$PM_{2.5}$ Concentration Profile around A SALSCS/AMSA: A Numerical Study under Different Ambient Conditions

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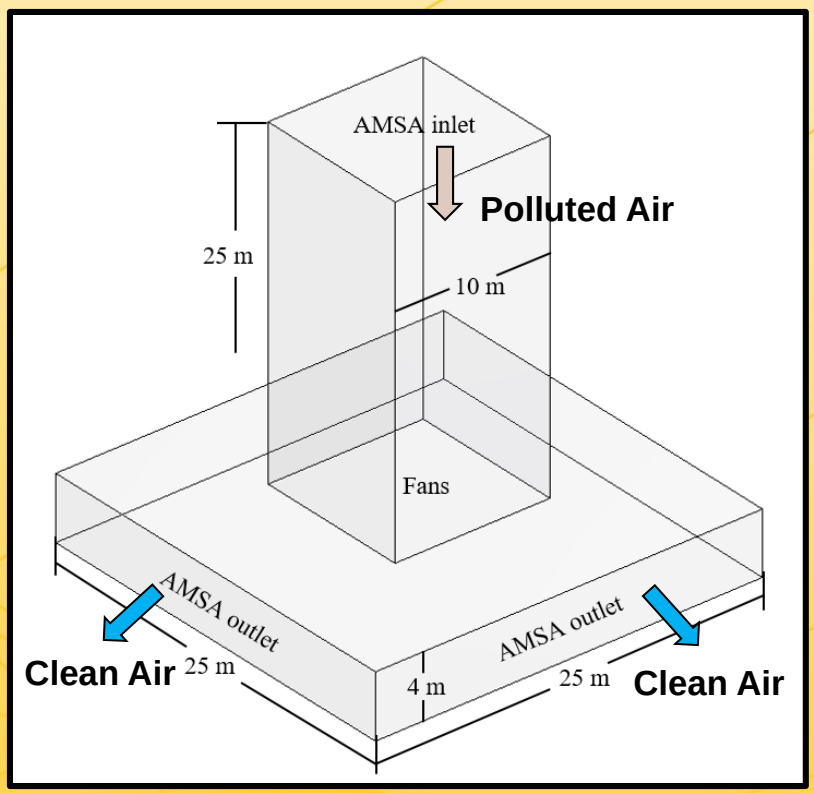
Outline

- Introduction;
- Model description;
- In a quiescent atmosphere;
- Under uniform ambient wind speeds;
- Summary and future work.

Introduction

- Picture showing dimensions and geometry of AMSA in the numerical model;
- Polluted air flows in through the inlet at the top;
- Clean air is delivered through the outlet at the base;
- To calculate the $PM_{2.5}$ concentration profiles around AMSA;
  - ✓ Under different idealized ambient conditions.
  - ✓ Using numerical method.
- ***Objective*: Conduct numerical simulations to determine the $PM_{2.5}$ concentration profiles around AMSA.**

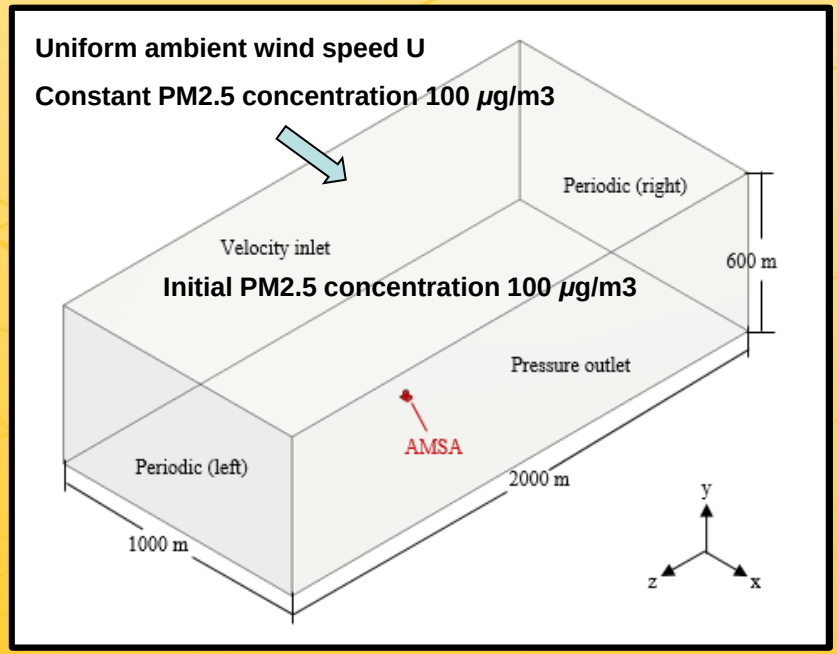


Model Description

- Reynolds number larger than 10^6, indicating a turbulent flow field.
- 3D incompressible Reynolds-Averaged Navier Stokes (RANS) equations.
- k-ε 2-equation turbulent model for Reynold stress closure.
- Assuming mixture of polluted ambient air and clean air from AMSA.
- Ambient $PM_{2.5}$ concentration 100 $\mu g/m^3$; clean air 0 $\mu g/m^3$.
- Physical air properties are set under -1.5 ºC (29.3 ºF).
- Species transport equation is solved for polluted ambient air.

➢ In a quiescent atmosphere.
  ✓ Transient model

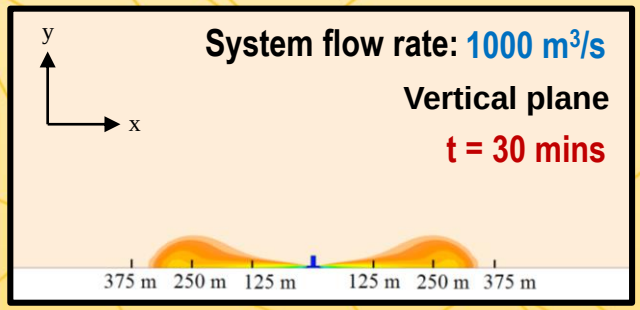
➢ Or under different uniform ambient velocities.
  ✓ Steady-state model

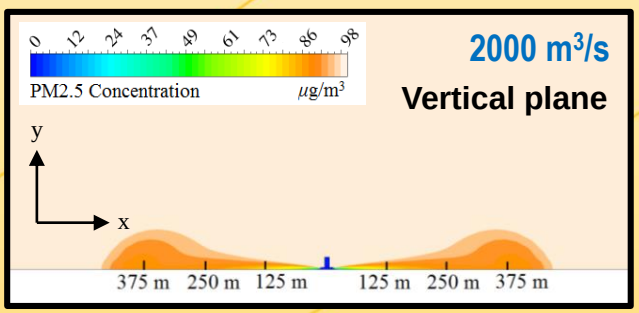


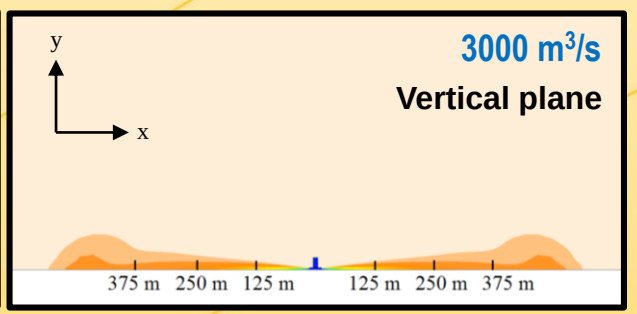
Numerical Results for AMSA under Quiescent Atmosphere

