2018 Winter Conference ★ Chicago, IL

SMNR 27:
Urban-Scale Energy Modeling,
Part 7

Sources of Errors in the Physical and Computational Modeling of Wind in the Urban Realm

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Session Learning Objectives

1. Provide an overview on "Array of Things" and microclimate in urban environment
2. Understand the differences between measured micro environment data versus predicted by ASHRAE formula
3. Describe how failure to understand local climate can lead to errors in physical and computational modeling
4. Learn when CFD and Wind Tunnel is more useful, and possibly appropriate, than the other

Acknowledgements/Credits

I have the privilege of working with some particularly intelligent people at “my firm” on very interesting projects for inspired clients.

The information presented here is the result of a collaborative effort of many people.

Outline

Types of wind issues we assess

Rationale for testing winds in Urban Realm

Presentation of work with City of London

- Compares WTT and CFD for pedestrian wind

Outline

We will be talking CFD and WT only.

Water-flumes (aka water tunnels) will not be discussed.

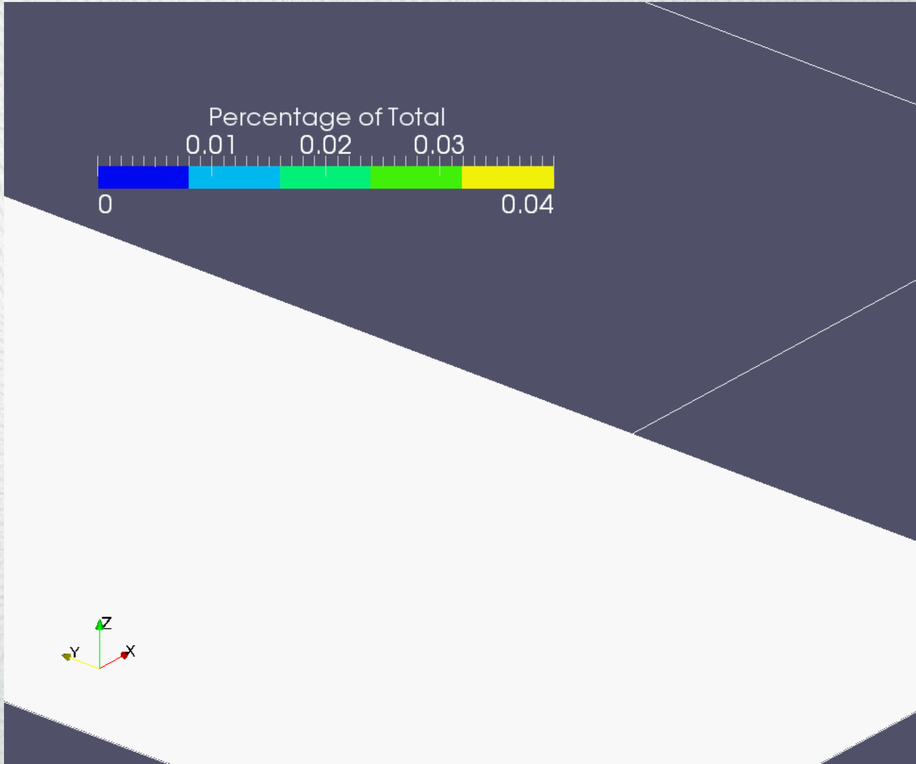
Why do we Model Wind?

What are the Issues?

Different Reasons to Model Wind

Whether done using physical or computational methods we assess wind for:

- Pedestrian level winds (PLW)
- Structural and cladding wind loads
- Pollutant dispersion
- Snow & sand drifting
- Rain infiltration
- Natural ventilation
- Construction safety and operational issues
- Entertainment (e.g. outdoor sporting /cultural events)
- Movie shoots



Rain Impact / Penetration on Building

Some Unusual Outdoor Simulation Work

There are pieces of physics that cannot be modeled in the wind tunnel

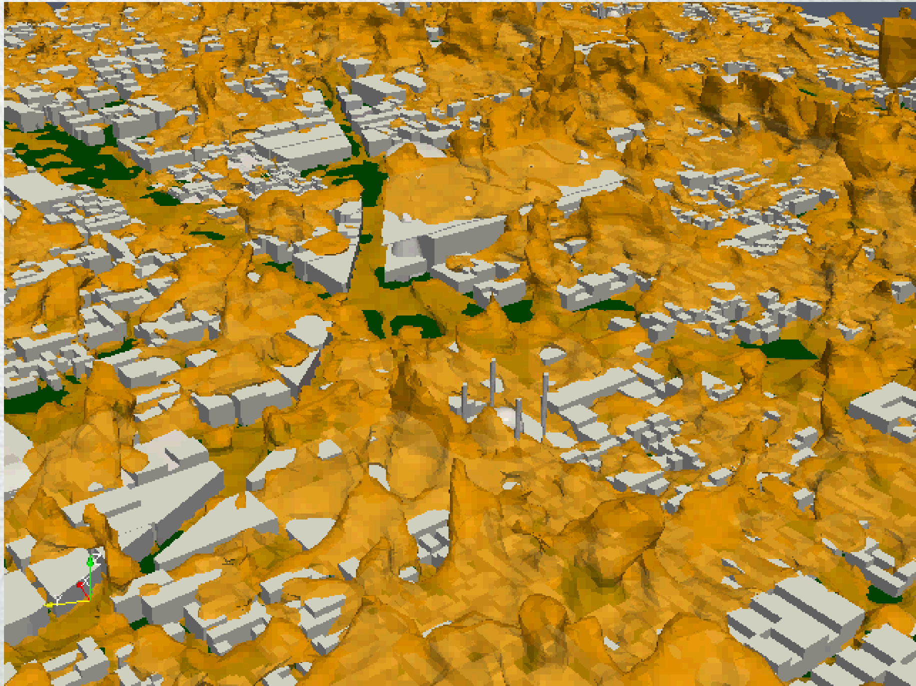
- Modelling wind flow over train tracks to assess sand deposition
- Problems involving heat transfer
- Modeling the movement of a high speed train and its impact on people standing nearby
- Particle trajectories where the particles have a different density to air
- Baseball trajectories vs. wind

High-Speed Train Passing Through Station

Wind Study Parameters

Study disciplines for wind tunnel modeling

What are we After	What Parameters do we Need
Wind Loads	Pressure distribution – positive and negative peaks
Wind Serviceability	Wind driven forces & moments – time series
Pollutant Dispersion	Concentrations – time series
Pedestrian Level Winds	Wind speeds at locations of interest – including gusts

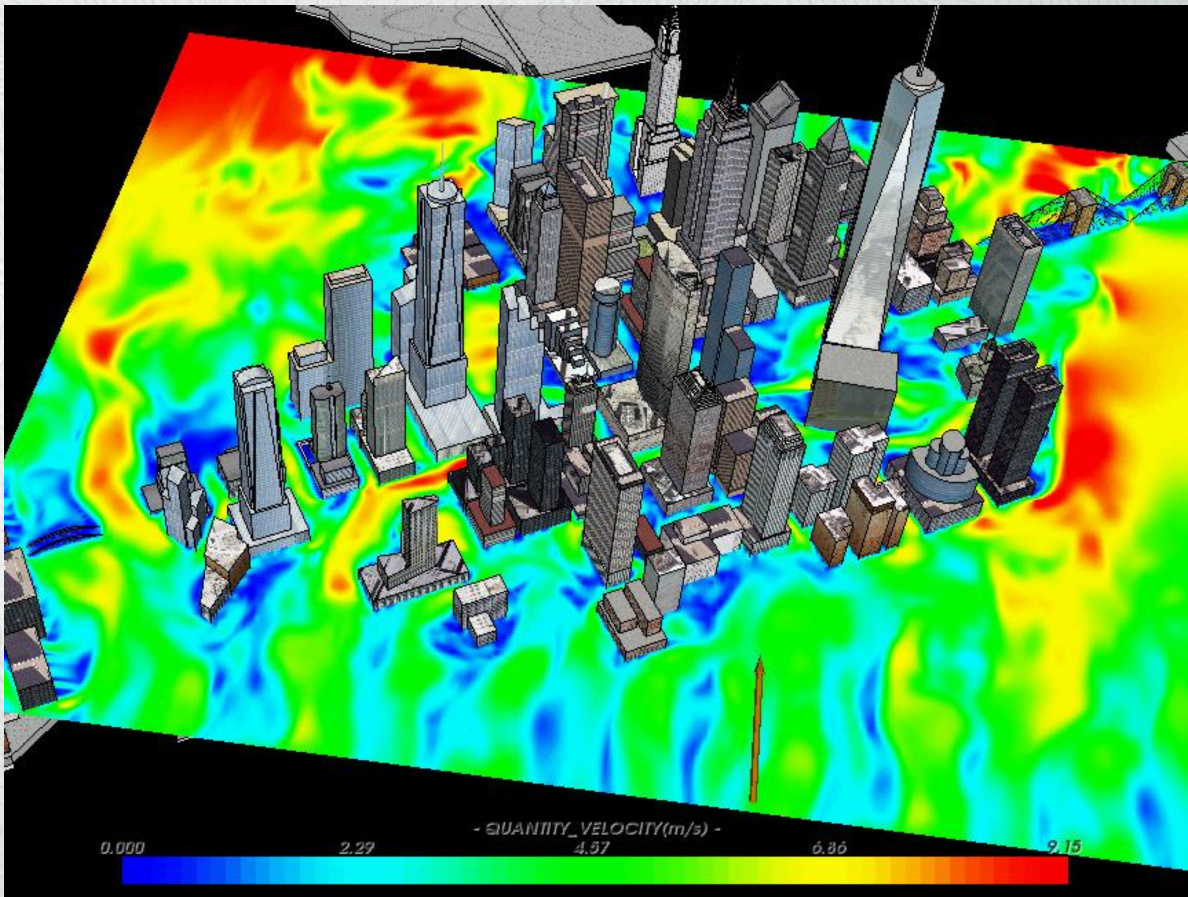


Heat Plumes Being Released from City

Wind Structure

This animation shows the dynamic nature of wind flow.

Any building under consideration could be behind other buildings

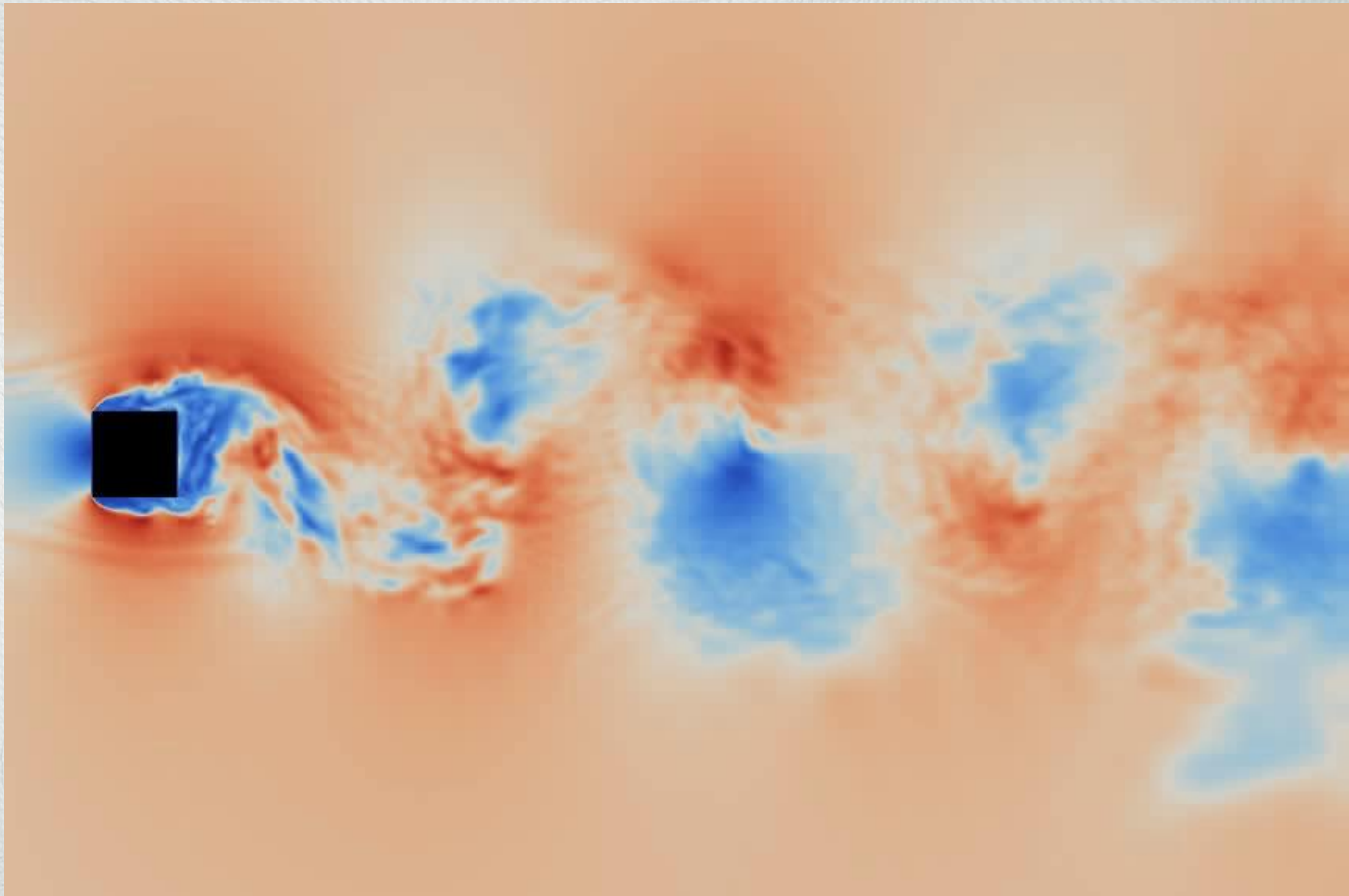


Wind Speed Around Buildings in City

Wind Structure Behind a Building

This flow separation behavior is what we would expect from this shape.

The frequency that the vortices separate is described by the Strouhal Number.



Wind Speed Contours Showing Vortex Shedding

What is Really Great About CFD

It can be used to model many different pieces of physics that wind tunnels cannot do

It permits one to diagnose the flow field anywhere within the domain

There is a perception it is less expensive and quicker than wind tunnel testing – we will speak to this later

CFD is available to anyone with a decent computer and some software is free

…. Oh, and the graphics are cool

What are the Issues with Using CFD

CFD modeling has a hard time with the flow separation and eddies

If we cannot get the separation right, then we won’t get the pressure distribution right

The eddies are responsible for the fluctuations and that lead to extreme values.

