

*Supplement of*

## **Measurement Report: Evolving Sources and Composition of Urban Submicron Aerosols in Dublin: Impacts of Emission Reductions and Transboundary Transport**

Lu Lei<sup>1\*</sup>, Wei Xu<sup>2</sup>, Chunshui Lin<sup>1,3</sup>, Kirsten N. Fossum<sup>1</sup>, Darius Ceburnis<sup>1</sup>, John Gallagher<sup>4</sup>, Colin O'Dowd<sup>1</sup> and Jurgita Ovadnevaite<sup>1\*</sup>

<sup>1</sup>School of Natural Sciences, Physics, Ryan Institute's Centre for Climate & Air Pollution Studies, University of Galway, Galway, H91 CF50, Ireland.

<sup>2</sup>State Key Laboratory of Advanced Environmental Technology, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen, 361021, China.

<sup>3</sup>State Key Laboratory of Loess and Quaternary Geology and Key Laboratory of Aerosol Chemistry and Physics, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, 710061, China.

<sup>4</sup>Department of Civil, Structural & Environmental Engineering, School of Engineering, Trinity College Dublin, the University of Dublin, Dublin, Ireland

*Correspondence to:* Lu Lei ([lu.lei@universityofgalway.ie](mailto:lu.lei@universityofgalway.ie)) and Jurgita Ovadnevaite ([jurgita.ovadnevaite@universityofgalway.ie](mailto:jurgita.ovadnevaite@universityofgalway.ie))

**Table S1. Mass ratios (eBC/OA) and correlation coefficients ( $r^2$ ) between eBC and OA for each year when eBC data was available from 2016 to 2023.**

Year	eBC/OA	$r^2$
2016-2017	0.31	0.76
2018	-	-
2019	-	-
2020	-	-
2021	0.18	0.88
2022	0.22	0.83
2023	0.26	0.86

**Table S2. Mann-Kendall test results for gaseous pollutants from 2016 to 2023, along with linear regression slopes and the 95% confidence intervals based on annual average mass concentrations. The upward arrows denote increasing trends, downward arrows denote decreasing trends, and the absence of arrows indicates non-significant trends ( $p > 0.05$ ).**

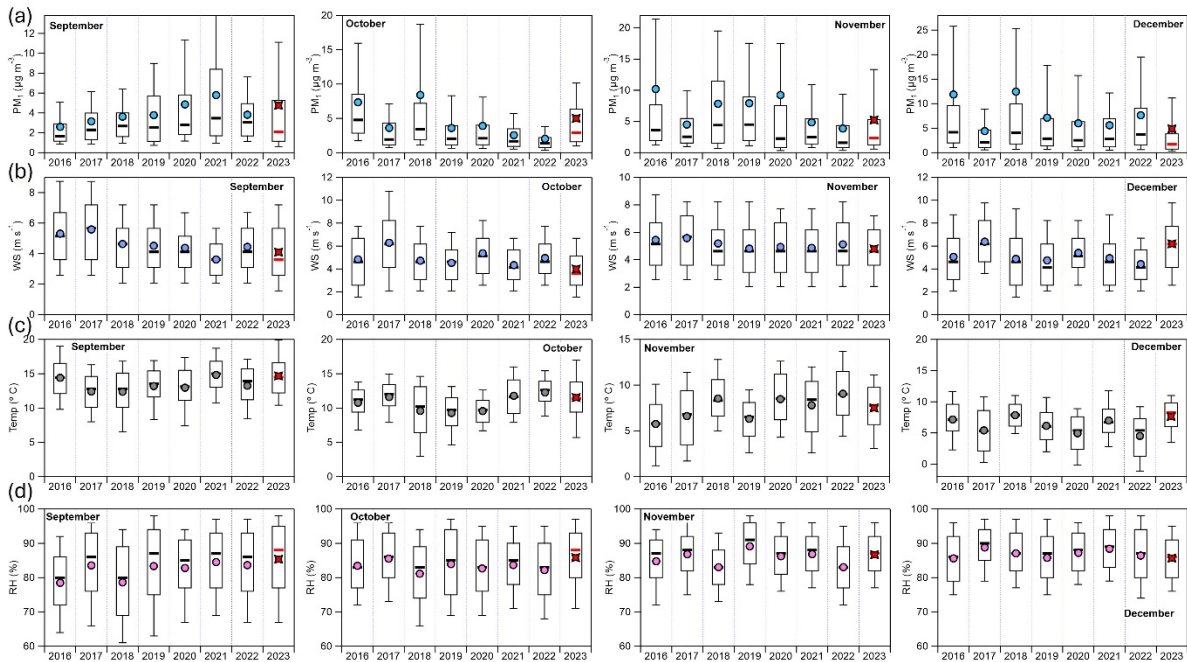
Species	P-value	Slope (95% CI) ( $\mu\text{g m}^{-3} \text{ year}^{-1}$ )
SO <sub>2</sub>	<0.05	0.05 (-0.30 – 0.40)↑
NO <sub>2</sub>	<0.05	-1.16 (-2.80 – 0.49)↓
O <sub>3</sub>	<0.05	2.21 (-0.11 – 4.53)↑