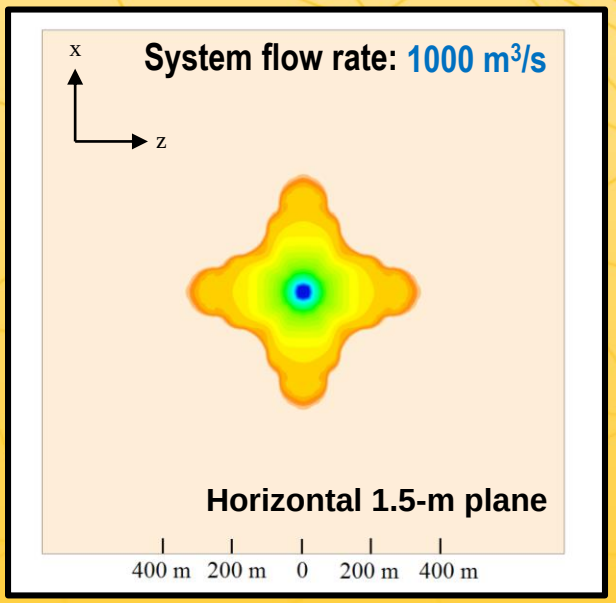
$PM_{2.5}$ Concentration Contours in Quiescent Atmosphere

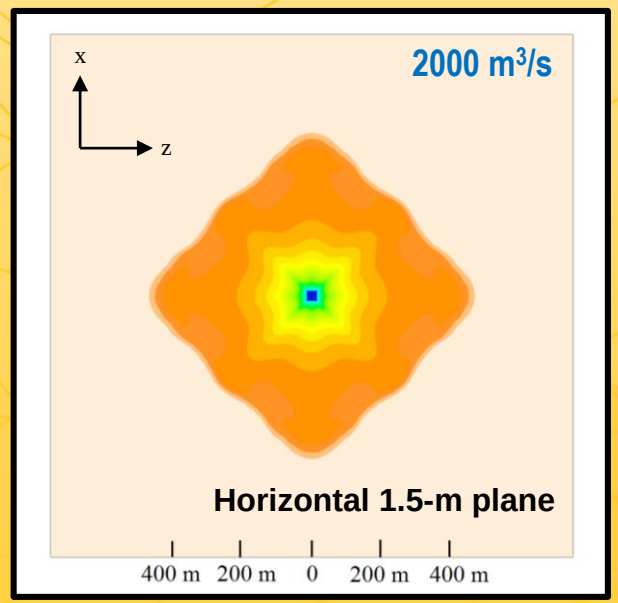
- Below are the contours of $PM_{2.5}$ concentration in a vertical plane at different flow rates.

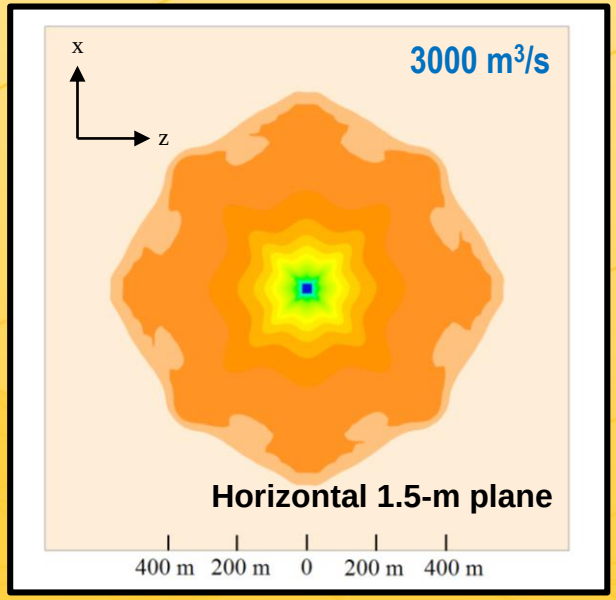








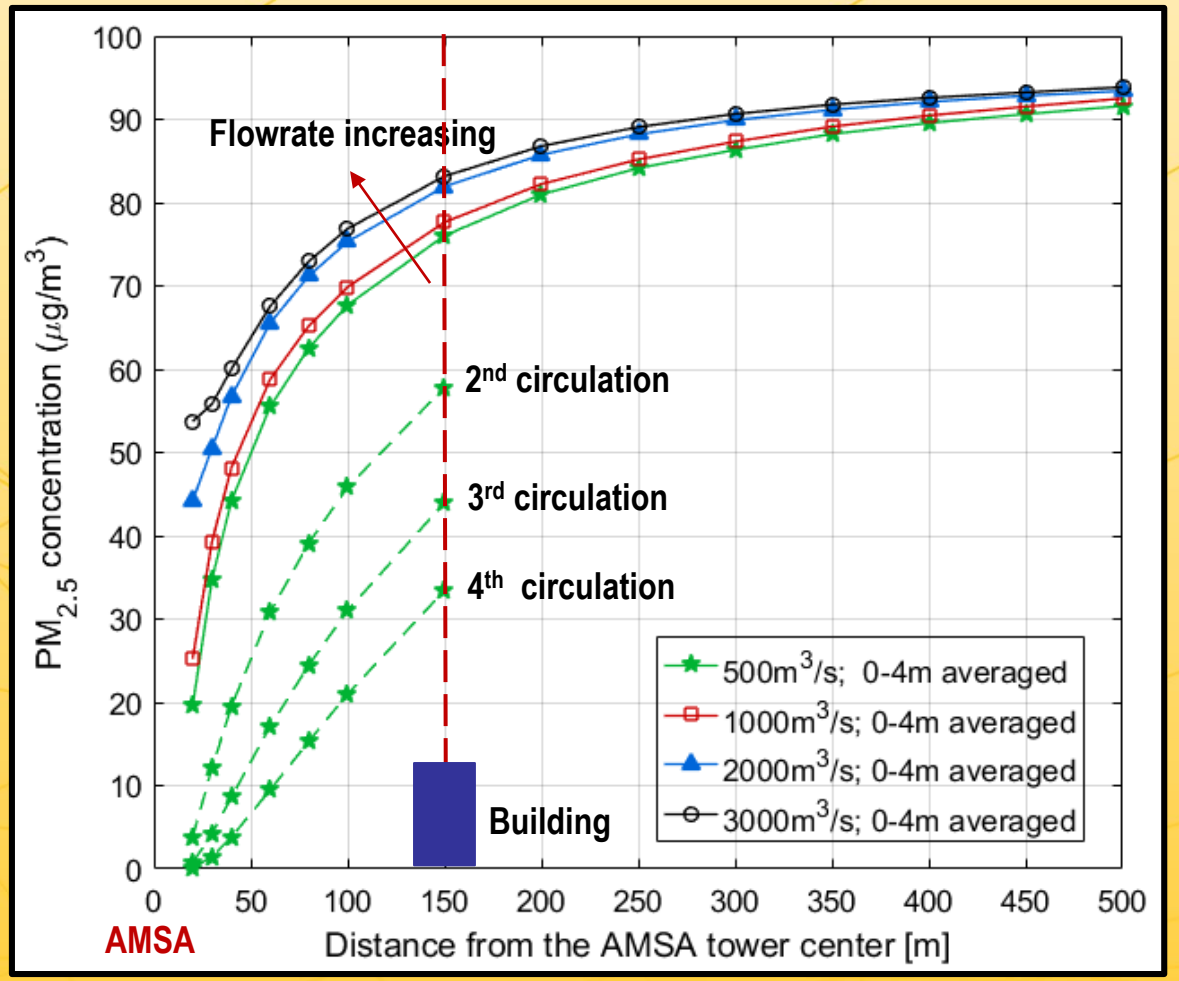




- Above are the horizontal contours at 1.5-m plane above the ground.

