# *Supplement of* Development of Low-Cost Air Quality Stations for Next Generation Monitoring Networks: Calibration and Validation of NO2 and O3 Sensors

**Table S1.** Summary of pre–deployment calibration and field validation procedures performed in the study.

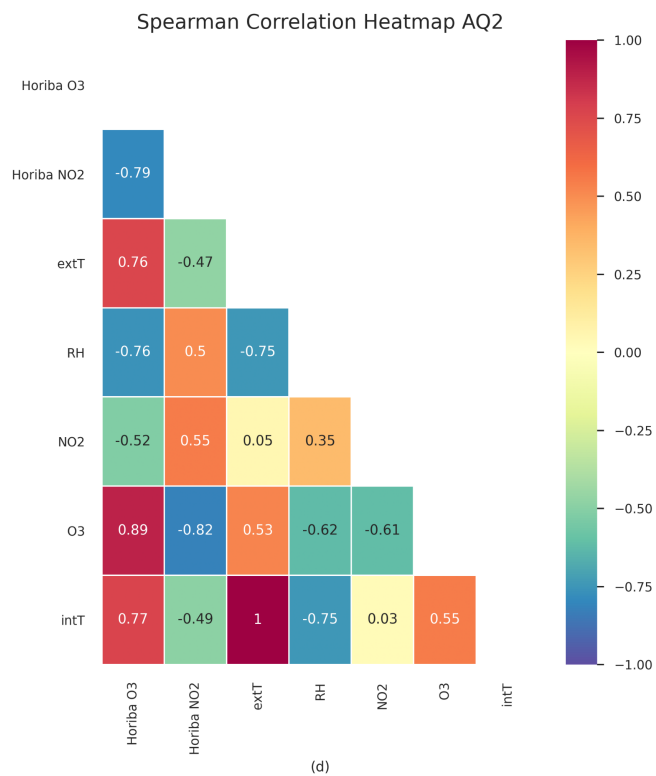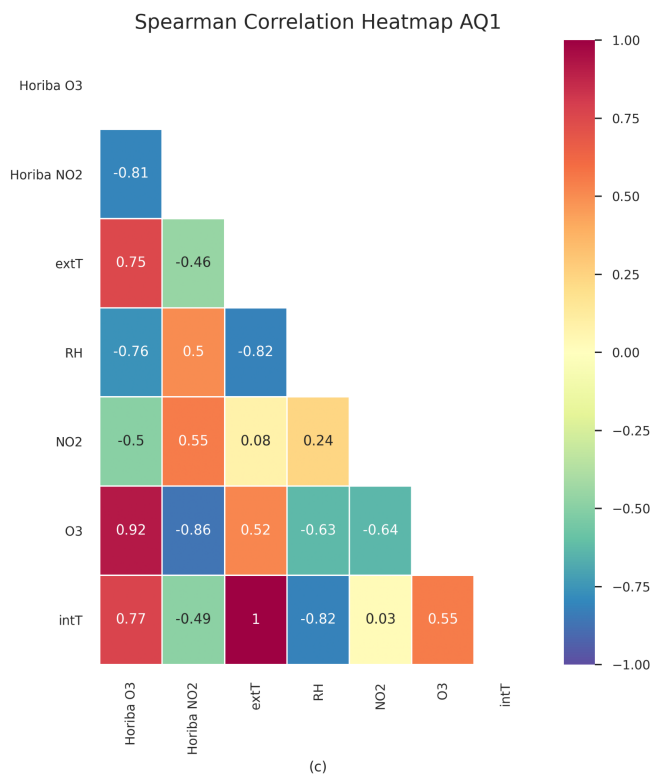| City | Lat. (deg N) | Lon. (deg E) | Time period | Time step | Process | No. records by pollutant (AQ1–AQ2) |
|---|---|---|---|---|---|---|
| Florence | 43°47'52" | 11°11'31" | 2017/07/19–2017/09/27 | 3 min | Pre–deployment calibration | NO2: 19223–17275 <br> O3: 19223–17275 |
| Montale | 43°54'57" | 11°00'26" | 2018/06/19–2019/08/22 | 1 H | Field validation | NO2: 7383–9340 <br> O3: 7344–9303 |