**Table S3. Mann-Kendall test results for gaseous pollutants from 2016 to 2023, along with linear regression slopes and the 95% confidence intervals based on annual average mass concentrations under low ( $\text{PM}_{10} < 15 \mu\text{g m}^{-3}$ ), moderate ( $15 \leq \text{PM}_{10} < 50 \mu\text{g m}^{-3}$ ) and high pollution ( $\text{PM}_{10} \geq 50 \mu\text{g m}^{-3}$ ) conditions. The upward arrows denote increasing trends, downward arrows denote decreasing trends, and the absence of arrows indicates non-significant trends ( $p > 0.05$ ).**

Species	P-value (Low)	Slope (95% CI) ( $\mu\text{g m}^{-3} \text{ year}^{-1}$ )	P-value (Moderate)	Slope (95% CI) ( $\mu\text{g m}^{-3} \text{ year}^{-1}$ )	P-value (High)	Slope (95% CI) ( $\mu\text{g m}^{-3} \text{ year}^{-1}$ )
SO <sub>2</sub>	<0.05	0.09 (-0.27 – 0.45)↑	<0.05	-0.01 (-0.36 – 0.34)↓	<0.05	-0.44 (-1.74 – 0.88)↓
NO <sub>2</sub>	<0.05	-0.90 (-2.60 – 0.79)↓	<0.05	-1.14 (-3.68 – 1.41)↓	<0.05	-2.30 (-5.23 – 0.70)↓
O <sub>3</sub>	<0.05	1.97 (-0.41 – 4.35)↑	<0.05	1.13 (-4.34 – 6.60)↑	<0.05	0.84 (-0.80 – 2.49)↑



**Figure S1.** Locations of the original UCD site, the new TCBG site, the EPA Rathmines monitoring station, and Dublin Airport, where meteorological parameters were recorded. Map data © 2025 Google.



**Figure S2.** Box plots comparing total PM<sub>1</sub> mass concentrations from September to December between the original UCD site (2016-2022) and the relocated TCBG site (2023). Corresponding box plots of meteorological parameters, including (b) wind speed (WS), (c) ambient temperature (Temp), and (d) relative humidity (RH), are also shown to assess interannual variability and support the comparability of long-term data across the two sites. The mean (circle), median (horizontal line), 25<sup>th</sup>-75<sup>th</sup> percentiles (box), and 10<sup>th</sup>-90<sup>th</sup> percentiles (whiskers) are shown. Note that meteorological data for both sites originate from Dublin Airport, thus, the box plots illustrate interannual meteorological variability rather than differences between the two measurement locations. The slightly higher PM<sub>1</sub> concentration at the new TCBG site may be explained by the relatively low wind speeds in October 2023 compared with previous years.

