TALLAWARRA B POWER STATION CFD PLUME MODELLING – GE MODIFIED PDD DESIGN VERSION 3B

SUMMARY REPORT

for Katestone

~~17~~6TH ~~MARCH~~ JULY 2023

Ref 2001

REVISION HISTORY			
No.	**Date**	**Comment**	**Signed**
0	28th February 2023	Draft to Katestone	
1	7th March 2023	Minor report updates	
2	17th March 2023	Implementation of calm wind cases – draft for review	
3	6th July 2023	Minor edits to correct wording and typos	

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EXECUTIVE SUMMARY

Stacey Agnew has been engaged to undertake a detailed 3-dimensional (3D) computational fluid dynamics (CFD) analysis of the stack plume generated by the Tallawarra B Power Station. The high flow and temperature of the plume has a big impact on the atmospheric flow around the stack, and the high vertical velocities in the plume can affect aircraft. It is desired to limit the plume rise velocities by adopting a stack-top diffuser (plume dispersion device or PDD).

This report covers the CFD plume modelling of the 'modified' stack-top diffuser design version 3B proposed by General Electric. The current PDD design version is a result of several design modification steps seeking to meet the project requirements. Geometric parameters and outlet conditions were provided by Katestone and General Electric.

The applied methodology and wind conditions of the plume modelling are based on the CFD validation study and previous studies already undertaken [9] and [11]. In addition to the 'initial' wind case, further investigations have been undertaken to analyse the plume behaviour under calm wind conditions.

The 'modified' PDD design version 3B was analysed for all wind cases using slightly increased flow parameters (2% higher mass flow rate and 5.6°C higher exhaust temperature) compared to the previous analysis [11].

Katestone and General Electric have provided the following details to Stacey Agnew for incorporation into the CFD model:

- Geometric parameters of the stack and plume dispersion device (PDD);
- Stack flow parameters and outlet conditions;
- Meteorological data, and;
- Atmospheric boundary layer (ABL) parameters.

Based on these input data and depending on the wind conditions, the analysed PDD (modified PDD design version 3B from General Electric) shows a total vertical plume rise (height when maximum absolute plume velocity reduces to ambient wind conditions) of up to 1080 m (3543 ft), and a horizontal plume displacement of up to approximately 430 m (1411 ft). These extents refer to the region within which the maximum plume velocity might exceed ambient wind conditions.

In this assessment the plume area is defined as the horizontal area over which the vertical plume velocity exceeds a specific value. This has been done for four different plume rise velocity criterion (areas over which the vertical plume velocity exceeds 6 m/s, 4 m/s, 2 m/s and 1 m/s). At an elevation of 1270 ft (about 387 m), the peak plume rise velocity is 12.9 m/s for the worst-case combined meteorological conditions (maximum value from all elevations above 650 ft of the three analysed cases and the examined flow period of up to 30 minutes). Depending on the plume area definition and the wind scenario, the average plume rise velocity at 200 m (about 650 ft) elevation varies between 7.9 m/s and 4.1 m/s. This wide variation suggests that average velocity over an arbitrarily selected area may not be useful in assessing performance, and another measure should be sought.

In addition to the plume rise velocity analysis already undertaken, an equivalent TAPM 'top hat' profile velocity and radius has been identified for three different heights. This allows a comparison of the CFD results with the TAPM model results, and with criteria based on TAPM outputs. Table 1 summarises the equivalent top hat profile values for the heights and wind cases examined. It also lists the results of a previous study of the initial design of 'modified' PDD for comparison [11].

The final PDD design version 3B has the openings uniformly distributed around the circumference, and therefore closer to each other compared to the 'initial' PDD design. The individual jets released at the PDD openings tend to reattach to each other due to their

proximity and the Coanda effect. Even if the plume extent is wider at lower elevations (related to the higher exit velocity and the 23° downgrade of every second jet), that still results in less air entrainment in the core of the plume and consequently in a larger area with high vertical velocities (related to buoyancy force) compared to the 'initial' PDD design with the 'initial' wind case. The maximum peak rise velocity is similar for both designs but can occur at higher elevations with the final PDD design version 3B.

Within the first 50 to 100 m (164 to 328 ft) in elevation, the individual jets released by the PDD are mainly affected by the density deficit and therefore by the buoyancy force. Above this initial plume region, the wind speed and direction become more relevant in the plume shape and displacement. The analysis of the different wind scenarios showed that, if the ambient temperature is higher, the individual vertical plume jets can stay separated to much higher elevations before they attach to each other. That results in lower plume temperatures and therefore lower plume rise velocities. At lower ambient temperatures and calm wind conditions, the maximum plume rise velocity can reach a peak value of up to 12.9 m/s. Higher wind speeds above 100 m (328 ft) disturb the plume shape more, which results in lower peak velocities compared to the calm wind condition.

All simulation cases showed a transient plume behaviour, where such peak values persisted only for a few seconds. The time-averaged maximum plume rise velocities are in general lower than the transient peaks by about 1 m/s (see Table 7 and Table 1).

As summarised in Table 1, for all three wind cases, the plume rise velocity values obtained with the final PDD design version 3B are very similar to those for the 'initial' PDD design [11].

Beyond the discussion of the relevant average plume rise velocity and the top hat profile equivalence approach in Section 4, CASA stated in their letter [10] that they will accept half of the peak plume rise velocity as the measure for potential impacts on aircraft.

Table 1. Summary of equivalent top hat profile values for different simulation cases and heights.

Plume definition	Unit	650 ft	700 ft	1000 ft
Initial PDD design with 'initial' wind case (initial stack flow parameters) [11]				
Equivalent top hat velocity (u)	m/s	5.5	4.9	3.9
Equivalent top hat radius (R)	m	58.6	69.4	114.3
Max. plume rise velocity from CFD	m/s	**11.5**	11.5	10.7
Initial PDD design with calm wind case (initial stack flow parameters) [11]				
Equivalent top hat velocity (u)	m/s	4.1	4.1	3.7
Equivalent top hat radius (R)	m	81.9	84.8	111.0
Max. plume rise velocity from CFD	m/s	**8.4**	8.1	7.3
Initial PDD design with 'combined' wind case (initial stack flow parameters) [11]				
Equivalent top hat velocity (u)[4]	m/s	6.7	6.6	6.1
Equivalent top hat radius (R)[4]	m	46.6	49.3	65.2
Max. plume rise velocity from CFD[4]	m/s	**11.9 ±0.4**	11.7±0.4	10.5±0.4
Adapted PDD# with 'initial' wind case (20140703_10)				
Equivalent top hat velocity (u)[1]	m/s	3.6	3.5	3.3
Equivalent top hat radius (R)[1]	m	103.7	109.0	152.0
Max. plume rise velocity from CFD at evaluated time step[1]	m/s	9.4	9.7	11.6
Max. plume rise velocity from CFD[5]	m/s	9.3 ±1.7	9.6 ±1.6	**10.8 ±0.8**
Adapted PDD# with calm wind case (20150308 – Calm)				
Equivalent top hat velocity (u)[2]	m/s	4.7	4.7	4.5
Equivalent top hat radius (R)[2]	m	73.6	76.0	89.9
Max. plume rise velocity from CFD at evaluated time step[2]	m/s	10.0	9.9	8.6
Max. plume rise velocity from CFD[5]	m/s	**8.9 ±1.2**	8.8 ±1.2	8.3 ±1.3
Adapted PDD# with 'combined' wind case (Wind: 20150308 – Calm, Temperature: 20140703_10)				
Equivalent top hat velocity (u)[3]		6.3	6.4	7.0
Equivalent top hat radius (R)[3]		53.7	54.5	62.2
Max. plume rise velocity from CFD at evaluated time step[3]		10.1	10.6	12.6
Max. plume rise velocity from CFD[5]	m/s	9.8 ±0.7	10.1 ±0.7	**11.6 ±1.1**

[1] Values are evaluated at 370 s (maximum value at 1000 ft AMSL over simulation period).

[2] Values are evaluated at 560 s (maximum value at 650 ft AMSL over simulation period).

[3] Values are evaluated at 1060 s (maximum value at 1000 ft AMSL over simulation period).

[4] Values are based on analysed timestep of a transient simulation. Fluctuations are observed over a period of about 20 minutes [11].

[5] Time averaged values over simulation period for comparison to the previous study [11].

Final PDD design version 3B with increased stack flow parameters.

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1 INTRODUCTION

Tallawarra B is a gas fired power project comprising an open-cycle gas turbine (OCGT) plant designed to meet the electricity demand in the NEM (National Electricity Market). The OCGT units produce a large volume of hot exhaust gas that rises quickly into the atmosphere, generating updraughts with potentially high vertical velocities at high elevations. These updraughts and vertical velocities have potential to adversely affect aircraft flying in the vicinity of the stack.

To reduce vertical velocity and temperature of the plume, General Electric has offered for consideration a modified plume dispersion device (PDD) design (initial 'modified' PDD solution) which has been adjusted during the design process. This report covers the CFD results only of the final modified PDD solution (PDD design version 3B) offered by General Electric (see Figure 2). Some of the previous results regarding the 'initial' design of 'modified' PDD solution are also included in Section 3.4 for comparative purposes only. The geometric parameters and stack outlet conditions were provided by General Electric.

A previous investigation covered a CFD validation study of a simple circular stack with defined boundary conditions that are applicable to the power station. These results were documented in a separate report [9]. The CFD study on the previous design of the modified diffuser solution (see Figure 1) with different wind cases is also documented in a separate report [11].

The simulation methodology and wind conditions for this investigation are adopted from the CFD studies already undertaken [9] [11]. The final design of the modified top stack diffuser (PDD version 3B) was analysed for three different wind case with the increased stack flow parameters.

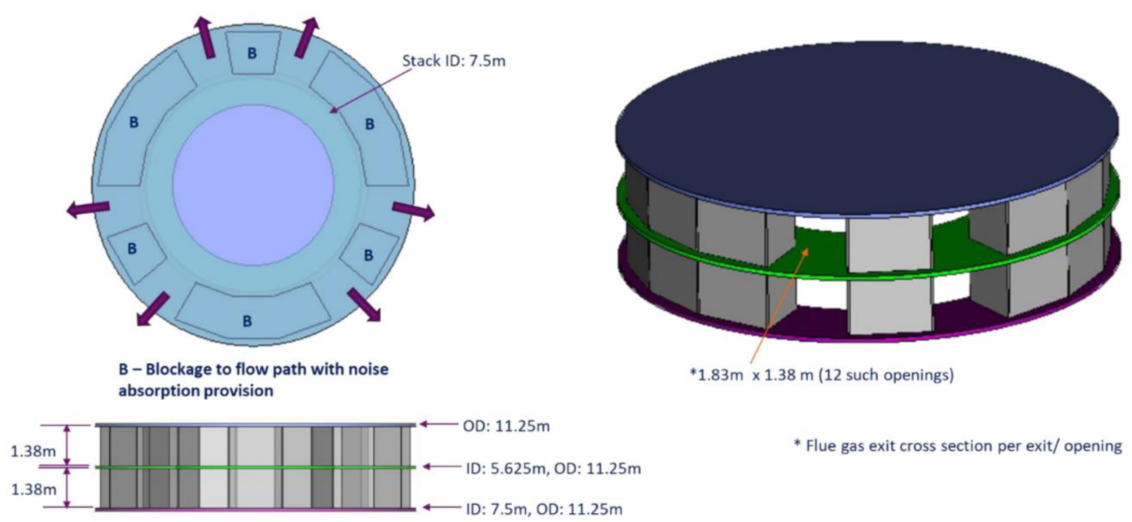


Figure 1. Sketch of initial design of 'modified' PDD solution proposed by GE [7].

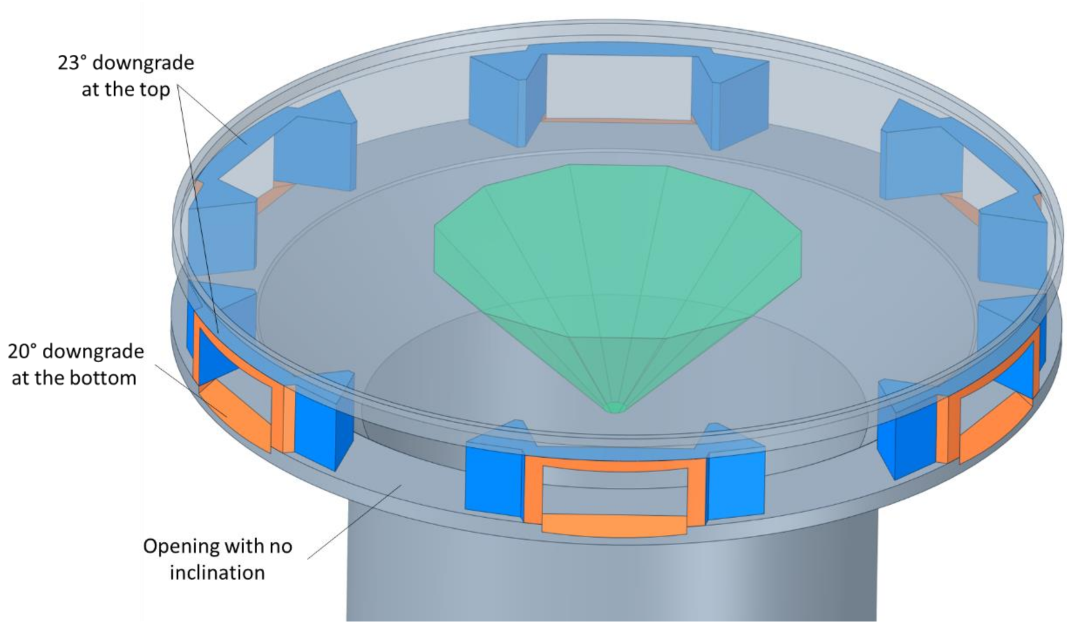


Figure 2. Sketch of the final PDD design version 3B proposed by GE [12].

2 METHODOLOGY

The simulation methodology used for this CFD study is based on the CFD validation case [9], summarised below.

2.1 Simulation Software

Tallawarra B Power Station plume modelling was carried out using the CFD-software ANSYS Fluent (Release 2020 R1) [1], [2], [3]. Fluent is a commercial generic CFD software for modelling fluid flow, heat transfer and chemical reactions in complex geometries. Table 2 lists the CFD model parameters used.

Table 2. CFD model parameters.

Parameter	Description
CFD-method and solver	Pressure based, steady-state Reynolds-averaged Navier-Stokes (RANS) solver with a spatial discretisation method of 2nd order. A second order discretisation method was used in order to avoid numerical diffusion. As the flow field gave indication of an transient behaviour, a unsteady Reynolds-average Navier-Stokes (URANS) solver was used to analyse the transient plume behaviour in a final stage.
Turbulence model	Realizable k-ε model with scalable wall function [2], [4]. The Realizable k-ε was developed to more accurately predict the spreading rate of planar and round jets (involving all jet regions) and provides adequate performance for flows involving rotation, boundary layers under strong adverse pressure gradients, separation and recirculation [1], [2]. This turbulence model was used because of the anticipated flow behaviour (jet flow at stack). A scalable wall function was used for the ground effects.
Thermal conditions	Ground surface was considered as flat, with a constant ground temperature according to the meteorological data provided [5]. The buoyancy effects of the hot smoke at the stack outlet are considered by using the incompressible ideal gas law and solving the energy equation rather than using the Boussinesq approach. The former approach determines the air density via the ideal gas law at a defined operating pressure, whereas the latter considers the buoyancy forces in the momentum equation where the density is determined via the thermal expansion coefficient β and a constant operating temperature T_0. The Boussinesq approximation eliminates the density from the buoyancy term and is only valid as long as changes in actual density are small $\beta(T-T_0) << 1$ [1].

2.2 Meteorological Conditions and Terrain

The meteorological input data for the validation case were provided by Katestone [5] and [6]. The following data were extracted from the "20140703_10" and 20150308 - Calm data set provided:

- Wind speed
- Wind direction

- Potential temperature (The temperature difference between a rising parcel of air and the adjacent ambient air)

Figure 3 illustrates the profiles of the applied atmospheric boundary layer (ABL). The plume rise was analysed for the meteorological conditions "20140703_10" as illustrated in Figure 3. These conditions were selected from the TAPM modelling output that resulted in the 99.9th percentile plume average vertical velocity at 700 ft. Based on the initial study and CFD results, a further wind case with rather calm wind conditions has been analysed, to assess the sensitivity of the plume behaviour and the maximum plume rise velocity to the wind. A calm wind was defined by Katestone as being less than 0.5 m/s.

Figure 4 shows the segment of occurring wind direction relative to the domain orientation for both wind cases. Depending on the height, the wind direction for the 'initial' wind case (20140703_10) changes from NNE (7°) to SSW (212°) and the wind speed from 0.5 to 6 m/s (2000 m above ground level). The wind profile for the calm wind case (20150308 – Calm) changes direction from NNE (17°) to W (272°) and the wind speed changes from 0.1 to 3.8 m/s as the elevation changes from 0 to 2000 m (0 to 6562 ft) above ground level. At around 210 m (about 700 ft), the wind speed is less than 0.5 m/s. In both wind cases, the potential temperature increases with height, which relates to a stable atmosphere. The domain orientation (as shown in Figure 4) was chosen to suit each wind profile so that the majority of the wind directions are captured with the inlet boundary conditions and so the domain orientation is different for the two wind profiles.

Compared to the initial wind profile, the average ambient temperature (from ground level to 2000 m or 6562 ft) for the calm wind profile is 7.2°C higher. A change of 7.2°C in the ambient temperature seems very minor. However, it seems that calm wind case has very different results to the 'initial' wind case, so there was a need to understand the temperature and wind effects separately. To analyse the sensitivity of the plume rise velocity to the wind speed and the ambient temperature individually, a third wind case has also been assessed. This 'rather artificial' wind case combines the wind direction and speed of the calm wind case (20150308 – Calm) with the "cooler" temperature profile of the 'initial' wind case (20140703_10). The resulting three wind cases analysed are summarised in Table 3 below.

Table 3. Wind cases used for the CFD-study.

Wind case	Wind profile	Temperature profile	Average ambient temperature
'Initial' wind case	20140703_10		16.4°C
Calm wind case	20150308 – Calm		23.6°C
'Combined' wind case	20150308 – Calm	20140703_10	16.4°C

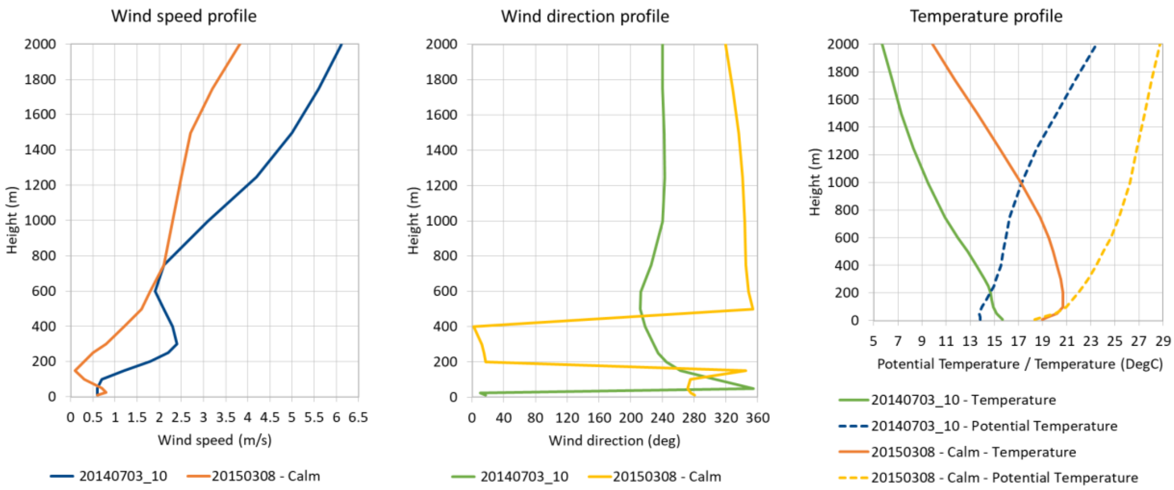


Figure 3. Profiles of wind speed (left), wind direction (middle) and temperature (right) used for the assessment [5], [6].

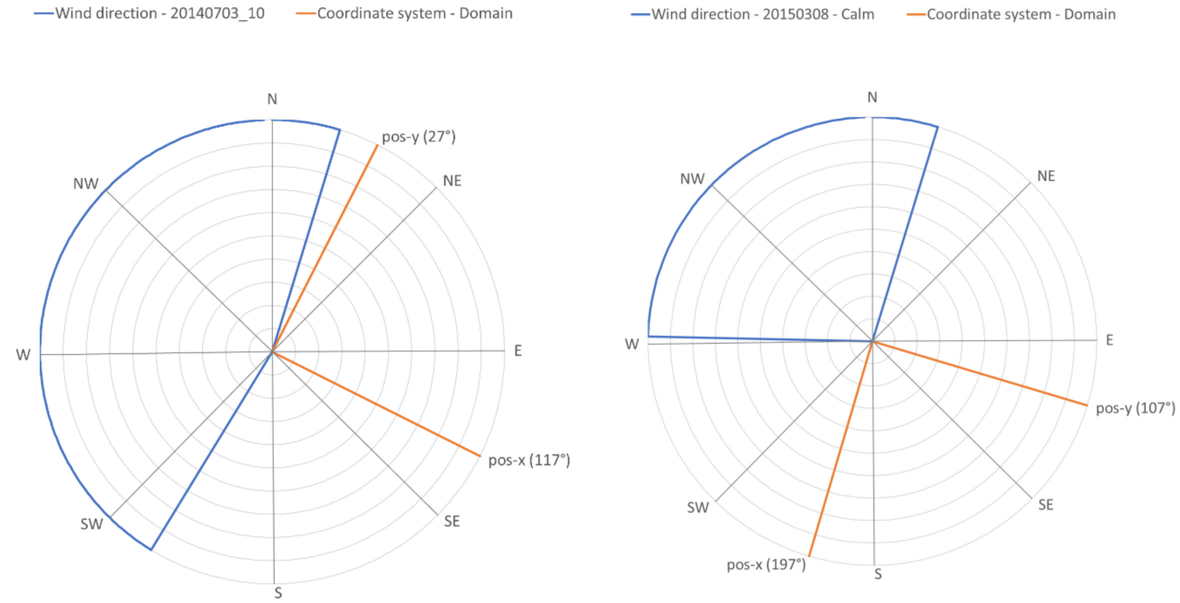


Figure 4. Segment of occuring wind direction (blue) and coordinate system of the computational domain (orange) for the 'initial' (left) and the calm (right) wind profile.

Figure 5 shows the terrain within an area of 34 × 34 km around the assessed site with a resolution of 1 km. As can be seen in Figure 5, the terrain around the power station within several kilometres is relatively flat (red circle). Because the domain for the CFD plume analysis is within the order of the terrain resolution, a flat terrain was used for the investigation. It was assumed that the terrain and surface influences were included in the velocity profile provided.

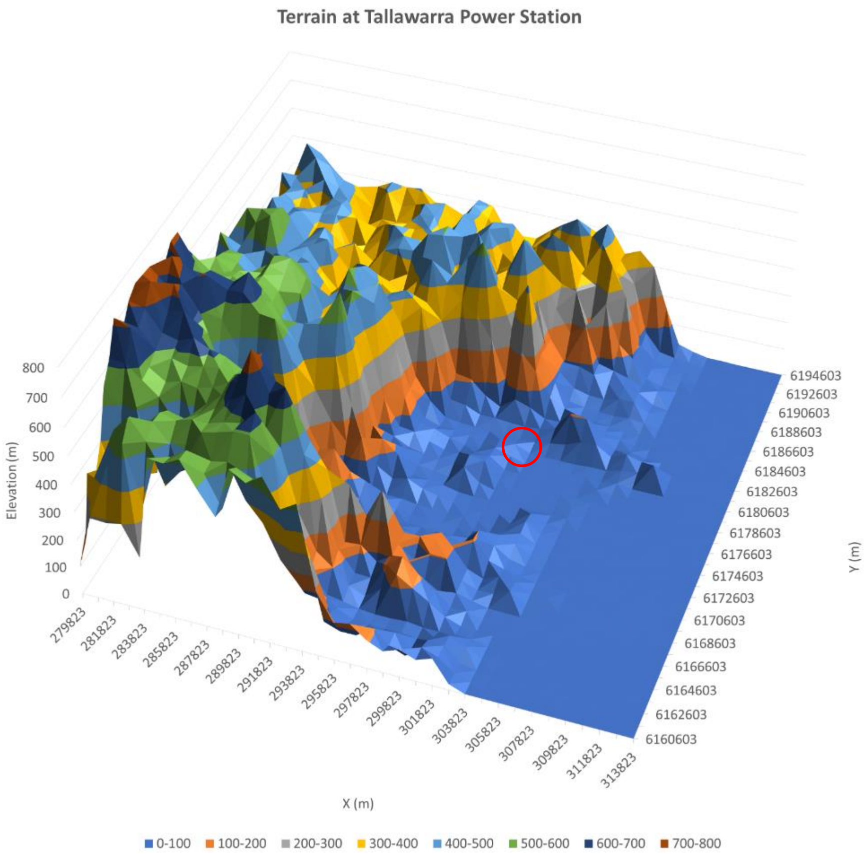


Figure 5. Terrain within an area of 34 km × 34 km around the site (resolution: 1 km).

2.3 Geometry and Computational Domain

Figure 6 depicts the computational domain and mesh for the plume modelling. An overall domain size of 3700 x 3700 m with a height of 2000 m was adopted so that the boundary conditions would have no adverse influence on the simulated plume flow around the stack. Domain orientation for the two velocity profiles is illustrated in Figure 4. The stack was positioned in the middle of the domain (in x-direction) and 3000 m upwind of the outlet boundary condition (in y-direction). The station building was not modelled. The point of origin is at the stack centre at ground level. The adapted design of the PDD (Version 3B) has in total 12 openings all at the same level evenly distributed around the circumference. To increase the separation between the individual jets and increase the overall entrainment, the outlet of every second opening has a downgrade inclination with a 23° deflector at the upper surface and a 20° chamfer at the bottom surface. Table 4 lists the geometric stack and PDD parameters according to [12] to [15][1] and repeats the parameters regarding the initial design of 'modified' PDD previously analysed [7]. Figure 2 and Figure 7 show a sketch of the modified PDD.

Table 4. Geometric parameters of the PDD solution according to [7] and [12] to [15].

PDD solution	Initial design of 'modified' PDD	Final PDD design version 3B
Stack X coordinate (m)	298,895	298,895
Stack Y coordinate (m)	6,177,812	6,177,812
PDD exit height above ground (m)	46.5	45
PDD outlet dimensions (m)	1.83 x 1.38	1.93 x 0.98 1.85[1] x 0.96 (inclined)
PDD total outlet area (m^2)	30.3	22.1
PDD outlet angle from vertical (deg)	90	90 113 (every 2nd opening)
PDD stack split number	12	12
PDD exit distance from stack CL (m)	5.6	5.7

[1] See footnote on page 12.

The geometry was meshed with polyhedral surface elements in combination with hexahedral-core elements (see Figure 6). Polyhedral elements are only employed to connect the prism with the hexahedral elements in the direct proximity of the walls and boundaries. As shown in Figure 6, the remaining domain is discretised with hexahedral elements exclusively. To resolve the boundary layer at walls, prism elements were used. The maximum element sizes employed were as follows:

- outer domain surface (top, sides and ground): 10 m
- stack surface: between 0.8 and 0.4 m, and;
- global mesh size within the domain: 25 m.

A body of influence with a total height of 200 m was to create a fine mesh around the stack plume for enhanced resolution. Element sizes were defined based on distance away from the stack as follows:

- 0.1 m within the internal diffuser region and immediately outside;

[1] The PDD diameter in the provided Parasolid 3D CAD file [14] was about 20 mm less than the PDD diameter (11.456 m) noted in the "as built" drawings [13]. The PDD diameter of the provided 3D CAD geometry used for the CFD study has been adjusted to reflect the "as built" diameter. That resulted into a slightly reduced opening area for the inclined openings. It also explains the slightly different opening width in Table 4 compared to Figure 7.

- 0.6 m within the first 40 m, and;
- 1.2 m within the following 120 m.

The resulting initial mesh had approximately 15 million elements.

Based on this initial mesh, several mesh refinement steps within the plume region were undertaken so that the plume area was sufficiently resolved. The refinement steps and mesh resolution used were obtained from the mesh refinement study already undertaken during the validation case. The final maximum element size within the plume region was about 3.2 m. These parameters resulted in a mesh size with approximately 35 million elements.

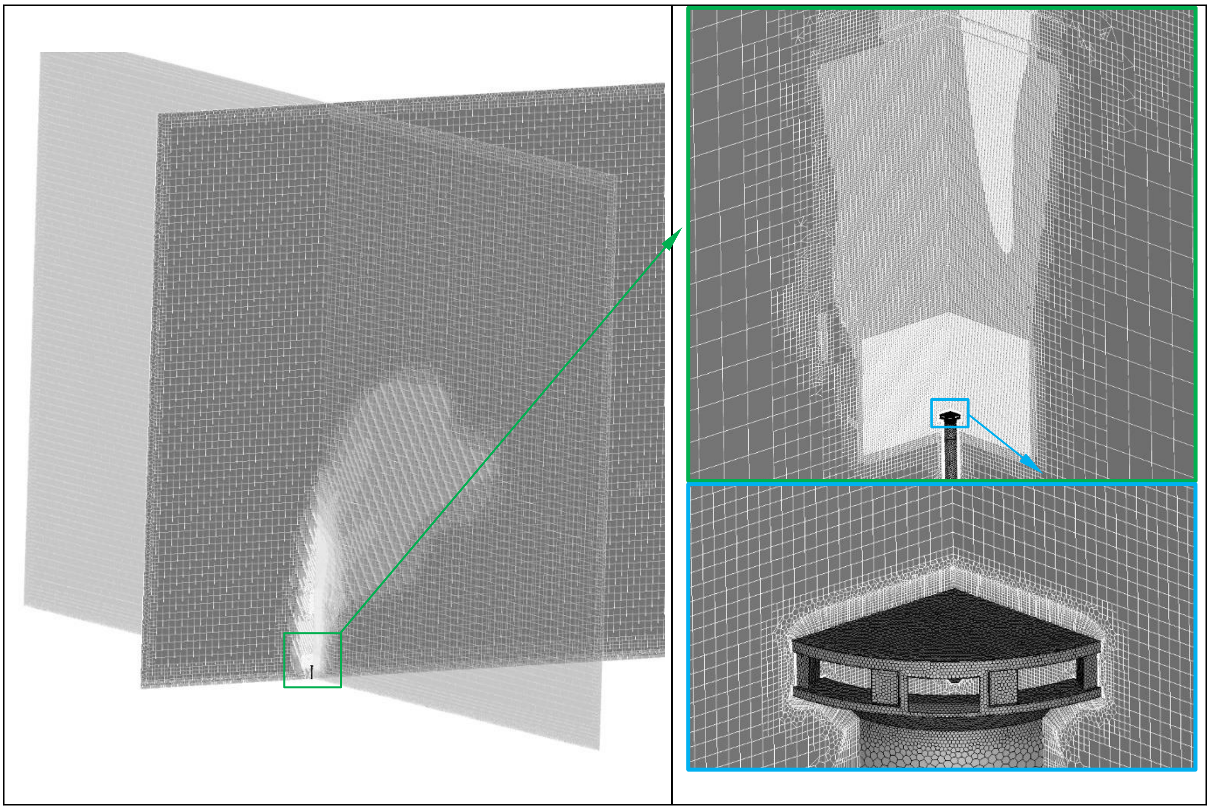


Figure 6. Computational mesh after several mesh refinement steps –final PDD design version 3B.

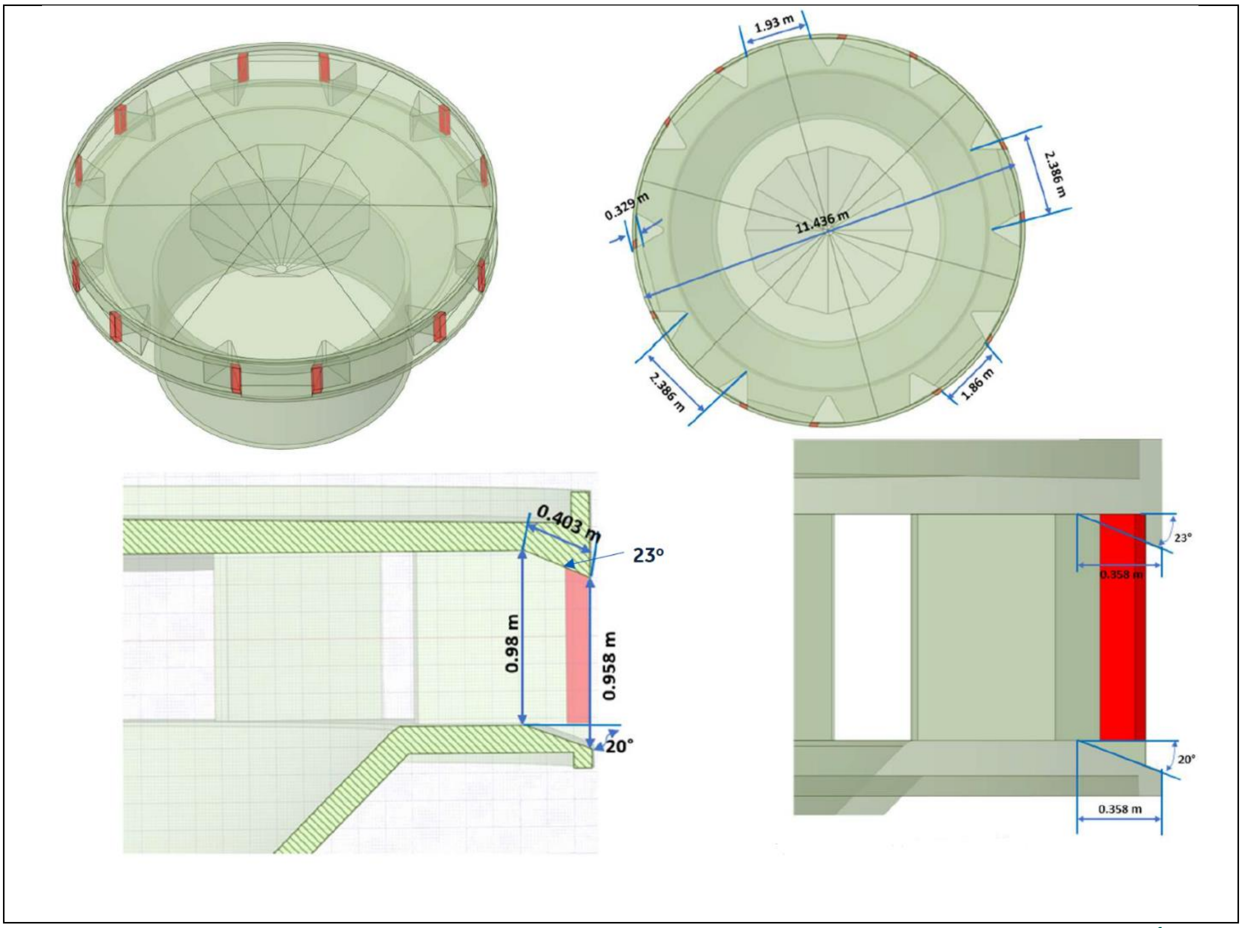


Figure 7. Sketch and dimensions of the final PDD design version 3B proposed by GE [13], [14] & [15][1].

2.4 Input Parameters and Boundary Conditions

The flow field around the stack is defined by the wind speed and temperature profile according to Figure 3. As the profiles of the ABL start at a height of 10 m, all values were extrapolated to the ground level. The wind direction and potential temperature were kept constant from 10 m to the ground, whereas the velocity was extrapolated by assuming 0 m/s and a roughness height of 0 m at ground level. The surface roughness has only a slight influence on the velocity profile below a relative elevation of 10 m. The stack flow parameters according to [7] and [15] are given in Table 5. For comparison, the average exit velocity based on the 'initial' PDD is also provided in Table 5. Table 6 lists all applied boundary conditions for the plume modelling.

The velocity vector (based on wind speed and direction at different heights) of the analysed wind profiles was decomposed in its x- and y-components according to the domain orientation (see also Figure 4). These height-dependent velocity components were applied on the 'inlet' boundaries (velocity inlet as noted in Table 6). A positive velocity component at the inlet boundary means flow is going into the domain and a negative velocity component means flow is going out of the domain. This is a general practice in CFD and allows to capture all wind speeds and directions at the two inlet boundaries. The applied velocity and temperature profile changes the pressure field in the whole domain. To maintain the velocity and consequently the temperature field in the whole domain, the appropriate pressure profile has to be applied at the 'outlet' boundary (pressure outlet as noted in Table 6). Depending on the local pressure at the outlet boundary, flow can come into or going out of the domain, as such boundary conditions allow for backflows. The appropriate backflow conditions were specified (see also Appendix B). More comprehensive and specific information on the functionality of the inlet and outlet boundaries applied can be found in [1] and [2].

The turbulent intensity at the inlet boundary is specified as 5% and the turbulent viscosity ratio as 10. However, the specification of the turbulence parameters at the inlet boundary has insignificant influence on the plume behaviour as the boundaries are far away from the stack outlet and the turbulence parameters are developed within the domain, based on the velocity and temperature profile and their gradients.

In order to demonstrate the correct implementation of the boundary conditions as listed in Table 5 and Table 6, as well as to provide more information on the flow behaviour through the domain, additional contour plots and vertical velocity and temperature profiles are given in Appendix B

Table 5. Stack flow parameters [7], [15].

Parameter	GE-initial stack flow parameters	GE-increased stack flow parameters
Average exit velocity at each nozzle outlet[2]	63.24 m/s[#]	89.15 m/s[*]
Total mass flow rate	746.0 kg/s	760.9 kg/s
Exit temperature	633.7 °C	639.3 °C

[2] Hand calculation based on average opening/outlet area, total mass flow rate, exit temperature / density and an atmospheric pressure of 101.325 kPa.

Calculation based on initial design of 'modified' PDD

* Calculation based on final PDD design version 3B

Table 6. Boundary conditions for the validation plume modelling.

Location	Boundary condition
Two sides of the domain (negative x and y)	Velocity inlet with ABL (including wind direction and temperature) according to Figure 3 [5].
Two sides of the domain (positive x and y)	Pressure outlet with temperature profile according to Figure 3
Top of the domain	Wall with full slip condition and constant temperature of 23.4°C to for wind case '20140703_10' and 28.8°C for wind case '20150308 – Calm' to maintain the velocity and temperature on the top of the domain.
Ground	Wall with fixed wall temperature of 13.9°C for wind case '20140703_10' and 18.4°C for wind case '20150308 – Calm' (surface roughness height $z_0 = 0.0\ m$)
Stack wall	Adiabatic wall
Stack outlet	Mass flow inlet (according to Table 5, right column) applied down in the cylindrical stack as the internal nozzle and stack geometry is resolved (see Figure 6).

3 RESULTS

The plume generated by the adapted PDD led to quite high fluctuations of the monitored plume velocities, indicating a transient behaviour. To appropriately assess the plume rise velocity, the flow field was finally analysed with a transient solver over a period of up to 30 minutes. Figure 8 to Figure 10 illustrate the time-dependent peak velocity fluctuations at different heights and the time steps at which the additional wind cases were assessed. The monitored values are the maximum occurring vertical velocity values within a horizontal plane cut through the whole domain. Based on the transient simulation, the detailed plume behaviour was assessed at the times when the maximum peak rise velocity occurred at the three monitored elevations for the individual wind cases.

For the 'initial' wind case this was at 1000 ft above mean sea level (AMSL) at 370 s, for the calm wind case it was at 650 ft (AMSL) at 560 s, and for the 'combined' wind case it was at 1000 ft (AMSL) at 1060 s. For the three wind cases, the average value, as well as the maximum and minimum occurring peak rise velocities observed during the simulation period of up to 30 minutes for the different elevations, are listed in Table 7.

Note that the plume rise velocity values at the different elevations were monitored at 1 s intervals, but result files were saved every 10 s. Therefore, a result file close to the observed peak value was chosen for the detailed analysis. That explains the slight difference between the peak values listed in Table 7 (based on 1 s intervals) compared to the peak values listed in Table 1 as well as in Table 8 to Table 10.

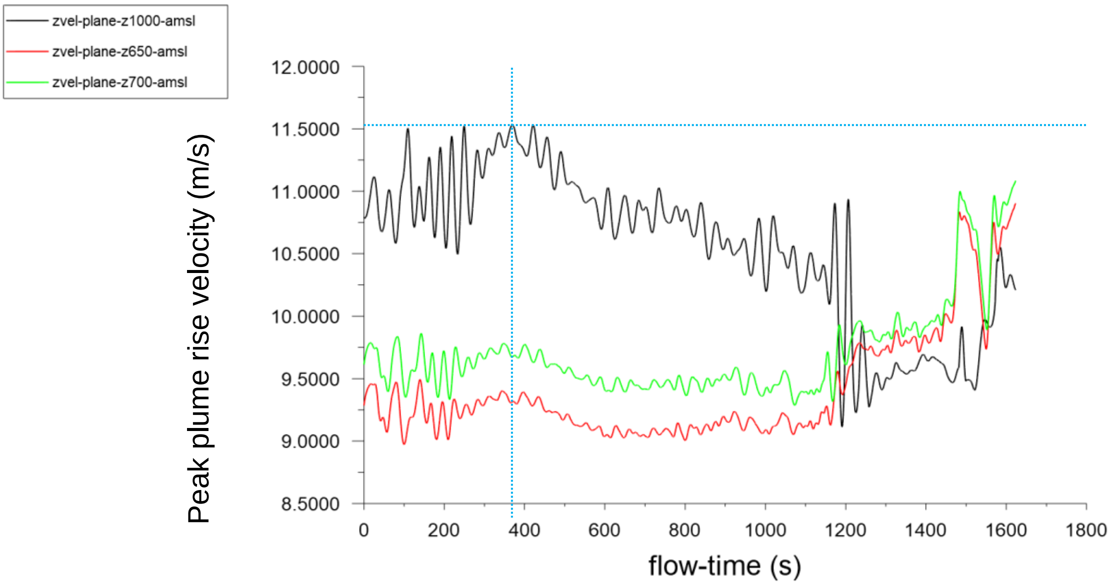


Figure 8. Monitored peak velocities at different heights depending on the simulation time – 'Initial' wind case. The blue dotted vertical line illustrates the simulation time chosen for the detailed analysis.

Figure 9. Monitored peak velocities at different heights depending on the simulation time – Calm wind case. The dashed orange vertical line illustrates the simulation time chosen for the detailed analysis.