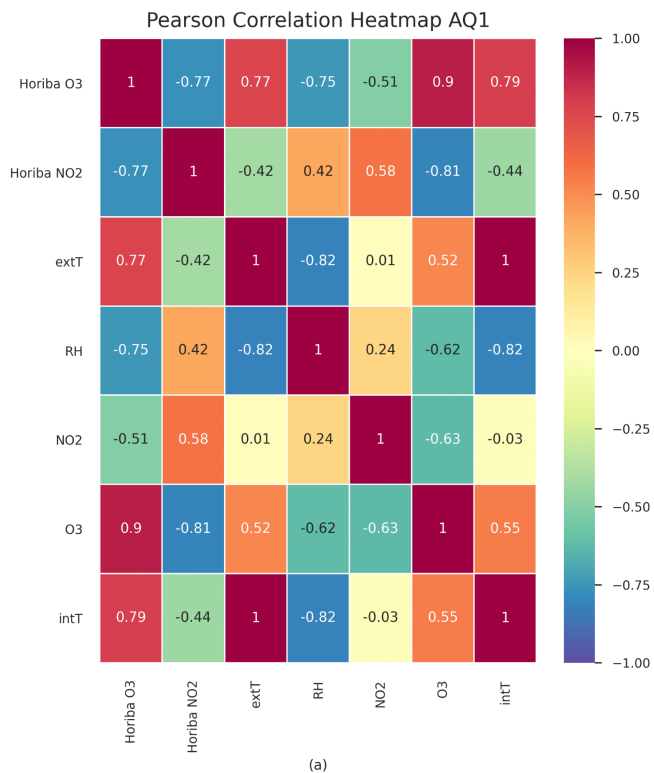**Figure S2.** Correlation matrices for AQ1 and AQ2 calibration: Pearson correlation for AQ1 (a) and AQ2 (b); Spearman correlation for AQ1 (c) and AQ2 (d).
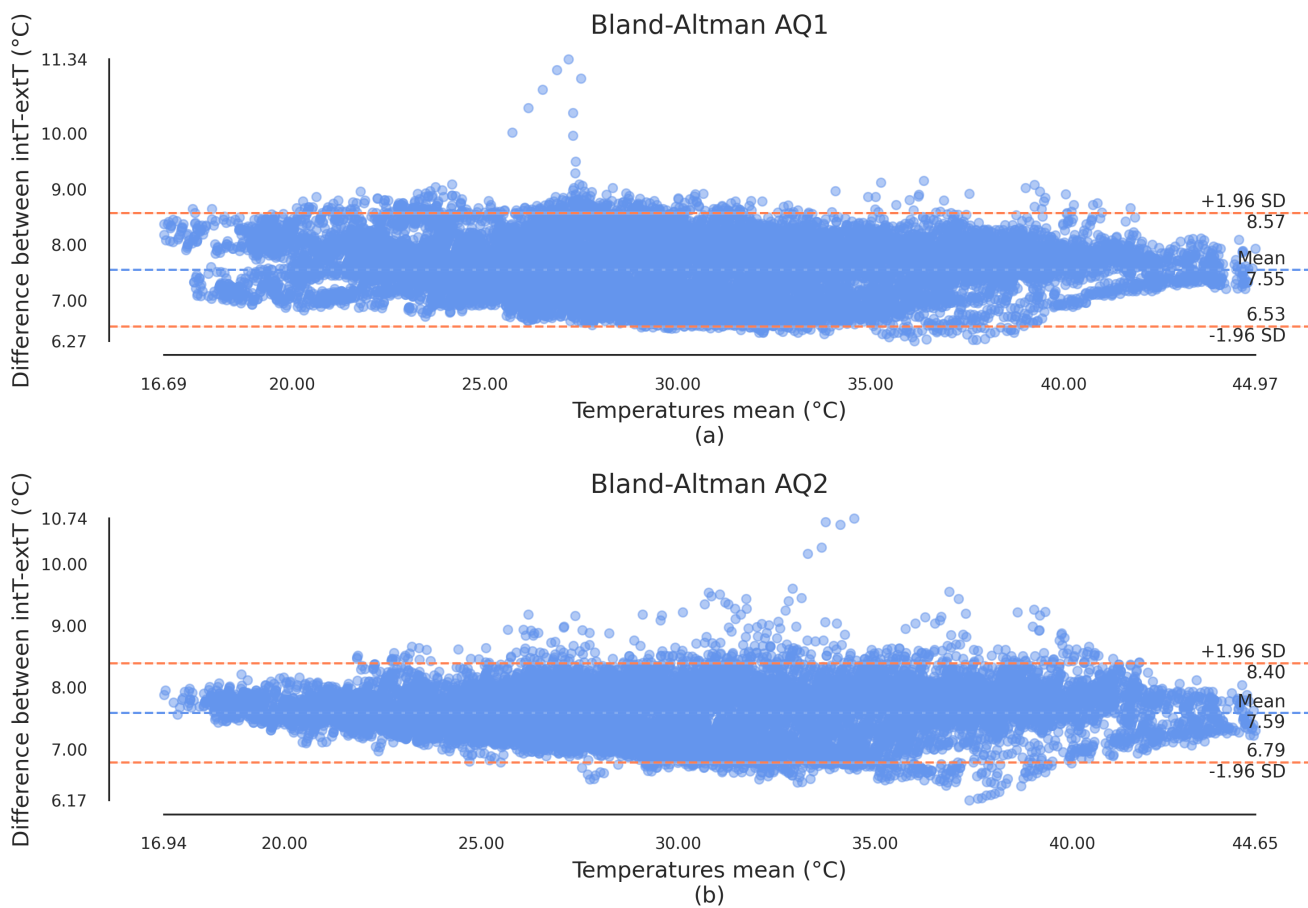
**Figure S3.** Bland–Altman plots of extT and intT for AQ1 (a) and AQ2 (b). The red lines indicate the limit of agreement ($\pm$ 1.96 SD) of temperature differences, whilst the blue lines show the average difference between the temperatures.