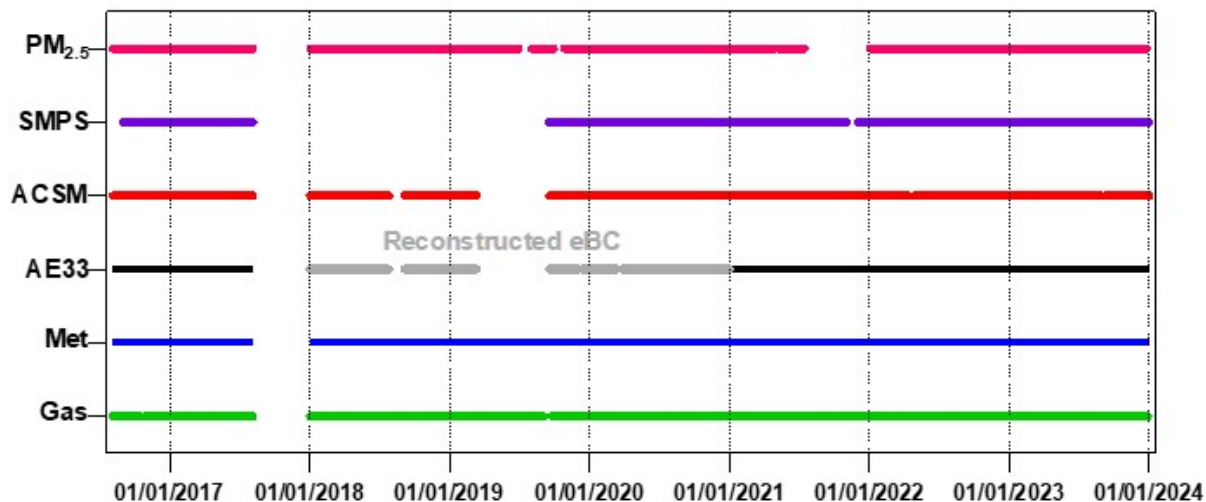


Figure S3. Hourly data coverage for  $PM_{2.5}$  concentrations and measurements from SMPS, ACSM (for  $PM_1$  chemical species), AE33 (for eBC), as well as meteorological parameters and trace gases, from 2016 to 2023 in Dublin.

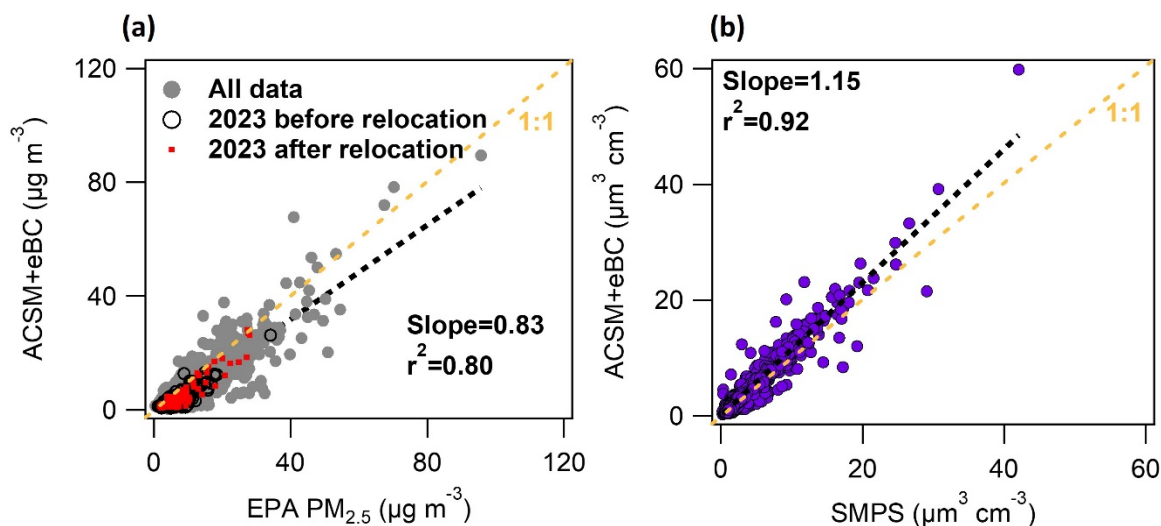


Figure S4. Scatter plots comparing multi-year  $PM_1$  measurements (Q-ACSM + AE33, i.e., NR- $PM_1$  + eBC) in Dublin from 2016 to 2023 with (a)  $PM_{2.5}$  concentrations from the Rathmines monitoring station and (b) particle volume concentrations from the collocated SMPS system. In panel (a), black open circles denote data from January to August 2023 (before site relocation), and red dots represent data from September to December 2023 (after relocation). The  $PM_1/PM_{2.5}$  ratios show no systematic change across the two periods, indicating that the site relocation did not affect the consistency of the measurements.

