清華大學核能技术设计研究院

Micro-SWIFT SPRAY modeling of atmospheric dispersion around a nuclear power plant site with complex topography

Xinwen Dong, Sheng Fang, Shuhan Zhuang

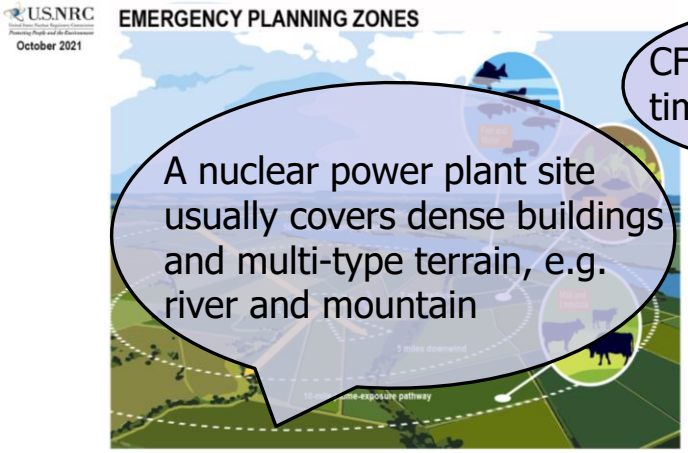
Institute of nuclear and new energy technology, Tsinghua University, Beijing, China

INET

EGU General Assembly 2022

Background

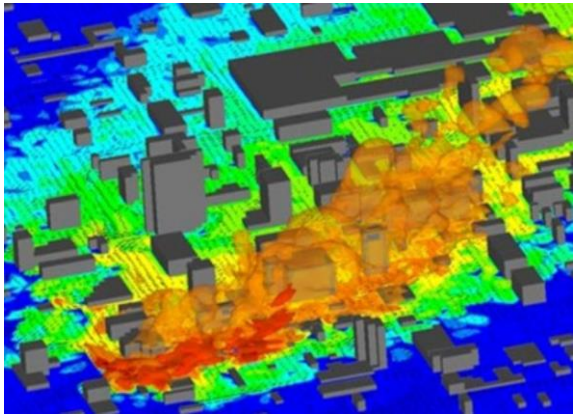
- The nuclear emergency response for accidental release around the nuclear power plant site (NPPs) requires a fast and accurate estimate of the influence caused by gaseous hazardous pollutants spreading.



A nuclear power plant site usually covers dense buildings and multi-type terrain, e.g. river and mountain

