Met Office

Grenfell Tower fire: modelling deposition of smoke particulates using NAME

Forecasting Research Technical Report No. 637

April 2019

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Publication:

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Date: April 2019

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Summary

We model the transport and subsequent deposition of the smoke plume from the active burning phase of the Grenfell Tower fire. This report is a continuation of work undertaken to model the potential air quality impact of the fire. We do not model large particulates or debris which may have been deposited in the immediate vicinity of the building.

There are many competing factors which influence the total extent of deposition; namely the amount of smoke, prevailing meteorology, land surface type, plume buoyancy, and the particle aerodynamic properties. Due to insufficient knowledge of the constituents of the plume, we model a range of particulate properties separately to indicate the likely areas of deposition for different particles. Thus, quantitative values should be considered as relative amounts for each type of particle.

Smoke particles are typically between 0.1 and 10μm in diameter and may vary in density and shape. Simulations indicate that 10μm particles are small enough that their aerodynamic properties have negligible influence on their transport in this scenario and therefore results for 10μm particles are representative of smoke particles that are also smaller than 10μm.

Although the bulk of the plume is believed to have consisted of particles 10μm or less, it is possible that particles of greater size and density could have been present, which may have been lofted and transported within the buoyant smoke plume. This could be material such as ash, dust and char. To take this into account, 100μm particles are also modelled. Particles with properties between these limits can be assumed to give a deposition distribution which falls somewhere between the modelled ranges.

We conclude that material is likely to have been deposited to the north-west of the site, with an indication of a downwind maximum at 3-5km from the tower for particles in the upper bounds of size and density. Results for 10μm particles are not sensitive to the range of density or shape properties considered here. However, 100μm particles exhibit a strong dependency on density and, to a lesser extent, shape. We note the limitations of the dispersion model in representing deposition close to the source and demonstrate the important role of mixing within the boundary layer in transporting material to the surface.

Introduction

At 00:54 BST on 14th June 2017, a fire was reported in a flat on the fourth floor of the Grenfell Tower residential building in North Kensington, London. The fire spread rapidly to all higher floors of the building and continued to burn for 24 hours [1]. The region was affected by very warm and dry meteorological conditions at the time of the fire [2].

This document continues work carried out to model the air concentration of particulates from the first 15.5 hours of the Grenfell Tower fire [3], which is considered the active burning phase. Here, we focus on investigating the deposition of smoke particulates possessing a range of sedimenting properties.

We modify the source characteristics used in the initial atmospheric dispersion study to account for particulates of varying size, shape and density, thus representing the deposition of a number of possible combustion products up to 100μm in size. We do not model for larger particulates and debris expected to have been deposited in the immediate vicinity of the building.

Model setup

The Met Office's Numerical Atmospheric-Dispersion Modelling Environment (NAME) [4] was used to model the dispersion of the smoke plume as small particulates. The model requires meteorological data and source information as input, and then tracks the release of model particles under the prescribed conditions. The model was set up following the approach described by Kendall et. al. (2019) [3]. The plume rise scheme was invoked to represent the buoyancy and momentum of the smoke plume and near-field dispersion at higher resolution. The dry deposition and sedimentation schemes were invoked to capture the deposition of particles with a range of sedimenting properties. Footage indicates that the most intense period of the fire persisted for approximately 3.5 hours [1], and so this investigation considers this period and the subsequent 12 hours of decreasing emissions. All times are presented in UTC, which is one hour behind the local time (BST) for the event.

Meteorology

Numerical Weather Prediction (NWP) analysis data at a horizontal resolution of 1.5km by 1.5km from the Met Office Unified Model [5] were used as meteorological input to the NAME model. At this scale, the building effects are not resolved and the urban area is represented using a combination of increased surface roughness lengths and modified surface fluxes and drag.

Figure 1 describes the evolution of air temperature and boundary layer depth during the simulation. The boundary layer is the part of the atmosphere which is directly influenced by the land, via surface drag and heat exchange processes. As the land warms during the day, the boundary layer grows and the air in this layer becomes turbulent, which acts to mix and disperse pollutants more effectively. Overnight, the boundary layer becomes shallow and stable in response to the cooling of the land and is less effective at mixing the air. The boundary layer also acts to somewhat contain a pollutant below or above its top. Pollutants above the boundary layer are typically subject to less vertical mixing, though they can become entrained into the boundary layer. Consequently, its behaviour plays a significant role in the dispersion of airborne pollutants.

Figure 1 shows that a minimum temperature of 15°C occurred at 04:00 UTC, and a maximum of 26°C from 15:00 to 17:00 UTC. The boundary layer depth reached a minimum of 90m at 04:00 UTC, climbing rapidly after 08:00 UTC, to reach a maximum of 2200m at 14:00 UTC.

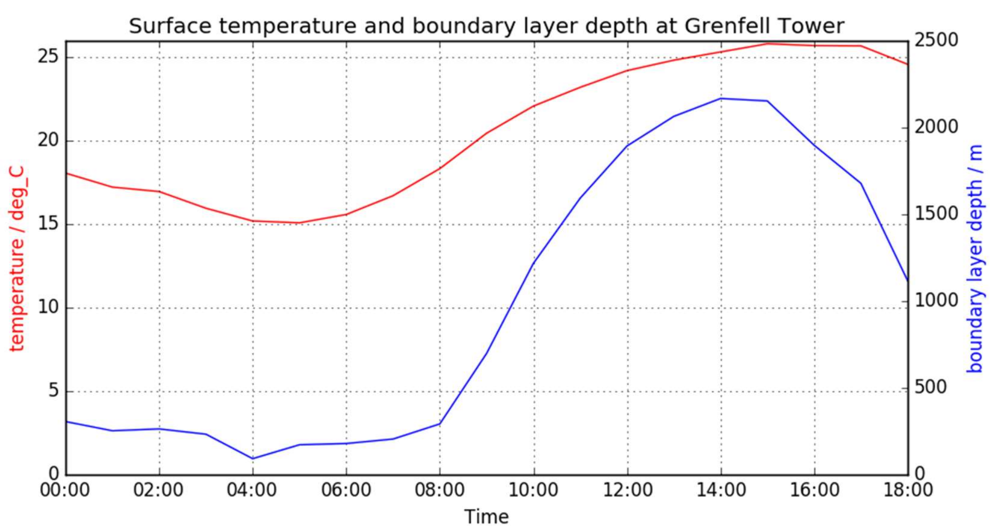


Figure 1: Air temperature (red) at the surface (0-10m) and boundary layer depth (blue) throughout the duration of the simulation on 14th June 2017, taken from NWP. Time in UTC.