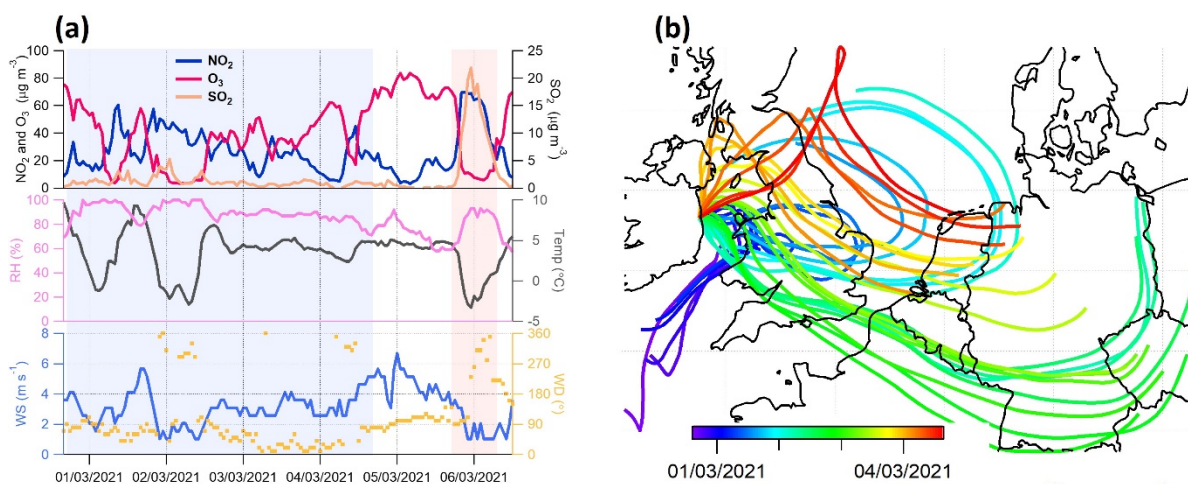


Figure S5. (a) Time series of meteorological parameters, including wind speed (WS), wind direction (WD), ambient temperature, relative humidity (RH), and gaseous pollutants ( $\text{NO}_2$ ,  $\text{SO}_2$ , and  $\text{O}_3$ ), during two representative pollution episodes dominated by transboundary transport (left, light blue shading) and local emissions (right, light pink shading). (b) 72-hour backward air mass trajectories during the transboundary transport episode, illustrating the regional origin of the polluted air masses.

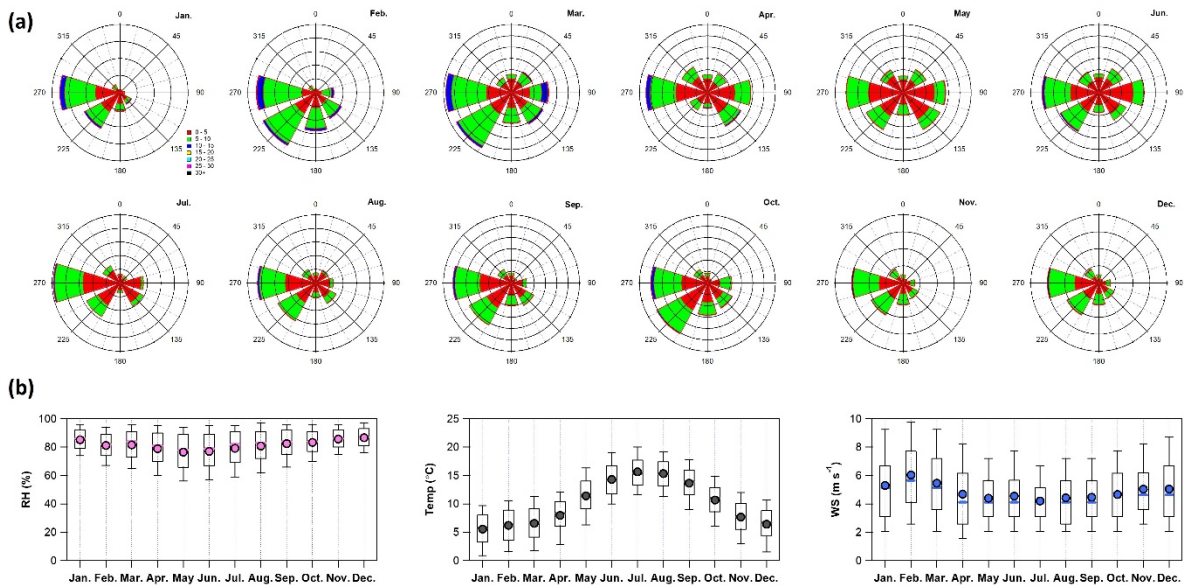


Figure S6. (a) Monthly average wind rose plots from January to December, and (b) box plots of monthly relative humidity (RH), ambient temperature, and wind speed (WS) based on data from 2016 to 2023 data in Dublin.

