Regional climate predictions by numerical modeling and artificial intelligence.

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1. Project Purpose

This project aims to advance regional climate prediction by integrating high-resolution numerical modeling and AI techniques. The core objectives include: (1) applying convection-permitting WRF simulations to investigate regional climate dynamics focusing urban influences across Asia; and (2) developing and evaluating the Land-Surface-Physics-based Downscaling (LSP-DS) method, which uses an offline land surface model (Noah-MP) for fine-scale climate projections in both urban and agricultural settings. LSP-DS offers a computationally efficient alternative to traditional dynamical downscaling. In addition, the project explores the potential of deep learning—primarily CNN-based models—for downscaling applications. These efforts aim to support the development of a flexible, regionally adaptable climate prediction framework.

2. Results

The MCRP-2024 project contributed to advancing regional climate prediction through both physics-based and AI-based approaches. This project's central activity involved the development and application of the Land-Surface-Physics-based Downscaling (LSP-DS) method, which operates offline using the Noah-MP land surface model. This method has been tested for its ability to resolve urban climate features, including the interaction between urban heat islands (UHIs) and heatwaves. Peer-reviewed studies in *Urban Climate* and *Journal of Geophysical Research: Atmospheres* suggest that LSP-DS can offer advantages over conventional dynamical downscaling under specific urban settings.

High-resolution simulations using the convection-permitting WRF model were also carried out to explore heatwave behavior in cities such as Colombo and Metro Manila and Kuala Lumpur. These studies point to the importance of high-quality land use data and regional parameterizations for representing extreme urban thermal conditions. The results support the continuing role of high-resolution modeling in capturing localized climate phenomena.

The project also began initial work on AI-based prediction of temperature and rainfall using convolutional neural networks (CNNs). Although these efforts are at an early stage, existing realysis data and gridded observational database serve as reference datasets for supervised learning and model evaluation. Future developments may include expanded use of architectures such as GANs, Transformers etc. within Earth emulator framework to enhance generalizability.

3. Roles of the MCRP and its significance

Understanding regional atmospheric processes requires the use of high-resolution numerical models. Urban environments, for instance, can enhance atmospheric instability and convective activity, leading to localized thunderstorms—an effect known as the urban heat island phenomenon. Topography also plays a key role in shaping local wind systems, cloud development, and precipitation patterns, which are often inadequately represented in low-resolution models. Moreover, the simulation of precipitation is complicated by intricate microphysical processes, contributing to substantial uncertainty. To better represent these dynamics, it is crucial to conduct long-term simulations that encompass the full range of natural variability.

4. Future plan

Looking ahead, the project will expand model applications to additional climate zones in Asia to evaluate the generalizability of WRF and LSP-DS. Targeted studies will focus on extreme precipitation and urban wind systems, particularly under evolving land use and warming trends. The development of AI-based tools such as CNNs and GANs will continue, with efforts to couple them with physical models for hybrid prediction. Further, collaboration with atmospheric chemistry modeling is planned to explore aerosol and pollutant effects. These directions support the long-term goal of building an integrated system for actionable climate information at the city scale.

5. Publications and conference presentations

(1) Journal papers

- Xue, L., Doan, Q.-V., Kusaka, H., He, C., & Chen, F. (2025). *Land-surface-physics-based downscaling versus conventional dynamical downscaling for high-resolution urban climate change information: The case study of two cities.* Urban Climate, 59, 102228. https://doi.org/10.1016/j.uclim.2024.102228
- Xue, L., Doan, Q.-V., Kusaka, H., He, C., & Chen, F. (2024). *Insights into urban heat island and heat waves synergies revealed by a land-surface-physics-based downscaling method.* Journal of Geophysical Research: Atmospheres, 129(13), e2023JD040531. https://doi.org/10.1029/2023JD040531
- Sathsara, K. T., & Kusaka, H. (2025). *Impact of high-resolution land use data on numerical simulations of Colombo's thermal environment during heatwaves.* Theoretical and Applied Climatology, 156, 106. https://doi.org/10.1007/s00704-024-05242-9
- Magnaye, A. M. T., & Kusaka, H. (2025). *Enhancing numerical simulation accuracy for extreme heat events in Metro Manila.* SOLA, 21, 76–84. https://doi.org/10.2151/sola.2025-010
- Mahbar, S. F., & Kusaka, H. (2024). *Synergistic interactions between urban heat islands and heat waves in the Greater Kuala Lumpur and surrounding areas.* International Journal of Climatology, 44(13), 4886–4906. https://doi.org/10.1002/joc.8614
- Magnaye, A. M. T., & Kusaka, H. (2024). *Potential effect of urbanization on extreme heat events in Metro Manila, Philippines using WRF-UCM.* Sustainable Cities and Society, 110, 105584. https://doi.org/10.1016/j.scs.2024.105584

(2) Presentations

Xue, L. B., Doan, Q.-V., Kusaka, H., He, C., & Chen, F. (2024). *Land-surface-physics-based downscaling: A new approach for urban climate prediction.*

Presented at the Asia Oceania Geosciences Society 2024 Annual Meeting, 26 June 2024, South Korea.

(3) Others

Supercomputer	Use	Allocated resources*		
		Initial resources	Transferred resources**	Additional resources
Cygnus	Yes/No	5600		
Pegasus	Yes/No	10500		
Wisteria/BDEC-01	Yes/No	120000		
	*in units of node-hour product ** If the budget transfer was performed, fill in here, such as “+2000” and “−1000”.			