Supplementary Material

Aerosols over East and South Asia: Type identification, optical properties, and implications for radiative forcing

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This supplemental material includes 3 tables and 7 figures.

Table S1. The differences in the percentages of individual aerosol types between 2-D and MD results (unit: %). For each sub-region, the 3 values (from top to bottom) in the "difference" column refers to the percentage difference between the results of 2-D SSA-EAE and MD, 2-D RRI-EAE and MD, and 2-D AAE-EAE and MD, respectively.

Table S2. The differences in the ARF_{TOA} ($ARFE_{TOA}$) of individual aerosol types between 2-D and MD results (unit: W/m^2 and $W/m^2/AOD_{550nm}$). For each sub-region, the 3 values (from top to bottom) in the "difference" column refers to the ARF (ARFE) difference between the results of 2-D SSA-EAE and MD, 2-D RRI-EAE and MD, and 2-D AAE-EAE and MD, respectively. Note the values in the parenthesis indicate the ARFE.

Table S3. The same as Table S2 except that ARF_{BOA} ($ARFE_{BOA}$) are shown.

Figure S1. Seasonal and annual averaged meteorological conditions for the period of March 1998 to February 2018: (a) spring (March, April and May); (b) summer (June, July and August); (c) autumn (September, October and November); (d) winter (December, January and February) and (e) annual. The arrow represents wind field at 1000 hPa, and the shaded represents the precipitation (Unit: mm/d).

Figure S2. The aerosol types at the AERONET sites (a–r) in IP identified by the 2-D clustering method with AAE and EAE for the period of March 1998 to February 2018. The blue asterisks on the map indicates the locations of the sites with enough valid data for analysis, while the black ones represent the sites that are not used. The green, red, yellow, and blue dots on the scatter plots represent the data in boreal spring (March, April, and May), summer (June, July, and August), autumn (September, October, and November), and winter (December, January, and February), respectively. The boxes plotted with dash lines indicate the sub-regions listed in Table 4. For each sub-region, the differences in per-centage (2-D result minus MD result) for the U/I, BB, dust, and undetermined aerosols are shown respectively.

Figure S3. The same as Figure S2 but for the aerosol classification by the 2-D clustering method using SSA and EAE at the AERONET sites (a–l) in Japan, Korea and southeast Russia.

Figure S4. The daily averaged ARF_{TOA} for various aerosol types based on (a) the MD method; (b) the 2-D SSA-EAE method; (c) the 2-D RRI-EAE method; (d) the 2-D AAE-EAE method (Unit: W/m^2).

Figure S5. The same as Figure S4 except that the daily averaged ARF_{BOA} are shown.

Figure S6. The daily averaged $ARFE_{TOA}$ for various aerosol types based on (a) the MD method; (b) the 2-D SSA-EAE method; (c) the 2-D RRI-EAE method; (d) the 2-D AAE-EAE method (Unit: $W/m^2/AOD_{550nm}$).

Figure S7. The same as Figure S6 except that the daily averaged $ARFE_{BOA}$ are shown.

Table S1. The differences in the percentages of individual aerosol types between 2-D and MD results (unit: %). For each sub-region, the 3 values (from top to bottom) in the "difference" column refers to the percentage difference between the results of 2-D SSA-EAE and MD, 2-D RRI-EAE and MD, and 2-D AAE-EAE and MD, respectively.

Sub-region	Dust		U/I		BB		Undetermined	
	MD	difference	MD	difference	MD	difference	MD	difference
Ussuriysk site	1.9	0.0	13.0	30.6	13.0	0.0	60.2	-10.2
		0.0		-3.7		18.5		-2.8
		-0.9		22.2		21.3		-15.7
SACOL site	17.3	-2.9	0.5	33.8	0.3	18.6	71.0	-26.6
		4.0		3.7		27.7		-24.5
		1.9		23.1		31.6		-36.4
Yulin site	5.2	-4.2	0.0	34.4	0.0	30.2	78.1	-30.2
		13.5		14.6		34.4		-45.8
		12.5		31.3		6.3		-31.3
Beijing area	2.5	-0.2	7.4	42.9	1.1	24.6	61.5	-28.5
		1.1		8.3		53.3		-35.2
		0.5		26.1		62.1		-45.3
Korea and Japan area	2.8	-1.9	22.9	27.2	0.6	6.6	57.3	-10.9
		-1.6		8.0		39.7		-29.8
		-2.0		16.9		52.0		-32.5
Hong Kong area	0.0	0.0	8.4	59.6	0.0	34.8	54.4	-36.8
		0.0		33.2		43.2		-39.2
		0.0		31.6		67.6		-42.4
Yangtze River Delta	0.5	0.3	12.4	45.4	0.2	16.4	60.7	-26.8
		0.3		27.5		37.7		-39.2
		0.0		29.4		66.8		-47.5
Taiwan area	0.1	0.1	9.1	36.1	0.2	5.4	68.1	-15.1
		0.1		43.3		36.0		-56.7
		0.1		40.6		48.1		-46.0
Dongsha_Island site	0.0	0.0	9.1	45.5	0.0	6.5	71.4	-28.6
		0.0		44.2		32.5		-57.1
		0.0		54.5		51.9		-57.1
Manila_Observatory site	0.0	0.0	12.4	38.1	0.0	54.6	67.0	-51.5
		0.0		32.0		26.8		-38.1
		0.0		48.5		48.5		-51.5
Mandalay_MTU site	0.0	0.0	0.0	48.7	0.0	62.8	98.7	-87.2
		0.0		17.9		59.0		-75.6
		0.0		7.7		89.7		-88.5
NIGP area	8.8	0.1	0.7	36.0	0.5	31.0	64.7	-27.7
		3.9		6.8		39.0		-24.3

