Figure S1. Vertical profiles of the vertical gradient of potential temperature (Δθ/Δz) [K km⁻¹], Relative Humidity [%], Wind speed [m s⁻¹], rBC mass concentration (M_rBC) [ng m⁻³] for each flight during 2021. The vertical dotted black line shows Δθ/Δz = 5 K km⁻¹.

Figure S2. Vertical profiles of the vertical gradient of potential temperature ($\Delta\theta/\Delta z$) [K km^{-1}], Relative Humidity [%], Wind speed [m s^{-1}], rBC mass concentration (M_{rBC}) [ng m^{-3}] for each flight during 2022. The vertical dotted black line shows $\Delta\theta/\Delta z = 5$ K km^{-1}.
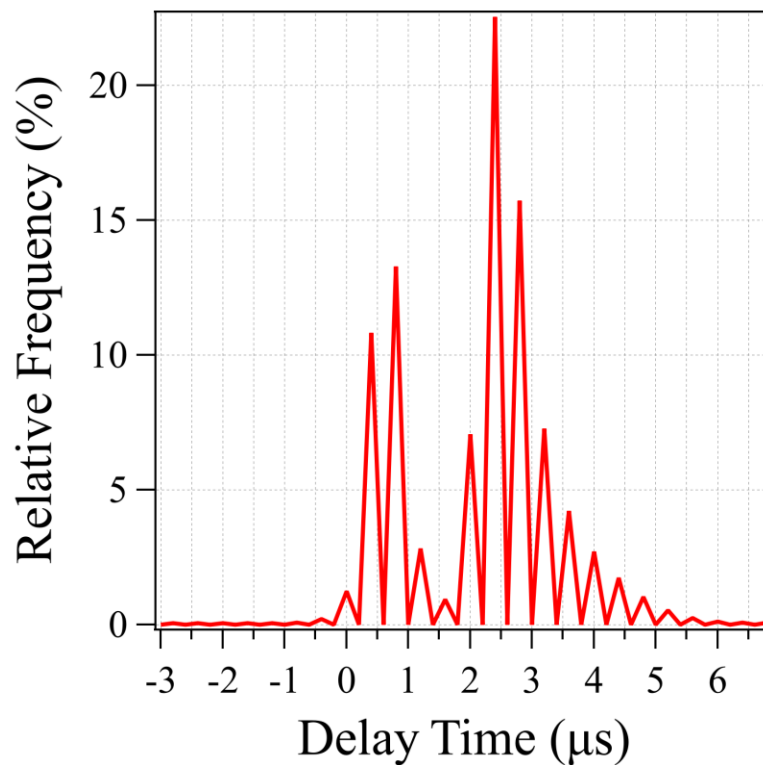
Figure S3. Distribution of delay time, defined as the difference between the incandescence and scattering channel signal peak times, for individual rBC particles observed during all flights over the Yellow Sea.
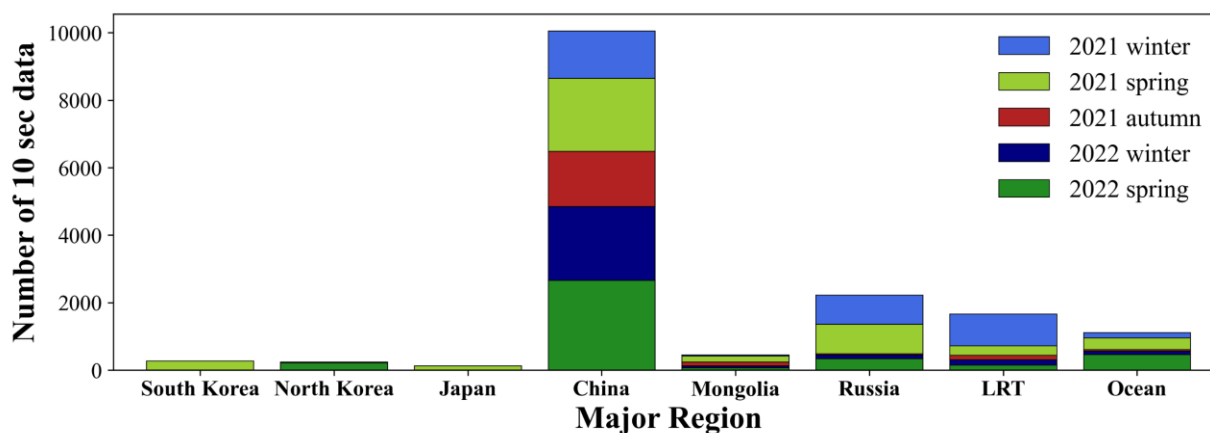
