LTP indicators based on observations

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LTP impact is increasing?

$$F_{\mathrm{L}} = \frac{C_{\mathrm{LTP}}}{C_{\mathrm{LTP}} + C_{\mathrm{LOCAL}}}$$

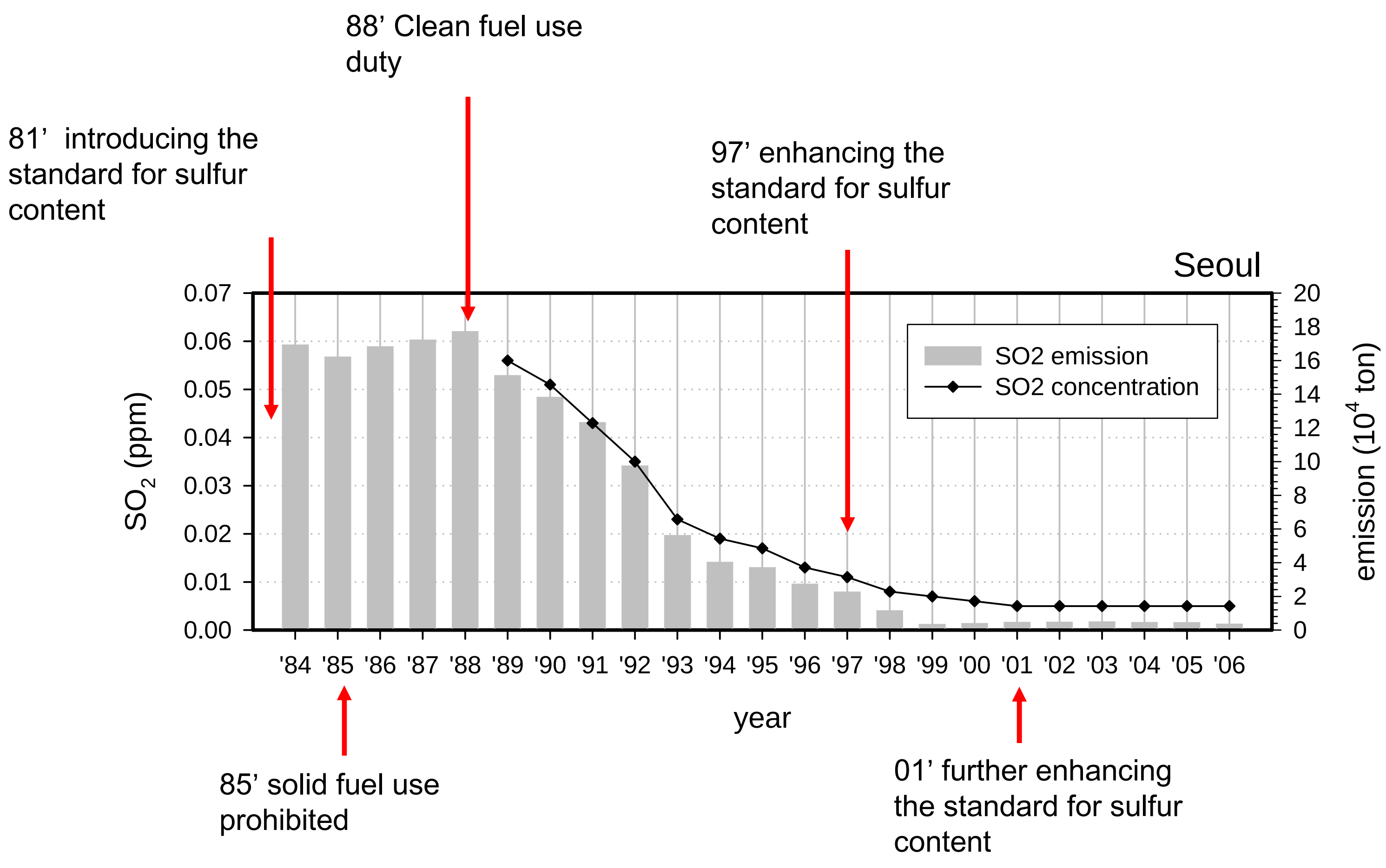
If C_{LTP} increases, F_{L} increases

If C_{LOCAL} decreases, F_{L} increases

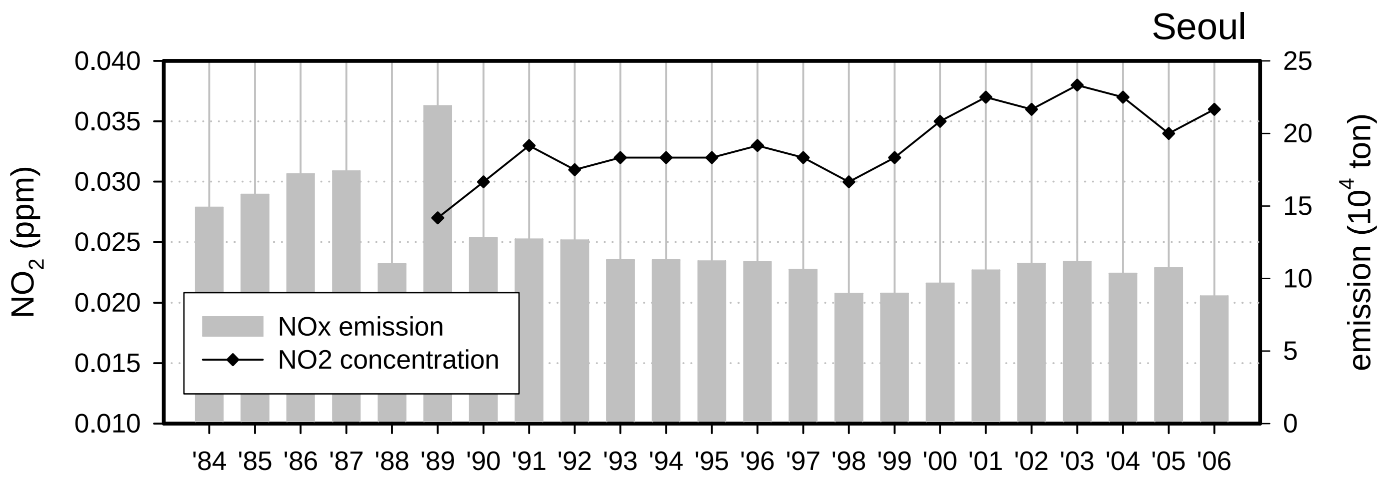
✓ More than 20 years, Korea has experienced a dramatic air quality improvement by emission control policies

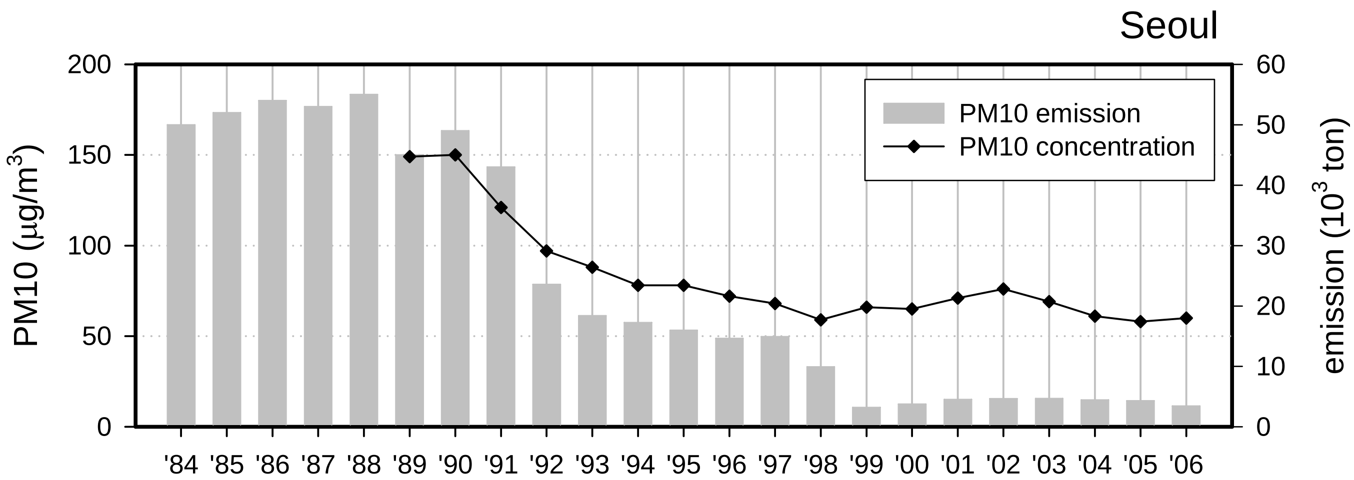
✓ LTP becomes one of key issues for Korean air quality

