# Wind Engineering Joint Usage/Research Center
# FY2019 Research Result Report

Research Field: Outdoor Environment
Research Year: FY2019
Research Number:
Research Theme:
Experimental Validation and Model Development for Urban Pollutant Source Tracking Method

Representative Researcher: Zhiqiang (John) Zhai

Budget [FY2019]: 400000Yen

*There is no limitation of the number of pages of this report.
*Figures can be included to the report and they can also be colored.
*Submitted reports will be uploaded to the JURC Homepage.

**1. Research Aims**

The goal of this project is to use both the numerical and experimental methods to improve our fundamental understanding of, and the ability to forecast, how buildings affect the intensity and heterogeneity of winds and transport of air pollutant in the urban canopy.

Results from the numerical and experimental studies will contribute to technology that provides authorities with more skillful short-term predictions of wind field; more detailed, accurate projections of wind and related damage; and more reliable guidance on long-term prediction of winds in the future at the city scale.

Results from the numerical and experimental studies on multiple air pollutants source identification will contribute to sensor distribution and sensor selection in the urban environment and furthermore other source-origin tracking problems.

The outcomes of the project will enhance what is known and understood about the characteristics of, and processes that influence winds and pollutant transport in the urban canopy:

- An investigation of the adjoint probability method on source-origin tracking problems
- A dataset of large-eddy simulation (LES) output depicting winds in the urban canopy of idealized inflow wind profile over several idealized urban and suburban configurations of buildings
- An investigation of how cities help to shape the complex and poorly understood internal boundary layers (IBLs)
- An investigation of whether the layouts of coastal cities and their suburbs can lead to consistent regions of minima and maxima in hurricane winds in the urban canopy, and if so, by what physical mechanisms
- A set of archetypal building configurations that can be used in other LES studies of urban and suburban weather

**2. Research Methods**

(1) Use wind tunnel at Tokyo Polytechnic University as the experimental tools and conduct experiments for different layout of blocks ($25mm$ (W) × $50mm$ (L) ×$100mm$ (H)) (shown as Figure 1). Measure the flow velocity using hotwire anemometer, and compare the experimental data with simulation results from CM1_LES and Fluent.

Our LES model of choice is CM1 (Bryan and Fritsch 2002). CM1 is an open-source, non-hydrostatic, three-dimensional, prognostic model developed by Dr. George Bryan at NCAR.

