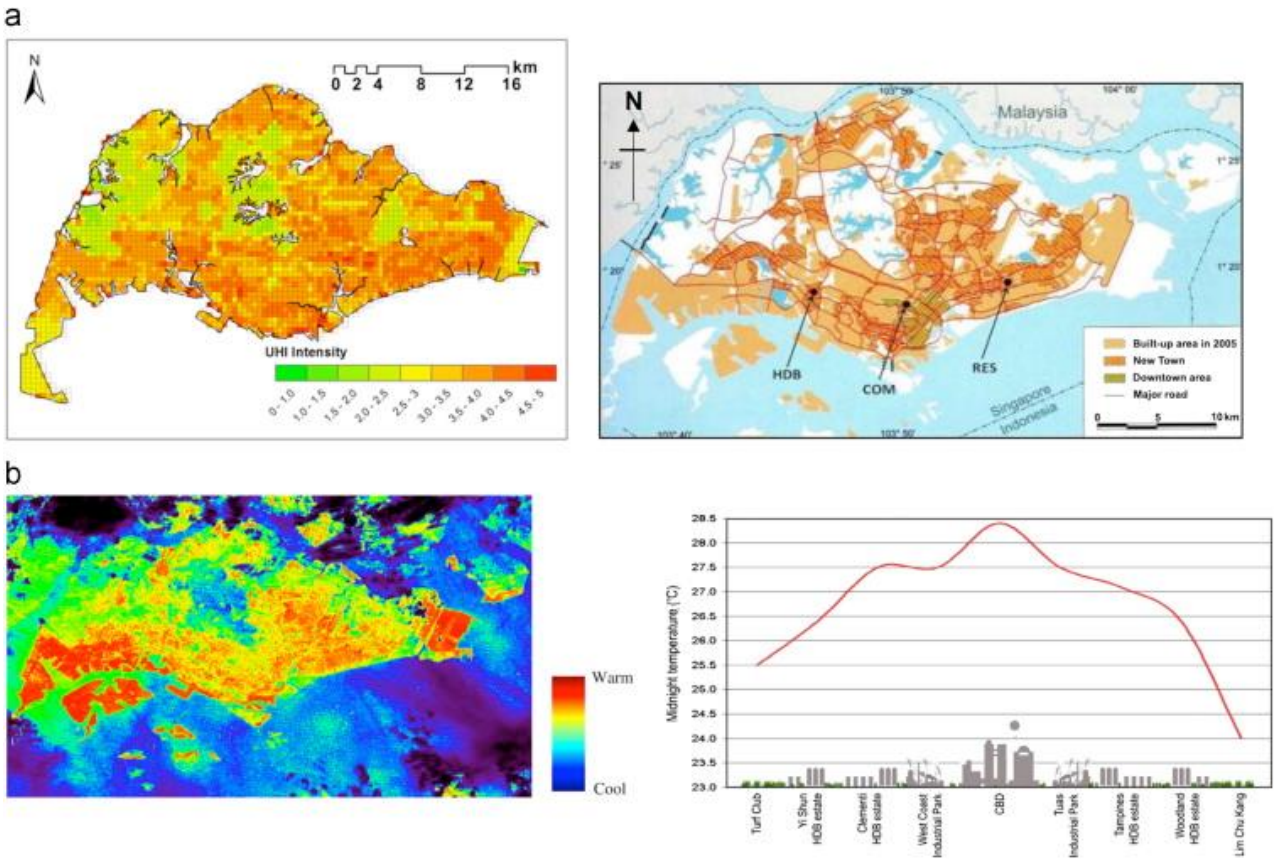
HPC for Urban Microclimate Simulations in Singapore

Lou Jing

Institute of High Performance Computing

Singapore UHI

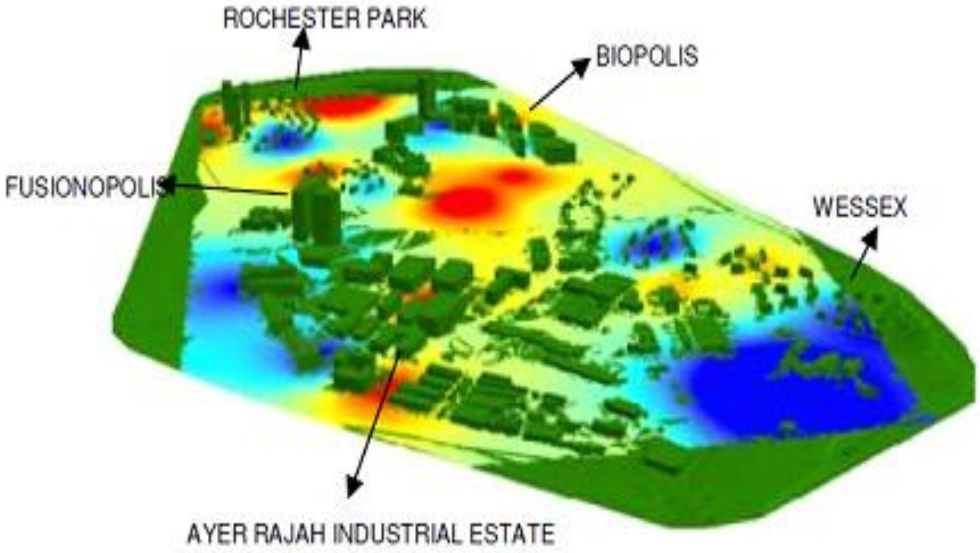
- Singapore UHI study in 2004 showed the UHI intensity between CBD and "rural" area was up to 4 degrees.

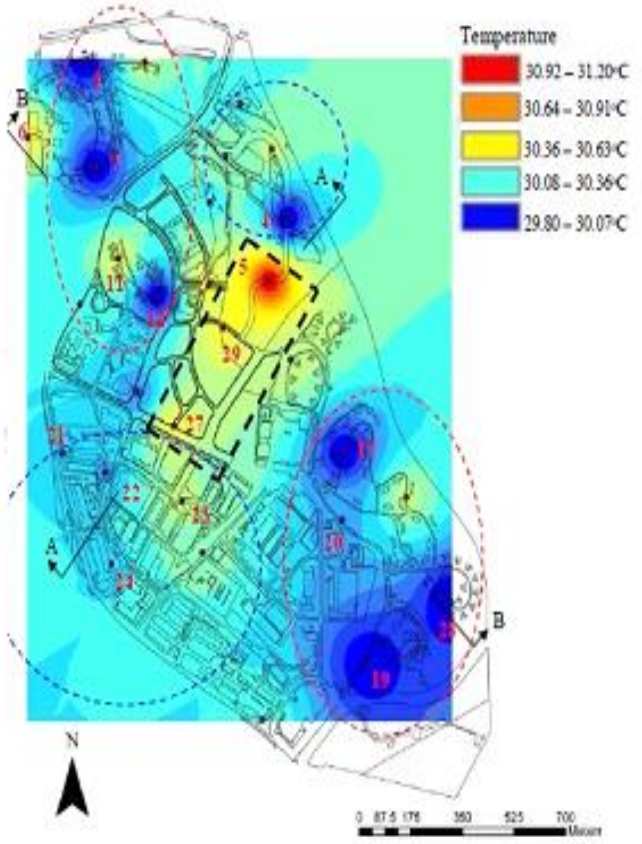


(a) UHI intensity map of Singapore (De Koninck et al., 2008)

(b) UHI profile of Singapore (Priyadarsini et al., 2008).