NWP winds at the surface were compared to data from the nearest observation site – Kew Gardens, 7km south-west of Grenfell Tower – to verify the NWP data [3]. From 01:00 to 08:00 UTC, observed wind speeds are lower than those in the NWP, with NWP values approximately 1-2m/s and observed values 0-1m/s (Figure 2). The NWP winds at Grenfell Tower and Kew Gardens bear a close similarity, so a similar discrepancy is assumed for the NWP at Grenfell Tower. This could affect the modelled plume dynamics and should be considered when interpreting results.

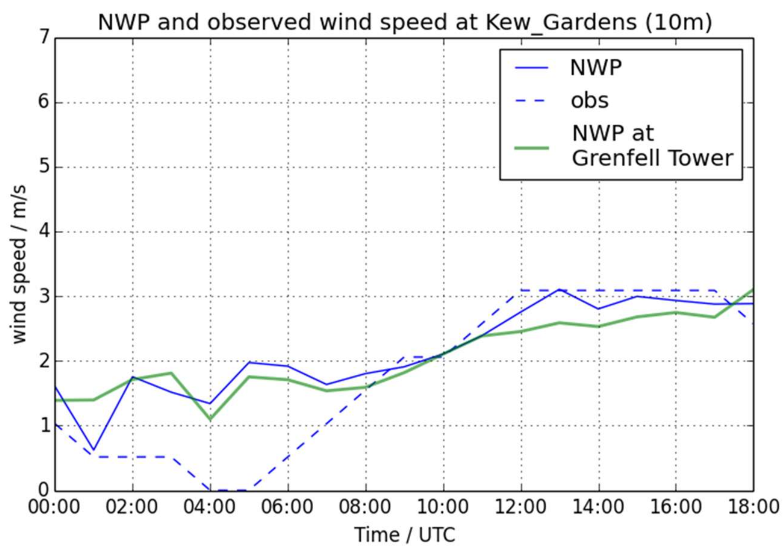


Figure 2: Modelled and observed wind speeds at Kew Gardens and modelled wind speed at Grenfell Tower (m/s).

Plume rise scheme

The NAME plume rise scheme models the initial rise of a hot plume due to buoyancy and momentum, based upon the conservation of momentum, heat, and mass [6]. The plume rise scheme requires a flat, circular surface from which to release model particles and is a simple representation of the plume source. Previous work [3] showed that a release height of 22m (one third of the building height) proved suitable for plume rise predictions of the fire.

Deposition and sedimentation schemes

There are several mechanisms by which material is deposited from the atmosphere onto the ground surface. Wet deposition is the removal of material from the atmosphere by precipitation such as rain or snow. Dry deposition is the process by which material is subject to meteorological transport to and uptake by the ground in the absence of precipitation. Sedimentation is the process driven by gravitational settling of ‘heavy’ particles, which are not merely carried along with the movement of the atmosphere but also fall independently towards the ground. These mechanisms are strongly dependent on factors such as the type of the pollutant (species), land surface type, and meteorological conditions.

To capture correctly the deposition of material in NAME, relevant deposition processes may be controlled by a range of species-specific parameters. Although wet deposition is important, the absence of rainfall during the modelled period means that for this instance this process is redundant. This leaves dry deposition and sedimentation as the dominant removal mechanisms. These processes in the model differ fundamentally in how they are applied to the modelled particles:

- Dry deposition is applied to every model particle under a specified height above ground level – known as the maximum deposition height. This assumes the average concentration of pollutant in this layer is representative of the near-surface concentration, and that a fraction of all the material in this layer will deposit on the ground. The fraction of material to be deposited may be controlled by using a prescribed deposition velocity.
- Sedimentation is applied to all model particles in these simulations and is controlled by a derived sedimentation velocity specific to the size and density properties of the particle. This mechanism physically transports model particles downwards and is applied regardless of a particle’s position.

The maximum deposition height is typically taken as the height of the boundary layer, as the boundary layer is effective at mixing material so that the average concentration in this layer is often representative of that at the ground. However, near to the source, the pollutant is not yet well mixed and therefore it is sensible to reduce the maximum deposition height for near-source studies. This can improve the accuracy of near-surface concentration values but may increase statistical noise if there are not enough model particles present with which to form a representative average across the output grid.

A maximum deposition height of 20m above ground level is used in order to avoid applying dry deposition to the rising plume itself. Sensitivity tests indicate that using a deposition height of 20m prevents material from being ‘artificially’ lost from the bulk of the rising plume close to the source, at the expense of a small increase in statistical noise. Though the source is just above this height, the model may still predict a small amount of buoyant material at this level very close to the source due to diffusion and turbulence. Further, there are many localised factors which cannot be fully represented and, as such, deposition results at very close range may be unreliable. Reassuringly, simulations using a maximum deposition height of 100m (not shown) give a very similar downwind deposition approximation, which indicates that downwind results are not overly sensitive to the selection.

Figure 3 illustrates the concepts of dry deposition and sedimentation in NAME. In this study, both the dry deposition velocity and sedimentation velocity are derived from the prescribed particle density and size, based on the equations of interaction detailed in Webster and Thomson (2011) [7].

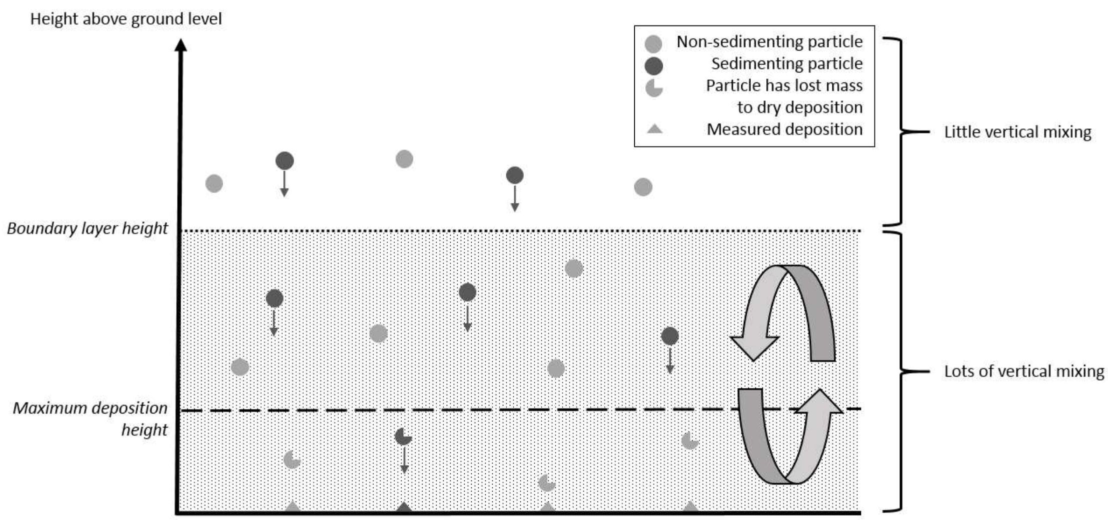


Figure 3: Illustrative example of the application of dry deposition and sedimentation to model particles in NAME. If particles are not well mixed vertically in the boundary layer, it is advisable to set a lower maximum deposition height to be more representative of the average air concentration near the ground.