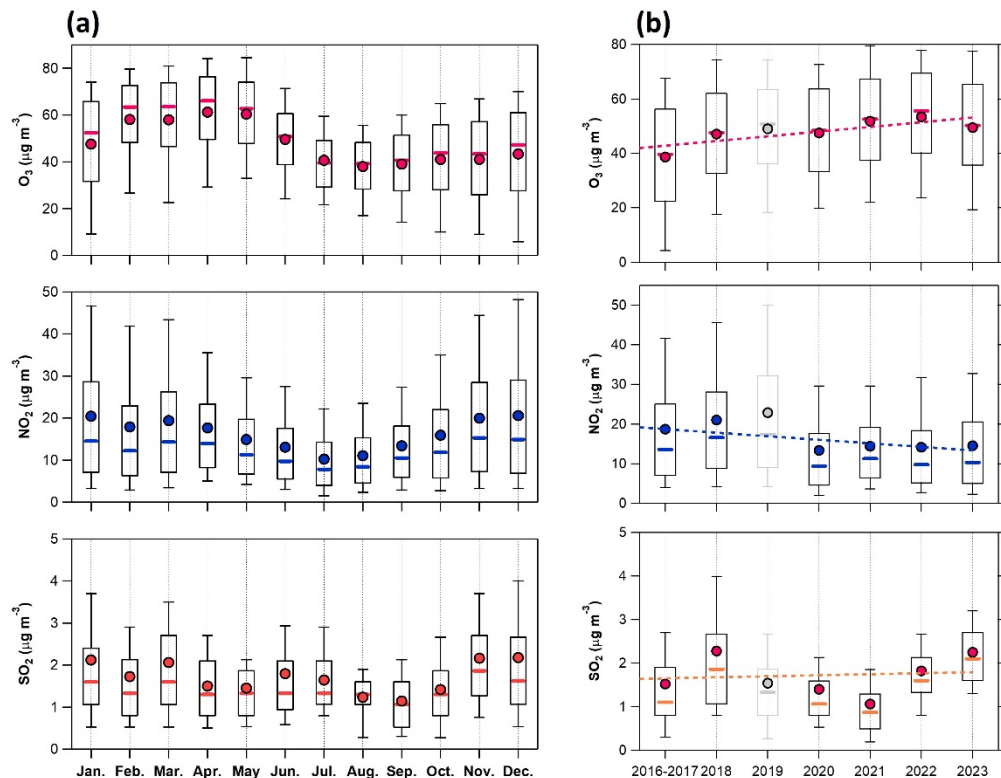


Figure S7. Box plots of (a) monthly mean and (b) annual mean concentrations of gaseous pollutants ( $\text{O}_3$ ,  $\text{NO}_2$ , and  $\text{SO}_2$ ) in Dublin from 2016 to 2023. The mean (circle), median (horizontal line), 25<sup>th</sup>-75<sup>th</sup> percentiles (box), and 10<sup>th</sup>-90<sup>th</sup> percentiles (whiskers) are shown. Please note that 2019 is excluded from long-term trend analysis and is shown in grey due to biased data coverage.

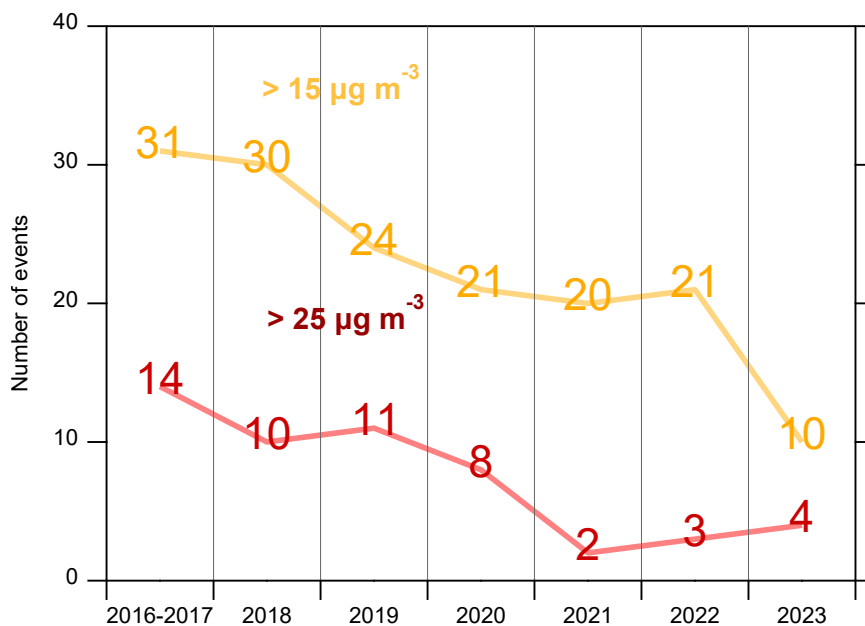


Figure S8. Long-term trends in the number of polluted days (daily  $\text{PM}_{10} > 15 \mu\text{g m}^{-3}$ ) in Dublin from 2016 to 2023. The orange line marks the current WHO daily guideline ( $15 \mu\text{g m}^{-3}$ ), while the red line indicates the previous guideline ( $25 \mu\text{g m}^{-3}$ ).