**Table S4.** Variance inflation factors (VIF) for the main covariates set.

| Pollutant | AQ id | Variables | Intercept | O3 | NO2 | intT | extT | RH |
|---|---|---|---|---|---|---|---|---|
| O3 | AQ1 | O3,intT | 47.38 | 1.44 | - | 1.44 | - | - |
| | | O3,intT,RH | 299.06 | 1.63 | - | 3.08 | - | 3.45 |
| | | O3,intT,extT,RH | 441.18 | 1.95 | - | 151.19 | 147.78 | 3.55 |
| | | O3,NO2,intT,RH | 304.88 | 3.13 | 2.25 | 4.00 | - | 3.61 |
| | | O3,NO2,intT,extT,RH | 465.46 | 3.24 | 2.35 | 153.54 | 154.09 | 3.77 |
| | AQ2 | O3,intT | 54.05 | 1.44 | - | 1.44 | - | - |
| | | O3,intT,RH | 210.67 | 1.63 | - | 2.30 | - | 2.52 |
| | | O3,intT,extT,RH | 472.01 | 1.92 | - | 237.86 | 232.71 | 2.57 |
| | | O3,NO2,intT,RH | 221.90 | 2.97 | 2.24 | 3.03 | - | 2.72 |
| | | O3,NO2,intT,extT,RH | 484.17 | 3.25 | 2.24 | 238.39 | 232.72 | 2.77 |
| NO2 | AQ1 | NO2,intT | 36.86 | - | 1.00 | 1.00 | - | - |
| | | NO2,intT,RH | 241.53 | - | 1.17 | 3.37 | - | 3.58 |
| | | NO2,intT,extT,RH | 434.86 | - | 1.42 | 144.55 | 149.03 | 3.70 |
| | | NO2,O3,intT,RH | 304.88 | 3.13 | 2.25 | 4.00 | - | 3.61 |
| | | NO2,O3,intT,extT,RH | 465.46 | 3.24 | 2.35 | 153.54 | 154.09 | 3.77 |
| | AQ2 | NO2,intT | 37.46 | - | 1.01 | 1.01 | - | - |
| | | NO2,intT,RH | 149.67 | - | 1.23 | 2.40 | - | 2.71 |
| | | NO2,intT,extT,RH | 472.57 | - | 1.32 | 211.00 | 212.93 | 2.74 |
| | | NO2,O3,intT,RH | 221.90 | 2.97 | 2.24 | 3.03 | - | 2.72 |
| | | NO2,O3,intT,extT,RH | 484.17 | 3.25 | 2.24 | 238.39 | 232.72 | 2.77 |

