WRF-Chem Simulation of East Asian Air Quality: Sensitivity to Emissions Distributions

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Introduction

- Developed finer resolution temporal (i.e. seasonal, day-of-week, diurnal) and vertical scaling for different categories and species of TRACE-P anthropogenic emissions inventory (Streets et al., 2003) in East Asia.

- Conducted two experiments in July of 2001: CTL (control run with default emissions) and SCL (scaling run with the new scaled emissions) to evaluate the roles of temporal and vertical scaling to prediction of NO_2, SO_2 and O_3.

- SCL continuous run four months: March, July, October and December of 2001 to evaluate model performance for East Asian air quality in different seasons.

  (7 day spin-up, i.e., 22-28, Feb., 24-30, Jul., Sep., and Dec.)

Model settings and observations data

- **Domain:**

  central: 35.18ºN, 110ºE

  30km (232×172)

  28 vertical levels (σ) with

  6 within PBL

  the first model layer at ~37m

- **Parameterizations:**

  long & shot wave radiation: CAM

  land surface model: NOAH

  boundary layer schem: YSU

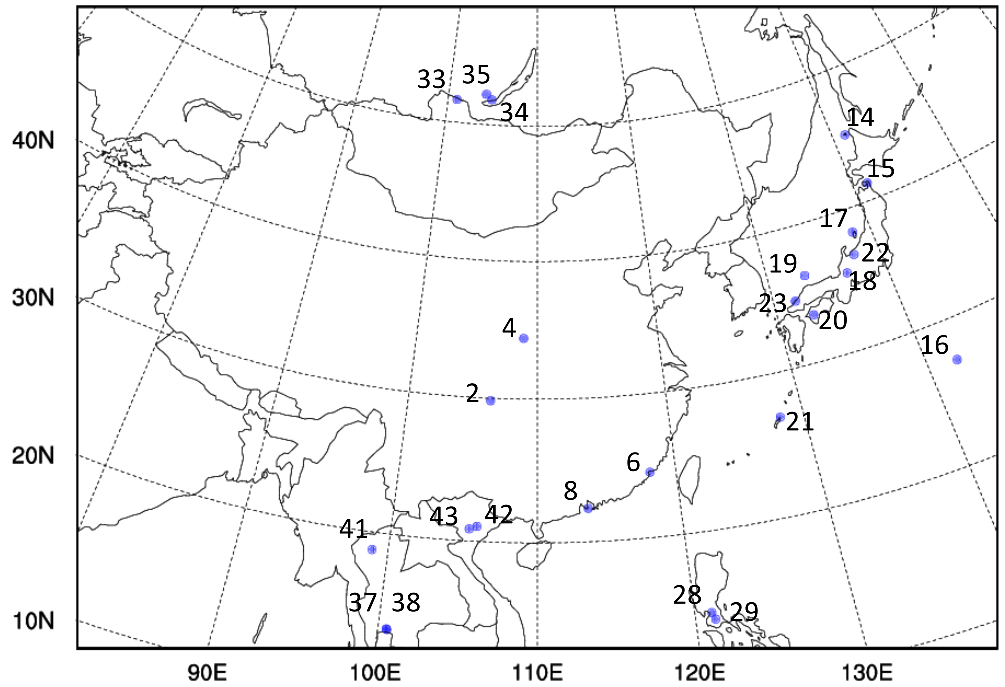
  dry deposition: Wesely (1989)

  photolysis scheme: Fast-J

  gas chemistry: RACM

  aerosol scheme: MADE/SORGAM

  as well as other parameters



- **Observations:**

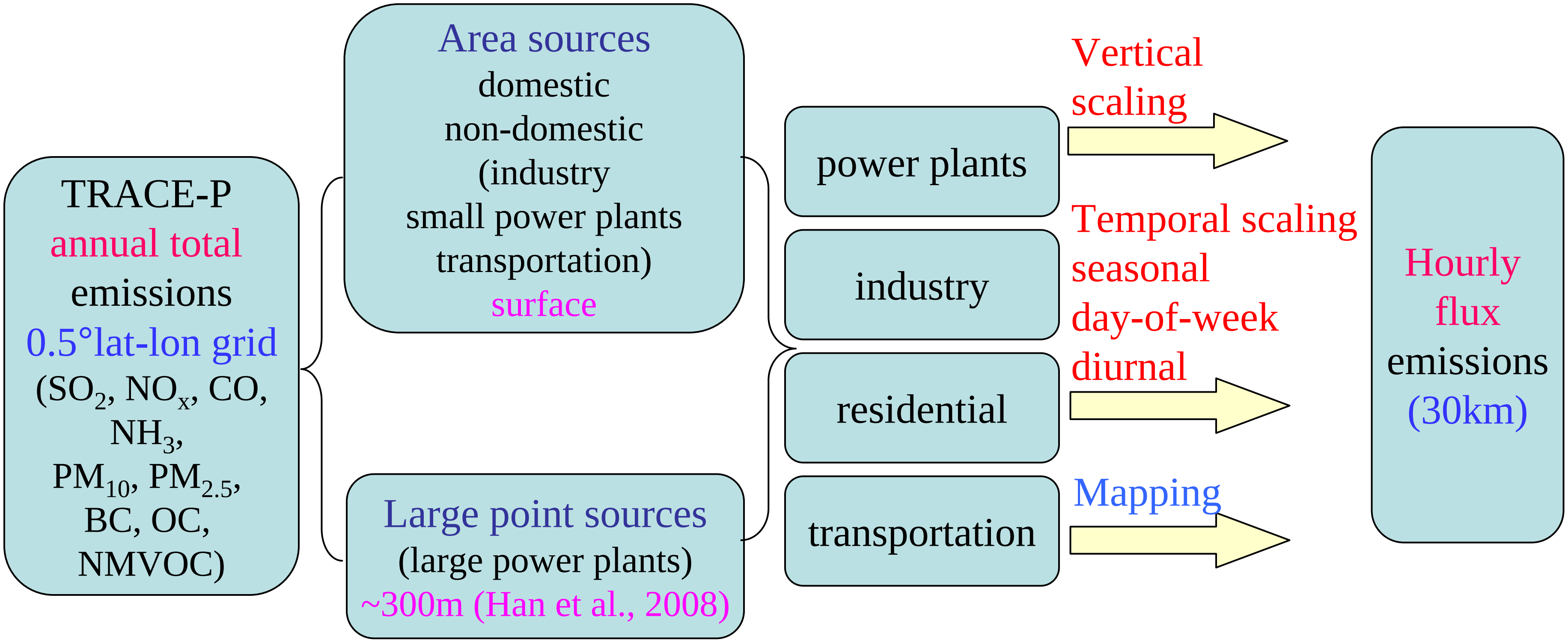
  The Acid Deposition Monitoring Network in East Asia (EANET)

