BAMS
Meeting Summary

Predicting and Projecting Extreme Precipitation in Coastal Cities with High-Resolution Modeling

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The Ninth Convection-Permitting Climate Modeling (CPCM) Workshop, Hong Kong, 2025

What: The ninth CPCM Workshop, hosted by the Hong Kong University of Science and Technology, brought together approximately 130 researchers from 22 countries and 38 institutions (Fig. 1). Contributors included senior scientists, early-career researchers, and decision-maker representatives from national/metropolitan weather services and water management agencies. A total of 53 abstracts were accepted, featuring both invited talks and posters.

When: 5–7 August 2025

Where: Hong Kong University of Science and Technology (HKUST) and online

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1. Introduction

On 5 August 2025, hours before the ninth convection-permitting climate modeling (CPCM) Workshop 2025 was set to begin in Hong Kong, participants were confined indoors from 0500 to 1700 LT by a historic extreme rainfall event. On this day, the Hong Kong Observatory (HKO) issued black rainstorm warnings twice, which was unprecedented. Its headquarters recorded 368.9 mm of rain, the highest August daily total since observations began in 1884. During this dramatic onset, with temperatures plunging to some of August's lowest, the workshop theme—extreme precipitation in tropical cities under a warming climate—could not have felt more urgent.

2. Workshop objectives and format

The main objectives of the workshop were the following:

1) To assess progress and challenges in representing extreme precipitation in convection-permitting models (CPMs) and storm-resolving simulations.
2) To explore methodological innovations, diagnostics, and tools [e.g., artificial intelligence (AI)/machine learning (ML), high-resolution observations].
3) To examine regional case studies of extremes under a warming climate and implications for adaptation/decision-making.

