jh230052

Investigating the global effects of realistic spatio-temporally varying anthropogenic heat emissions using a high-resolution global climate model

Alvin C.G. Varquez (Tokyo Institute of Technology)

Abstract

To deepen our understanding of the urban climate and to address the societal issues in cities, climate modeling with detailed urban representation (e.g. building morphology, anthropogenic heating) is vital. Typically, these investigations are on neighborhood or regional scales of cities. Hence, global datasets of anthropogenic heat emissions (AHE), which corresponds to the added energy from the surface due to human use of energy, are becoming available at high spatial resolutions (e.g. 1-km). Meanwhile, global-scale models, ranging from general circulation models to earth system models, are rapidly advancing computationally (i.e. improved efficiency at high spatial resolutions) but with main emphasis on the global climate change. Furthermore, applications of high-resolution global climate models are still lacking. This project aims to bridge the gap by modeling and investigating the spatio-temporal effects of detailed anthropogenic heat emission (AHE) at a global scale using a 14-km spatial resolving general circulation model (GCM). The findings will provide insights to the spatio-temporal extent of impacts of cities to global climate, in addition to the widely known greenhouse gas effect.

1 Basic information

1.1 Collaborating JHPCN centers

- Tokyo Institute of Technology

1.2 Theme area

- Large-scale computational science

1.3 Research area

- Very large-scale numerical computation

1.4 Project members and their roles

1. VARQUEZ Alvin C.G., Tokyo Institute of Technology, Administration/Code development/Input preparation/Simulation/Reporting
2. NAKANO Masuo, Japan Agency for Marine-Earth Science and Technology, Code development/Input preparation/Simulation
3. NAKAYOSHI Makoto, Tokyo University of Science, Simulation analyses
4. TAKANE Yuya, National Institute of Advanced Industrial Science and Technology, Simulation analyses
5. KHANH Do Ngoc, Tokyo Institute of

Technology, Compilation/analyses

2 Purpose and Significance of the Research

The influence of cities are mostly investigated at the regional scale. Human activities generate anthropogenic heat emissions (AHE) that affect the energy balance of the surface. The energy balance influences the atmosphere above. While regional investigations (surrounding cities) on the AHE effects have been investigated, there is limited understanding about its effects on the global climate. Furthermore, in regional models, consideration of AHE were almost uniform (i.e. relying on categorical distributions) or not depending on the seasions.

Recent general circulation models (GCM) have been improving in performance owing to improved algorithms and processors. With the use of high-performance computing infrastructures, such as supercomputers, growing number of GCMs are capable of running at finer resolutions (i.e., a grid of the model can be finer than 20-km). The Nonhydrostatic Icosahedral Atmospheric Model (NICAM), developed mainly in AORI, JAMSTEC, NIES, and R-CCS, is such a model that exploits the features of icosahedral grids to speed up simulation without sacrificing accuracy. The highest resolution it can perform so far is 3-km, with tests being conducted at 1-km.

Meanwhile, global distributions of anthropogenic heat datasets have been increasing for use in urban planning and in climate modeling. In particular, AH4GUC is one of such dataset that provides 1-km AHE distributions for the present (2010s) and the future (2050s) which considers country-level energy consumption, climate past information and future projections, sociodemography, and other satellite datasets (e.g. nighttime lights) in their estimation. It is widely used in regional climate modelling such as in the Weather Research & Forecasting (WRF) model.

In this 1-year project, we enabled the NICAM model, which is capable of simulating the climate at 14-km resolution, to utilize as surface input the AH4GUC. This enabled us to investigate human's direct influence to climate at a global scale. We first investigated its effects over the month of July 2023, which was characterized with multiple heatwave events worldwide. Through the Tsubame supercomputer, we could also run multiple lagged ensembles at the same 14-km resolution. The work will contribute to climate-change investigations that are mainly focused on the greenhouse gas effects. In addition to the greenhouse gas effects, we hope that the AHE effect will also be considered an important factor to warming, especially in cities. This knowledge may help promote more sustainable energy supply/consumption worldwide, given that the main source of the anthropogenic heat emissions is energy consumption.

