

Supplementary Material for

Characterization of PM Using Multiple Site Data in a Heavily Industrialized Region of Turkey

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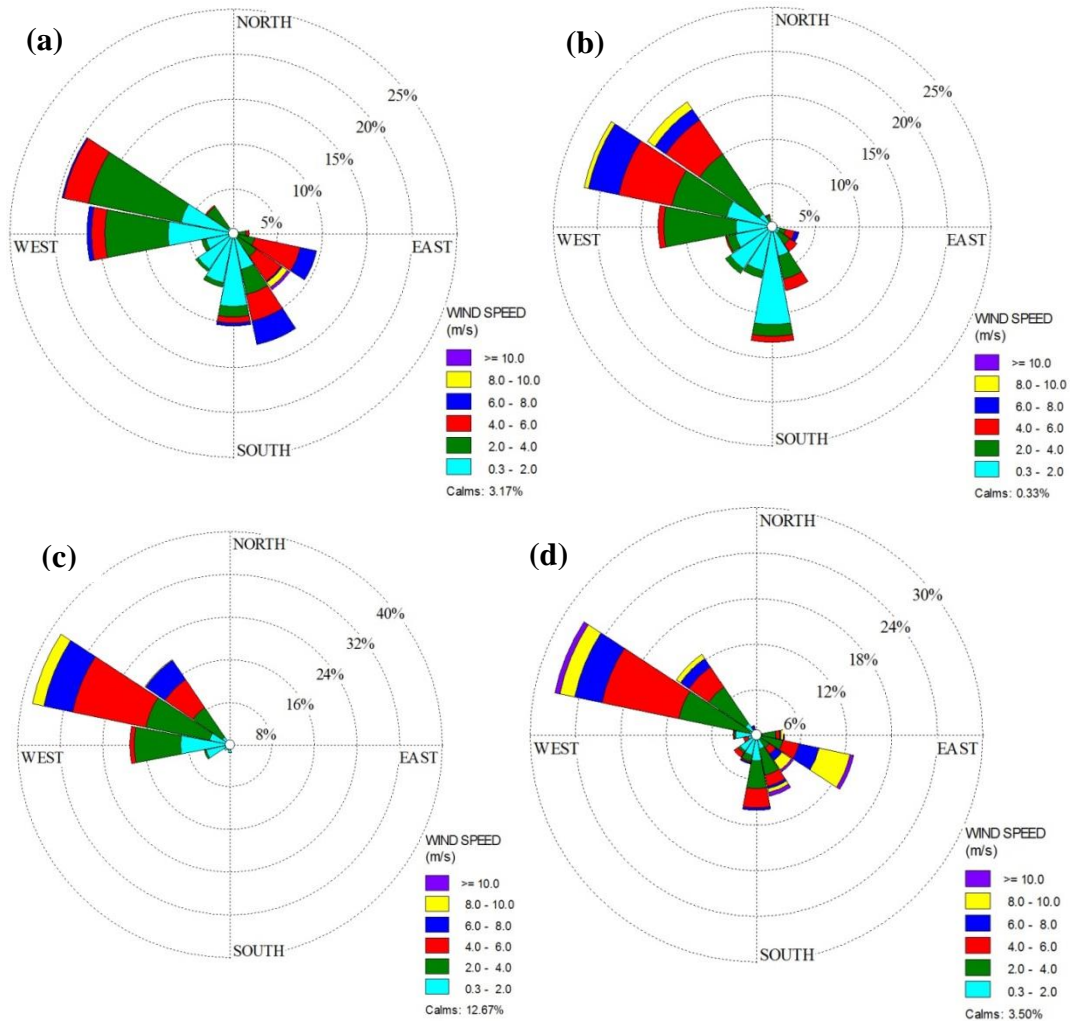


Fig. S1. Wind roses for four sampling periods a) summer, b) fall, c) winter, and d) spring.

Elemental Concentrations

In addition, $PM_{2.5}/PM_{10}$ ratios for the elements are listed in Table S2. The elements (i.e. Fe, Al, Ca, Na, Mg, Ba, Sr, and lanthanides) had low $PM_{2.5}/PM_{10}$ ratios and were mainly related to mineral matter. The elements represented in the fine fraction and with high $PM_{2.5}/PM_{10}$ ratios were mainly related to anthropogenic emissions (i.e. Zn, K, Pb, Cr, Cu, V, Sn, B, Mo, Sb, Cd, As, Rb, Ag, Bi, Se, Hg, and Tl). The elements related to coal and wood burning (As, K, B, Rb, Se, Hg, and Tl) for residential heating had also mainly higher $PM_{2.5}/PM_{10}$ in winter than in the other seasons. These results were consistent with findings in Switzerland by Minguillon et al. (2012) .

The concentrations of some elements (i.e. Fe, Zn, Mn, Pb, Cr) emitted from scrap handling and iron-steel production were quite high since these plants and their activities are the dominant PM sources in the study region. The mean concentrations for Fe, Zn, Pb, Mn, and Cr in Bozkoy that are mostly affected from Nemrut area activities were 2959, 2043, 379, 159, and 60 ng/m³, respectively. Compared these values with previous studies (Alleman et al., 2010; Carvalho and Freitas, 2011; Gupta et al., 2007; Kim et al., 2002), these levels were higher than those measured in several industrial areas. Table S3 compared selected elemental concentrations in PM₁₀ samples collected from different industrial areas.

