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Grenfell Tower fire: modelling smoke plume dispersion and air quality impact using NAME

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E. L. Kendall, M. C. Hort and
C. S. Witham

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Grenfell Tower fire: modelling smoke plume dispersion and air quality impact using NAME

Written by Met Office.

Certain technical content provided by Graham Atkinson of the Health and Safety Laboratory.

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Summary

This report considers the dispersion of the smoke plume from the Grenfell Tower fire and its impact on local PM10 air quality. The plume dispersion was modelled using the Met Office's atmospheric dispersion model, NAME, and meteorological data from observations and the Met Office UK weather forecast. Estimates of emissions from the fire were provided by the Health and Safety Laboratory. The content of the smoke plume was modelled as small, non-sedimenting particulates. This study did not focus on the presence of larger particles or embers within the plume. We model only the first 15.5 hours of the event – the duration of the main fire – hence do not consider any persisting emissions from the site in the hours or days after the main fire was extinguished.

Model results suggest a negligible, short lived air quality impact, with peaks at nearby observation sites not exceeding 20µg/m^3 above background. Observations are limited, but where they exist, there is overarching agreement to the model both in terms of general plume structure from photography and local air quality measurements.

The impact of uncertainties in mass release rate, plume buoyancy, and meteorology were considered by conducting sensitivity tests.

- Mass release rate uncertainties have the largest impact on air concentration.
- Modelled plume lift-off is affected by overestimated low level wind speeds in the weather forecast data. However, this has negligible impact on resulting ground level air concentration values.
- Atmospheric boundary layer depth also affects plume dispersion and resulting ground level concentrations.

Alternative scenario simulations showed that, had the fire occurred six hours later under a low boundary layer, or if combustion levels had been sustained throughout the day, there would have been a more significant impact on air quality.

1 Introduction

The dispersion of the smoke plume of the Grenfell Tower fire was modelled using the Met Office's atmospheric dispersion model, NAME, to evaluate the consequence of the active fire on local air quality. The source term was derived from heat and mass release estimations calculated by the Health and Safety Laboratory (HSL). Simulations were conducted using meteorological data from both NWP (Numerical Weather Prediction Model) and observations. A comparison of results to available air quality observations was performed and tests were conducted on the sensitivity of results to plume buoyancy and meteorology.

Incident background

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 24-storey building, believed to have been facilitated by the exterior cladding, 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].

2 Model Setup

The Met Office's Numerical Atmospheric-Dispersion Modelling Environment (NAME) [3] was used to model the dispersion of the smoke plume as small, non-sedimenting particulates. The model requires meteorological data and source information as input. The plume rise scheme and velocity memory scheme were invoked to represent the buoyancy and momentum of the smoke plume and near-field dispersion at higher resolution. 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 subsequent 12 hours of decreasing emissions. The simulation runs until 18:00 UTC. All times are presented in UTC, one hour behind local time (BST) at the time of the event.

Plume rise and velocity memory schemes

The plume rise scheme models the initial rise of a hot plume due to buoyancy and momentum until it becomes passive, based upon the conservation of momentum, heat, and mass [4]. The plume rise scheme requires a flat, circular surface from which to release model particles. It was not designed for plumes from fires, rather, for industrial stack emissions, so ought to be considered a simplified representation of the plume.

Assuming the plume mostly consists of hot air, the buoyancy and momentum are dependent on the relative velocity of the effluent particles, excess temperature to the ambient air, and the plume radius [5]. Flow velocity and release temperature at the source must therefore be specified as input parameters. Estimates of these quantities can be derived from a given heat release rate, Q, using the following equation:

$$Q = \pi \left(\frac{d}{2}\right)^2 v_f \, \rho_r \, c_p (T_r - T_a)$$

[1]

with variables defined as follows:

- d = source diameter (m)
- v_f = flow velocity (m/s)
- c_p = specific heat capacity of air (c_p= 1 kJ/kgK)
- T_r = release temperature (K)
- T_a = ambient air temperature (K)
- ρ_r = release density (kg/m^3) where ρ_r = ρ_a (T_a/T_r) and
- ρ_a = density of ambient air (ρ_a = 1.25 kg/m^3)

To obtain approximations for flow velocity and release temperature, assumptions can be made for specific heat capacity and density of ambient air, and ambient air temperature taken from the input meteorology. The source diameter must be provided to calculate the surface area from which to release. Then, sensible combinations of release temperature and flow velocity can be used to obtain the desired heat release rate.

Over short ranges, it is relevant to model the turbulent motions of the particles and gases in the atmosphere using NAME's velocity memory scheme [6]. This is a random walk scheme with a Langevin-type approach where a particle's turbulent velocities are correlated in time. In this simulation, it was invoked for the first hour after a particle's release. After the first hour, a simpler diffusion scheme is used.

Meteorology

Analysis NWP data, at a horizontal resolution of approximately 1.5km by 1.5km, from the Met Office Unified Model [7] were used as meteorological input. At 1.5km the buildings are not resolved, and the urban area is modelled using a combination of increased roughness lengths and modified surface fluxes and drag. Figure 1 illustrates the changes in surface temperature and boundary layer depth given by NWP at Grenfell Tower over the course of the simulation.

The boundary layer is the part of the atmosphere which is directly influenced by the land, via surface drag and heating processes. As land absorbs solar irradiation throughout the day, it heats up and transfers some of this heat to the atmosphere via conduction. The heat is then mixed higher by convection, increasing the boundary layer depth. This causes air in the boundary layer to become turbulent and well mixed, which acts to disperse pollutants more effectively. At night the land cools by radiation, ceasing to heat the atmosphere, which in turn tends to reduce turbulence and the boundary layer depth. The boundary layer also acts to somewhat contain a pollutant below or above its top. Pollutants above the boundary layer, in the free troposphere, are typically subject to less vertical mixing, though they can become entrained into the boundary layer. Consequently, the boundary layer 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. 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.

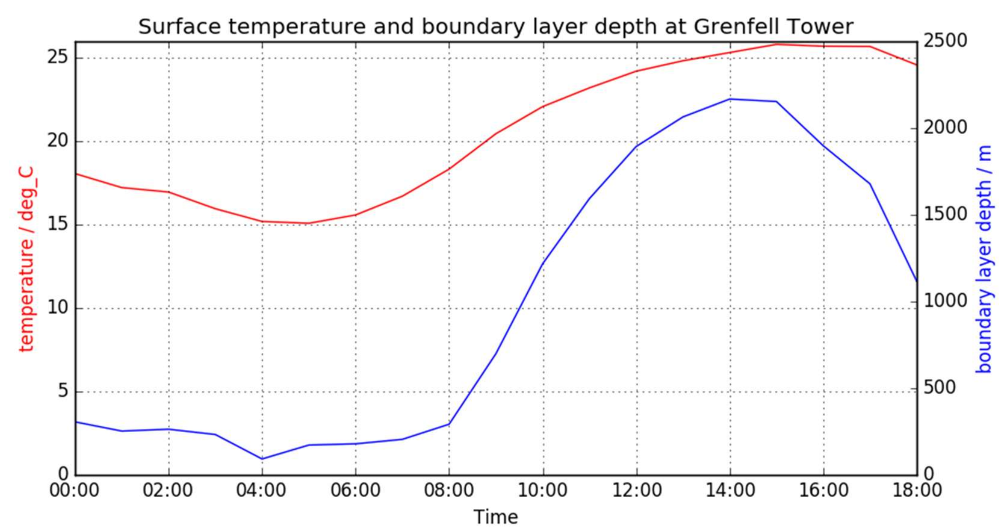


Figure 1: Air temperature at surface (0-10m) and boundary layer depth throughout the duration of the simulation, taken from NWP. Time in UTC.

NWP wind speeds at various heights are illustrated in Figure 2. Near the ground, they increase steadily from approximately 1m/s to 3m/s during the simulation. Initially, winds increase with height and vary with time, but after approximately 10:00 UTC, wind speeds at 100-500m become more uniform.

The surface NWP winds were compared to data from the nearest observation site – Kew Gardens, 7km south-west of Grenfell Tower – to verify the NWP analysis. Figure 3 indicates that observed wind speeds were lower than the NWP during the main period of the fire, with NWP values approximately 1-2m/s and observed values 0-1m/s. With NWP wind speed values at Grenfell Tower and Kew Gardens bearing a close similarity (Figure 3), a similar error is assumed for NWP at Grenfell Tower. An error of this relative magnitude may affect the modelled plume dynamics, and this should be considered when interpreting results.

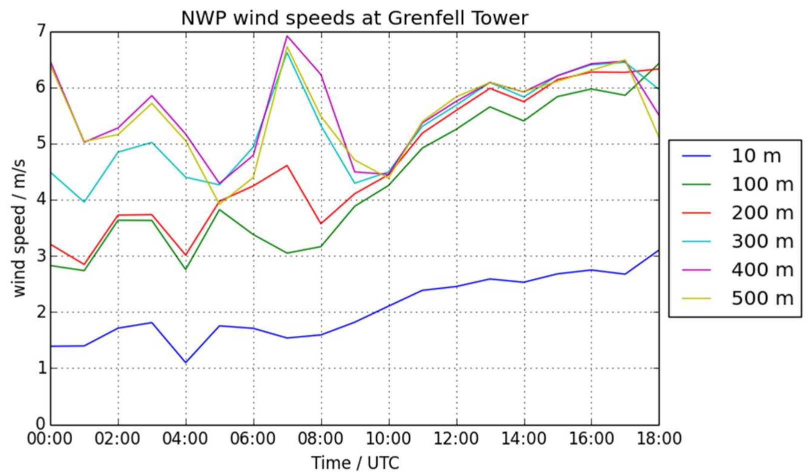


Figure 2: NWP wind speeds at varying heights.

