

Vertical profiles of PM_{2.5} and O₃ measured using unmanned aerial vehicle (UAV) and their relationships with synoptic- and local-scale air movement

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Table S1. Statistical description of the meteorological and environmental conditions measured at Gyeonggi Air Quality Management Office in 2023.

Category	Factor	Mean	Std. Dev.	Q1	Q2	Q3
January– March	Temperature [°C]	3.1	6.6	-1.4	2.9	7.0
	Relative Humidity [%]	60.4	19.1	46.2	59.7	75.0
	Wind Speed [m/s]	0.8	0.7	0.3	0.5	1.1
	PM _{2.5} [µg/m ³]	39.5	26.0	20.0	32.0	53.0
	O ₃ [ppm]	0.022	0.018	0.004	0.021	0.034
April– June	Temperature [°C]	18.7	5.8	14.4	19.3	23.0
	Relative Humidity [%]	65.0	21.7	48.5	66.9	84.5
	Wind Speed [m/s]	0.8	0.6	0.4	0.6	1.0
	PM _{2.5} [µg/m ³]	26.6	15.5	17.0	24.0	34.0
	O ₃ [ppm]	0.037	0.019	0.023	0.038	0.050
July– September	Temperature [°C]	26.4	3.7	24.0	26.1	28.8
	Relative Humidity [%]	76.0	15.1	64.4	78.5	89.7
	Wind Speed [m/s]	0.7	0.5	0.4	0.5	0.8
	PM _{2.5} [µg/m ³]	14.6	9.4	8.0	14.0	20.0
	O ₃ [ppm]	0.030	0.022	0.014	0.026	0.043
October– December	Temperature [°C]	8.1	8.7	1.5	8.6	15.6
	Relative Humidity [%]	69.5	16.9	57.2	69.0	84.6
	Wind Speed [m/s]	0.9	0.8	0.3	0.5	1.1
	PM _{2.5} [µg/m ³]	22.9	16.4	11.0	19.0	29.0
	O ₃ [ppm]	0.022	0.017	0.006	0.022	0.033
6 am	Temperature [°C]	11.2	10.8	1.9	12.4	20.5
	Relative Humidity [%]	79.3	15.0	69.7	84.0	92.1
	Wind Speed [m/s]	0.5	0.4	0.2	0.4	0.5
	PM _{2.5} [µg/m ³]	26.8	19.6	13.0	23.0	36.0
	O ₃ [ppm]	0.015	0.014	0.002	0.012	0.026
12 pm	Temperature [°C]	16.3	11.3	6.5	18.5	25.4
	Relative Humidity [%]	57.6	19.3	44.2	56.1	69.4
	Wind Speed [m/s]	1.0	0.6	0.6	0.7	1.1
	PM _{2.5} [µg/m ³]	26.4	18.9	14.0	22.0	34.0
	O ₃ [ppm]	0.035	0.017	0.023	0.033	0.045
6 pm	Temperature [°C]	16.3	10.9	6.8	18.4	25.0
	Relative Humidity [%]	59.4	18.1	46.5	58.4	70.5
	Wind Speed [m/s]	1.1	0.7	0.5	1.0	1.5
	PM _{2.5} [µg/m ³]	24.1	20.2	11.0	19.0	29.5
	O ₃ [ppm]	0.040	0.019	0.026	0.040	0.054
12 am	Temperature [°C]	12.8	10.6	4.1	13.8	21.8
	Relative Humidity [%]	74.0	15.8	63.4	77.0	87.0
	Wind Speed [m/s]	0.5	0.6	0.2	0.4	0.6
	PM _{2.5} [µg/m ³]	26.9	20.1	14.0	23.0	33.0
	O ₃ [ppm]	0.022	0.017	0.005	0.021	0.034