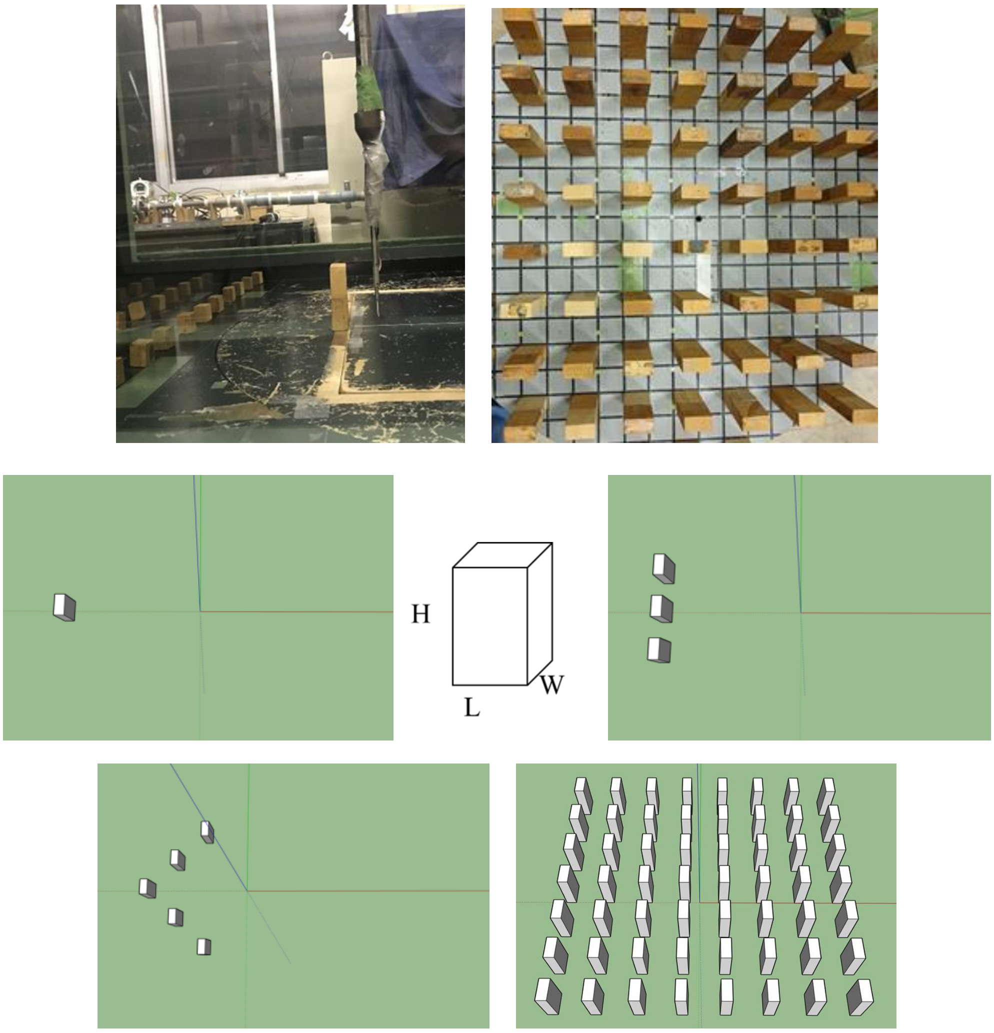



Fig 1 Overview of experimental design

(2) Use wind tunnel experiment with urban blocks (each block's dimension is (25$mm$ (W) × 50$mm$ (L) ×100$mm$ (H)) (shown as Figure 2) and real urban district model (shown as Figure 3) to study the pollutant transportation in the urban canopy. The experiment uses $C_2H_4$ as contaminant. Test the contaminant concentration at different points in the area (the grid resolution for measurement in horizontal level is 25mm×50$mm$; and in vertical level is 10mm, 50mm and 110mm). Then choose the data from the measurements to calculate the location and strength of the contaminant source by using the adjoint probability method with different scenarios:

  (a) Identify one source with three sensors' data under steady state wind;
  (b) Identify one source with one sensor's data but changing inflow wind directions;
  (c) Identify three sources with limited sensors' data.

Verify the simulation results with the experimental data. Source numbers can be one, two and three, the wind direction changes from −30° to 0° to 30° (shown as Table 1).