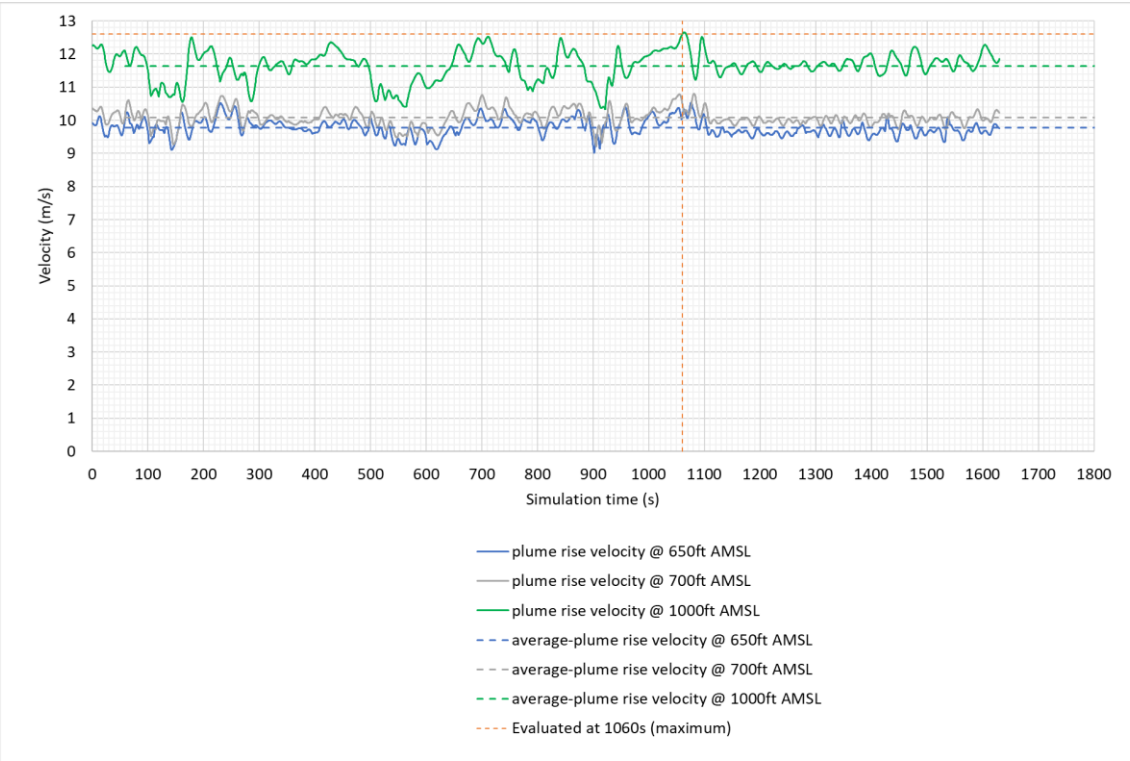


Figure 10. Monitored peak velocities at different heights depending on the simulation time – 'Combined' wind case. The dashed orange vertical line illustrates the simulaton time chosen for the detailed analysis.

Table 7. Average values and outliers of the peak plume rise velocity at different hights observerd during the simulation period of about 30 minutes. Numbers in parentheses are deviations from the average.

Elevation	Average peak plume rise velocity (m/s)	Maximum peak plume rise velocity (m/s)	Minimum peak plume rise velocity (m/s)
'Initial' wind case (20140703_10)			
650 ft AMSL	9.3	11.0 (+1.7)	9.0 (-0.3)
700 ft AMSL	9.6	11.2 (+1.6)	9.3 (-0.3)
1000 ft AMSL	10.8	11.6 (+0.8)	9.1 (-1.7)
Calm wind case (20150308 – Calm)			
650 ft AMSL	8.9	10.1 (+1.2)	7.2 (-1.7)
700 ft AMSL	8.8	10.0 (+1.2)	7.1 (-1.7)
1000 ft AMSL	8.3	9.6 (+1.3)	6.9 (-1.5)
'Combined' wind case (Wind: 20150308 – Calm, Temperature: 20140703_10)			
650 ft AMSL	9.8	10.5 (+0.7)	9.0 (-0.8)
700 ft AMSL	10.1	10.8 (+0.7)	9.2 (-0.9)
1000 ft AMSL	11.6	12.7 (+1.1)	10.3 (-1.3)

To analyse the plume velocity as well as plume temperature against height and downwind distance, two different plume trajectories were defined. The first trajectory was created by evaluating the maximum absolute plume velocity at different heights at 1 m intervals. The second trajectory was created by evaluating the maximum vertical plume velocity, also at different heights at 1 m intervals.

The following Sections 3.1 to 3.3 describe and evaluate the plume behaviour for the adapted PDD design version 3B with the increased stack flow parameters (see Table 5) and the 'initial' wind case according to Table 3. Section 3.4 provides a comparison of the adapted PDD design (version 3B, with increased stack flow parameters) against the previous CFD results regarding the 'initial' design of the modified PDD (initial stack flow parameters), both with the 'initial' wind case. The results for the different wind conditions based on the adapted PDD design version 3B are compared in Section 3.5. Equivalent plots of plume velocity, extend and displacement as well as comprehensive contour plots as given in Sections 3.1 to 3.3 for the adapted PDD design with the 'initial' wind case are also given for the sensitivity wind cases in Appendix A . More details about the results of the previous CFD model regarding the initial PDD design are given in [11].

3.1 Plume Velocity and Temperature Against Height – 'Initial' Wind Case for Final PDD Design Version 3B

Figure 11 shows the plume volume where the vertical plume velocity is > 6 m/s. The volume colour refers to the plume height.

Figure 12 (left) shows the maximum vertical and absolute plume velocity against height as well as the atmospheric wind speed profile according to Figure 3. The bottom plot in Figure 12 shows the plume velocities in greater detail, with lines indicating the elevations 650 ft, 700 ft and 1000 ft above mean sea level. The red line in those plots is a mark of twice the average plume rise velocity requirement.

The maximum plume velocity reaches the ambient wind value at approximately 910 m (2986 ft) above the ground level. The maximum vertical plume velocity at this point is approximately 1.3 m/s. The plume temperature (right side of Figure 12) decreases rapidly with height and comes to within 0.5°C of the ambient value at about 800 m (2625 ft) above ground.

Figure 13 depicts the plume area against height (left) and the average plume velocities (right) within this area. Here the plume area is defined as horizontal area in which the vertical plume velocity is > 6 m/s. In addition, Figure 14 shows a similar plot and compares the plume area and average vertical plume velocity for different plume area definitions (area in which vertical plume velocity is > 6 m/s, > 4 m/s, > 2 m/s and > 1 m/s). Depending on the plume area definition, the average plume rise velocity varies between 7.5 m/s and 4.6 m/s at an elevation of 200 m (about 650 ft). Figure 17 illustrates the plume extent for the different vertical plume velocity criteria, based on value-clipped contour plots for vertical velocity.

The average vertical velocity and the plume area both vary dramatically with the choice of the vertical velocity taken as defining the plume edge. It is not clear whether any of the plume edge definitions gives a measure relevant to the effect on aircraft. Another measure that is not sensitive to the definition of the edge would be preferable.

In order to compare the CFD results with the TAPM model results and consequently with criteria based on TAPM outputs, a different averaging method has to be used (see Section 4).

The energy released by the stack is relatively large (high mass flow rate and temperature), which causes, in combination with the proposed PDD, an unusual jet flow behaviour within the first 200 m (656 ft) in height. The stack exhaust is alternately expelled in the horizontal direction, and slightly downward, at every second opening (90° and 113° to the stack, respectively) with a very high temperature. This high temperature (low density) generates high buoyancy forces, which turn the horizontal and downward jets upwards, coalescing into a large single vertical jet (requires about 100 m or 329 ft in height). As soon as the plume is vertical and joined together, the remaining plume temperature difference (low density), and therefore the buoyancy head, is still high enough to further accelerate the plume from approximately 7.4 to 11.8 m/s (maximum plume rise velocity). This explains the increase in plume rise velocity from an elevation of about 95 m to 340 m (312 ft to 1115 ft). Due to the almost horizontal release of the plume, the vertical plume velocity within the first 20 m (66 ft) is much lower than the absolute velocity (see Figure 12 and Figure 13). Once the plume rises vertically, the maximum vertical and absolute plume velocity are very similar. Figure 15 and Figure 16 illustrate the velocity and temperature distribution of the initial jet flow region. Figure 16 illustrates well the dispersion benefit of deflecting every second jet downwards.

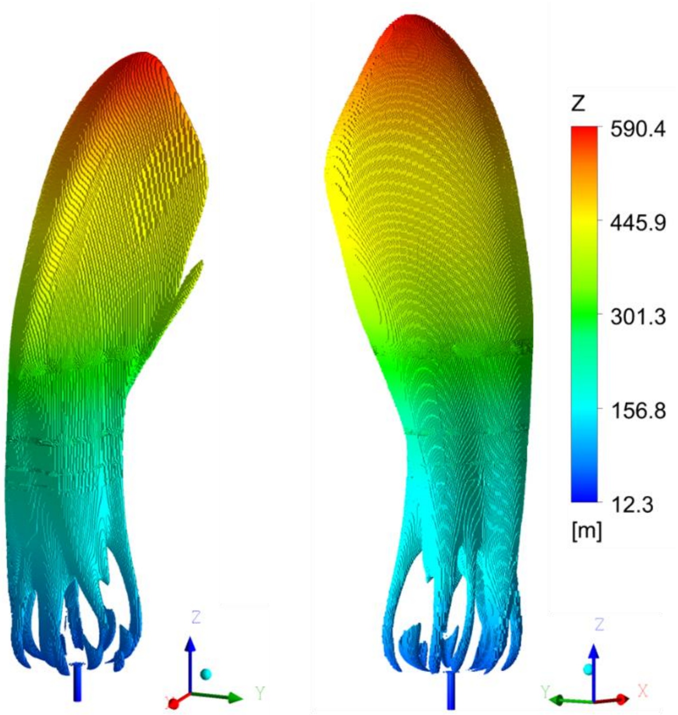


Figure 11. Plume volume where vertical plume velocity is > 6 m/s – 'Initial' wind case. Colours refer to the plume height.

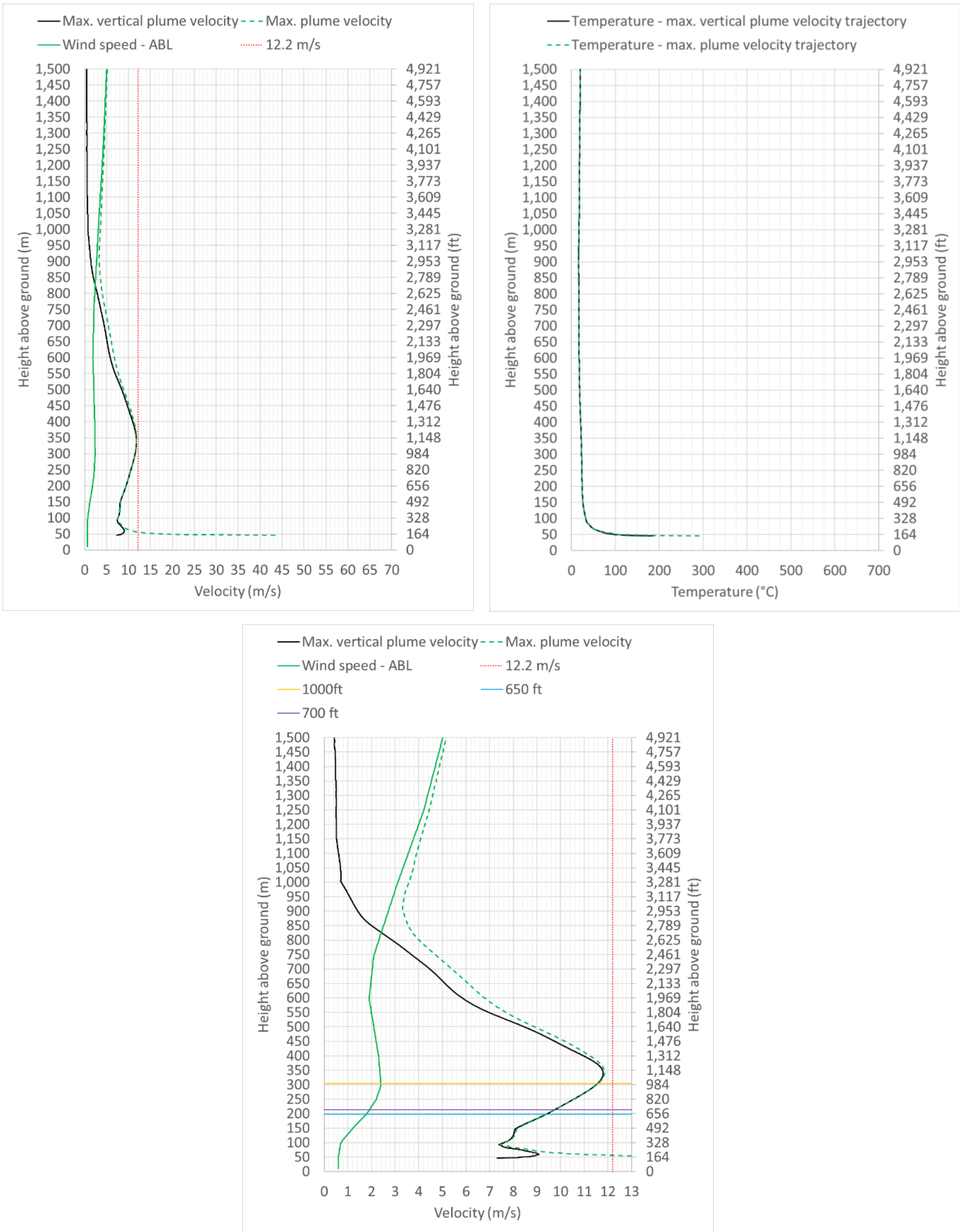


Figure 12. Wind speed and maximum vertical and absolute plume velocity against height (left) and plume temperature along both trajectories (right) – 'Initial' wind case. Plot at the bottom shows the plume velocities on an expanded scale.

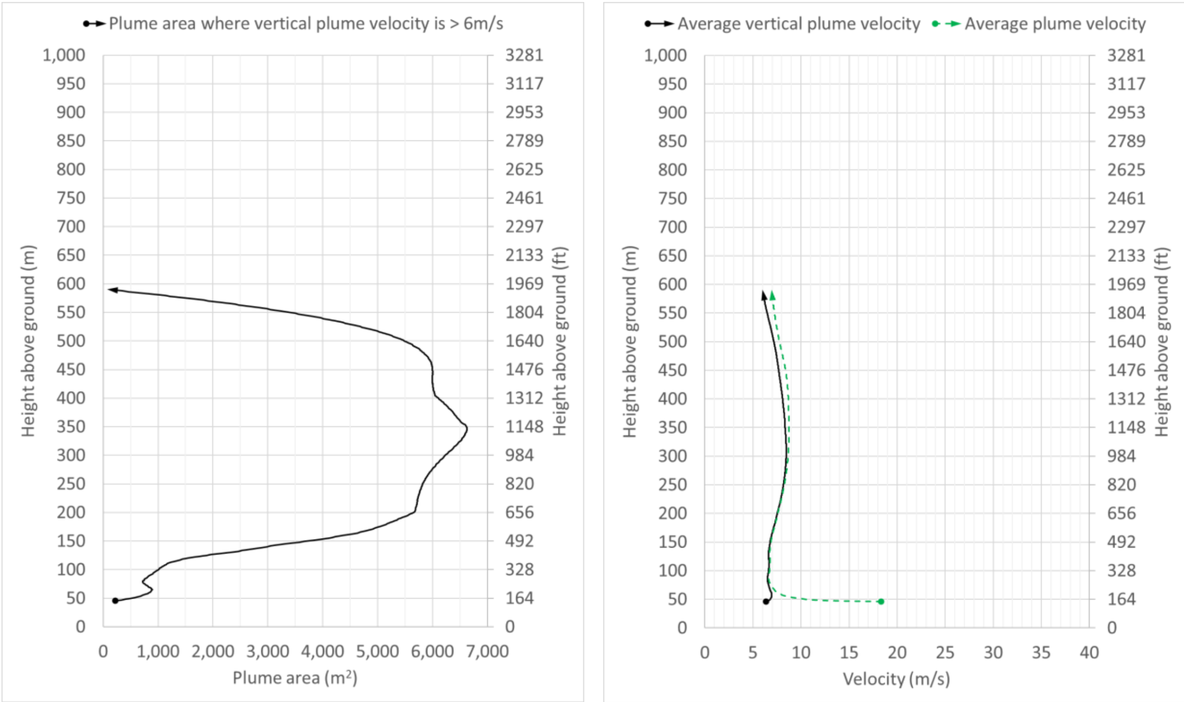


Figure 13. Plume area (area where vertical plume velocity is > 6 m/s) (left) and average plume velocities against height (right) – 'Initial' wind case. Note that with the definition of plume area being where the vertical velocity exceeds 6 m/s, the average vertical velocity in the 'plume' clearly can't fall below 6 m/s.

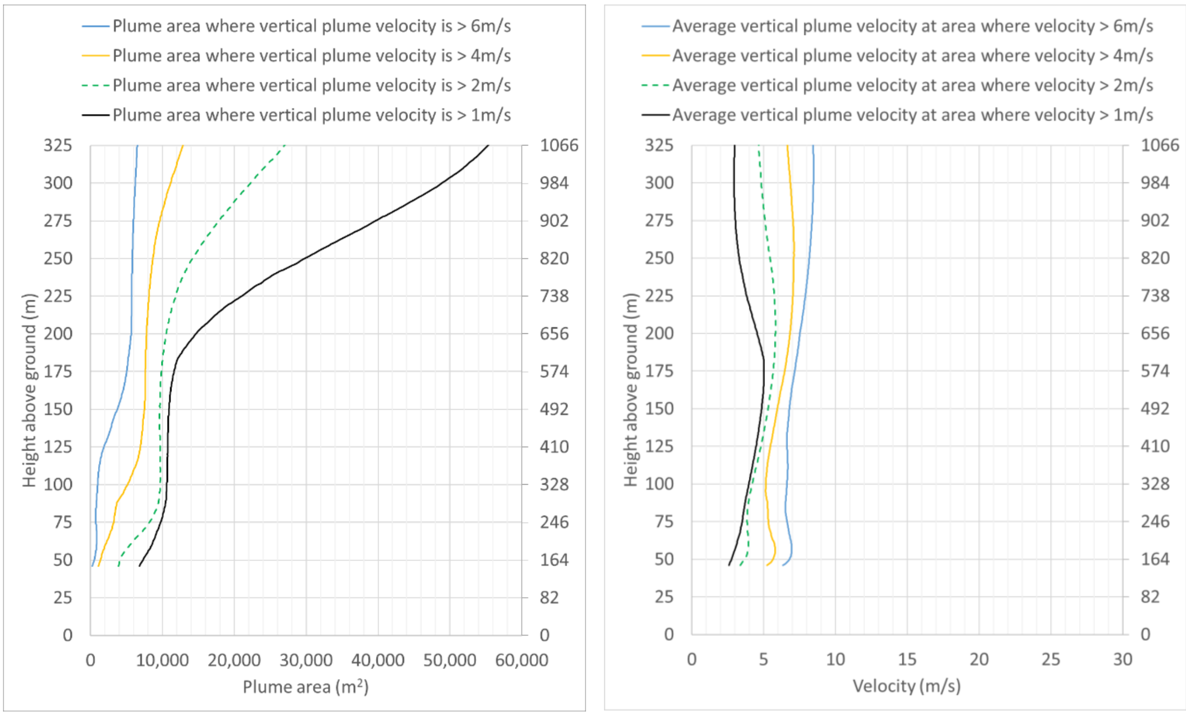


Figure 14. Plume area (left) and average plume velocities against height (right) for different plume area definitions – 'Initial' wind case.

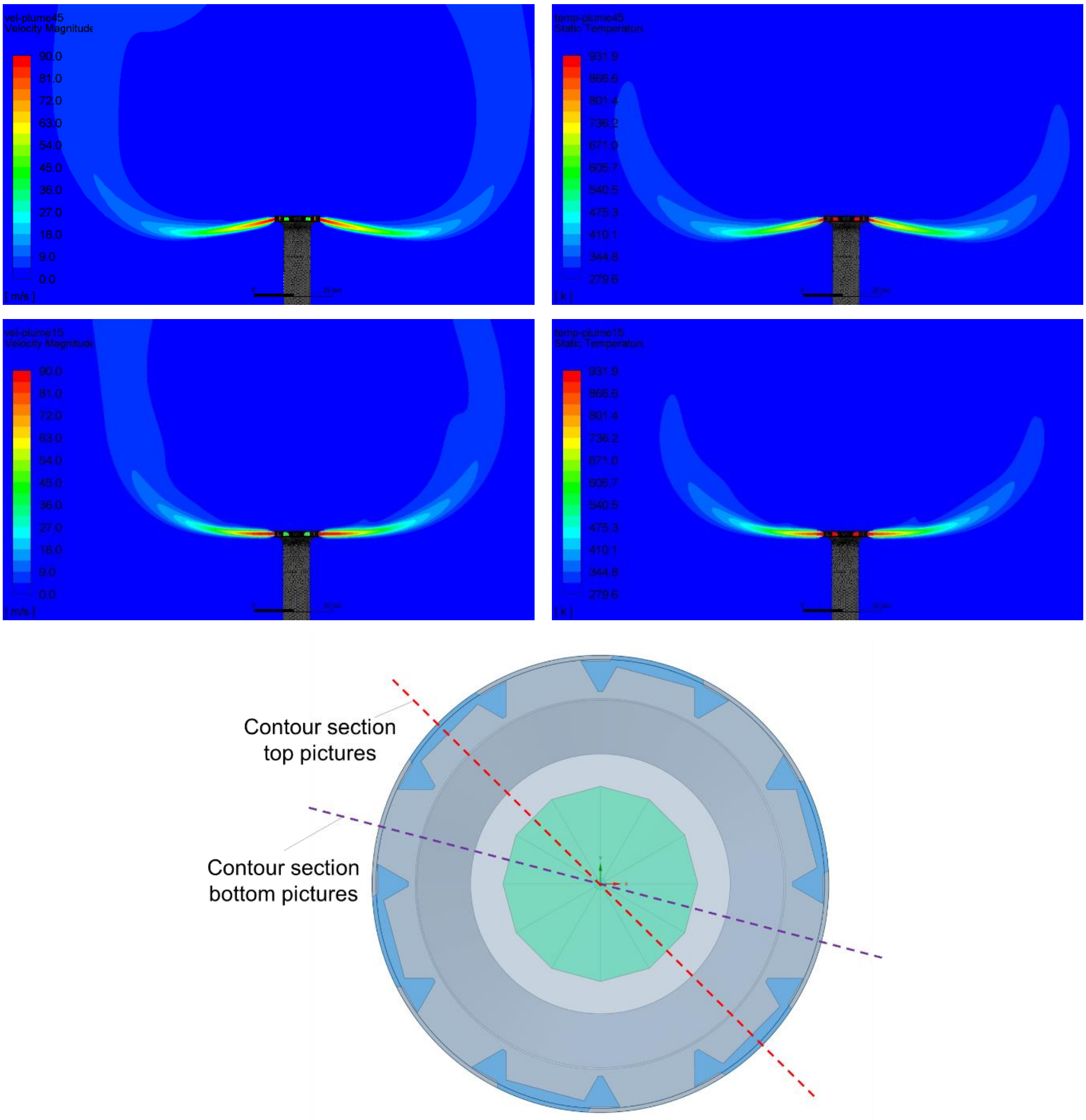


Figure 15. Contours of velocity (left pictures) and temperature (right pictures) close to the stack – 'Initial' wind case. The top pictures show a section through the downward deflected openings and the bottom pictues a section through the horizontal openings.

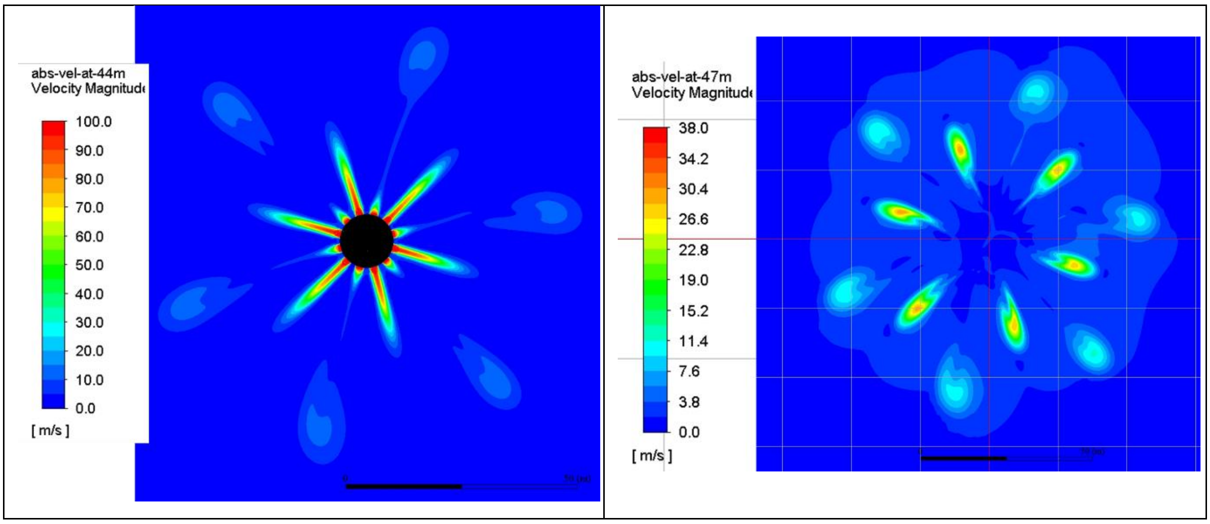


Figure 16. Contour of velocity through the nozzle openings (~~top~~left) and about 2 m above the stack outlet in plan view (~~bottom~~right) – 'Initial' wind case. Grid spacing in the ~~bottom~~ right picture is 20 m.

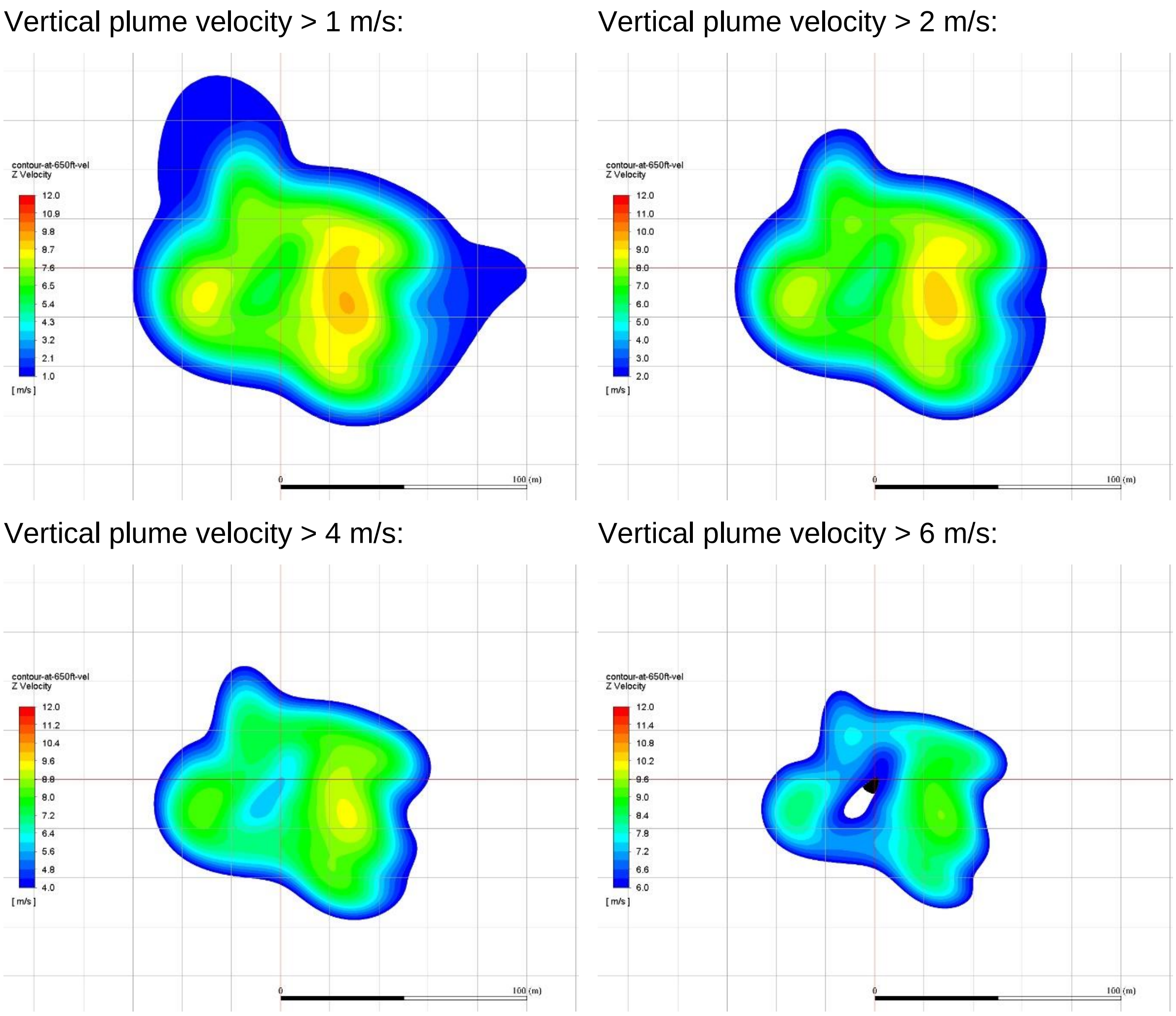


Figure 17. Plume extent shown as contour plots of vertical velocity in a horizontal plane at 198 m (650 ft) elevation – 'Initial' wind case. The plume area in each contour plot is clipped to a different vertical plume velocity: > 6 m/s (bottom right), > 4 m/s (bottom left), > 2 m/s (top right) and > 1 m/s (top left). Grid spacing is 20 m with stack centre at the origin (red lines).

3.2 Plume Core Velocity Displacement – 'Initial' Wind Case for Final PDD Design Version 3B

Because the plume rapidly turns nearly vertical, the growth in horizontal displacement of the locations of the maximum absolute plume velocity and maximum vertical velocity are very similar, as illustrated in Figure 18.

The maximum absolute plume velocity is a superposition of the plume rise velocity and the ambient wind speed. Once the plume core velocity drops nearly to ambient wind speed, the location of the maximum absolute plume velocity is sensitive to the local wind components. In this region, the location of the maximum absolute plume velocity can be slightly different to the location of the maximum vertical velocity.

In the figures, the coordinates are based on the domain, which means that positive y aligns with the direction NNE (27°). The maximum plume velocity reaches ambient wind conditions at an elevation of approximately 910 m (2986 ft) (where green lines join together, top left plot in Figure 12). The maximum plume velocity varies with height between the several jets, which leads to the displacement jumps seen at lower elevation in Figure 18. The individual jets coalesce at an elevation of approximately 150 m (492 ft). The total horizontal displacement of the plume core is approximately 430 m (1411 ft).

Figure 19 shows the horizontal trajectory of the maximum vertical velocity component as well as the maximum absolute plume velocity in compass coordinates (abscissa towards north and ordinate towards east).

In general, the horizontal displacement of the plume is mainly caused by the applied wind conditions and will vary for different wind speeds and directions.

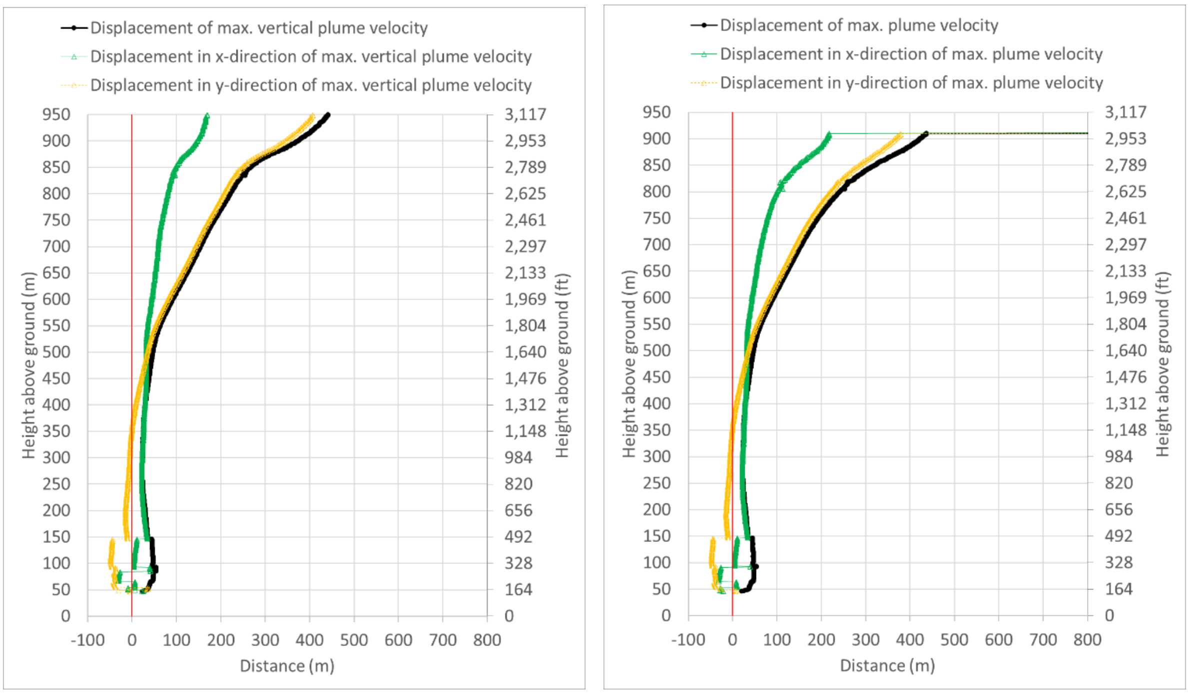


Figure 18. Displacement of maximum vertical velocity component (left) and of maximum absolute velocity (right) against height – 'Initial' wind case.

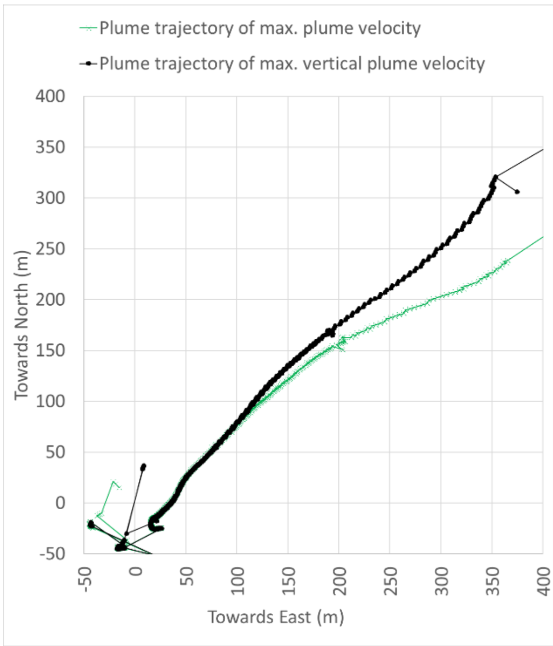


Figure 19. Horizontal trajectory of maximum vertical velocity and plume core velocity in compass coordinates – 'Initial' wind case.

3.3 Contour Plots – 'Initial' Wind Case for Final PDD Design Version 3B

Figure 20 to Figure 23 are contour plots of velocity magnitude, vertical velocity, and air temperature on x-z and y-z planes through the stack centre, or on horizontal planes at different heights. The black lines in Figure 21 to Figure 23 show the x and y planes through the stack centre. Contours are clipped for clarity.

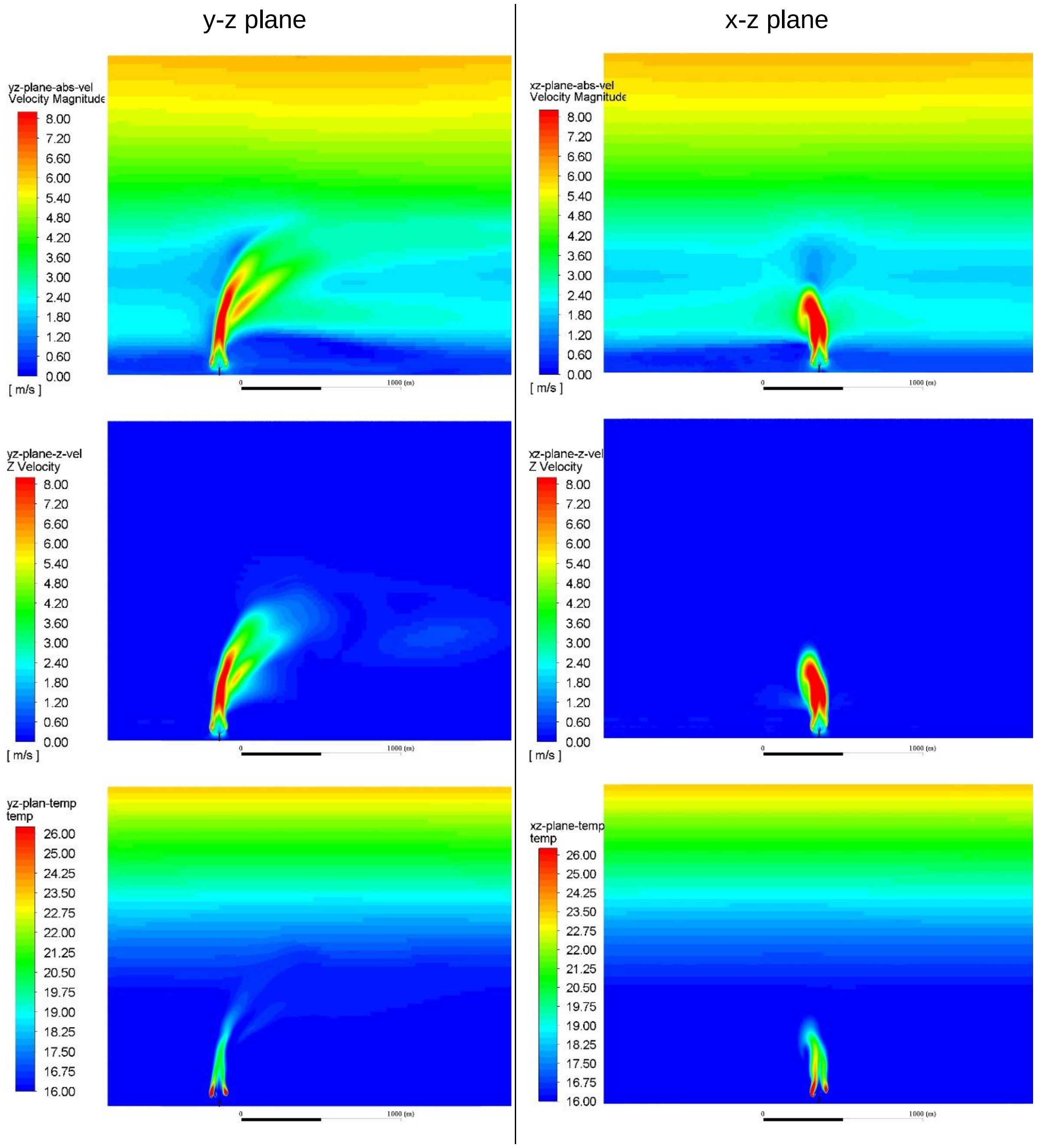


Figure 20. Contour plot in y-z plane (left) and x-z plane (right) through the stack centre for velocity magnitude (top), vertical velocity (middle), and temperature (bottom) – 'Initial' wind case for final PDD design version 3B.

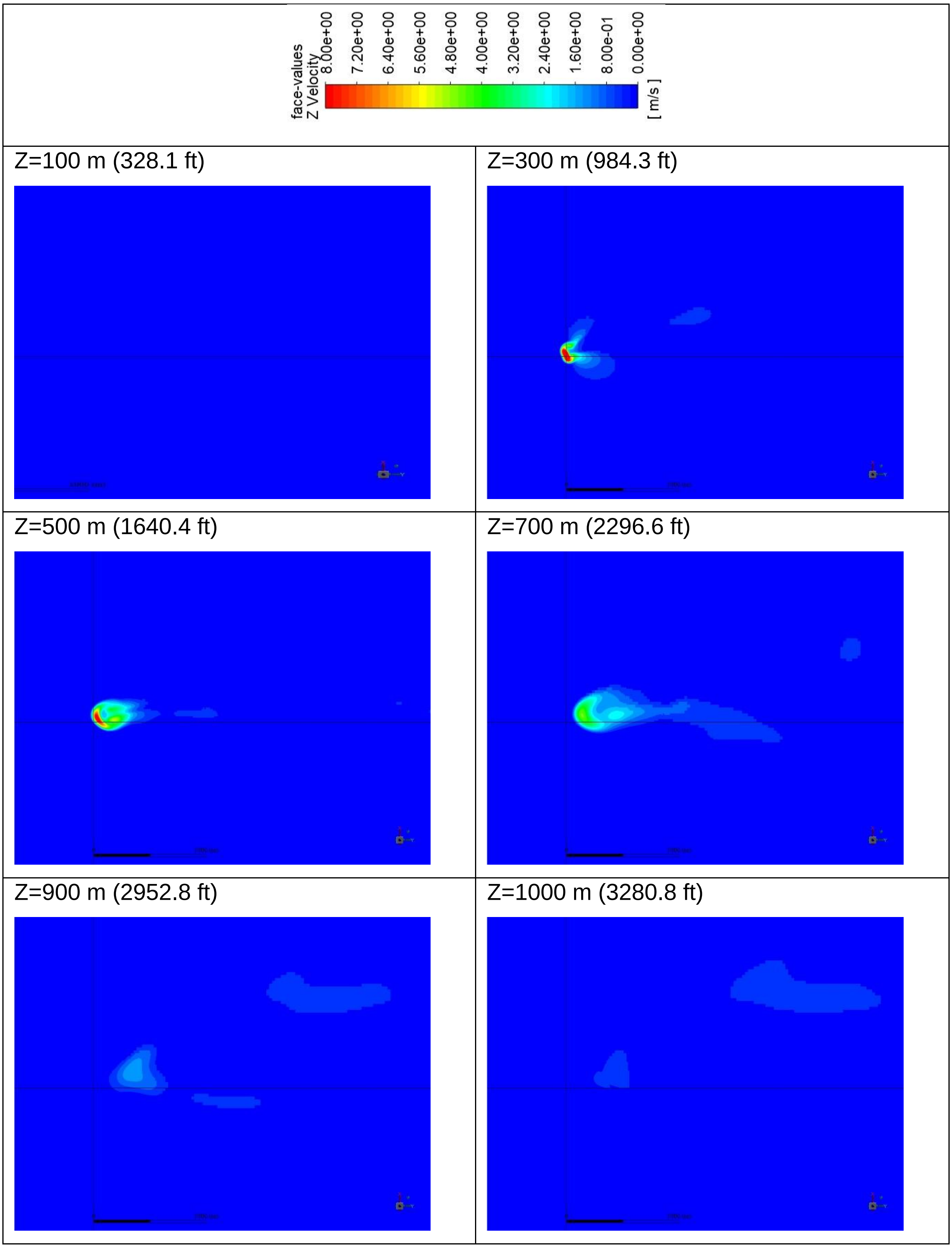


Figure 21. Contour plots of vertical velocity in plan at different heights – 'Initial' wind case. Black lines define the stack centre.