Additionally, a particle shape can be specified to represent the slower sedimentation rate of non-spherical particles. A modified drag coefficient, defined by Ganser (1993) [8] through empirical studies, is applied to the sedimentation velocity for a given particle sphericity. The sphericity, $0 < \Psi \leq 1$, describes the degree to which a particle approaches a spherical shape. This is defined as the ratio of the surface area of a sphere with equivalent volume to the actual surface area of the particle, where a value of 1 is a perfect sphere and 0.2 equivalent to a disk shape. Figure 4 illustrates some examples of particles with sphericity between 1 and 0.2.

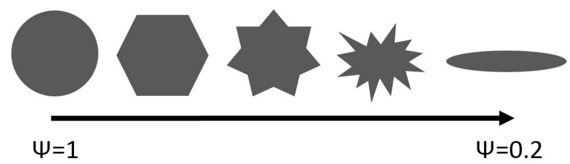


Figure 4: Examples of particle shapes with sphericity between 1 and 0.2.

Source term

An analysis of the fire by the Health and Safety Laboratory [9] provided an estimate of the mass release rate of particulate emissions and the convective heat release rate, which were used to derive the emissions parameters in NAME.

Table 1 indicates the source information used. The source shape was limited to a circular flat surface due to the requirements of the plume rise scheme. The surface was assumed to be 22m in diameter (width of the building) at a height of 22m above ground level (one third the height of the building).

Table 1: Source term used for modelling the Grenfell Tower fire.

Source parameter	
Location (Lat, Lon)	51.5141N, 0.2158W
Height (m)	22 (1/3 building height)
Shape	Flat circular surface
Diameter (m)	22 (building width)
Species	Particulate matter (PM)

The most intense part of the fire lasted for 3.5 hours [1]. During this time, it spread around the external cladding to different parts of the building. The contents of the residences were set alight in sequence and burned fiercely for periods of tens of minutes. After this time, the combustible parts of the cladding had been consumed and fires in the properties were also largely burned out. Residual burning and smouldering of the building contents continued at a decreasing rate for several hours [9].

Convective heat in the plume is deemed to have reduced at a much slower rate, due to the residual heat emitted by the concrete building. Therefore, the release in NAME is discretised with the mass release rate of plume material falling sharply after the most intense period of the fire and the heat release rate diminishing more gradually over the following 12 hours (Figure 5).

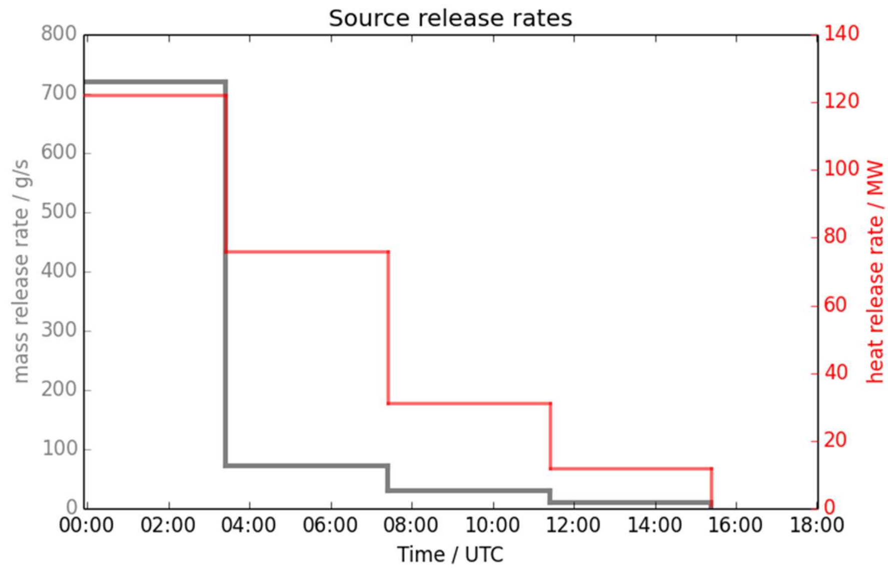
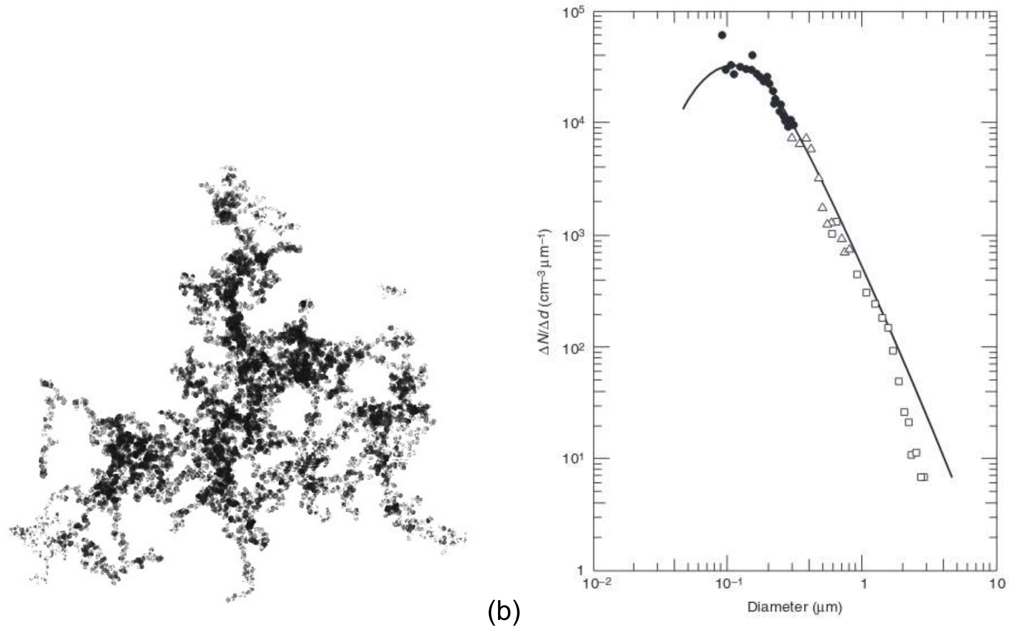


Figure 5: Mass and heat release rates over the course of the simulation.