In the region, the lanthanides (La, Ce, Nd, Pr, Sm, Gd, Dy, Er, Yb, and Y) concentrations were measured as either low or below detection limits in several PM₁₀ and PM_{2.5} samples. The REEs ratios were examined to determine whether these element concentrations were related to refinery emissions due to catalyst usage (Olmez and Gordon, 1985). The La/Ce ratios in PM₁₀ ranged between 0.52 and 0.61 in all sampling sites excluding Cakmakli. The La/Ce ratio (0.68) was slightly higher in Cakmakli than other sites. The common lanthanide Ce is typically around

twice as abundant as lighter immediate neighbor La, producing natural La/Ce ratios of 0.4-0.6 in uncontaminated rocks and soils (Rudnick and Gao, 2014). On the other hand, the La/Sm ratios were ranged between 6.9 and 9.1 in all sampling sites. Similar to La/Ce, the ratio La/Sm were slightly higher in Cakmakli. In PM_{2.5}, the mean La/Ce and La/Sm values observed 0.6 and 5.8, respectively. These values indicated that the ambient PM samples were not influenced by the catalysts in the refinery and lanthanides in particulate matter were of crustal origin. Whereas, La/Ce and La/Sm ratios in PM_{2.5} samples were found to be 2.9 and 53.7 in the vicinity of refinery complex located in Houston, TX (Kulkarni et al., 2006).

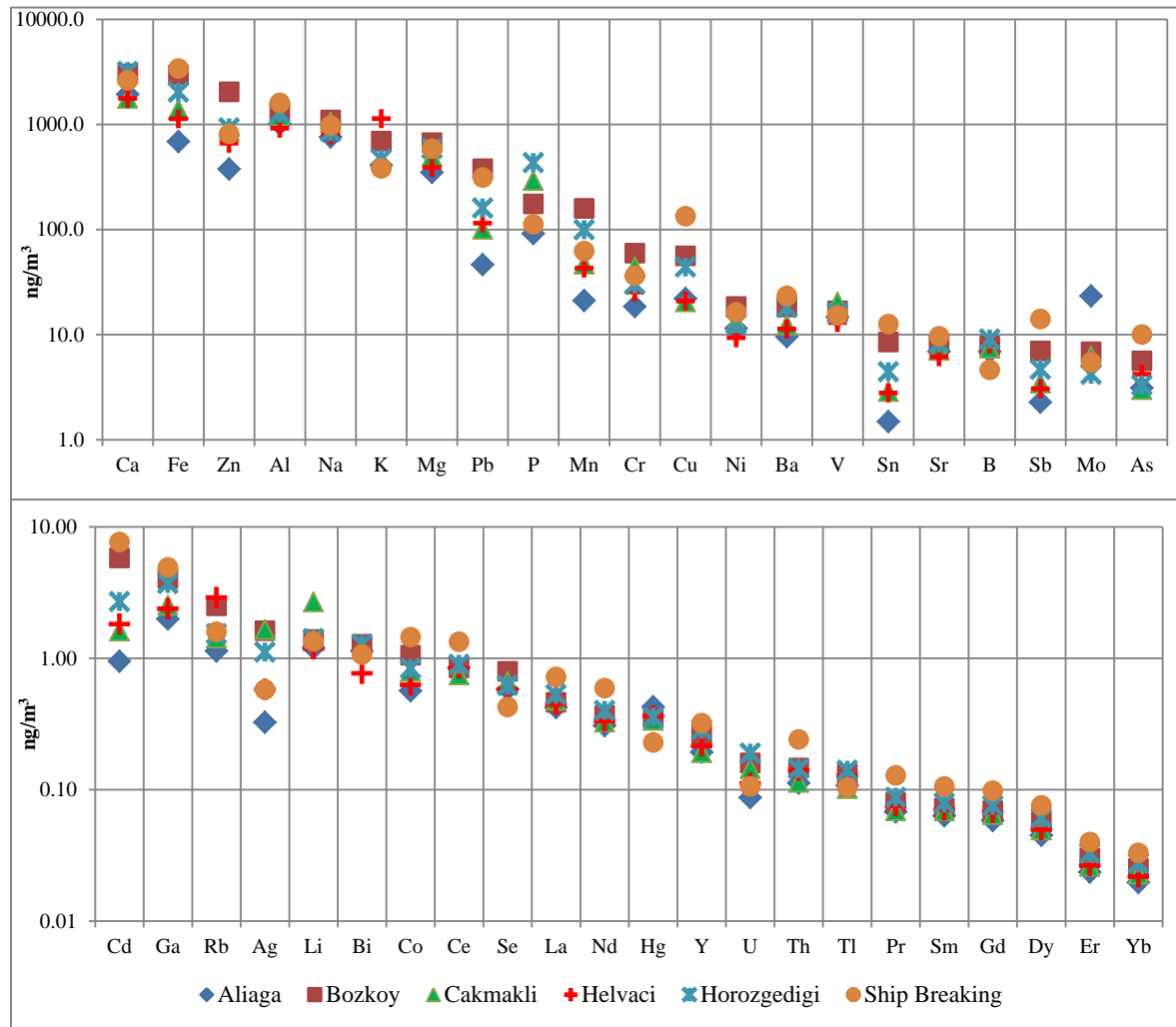


Fig. S2. Average trace element concentrations for six sampling sites.

