Long-term Research Visits (Project No.: 30L-01)

Project title: Study on surface roughness effect to flow characteristics in tornado
Principal Investigator: David Bodine
Affiliation: University of Oklahoma
Name of DPRI collaborative researcher: Professor Takashi Maruyama
Name of visitor (Affiliation): David Bodine
Period of stay: Aug 15, 2018 ~ Oct 15, 2018
Location of stay: Kyoto University
Number of participants in the collaborative research: 5 (provide numbers for DPRI and non-DPRI staff)
- Number of graduate students: 3 Masters students
- Participation role of graduate students: The collaboration has tremendously benefited M.S. student Martin Satrio, whose thesis focuses on terrain effects on tornado dynamics. Martin has used the LES model data to study different terrain types and how they impact tornado dynamics. Two new M.S. students, who will start in Fall 2019, will use the Large-Eddy Simulation model and wind tunnel data to study simulated radar signatures of tornadoes and debris.

Anticipated impact for research and education

New understanding of how terrain effects tornadoes is critical to predicting and evaluating the impact of tornadoes on society both in United States and Japan. The research has contributed to the development of an early-career research at the University of Oklahoma, furthering an ongoing collaboration that started when Dr. Bodine visited Professor Maruyama during a JSPS summer program stay in 2012. The collaboration has also tremendously benefited M.S. student Martin Satrio, whose thesis focuses on terrain effects on tornado dynamics as well as two new M.S. students who will start in Fall 2019 to analyze simulated radar signatures of tornadoes and debris.

Research report

(1) Purpose

The goal of the long-term research visit was to study the effects of surface roughness on tornadoes and further develop tools to simulate radar signatures of tornadoes. To date, high-resolution numerical simulations of tornadoes traversing realistic terrain are very limited. Thus, we sought to understand how different types of terrain (hills, valleys, ridges) impacted the wind structure of the tornado and what dynamical processes were involved. To do this, an immersed boundary method and curvilinear coordinate Large-Eddy Simulations (LESs) have been conducted. Intercomparisons between wind tunnel measurements and the numerical model were also desired to evaluate how well the model represents the actual flow. Finally, Dr. Bodine and Professor Maruyama discussed the ongoing research to simulate radar signatures of tornadoes, which use aerodynamic data from the Kyoto University wind tunnel. Professor Maruyama provided new sets of aerodynamic measurements for different debris types, which will enable a wide range of new radar simulations.

(2) Summary of research progress

During David's stay in Japan, he worked with Professor Maruyama on curvilinear coordinate LESs (Figure 1, Uchida and Ohya 2003). David spent extensive time learning how to run this simulation code and modify it for experiments for different terrain types as well as the tornado's flow. David has used this program to simulate different types of terrain in the LES model. In the forthcoming months, an extensive suite of simulations will be conducted for tornado simulations. These will be compared to an existing immersed boundary method implement in the LES, the first such intercomparison study for terrain effects on tornado dynamics. An example analysis is shown for different hill heights for a tornado simulation in Figures 2 and 3.

David also worked with Professor Maruyama and the wind tunnel research group to conduct experiments to model the effects of trees on the airflow. We set up the wind tunnel with a uniform flow of 10 m/s and made measurements of the vertical wind profiles downstream from tree-like objects placed in different configurations. The goal is to compare these vertical wind profiles to numerically model simulations using a canopy model to evaluate how realistically the model captures the observed behavior. By conducting experiments in the Kyoto University wind tunnel, David also became more familiar with the methodology used to obtain aerodynamic data for the tornado debris studies. This will be beneficial for the subsequent interpretation and analysis of the debris trajectories and understanding the strengths and limitations of wind tunnel data for representing the aerodynamic characteristics of debris in tornadoes.

Professor Maruyama's research group also provided aerodynamic data for different debris types to use in the University of Oklahoma polarimetric radar simulator, which the OU-Kyoto team has used to study radar signatures of tornadoes (Cheong et al. 2017). We have developed a framework to ingest the new aerodynamic data into the radar simulator and are analyzing the simulated radar signatures. An example of the radar simulator output is shown in Figure 4.

(3) Summary of research findings

We have conducted analyses of the tornado simulations over terrain. For the relatively small hill (25-m tall), the tornado wind speeds are maximized on and just past the hill. However, as the hill height increases, the strong winds are found in the gaps between the hill and on the uphill slope. As the hill height increases, the greater effects of friction on the hill likely reduce the maximum wind speeds. However, gaps between the hills funnel the inflow into the tornado. The enhanced inflow into the tornado transports angular momentum into a smaller radius as well, leading to an intensification of the tornado by conservation of angular momentum. These initial studies show the importance of terrain effects on tornado dynamics and height a wide range of behavior that is important for tornadoes.