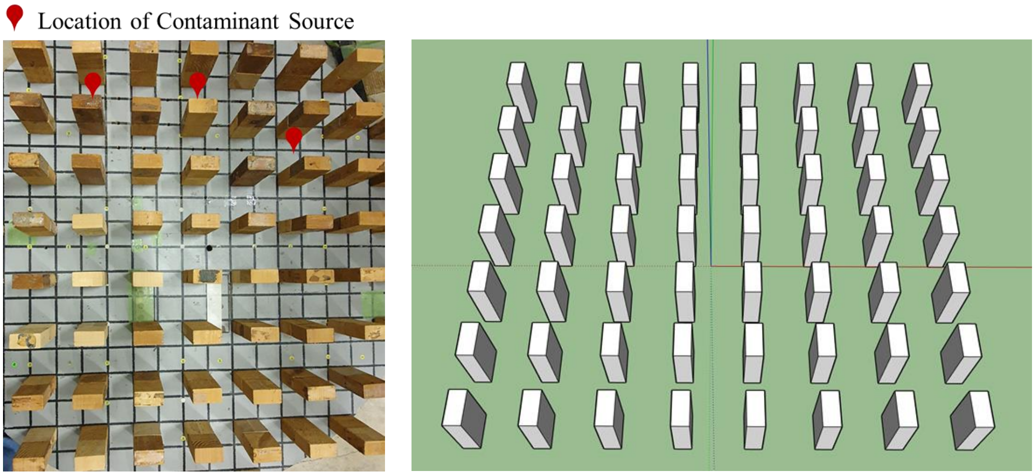



Fig 2 Blocks of 8rows×7ranks for contaminant experiment and simulation

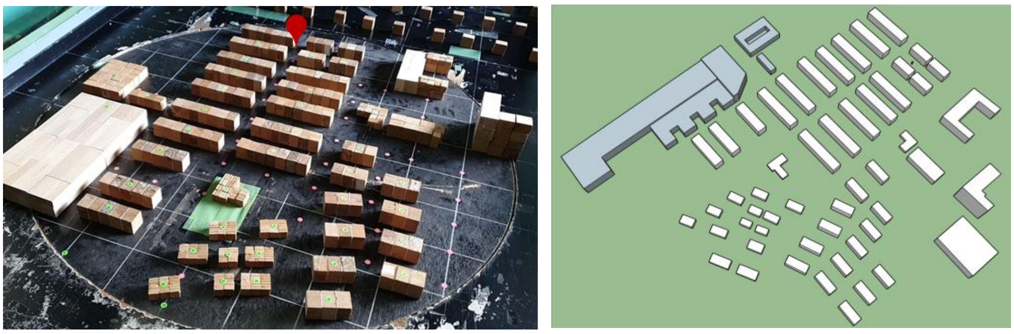


Fig 3 Urban district model

Table 1 Contaminant experiment parameters

| | Strength (ml/min) | Location X (mm) | Location Y (mm) | Location Z (mm) | Angle |
|---|---|---|---|---|---|
| 1 | Blocks Model | | | | |
| | 100 | -300 | 25 | 10 | 0 |
| | 100 | -200 | 150 | 10 | 0 |
| | 100 | -300 | -150 | 10 | 0 |
| 2 | Blocks Model | | | | |
| | 250 | -400 | 0 | 100 | 0 |
| | 250 | -400 | 0 | 100 | 30 |
| | 250 | -400 | 0 | 100 | -30 |
| 3 | Blocks Model | | | | |
| | 250 | -400 | 0 | 50 | 0 |
| | 250 | -400 | 0 | 50 | 30 |
| | 250 | -400 | 0 | 50 | -30 |
| 4 | Real City Model | | | | |
| | 100 | -345 | -35 | 5 | 0 |
| | 100 | -345 | -35 | 5 | 30 |
| | 100 | -345 | -35 | 5 | -30 |
| 5 | Real City Model | | | | |
| | 250 | -345 | -35 | 5 | 0 |
| | 100 | -345 | 0 | 5 | 0 |

## 3. Research Results

*(1) Experimental and numerical studies on wind field in the urban canopy layer*

CM1 has been used extensively for idealized simulations, from LES to the fine mesoscale (grid intervals of orders 1–1000 m), of moist atmospheric phenomena, especially individual thunderstorms, complexes of thunderstorms, and hurricanes. The new code to represent vertical surfaces is added to CM1 model, such as the walls of buildings, with a three-dimensional immersed boundary method (IBM). IBM is often used for studying detailed flow patterns in urban environments and over steep terrain. Atmospheric models that use IBM include the Parallelized Large-Eddy Simulation Model (PALM) and a version of the WRF. However, CM1 is computationally cheaper than the WRF model (by roughly a factor of 2 in terms of supercomputer core hours). A simulation using CM1 without buildings, in which urban development is crudely represented as just a patch of higher surface roughness length, does not generate a pronounced shadow as used in IBM. CM1 with IBM has been validated against published results from field, laboratory, and numerical studies (shown in Figure 4), and from investigations with other models that have become standards in research into about how buildings affect weather and climate.

This distinct of this study is the focus on the high inflow wind velocity, which is different as the published results from field, laboratory. The results (Figure 5 and 6) show that the improved CM1 model using IBM method agree well with the experimental data. The results improve our understanding the process that govern urban-canopy winds especially under high wind situation, like storms or hurricanes and how cities shape the complex and poorly understood IBLS especially hurricane landing. The results from this study will serve as a standard of comparison for evaluating the coarser mesoscale simulations. The results from this study will be applied to other research in urban meteorology and climatology.