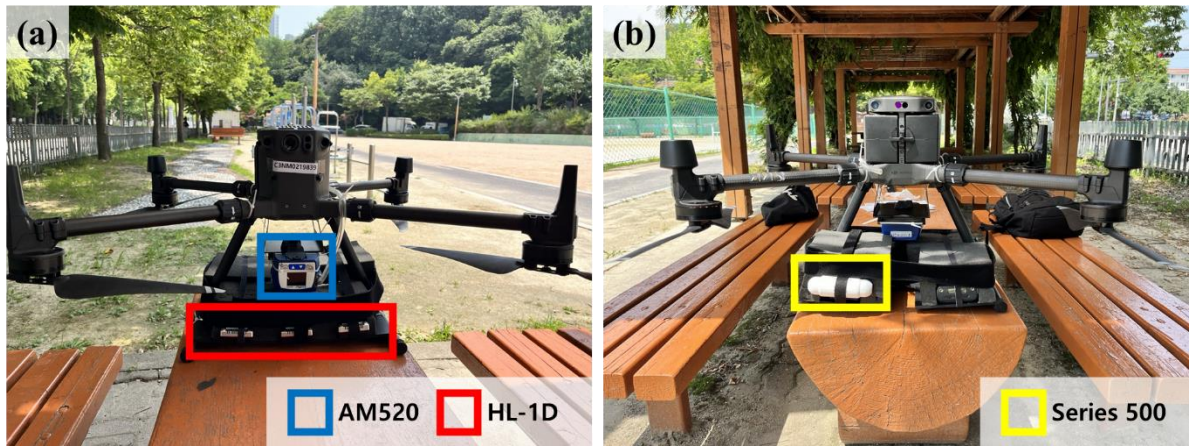


Figure S1. Matrice 300 RTK (DJI, China) equipped the (a) AM520 (TSI, USA), HL-1D (Rotronic, Switzerland), and (b) Series 500 (Aeroqual, New Zealand).

Table S2. Flight and measurement information. O indicates the successful measurement.

Date	Time	PM _{2.5}	O ₃	Temperature	Humidity
2023-08-01	10:00	O	O	O	O
2023-08-17	12:00	O	O	O	O
2023-08-25	7:00	O	-	O	O
2023-08-25	10:00	O	O	O	O
2023-08-25	12:00	O	O	O	O
2023-08-25	14:00	O	-	O	O
2023-08-25	18:00	O	O	O	O
2023-08-26	7:00	O	O	O	O
2023-08-26	10:00	O	O	O	O
2023-08-26	12:00	O	O	O	O
2023-08-26	14:00	O	O	O	O
2023-08-26	18:00	O	O	O	O
2023-08-27	7:00	-	-	O	O
2023-08-27	10:00	-	O	O	O
2023-08-27	12:00	-	O	O	O
2023-08-27	14:00	-	O	O	O
2023-08-27	18:00	-	O	O	O
2023-08-31	7:00	O	-	O	O
2023-08-31	10:00	O	O	O	O
2023-08-31	12:00	O	-	O	O
2023-08-31	14:00	O	O	O	O
2023-08-31	18:00	O	O	O	O
2023-09-01	7:00	-	-	O	O
2023-09-01	10:00	-	O	O	O
2023-09-01	12:00	O	O	O	O
2023-09-01	14:00	O	O	O	O
2023-09-01	18:00	O	O	O	O
2023-09-23	7:00	O	-	O	O
2023-09-23	10:00	O	O	O	O
2023-09-23	12:00	O	-	O	O
2023-09-23	14:00	O	O	O	O
2023-09-23	18:00	O	O	O	O
Total		25	24	32	32

Table S3. Coefficients and performance of correction models.

Pollutant	Formulas	Coefficients		R ²
		UAV	RH	
PM _{2.5}	PM _{2.5} (AQMO) ~ PM _{2.5} (UAV)+RH	0.501*	0.036*	0.981
O ₃	O ₃ (AQMO) ~ O ₃ (UAV)	0.632*	-	0.968