		3.1		35.9		39.3	-36.2
Central Nepal area	0.5	-0.4	5.1	41.0	6.3	52.4	50.1 -35.5
		-0.3		12.4		55.6	-29.7
		-0.3		51.6		58.2	-41.0
Pune site	0.8	-0.1	0.3	35.7	0.1	49.1	71.0 -40.9
		-0.1		12.0		60.3	-44.4
		-0.4		68.2		37.9	-57.3
Bangladesh area	0.0	0.0	0.2	52.0	0.0	60.1	65.7 -57.0
		0.0		23.8		62.7	-52.5
		0.0		57.8		64.7	-59.9
CIP area	0.0	0.0	11.6	41.8	24.3	10.4	49.0 -20.6
		0.0		16.8		-6.0	4.3
		0.0		14.3		17.4	-2.6
Hanoi area	0.0	0.0	6.0	59.7	2.1	20.3	60.4 -34.9
		0.0		46.4		32.0	-46.9
		0.0		30.5		73.0	-52.2

Table S2. The differences in the ARF_{TOA} ($ARFE_{TOA}$) of individual aerosol types between 2-D and MD results (unit: W/m^2 and $W/m^2/AOD_{550nm}$). For each sub-region, the 3 values (from top to bottom) in the "difference" column refers to the ARF (ARFE) difference between the results of 2-D SSA-EAE and MD, 2-D RRI-EAE and MD, and 2-D AAE-EAE and MD, respectively. Note the values in the parenthesis indicate the ARFE.

Sub-region	Dust		U/l		BB		Undetermined	
	MD	difference	MD	difference	MD	difference	MD	difference
Ussuriysk site	-36.0 (-68.6)	-2.4 (-17.9) -2.4 (-17.9) -5.2 (-14.2)	-26.7 (-66.5)	-0.5 (4.6) 0.2 (10.1) -1.8 (4.8)	-20.3 (-54.8)	-3.8 (2.2) -10.7 (-11.1) -12.8 (-13.3)	-28.7 (-62.4)	-0.9 (-5.1) 2.0 (-2.1) 4.6 (-0.8)
SACOL site	-34.9 (-67.1)	-5.8 (-2.7) -8.8 (0.0) -6.5 (0.1)	-22.4 (-60.7)	-4.2 (-2.7) -10.7 (2.0) -4.1 (1.4)	-15.2 (-50.0)	-5.8 (-10.1) -10.3 (-11.9) -11.3 (-14.5)	-30.4 (-63.8)	-3.8 (-2.5) 1.5 (-2.7) -1.4 (-3.4)
Yulin site	-36.1 (-60.2)	10.8 (-8.6) 7.0 (3.0) 8.5 (6.2)	/	/ (/) / (/) / (/)	/	/ (/) / (/) / (/)	-20.8 (-36.2)	-0.1 (-3.4) 0.9 (0.3) 3.1 (5.5)
Beijing area	-50.5 (-69.0)	0.1 (-6.1) 0.4 (-1.8) -0.5 (1.3)	-47.3 (-57.8)	-1.5 (1.3) -5.7 (2.7) -1.7 (3.7)	-40.7 (-60.0)	7.5 (0.3) -7.4 (3.4) -9.0 (2.8)	-49.6 (-58.4)	-6.6 (-0.6) 3.2 (-3.6) 5.4 (-6.9)
Korea and Japan area	-42.1 (-78.4)	-4.2 (-8.2) -2.9 (-8.2) -2.9 (-6.7)	-33.8 (-70.9)	-0.1 (1.4) -4.0 (3.2) -1.1 (3.0)	-22.2 (-60.9)	-4.1 (-7.0) -15.0 (-9.3) -16.6 (-10.7)	-38.4 (-71.3)	-2.0 (-0.6) 3.8 (-2.7) 2.1 (-1.4)
Hong Kong area	/	/ (/) / (/) / (/)	-42.7 (-75.0)	5.0 (4.9) 5.5 (5.3) 4.2 (5.7)	/	/ (/) / (/) / (/)	-35.0 (-67.9)	-9.4 (-7.8) 1.1 (-4.8) -4.8 (-1.2)

Yangtze River Delta	-50.3 (-82.8)	-29.7 (11.5)	-50.0 (-67.2)	2.3 (1.0)	-46.1 (-56.7)	13.9 (-3.7)	-52.7 (-69.0)	-2.8 (-1.0)
		-29.7 (11.5)		1.9 (2.3)		-4.9 (-9.0)		6.5 (-2.4)
		-37.2 (18.8)		6.3 (3.6)		-5.2 (-9.3)		6.1 (-5.1)
Taiwan area	-35.0 (-72.0)	0.6 (-0.9)	-29.1 (-65.9)	-2.7 (6.8)	-26.7 (-45.7)	3.9 (-5.0)	-34.2 (-62.7)	-3.3 (-3.9)
		0.6 (-0.9)		-6.5 (3.4)		-8.0 (-17.7)		4.6 (0.6)
		0.6 (-0.9)		-5.4 (4.0)		-10.8 (-18.6)		4.2 (1.5)
Dongsha_Island site	/	/ (/)	-32.5 (-81.6)	-5.4 (7.8)	/	/ (/)	-38.5 (-77.5)	1.5 (-4.4)
		/ (/)		-3.6 (5.3)		/ (/)		1.1 (1.2)
		/ (/)		-3.2 (6.2)		/ (/)		9.6 (-4.0)
Manila_Observatory site	/	/ (/)	-27.2 (-63.1)	0.4 (3.9)	/	/ (/)	-23.3 (-54.3)	1.6 (-2.9)
		/ (/)		2.2 (8.8)		/ (/)		0.7 (-4.0)
		/ (/)		5.3 (9.8)		/ (/)		-0.1 (-8.2)
Mandalay_MTU site	/	/ (/)	/	/ (/)	/	/ (/)	-29.4 (-51.4)	7.0 (7.3)
		/ (/)		/ (/)		/ (/)		2.1 (6.7)
		/ (/)		/ (/)		/ (/)		-1.3 (-9.0)
NIGP area	-33.7 (-56.2)	-3.3 (-2.8)	-31.6 (-52.3)	0.4 (4.8)	-21.7 (-49.2)	-1.8 (5.7)	-28.1 (-47.1)	-0.4 (-3.3)
		-1.6 (-0.3)		0.7 (6.3)		-6.6 (3.8)		1.1 (-2.6)
		-1.9 (0.7)		4.8 (9.7)		-6.8 (1.8)		0.3 (-4.9)
Central Nepal area	-36.2 (-64.4)	-13.0 (11.2)	-31.9 (-50.4)	-0.1 (-2.5)	-32.5 (-47.0)	7.1 (-1.8)	-26.4 (-50.2)	2.0 (6.8)
		-5.8 (18.7)		2.6 (-2.8)		5.4 (-1.1)		-0.4 (-1.1)
		-5.8 (18.7)		5.2 (4.1)		4.5 (-5.3)		1.5 (6.7)
Pune site	-31.0 (-69.1)	-2.5 (3.0)	-30.7 (-62.2)	2.6 (5.9)	-22.1 (-61.4)	0.3 (11.6)	-21.8 (-49.4)	3.4 (2.9)