A dramatic improvement of local air quality



not clear about NOx and O_3





LTP indicators

- ✓ Two points of views

1. Meteorological patterns

   - analyzing synoptic conditions for highly polluted days

2. Chemical compositional characteristics

   - analyzing chemical compositions in aerosols during LTP days

LTP indicators I

- ✓ Two points of views

1. Meteorological patterns

- analyzing synoptic conditions for highly polluted days

2. Chemical compositional characteristics

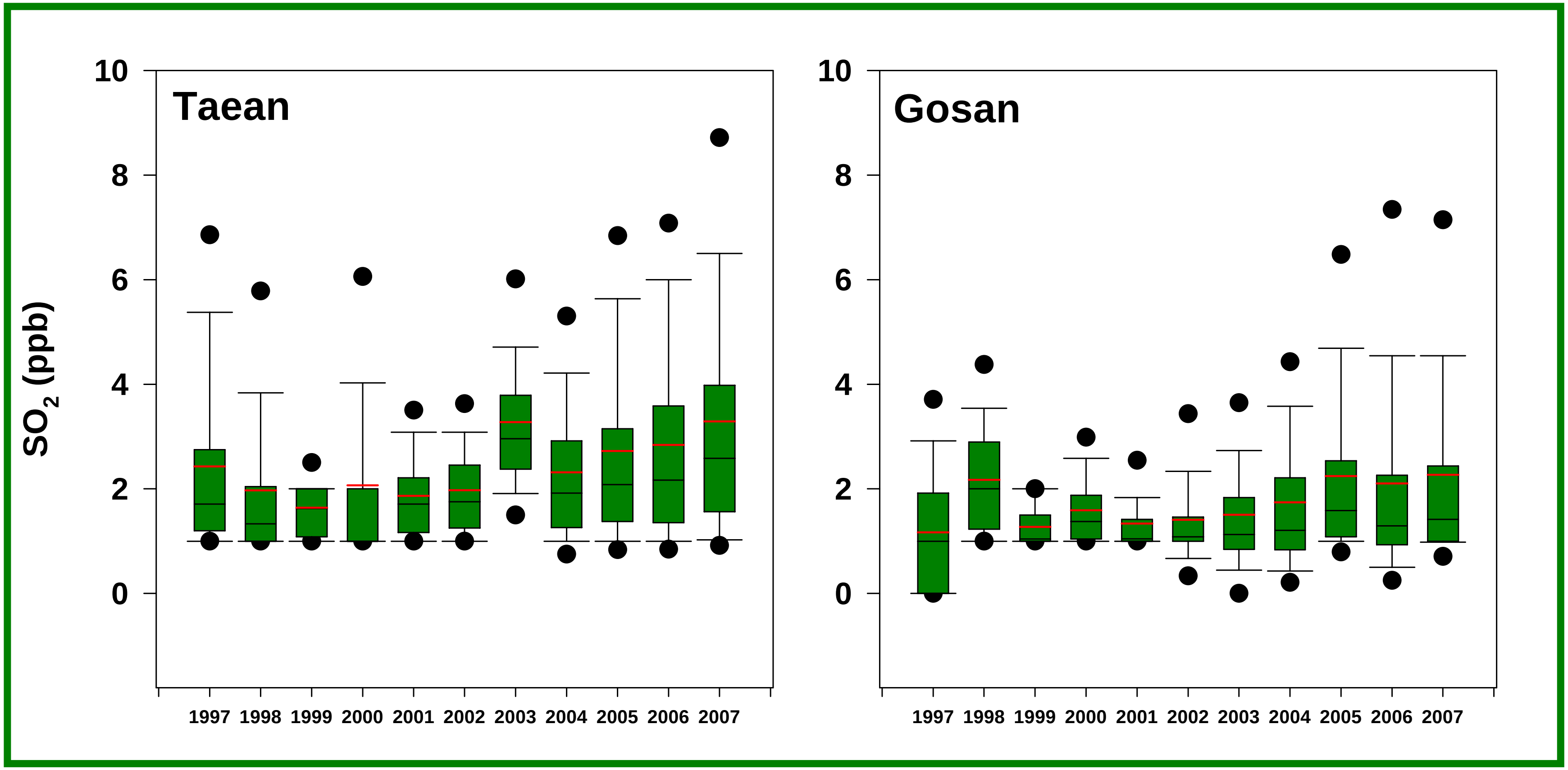
- analyzing chemical compositions in aerosols during LTP days

Summary for aerial measurement (1998-2006)

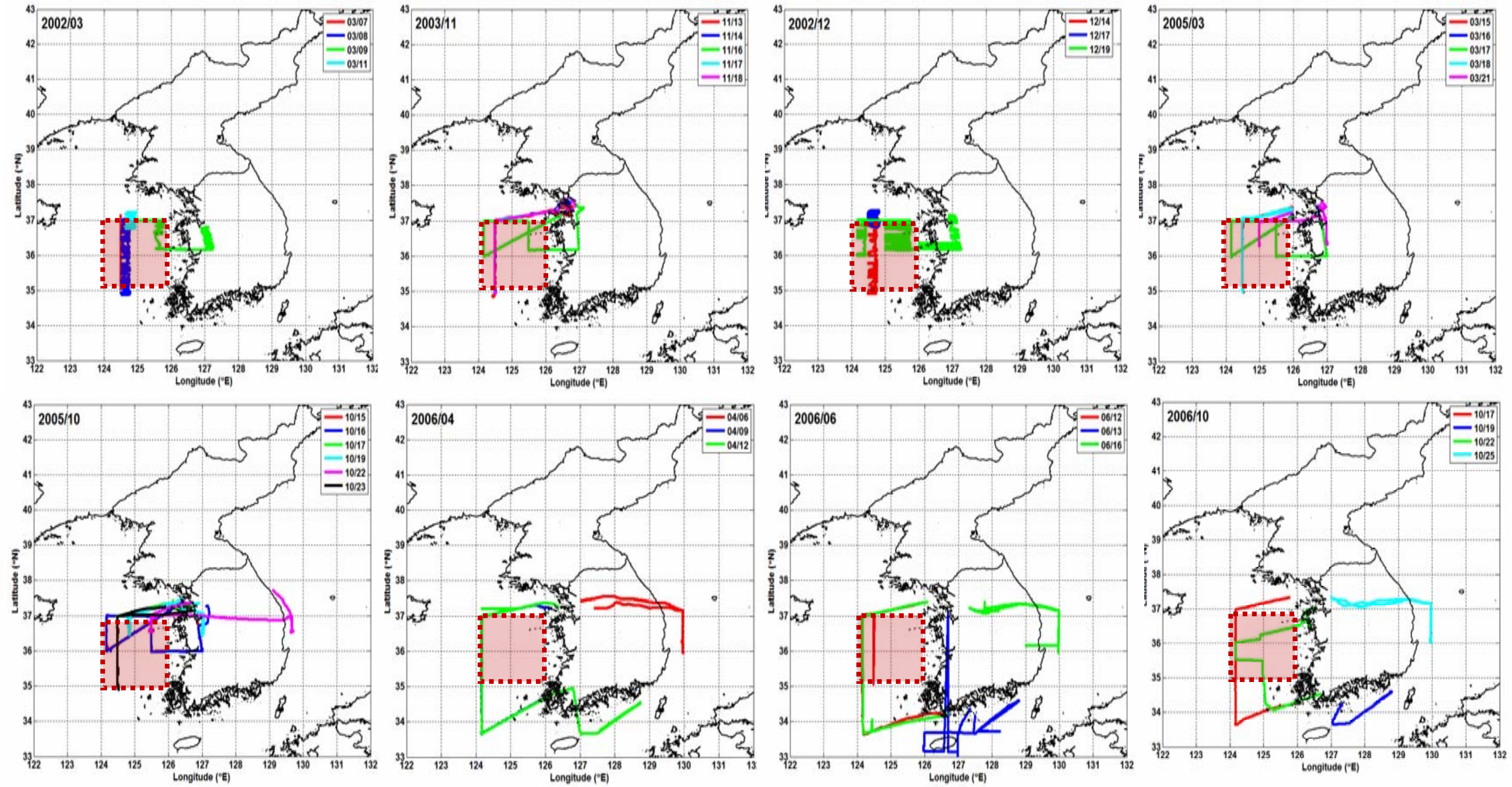
No	Date	Time	Latitude	Longitude	Altitude
1	1998.11.7	142855 ~ 182450	36.10 ~ 37.30	125.10 ~ 126.70	1000.00 ~ 2224.00
2	1998.11.8	145900 ~ 170915	34.58 ~ 35.90	124.56 ~ 126.70	106.00 ~ 1129.00
3	1998.11.9	135550 ~ 164355	37.10 ~ 37.90	125.45 ~ 126.90	64.00 ~ 2852.00
4	1999.4.9	094040 ~ 161830	35.02 ~ 37.34	124.38 ~ 126.51	3.00 ~ 2698.00
5	1999.4.10	144415 ~ 182115	NaN	NaN	890.00 ~ 2568.00
6	1999.4.11	142630 ~ 164940	36.39 ~ 37.33	124.57 ~ 126.59	40.00 ~ 3128.00
7	1999.6.19	135450 ~ 161535	34.53 ~ 37.35	125.28 ~ 128.57	0.00 ~ 2585.00
8	1999.6.20	101805 ~ 162445	33.32 ~ 36.25	127.01 ~ 130.41	1.00 ~ 2962.00
9	1999.6.21	141125 ~ 153130	35.05 ~ 36.31	129.08 ~ 130.43	939.00 ~ 2849.00
10	1999.6.22	135505 ~ 155630	35.10 ~ 37.33	126.46 ~ 129.05	43.00 ~ 2992.00
11	2001.4.13	064309 ~ 163355	36.48 ~ 37.90	125.27 ~ 126.90	27.00 ~ 2862.00
12	2001.4.15	085253 ~ 175418	36.28 ~ 38.10	125.28 ~ 130.90	16.00 ~ 2027.00
13	2001.4.16	103423 ~ 143355	34.29 ~ 37.90	124.28 ~ 128.90	25.00 ~ 1566.00
14	2001.4.17	085309 ~ 175501	33.10 ~ 37.90	124.30 ~ 128.90	10.00 ~ 2150.00
15	2001.8.9	142639 ~ 174555	34.00 ~ 37.90	124.58 ~ 128.90	25.00 ~ 2608.00
16	2001.8.10	091000 ~ 124519	35.10 ~ 37.90	126.33 ~ 130.90	14.00 ~ 2709.00
17	2001.11.7	153701 ~ 163822	36.46 ~ 37.90	125.28 ~ 125.34	281.00 ~ 2829.00
18	2001.11.8	143949 ~ 165811	34.56 ~ 37.90	124.28 ~ 126.90	414.00 ~ 1941.00
19	2001.11.10	133943 ~ 161145	35.57 ~ 37.00	124.10 ~ 126.90	467.00 ~ 1060.00
20	2002.3.7	140000 ~ 154500	35.00 ~ 37.17	124.50 ~ 124.50	270.00 ~ 2700.00
21	2002.3.8	140657 ~ 155503	34.88 ~ 37.03	124.50 ~ 124.84	301.00 ~ 2201.00
22	2002.3.9	143029 ~ 154811	36.17 ~ 37.00	124.95 ~ 127.26	663.00 ~ 868.00
23	2002.3.11	144948 ~ 160059	36.77 ~ 37.23	124.63 ~ 124.97	291.00 ~ 2111.00
24	2002.4.24	102400 ~ 182000	34.93 ~ 37.27	124.48 ~ 126.22	300.00 ~ 2200.00
25	2002.12.14	142921 ~ 162133	34.92 ~ 37.03	124.48 ~ 124.84	299.00 ~ 2521.00
26	2002.12.17	152528 ~ 165749	36.82 ~ 37.28	124.47 ~ 124.85	283.00 ~ 2500.00
27	2002.12.19	144138 ~ 170417	36.00 ~ 37.15	124.16 ~ 127.27	663.00 ~ 997.00
28	2003.11.13	133725 ~ 173118	34.85 ~ 37.44	124.42 ~ 126.83	328.60 ~ 2783.87
29	2003.11.14	124744 ~ 163343	34.95 ~ 37.62	124.47 ~ 126.78	26.42 ~ 1871.87
30	2003.11.16	124438 ~ 161538	36.00 ~ 37.55	103.46 ~ 127.13	30.60 ~ 1257.19

