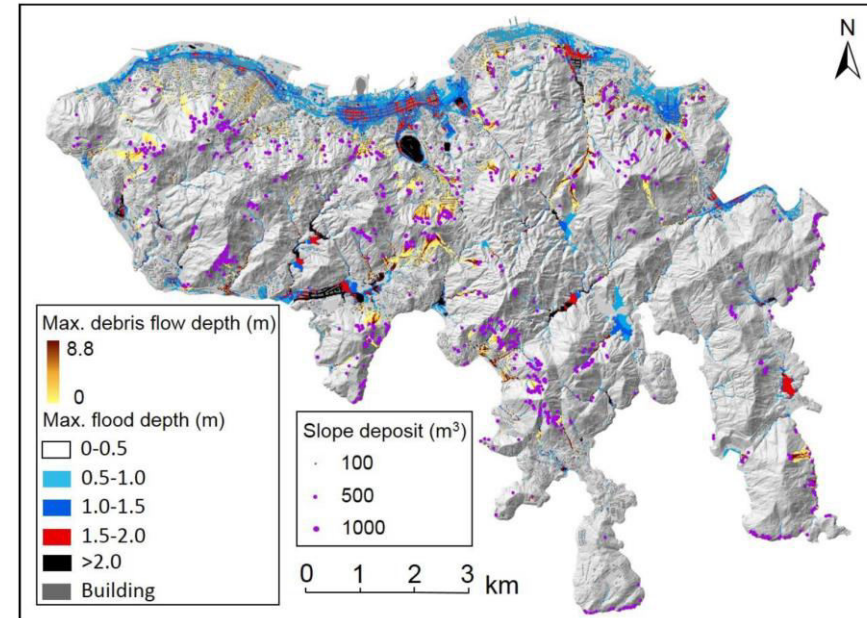
Shen, P., Zhang, L.M., Chen, H.X., Fan, R.L. (2018). EDDA 2.0: integrated simulation of debris flow initiation and dynamics considering two initiation mechanisms. *Geoscientific Model Development*, 11(7), 2841-2856.



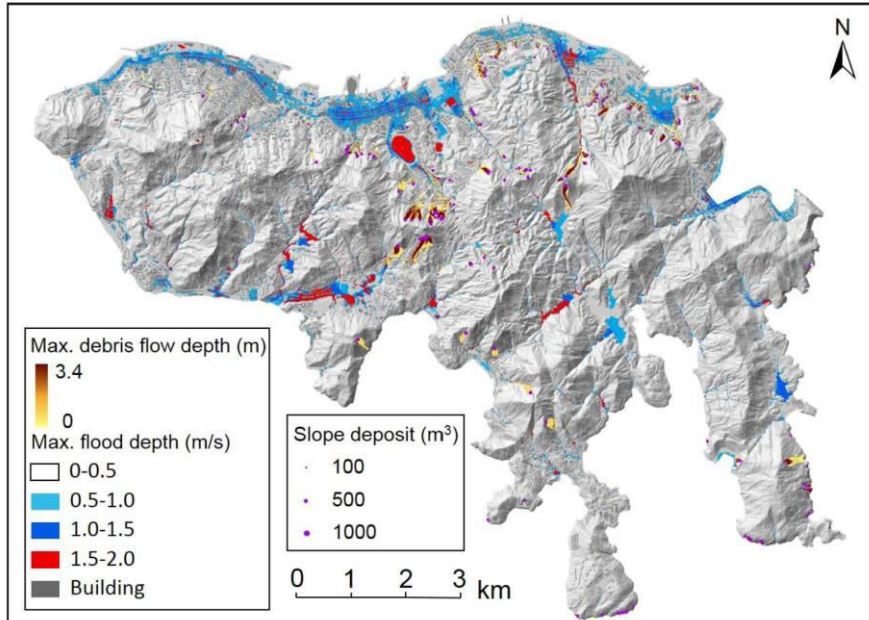
Stress testing of hazard scenarios, Hong Kong Island