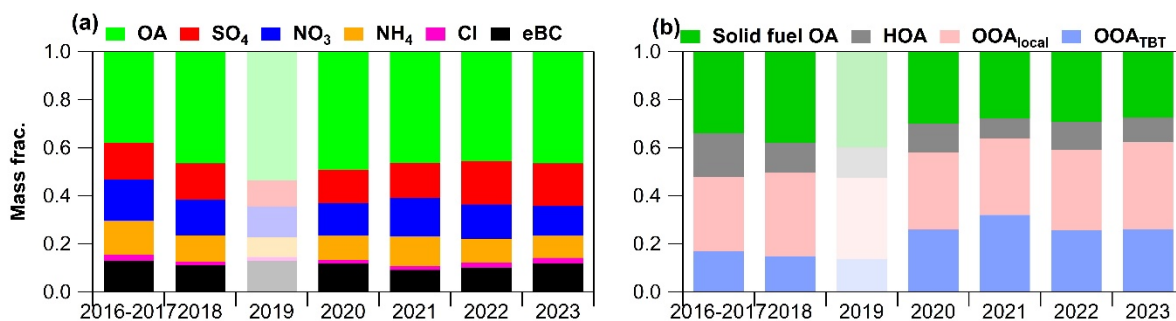


Figure S9. Annual average composition of  $\text{PM}_{10}$  and OA from 2016 to 2023. Data for 2019 are excluded from long-term comparisons due to limited coverage and are shown in grey for reference.

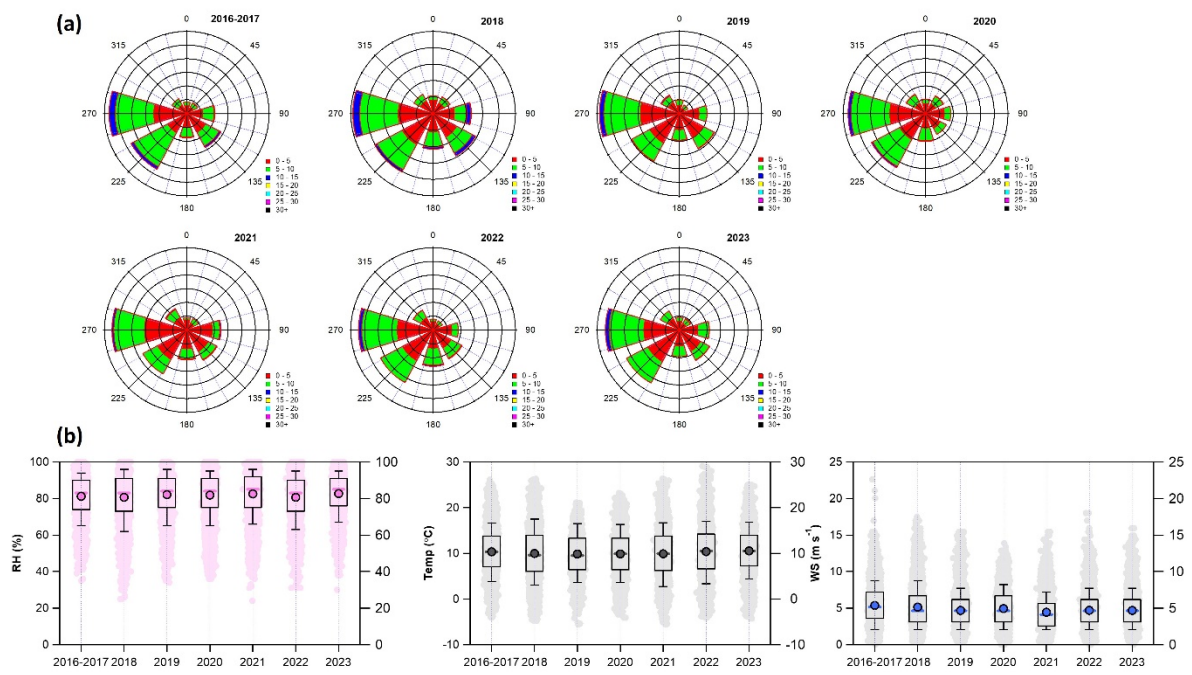


Figure S10. (a) Annual average wind rose plots, and (b) box plots of annual relative humidity (RH), ambient temperature, and wind speed (WS) based on data from 2016 to 2023 data in Dublin.