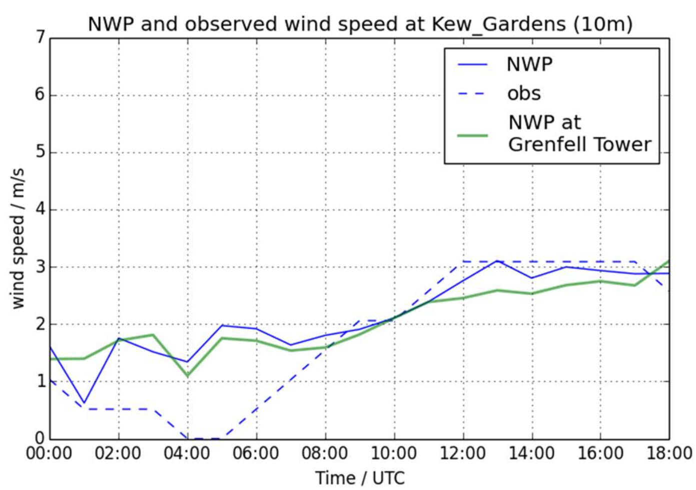


Figure 3: Modelled and observed wind speeds at Kew Gardens and modelled wind speed at Grenfell Tower.

Source term

An analysis of the fire by the Health and Safety Laboratory (HSL) provided an estimate of the particulate emissions and convective heat release rate, which were used to derive source term parameters in NAME.

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). The most intense part of the fire was deemed to have persisted for 3.5 hours [1], after which point the amount of combustion is considered to have reduced significantly. 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 mass release rate falling sharply after the most intense period of the fire and heat release rate diminishing more gradually over the following 12 hours.

For the most intense part of the fire, a minimum credible value of the convective outflow of heat contributing to plume lift-off was estimated by HSL as 127MW. A maximum credible mass release rate of 720g/s was estimated from an analysis of combustion conditions, fire duration and building composition [8]. These values provide a release approximation with reasonable confidence of no underestimation of the ground level impacts.

Using the value for convective heat release in Eqn 1, a flow velocity of 6m/s and plume temperature of 67°C were derived as sensible initial values for the plume rise scheme, to be applied uniformly across the 22m radius release area. However, combinations of other values could be used to obtain an equivalent estimation of buoyancy providing that the resulting value for heat release rate were conserved, which would be expected to yield very similar plume rise behaviour. Incremental reductions were applied to flow velocity and temperature in order to obtain sensible estimates for the evolution of mass and heat release rates.

As the focus of this study is on acute air quality impact, the smoke plume is modelled as small particulates without sedimentation. We do not consider the presence of larger particles or embers within the plume which may be subject to gravitational settling.

Tables 1 and 2 indicate the source and release characteristics. Figure 4 is a graphical depiction of the heat and mass release rates with time.

Table 1: Source term – Grenfell Tower.

Source parameter	
Location	0.2158W, 51.5141N
Height	22m (1/3 building height)
Shape	Ellipsoid (dZ = 0)
Diameter	22m (dX = dY)
Species	Small non-sedimenting particulate

Table 2: Release terms – parametrization of PM10 emissions.

Release	Start time (UTC)	End time (UTC)	Mass release rate (g/s)	Release temp. (K (°C))	Flow velocity (m/s)	Heat release rate estimate (MW)
1	13/06 23:54	14/06 03:24	720	340 (67)	6	122
2	14/06 03:24	14/06 07:24	72	335 (62)	4	76
3	14/06 07:24	14/06 11:24	30	330 (57)	2	31
4	14/06 11:24	14/06 15:24	11	325 (52)	1	12

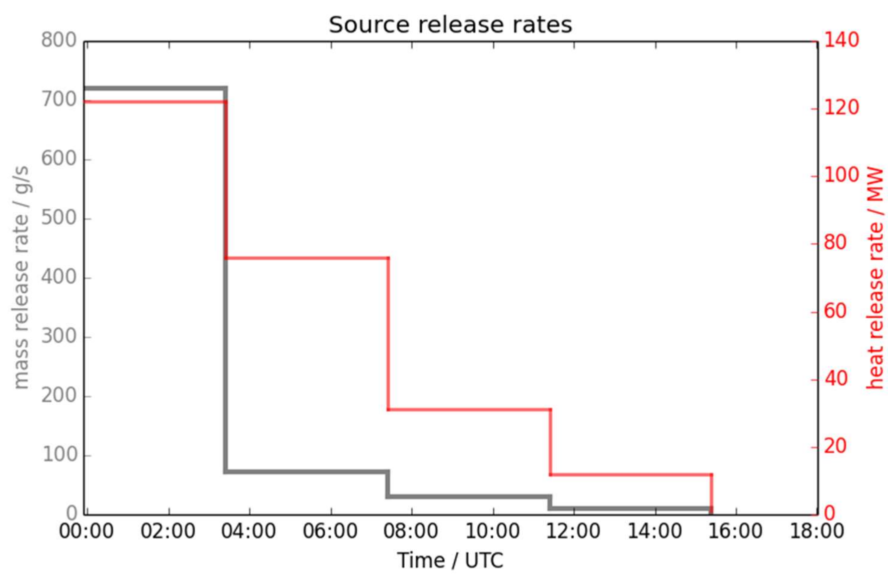


Figure 4: Mass and heat release rates over the course of the simulation.

Assumptions and uncertainties

The model setup does not explicitly resolve buildings or street canyons. In both the NWP and dispersion models, the presence of buildings is represented though aerially averaged surface roughness, drag, and surface flux parameters. This lack of explicit representation is not deemed to significantly impact the results as:

- The buoyancy of the fire means that the main part of the plume rises above the height of Grenfell Tower and the surrounding buildings.
- Once the plume mixes downwards, it is sufficiently dispersed that flow around individual buildings is adequately represented by the enhanced mixing in the model.

Besides inherent uncertainties in meteorological data, the assumptions made in the derivation and discretisation of release terms also introduce uncertainty into model simulations. The impact of some uncertainties in meteorology, convective heat release and mass release rate are considered in a range of sensitivity studies in Chapter 5.

3 Results

NAME results are hourly time-averaged concentration values presented in a 10km x 12km domain. A horizontal resolution of 0.001° x 0.001° equates to approximately 70m x 110m, with a vertical resolution of 10m up to 1km and 100m up to 5km above ground level (agl). Timestamps indicate the end of the hourly averaging period if both start and end are not specified. All times are in UTC.

