PHOENICS Case Study: Environmental - Large-scale Parallel-Processing Model: Wind Flows through an Urban Cityscape

In this demonstration, PHOENICS/FLAIR was applied to the simulation of air flows through a cityscape of the Tsim Sha Tsui area within Hong Kong as part of an Air Ventilation Assessment (AVA) study under consideration by the Hong Kong Planning Department.

Preliminary Technical Requirements

The study required an extremely fine grid. The original specification stipulated a horizontal grid of 1 metre to capture the detailed flow conditions at street level and between buildings and, vertically, at 0.5m for the first 4 layers below 2m above ground, then increasing in a ratio of 1.3 above 2m.

In the example shown, building geometry was imported as a DXF file in two interlocking sections (shown as green / grey). The wind was specified from the North-East at 10 m/s at a height of 10 metres. The Domain size requested was 5H (inflow) x 15H (outflow) x 5H (height) where H=Height of the tallest building at around 250m.

Geometry - Cityscape Model – Tsim Sha Tsui region

Zoom view

↗ **North**
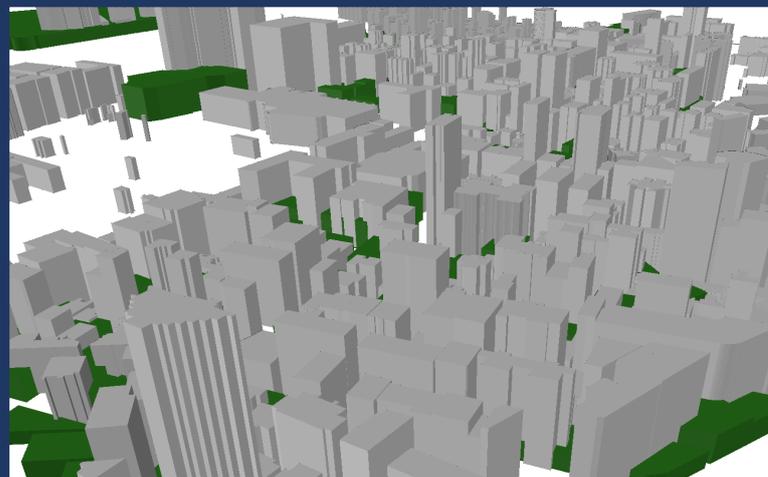
The following normalised wind data was supplied by the HK Planning Dept. When the data cannot be fitted by logarithmic or power-law expressions, the data can be introduced to PHOENICS/FLAIR via INFORM – a facility for introducing any user-defined functions.
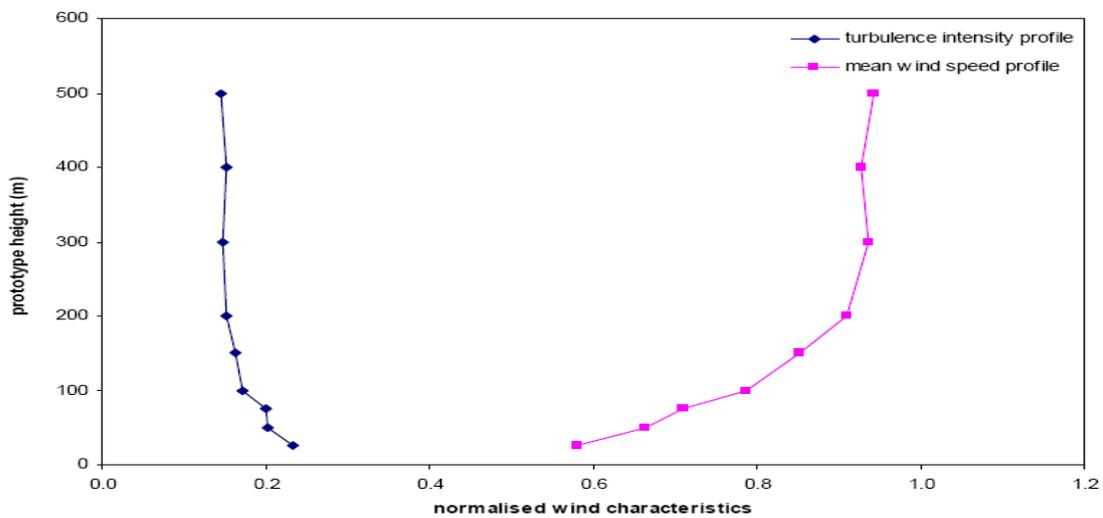