Emissions inventory

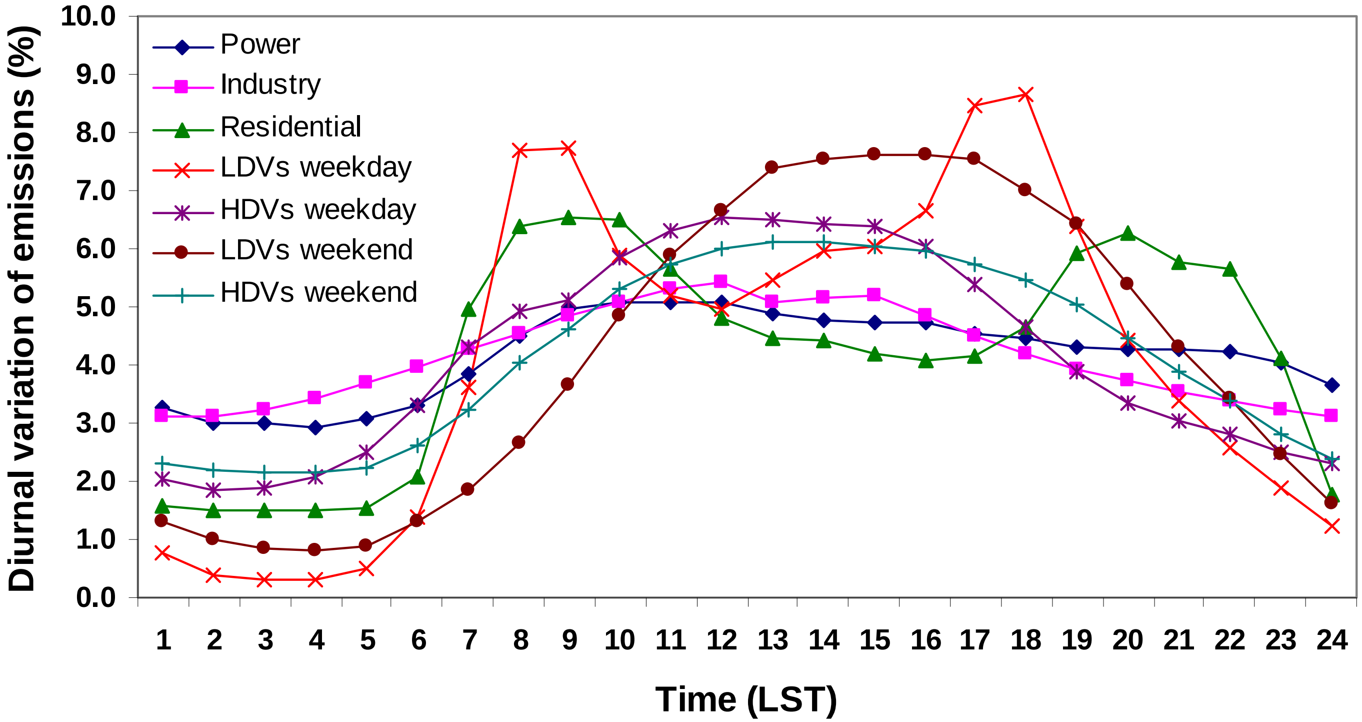
- **Biogenic emissions**: calculated "online" within WRF-Chem using Guenther et al. (1994).
- **Biomass burning**: monthly averaged emissions from Streets et al. (2003) and Woo et al. (2003).
- **Volcano SO_2 emissions**: monthly averaged emissions at Miyakejima (139.53ºE, 34.08ºN, 813m MSL and located in the west Pacific Ocean) from Kajino et al. (2004)

  placed in the fifth model layer (925hPa)
  (estimated smoke height: 450-760m)
- **Anthropogenic emissions**: TRACE-P emissions inventory.

New scaling for anthropogenic emissions



Diurnal variations for each sector of TRACE-P anthropogenic emissions



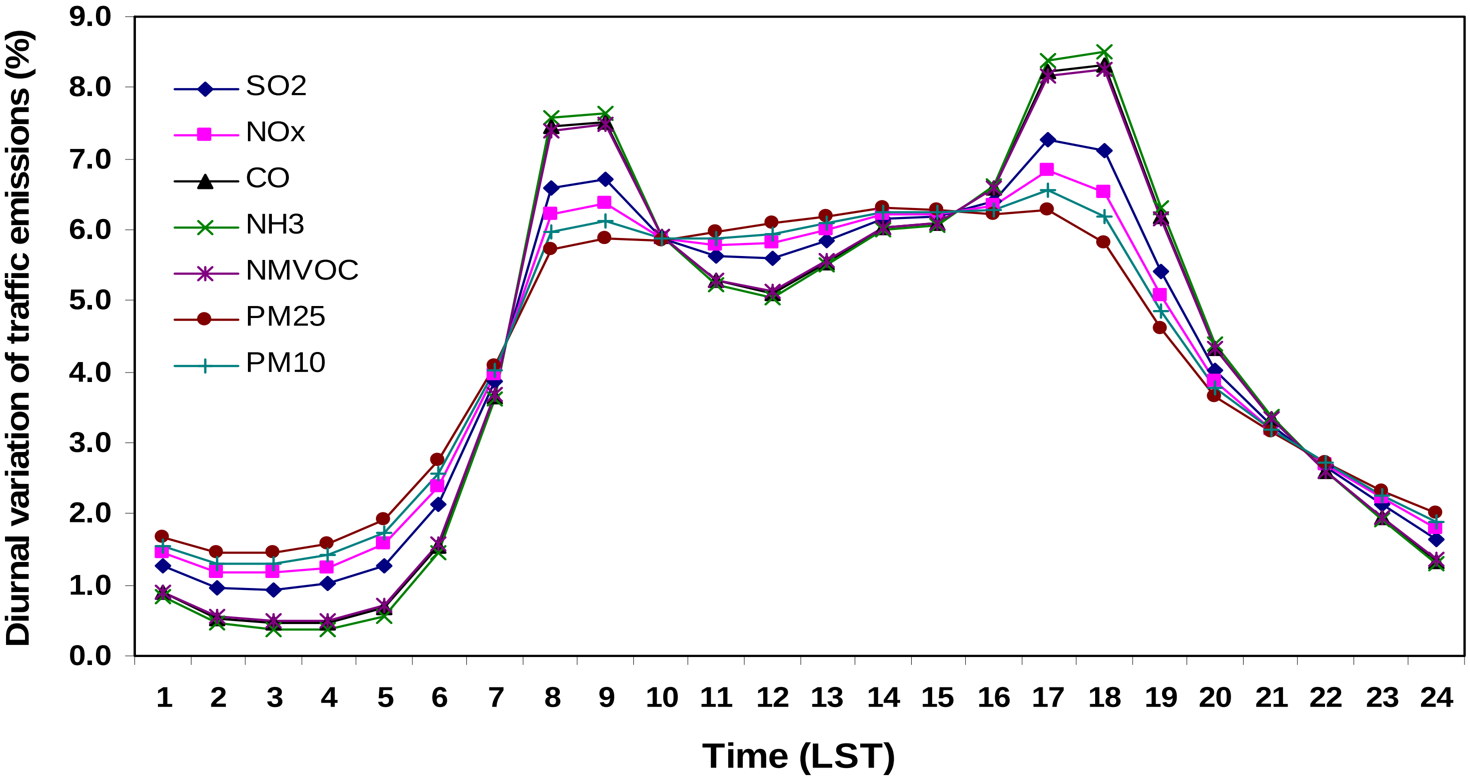
Sources:

Olivier et al. (2003)

WRAP, 2006

- Residential & weekday LDVs have 2 peaks;
- Percentage of LDVs & HDVs for each species was derived from U.S. EPA Nation Emissions Inventory 99.

Diurnal variations for seven major species of weekday transportation emissions



- CO, NMVOC & NH3 have 2 peaks (LDVs domaints 90%);
- SO_2, NO_x peaks relatively small;
- PM_{10} & $PM_{2.5}$ relatively leveled during daytime;
- BC & OC use the same profile as $PM_{2.5}$.

Vertical scaling for power plants emissions

Species	Height of Emission Layer (m) 0-76	76-153	153-308	308-547	547-871
SO_2	5	30	35	25	5
NO_x	5	40	25	25	5
CO	5	70	20	5	
NH_3	5	75	15	5	
NMVOC	5	85	10		
$PM_{2.5}$	5	45	25	20	5
PM_{10}	5	55	20	15	5
BC	5	65	20	10	
OC	5	70	15	10	

- Derived from U.S. EPA NEI 99;
- SO2: largest in the 3rd model layer, others: maximized in the 2nd layer;
- All species are small near the surface and above 500m.

Statistics of daily mean NO_2, SO_2 & O_3 in Jul., 2001 for SCL & CTL vs. observations

Site	Statistics	NO_2		SO_2		O_3	
		SCL	CTL	SCL	CTL	SCL	CTL
China	R	0.38	0.36	0.54	0.54		
	Bias	0.46	2.30	-1.09	1.43		
	GE	3.28	3.93	2.81	3.15		
	NGE	106.22	144.27	95.91	142.54		
Japan	R	0.64	0.65	0.84	0.83	0.67	0.67
	Bias	-0.04	0.47	-0.10	0.05	2.87	2.11
	GE	0.89	1.06	0.52	0.55	8.96	8.87
	NGE	82.33	114.74	92.53	109.95	42.90	42.05

$$\text{Bias} = \frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)$$

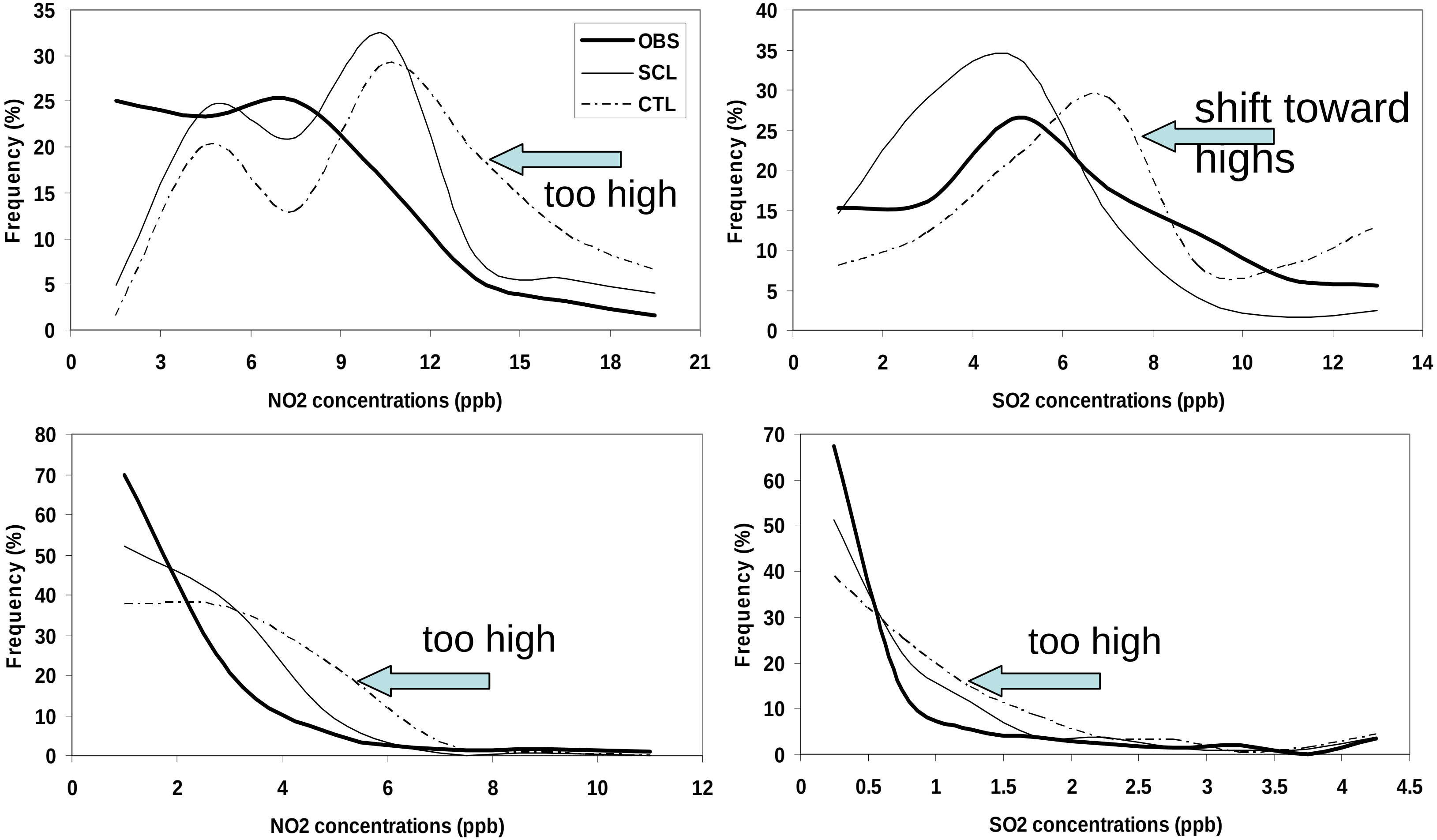
$$\text{GE} = \frac{1}{N}\sum_{i=1}^{N}(|P_i - O_i|)$$