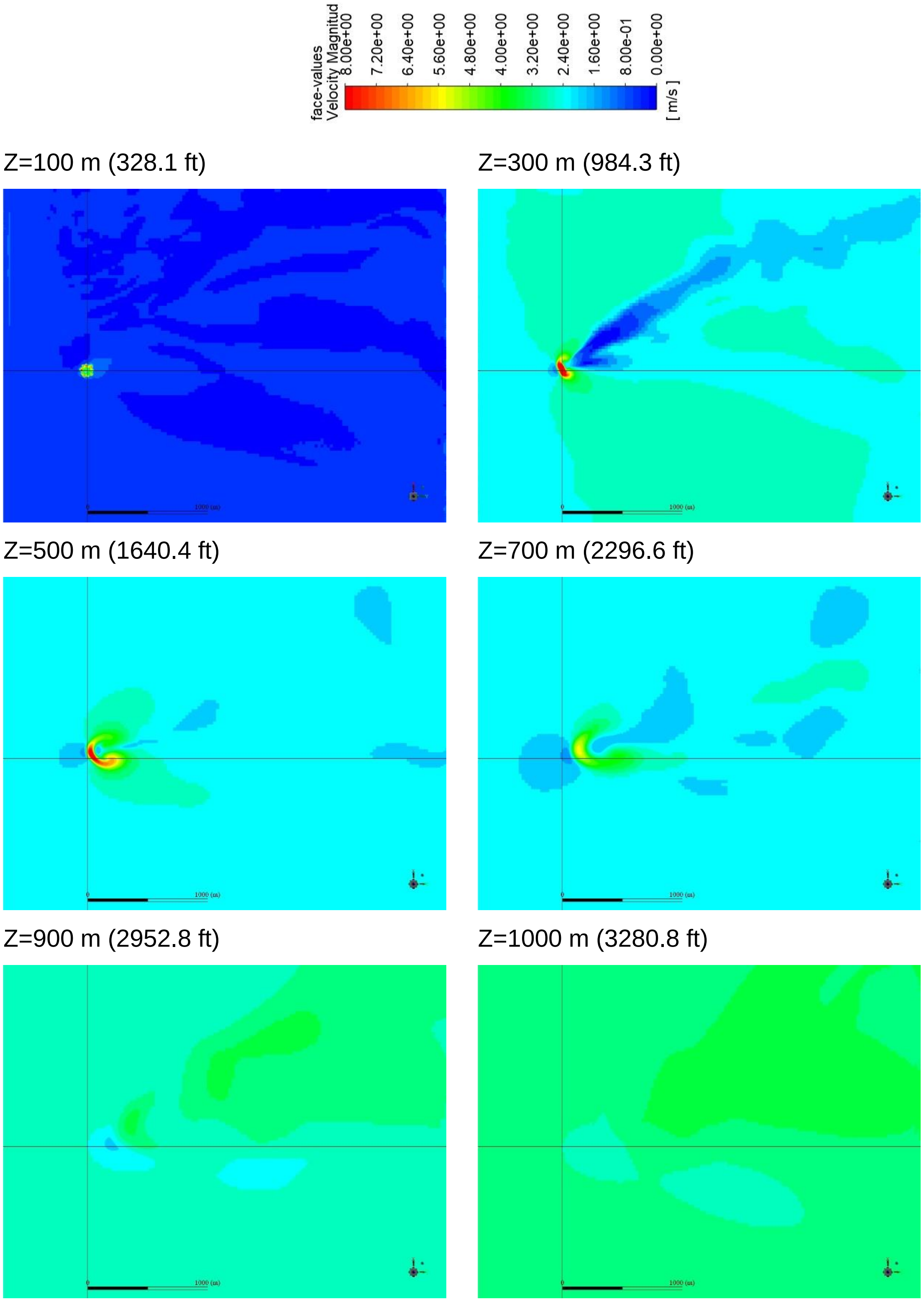


Figure 22. Contour plots of velocity magnitude in plan at different heights – 'Initial' wind case. Black lines define the stack centre.

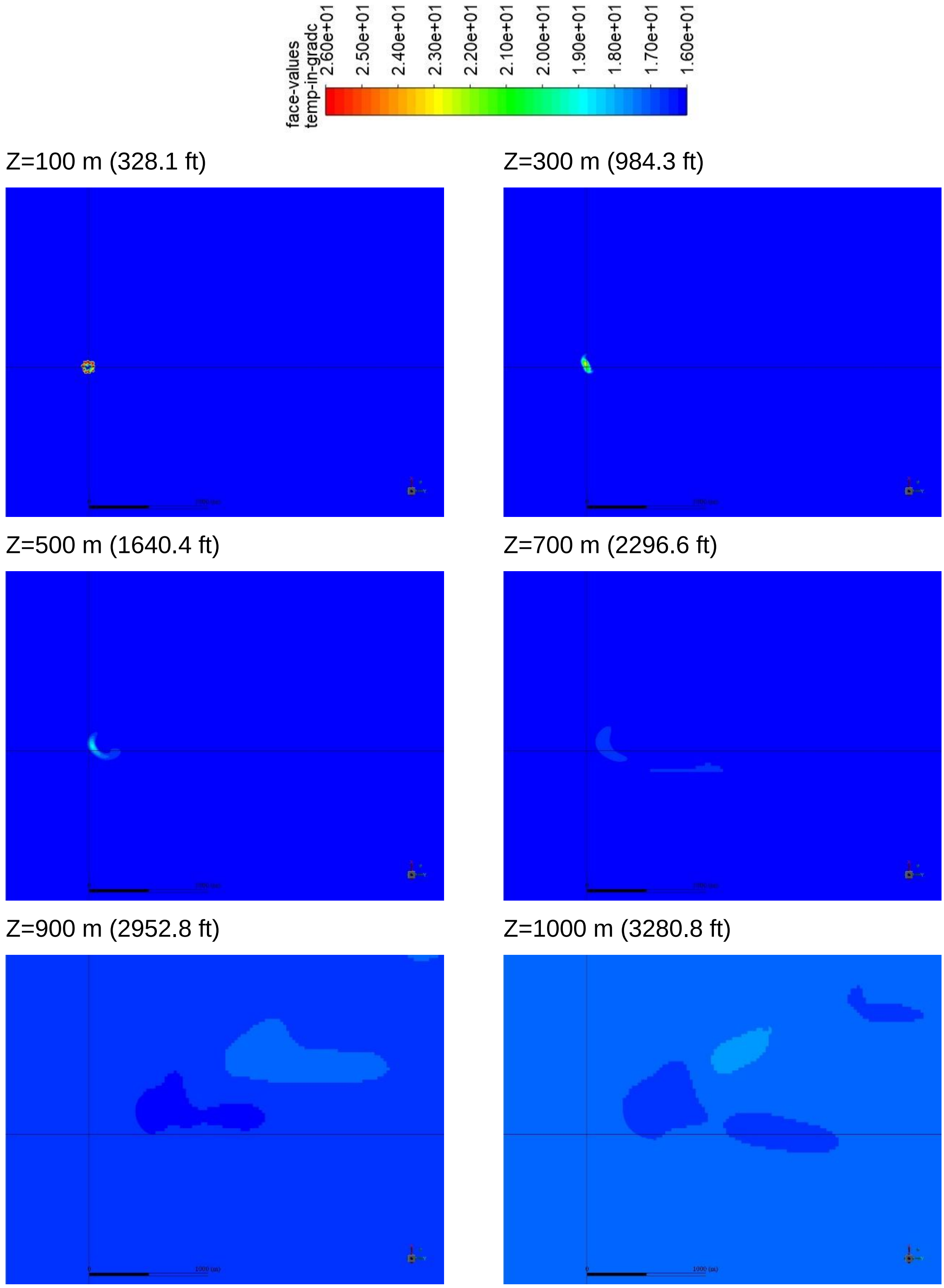


Figure 23. Contour plots of temperature in plan at different heights – 'Initial' wind case. Black lines define the stack centre.

3.4 Comparison of 'Initial' PDD Solution with Adapted Final PDD Design Version 3B

This section compares the results of a previous plume modelling regarding the initial design of 'modified' PDD ("Initial case") with the final PDD design version 3B ("Adapted PDD case"). A more comprehensive discussion on the previous CFD study can be found in [11]. Both PDD designs were assessed based on the same 'initial' wind case as shown in Figure 3. However, the final PDD design was assessed with slightly increased stack flow parameters (see Table 5)

Figure 24 to Figure 27 below show the plume rise velocity 6 m/s envelope for the two PDD designs, as well as contour plots of absolute velocity, temperature and vertical velocity in vertical planes through the stack.

For the 'Initial case', the released horizontal jets get bent upwards due to the density deficit and the resulting high buoyancy force. Similar to the Coanda effect, the now vertical jets tend to attach to each other, so that a single vertical plume jet is formed. The plume temperature in the core of the formed single jet is still high enough to further accelerate the plume rise velocity to a maximum value of 11.5 m/s (at 700 ft).

The 'initial' PDD design has basically 6 openings which are divided vertically only by a ring plate. Due to the arrangement of the openings of the initial PDD design, the individual jets combine to 3 bigger horizontal jets and later to a big single vertical jet. The 3 bigger jets are more separated (see Figure 84 in Appendix D vs. Figure 17) which leads to a high entrainment and lower plume core temperatures at higher elevations (see Figure 26) compared to the final PDD design version 3B.

The openings of the adapted PDD design are uniformly distributed along the circumference of the PDD and therefore closer to each other. To increase the separation of the individual jets and consequently the entrainment, every second jet is inclined downwards by about 23°. In addition, the total open area of the adapted PDD is decreased by 27%, which leads to higher average velocities and jet momentum. Both adjustments are intended to increase the separation between the jets and the horizontal displacement of the jets.

Even though the horizontal displacement of the jets is higher compared to the 'initial' design, the jets are still close to each other (due to being uniformly distributed around the circumference) so that only limited air can be entrained in the core of the plume. This causes that the upwardly bent jets to move closer together and form a narrower single jet (see Figure 24 right). After coalescing in that way, the plume heat and temperature are maintained better, through reduced mixing, which leads to a larger area with high vertical velocities (related to buoyancy force) compared to the initial PDD design (see Figure 25 to Figure 27). The maximum peak rise velocity is similar for both designs, but can reach higher elevations with the final PDD design Version 3B. Note that the plume has a transient behaviour so that the appearance and the magnitude of the maximum plume rise velocity depends on the time selected from the simulation (see Figure 8 and Table 7). The plume rise velocity for the case with the final PDD design Version 3B reaches a peak value of 11.8 m/s at 1115 ft (340 m) at the selected simulation time (370 s). In comparison, with the 'initial' PDD design, the peak value is 11.5 m/s at 650 ft (198 m). These values are the maximum occurring peak values from all elevations > 650ft.

Initial case [11]	**Adapted PDD case**
Initial design of 'modified' PDD	Final PDD design version 3B
Initial stack flow parameters	Increased stack flow parameters

Plume envelope where vertical plume velocity is 6 m/s. Colours refer to plume height.

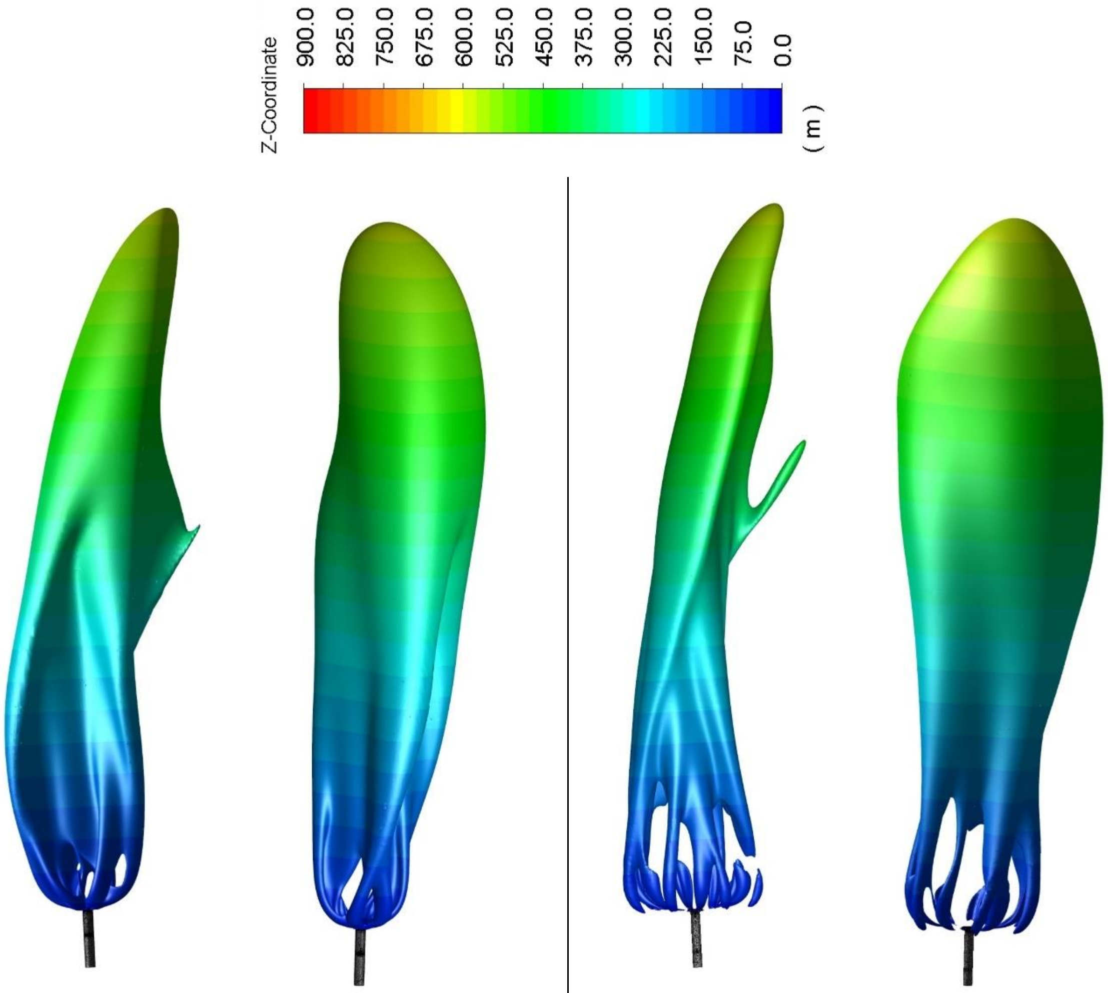


Figure 24. Plume envelope where the plume rise velocity is 6 m/s for the different PDD designs with 'initial' wind case. Colouring of the envelope depicts the plume height.

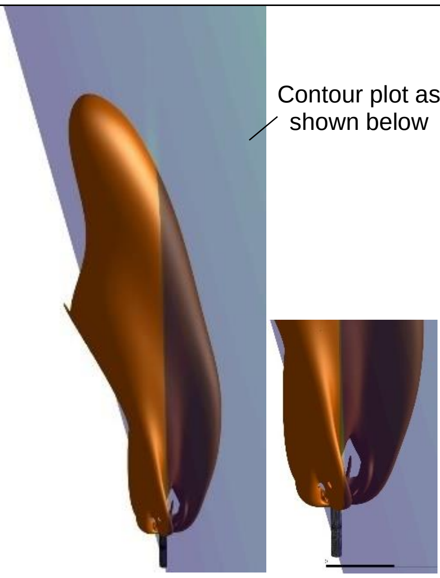
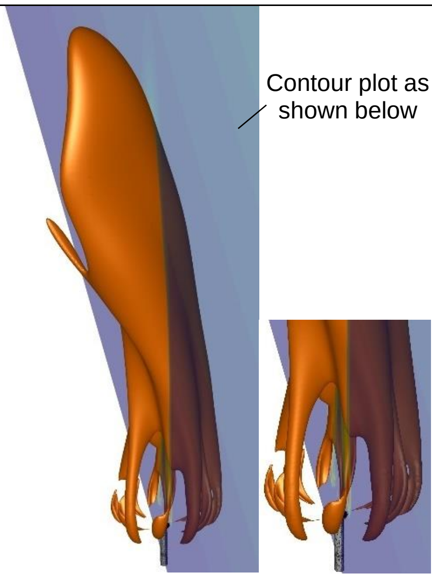
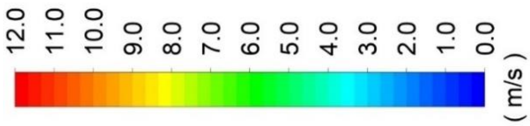
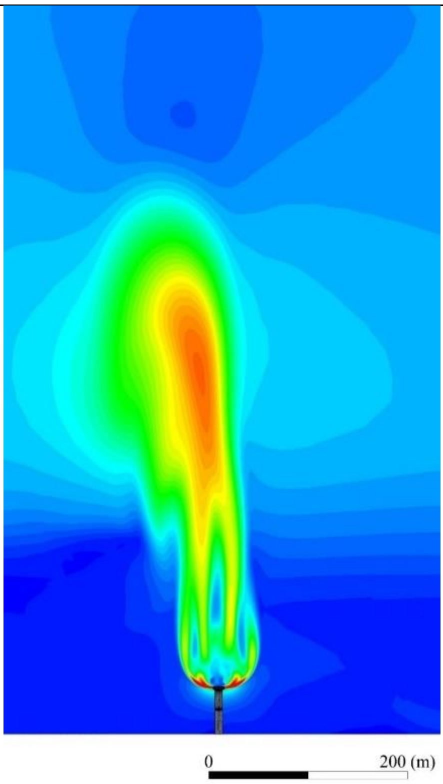
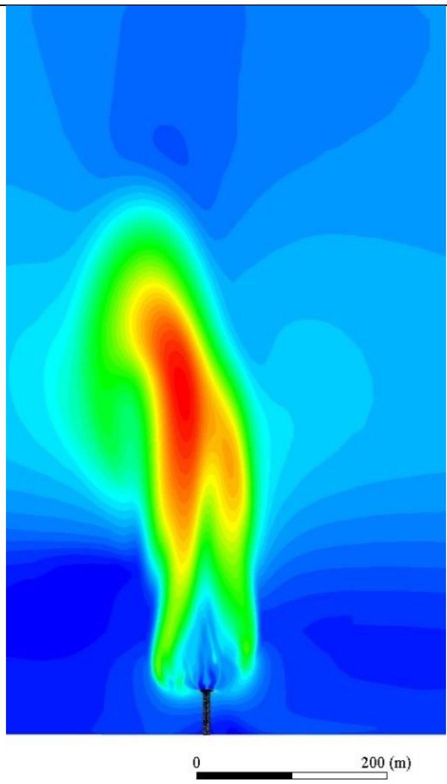
Initial case [11] Initial design of 'modified' PDD Initial stack flow parameters	**Adapted PDD case** Final PDD design version 3B Increased stack flow parameters
 	
Contour plot of absolute velocity in plane through the nozzle as shown above  	
 	

Figure 25. Plume envelope where the plume rise velocity is 6 m/s (top) and contour plot of absolute velocity in plane through the stack (bottom) for the different PDD designs with 'initial' wind case.

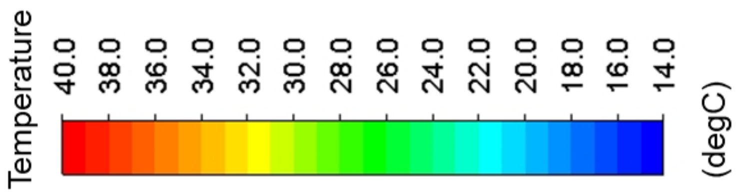
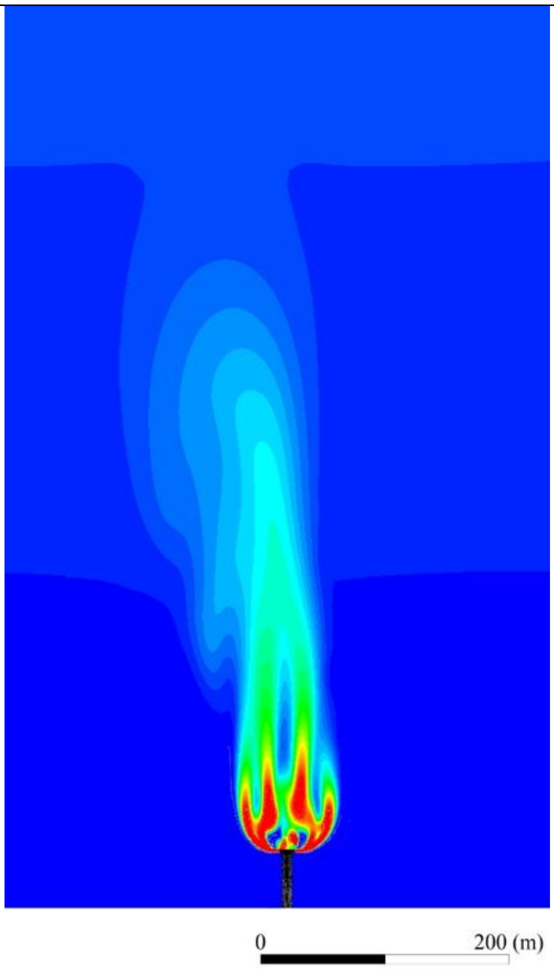
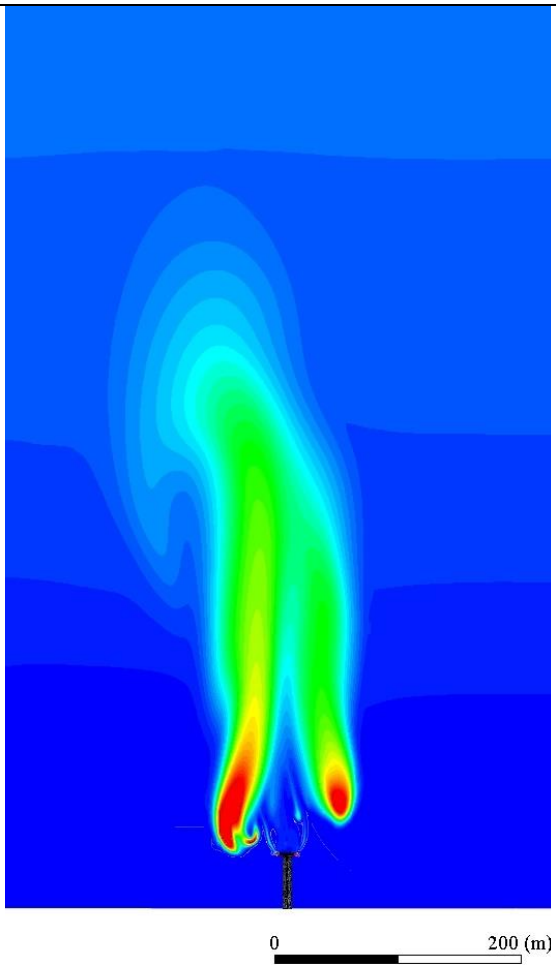
<table>
<tr><td>Initial case [11]
Initial design of ‘modified’ PDD
Initial stack flow parameters</td><td>Adapted PDD case
Final PDD design version 3B
Increased stack flow parameters</td></tr>
<tr><td colspan="2">Contour plot of temperature in plane through the nozzle as shown in Figure 25
</td></tr>
<tr><td></td><td></td></tr>
</table>

Figure 26. Contour plot of absolute velocity in plane through the stack for the different PDD designs with ‘initial’ wind case.

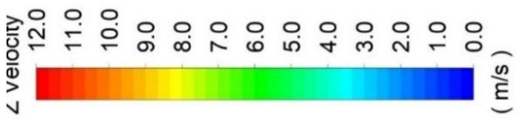
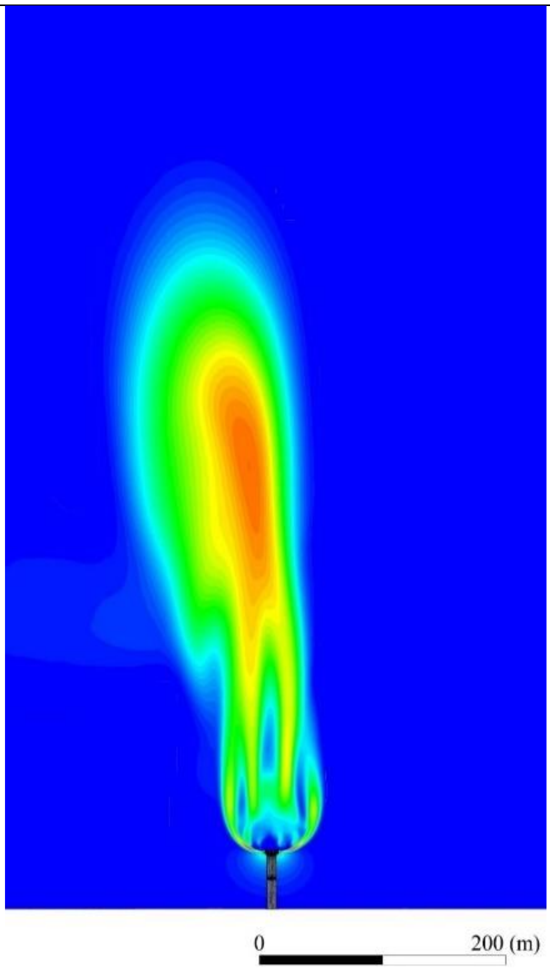
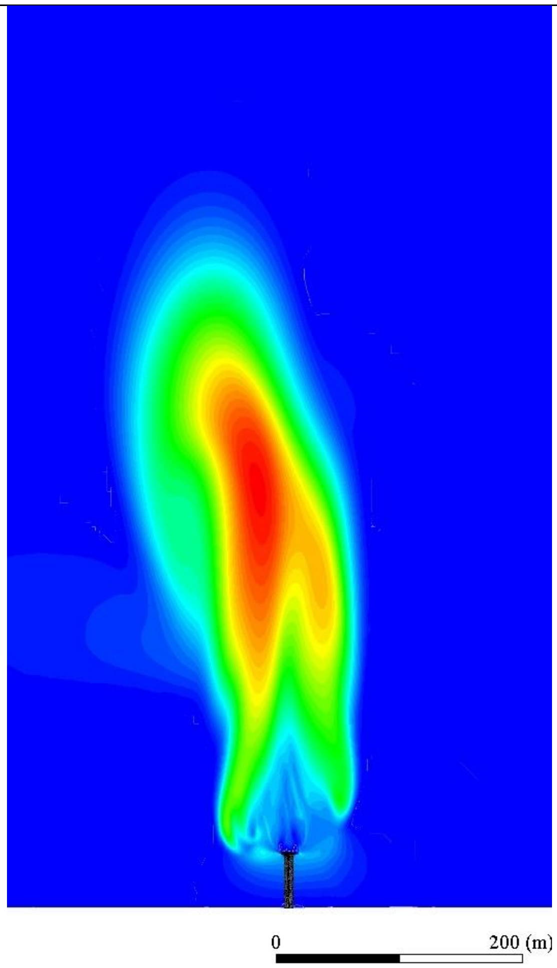
<table>
<tr><th>Initial case [11]
Initial design of ‘modified’ PDD
Initial stack flow parameters</th><th>Adapted PDD case
Adapted design of ‘modified’ PDD
Increased stack flow parameters</th></tr>
<tr><td colspan="2">Contour plot of vertical velocity in plane through the nozzle as shown in Figure 25

</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Figure 27. Contour plot of vertical velocity in plane through the stack for the different PDD designs with ‘initial’ wind case.

3.5 Plume Behaviour Sensitivity on Different Wind Conditions

As already mentioned, the nozzle design and corresponding detailed plume behaviour was first analysed for the 'initial' wind conditions. These conditions were selected from the TAPM modelling output that resulted in the 99.9th percentile plume average vertical velocity at 700 ft. As the basis of a sensitivity analysis, the plume behaviour with the same nozzle design, computational domain and stack parameters has also been assessed for a calm wind case. Compared to the 'initial' wind condition, the calm wind case has, in general, lower wind speeds, but ambient average temperature is higher by about 7.2°C. The wind speed and direction impact the plume shape, entrainment, horizontal plume transportation and the natural plume convection, whereas the ambient temperature has an impact on the buoyancy force.

Figure 28 to Figure 31 below show the plume envelope of 6 m/s velocity for the different simulation cases, as well as contour plots of absolute velocity, temperature and vertical velocity on a vertical plane through the stack.

Compared to the 'initial' wind case, the higher ambient temperature (on average) for the calm wind conditions reduces the buoyancy force and presumably also reduces the resistance acting on the ejected jets, so that the horizontal displacement of the individual jets is higher. It seems that, even though the input differences are slight, the increased displacement is enough that the individual jets (after they bend upwards) stay separated for longer, and therefore form a single vertical jet at a much higher elevation. The core temperature in the single jets is cooler, due to the ratio between the plume volume and the plume surface interacting with the ambient air. That results into lower plume rise velocities, with a peak value of 10.0 m/s at 650 ft at the simulated time (560s). However, after the single individual vertical jets are coalesced, the temperature is then better maintained, due to the lower wind speeds interacting with the rising plume. As a result, the peak plume rises velocity decays at a lower rate so that the peak plume rise velocity fells below 6 m/s at a higher elevation (see Figure 12 vs. Figure 33). Detailed analysis of the plume extents, displacement and velocities as a function of height, as well as further contour plots, can be found in Appendix A Section A.1.

Based on previous observations regarding the plume behaviour under calm wind conditions [11], a further wind scenario with wind speed and direction from the calm wind profile (20150308 according to Figure 3) but with the lower ambient temperatures according to the temperature profile from the 'initial' wind conditions (20140703_10, according to Figure 3) was also analysed with the final PDD design. The objective is to confirm the observations made and to see if the lower ambient temperature would lead to a single vertical jet at lower elevations again. Corresponding results are shown, and compared to the previous simulation cases, in Figure 28 to Figure 31.

This 'combined' wind case confirms that the ambient air temperature has a meaningful influence on the plume behaviour in general and the individual jets in particular. The buoyancy force at lower ambient temperatures is higher, so that the individual jets bend upwards at an earlier stage. Therefore, the horizontal separation of the jets is lower and they are closer to each other once they are vertical. Like the simulation with the 'initial' wind case, the individual jets tend to attach to each other, so that a single vertical plume jet is formed again. The lower wind speed around the jets further helps to attach the individual jets, as the flow around and between the jets is lower (lack of air between the jets). Moreover, lower wind speeds reduce plume cooling, disturbance of the plume shape and natural convection as well as reduce the plume displacement in general. This leads to a slimmer and more vertical stretched single jet where the core temperature is slightly higher and more maintained. In turn, this leads to higher buoyancy forces and plume rise velocity, with a peak value of 12.9 m/s at 1270 ft at the simulated time (1060 s). Detailed analysis of the plume extents, displacement and velocities as a function of height, as well as further contour plots of the evaluated time step can be found in Appendix A Section A.2.

When comparing the plume envelope of the ‘initial’ wind case with the ‘combined’ wind case in Figure 25, the wind speed has minor impact in the jet formation but has more impact in the upper region where the plume velocities are much lower.

The plume rise velocities obtained with the final PDD design Version 3B show very similar values ~~for all three wind cases~~ compared to the ‘initial’ PDD design [11] for the individual wind cases, respectively.

To demonstrate the transient plume behaviour, videos of the time-dependent plume envelope for all three wind cases are attached to this report. The envelope in the video is an iso-velocity surface at a vertical velocity of 6 m/s. Contour colour depicts the plume height. Depending on the time, height and wind speed, jets detach and attach again, so that the plume rise velocity increases and decreases depending on the height (see Figure 33 and Figure 45 in Appendix A).

‘Initial’ wind case	**Calm wind case**	**‘Combined’ wind case**
Average ambient temperature: 16.4 °C	Average ambient temperature: 23.6°C	Average ambient temperature: 16.4 °C
Initial wind profile	Calm wind profile	Calm wind profile
Plume envelope where vertical plume velocity is 6 m/s. Contour plot refers to plume height.		

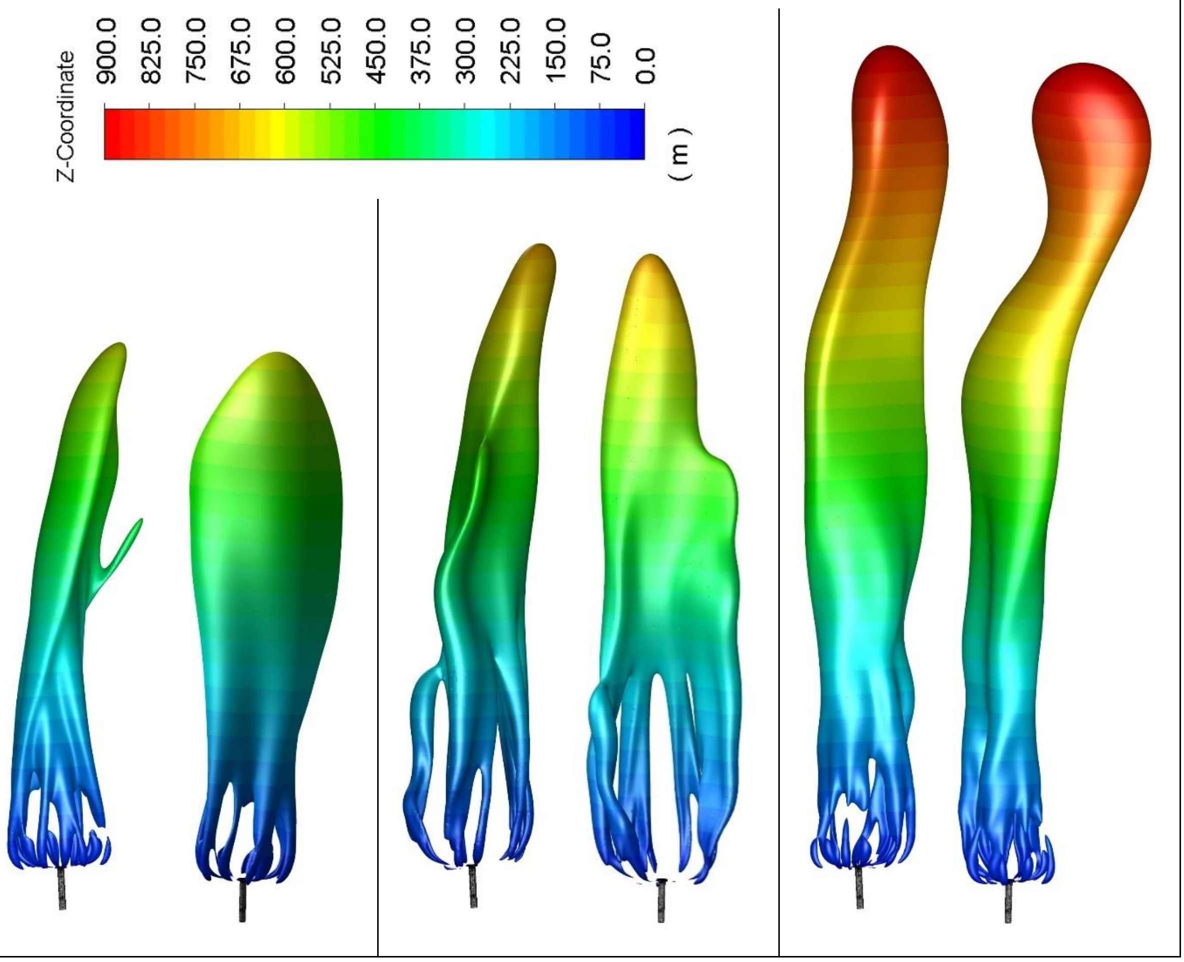
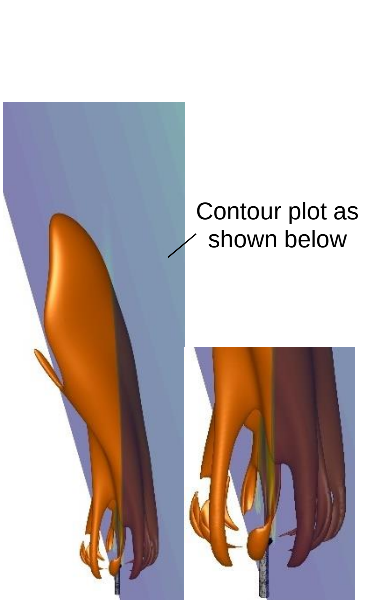
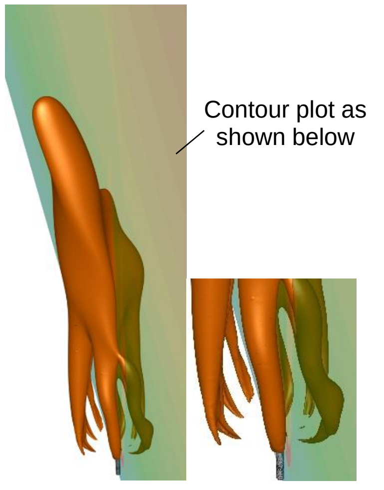
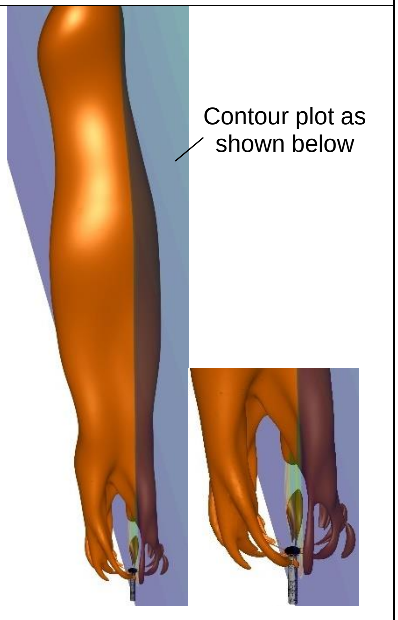


Figure 28. Plume envelope where the plume rise velocity is 6 m/s for final PDD design version 3B and the different wind scenarios. Colouring of the envelope depicts the plume height.

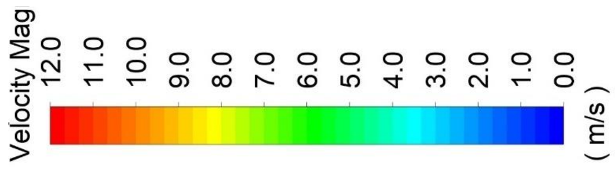
'Initial' wind case	Calm wind case	'Combined' wind case
Average ambient temperature: 16.4 °C	Average ambient temperature: 23.6°C	Average ambient temperature: 16.4 °C
Initial wind profile	Calm wind profile	Calm wind profile

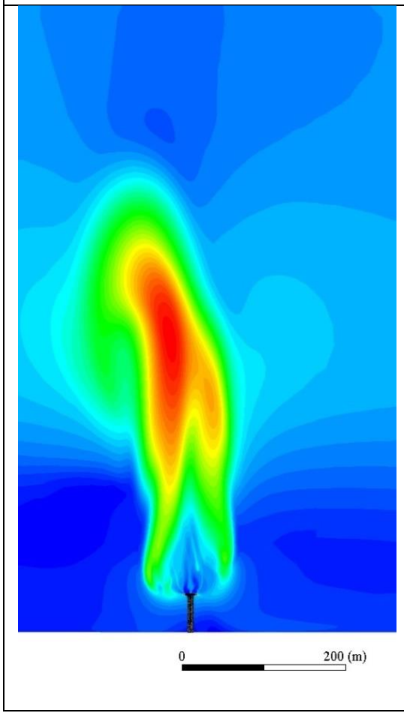


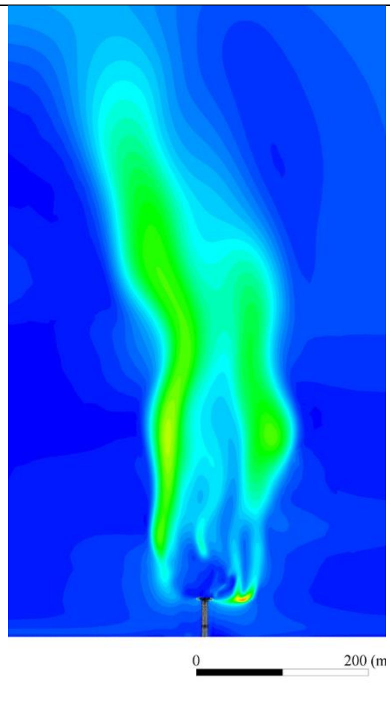




Contour plot of absolute velocity in plane through the nozzle as shown above







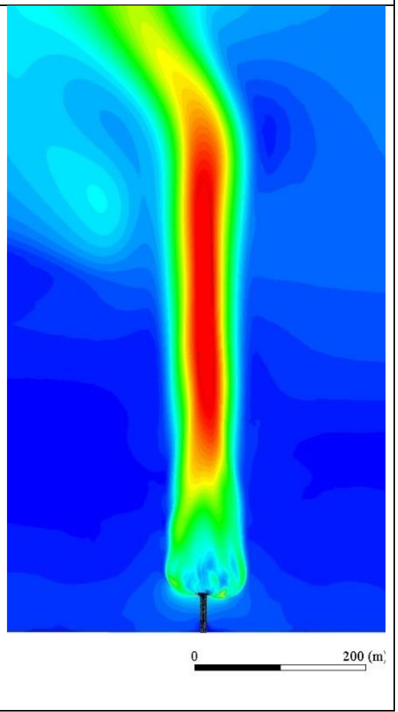


Figure 29. Plume envelope where the plume rise velocity is 6 m/s for the different simulation cases (top) and contour plot of absolute velocity in plane through the stack (bottom) for adapted PDD design version 3B and the different wind scenarios.

'Initial' wind case Average ambient temperature: 16.4 °C Initial wind profile	**Calm wind case** Average ambient temperature: 23.6°C Calm wind profile	**'Combined' wind case** Average ambient temperature: 16.4 °C Calm wind profile
Contour plot of temperature in plane through the nozzle as shown in Figure 25		

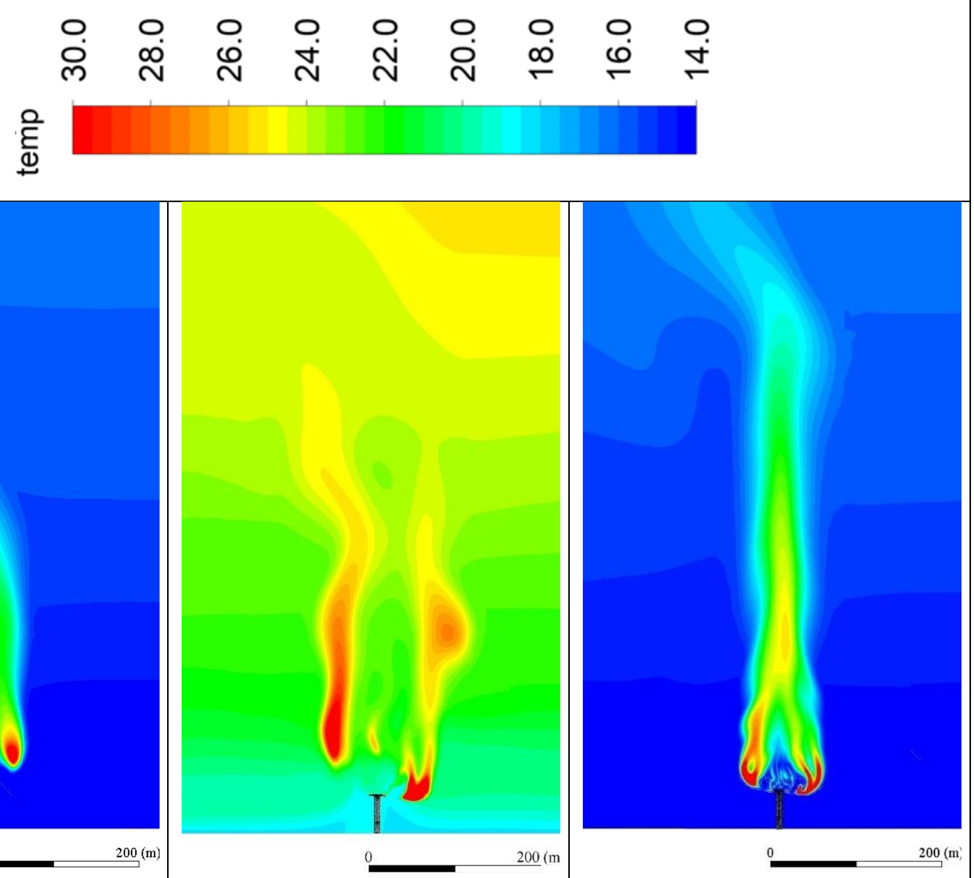


Figure 30. Contour plot of absolute velocity in plane through the stack for the adapted PDD design version 3B and different wind scenarios.