Table S1. Average seasonal elemental concentrations for PM₁₀ (ng/m³)

	Summer	Fall	Winter	Spring
Ca	2638 ± 1609	2305 ± 1685	1189 ± 1346	3157 ± 2608
Fe	1878 ± 1728	1791 ± 1844	893 ± 961	2626 ± 1961
Al	880 ± 510	1329 ± 816	776 ± 475	1686 ± 907
Zn	908 ± 863	988 ± 1188	892 ± 1289	1220 ± 1286
Na	1175 ± 278	976 ± 517	429 ± 257	1077 ± 473
K	709 ± 441	611 ± 399	476 ± 529	620 ± 445
Mg	485 ± 221	550 ± 336	262 ± 196	704 ± 379
P	128 ± 34	277 ± 237	470 ± 648	142 ± 76
Pb	158 ± 227	138 ± 205	136 ± 229	275 ± 283
Mn	88 ± 111	75 ± 94	39 ± 59	96 ± 88
Cu	42 ± 38	31 ± 33	38 ± 43	57 ± 67
Cr	45 ± 61	29 ± 29	27 ± 20	45 ± 19
V	26 ± 12	16 ± 8.7	5.8 ± 5.4	17 ± 9.4
Ba	15 ± 8.3	16 ± 9	7.9 ± 5.1	19 ± 11
Ni	22 ± 22	14 ± 11	6.8 ± 6.4	12 ± 6.3
B	6.3 ± 1.7	9.3 ± 4.3	7.5 ± 5.2	6.9 ± 2.6
Mo	14 ± 18	6.9 ± 7	2.6 ± 2.9	6.6 ± 5.6
Sr	8.6 ± 3.9	6.4 ± 2.6	3.3 ± 1.7	11 ± 9.8
Sn	3.7 ± 4.5	3.5 ± 4.2	4.1 ± 5.2	8 ± 7.3
Ga	3.2 ± 1.7	3.4 ± 2.1	1.7 ± 1.1	4 ± 2.4
As	2.5 ± 1.3	3 ± 2	7.2 ± 4.8	5 ± 4.6
Cd	2.2 ± 2.7	2.7 ± 4.1	3.1 ± 4.8	4.3 ± 4.3
Sb	8.4 ± 15	2.3 ± 1.8	5.7 ± 5.8	6.1 ± 6.5
Rb	1.8 ± 0.97	1.7 ± 0.99	1.5 ± 1.3	2.4 ± 1.4
Li	1.3 ± 0.19	1.3 ± 0.23	1.3 ± 0.34	1.5 ± 0.48
Ce	0.89 ± 0.27	0.85 ± 0.26	0.35 ± 0.18	1.3 ± 1
Bi	1.3 ± 0.9	0.84 ± 0.45	1.3 ± 0.93	1.2 ± 0.74
Co	0.95 ± 0.45	0.78 ± 0.51	0.7 ± 0.39	0.97 ± 0.62
Ag	1.6 ± 1.9	0.67 ± 0.88	0.69 ± 0.81	1.2 ± 1.4
Se	0.87 ± 0.21	0.64 ± 0.25	0.45 ± 0.24	0.54 ± 0.18
La	0.45 ± 0.13	0.48 ± 0.14	0.21 ± 0.11	0.76 ± 0.5
Nd	0.34 ± 0.11	0.35 ± 0.12	0.16 ± 0.08	0.59 ± 0.46
Y	0.24 ± 0.08	0.24 ± 0.1	0.13 ± 0.12	0.33 ± 0.26
Hg	0.25 ± 0.2	0.19 ± 0.04	0.29 ± 0.14	0.37 ± 0.21
U	0.09 ± 0.04	0.18 ± 0.14	0.14 ± 0.16	0.13 ± 0.09
Th	0.14 ± 0.05	0.14 ± 0.05	0.06 ± 0.04	0.2 ± 0.16
Tl	0.07 ± 0.02	0.14 ± 0.14	0.12 ± 0.06	0.14 ± 0.09
Pr	0.08 ± 0.02	0.08 ± 0.03	0.03 ± 0.02	0.12 ± 0.1
Sm	0.07 ± 0.02	0.06 ± 0.02	0.03 ± 0.01	0.11 ± 0.09
Gd	0.06 ± 0.02	0.06 ± 0.02	0.03 ± 0.02	0.10 ± 0.08
Dy	0.05 ± 0.02	0.05 ± 0.02	0.03 ± 0.02	0.08 ± 0.07
Er	0.03 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	0.04 ± 0.03
Yb	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.03 ± 0.02