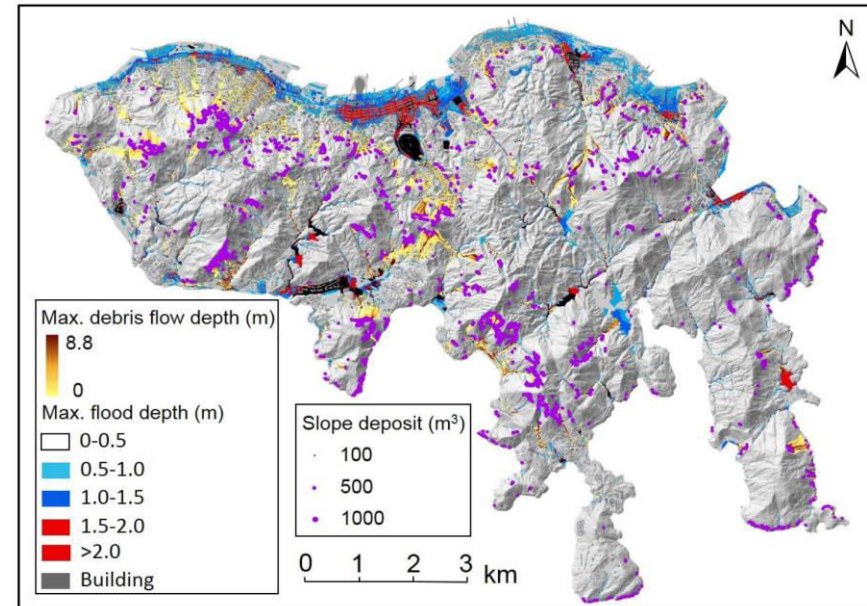
29%PMP



65%PMP



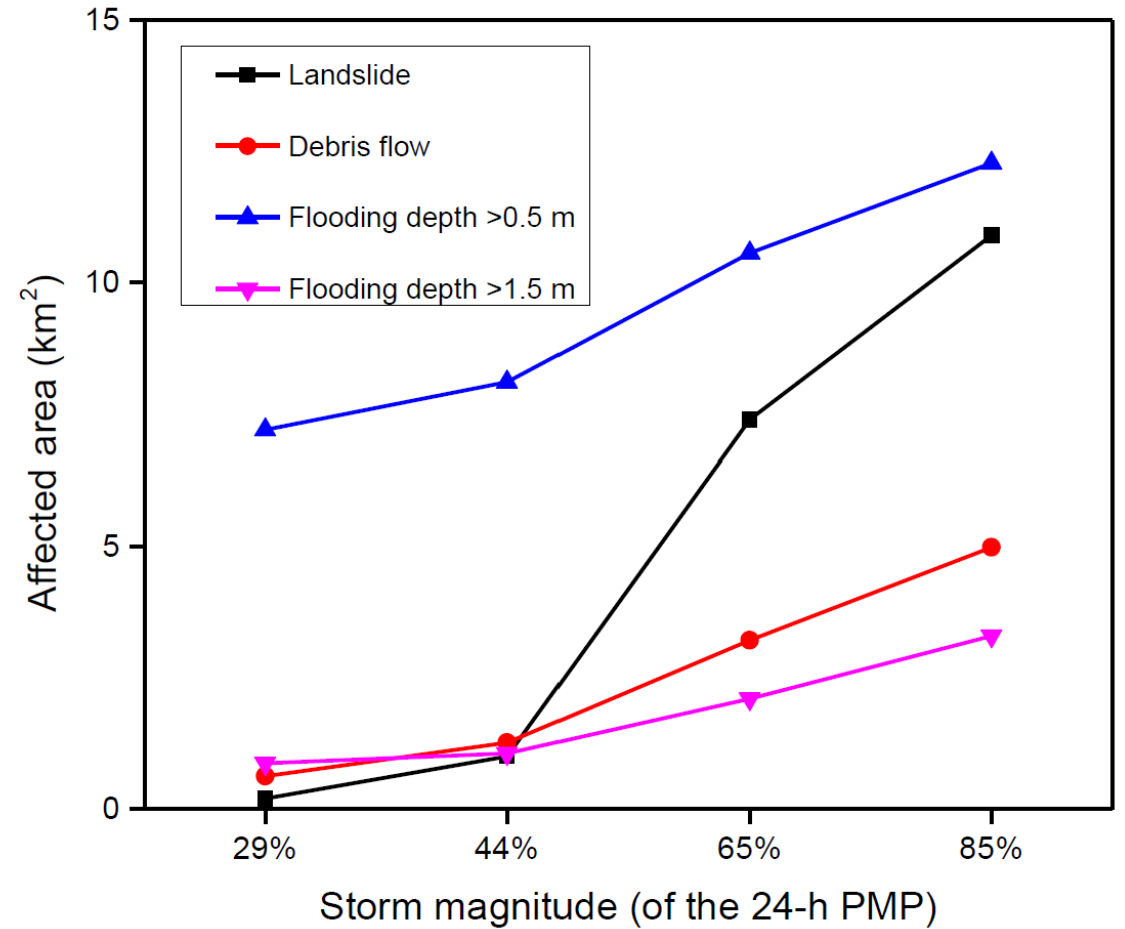
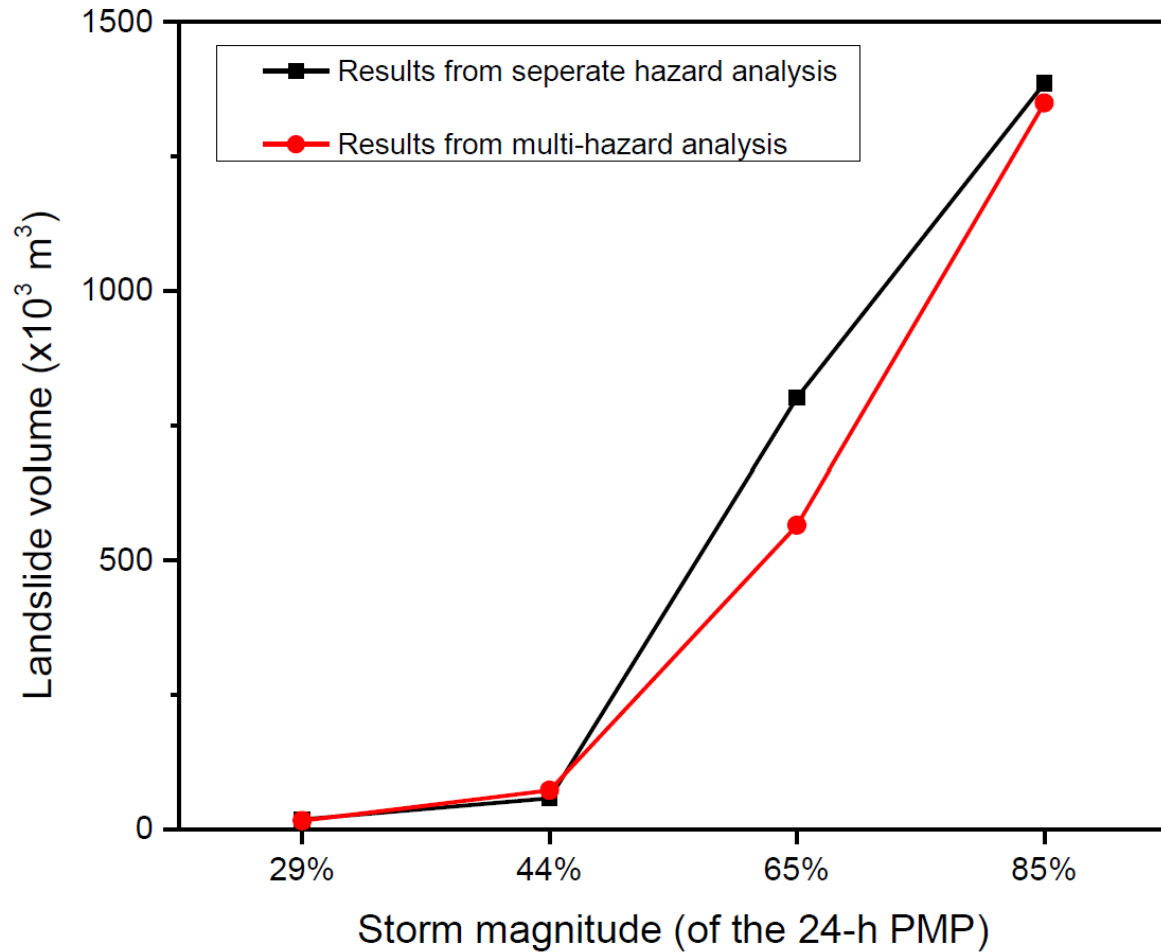
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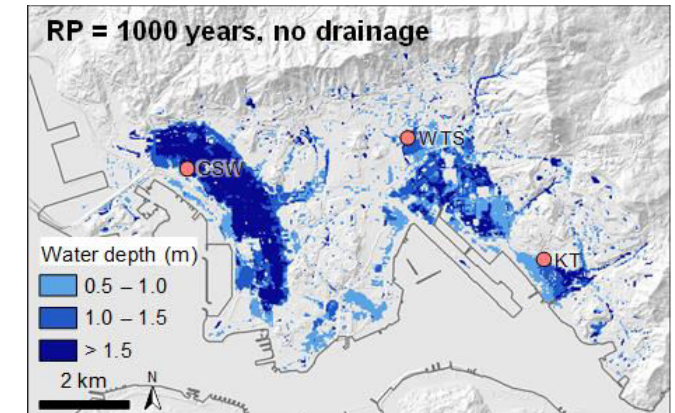
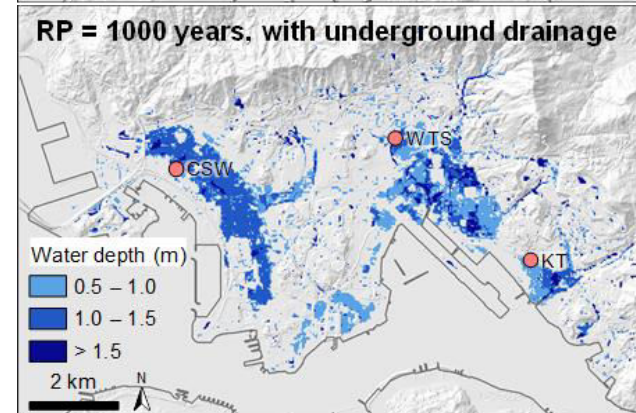