No	Date	Time	Latitude	Longitude	Altitude
31	2003.11.17	070139 ~ 185600	34.95 ~ 37.62	124.47 ~ 126.78	19.47 ~ 1595.92
32	2003.11.18	121832 ~ 160340	34.95 ~ 37.63	104.57 ~ 126.88	25.65 ~ 1597.65
33	2004.3.16		34.90 ~ 36.88	124.48 ~ 124.60	311.99 ~ 2835.64
34	2004.3.19		34.93 ~ 37.09	124.54 ~ 124.87	316.39 ~ 2728.09
35	2004.3.20		36.17 ~ 37.28	124.15 ~ 127.00	290.07 ~ 1734.84
36	2004.6.15		37.21 ~ 37.67	126.00 ~ 127.20	372.30 ~ 1665.70
37	2004.10.13		37.24 ~ 37.65	126.03 ~ 127.25	296.74 ~ 1493.16
38	2004.6.16		34.97 ~ 36.95	124.47 ~ 124.57	377.67 ~ 2811.38
39	2004.10.13		36.00 ~ 37.00	124.13 ~ 126.97	571.08 ~ 1243.17
40	2004.10.16		35.98 ~ 37.63	124.13 ~ 127.02	550.66 ~ 1340.00
41	2004.10.19		34.97 ~ 37.02	124.47 ~ 124.52	311.13 ~ 1896.09
42	2004.10.21		36.48 ~ 38.25	125.47 ~ 130.13	347.35 ~ 1941.94
43	2005.4.15	143317 ~ 172355	34.97 ~ 37.40	124.48 ~ 126.00	303.74 ~ 2333.82
44	2005.4.16	140304 ~ 173411	36.00 ~ 37.40	124.15 ~ 127.00	667.30 ~ 1315.88
45	2005.4.17	134858 ~ 165623	35.97 ~ 37.15	124.13 ~ 127.00	250.80 ~ 1500.16
46	2005.4.18	132751 ~ 161550	34.98 ~ 37.35	124.48 ~ 126.00	313.90 ~ 2659.45
47	2005.4.21	152116 ~ 182920	36.28 ~ 37.52	124.98 ~ 127.02	228.80 ~ 2208.00
48	2005.10.16	130826 ~ 164230	35.98 ~ 37.45	124.13 ~ 127.22	398.30 ~ 975.80
49	2005.10.17	121442 ~ 152955	34.93 ~ 37.42	124.47 ~ 126.68	9.00 ~ 2742.10
50	2005.10.19	131003 ~ 160956	36.47 ~ 37.48	124.77 ~ 127.05	1.20 ~ 2200.30
51	2005.10.22	171627 ~ 210038	36.53 ~ 37.73	125.35 ~ 129.72	0.00 ~ 6054.50
52	2005.10.23	134448 ~ 163954	34.90 ~ 37.27	124.47 ~ 126.73	0.00 ~ 5640.70
53	2006.4.6	131539 ~ 160348	35.97 ~ 37.55	127.00 ~ 129.98	452.50 ~ 2491.90
54	2006.4.9	125411 ~ 161604	33.65 ~ 37.32	124.15 ~ 126.20	924.00 ~ 1470.70
55	2006.4.12	110115 ~ 173417	33.65 ~ 37.38	124.13 ~ 128.75	505.90 ~ 1512.90
56	2006.6.12	141724 ~ 170819	33.63 ~ 38.42	124.13 ~ 126.58	97.00 ~ 1956.90
57	2006.6.13	132040 ~ 161318	33.02 ~ 37.13	125.97 ~ 128.80	821.32 ~ 5388.40
58	2006.6.16	101819 ~ 184857	33.65 ~ 37.80	124.15 ~ 130.00	536.70 ~ 9666.80
59	2006.10.17	151112 ~ 174714	33.63 ~ 37.60	124.15 ~ 126.02	927.70 ~ 1038.00
60	2006.10.19	155138 ~ 170342	33.65 ~ 34.60	127.03 ~ 128.80	960.10 ~ 1497.10
61	2006.10.22	082734 ~ 110749	34.07 ~ 37.03	124.17 ~ 126.72	1197.90 ~ 2867.40
62	2006.10.25	103935 ~ 133203	36.02 ~ 37.33	126.98 ~ 129.98	475.30 ~ 3137.80

Annual variation of SO_2 at ground site



Flight path



2002/03
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2006/10
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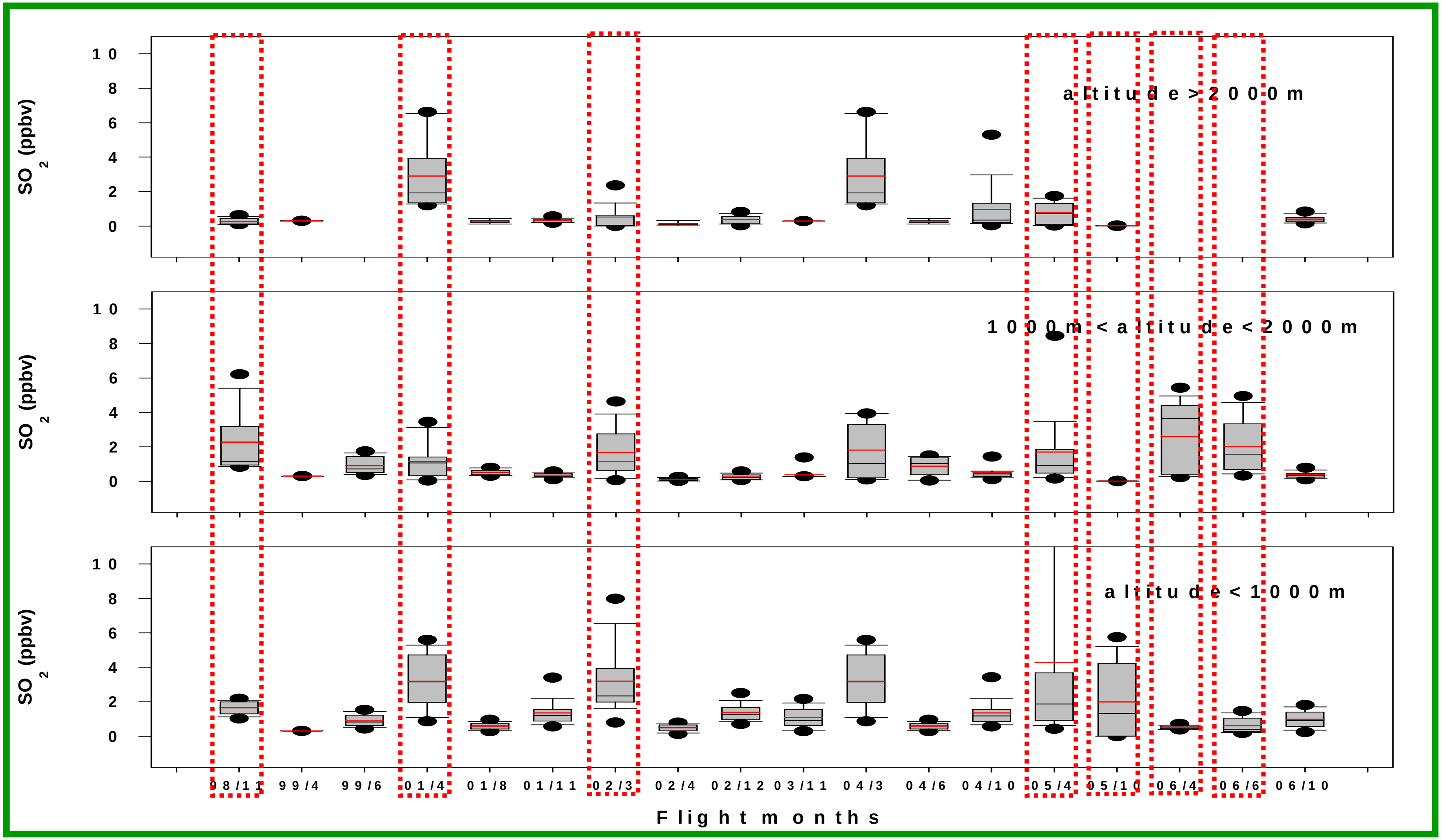
10/25
Latitude (°N)
Longitude (°E)

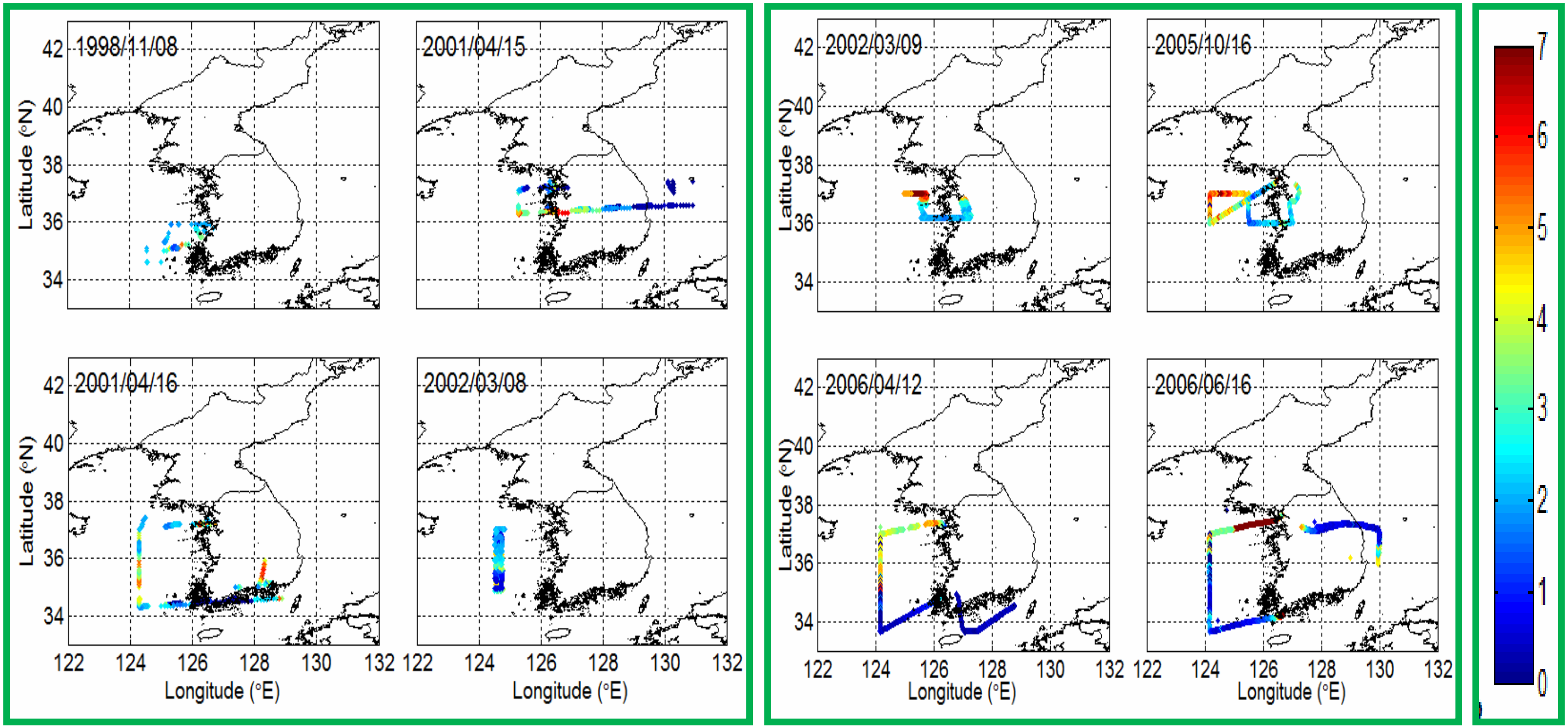
SO_2 measurements results over Yellow sea (35-37N & 124-126E)