**Table S5.** Summary of MLR O3 models for AQ1 and AQ2.

| Pollutant | AQ id | Variables | $\beta 0$ | $\beta 1$ | $\beta 2$ | $\beta 3$ | $\beta 4$ | $R^2$ | RMSE | AIC | AdjR$^2$ | MAE | MBE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Coefficient | | | | | Stat. | | | | | |
| O3 | AQ1 | O3 | -146.10 | 0.40 | - | - | - | 0.81 | 16.92 | 1.09E+05 | 0.81 | 13.42 | -0.28 |
| | | intT | -109.92 | 5.46 | - | - | - | 0.61 | 24.33 | 1.19E+05 | 0.62 | 19.56 | 0.21 |
| | | RH | 165.02 | -1.71 | - | - | - | 0.57 | 25.61 | 1.21E+05 | 0.57 | 20.35 | -0.17 |
| | | NO2 | 97.15 | -0.31 | - | - | - | 0.27 | 33.63 | 1.27E+05 | 0.27 | 27.42 | -0.46 |
| | | O3,intT | -186.58 | 0.30 | 2.88 | - | - | 0.94 | 9.92 | 9.52E+04 | 0.94 | 7.39 | -0.06 |
| | | O3,RH | -61.47 | 0.32 | -0.71 | - | - | 0.88 | 13.61 | 1.04E+05 | 0.88 | 10.69 | -0.26 |
| | | NO2,O3 | -162.73 | 0.05 | 0.43 | - | - | 0.82 | 16.74 | 1.09E+05 | 0.82 | 13.24 | -0.23 |
| | | RH,intT | -12.71 | -0.71 | 3.70 | - | - | 0.65 | 23.07 | 1.17E+05 | 0.65 | 18.21 | 0.09 |
| | | NO2,intT | -84.20 | -0.29 | 5.36 | - | - | 0.86 | 14.52 | 1.05E+05 | 0.86 | 11.35 | -0.11 |
| | | NO2,RH | 170.74 | -0.21 | -1.52 | - | - | 0.69 | 21.88 | 1.17E+05 | 0.69 | 17.50 | -0.39 |
| | | O3,RH,intT | -193.19 | 0.30 | 0.04 | 2.97 | - | 0.94 | 9.93 | 9.52E+04 | 0.94 | 7.39 | -0.06 |
| | | NO2,O3,intT | -159.76 | -0.10 | 0.23 | 3.44 | - | 0.95 | 8.69 | 9.18E+04 | 0.95 | 6.39 | -0.12 |
| | | NO2,O3,RH | -64.32 | 0.01 | 0.32 | -0.71 | - | 0.88 | 13.60 | 1.04E+05 | 0.88 | 10.69 | -0.26 |
| | | NO2,RH,intT | -87.77 | -0.29 | 0.03 | 5.42 | - | 0.86 | 14.52 | 1.05E+05 | 0.86 | 11.36 | -0.11 |
| | | NO2,O3,RH,intT | -180.76 | -0.11 | 0.23 | 0.15 | 3.79 | 0.95 | 8.62 | 9.14E+04 | 0.95 | 6.30 | -0.10 |
| | AQ2 | O3 | -140.53 | 0.31 | - | - | - | 0.77 | 17.58 | 9.93E+04 | 0.77 | 14.11 | 0.14 |
| | | intT | -90.68 | 5.04 | - | - | - | 0.64 | 22.12 | 1.04E+05 | 0.64 | 18.07 | -0.24 |
| | | RH | 148.13 | -1.37 | - | - | - | 0.55 | 24.62 | 1.07E+05 | 0.55 | 19.48 | -0.29 |
| | | NO2 | 101.33 | -0.34 | - | - | - | 0.31 | 30.43 | 1.12E+05 | 0.31 | 24.74 | 0.23 |
| | | O3,intT | -174.35 | 0.23 | 2.86 | - | - | 0.91 | 10.86 | 8.83E+04 | 0.91 | 8.18 | -0.05 |
| | | O3,RH | -59.90 | 0.24 | -0.61 | - | - | 0.84 | 14.77 | 9.51E+04 | 0.84 | 11.96 | -0.03 |
| | | NO2,O3 | -139.86 | -0.00 | 0.31 | - | - | 0.77 | 17.58 | 9.93E+04 | 0.77 | 14.11 | 0.14 |
| | | RH,intT | -9.43 | -0.60 | 3.52 | - | - | 0.69 | 20.50 | 1.03E+05 | 0.69 | 16.33 | -0.30 |
| | | NO2,intT | -62.83 | -0.30 | 4.79 | - | - | 0.89 | 12.22 | 9.07E+04 | 0.89 | 9.52 | -0.08 |
| | | NO2,RH | 150.72 | -0.21 | -1.15 | - | - | 0.65 | 21.64 | 1.04E+05 | 0.65 | 17.38 | -0.13 |
| | | O3,RH,intT | -155.80 | 0.22 | -0.12 | 2.62 | - | 0.91 | 10.76 | 8.81E+04 | 0.91 | 8.18 | -0.07 |
| | | NO2,O3,intT | -129.74 | -0.16 | 0.14 | 3.51 | - | 0.94 | 8.59 | 8.30E+04 | 0.95 | 6.51 | -0.04 |
| | | NO2,O3,RH | -53.73 | -0.02 | 0.24 | -0.62 | - | 0.84 | 14.76 | 9.51E+04 | 0.84 | 11.96 | -0.03 |
| | | NO2,RH,intT | -60.82 | -0.30 | -0.02 | 4.76 | - | 0.89 | 12.21 | 9.07E+04 | 0.89 | 9.52 | -0.09 |
| | | NO2,O3,RH,intT | -133.43 | -0.16 | 0.14 | 0.03 | 3.58 | 0.94 | 8.58 | 8.29E+04 | 0.95 | 6.50 | -0.03 |