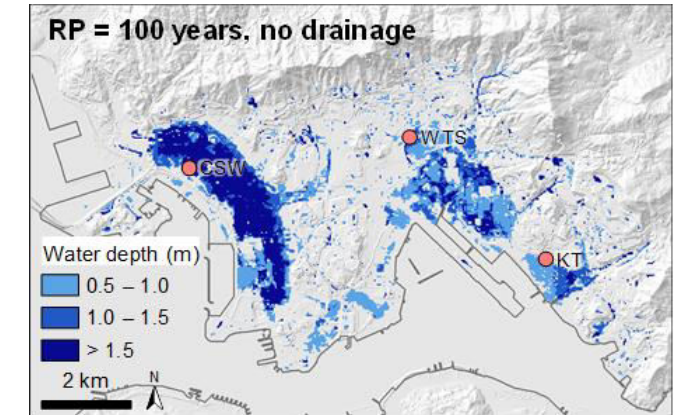
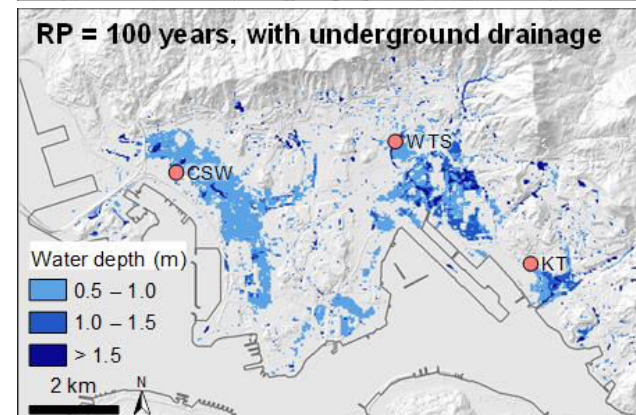
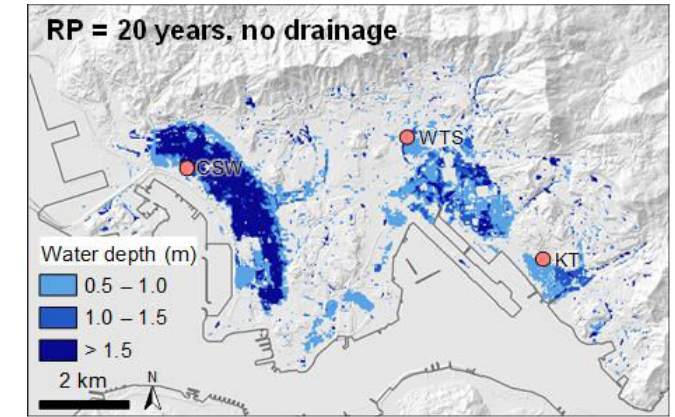
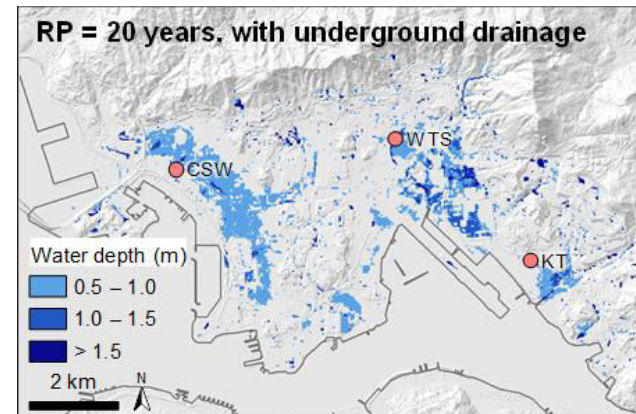
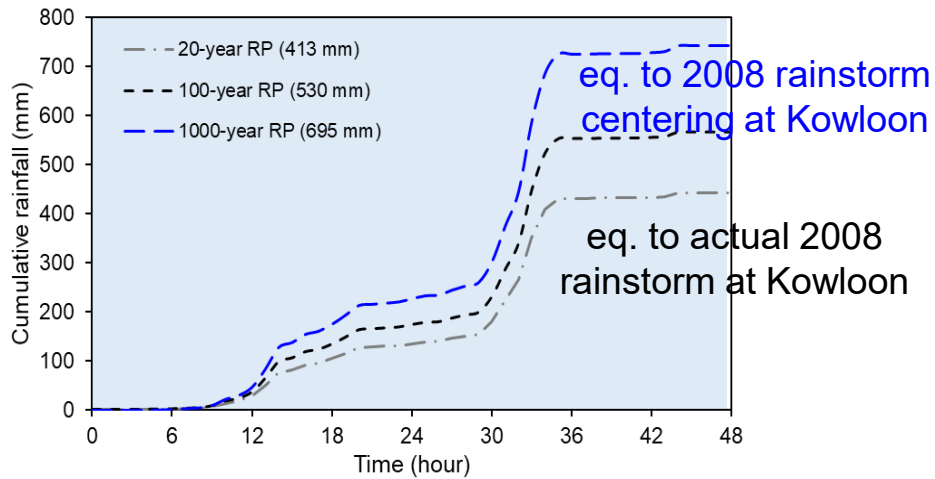
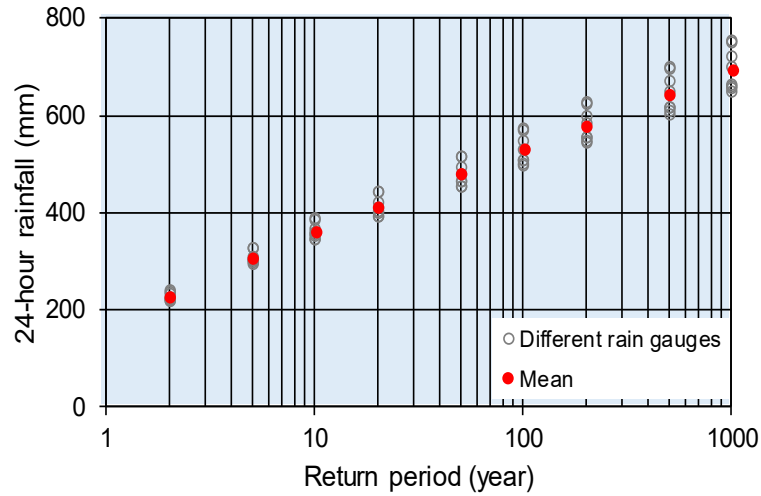
85%PMP