		-2.5 (3.0)		5.4 (9.9)		-0.1 (12.9)		-0.2 (-4.0)
		-4.0 (5.8)		9.5 (15.1)		-2.8 (7.4)		-1.2 (-6.4)
Bangladesh area	/	/ (/)	-43.7 (-66.8)	2.0 (16.9)	/	/ (/)	-38.1 (-49.8)	-1.8 (-2.2)
		/ (/)		4.9 (16.4)		/ (/)		1.7 (-2.3)
		/ (/)		8.6 (20.5)		/ (/)		5.2 (-1.7)
CIP area	/	/ (/)	-35.2 (-56.9)	4.3 (4.0)	-32.9 (-44.6)	7.8 (-1.6)	-27.8 (-47.5)	-3.9 (-1.0)
		/ (/)		4.4 (2.8)		5.2 (-8.6)		-1.8 (0.8)
		/ (/)		8.6 (6.8)		2.6 (-9.1)		-2.3 (1.8)
Hanoi area	/	/ (/)	-38.0 (-60.4)	-2.2 (3.6)	-50.5 (-38.0)	19.9 (-12.7)	-41.5 (-54.5)	-4.2 (-3.7)
		/ (/)		-3.1 (2.4)		9.9 (-15.7)		4.0 (1.0)
		/ (/)		-1.2 (7.2)		8.6 (-19.3)		6.4 (0.9)

Table S3. The same as Table S2 except that ARF_{BOA} ($ARFE_{BOA}$) are shown.

Sub-region	Dust		U/I		BB		Undetermined	
	MD	difference	MD	difference	MD	difference	MD	difference
Ussuriysk site	-80.6 (-154.0)	9.2 (-7.9)	-57.5 (-140.0)	-12.1 (-11.8)	-73.3 (-198.0)	-4.5 (25.3)	-68.4 (-147.1)	5.8 (-1.2)
		9.2 (-7.9)		-6.3 (2.3)		1.9 (54.8)		4.6 (-12.7)
		8.5 (9.0)		-8.9 (0.1)		2.3 (54.6)		5.4 (-18.8)
SACOL site	-83.5 (-163.6)	-6.4 (7.5)	-49.5 (-132.2)	-20.4 (-36.9)	-50.0 (-163.7)	-17.5 (-32.2)	-78.4 (-174.4)	-3.1 (7.2)
		-17.2 (4.4)		-20.8 (-16.4)		-17.2 (-5.6)		4.7 (-2.1)
		-13.7 (1.7)		-22.5 (-41.3)		-18.8 (-10.1)		2.2 (5.3)
Yulin site	-92.3 (-163.4)	34.2 (6.0)	/	/ (/)	/	/ (/)	-102.2 (-189.2)	3.4 (-16.6)
		3.7 (-17.5)		/ (/)		/ (/)		0.5 (-12.1)
		1.2 (-21.7)		/ (/)		/ (/)		-2.7 (-4.0)
Beijing area	-110.2 (-147.2)	5.8 (-4.1)	-99.7 (-121.9)	-19.2 (-13.9)	-111.6 (-163.1)	13.7 (-12.9)	-115.1 (-139.8)	2.8 (15.4)
		0.9 (-4.6)		-12.4 (0.7)		-3.9 (22.2)		8.8 (-8.7)
		-6.1 (-5.5)		-15.2 (-10.2)		-4.0 (23.2)		16.1 (-9.1)
Korea and Japan area	-82.9 (-154.5)	1.1 (1.2)	-64.1 (-135.6)	-8.0 (-14.4)	-61.6 (-168.7)	-9.6 (-11.0)	-72.8 (-137.5)	3.8 (13.2)
		2.3 (-1.3)		-4.7 (9.3)		-12.2 (26.9)		4.6 (-10.9)
		0.9 (-2.0)		-3.9 (0.1)		-10.7 (32.1)		1.1 (-7.7)
Hong Kong area	/	/ (/)	-79.9 (-140.5)	-5.9 (-17.7)	/	/ (/)	-86.2 (-170.4)	13.6 (42.2)
		/ (/)		-4.0 (-21.0)		/ (/)		7.9 (2.0)
		/ (/)		-4.9 (-13.1)		/ (/)		5.4 (26.6)
Yangtze River Delta	-94.2 (-153.4)	-44.0 (32.7)	-92.4 (-124.1)	-10.4 (-18.2)	-127.2 (-156.4)	30.8 (-23.2)	-100.8 (-134.5)	5.4 (12.6)
		-44.0 (32.7)		-0.6 (-3.8)		18.7 (11.0)		4.5 (-14.8)