	PM _{2.5} , ng/m ³				PM _{2.5} /PM ₁₀			
	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring
Zn	1448 ± 422	1538 ± 1547	1189 ± 1380	1214 ± 1051	0.65	0.58	0.62	0.66
Fe	1135 ± 531	1182 ± 1329	500 ± 560	959 ± 776	0.24	0.26	0.34	0.32
Al	206 ± 28	1267 ± 441	500 ± 166	737 ± 379	0.22	0.42	0.51	0.43
Ca	597 ± 412	457 ± 279	908 ± 1302	734 ± 589	0.14	0.13	0.46	0.16
Na	432 ± 123	640 ± 402	414 ± 317	539 ± 312	0.33	0.42	0.63	0.46
K	373 ± 102	616 ± 384	486 ± 468	381 ± 239	0.52	0.60	0.93	0.69
Pb	350 ± 181	241 ± 294	191 ± 282	310 ± 283	0.68	0.59	0.76	0.72
Mg	151 ± 63	420 ± 190	233 ± 92	281 ± 161	0.20	0.36	0.51	0.35
P	<i>BDL</i>	113 ± 23	92 ± 3.6	92 ± 0	NA	0.43	0.29	0.54
Mn	106 ± 48	78 ± 91	35 ± 45	75 ± 66	0.41	0.36	0.50	0.48
Cr	33 ± 22	19 ± 11	14 ± 8.4	36 ± 9.4	0.43	0.43	0.56	0.55
Cu	58 ± 35	41 ± 48	22 ± 23	35 ± 30	0.68	0.55	0.72	0.67
V	27 ± 18	12 ± 7.5	2.2 ± 0.87	8.4 ± 5.7	0.80	0.69	0.62	0.69
Sn	7.6 ± 3.8	6.1 ± 6.3	4.3 ± 4.9	8.3 ± 8.2	0.73	0.69	0.78	0.74
Ni	17 ± 11	7.9 ± 6.7	2.4 ± 1.6	7 ± 5.5	0.54	0.52	0.60	0.59
B	5.3 ± 1.3	6.7 ± 2.9	6.7 ± 3.7	6.4 ± 2	0.59	0.68	0.80	0.70
Mo	5.4 ± 3	5.3 ± 1.8	2.2 ± 0.25	4.9 ± 4.6	0.69	0.88	0.88	0.92
Ba	5 ± 3.6	4.5 ± 3.4	2.3 ± 1.8	4.4 ± 2.6	0.18	0.20	0.29	0.25
Sb	12 ± 19	3.7 ± 2.2	3.2 ± 3.2	4.3 ± 3.3	0.72	0.73	0.91	0.78
Cd	4.1 ± 1.7	4.8 ± 6	3.6 ± 5.8	3.9 ± 3.4	0.63	0.62	0.77	0.71
As	2.9 ± 1.2	3.3 ± 2.7	7.5 ± 5.4	3.2 ± 1.7	0.66	0.59	0.84	0.75
Sr	2.2 ± 1	1.7 ± 0.54	1.7 ± 0.63	2.8 ± 2.3	0.18	0.20	0.35	0.23
Rb	1.3 ± 0.42	1.3 ± 1.1	1.8 ± 1.2	1.7 ± 0.99	0.47	0.46	0.80	0.62
Ag	1.5 ± 0.55	1.7 ± 1.2	0.83 ± 0.96	1.7 ± 1.6	0.80	0.83	0.85	0.82
Bi	0.71 ± 0.19	1 ± 0.55	1.3 ± 0.52	1.2 ± 0.63	0.69	0.75	0.75	0.73
Ga	1.3 ± 0.79	1.4 ± 1.1	0.68 ± 0.56	1.1 ± 0.71	0.22	0.24	0.36	0.30
Li	<i>BDL</i>	<i>BDL</i>	1.18 ± 0	1.11 ± 0	NA	NA	0.58	0.55
Se	0.85 ± 0.19	0.74 ± 0.31	0.52 ± 0.33	0.56 ± 0.22	0.77	0.79	0.99	0.96
Co	0.49 ± 0.16	0.58 ± 0.33	0.84 ± 0.84	0.52 ± 0.15	0.35	0.38	0.61	0.51
Hg	0.2 ± 0.05	<i>BDL</i>	0.24 ± 0.11	0.32 ± 0.17	0.53	NA	0.81	0.67
Ce	0.15 ± 0.03	0.17 ± 0.04	0.09 ± 0.02	0.26 ± 0.22	0.14	0.18	0.21	0.24
La	0.09 ± 0.02	0.11 ± 0.03	0.06 ± 0.01	0.13 ± 0.1	0.16	0.21	0.26	0.23
Nd	0.07 ± 0	0.07 ± 0.01	<i>BDL</i>	0.13 ± 0.1	0.13	0.14	NA	0.24
Tl	0.06 ± 0.01	0.12 ± 0.09	0.12 ± 0.06	0.1 ± 0.05	0.67	0.71	0.88	0.76
Y	0.04 ± 0.01	0.05 ± 0.02	0.03 ± 0.01	0.06 ± 0.06	0.13	0.15	0.18	0.20
Th	0.03 ± 0.01	0.02 ± 0	<i>BDL</i>	0.06 ± 0.03	0.11	0.14	NA	0.19
Sm	<i>BDL</i>	<i>BDL</i>	<i>BDL</i>	0.05 ± 0.01	NA	NA	NA	0.23
U	0.03 ± 0.01	0.05 ± 0.02	0.05 ± 0.02	0.04 ± 0.01	0.18	0.24	0.31	0.31
Gd	<i>BDL</i>	0.02 ± 0	<i>BDL</i>	0.03 ± 0.02	NA	0.19	NA	0.21
Dy	0.01 ± 0	0.01 ± 0	<i>BDL</i>	0.03 ± 0.02	0.18	0.18	NA	0.23
Pr	0.01 ± 0	0.01 ± 0	<i>BDL</i>	0.03 ± 0.02	0.11	0.15	NA	0.20
Er	<i>BDL</i>	<i>BDL</i>	<i>BDL</i>	0.02 ± 0.01	NA	NA	NA	0.27
Yb	<i>BDL</i>	0.01 ± 0	<i>BDL</i>	0.01 ± 0	NA	0.21	NA	0.21

Table S3. The elemental concentrations (ng/m³) in comparison with other industrial sites.

Region	Fe	Zn	Pb	Mn	Cr	Cu	Ni	V	Sb	As	Cd	Reference
Aliaga, Turkey	1932	948	185	71.9	35.6	49.6	13.5	16	5.7	4.9	3.4	This study
Dunkirk, France	977	80	37.5	147	7.5	12.6	12.4		2.3	5.1	1.3	Alleman <i>et al.</i> (2010)
Kolkata, India	123	535	118	2.1	6.3		8.3				5.2	Gupta <i>et al.</i> (2007)
Tito Scalo, Italy	589	214	30	6	34	13	85				5	Ragosta <i>et al.</i> (2006)
Taejon city, Korea	1633	240	243	50.3	25.1		37.9	13.1	7.7	6.1	3.2	Kim <i>et al.</i> (2002)
Bobadela, Lisbon	430	92			20.3				3.8	0.6		Carvalho and Freitas (2011)
Daejeon city, Korea	1393	146	204	48.2	17.3		30.7	5.5	12.3	3.2	2.4	Lim <i>et al.</i> (2010)
Dunkirk, France	250	50	17	60	13		8		1.1	2.5	0.5	Mbengue <i>et al.</i> (2014)
Spain	692	269		7.8			3.6	4.9				Pandolfi <i>et al.</i> (2008)
Houston, Texas	228	23	2.6	5.1	5	6.8	3.1	3.7	0.6	0.6	0.1	Bozlaker <i>et al.</i> (2013)
Dhaka, Bangladesh	2242	652	456	48	26	16	12.2					Begum <i>et al.</i> (2005)

Table S4. The marker elements belong to different sources resolved by PMF.