Singapore UHI: Impact of land usage



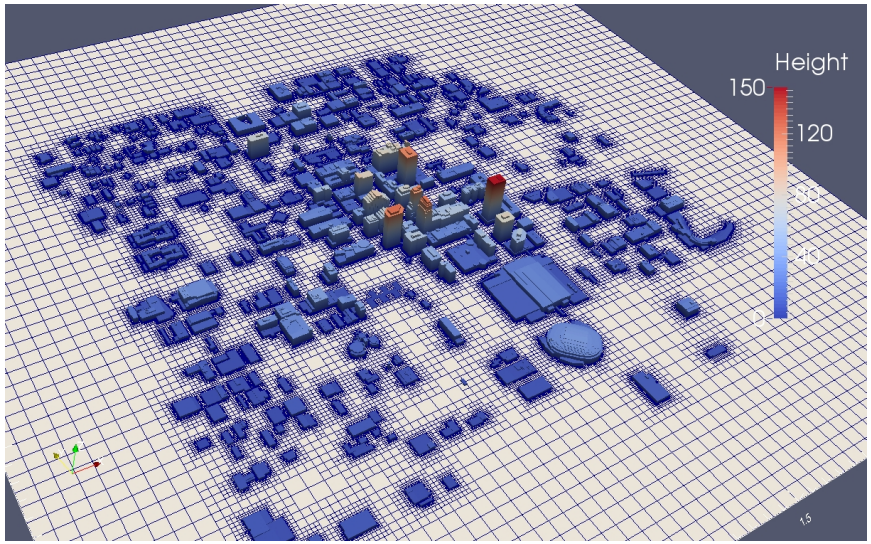


CFD + HPC: A New Research Tool

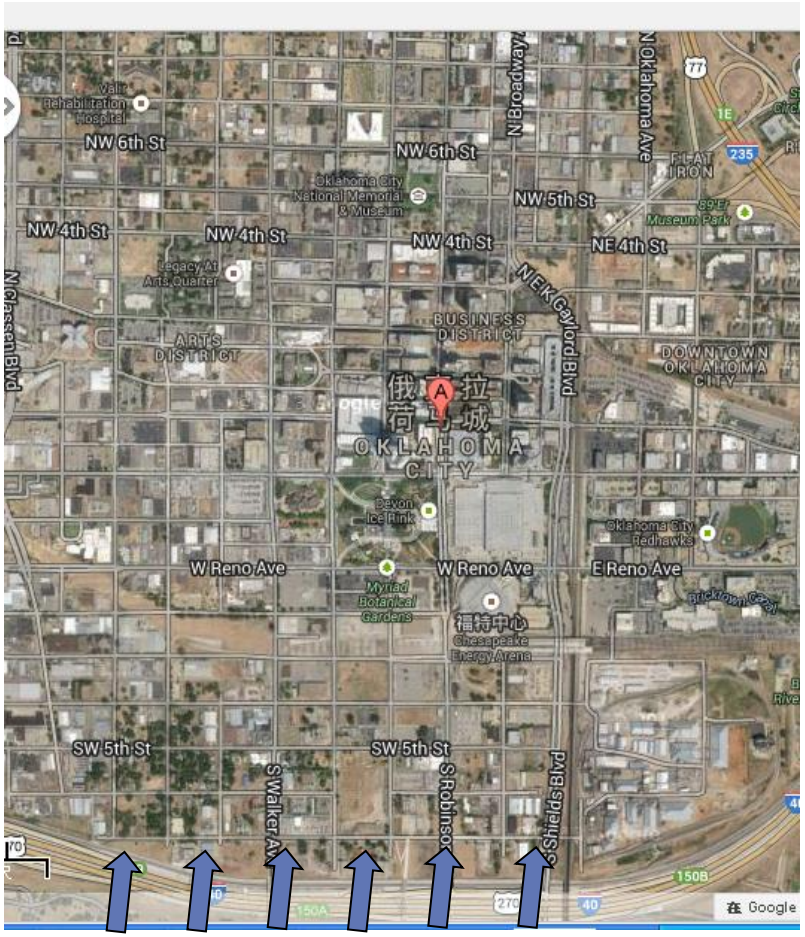
- **Climate modeling**
  - Large scale, atmospheric physics
  - Low resolution, simplified parameterization
- **CFD**
  - High resolution: resolve buildings, streets……
  - Fine results of wind & temperature
- **OpenFOAM**
  - Free & open source
  - Extendable
- **HPC**
  - Model optimization
  - Scalability

Validation– Joint Urban 2003 (Oklahoma City)

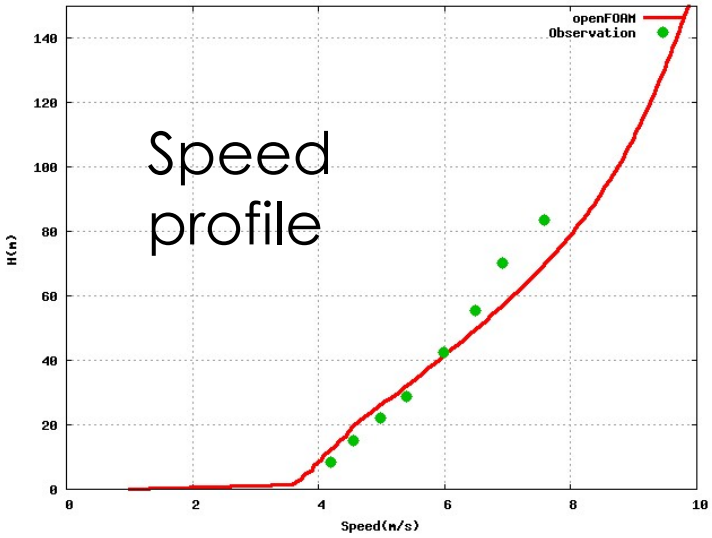
- **Area**: 2.5km*2.5km
- **Time**: 7 July 2003,11:00
- **Inlet BC**: WRF model
- **Mesh #:** 5 million
- **Resolution:** 1.25m - 41m