**Table S6.** Summary of MLR NO2 models for AQ1 and AQ2.

| Pollutant | AQ id | Variables | Coefficient | | | | | Stat | | | | | |
| | | | $\beta0$ | $\beta1$ | $\beta2$ | $\beta3$ | $\beta4$ | $R^2$ | RMSE | AIC | $AdjR^2$ | MAE | MBE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NO2 | AQ1 | NO2 | 13.03 | 0.15 | - | - | - | 0.34 | 14.22 | 1.05E+05 | 0.34 | 10.91 | 0.09 |
| | | intT | 70.28 | -1.36 | - | - | - | 0.19 | 15.72 | 1.07E+05 | 0.19 | 12.14 | -0.16 |
| | | RH | 2.19 | 0.42 | - | - | - | 0.18 | 15.81 | 1.08E+05 | 0.18 | 12.25 | -0.07 |
| | | O3 | 111.52 | -0.16 | - | - | - | 0.66 | 10.22 | 9.61E+04 | 0.66 | 7.74 | -0.01 |
| | | NO2,intT | 57.18 | 0.15 | -1.30 | - | - | 0.52 | 12.14 | 1.01E+05 | 0.52 | 9.17 | 0.01 |
| | | NO2,RH | -1.44 | 0.13 | 0.30 | - | - | 0.42 | 13.28 | 1.03E+05 | 0.42 | 9.99 | 0.08 |
| | | NO2,O3 | 101.09 | 0.03 | -0.14 | - | - | 0.67 | 10.09 | 9.57E+04 | 0.67 | 7.64 | 0.01 |
| | | RH,intT | 47.73 | 0.17 | -0.95 | - | - | 0.20 | 15.59 | 1.07E+05 | 0.20 | 12.02 | -0.13 |
| | | O3,intT | 111.23 | -0.16 | 0.02 | - | - | 0.66 | 10.22 | 9.61E+04 | 0.66 | 7.74 | -0.01 |
| | | O3,RH | 127.09 | -0.18 | -0.13 | - | - | 0.67 | 10.10 | 9.57E+04 | 0.67 | 7.67 | -0.01 |