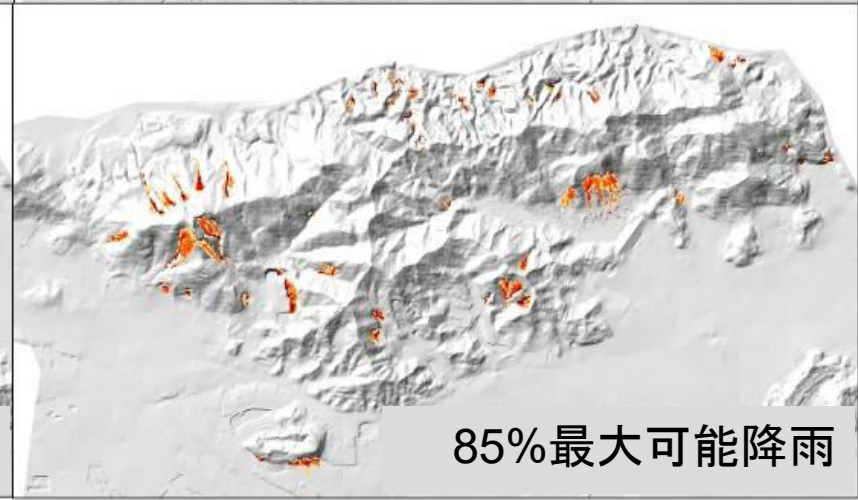
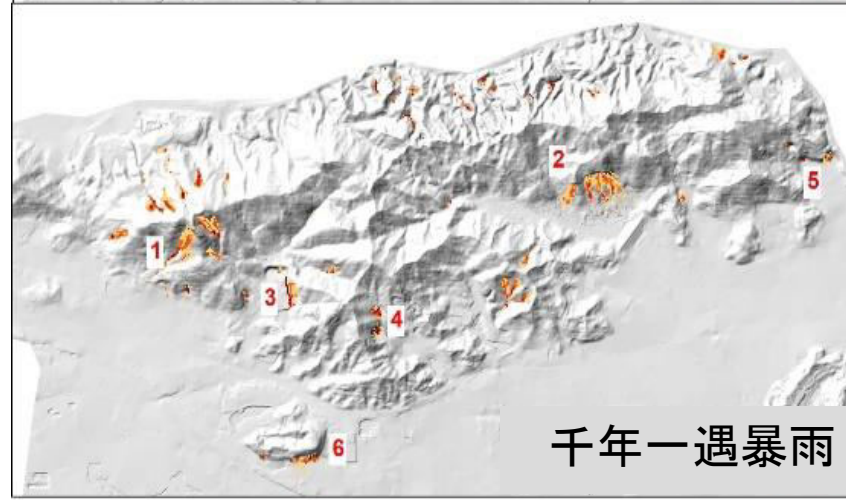
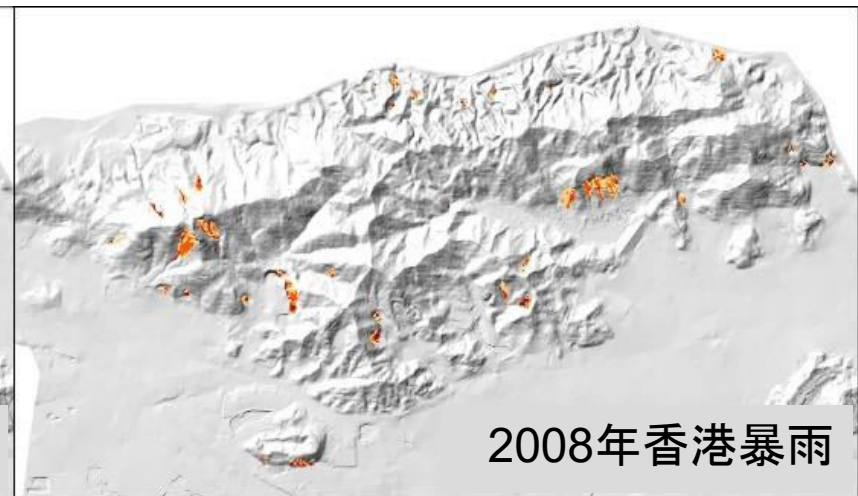
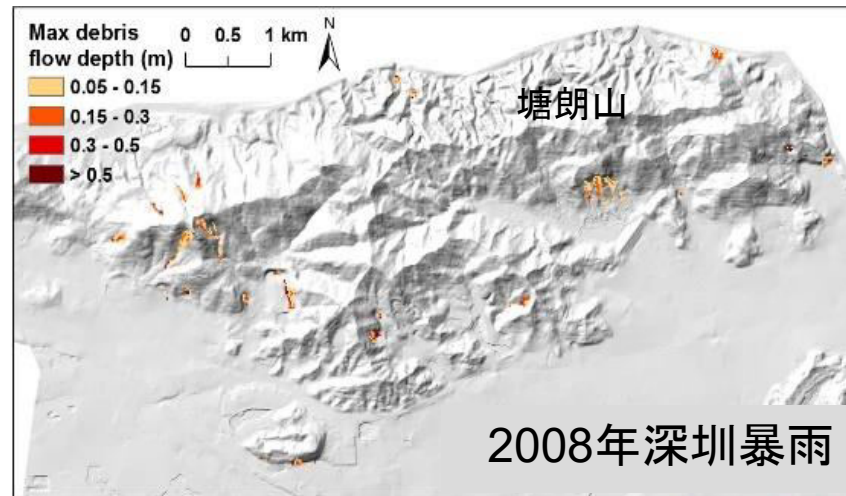
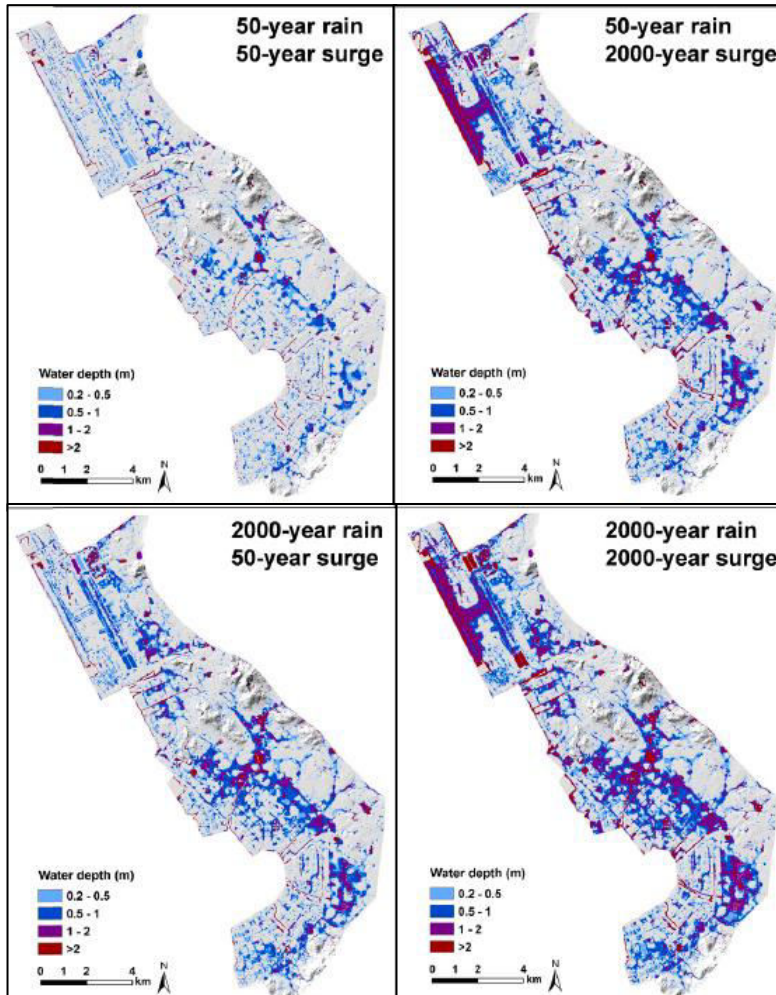
How the impact increase with the rainfall intensity?