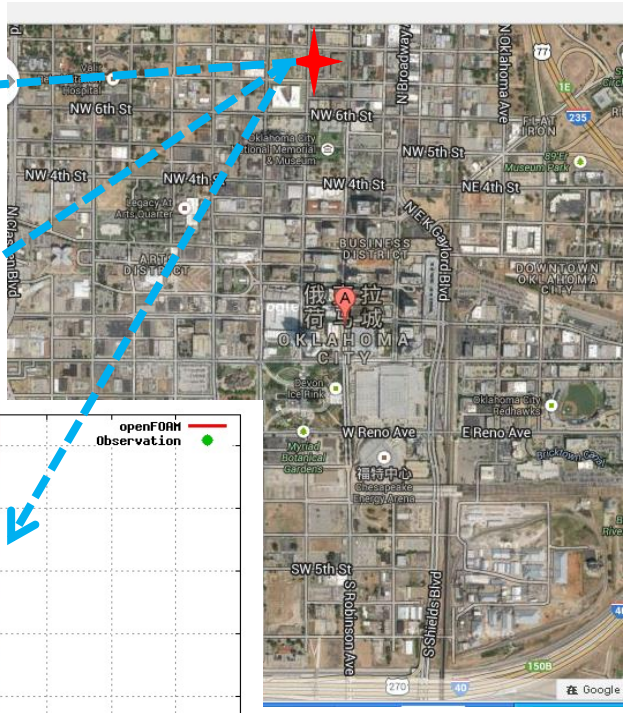


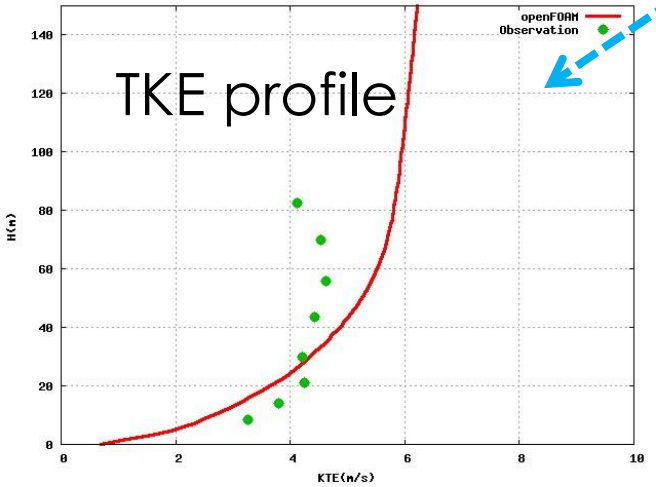
Simulation Domain

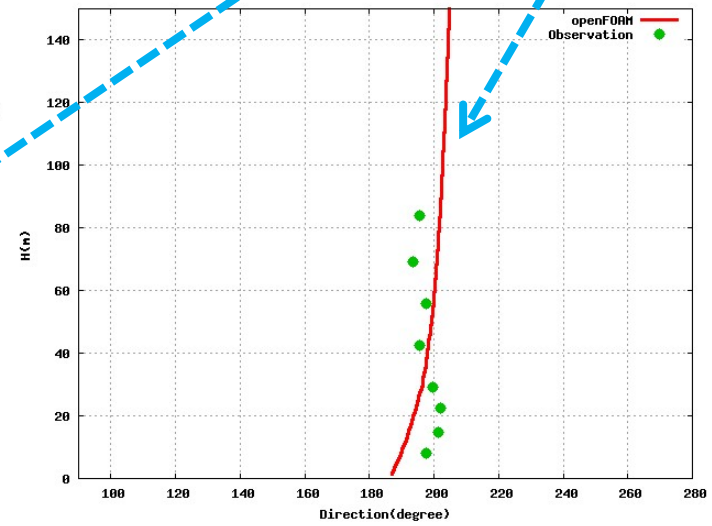


Calibration: model results vs observation



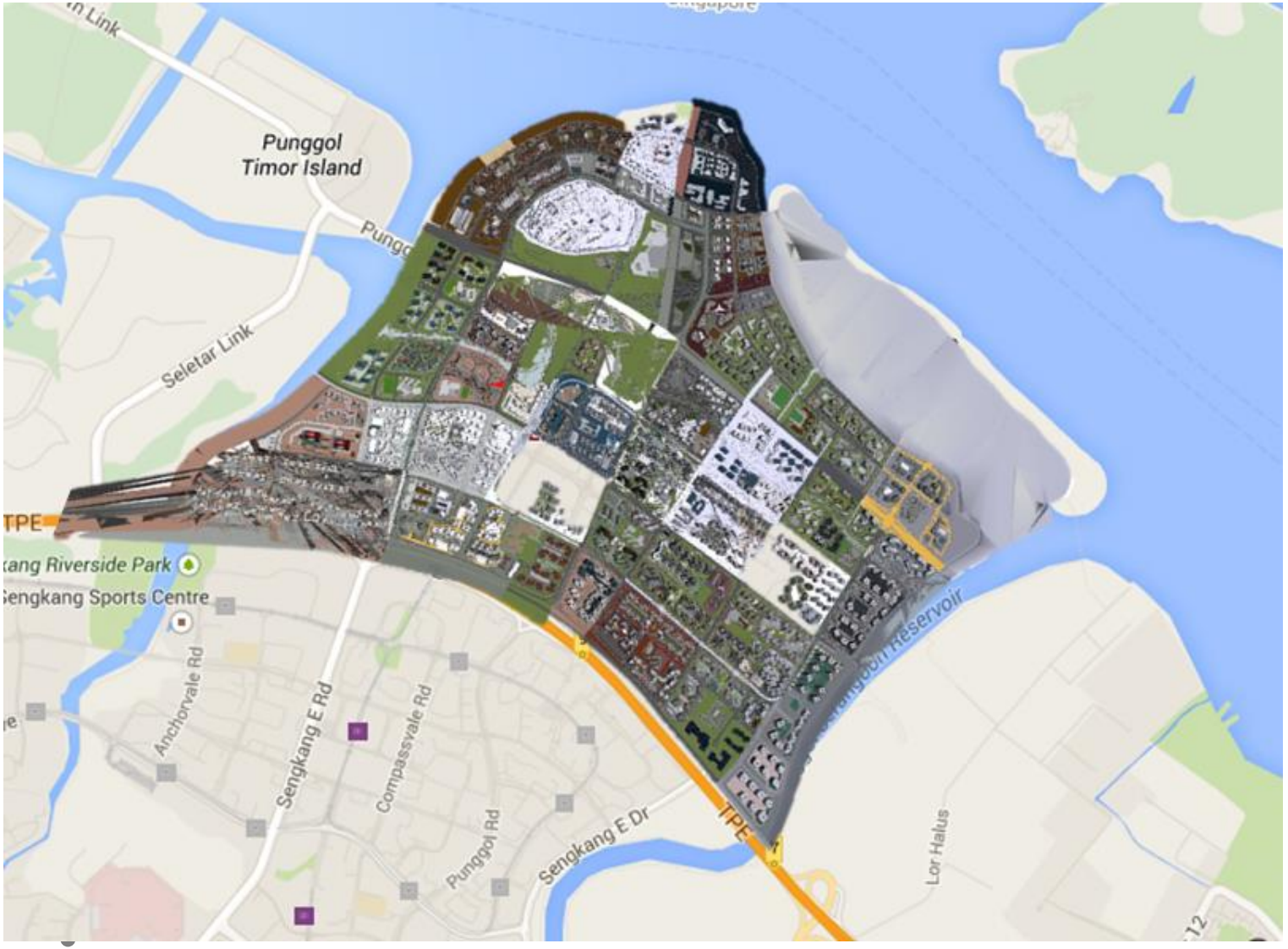






Direction profile

Punggol Town Study



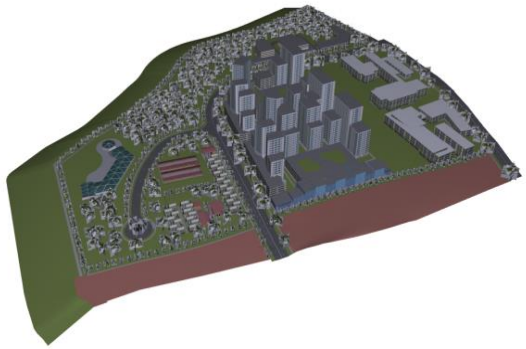
Town

District

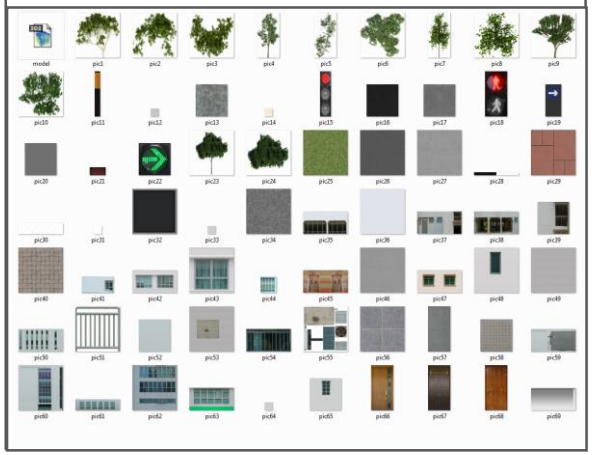
Precinct

Model Separation (materials)

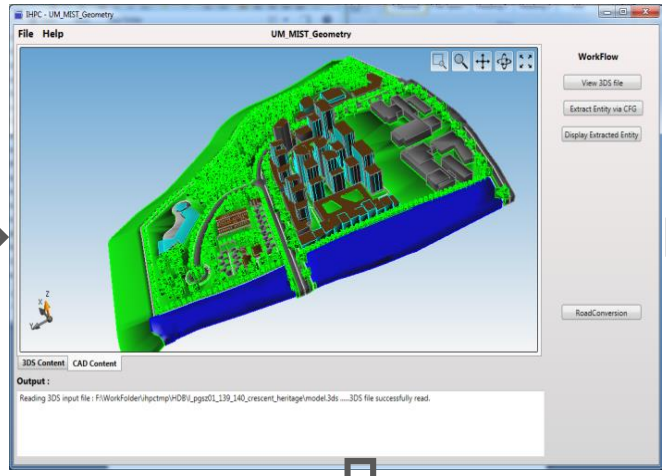
Geometry model in 3DS format (Precinct Model)