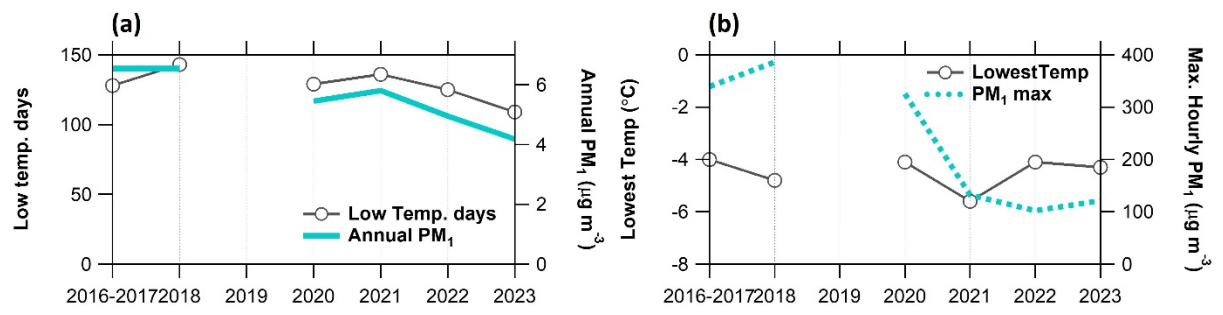


Figure S11. Long-term trends in (a) low-temperature days (daily minimum < 5 °C) and (b) annual minimum temperature from 2016 to 2023 (excluding 2019). Annual average and maximum PM<sub>1</sub> concentrations are also shown.

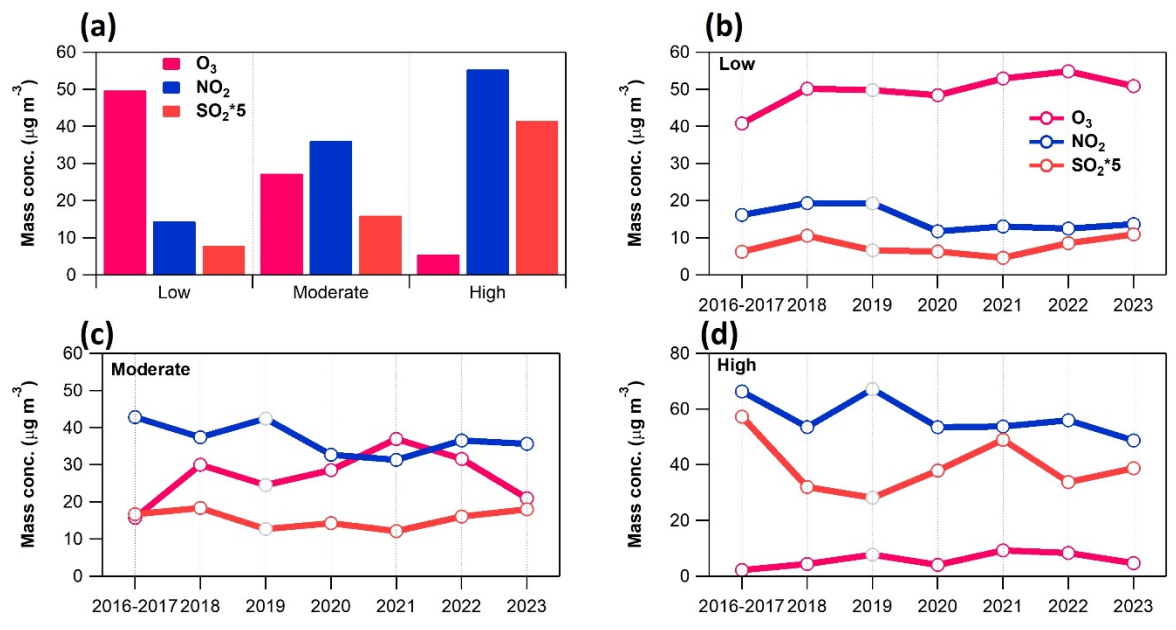


Figure S12. (a) Average concentrations of gaseous pollutants and (b-d) their long-term trends based on annual means under low, moderate, and high pollution levels from 2016 to 2023.

