Benjamin Drummond[1] & Ailish Graham[2]
[1]Met Office, UK
[2]University of Leeds, UK

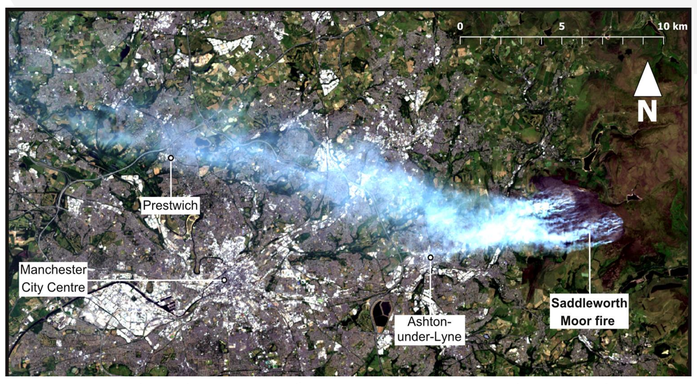
Saddleworth Moor Fire 2018 air quality impacts:

comparing Eulerian and Lagrangian methods at a range of spatial resolutions

The Saddleworth Moor and Winter Hill fires – North West England 2018

- **What**: **one of the highest impact wildfire events to occur in the UK** in recent times [*1*,*2*]
- **When**: initiated on 24th June 2018 and burned until 5th July – 12 days – peaked on 27th June
- **Where**: moorland to the east and north-west of the city of Manchester, **within the boundaries of the densely populated Greater Manchester region**
- **Why**: prolonged **period of warm, dry weather and windy conditions** made vegetation and surface susceptible to fire spread - ignition source unknown, but like human
- **Impact**: easterly winds blew the smoke plume over Manchester and other major urban areas. **Major incident declared**: homes evacuated, schools closed and residents advised to stay inside and keep windows closed

Wildfires are a **major source of atmospheric pollution**. In a global context, UK wildfires are relatively small and often rapidly extinguished. However, when they occur at the urban-rural interface they can lead to a significant deterioration in air quality [*2*]. The **risk of wildfire in the UK is expected to increase due to climate change** [*3*]. It is therefore important to better understand how wildfires impact air quality and health in the UK. Regional-scale routinely-running air quality forecast models, which tend to include wildfire pollutant emissions, often use **an Eulerian approach, where the domain is discretised onto a defined computational grid**. On the other hand, **Lagrangian particle dispersion models are commonly used in emergency response situations** to forecast the plume dispersion from a particular event. Eulerian and Lagrangian methods have their individual strengths and limitations.



USGS Landsat-8 imagery on 27th June 2018. Source: USGS/NASA Landsat

Aerial photograph of smoke plume. Source: SWNS/BBC

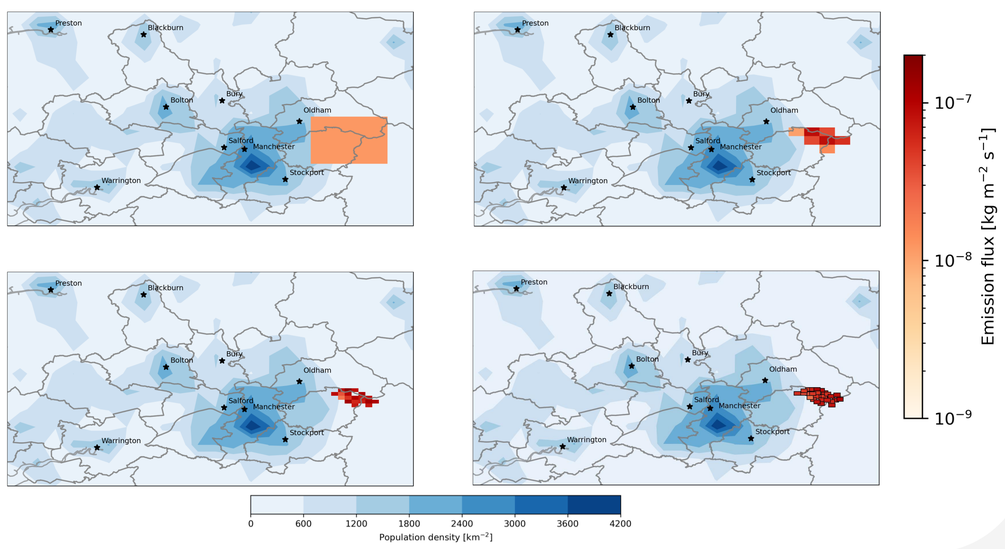
Model setup and experiments

UK Met Office atmospheric dispersion model, NAME (v8.4):