| | | NO2,RH,intT | 89.29 | 0.16 | -0.24 | -1.90 | - | 0.53 | 11.96 | 1.00E+05 | 0.53 | 9.09 | -0.02 |
| | | NO2,O3,intT | 100.92 | 0.04 | -0.13 | -0.19 | - | 0.67 | 10.06 | 9.57E+04 | 0.67 | 7.61 | 0.01 |
| | | NO2,O3,RH | 116.25 | 0.02 | -0.16 | -0.11 | - | 0.67 | 10.01 | 9.55E+04 | 0.67 | 7.61 | 0.01 |
| | | O3,RH,intT | 150.78 | -0.17 | -0.27 | -0.54 | - | 0.68 | 9.97 | 9.53E+04 | 0.67 | 7.57 | -0.05 |
| | | NO2,O3,RH,intT | 144.78 | 0.05 | -0.14 | -0.32 | -0.93 | 0.69 | 9.68 | 9.45E+04 | 0.69 | 7.36 | -0.03 |
| | AQ2 | NO2 | 11.81 | 0.16 | - | - | - | 0.38 | 12.86 | 9.22E+04 | 0.38 | 9.83 | -0.09 |
| | | intT | 66.88 | -1.31 | - | - | - | 0.21 | 14.45 | 9.49E+04 | 0.21 | 10.91 | 0.07 |
| | | RH | 4.94 | 0.35 | - | - | - | 0.19 | 14.67 | 9.54E+04 | 0.19 | 11.09 | 0.08 |
| | | O3 | 113.00 | -0.13 | - | - | - | 0.64 | 9.79 | 8.58E+04 | 0.64 | 7.35 | -0.04 |
| | | NO2,intT | 52.45 | 0.16 | -1.19 | - | - | 0.55 | 10.91 | 8.85E+04 | 0.55 | 8.19 | -0.01 |
| | | NO2,RH | 3.19 | 0.14 | 0.20 | - | - | 0.43 | 12.28 | 9.12E+04 | 0.43 | 9.25 | -0.03 |
| | | NO2,O3 | 97.76 | 0.05 | -0.11 | - | - | 0.66 | 9.53 | 8.52E+04 | 0.66 | 7.15 | -0.06 |