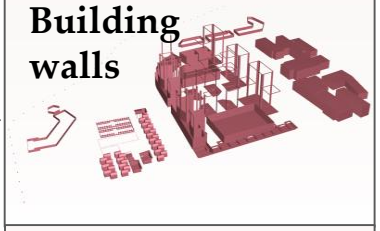
Sample textures



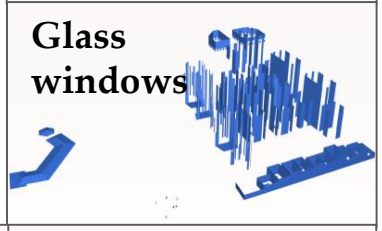
Geometry Tool



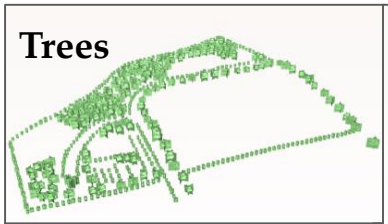
Building walls



Glass windows



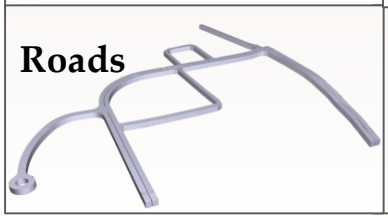
Trees



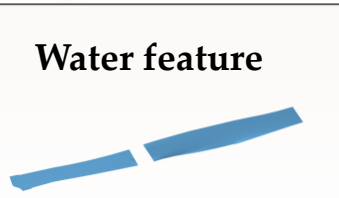
Grass

Roof

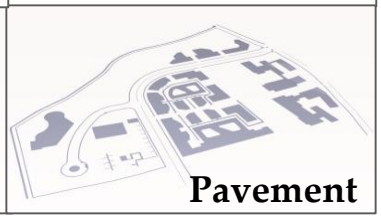
Roads



Water feature

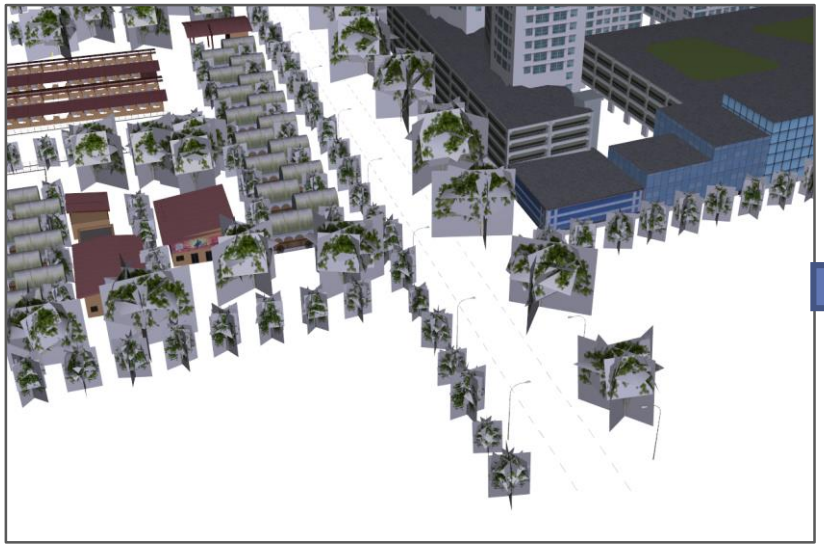


Pavement

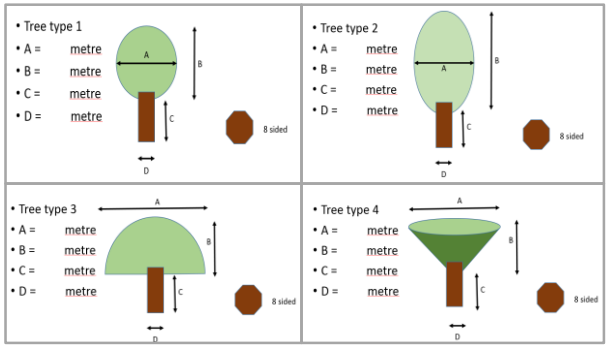


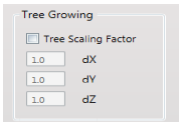
Tree Simplification

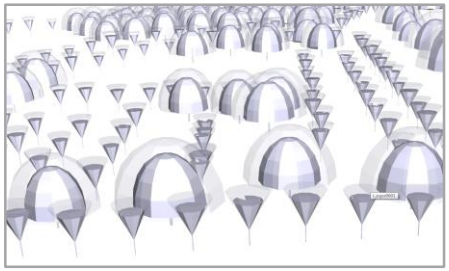
Input tree models – These are simple facets and are not suitable for simulations



Geometry tool converts “faceted” trees into 3D “closed” meshes, separating trunks and tree crowns.