* p-value < 0.05

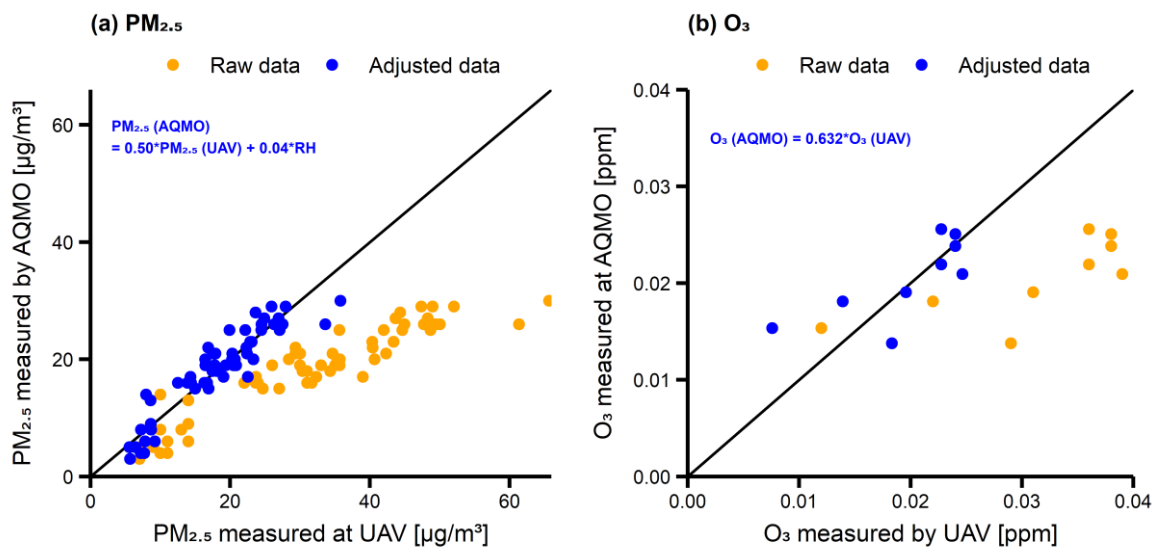


Figure S2. Comparison between Gyeonggi Air Quality Management Office data and UAV measurement data. Orange dots show uncorrected measurement results, and blue dots show the measurement results corrected based on the model shown in Table S3.

Table S4. Summary of PM_{2.5} and O₃ concentration, temperature, and relative humidity by altitude.

Altitude (m)	PM _{2.5} (µg/m ³)	O ₃ (ppm)	Temperature (°C)	Humidity (%)
30	16.2	0.026	26.9	63.7
60	16.3	0.029	26.5	63.3
90	16.4	0.032	26.3	63.5
120	16.6	0.033	26.0	64.4
145	16.9	0.034	25.8	64.9
Average	16.5	0.031	26.3	63.9
Standard deviation	0.3	0.003	0.4	0.7

Table S5. Summary of PM_{2.5} concentrations by altitude over time.

Altitude (m)	PM _{2.5} (µg/m ³)				
	7:00	10:00	12:00	14:00	18:00
30	29.9	16.4	13.5	13.5	11.2
60	29.8	16.8	13.6	14.0	11.0
90	30.1	16.9	14.0	13.9	10.9
120	30.8	17.3	14.3	14.9	10.9
145	31.1	17.6	14.8	14.6	11.1
Average	30.4	17.0	14.0	14.2	11.0
Standard deviation	0.6	0.5	0.5	0.5	0.1

Table S6. Summary of O₃ concentrations by altitude over time.

Altitude (m)	O ₃ (ppm)				
	7:00	10:00	12:00	14:00	18:00
30	0.010	0.012	0.036	0.037	0.025
60	0.008	0.020	0.032	0.044	0.029
90	0.015	0.020	0.039	0.042	0.034
120	0.013	0.022	0.038	0.047	0.033
145	0.012	0.022	0.039	0.051	0.032
Average	0.012	0.019	0.037	0.044	0.031
Standard deviation	0.003	0.004	0.003	0.005	0.004

Table S7. Summary of temperature by altitude over time.

Altitude (m)	Temperature (°C)				
	7:00	10:00	12:00	14:00	18:00
30	22.5	27.3	28.7	29.1	26.6
60	22.4	26.8	28.1	28.2	27.0
90	22.3	26.5	27.8	27.8	27.1
120	22.2	26.2	27.4	27.5	26.9
145	22.1	26.1	26.9	27.3	26.6
Average	22.3	26.6	27.8	28.0	26.8
Standard deviation	0.2	0.5	0.7	0.7	0.2

Table S8. Summary of humidity by altitude over time.

Altitude (m)	Humidity (%)				
	7:00	10:00	12:00	14:00	18:00
30	86.7	63.9	54.3	52.2	62.8
60	86.0	64.9	55.2	52.8	58.6
90	85.8	65.2	56.1	53.7	57.8
120	85.9	66.3	57.2	53.9	58.2
145	85.8	66.4	58.3	54.4	59.0
Average	86.0	65.3	56.2	53.4	59.3
Standard deviation	0.4	1.0	1.6	0.9	2.0

Table S9. Classification result of 32 trajectories.