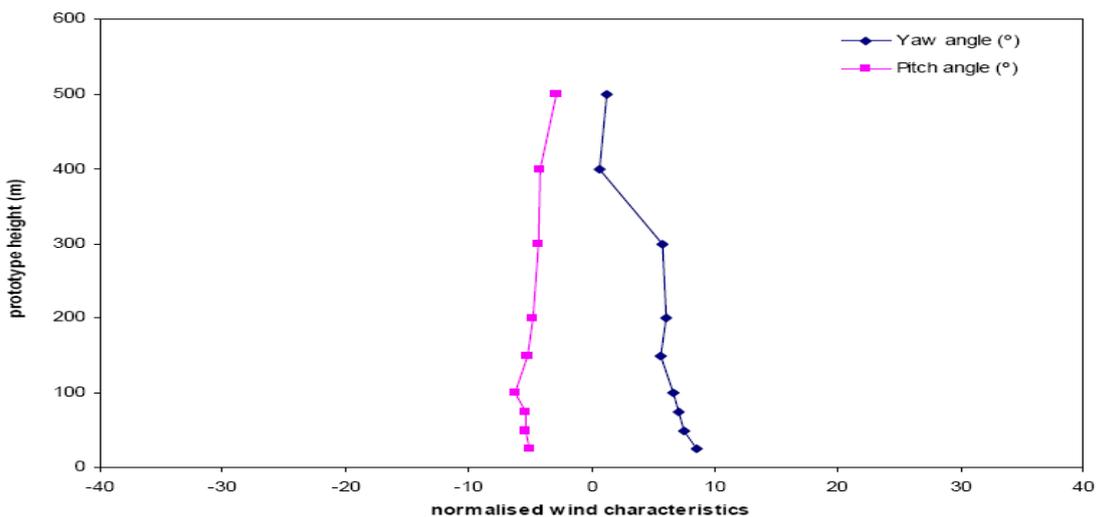Figure 8a: Wind characteristics, Tsim Sha Tsui, 45°

Figure 8b: Mean wind direction, Tsim Sha Tsui, 45°

Practical Considerations

The CFD model described above involves a case size utilising ~100 million cells. Such a case is only deemed to be practical using 64-bit computer systems with a large RAM capacity, running in parallel-processing mode. Even then, the run times will be extremely lengthy involving days rather than hours of CPU time.

In view of the immediacy of the requirement stated by the customer, a reduced-size (yet representative) case was created in preliminary form and is outlined below. The case was created and performed on a Dell T7400 quad-core system with 16Gb RAM.

Physical Domain size: 2587m * 1711m * 1000m (roughly 10H * 7H * 4H). In the X-Y plane, this is the size of the geometry files supplied. The original specification is not precise enough to define a different domain size.

Grid size: 744 * 704 * 45 (23.57 million cells). The grid was divided into 3 regions in X and Y. The central region of 750m was assigned 500 cells, giving a cell-size of 1.5m. Outside the central zone, the grid was allowed to expand towards the domain boundaries. The largest cells at the domain boundaries were roughly 10m in size. In the Z (height) direction, the first 45m (up to the top of the green buildings) contained 17 uniform cells, the next 175m (up to the top of the highest building) 15 cells expanding away from the ground and the remaining 778m to the sky boundary a further 13 expanding cells.

Wind Velocity: The wind speed at 10m was taken to be 10m/s, from the Northeast. A logarithmic profile was used with a reference roughness height of 0.25m (equivalent to 'scattered obstacles').

The geometry supplied had been exported from AutoCAD as a DXF file containing the surfaces of the roof tops. This file was used in AC3D to extrude down to the ground plane thus creating the closed volumes required by PHOENICS. The resulting files were then imported into PHOENICS.

Whilst PHOENICS has a variety of meshing options – Cartesian, Polar, Curvilinear and Unstructured – a Cartesian mesh was used. This is the most commonly mesh used for built environment applications of this type – ie a standard structured Cartesian mesh, coupled with the PARSOL cut-cell feature designed for handling complex geometries. PARSOL is described on CHAM's web site at: http://www.cham.co.uk/phoenics/d_polis/d_enc/in-form.htm.

Similarly, the Chen-Kim k-epsilon model was selected from the many available within PHOENICS, as the most suitable for cases of this type.

The inbuilt wind-profiling feature of PHOENICS/FLAIR was used. The wind speed is calculated from:

$$U/U^* = \ln(z/z_o)/\kappa$$

And the turbulence quantities are set to:

$$k = U^{*2}/0.3; \quad \varepsilon = U^{*3}/(\kappa*z)$$

Where U is the total velocity at a height z from the ground; κ is von Karman's constant (=0.41), z_o is the effective roughness height of the ground terrain; and U_r is the reference velocity at the reference height z_r. The total friction velocity U^* is given by:

$$U^* = U_r \kappa/\ln(z_r/z_o)$$

The reference velocity was taken to be 10m/s at a reference height of 10m. The effective roughness height was taken to be 0.25m. In this case, a WIND object was employed. As the wind direction does not match the grid, the WIND object decomposes the wind speed into the velocity components at the up-wind domain faces and fixed pressure

boundaries at the down-wind faces and the sky boundary. The WIND feature allows changes in wind direction to be introduced easily.