$PM_{2.5}$ Concentration Profiles in Quiescent Atmosphere

- Figure showing the $PM_{2.5}$ concentration vs. distance for 4 different system flowrates.
- Simulation time long enough so that the concentration profiles reach steady state inside the radius of 500 m.
- ✓ Lower flowrate achieves lower $PM_{2.5}$ concentration.
- If we can create more circulation within the first 150 m, concentration can be further reduced.



An Explanation of the Conclusion

- Clean air concentration defined as

$$C_{clean\ air} = \frac{Volume\ of\ clean\ air\ delivered\ by\ SALSCS}{Volume\ of\ atmospheric\ air\ covered\ by\ SALSCS\ clean\ air}$$

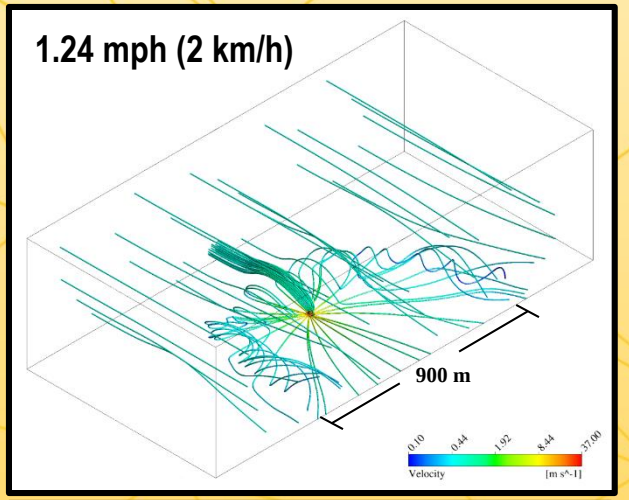
- If we increase the flowrate, both the numbers in numerator and denominator will be increased.
- Volume of clean air is related to flow rate and time.
- Volume of the denominator depends the penetration velocity of clean air in the atmosphere.
- Detailed explanation can be referred to

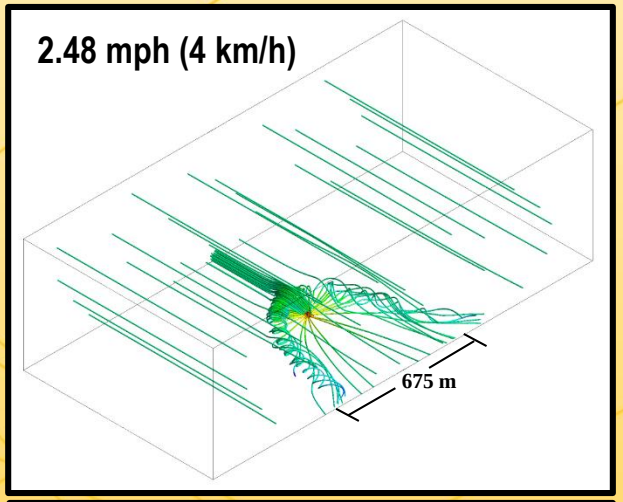
Q. Cao, L. Shen, S.-C. Chen, D.Y.H. Pui. CFD Analysis on PM2.5 Concentration Profiles Around A SALSCS/AMSA under Idealized Ambient Conditions. (2018). (In Preparation).

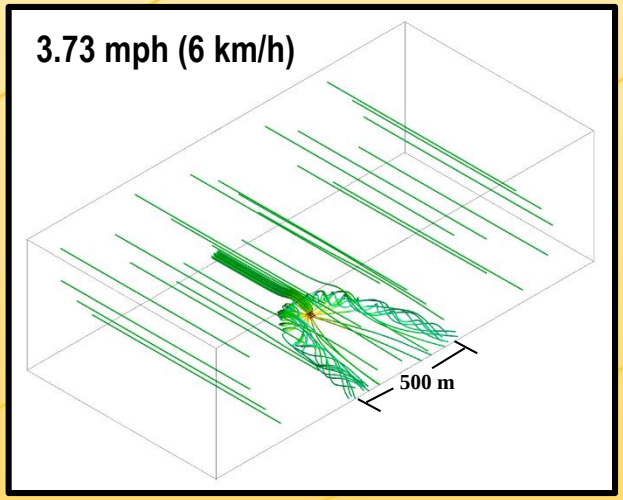
Numerical Results for AMSA under Uniform Ambient Velocity

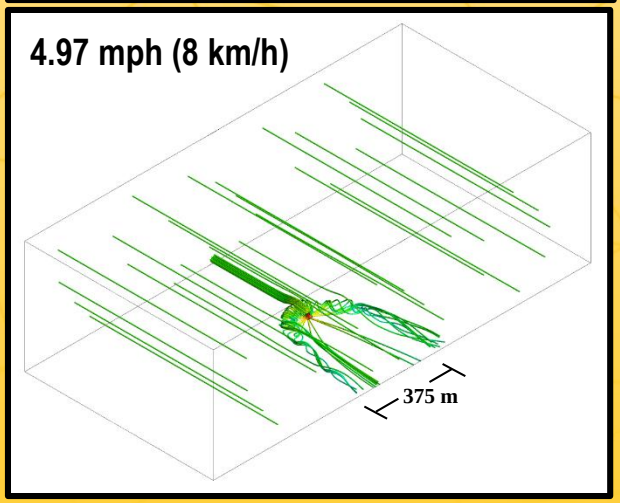
AMSA under Uniform Ambient Wind Speeds

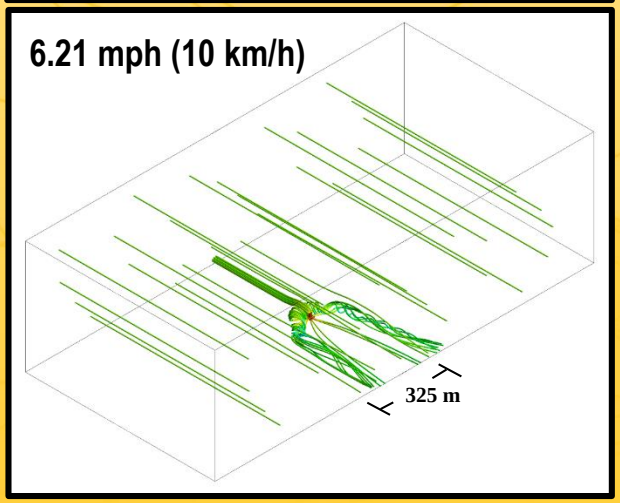
- Streamlines colored by velocity at system flowrate of 2000 m^3/s.