Date	Time	Cluster Index
2023-08-01	10:00	Cluster 3
2023-08-17	12:00	Cluster 2
2023-08-25	7:00	Cluster 5
2023-08-25	10:00	Cluster 5
2023-08-25	12:00	Cluster 5
2023-08-25	14:00	Cluster 5
2023-08-25	18:00	Cluster 5
2023-08-26	7:00	Cluster 1
2023-08-26	10:00	Cluster 1
2023-08-26	12:00	Cluster 1
2023-08-26	14:00	Cluster 1
2023-08-26	18:00	Cluster 1
2023-08-27	7:00	Cluster 2
2023-08-27	10:00	Cluster 2
2023-08-27	12:00	Cluster 2
2023-08-27	14:00	Cluster 2
2023-08-27	18:00	Cluster 2
2023-08-31	7:00	Cluster 1
2023-08-31	10:00	Cluster 1
2023-08-31	12:00	Cluster 1
2023-08-31	14:00	Cluster 1
2023-08-31	18:00	Cluster 1
2023-09-01	7:00	Cluster 1
2023-09-01	10:00	Cluster 1
2023-09-01	12:00	Cluster 1
2023-09-01	14:00	Cluster 1
2023-09-01	18:00	Cluster 1
2023-09-23	7:00	Cluster 3
2023-09-23	10:00	Cluster 3
2023-09-23	12:00	Cluster 3
2023-09-23	14:00	Cluster 3
2023-09-23	18:00	Cluster 4

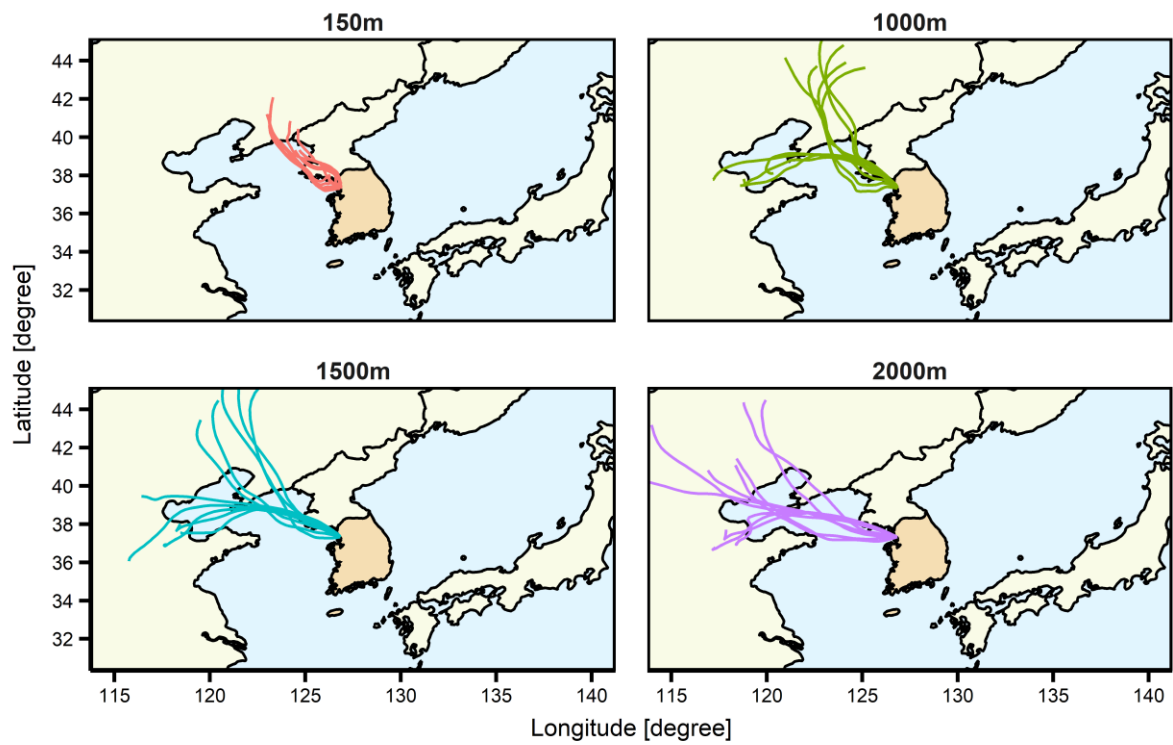


Figure S3. Backward air trajectories for Cluster 1 estimated at the arriving altitudes of 150m, 1000m, 1500m, and 2000m.