Varying particle properties

Due to insufficient knowledge of the material components within the plume, several possible particle properties are modelled individually. This allows for capture of the variability in deposition due to the given particle properties. It is sensible to assume that black carbon aggregates – soot – constituted the majority of the plume material. Soot is typically 0.1 to 10μm in size (Figure 6) and can vary in density from 15 to 1000kg/m^3 (though this is considered a rather extreme upper bound). However, it is also possible that larger particles may have been lofted and transported within the smoke plume. Hence, we model deposition for releases of both 10μm and 100μm particles. Figure 7 provides some context to particle size. Table 2 describes the particle properties which have been considered for this study, with values chosen based on consultation with Public Health England and the Health and Safety Laboratory [10]. These values represent a range of possible materials that could have been associated with emissions from the fire.

A particle's shape can also influence how quickly it may fall through the atmosphere. A range of particle shapes may have been present in the plume, hence, two extremes of particle sphericity have been selected – a perfect sphere (sphericity = 1) and a disk shape equivalent (sphericity = 0.2).



(a) (b)

Figure 6: (a) Transmission electron micrograph of a soot particle. Overall size is approximately 6µm. (b) Number size distribution of smoke particles generated by cellulosic insulation indicates particle diameters are within a range of 0.1 to 10µm. Taken from Figure 2-13.4 and Figure 2-13.2 respectively in the SFPE Handbook of Fire Protection Engineering [11].

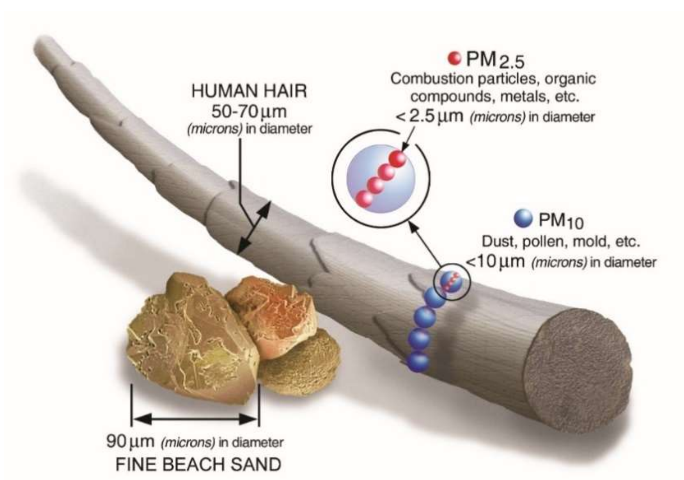


Figure 7: Indication of particle size for a range of particulate matter. Image courtesy of United States Environmental Protection Agency.

Table 2: Particle aerodynamic properties modelled.

Particle properties	
Particle diameter (µm)	10, 100
Particle density (kg/m^3)	15, 150, 1000
Particle shape (sphericity)	1, 0.2

Limitations and uncertainties

The focus of this study is on simulating the spatial distribution and relative quantity of deposits from emissions of a number of specific particle size, density and shape properties. This is due to lack of knowledge of the actual characteristics of the emitted particles during the event. Therefore, results should be used as indicative rather than quantitative deposition values. Uncertainties in the meteorology, such as wind speed and direction and boundary layer height, and the source estimates, such as heat and mass release rate, will contribute to uncertainty in total deposition fields.

Significant limitations to consider in the modelling of this incident are summarised below:

- NAME does not represent the small-scale effects of the fire or building structure.
- We do not consider larger debris (>100μm) which may have been deposited in the immediate vicinity of the building.
- The input meteorology overestimates the wind speeds at the surface during the most intense period of the fire, which may underestimate initial plume lift-off. However, this was deemed to have not affected results beyond the immediate vicinity of the source.
- NAME may not appropriately represent deposition at close proximity to the source (within around 300m) due to the model's assumption that plume material is well mixed below the maximum deposition height.
- The NAME plume rise scheme was not designed for use with sedimenting particles – there is an assumption that there is no downward component to the particle velocity during the plume rise phase. However, testing has demonstrated that the model performs satisfactorily for the purposes of this investigation, as the average rise velocity is much greater than the typical sedimentation velocity of the particles considered, and the plume rise phase is sufficiently short-lived as to not adversely affect downwind particle sedimentation.

Results

Maps of total deposition from the start of the release until 17:00 UTC (after which no further material is deposited in the simulation) are presented for simulations of given particle size, density and shape properties. The mass release rate in each simulation is as described in Figure 5. Quantities are calculated by averaging the values assigned to model particles onto an output grid of approximately 70m by 110m horizontal resolution. To aid interpretation, plots of the vertical distribution of material at hourly-averaged time intervals are also included, and reference to photography. Additionally, a selection of particle trajectory plots illustrates the factors influencing the transport of model particles of different properties.

Total deposition fields

We consider a spatial domain spanning approximately 5km by 5km, indicated by Figure 8 with Local Authority boundaries overlaid. Total deposition maps for the modelled period are presented for individual simulations of 10μm and 100μm particles of density 15, 150 and 1000kg/m^3, and sphericity 1 and 0.2 (Figures 9 and 10). Values below 10^{-3}g/m^2 are masked.

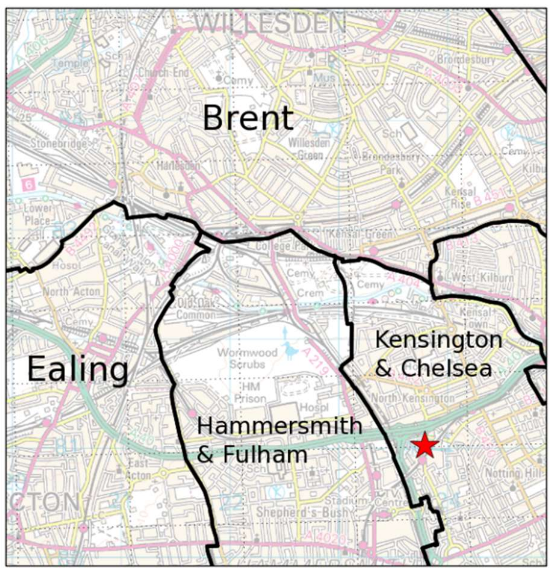


Figure 8: Domain considered, including local authorities. Approximately 5km by 5km. Location of Grenfell Tower indicated by red star.