Treatment of terrain

A terrain data file was supplied, but it did not appear to cover the same area as the geometry files. When it was imported at its nominal position, it covered a smaller area than the buildings, leaving a step on the ground plane. Many buildings also disappeared under the ground plane which did not appear correct. The Tsim Shah Tsui area is predominantly flat in any case, hence, in the interests of expedience, it was decided to omit the terrain object from the demonstration and use a flat ground plane with a roughness height of 0.25m. In principle, any terrain would be imported and handled in the same manner as the buildings.

Conclusions

Once the initial geometry issues had been and established and resolved, the above reduced-size case was created and run with a few hours of man-time effort, and 72 hours of computer time when running in parallel-mode on a quad-core computer. The case occupied 13GB of RAM.

The results readily show the variation in wind speed through the street canyons, areas of high turbulence, and calm regions. The plots shown below have been generated using the standard VR-Viewer post-processor which can display vectors, contours, iso-surfaces, high & low spots, and animated view options.

In the same way that alternative CAD products can be used for geometry creation and import into PHOENICS, users also have the option to export the results to third-party post-processors [such as FEMView, Fieldview, Paraview, TECPLOT and Wavefront] for which interfaces are available within PHOENICS.

The case has been passed onto the customer for onward modification and refinement upon larger-capacity computers to meet the stated meshing requirement. It should be noted that the domain may need to be enlarged to meet the original specification, and the meshing increased to provide the stated mesh density requirement. From a practical viewpoint, the resulting calculation will be enormous, and it is then doubtful if it will produce substantially more meaningful results, overall, than the reduced-size model. A more pragmatic solution would be to concentrate mesh in particular areas of interest, rather than model the entire cityscape with the same degree of accuracy.
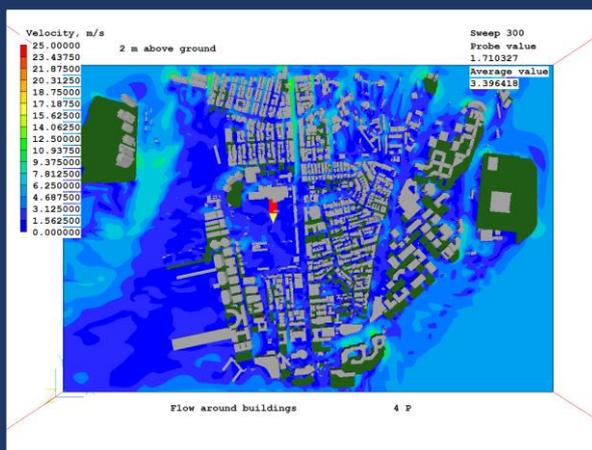
Results

The following images were generated and are shown below:

PLAN VIEW

1.   Wind velocity contours @ 2m above ground
2.   Wind velocity contours @ 5m above ground
3.   Wind velocity contours @ 10m above ground
4.   Wind velocity contours @ 20m above ground
5.   Wind velocity vectors @ 2m above ground
6.   Wind velocity vectors @ 5m above ground
7.   Wind velocity vectors @ 10m above ground
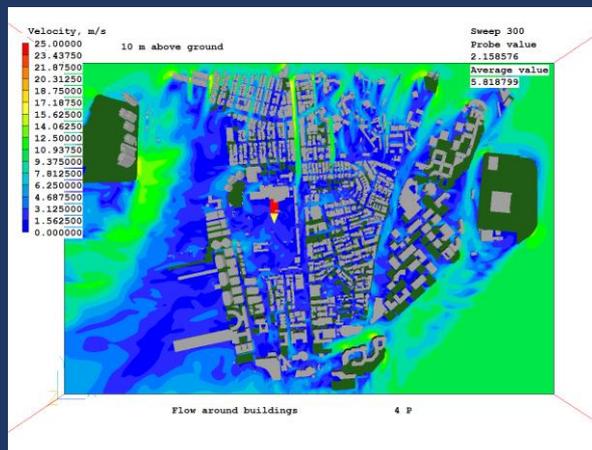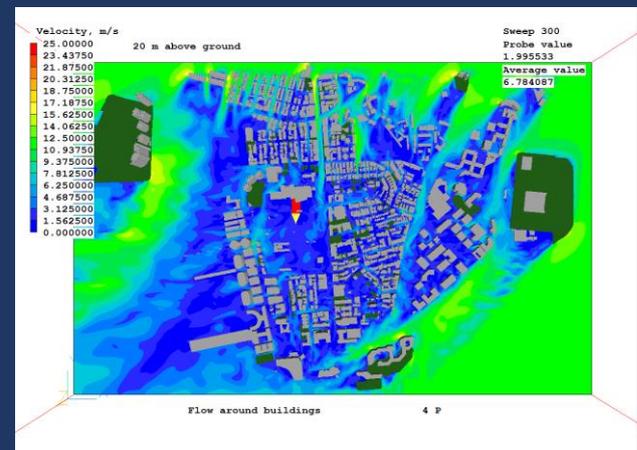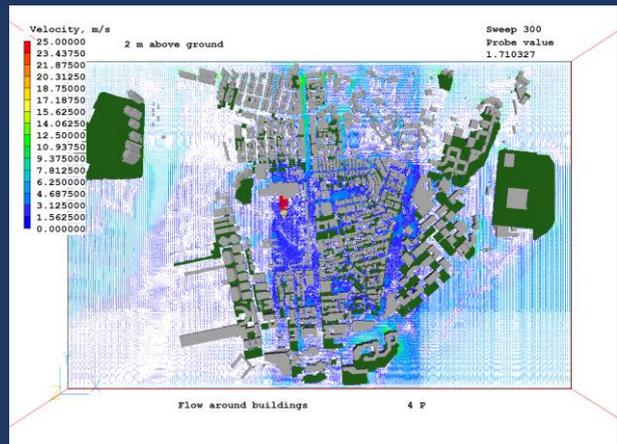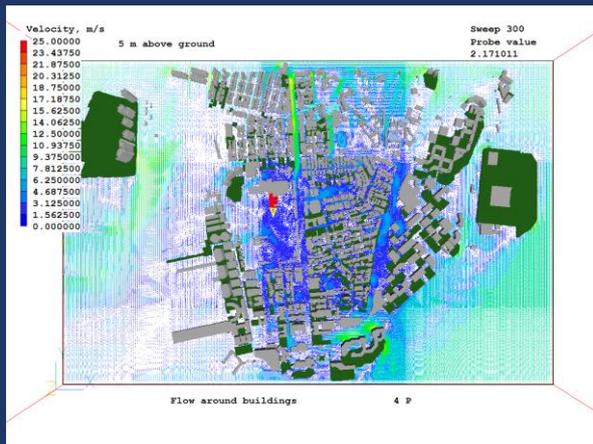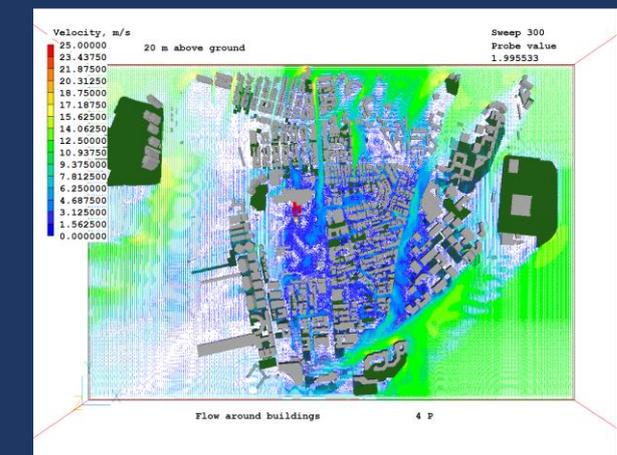8.   Wind velocity vectors @ 20m above ground

9. Zoom image - Wind velocity vectors @ 2m above ground

10. Zoom image - Wind velocity vectors @ 5m above ground