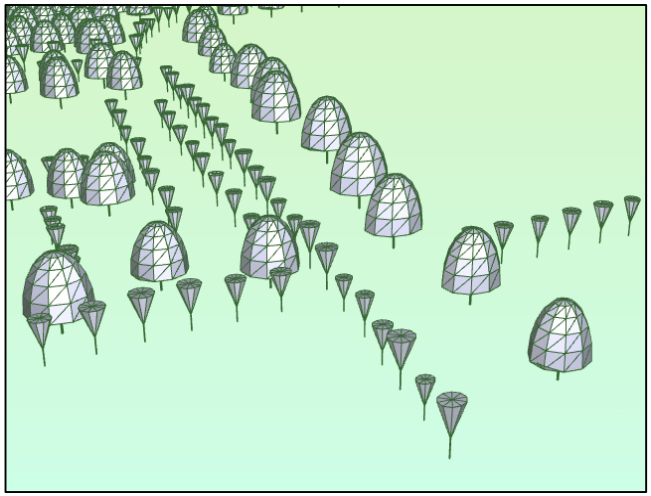




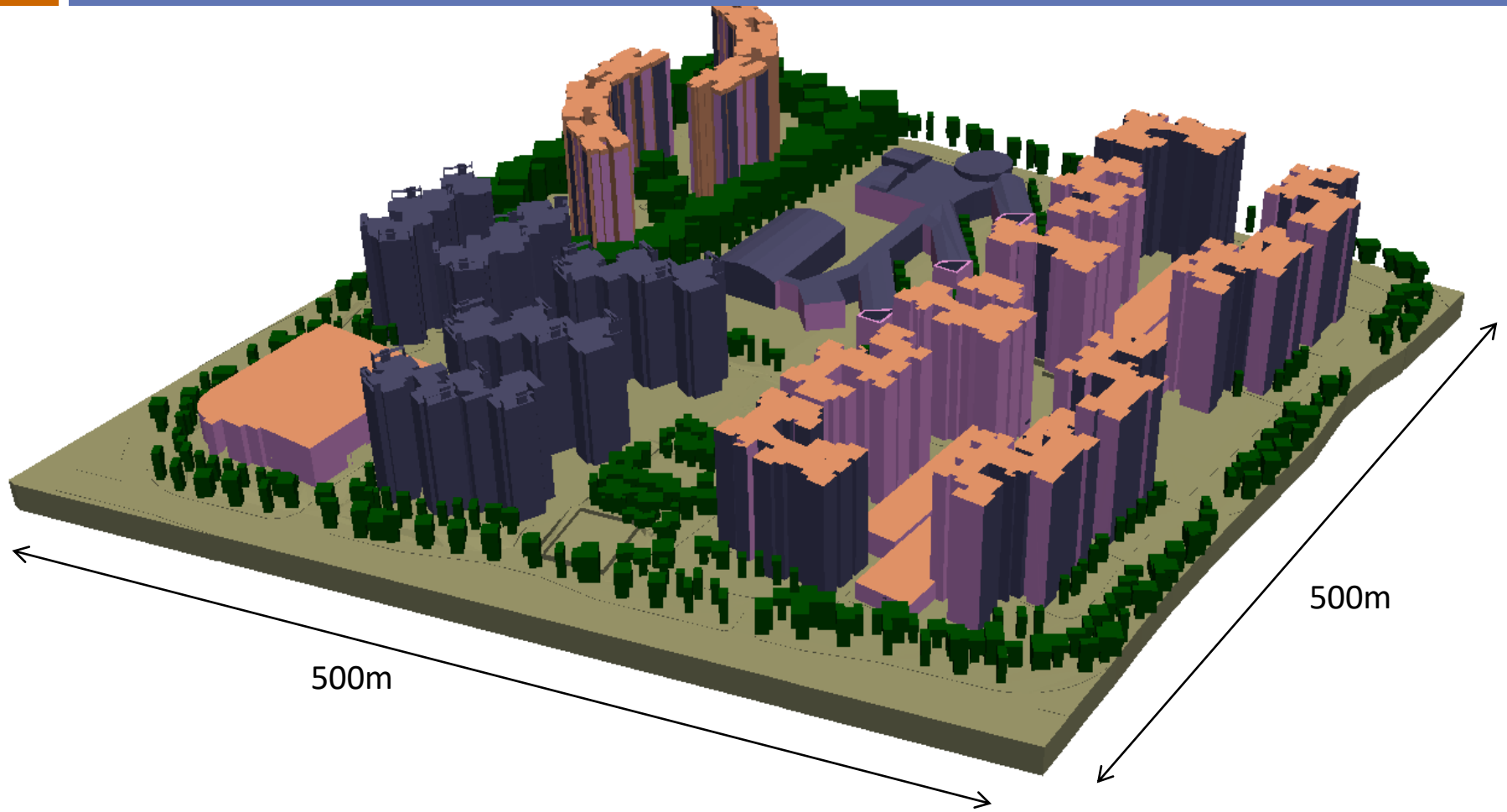


Tree “growing” template

Output Tree model



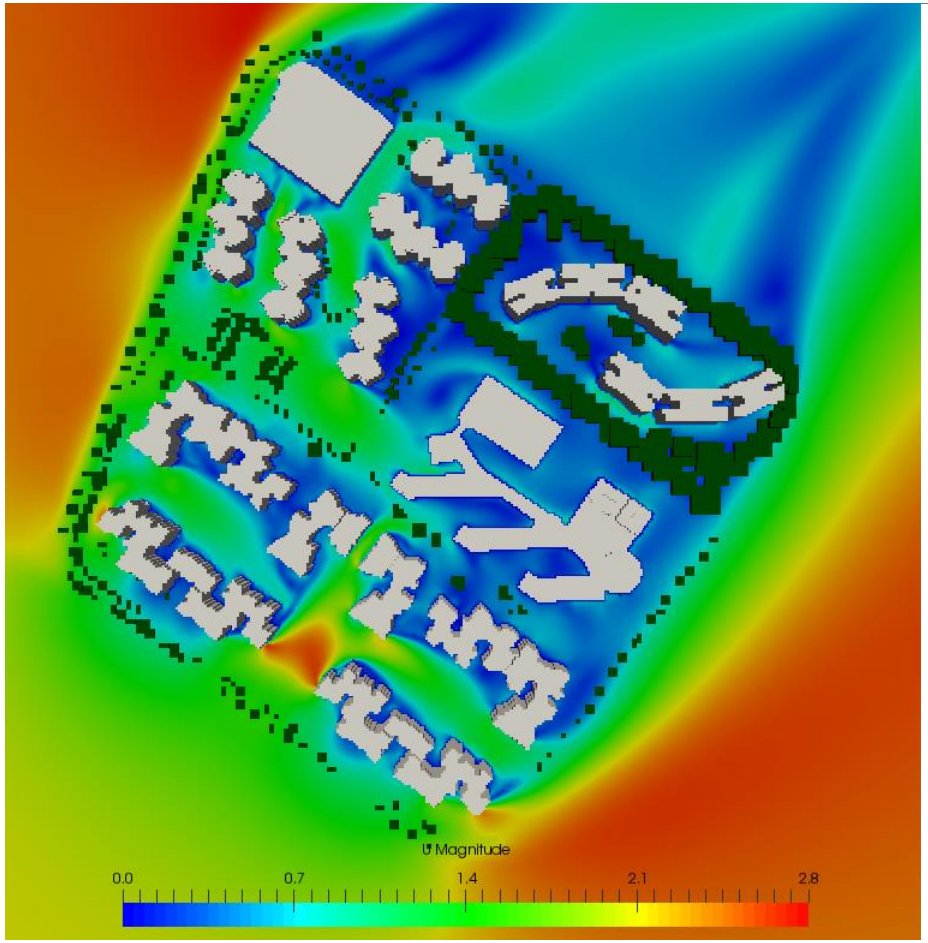
CFD simulation for Waterbay precinct



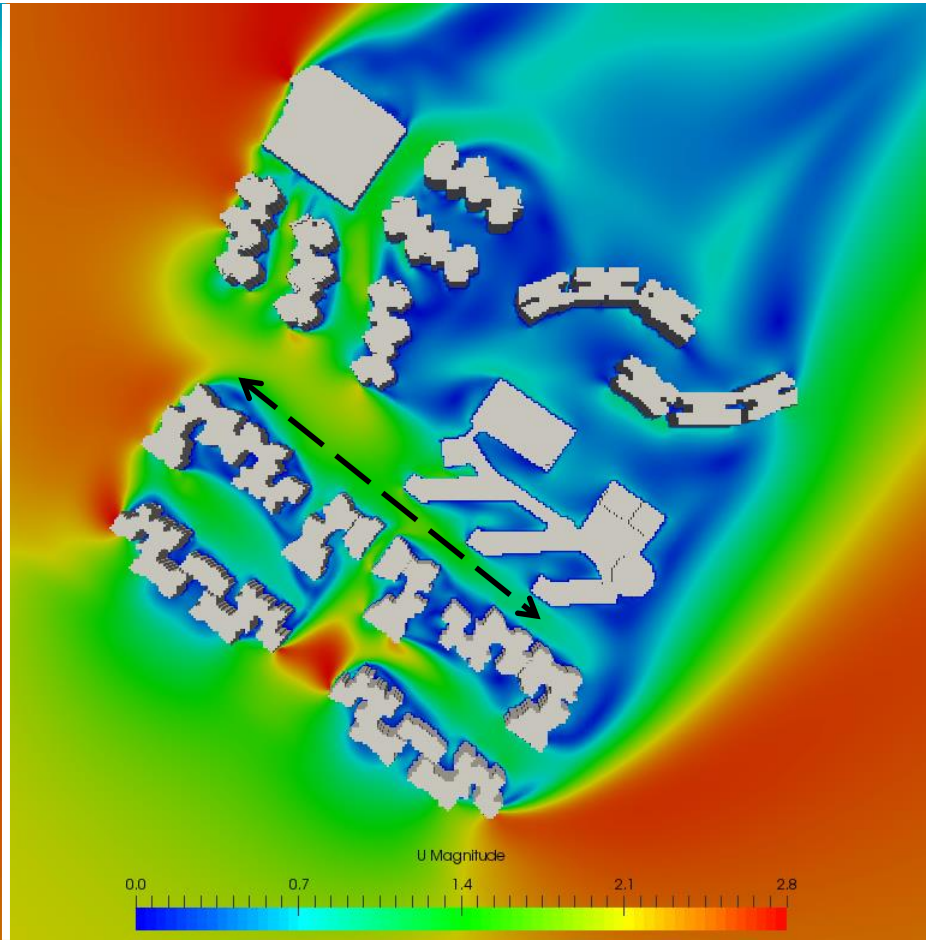
1. All textures i.e. grass, waterbody (a small swimming pool), road, pavement, road, window, roof and building walls are considered as wall surfaces.
2. The CFD domain size is 1840 m x 1840 m x 500 m (height)