The dispersion present in the turbulent eddies makes contaminant concentrations very difficult to get right

…. Oh, and wind flow is always transient with eddies

Why to we Assess Pedestrian Level Winds?

Urban Environments are Important

Increasing desire to create high quality external spaces …

Need to create safe spaces around buildings …

Why do we Model Pedestrian Level Wind (PLW)?

Edward Slaney died when a vehicle toppled over in Leeds adjacent to Bridgewater Place, Leeds


Image Credit: BBC News

Many Jurisdictions Across the Planet Require a PLW Test as Part of the Planning Process

The challenge is what is the correct tool to use – easy access to CFD means many firms without wind tunnels are using CFD.

Firms with wind tunnels also using CFD.

Canada

- Calgary
- Edmonton
- Montreal
- Toronto

USA

- Boston
- Denver
- San Francisco
- Oakland

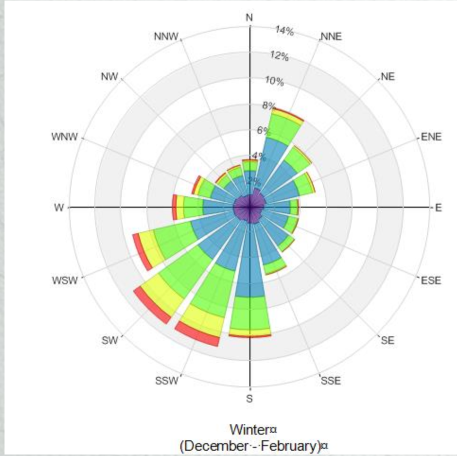
Smaller Cities

- Burlington
- Ottawa
- Waterloo

World

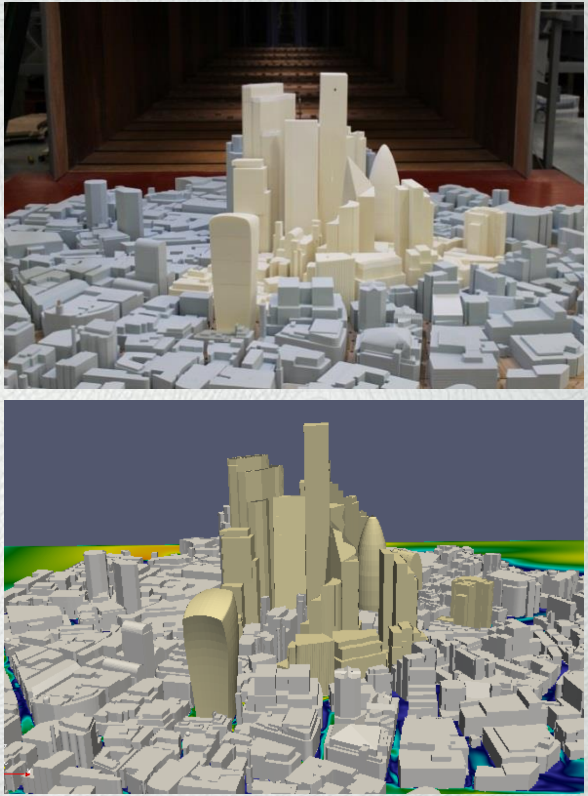
- London
- Hong Kong

Wind Assessment Ingredients



Meteorological data

Terrain roughness

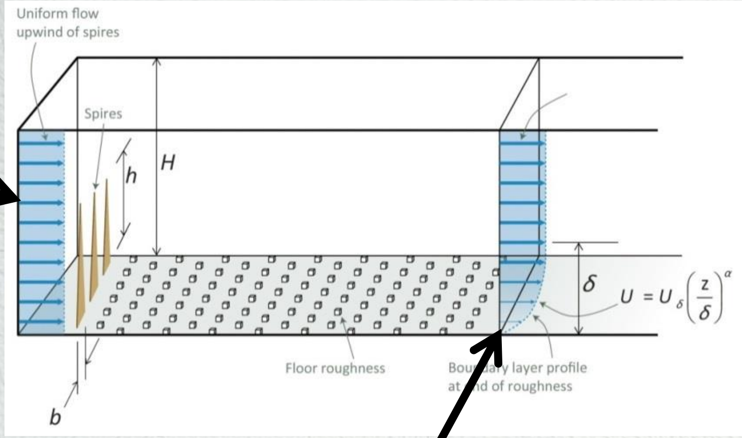


Predictions of local wind speeds (CFD or Wind Tunnel)

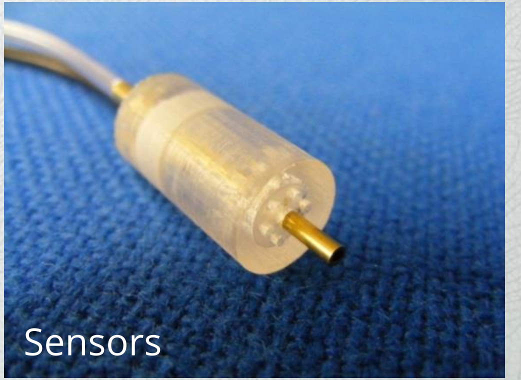
Once the test is done, one needs to combine the results of the simulation with the statistics of the meteorological data.

Wind Tunnel Testing

Fans deliver air to fetch



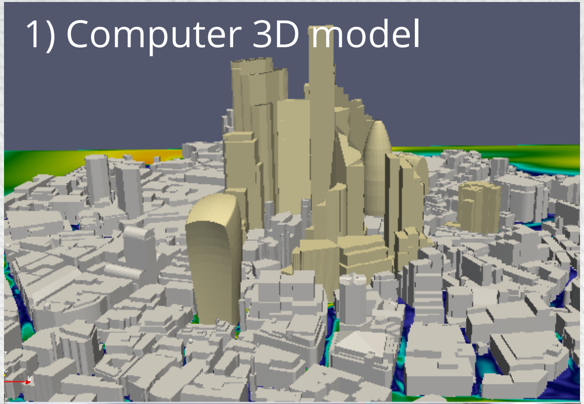
Combination of spires and roughness condition wind



Computational Fluid Dynamics (CFD) Modeling

In "the old days" these calculations were done by 'computers' … who were people …

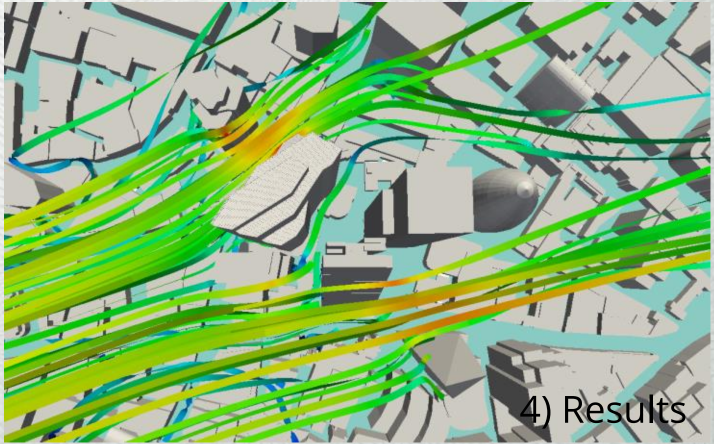
… well, engineers and mathematicians really …



1) Computer 3D model

2) "Gridding" the mesh

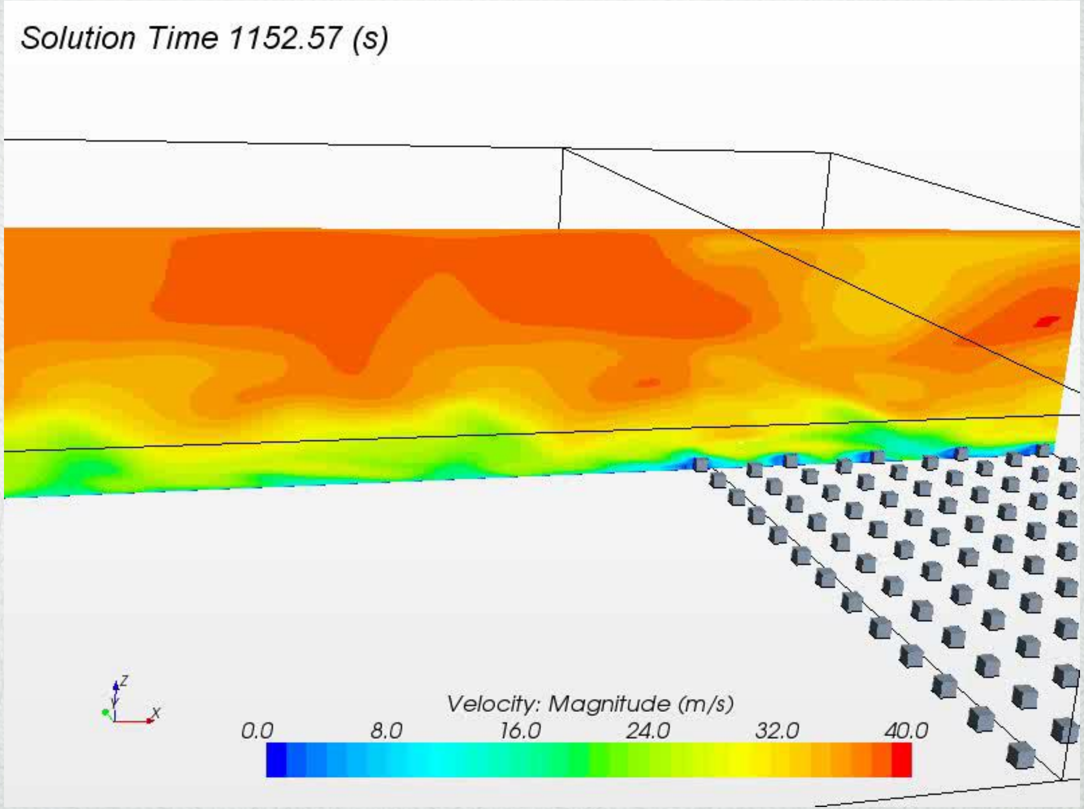
3) High Performance Computers



4) Results

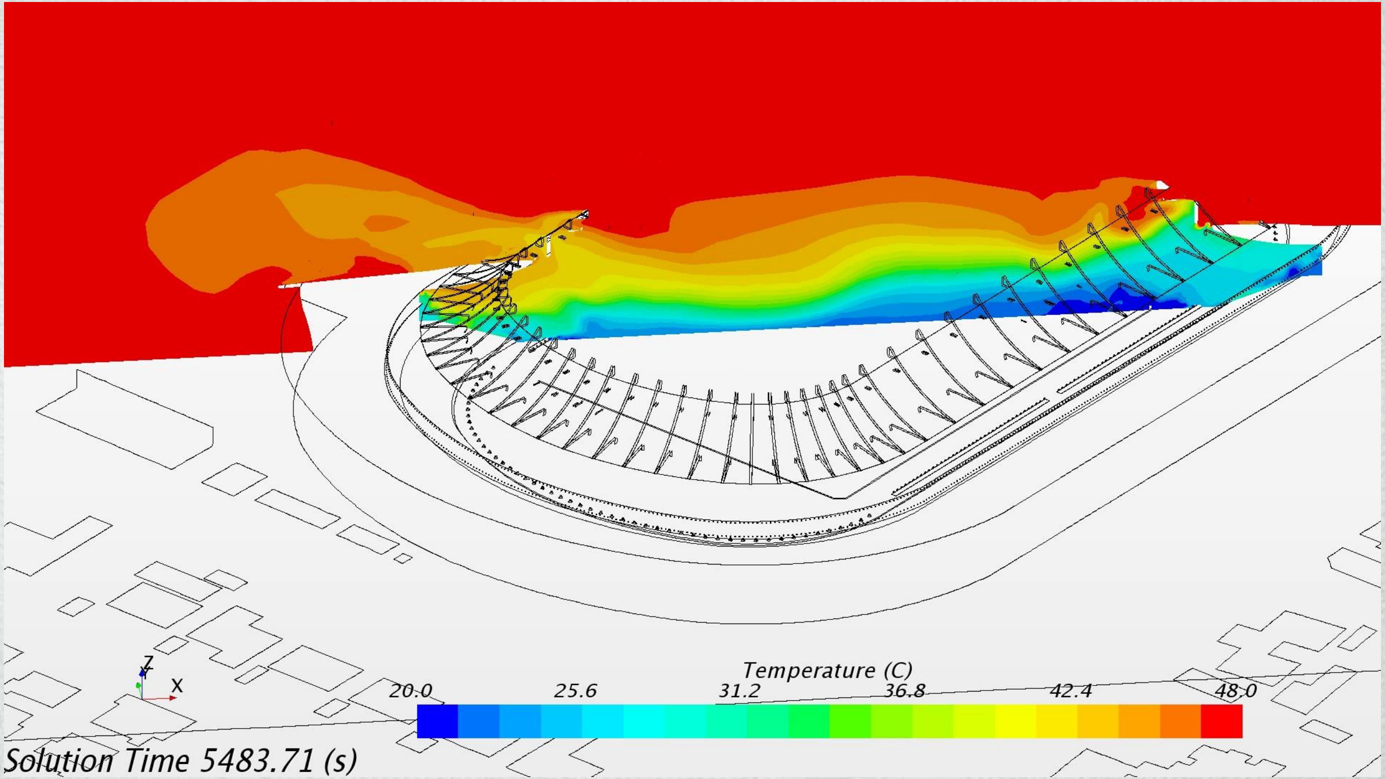
Modeling Atmospheric Boundary Layer and Turbulence