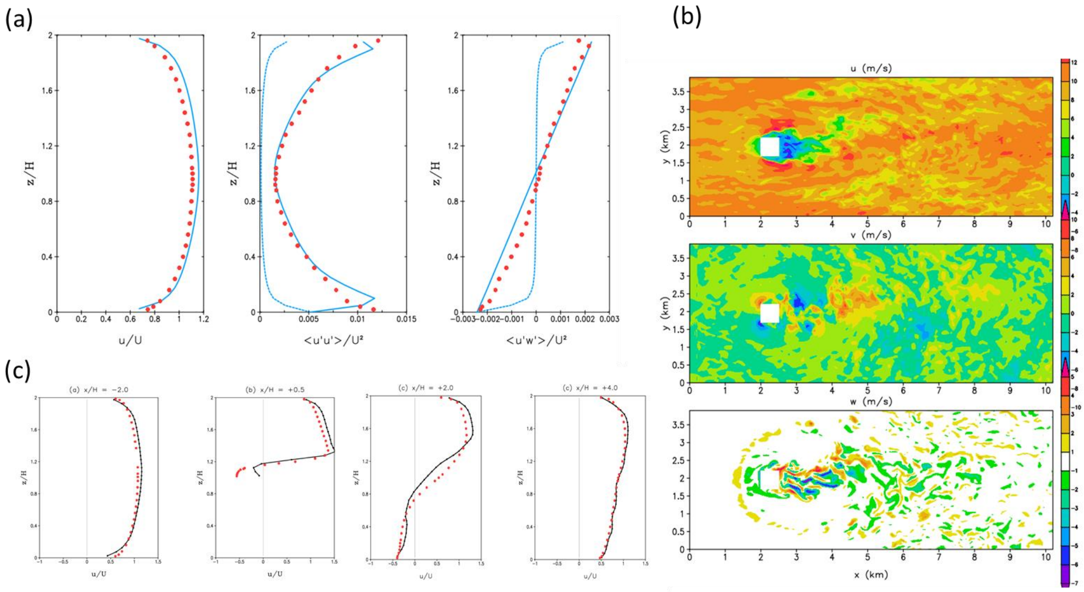



Fig 4 CM1_IBM simulation against with experimental studies from Letzel (2007). (a) Evaluation of CM1_IBM Precursor Simulation; (b) CM1_IBM Production Run results; (c) Evaluation of CM1_IBM Production Run Simulation

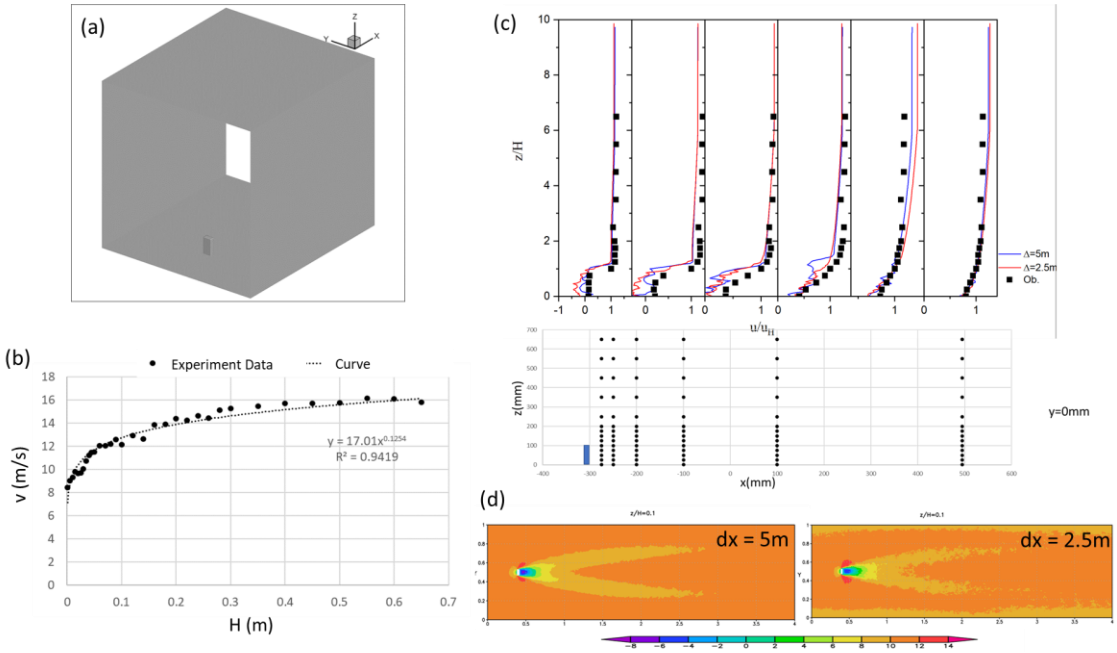



Fig 5 CM1_IBM simulation against with experimental studies using one block. (a) Computation domain; (b) Measured inflow wind structure in the wind tunnel; (c) Evaluation of CM1_IBM model with experimental data (d) Simulation results using different grid resolutions