CFD with solar coupling and trees – wind velocity at 15 m elevation

With trees



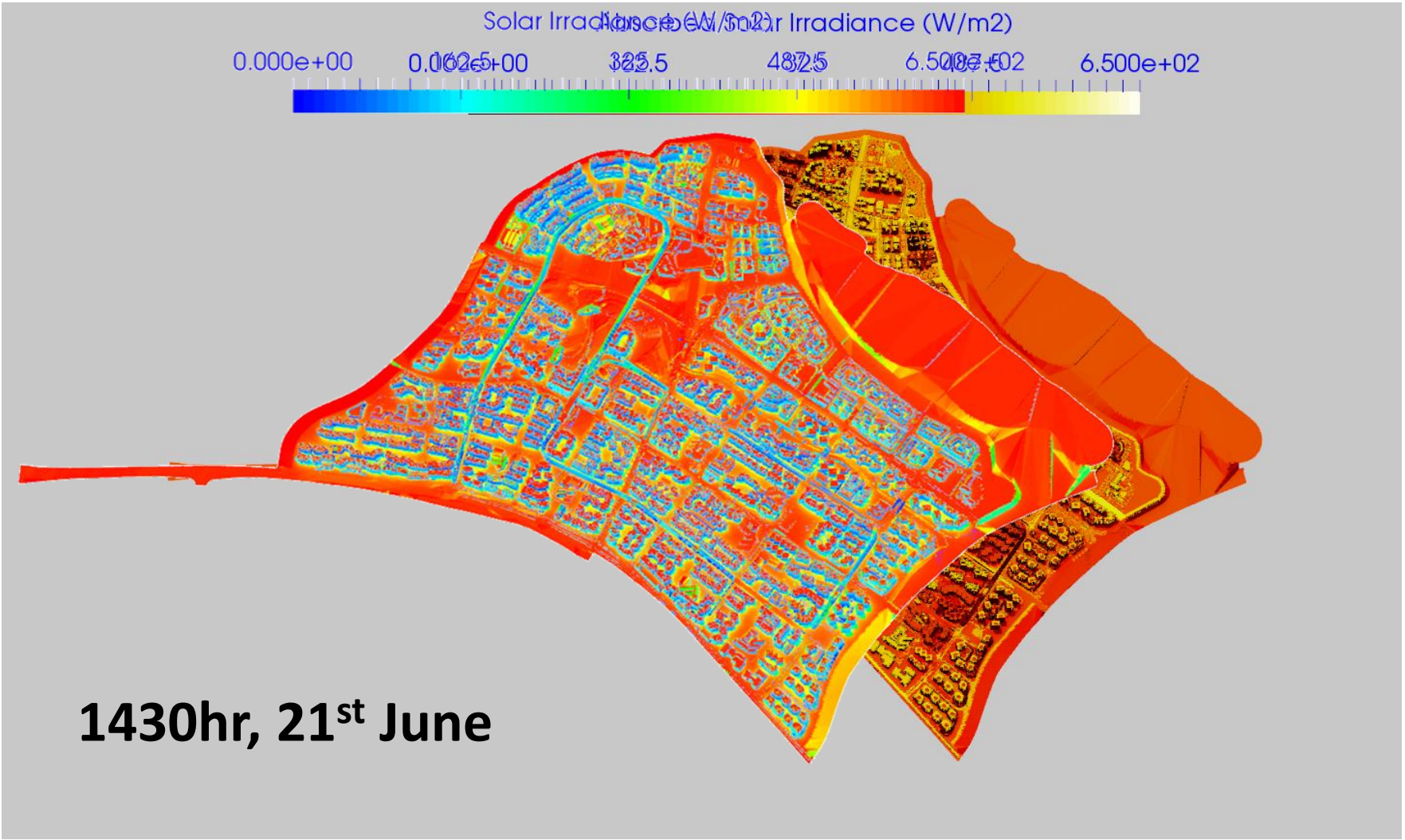
No trees



- Trees are modelled as cuboids with constant leaf area density.
- Only the aerodynamic effects of trees are considered.

➢ *As a result, notable alteration in wind speed can be observed at a few locations.*

Solar Irradiance / Absorption for Punggol Town



Noise With/Without meteorological effects

Simulation flow

Large eddy simulations by OpenFOAM

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Atmospheric flow simulation

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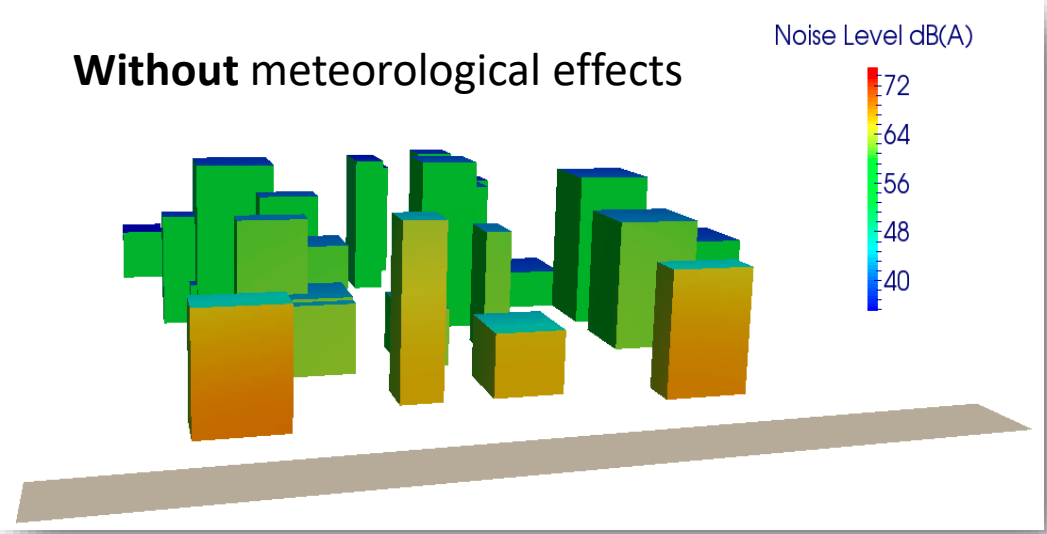
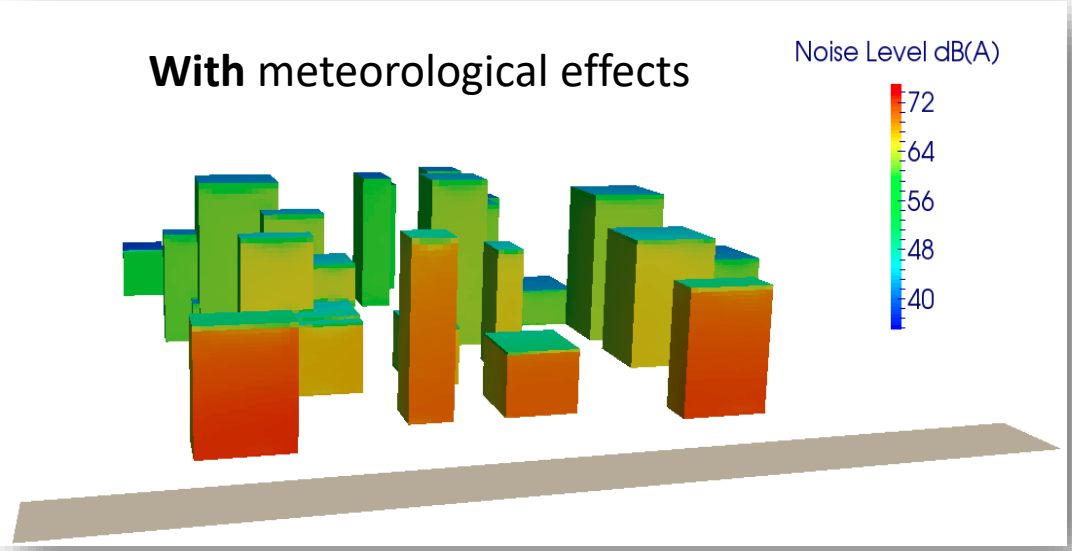
Time-averaged values of meteorological parameters
including wind speed, wind shear, and lapse rate at the noise modeling observation points