- Eulerian UK air quality research configuration with wildfire $PM_{2.5}$ emissions added
- Anthropogenic emissions from UK National Atmospheric Emissions Inventory (2018)
- Met Office UKV Unified Model NWP (~1.5 km)
- Three horizontal resolutions: 12 km, 2.2 km and 1 km
- Wildfire emissions of primary $PM_{2.5}$ added derived from the FINN (v2.5) wildfire emissions inventory [4], in two different ways:

Eulerian Simulations
Wildfire emissions added to gridded anthropogenic emissions and advected as an Eulerian field

Lagrangian Simulations
Wildfire emissions injected and transported as Lagrangian particles. 'Model resolution' is that of the output concentration grid

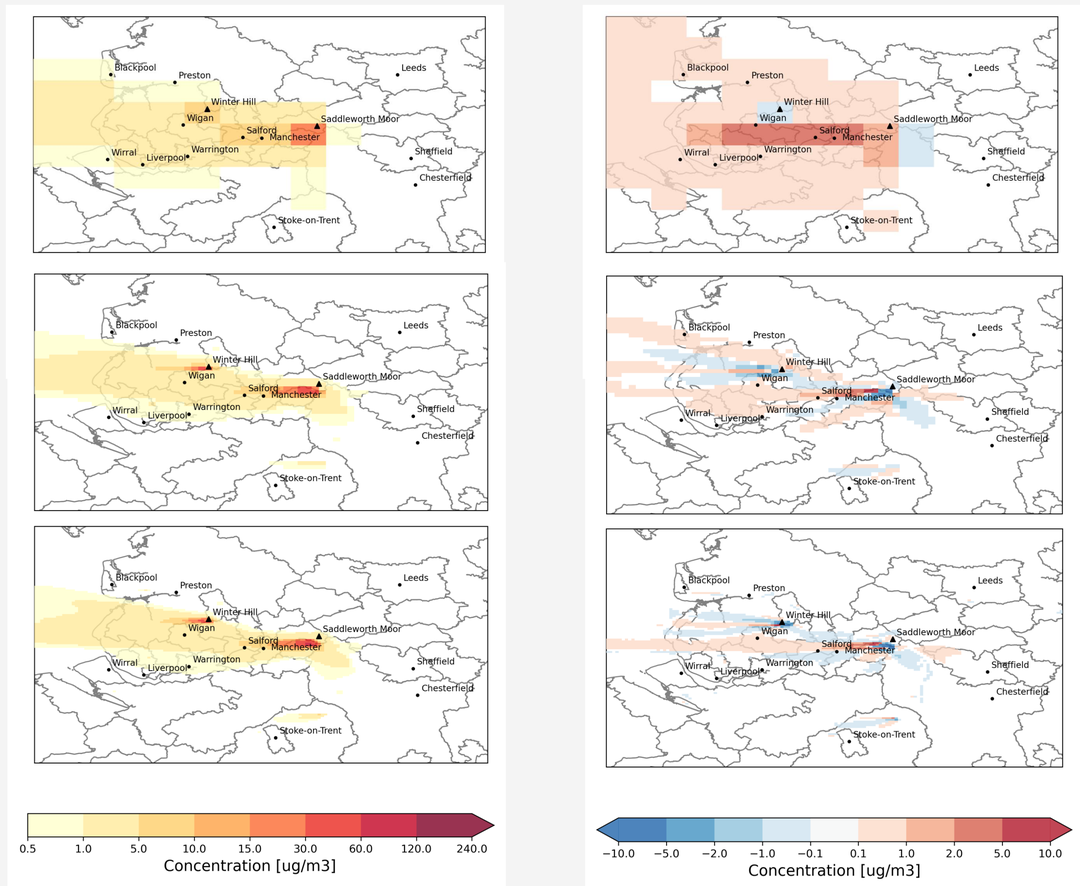


Gridded primary wildfire $PM_{2.5}$ emissions (red colour scale) for the Eulerian simulations at 12 km (top left), 2.2 km (top right), and 1 km (bottom left) horizontal resolution. Primary wildfire $PM_{2.5}$ emissions as individual 1 km^2 cuboid sources centred on FINN fire point locations as used in the Lagrangian simulations. Population density is also shown as filled blue contours. Daily-mean emissions are shown for the peak day of the fire: 27th June 2018.