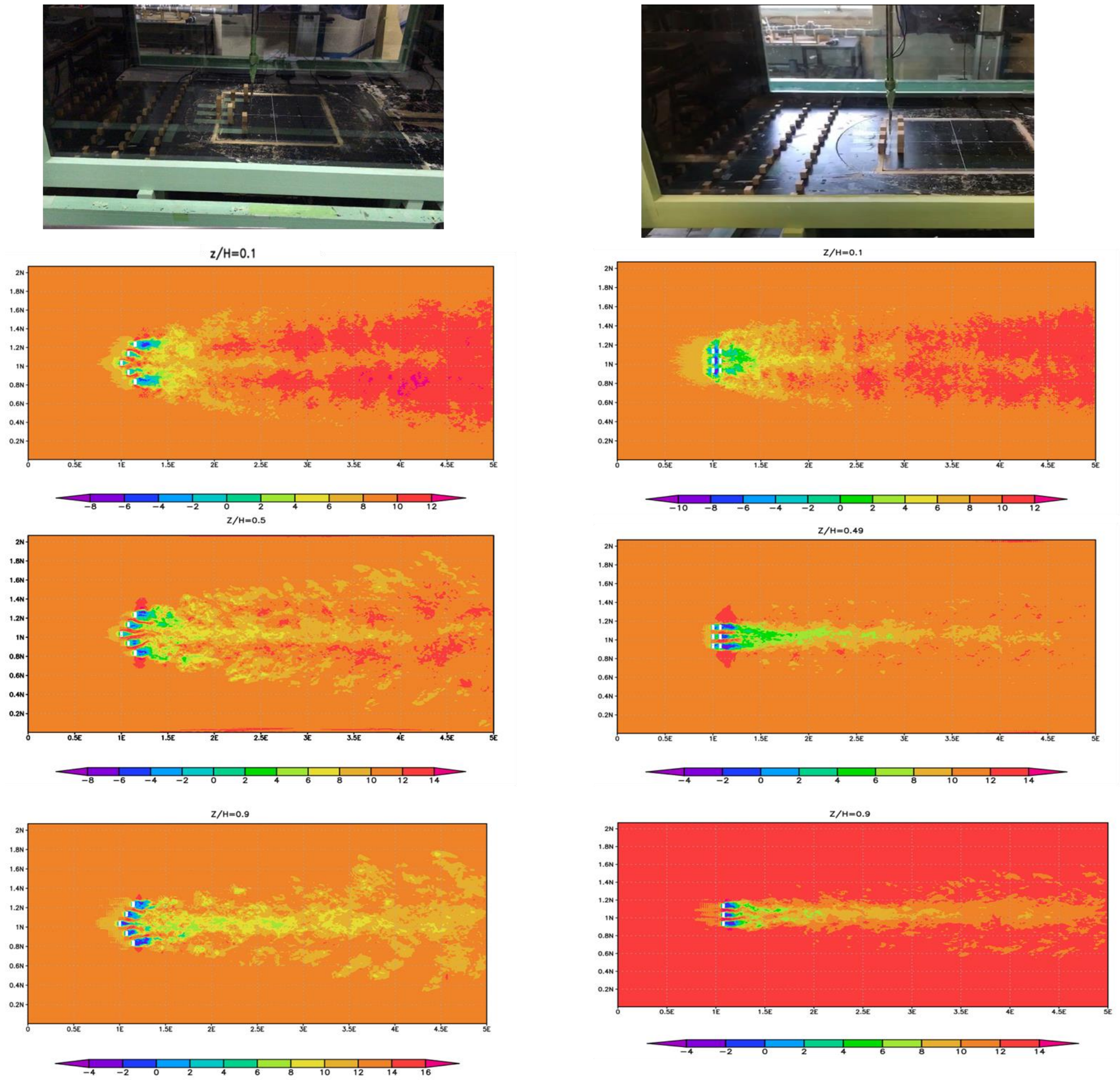



Fig 6 CM1_IBM simulation results under different building configurations

*(2) Experimental and numerical studies on pollutant transportation in the urban canopy layer*

The adjoint probability based method succeeds in identifying one source with randomly selected three sensors' data. Figure 9 and Figure 10 show the identification result in both blocks model and city model.