↓

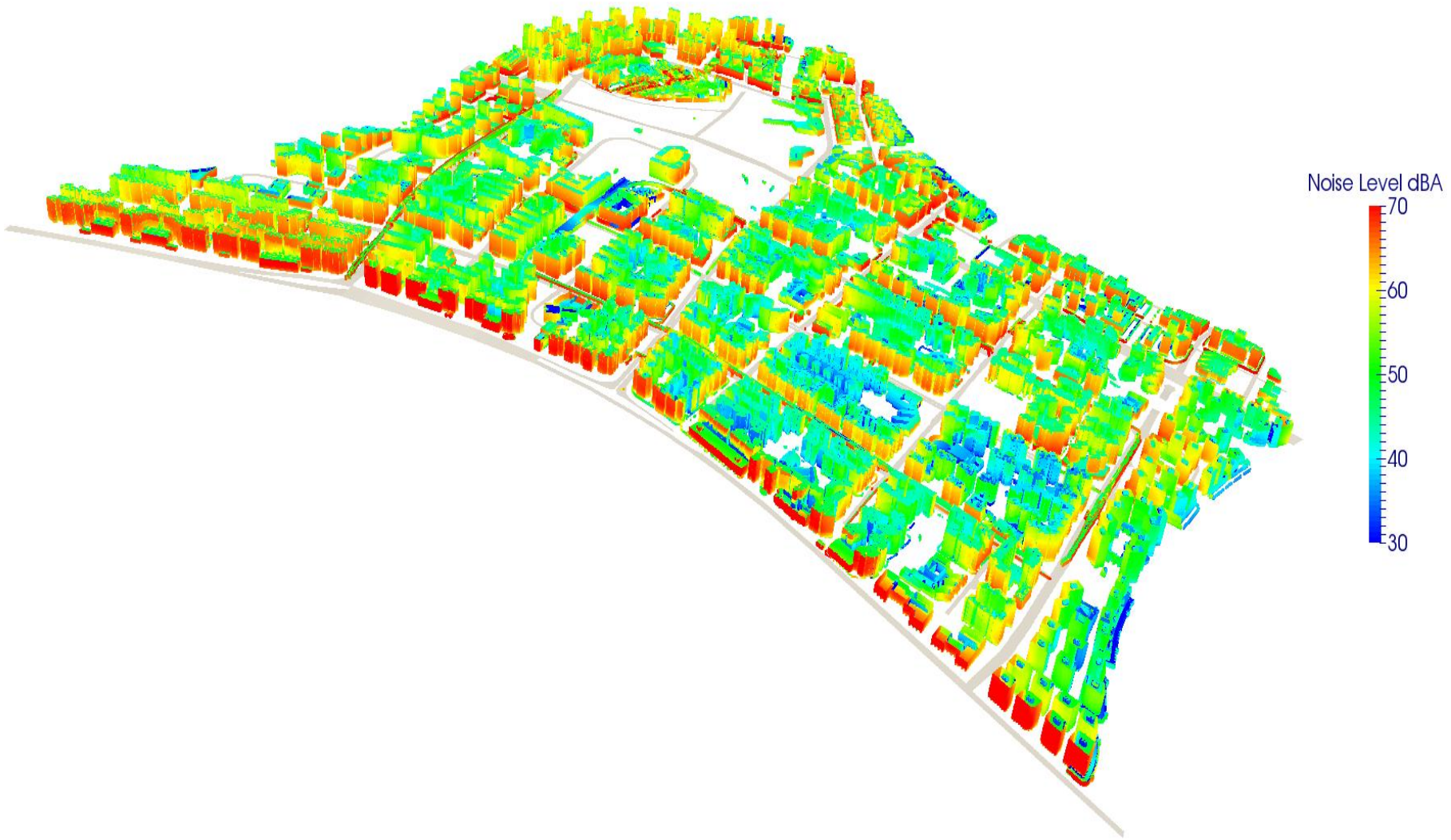
Noise Model
CRTN plus the atmospheric refraction model



Peak noise value different about 3-4 dB



Noise mapping of Punggol town



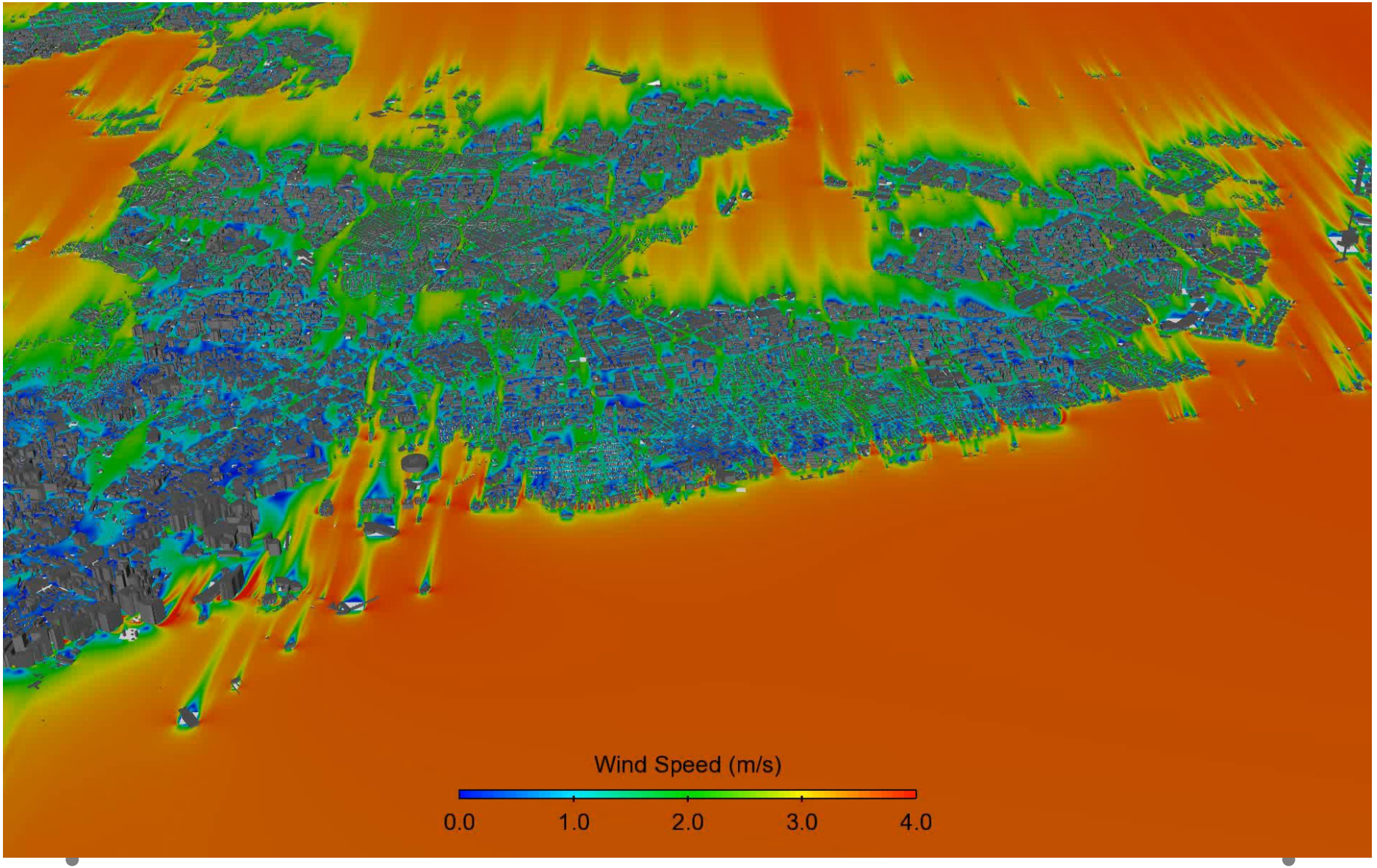
Islandwide Questions

- Which areas are most windy in Singapore and why?
- Which areas are suitable for creating new townships or what areas are to be modified?