<table>
<tr><th>‘Initial’ wind case

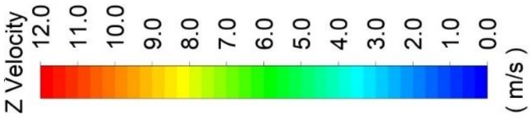
Average ambient temperature: 16.4 °C

Initial wind profile</th><th>Calm wind case

Average ambient temperature: 23.6°C

Calm wind profile</th><th>‘Combined’ wind case

Average ambient temperature: 16.4 °C

Calm wind profile</th></tr>
<tr><td colspan="3">Contour plot of vertical velocity in plane through the nozzle as shown in Figure 25

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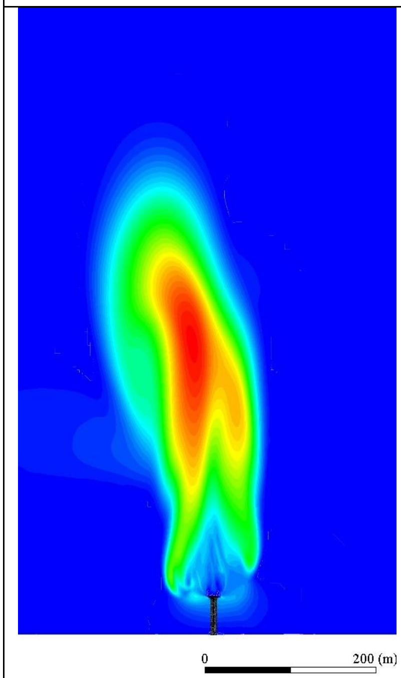
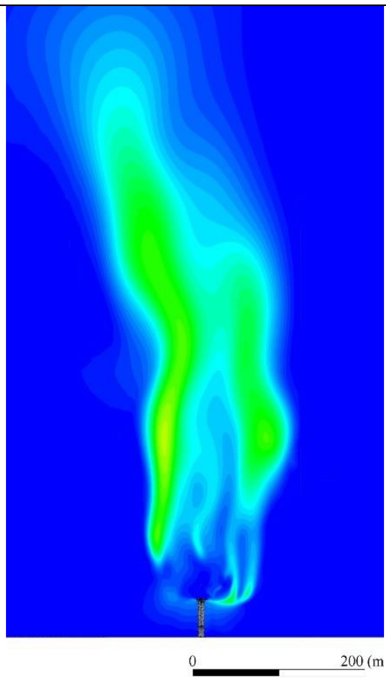
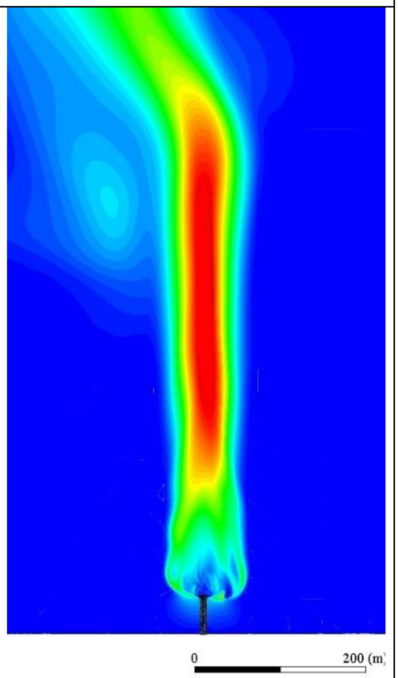
<tr><td>
</td><td>
</td><td>
</td></tr>
</table>

Figure 31. Contour plot of vertical velocity in plane through the stack for the adapted PDD design version 3B and different wind scenarios.

4 TOP HAT PROFILE EQUIVALENCE

The CASA plume rise velocity criterion is a single number which refers to an average velocity resulting from TAPM. TAPM approximates the plume to a 'top hat' velocity profile in which there is only one velocity inside the plume, making the average velocity also the maximum. To compare the CFD results with the TAPM model results, an equivalent 'top hat' velocity needs to be determined.

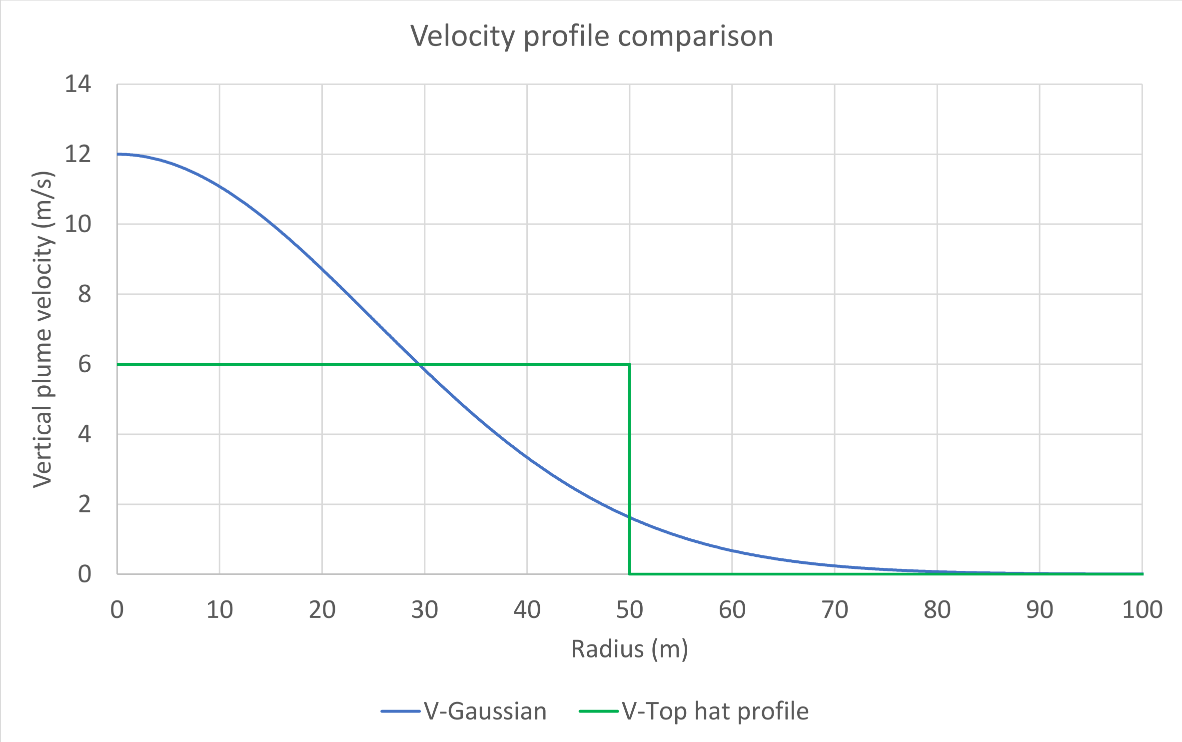


Figure 32. Velocity profile of a 'top hat', and a Gaussian distribution with a standard deviation of 25 m.

The TAPM parameters are specified in such a way that the top hat profile seeks to match the momentum and flow rate of the real plume. When assuming that the vertical velocity profile of an individual plume has a perfect Gaussian distribution, the equivalent top hat radius is defined mathematically as being two times the Gaussian standard deviation, and so the top hat velocity becomes half of the maximum velocity in the centre of the Gaussian plume. However, the velocity profile of a plume released by a PDD does not have a Gaussian distribution. That is the whole point of the PDD. Depending on the wind conditions, the PDD design, the turbulence, the plume height, and the entrainment rate, this velocity profile can have several peaks and/or be asymmetrical. In order to determine an equivalent top hat velocity and radius based on the CFD results, (as for the top hat and Gaussian profile correlation) the flow rate and the momentum of the top hat profile were matched to those of the plume profile resulting from the CFD simulation. As the real velocity profile differs from a Gaussian distribution, the equivalent top hat velocity will no longer necessarily be half of the maximum velocity. The same divergence applies to the correlations for top hat radius and standard deviation. The analysis made here is based on following assumptions and definitions:

Flow rate of top hat profile Q_{TH} to be matched with flow rate resulting from CFD simulation Q_{CFD} at specific height.

$$Q_{CFD} = Q_{TH} = u\,\pi R^2$$

Momentum of top hat profile M_{TH} to be matched with momentum resulting from CFD simulation M_{CFD} at specific height.

$$M_{CFD} = M_{TH} = u^2 \rho \pi R^2$$

Rearranging both equations above leads to a definition of an equivalent top hat velocity u (momentum-weighted average plume rise velocity) and radius R as follows:

$$u = \frac{M_{CFD}}{Q_{CFD} \cdot \rho}$$

$$R = Q_{CFD} \sqrt{\frac{\rho}{M_{CFD} \cdot \pi}}$$

M_{CFD}	Total momentum determined based on CFD results at a specific height (N)
Q_{CFD}	Total flow rate determined based on CFD results at a specific height (m^3/s)
M_{TH}	Total momentum of top hat profile (N)
Q_{TH}	Total flow rate of top hat profile (m^3/s)
u	Top hat velocity (m/s)
ρ	Top hat density (average plume density at a specific height determined based on CFD results) (kg/m^3)
R	Top hat radius (m)

Based on the correlations above, the equivalent top hat velocity and radius has been analysed at three different heights. The plume momentum and flow rate were determined by clipping the general up- and downdrafts ('clip-velocity') in the computational domain (caused by the general advection) and integrating the vertical velocities from the 'clip-velocity' (which was up to 0.67 m/s) to the peak plume rise velocity. This results in a slightly smaller plume flow rate (about 7.1% lower) and momentum (about 0.5% lower) compared to an integration from zero to the peak value. However, this was corrected by comparing the flow rate and momentum of a Gaussian velocity profile integrated from the 'clip-velocity' to the peak plume rise velocity, with the same profile integrated from zero to the peak plume rise velocity. The flow rate (Q_{CFD}) and momentum (M_{CFD}) are already the corrected values. Table 8 to Table 10 below lists the results of the correlation for all three analysed wind cases with the final PDD design version 3B.

The plume for all three wind cases has a transient behaviour and has only been analysed for a specific simulation time (where peak plume rise velocity achieved a maximum value over the simulation period of up to 30 minutes, see Figure 8 to Figure 10).

Table 8. Top hat profile equivalence for simulation with final PDD design version 3B and with 'initial' wind case.

Plume definition	Unit	650 ft	700 ft	1000 ft
'Clip-velocity'[2]	m/s	0.67	0.66	0.62
Flow rate CFD (Q_{CFD})	m^3/s	111640	123083	224714
Momentum CFD (M_{CFD})	N	520879	569442	948074
Average density within the plume area (ρ)[3]	kg/m^3	1.224	1.224	1.224
Equivalent top hat velocity (u)	**m/s**	**3.6**	**3.5**	**3.3**
Equivalent top hat radius (R)	m	103.7	109.0	152.0
Max. plume rise velocity from CFD	**m/s**	**9.4**	**9.7**	**11.6**
Standard deviation[4]	m	39.3	39.6	43.0

Table 9. Top hat profile equivalence for simulation with final PDD design version 3B and with calm wind case.

Plume definition	Unit	650 ft	700 ft	1000 ft
'Clip-velocity'[2]	m/s	0.24	0.29	0.38
Flow rate CFD (Q_{CFD})	m^3/s	79975	85933	114819
Momentum CFD (M_{CFD})	N	445937	482875	617523
Average density within the plume area (ρ)[3]	kg/m^3	1.186	1.186	1.189
Equivalent top hat velocity (u)	**m/s**	**4.7**	**4.7**	**4.5**
Equivalent top hat radius (R)	m	73.6	76.0	89.9
Max. plume rise velocity from CFD	**m/s**	**10.0**	**9.9**	**8.6**
Standard deviation[4]	m	34.5	36.2	47.3

[2] Integration is based on a minimum vertical velocity ('clip velocity') to avoid integration of general up- and downdrafts in the computational domain. 'Clip velocity' is the vertical velocity which defines the plume edge. General up- and downdrafts are below the 'Clip velocity' value.

[3] Average density within the plume area was determined based on the CFD results.

[4] Determined by adjusting a Gaussian velocity profile to the top hat profile by matching the momentum. Gaussian profile is based on the maximum plume rise velocity. This may not be meaningful for an oddly shaped plume.

Table 10. Top hat profile equivalence for simulation with final PDD design version 3B and with 'combined' wind case.

Plume definition	Unit	650 ft	700 ft	1000 ft
'Clip-velocity'[2]	m/s	0.31	0.31	0.42
Flow rate CFD (Q_{CFD})	m^3/s	56799	59945	84527
Momentum CFD (M_{CFD})	N	430432	466181	714536
Average density within the plume area (ρ)[3]	kg/m^3	1.210	1.211	1.214
Equivalent top hat velocity (u)	**m/s**	**6.3**	**6.4**	**7.0**
Equivalent top hat radius (R)	m	53.7	54.5	62.2
Max. plume rise velocity from CFD	**m/s**	**10.1**	**10.6**	**12.6**
Standard deviation[4]	m	33.4	32.9	34.3

Beyond the discussion of the relevant average plume rise velocity and the top hat profile equivalence approach in Section 4, CASA stated in their letter [10] that they will accept half of the peak plume rise velocity as measure for potential impacts on aircraft.

5 REFERENCES

[1] Ansys, Inc.: ANSYS Fluent User's Guide, Release 2020 R1, USA, January 2020

[2] Ansys, Inc.: ANSYS Fluent Theory Guide, Release 2020 R1, USA, January 2020

[3] Ansys, Inc.: ANSYS Fluid Dynamics Verification Manual, Release 2020 R1, USA, January 2020

[4] T.-H. Shih,W.W. Liou, A. Shabbir, Z. Yang, and J. Zhu. "A New - Eddy-Viscosity Model for High Reynolds Number Turbulent Flows - Model Development and Validation". Computers Fluids. 24(3). 227–238. 1995.

[5] Meteorological data (case: 20140703_10) provided to Stacey Agnew on 31 January 2020 per email.

[6] Meteorological data (case: 20150308) provided to Stacey Agnew on 28 April 2021 per email.

[7] GE Exhaust Stack Modification for CASA Compliance 02April2020.pdf provided to Stacey Agnew on 15 April 2020 per email.

[8] Terrain data provided to Stacey Agnew on 5 February 2020 per email.

[9] Stacey Agnew: Tallawarra B Power Station CFD Plume Modelling – Validation Case, Short Summary Report from 11th February 2020 - Draft.

[10] Australian Government – Civil Aviation Safety Authority – Air Navigation, Airspace and Aerodromes, Letter regarding Tallawarra B Gas-Fire Power Station Project, File Ref: F17/8039-27 from 29/03/2021.

[11] Stacey Agnew: Tallawarra B Power Station CFD Plume Modelling – GE-Modified PDD Design, Summary Report from 13th August 2021 version 6.

[12] General Electric: Tallawarra B Power Station Plume Dispersion Device – CFD Report, Rev C2, TALLAB-GECL-61810-MEC020-0002 from 22nd April 2022.

[13] General Electric: Tallawarra B Power Station Arrangement Exhaust System GA DIS100, Rev C, Document ID 116V3531 from 4th May 2022.

[14] General Electric: 3D CAD Parasolid PDD geometry file (PDD_MOD3B_20DegBot_23DegTop_Final_01Feb23.x_t) provided per email by Tony Anthony on 9th February 2023.

[15] General Electric: 1431277 – 9F.05 FL18 Tallawarra B – Plume Dispersion Device (PDD) Modification 3B – CFD Report, Revision R0 from 8th February 2023 (9F05_Tallawarra_Modification-3B_PDD_CFD_Report_EA_08Feb2022-R0.pdf) provided per email by Simon Welchman on 16th February 2023.

APPENDIX A

A.1. Calm Wind Case (Wind and Temperature Profile: 20150308 – Calm)

Figure 33 (left) shows the maximum vertical and absolute plume velocities against height as well as the atmospheric wind speed profile according to Figure 3. The maximum plume velocity decays to the ambient wind value at approximately 880 m (2887 ft) above the ground level. The maximum vertical plume velocity at this point is about 1.7 m/s. The plume temperature (right side of Figure 33) decreases rapidly with height and comes to within about 0.5°C of the ambient value at 880 m (2887 ft) above ground.

Figure 34 depicts the plume area against height (left) and the average plume velocities (right) within this area. Here the plume area is defined as horizontal area in which the vertical plume velocity is > 6 m/s. In addition, Figure 35 shows a similar plot and compares the plume area and average vertical plume velocity for different plume area definitions (area in which vertical plume velocity is > 6 m/s, > 4 m/s, > 2 m/s and > 1 m/s).

Figure 36 and Figure 37 illustrate the velocity and temperature distribution of the initial jet flow region and Figure 38 the plume extent for the different vertical plume velocity criteria, based on value-clipped contour plots for vertical velocity.

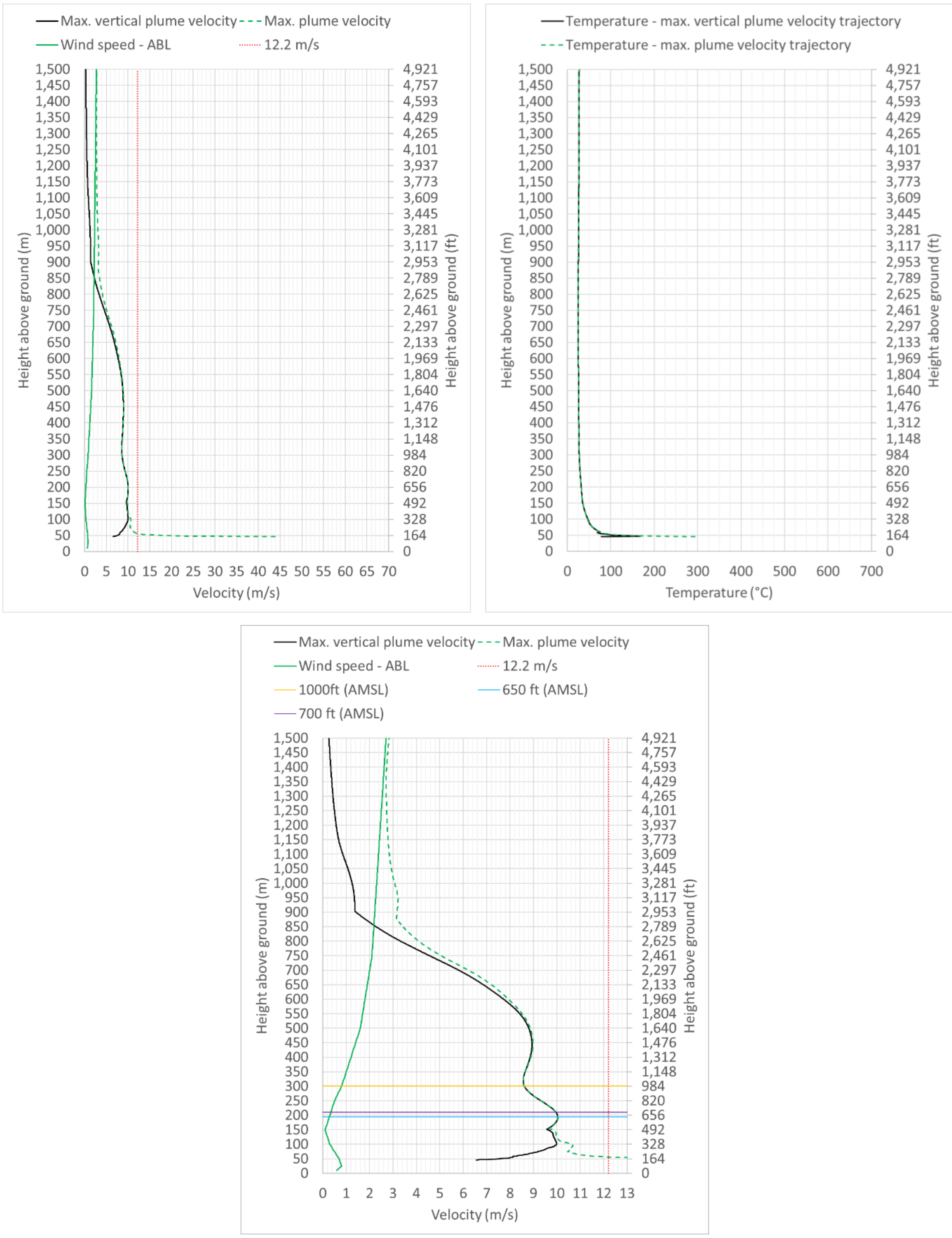


Figure 33. Wind speed and maximum vertical and absolute plume velocity against height (left) and plume temperature along both trajectories (right) – Calm wind case for final PDD design version 3B. Plot at the bottom shows the plume velocities on an expanded scale.

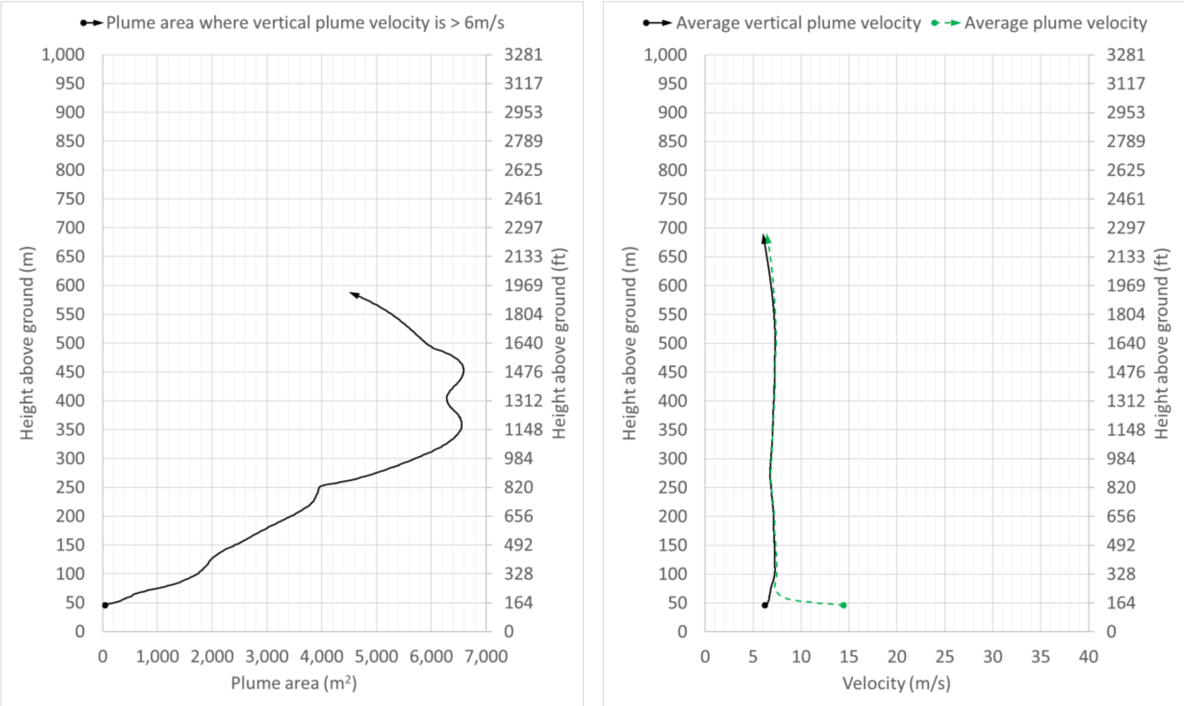


Figure 34. Plume area (area where vertical plume velocity is > 6 m/s) (left) and average plume velocities against height (right) – Calm wind case for final PDD design version 3B. Note that with the definition of plume area as being where the vertical velocity exceeds 6 m/s, the average vertical velocity in the 'plume' clearly can't fall below 6 m/s.

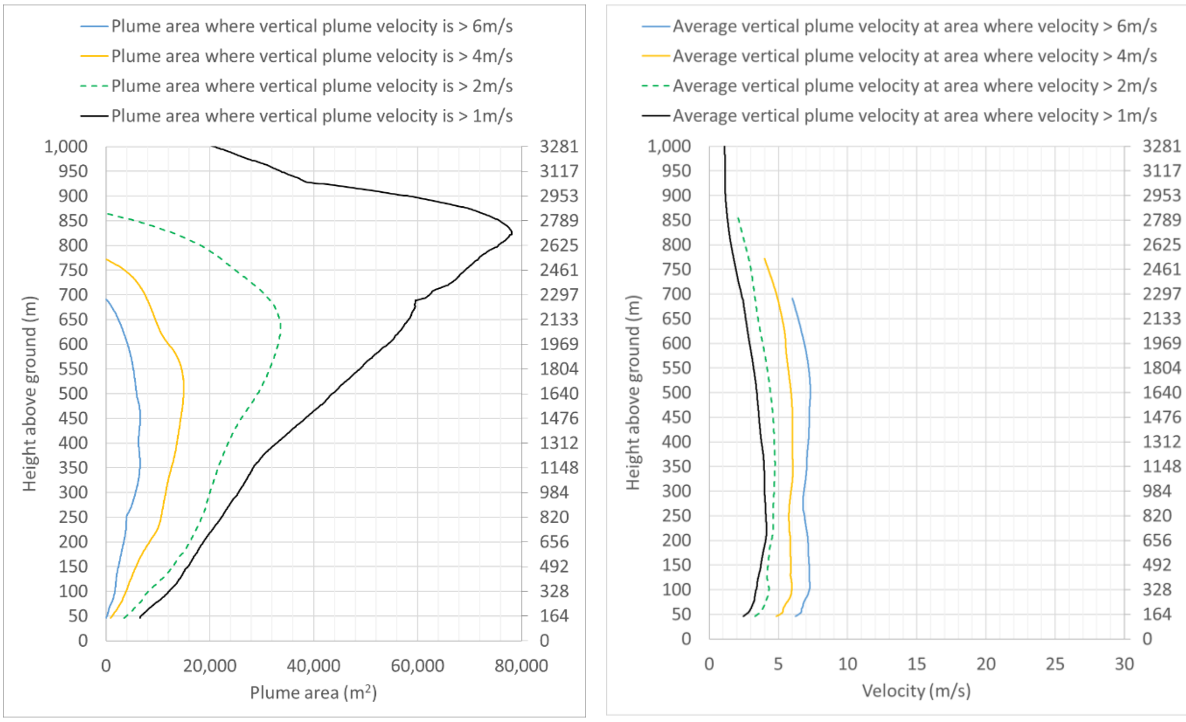


Figure 35. Plume area (left) and average plume velocities against height (right) for different plume area definitions - Calm wind case for final PDD design version 3B.

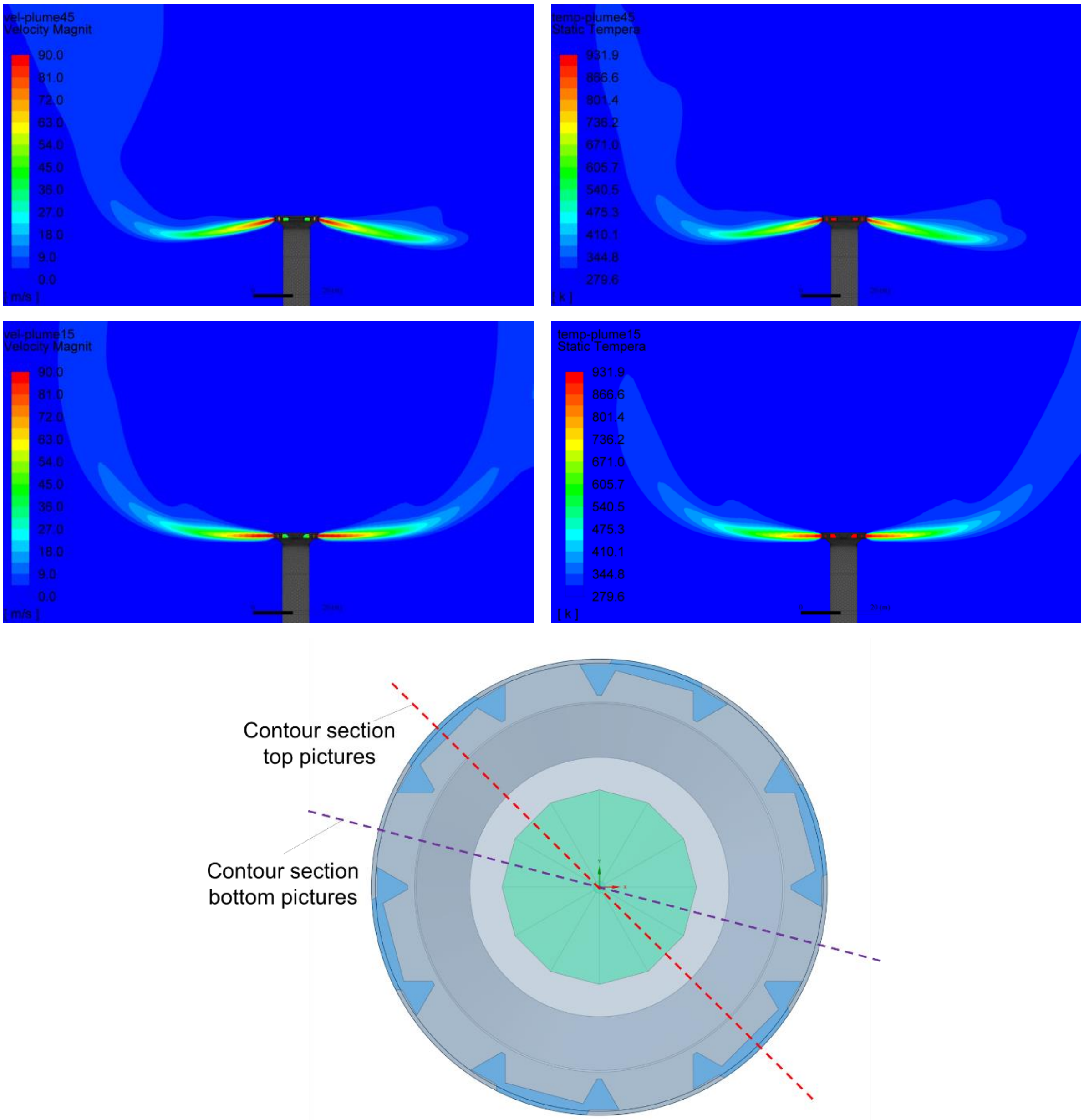


Figure 36. Contours of velocity (left pictures) and temperature (right pictures) close to the stack. The top pictures show a section through the downward deflected openings and the bottom pictues a section through the horizontal openings – Calm wind case for final PDD design version 3B.

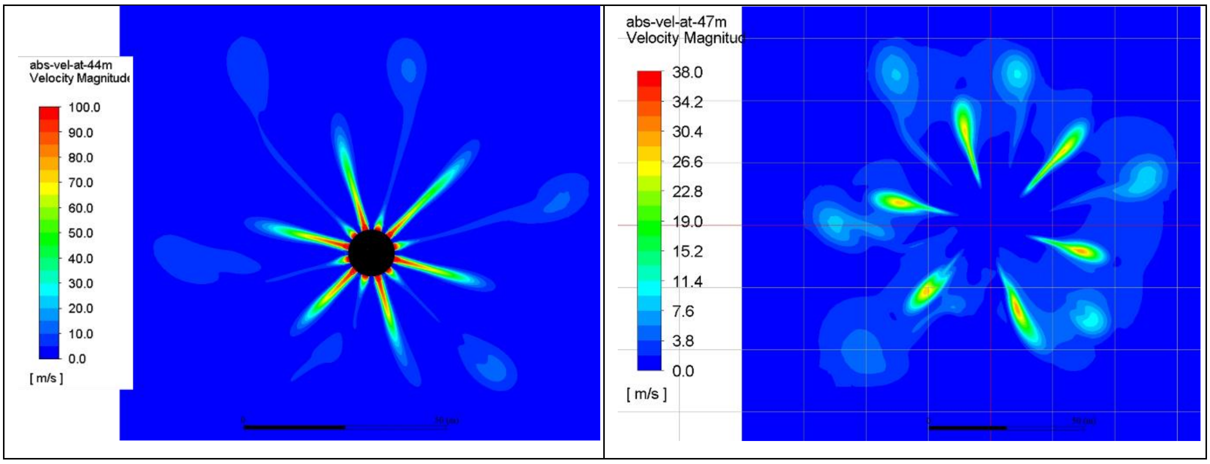


Figure 37. Contour of velocity through the nozzle openings (~~top~~left) and about 2 m above the stack outlet in plan view (right) – Calm wind case for final PDD design version 3B. Grid spacing in the right picture is 20 m.

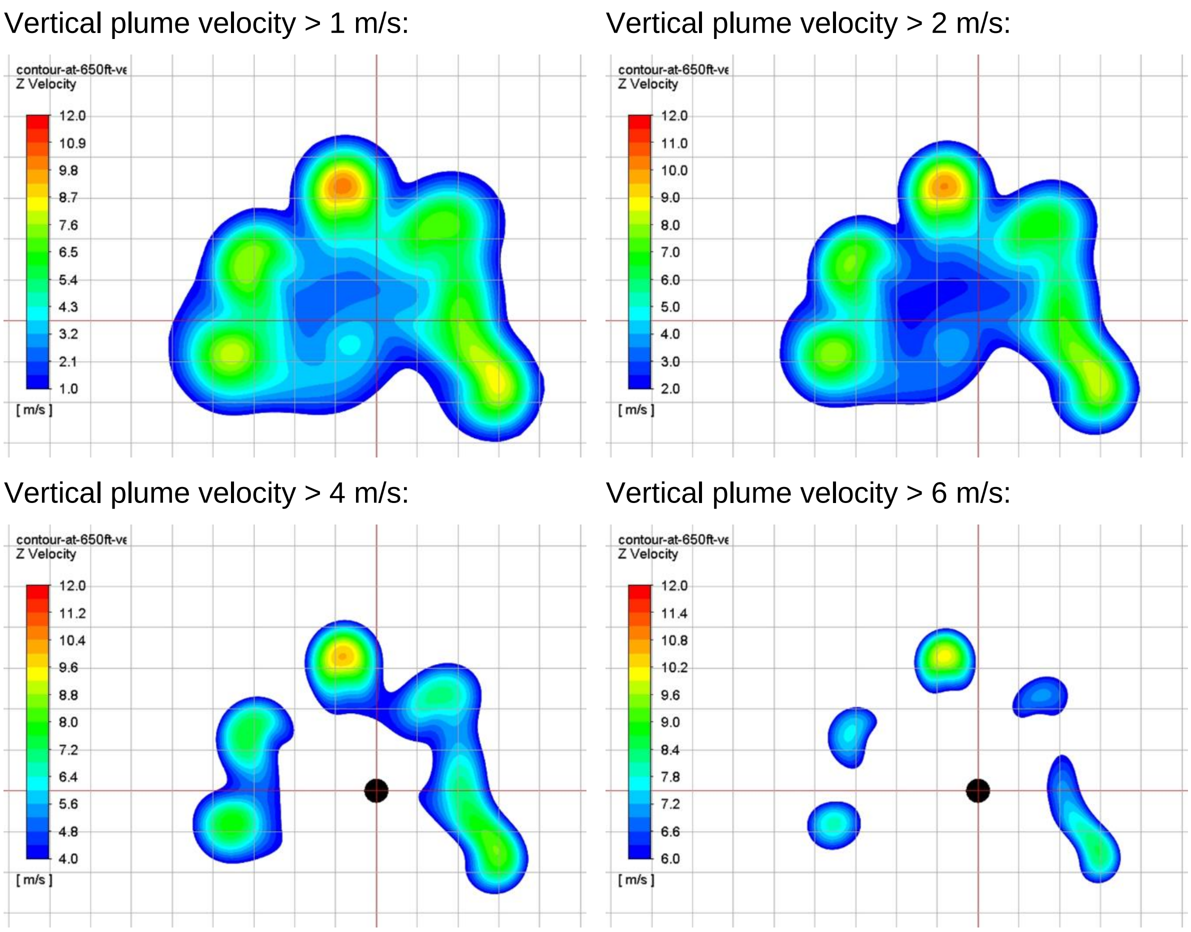


Figure 38. Plume extent shown as a contour plots of vertical velocity in a horizontal plane at 198 m (650 ft) elevation – Calm wind case for final PDD design version 3B. The plume area in each contour plot is clipped to a different vertical plume velocity: > 6 m/s (bottom right), > 4 m/s (bottom left), > 2 m/s (top right) and > 1 m/s (top left). Grid spacing is 20 m with stack centre at the origin (red lines).

Figure 39 depicts the growth in horizontal displacement of the locations of the maximum absolute plume velocity and maximum vertical velocity. The coordinates are based on the domain, which means that positive y aligns with the direction ESE (107°) and positive x with SSW (197°). The total horizontal displacement of the plume core is approximately 210 m.

Figure 40 shows the horizontal trajectory of the maximum vertical velocity component as well as the maximum absolute plume velocity in compass coordinates (positive abscissa towards east and positive ordinate towards north).

Both Figure 39 and Figure 40 show discontinuities that are associated with minor oscillations in the individual jets interacting with the ambient wind, such that the location of the maximum vertical velocity jumps around between the individual jets, creating a pattern that is hard to interpret.

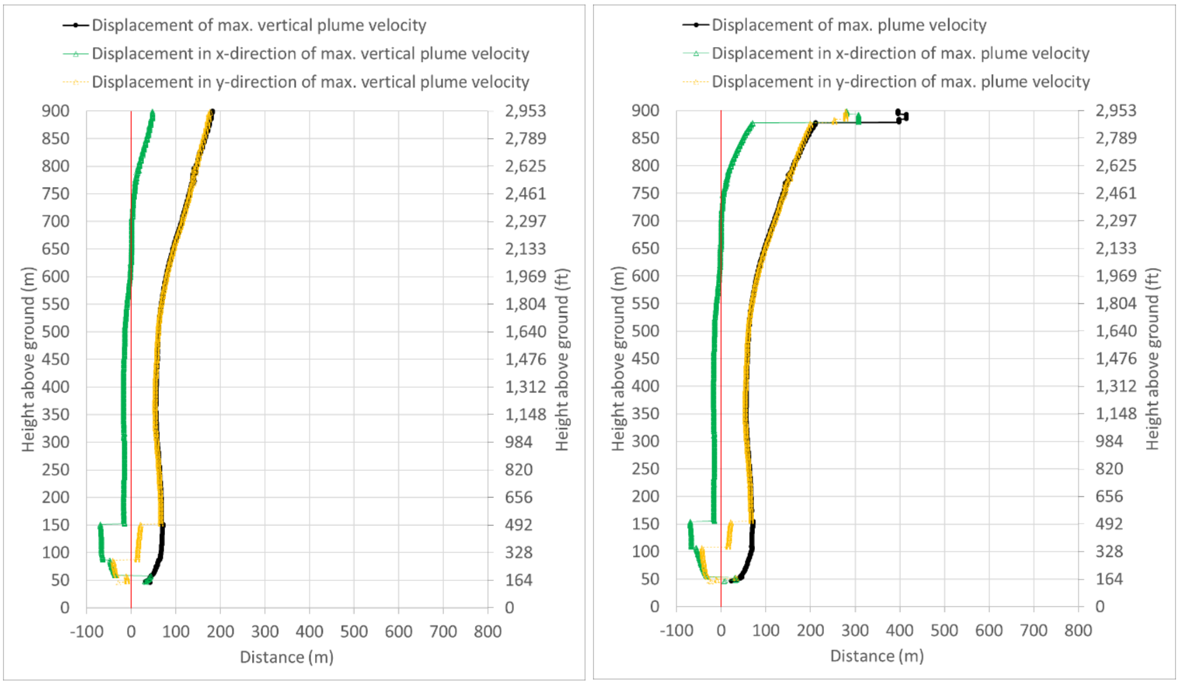


Figure 39. Displacement of maximum vertical velocity component (left) and of absolute core velocity (right) against height – Calm wind case for final PDD design version 3B.

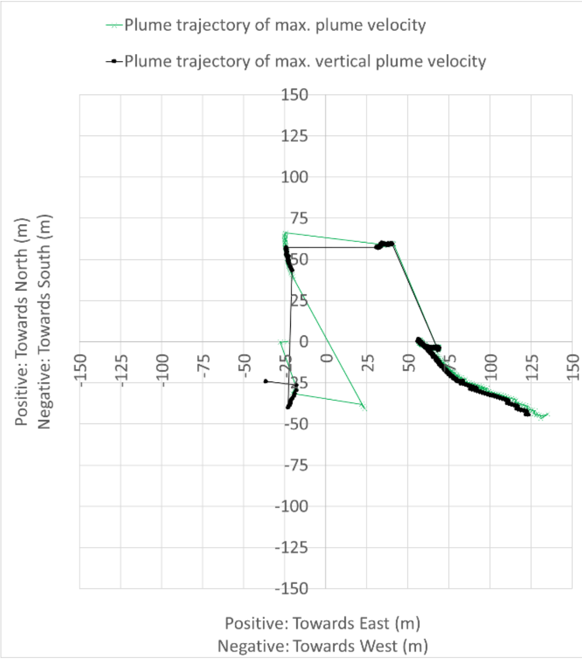


Figure 40. Horizontal trajectory of maximum vertical velocity and plume core velocity in compass coordinates – Calm wind case for final PDD design version 3B.

Figure 41 to Figure 44 are contour plots of velocity magnitude, vertical velocity, and air temperature on x-z and y-z planes through the stack centre, or on horizontal planes at different heights. The black lines in Figure 42 to Figure 44 show the x and y planes through the stack centre. Contours are clipped for clarity.

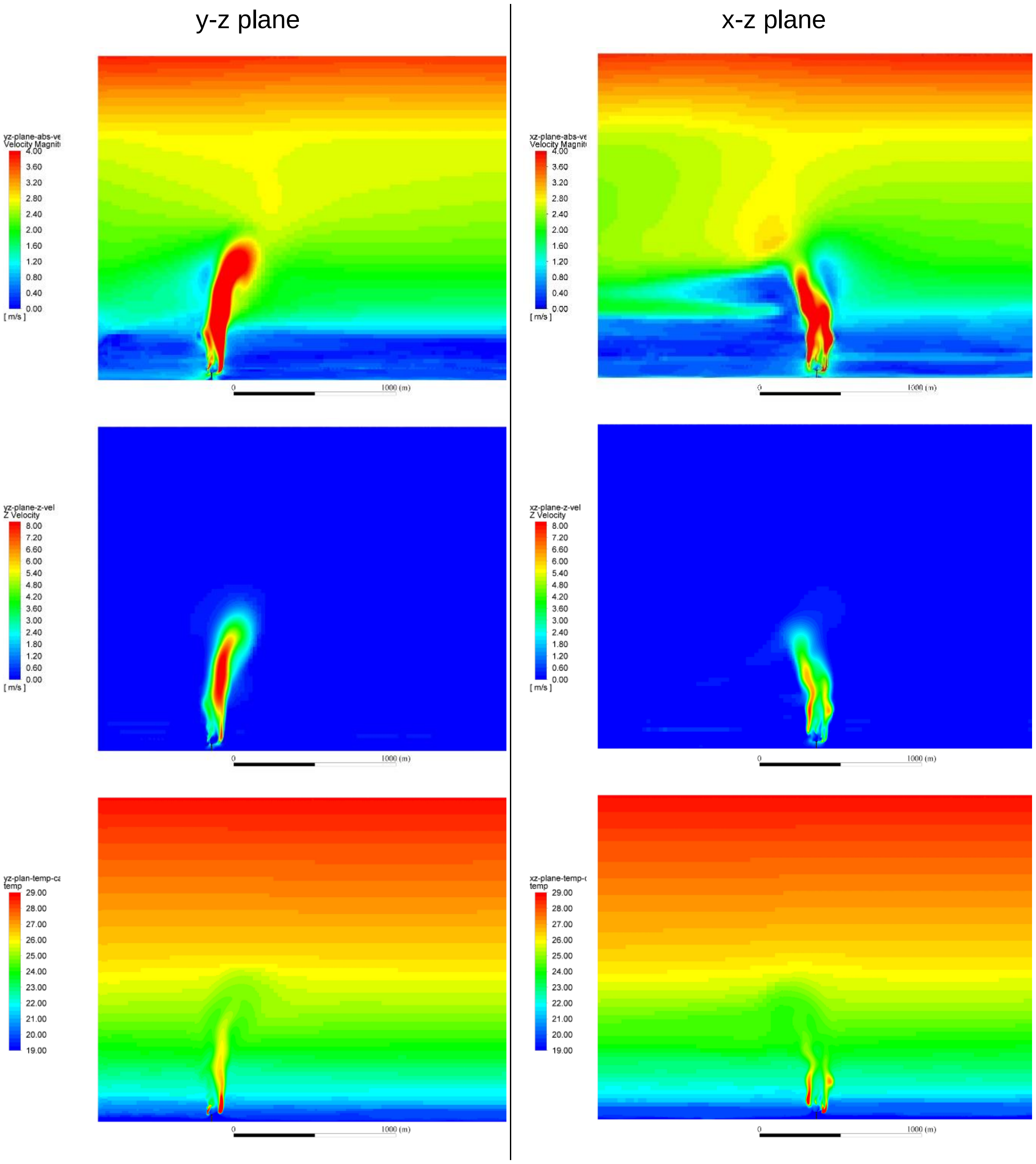


Figure 41. Contour plot in y-z plane (left) and x-z plane (right) through the stack centre for velocity magnitude (top), vertical velocity (middle), and temperature (bottom) – Calm wind case for final PDD design version 3B.