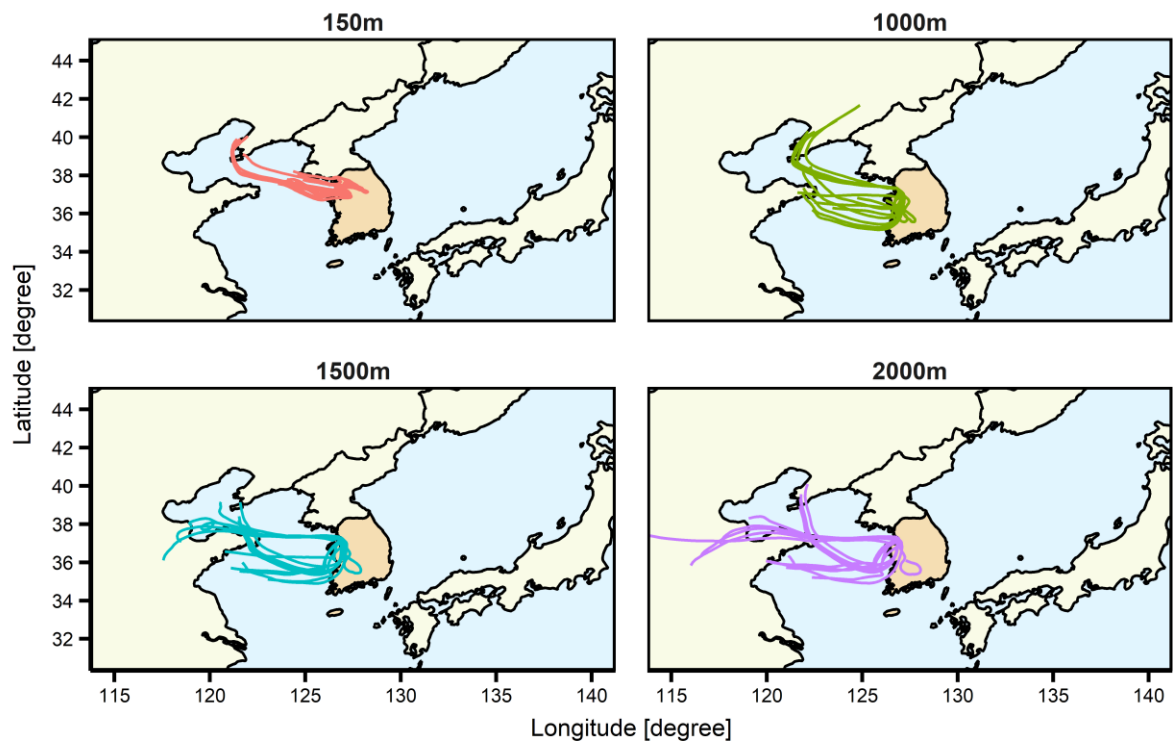


Figure S4. Backward air trajectories for Cluster 2 estimated at the arriving altitudes of 150m, 1000m, 1500m, and 2000m.