Statistical results SO_2 measurements

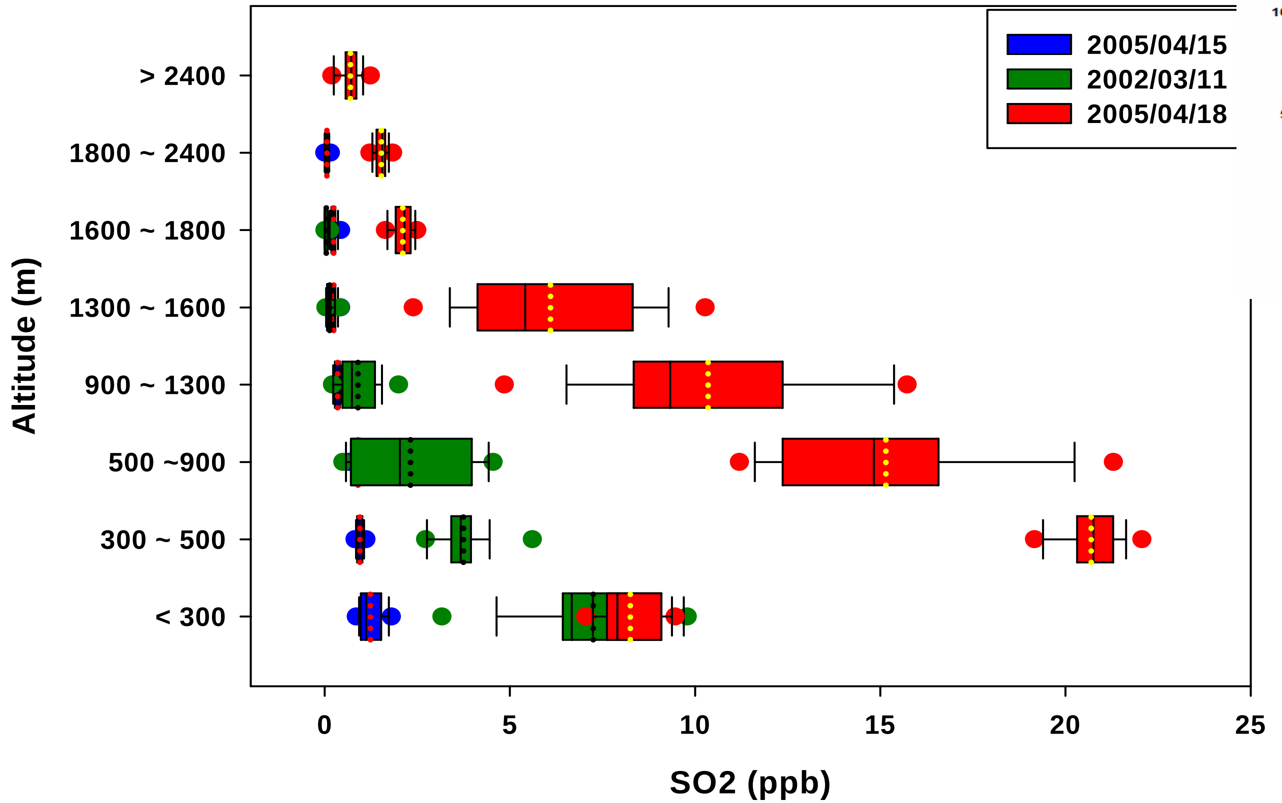
Period / Altitude	Statistics	98/11	99/4	99/6	01/4	01/8	01/11	02/3	02/4	02/12	03/11	04/3	04/6	04/10	05/4	05/10	06/4	06/6	06/10	Total Ave.
<1000m	95%	2.2	0.3	1.5	5.6	1.0	3.4	8.0	0.8	2.5	2.2	5.6	1.0	3.4	19.7	5.7	0.7	1.5	1.8	
	75%	2.0	0.3	1.2	4.7	0.7	1.6	4.0	0.7	1.7	1.6	4.7	0.7	1.6	3.7	4.2	0.6	1.1	1.4	
	mean	1.7	0.3	0.9	3.2	0.6	1.4	3.2	0.5	1.4	1.1	3.2	0.6	1.4	4.3	2.0	0.5	0.6	1.0	1.5
	median	1.7	0.3	0.8	3.2	0.6	1.2	2.3	0.5	1.3	0.9	3.2	0.6	1.2	1.9	1.3	0.5	0.4	0.9	1.3
	25%	1.3	0.3	0.6	2.0	0.4	0.9	2.0	0.3	1.0	0.6	2.0	0.4	0.9	0.9	0.0	0.5	0.3	0.6	
	5%	1.0	0.3	0.5	0.9	0.3	0.6	0.8	0.1	0.7	0.3	0.9	0.3	0.6	0.4	0.0	0.4	0.2	0.2	
1000~ 2000m	95%	6.0	0.3	1.7	3.4	0.8	0.6	4.6	0.2	0.6	1.3	3.9	1.5	1.4	8.4	0.0	5.4	5.0	0.8	
	75%	3.2	0.3	1.4	1.4	0.6	0.4	2.8	0.2	0.4	0.3	3.3	1.4	0.4	1.9	0.0	4.4	3.3	0.5	
	mean	2.3	0.3	0.9	1.1	0.5	0.4	1.7	0.1	0.3	0.4	1.8	0.9	0.5	1.7	0.0	2.6	2.0	0.4	1.0
	median	1.2	0.3	0.7	1.1	0.5	0.4	1.1	0.1	0.2	0.3	1.0	1.0	0.4	0.9	0.0	3.7	1.6	0.3	0.8
	25%	1.0	0.3	0.5	0.3	0.4	0.3	0.6	0.1	0.1	0.3	0.2	0.4	0.3	0.5	0.0	0.4	0.7	0.2	
	5%	0.8	0.3	0.4	0.0	0.3	0.1	0.1	0.0	0.1	0.3	0.1	0.0	0.1	0.2	0.0	0.2	0.3	0.1	
>2000m	95%	0.6	0.3	NaN	6.6	0.4	0.6	2.2	0.3	0.8	0.3	6.6	0.4	5.3	1.7	0.0	NaN	NaN	0.8	
	75%	0.4	0.3	NaN	3.7	0.3	0.4	0.6	0.2	0.6	0.3	3.7	0.3	1.3	1.3	0.0	NaN	NaN	0.5	
	mean	0.3	0.3	NaN	2.9	0.3	0.3	0.6	0.1	0.4	0.3	2.9	0.3	1.0	0.8	0.0	NaN	NaN	0.4	0.7
	median	0.1	0.3	NaN	1.9	0.2	0.3	0.5	0.1	0.4	0.3	1.9	0.2	0.3	0.7	0.0	NaN	NaN	0.4	0.5
	25%	0.1	0.3	NaN	1.4	0.2	0.2	0.0	0.1	0.2	0.3	1.4	0.2	0.2	0.1	0.0	NaN	NaN	0.3	
	5%	0.1	0.3	NaN	1.2	0.1	0.2	0.0	0.1	0.1	0.3	1.2	0.1	0.1	0.0	0.0	NaN	NaN	0.2	

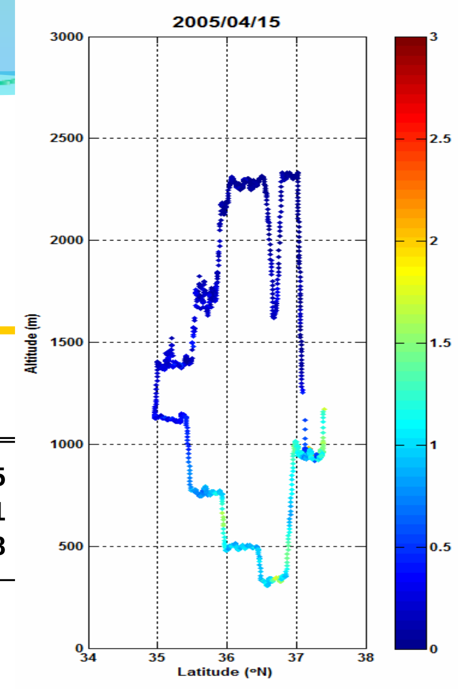
Horizontal distribution of [SO_2]