| | | RH,intT | 47.54 | 0.14 | -0.95 | - | - | 0.23 | 14.28 | 9.47E+04 | 0.23 | 10.73 | 0.08 |
| | | O3,intT | 114.00 | -0.13 | -0.08 | - | - | 0.64 | 9.78 | 8.58E+04 | 0.64 | 7.34 | -0.04 |
| | | O3,RH | 123.40 | -0.14 | -0.08 | - | - | 0.64 | 9.72 | 8.56E+04 | 0.64 | 7.32 | -0.07 |
| | | NO2,RH,intT | 77.38 | 0.17 | -0.20 | -1.67 | - | 0.57 | 10.71 | 8.79E+04 | 0.57 | 8.07 | -0.04 |
| | | NO2,O3,intT | 96.78 | 0.06 | -0.10 | -0.34 | - | 0.67 | 9.41 | 8.50E+04 | 0.67 | 7.04 | -0.04 |
| | | NO2,O3,RH | 107.47 | 0.04 | -0.12 | -0.07 | - | 0.66 | 9.48 | 8.51E+04 | 0.66 | 7.14 | -0.08 |
| | | O3,RH,intT | 137.80 | -0.13 | -0.15 | -0.39 | - | 0.65 | 9.63 | 8.53E+04 | 0.65 | 7.26 | -0.06 |
| | | NO2,O3,RH,intT | 126.78 | 0.08 | -0.10 | -0.23 | -0.87 | 0.69 | 9.07 | 8.40E+04 | 0.69 | 6.83 | -0.08 |
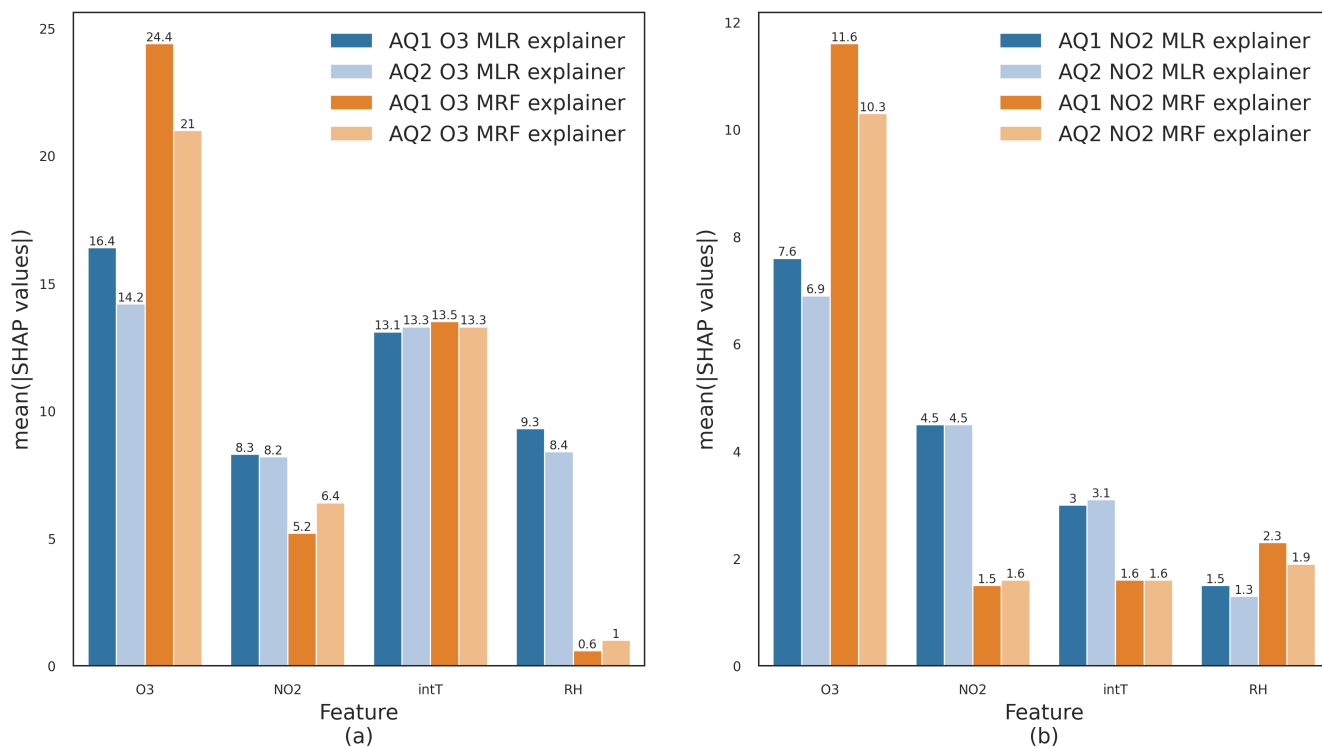
**Figure S7.** Mean absolute SHAP values of all features for MLR and MRF models for O3 and NO2 concentrations at AQ1 and AQ2 stations. The effect of intT, RH, O3 and NO2 raw data on the overall output of the training model is also shown.
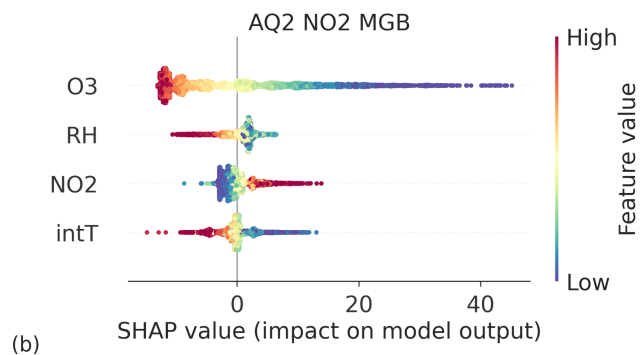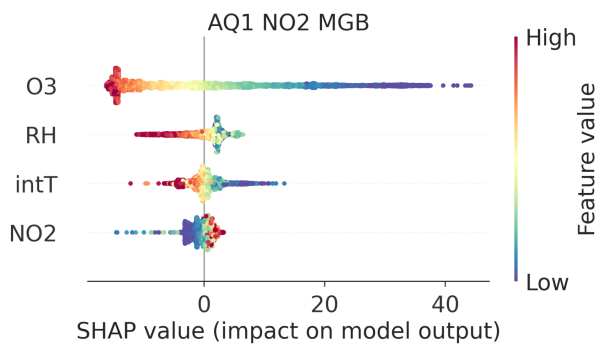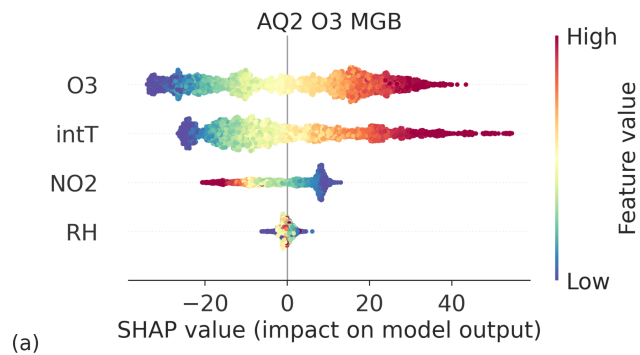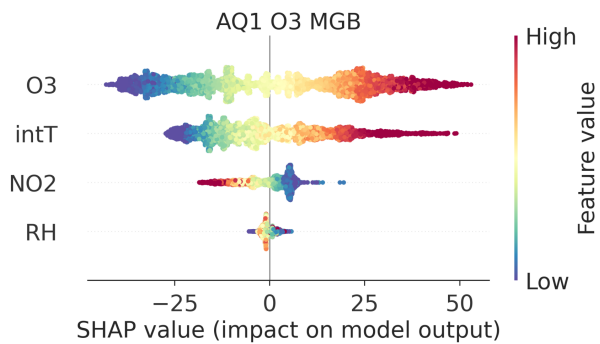
(a)