$$\text{NGE} = \frac{1}{N}\sum_{i=1}^{N}(|P_i - O_i|/O_i)$$

N: the number of observations;
P: WRF-Chem predictions;
O: observed values.

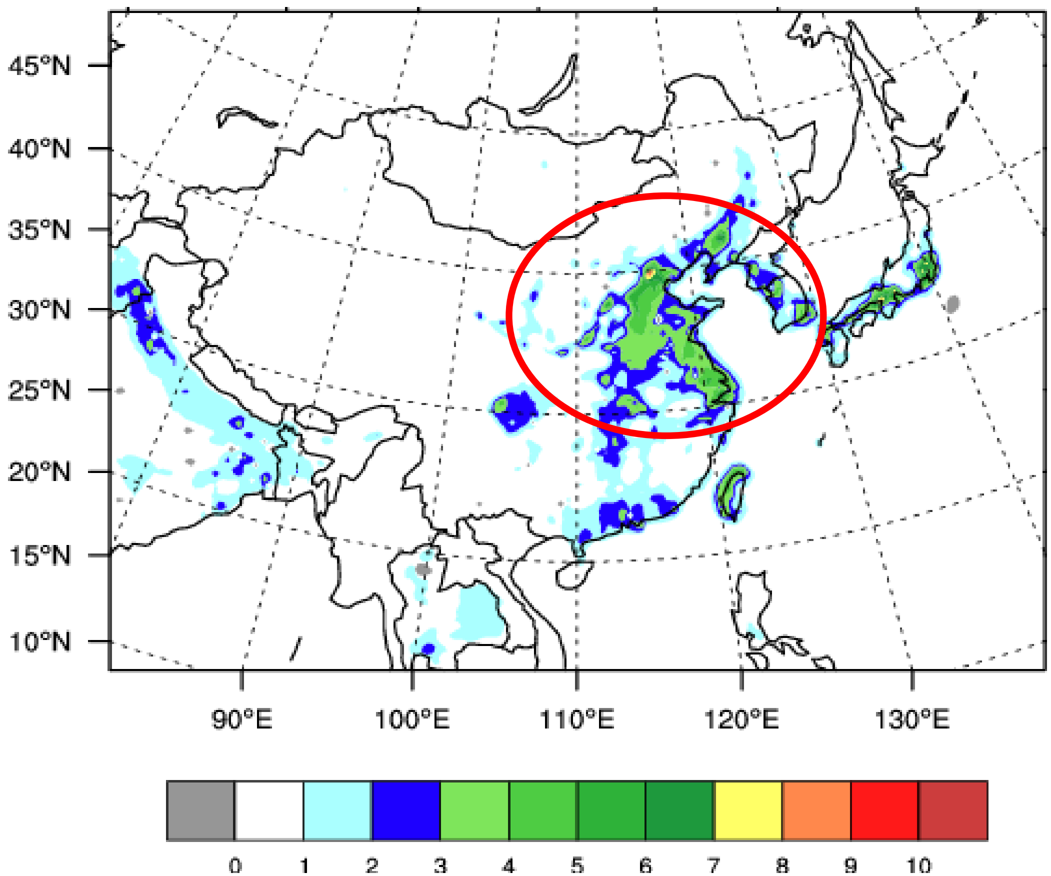
- SCL simulation for NO_2 & SO_2 is in better agreement with observations at EANET sites in China and Japan, with higher correlation, lower bias, gross error & normalize gross error;
- SCL simulation is close to CTL for O_3 at sites in Japan.

Frequency Distributions of NO_2 and SO_2 at EANET sites in China (top) & Japan (bottom) in Jul., 2001