Profiles of $[SO_2]$

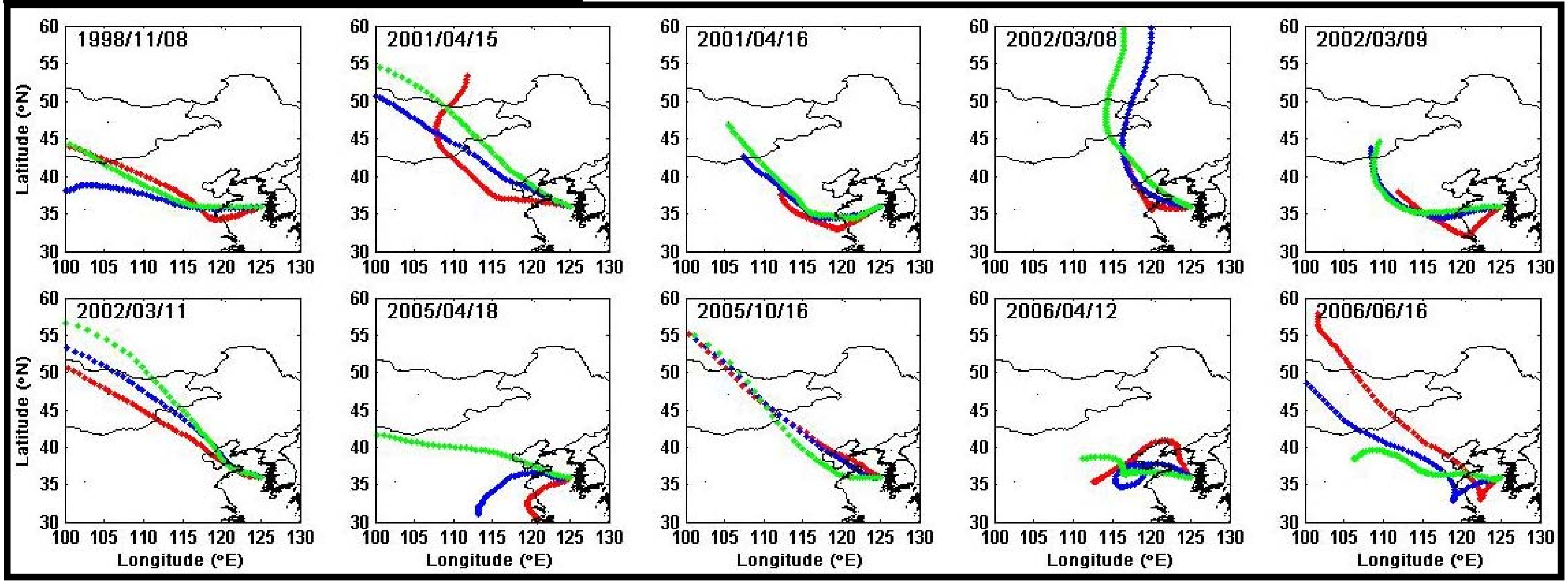
Clear day vs Polluted days





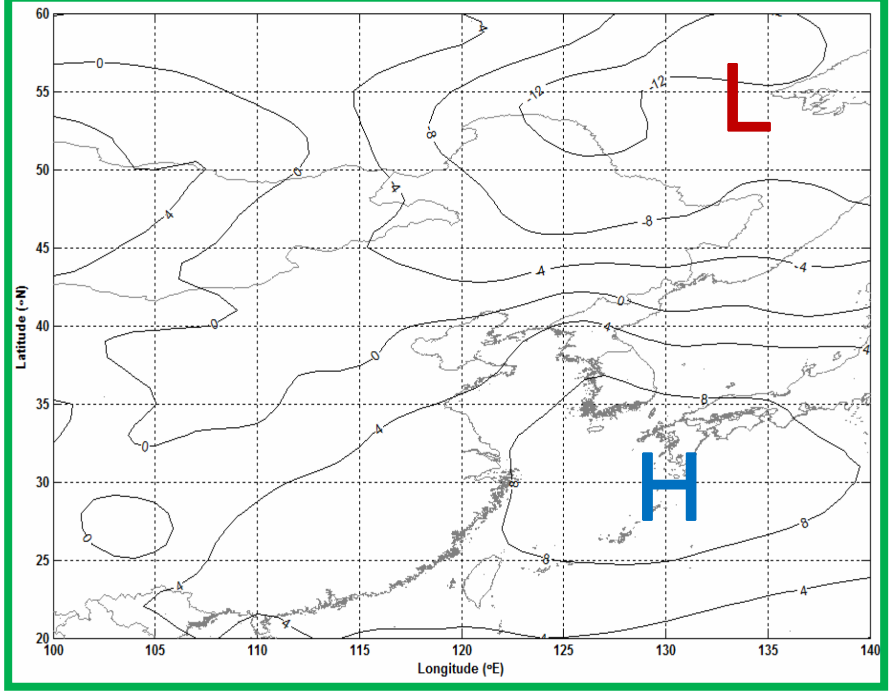
Backward trajectory at highly polluted days

● 1000m ● 2000m ● 3000m

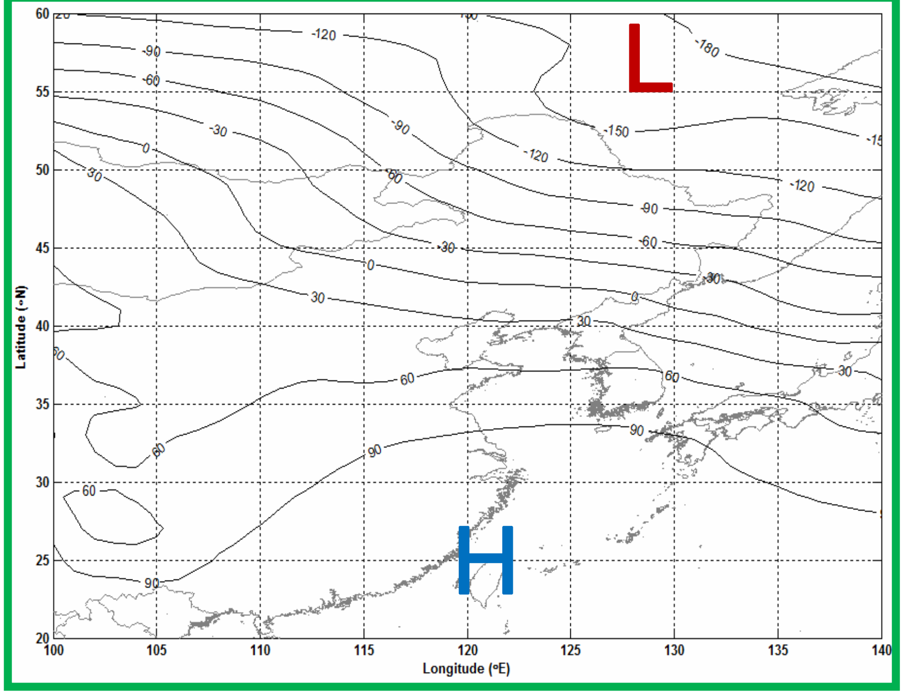


Synoptic pattern A

SFC
; 2001/04/15, 2002/03/08, 2002/03/09

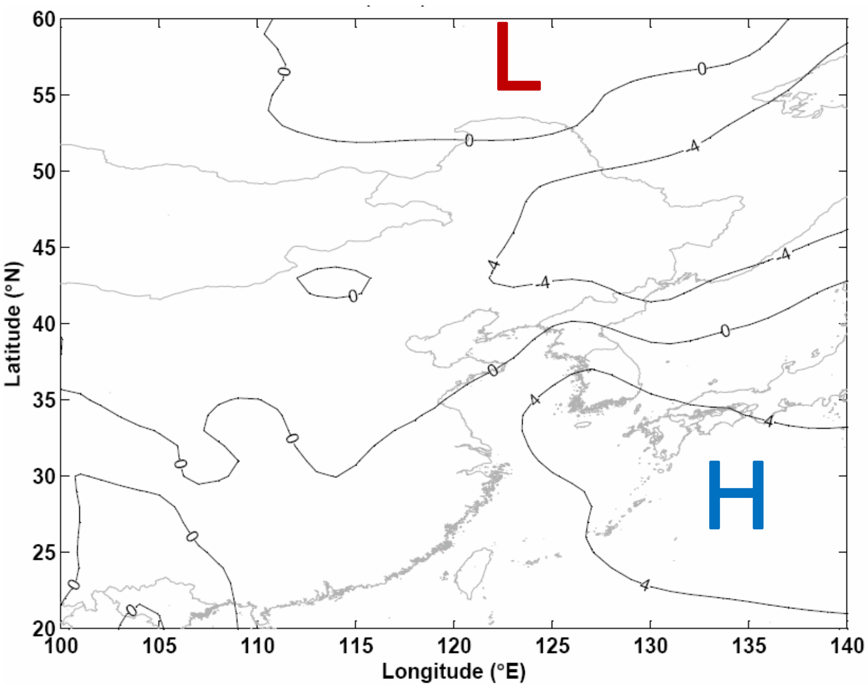


850hPa
; 2001/04/15, 2002/03/08, 2002/03/09

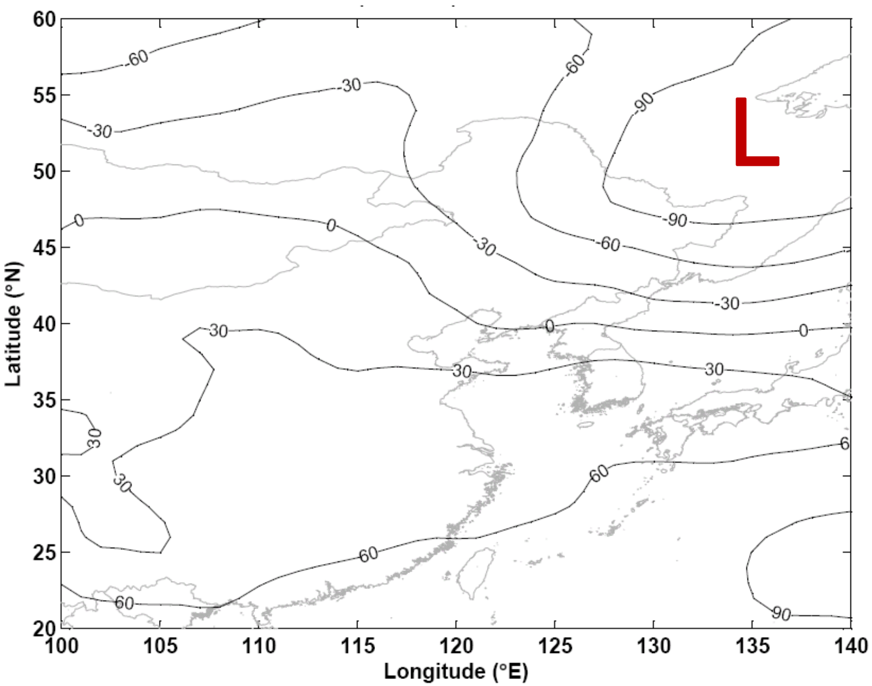


Synoptic pattern B

SFC
; 01/04/16, 02/03/11, 06/06/16



850hPa
; 01/04/16, 02/03/11, 06/06/16



LTP indicators

- ✓ Two points of views

1. Meteorological patterns

   - analyzing synoptic conditions for highly polluted days

2. Chemical compositional characteristics

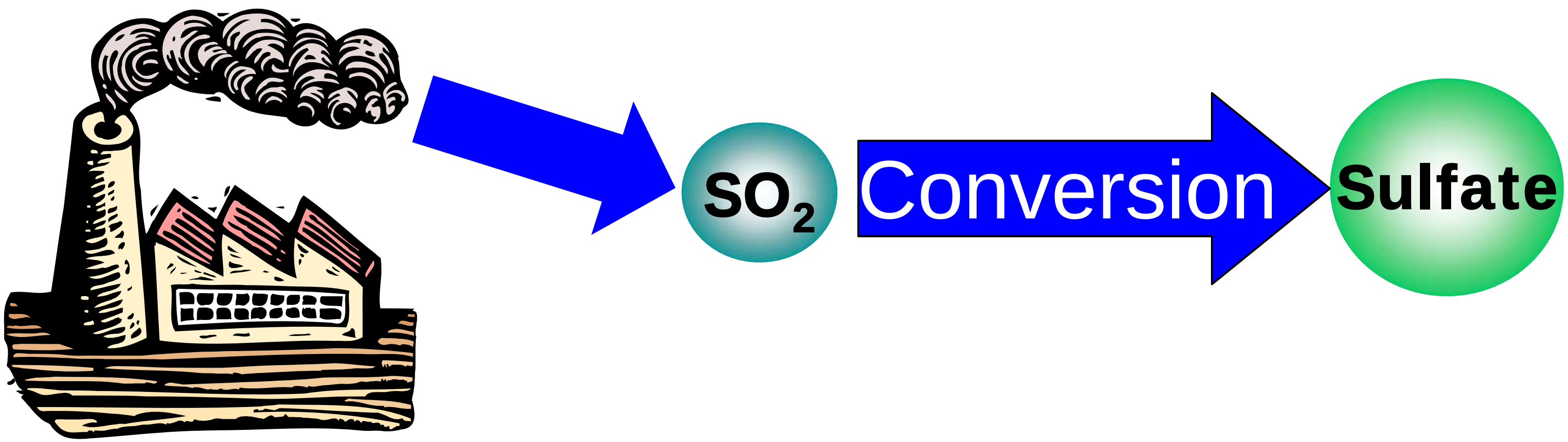
   - analyzing chemical compositions in aerosols during LTP days