		-62.4 (39.5)		-1.3 (-17.0)		23.4 (19.0)		10.4 (-11.9)
Taiwan area	-63.9 (-131.6)	4.3 (5.6)	-57.4 (-129.3)	-21.6 (-16.7)	-99.3 (-171.5)	14.9 (-9.8)	-70.6 (-131.9)	6.5 (17.7)
		4.3 (5.6)		-11.9 (6.7)		24.3 (34.6)		2.3 (-9.8)
		4.3 (5.6)		-15.8 (-1.0)		27.3 (47.2)		3.5 (-6.1)
Dongsha_Island site	/	/ (/)	-60.4 (-147.4)	-18.6 (-6.7)	/	/ (/)	-68.3 (-137.8)	13.3 (13.1)
		/ (/)		-3.8 (10.0)		/ (/)		-8.8 (-10.7)
		/ (/)		-9.4 (1.5)		/ (/)		16.2 (-7.0)
Manila_Observatory site	/	/ (/)	-69.0 (-157.6)	-2.5 (-3.1)	/	/ (/)	-71.7 (-177.7)	10.1 (-7.7)
		/ (/)		-4.7 (-9.5)		/ (/)		5.9 (-3.7)
		/ (/)		-2.3 (-22.6)		/ (/)		7.9 (5.9)
Mandalay_MTU site	/	/ (/)	/	/ (/)	/	/ (/)	-98.9 (-165.7)	-10.6 (-34.7)
		/ (/)		/ (/)		/ (/)		-20.3 (-11.4)
		/ (/)		/ (/)		/ (/)		14.0 (22.4)
NIGP area	-84.3 (-141.1)	-2.5 (3.2)	-82.0 (-138.6)	-16.9 (-11.3)	-78.4 (-177.2)	-19.3 (-0.1)	-96.6 (-164.6)	6.7 (4.1)
		-5.1 (-2.4)		-8.6 (-2.9)		-22.5 (15.3)		7.0 (-0.7)
		-7.3 (-2.0)		-19.8 (-24.8)		-17.9 (15.6)		10.4 (3.0)
Central Nepal area	-80.0 (-141.6)	-21.8 (31.4)	-102.7 (-155.3)	4.6 (-1.2)	-128.1 (-176.9)	28.1 (-7.8)	-101.3 (-186.8)	-4.3 (-1.5)
		-44.5 (5.0)		8.7 (-11.4)		27.3 (0.8)		2.0 (3.7)
		-44.5 (5.0)		-0.2 (-20.9)		32.6 (1.1)		-4.3 (3.7)
Pune site	-64.3 (-144.6)	-3.3 (7.5)	-71.2 (-145.8)	-10.4 (-18.4)	-73.3 (-198.3)	-16.1 (-2.1)	-85.7 (-200.0)	3.5 (-19.8)
		-3.3 (7.5)		-12.7 (-33.3)		-15.1 (-0.6)		6.0 (-0.2)
		-8.2 (9.7)		-16.9 (-55.8)		-10.9 (5.2)		9.6 (13.9)

Bangladesh area	/	/ (/) / (/) / (/)	-82.6 (-126.9)	-32.3 (-8.3) -22.4 (-14.6) -35.1 (-32.1)	/	/ (/) / (/) / (/)	-118.9 (-156.9)	16.9 (11.5) 12.9 (1.4) 29.6 (15.1)
CIP area	/	/ (/) / (/) / (/)	-91.3 (-141.1)	0.1 (-11.7) 5.9 (-9.5) 5.2 (-20.2)	-125.7 (-163.0)	25.5 (-16.4) 42.5 (3.8) 36.4 (6.3)	-105.4 (-172.6)	-8.0 (8.2) -7.2 (1.6) -12.7 (1.4)
Hanoi area	/	/ (/) / (/) / (/)	-83.0 (-124.1)	-14.0 (-10.8) -5.6 (-1.2) -14.6 (-10.2)	-192.0 (-139.4)	85.7 (-25.0) 88.8 (0.5) 97.1 (9.2)	-99.1 (-129.7)	12.0 (18.1) -11.1 (-13.1) -2.0 (-6.7)