11. Zoom image - Wind velocity vectors @ 10m above ground

12. Zoom image - Wind velocity vectors @ 50m above ground

13. Zoom image - Wind velocity vectors @ 75m above ground

14. Wind velocity contours @ 75m above ground

15. Wind velocity vectors @ 75m above ground ANGLED VIEW

16. Zoom image - Wind velocity vectors @ 75m above ground

17. Streamlines @ 2m above ground

18. Streamlines @ 20m above ground

19. Streamlines @ 50m above ground

Wind velocity contours @ 2m above ground   ↑ North

Wind velocity contours @ 5m above ground   ↙ Wind

Wind velocity contours @ 10m above ground   ↑ North
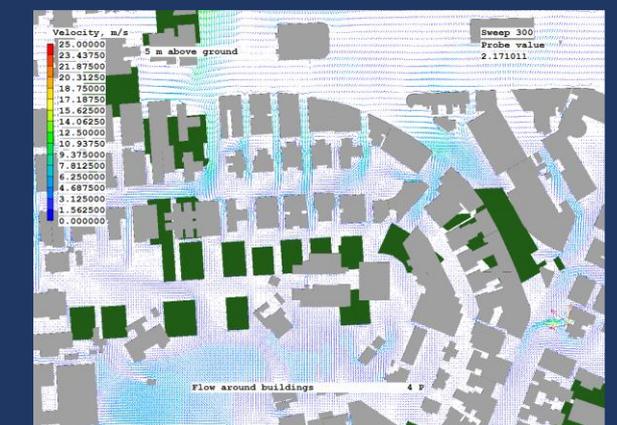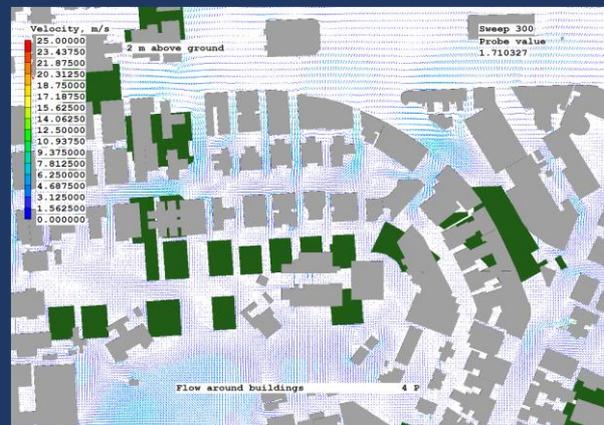
Wind velocity contours @ 20m above ground   ↙ Wind