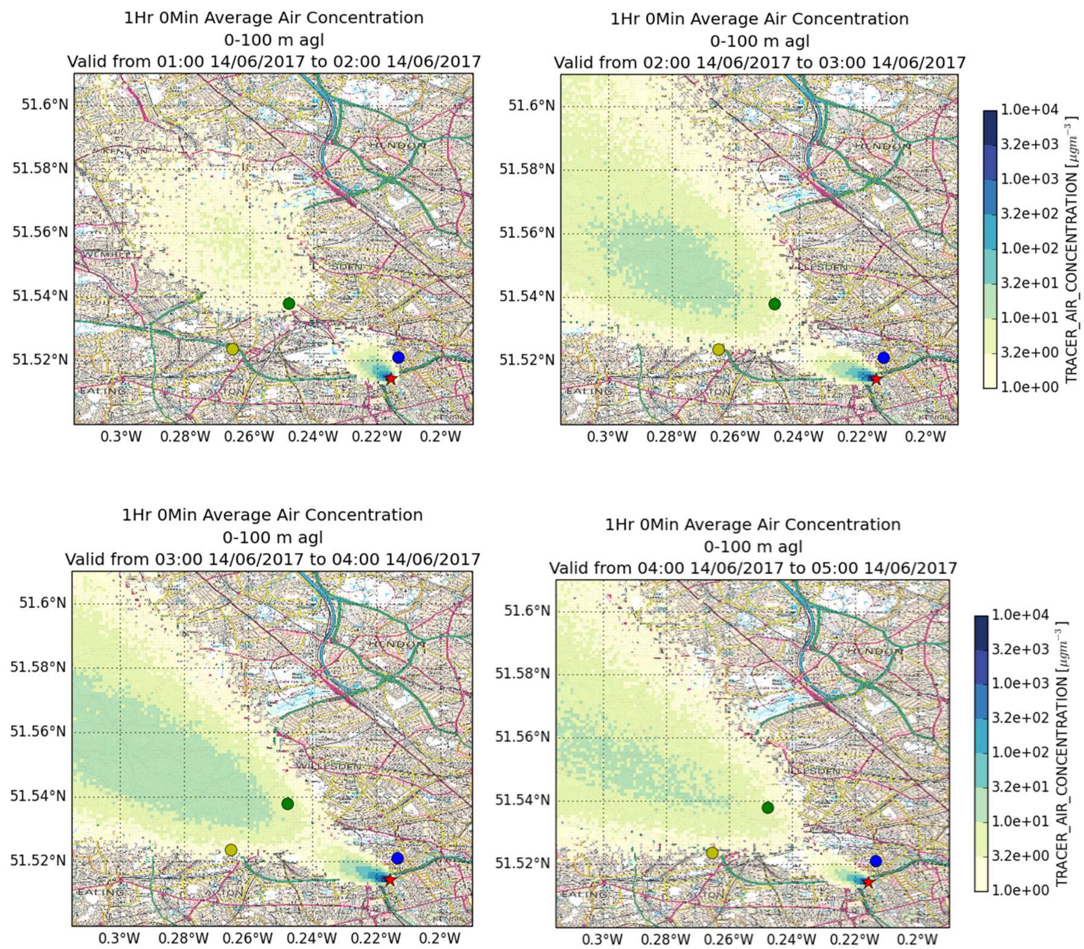
0-100m field layer

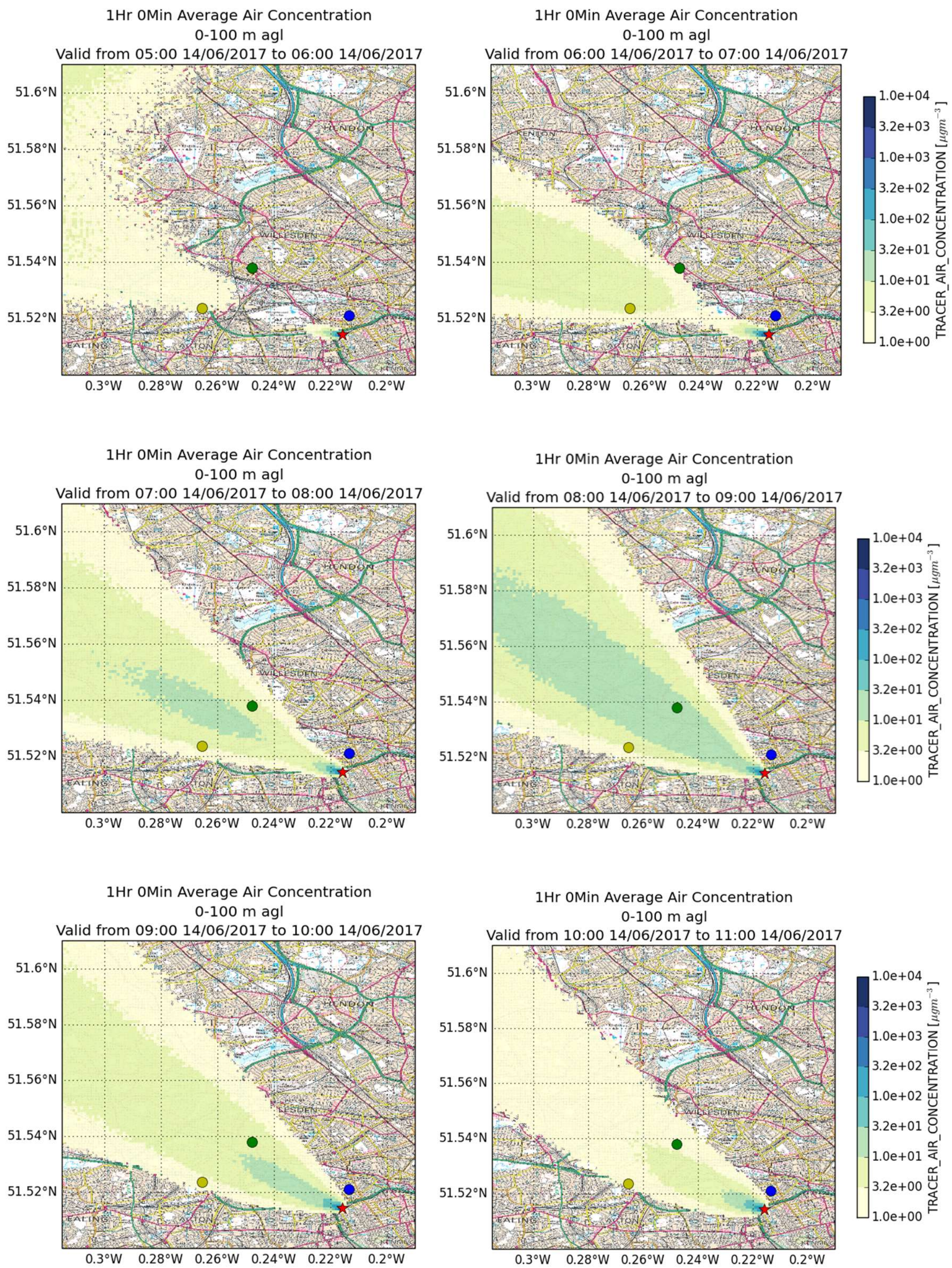
Hourly-averaged results of concentration averaged across the 0-100m vertical layer from 01:00 to 18:00 UTC are presented in Figure 5. Present within this layer is the source itself and the immediate rising plume, which is not well mixed across the whole 100m layer. The very high values close to the source in this layer are attributed to the material still rising in the buoyant plume and as such are not representative of air concentration near the ground. With this in mind, it is thus appropriate to disregard results at close proximity to the source.

Also plotted is the source location at Grenfell Tower (red) and the locations of three air quality monitoring sites of closest proximity to the plume: North Kensington (blue), Ealing – Western Ave (yellow) and Brent – John Keble School (green).

Throughout the simulation, the direction of plume dispersion remains reasonably constant towards the north-west, with downwind grounding occurring a short distance from the source and reaching a maximum concentration at 08:00-09:00 UTC. The mixing effect of the rising boundary layer as it captures the plume is evident at 08:00 in comparison to 05:00, with higher concentration manifesting nearer to the source, although values remain under 32µg/m^3. By 18:00, there is assumed to be no remaining material in this layer as there is no value above 1µg/m^3.

For much of the simulation, none of the air quality observation sites are directly downwind of the plume and therefore are not continuously subject to the highest concentration levels.




1Hr 0Min Average Air Concentration
0-100 m agl
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0.2°W
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TRACER_AIR_CONCENTRATION [$\mu g m^{-3}$]
HENDON
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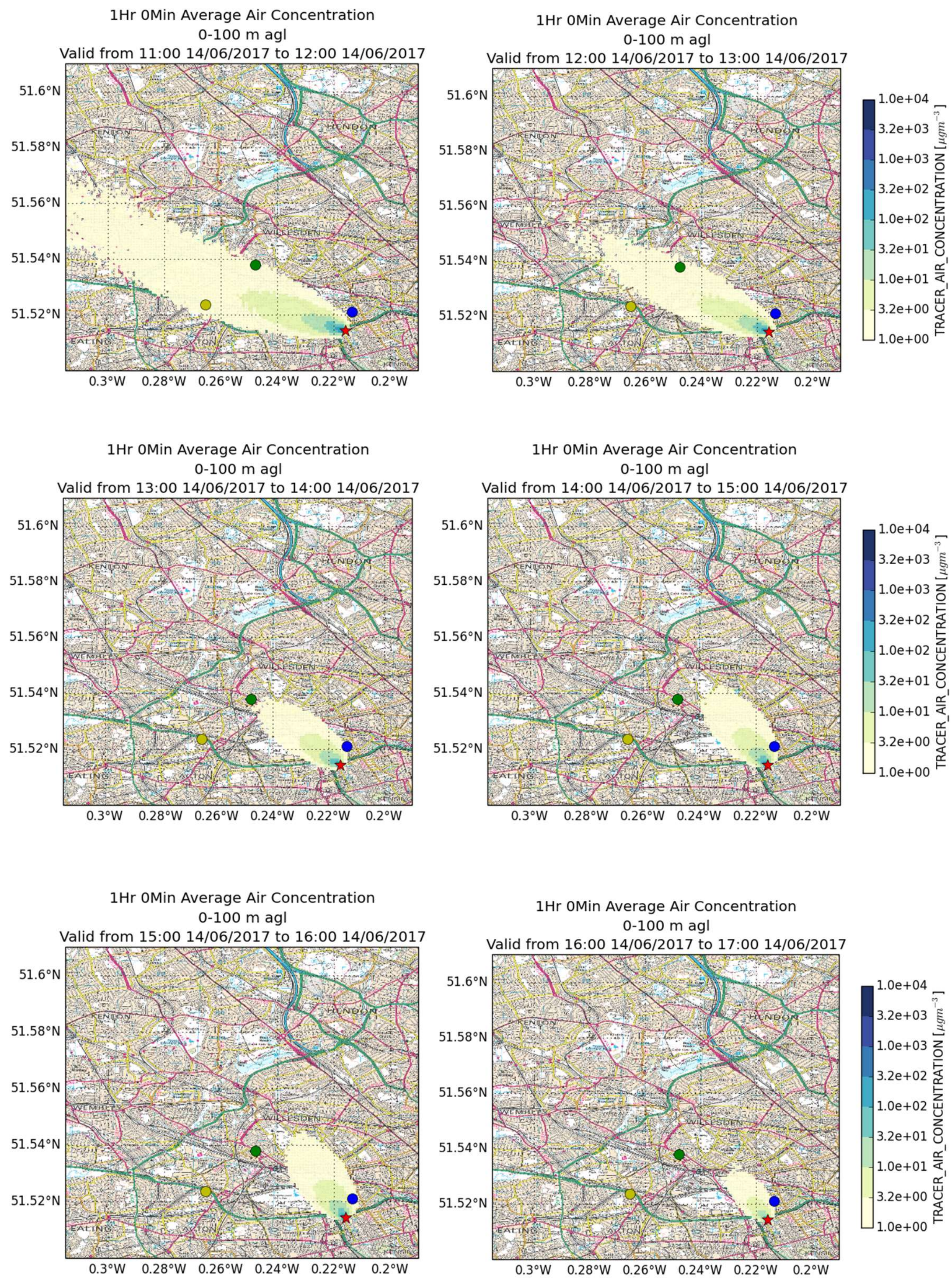
EALING


1Hr 0Min Average Air Concentration
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TRACER_AIR_CONCENTRATION [$\mu g m^{-3}$]

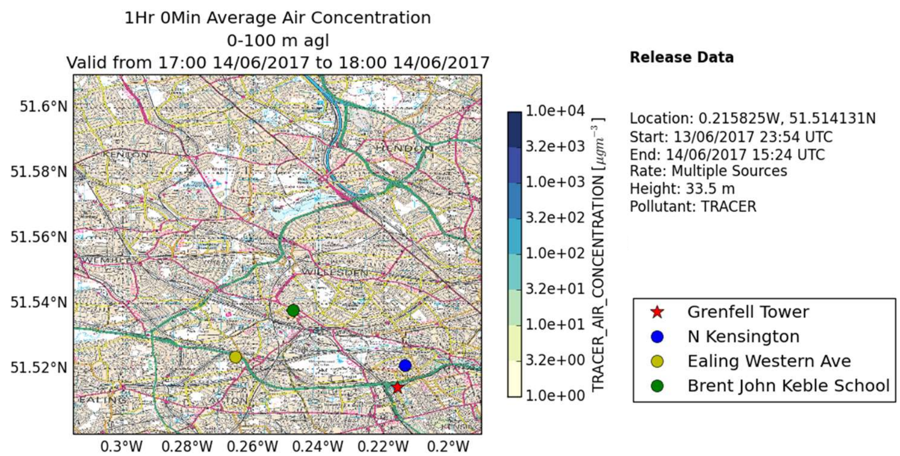

Figure 5 (17 subfigures): Hourly-averaged air concentration in 0-100m vertical layer for 01:00 to 18:00 UTC. Values below 1 µg/m^3 are masked.

Vertical distribution

The vertical distribution of mass in the domain is also investigated. Firstly, total mass at each 10m height level with time is considered in Figure 6, followed by the mass at each height level vs. longitude (i.e. representing a north-looking view of the plume) for each hour (Figure 7). Boundary layer depth information is overlaid.