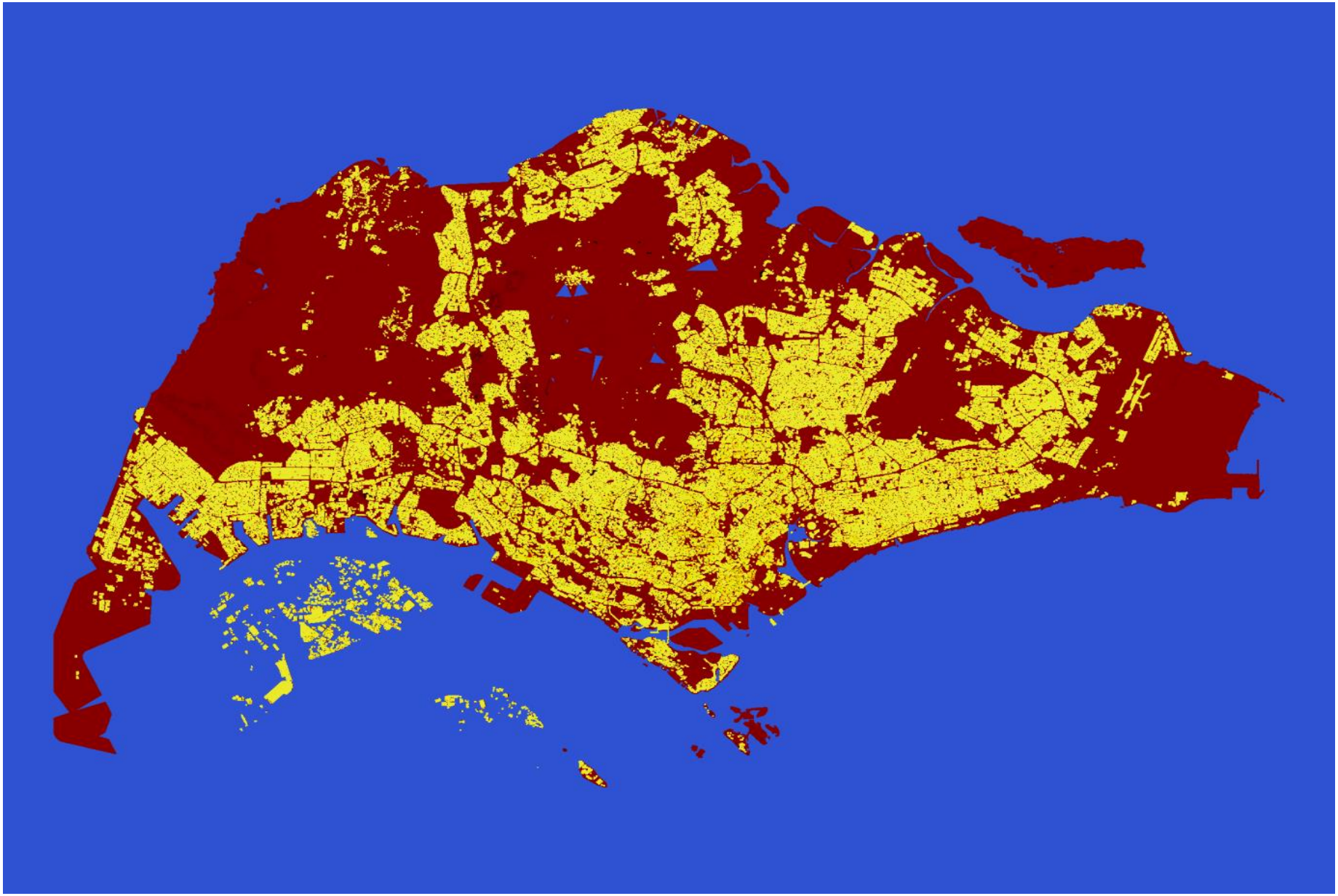
- A 'global' perspective of wind distribution across whole island can address above topics, but are computationally very expensive.

- How much computational resources are actually required and for how long to obtain high resolution wind flow over Singapore?

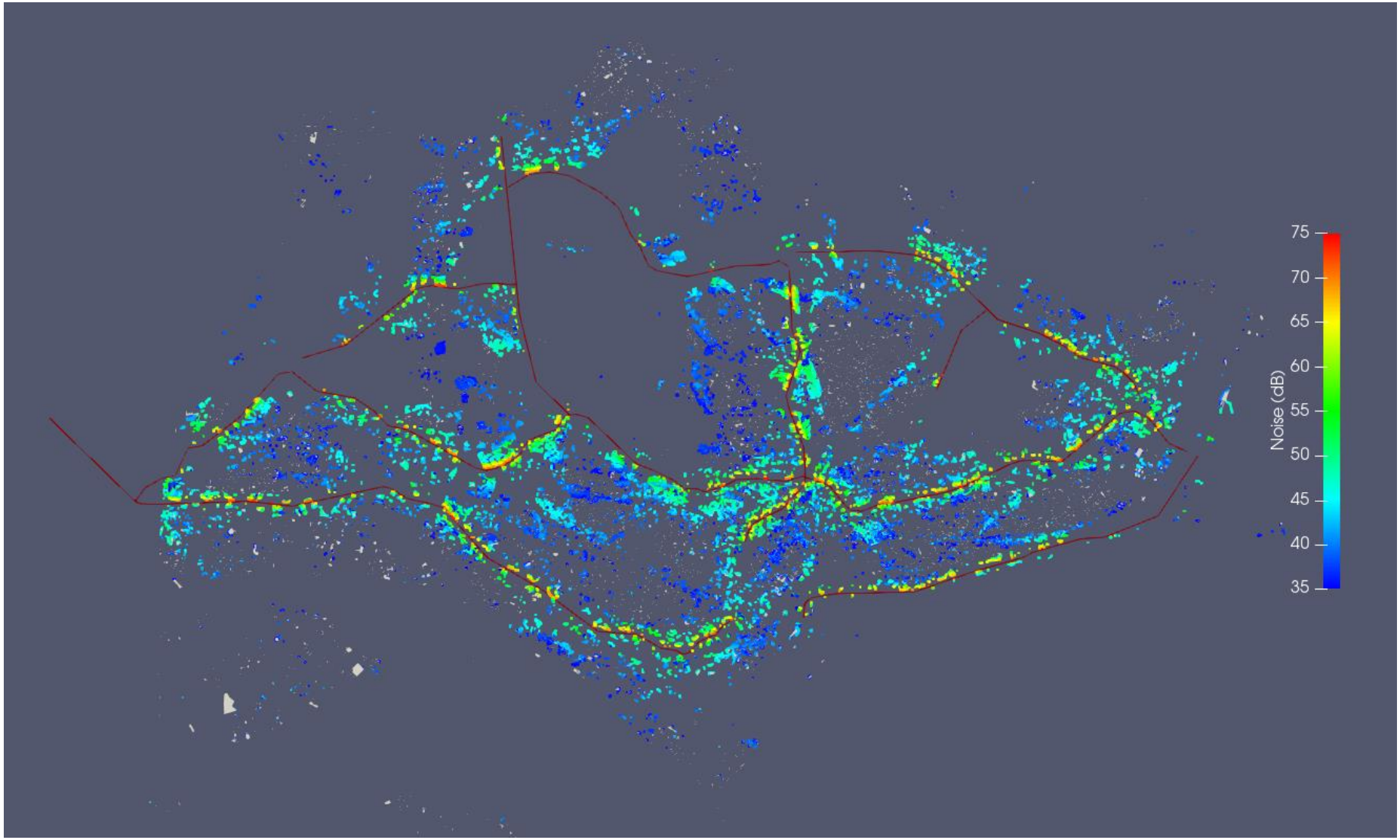
Whole Island Airflow Simulation



Solar Simulation for Whole of Singapore



Noise Simulation for Whole of Singapore



Using above ground expressways and 5 m resolution for building surfaces

How Aspire 1 support project's objectives

- The total mesh count for whole island CFD approaches 1 billion.
- The background mesh requires a 'large memory' node of more than 1 TB and the simulations on 6000 cores required approximately five days to complete.

✓ Only with Aspire 1, it has been possible to accomplish such a large-scale CFD simulation for the first time in Singapore within a week's time.

✓ This success study demonstrates the scalability of OpenFOAM for urban simulations and opens up possibilities of conducting many such large scale computations by other researchers and agencies.

Benefits of using Aspire 1

- ✓ High resolution, large scale CFD simulations demand very intensive computational resources.
- ✓ With latest ASPIRE resources at NSCC and continuous support from NSCC researchers, the 'urban wind flow' simulations have been successfully conducted for whole Singapore.
- ✓ This opens up the possibilities of extending such island-wide simulations to temperature mapping, greenery effect and land usage optimization that are useful for relevant organizations and agencies.

Future Study

- ✓ Consider land usage input
- ✓ Couple solar irradiance for temperature mapping
- ✓ Transient analysis
- ✓ LES model for wind flow
- ✓ Towards urban microclimate forecast (~ 100x of the current fastest HPC)

Acknowledgement

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Stephen Wong