9th City AQM Workshop , Regional Air Quality Management and Collaboration

Emissions of anthropogenic air pollutants and CO_2 in China 2005-2010

Recent trends, uncertainties, and implications of improved energy efficiency and emission control

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Pearl River Delta Session   Mar 20 2013

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- Background and methods
- Compiling the emission factor database
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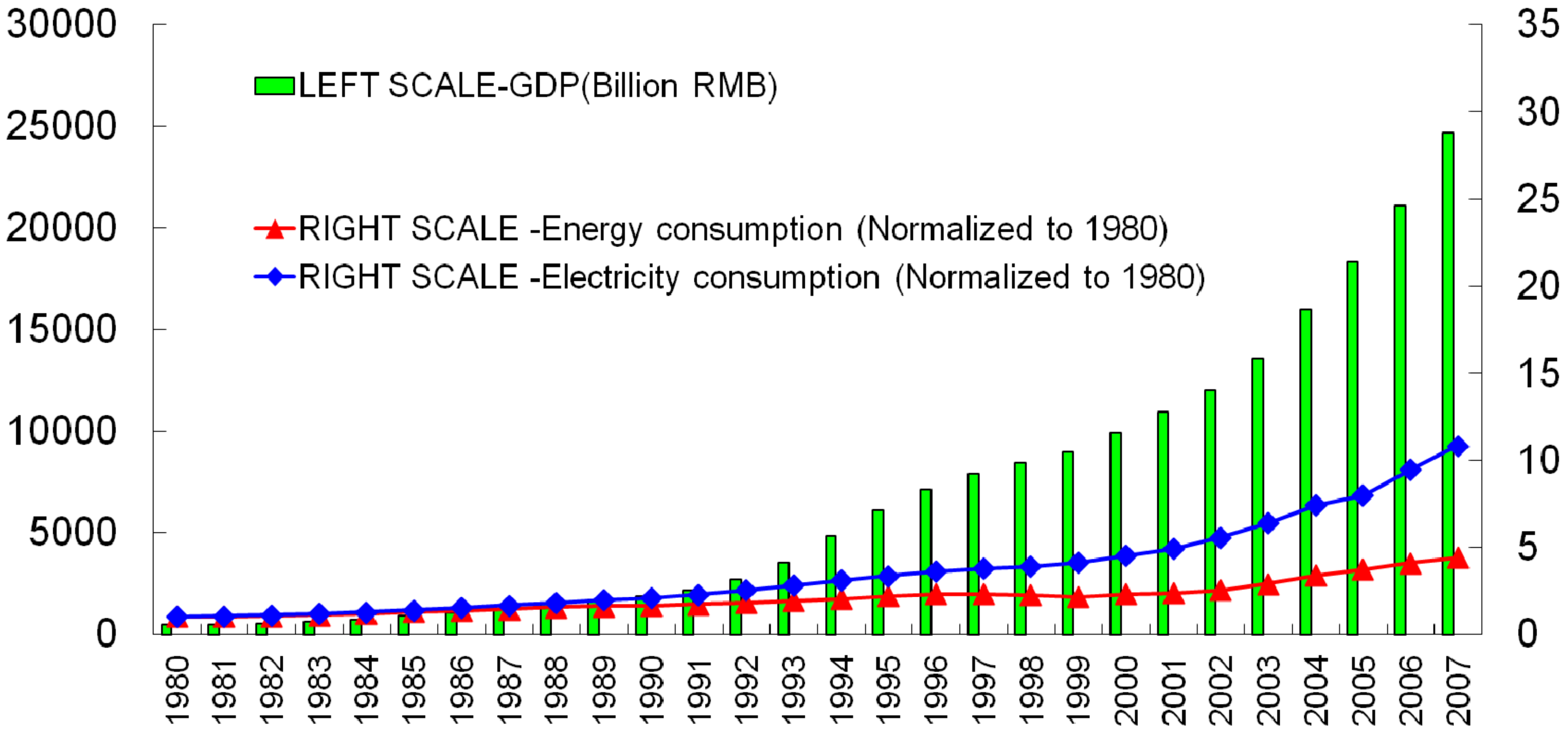
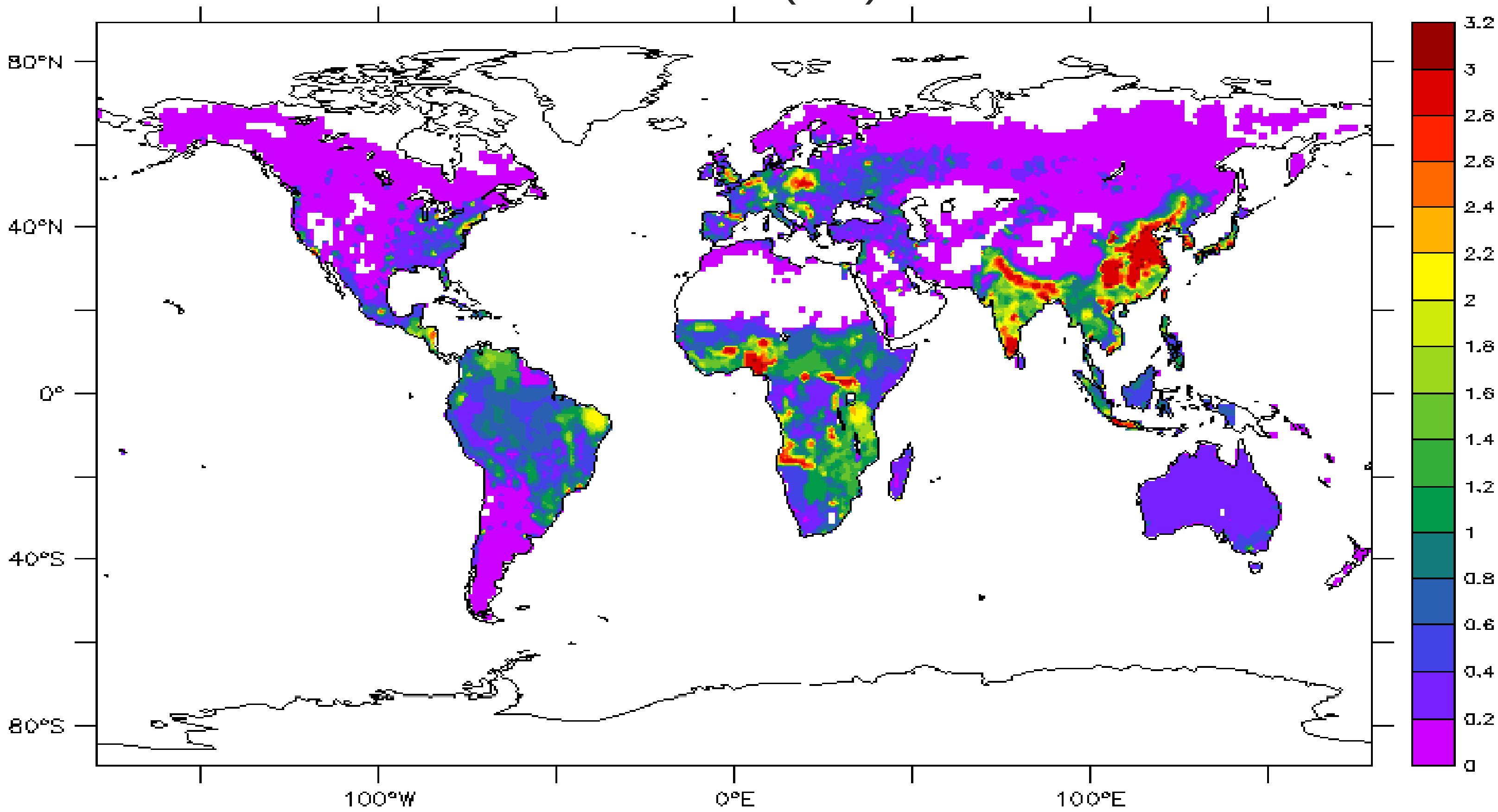
Fast increase in economy and energy consumption