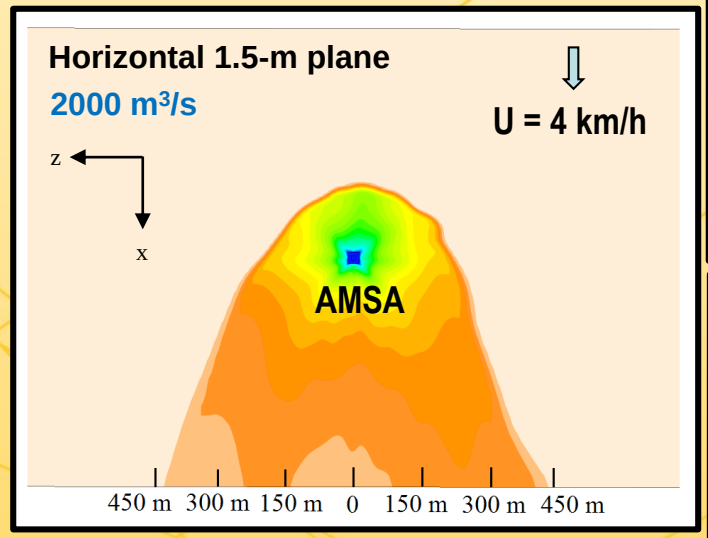


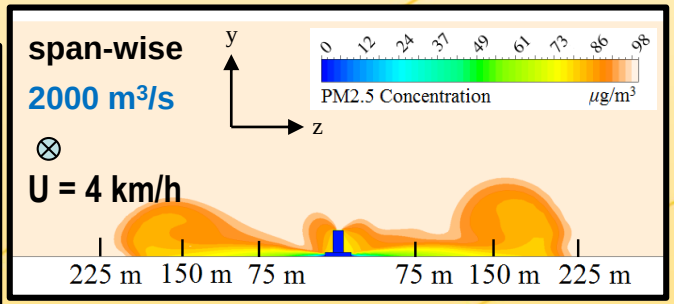


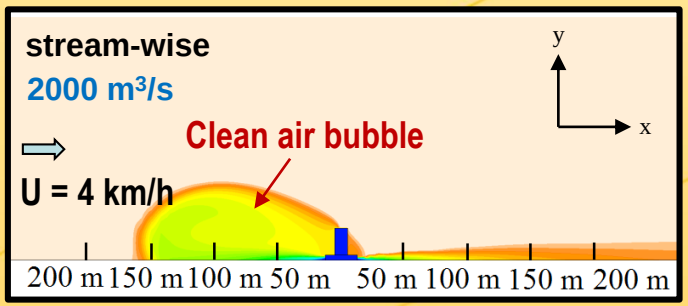
- Downstream vortex are generated.
- It expands as wind speed decreases.

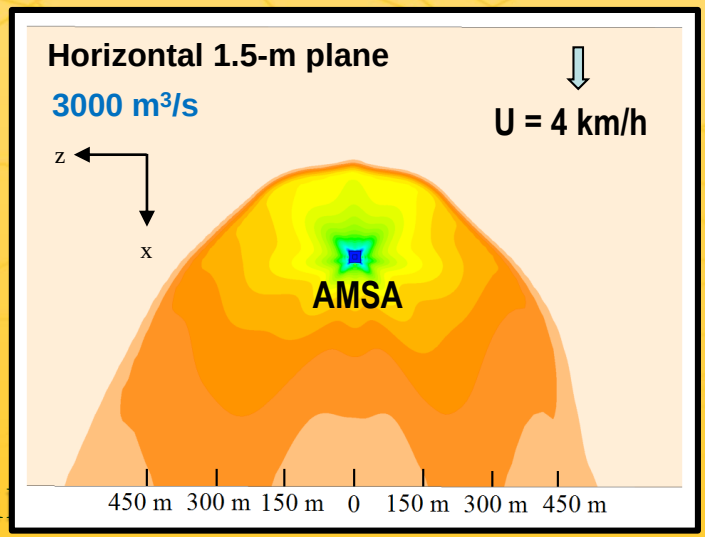
$PM_{2.5}$ Concentration Contours under Ambient Wind Speed of 4 km/h

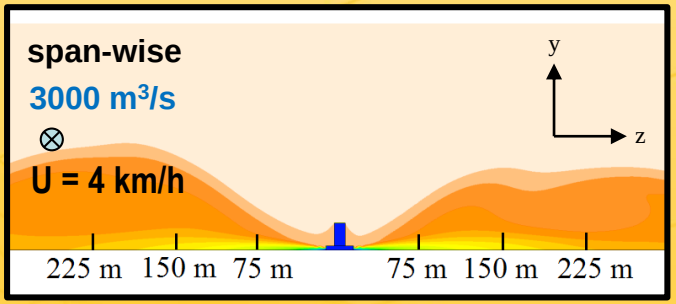
- Contours of $PM_{2.5}$ concentration at ambient wind speed of 2.48 mph (4km/h).
- Clean air bubble appears at upstream of AMSA.
- A higher flowrate gives a larger cleaning area.
- But local $PM_{2.5}$ concentration may not be lower.