Conclusions

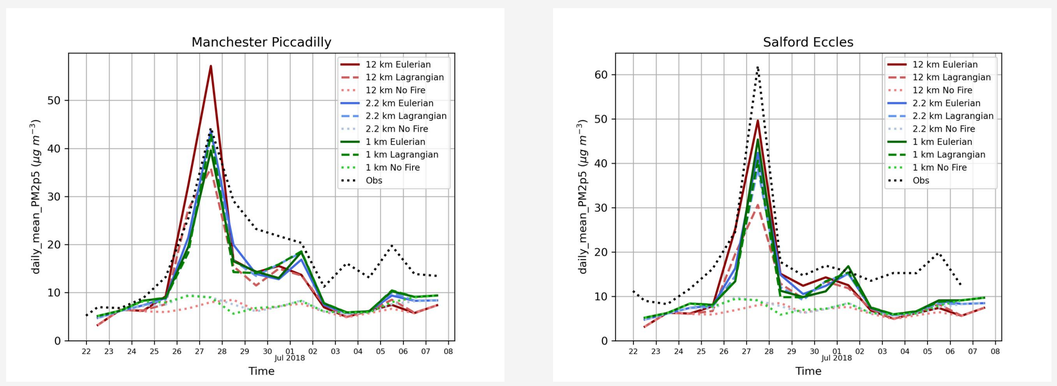
Modelled surface $PM_{2.5}$ concentrations and associated health impacts were found to be sensitive to the modelling approach (Eulerian vs Lagrangian) and the model spatial resolution for a major wildfire that occurred at the urban-rural interface. We found that finer spatial resolution leads to lower estimated health impacts from exposure to wildfire emitted $PM_{2.5}$, although a larger population was predicted to be exposed to very high (>100 μg m^{-3}) $PM_{2.5}$ concentrations. The difference between Eulerian and Lagrangian simulations were largest for the coarsest spatial resolution and became smaller as the model grid was made finer.

Impact of fires on surface $PM_{2.5}$ concentration



Left: Time-averaged wildfire $PM_{2.5}$ model concentrations for the period 22nd June – 8th July 2018 for the 12 km (top), 2.2 km (middle) and 1 km (bottom) Eulerian simulations. Right: The difference between Eulerian and Lagrangian simulations where positive (red) values indicate higher concentrations in the Eulerian simulation

- Finer spatial resolutions result in a smaller geographical area impacted by wildfire emissions, though closer to the fires predicted concentrations are higher
- At 12 km resolution the Eulerian simulation predicts generally higher concentrations than the Lagrangian simulation. The differences are more complex for finer resolutions, though generally the Eulerian simulations give 1) lower concentrations at the fire location, 2) higher concentrations in the core of the downwind plume, and 3) lower concentrations on the edge of the downwind plume



Time-series of modelled and observed daily-mean $PM_{2.5}$ concentrations at Manchester Piccadilly (left) and Salford Eccles (right) urban-background air quality monitoring sites. These figures show total predicted $PM_{2.5}$, i.e. wildfire + background (anthropogenic)

Health impact assessment

- We repeated the health impact assessment presented in *[1]* using a short-term exposure response function to calculate the number of deaths brought forward from fires ($PM_{2.5\ Fires}$ - $PM_{2.5\ No\ Fires}$)
- The **health impact was found to depend on model spatial resolution**, with a finer spatial resolution leading to fewer estimated deaths brought forward and a smaller population-weighted wildfire PM2.5 concentration
- Finer spatial resolution models predict **considerably higher maximum concentrations**
- The Lagrangian approach was found to be less sensitive to spatial resolution than Eulerian

	12 km	2.2 km	1 km
	Health Impact Assessment: number of deaths brought forward due to wildfire $PM_{2.5}$ exposure		
Eulerian	8.1	5.6	5.2
Lagrangian	5.6	5.2	5.0
	Population weighted mean wildfire $PM_{2.5}$ concentration (μg m^{-3})		
Eulerian	1.44	1.03	0.93
Lagrangian	1.01	0.95	0.90
	Population exposed to maximum hourly-mean concentration > 100 μg m^{-3} (x10^6)		
Eulerian	0.39	0.82	1.38
Lagrangian	0.24	1.05	1.07

A table showing various health impact and exposure related metrics

Met Office FitzRoy Road, Exeter, Devon, EX1 3PB United Kingdom
Tel: +44 1392 885680 Fax: +44 1392 885681
Email: benjamin.drummond@metoffice.gov.uk

Acknowledgements

The authors thank Richard Pope and members of ADAQ for useful discussion throughout this project. This work was supported by a Met Office Academic Partnership (MOAP) Collaboration Fund travel grant.

References

[*1*] A M Graham et al 2020 Environ. Res. Lett. 15 074018
[*2*] A M Graham et al 2020 Environ. Res. Commun. 2 031001
[*3*] N W Arnell et al 2021 Environ. Res. Commun. 3 095005
[4] C Wiedinmyer et al 2023 Geosci. Model Dev. 16 3873–3891