Hazard scenarios 复合灾害情景推演：香港九龙 Kowloon



Hazard scenarios 复合灾害情景推演：前海地区深圳中心城区

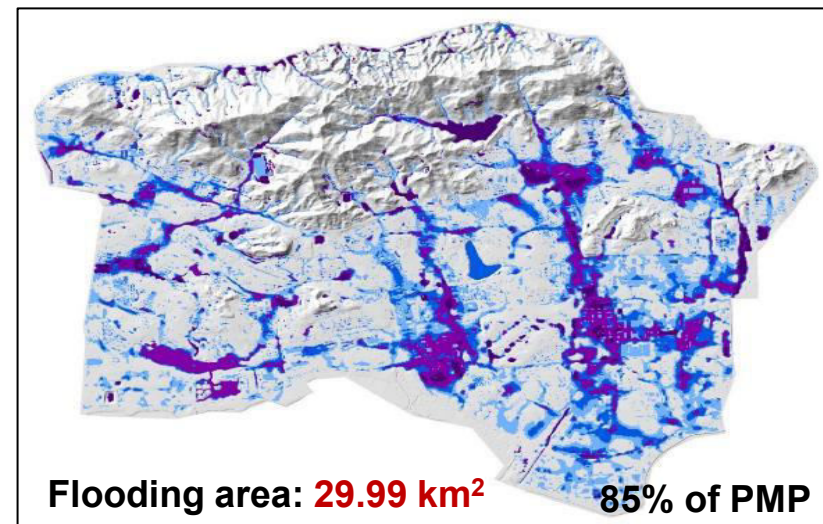
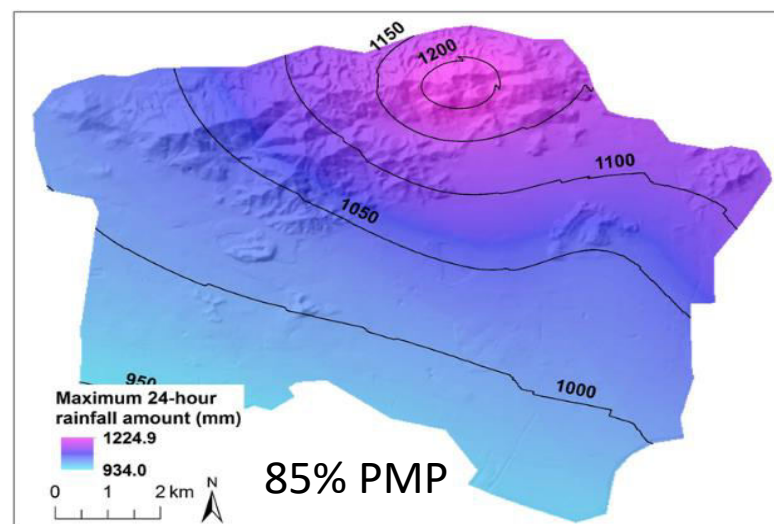
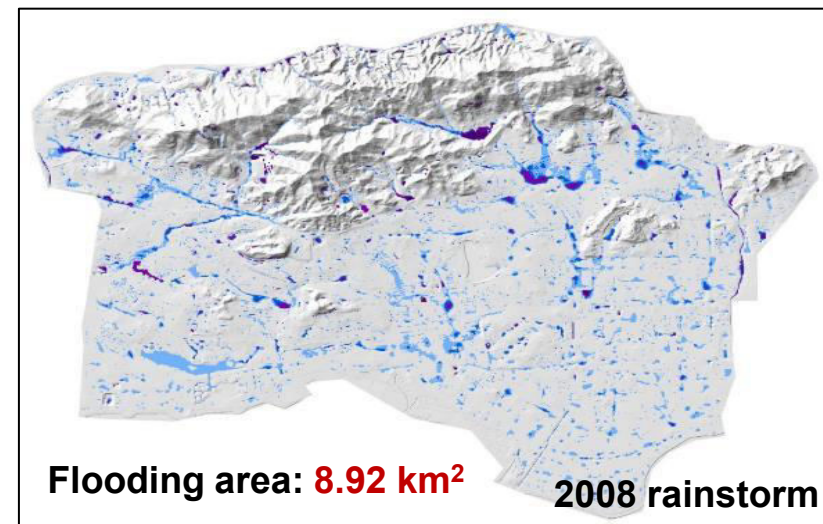
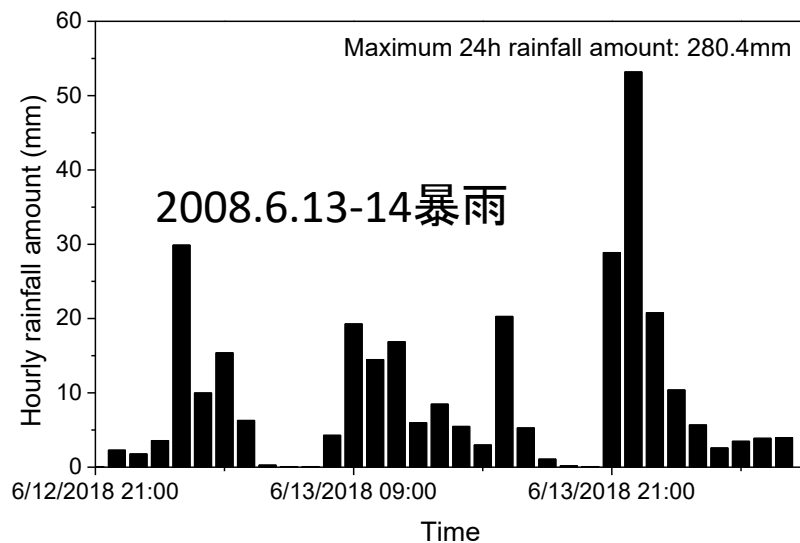
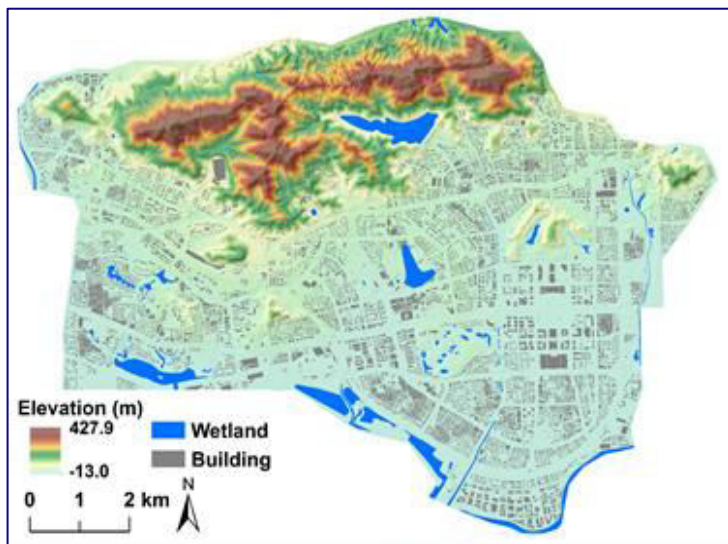