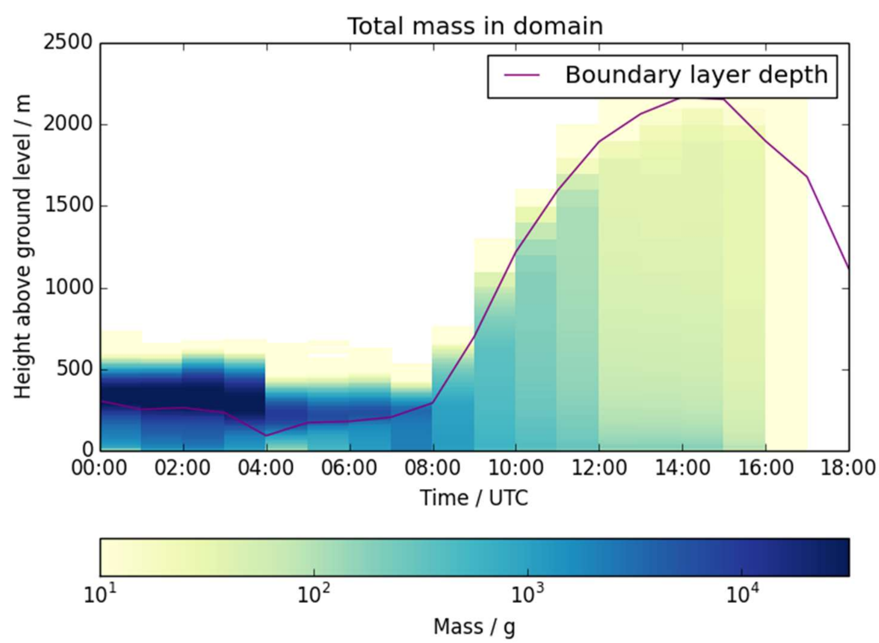

Figure 6: Total mass within 10m vertical layers during simulation, overlaid with boundary layer depth. The influence of the boundary layer on dispersion of mass is apparent. Values below 10g are masked.

Figure 6 illustrates the evolution of vertical mass distribution in the domain over the course of the simulation. It can be roughly categorised into four periods:

00:00 to 04:00 During the most intense part of the fire, the plume is sufficiently buoyant as to penetrate the boundary layer top and, although some material reaches low levels, most is maintained in the free troposphere above. Little vertical mixing is occurring here compared to within the boundary layer. Plume top height reaches approximately 500m.

04:00 to 08:00 As plume buoyancy decreases, mass accumulates at a lower height. There is a significant decrease in the mass release rate. However, as boundary layer depth increases, material at height becomes entrained and mixes down to ground level.

08:00 to 12:00 Plume buoyancy and mass release reduce further, as the boundary layer depth increases sharply. As a result, vertical mixing occurs up to much higher vertical levels and the mass near ground level reduces.

12:00 to 17:00 Much of the material has left the model domain. The plume buoyancy and mass release reduce further, eventually ceasing, with mass continuing to mix vertically within the deep boundary layer.

The breakdown of mass distribution across the longitudinal axis (north-looking view of the plume) in Figure 7 reveals further information. The rise and downwind grounding of the plume is visible in greater detail. Significant grounding begins to occur at approximately 3km longitudinal distance from the source at 02:00 UTC (4.25km distance if north-west heading), persisting until the mass release rate reduces, and occurring again as the rising boundary layer envelops the less buoyant plume at 06:00 UTC. By this time there is substantially less material in the domain. However, once the plume is captured within the boundary layer, downwind grounding occurs much closer to the source.

The plume at the source appears bent over throughout the simulation. There are changing winds with height, which introduce the east-heading component of the top of the plume from 03:00 to 05:00 UTC.

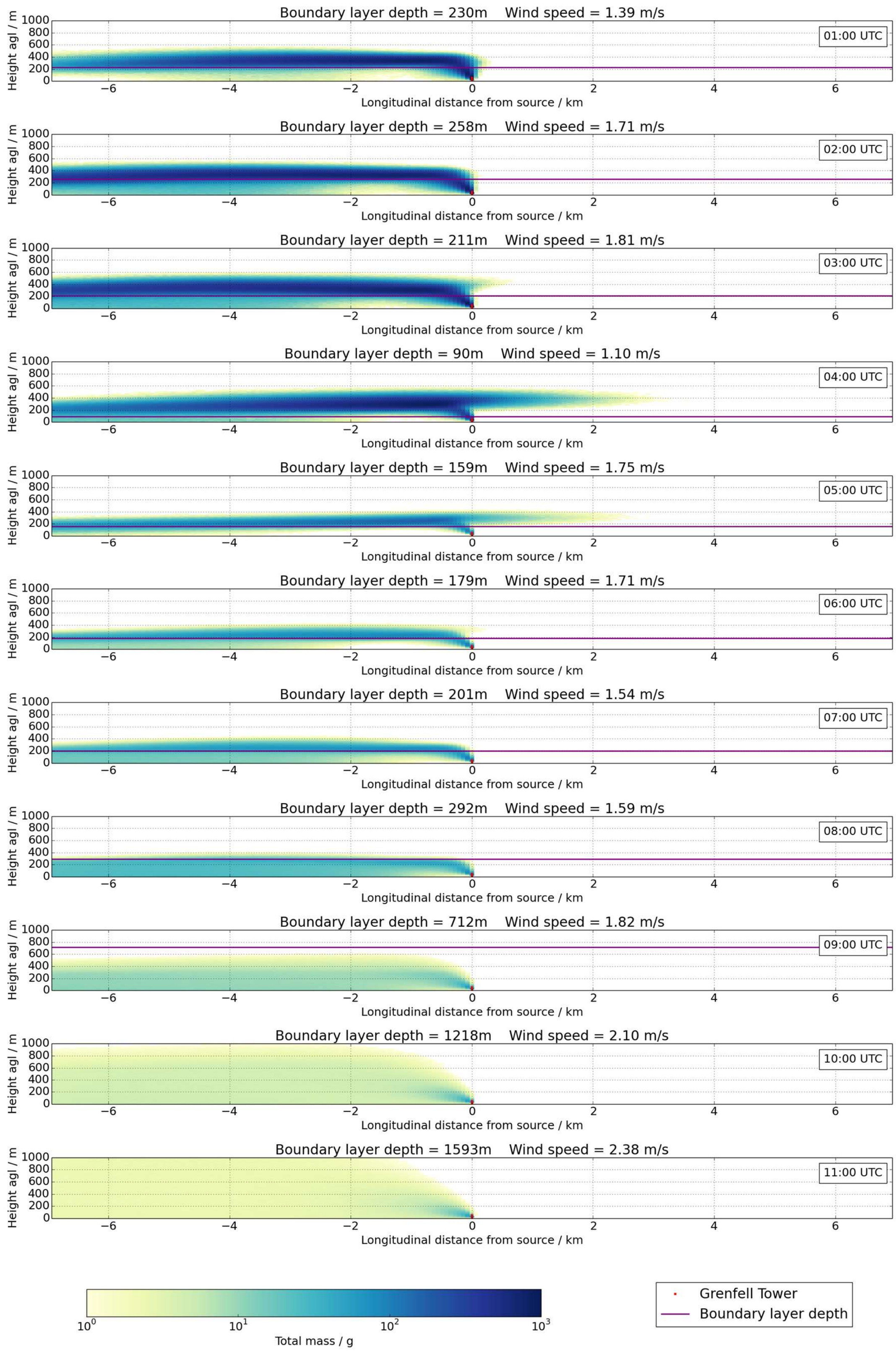

Figure 7: Total mass within each vertical layer summed across latitude (north-looking view) until 11:00 UTC.

4 Validation

Available photography and observations at nearby air quality monitoring sites were used as a means of validating the model results.

Photography

Footage captured during the incident provides some indication of the plume behaviour and dispersion with time and allows for basic qualitative validation of the results. Plume height can be judged against the tower height (67m), and plume direction can be interpreted with respect to neighbouring tower blocks with the aid of Figure 8.

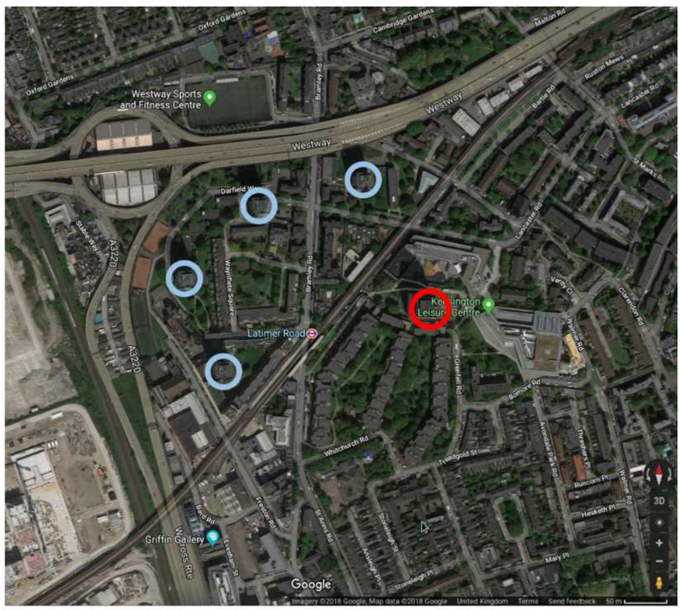

Figure 8: Location of Grenfell Tower (red) and nearby tower blocks (light blue) situated to the west and north-west of the site. Major roundabout situated to the north-west and major roads to north and west. Credit Google Maps.

A comparison of images 1 to 4 suggests there is a more massive and well mixed plume at 02:00 than at 05:00 UTC, though both plumes reach a similar height of 300-400m. This is in broad agreement to model results at these hours. Image 2 indicates that negligible winds were present near ground level during early morning, allowing the plume to rise to approximately 400m.

Images 5 to 7 show the release at a later stage. The plume appears bent over in Image 5, and Image 6 highlights the complexity of the release and light winds after sunrise. Image 7 indicates that the plume has significantly diminished by 09:00 UTC.

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. Vertical plume rises to several hundred metres, suggestive of negligible wind near ground level.
Credit: Selim Halulu

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

Image 4: Plume rising to approximately 300m and dispersing laterally in northward direction. Remaining at height, little downwind grounding at 05:15 UTC.
Credit: Selim Halulu

Images 1-4: Photography overnight and early morning, timestamped where information available.