Getting the boundary layer represented properly can be a challenge to do well



Getting The Boundary Right is Crucial

Animation here shows impact of turbulent gusts on tempered stadium



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Case Study

City of London

Work Recently Won Two Awards

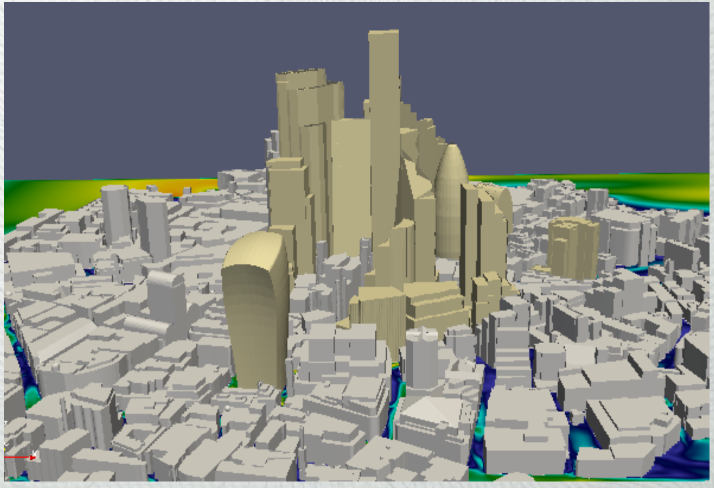
London Planning Awards

Best Conceptual Project

Mayor’s Award for Planning Excellence

Case Study – The City of London

Wind tunnel testing



CFD modelling

A) Modeling Considerations

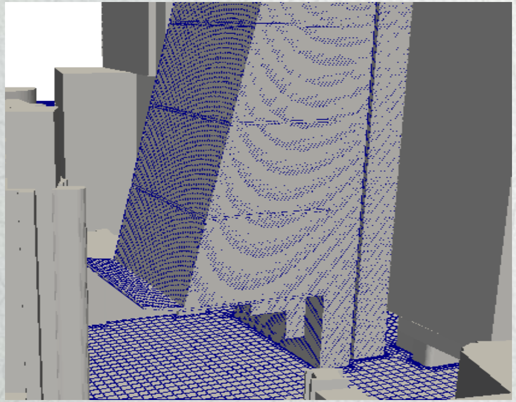
A1) Geometric Considerations

Details are only important if they will actually be built

Typically features below 0.5m (~1.5') are not included - for either wind tunnel or CFD

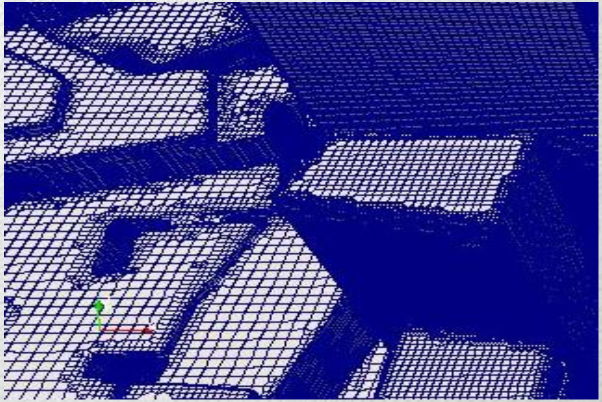
The CFD geometry needs to be meshed, it does not matter how detailed your model is if you do not have a mesh which can capture the flow features

Phasing and future surrounding buildings are important



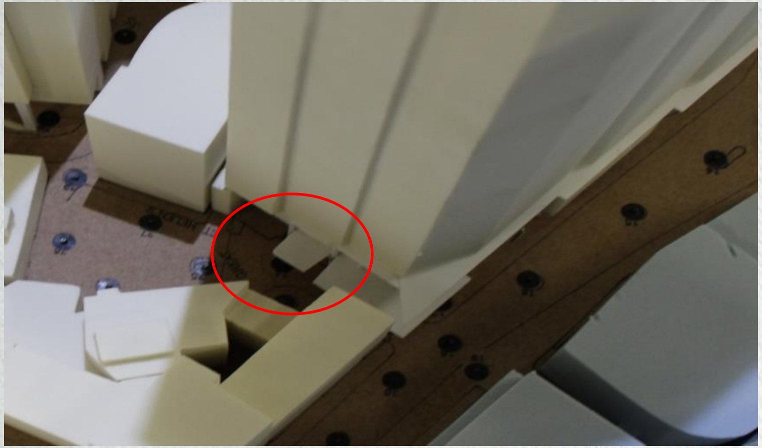
CFD Leadenhall Building

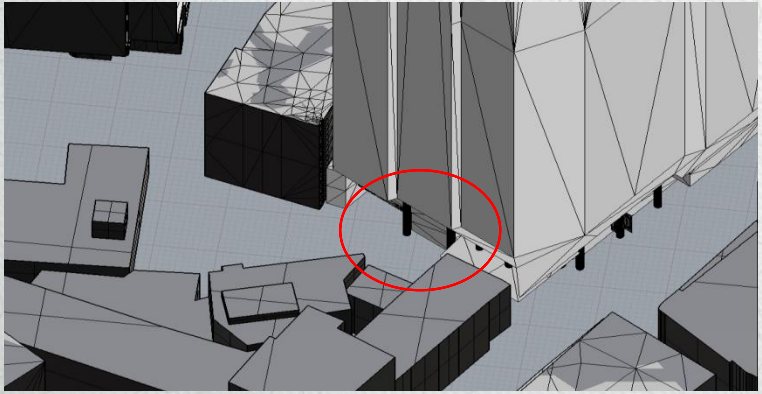
Wind Tunnel Leadenhall Building

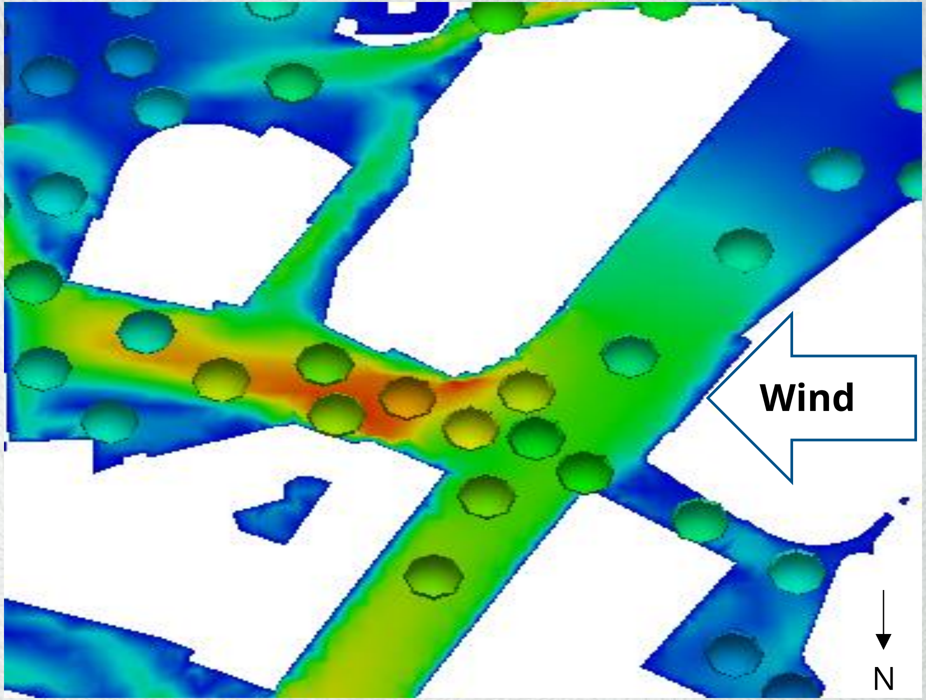


Meshing example

A1) Geometry Considerations







- Canopy missed from CFD model but included in wind tunnel testing.
- Predicted wind velocities far higher for CFD modeling, influence of canopy is significant

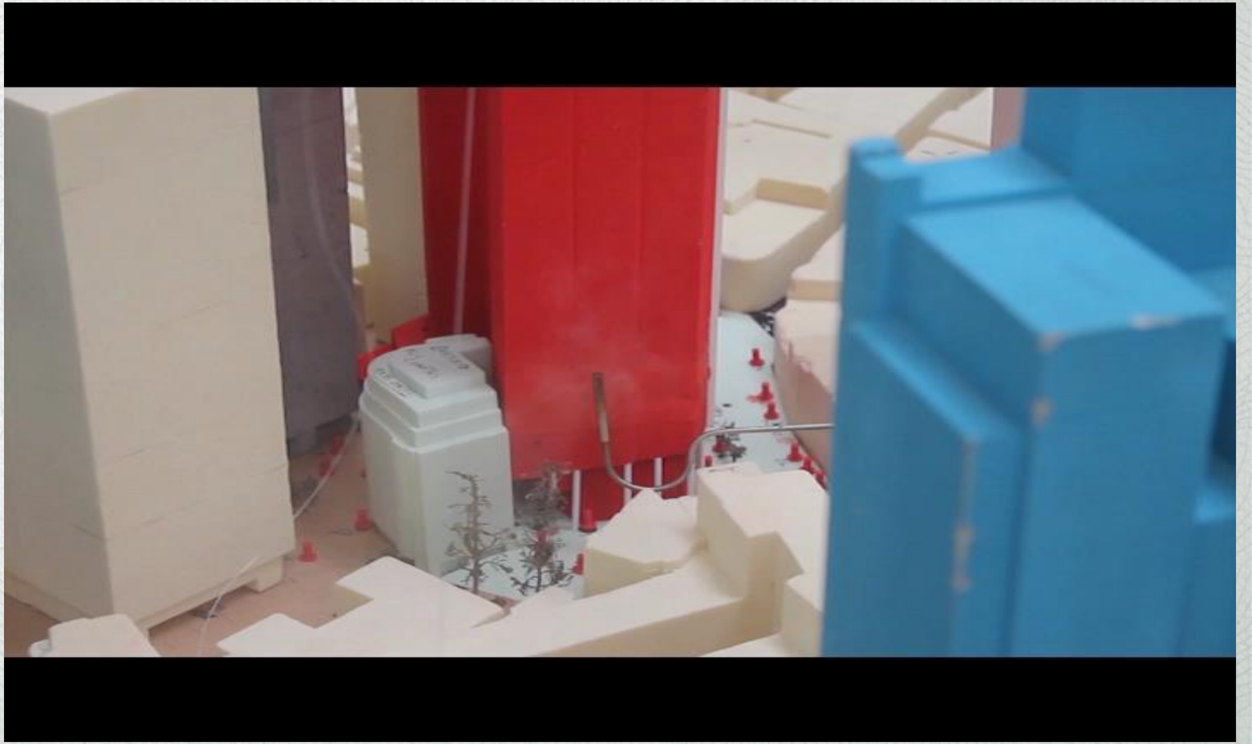
A2) Temporal Resolution

CFD can capture flow fluctuations, it is computationally expensive.

Two values are considered

1) Average or mean velocity

2) Gusts, which are values averaged over a short duration

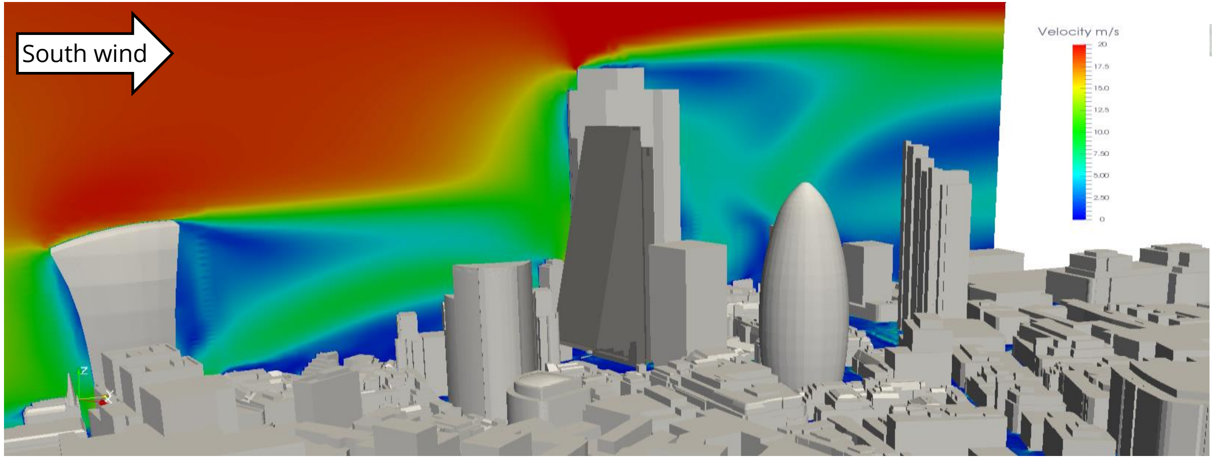


Both these characteristics of the flow are crucial for a robust wind assessment as they can have an effect on both the comfort and safety around a Site.

A2) Temporal Resolution: Transient CFD

Steady state solution
This is the type of analysis that is typically undertaken

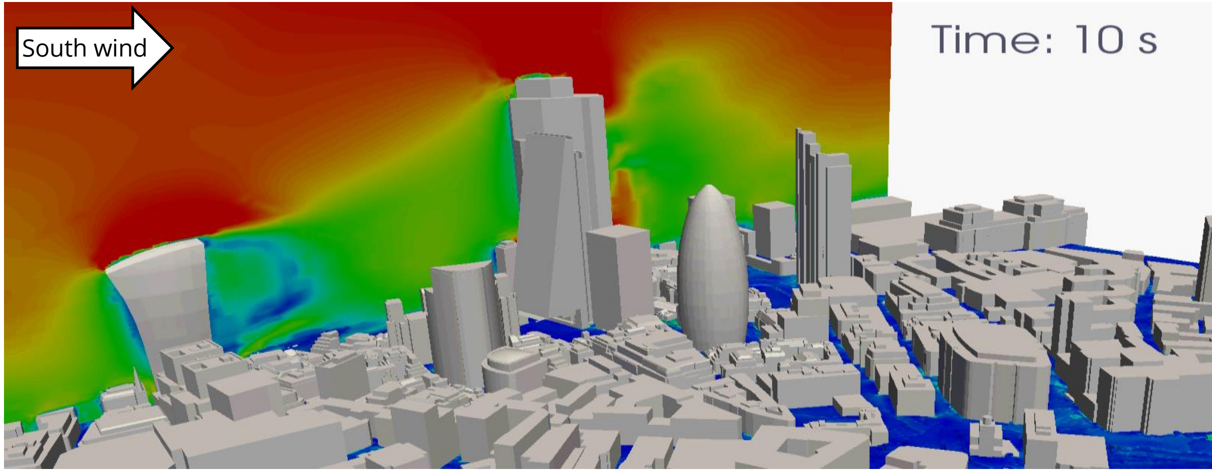
Single mean solution from the analysis



Transient
This is an 80 second real time transient simulation.