Place	Soil	Traffic- Road Dust	Motor vehicle	Diesel	Industry	Reference
Spain	Ca, Fe, K, Mg, Na	Cu, Fe, Zn				Aldabe <i>et al.</i> (2011)
Bangladesh	Al, Ca, Fe, K, Si, Ti	Al, Ca, Fe, K, Mg, Na, P, S, Si	Fe, Zn			Begum <i>et al.</i> (2004)
USA	Al, Ca, Fe, Si, Ti	Ca, Fe, S, Si, Ti, Zn		EC, Fe, Zn		Begum <i>et al.</i> (2005)
Bangladesh	Al, Mg, Na, P, S, Si	Mg, Na, Pb, Si	BC, S			Begum <i>et al.</i> (2005)
Bangladesh	Al, Ca, Fe, K, Si	K, Pb, S, Si	BC, K, S			Begum <i>et al.</i> (2010)
Thailand	Al, Ca, Fe, La, Mn	Al, Ca, Fe, Mn, Zn				Chueinta <i>et al.</i> (2000)
Italy		Pb, Sb, Zn			Cu, Cr, Fe, Pb, Zn	Contini <i>et al.</i> (2012)
Spain	Al, Ca, Fe, K, Mg, Na, Ti	Al, Cu, Fe, Pb, Sb				Escrig <i>et al.</i> (2009)
France		Cu, Fe, Mn, Pb, Sb, Sn, Zn				Fabretti <i>et al.</i> (2009)
Switzerland	Al, Ca, La, Mg, Nd, Sr, Ti, Y	Ba, Cr, Cu, Fe, Mn, Mo, Sb, Zn				Gianini <i>et al.</i> (2012a)
USA	Al, Ca, Fe, Si				Fe, Pb	Gildemeister <i>et al.</i> (2007)
South Korea	Al, Ca, Fe, K, Mg, Si	Al, Br, Pb, Si, Zn		Cu, EC, Fe, OC, Zn	Br, Cu, Fe, Zn,	Heo <i>et al.</i> (2009)
India	Al, Ca, Fe, Mn, Na, Si				Cd, Co, Cu, Ni, Te, Zn	Khare and Baruah (2010)
USA	Al, Fe, K, Si, Ti		EC, Fe, OC, Si			Kim <i>et al.</i> (2003)
USA	Al, Ca, Fe, Si, Ti		OC, Pb, Zn	EC, Fe, S		Kim <i>et al.</i> (2004)
India	Ca, Fe, Sc, Si, Ti	Co, Sb, Sc, Zn				Kothai <i>et al.</i> (2008)
USA	Al, Ca, Fe, Na, Si, Ti			Ca, Cu, Si		Lee and Hopke (2006)
Pakistan		Al, Ba, Ca, Mg	Cd, Pb, Sb, Zn		As, Cd, Co, Sb, Se, V	Mansha <i>et al.</i> (2012)
Italy	Al, Si	Cu, Pb, Zn				Mazzei <i>et al.</i> (2008)
USA		Fe, Cu, Mn Zn		Cr, EC, Mn		Ogulei <i>et al.</i> (2006)
USA	Al, Ca, Fe, Si		EC, OC	EC, Fe, S		Ramadan <i>et al.</i> (2000)
Indonesia	Al, Ca, Fe, K, Si	Al, Br, Fe, S, Si, Zn	Pb, S, Zn			Santoso <i>et al.</i> (2008)
Canada	Al, Ca, La, Mn, Si, Sm, Ti				As, Pb, Sb, Se, V, Zn	Xie <i>et al.</i> (1999)
Spain	Al, Ca, Fe, Sr, Ti	Al, Ba, Ca, Fe, Zn				Zabalza <i>et al.</i> (2006)

Table S4. Continued.

Place	Iron-Steel Processing	Fuel Oil	Wood and Biomass Burning	Sea salt	Coal	Reference
Spain				Cl, Mg, Na		Aldabe <i>et al.</i> (2011)
Bangladesh	Fe, K, Mn, Pb Zn		BC, K	Cl, Na		Begum <i>et al.</i> (2004)
USA		Ni, V	K, OC, S	Na, S	OC, S, Se	Begum <i>et al.</i> (2005)
Bangladesh			BC, K, S			Begum <i>et al.</i> (2005)
Bangladesh	Cu, Cr, Fe, Pb, S Zn		BC, Fe, K, S	Br, Cl, Na		Begum <i>et al.</i> (2010)
Thailand		Sb, V	K, Na, Sb	Cl, Na		Chueinta <i>et al.</i> (2000)
Italy		Ni, V				Contini <i>et al.</i> (2012)
Spain	As, Cd, Cs, K, Pb, Tl, Zn	Ni, S, V, Zr				Escrig <i>et al.</i> (2009)
France		Co, Ni, V				Fabretti <i>et al.</i> (2009)
Switzerland			K, Rb			Gianini <i>et al.</i> (2012a)
USA	Ca, Fe, K, Mn, Zn			Ca, Cl, Na		Gildemeister <i>et al.</i> (2007)
South Korea			K, OC, Pb, Si, Zn			Heo <i>et al.</i> (2009)
India			K		Fe, Mn, P, Te, V	Khare and Baruah (2010)
USA	Br, Fe, Mn, Pb, Sn, Zn		K, Si			Kim <i>et al.</i> (2003)
USA	Cu, Cr, Fe, Mn	Ni, S, V	K, OC, S			Kim <i>et al.</i> (2004)
India	Cr, Ni, Pb			K, Na		Kothai <i>et al.</i> (2008)
USA	Al, Fe, Mn, Zn		Ca, K			Lee and Hopke (2006)
Pakistan	Co, Cr, Fe, Mn, Mo, Ni, Sn					Mansha <i>et al.</i> (2012)
Italy		Ni, V		Br, Cl, Na		Mazzei <i>et al.</i> (2008)
USA	Cu, Fe, Pb	Ni			As, Mn, Se, Zn	Ogulei <i>et al.</i> (2006)
USA			EC, K, Na, OC, S	Cl, K, Na	EC, La, OC, S	Ramadan <i>et al.</i> (2000)
Indonesia			BC, K			Santoso <i>et al.</i> (2008)
Canada				Cl, K, Na		Xie <i>et al.</i> (1999)
Spain	Mn, Pb, Zn			Cl, Na		Zabalza <i>et al.</i> (2006)