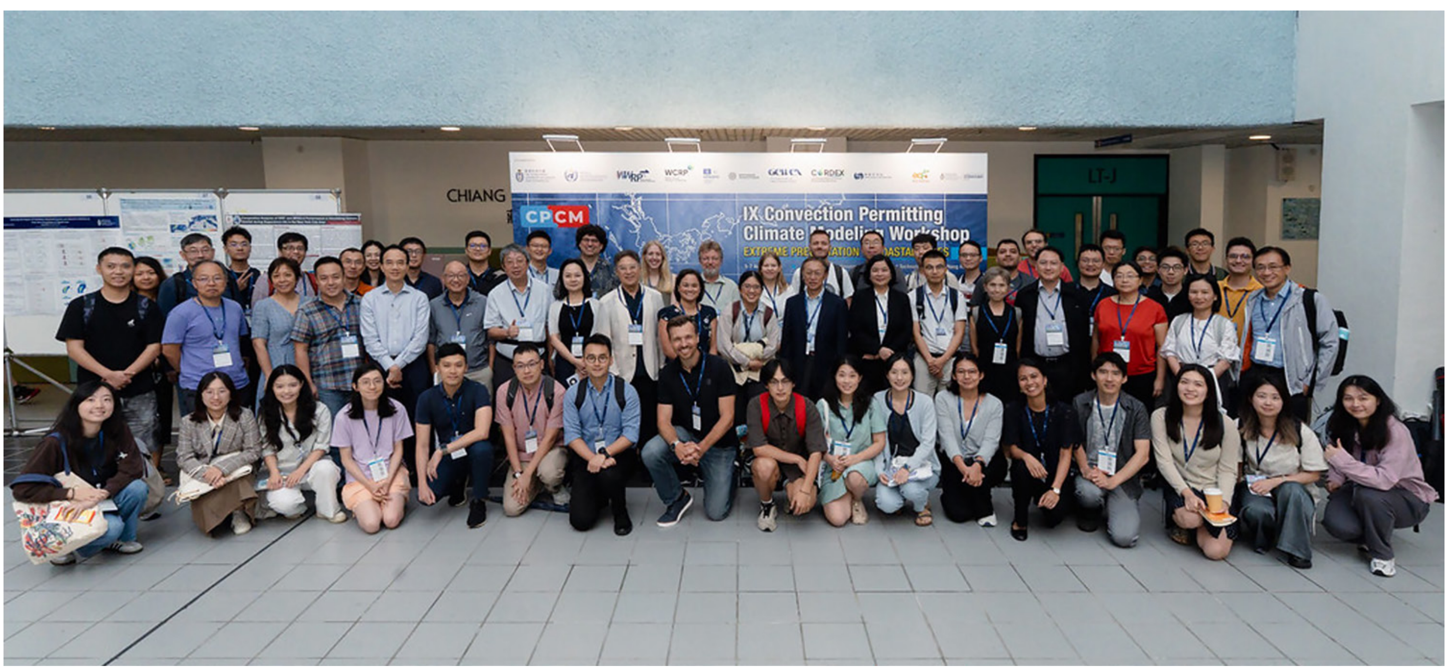

Fig. 1. The in-person participants of the ninth CPCM workshop at the Hong Kong University of Science and Technology.

4) To strengthen collaboration, data sharing, and capacity, particularly in Asia and other regions with evolving observational and modeling infrastructure.

3. Major scientific themes and highlights

Recent advances in storm-resolving and convection-permitting modeling were a central focus of the discussions. Multiple studies assessed model performance at different horizontal resolutions across monsoon, tropical cyclone, and midlatitude regimes. One study demonstrated that refining resolution from around 4 to 1 km reduced seasonal rainfall biases over Southeast Asia by roughly 20%. Global storm-resolving models also proved valuable in exploring rainfall extremes in tropical cyclone environments, generally projecting an intensification of extreme precipitation under future warming scenarios. Despite these improvements, notable limitations remain. Models still revealed discrepancies in storm clustering and in the spatial extent of rainfall. Higher resolution clearly improved the localization of extreme events such as convective cores, yet challenges persist in capturing onset timing and the diurnal cycle, particularly for short-duration extremes at 1–3-h scales. Simulating rapidly evolving, highly localized rainfall in moisture-rich tropical cities is particularly difficult because most weather prediction models were originally designed and tuned for midlatitude conditions and perform worst in the tropics. This underscores the urgent need for greater investment in model development tailored to tropical urban environments.

A second theme concerned the structure, duration, frequency, and intensity of extreme precipitation. Researchers examined processes such as convective bursts, cold pool interactions, storm clustering, and large-scale moisture transport, showing how these combine to amplify rainfall in orographic regions. The duration of precipitation events emerged as an important factor: While short but intense bursts create flash flood hazards, multiday accumulations often additionally drive larger floods and landslides. Some studies highlighted an increasing frequency of such prolonged rainfall events in historical simulations. Regional differences also featured prominently, from the changing intensity and timing of South Asia's monsoon transition, with heightened flash flood risks in urban areas, to the dynamics of tropical cyclones in West Africa, whose propagation and lifetime appear sensitive to warming.

Observational advances and methodological innovation formed another important theme. Presentations showcased improvements in radar networks, denser rain gauge networks, and novel field campaigns in East and Southeast Asia, all of which are essential for validating convection at fine scales. Alongside these, new diagnostic tools were introduced, including metrics for convective initiation delays, cold pool strength, clustering, intermittency, and rainfall structure. Artificial intelligence and machine learning approaches emerge as a vastly growing area. Studies demonstrated the potential of ML for postprocessing model output, downscaling large-scale simulations, and forecasting convective events.

Finally, regional case studies underscored the societal relevance of these scientific advances. Urban flooding emerged as a recurring concern, with reports from Hong Kong, Malaysia, and Australia describing how subhourly and hourly extreme rainfall increasingly overwhelms city drainage systems. Prototype early warning systems that combine high-resolution model output with real-time observations were presented as promising tools. Mountainous regions in Asia and South America also received attention, with research showing how orography channels moisture convergence and enhances extreme rainfall. Many sessions explicitly linked science to policy and practice, highlighting disaster risk reduction, infrastructure design, flood insurance, and water management as key areas where modeling progress and new observational tools could support climate adaptation.

