

# Analysis of the Short-Duration Urban Dust Storm in Bratislava on 23 March 2024

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## OVERVIEW

**Event Overview:** a short but intense particulate matter (PM) episode occurred in Bratislava on 23 March 2024

**Meteorological Triggers:** the event followed a prolonged dry period and triggered by a fast-moving cold front

**Threshold Response:** peak PM<sub>10</sub> and PM<sub>2.5</sub> concentrations recorded before maximum wind speeds

**Localized Impact:** the concentration spike primarily confined to central urban monitoring stations peripheral sites less affected

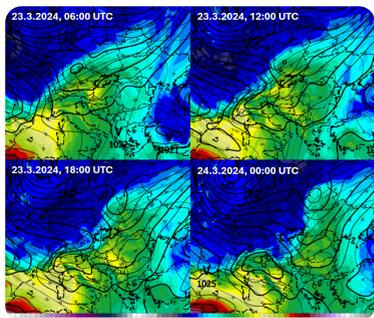
**Source Identification:** based on upwind land cover (urban/forested) and lack of agricultural sources, the episode was attributed to local wind-driven resuspension rather than regional transport

**CFD Insights:** while initial resuspension bursts last only seconds, subsequent dispersion through street canyons sustains elevated levels for tens of minutes

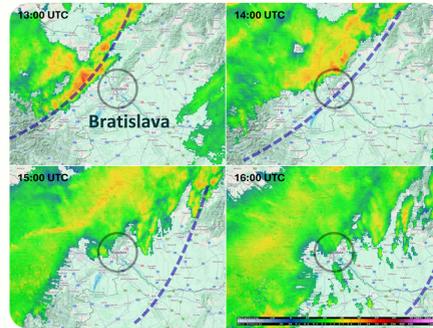
**Data Interpretation:** this "concentration tail" explains how brief physical events result in the high hourly averages recorded by standard monitoring networks.



Dust veils rising above the city at 14:09 UTC on 23 March 2024. Inset map (left) shows the observer's location and field of view. Photo: M. Šinger.

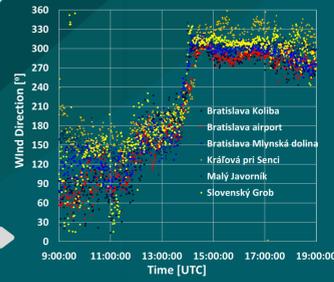


**Cold front passage across Central Europe**  
Mean Sea Level Pressure (hPa, black solid contours).  
500 hPa geopotential height (gpm, dotted contours).  
850 hPa temperature (°C, colour scale).  
ECMWF analyses.

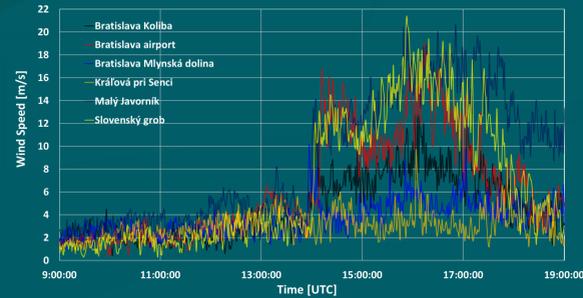


**Radar Reflectivity CAPPI 2 km Composite, 23 March 2024**

The low-level frontal boundary decoupled from the mid-level precipitation area, allowing for strong winds to occur before any rain.