(b)

**Figure S8.** Beeswarm MGB

**Table S9.** Statistics of the MLR and MRF calibrated models assessed during the field validation procedure.

| Pollutant | AQ id | Stat. | MLR | MRF |
|---|---|---|---|---|
| O3 | AQ1 | r | 0.92 | 0.81 |
| | | CRMSD | 15.98 | 24.13 |
| | | RMSE | 16.52 | 29.08 |
| | | MAE | 12.96 | 22.22 |
| | | MBE | 4.20 | 16.23 |
| | AQ2 | r | 0.93 | 0.76 |
| | | CRMSD | 15.35 | 25.44 |
| | | RMSE | 17.88 | 42.98 |
| | | MAE | 13.99 | 36.24 |
| | | MBE | 9.17 | 34.64 |
| NO2 | AQ1 | r | 0.75 | 0.65 |
| | | CRMSD | 11.25 | 11.83 |
| | | RMSE | 12.64 | 13.48 |
| | | MAE | 9.40 | 9.97 |
| | | MBE | 5.75 | 6.46 |
| | AQ2 | r | 0.78 | 0.58 |
| | | CRMSD | 10.63 | 11.77 |
| | | RMSE | 10.65 | 11.94 |
| | | MAE | 7.72 | 9.12 |
| | | MBE | -0.69 | 2.03 |

**Figure S10.** Trend analysis of 7–day average O3 and NO2 concentrations measured at the validation site by the calibrated AQ1 and AQ2 stations compared to the ARPAT reference station (17 June 2019–22 August 2019).

**Table S11.** Seasonal analysis of MFR validation. Min–Max ($\mu g\,m^{-3}$) represents the minimum and maximum concentrations measured by the reference station, while intT is the average internal temperature measured by the AQ stations.

| Year | Season | Pollutant | AQ id | min-max | intT | r | nRMSE | MAE | MBE |
|------|--------|-----------|-------|---------|------|---|-------|-----|-----|
| 2018 | Summer | O3 | AQ1 | 6 - 166 | 34.65 | 0.90 | 10.20 | 12.58 | -4.91 |
| | | | AQ2 | 6 - 166 | 34.20 | 0.84 | 15.59 | 20.68 | 16.52 |
| | | NO2 | AQ1 | 1 - 47 | 34.62 | 0.64 | 42.26 | 16.00 | 15.87 |
| | | | AQ2 | 1 - 47 | 34.16 | 0.51 | 18.93 | 7.27 | 5.41 |
| | Autumn | O3 | AQ1 | 2 - 146 | 28.06 | 0.84 | 21.49 | 24.43 | 22.53 |
| | | | AQ2 | 2 - 146 | 25.53 | 0.76 | 35.59 | 46.81 | 46.57 |
| | | NO2 | AQ1 | 1 - 62 | 28.07 | 0.65 | 21.83 | 9.58 | 6.71 |
| | | | AQ2 | 1 - 62 | 25.54 | 0.43 | 18.02 | 8.85 | 1.04 |
| | Winter | O3 | AQ1 | 2 - 65 | 16.60 | 0.88 | 52.57 | 22.13 | 21.12 |
| | | | AQ2 | 2 - 72 | 14.53 | 0.83 | 67.43 | 39.32 | 39.17 |
| | | NO2 | AQ1 | 3 - 88 | 16.59 | 0.71 | 17.59 | 11.65 | 3.42 |
| | | | AQ2 | 2 - 88 | 14.53 | 0.57 | 20.64 | 13.40 | -2.82 |
| 2019 | Spring | O3 | AQ1 | 2 - 132 | 22.41 | 0.75 | 29.11 | 32.63 | 31.92 |
| | | | AQ2 | 2 - 132 | 21.14 | 0.68 | 35.91 | 40.38 | 39.57 |
| | | NO2 | AQ1 | 2 - 63 | 22.32 | 0.67 | 12.73 | 5.67 | -0.54 |
| | | | AQ2 | 2 - 63 | 21.09 | 0.34 | 17.18 | 8.29 | 2.31 |
| | Summer | O3 | AQ1 | 7 - 185 | 34.98 | 0.82 | 13.42 | 19.44 | 12.35 |
| | | | AQ2 | 7 - 185 | 32.29 | 0.75 | 20.71 | 31.31 | 28.19 |
| | | NO2 | AQ1 | 0 - 47 | 34.94 | 0.50 | 22.19 | 8.19 | 6.81 |
| | | | AQ2 | 0 - 47 | 32.25 | 0.34 | 18.00 | 7.28 | 5.05 |

Note: column group heading "Stat." spans nRMSE, MAE, MBE.