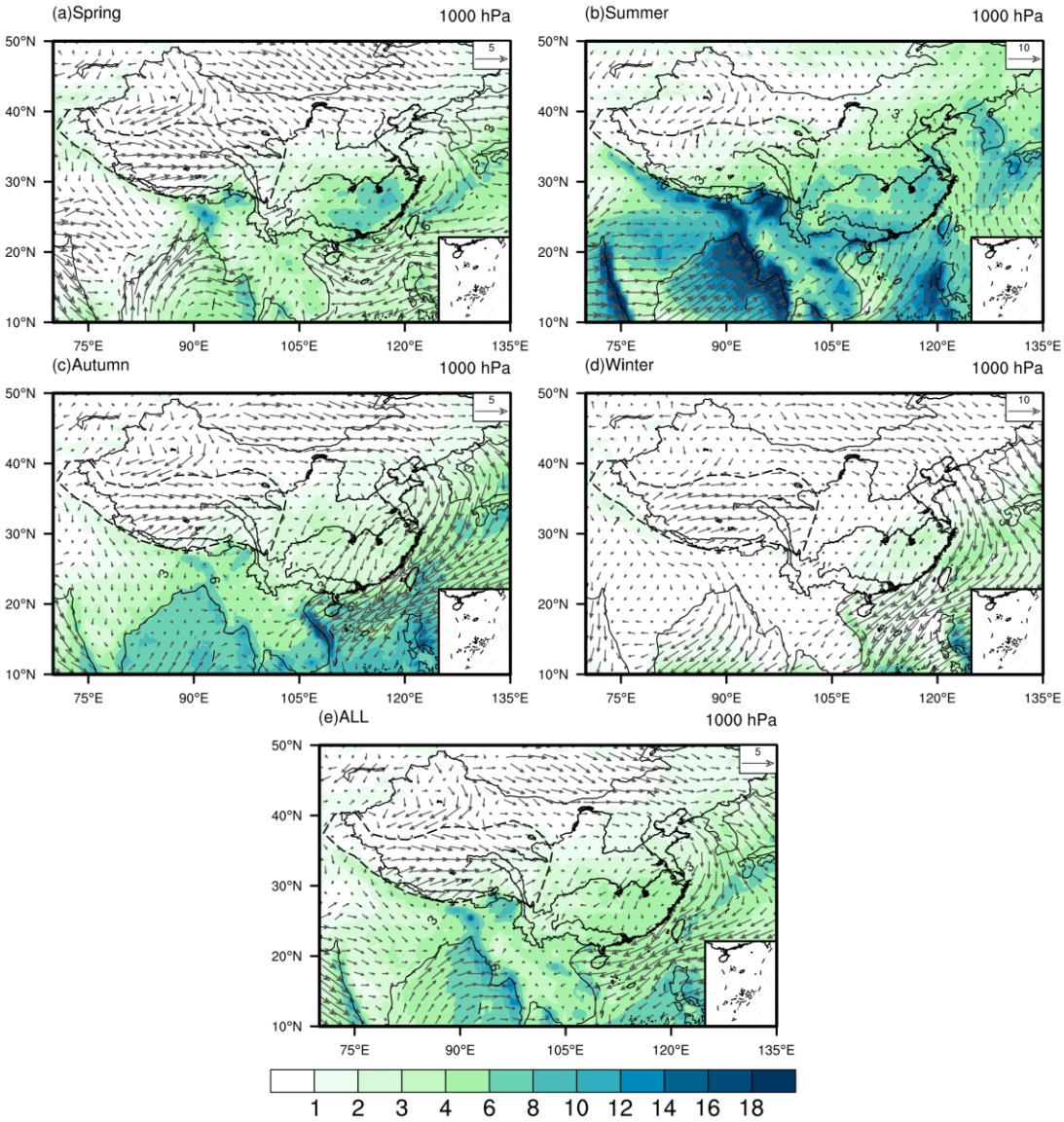

Figure S1. Seasonal and annual averaged meteorological conditions for the period of March 1998 to February 2018: (a) spring (March, April and May); (b) summer (June, July and August); (c) autumn (September, October and November); (d) winter (December, January and February) and (e) annual. The arrow represents wind field at 1000 hPa, and the shaded represents the precipitation (Unit: mm/d).

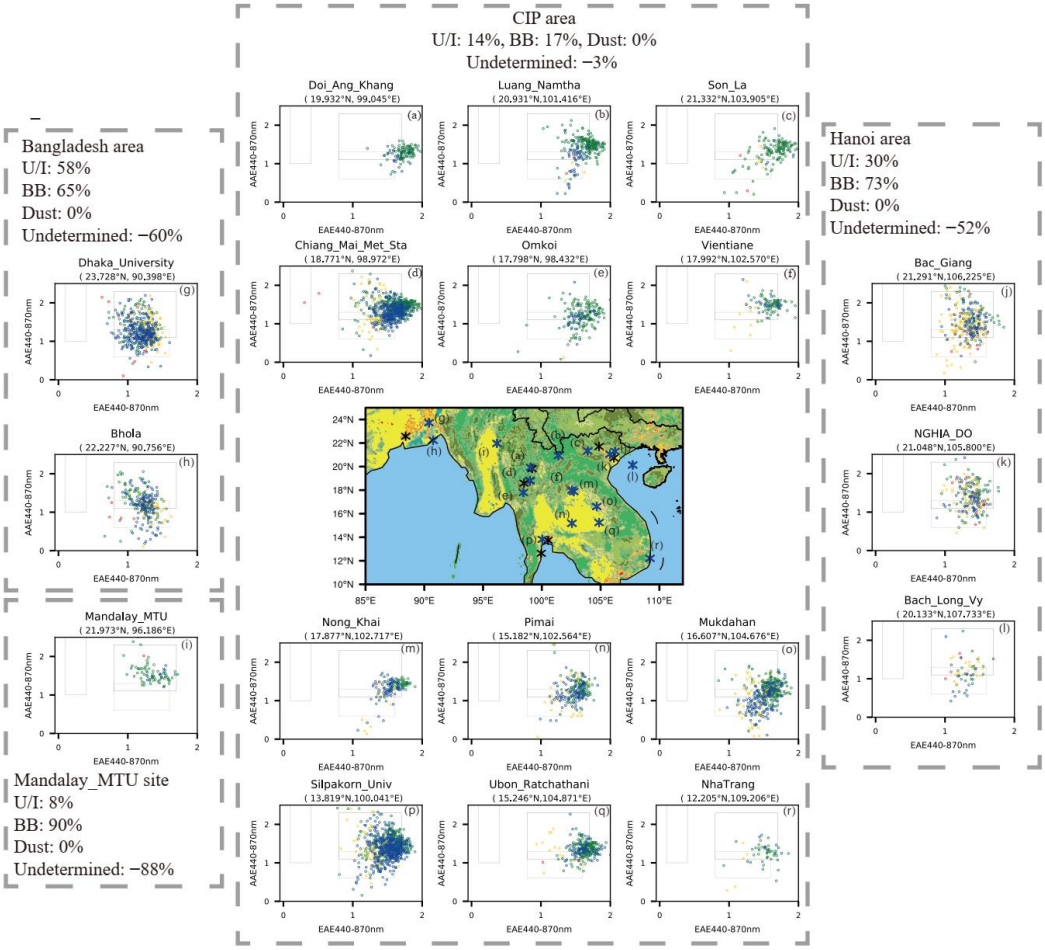

Figure S2. The aerosol types at the AERONET sites (a–r) in IP identified by the 2-D clustering method with AAE and EAE for the period of March 1998 to February 2018. The blue asterisks on the map indicates the locations of the sites with enough valid data for analysis, while the black ones represent the sites that are not used. The green, red, yellow, and blue dots on the scatter plots represent the data in boreal spring (March, April, and May), summer (June, July, and August), autumn (September, October, and November), and winter (December, January, and February), respectively. The boxes plotted with dash lines indicate the sub-regions listed in Table 4. For each sub-region, the differences in per-centage (2-D result minus MD result) for the U/I, BB, dust, and undetermined aerosols are shown respectively.