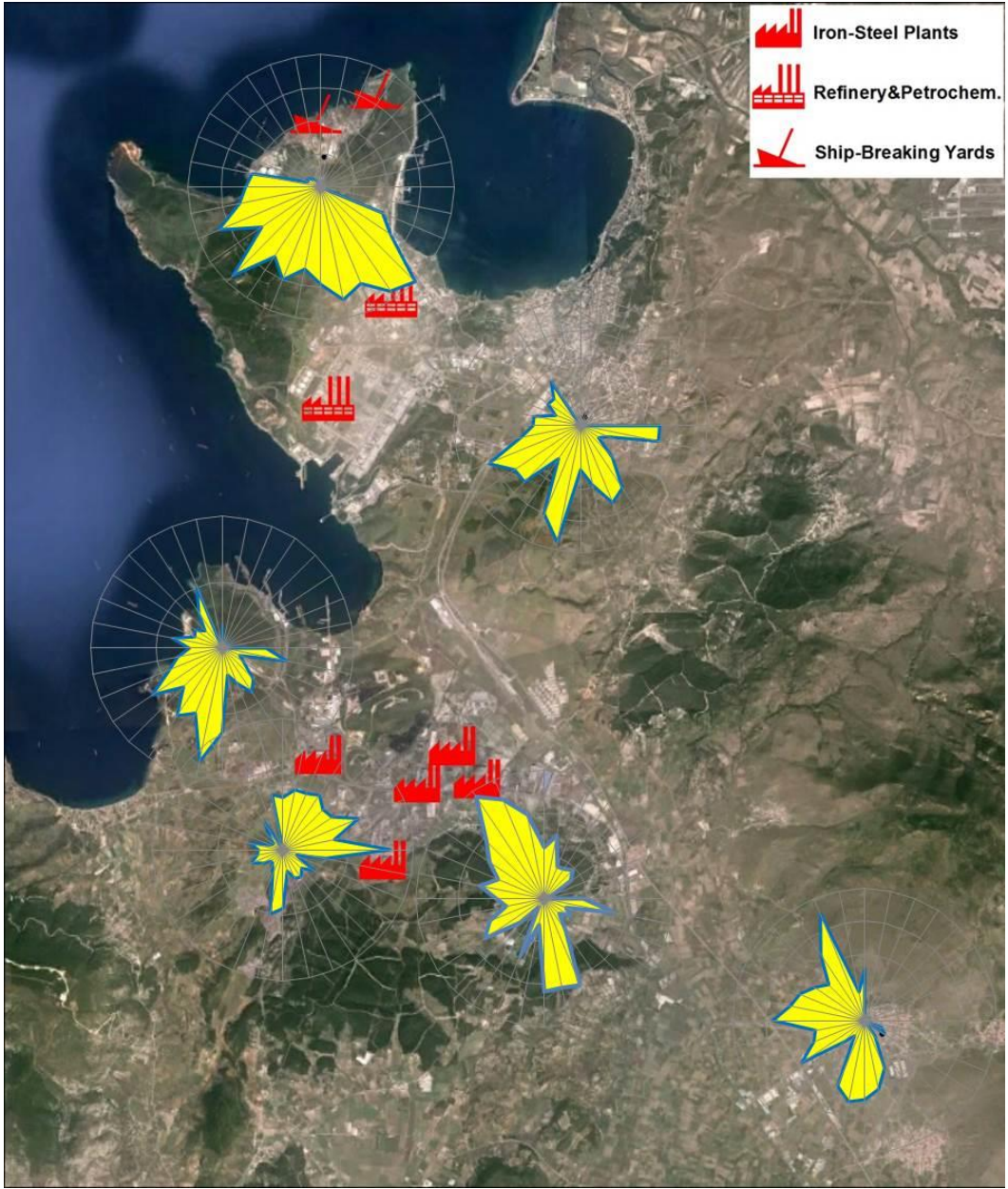


Fig. S3. The CPF plot showing directions for crustal and soil.