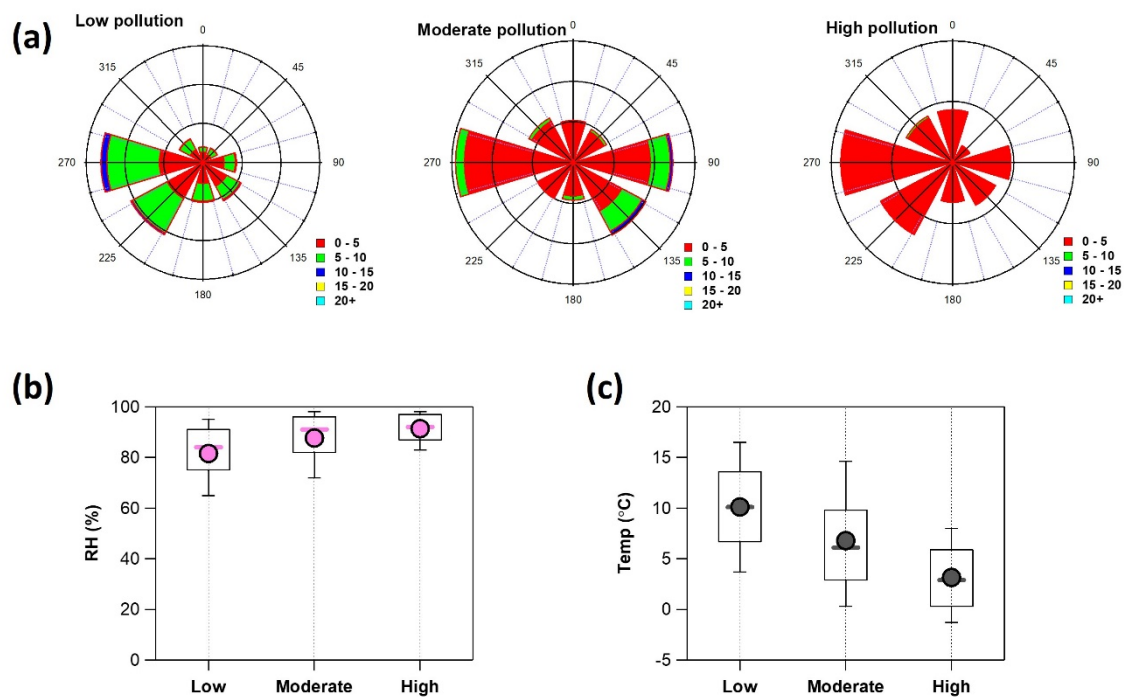


Figure S13. (a) Wind rose plots and box plots of (b) relative humidity (RH) and (c) ambient temperature (Temp) under low, moderate, and high pollution conditions. Higher pollution levels are generally associated with more stagnant meteorological conditions, including lower wind speeds and Temp, and elevated RH.

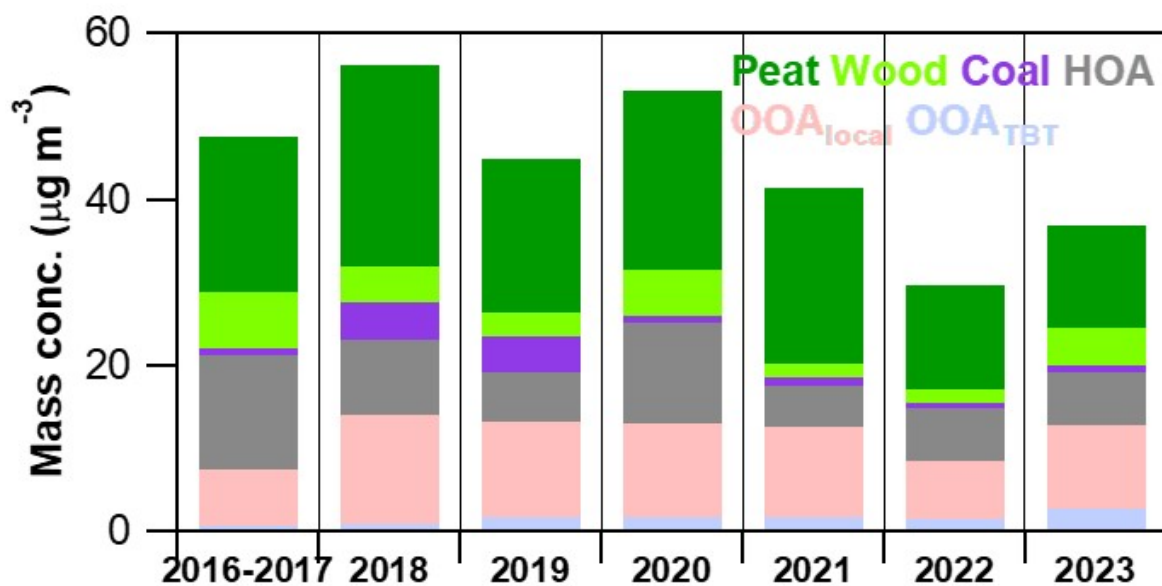


Figure S14. Long-term trends of detailed OA factors, including peat, wood, coal, HOA,  $\text{OOA}_{\text{local}}$ , and  $\text{OOA}_{\text{TBT}}$  under high pollution conditions in Dublin from 2016 to 2023.