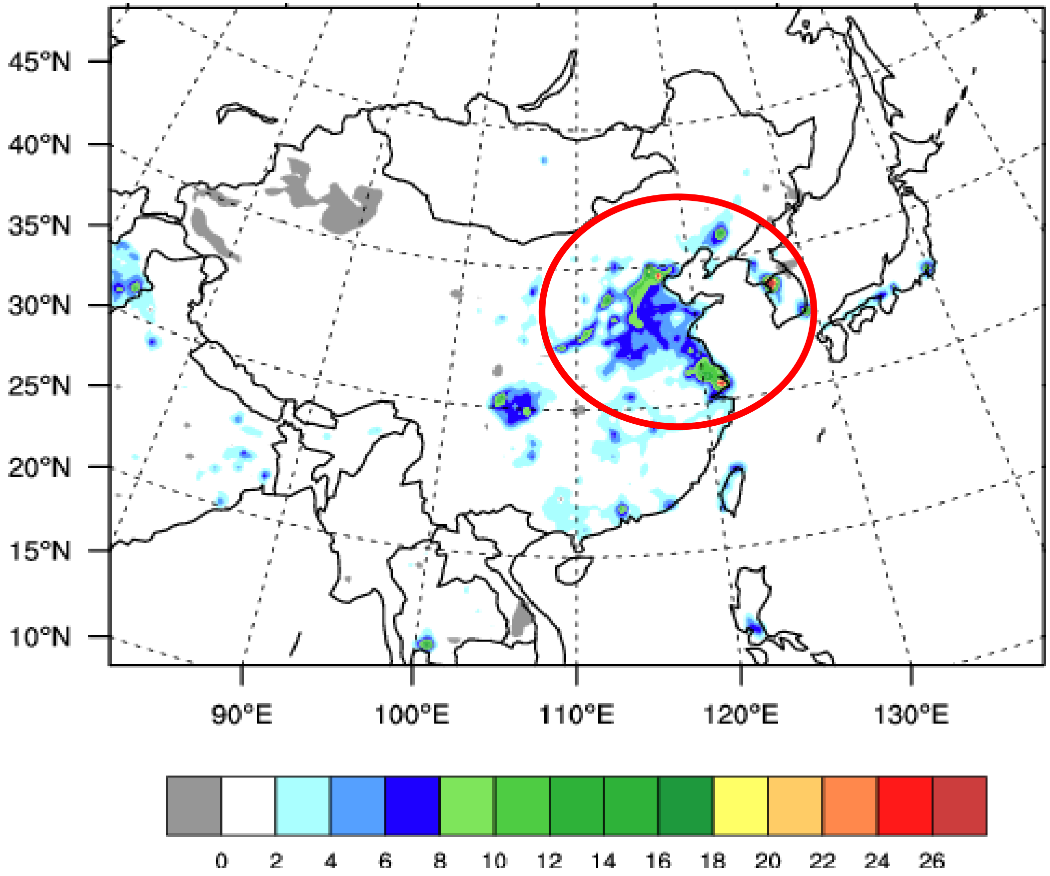
- Over China: SCL frequency of NO_2 lower for lows; SO_2 lower for highs; SCL is better than CTL
- Over Japan: SCL frequencies are in better agreement with observations for NO_2 & SO_2

CTL-SCL: Surface NO_2 difference in Jul., 2001



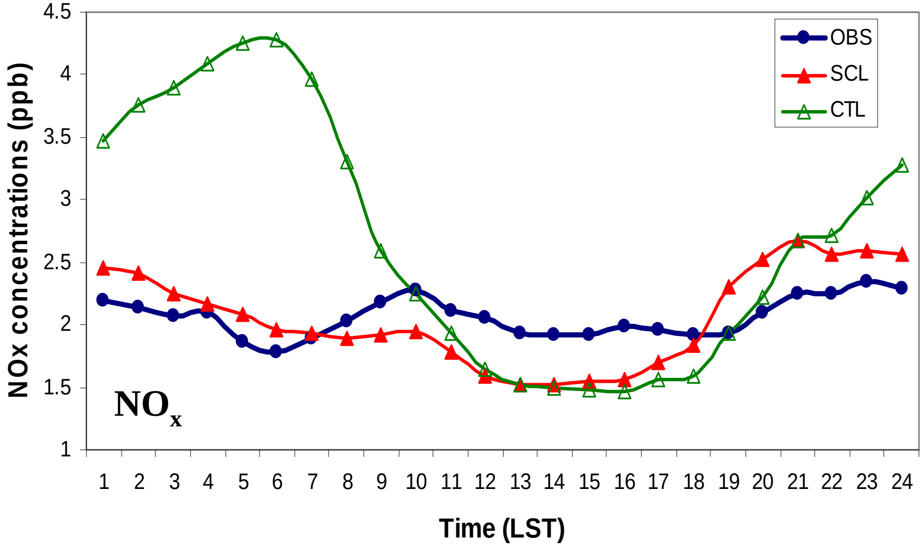
- differences all positive: CTL allocates more NO_x emissions in the surface layer
- large in major cities and industrial regions over China: 3-7 ppb
- largest in Beijing: up to 9 ppb
- small in South Korea & Japan

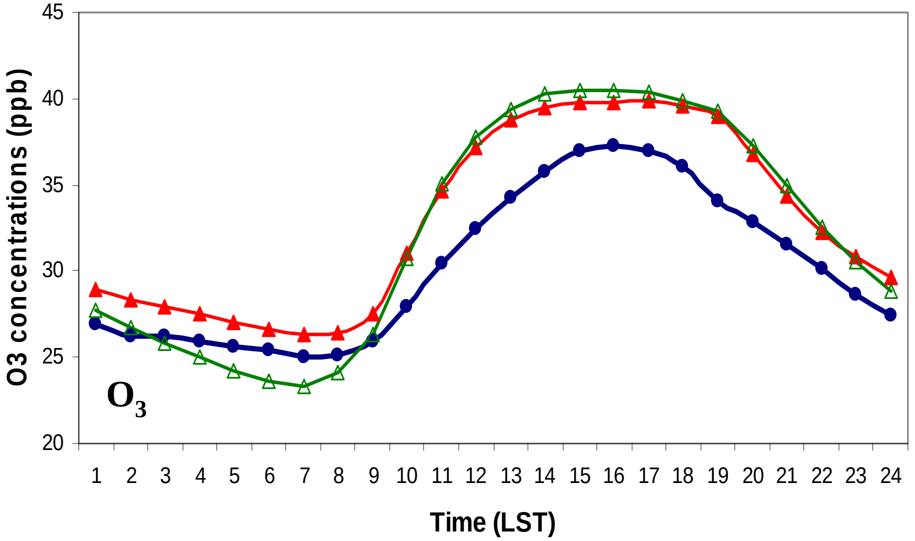
CTL-SCL: Surface SO_2 difference in Jul., 2001



- differences all positive
- 6~8 ppb over northern and eastern China, Sichuan Basin, up to 10~12 in Chongqing, Taiyuan
- over 26 ppb in Beijng, Shanghai & Seoul
- less than 10 ppb over Japan