Largest emissions estimated over the world

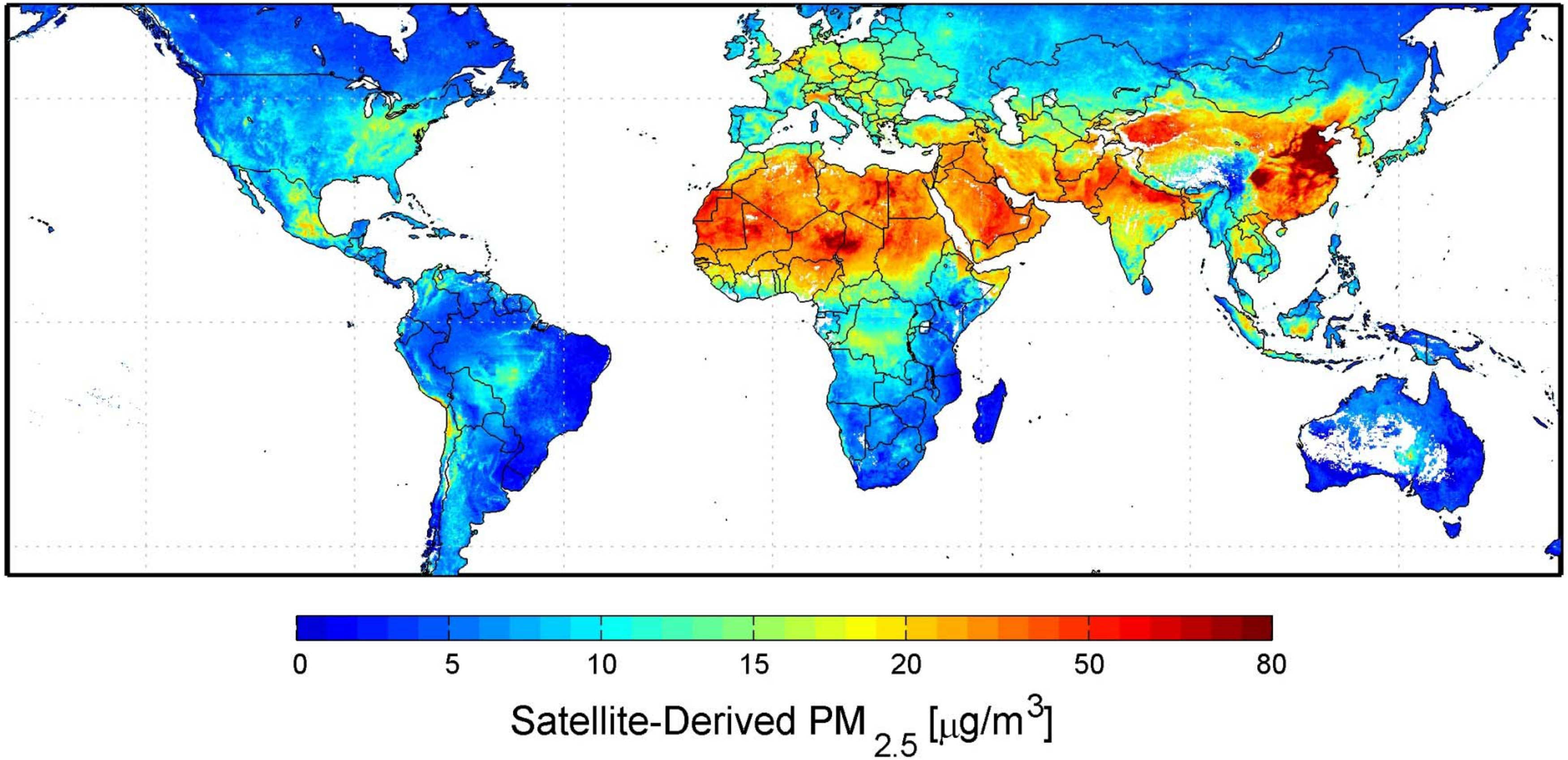
Global black carbon (BC) emissions 1996



Source: Bond et al., *Journal of Geophysical Research* 2004

Highest pollution levels found over the world

Global $PM_{2.5}$ concentrations 2001-2006 derived from MODIS



Source: van Donkelaar et al., ***Environmental Health Perspectives*** **2010**

The 11th Five Year (2006-2010) Plan (11th FYP)

Targets on resources and environment

- Energy consumption per unit of GDP -20% (Compulsory)
- Decrease of major pollutants (SO_2 and COD) -10% (Compulsory)