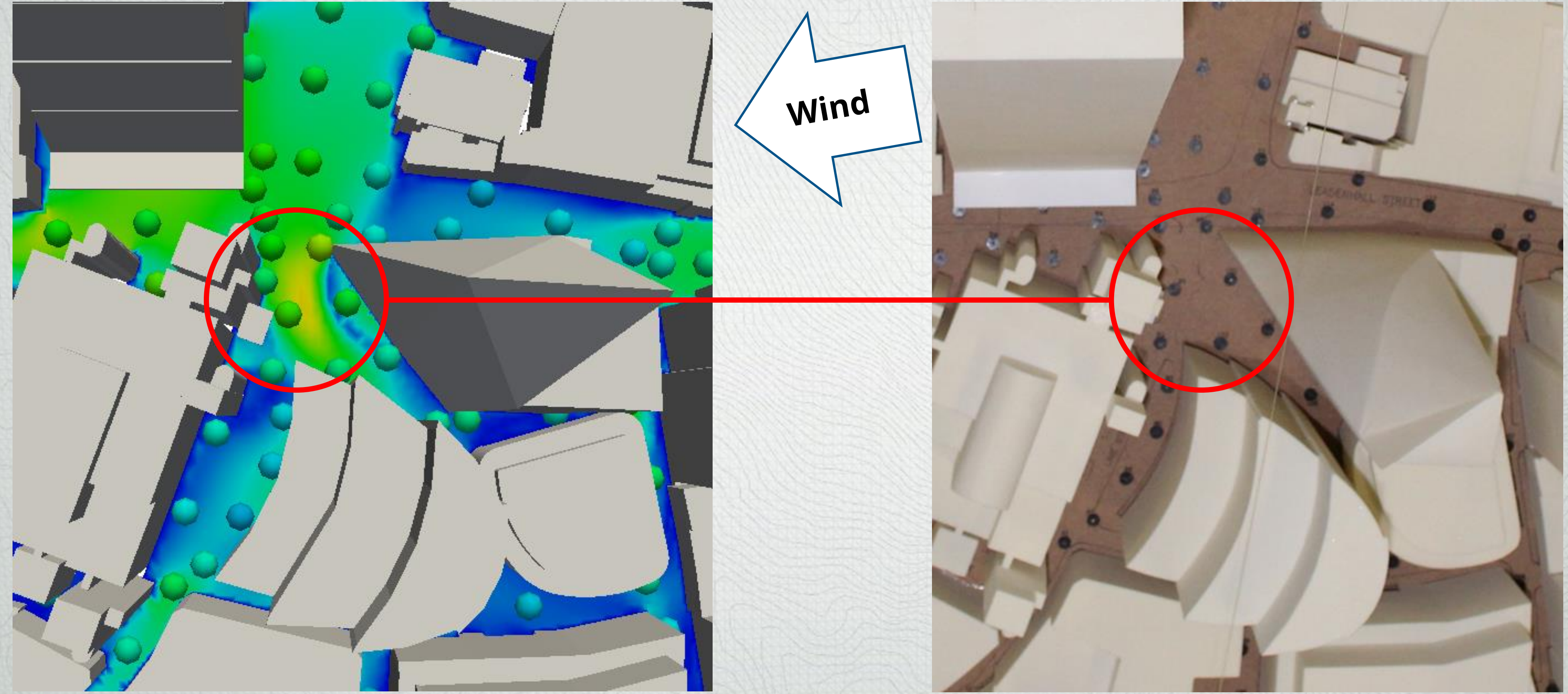
Simulating >20 minutes of time in a transient simulation gives output similar to a wind tunnel test

Both mean and gusts can be simulated



A3) Spatial Variation & Visualization

WT requires that you place measurement sensors well

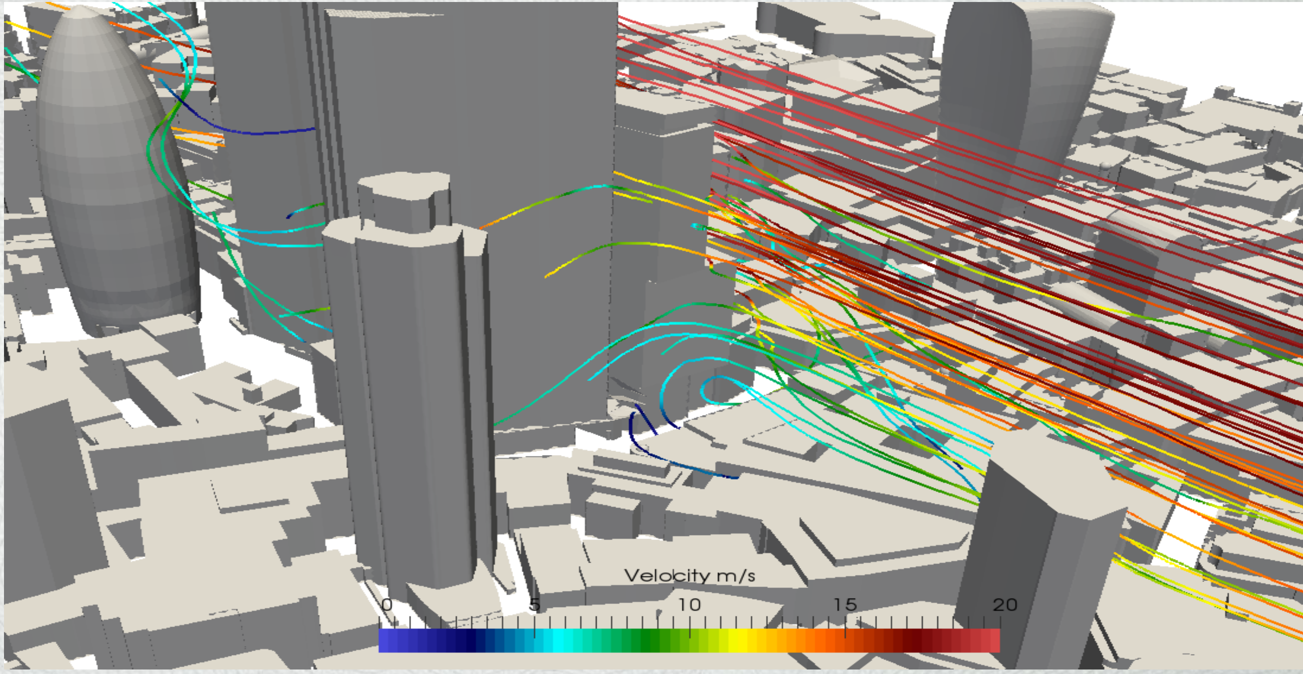


A3) Spatial Variation & Visualization

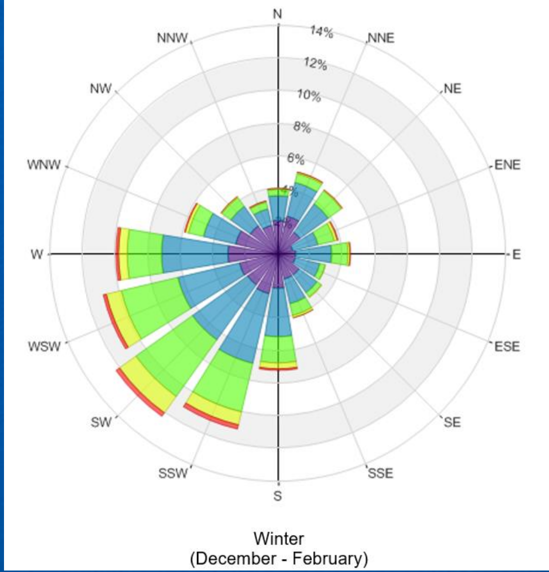
CFD excels in presentation – sometimes it is too compelling

Wind tunnel only gives output where sensors are located, although smoke can be used to visualise the flow

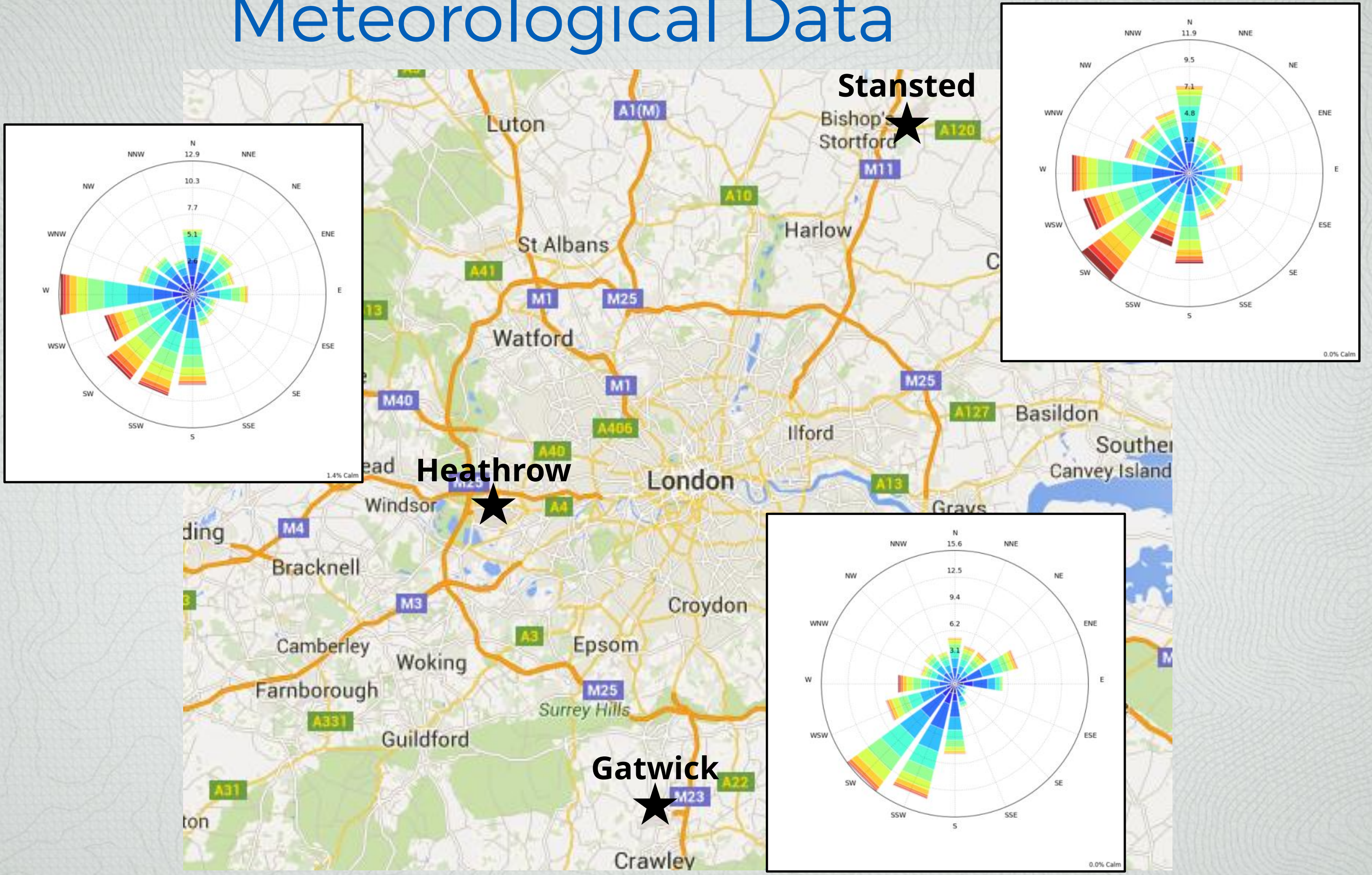
CFD can provide visual output at all scales, which assists in understanding the flow features



B) Meteorological Data



Meteorological Data



Many Cities Have Multiple Airports with Local Climates

Knowing which airport to use, and for where is part of the science.

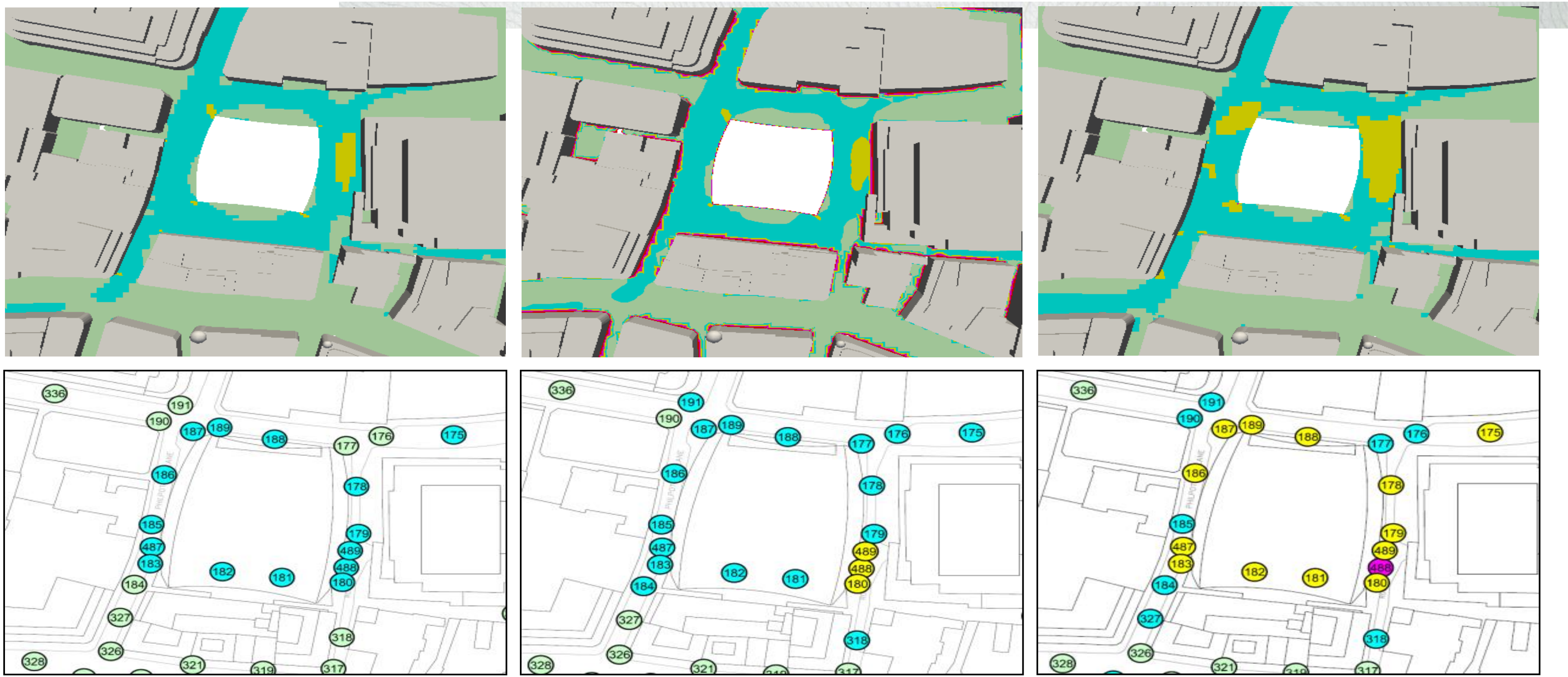
Other cities with multiple airports include:

- New York
- Toronto
- Chicago
- Los Angeles
- Taipei
- Kuala Lumpur
- Dubai

It is possible to use a blended approach for the data

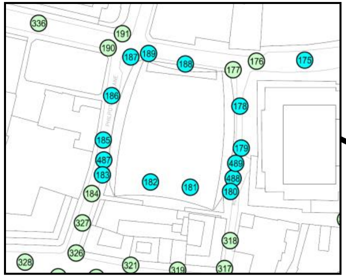
For example, in Toronto one can postulate a line where the Island Airport and Pearson data transition.