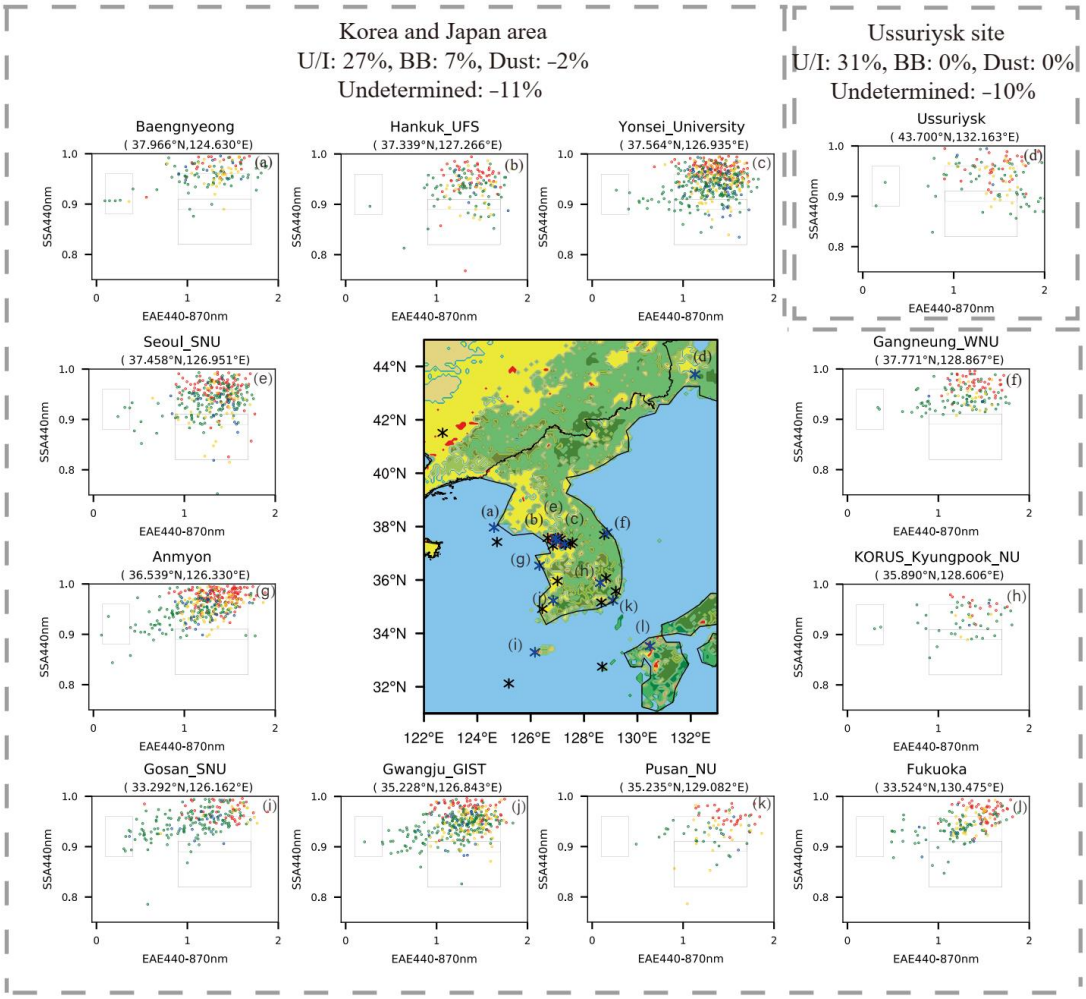

Figure S3. The same as Figure S2 but for the aerosol classification by the 2-D clustering method using SSA and EAE at the AERONET sites (a–l) in Japan, Korea and southeast Russia.

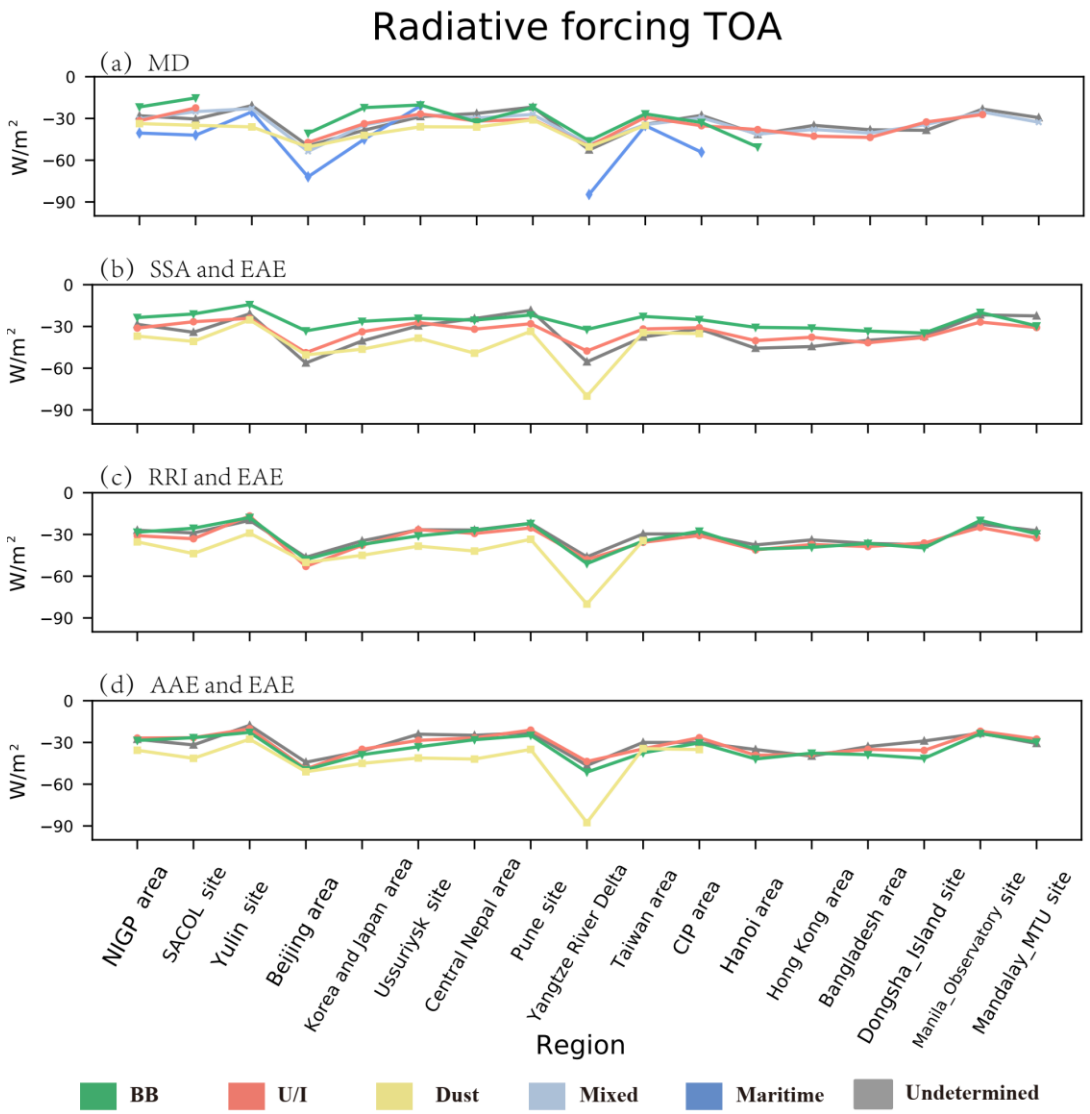

Figure S4. The daily averaged ARF_{TOA} for various aerosol types based on (a) the MD method; (b) the 2-D SSA-EAE method; (c) the 2-D RRI-EAE method; (d) the 2-D AAE-EAE method (Unit: W/m^2).