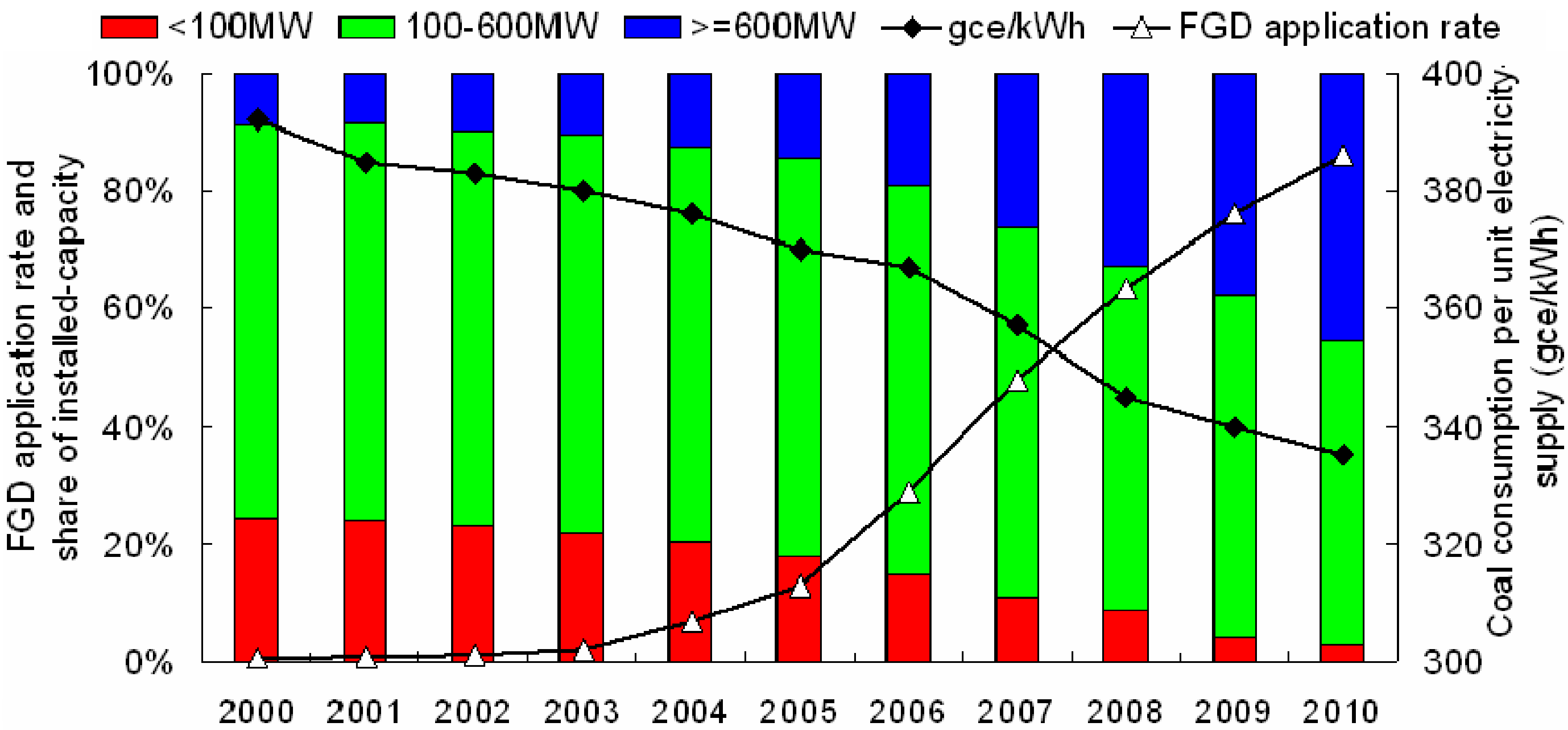
Plans on coal-fired power plants

- FGD application: all the new-built units and considerable existing ones
- Closing old, non-efficient small units, up to 50 GW – Actually ~70GW
- New-built electricity generation units: should be larger than 300 MW