Image 5: Plume bent over at source due to increased wind speed and reduced buoyancy.
Credit: Matt Dunham

Image 6: A changing release. Two separate plumes from different faces of the building subject to light and variable winds.
Credit: Jeremy Selwyn

Image 7: Further reduced emissions and bent over plume at 09:00 UTC.
Credit: BBC News

Images 5-7: Photography of release after main period of fire.

Photography indicates a vertical plume lift-off during very early morning, suggesting negligible wind speeds at low levels, with neutral buoyancy occurring at approximately 300-400m and material drifting in a north or north-west direction. At a later stage, the plume appears bent over, suggesting an increase in wind speeds and lower plume buoyancy. In contrast, the model results suggest a bent over plume throughout the release, likely on account of overestimated NWP wind speeds at the surface during early morning.

Image 8 provides information on downwind spread at a larger scale, from a south-east view. Figure 9 presents a west-looking view of the modelled plume for comparison, in addition to the north-looking view in Figure 7. There is broad agreement to Image 8 in terms of plume top height and downwind structure.

Image 8: plume viewed from South-East London at 06:00 UTC, suggesting a north / east heading plume reaching several kilometres. Credit: Prioryman, Wikimedia Commons.

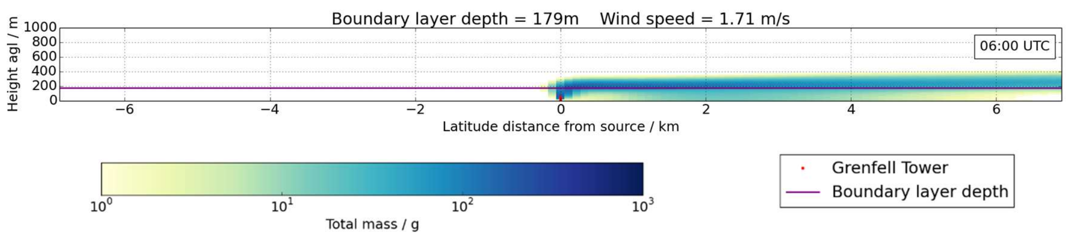

Figure 9: West-looking view of plume at 06:00 UTC.

Overall, the model performs well given the limits of the NWP, and the model results agree largely with timestamped photography. However, there are few plume observations before sunrise, which presents difficulty in verifying the plume extent during the main period of the fire.

Air quality observations

Time series of modelled air concentration at the locations of three nearby air quality sites are compared to observations of PM10 (Figure 10). Observations are hourly-averaged at 5m agl and model output is averaged in the 0-10m vertical layer. Model output only contains the contribution from the modelled plume while observations measure emissions from all sources, such as traffic and industrial activity. Therefore, model results are offset from observations by the ambient background levels.

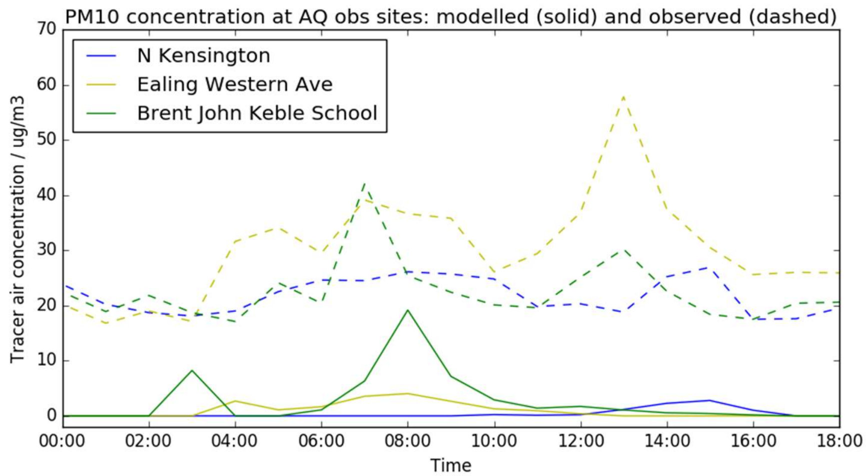

Figure 10: Timeseries of modelled air concentration (solid line) and observations (dashed line) at air three nearby quality sites. Modelled values do not account for background PM10. Time in UTC

The largest peak in modelled concentration at the three sites occurs at Brent – John Keble School at 08:00 UTC with a magnitude of 20μg/m^3. This is comparable in timing and magnitude to the observed peak above background level. However, the model does not appear to represent the larger peak observed at Ealing – Western Avenue later in the day. This discrepancy could be the result of a small error in modelled wind direction as the site appears to be on the edge of the plume, or the observed peak could be on account of contributions from other sources. There is little material which appears to reach North Kensington in both the model and observations, despite the site being closest to the source.

Whilst the results indicate that material does reach the monitoring sites, it is not of significant magnitude. In terms of the Defra Daily Air Quality Index (Figure 11), a level of PM10 pollution considered moderate or above is defined as a daily mean value of over 50μg/m^3 [9]. Given an approximate background value of 20μg/m^3 at the time of the incident, a daily averaged modelled value of 30μg/m^3 would be needed to surpass this threshold. Generally, the model suggests low values are reaching the observation sites and any elevated values are not sustained. However, there is likely to be a higher concentration of PM10 experienced directly downwind of the source.

PM10 Particles

Based on the daily mean concentration for historical data, latest 24 hour running mean for the current day.

Index	1	2	3	4	5	6	7	8	9	10
Band	Low	Low	Low	Moderate	Moderate	Moderate	High	High	High	Very High
µg/m³	0-16	17-33	34-50	51-58	59-66	67-75	76-83	84-91	92-100	101 or more

Figure 11: Defra Daily Air Quality Index for PM10.

2-week air quality observations

For additional context, air quality observations from the London Air Quality Network [10] over a 2-week period, centred on the day of the event, were evaluated (Figure 12). Though there are peaks in PM10 on 14th June (day of event), they are among background values considering the 2-week period. These observations further support the model results suggesting a minimal air quality impact.

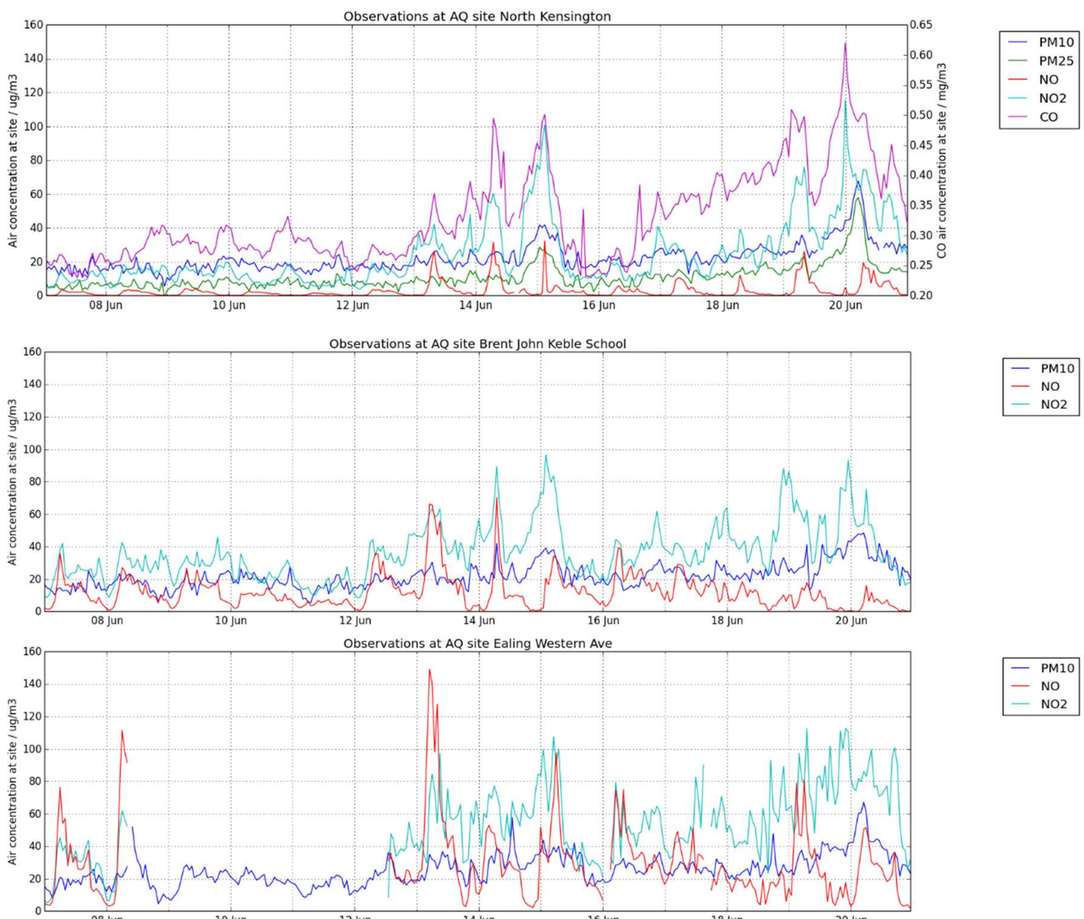

Figure 12: Observations at nearby air quality monitoring sites. PM10 in blue. Data from London Air Quality Network.

5 Sensitivity Studies

To address the uncertainties in the source term and meteorology, a series of sensitivity tests were conducted.

Single site meteorology using observed winds

A comparison of NWP wind speeds to nearby observations suggested that the model wind speeds near the ground during the most intense period of the fire were too high (Figure 3). Therefore, a simulation was conducted using single site meteorology from observations data. It was deemed that NWP wind speeds at Grenfell Tower and Kew Gardens were similar enough that the observed wind speeds at Kew Gardens were representative of those at Grenfell Tower. Hence, they were used as single site meteorology input for wind speed and direction, which is applied uniformly in the horizontal and extrapolated vertically. This also provides a means of testing the sensitivity of the plume to specific meteorology and the suitability of using single site meteorology input in place of NWP.