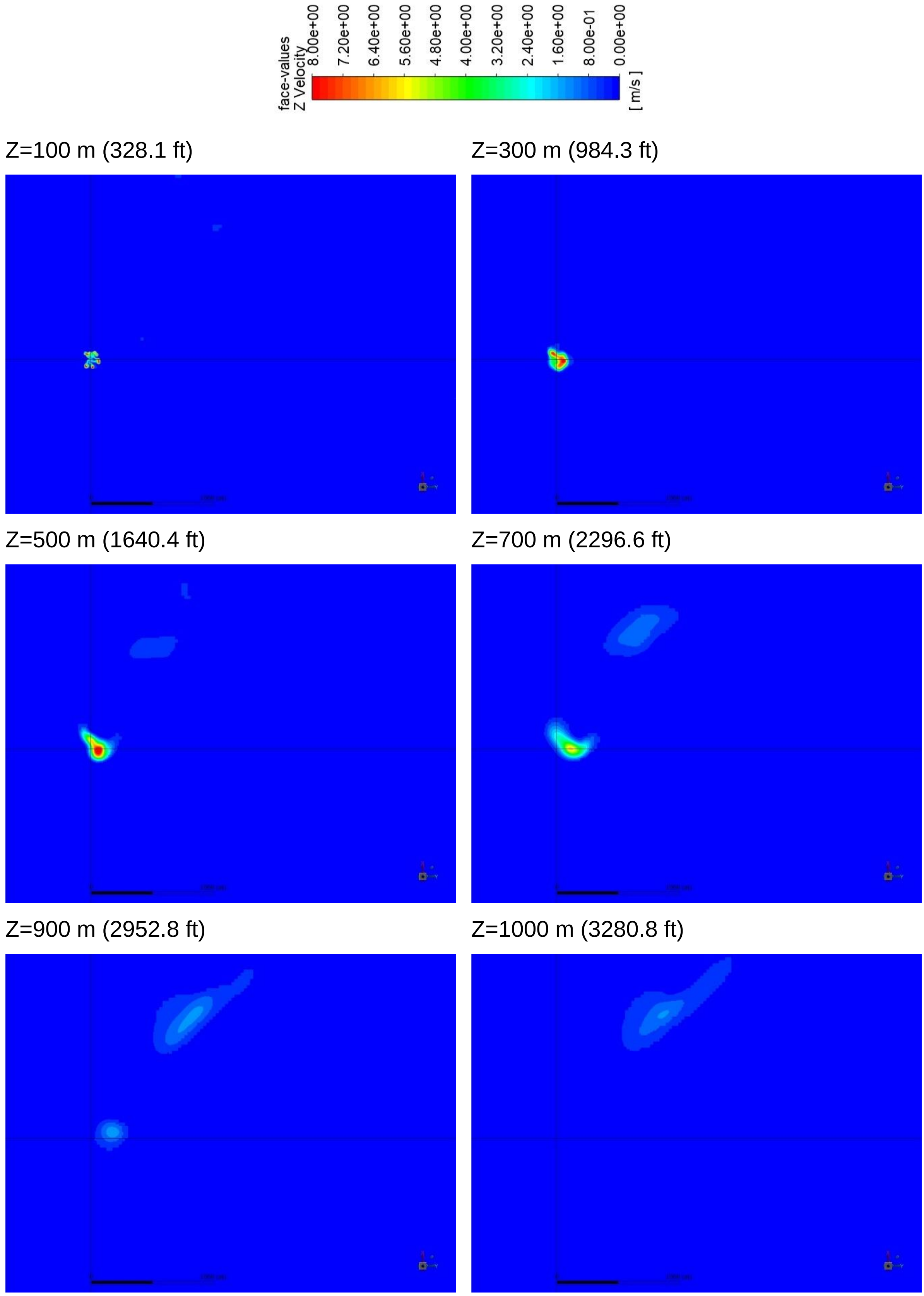


Figure 42. Contour plot of vertical velocity in plan at different heights – Calm wind case for final PDD design version 3B. Black lines define the stack centre.

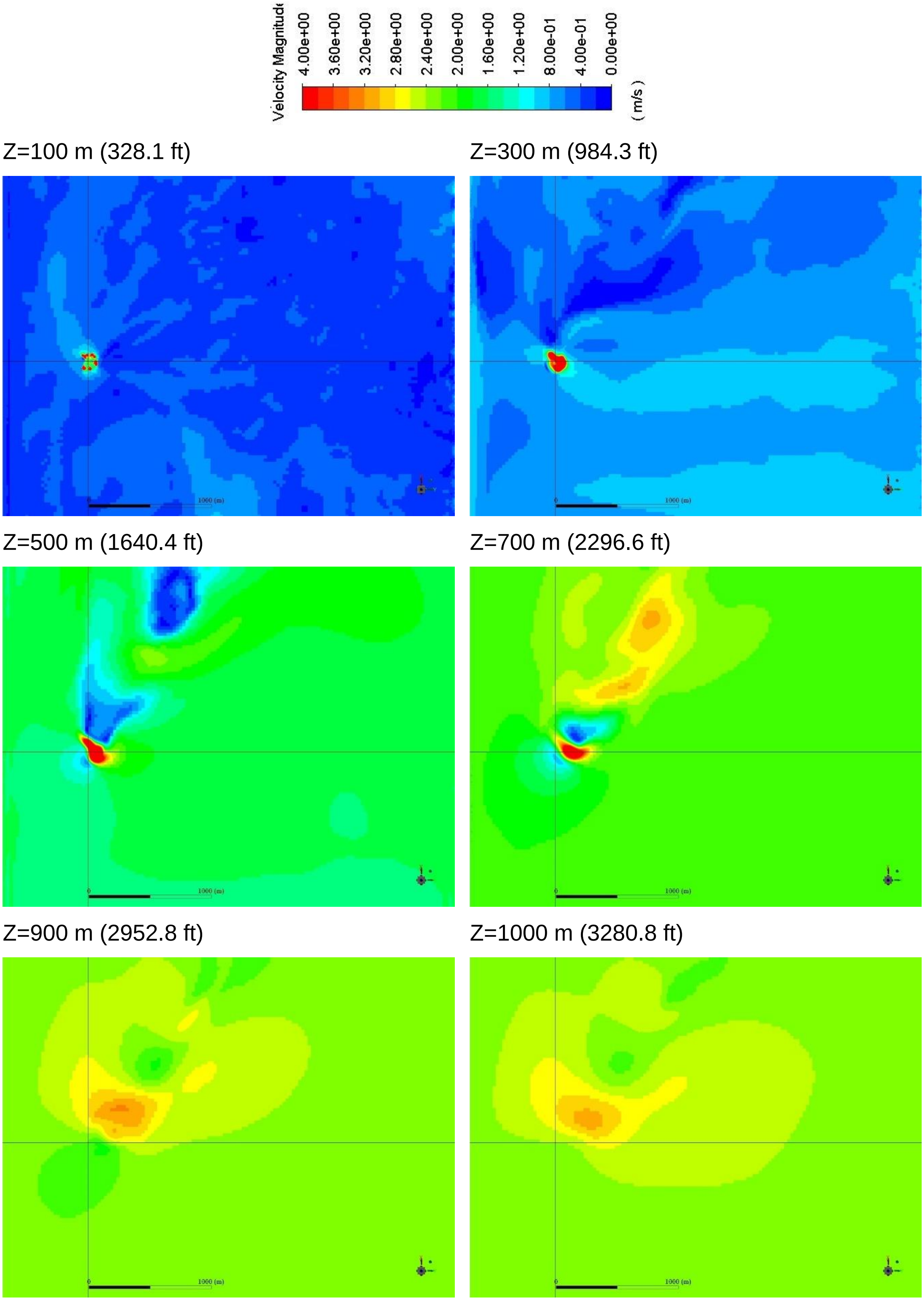


Figure 43. Contour plot of velocity magnitude in plan at different heights - Calm wind case for final PDD design version 3B. Black lines define the stack centre.

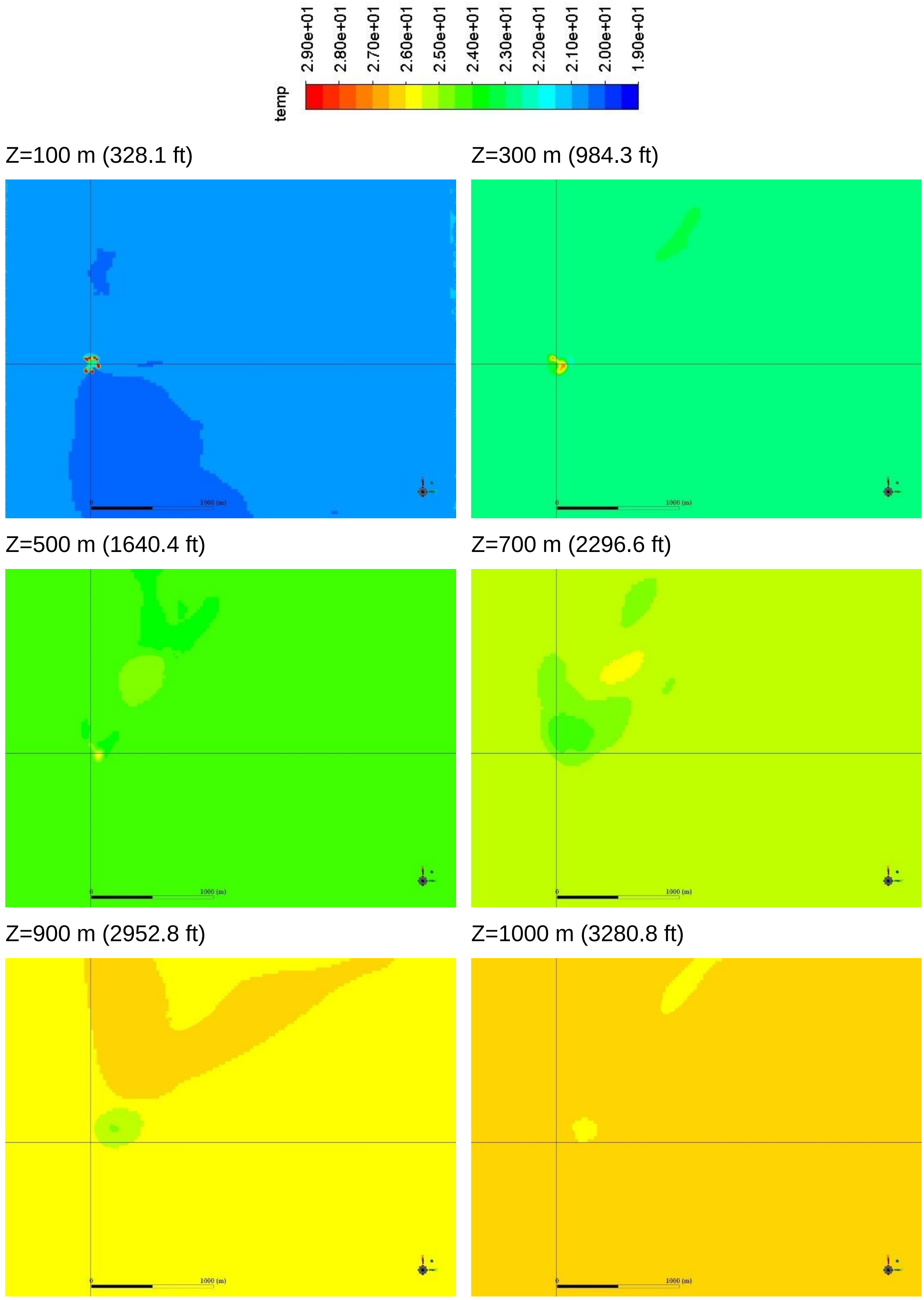


Figure 44. Contour plots of temperature in plan at different heights - Calm wind case for final PDD design version 3B. Black lines define the stack centre.

A.2. 'Combined' Wind Case (Wind profile: 20150308 – Calm and Temperature profile 20140703_10)

Figure 45 (left) shows the maximum vertical and absolute plume velocity against height as well as the atmospheric wind speed profile according to Figure 3. The maximum plume velocity ~~reaches~~ falls to the ambient wind value at approximately 1080 m (3543 ft) above the ground level. The maximum vertical plume velocity at this point is about 2.3 m/s. The plume temperature (right side of Figure 45) decreases rapidly with height and comes to within 0.5°C of the ambient value at about 900 m (2953 ft) above ground.

Figure 46 depicts the plume area against height (left) and the average plume velocities (right) within this area. Here the plume area is defined as horizontal area in which the vertical plume velocity is > 6 m/s. In addition, Figure 47 shows a similar plot and compares the plume area and average vertical plume velocity for different plume area definitions (area in which vertical plume velocity is > 6 m/s, > 4 m/s, > 2 m/s and > 1 m/s).

Figure 48 and Figure 49 illustrate the velocity and temperature distribution of the initial jet flow region and Figure 50 the plume extent for the different vertical plume velocity criteria, based on value-clipped contour plots for vertical velocity.

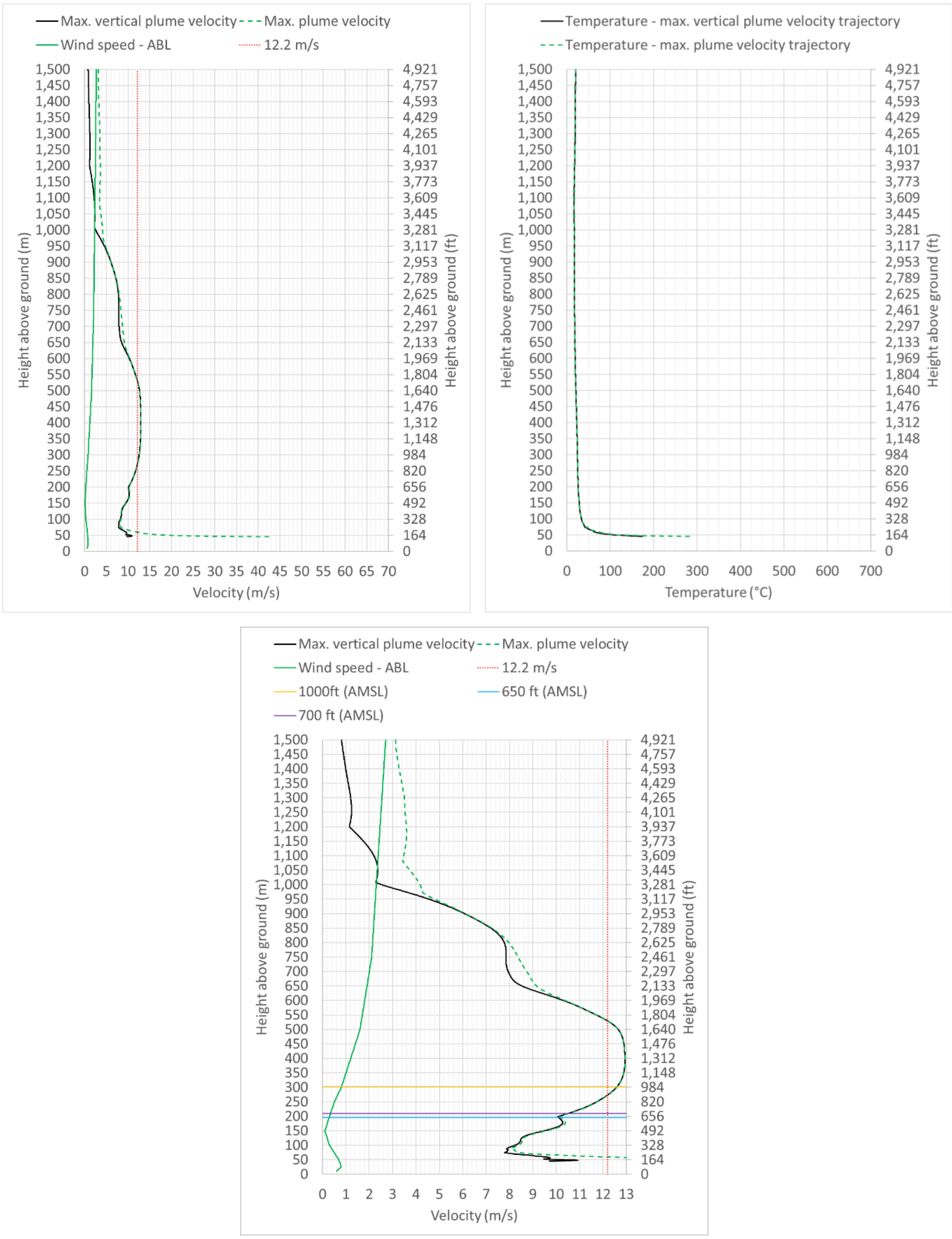


Figure 45. Wind speed and maximum vertical and absolute plume velocity against height (left) and plume temperature along both trajectories (right) – 'Combined' wind case for final PDD design version 3B. Plot at the bottom shows the plume velocities on an expanded scale.

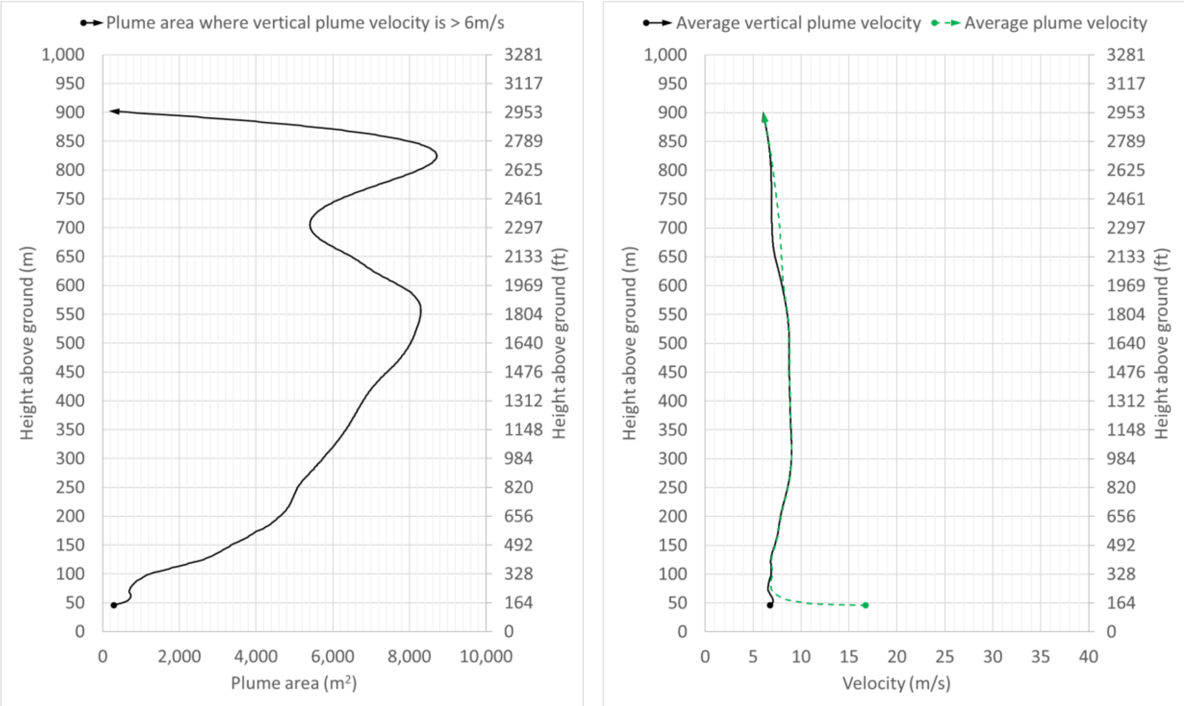


Figure 46. Plume area (area where vertical plume velocity is > 6 m/s) (left) and average plume velocities against height (right) – 'Combined' wind case for final PDD design version 3B. Note that with the definition of plume area as being where the vertical velocity exceeds 6 m/s, the average vertical velocity in the 'plume' clearly can't fall below 6 m/s.

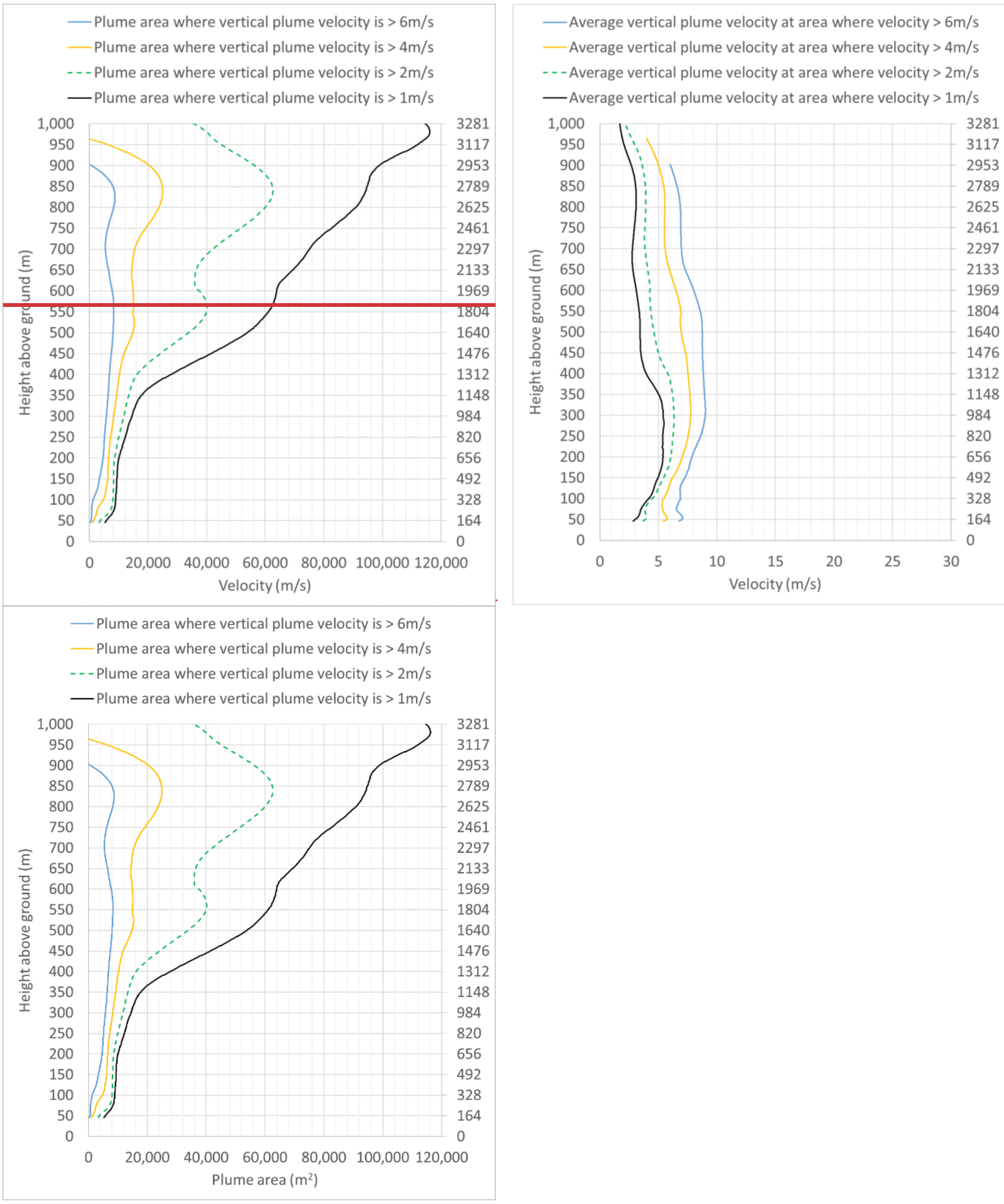


Figure 47. Plume area (left) and average plume velocities against height (right) for different plume area definitions - 'Combined' wind case for final PDD design version 3B.

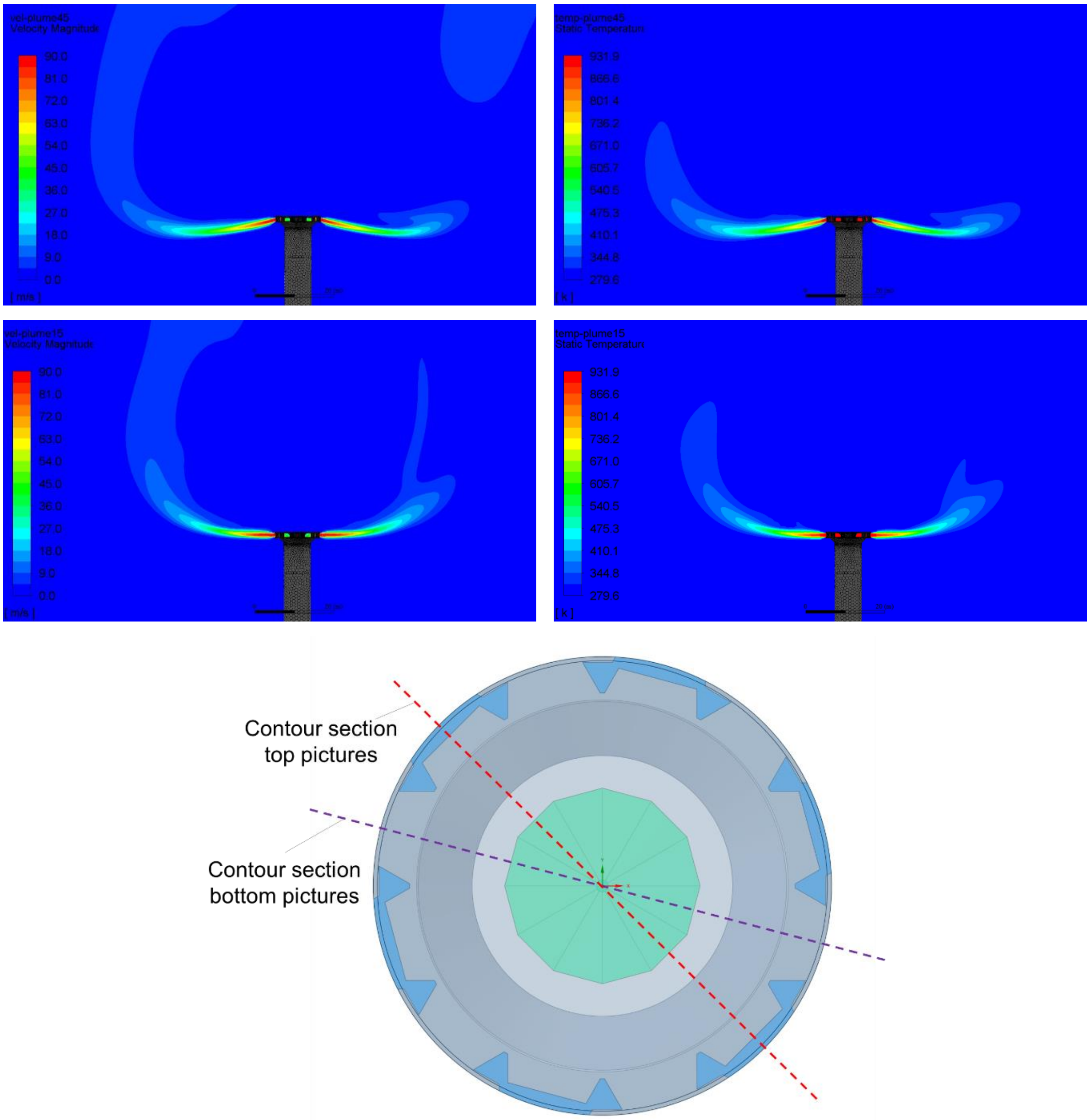


Figure 48. Contours of velocity (left pictures) and temperature (right pictures) close to the stack. The top pictures show a section through the downward deflected openings and the bottom pictues a section through the horizontal openings – 'Combined' wind case for final PDD design version 3B.

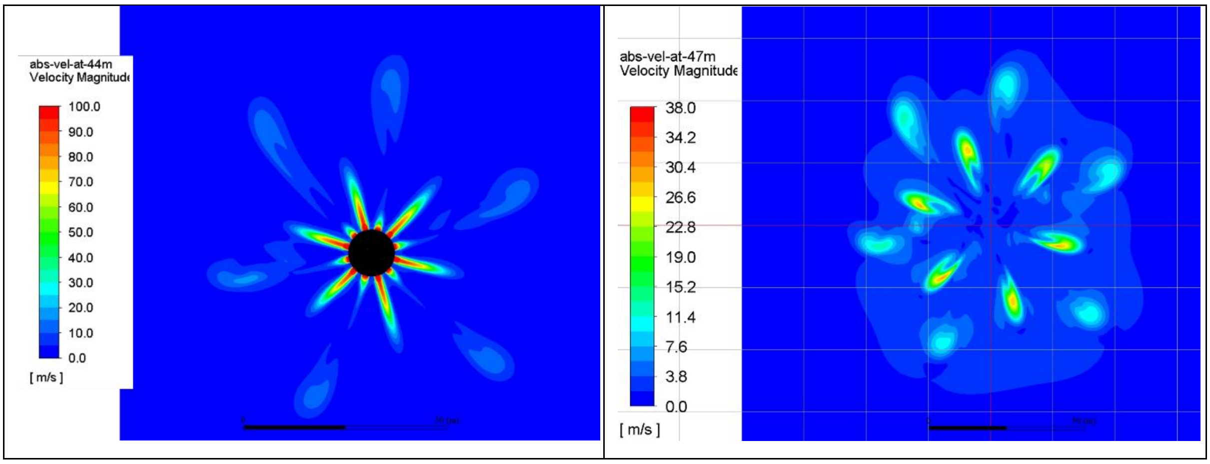
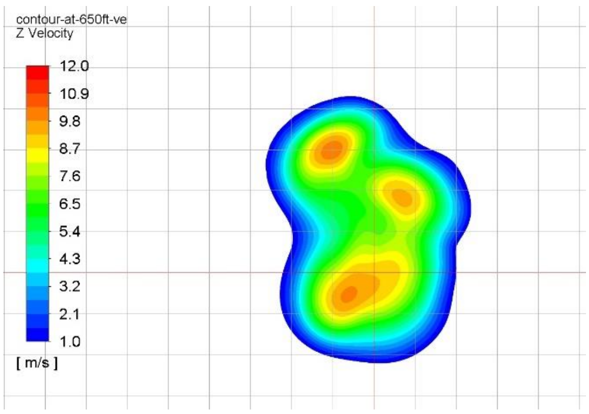
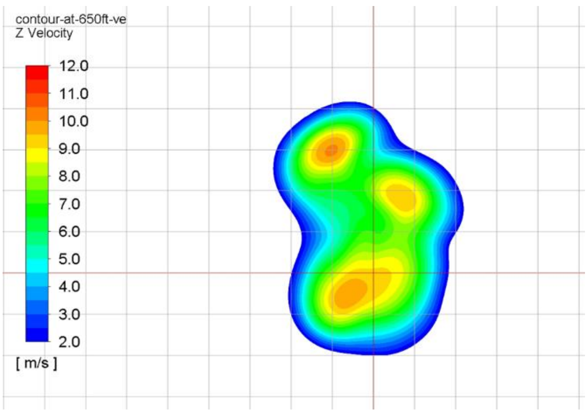


Figure 49. Contour of velocity through the nozzle openings (~~top~~left) and about 2 m above the stack outlet in plan view (~~bottom~~right) – 'Combined' wind case for final PDD design version 3B. Grid spacing in the ~~bottom~~ right picture is 20 m.

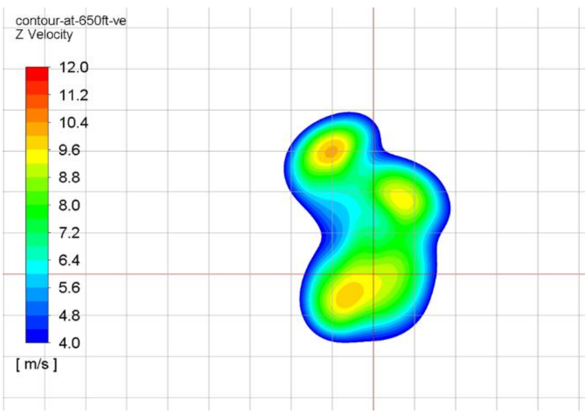
Vertical plume velocity > 1 m/s:



Vertical plume velocity > 2 m/s:



Vertical plume velocity > 4 m/s:



Vertical plume velocity > 6 m/s:

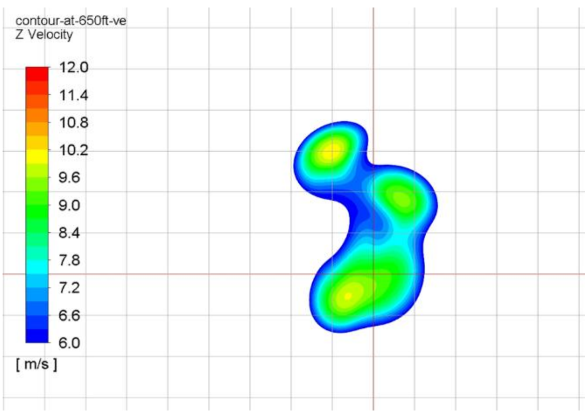


Figure 50. Plume extent shown as a contour plots of vertical velocity in a horizontal plane at 198 m (650 ft) elevation – 'Combined' wind case for final PDD design version 3B. The plume area in each contour plot is clipped to a different vertical plume velocity: > 6 m/s (bottom right), > 4 m/s (bottom left), > 2 m/s (top right) and > 1 m/s (top left). Grid spacing is 20 m with stack centre at the origin (red lines).

Figure 51 depicts the growth in horizontal displacement of the locations of the maximum absolute plume velocity and maximum vertical velocity. The coordinates are based on the domain, which means that positive y aligns with the direction ESE (107°) and positive x with SSW (197°). The total horizontal displacement of the plume core is approximately 275 m.

Figure 52 shows the horizontal trajectory of the maximum vertical velocity component as well as the maximum absolute plume velocity in compass coordinates (positive abscissa towards East and positive ordinate towards North).

Both Figure 51 and Figure 52 show discontinuities that are associated with minor oscillations in the individual jets interacting with the ambient wind, such that the location of the maximum vertical velocity jumps around between the individual jets, creating a pattern that is hard to interpret.

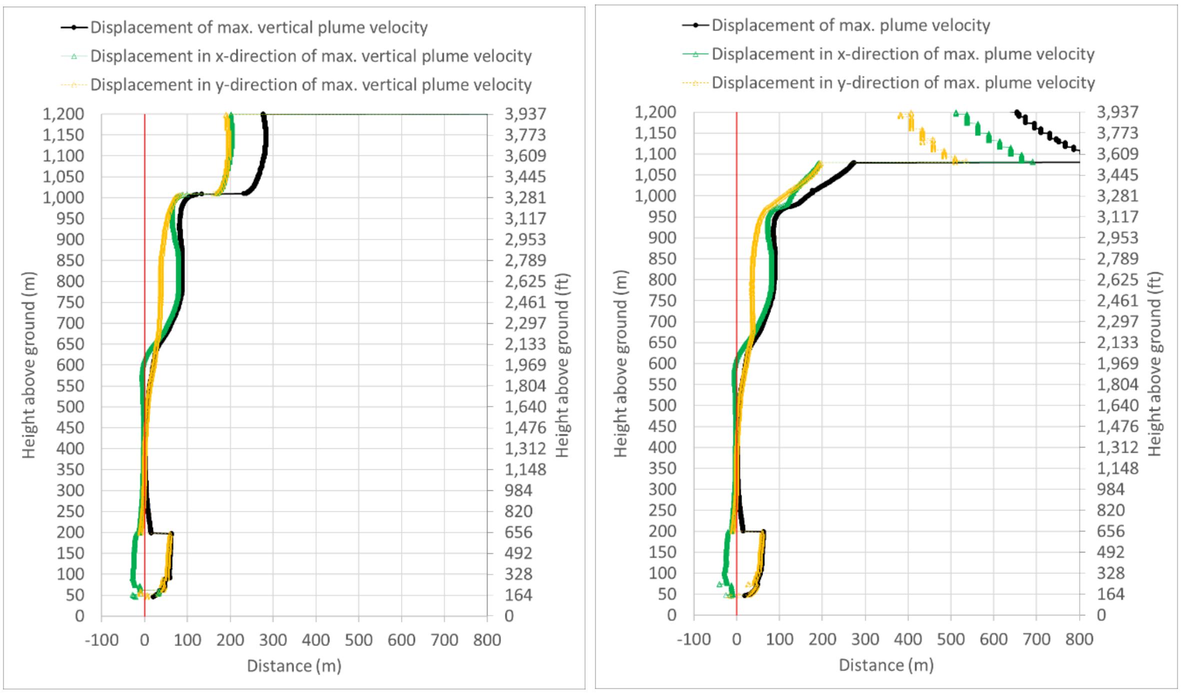


Figure 51. Displacement of maximum vertical velocity component (left) and of absolute core velocity (right) against height – 'Combined' wind case for final PDD design version 3B.

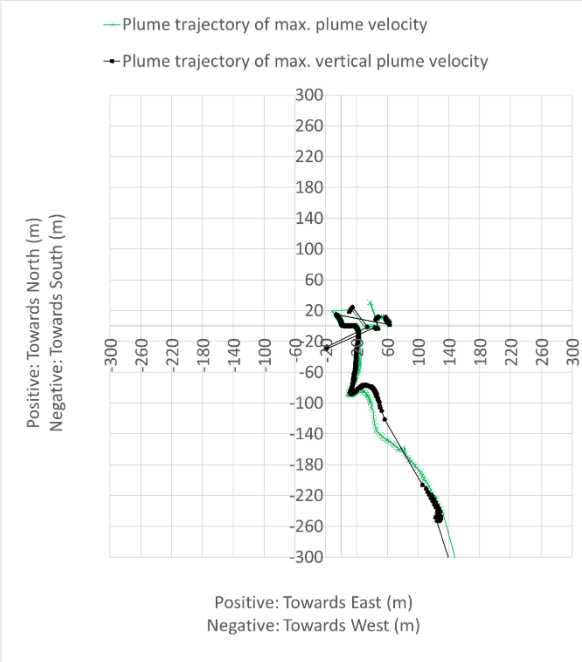


Figure 52. Horizontal trajectory of maximum vertical velocity and plume core velocity in compass coordinates – 'Combined' wind case for final PDD design version 3B.

Figure 53 to Figure 56 are contour plots of velocity magnitude, vertical velocity, and air temperature on x-z and y-z planes through the stack centre, or on horizontal planes at different heights. The black lines in Figure 54 to Figure 56 show the x and y planes through the stack centre. Contours are clipped for clarity.

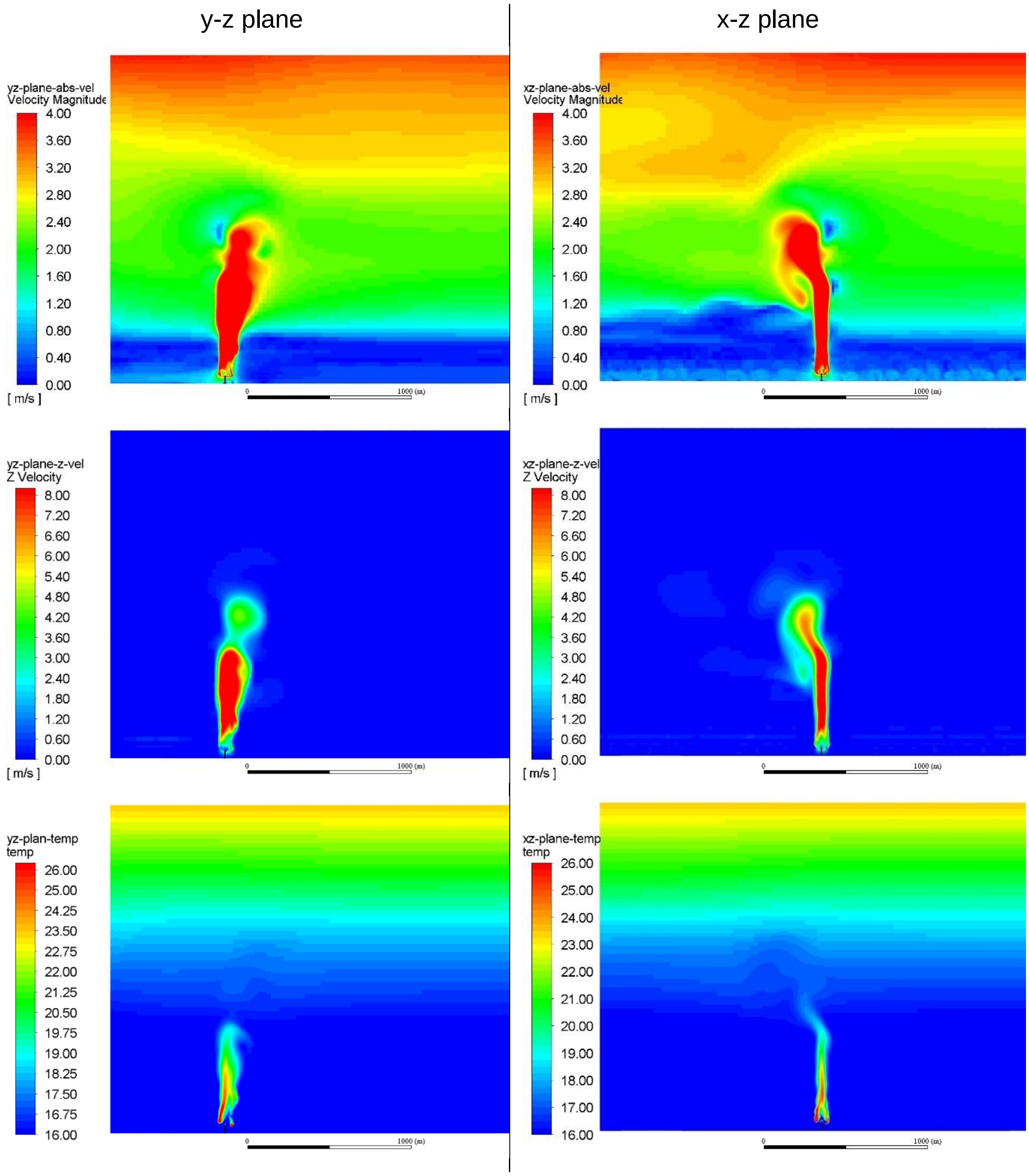


Figure 53. Contour plot in y-z plane (left) and x-z plane (right) through the stack centre for velocity magnitude (top), vertical velocity (middle), and temperature (bottom) – 'Combined' wind case for final PDD design version 3B.