Wind velocity vectors @ 2m above ground ↑North

Wind velocity vectors @ 5m above ground ↙ Wind

Wind velocity vectors @ 10m above ground ↑North
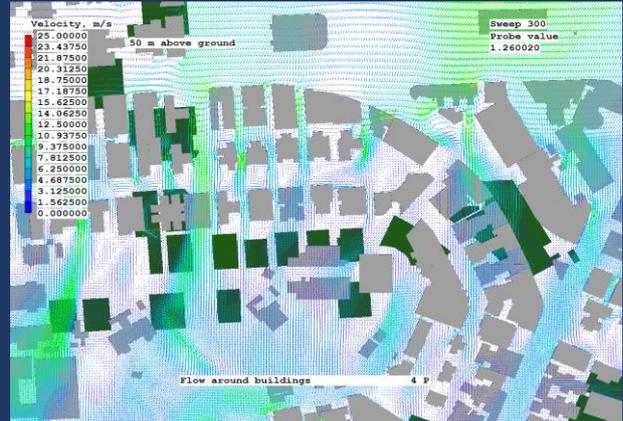

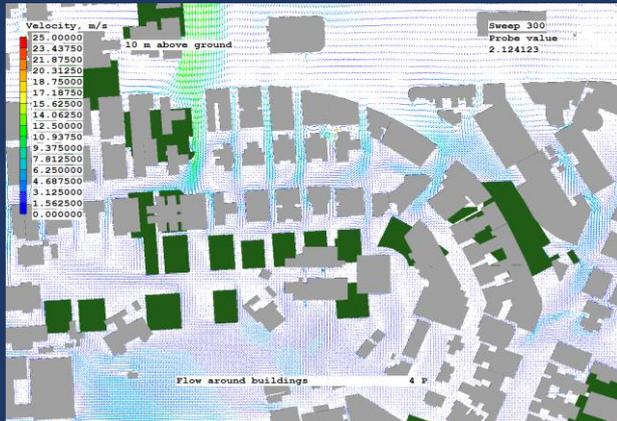**Wind velocity vectors @ 20m above ground** ↙ Wind

Zoom image-Wind velocity vectors @ 2m above ground

↑North

Wind velocity vectors @ 10m above ground
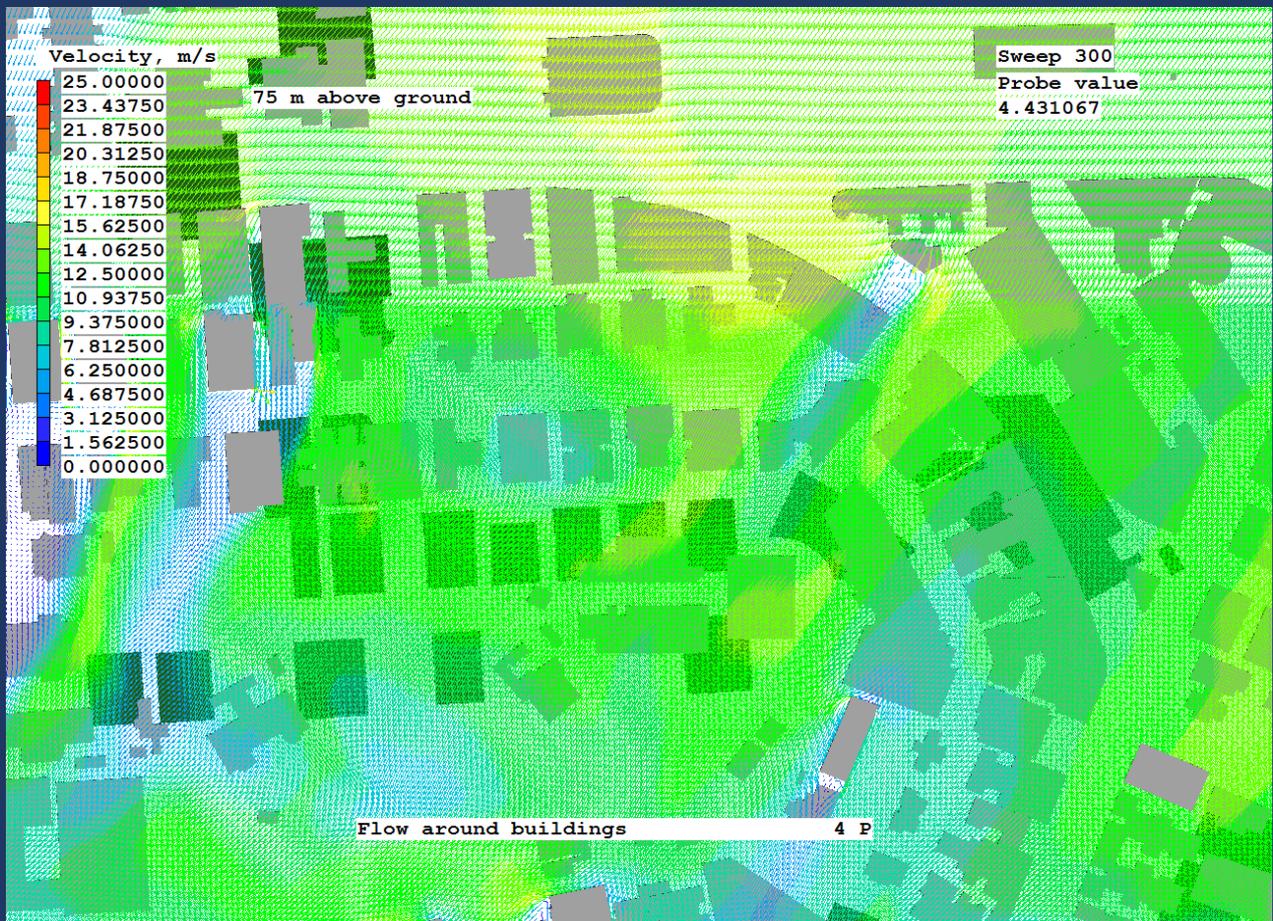
↙ Wind