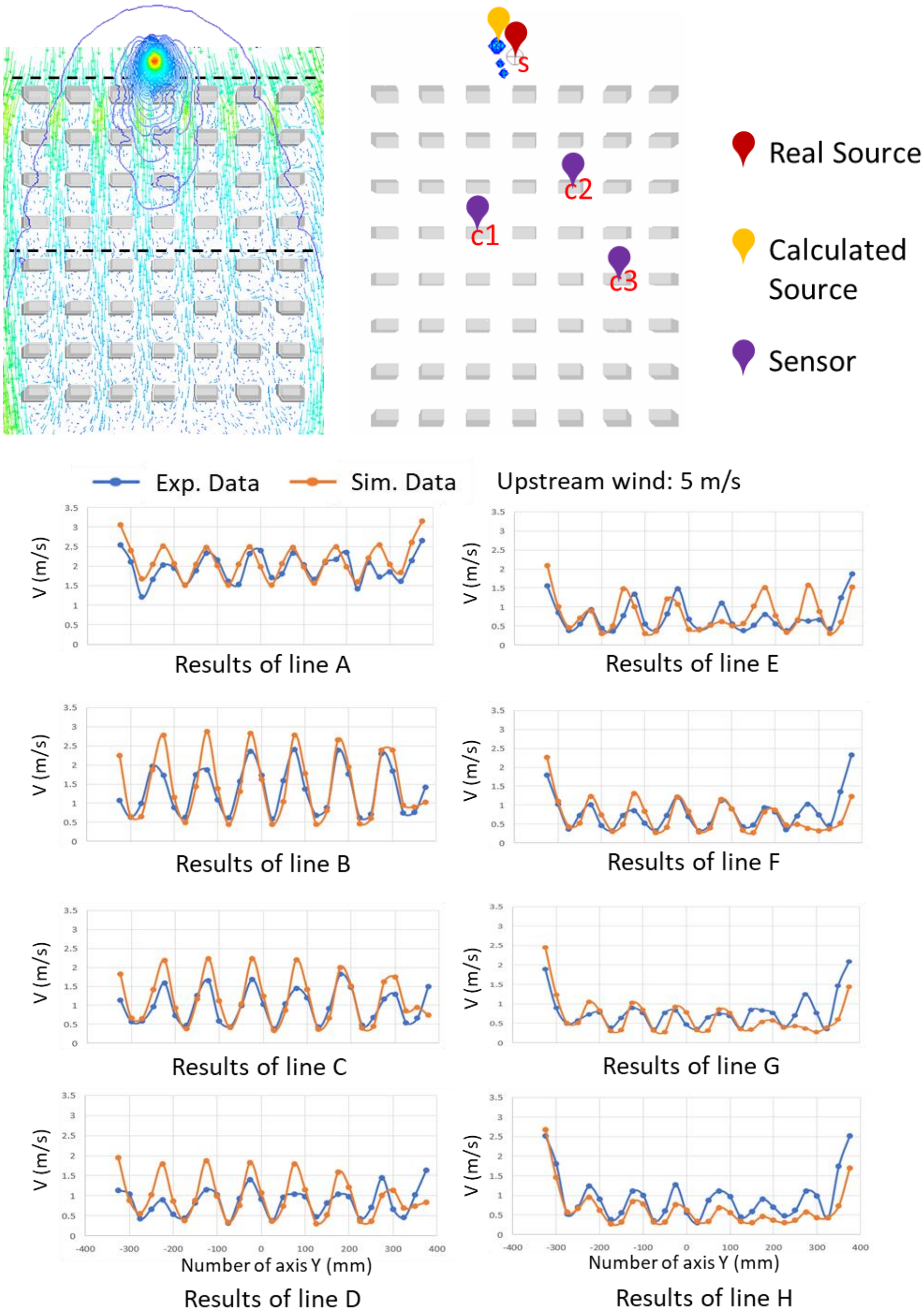



Fig 9 Flow field of blocks model and the identification result with three sensors' data

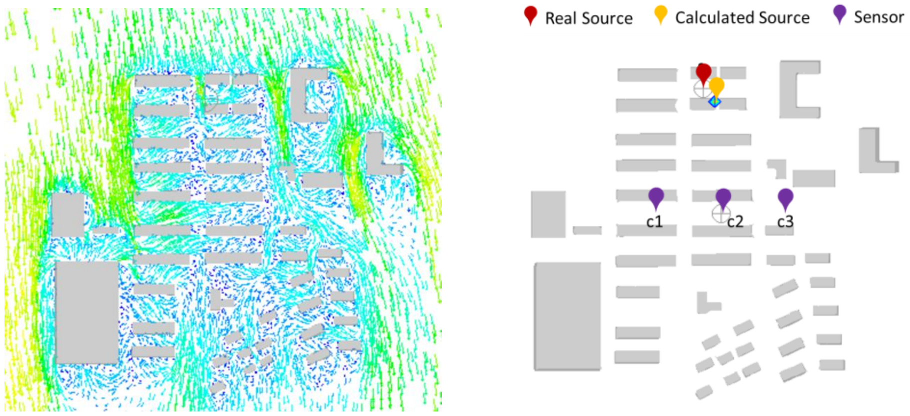
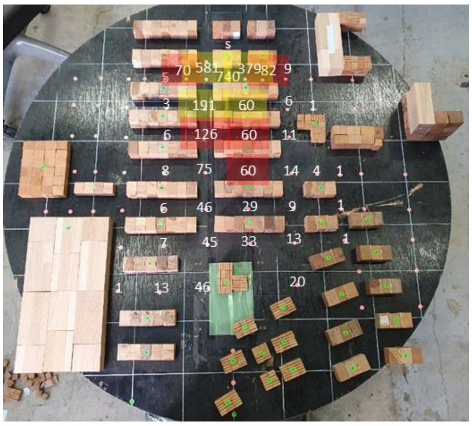