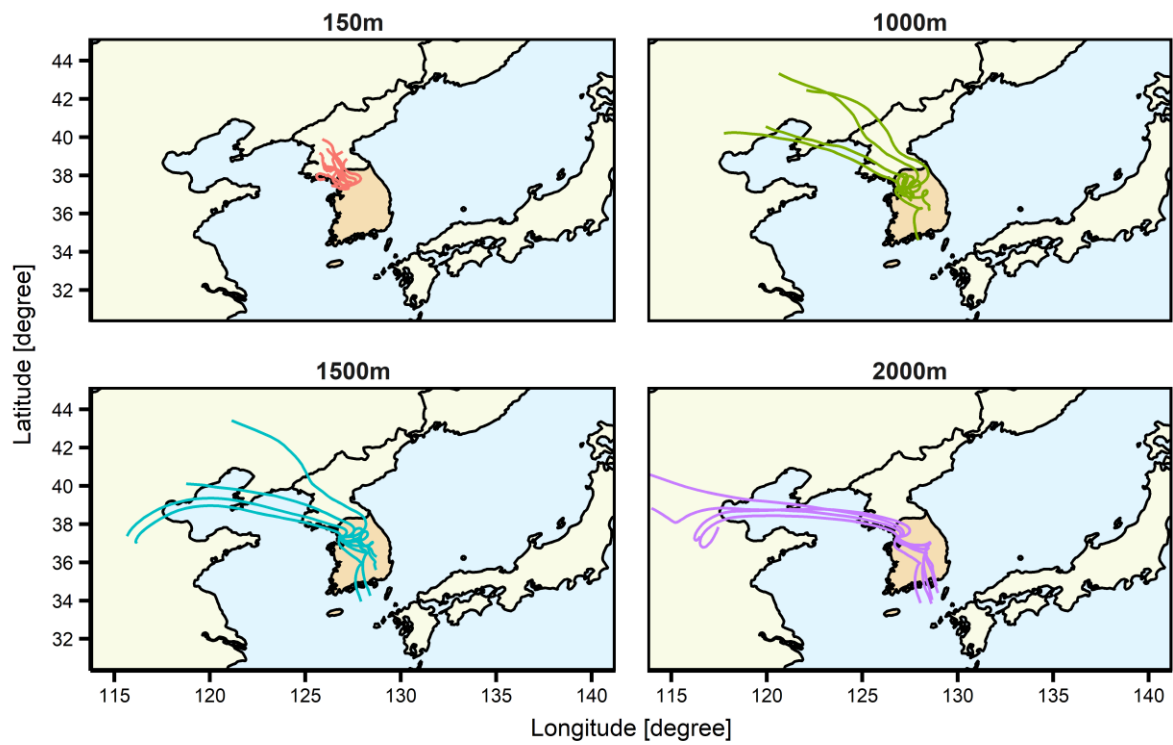


Figure S5. Backward air trajectories for Cluster 3 estimated at the arriving altitudes of 150m, 1000m, 1500m, and 2000m.

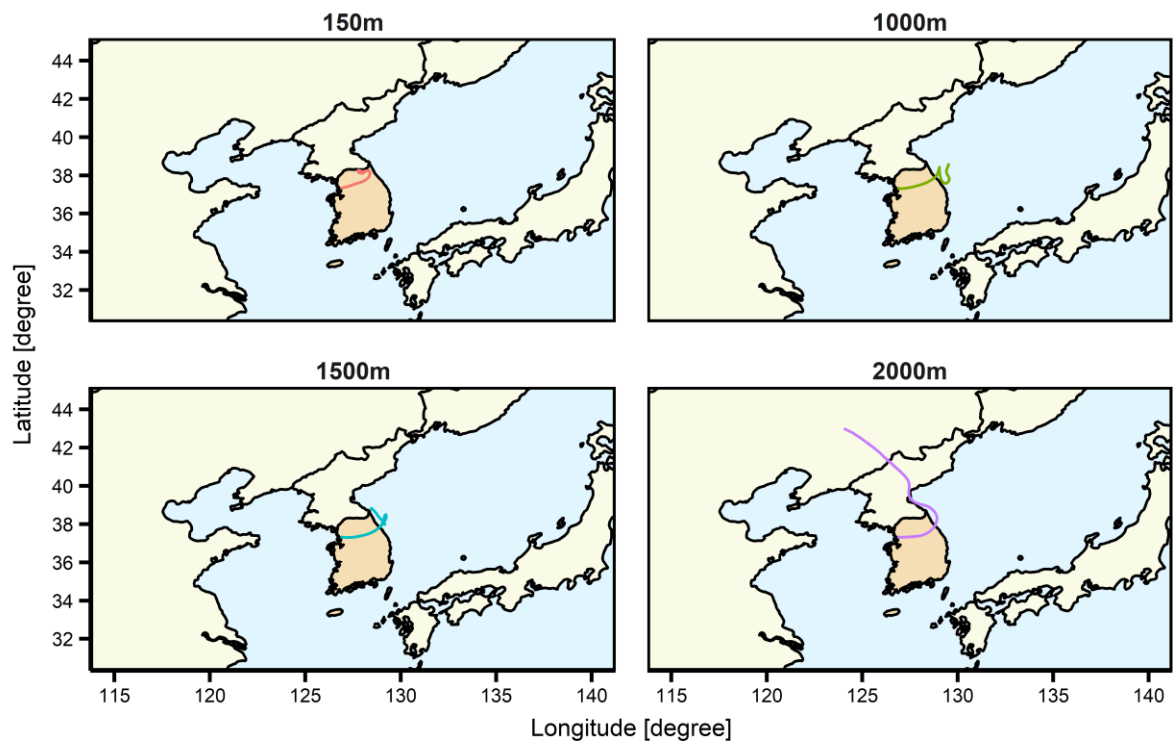


Figure S6. Backward air trajectories for Cluster 4 estimated at the arriving altitudes of 150m, 1000m, 1500m, and 2000m.