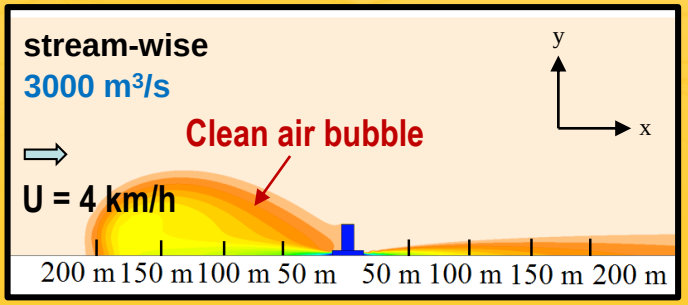






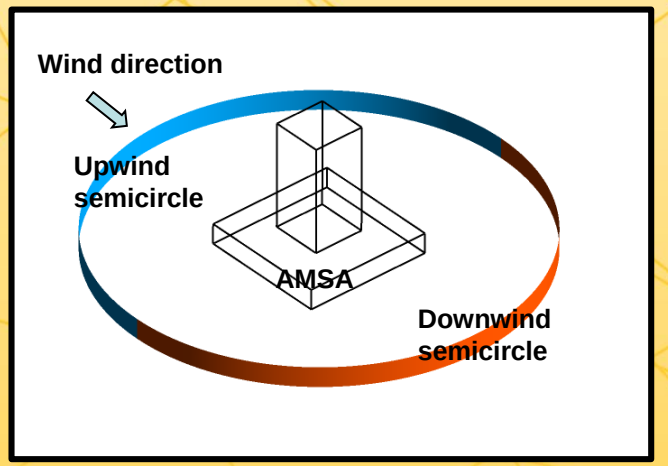


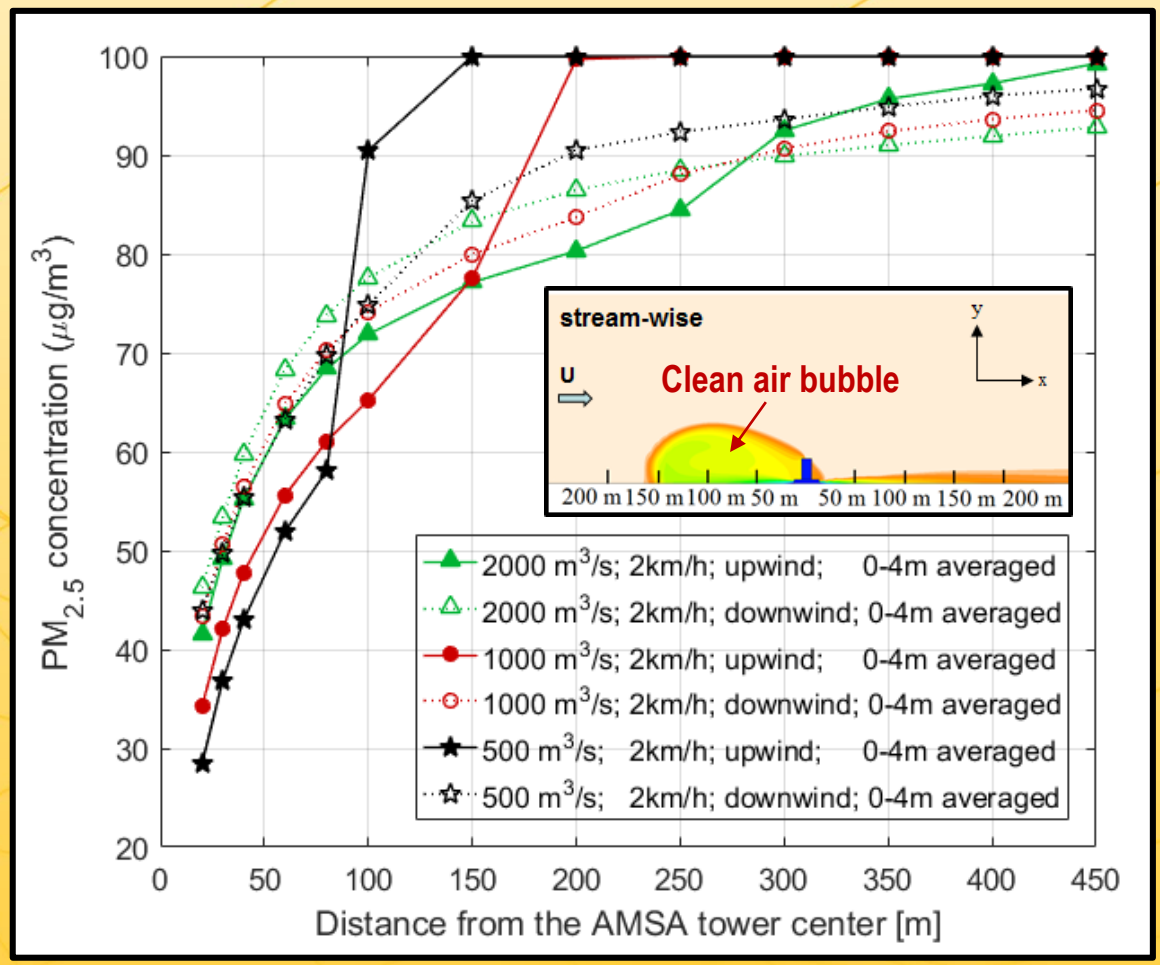




Effect of System Flowrate on $PM_{2.5}$ Concentration with Wind Speed of 2 km/h

- Figure showing the effect of flowrate on $PM_{2.5}$ concentration at a uniform wind speed of 2 km/h.



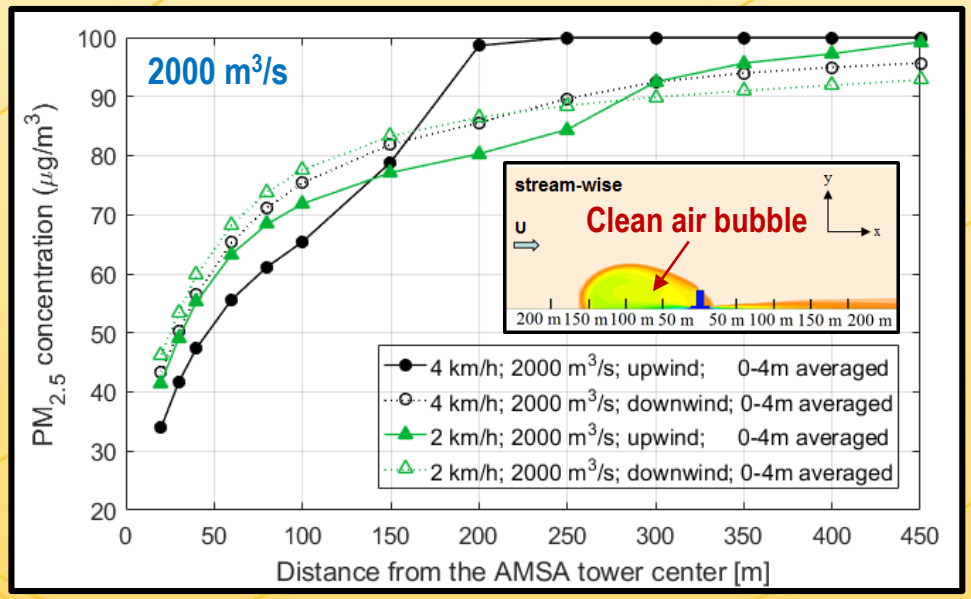


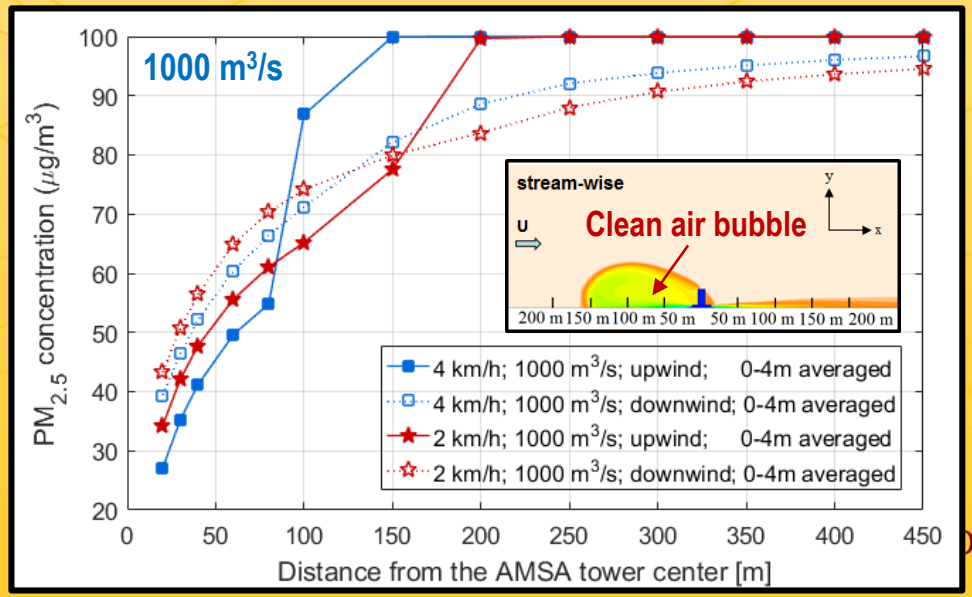
- Upwind: sharper concentration gradient between 75 - 200 m indicating the edge of clean air bubble.
- Downwind: smoother concentration gradient.
- As flowrate decreases, $PM_{2.5}$ concentration becomes lower close to AMSA, and higher at the locations far away.