Fig 10 Flow field of city model and the identification result with three sensors' data

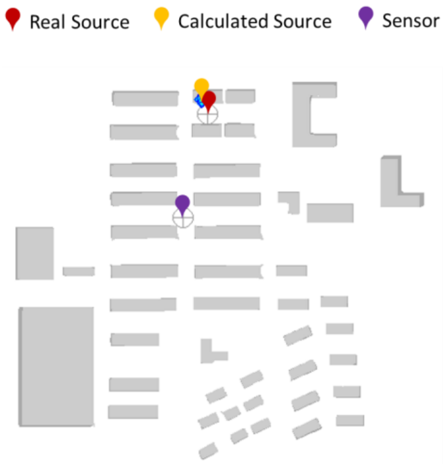
The adjoint function based method succeeds in identifying one source's location with one sensor's data in three different wind directions. Figure 11 shows the inverse identification result in city model.



(a)

(b)

(c)




(d)

Fig 11 Identify one contaminant source with one sensor's data in different wind direction: (a) Contaminant concentration field with north wind; (b) Contaminant concentration field with northeast wind; (c) Contaminant concentration field with northwest wind; (d) Identified result with one sensor's data in three different direction winds

The adjoint probability based method succeeds in identifying multiple sources with limited sensors' data. Figure 12 shows the procedure to identify two contaminant sources with contaminant concentrations at only six locations: (a) calculate the first potential source S1(1) with random selected three locations' contaminant concentration; (b) head to S1(1) to check if it is the source, if not, take another three locations' data to calculate the second potential location of source S1(2), then head to S1(2), it is easy to confirm that S1(2) is close to one of the real source; (c) simulate the contaminant concentration field produced by S1, subtract it from previous data; (d) identify the second source's location with the updated data.