Diurnal cycle of surface NO_x and O_3 at EANET sites in Japan in Jul., 2001

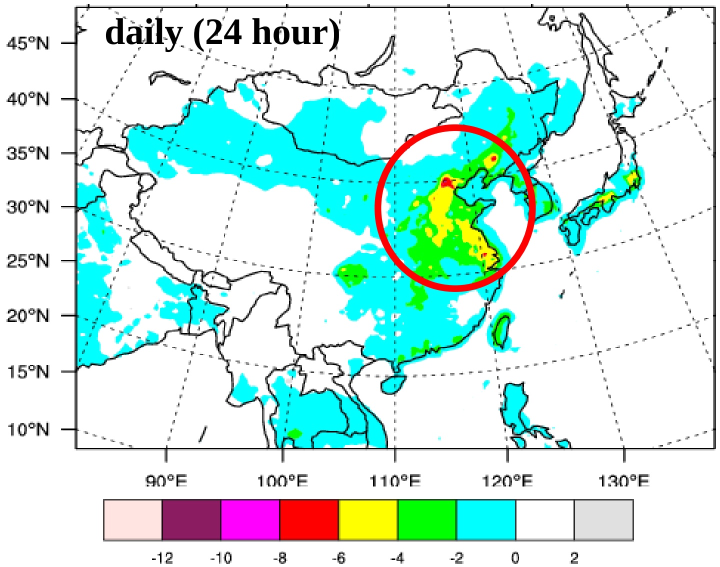




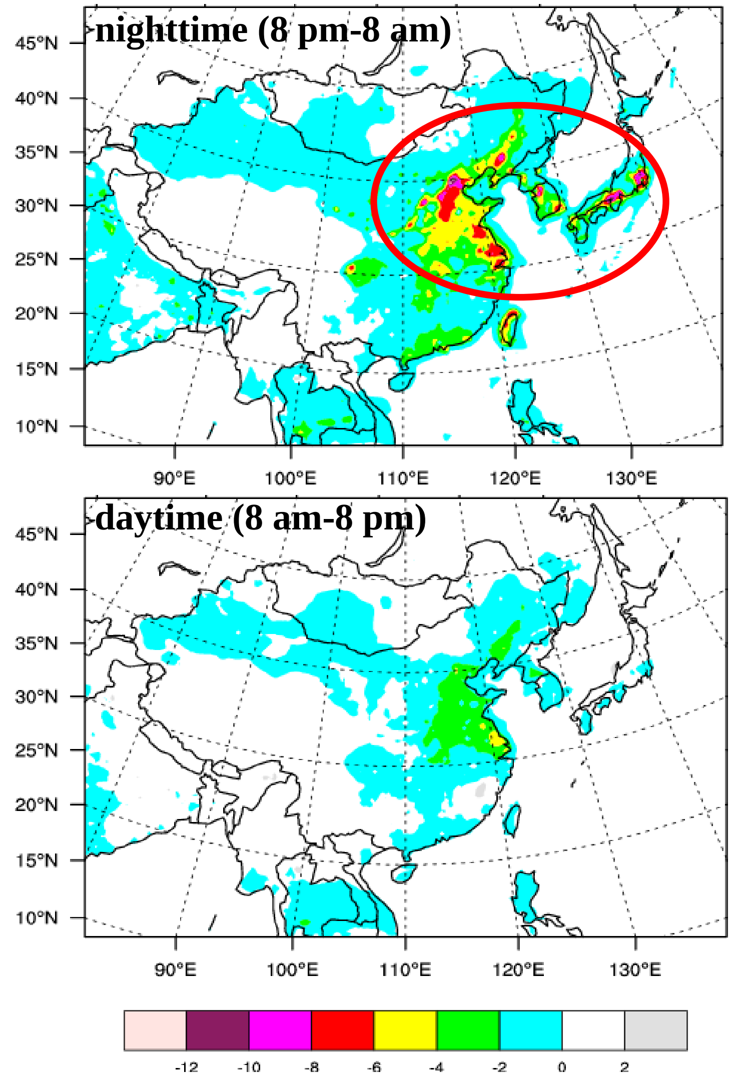
- daytime: SCL close to CTL, both 0.4 ppb lower than observations at noon;
- nighttime: SCL agree well with observations, CTL significantly overestimates NOx by a factor of 1.2~2.5.

- both realistically predict daily maximum (4:00 pm) and minimum O_3 (7:00 am);
- daytime: SCL close to CTL, both 4 ppb higher than observations after 10: am;
- nighttime: SCL overestimate 2 ppb, CTL underestimate 2 ppb.

CTL-SCL: Surface daily, nighttime & daytime O_3 difference in Jul., 2001



- daily: -4~-6 ppb in northern & eastern China,
  -8 ppb in Beijing;
- nighttime: larger, -8 ppb over northern and eastern China, -12 ppb in Beijing;
- daytime: within ±2 ppb over vast areas of East Asia
  -2~-4 ppb in northern & eastern China.
- reason for negative difference:
  (1) larger NOx emissions at night for CTL produce high NOx concentrations, titrate more O_3;
  (2) large portion of nighttime NOx emissions available for the next day for CTL, close to CTL.



Statistics of daily mean NO_2, SO_2 & O_3 in Mar., Jul., Oct., and Dec., 2001 (SCL vs. EANET observations)

NO_2	Statistics	March	July	October	December	Four periods
China	R	0.52	0.38	0.54	0.65	0.58
	Bias	-0.28	0.46	-1.70	-4.03	-1.39
	GE	4.16	3.28	6.53	8.01	5.49
Japan	R	0.59	0.64	0.61	0.62	0.60
	Bias	-0.10	-0.04	0.30	0.18	0.09
	GE	1.03	0.89	1.03	1.00	0.99

SO_2	Statistics	March	July	October	December	Four periods
China	R	0.55	0.54	0.45	0.62	0.61
	Bias	-2.12	-1.09	-2.00	-3.55	-2.18
	GE	5.33	2.81	3.90	5.03	4.27
Japan	R	0.45	0.84	0.74	0.56	0.62
	Bias	0.32	-0.10	0.29	0.16	0.15
	GE	0.68	0.52	0.37	0.31	0.47

O_3	Statistics	March	July	October	December	Four periods
Japan	R	0.45	0.67	0.69	0.76	0.67
	Bias	-7.00	2.87	0.38	-0.24	-1.06
	GE	9.73	8.96	8.17	5.16	8.04

