Studies on the Urban Climate and Mountain Weather Using the WRF and CM1 Models

DOAN Quang Van
Center for Computational Sciences, University of Tsukuba

1. Project Purpose

Atmospheric phenomena at a city and mountain scale are not adequately understood due to the complex interactions between local geographical factors and large-scale atmospheric circulations. One helpful approach to advance our understanding of these phenomena is using numerical simulation with high-resolution numerical atmospheric models. This project is primarily purposed to (i) investigate the urban climate change with a focus on high-impact weather and climate events for cities considering the coupled impacts of localized urbanization and global climate changes; (ii) clarify local wind mechanisms with case studies of foehn and gap winds occurring over coastal areas in Japan.

2. Results

Numerical climate projections using the dynamical downscaling method with the convection-permitting Weather Research and Forecast model were conducted for cities with different climate backgrounds, such as Tokyo and Singapore. Climate projections have been achieved under the assumption of global warming up to the end of the 21st century. The results were analyzed, and future extreme precipitation (EP) changes were identified. The “new normal” in EP is characterized by the “extreme get more extreme” (EGME) paradigm under a warmer climate regime. Consistent results were obtained for both mid- and low-latitude cities of interest, though the response extent to the global warming effect is different. In detail, future precipitation is predicted to substantially enhance both frequency and intensity. The higher-quantile precipitation is intensified much stronger than the moderate and light precipitation. EGME is attributed to increases in both convective available potential energy and convective inhibition. Convective inhibition suppresses weak convections, allowing them to build up further, and the convections become intense when it does trigger (Doan et al., 2022).

3. Roles of the MCRP and its significance

Fine-resolution numerical simulations are essential in studying city or mountain scale atmospheric phenomena. It is because localized factors such as terrain or urban land surface modulate atmospheric phenomena at such scales. For example, it is well known that localized thunderstorms could be affected by the urban heat island effect, enhancing atmospheric instability and convections. Also, terrain plays a vital role in shaping localized precipitation patterns. Such effects are ignored in rough-resolution simulations. Also, precipitation results from complex atmospheric microphysical processes, implying high uncertainty in its simulation, thus requiring a long-term model run in favor of robust results. The requirements for high-resolution and long-term simulations for small-scale atmospheric phenomena explain why MCRP is necessary for this research.

４．Future plan

Identifying the change in extreme urban precipitation is essential but not an easy issue. The reason is the issue's complexity that underlies high uncertainties of knowledge obtained. Expanding the research to different areas with diverse climates and geographical backgrounds is required. Also, the question of how extreme precipitation in different seasons responds to the global warming effect is valuable to answer.

５．Publications and conference presentations

(1) Journal papers

Doan Q-V, Chen F, Kusaka H, Dipankar A, Khan A, Hamdi R, Roth M, Niyogi D. 2022. Increased Risk of Extreme Precipitation over an Urban Agglomeration with Future Global Warming. *AGU Earth's Future*, e2021EF002563. https://doi.org/10.1029/2021EF002563.

Vitanova LL, Kusaka H, Doan Q-V, Subasinghe S. 2021. How urban growth changes the heat island effect and human thermal sensations over the last 100 years and towards the future in a European city? *Meteorological Applications*, 28(4): e2019. https://doi.org/10.1002/met.2019.

(2) Presentations

Doan Q-V, Kusaka H. 2022. Global warming impact on urban heavy precipitation. Proceedings of the General Meeting of the Association of Japanese Geographers, Mar 2022.

Doan Q-V, Vijayaraghavan S, Nguyen NS. 2021. Sea breeze change and heat-related risk in urban environment under global warming. AGU Fall Meeting, Dec 2021.

Doan Q-V, Chen F, Kusaka H. 2021. Change in extreme precipitation characteristics in urban areas under global warming. AGU Fall Meeting, Dec 2021.

Vitanova LL, Yamamura S, Doan Q-V. 2021a. Study on multiple impacts of COVID-19 pandemic on the urban environment in Tokyo metropolitan area. AGU Fall Meeting, Dec 2021.

Doan Q-V, Chen F, Kusaka H, Khan A, Dipankar A, Hamdi R, Gupta A, Niyogi D. 2021. Response of Extreme Convective Rainfall in a Tropical City to the Future Warming Climate. AOGS 2021 18th Annual Meeting, Aug 2021.

Doan Q-V, Chen F, Kusaka H, Wang J, Kajino M, Takemi T. 2021c. Global Warming and Extreme Precipitation in a Mega City: A Case Study of Tokyo, Japan. AOGS 2021 18th Annual Meeting, Aug 2021.

Kusaka H, Doan Q-V, Nakamura S, Vitanova LL, Estoque R. 2021. The Impact of Urbanization in Southeast Asia on the Local Climate Over the Last 100 Years: Numerical Study with Regional Climate WRF Model. AOGS 2021 18th Annual Meeting, Aug 2021.

Nguyen TH, Nagashima T, Doan Q-V. 2021. A High-resolution Emission Inventory of Air Pollutants for Air Quality Modelling Studies in Hanoi, Vietnam for 2017. AOGS 2021 18th Annual Meeting, Aug 2021.

Vitanova LL, Yamamura S, Kusaka H, Doan Q-V. 2021b. Numerical Study of the Railway-Associated Urban Development on the Thermal Environment at the Neighborhood Scale. AOGS 2021 18th Annual Meeting, Aug 2021.

(3) Others

Supercomputer	Use	Allocated resources*	
		Initial resources	Additional resources
Cygnus	No		
Oakforest-PACS	Yes	229,500	
*in units of node-hour product			