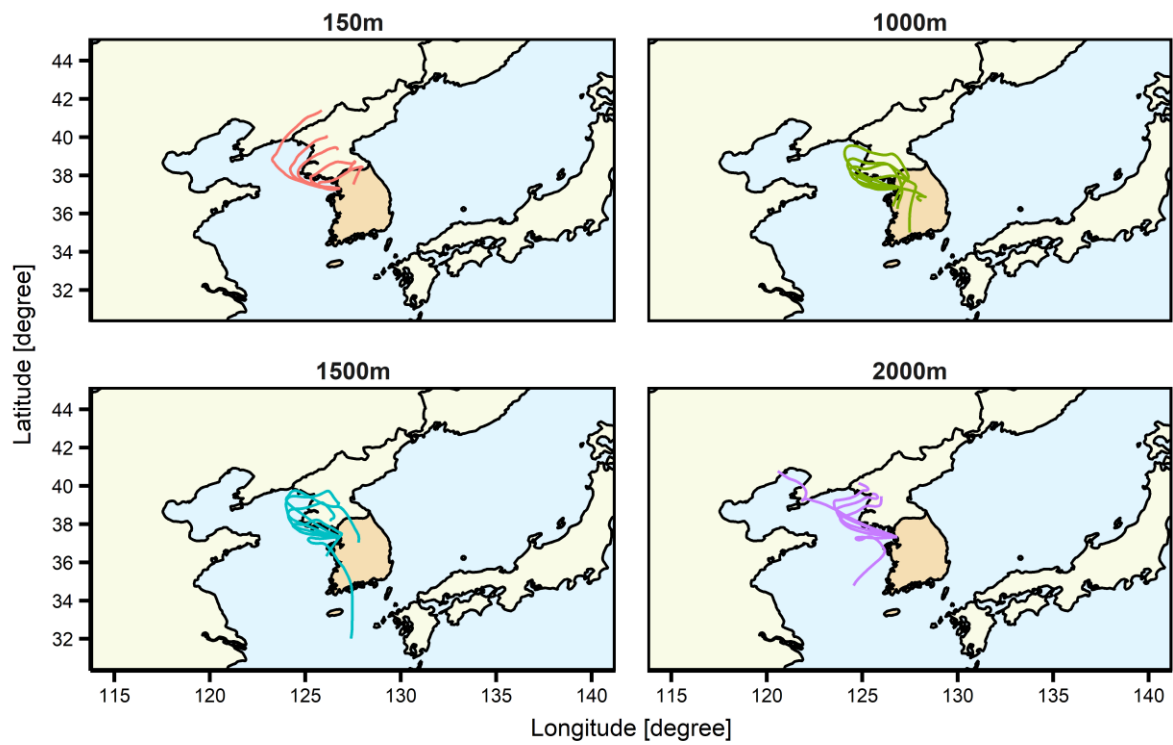


Figure S7. Backward air trajectories for Cluster 5 estimated at the arriving altitudes of 150m, 1000m, 1500m, and 2000m.

Table S10. PM_{2.5} and O₃ concentrations measured by UAV for the five cluster types.

Pollutant	Altitude (m)	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
PM _{2.5} (µg/m ³)	30	21.8	13.5	7.8	3.5	12.3
	60	22.0	14.3	7.7	2.6	12.5
	90	21.9	15.5	8.9	2.2	12.7
	120	22.6	16.2	7.8	2.1	13.1
	145	22.8	16.5	8.8	2.2	13.3
	Average	22.2	15.2	8.2	2.5	12.8
	Standard deviation	0.4	1.3	0.6	0.6	0.4
O ₃ (ppm)	30	0.029	0.026	0.018	0.024	0.017
	60	0.029	0.040	0.025	0.024	0.019
	90	0.031	0.046	0.026	0.042	0.019
	120	0.034	0.042	0.024	0.032	0.022
	145	0.033	0.048	0.024	0.037	0.020
	Average	0.031	0.040	0.024	0.032	0.019
	Standard deviation	0.002	0.009	0.003	0.008	0.002