Results are indicative of the distribution of deposition for the given particle properties and should be interpreted as relative quantities. In reality, the plume will have consisted of particles of a range of properties and the mass of material would have been distributed across these. Regions of 'speckled' results are due to statistical noise and therefore the location of defined contour boundaries should not be over interpreted.

In all simulations, deposition occurs predominantly in the quadrant to the north-west of the site, on account of the light south-easterly wind throughout the modelled period. It can be inferred that particles with properties between the upper and lower bounds result in a deposition distribution which falls in between the modelled values, though this cannot be interpolated linearly. It is, however, expected that the plume consisted mostly of particles 10μm in size or less.

Results within approximately 300m of the source should not be considered reliable. This is because, despite employing a maximum deposition height of 20m (just below the emission height), overestimated surface wind speeds by the NWP may result in underestimated plume lift off and, as such, the model may inaccurately represent a small amount of material at this height at close range to the source. Consequently, the dry deposition mechanism may be applied to material which is not well mixed and is in fact still rising. We also note that there are localised flows and dispersion processes near to the building and the fire that are not represented in NAME, which may cause material to be deposited very close by. Hence, results in this region – indicated by the grey zone in Figures 9 and 10 – should be ignored.

Beyond the grey zone, the deposition maxima out to approximately 1km downwind are considered reliable and a consequence of plume grounding after 08:00 UTC, when the plume buoyancy had decreased and material was subject to effective boundary layer mixing.

Results indicate that, for spherical 10μm particles, the greatest deposition occurs within 1km of the tower and does not exceed 3.2×10^{-2}g/m^2 (0.032 g/m^2). For reference, 3.0×10^{-1} g/m^2 (0.3 g/m^2) of soot would appear as a visible black layer deposited on a surface. The density of these particles has very little impact on the spatial distribution or quantity of total deposition (Figure 9a, 9c, 9e). There is some indication of increased deposition with density at around 3-5km downwind, though this is within the realms of statistical noise.

For 100μm particles, there is greater downwind deposition due to the effect of sedimentation. Density of particles of this size has a significant influence on the deposition distribution (Figure 9b, 9d, 9f). With increasing density, a larger deposition maximum emerges at 3-5km downwind, and deposition appears to be more widespread. It should be noted that a peak value of up to 3.2g/m^2 observed in the upper bound simulation (Figure 9f) is representative of a plume consisting entirely of dense 100μm particles, whereas in reality such particles are likely to represent only a very small fraction of the plume. Therefore, this value should not be considered a real quantitative estimate of deposition.

Equivalent simulations with non-spherical particles (sphericity 0.2) demonstrate the impact of particle shape on deposition (Figure 10). In comparison to Figure 9, downwind deposition decreases with decreasing sphericity. This is because non-spherical particles are subject to increased atmospheric drag, which acts to reduce the sedimentation velocity. However, shape has a smaller influence than the particle size or density range considered here, and for 10μm particles, its impact is negligible.

Of the particle properties considered, size has a first order effect on deposition rate, followed by density, and thirdly, particle shape. Specifically, 10μm particles appear to have little sensitivity to prescribed density or shape. Whereas 100μm particles are particularly sensitive to density and, to a lesser extent, shape.

There are several factors which are likely to have influenced the extent of deposition, beyond particle properties. It is therefore important to interpret these results with the aid of additional information provided in the following sections.

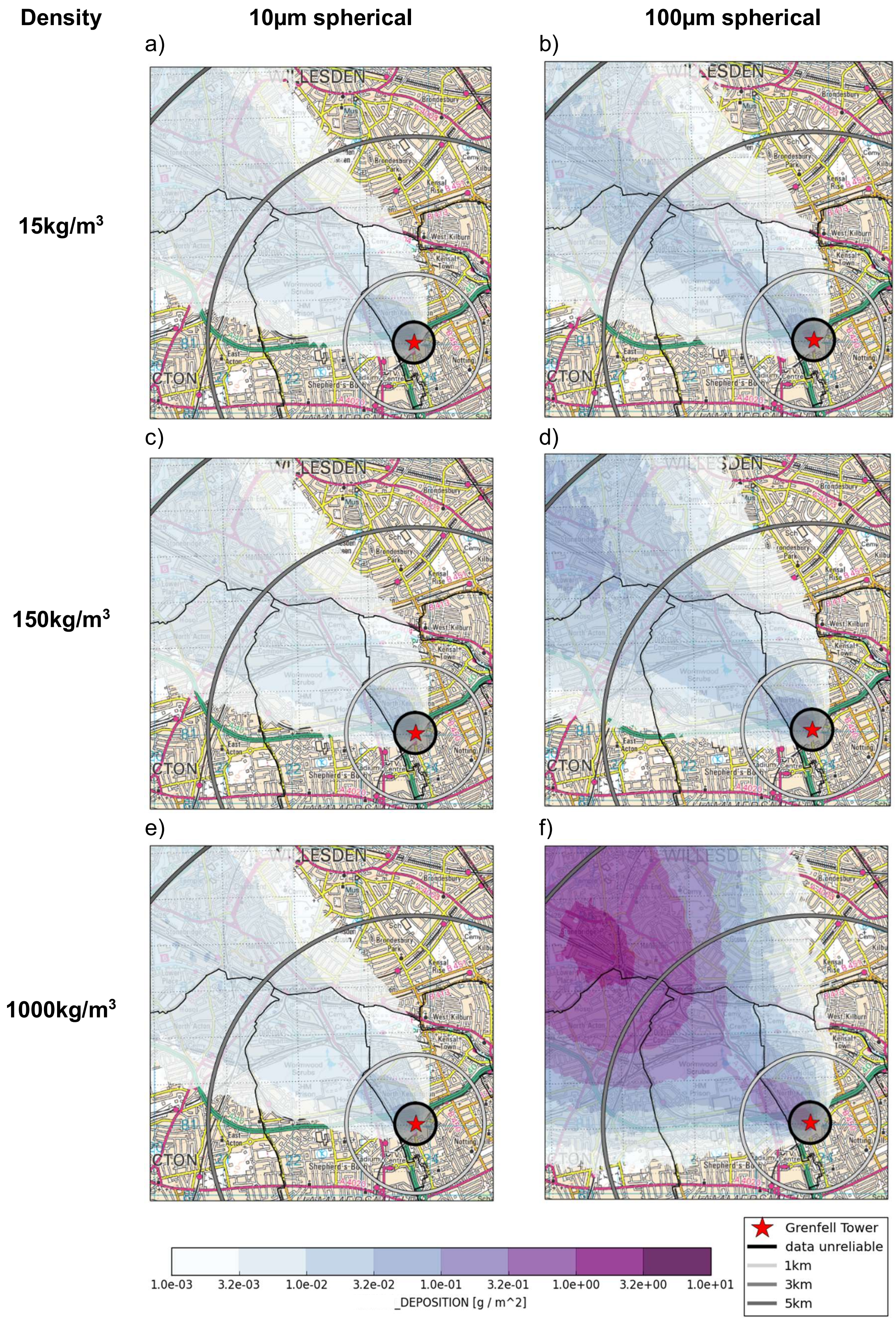


Figure 9: Total deposition for 10µm and 100µm spherical particles of varying density. Model results are not reliable within around 300m from source, indicated by grey zone. Local authority boundaries overlaid. Values presented are relative quantities for particle type. Values below 10^{-3} g/m^2 masked.