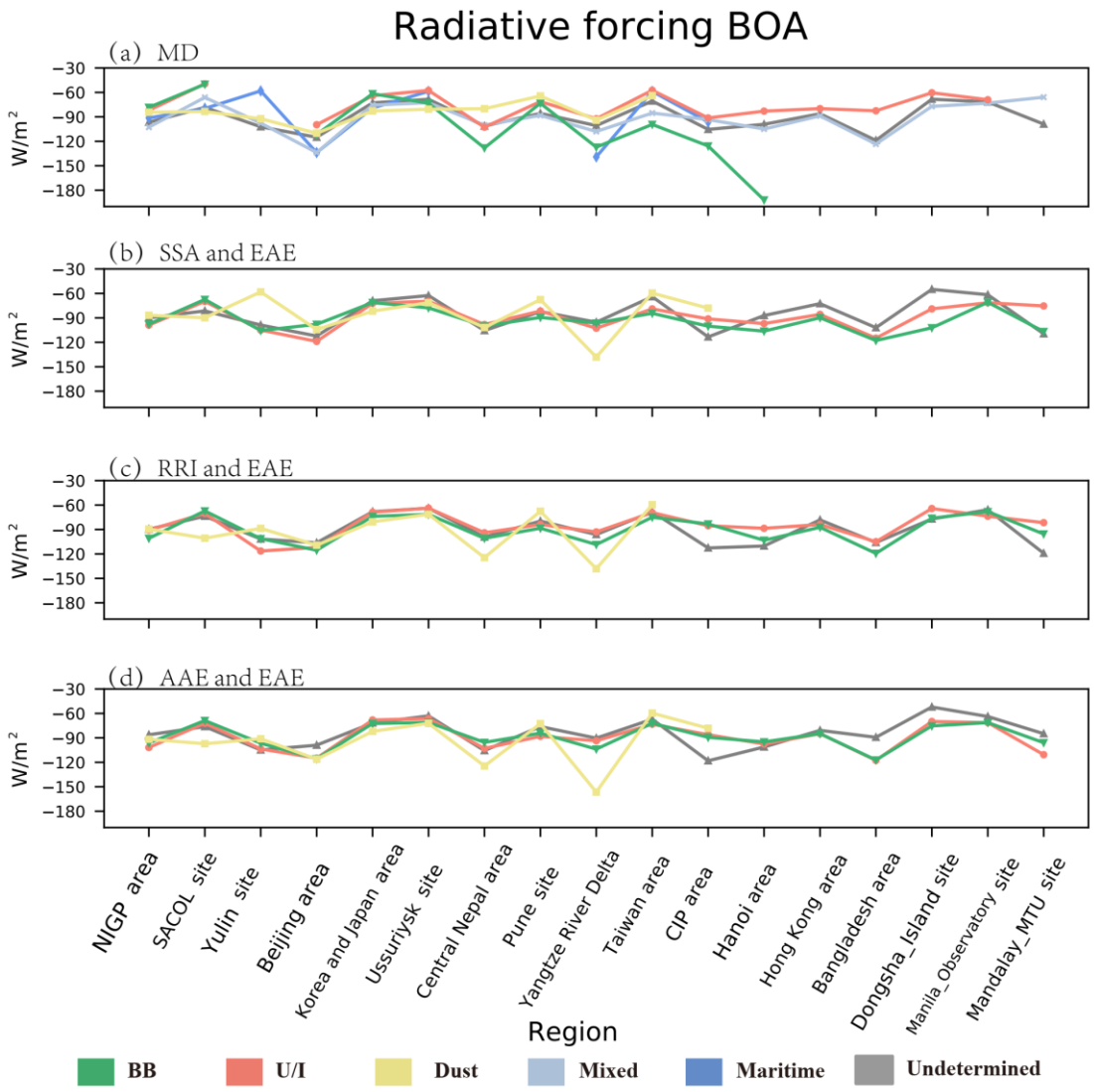

Figure S5. The same as Figure S4 except that the daily averaged ARF_{BOA} are shown.