Conversion of SO_2 to sulfate

- ✓Grosjean and Friedlander (1975) and Kadowaki (1986) defined the conversion ratios for sulfur (F_S, %) in the modified forms of the gas–particle distribution factors:

$$F_S = \frac{S_{SO_4^{2-}}}{S_{SO_2} + S_{SO_4^{2-}}}$$

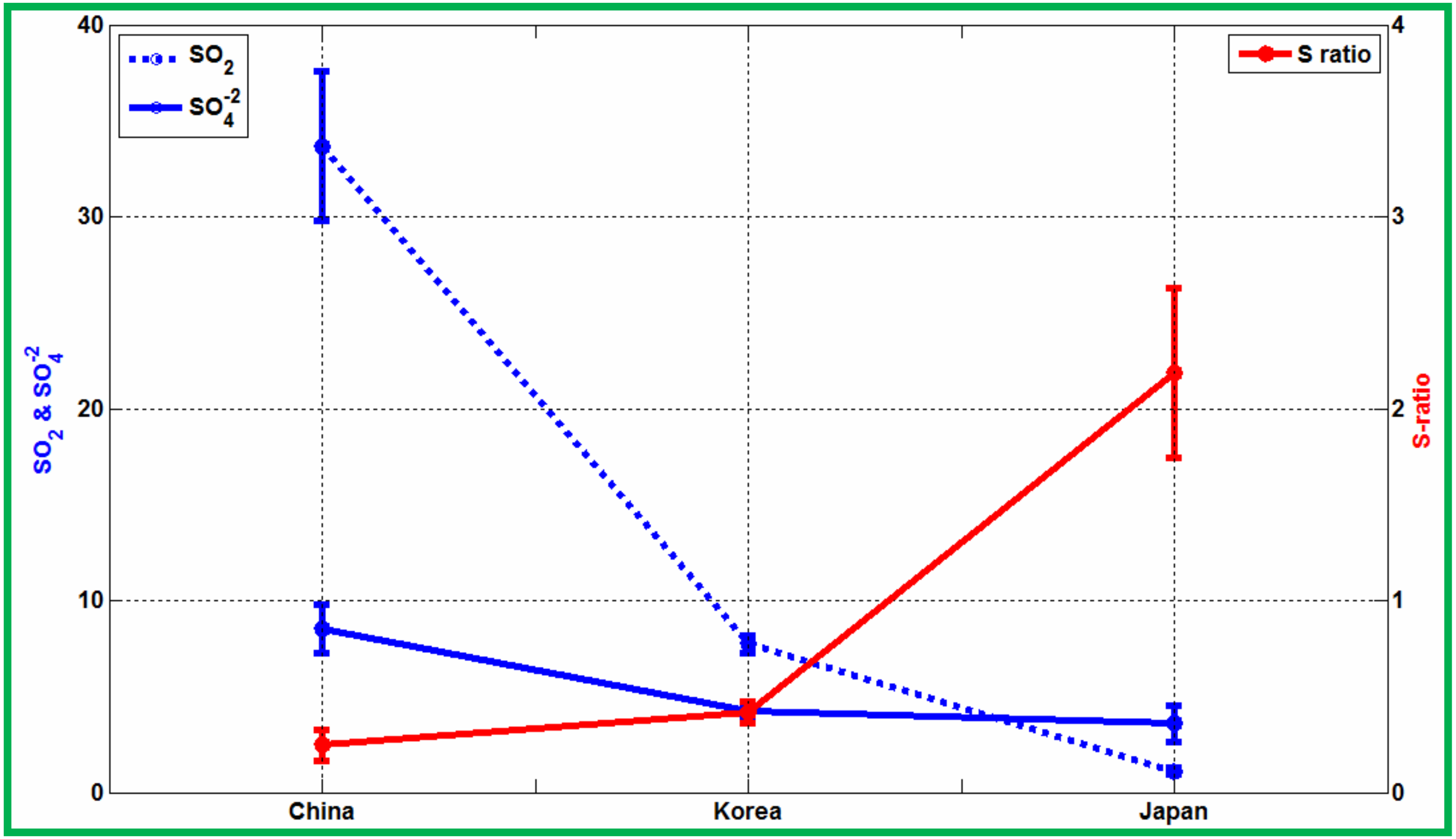
where SO_4^{2-} was particulate sulfate in the atmosphere, the unit is in μg m^{-3}; SO_2 is the gas phase SO_2 concentration, converted from ppb to μg m^{-3}.



Tendency of F_S among China·Korea·Japan

	China								Korea																Japan							
	Dalian				Xiaman				Gangwha				Taean				Gosan				Geoje				Rishiri				Oki			
	SO4	SO2		S-ratio	SO4	SO2		S-ratio	SO4	SO2		S-ratio	SO4	SO2		S-ratio	SO4	SO2		S-ratio	SO4	SO2		S-ratio	SO4	SO2		S-ratio	SO4	SO2		S-ratio
	µg/m3	ppb	µg/m3		µg/m3	ppb	µg/m3		µg/m3	ppb	µg/m3		µg/m3	ppb	µg/m3		µg/m3	ppb	µg/m3		µg/m3	ppb	µg/m3		µg/m3	ppb	µg/m3		µg/m3	ppb	µg/m3	
1995			55.00											3.00	8.57																	
1996			60.00											2.00	5.71																	
1997			47.00							3.00	8.57			3.00	8.57																	
1998			47.00							2.00	5.71			2.00	5.71			1.00	2.86													
1999			28.00							3.10	8.81			1.80	5.24			1.30	3.57			5.00	14.29									
2000		4.20	12.00			5.30	15.14		1.36	5.00	14.29	0.06	4.80	2.00	5.71	0.56	4.79	2.00	5.71	0.56	3.49	4.00	11.43	0.20		0.11	0.31			0.28	0.80	
2001		5.10	14.00			8.50	24.29		4.71	5.70	16.29	0.19	4.27	1.70	4.86	0.59	5.43	1.40	4.00	0.91	2.15	3.20	9.14	0.16		0.21	0.60			0.63	1.80	
2002		12.10	34.00			9.50	27.14		5.20	3.40	9.71	0.36	5.54	1.80	5.15	0.72	1.91	1.40	4.00	0.32	4.36	3.40	9.71	0.30		0.21	0.59			0.43	1.21	
2003	3.69				3.58				1.68	4.10	11.71	0.10	2.26	2.80	8.00	0.19	2.24	1.60	4.57	0.33	9.95	2.60	7.43	0.89		0.21	0.59			0.41	1.18	
2004	8.08	13.70	39.00	0.14	11.29	6.80	19.00	0.40	4.51	3.50	10.00	0.30	5.36	2.80	8.00	0.45	6.49	1.50	4.29	1.01	6.01	3.60	10.29	0.39	3.55	0.20	0.57	4.14	4.03	0.75	2.14	1.25
2005	8.59	16.00	46.00	0.12	16.09	7.70	22.00	0.49	3.10	3.00	8.57	0.24	3.10	2.60	7.43	0.28	4.60	2.10	6.00	0.51					1.78	0.18	0.51	2.30	5.35	0.74	2.11	1.69
2006	7.91	20.20	58.00	0.09		8.70	25.00			2.70	7.71			2.60	7.43			2.10	6.00						1.40	0.26	0.74	1.26	8.05	0.76	2.17	2.47
2007	8.14				9.23					3.00	8.57			3.20	9.14			2.20	6.29						1.10							
mean	7.28	11.88	40.00	0.12	10.05	7.75	22.10	0.44	3.43	3.50	10.00	0.21	4.22	2.41	6.89	0.46	4.24	1.66	4.73	0.60	5.19	3.63	10.38	0.39	1.96	0.20	0.56	2.57	5.81	0.57	1.63	1.80

Conversion ratio for sulfur F_S



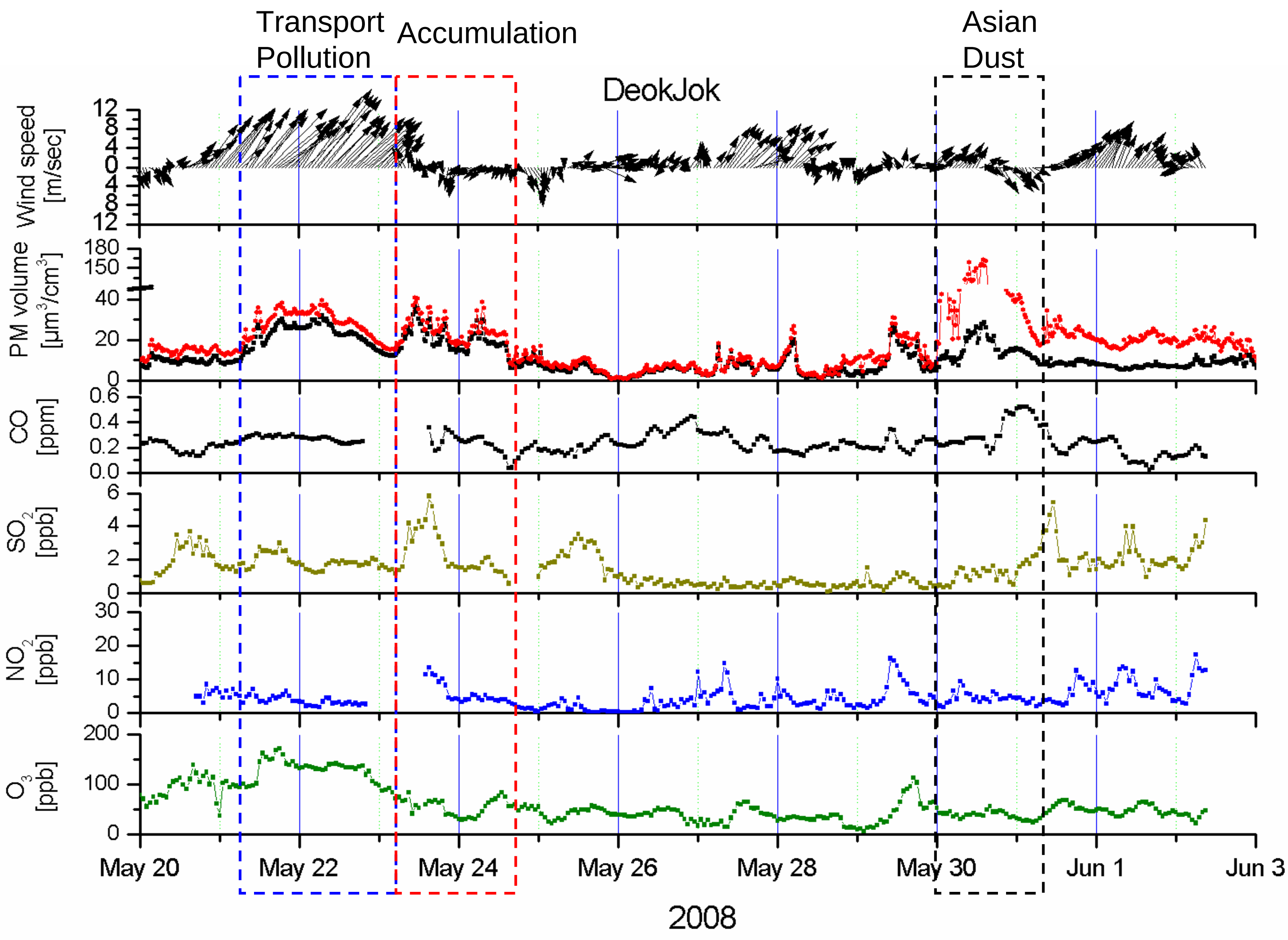
- China
  SO_2 : 1995 – 2006 (2003, 2007 excluded)
  SO_4^{-2} : 2003 – 2007
  S-ratio : 2004 – 2006
- Korea
  SO_2 : 2000년– 2005
  SO_4^{-2} : 1997 – 2007
  S-ratio : 2000년– 2005
- Japan
  SO_2 : 2004 – 2007
  SO_4^{-2} : 2000 – 2006
  S-ratio : 2004– 2006