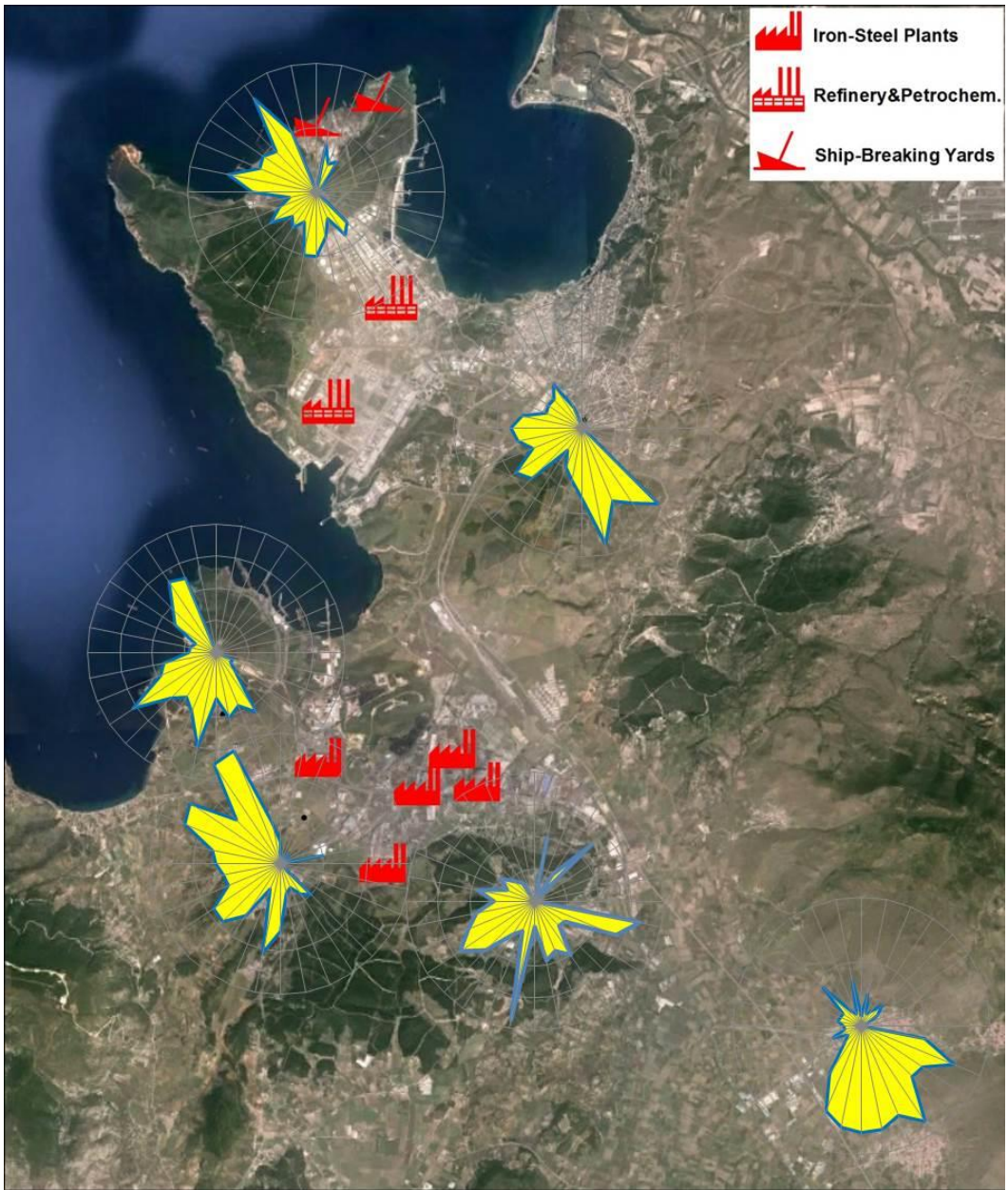


Fig. S4. The CPF plot showing directions for marine aerosol.