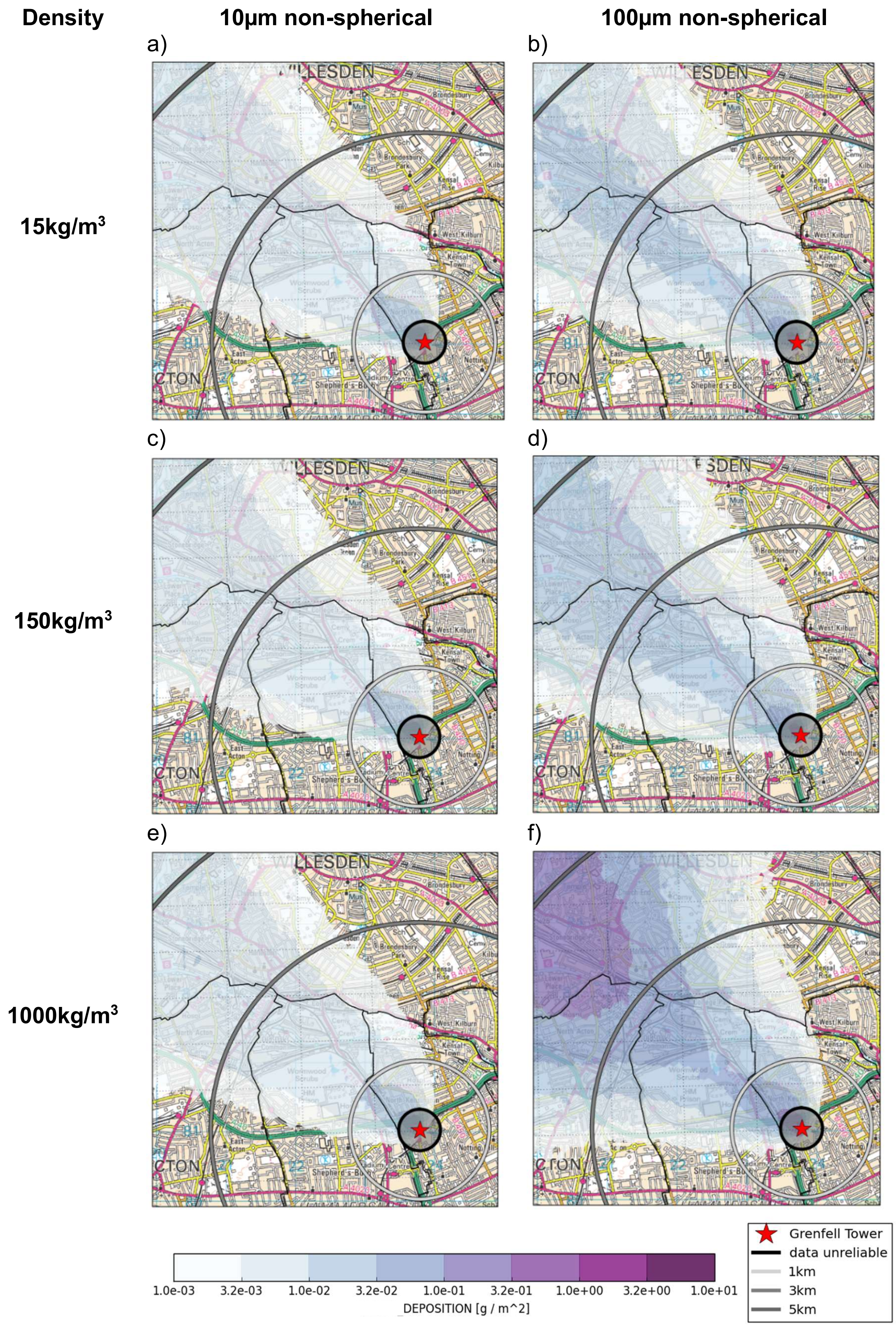


Figure 10: Total deposition for 10µm and 100µm non-spherical particles of varying density. Results are not reliable within around 300m from source, indicated by grey zone. Local authority boundaries overlaid. Values presented are relative quantities for particle type. Values below 10^{-3} g/m^2 masked.

Vertical distribution of mass

An assessment of the mass distribution for the densest particles (1000kg/m^3) in the vertical plane (akin to a north-looking view of the plume, but not perpendicular to the plume axis) at hourly-averaged resolution until 11:00 UTC is useful in understanding the evolution of the plume behaviour and the resulting deposition estimates.

Figure 11 reveals that, during the most active period of the fire (between 00:00 and 04:00 UTC), 10µm particles mostly remain above the boundary layer and are therefore not mixed downwards towards the surface, preventing significant deposition. Conversely, 100µm particles are subject to sedimentation into the shallow boundary layer and subsequently exposed to boundary layer mixing.

Beyond 04:00 UTC, the heat release rate of the fire is reduced, which acts to lower the plume buoyancy and facilitate plume grounding closer to the tower. However, the mass release rate also diminishes significantly, and the boundary layer grows so as to mix material over a greater vertical range. It is a combination of all these factors which determines the total quantity of deposition.

The deposition rate for 10µm particles is greatest at approximately 08:00-09:00 UTC, despite emissions having been reduced considerably. This is driven by the lower plume buoyancy and entrainment into the growing boundary layer mixing the plume down to the surface. 100µm particles exhibit the highest deposition rate during 01:00-04:00 UTC, when emission rates are highest, as they readily sediment into the boundary layer, hence they are not as dependent on boundary layer characteristics as 10µm particles.

An assessment of photography (Images 1-4) shows little evidence of plume grounding during early morning, as the plume remains mostly at height. This could suggest that it is likely to have consisted of mostly smaller particles as in Figure 11a, although doesn’t rule out the presence and deposition of larger particles.