(4) Publication of research findings

We presented two papers at the 2018 Severe Local Storms conference in Stowe, Vermont. Based on the most recent findings, we have submitted abstracts to the 2019 AMS Radar Conference in Nara, Japan. We are preparing a publication on our findings from the simulations of tornadoes traversing different types of terrain, which will be submitted in Summer 2019 to the Journal of Atmospheric Sciences. We will also prepare publications on the radar signatures of tornadoes that use the wind tunnel data. This will be done in the Fall of 2019 and Spring of 2020.

Conference proceedings:
Bodine, D. J., A. E. Reinhart, M. A. Satrio, T. Maruyama, and F. T. Lombardo, Investigation of the impact of terrain and buildings on tornado dynamics using high-resolution simulations, 29th Conf. on Severe Local Storms, Stowe, Vermont, October 21 – 26, 2018.

Satrio, M. A., D. J. Bodine, A. E. Reinhart, and T. Maruyama, The effects of varying surface roughness, translation velocity and swirl ratio on an idealized tornado, 29th Conf. on Severe Local Storms, Stowe, VT, October 22 – 26, 2018.

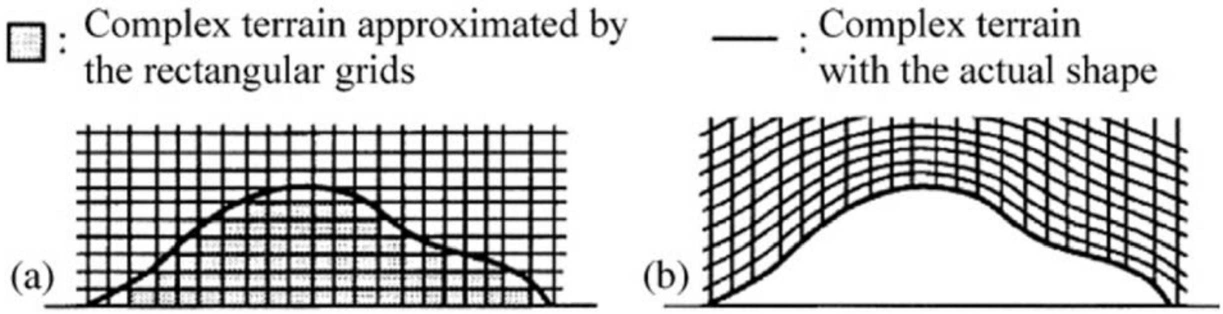

Figure 1: Example of a) terrain modeled by rectangular grid and b) modeling of terrain using curivilinear coordinates (adapted from Uchida and Ohya 2003).

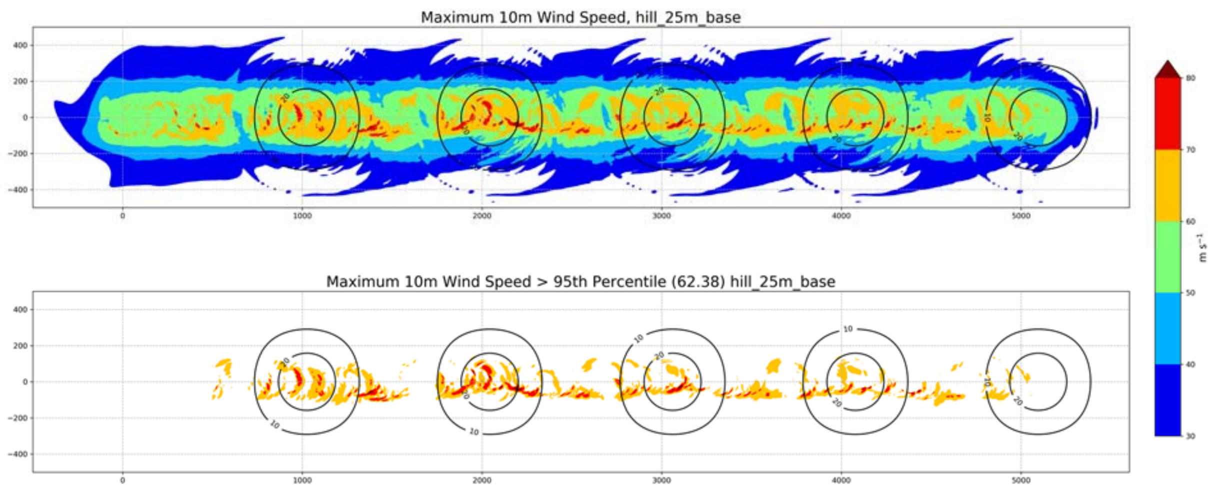

Figure 2: (top) Simulation of a tornado traversing a series of 25 m hills. Plots show the maximum wind speed at 10 m AGL along the tornado's track and (bottom) areas exceeding the 95th percentile wind speed.