前海地区洪涝情景推演

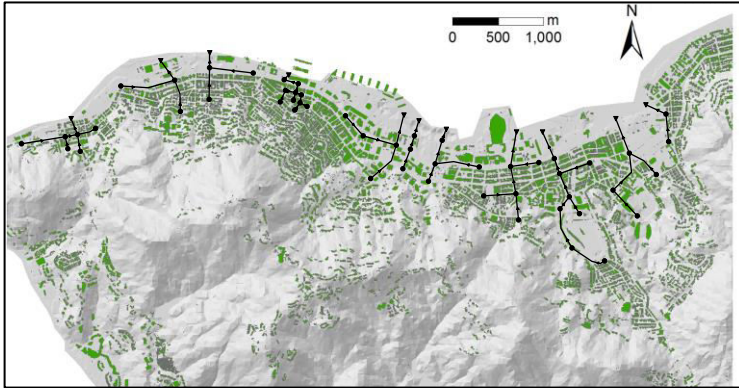
深圳中心城区复合地质灾害情景推演



Hazard scenarios 复合灾害情景推演：深圳中心城区 (100 km²)

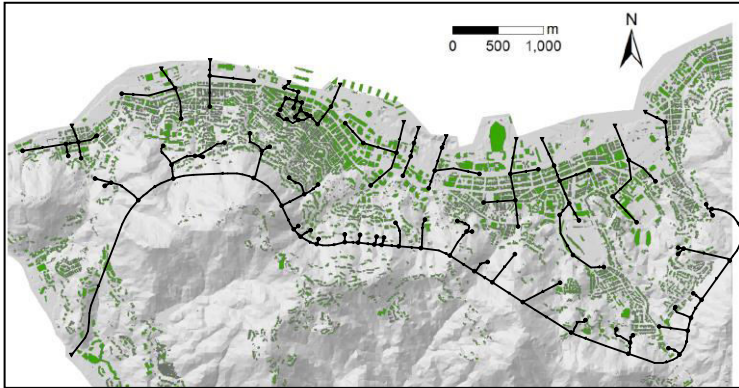


Management strategies 风险防控关键技术有效性



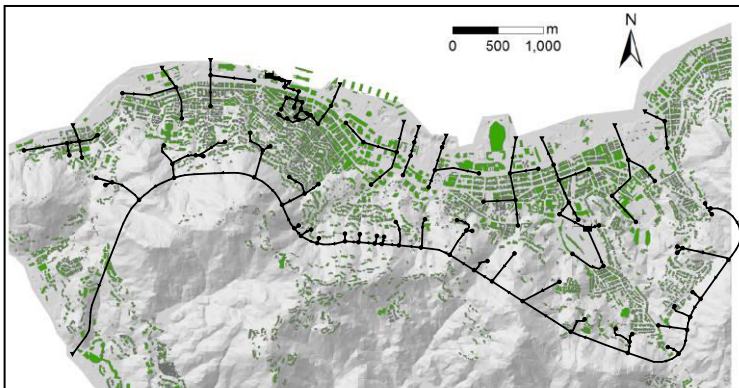
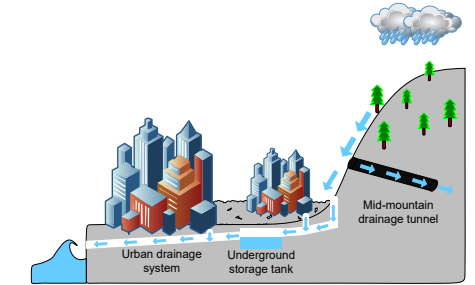
Phase 1

- The urban drainage system



Phase 2

- Urban drainage system, West drainage tunnel, 2012
- 660 m intercepting drains of Sheung Wan flood relief projects



Phase 3

- All drainage works in Phase 2
- The underground storage tanks of Sheung Wan and Happy Valley, 2017