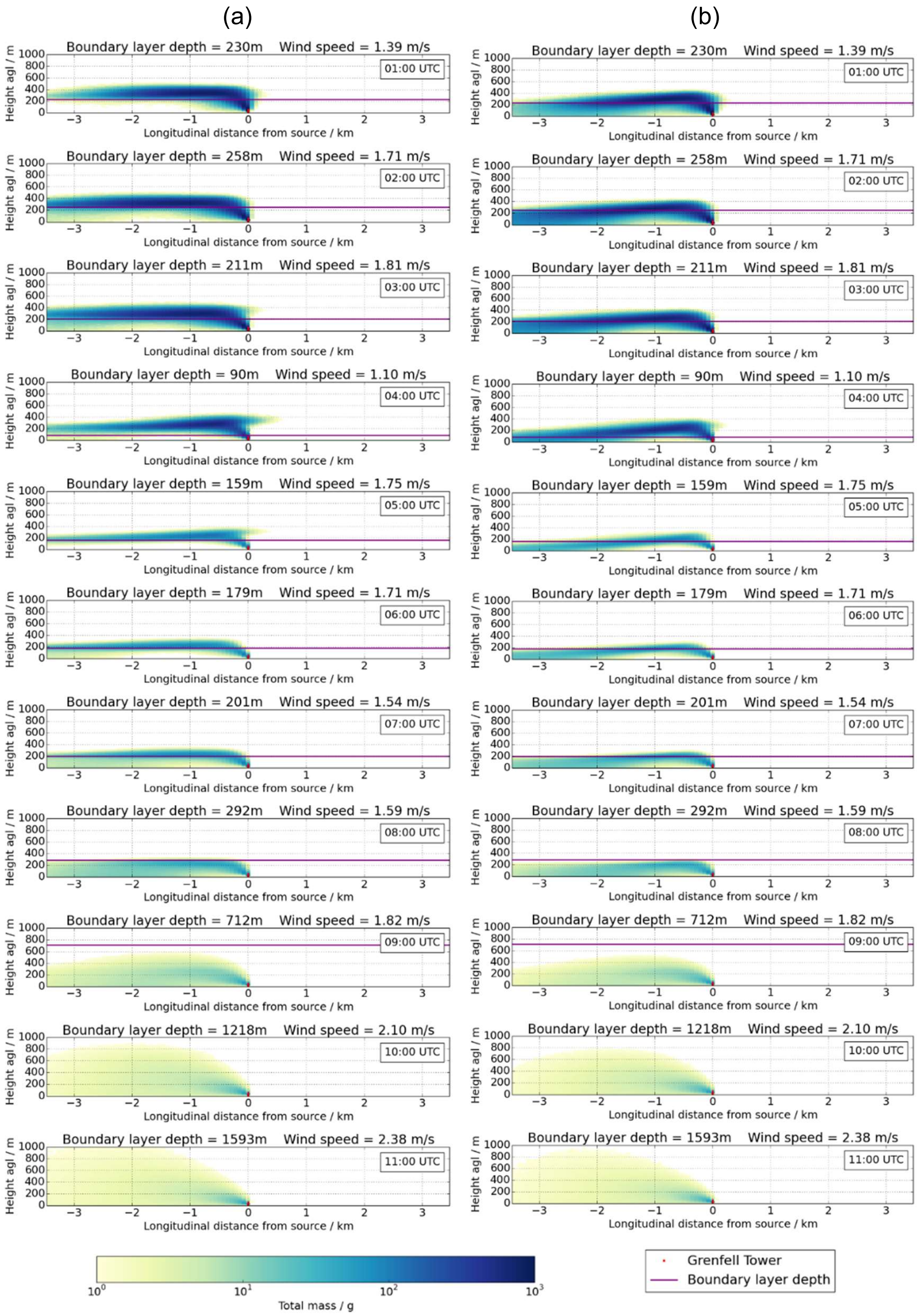


Figure 11: Hourly averaged values of total mass in each 10m height layer vs longitude (i.e. north-looking view of plume) until 11:00 UTC for a release of (a) 10μm and (b) 100μm particles of density 1000kg/m^3 on 14th June 2017. This serves to illustrate the evolution of the plume and origin of downwind deposition results. Much of the mass initially remains above the boundary layer in (a) and is not transported towards the ground, in contrast to the larger particles in (b).

Image 1: Plume of main fire reaching 300-400m, heading approximately north / north-west at 02:00 UTC.
Credit: Alexander Straub / Medium

Image 2: Emissions somewhat reduced. Plume rises to several hundred metres and is suggestive of negligible wind near ground level. Exact time unknown.
Credit: Selim Halulu

Image 3: Plume continuing to rise to around 300-400m, experiencing some downwind mixing at 04:30 UTC.
Credit: Sky News

Image 4: Plume rising to approximately 300m and remaining at height, little downwind grounding at 05:15 UTC.
Credit: Selim Halulu

Images 1-4: Photography overnight and early morning on 14th June 2017, timestamped where information available. Suggestive that much of the plume material remained aloft.

Trajectories

Trajectory plots of model particles released over specific hours of the simulation illustrate the competing effects of particle aerodynamic properties and boundary layer processes on their transport. Particles below the prescribed maximum deposition height will contribute to the total calculated dry deposition. For visual clarity, we show 100 particle trajectories per simulation per hour (equivalent to 0.02% of the actual release rate of model particles).

Figures 12 and 13 show the transport of model particles released during the first hour of the simulation. 10µm particles have little sensitivity to density and remain mostly above 200m before leaving the model domain (Figure 12). 100µm particles of low density behave similarly, however, high density 100µm particles sediment readily, beginning to ground at around 2km longitudinal (East-West) distance from the source (Figure 13 - top). A low sphericity acts to reduce sedimentation velocity, hence particles ground further downwind (Figure 13 - bottom).

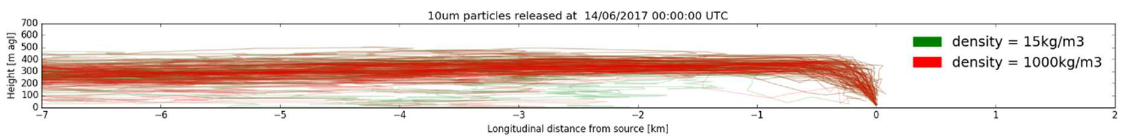


Figure 12: Particles released during first hour of simulation. 10µm particles are not sensitive to density.