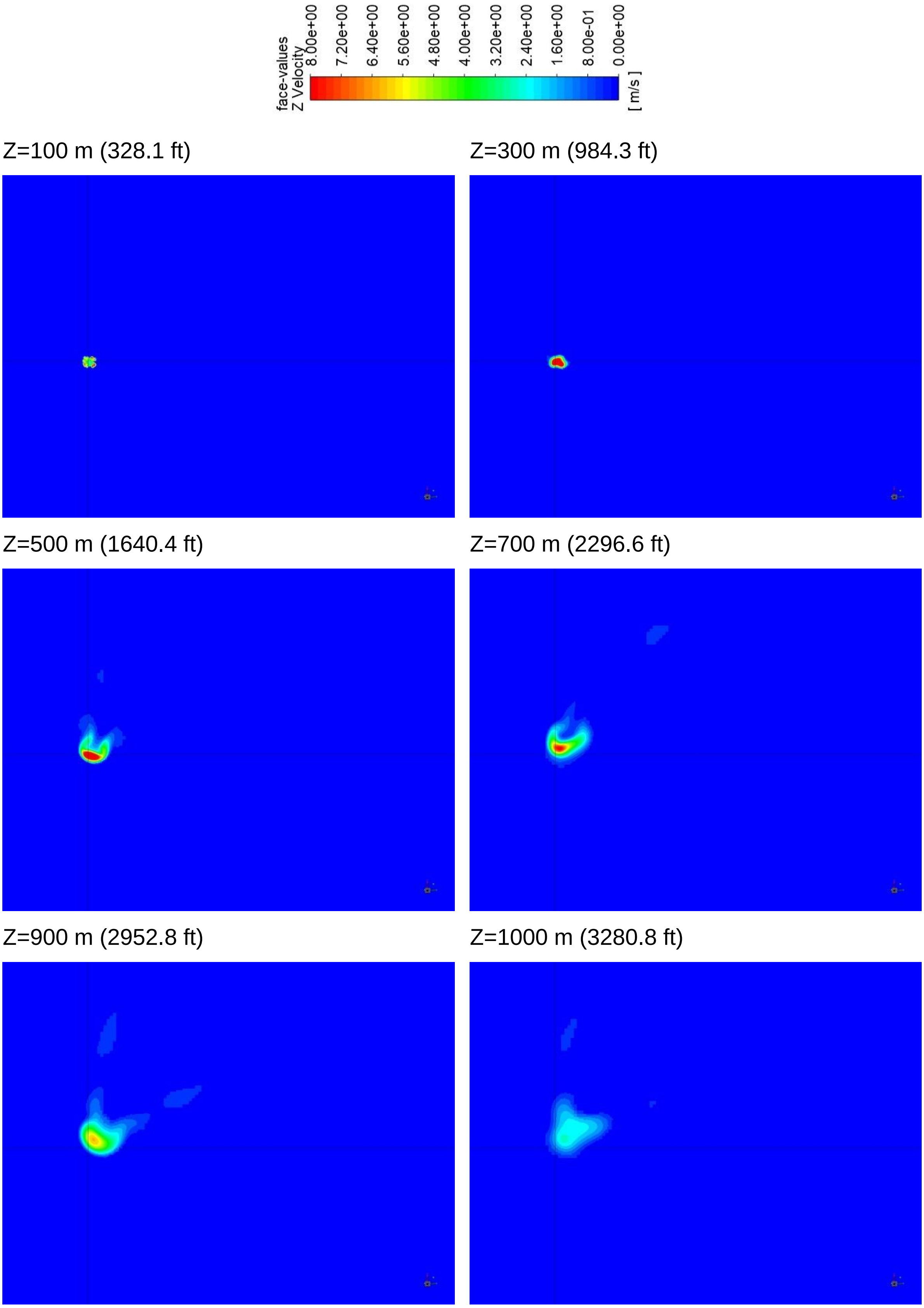


Figure 54. Contour plot of vertical velocity in plan at different horizontal plane heights – 'Combined' wind case for final PDD design version 3B. Black lines define the stack centre.

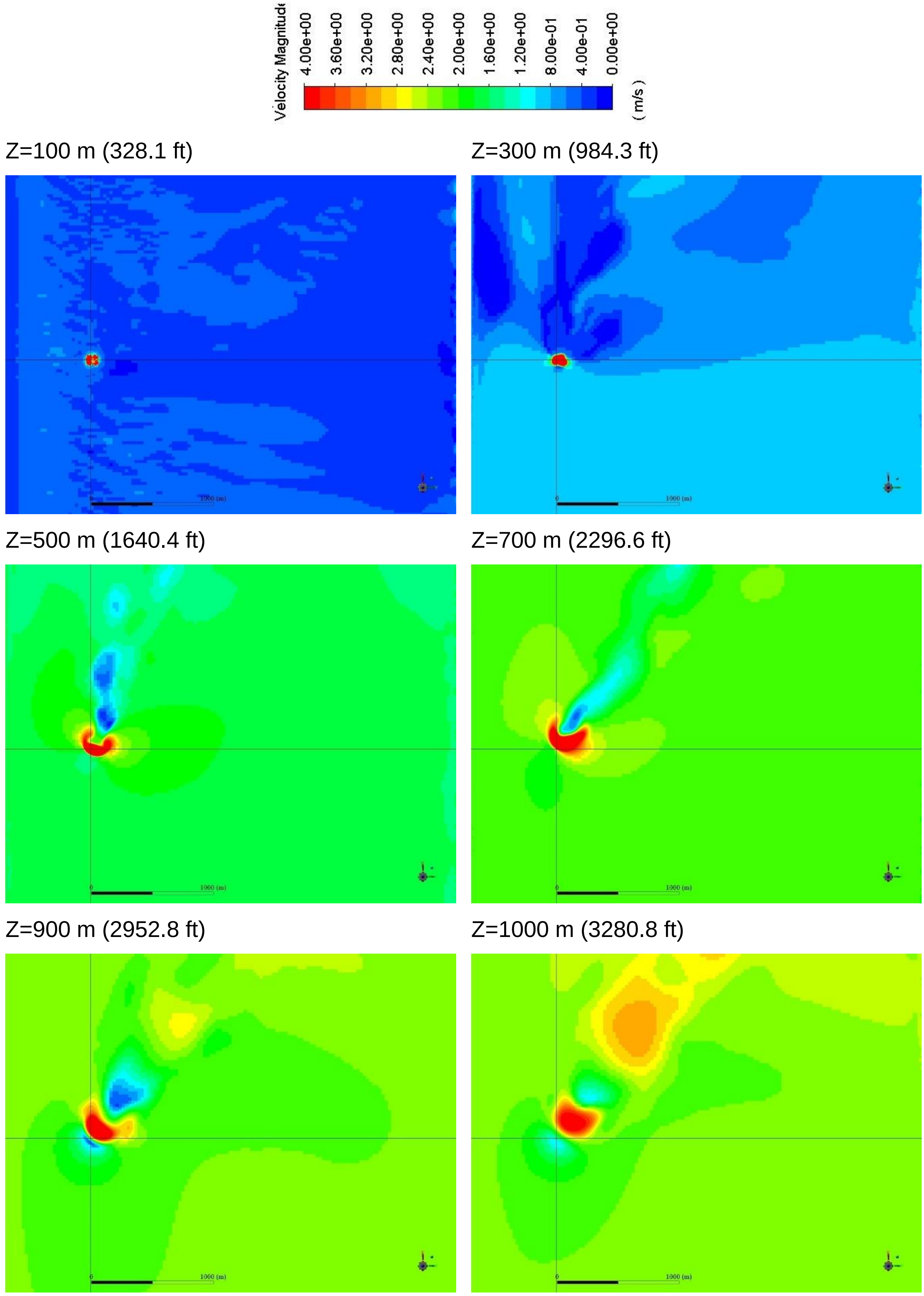


Figure 55. Contour plot of velocity magnitude in plan at different horizontal plane heights - 'Combined' wind case for final PDD design version 3B. Black lines define the stack centre.

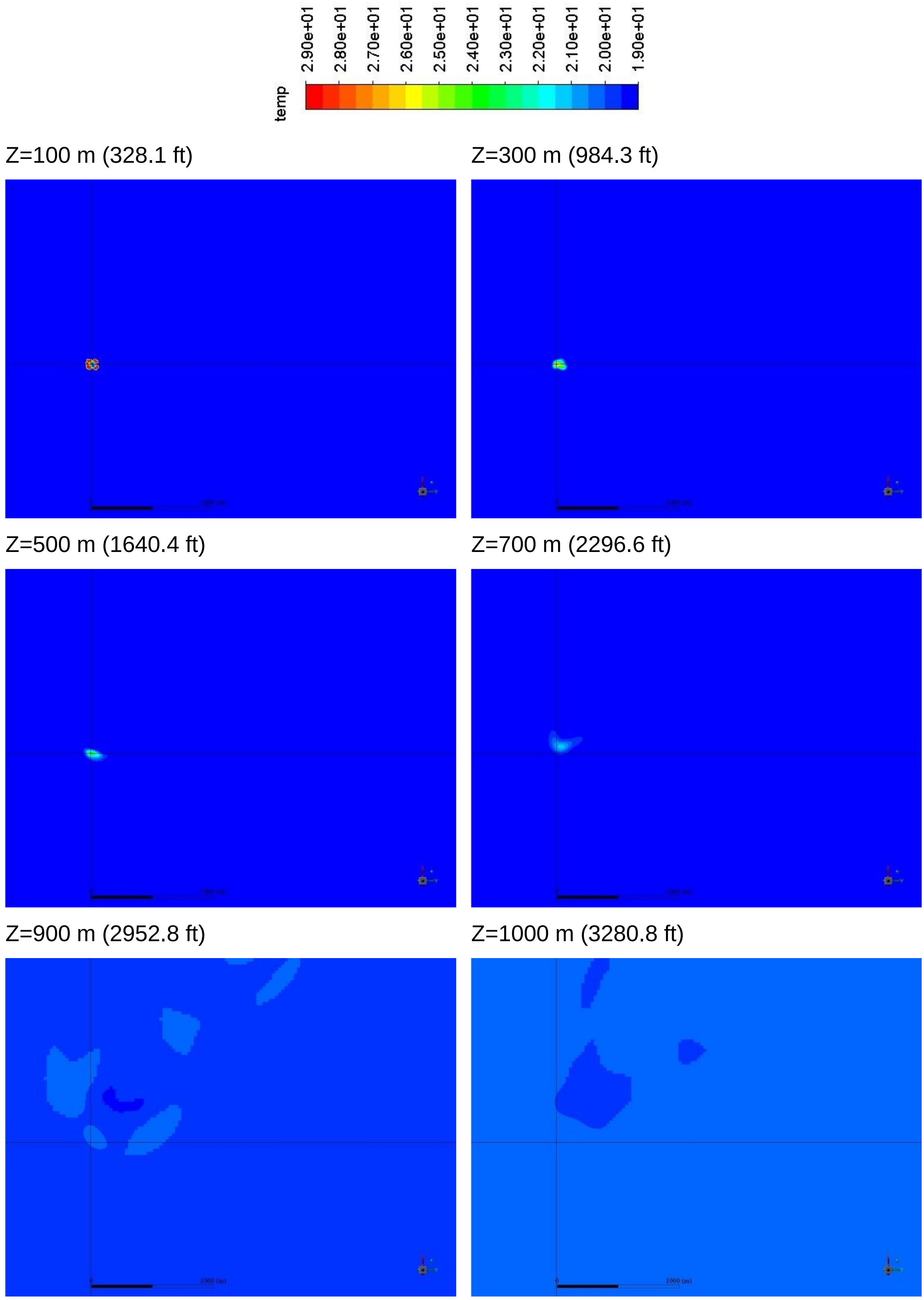


Figure 56. Contour plots of temperature in plan at different heights - 'Combined' wind case for final PDD design version 3B. Black lines define the stack centre.

APPENDIX B VERIFICATION OF CORRECT IMPLEMENTATION OF THE APPLIED BOUNDARY CONDITIONS

This section is to verify the correct implementation of the essential applied boundary conditions like wind speed, direction, and temperature, as well as the stack characteristics (mass flow rate and temperature) as listed in Table 4 and Table 5. The validation has been done for all ~~different~~ three wind scenarios as given in section B.1. to B.3. respectively.

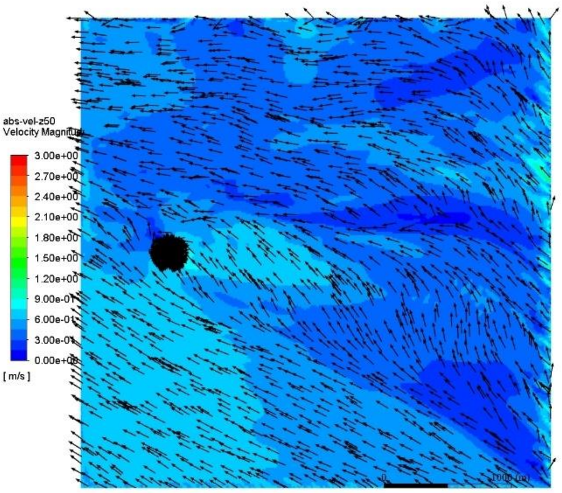
Figure 57, Figure 66 and Figure 72 illustrate the implementation of the wind field in the computational domain, based on contour plots of velocity magnitude and normalised velocity vectors (black) at different heights. ~~It is clear that t~~The wind direction is maintained less accurately where the wind speed is very low~~,~~ and the wind direction changes quickly in elevation.

Vertical 'sample' lines (from ground level to 2000 m) at several points up- and downstream of the stack have been introduced in the domain, to evaluate the correct implementation of the wind profile as well as to demonstrate that the wind profile is maintained. Figure 58, Figure 67 and Figure 76 illustrate the different positions of the vertical lines in the domain for the individual cases~~, respectively~~. The velocity and temperature profiles in Figure 59 to Figure 62, Figure 68 to Figure 71, and Figure 77 ~~and~~ to Figure 80, clearly show that the applied wind and temperature profiles are ~~is~~ influenced by the plume, but ~~is~~ are maintained far away from the plume region. The plume can simply be seen as an obstacle that the flow must go around. In addition, the temperature profiles also verify the applied temperature at the ground and the top of the domain.

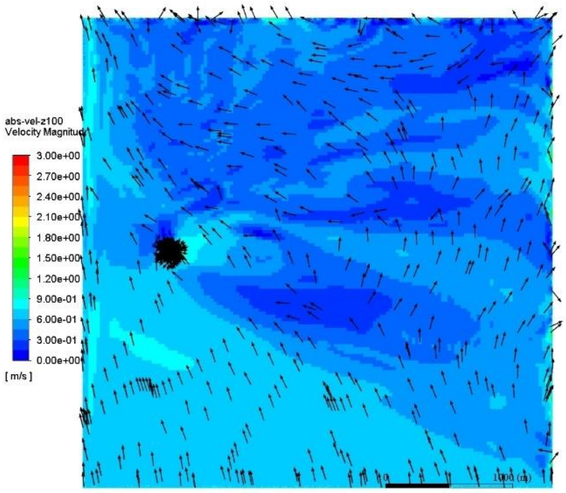
The implementation of the correct stack flow parameters is verified in Figure 63 to Figure 65, Figure 72 to Figure 74~~Figure 75~~ and Figure 81 to Figure 83. The vertical temperature distribution is also shown in Figure 20, Figure 41 and Figure 53. Horizontal temperature plots in different levels are also shown in Figure 23, Figure 44 and Figure 56.

B.1. ‘Initial’ Wind Case for final PDD design version 3B (Wind and Temperature Profile: 20140703_10)

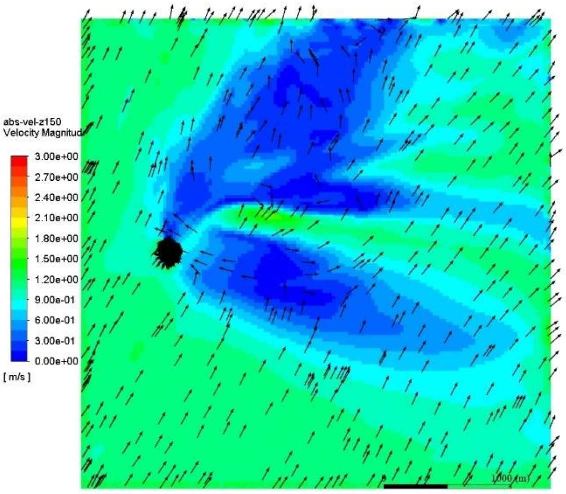
Z = 50 m (164 ft)



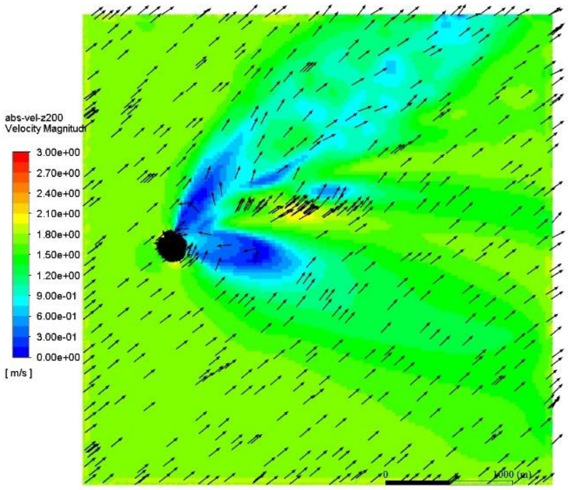
Z = 100 m (328 ft)



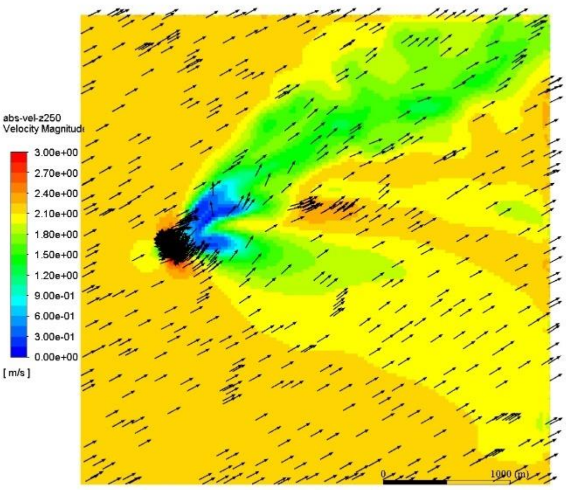
Z = 150 m (656 ft)



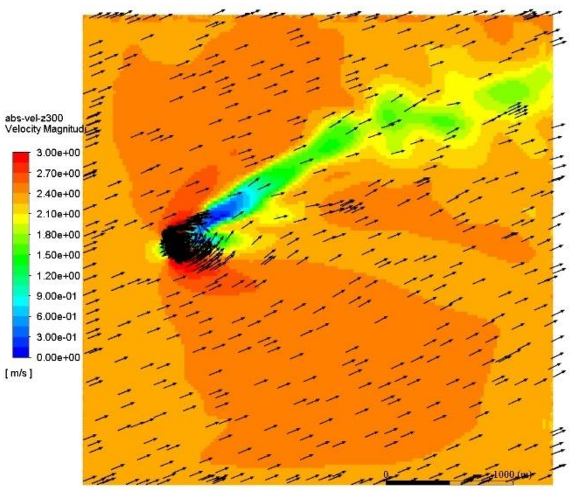
Z = 200 m (492 ft)



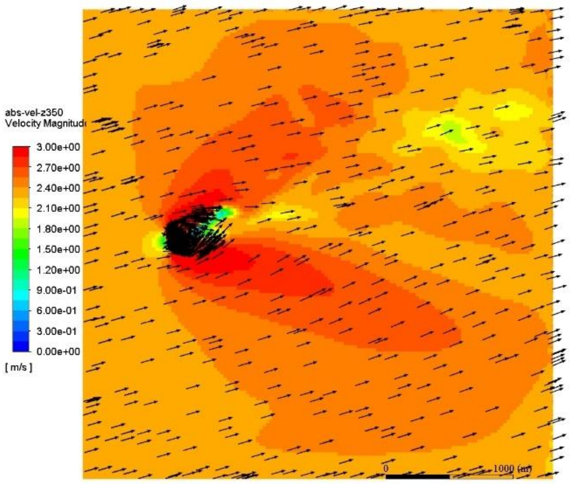
Z = 250 m (820 ft)



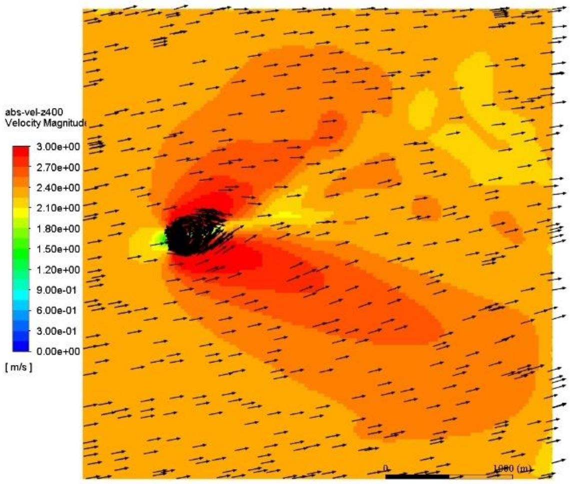
Z = 300 m (984 ft)



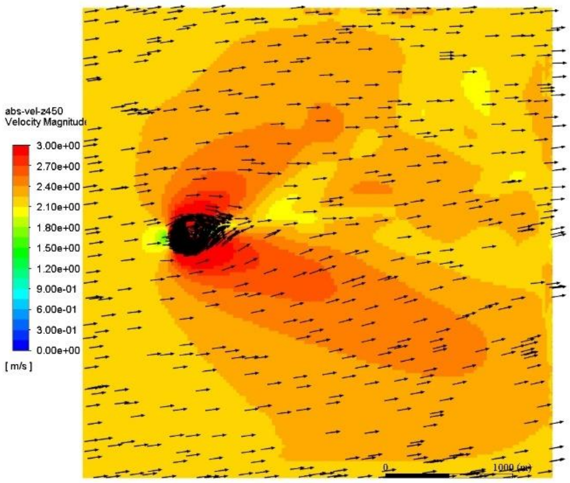
Z = 350 m (1148 ft)



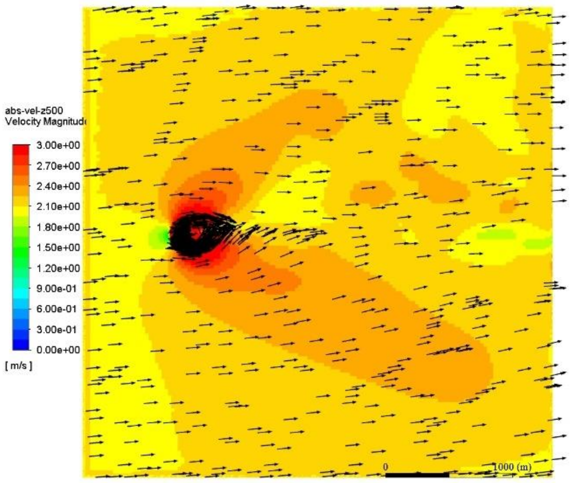
Z = 400 m (1312 ft)



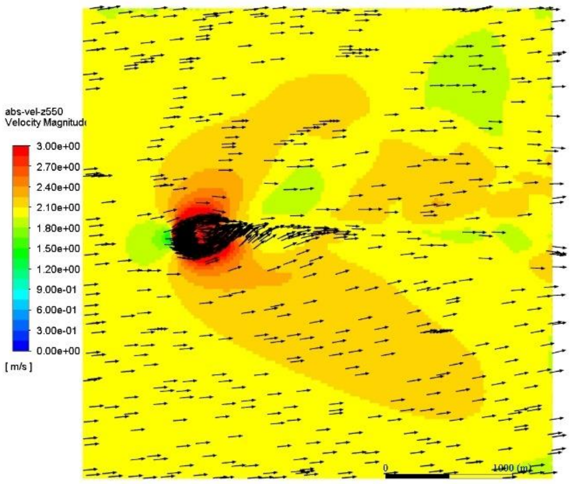
Z = 450 m (1476 ft)



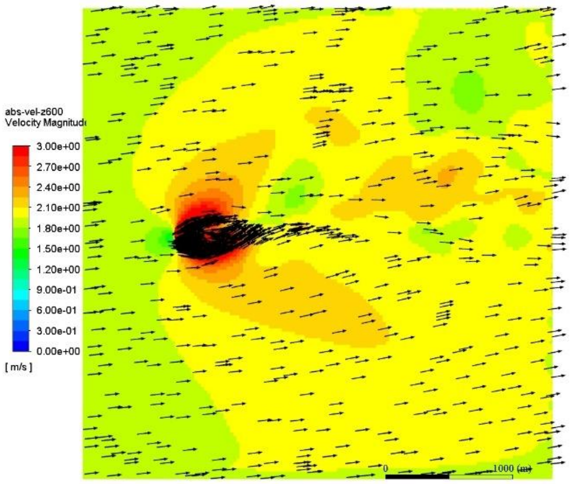
Z = 500 m (1640 ft)



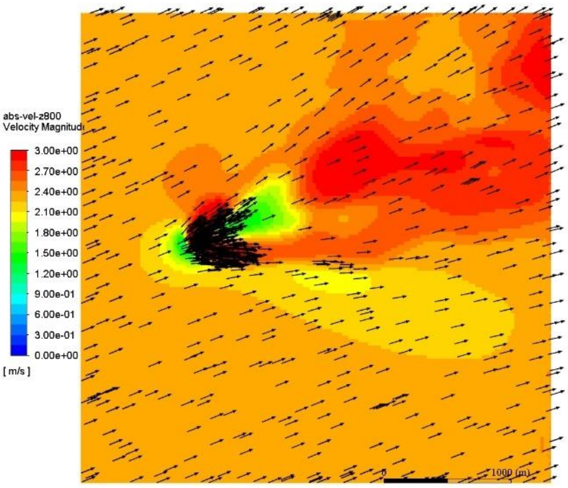
Z = 550 m (1804 ft)



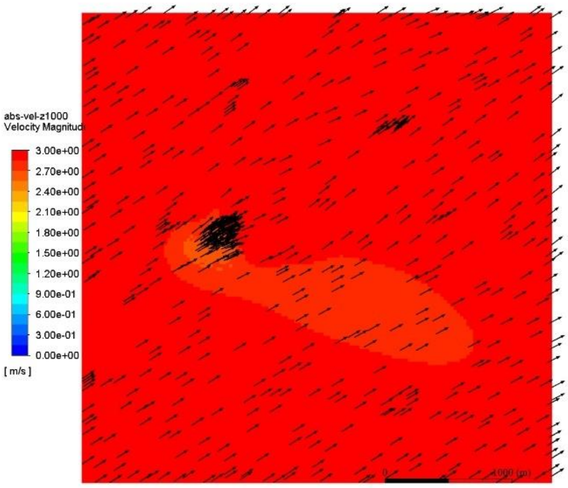
Z = 600 m (1969 ft)



Z = 800 m (2625 ft)



Z = 1000 m (3281 ft)



Z = 1500 m (4921 ft)

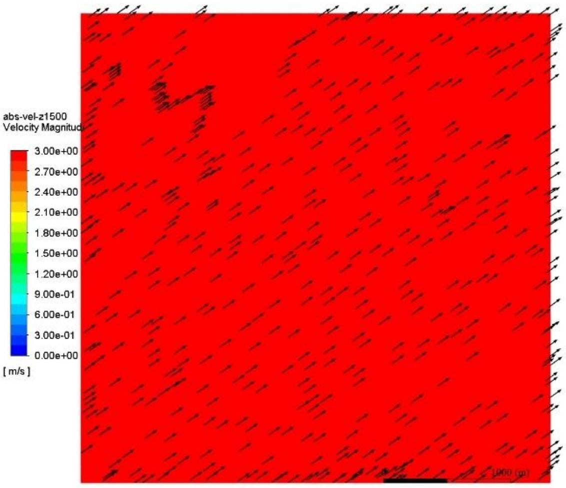


Figure ~~-~~57. Contour plots of velocity magnitude with normalised velocity vectors at different heights – 'Initial' wind case for final PDD design version 3B.

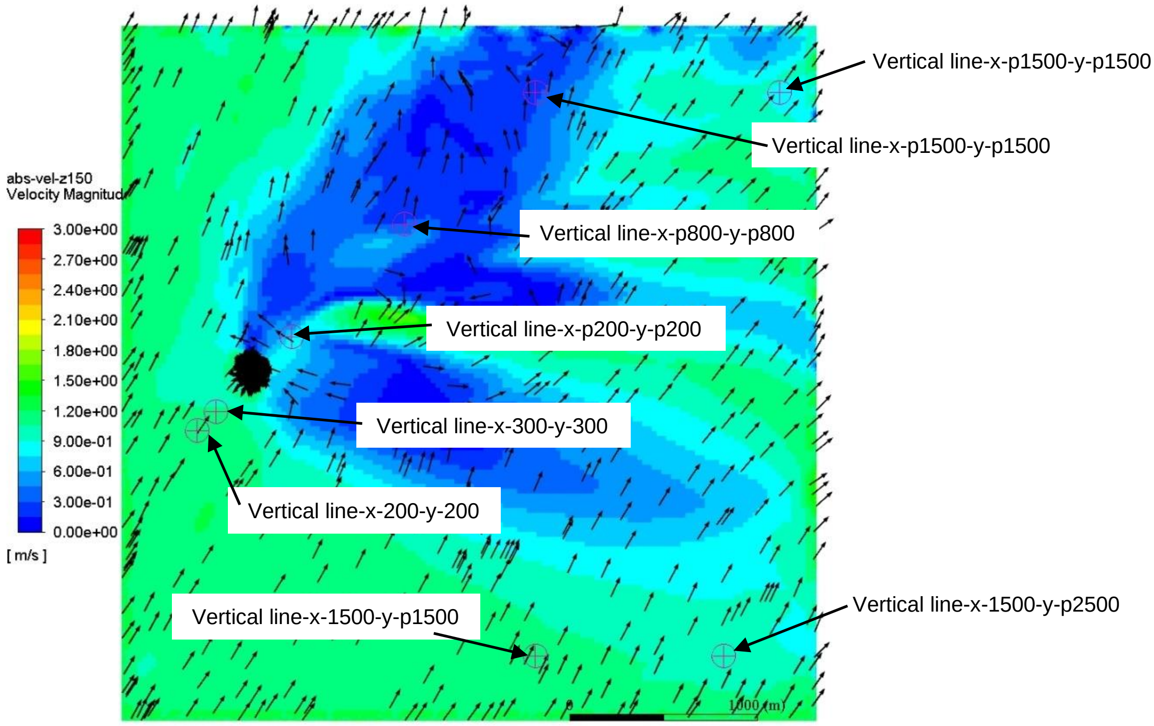


Figure 58. Position of vertical sample lines (from ground level to 2000 m) for analysing the correct implementation of the wind profile – 'Initial' wind case for final PDD design version 3B.

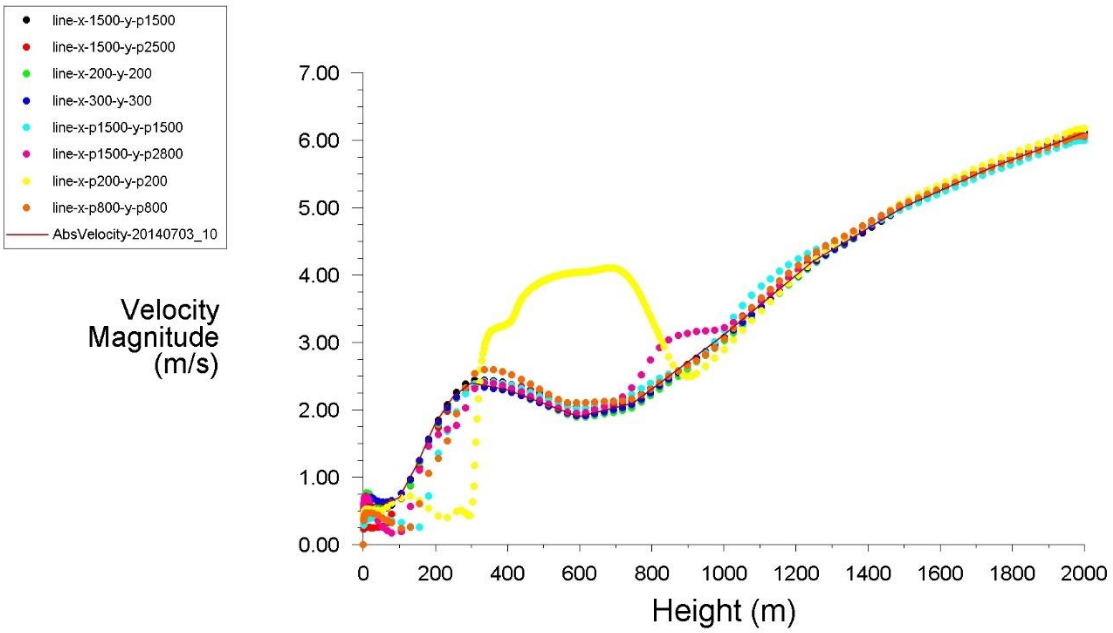


Figure 59. Velocity magnitude along a vertical sample line (from ground level to 2000 m) at different positions in the domain (see Figure 58). Red line demonstrates the applied wind profile according to Figure 3 – 'Initial' wind case for final PDD design version 3B.

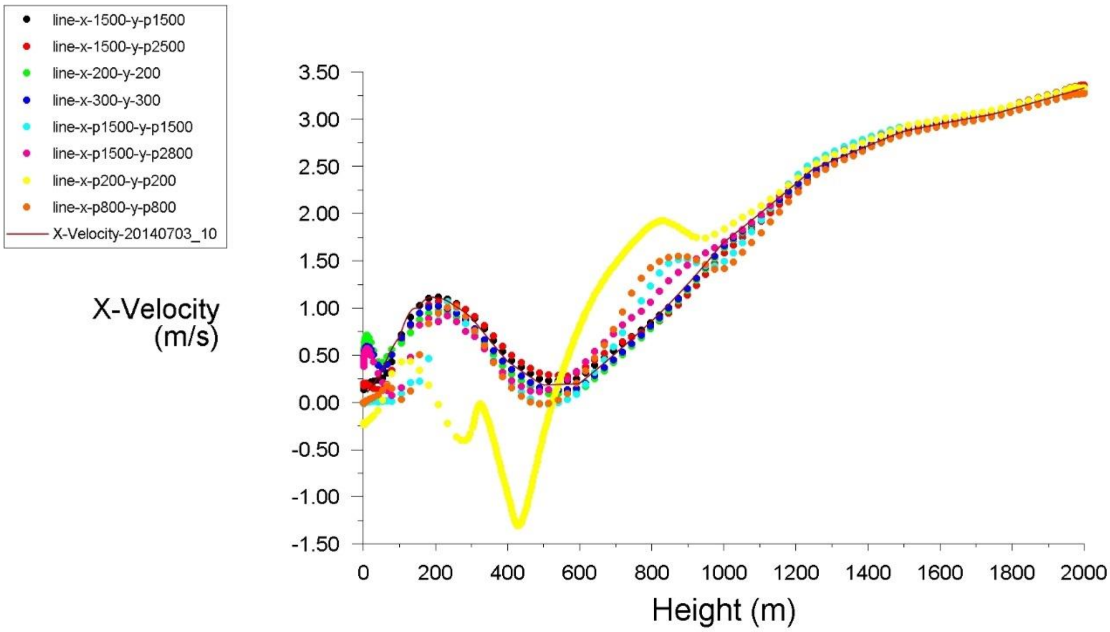


Figure 60. Velocity in the x-direction of the domain along a vertical sample line (from ground level to 2000 m) at different positions in the domain (see Figure 58). Red line demonstrates the applied wind profile according to Figure 3 – 'Initial' wind case for final PDD design version 3B.

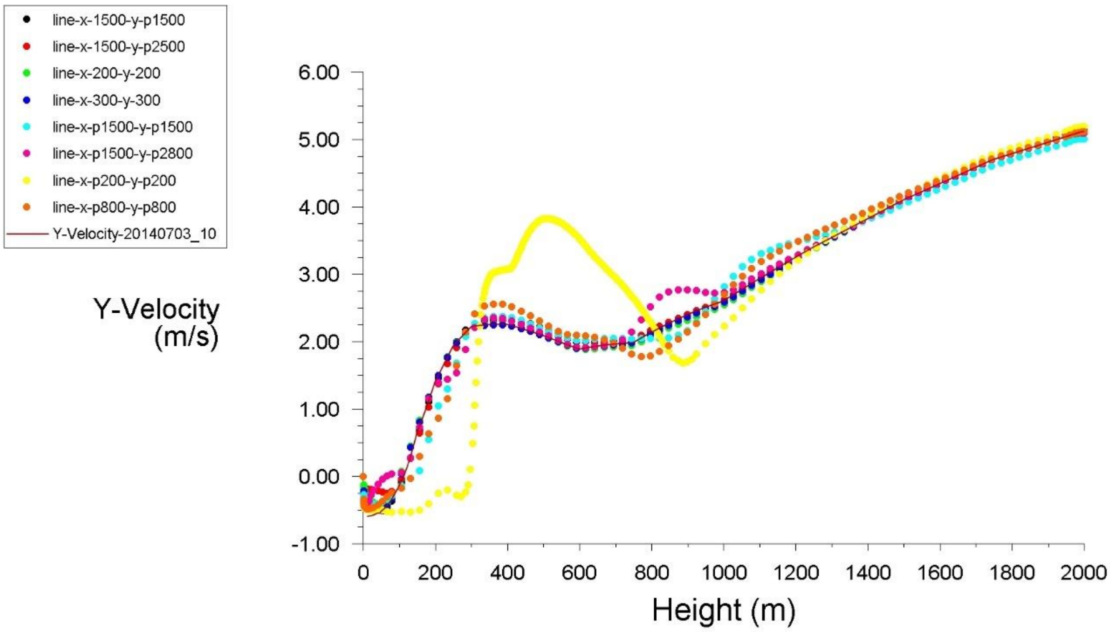


Figure 61. Velocity in the y-direction of the domain along a vertical sample line (from ground level to 2000 m) at different positions in the domain (see Figure 58). Red line demonstrates the applied wind profile according to Figure 3 – 'Initial' wind case for final PDD design version 3B.

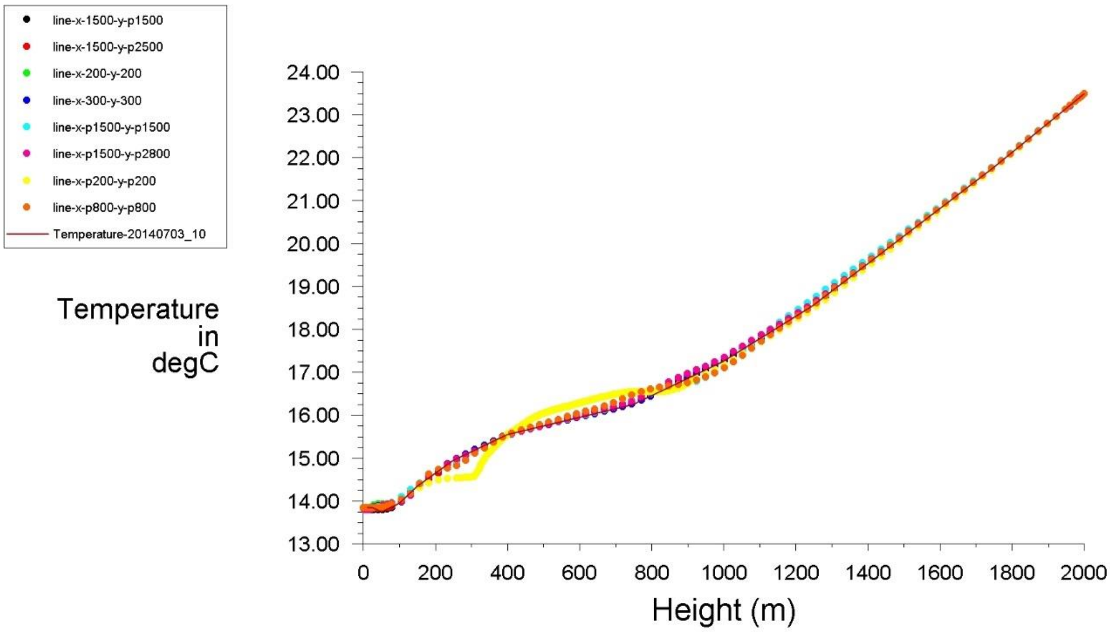


Figure 62. Temperature along a vertical sample line (from ground level to 2000 m) at different positions in the domain (see Figure 58). Red line demonstrates the applied ~~wind~~ temperature profile according to Figure 3 - 'Initial' wind case for final PDD design version 3B.

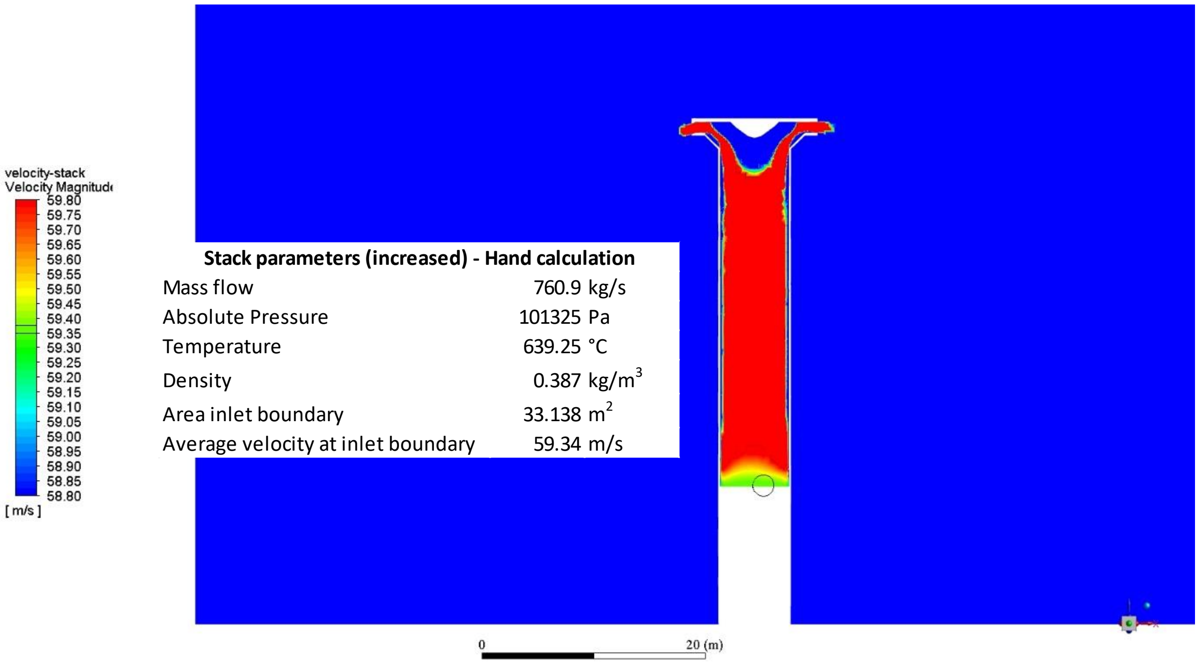


Figure 63. Contour plot of velocity magnitude through the stack and PDD. The centre of the circle indicates the location of the probe highlighted in the colour map - 'Initial' wind case for final PDD design version 3B.