B1) London Climate : Choice of Airport Very Important

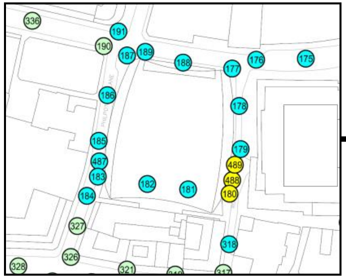


Gatwick Heathrow Stansted

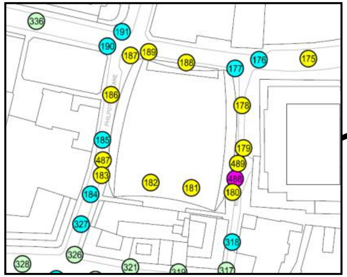
B1) Combined Climate Model for London



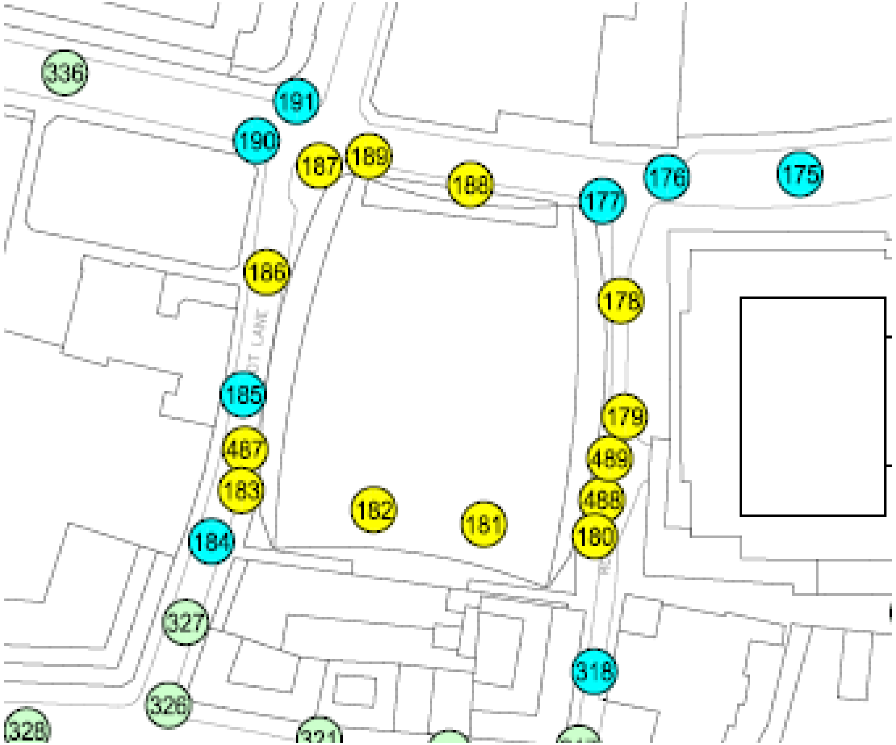
Gatwick



Heathrow



Stansted

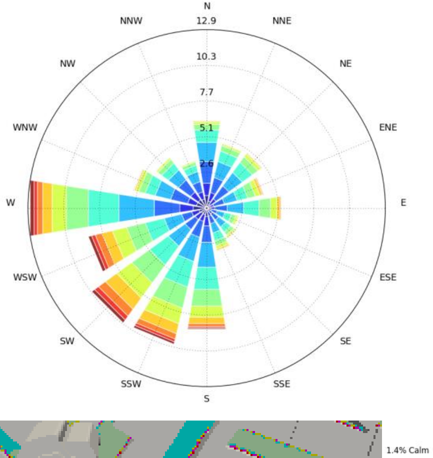


London Combined

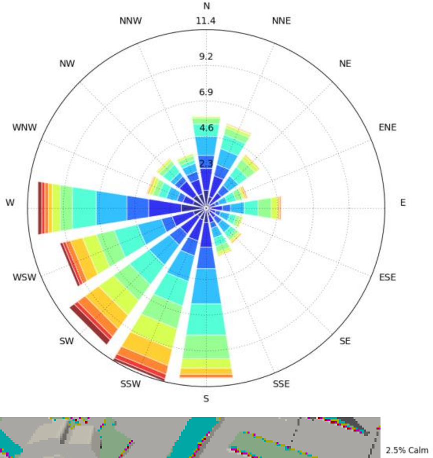
B2) Other Sources of Climate Data

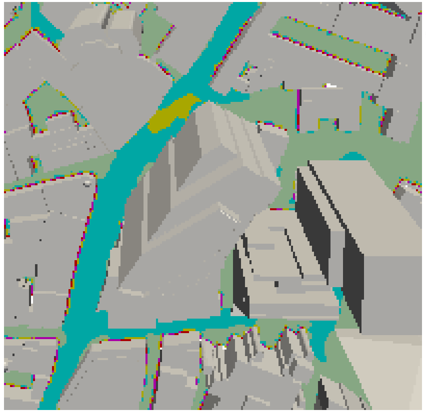
Using TMY, TRY or other filtered data (EPW) means just that, the data is filtered