Effect of Ambient Wind Speeds on $PM_{2.5}$ Concentration Profiles

- Figure showing the effect of ambient velocity on $PM_{2.5}$ concentration at two flowrates.
- As ambient velocity increases, the upwind clean air bubble has a smaller volume, but the $PM_{2.5}$ concentration is lower close to AMSA.
- At downwind location, a higher ambient velocity also decreases the $PM_{2.5}$ concentration close to AMSA, but far away from AMSA, the concentration becomes higher.

✓ In general, the upwind location is cleaner than the downwind, because of the accumulation of clean air inside the upwind bubble.





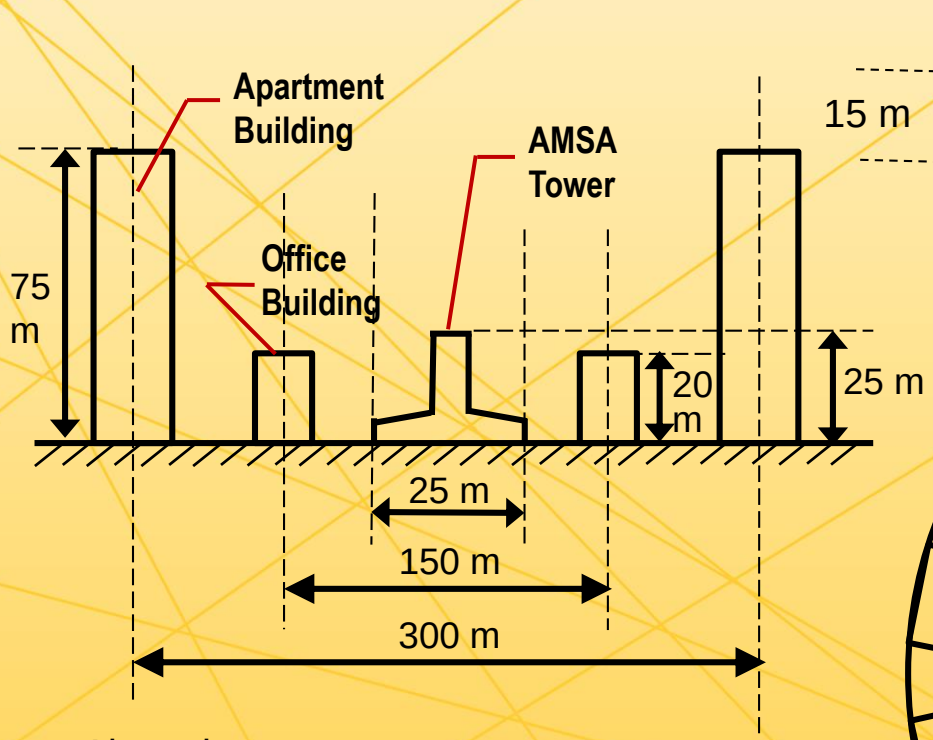
Summary

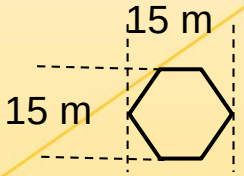
- Numerical simulations have been conducted to study the $PM_{2.5}$ concentration profiles of AMSA under different ambient conditions.
- A higher system flowrate benefits a larger area but doesn't decrease the local $PM_{2.5}$ concentration significantly.
- Under a quiescent atmosphere, a lower system flowrate gives lower $PM_{2.5}$ concentration.
- With uniform ambient wind speeds, a clean air bubble is generated at the upwind location, contributing to a lower $PM_{2.5}$ concentration than the downwind.
- At a constant system flowrate, a lower clean air flow velocity helps to achieve a lower local $PM_{2.5}$ concentration.
- Under real urban conditions, the $PM_{2.5}$ concentration profile results may be different.

Future Work

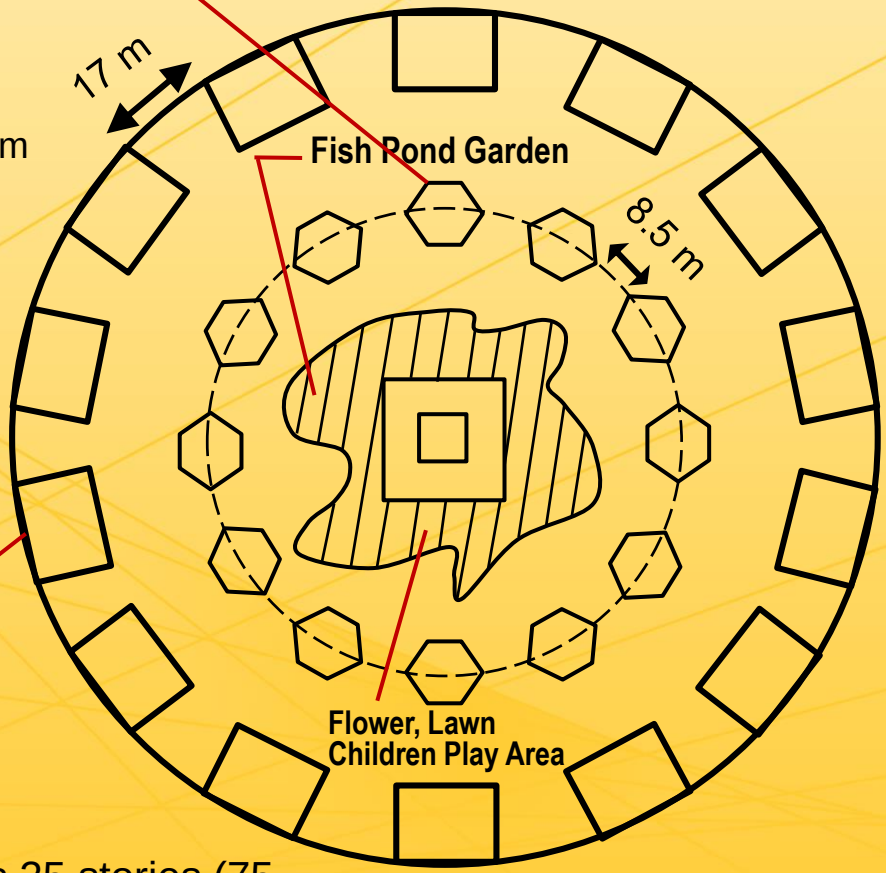
- To study $PM_{2.5}$ concentration profiles under real urban conditions.

AMSA Green Community





- There are 10 office buildings, each has 5 stories (20 m tall) and only 1 unit on a floor.