As the model domain is relatively small, the lack of horizontal variation in meteorology was deemed acceptable. However, in this mode NAME assumes a simple vertical profile which does not take building effects into account except via a roughness length and which may produce less accurate wind speeds at upper levels. Figure 13 and Figure 14 compare the vertical profiles of wind speed and direction for NWP at Grenfell Tower and single site meteorology from 10m wind observations at Kew Gardens between 01:00 and 06:00 UTC, overlaid with corresponding boundary layer depth information.

There is a large discrepancy between upper level wind speeds in the NWP and single site meteorology, with wind speeds significantly underrepresented by the simplified vertical profile, particularly above the boundary layer. For example, at 03:00 UTC, wind speed at 400m – a height at which much of the plume material is suspended – remains at under 1m/s in single site meteorology but reaches 6m/s in NWP. This is an expense which comes at the benefit of a ground level wind speed correction of no more than 2m/s. Wind direction also exhibits a simplified profile, constant with height above the boundary layer. This results in a discrepancy of as much as 50° at 400m height. Single site meteorology is thus deemed unsuitable for use at height, particularly above the boundary layer, and NWP is probably more reliable overall.

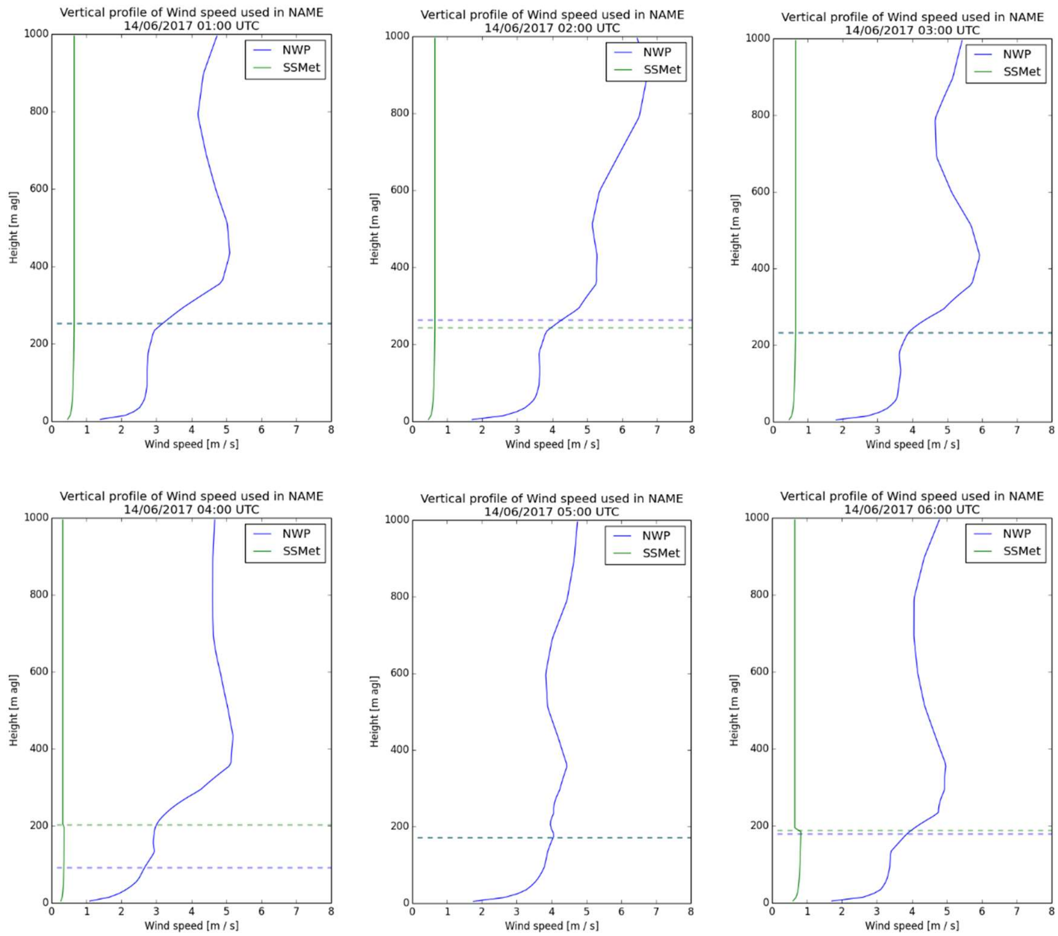

Figure 13: Vertical profiles of wind speeds from 01:00 to 06:00 UTC from NWP and single site meteorology, with boundary layer depth indicated by dashed lines.

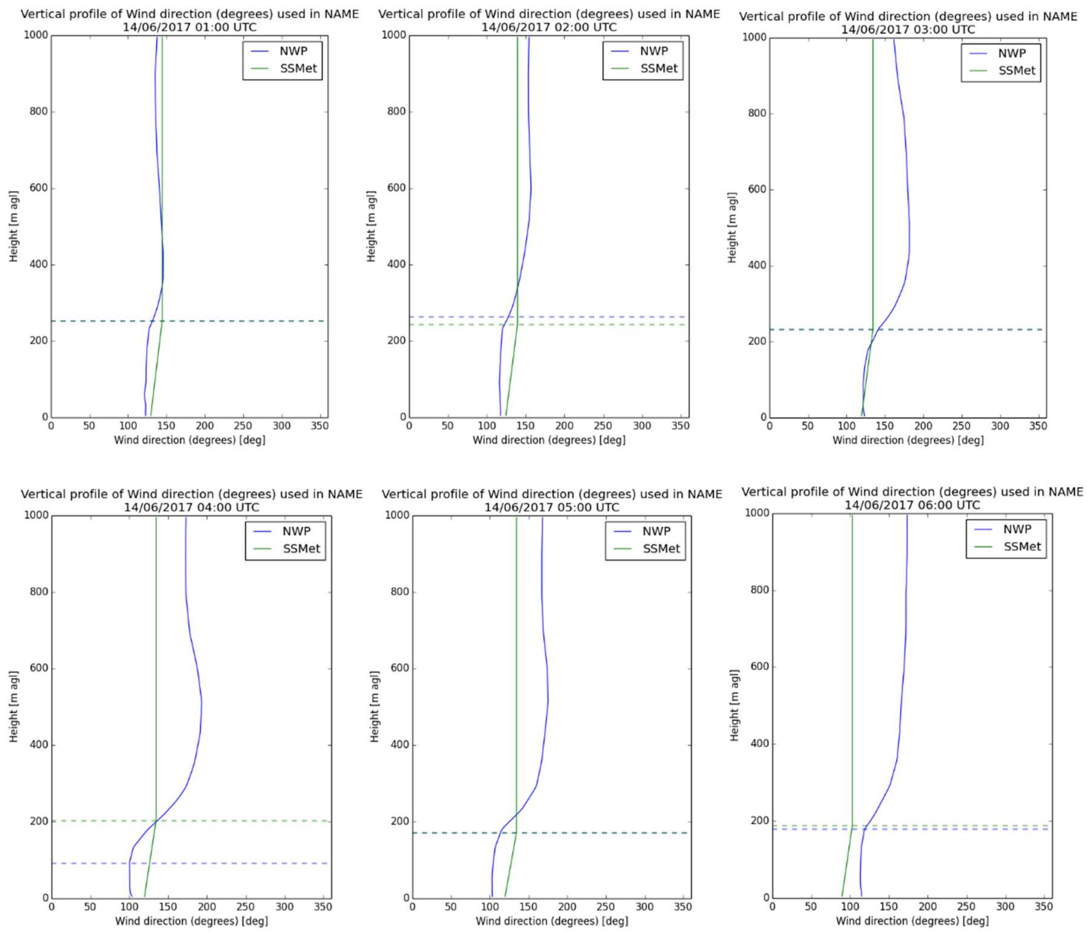

Figure 14: Hourly average wind direction 01:00-06:00 UTC NWP and single site meteorology, with boundary layer depth indicated by dashed lines.

The result of using the single site wind profiles in place of NWP are presented in Figure 15. Due to the negligible upper level winds (not exceeding 1m/s), the plume top height reaches 1000m and material is transported out of the domain at a slower rate. Much of the mass accumulates between 400m and 900m agl. Due to the underestimated winds at height, the plume dispersion appears to be less realistic than that using NWP.