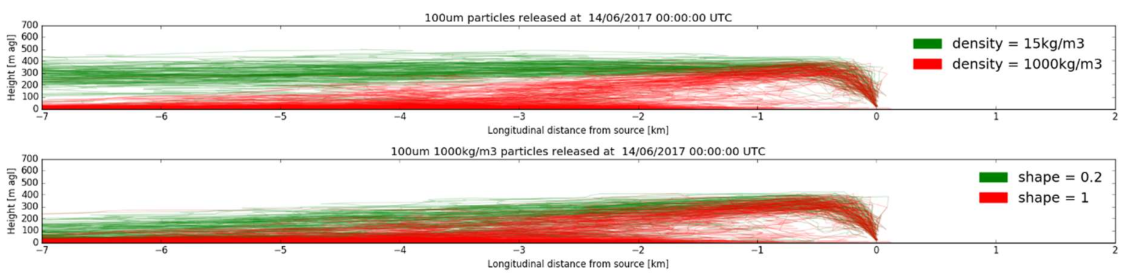


Figure 13: Influence of density and shape on 100µm particles released during first hour of simulation.

Figure 14 illustrates the influence of the growing boundary layer on the vertical transport of dense particles with time. During early morning, while the boundary layer is relatively shallow, 10µm particles (green) mostly remain suspended above. Conversely, 100µm particles (red) sediment into the boundary layer and are then subject to significant mixing within the shallow boundary layer. As the boundary layer deepens, all particles are captured and mixed to greater vertical extents, and boundary layer mixing tends to dominate particle properties in the vertical transport of particles.

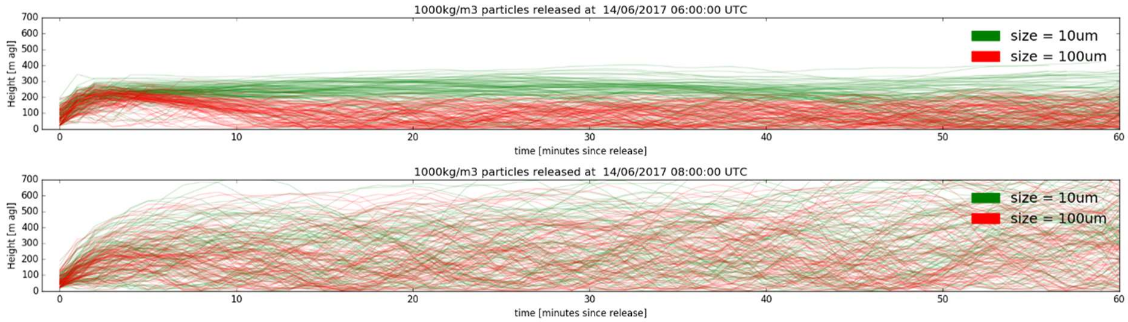


Figure 14: Influence of the boundary layer depth on particles of varying size. Top: shallow boundary layer (depth around 200m). Bottom: Deeper boundary layer (depth over 500m).

3-day wind observations

This study only considers emissions during what is considered the active burning phase of the fire. An assessment of the meteorological conditions beyond the modelled period of 15.5 hours may be useful if considering possible residual emissions after the active fire period.

Observations at Kew Gardens (approximately 7km from Grenfell Tower) in Figure 15 indicate a light, south-easterly wind increasing in magnitude from 1-4mph from 00:00 until 20:00 UTC 14/06/2017 – a period which encompasses the entire duration of the modelled plume dispersion. Overnight, between 20:00 UTC 14/06/2017 and 07:00 UTC 15/06/2017, there are very light and variable winds shifting from easterly to south-westerly. From 07:00 UTC 15/06/2017 onwards, wind speeds increase and remain generally consistent at 4-6mph during the daytime and 2-4mph overnight, from a mostly westerly direction. This indicates that any residual emissions could have been dispersed and deposited to the east of the site.

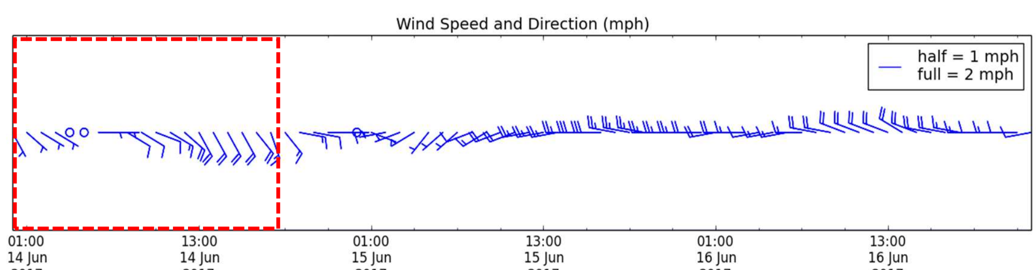


Figure 15: Wind speed and direction observations at Kew Gardens over a 72 hour period from the start of release. The simulation period is indicated by the red box. Times in UTC, wind speed in mph.

Conclusion

The deposition of particles representing possible components of the smoke plume from the Grenfell Tower fire has been modelled. We have considered a discretised release of buoyant particles over 15.5 hours and present deposition results on a spatial grid of approximately 5km by 5km. We do not model particles and debris greater than 100μm in diameter, which are likely to have been deposited in the vicinity of the building.

Due to insufficient knowledge of the particles constituting the smoke plume, a variety of possible values of size, density and shape have been modelled individually and should be considered as upper and lower bound results. Particles with properties between the values modelled will yield deposition results which fall in between, although cannot be linearly interpolated. In reality, the plume will have consisted of particles with a range of sizes, densities and aerodynamic properties, with the majority being soot, which resembles the lower size bounds modelled. This is supported by photography.

Results indicate that deposition occurs predominantly towards the north-west of the site, driven by the light south-easterly wind during the modelled period. For particles of upper bounds of size and density, a maximum emerges at 3-5km downwind.

We demonstrate that, for 10μm particles, the effects of particle density and shape are negligible on the total distribution and relative quantity of deposition. For 100μm particles, however, sedimentation is particularly sensitive to density and, to a lesser extent, shape.

These results are intended to be indicative of the likely areas of deposition and deposition values should be interpreted as relative quantities for the given particle properties. Results within 300m of the source, indicated by the grey zone, should not be considered reliable due to the limitations of the dispersion model.

Uncertainties in both the meteorological data and emission estimates will contribute to uncertainty in deposition estimates. We illustrate the importance of the role of boundary layer mixing processes in dispersing material. Beyond the modelled period, there is a change in wind to a mostly westerly wind direction.

Acknowledgements

This investigation has been conducted in collaboration with Public Health England and the Health and Safety Laboratory. The findings presented in this document have been subject to a joint review process.

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