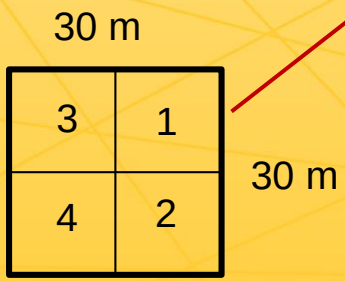


- Air exchange rate:

$$= \frac{control\ volume}{clean\ air\ \ flow\ rate}$$

$$= \frac{75\ m \times 300\ m \times 300\ m \times \pi / 4}{2000\ m^3 / \sec}$$

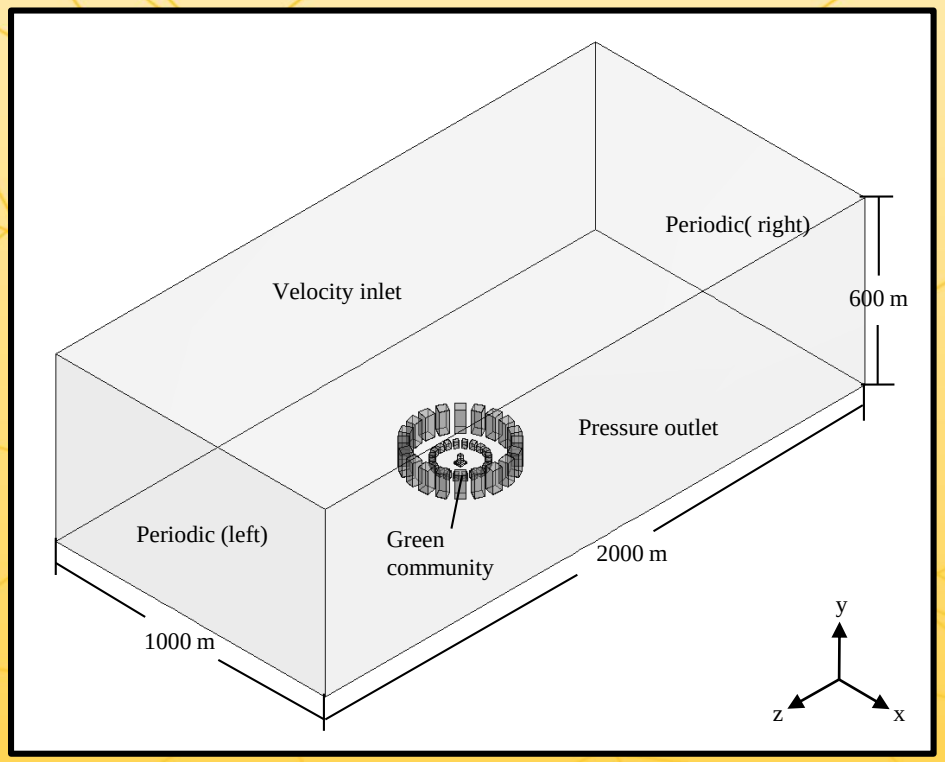
$$= 2650 \sec = 45 \min$$

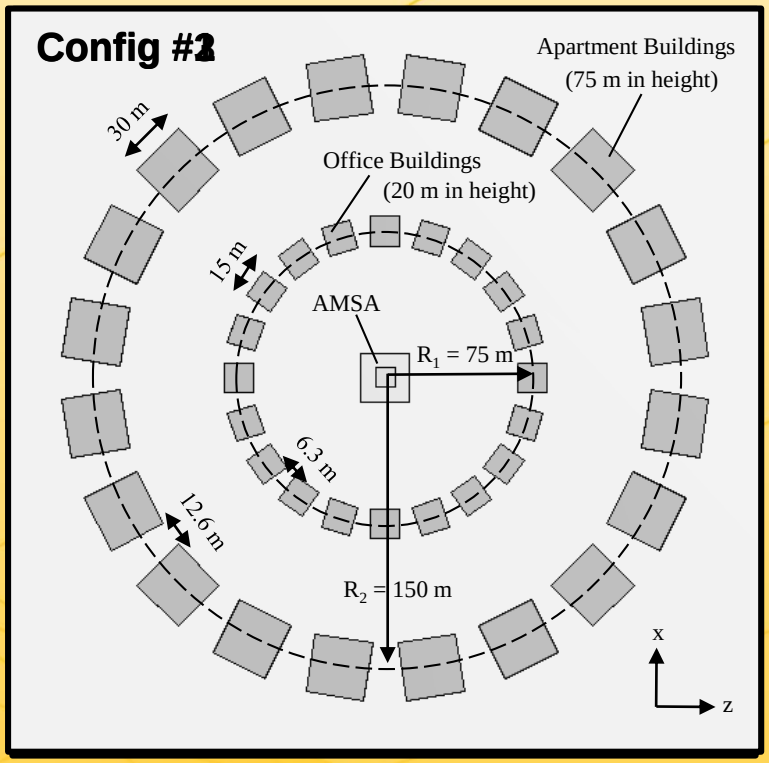


- There are 20 apartment buildings, each has 25 stories (75 m tall) and 4 units on a floor.
- Each unit has 225 m^2 area including public utilities.

AMSA inside a Green Community

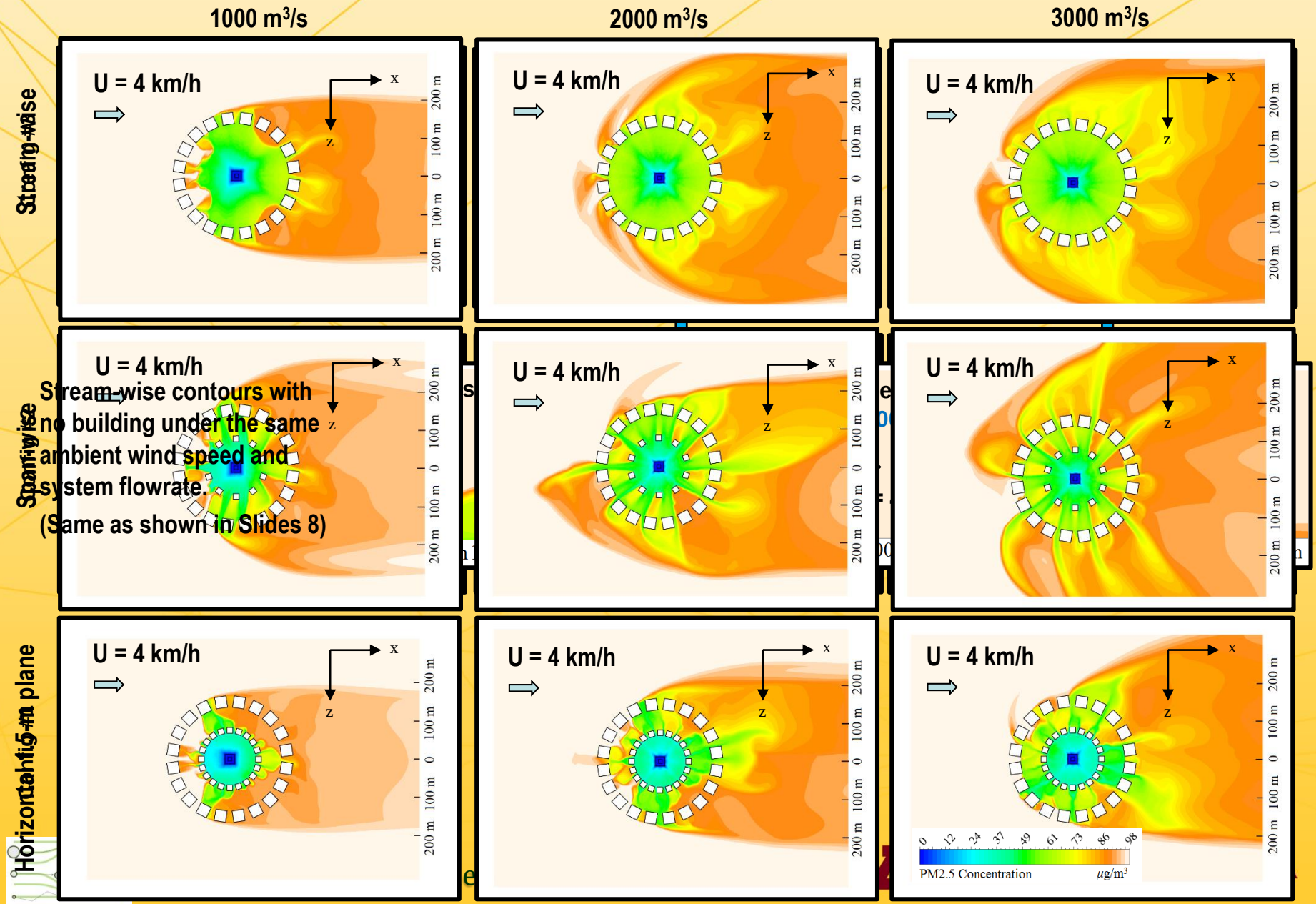
- Two circles of buildings are installed around AMSA.