Actions on other emission sources

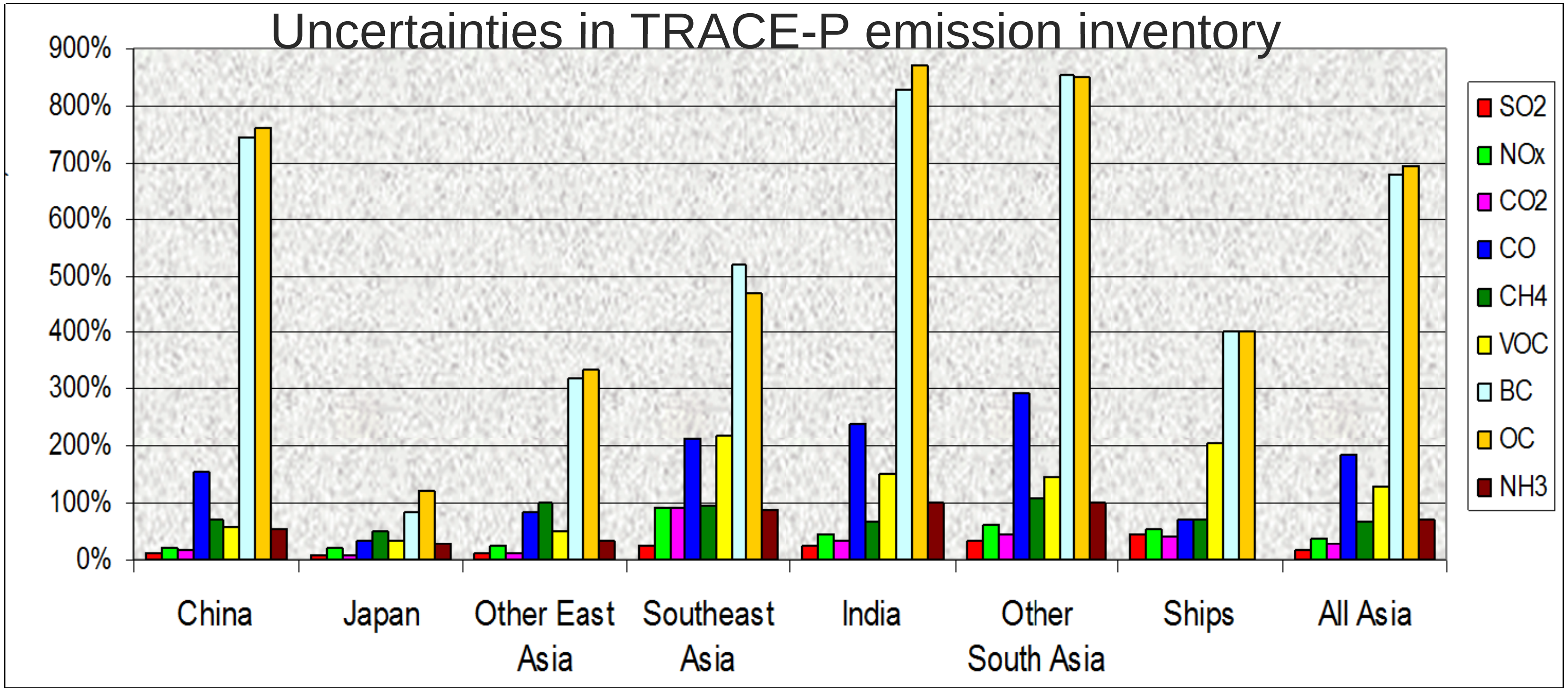
- Improved technology and energy efficiency for industrial sectors
- Staged emission and fuel quality standards for on-road vehicles

Changes in coal-fired power units 2000-2010



What we wanted to know:

- The effects of polices on national (and local) emission trends
- The uncertainty of emission estimates for China
- The consistence between emissions and observation