Figure S4. Number of 10-second data for each Major Region categorized. Major Regions include South Korea, North Korea, Japan, China, Mongolia, Russia, LRT, and Ocean. Seasonal classifications are as follows: Winter (Feb.–Mar.), Spring (Apr.–May), and Autumn (Oct.–Nov.).
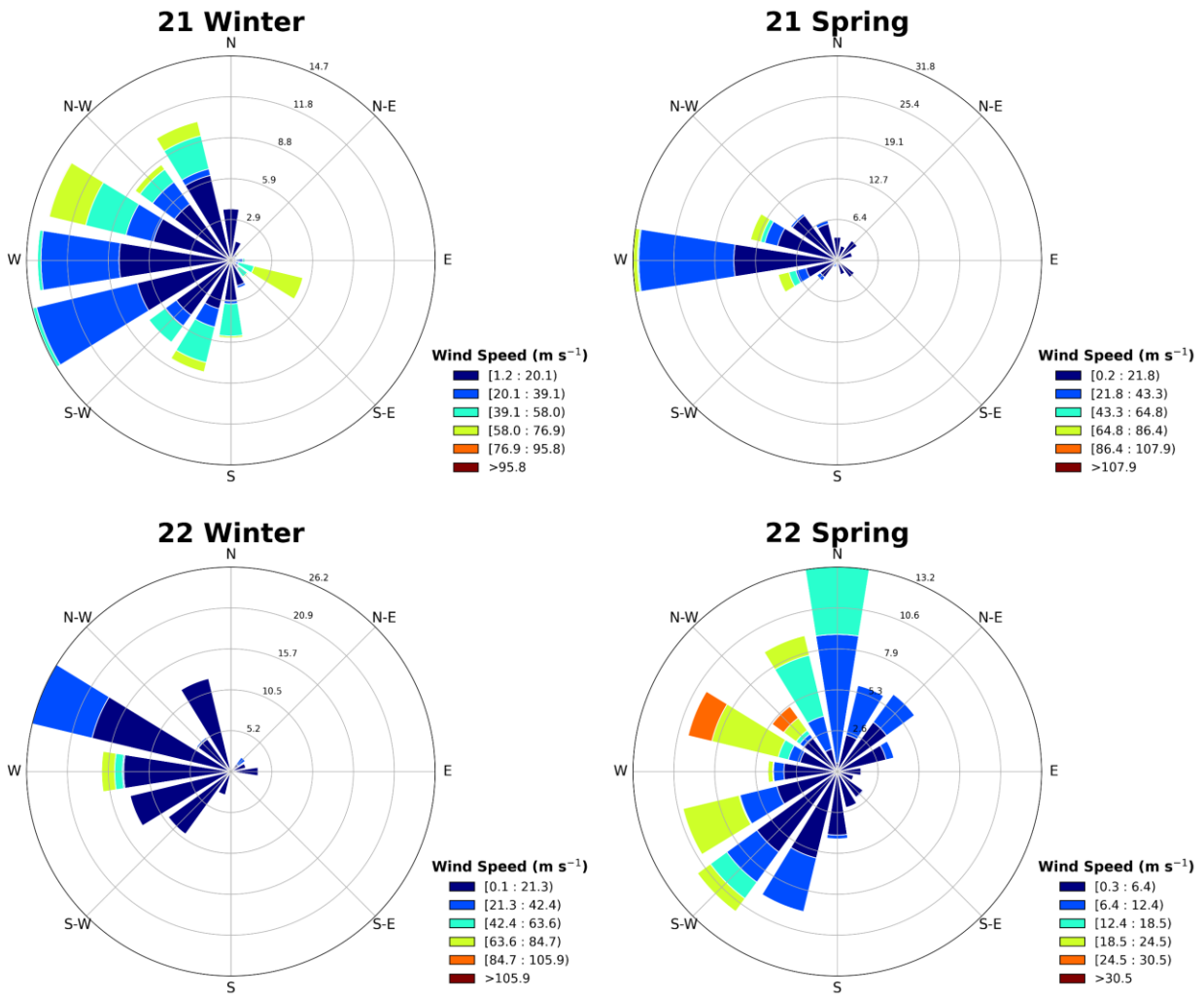
Figure S5. Seasonal wind rose plots showing wind direction and speed distributions for winter (February–March) and spring (April–May) flights in 2021 and 2022 over the Yellow Sea. Wind speed bins are color-coded, with ranges specific to each panel as indicated in the legends.
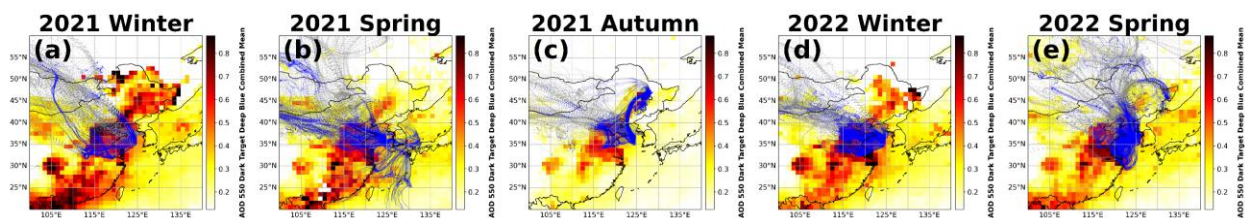
Figure S6. 5-day back trajectories and Aerosol Optical Depth (AOD): (a) 2021 Winter, (b) 2021 Spring, (c) 2021 Autumn, (d) 2022 Winter, and (e) 2022 Spring. Blue markers indicate trajectory points with altitudes below 2,500 m, and gray markers indicate points above 2,500 m. The map grid colors represent the 550 nm AOD from the Dark Target Deep Blue Combined Mean product (MODIS08 D3).