- Three community configurations are tested.
  - ✓ Config #1: 20 inner-circle buildings;
  - ✓ Config #2: 10 inner-circle buildings;
  - ✓ Config #3: zero inner-circle buildings;

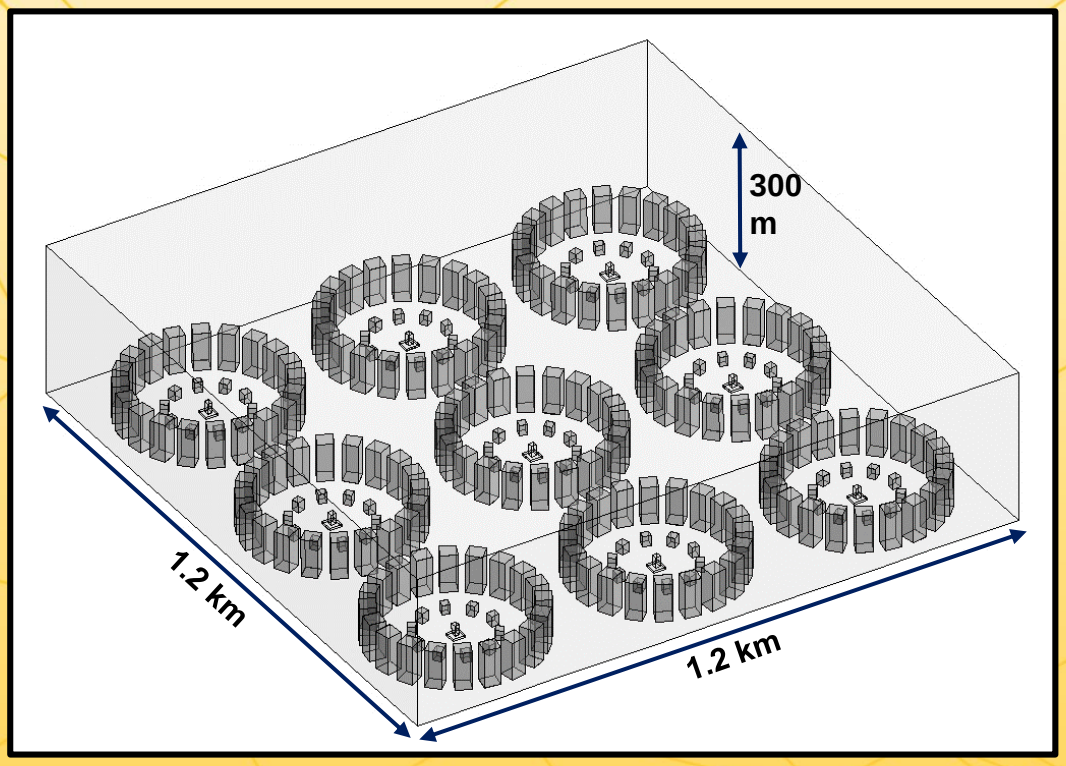
Contours of $PM_{2.5}$ Concentration: A Comparison



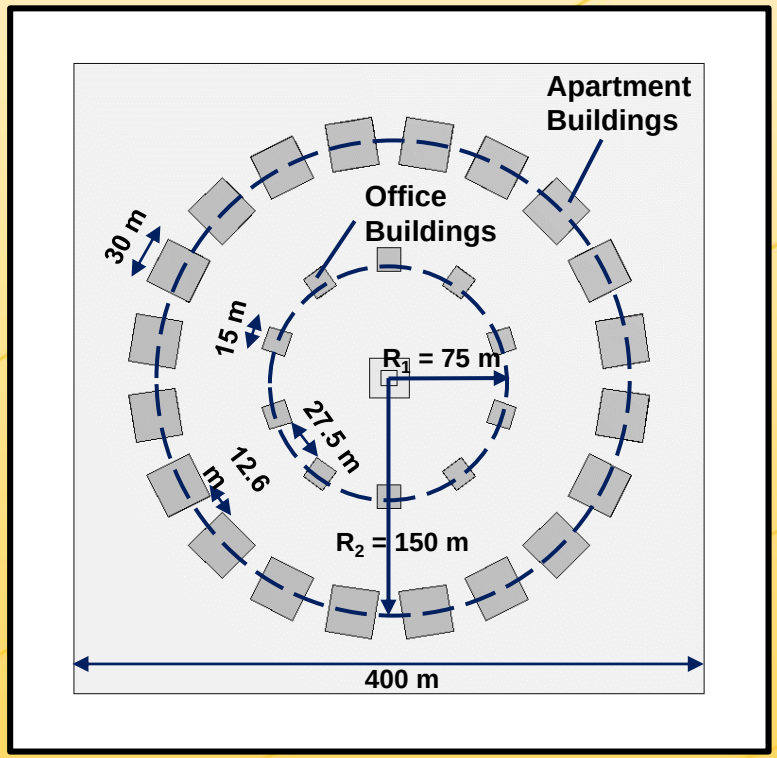
Stream-wise contours with no building under the same ambient wind speed and system flowrate.

(Same as shown in Slides 8)

Geometry and Dimensions



A cluster of AMSA green community



Computational domain

- The AMSA has a tower of 25 m in height. The tower has a dimension of 10 m.
- The base of the system has a horizontal dimension of 25 × 25 m^2 with a height of 4 m.
- The office and apartment buildings are 20 m and 75 m tall, respectively.
- There are 20 apartment buildings for each community. The number of office buildings will be 20, 10 or 0 in our simulation.
- By employing periodic boundary conditions at the horizontal boundaries of the computational domain, we can simulate the flow pattern for the green community which is among a cluster of many communities.

$PM_{2.5}$ Concentration Profile around A SALSCS/AMSA: A Numerical Study under Different Ambient Conditions

Thank You

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October 6th, 2017