Zoom image-Wind velocity vectors @ 10m above ground

**Zoom image-Wind velocity vectors @ 50m above ground**
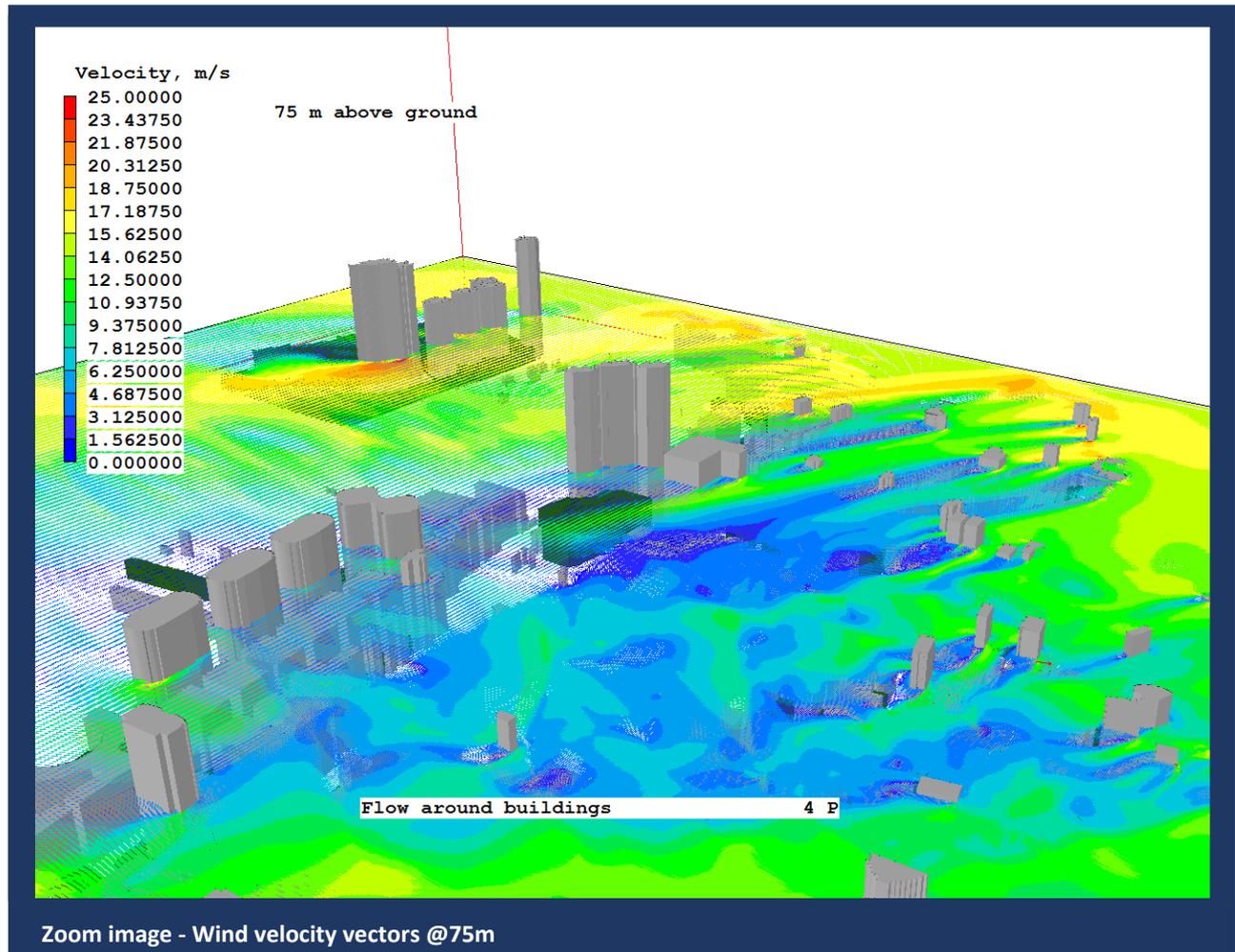
↑**North**

↙ **Wind**

**Zoom image - Wind velocity vectors @ 75m above ground**

The vector fields show interesting zones where the air direction is quite different from the prevailing wind. In Figures 9, 10 and 11 for example, the air near the building at the bottom left (labelled A. in Figure 13) is travelling north.

By 75m above ground, it is travelling South West and has reversed direction. When the image is enlarged, similar features can be seen in many other places. However, it can sometimes be hard to find individual regions of interest if the model becomes too cluttered by detail.

Wind velocity contours @75m above ground
↗**North**

Wind velocity vectors @75m above ground
←**Wind**
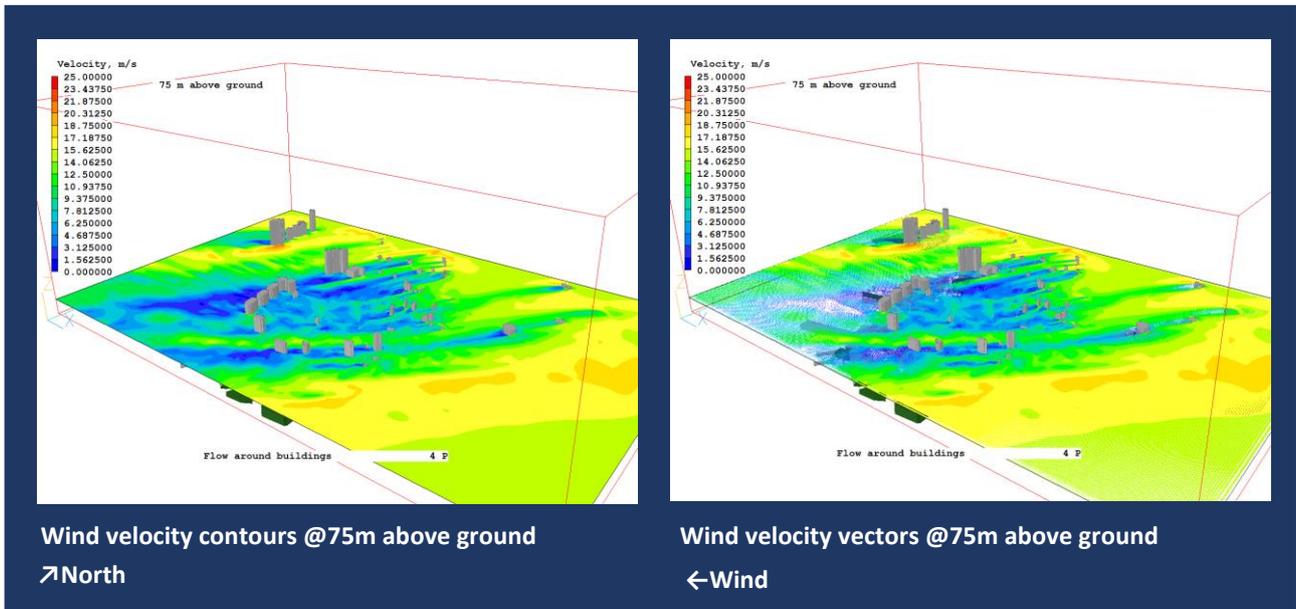
The wakes behind the tall buildings can clearly be seen as blue zones of low velocity downstream, and as regions of higher velocity to the side.