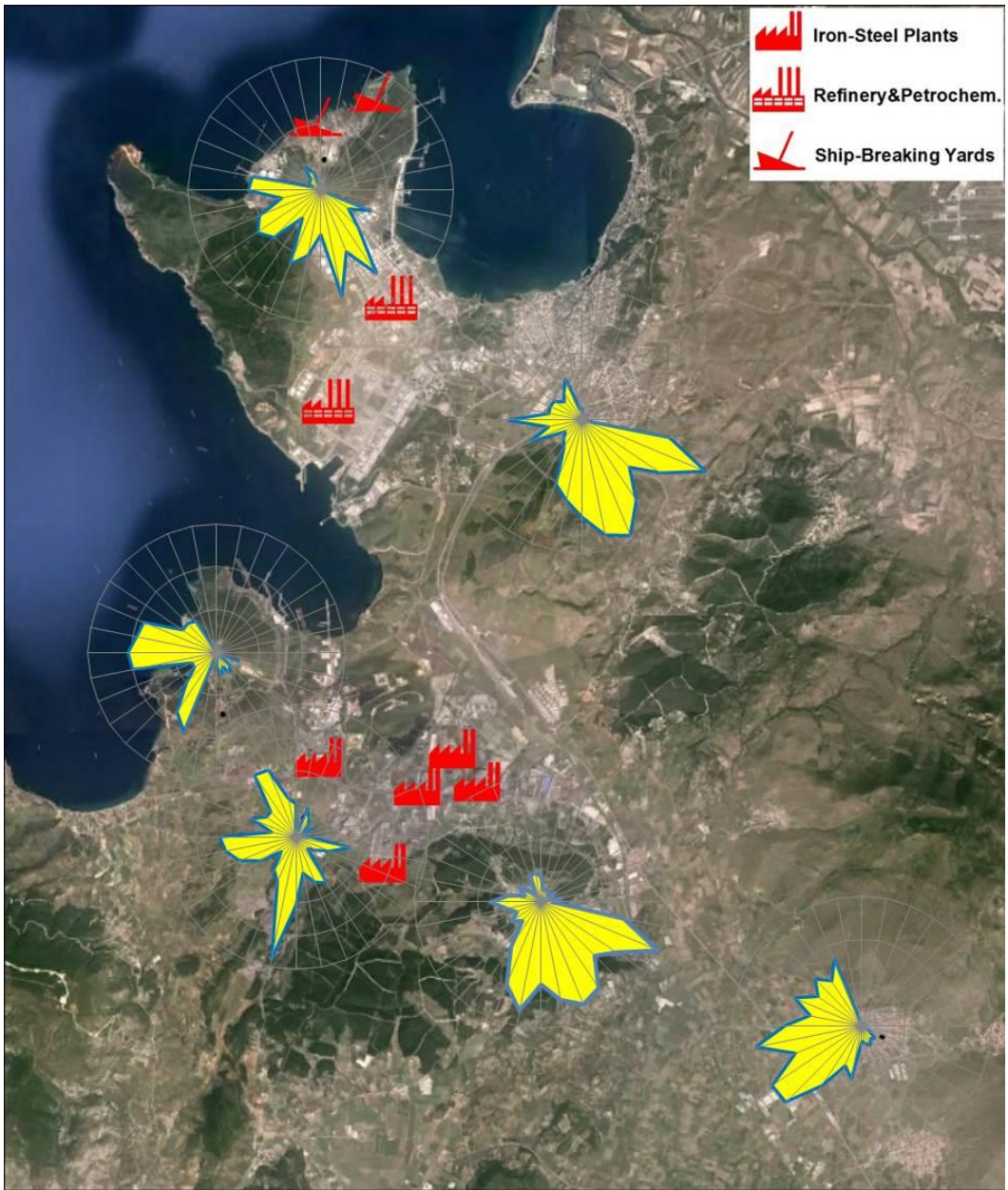


Fig. S5. The CPF plot showing directions for biomass and wood combustion.

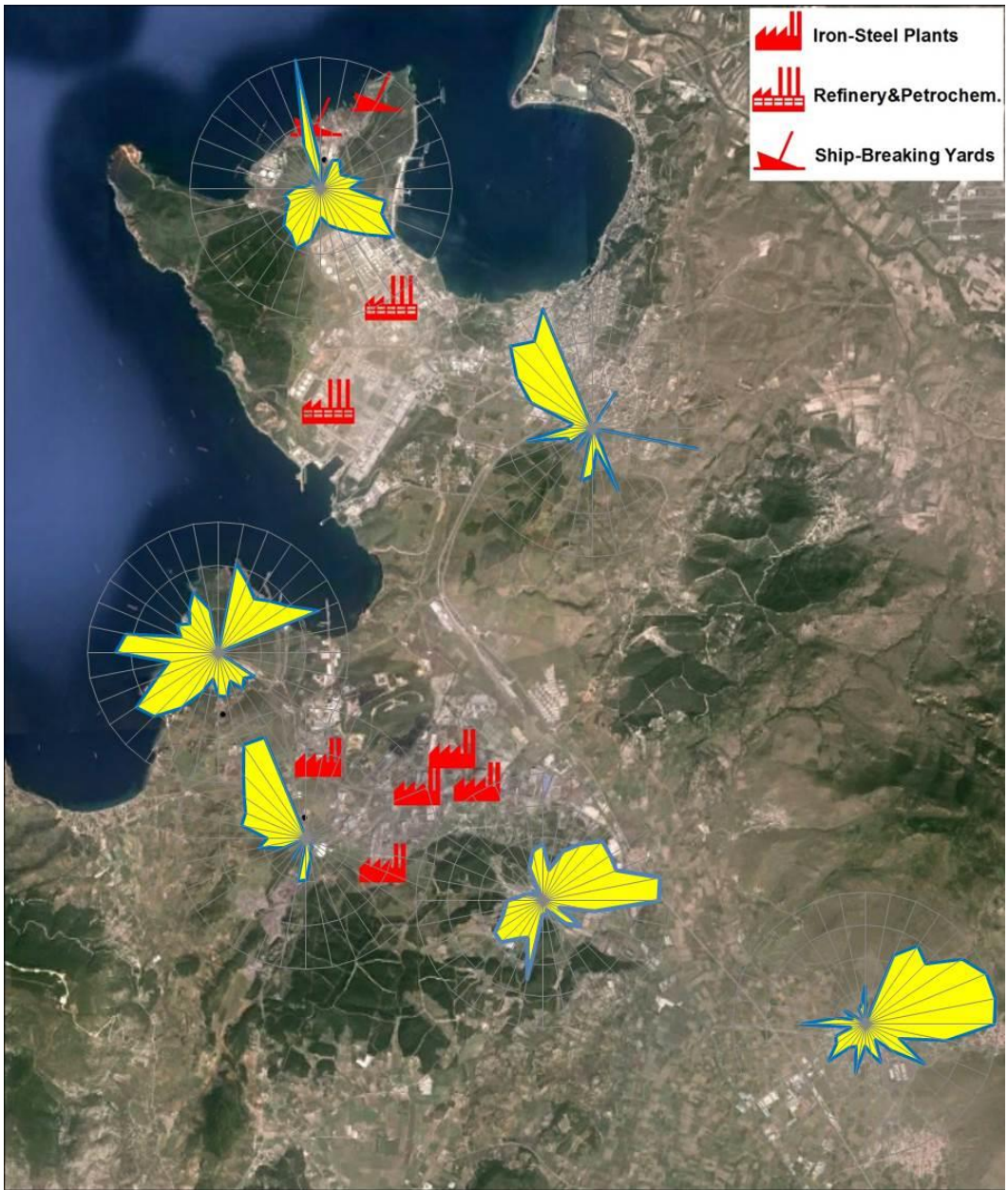


Fig. S6. The CPF plot showing directions for coal combustion.

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