CFD method is time-consuming

Supplement Support

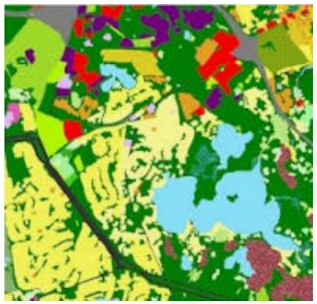


Concentration of pollutants

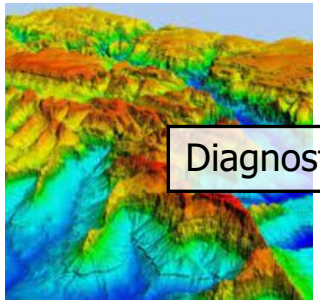
Dispersion model

Emergency plans/responses

Weather monitoring

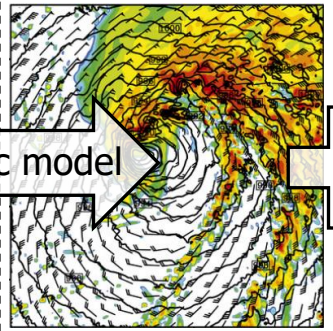


Land use

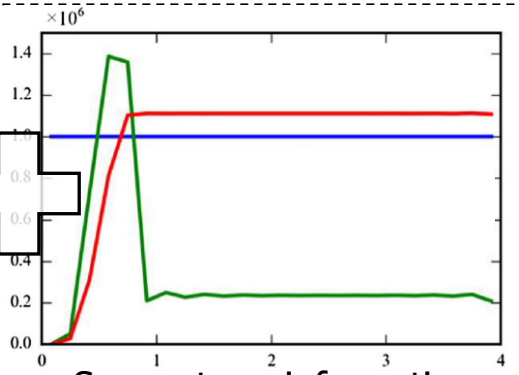


DEM data

Diagnostic model



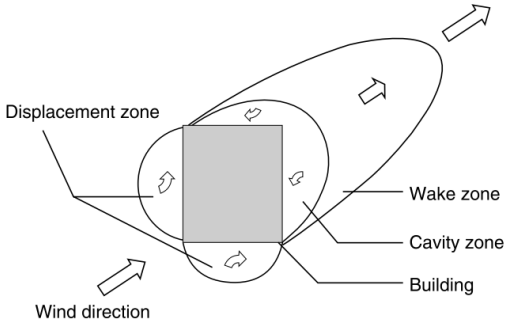
Wind field



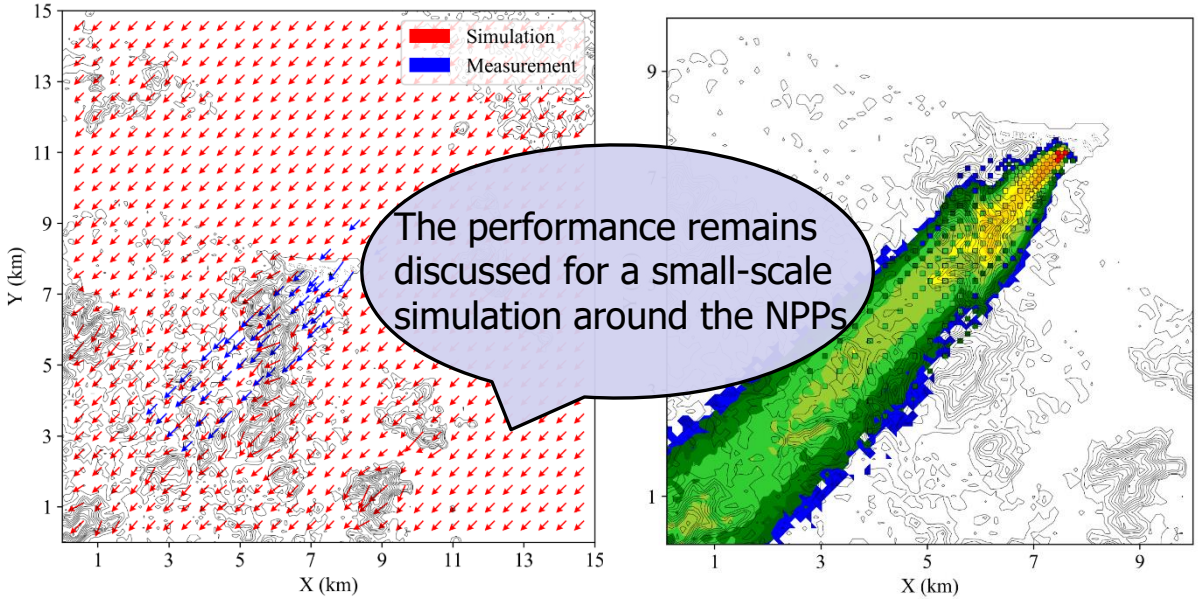
Source term information

Background

- Many air dispersion models have been developed for this task. One is the Micro-SWIFT SPRAY (MSS) which consists of a SWIFT and a SPRAY model.
- SWIFT is a diagnostic model for wind and turbulence fields computations, dedicated to built-up areas due to a separate module to model obstacles.
- SPRAY is a Lagrangian particle model for simulating airborne pollutant dispersion in urban, in which buildings are treated as impermeable cells.



Flow zones near obstacle(s)

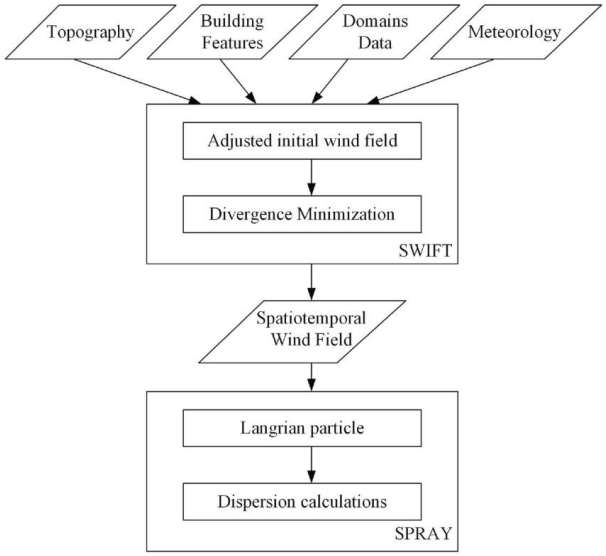


Wind and concentration fields in a local-scale simulation (15km*15km)