Table S1. Summary of airborne measurements including flight information and events captured during the flight missions conducted over the Yellow Sea from February 2021 to May 2022.

Flight ID (F+YYMMDD)	Latitude (°N)	Longitude (°E)	Altitude (m asl.)	Flight time (HH:MM) Outbound	Flight time (HH:MM) Inbound	Events*
F210208	34.8–37.5	124.2–126.5	442–4,794	13:04–14:35	14:35–15:27	
F210219	34.8–37.6	124.2–126.5	421–4,828	13:06–14:44	14:44–15:59	
F210316	34.8–37.6	124.2–126.5	477–4,965	11:58–13:10	13:10–14:36	
F210323	34.8–37.4	124.4–126.5	390–4,969	13:14–15:00	15:00–15:57	
F210329	34.8–37.6	124.4–126.5	457–4,858	13:09–14:56	14:57–15:33	Asian dust
F210414	34.8–37.4	124.2–126.5	462–4,869	10:05–11:37	11:37–13:10	
F210416	36.0–37.5	124.2–126.5	299–4,889	14:08–15:37	15:37–16:52	
F210428	34.6–37.5	124.2–126.5	300–4,916	10:04–11:48	11:48–13:16	Asian dust, Haze
F210429	35.9–37.6	124.2–126.5	279–4,801	12:27–13:49	13:49–15:05	
F210507	36.0–37.6	124.2–126.5	320–4,875	13:05–14:40	14:40–15:56	Asian dust
F210513	34.8–37.5	124.2–126.5	471–5,049	13:11–14:42	14:45–16:04	
F211001	34.8–37.4	124.2–126.5	477–5,025	10:07–11:36	11:36–12:57	
F211102	34.8–37.4	124.2–126.5	447–4,982	13:12–14:52	14:52–16:21	
F211125	34.8–37.5	124.2–126.5	455–4,843	12:11–13:40	13:40–15:04	
F220210	34.8–37.5	124.2–126.5	445–4,769	14:14–15:44	15:45–17:10	Haze
F220303	34.8–37.5	124.2–126.4	438–4,821	10:13–11:48	11:48–13:05	Asian dust, Haze
F220324	34.8–37.4	124.2–126.5	460–4,912	10:28–12:08	12:09–13:24	Haze
F220328	36.0–37.6	124.2–126.5	468–4,921	10:04–11:28	11:28–12:33	
F220406	34.8–37.5	124.2–126.5	548–4,954	10:05–11:38	11:38–12:38	
F220419	34.8–37.2	124.2–126.5	458–3,009	12:38–13:37	13:37–15:00	
F220420	36.0–37.4	124.2–126.5	290–4,624	12:49–13:57	13:58–14:44	
F220428	34.8–37.4	124.2–126.5	447–5,033	10:09–11:40	11:40–12:59	
F220502	34.8–37.5	124.2–126.5	468–4,836	12:59–14:27	14:27–16:03	

* Event information is identified and provided by KMA (https://www.weather.go.kr).