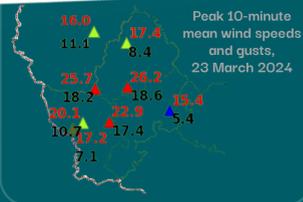
1-min wind evolution on 23 March 2024



## SYNOPTIC & MESOSCALE PROCESSES

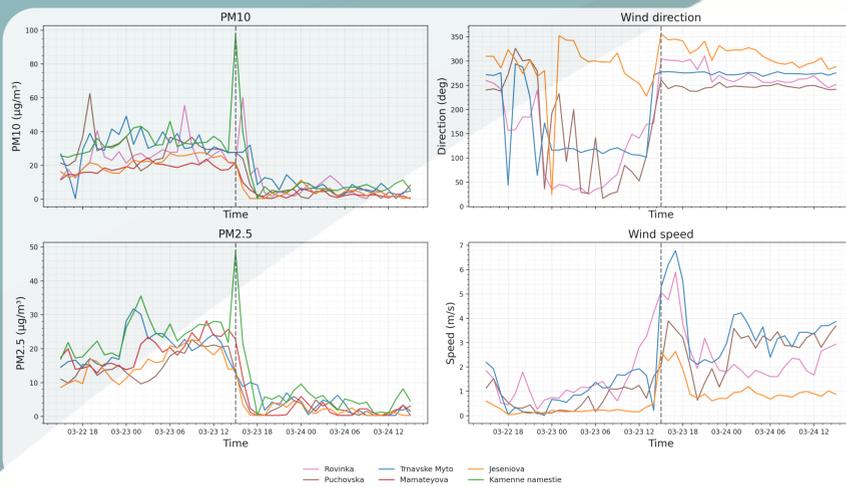
- Synoptic Configuration:** A cold front associated with a deepening shallow low over Central Europe moved eastward, significantly intensifying the pressure gradient.
- Orographic Forcing:** The Alpine barrier caused flow splitting, forcing cold air to accelerate into Slovakia.
- Pressure Dynamics:** Low-level cold air advection and orographic blocking triggered a localized pressure rise => increasing frontal tilt => decoupling low-level front from precipitation area.
- Local Acceleration:** Wind speeds further amplified by downslope winds over the Malé Karpaty Mountains Slovenský Grob and Bratislava airport stations.
- 10-minute NW-W mean wind speeds reached **18.6 m/s** with gusts up to **26.2 m/s**

## METEOANALYSIS



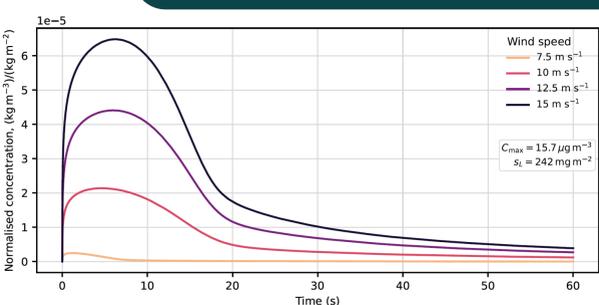
## AIR QUALITY IMPACT

### AIR QUALITY DATA



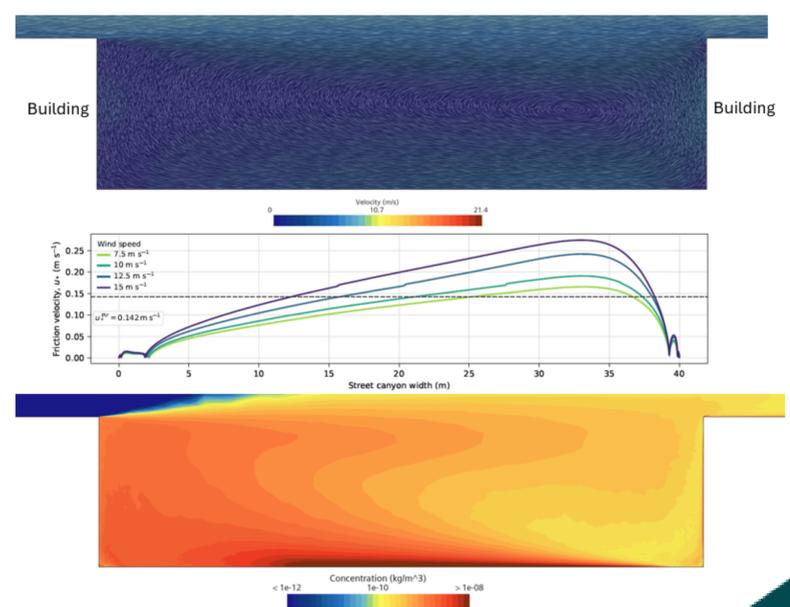
On 23 March 2024, a short but intense PM<sub>10</sub> and PM<sub>2.5</sub> peak occurred in Bratislava after a prolonged dry period during a cold-front passage. The peak appeared before maximum wind speed and was confined to the city centre, indicating a threshold-driven urban resuspension event rather than regional transport. A retrospective analysis (2009–2024) identified several similar events, showing that such episodes recur episodically.

## TRANSIENT SIMULATION



Unsteady simulations indicate that concentrations rise within seconds, peaking after ~6–8 s. Instantaneous values can reach several hundred  $\mu\text{g}\cdot\text{m}^{-3}$ , followed by a low-intensity tail sustained by inter-canyon transport. Hourly averages therefore underestimate true peak exposure.

## CFD MODEL



CFD simulations show airflow between buildings forming street-canyon vortices with localized wall shear stress maxima. Where the friction velocity exceeds the threshold, particles are detached from the surface. Resuspension is therefore spatially limited and directly controlled by near-wall flow. The resulting concentration field is strongly heterogeneous.

More info about case



## Literature

Linda, J., Hasečić, A., Pospíšil, J., Kudela, L., & Brzezina, J. (2025). Impact of wind-induced resuspension on urban air quality: a CFD study with air quality data comparison. *npj Climate and Atmospheric Science*, 8(1). doi.org/10.1038/s41612-025-00969-2.

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