Heathrow 30 years

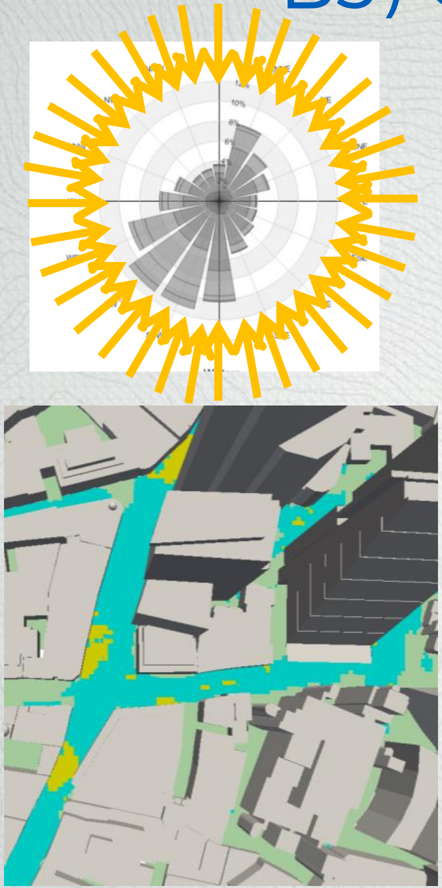


CIBSE test reference year

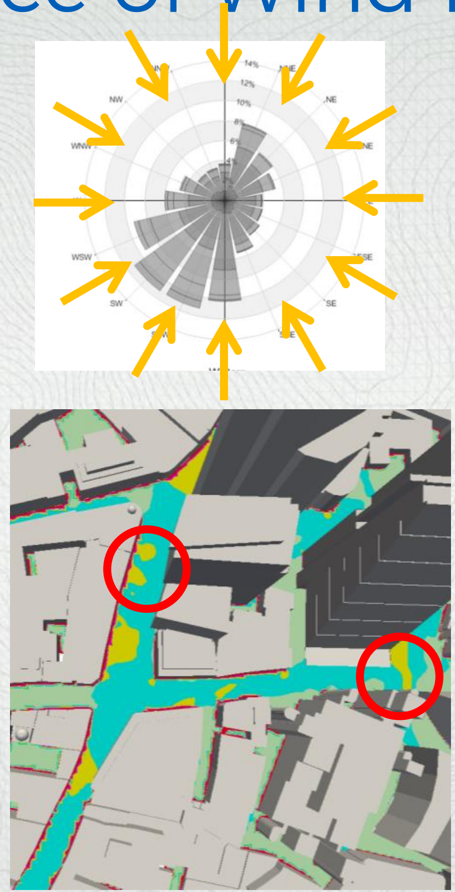




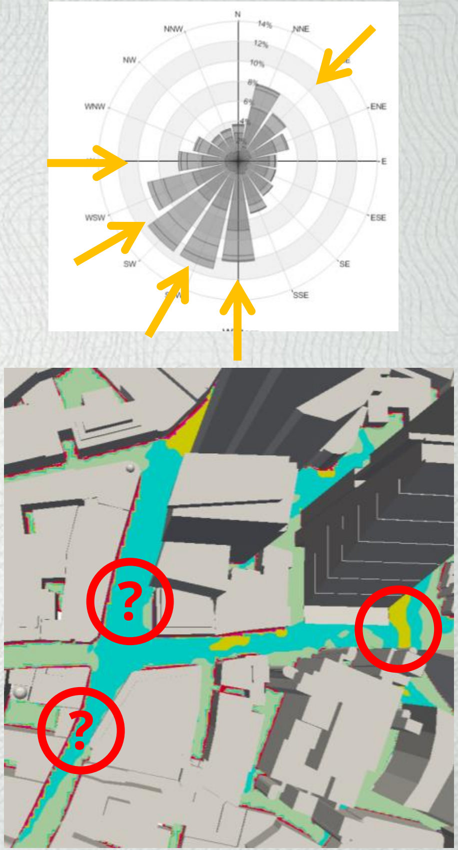
B3) Choice of Wind Directions



36 directions

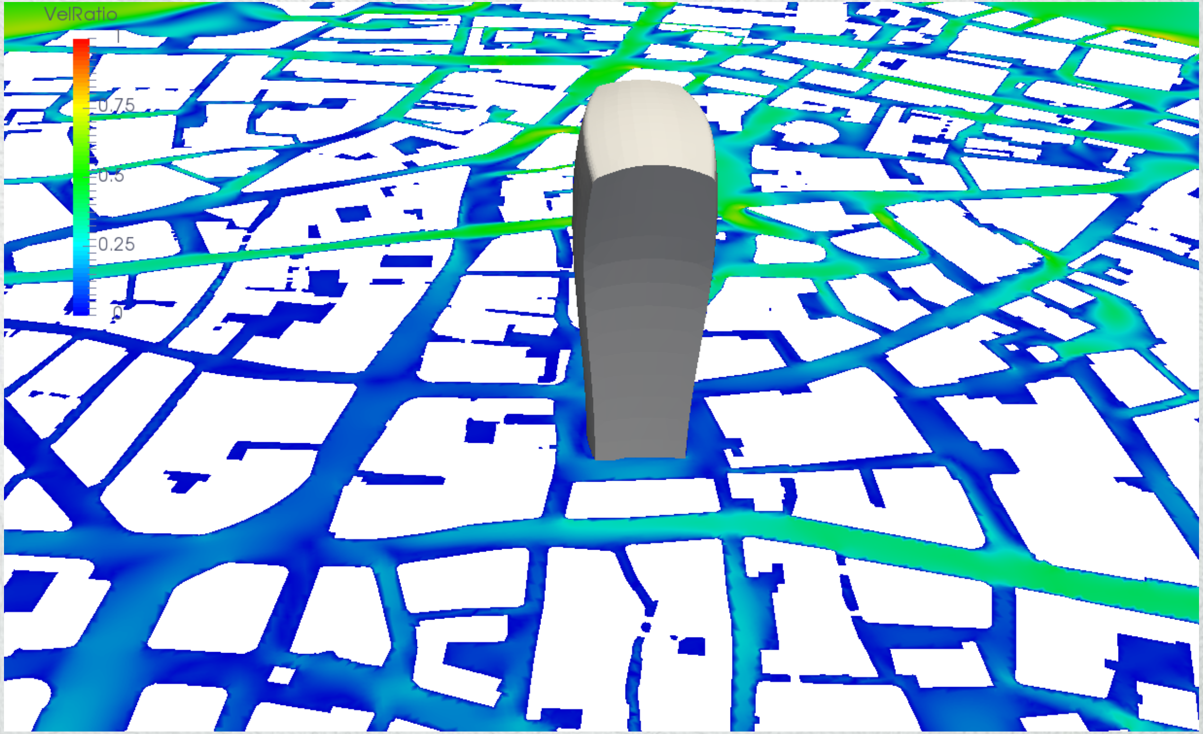


12 directions

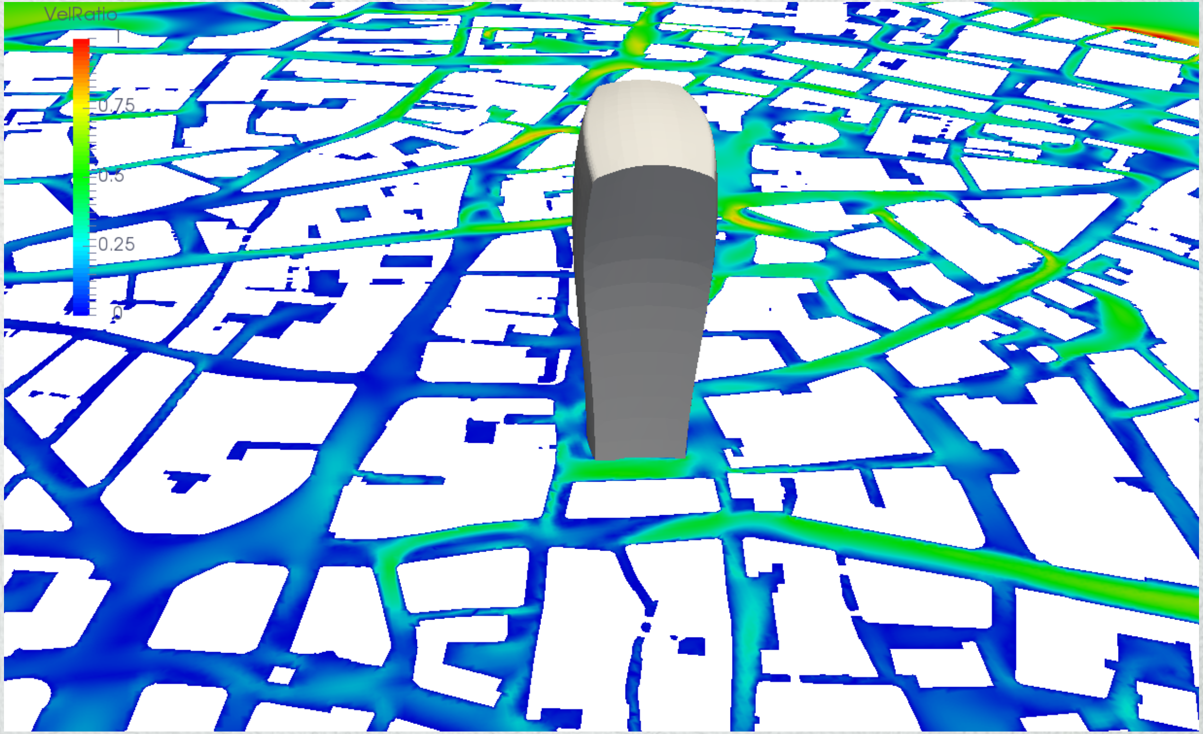


5 directions

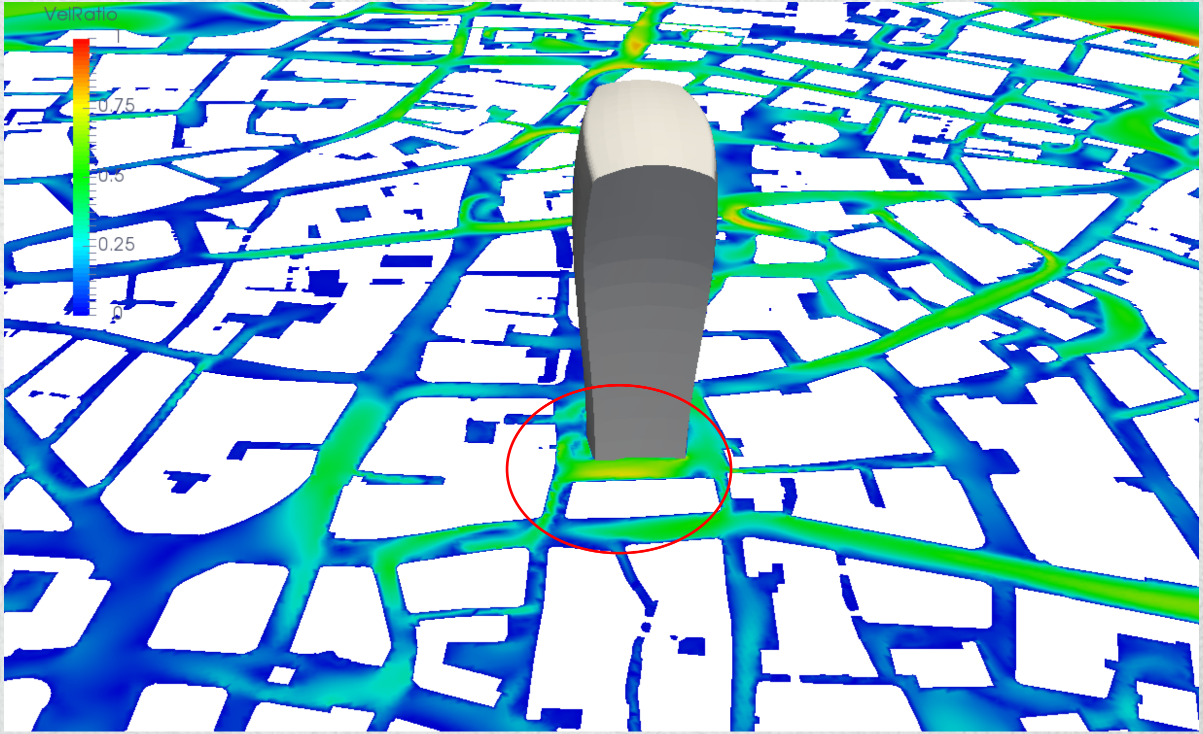
B3) Impact of Choice of Wind Directions (50°)



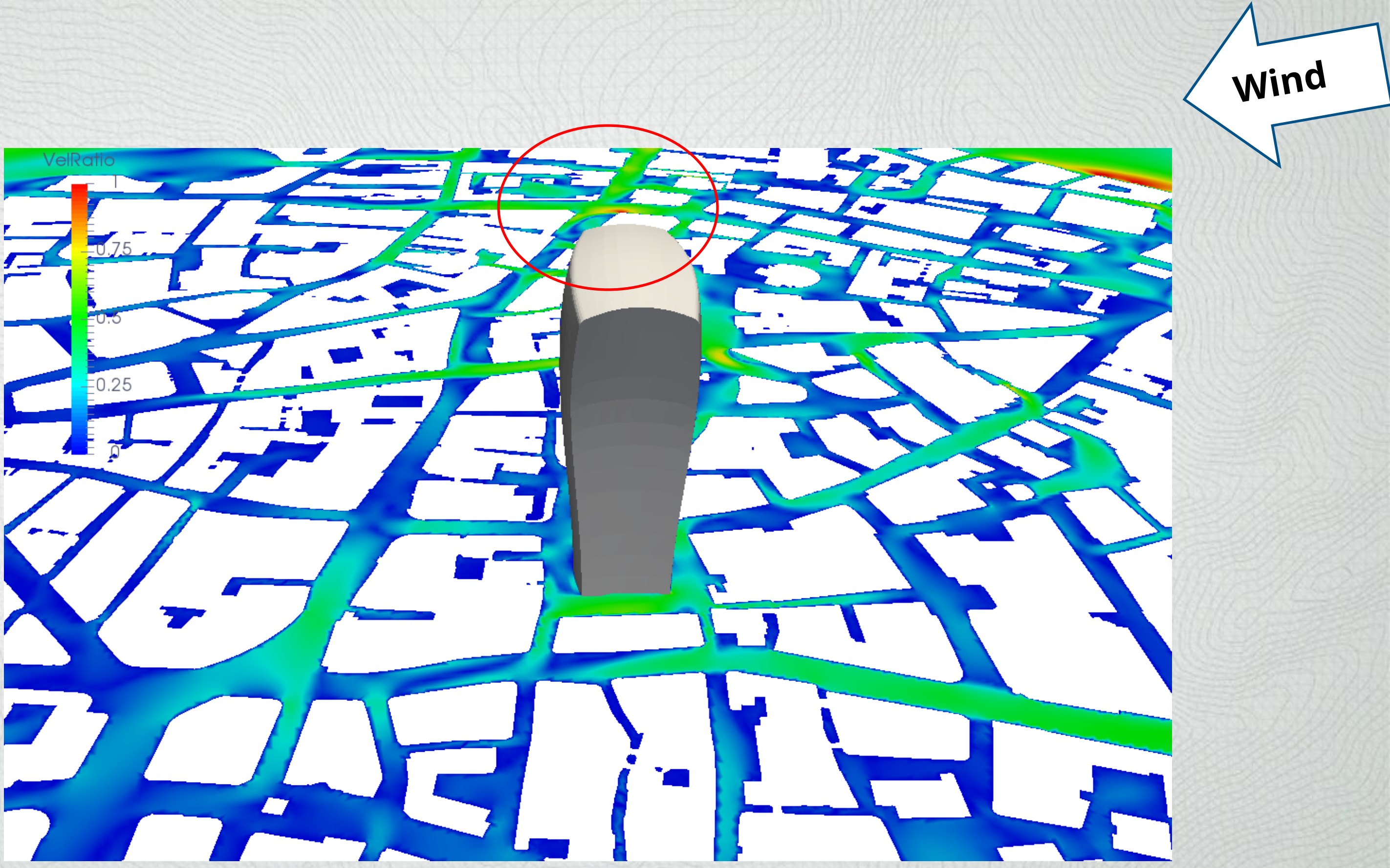
B3) Impact of Choice of Wind Directions (60°)



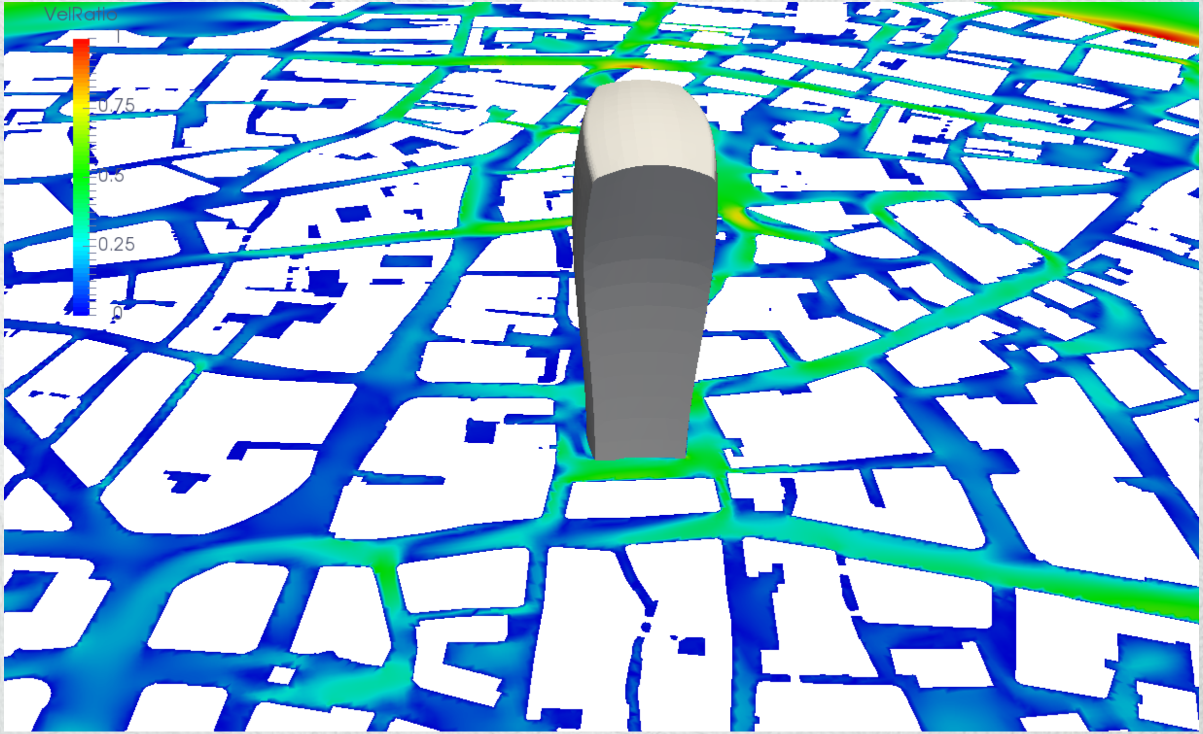
B3) Impact of Choice of Wind Directions (70°)



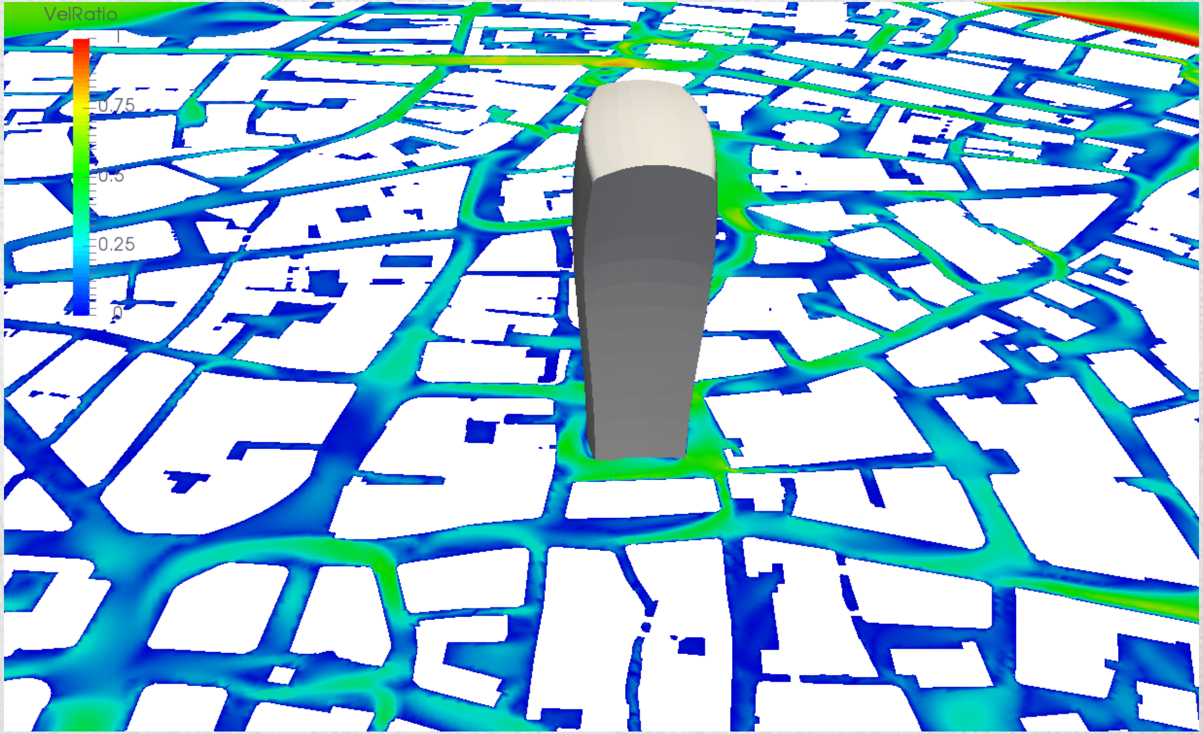
B3) Impact of Choice of Wind Directions (80°)