Management strategies 风险防控关键技术有效性

洪涝防控技术



海堤防浪墙



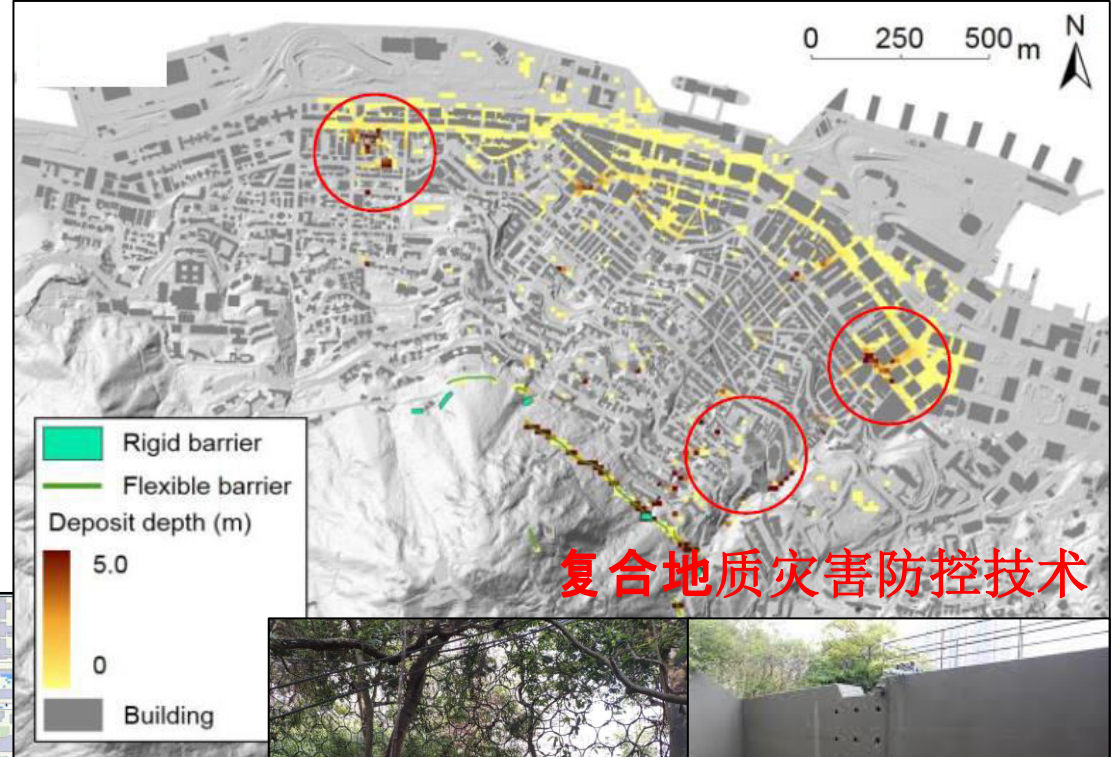
排水口止回阀



设排水系统

设止回阀

设防浪墙



复合地质灾害防控技术



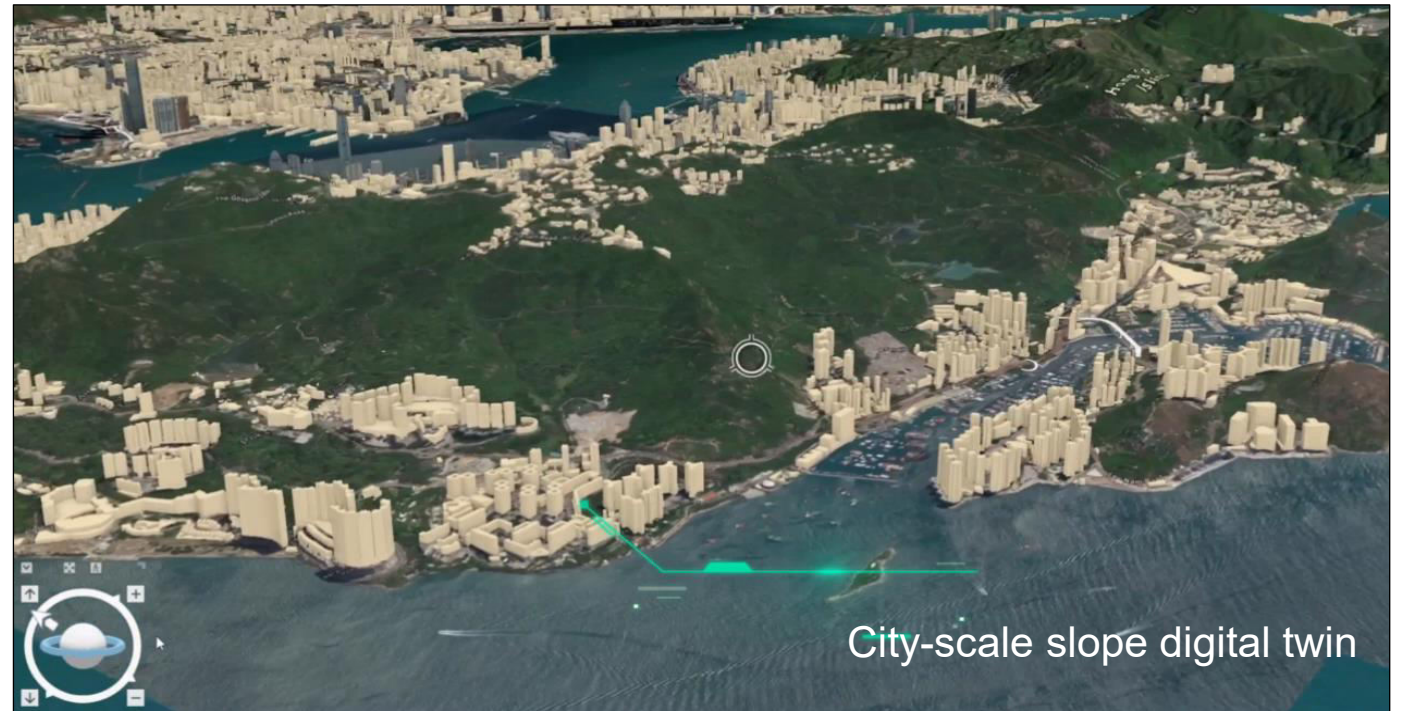
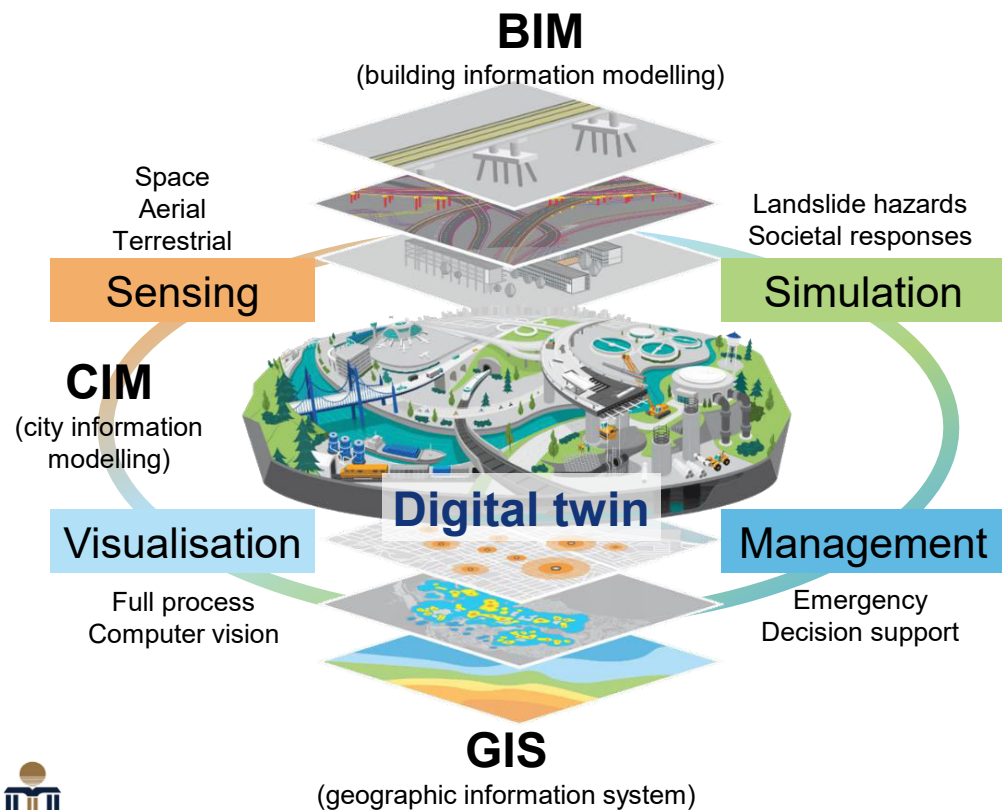
柔性防护网