**Zoom image - Wind velocity vectors @75m**
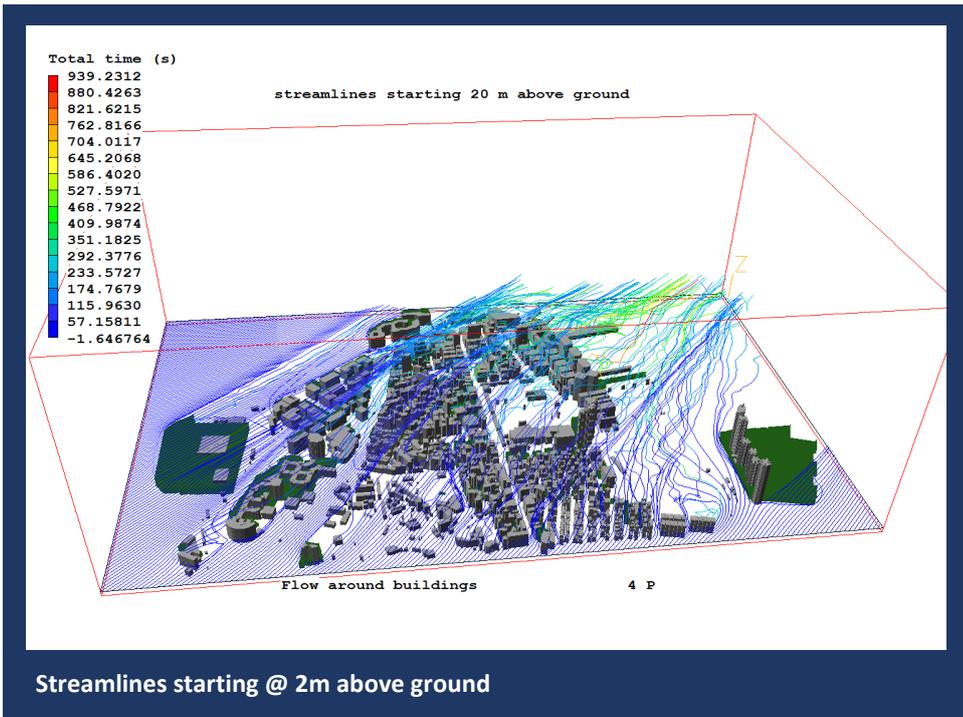
Streamlines starting @ 2m above ground

The streamlines are tracks of 'mass-less' particles. 150 tracks are started along the North face of the domain, and 100 along the East face. Here flow can be seen travelling up the street roughly half-way along the domain. The buildings on either side are quite high and they protect the near-floor flow from the prevailing wind. After a distance, the buildings on the right (West) side become lower with an open space behind them. This allows the wind to pull the air out of the street canyon.

The big green building on the left is forcing the air at this level to pass either side of it.

The time shown on the scale is the time for the slowest track to reach the other side of the domain. [The tracks start roughly 10m inboard of the domain edge, hence the short negative time shown, (which is the time the tracks took to reach the start line from the domain edge.]
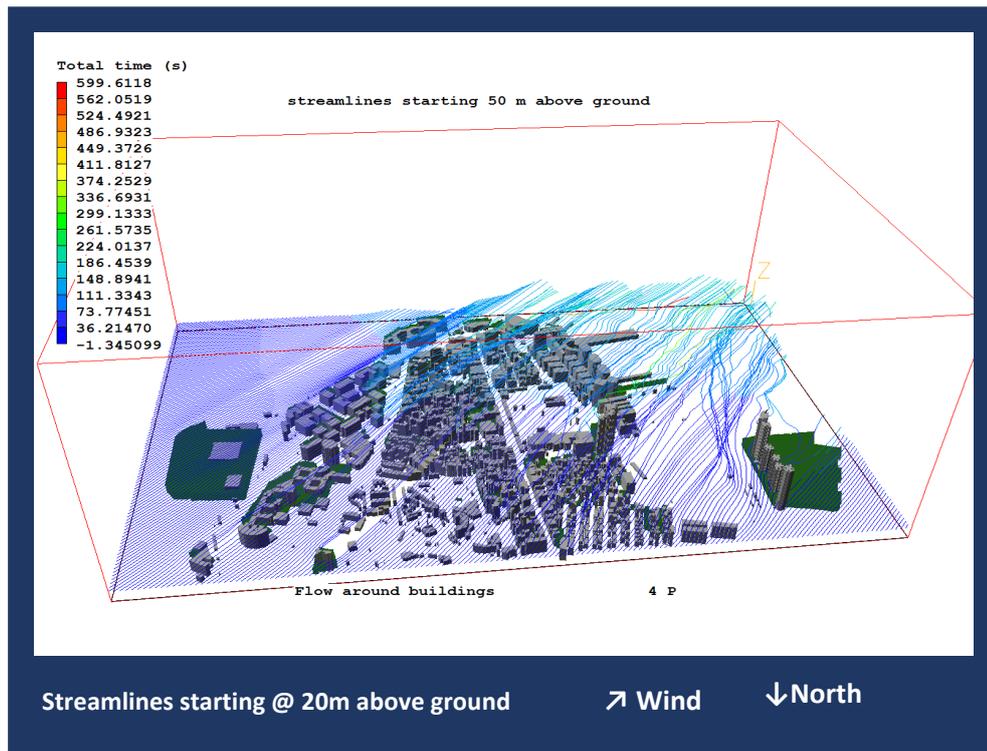
Streamlines starting @ 20m above ground   ↗ **Wind**   ↓**North**

At this height, the canyon effect is much less pronounced. The air now passes over the building on the left. The group of tall buildings on the right act as a barrier forcing air sideways.

Air is now mainly deflected upwards by the buildings below, with only the taller buildings acting as barriers.

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