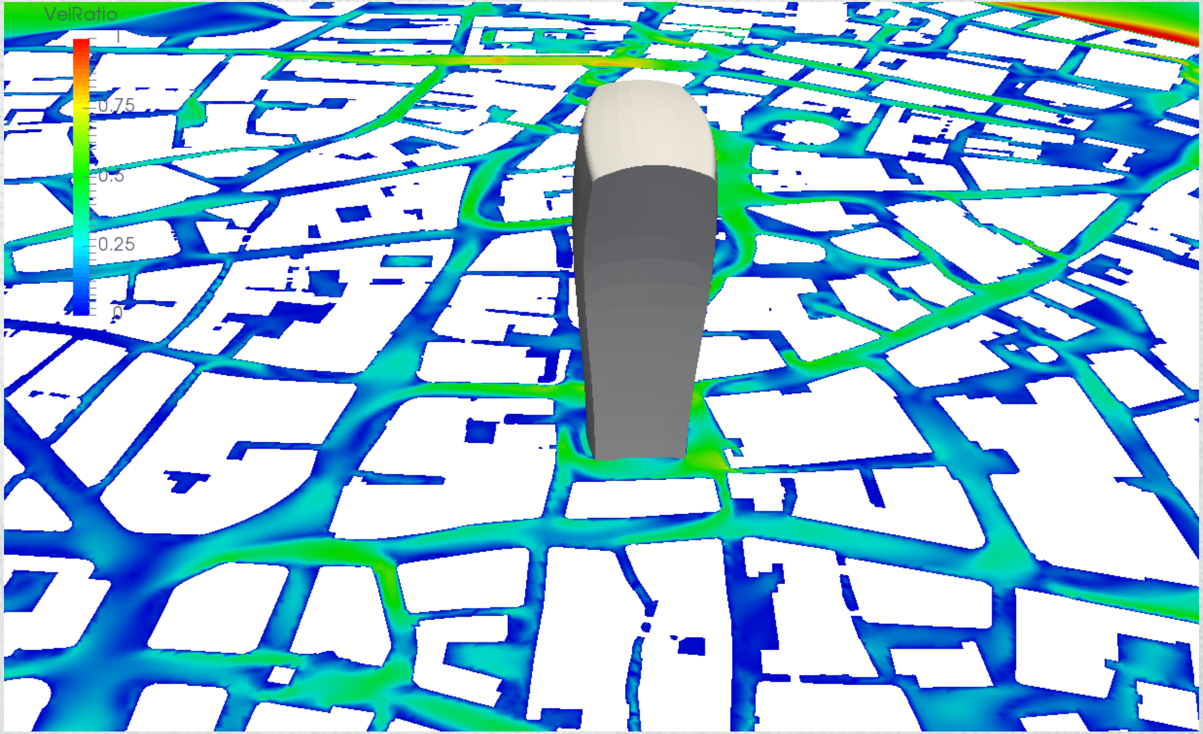
B3) Impact of Choice of Wind Directions (90°)



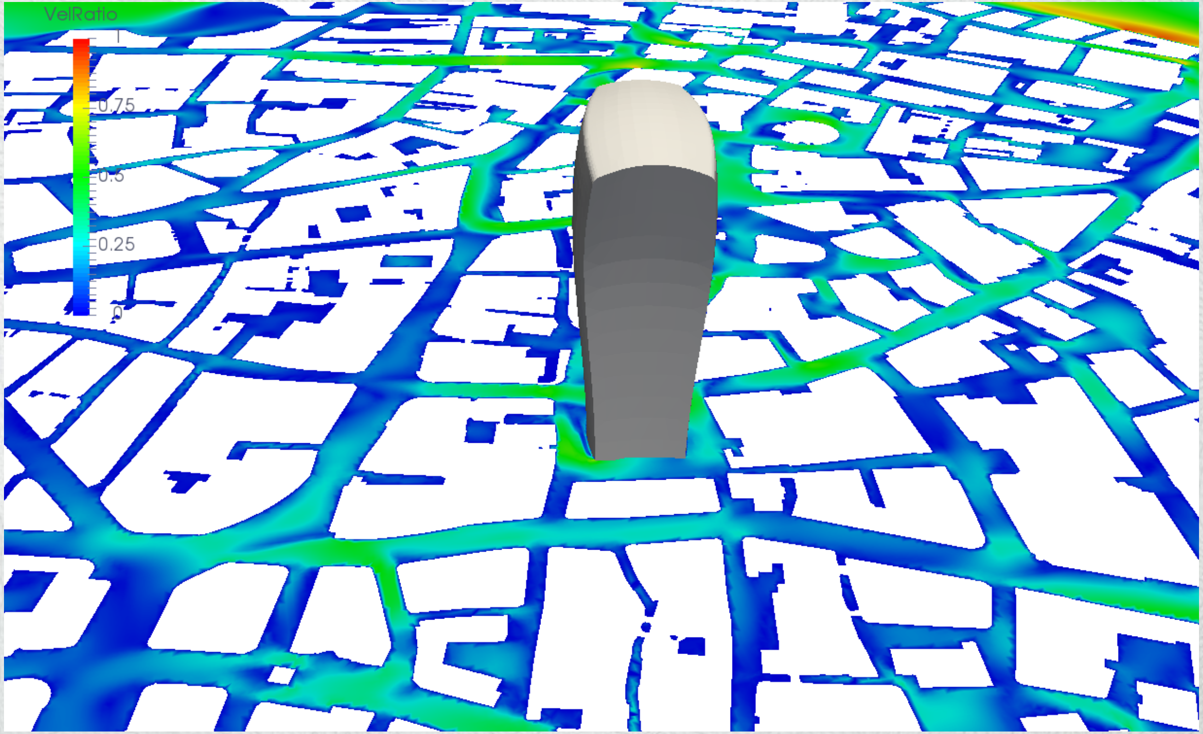
B3) Impact of Choice of Wind Directions (100°)



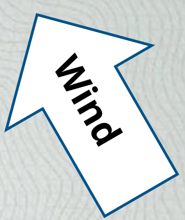
B3) Impact of Choice of Wind Directions (110°)



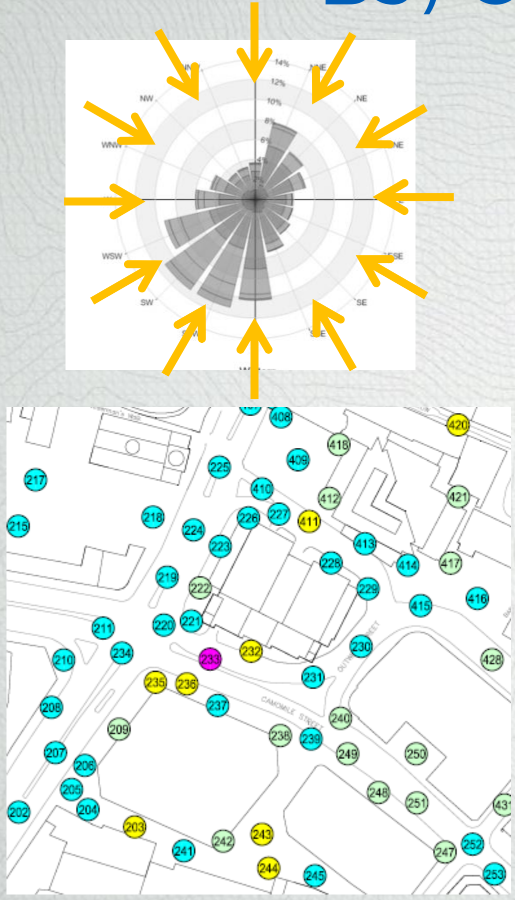
B3) Impact of Choice of Wind Directions (120°)



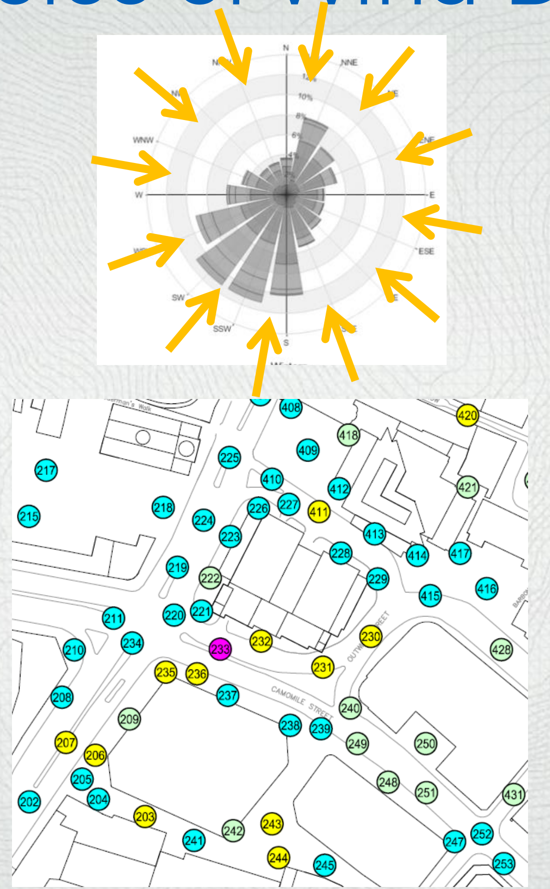
B3) Impact of Choice of Wind Directions (130°)



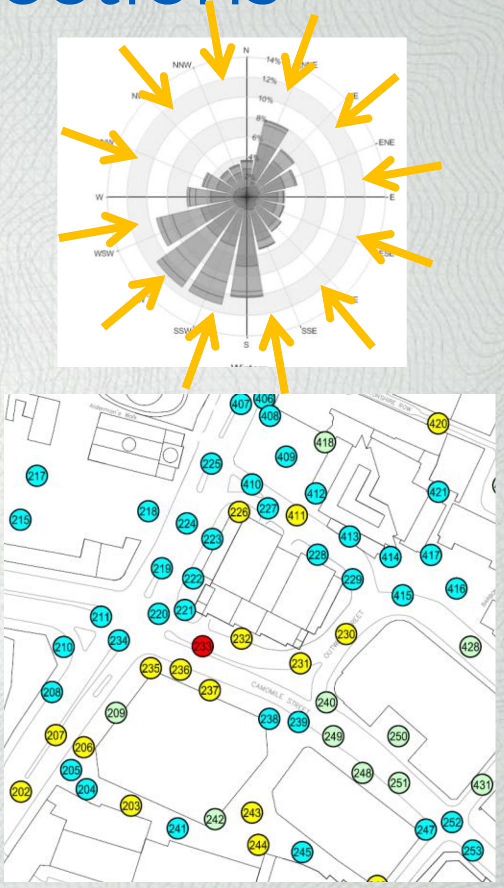
B3) Choice of Wind Directions



0˚, 30˚, 60˚, 90˚, 120˚, 150˚, 180˚, 210˚, 240˚, 270˚, 300˚, 330˚

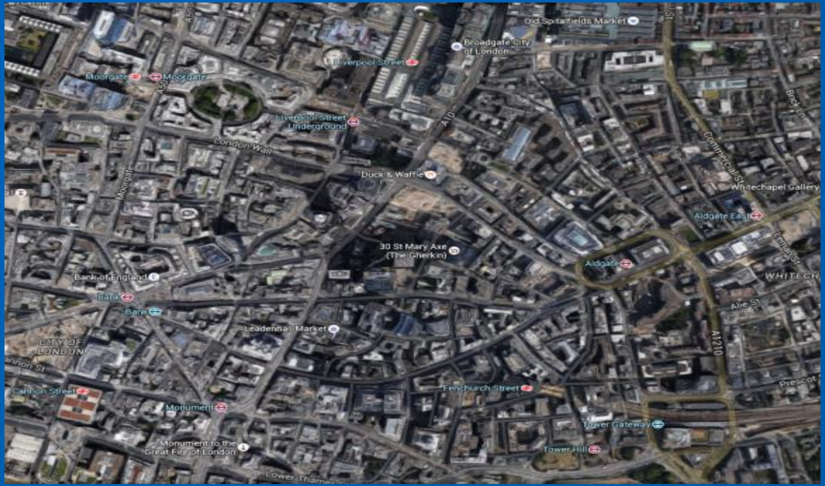


10˚, 40˚, 70˚, 100˚, 120˚, 160˚, 190˚, 220˚, 250˚, 280˚, 310˚, 340˚



20˚, 50˚, 80˚, 110˚, 140˚, 170˚, 200˚, 230˚, 260˚, 290˚, 320˚, 350˚

C) Terrain

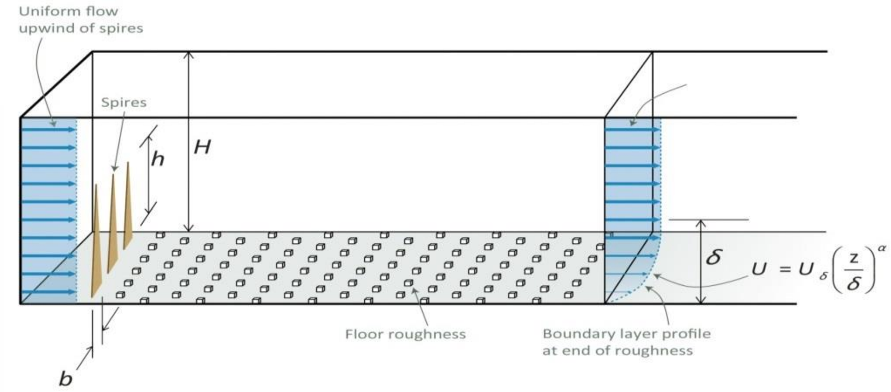

Old Spitalfields Market
Broadgate City of London
Liverpool Street
Moorgate
Moorgate
Liverpool Street Underground
London Wall
Duck & Waffle
Whitechapel Gallery
Aldgate East
30 St Mary Axe (The Gherkin)
Aldgate
Bank of England
Bank
Bank
Leadenhall Market
CITY OF LONDON
Cannon Street
Monument
Fenchurch Street
Tower Gateway
Tower Hill
Monument to the Great Fire of London