3 Significance as JHPCN Joint Research Project

The research requires massive computational resources for model development and model application. Specifically, climate models rely on parallel computing to deliver timely meteorological outputs and consider complex processes for every calculation grid. Through the JHPCN joint research project, multiple high-resolution global climate simulations could be accomplished. This work focuses not only coarse resolution (e.g. >100-km grid spacing) runs of GCMs, but also at a relatively high resolution of 14-km. The NICAM is a GCM that has been widelfy verified and used for research using the Earth Simulator of JAMSTEC. The PI also belongs to Tokyo Institute of Technology that has the Tsubame Supercomputer. In the FY2023, Tsubame 3.0 was used.

4 Outline of Research Achievements up to FY2022 (Only for continuous projects)

Not applicable for this project.

5 Details of FY2023 Research Achievements

Within a year, we have successfully accomplished three items with the help of the Tsubame 3.0 supercomputer of Tokyo Tech. They are as follows.

1. Revised the NICAM model to consider spatio-temporal (hourly) variations of prescribed anthropogenic heat dataset. Developed a program to resample the spatio-temporal dataset and convert it to a format compatible with NICAM.
2. Confirmed that the modifications work for coarse and fine run simulation. The finest resolution tested was 14-km.
3. Initially evaluated the effects of temporally-changing anthropogenic heat on the 14-km resolution global climate during the heat wave-frequent month of July 2023. Lagged ensembles were created within the month.

We found that the effect of AHE on climate varies between global and regional climate models. Unlike the latter where the boundary conditions are not influenced by AHE, the former tends to show drastic differences in climate owing to AHE after more than 2-days of the simulation. It is widely known in regional climate modeling that areas with large AHEs tend to generate warmer temperatures, but from our numerical experiments with the GCM, we found that the effect can disperse at long distances as the simulated time progresses. Thus, further treatment on the simulation outputs are needed to reasonably quantify the effects of AHE from GCMs. Nevertheless, the AHE effect is significant.

On February 2024, the work was submitted and accepted for an oral presentation at the Japan Geoscience Union (JpGU) Meeting 2024 under the session title, “Weather, Climate, and Environmental Science Studies using High-Performance Computing” (see details below). A publication draft is underway for submission to an international journal that focuses on advance climate models.

6 Self-review of Current Progress and Future Prospects

The main objective of the project to enable a global climate model to consider spatio-temporal distributions of anthropogenic heat emissions was achieved. This was done by modifying relevant source codes of the NICAM model to read the hourly-changing AHE and resample it to match the standard resolutions of NICAM. Two versions of NICAM were branched that can consider AHE. The differences between the two are in which modules of the model the AHE is considered. It is either in the land surface model or in the whole surface model that also considers the other surface types. The process was documented and stored in git repository for future use. The project was right on schedule, and its findings being summarized into a publication.

The future prospects can be grouped into the following interconnected components specifically on the treatment and investigation of the AHE effects on climate.

1. Running a long-term resolution at 14-km resolution to see whether the effects of AHE converges at a certain time. This will be challenging because it is uncertain how long the simulation has to be conducted to reach an equilibrium state given the AHE changes hourly for each month. Modifications to the read-write function of NICAM will be modified further to consider montly changs in the diurnal AHE at global scale.
2. Consider the scale-dependence of the effect of AHE globally by running coarse (i.e. typical GCM resolutions), fine (i.e. 14-km), and very fine (i.e. 3-km) resolutions. The finest resolution of 3-km was not tested yet, but possible given that the native resolution of the AH4GUC is 1-km.
3. Incorporate a simple model to adjust the AH4GUC inputs to allow a level of dependency of AHE to the simulated climate. For example, air temperature influences household energy consumption. Dr. Yuya Takane is currently undertaking this in his own research project. Our current collaboration may be able to supplement it.

7 List of publications and presentations

Presentations at International conference (Non-refereed)

1. ACG. Varquez(+), Y. Nakano, M.Nakayoshi, Y. Takane, DN. Khanh, ‘Effects of spatio-temporally-varying anthropogenic heat on high-resolution modelled global climate’, Japan Geoscience Union Meeting 2024, Makuhari Messe, Chiba, Japan, May 26 - 31, 2024 (oral presentation scheduled on May 29, 2024)