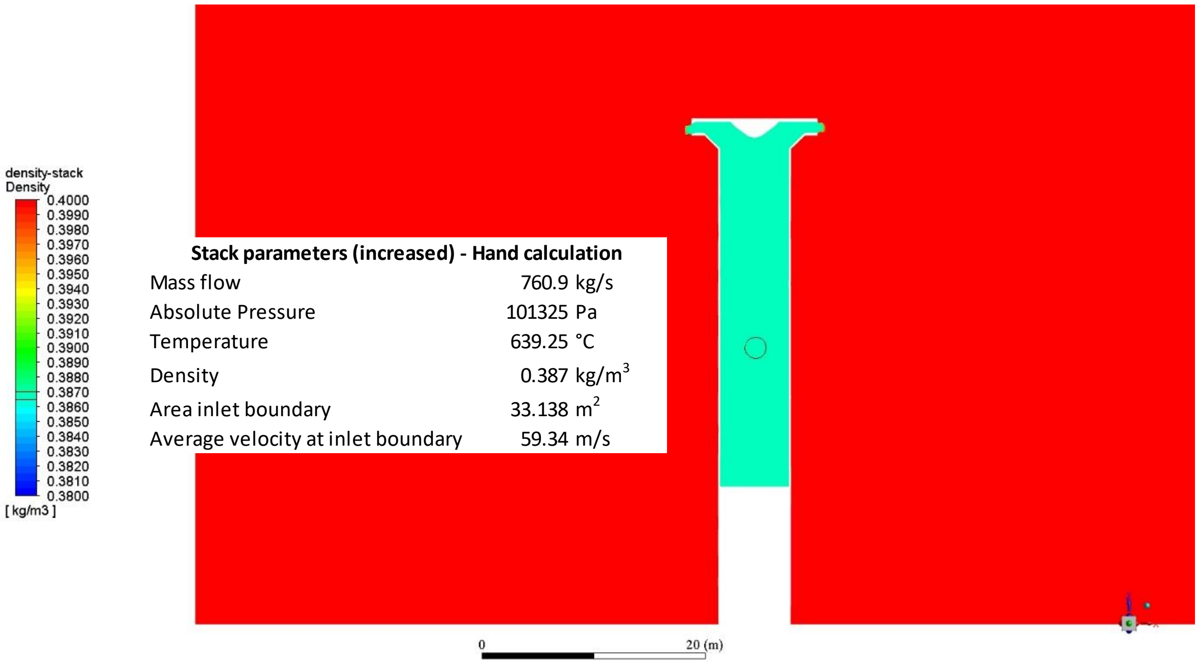


Figure 64. Contour plot of air density through the stack and PDD. The centre of the circle indicates the location of the probe highlighted in the colour map - 'Initial' wind case for final PDD design version 3B.

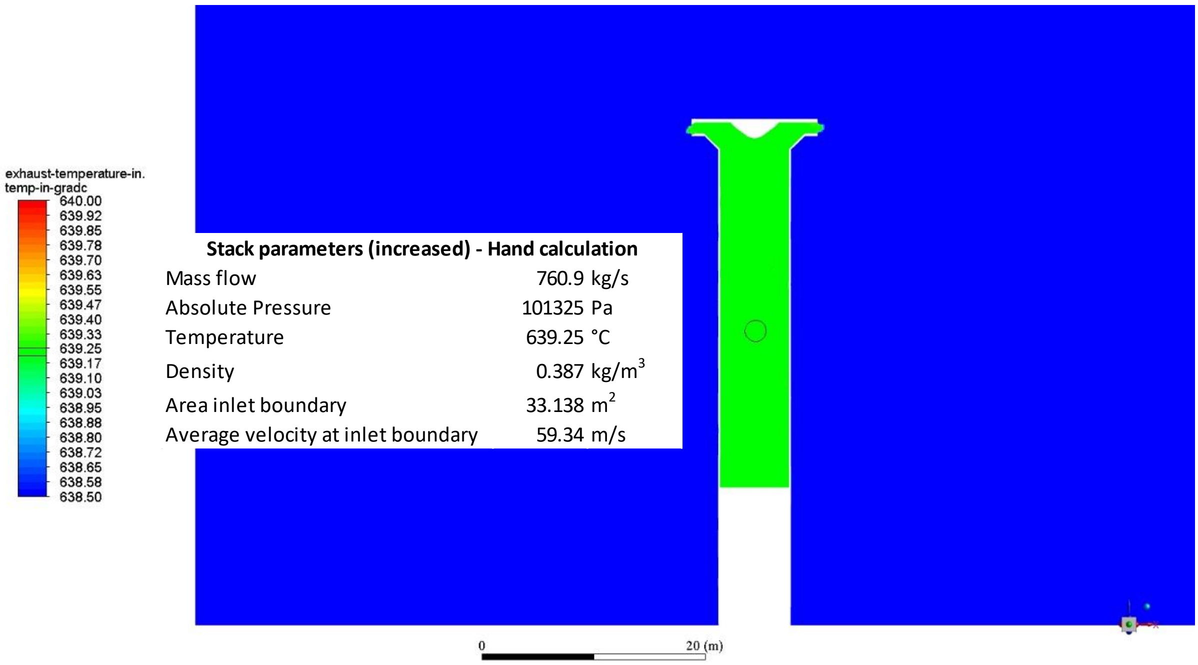
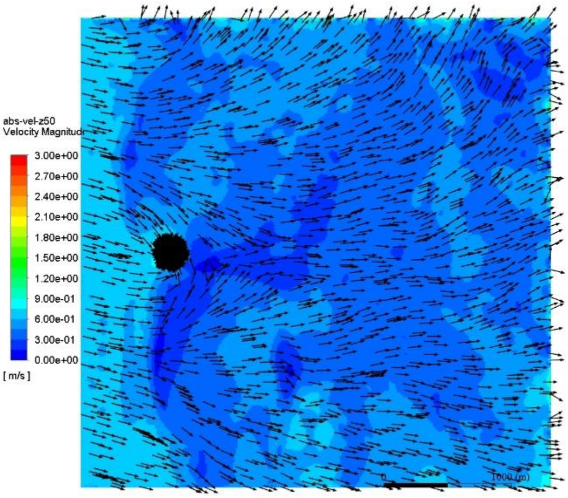


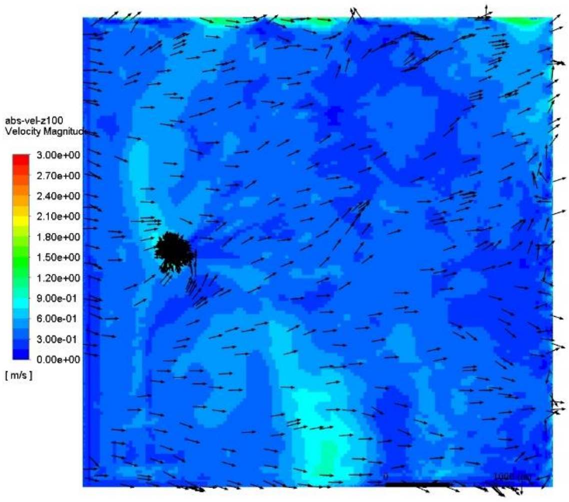
Figure 65. Contour plot of temperature in °C through the stack and PDD. The centre of the circle indicates the location of the probe highlighted in the colour map - 'Initial' wind case for final PDD design version 3B.

B.2. Calm Wind Case for final PDD design version 3B (Wind and Temperature Profile: 20150308 – Calm)

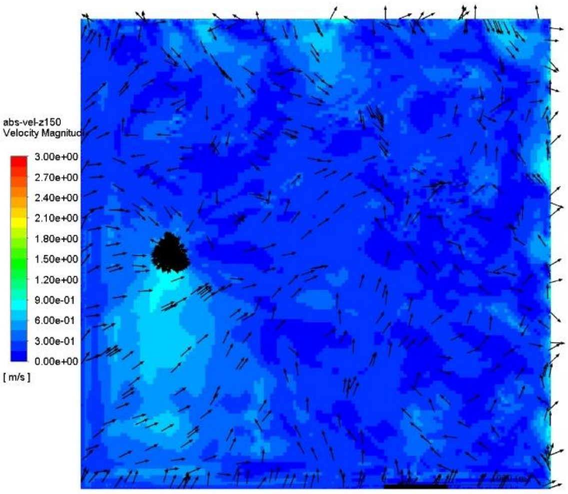
Z = 50 m (164 ft)



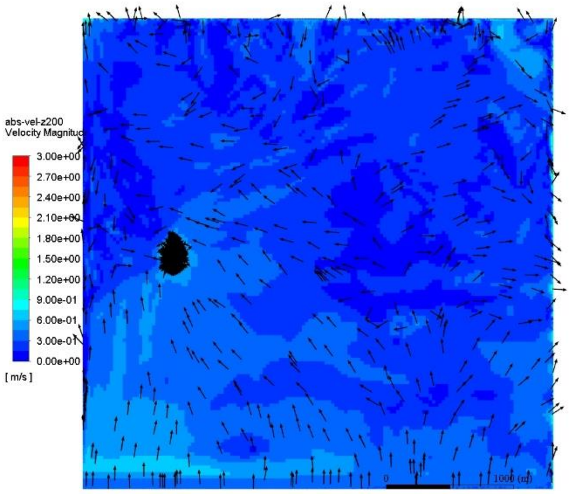
Z = 100 m (328 ft)



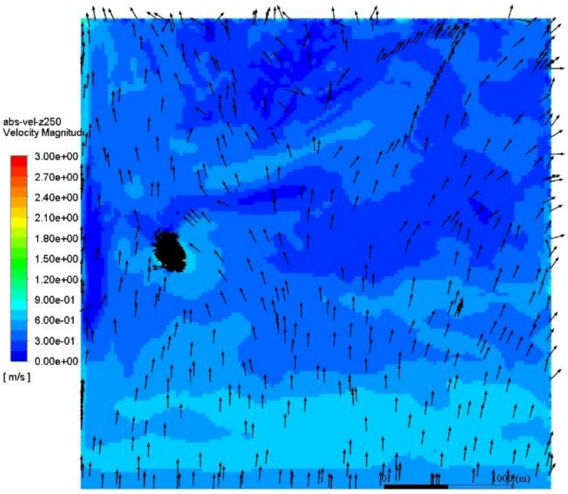
Z = 150 m (656 ft)



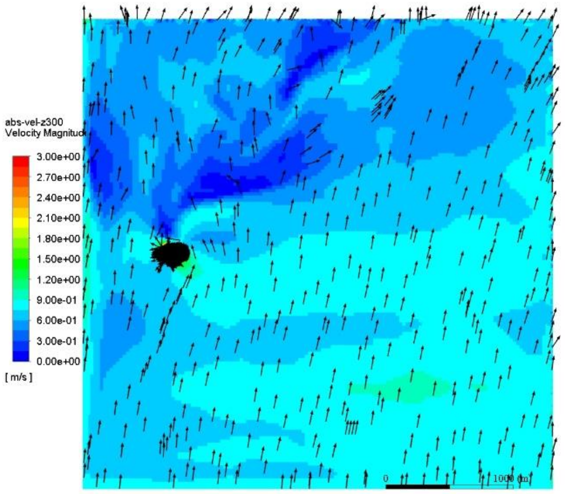
Z = 200 m (492 ft)



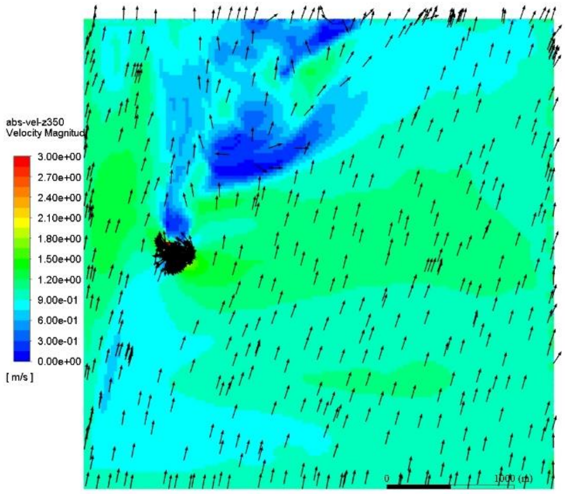
Z = 250 m (820 ft)



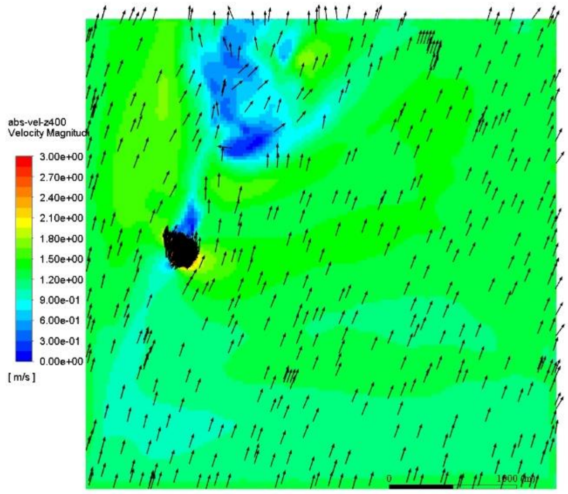
Z = 300 m (984 ft)



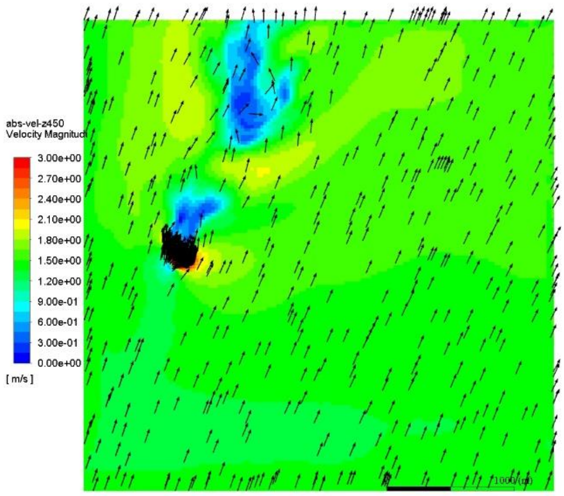
Z = 350 m (1148 ft)



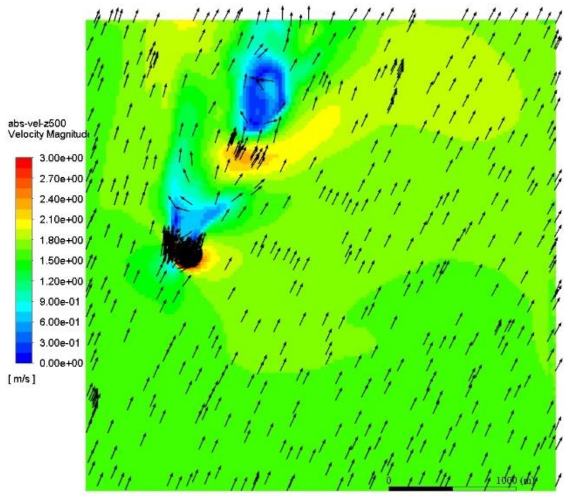
Z = 400 m (1312 ft)



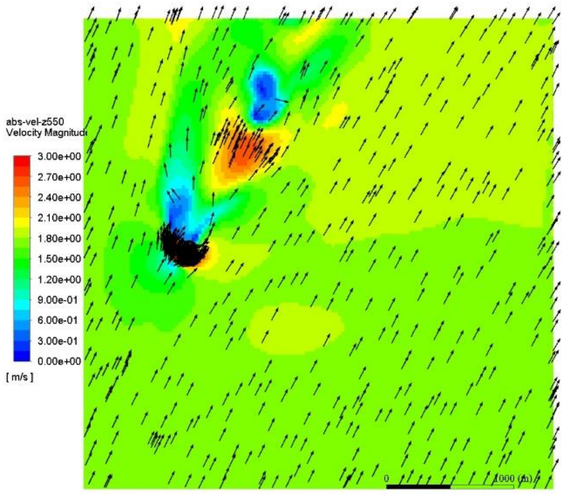
Z = 450 m (1476 ft)



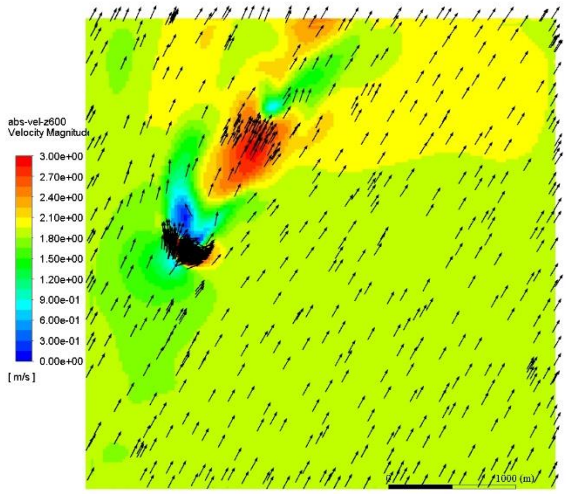
Z = 500 m (1640 ft)



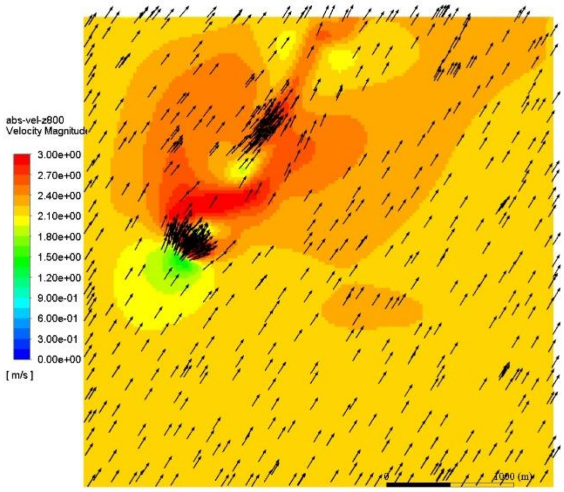
Z = 550 m (1804 ft)



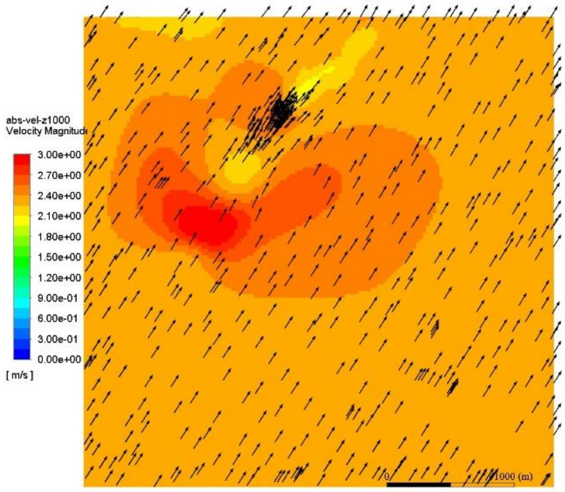
Z = 600 m (1969 ft)



Z = 800 m (2625 ft)



Z = 1000 m (3281 ft)



Z = 1500 m (4921 ft)

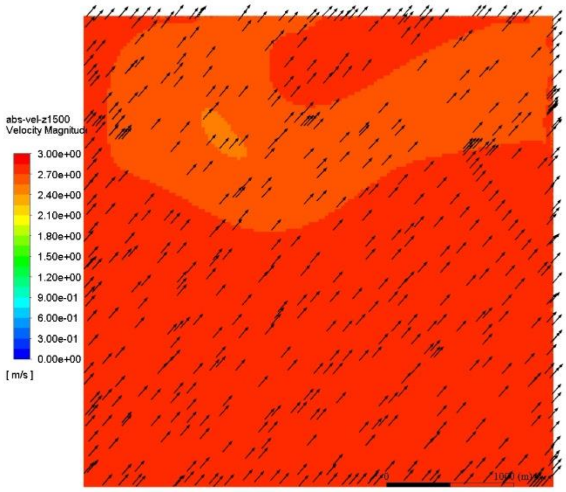


Figure 66. Contour plots of velocity magnitude with normalised velocity vectors at different heights – Calm wind case for final PDD design version 3B.

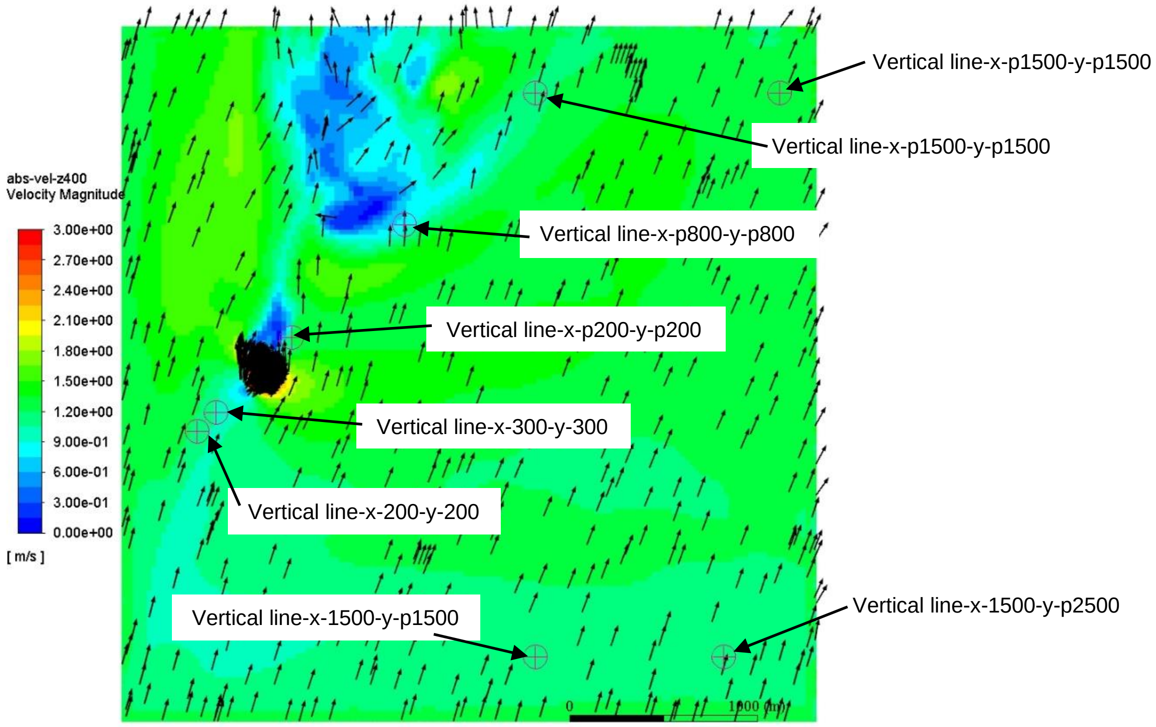


Figure 67. Position of vertical sample lines (from ground level to 2000 m) for analysing the correct implementation of the wind profile – Calm wind case for final PDD design version 3B.

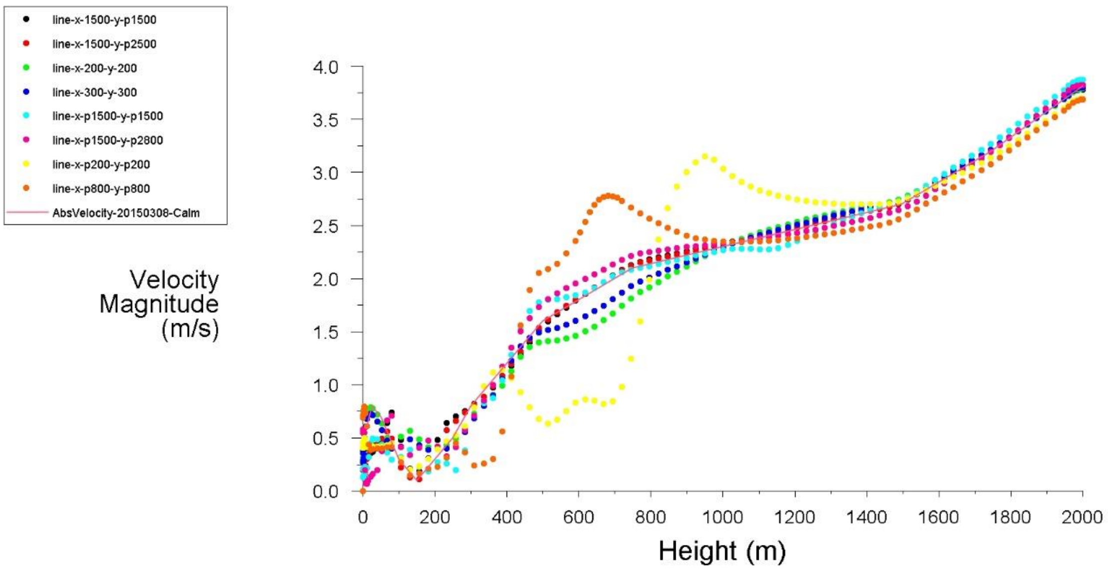


Figure 68. Velocity magnitude along a vertical sample line (from ground level to 2000 m) at different positions in the domain (see Figure 58). Red line demonstrates the applied wind profile according to Figure 3 – Calm wind case for final PDD design version 3B.

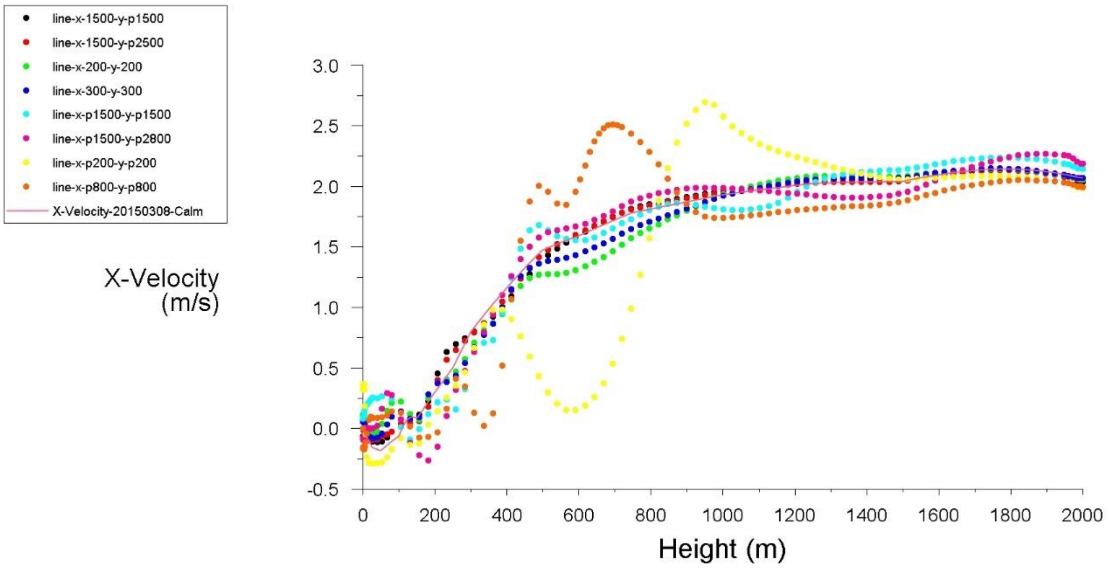


Figure 69. Velocity in the x-direction of the domain along a vertical sample line (from ground level to 2000 m) at different positions in the domain (see Figure 58). Red line demonstrates the applied wind profile according to Figure 3 – Calm wind case for final PDD design version 3B.

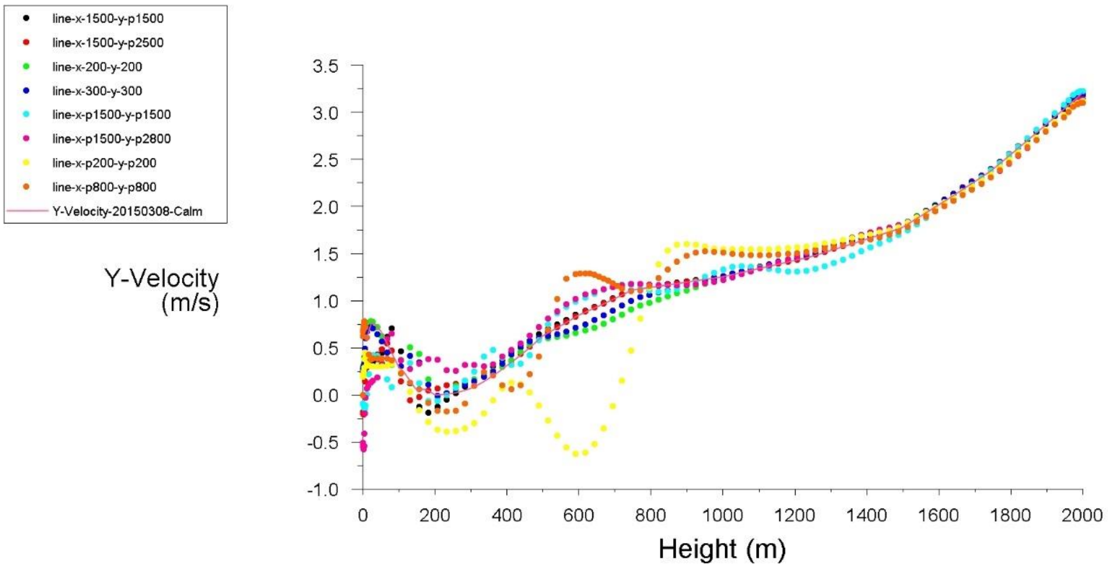


Figure 70. Velocity in the y-direction of the domain along a vertical sample line (from ground level to 2000 m) at different positions in the domain (see Figure 58). Red line demonstrates the applied wind profile according to Figure 3 – Calm wind case for final PDD design version 3B.

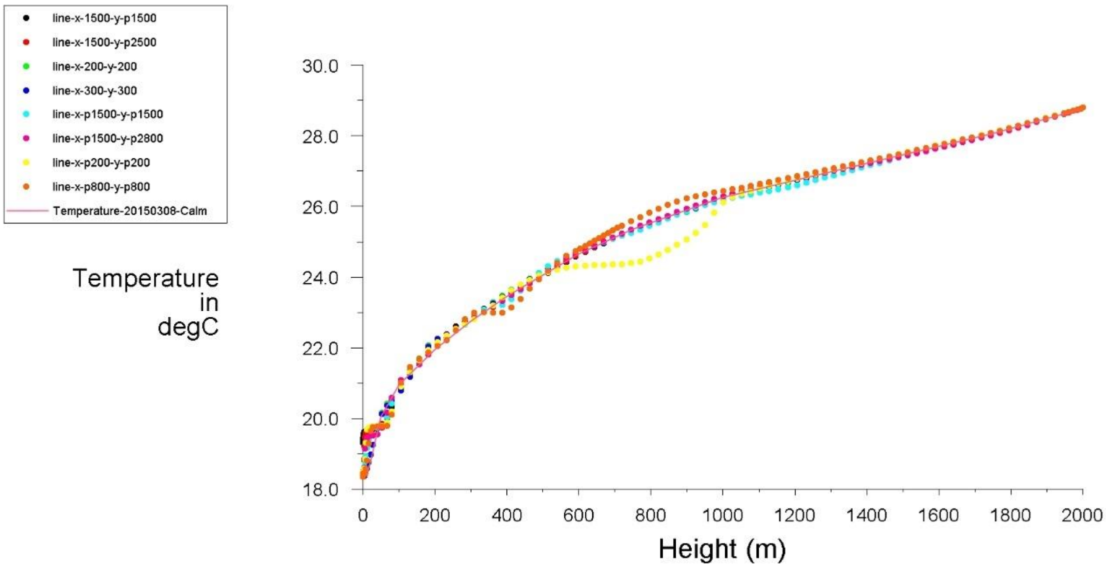


Figure 71. Temperature along a vertical sample line (from ground level to 2000 m) at different positions in the domain (see Figure 58). Red line demonstrates the applied ~~wind~~ temperature profile according to Figure 3 - Calm wind case for final PDD design version 3B.

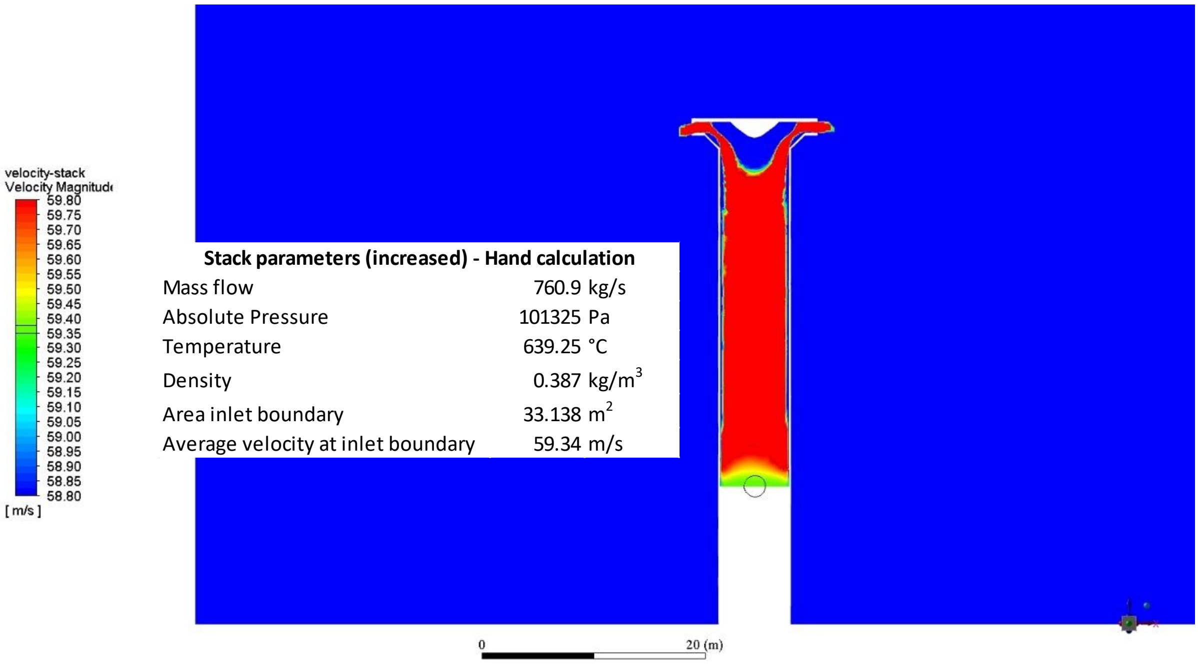


Figure 72. Contour plot of velocity magnitude through the stack and PDD. The centre of the circle indicates the location of the probe highlighted in the colour map - Calm wind case for final PDD design version 3B.

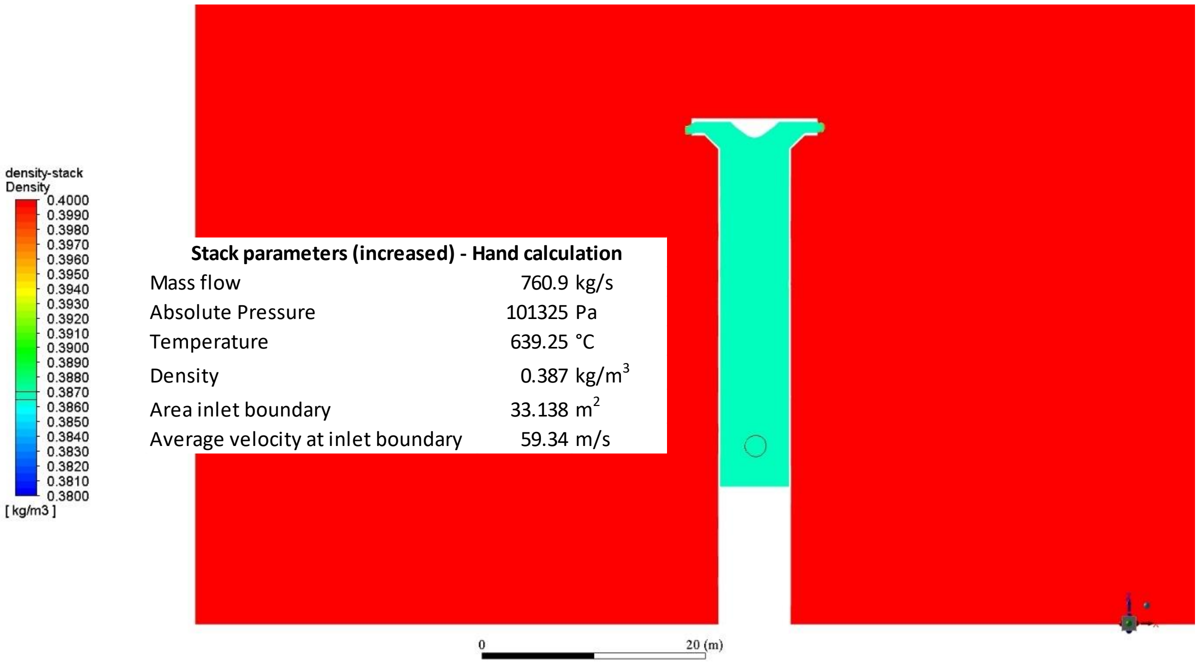


Figure 73. Contour plot of air density through the stack and PDD. The centre of the circle indicates the location of the probe highlighted in the colour map - Calm wind case for final PDD design version 3B.

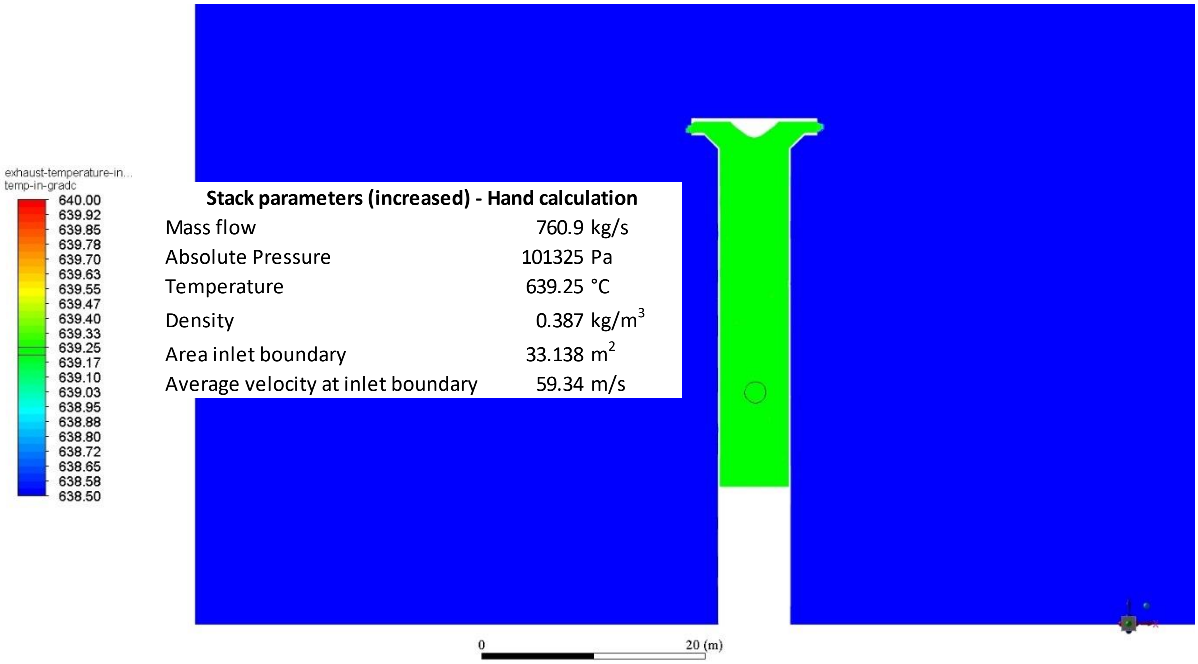
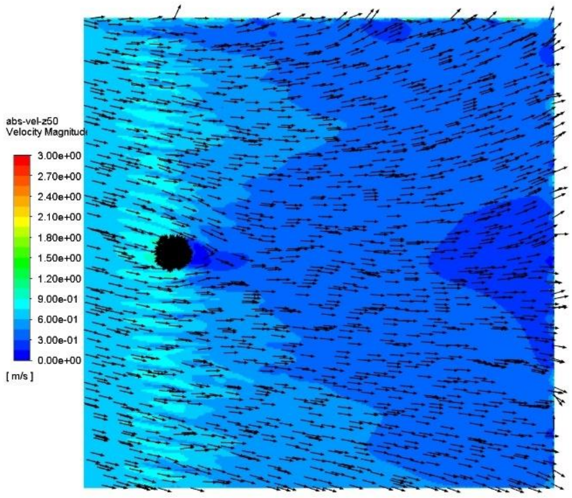


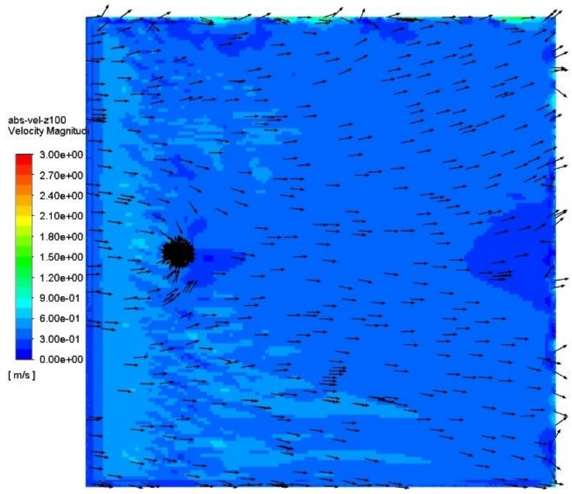
Figure 74. Contour plot of temperature in °C through the stack and PDD. The centre of the circle indicates the location of the probe highlighted in the colour map - Calm wind case for final PDD design version 3B.