Surface measurement sites

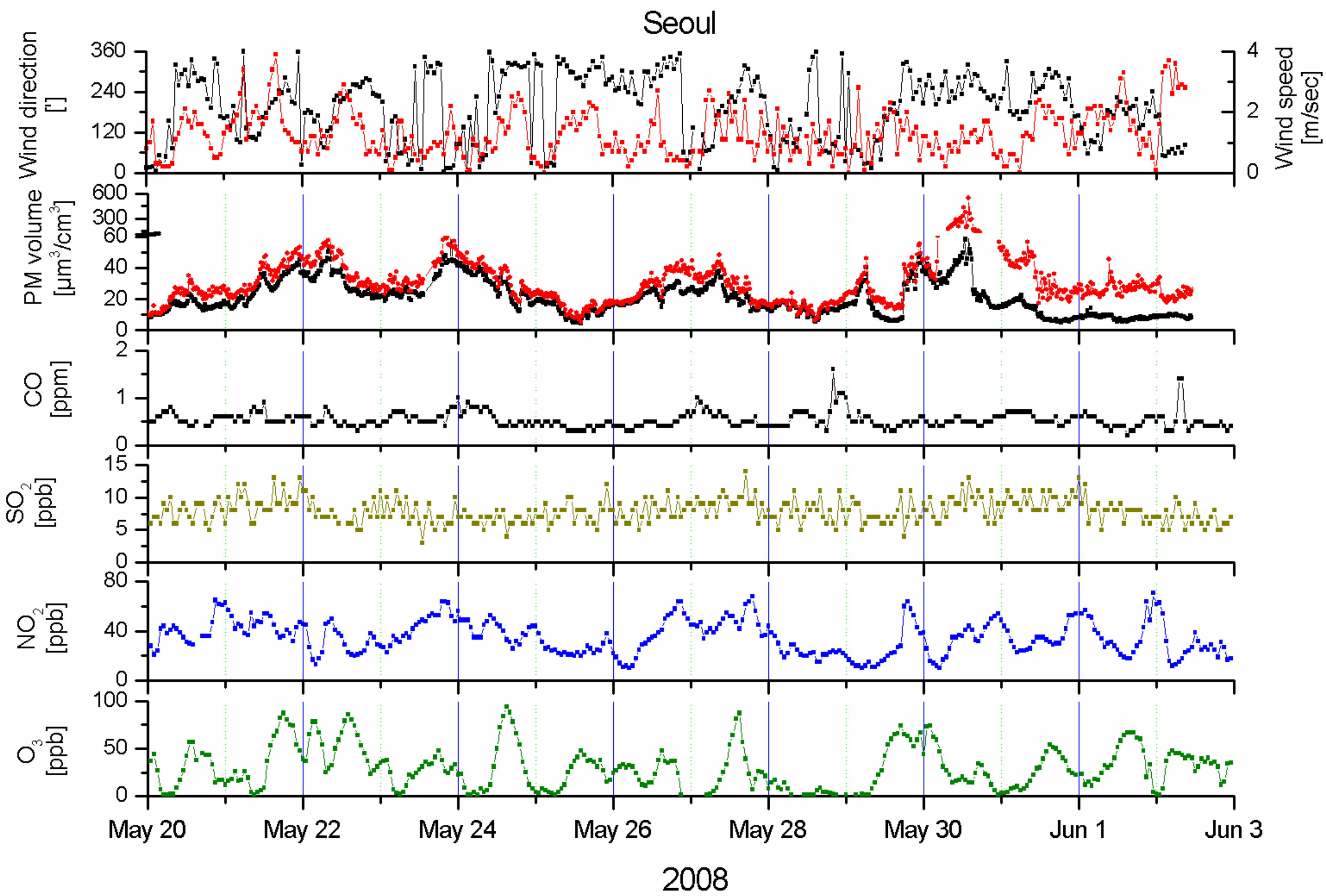
Measurement items

items	Size	Sampler	instruments
Mass concentrations	PM_{10}, $PM_{2.5}$	URG sampler	Microbalance (Sartorius AG, SC2)
	0.056~18 μm, 8 channel	MOUDI sampler	
Ion (SO_4^{2-}, NO_3^-, Cl-, Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+})	PM_{10}, $PM_{2.5}$	URG sampler	Ion chromatogrphy (Dionex, DX-120)
	0.056~18 μm, 8 channel	MOUDI sampler	
Gas (NH_3, HNO_3 etc)		URG sampler	Ion chromatogrphy (Dionex, DX-120)
Molecule (Al, Fe, Mg, Mn, Cu, Zn, Pb, Ni, Cd, Cr, Ba, Ti, S, Be, Co, Se, Sr, As)	PM_{10}, $PM_{2.5}$	URG sampler	PIXE
Carbon (OC, EC)	$PM_{2.5}$	URG sampler	OC/EC analyzer (Sunset, 3014)
Number concentrations	0.25~32 μm		Grimm aerosol spectrometer
VOCs	TO-14A (31)	Mini sampler	Gas chromatography
Gas species (SO2, O3, NOx, CO)			Mandatory
Meteorological variables (temp, relative humidity, wind speed/direction)			Mandatory