4. Gaps, challenges, and prospects

Throughout the meeting, participants identified several recurring challenges and open questions:

- Subdaily vs longer-duration extremes: Capturing localized hourly and subhourly extreme rainfall remains difficult for many CPMs, especially in terms of magnitude, timing, spatial pattern, and tropical environments. Observational data at those scales are often sparse or unevenly validated.
- Physical process uncertainty: Convective initiation, cold-pool formation, microscale turbulence, urban and coastal boundary layer, and how these interact with phenomena at other scales remain uncertain. Also, how cloud microphysics parameterizations affect extremes continues to be underexplored.
- Computational resource limits: Running long multiyear simulations at high resolution (1 km or finer) is computationally expensive; many institutions struggled with limited high-performance computing (HPC) access. Trade-offs between domain size, resolution, and ensemble size are still major constraints.
- Data sharing, benchmarking, and standardization: While many observational datasets are improving, there remain inconsistencies in gauge/radar calibration, differences in interpolation methods, and a lack of shared and standardized diagnostic tools and metrics for evaluating extremes.
- Bridging research and decision-making: Translating CPM outputs into usable inputs for infrastructure design, early warning systems, irrigation planning, etc., remains challenging. Uncertainty in projections, especially for extremes, and difficulty in communicating risks are ongoing issues.

5. Actionable outcomes and future directions

From discussions, poster sessions, and working groups, several concrete outcomes and directions emerged:

- Regional observational campaigns and data infrastructure: There was strong support for expanding high-resolution observational networks in Southeast Asia, particularly dense radar deployments and ground station networks. Several institutions offered to share both data and tools.
- Intercomparison projects: Proposals were made for a coordinated CPM intercomparison over Asia and monsoon regions, focusing on extremes (short duration, multiday). Suggested metrics include peak intensity, convective clustering, and timing relative to synoptic forcing.
- Capacity building: Mentorship programs and workshops targeted to early career scientists and underresourced institutions. Sharing of software, code repositories, and model setups (open source where possible) was discussed.
- Methodological innovations: Creation of standard diagnostic packages (e.g. open-source toolboxes) to systematically benchmark model performance in simulating extremes. More integration of AI/ML for bias correction, downscaling, and forecasting; exploring hybrid statistical–physical methods. Long-term kilometer-scale downscaling and reanalysis datasets (e.g., CONUS404 for the United States and SEA4C for Southeast Asia) offer valuable training resources for AI/ML models, with the potential to substantially improve both the accuracy and efficiency of extreme-event prediction.
- Decision-maker engagement and policy input: A desire to more directly incorporate climate service agencies, urban planners, and disaster risk agencies into modeling

planning. Using workshop outcomes to inform infrastructure guidelines, flood insurance policy, and urban drainage design.

6. Reflections and looking ahead

The unprecedented rainfall that kicked off the workshop served not just as a metaphor but as immediate evidence of the phenomena being studied. Many participants remarked that the scientific discussions were not abstract; they mirrored the lived reality of rising risk in populous urban regions.

The ninth CPCM Workshop made clear that significant scientific progress has been made: Higher-resolution models are improving, diagnostics are more sophisticated, observational networks are expanding, and AI tools are being deployed in more contexts. But equally clear were the limits that remain: resource constraints, observational gaps, biases in models, and the challenge of delivering actionable predictions for decision-makers.

As the CPCM community moves forward, the following seem especially critical:

- Greater coordination on experiments and datasets so results are comparable.
- A stronger emphasis on process understanding and modeling (e.g., convective initiation, cold pools) rather than only empirical or statistical description.
- Incorporating the human impact on the climate system such as growing urban regions, agricultural expansion, and water management in high-resolution modeling systems.
- Strengthening links between modeling, operational forecasting, and societal risk management to improve actionable early warnings and resilience planning.
- Targeted improvements in modeling, observation, and research capacity in regions most at risk but with fewer resources.
- Development of community high-resolution, kilometer-scale datasets including long-term CPM simulations and dense urban observation networks to train, validate, and benchmark AI/ML models for downscaling, emulation, and, critically, predicting extreme events with greater accuracy and efficiency.