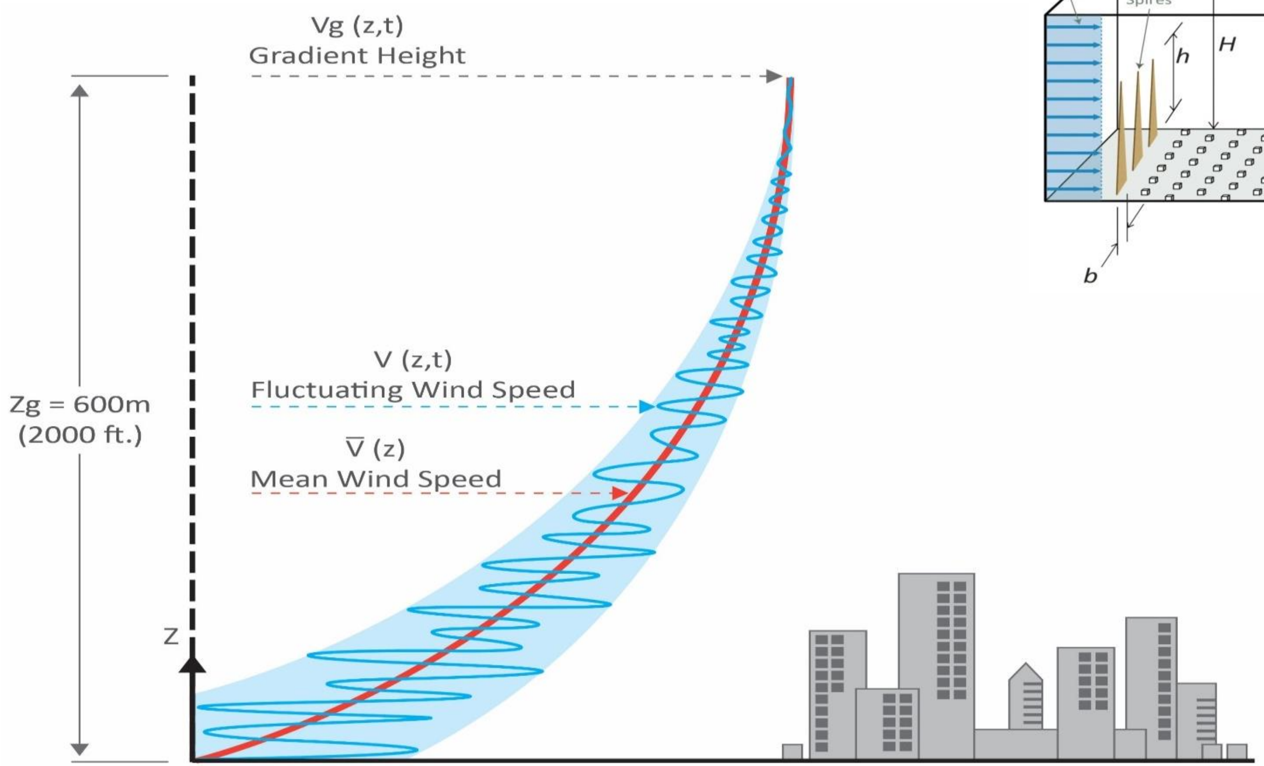
C) Terrain Roughness Analysis

Built up urban area – lots of obstructions

Open country – few obstructions

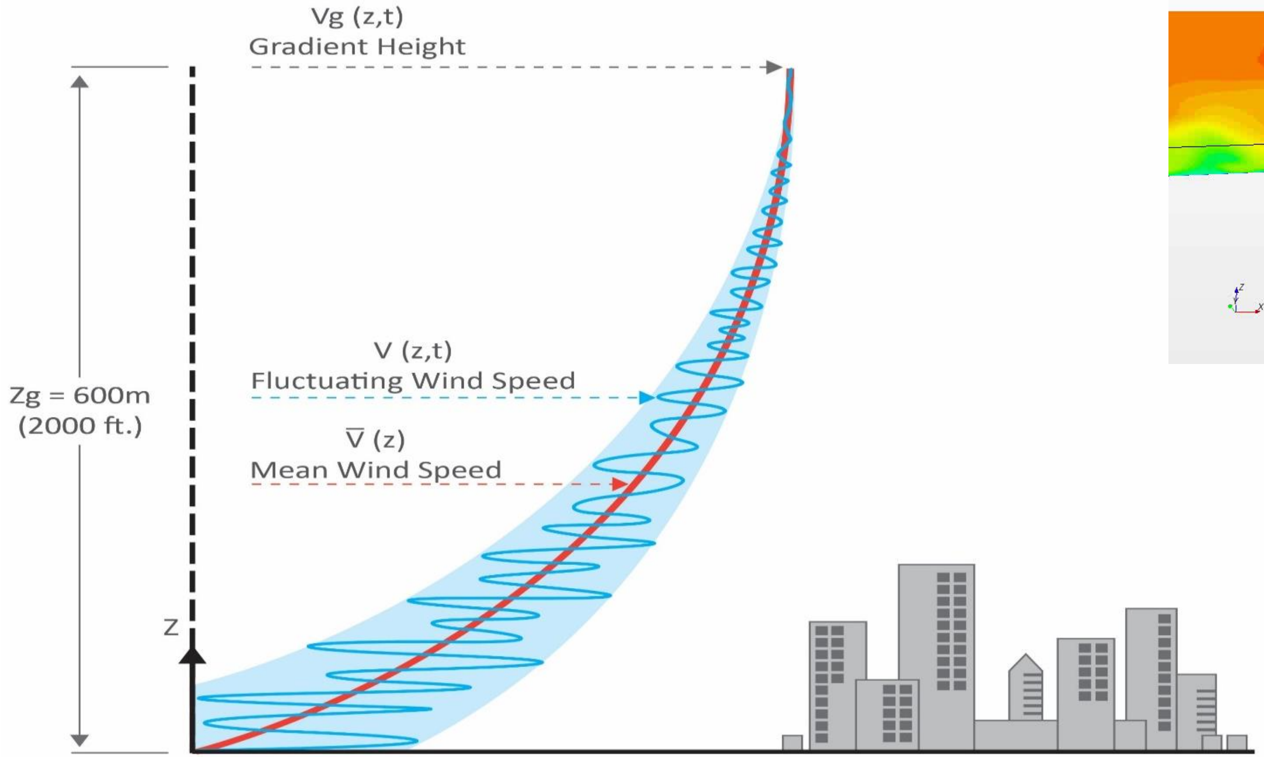
C) Planetary Boundary Layer and Surface Roughness

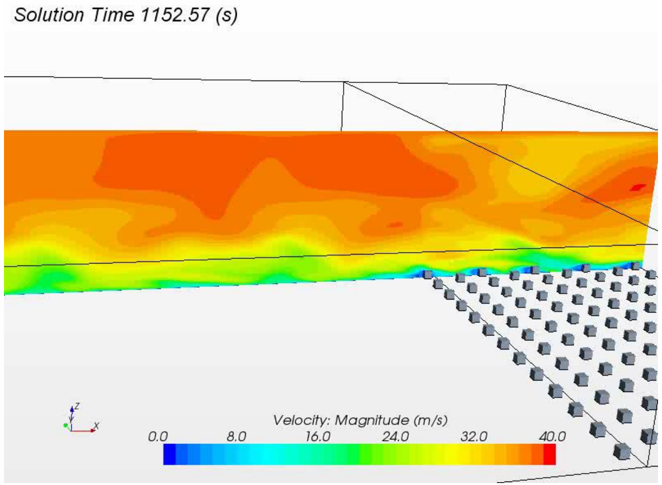




One of the challenges in CFD is maintaining the boundary layer profile through the simulation domain.

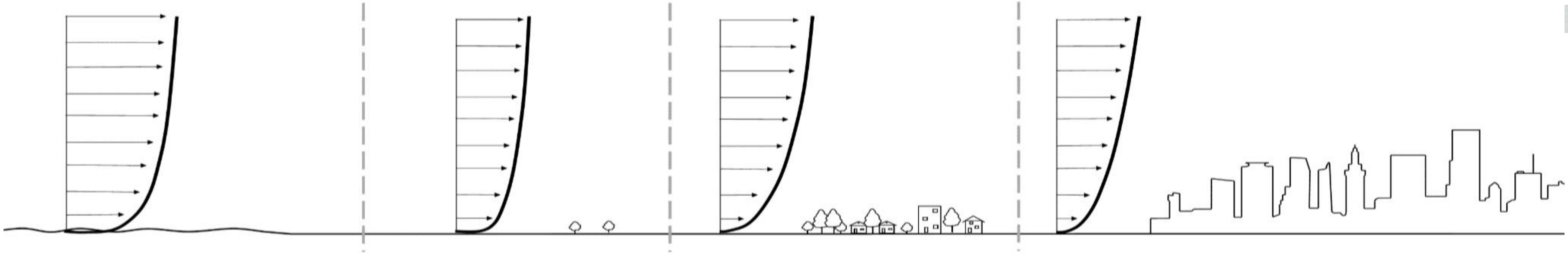
C) Planetary Boundary Layer and Surface Roughness



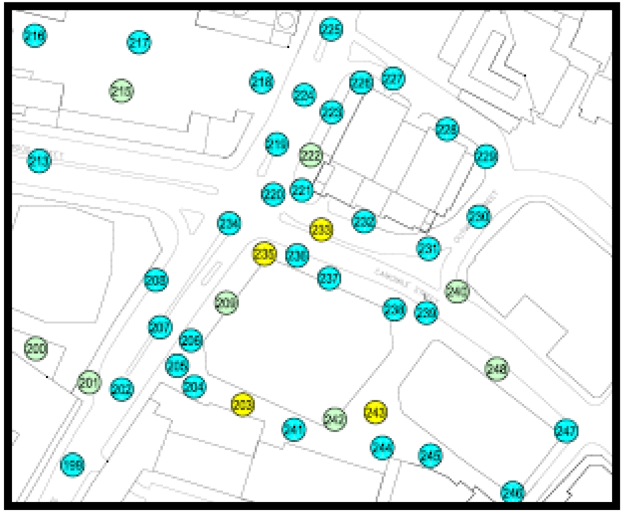


One of the challenges in CFD is maintaining the boundary layer profile through the simulation domain.

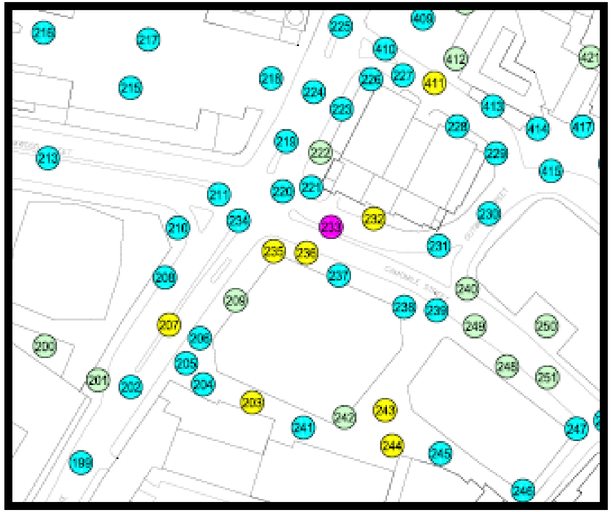
C) Wind Profiles



Open **Open/sub** **Suburban** **Urban**



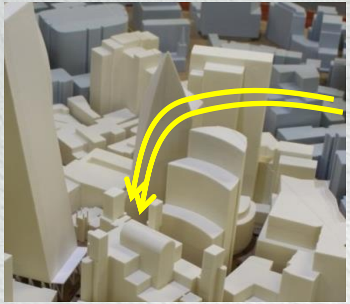
Open

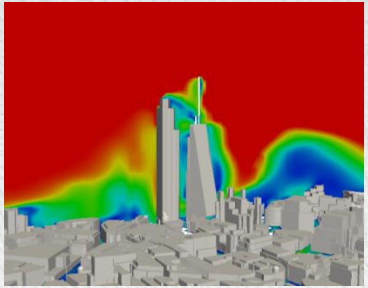


Suburban

Conclusions

Choice of Assessment Tool





Design Advice	CFD Simulation	Wind Tunnel Testing
Very quick and inexpensive	Relatively quick and inexpensive to provide initial outputs (1-2 weeks) – it really depends on the model	Slower to produce initial outputs (~can be less than 3 weeks if everything goes brilliantly smoothly)
Output in the form of a workshop or short report with diagrams	Strong visual output to illustrate the flow behaviour	Results only where sensors are placed
Quick to consider different options	Relatively slow to iterate different options unless known in advance	Quick to consider different options (~ 5 per day) with detailed analysis
Cannot necessarily discern nuances of different wind directions	Check to see whether there is a limited number of wind directions assessed (4-12?)	Typically 18 - 36 wind directions tested
Bulk flow features and general mitigation	Mean flow behavior only with this turn around time – no safety assessment	Full temporal output and robust assessment of safety issues

All options require interpretation by someone experienced

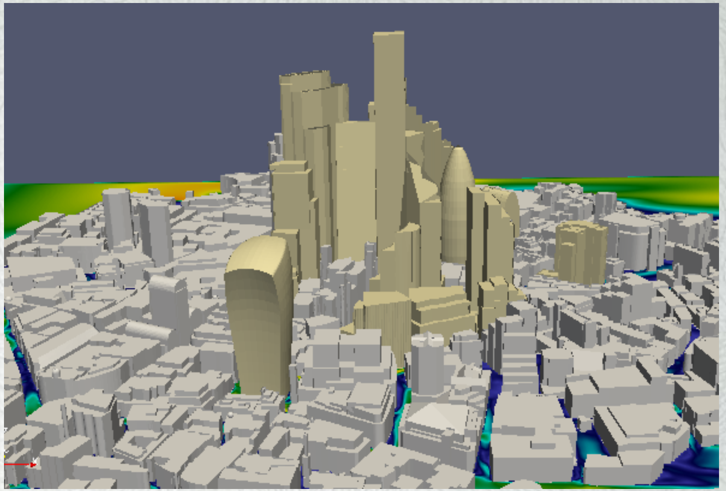
Conclusions

The Big Scale Conclusions are:

- The appropriate tool to quantify the wind environment depends upon the scale of the development and the stage of design

- CFD can do a reasonable job for planning but will not capture safety issues.

- Individuals doing the work must understand limitations of any tool used.



Conclusions

- The turbulent behavior of wind needs to be understood well in order to simulate it in either the wind tunnel or CFD
- The transient behaviour of wind must be captured – note steady state CFD modeling does not capture the turbulent gusts
- Wind assessments for planning considers both pedestrian wind comfort and safety – CFD has a hard time with safety assessment
- If modeling the turbulence is so difficult, getting dispersion and wind loads correct will be very difficult – Webinar on this at later date.
- Where we assess data is important – positioning of probes in wind tunnel testing is key – ideally locations known in advance
- It does matter how many wind directions we simulate, the choice of climate data is important and it must be corrected for terrain
- For safety issues on wind force and dispersion, the wind tunnel is the only viable option at the moment

Thank you for your time!
Questions?

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