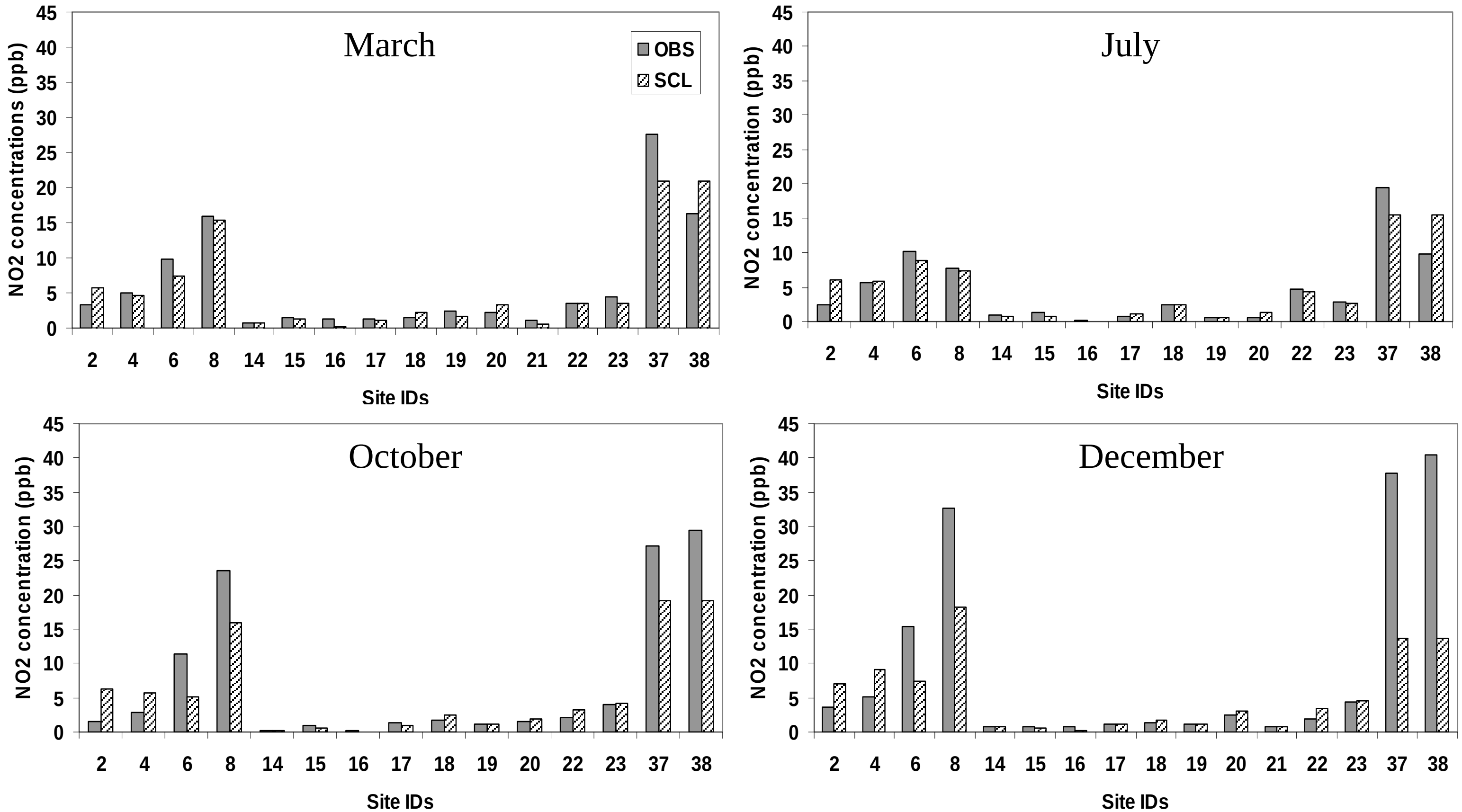
$$\text{Bias} = \frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)$$

$$\text{GE} = \frac{1}{N}\sum_{i=1}^{N}(|P_i - O_i|)$$

N: the number of observations;
P: WRF-Chem predictions;
O: observed values.

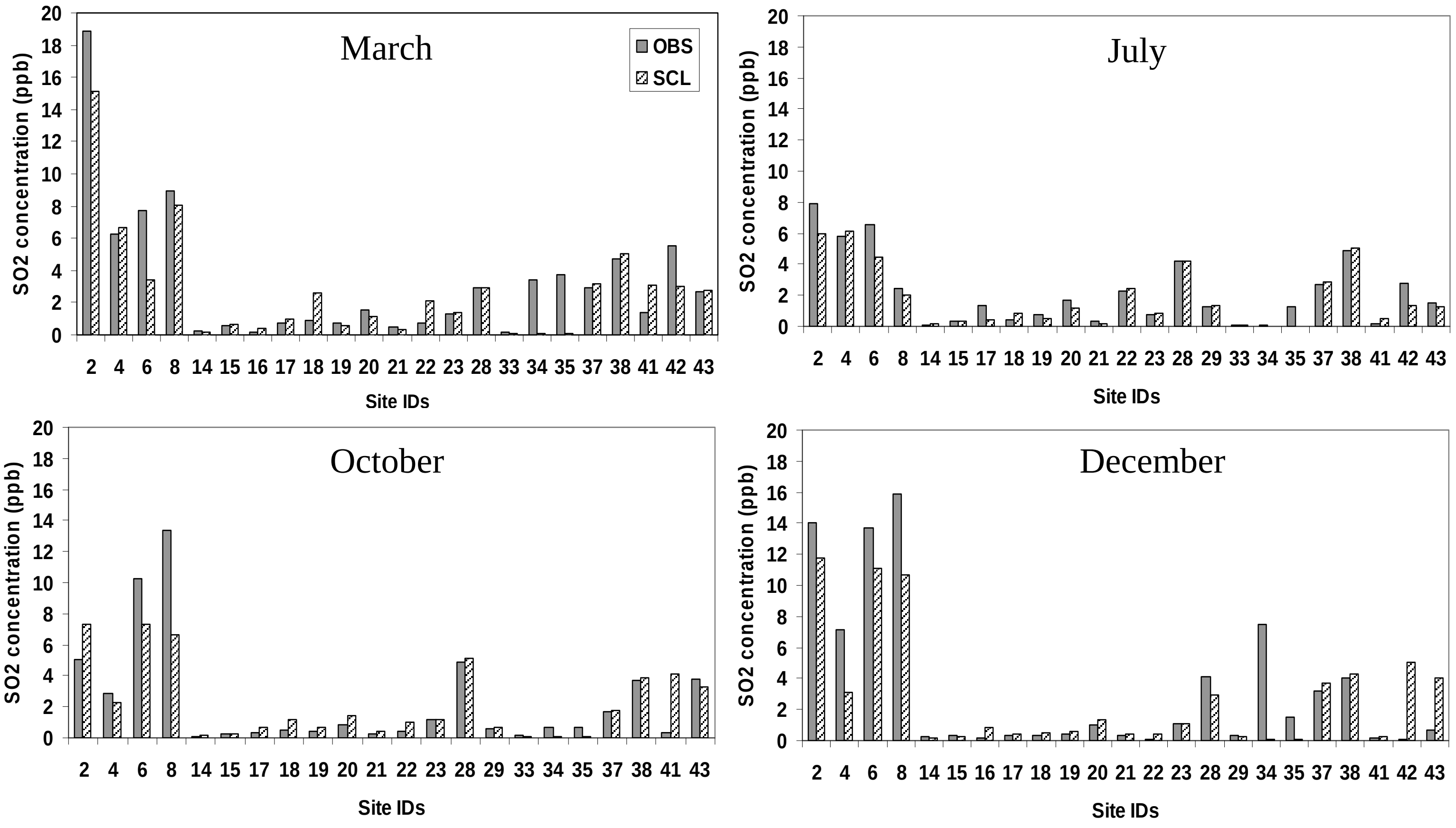
SCL simulations and observations of NO_2 at EANET sites in Mar., Jul., Oct., and Dec., 2001