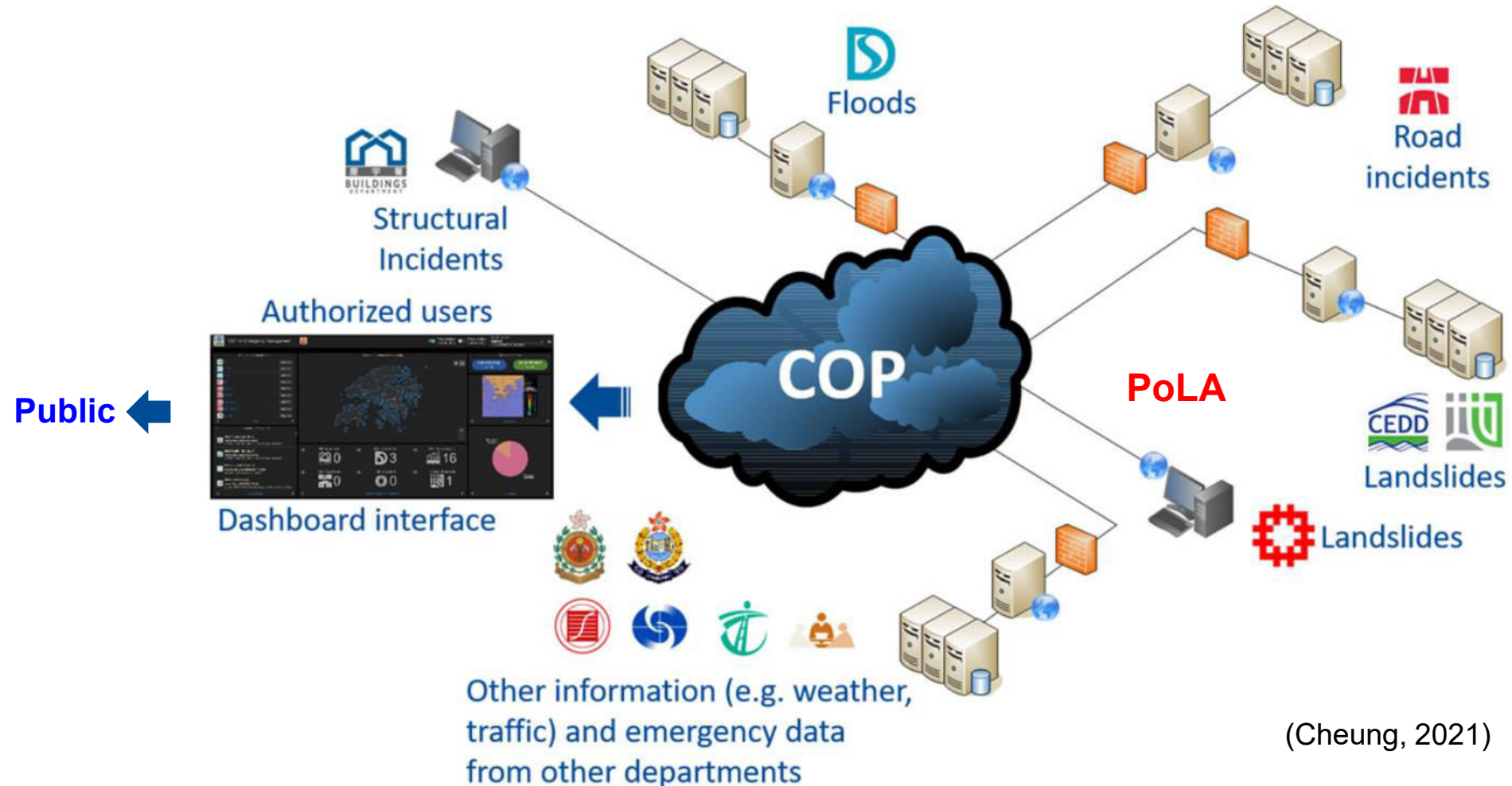
刚性拦挡坝

City-scale digital twin 城市尺度复合灾害数值孪生

- Develop a **unique city-scale digital twin** as an integrated platform for managing landslide hazards and coordinating societal responses.
- To create a new paradigm of natural hazard emergency risk management science in the digital era.



Common Operating Platform for emergency management



Common Operating Platform (COP) for emergency information sharing among government departments and the public.

Summary

- ✓ **Climate change clearly intensifies rainfall intensity and frequency.**
- ✓ **Effective landslide and flood emergency management is important for climate change adaptation.**
- ✓ **A prompt landslide risk assessment (PoLA) method has been developed, which provides critical information for emergency management.**
- ✓ **A cell-based multi-hazard analysis model EDDA helps identify possible future hazard scenarios and evaluate effectiveness of engineering risk mitigation measures.**



Together keep the public safe!