B.3. 'Combined' Wind Case for final PDD design version 3B (Wind profile: 20150308 – Calm and Temperature profile 20140703_10)

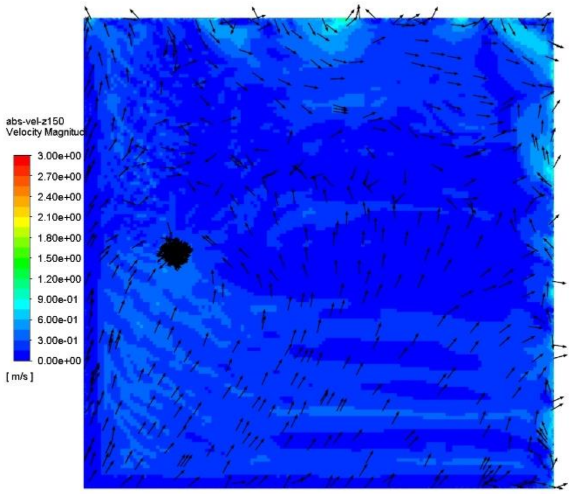
Z = 50 m (164 ft)



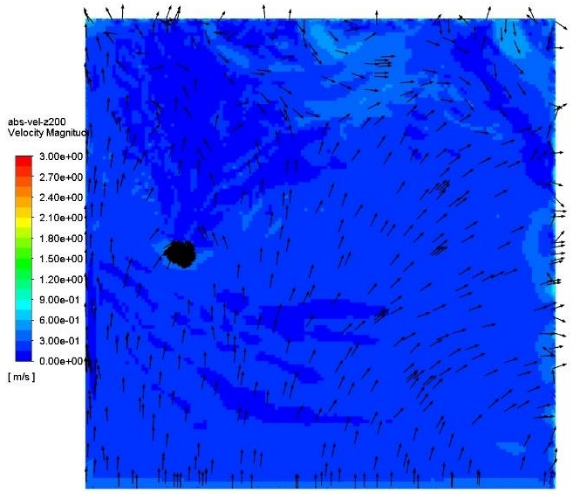
Z = 100 m (328 ft)



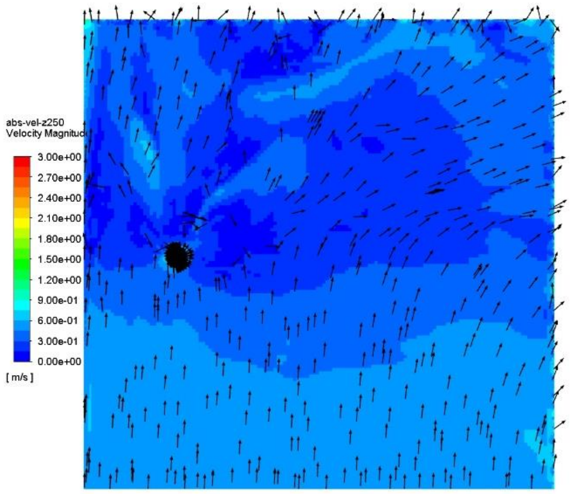
Z = 150 m (656 ft)



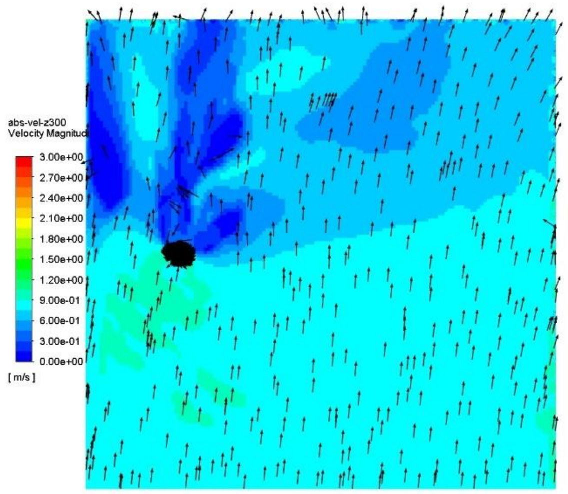
Z = 200 m (492 ft)



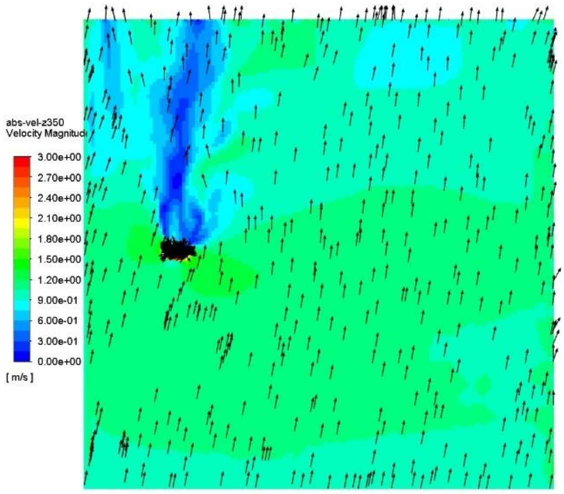
Z = 250 m (820 ft)



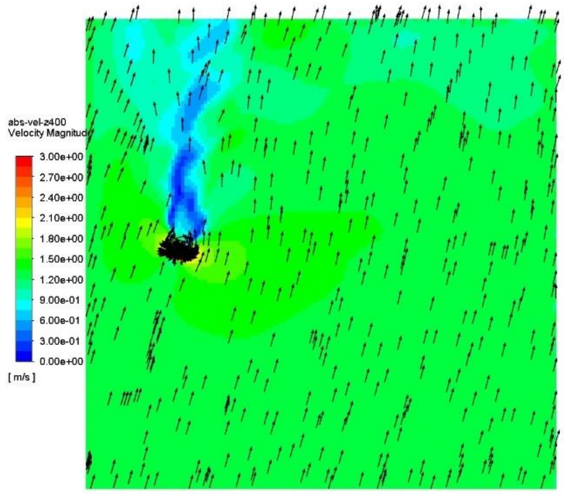
Z = 300 m (984 ft)



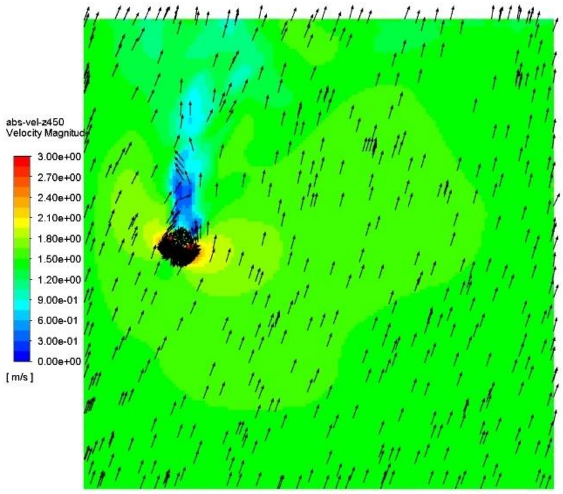
Z = 350 m (1148 ft)



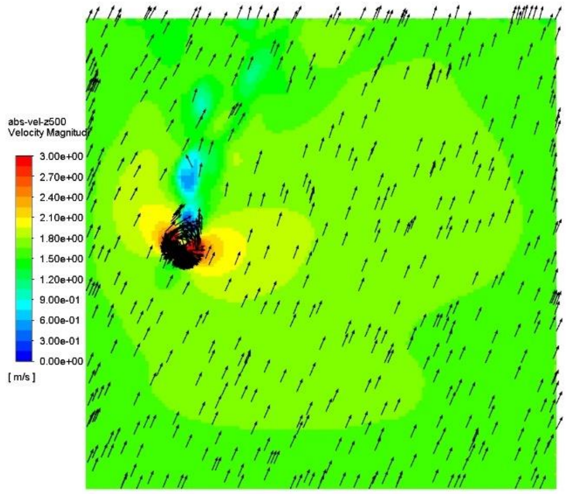
Z = 400 m (1312 ft)



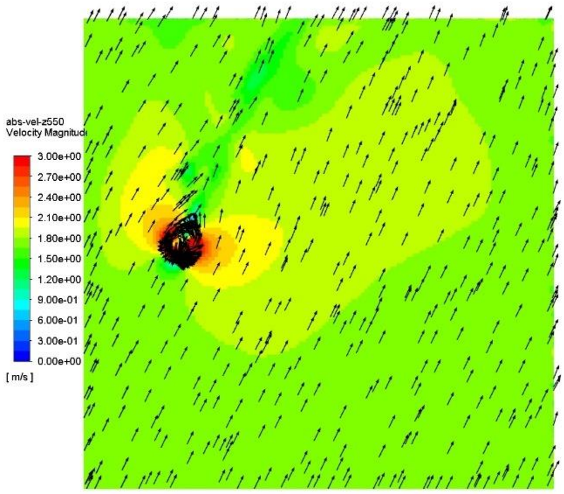
Z = 450 m (1476 ft)



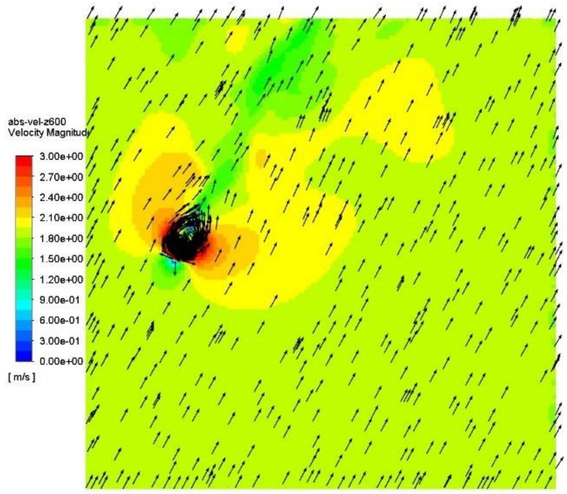
Z = 500 m (1640 ft)



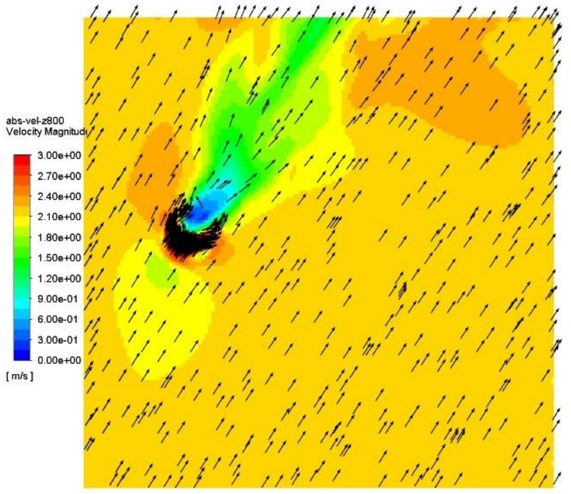
Z = 550 m (1804 ft)



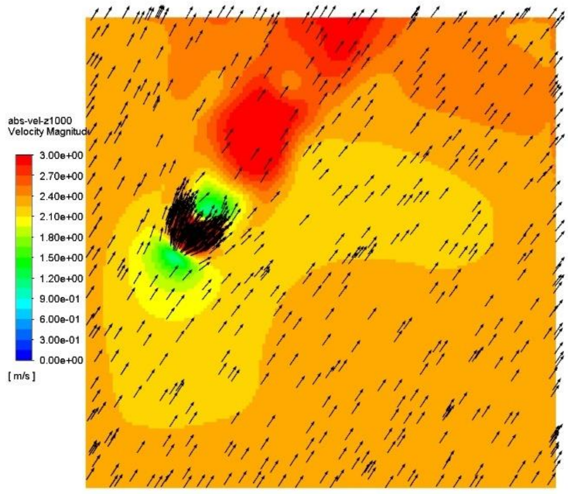
Z = 600 m (1969 ft)



Z = 800 m (2625 ft)



Z = 1000 m (3281 ft)



Z = 1500 m (4921 ft)

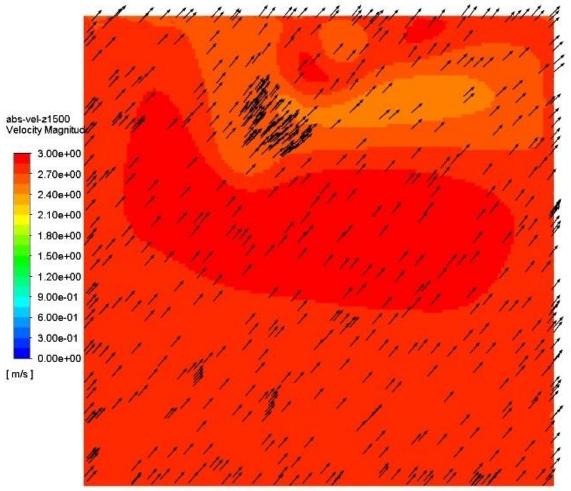


Figure 75. Contour plots of velocity magnitude with normalised velocity vectors at different heights – 'Combined' wind case for final PDD design version 3B.

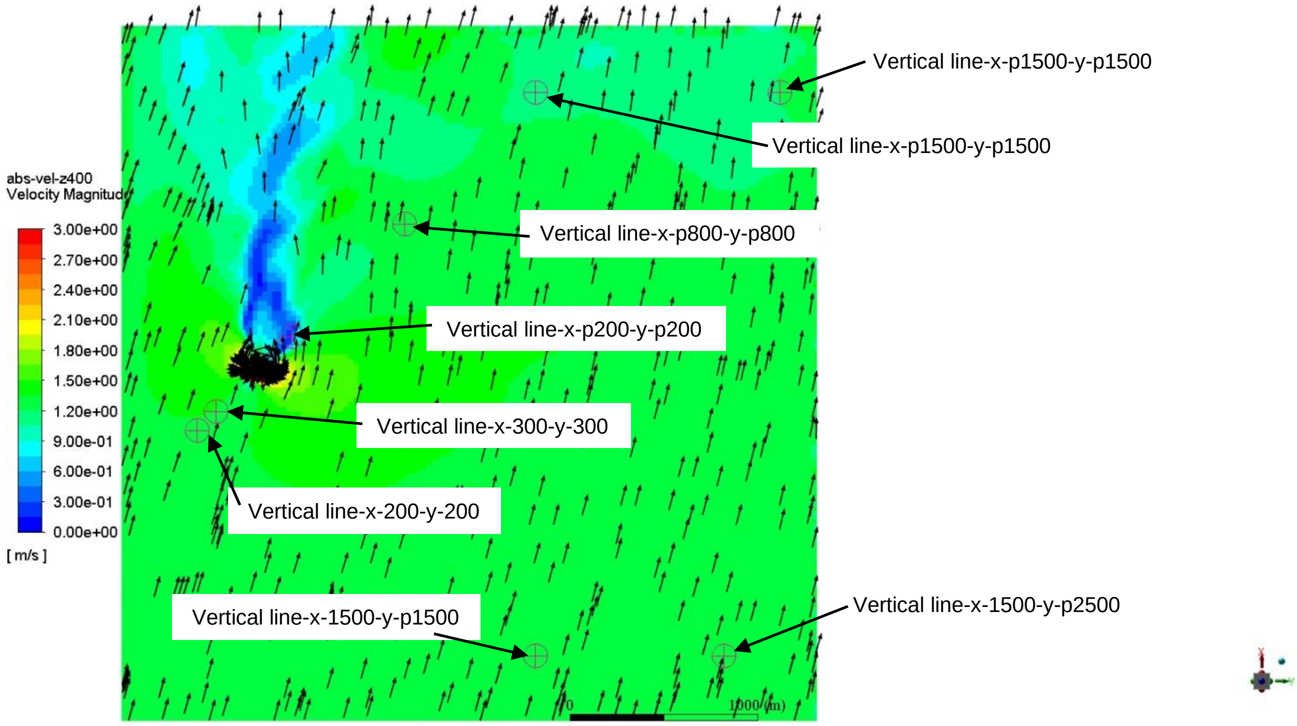


Figure 76. Position of vertical sample lines (from ground level to 2000 m) for analysing the correct implementation of the wind profile – 'Combined' wind case for final PDD design version 3B.

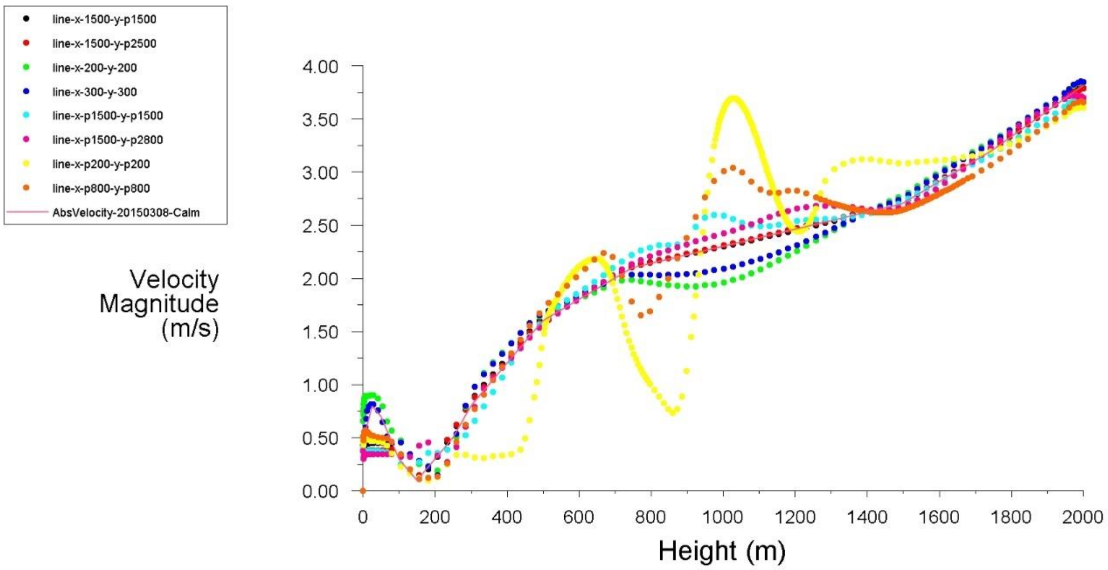


Figure 77. Velocity magnitude along a vertical sample line (from ground level to 2000 m) at different positions in the domain (see Figure 58). Red line demonstrates the applied wind profile according to Figure 3 – 'Combined' wind case for final PDD design version 3B.

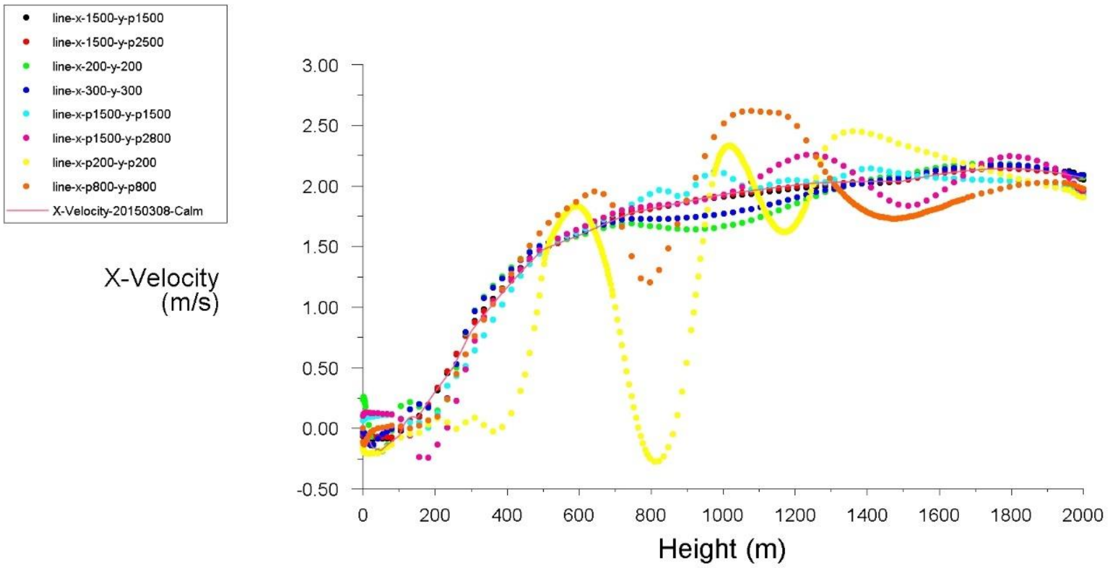


Figure 78. Velocity in the x-direction of the domain along a vertical sample line (from ground level to 2000 m) at different positions in the domain (see Figure 58). Red line demonstrates the applied wind profile according to Figure 3 – 'Combined' wind case for final PDD design version 3B.

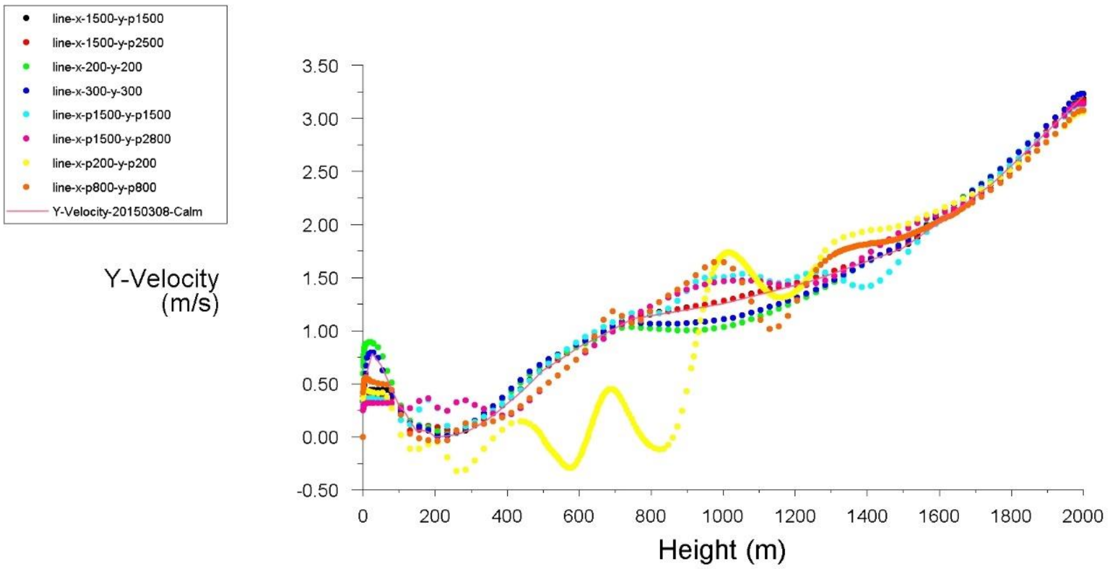


Figure 79. Velocity in the y-direction of the domain along a vertical sample line (from ground level to 2000 m) at different positions in the domain (see Figure 58). Red line demonstrates the applied wind profile according to Figure 3 – 'Combined' wind case for final PDD design version 3B.

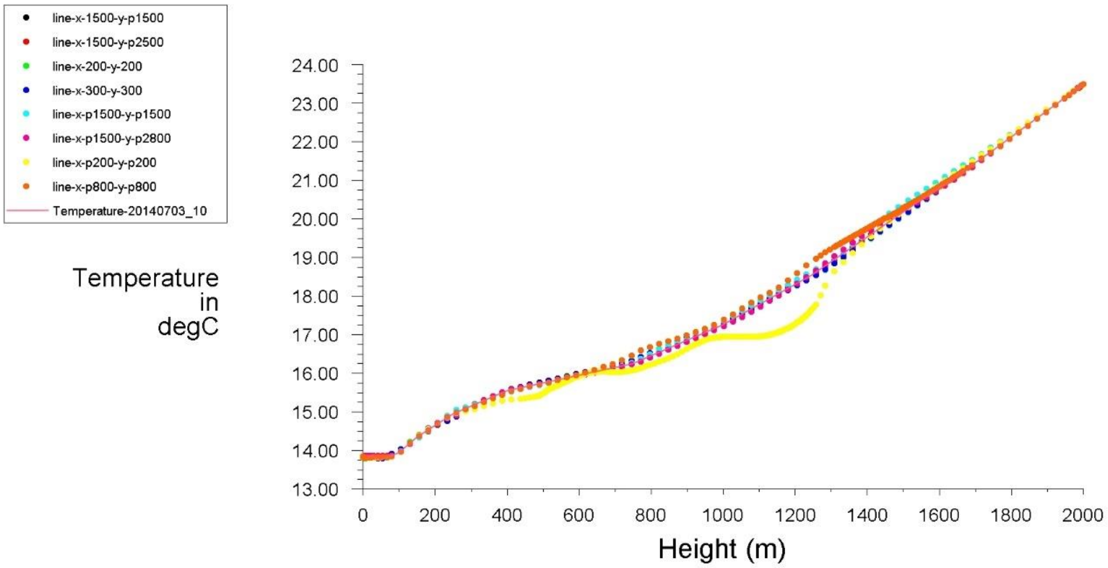


Figure 80. Temperature along a vertical sample line (from ground level to 2000 m) at different positions in the domain (see Figure 58). Red line demonstrates the applied ~~wind~~ temperature profile according to Figure 3 - 'Combined' wind case for final PDD design version 3B.

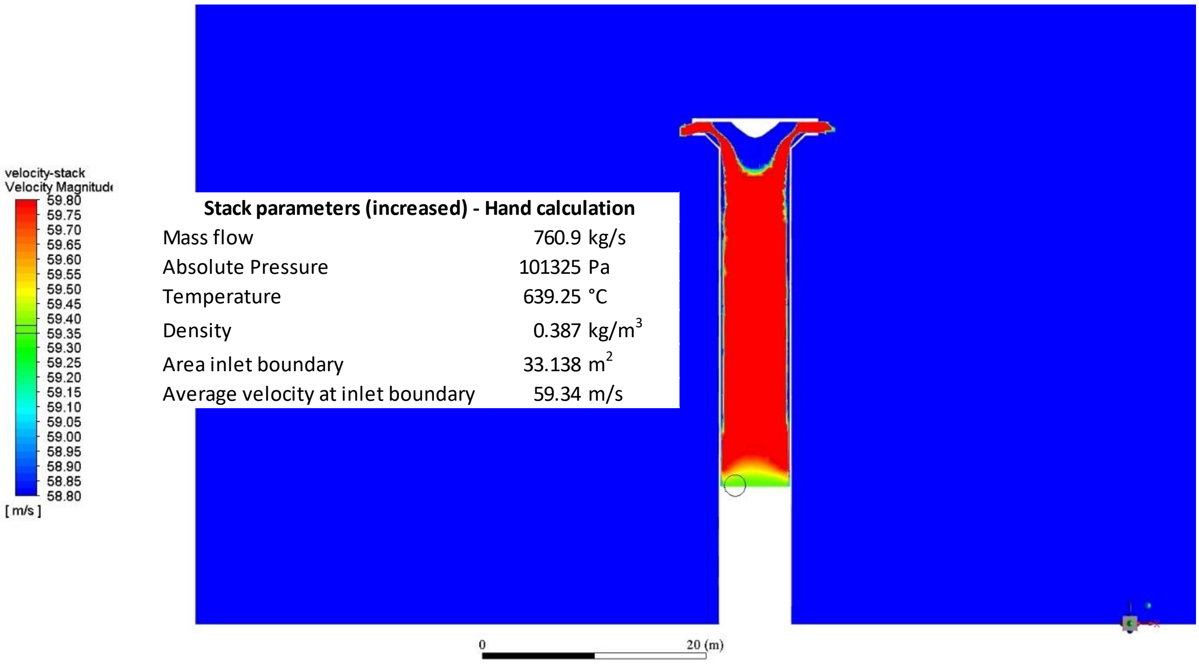


Figure 81. Contour plot of velocity magnitude through the stack and PDD. The centre of the circle indicates the location of the probe highlighted in the colour map - 'Combined' wind case for final PDD design version 3B.

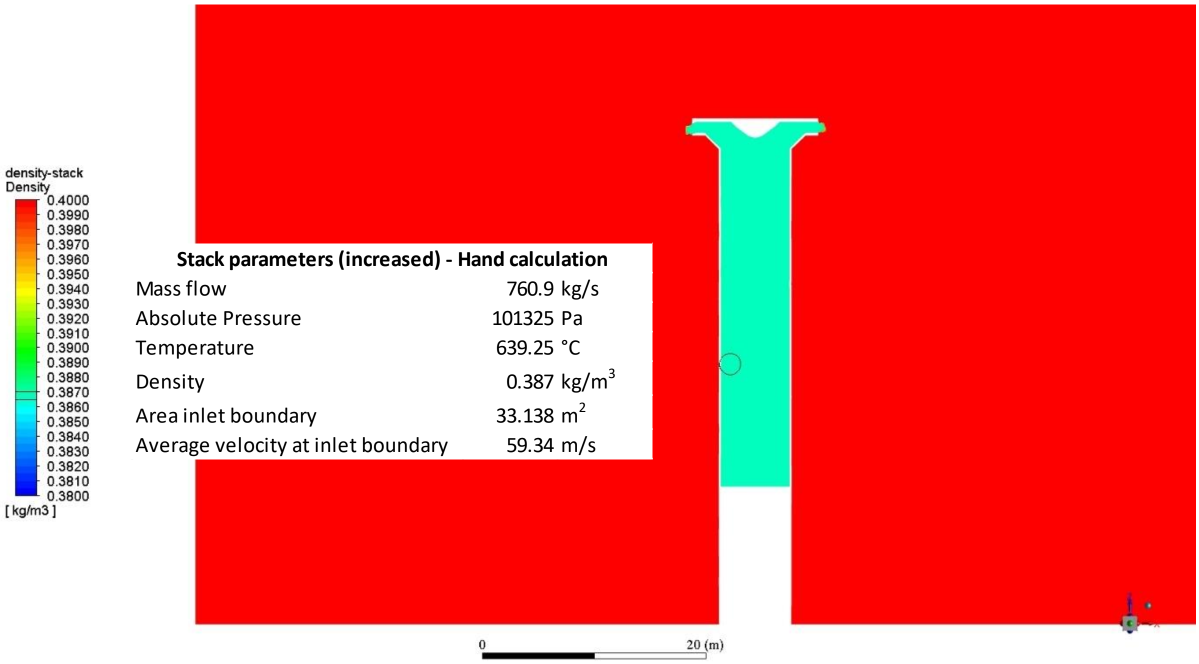


Figure 82. Contour plot of air density through the stack and PDD. The centre of the circle indicates the location of the probe highlighted in the colour map - 'Combined' wind case for final PDD design version 3B.

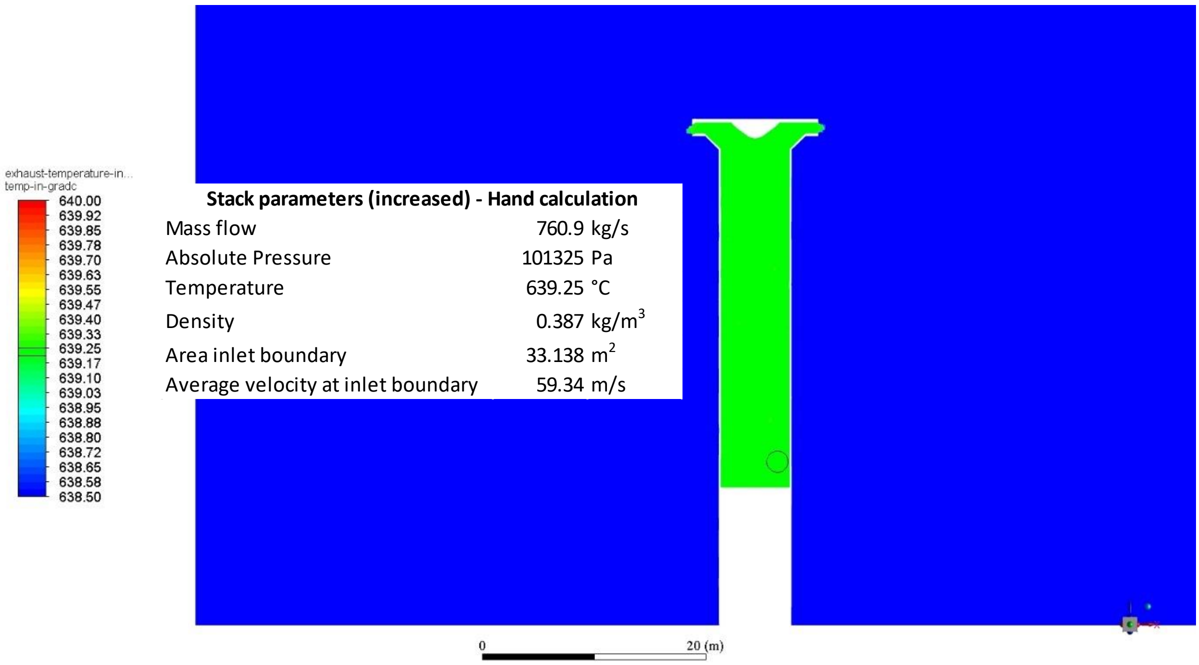


Figure 83. Contour plot of temperature in °C through the stack and PDD. The centre of the circle indicates the location of the probe highlighted in the colour map - 'Combined' wind case for final PDD design version 3B.

APPENDIX C

- CSV-Files for case with final PDD design version 3B and 'initial' wind case at 370 s:
  - CSV-File of velocity magnitude, u-, v-velocity and temperature along plume trajectory based on maximum plume velocity (TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-max-velocity-trajectory-20230224.csv)
  - CSV-File of vertical velocity and temperature along plume trajectory based on maximum vertical plume velocity (TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-max-vertical-velocity-trajectory-20230224.csv).
  - CSV-File of average vertical and absolute plume velocity as well as plume area. Plume area is defined as horizontal area in which the vertical plume velocity is > 6 m/s. (TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-average-plume-velocity-and-area-6m-s-20230224.csv).
  - CSV-File of average vertical and absolute plume velocity as well as plume area. Plume area is defined as horizontal area in which the vertical plume velocity is > 4 m/s. (TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-average-plume-velocity-and-area-4m-s-20230224.csv).
  - CSV-File of average vertical and absolute plume velocity as well as plume area. Plume area is defined as horizontal area in which the vertical plume velocity is > 2 m/s. (TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-average-plume-velocity-and-area-2m-s-20230224.csv).
  - CSV-File of average vertical and absolute plume velocity as well as plume area. Plume area is defined as horizontal area in which the vertical plume velocity is > 1 m/s. (TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-average-plume-velocity-and-area-1m-s-20230224.csv).
- CSV-Files for case with final PDD design version 3B and calm wind case at 560 s:
  - CSV-File of velocity magnitude, u-, v-velocity and temperature along plume trajectory based on maximum plume velocity (TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-max-velocity-trajectory-20230316.csv)
  - CSV-File of vertical velocity and temperature along plume trajectory based on maximum vertical plume velocity (TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-max-vertical-velocity-trajectory-20230316.csv).
  - CSV-File of average vertical and absolute plume velocity as well as plume area. Plume area is defined as horizontal area in which the vertical plume velocity is > 6 m/s. (TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-average-plume-velocity-and-area-6m-s-20230316.csv).
  - CSV-File of average vertical and absolute plume velocity as well as plume area. Plume area is defined as horizontal area in which the vertical plume velocity is > 4 m/s. (TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-average-plume-velocity-and-area-4m-s-20230316.csv).
  - CSV-File of average vertical and absolute plume velocity as well as plume area. Plume area is defined as horizontal area in which the vertical plume velocity is > 2 m/s. (TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-average-plume-velocity-and-area-2m-s-20230316.csv).

- CSV-File of average vertical and absolute plume velocity as well as plume area. Plume area is defined as horizontal area in which the vertical plume velocity is > 1 m/s. (TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-average-plume-velocity-and-area-1m-s-20230316.csv).

- CSV-Files for case with final PDD design version 3B and 'combined' wind case at 1060 s:
  - CSV-File of velocity magnitude, u-, v-velocity and temperature along plume trajectory based on maximum plume velocity (TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s-max-velocity-trajectory-20230316.csv)

  - CSV-File of vertical velocity and temperature along plume trajectory based on maximum vertical plume velocity (TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s-max-vertical-velocity-trajectory-20230316.csv).

  - CSV-File of average vertical and absolute plume velocity as well as plume area. Plume area is defined as horizontal area in which the vertical plume velocity is > 6 m/s. (TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s-20230316.csv).

  - CSV-File of average vertical and absolute plume velocity as well as plume area. Plume area is defined as horizontal area in which the vertical plume velocity is > 4 m/s. (TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s-average-plume-velocity-and-area-4m-s-20230316.csv).

  - CSV-File of average vertical and absolute plume velocity as well as plume area. Plume area is defined as horizontal area in which the vertical plume velocity is > 2 m/s. (TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s-average-plume-velocity-and-area-2m-s-20230316.csv).

  - CSV-File of average vertical and absolute plume velocity as well as plume area. Plume area is defined as horizontal area in which the vertical plume velocity is > 1 m/s. (TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s-average-plume-velocity-and-area-1m-s-20230316.csv).

- Plume extent shown as a contour plots of vertical velocity in a horizontal plane at 198 m (650 ft) elevation (above MSL) for the final PDD design version 3B and all three wind cases. Plume area is clipped to vertical plume velocity of >1, >2, >3, >4, >5, >6, >7, >8, >9, and >10 m/s. Grid spacing in plots is 20 m with stack centre at the origin (red lines).
  - 'Initial' wind case at 370s
    - TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel1-650ft-b*.jpg*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel2-650ft-b*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel3-650ft-b*

        - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel4-650ft-b*
        - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel5-650ft-b*
        - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel6-650ft-b*
        - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel7-650ft-b*
        - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel8-650ft-b*
        - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel9-650ft-b*
        - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel10-650ft-b*

    - Calm wind case at 560s
        - TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel1-650ft-b.*jpg*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel2-650ft-b*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel3-650ft-b*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel4-650ft-b*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel5-650ft-b*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel6-650ft-b*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel7-650ft-b*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel8-650ft-b*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel9-650ft-b*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel10-650ft-b*

        - TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel1-650ft.*jpg*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel2-650ft*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel3-650ft*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel4-650ft*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel5-650ft*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel6-650ft*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel7-650ft*
        - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel8-650ft*

    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel9-650ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel10-650ft*

- ‘Combined’ wind case at 1060s
    - TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel1-650ft-b*.jpg*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel2-650ft-b*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel3-650ft-b*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel4-650ft-b*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel5-650ft-b*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel6-650ft-b*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel7-650ft-b*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel8-650ft-b*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel9-650ft-b*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel10-650ft-b*

    - TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel1-650ft-13mps-b*.jpg*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel2-650ft*-13mps-b
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel3-650ft*-13mps-b
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel4-650ft*-13mps-b
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel5-650ft*-13mps-b
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel6-650ft*-13mps-b
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel7-650ft*-13mps-b
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel8-650ft*-13mps-b
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel9-650ft*-13mps-b
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel10-650ft-13mps-b*

- Plume extent shown as a contour plots of vertical velocity in a horizontal plane at 213 m (700 ft) elevation (above MSL) for the final PDD design version 3B and all three wind cases . Plume area is clipped to vertical plume velocity of >1, >2, >3, >4, >5, >6, >7, >8, >9, and >10 m/s. Grid spacing in plots is 20 m with stack centre at the origin (red lines).
  - ‘Initial’ wind case at 370s
    - TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel1-700ft.*jpg*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel2-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel3-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel4-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel5-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel6-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel7-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel8-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel9-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel10-700ft*

  - Calm wind case at 560s
    - TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel1-700ft.*jpg*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel2-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel3-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel4-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel5-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel6-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel7-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel8-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel9-700ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel10-700ft*

  - ‘Combined’ wind case at 1060s
    - TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel1-700ft.*jpg*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel2-700ft*

- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel3-700ft*
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel4-700ft*
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel5-700ft*
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel6-700ft*
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel7-700ft*
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel8-700ft*
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel9-700ft*
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel10-700ft*

- TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel1-700ft-13mps*.jpg*
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel2-700ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel3-700ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel4-700ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel5-700ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel6-700ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel7-700ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel8-700ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel9-700ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel10-700ft-13mps*

- Plume extent shown as a contour plots of vertical velocity in a horizontal plane at 305 m (1000 ft) elevation (above MSL) for the final PDD design version 3B and all three wind cases . Plume area is clipped to vertical plume velocity of >1, >2, >3, >4, >5, >6, >7, >8, >9, and >10 m/s. Grid spacing in plots is 20 m with stack centre at the origin (red lines).
  - 'Initial' wind case at 370s
    - TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel1-1000ft*.jpg*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel2-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel3-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel4-1000ft*

    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel5-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel6-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel7-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel8-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel9-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20140703_10-01-370s-plume-area-Zvel10-1000ft*

  - Calm wind case at 560s
    - TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel1-1000ft.*jpg*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel2-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel3-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel4-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel5-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel6-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel7-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel8-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel9-1000ft*
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-560s-plume-area-Zvel10-1000ft*

  - 'Combined' wind case at 1060s
    - TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel1-1000ft.*jpg*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel2-1000ft*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel3-1000ft*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel4-1000ft*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel5-1000ft*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel6-1000ft*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel7-1000ft*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel8-1000ft*
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel9-1000ft*

- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel10-1000ft*

- TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel1-1000ft-13mps.*jpg*
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel2-1000ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel3-1000ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel4-1000ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel5-1000ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel6-1000ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel7-1000ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel8-1000ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel9-1000ft*-13mps
- *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-1060s -plume-area-Zvel10-1000ft-13mps*

- Video of transient plume behaviour for final PDD design version 3B for all three wind cases. The video shows the plume envelope for a vertical velocity of 6 m/s. The colour indicates the height of the envelope. Videos are created based on images saved every second during the run.
  - 'Initial' wind case up to 1710s
    - TPM15-GE-ModDesignV9-3B-Case20140703_10-01-upTo1710s-envelope-Zvel6.mov
  - Calm wind case up to 1690s
    - *TPM15-GE-ModDesignV9-3B-Case20150308_Calm-01-upTo1690s-envelope-zVel6.mov*
  - 'Combined' wind case up to 1630s
    - *TPM15-GE-ModDesignV9-3B-CaseW_20150308_Calm_T_20140703_10-01-upTo1630s-envelope-zVel6.mov*

APPENDIX D PLUME EXTENT OF INITIAL DESIGN OF MODIFIED PDD (INITIAL CASE [13])

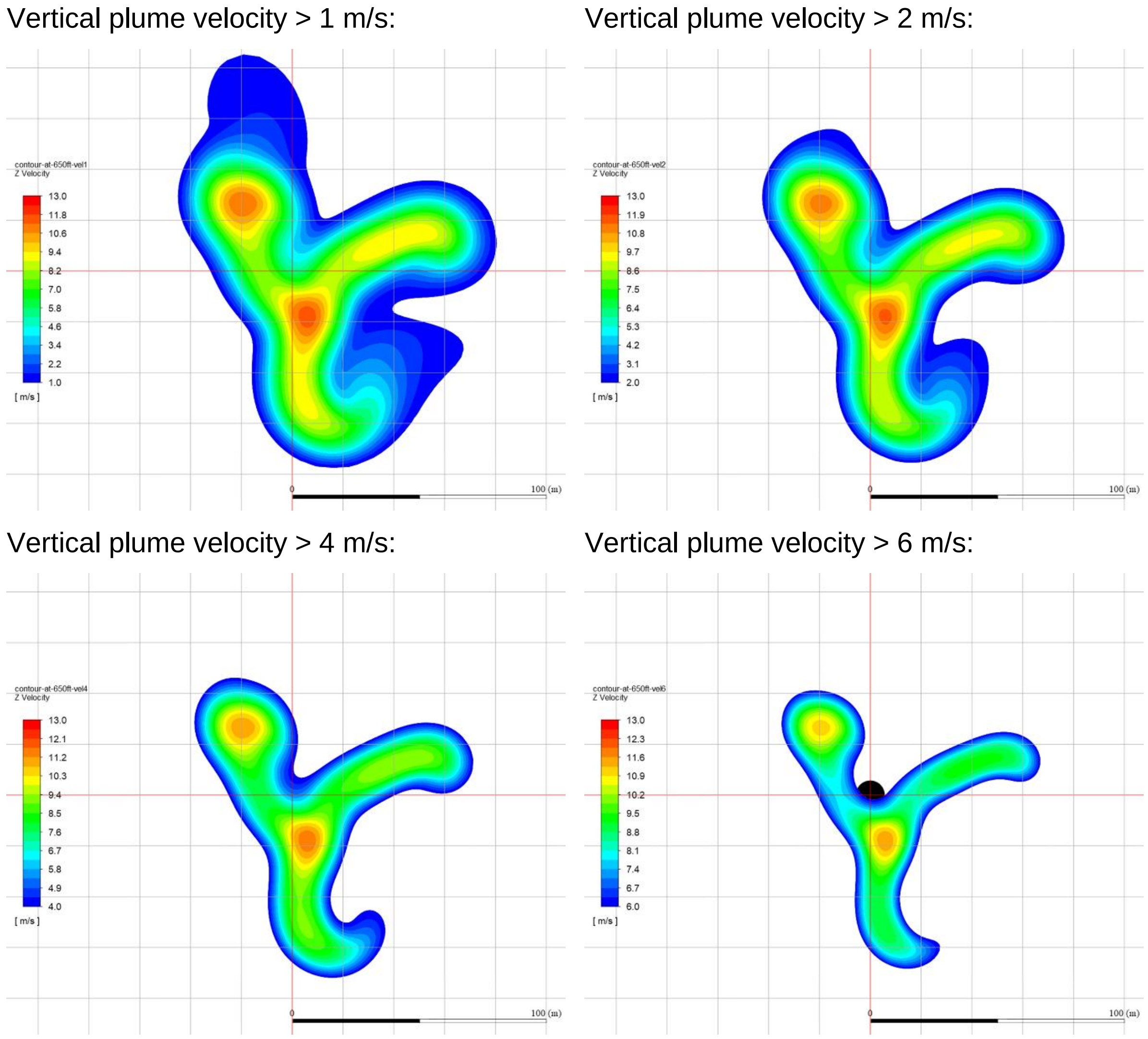


Figure 84. Plume extent shown as a contour plots of vertical velocity in a horizontal plane at 198 m (650 ft) elevation for 'initial case' (initial design of modified PDD and wind condition as given in Figure 3) [13]. The plume area in each contour plot is clipped to a different vertical plume velocity: > 6 m/s (bottom right), > 4 m/s (bottom left), > 2 m/s (top right) and > 1 m/s (top left). Grid spacing is 20 m with stack centre at the origin (red lines).