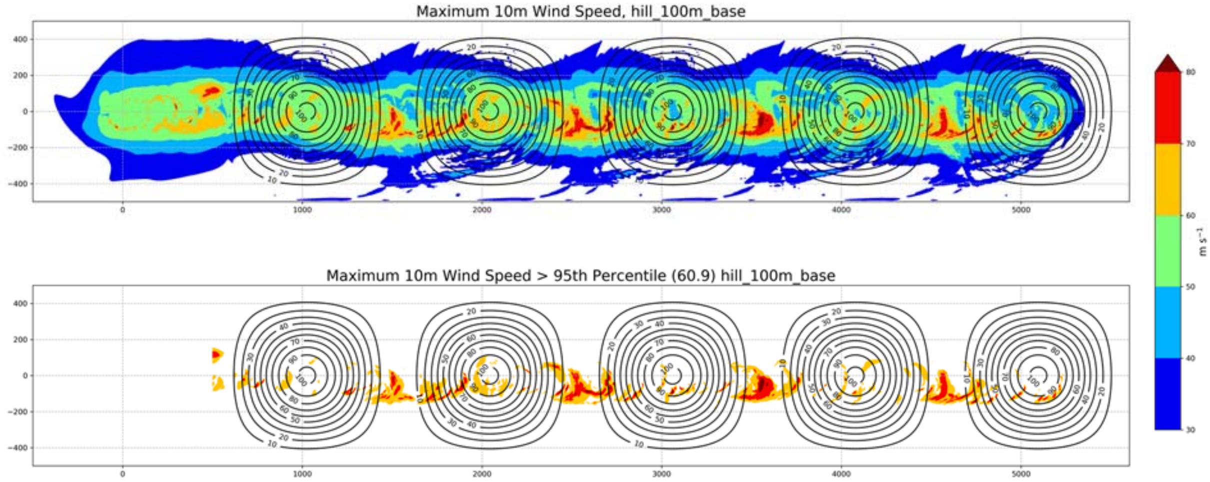

Figure 3: Same as Figure 1 except for a tornado traversing 100 m hills.

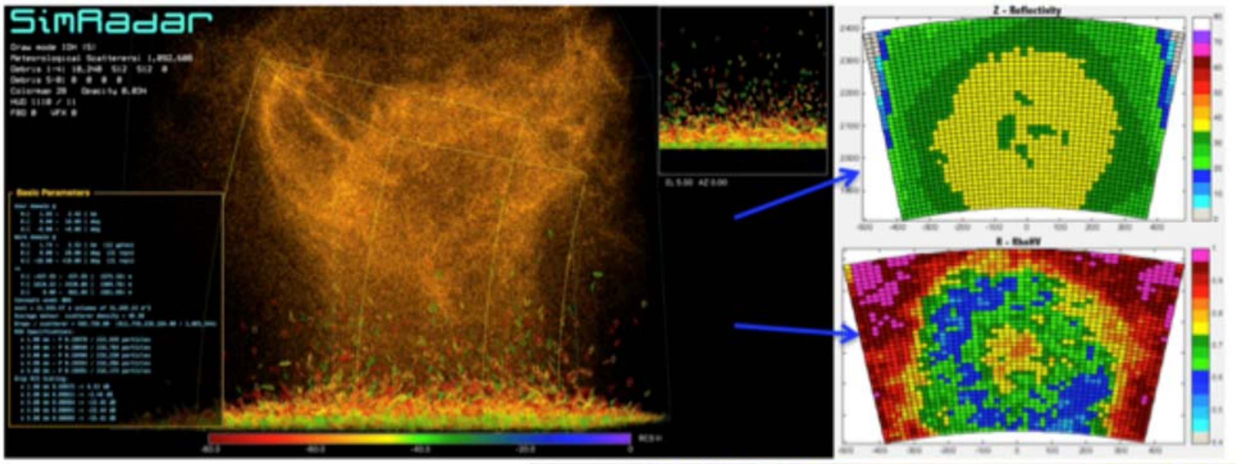

Figure 4: Example output from SimRadar, including the (left) debris positions and orientations based on aerodynamic data from Kyoto University and (right) the simulated radar output.