Materials and methods

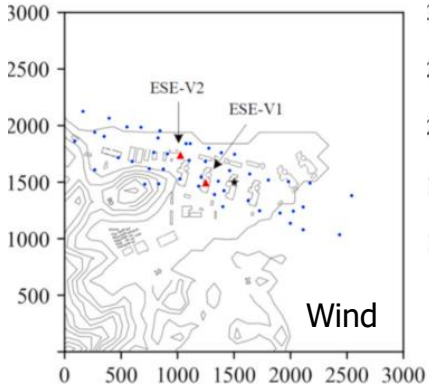
- Parameter setting and work procedures of MSS

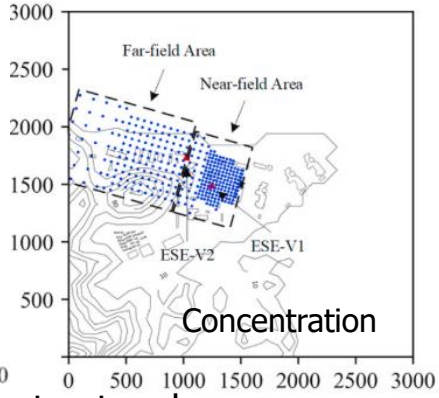
Parameters	Value
Horizontal grid size	5 m
Vertical grid size	5 m
Emission time step	1 s
Particle number (per time step)	10000
Averaging period	600 s
Turbulence model	The Louis model
Low bound of turbulence intensity (m/s) SUMIN, SVMIN, SWMIN	0.3, 0.3, 0.3 (Default)



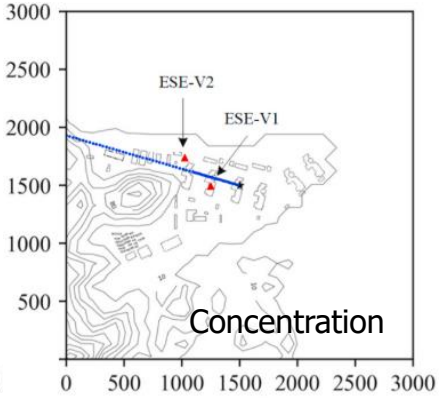
- Observations acquisition
  - Wind tunnel experiment[1]