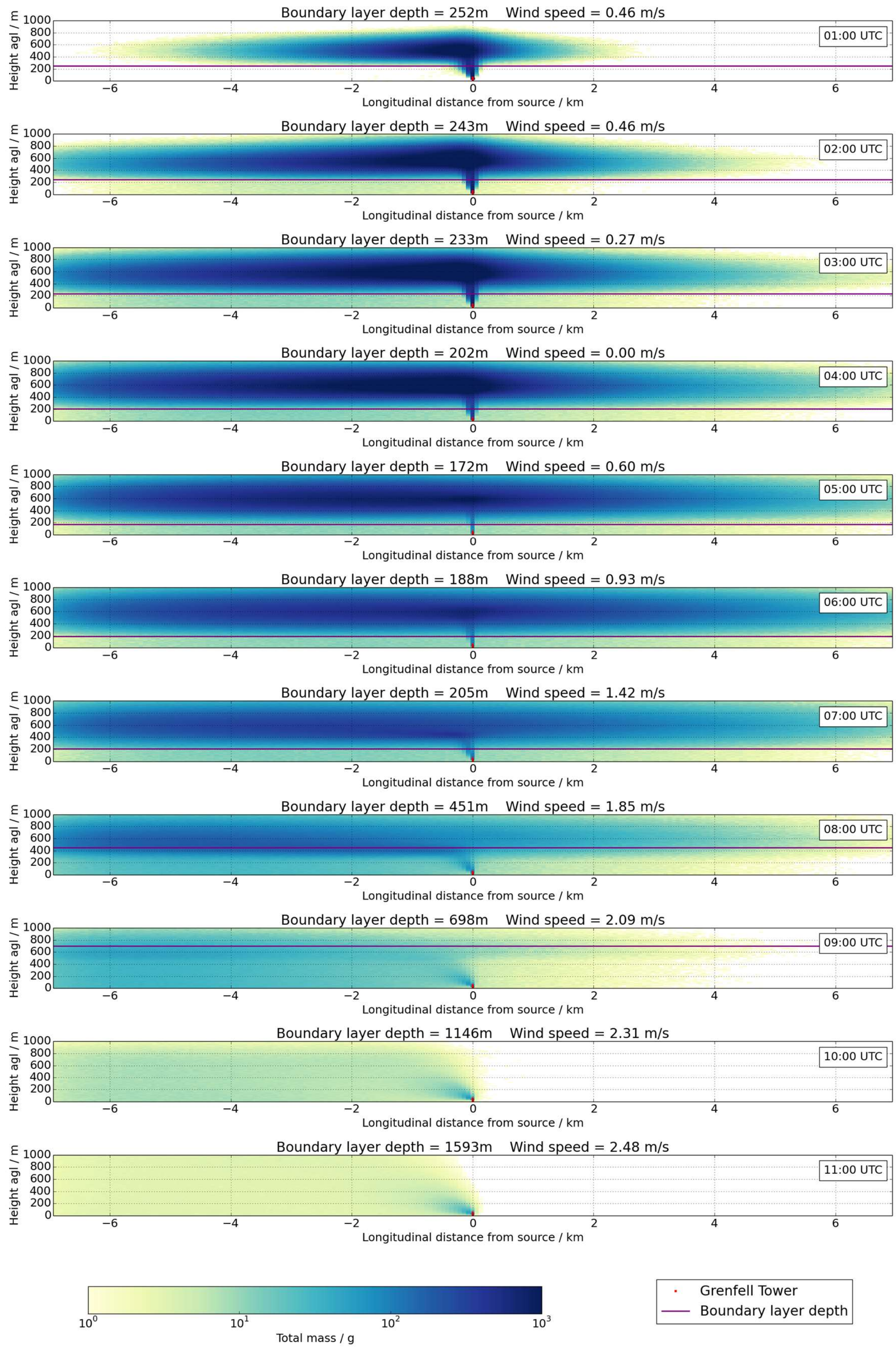

Figure 15: Total mass within each vertical layer summed across latitude (north-looking view) in simulation with single site meteorology.

Timeseries of the simulation (Figure 16) show there is little difference in ground level values at air quality sites compared to when using NWP (Figure 10). Additionally, 0-100m field plots also exhibit little difference in concentration values (not shown). This suggests that, despite overestimated wind speeds at ground level, the NWP is still able to adequately represent the surface air quality impact of the fire, hence this simulation is perhaps overall a better representation of the event than that using single site meteorology.

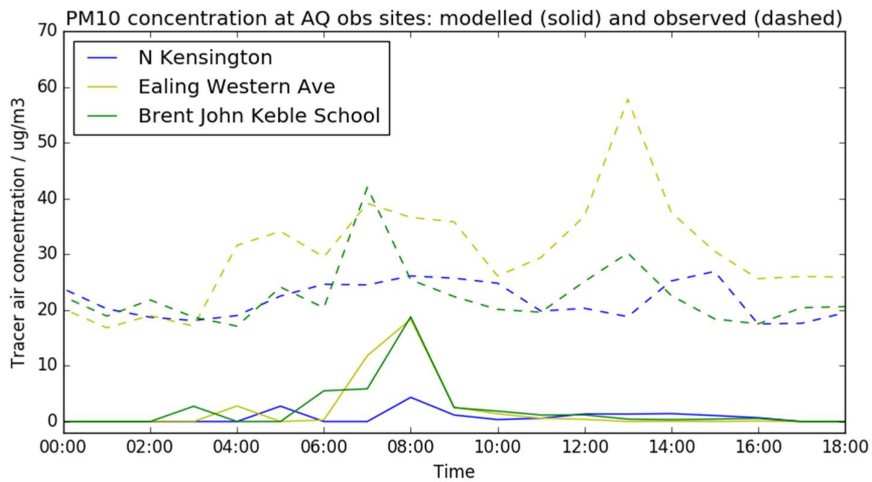

Figure 16: Modelled air concentration at air quality sites when using single site meteorology with reduced wind speeds. Time in UTC.

Plume buoyancy and momentum

The sensitivity of results to prescribed buoyancy and momentum of the plume were investigated by conducting simulations with -20% and +20% of the estimated heat release rate. This translated to a difference in flow velocity of no more than 1m/s and release temperature of no more than 10°C from the original values. Tables 3 and 4 describe the modified values and resulting heat release rates.

Table 3: Heat release rate + 20%.

Release	Start time (UTC)	End time (UTC)	Mass release rate (g/s)	Release temp. (K (C))	Flow velocity (m/s)	Heat release rate estimate (MW)
1	13/06 23:54	14/06 03:24	720	350 (77)	6.2	146
2	14/06 03:24	14/06 07:24	72	340 (67)	4.4	91
3	14/06 07:24	14/06 11:24	30	330 (57)	2.4	38
4	14/06 11:24	14/06 15:24	11	325 (52)	1.2	15

Table 4: Heat release rate - 20%.

Release	Start time (UTC)	End time (UTC)	Mass release rate (g/s)	Release temp. (K (C))	Flow velocity (m/s)	Heat release rate estimate (MW)
1	13/06 23:54	14/06 03:24	720	338 (65)	5.0	98
2	14/06 03:24	14/06 07:24	72	332 (59)	3.5	61
3	14/06 07:24	14/06 11:24	30	327 (54)	1.7	25
4	14/06 11:24	14/06 15:24	11	320 (47)	1.0	10

Results for vertical mass distribution indicate that, for a plume with buoyancy of this order, there is relatively little difference between an increase of 20% and decrease of 20% heat release rate on the vertical distribution of mass for this scenario (Figure 17).

The level of neutral buoyancy differs at most by 50m, with the less buoyant plume lower than the more buoyant plume, as expected. In the lower buoyancy simulation, there is a greater air concentration value in lower vertical levels, particularly within the boundary layer, as more material remains closer to the ground and is subject to boundary layer mixing.

The largest difference occurs at ground level with approximately twice the amount of mass present in the lower buoyancy simulation compared to that of the upper bound at 02:00-04:00 UTC and 06:00-08:00 UTC. These are periods when the plume is not completely clear of the boundary layer top and is somewhat contained by the shallow boundary layer, and therefore is a case where a small difference in the height of neutral buoyancy could lead to a significant difference in the amount of material mixing to lower levels. However, for this simulation, air concentration values at monitoring sites are increased by no more than 3µg/m^3 (figure not shown) and so they remain small. This result suggests that the uncertainty in heat release rate, which determines plume buoyancy, does not have a dominant impact on modelled air quality for this case.

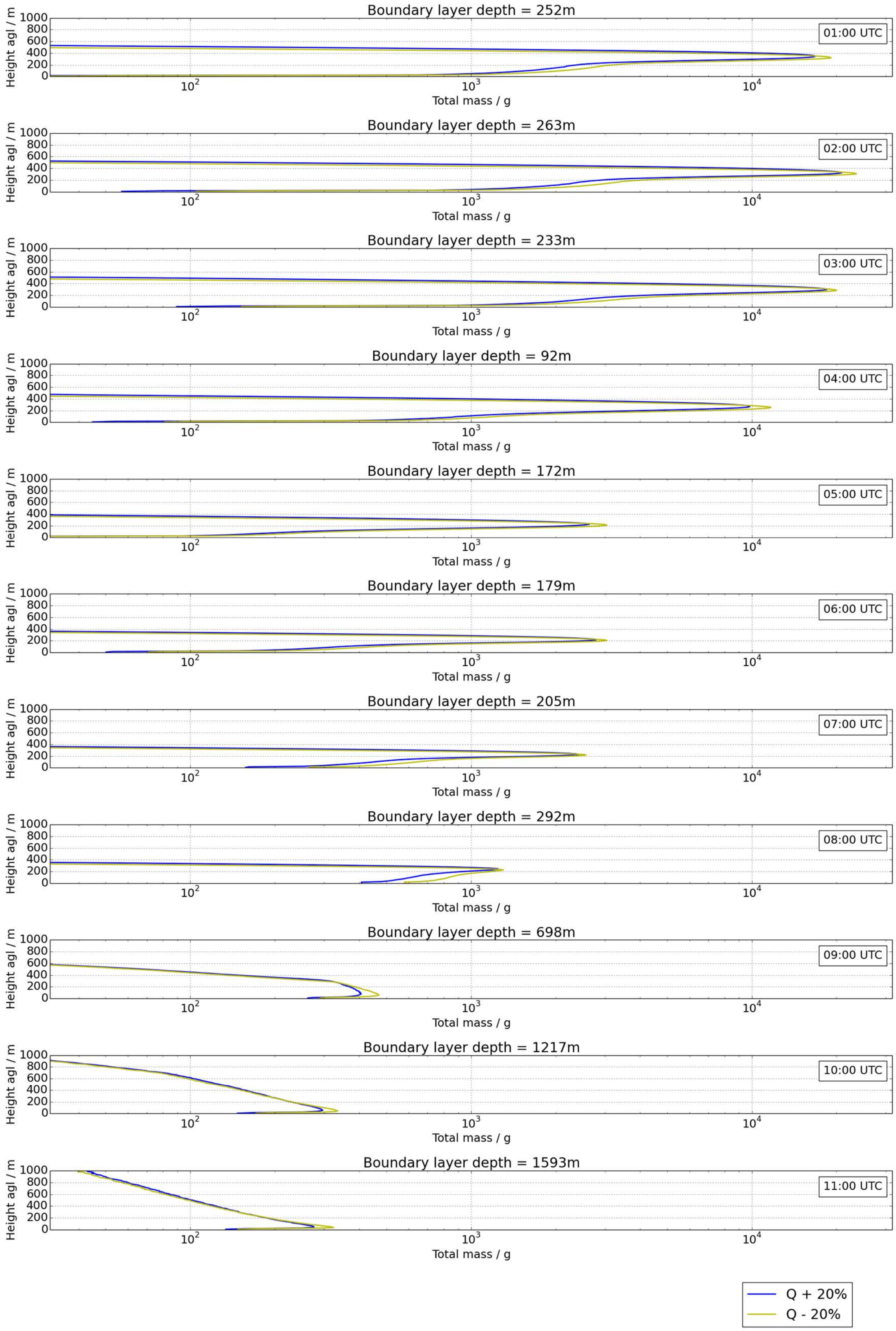

Figure 17: Total mass with height for heat release rate +/- 20%.