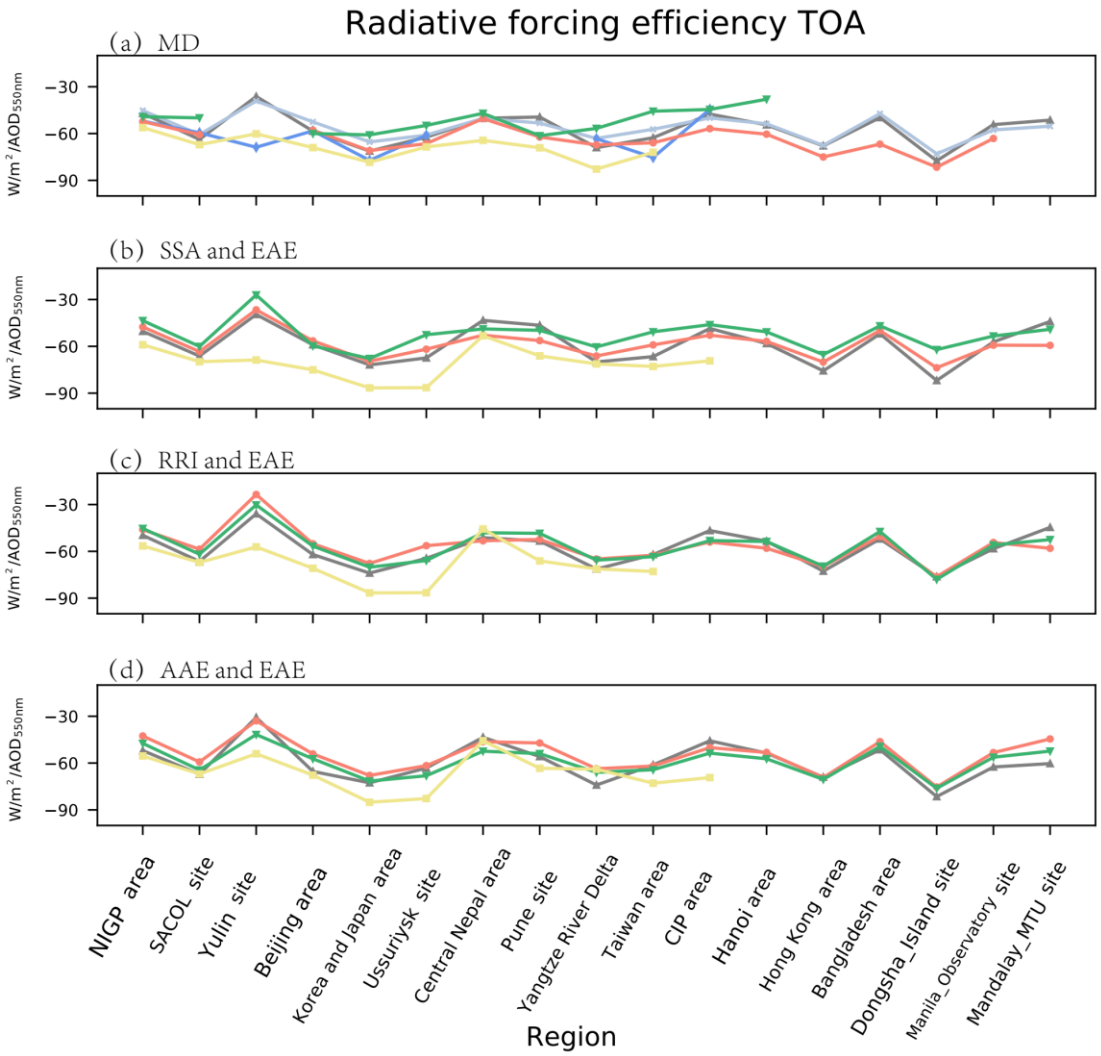

Figure S6. The daily averaged $ARFE_{TOA}$ for various aerosol types based on (a) the MD method; (b) the 2-D SSA-EAE method; (c) the 2-D RRI-EAE method; (d) the 2-D AAE-EAE method (Unit: $W/m^2/AOD_{550nm}$).

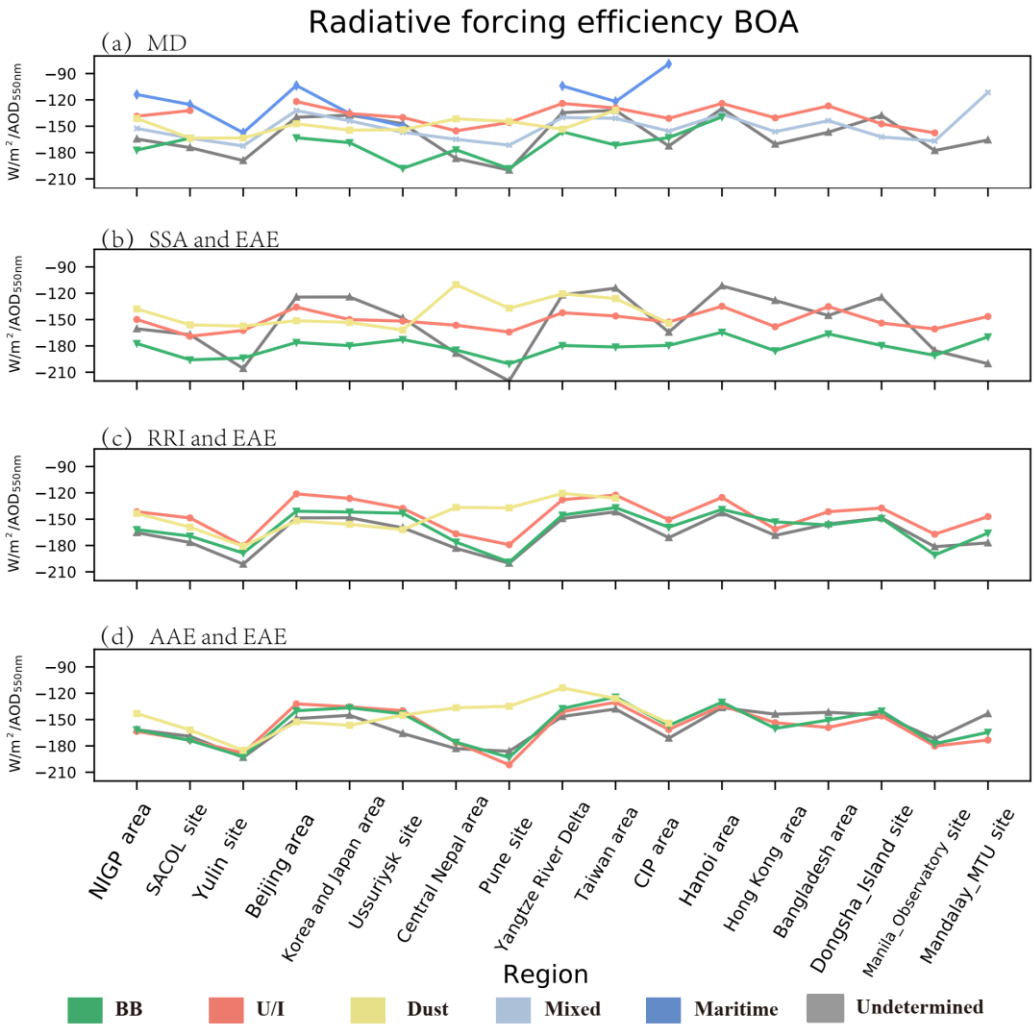

Figure S7. The same as Figure S6 except that the daily averaged ARFE$_{BOA}$ are shown.