1:600 scaled model





Measurement networks



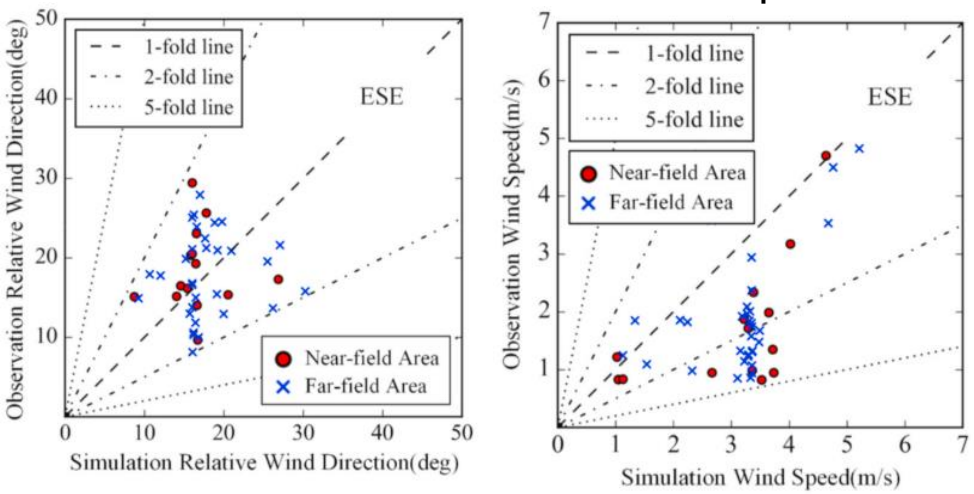
Axial sites

- Statistical metrics: FAC5, FAC2, MG, VG, PCC

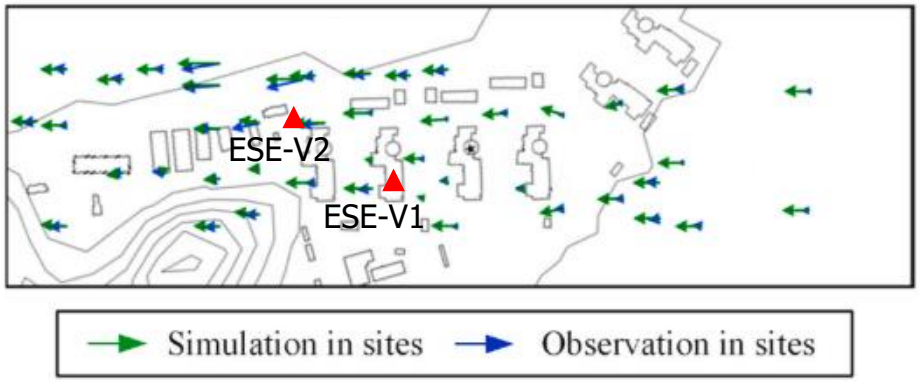
1. The wind tunnel experiment is conducted in the atmospheric boundary layer wind tunnel of China Institute for Radiation Protection (CIRP).

Results and discussions

- Comparison of wind field
  - Scatters of wind direction and wind speed



  - Airflows at sites

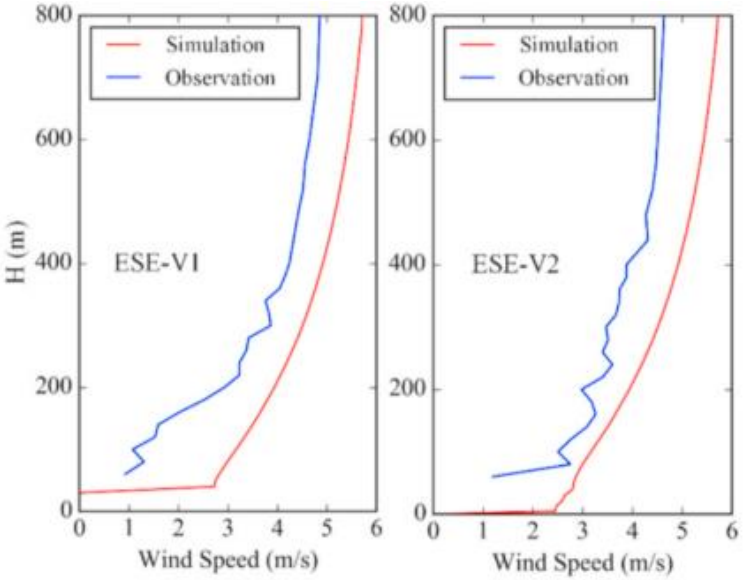


(1) Higher accuracy in reproducing the wind direction than the speed.

(2) There display clusters of around 16 deg and 3.2 m/s, of which the positions are along two sides of the building layout.

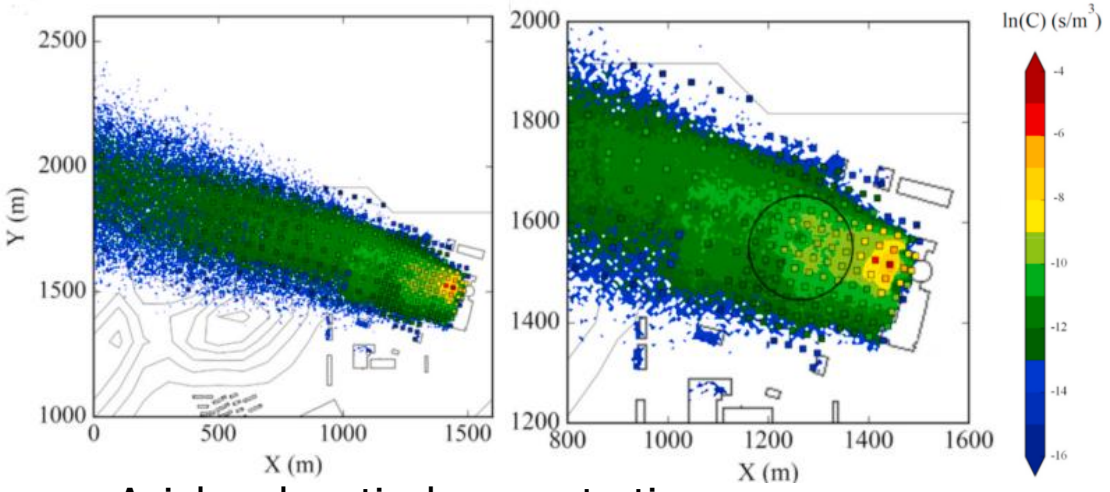
(3) The simulated vertical profiles of speed is overestimated.