Table S2. Summary of the planetary boundary layer height (PBLH), and entrainment zone (EZ) depth. PBLH and EZ depth are categorized into outbound and inbound flights.

	PBLH (m)		EZ depth (m)	
	outbound	inbound	outbound	inbound
All	-	-	-	-
F210208	1,500	1,450	400	1,250
F210219	800	850	250	500
F210316	500 (inbound)		700 (inbound)	
F210323	850 (outbound)		250 (outbound)	
F210329	1,400 (outbound)		300 (outbound)	
F210414	750	750	225	375
F210416	1,350	1,200	450	750
F210428	300	300	50	500
F210429	350	300	150	600
F210507	675	900	450	900
F210513	400	1,000	200	400
F211001	800	950	150	250
F211102	1,300	1,250	450	500
F211125	1,350	1,275	300	975
F220210	700	900	200	200
F220303	525	600	75	75
F220324	600	700	300	400
F220328	1,200	1,350	450	1,500
F220406	1,500	1,600	150	500
F220419	600	600	200	900
F220420	300 (outbound)		250 (outbound)	
F220428	950	950	600	800
F220502	975 (inbound)		750 (inbound)	

Table S3. Number of 10-second data points for each major region categorized by season. Major Regions include South Korea, North Korea, Japan, China, Mongolia, Russia, LRT, and Ocean. Seasonal classifications are as follows: Winter (Feb.–Mar.), Spring (Apr.–May), and Autumn (Oct.–Nov.). The total number of data points for each region is also presented.

	2021 Winter	2021 Spring	2021 Autumn	2022 Winter	2022 Spring	Sum
South Korea[*]	0	273	0	0	0	273
North Korea[*]	1	3	10	10	213	237
Japan[*]	0	122	0	0	0	122
China	1,402	2,161	1,640	2,184	2,663	10,050
Mongolia	41	180	113	55	66	455
Russia	865	880	29	110	342	2,226
LRT	943	278	136	150	150	1,657
Ocean	158	354	45	97	462	1,116
Sum	3,410	4,251	1,973	2,606	3,896	16,136

[*]Most data (more than 90% of each Major Region data) are concentrated in a specific season.

Table S4. Total BC emissions (Gg) from the EDGAR v8.1 inventory for South Korea, North Korea, Japan, China, Mongolia, and Russia. Seasonal classifications are as follows: Winter (Feb.–Mar.), Spring (Apr.–May), and Autumn (Oct.–Nov.).

	BC emission (Gg)				
	21 Winter	21 Spring	21 Autumn	22 Winter	22 Spring
South Korea	2.4	2.2	2.3	2.5	2.1
North Korea	1.9	1.3	1.6	1.9	1.3
Japan	4.7	4.0	4.1	4.9	4.0
China	181.9	169.9	190.5	188.6	168.9
Mongolia	0.4	0.3	0.4	0.4	0.3
Russia	9.8	9.3	10.9	9.8	9.6

Table S5. Slopes for rBC/CO and CO/CO$_2$ in each Major Region and the corresponding BC/CO, CO/CO$_{-2}$ ratios from the EDGAR v8.1 emission inventory. Values in parentheses indicate R^2.

	BC/CO (ng m^{-3} ppbv^{-1})		CO/CO$_2$ (ppmv ppmv^{-1} %)	
	This study	Emission inventory	This study	Emission inventory
South Korea	0.67(0.87)	5.97	2.44(0.98)	0.67
North Korea	3.82(0.70)	8.81	0.54(0.46)	3.37
Japan	1.11(0.93)	6.83	2.40(0.99)	0.63
China	2.43(0.63)	10.96	1.33(0.69)	1.37
Mongolia	1.41(0.79)	14.89	1.82(0.91)	1.12
Russia	0.98(0.34)	5.10	1.55(0.75)	1.09