Mass release rate

Air concentration values (μg/m³) are directly proportional to the prescribed mass release rate (g/s) as the total released mass is divided up between the released model particles. For example, a 20% reduction in mass release rate is a 20% reduction in corresponding mass assigned to each model particle and therefore a 20% reduction in average concentration of mass in the volume of air. Therefore, air concentration results can simply be scaled linearly to mass release rate.

A difference of +/- 20% to modelled air concentration values at ground level observation sites would have negligible impact on the Defra Air Quality Index given the low values and short-lived emissions. However, the uncertainty in mass release rate would become significant for a case where average air concentration values are elevated.

6 Alternative Scenarios

Alternative case simulations were conducted to explore risks of more severe air quality impact for this incident under perturbed conditions.

Daytime meteorology

A scenario is considered where the fire is subject to daytime meteorology rather than overnight conditions, demonstrating the consequence at ground level if the fire had occurred six hours later. Figure 18 illustrates the results for the first three hours of the release. In this case, the plume of the most active period of the fire is captured under the rising boundary layer. This would have resulted in much higher concentrations at the ground.

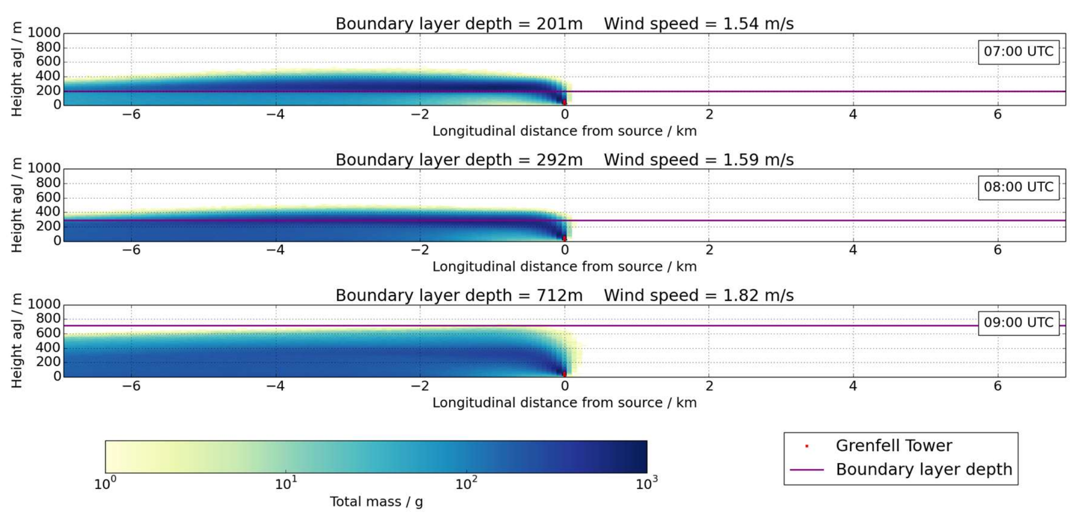

Figure 18: Mass contained under low boundary layer, mixing material down to ground level.

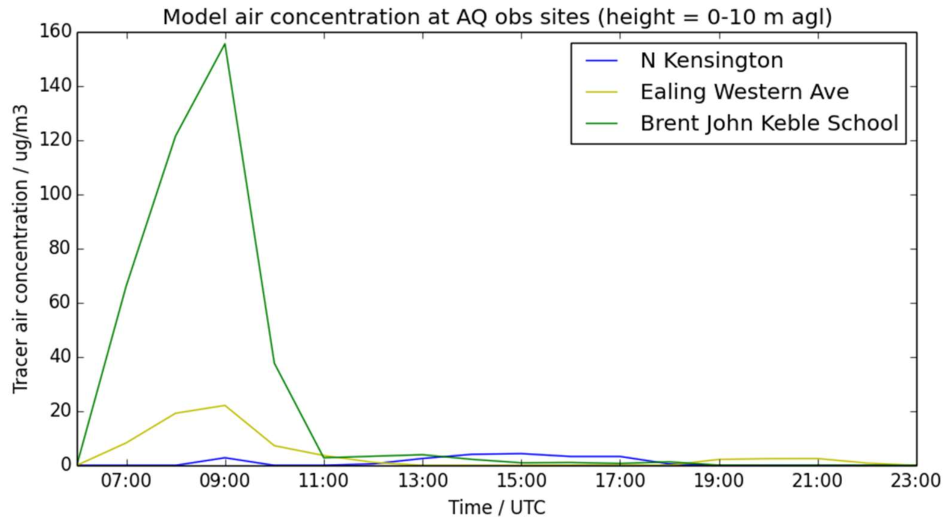

Figure 19: Modelled air concentration at air quality sites if release had begun at 05:54 UTC.

Figure 19 shows that ground level predictions at Brent – John Keble School in this scenario increase by almost an order of magnitude. Concentration peaks at 160 μg/m^3 at 09:00 and remains above 20 μg/m^3 for a 3-hour period. A rapid increase in boundary layer depth and reduction in mass release rate lead to the drop to negligible levels after this period.

This result suggests that, had the plume of the most intense period of the fire been contained under the morning boundary layer, there would have been a more significant air quality impact.

Continuous release

A scenario is considered where the release is uniform and continuous, i.e. the combustion and heat release of the most intense period of the fire is sustained throughout the day. Figure 20 shows values increase rapidly as the plume is captured under the rising boundary layer at 08:00 UTC. At Brent – John Keble School, this results in very high air concentration (~200 μg/m^3) when the boundary layer starts to rise and the plume becomes entrained. As the boundary layer continues to rise, ground level concentration across the three observation sites settles at roughly 20-50μg/m^3 above background.

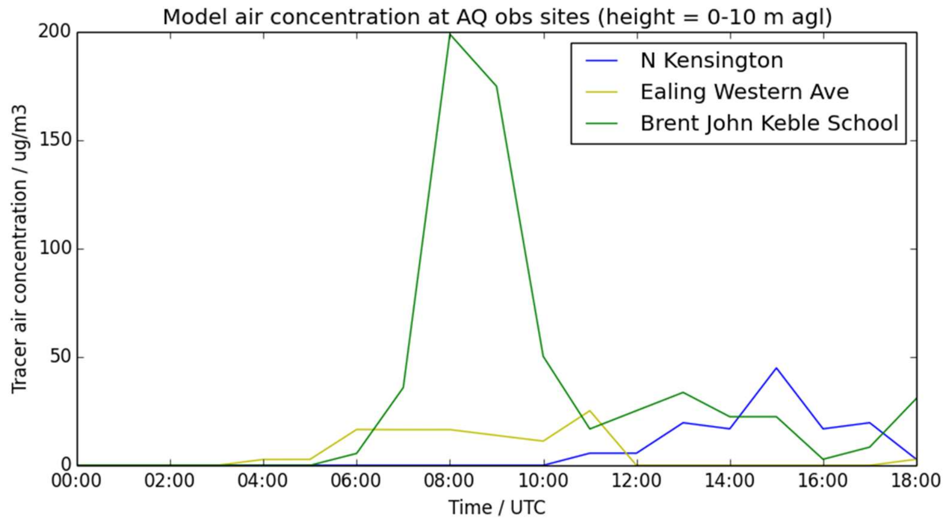

Figure 20: Air concentration values at observation sites for a sustained release on the scale of the main period of the fire.

7 Conclusions

The dispersion of the smoke plume from the Grenfell Tower fire and its impact on local air quality were modelled using NAME. 1.5km resolution NWP and a source term derived from a comprehensive emissions estimate from the Health and Safety Laboratory were used as model input.

Results suggest a negligible, short lived air quality impact, with peaks at nearby observation sites not exceeding 20µg/m^3 above background and not sustained. 0-100m vertical average concentrations (not including the source itself) do not exceed 32 µg/m^3 above background. There is overarching agreement with observations both in terms of general plume structure from photography and local air quality measurements. Modelled plume lift-off is affected somewhat by overestimated low level wind speeds in NWP, however this has negligible impact on resulting ground level air concentration values.

The impact of uncertainties in mass release rate, plume buoyancy, and meteorology were considered by conducting sensitivity tests. It was shown that a modest uncertainty in each of these variables presents negligible impact on modelled ground level air concentration and Defra Air Quality Index value for this incident. However, any uncertainty in mass release rate is directly carried through to uncertainty in air concentration and thus for greater emissions this uncertainty would become significant.

This study highlights the important role of the boundary layer in air pollution dispersion. Results are therefore highly dependent on accurate representation of the boundary layer depth in meteorological input, particularly if it is of similar depth to the plume height.

Alternative scenario simulations showed that, had the fire occurred six hours later, or if combustion levels had been sustained throughout the day, there would have been a more significant impact on air quality.

This study also highlights the process of interpreting emission estimates for a building fire in terms of NAME input values. Along with the findings on impacts of uncertainty, this could have useful implications for informing more appropriate source term estimations for the CHEMET product and further emergency response procedures such as the Met Office's role in an Air Quality Cell.

This report focuses on the acute air quality impact of the particulate smoke plume of the first 15.5 hours of the event and has therefore not considered the emission of other toxic chemical species or any persisting emissions from the site in the hours or days after the fire was extinguished. The simplified representation and uncertainty of the emissions may likely be a source of some error. Further investigations could include modelling a more complex release (varying content of plume including particle size, density, shape) and over a longer period. Neither the meteorology used here, nor NAME include building scale modelling, hence additional simulations could involve use of the Urban scheme in NAME once fully operational which may reduce NWP wind speeds at the building canopy height. Additionally, an experimental boundary layer depth measuring lidar situated in London could perhaps provide some verification of NWP estimates of the boundary layer. Finally, wind observations from the BT Tower may be useful in confirming upper level wind values.

8 Acknowledgements and references

With thanks to Graham Atkinson at the Health and Safety Laboratory for sharing comprehensive estimates of emission characteristics and advice on representation of these in NAME.

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Met Office
FitzRoy Road, Exeter
Devon EX1 3PB
United Kingdom

Tel (UK): 0870 900 0100 (Int) : +44 1392 885680
Fax (UK): 0870 900 5050 (Int) :+44 1392 885681
enquiries@metoffice.gov.uk
www.metoffice.gov.uk