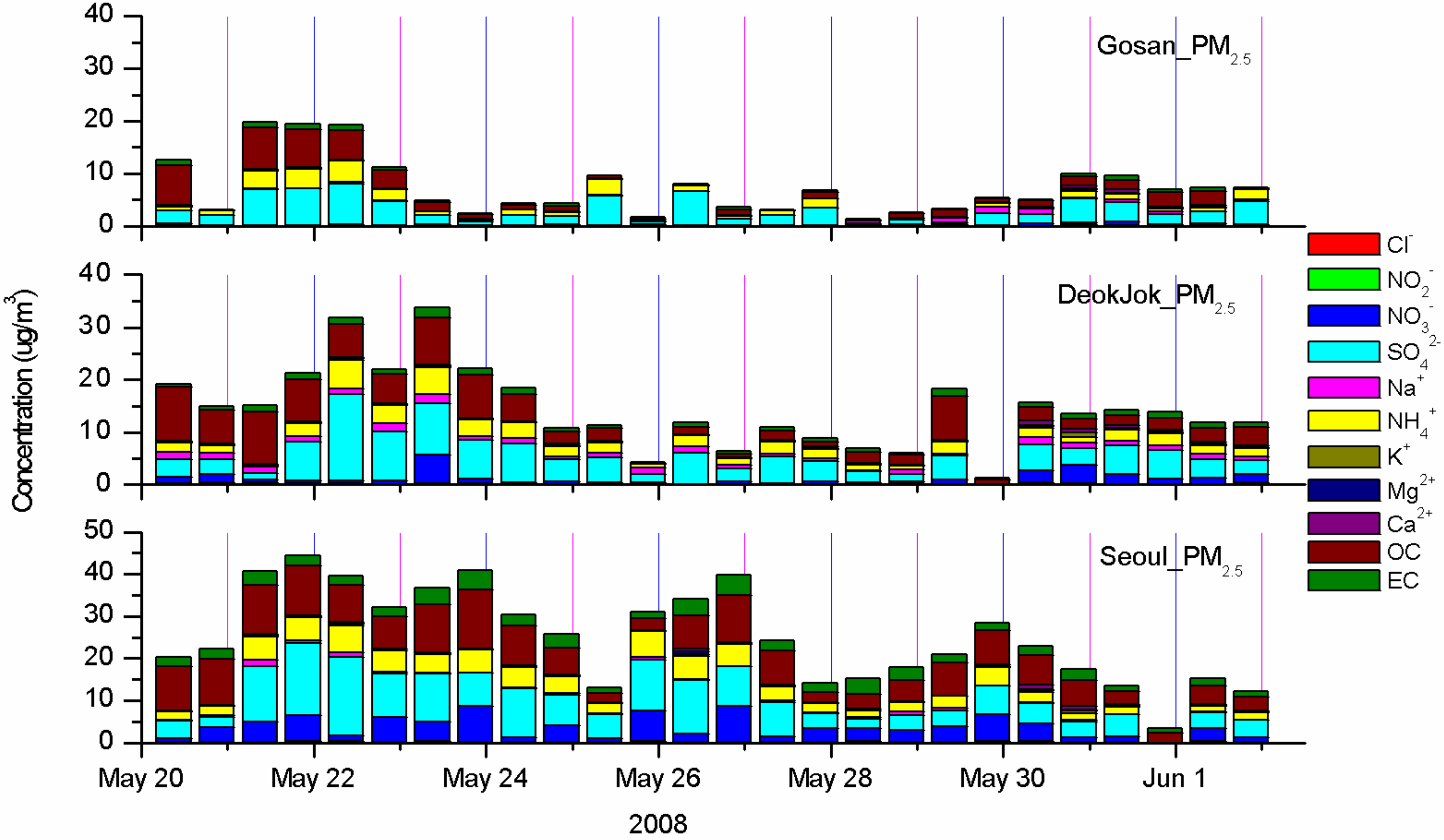
Temporal variations in Deokjokdo



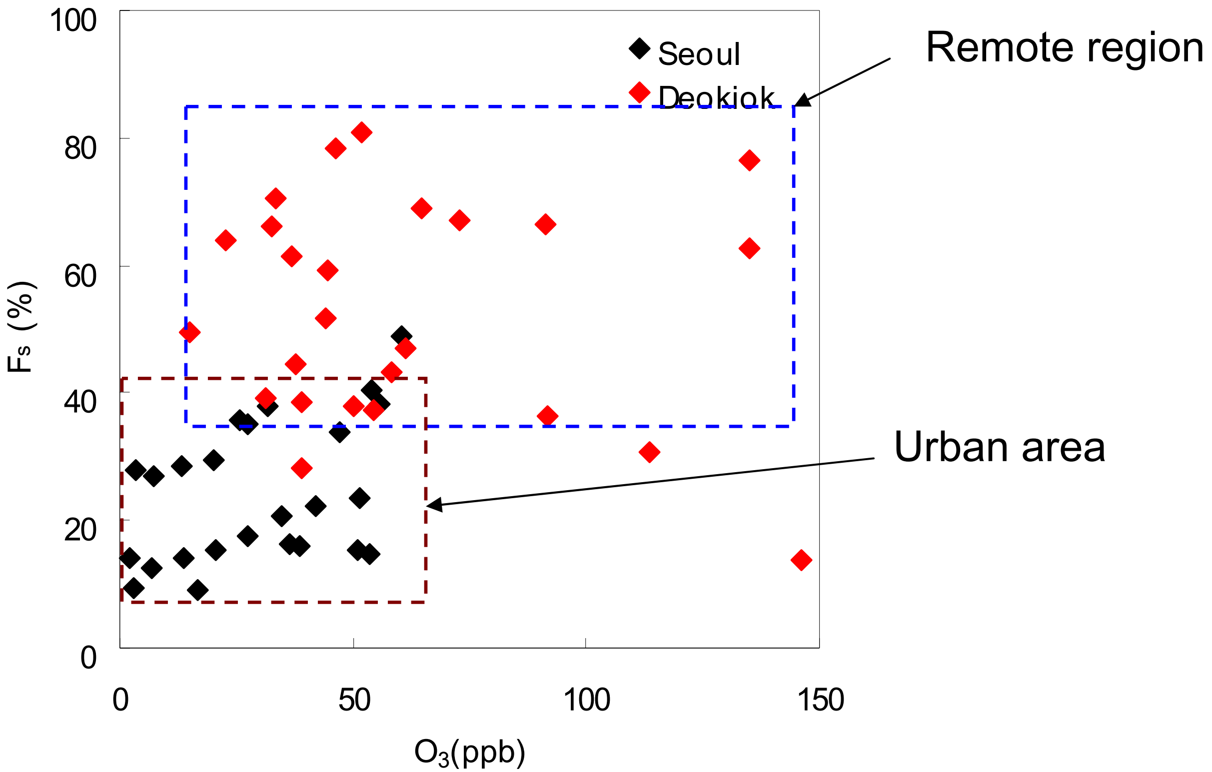
Temporal variations in Seoul



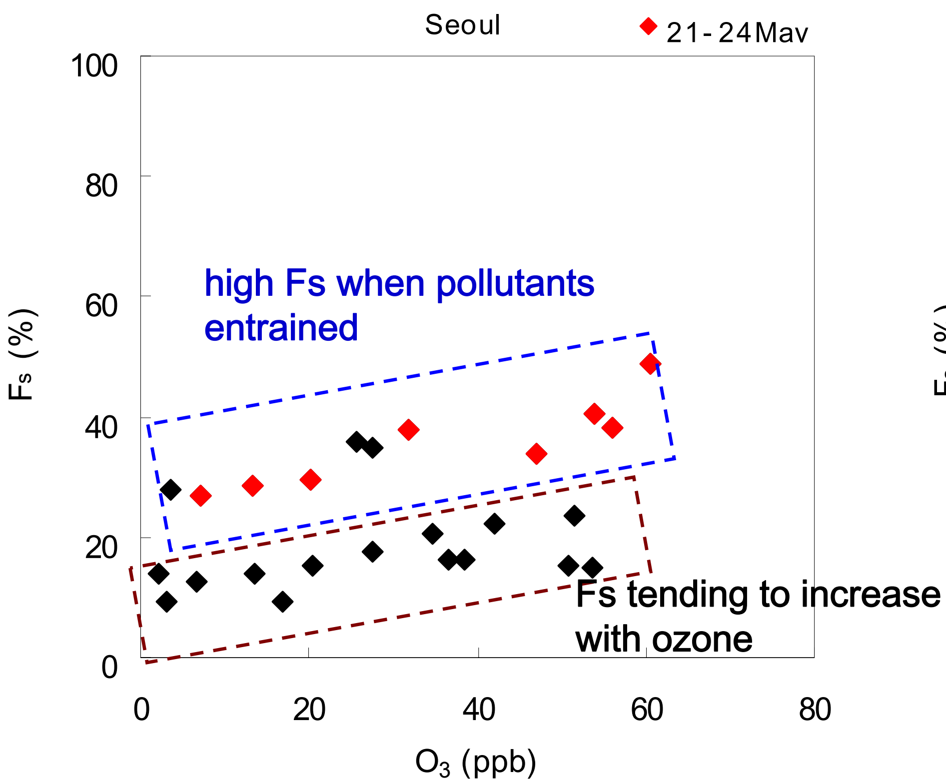
Temporal variations of chemical compositions in $\mathbf{PM_{2.5}}$

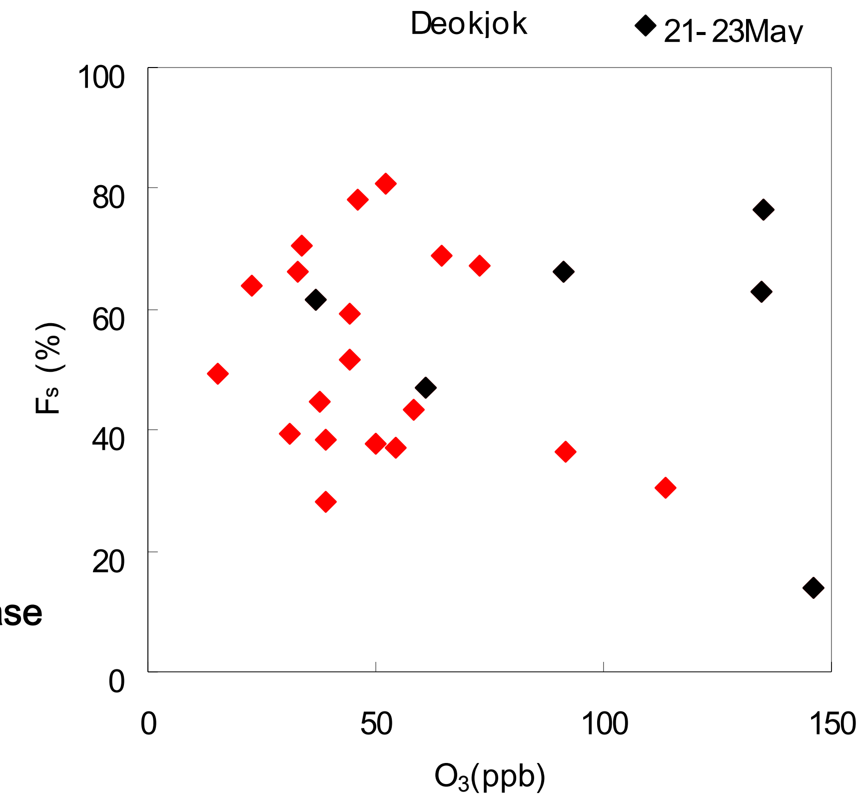


Conversion ratio for sulfur



Conversion ratios for sulfur

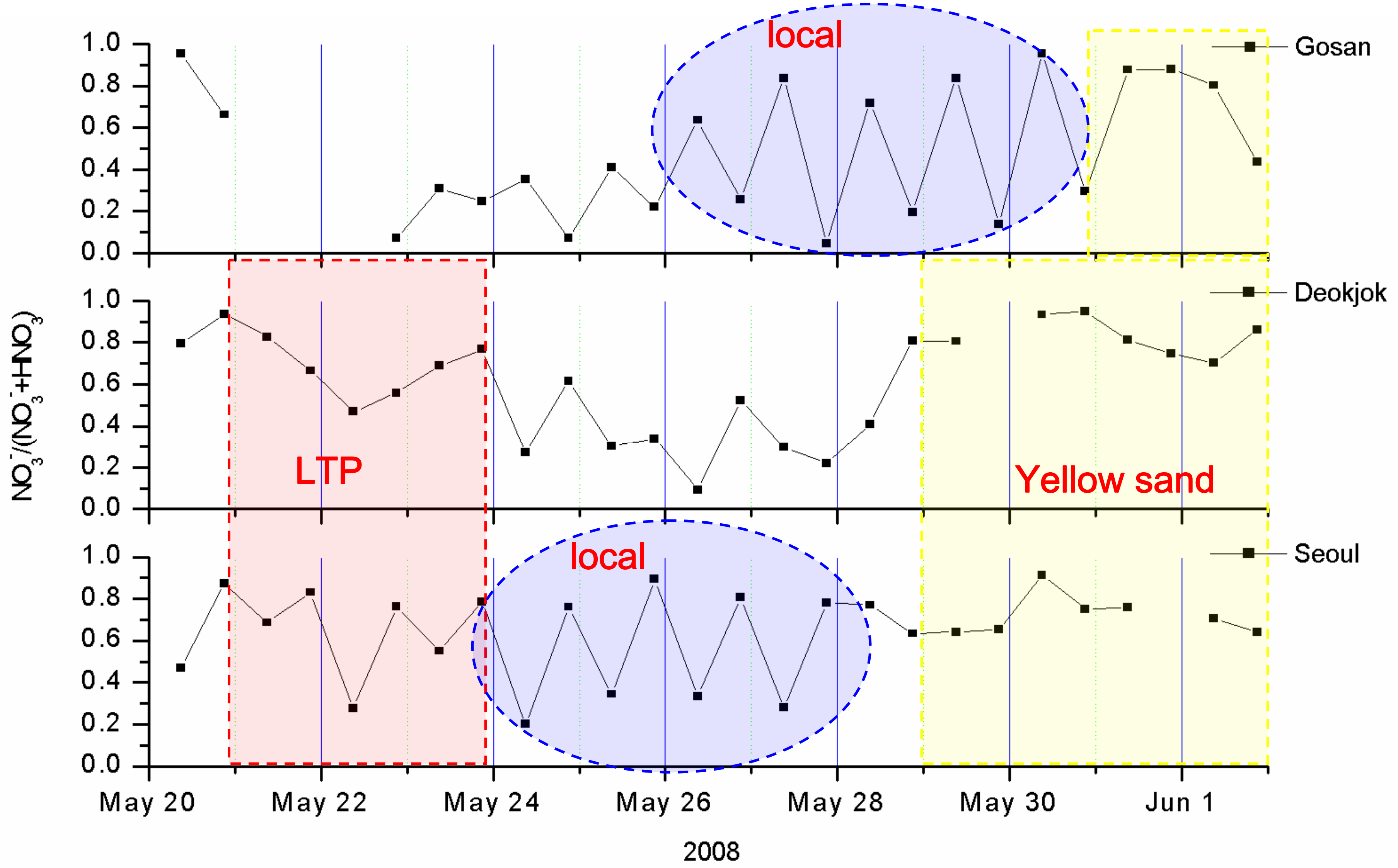




Indicating photochemical reaction is important for the oxidation of SO2 to sulfate.

No tendency

$HNO_3 \rightarrow NO_3^-$ conversion



Summary

✓When haze from China was entrained into Korea over Yellow sea, air quality in Korea was worse than usual.
✓Composite map of meteorological field made for high polluted days
➔When high and low pressure systems were aligned vertically, LTP occurred by strong zonal wind
✓Sulfur content increased when LTP occurred
✓Generally Fs (conversion rate of sulfur) was high in remote region while it was low in urban area ➔ Fs can be one of candidates for LTP indicator

Thank you for attention !!!