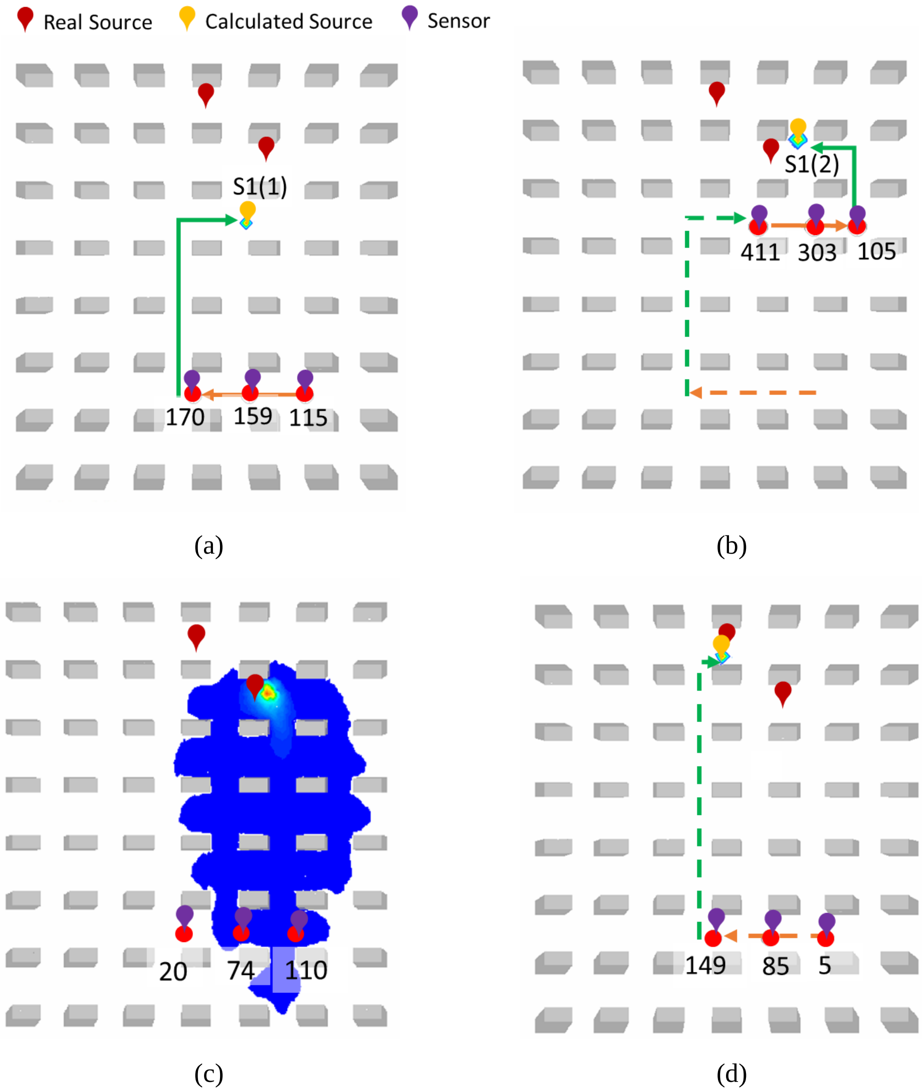



Fig 12 Identify two contaminant sources with only six locations' contaminant concentrations

**4. Published Paper etc.**

[Underline the representative researcher and collaborate researchers]

[Published papers]

1.

[Presentations at academic societies]

1.

[Published books]

1.

[Other]

Intellectual property rights, Homepage etc.

## 5. Research Group

(1) Representative Researcher

Prof. Zhiqiang (John) Zhai, University of Colorado at Boulder, US

(2) Collaborate Researchers

- Dr. Yingli Xuan, Tokyo Polytechnic University, Japan
- Dr. Yu Xue, Dalian University of Technology, China
- Dr. Yi Wang, National Center for Atmospheric Research, US

## 6. Abstract (half page)

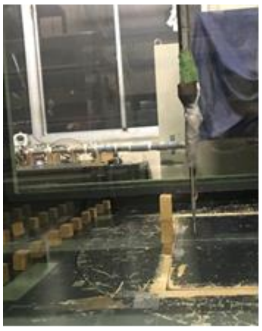
Research Theme: Experimental Validation and Model Development for Urban Pollutant Source Tracking Method

Representative Researcher (Affiliation): Prof. Zhiqiang (John) Zhai (University of Colorado at Boulder)

Summary・Figures

The research studied the flow field and contaminant field from microscale to mesoscale (blocks and urban district model), and validated the accuracy of the urban environment simulation model CM1_IBM and the inverse identify method for contaminant sources. The new developed model CM1_IBM is able to simulate flow field around buildings with high accuracy. The study improves the understanding the process that governs urban-canopy winds especially under high wind situation and how cities shape the complex while poorly understood internal boundary layers (IBLs). The results from CM1_IBM will serve as a standard of comparison for evaluating the coarser mesoscale simulations in WRF.

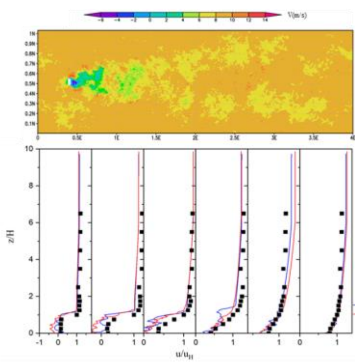
The adjoint probability based inverse identify method succeeds in tracking multiple contaminant sources with limited sensor data and identifying contaminant source with only one sensor's data under different wind directions. The developed methods make it possible to fast and accurately identify air pollution sources in the urban canopy. The findings will contribute to proper sensor distribution and sensor selection in the urban environment and address other source-origin problems. The outcomes of this study can also be applied to other researches in urban meteorology and climatology.



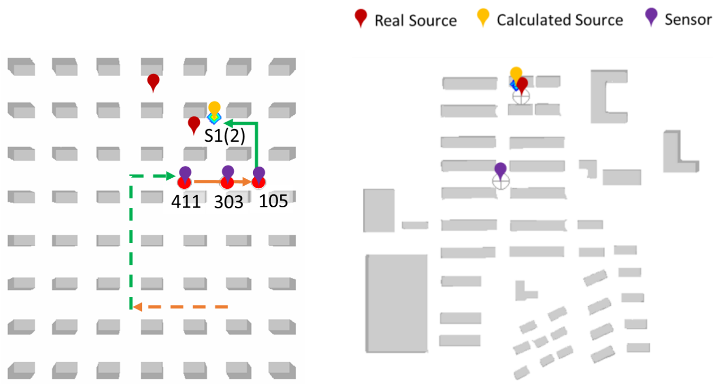
**One block model**


**8row×7rank blocks model**

**City model**



**CM1_IBM simulation results fits well with experiment results**




**Adjoint probability based method succeeds in identifying contaminant sources with limited contaminant info**