Statistics	R	Bias (ppb)	GE (ppb)
NO_2 (6.9 ppb)	0.81	-1.11	3.10



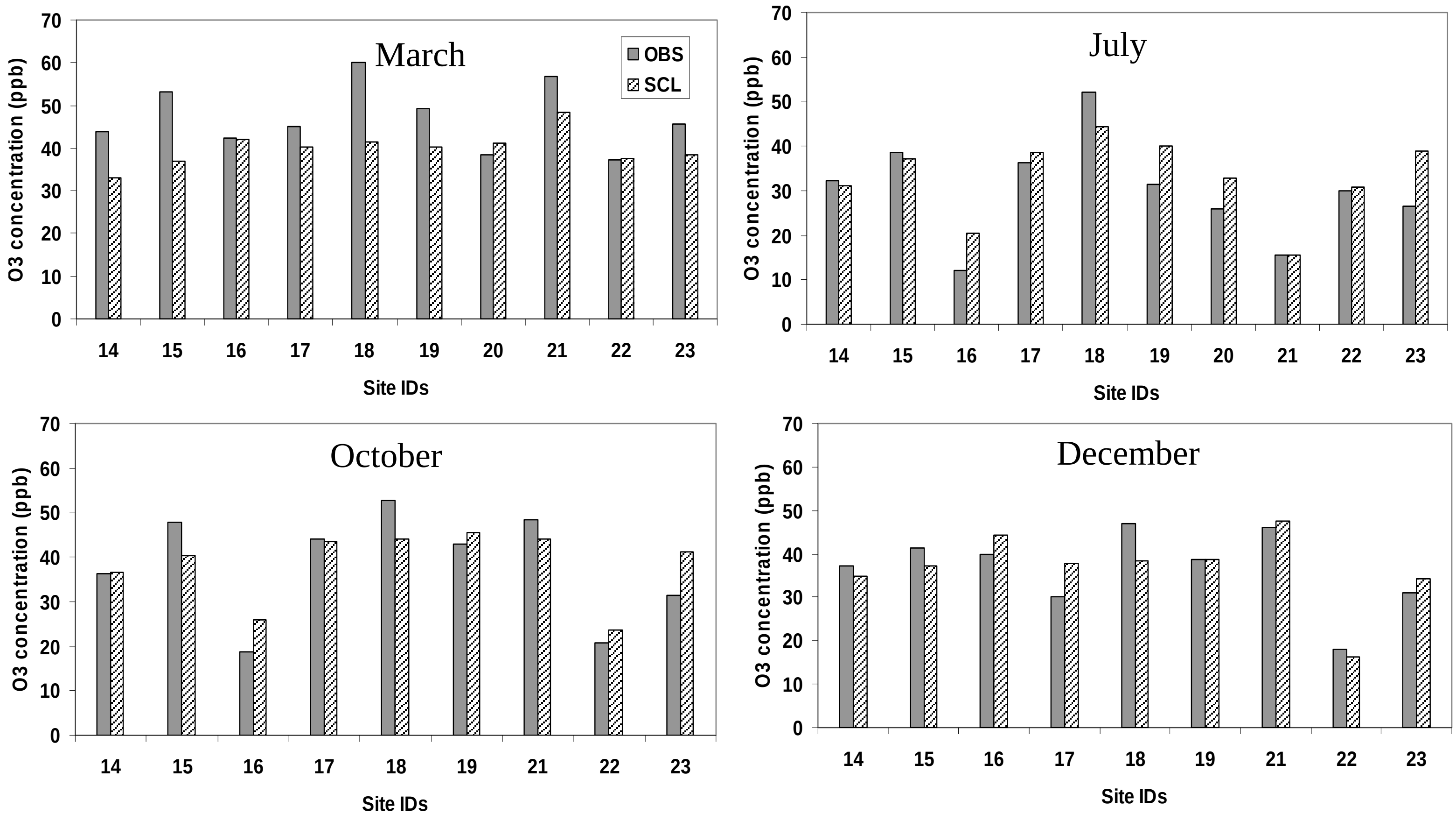
SCL simulations and observations of SO_2 at EANET sites in Mar., Jul., Oct., and Dec., 2001

Statistics	R	Bias (ppb)	GE (ppb)
SO_2 (2.8 ppb)	0.88	-0.44	1.07



SCL simulations and observations of O_3 at EANET sites in Mar., Jul., Oct., and Dec., 2001

Statistics	R	Bias (ppb)	GE (ppb)
O_3 (38.0 ppb)	0.81	-1.10	5.92



Summary

- Developed finer resolution temporal (i.e. seasonal, day-of-week, diurnal) and vertical scaling for different categories (i.e., power generators, industry, residential and transportation) and each species for TRACE-P anthropogenic emissions.

- Temporal and vertical distribution play and essential role on air quality modeling in East Asia.New scaled emissions improved WRF-Chem performance in predicting NO_2 and SO_2 (statistics and frequency distribution). The sensitivity is significantly large for NO_2 and SO_2.

- Performance of both default and new scaled emissions are statistically similar for O_3. The sensitivity is relatively weak for O_3.

- New scaled emissions could well predict spatial and seasonal variation of NO_2, SO_2 and O_3 over East Asia.