- Vertical profile of speed at sites

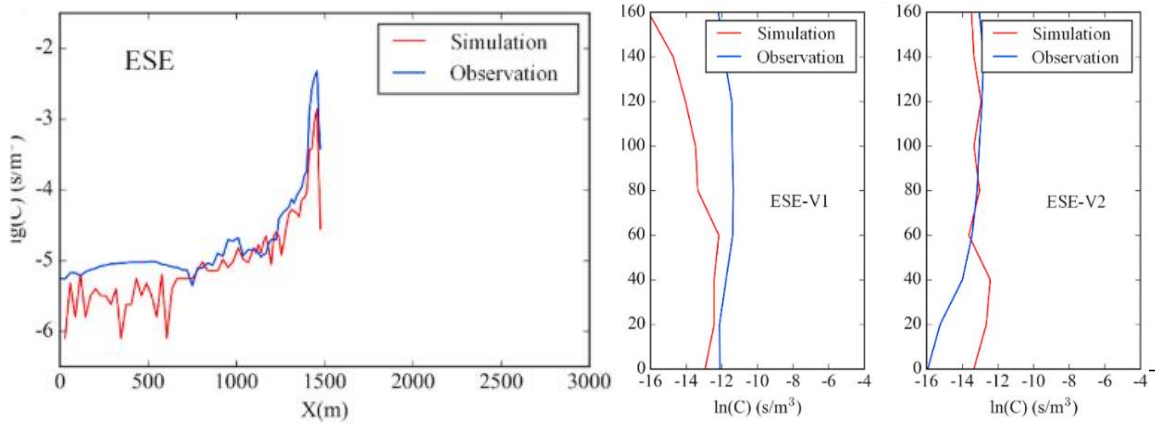


Results and discussions

- Comparison of concentration field
  - Concentration plume (left: entire, and right: a zoom-in plot)



  - Axial and vertical concentration



(1) MSS reproduces the highest concentrations and brings high consistency to the observations in the circle place.

(2) there is an underestimation of about 33% at the release point. The simulations match the observations well from 700 m to 1400 m.

(3) Satisfactory metrics indicate a robust performance of MSS in simulating concentration. Large MG appears in the near-field area, which means more extreme biases there.

- Performance metrics

Domain	FAC5 0.7–1	FAC2 0.4–1	MG 0.5–2	VG 1–4	PCC
Near-field area	0.991	0.965	1.760	2.880	0.867
Far-field area	0.885	0.793	0.959	2.919	0.757
Whole area	0.945	0.891	1.353	2.895	0.855

Summary

- MSS is comprehensively evaluated against a wind tunnel experiment with a 1:600 scale for the small-scale (3 km × 3km) atmospheric dispersion modeling. Tens of buildings located in this scenario of a NPPs surrounded by a mountain and river.
- Aspects:
  - the wind speed, direction, distribution of horizontal airflows, and vertical profiles of speed at representative sites;
  - the horizontal concentration distribution, axis profile, and vertical profiles at representative sites.
- Brief conclusion:
  - MSS reproduces fine changes of airflow direction near buildings, but overestimates the speed as well as those of vertical profiles.
  - MSS reproduces the highest concentration place and matches the observations well. The axis profile of concentration is underestimated and the vertical profile exhibits accurate prediction within the building height.
  - Compared with the observations, the FAC5 and FAC2 of concentration simulation reach 0.945 and 0.891 in the entire calculation domain, which convinces the performance of MSS in small-scale modeling.

Thank you for your attention!