Source: Streets et al., *Journal of Geophysical Research* 2003

Framework of bottom-up emission inventory

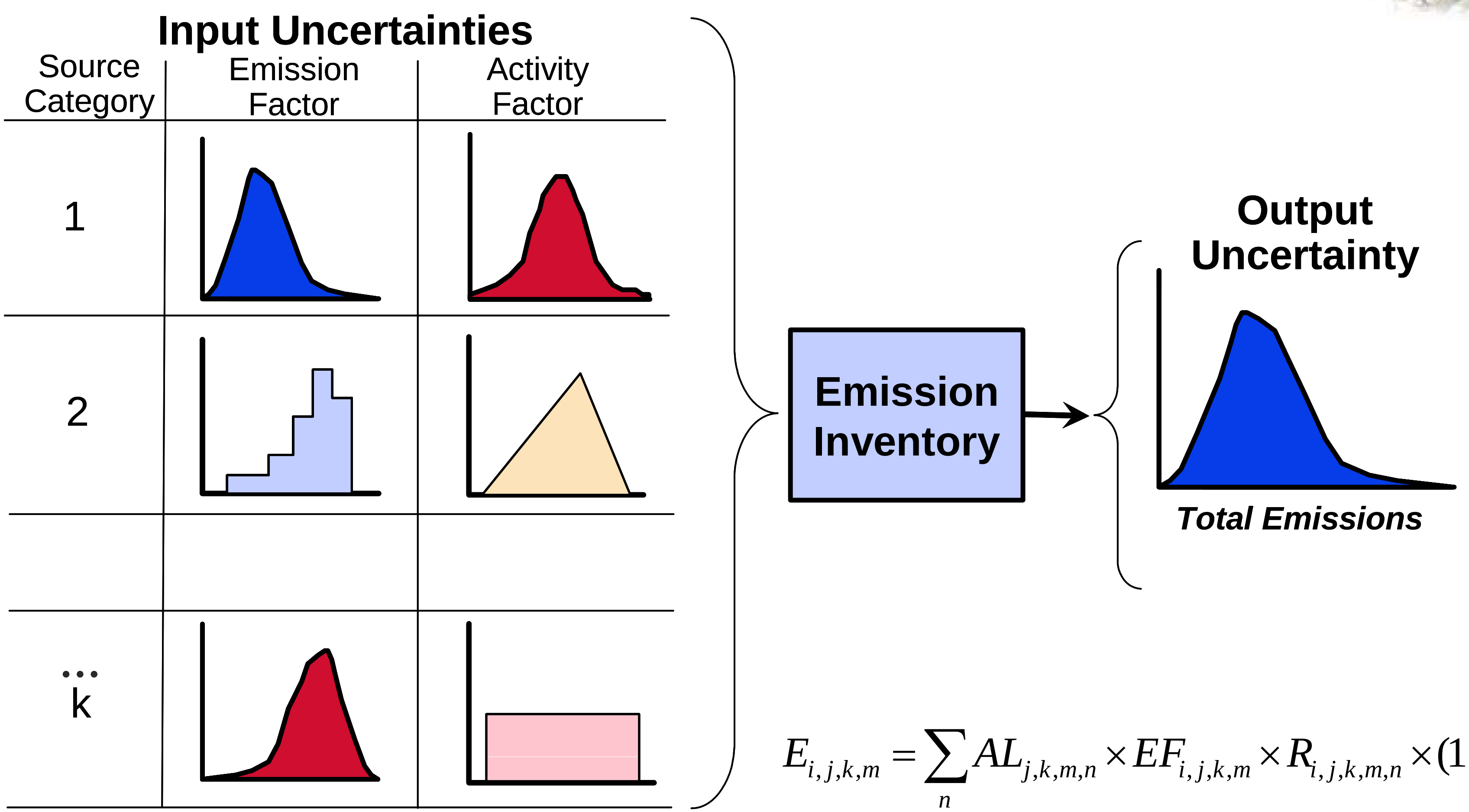
$$E_{i,j,k,m} = \sum_{n} AL_{j,k,m,n} \times EF_{i,j,k,m} \times R_{i,j,k,m,n} \times (1-\eta_{i,n})$$

Emission	Activity level	Emission factor	Penetration rate	Removal efficiency

i, species
j, regions (provinces)
k, sectors
m, technology/fuel types
n, emission control technology

SECTOR	SOURCE	TECHNOLOGY/FUEL	SPATIAL ALLOCATION
Power plants	Power plants (CPP)	Pulverized; Grate; CFB; Oil and gas plants	Point sources
Industry (IND)	Cement (CEM)	Precalciner; Shaft; Other rotary kilns	Point sources
Industry (IND)	Iron and steel (ISP)	Coke; Sintering; Pig iron; Steel making; casting	Point sources
Industry (IND)	Industrial boilers (OIB)	Grate/CFB boiler; Oil and gas plants	Area sources
Industry (IND)	Other processes (PRO)	Lime; Smelting; Chemical engineering; etc	Area sources
Residential combustion (RES)	Domestic fossil fuel	Grate boiler; hot water system; stove	Area sources
Residential combustion (RES)	Biofuel/biomass	Biofuel use; Biomass open burning	Area sources
Transportation (TRA)	On-road sources	LDGV, HDGV, LDDV, HDDV, MC, etc	Mobile sources
Transportation (TRA)	Non-road sources	RV, railway, inland shipping, machines, etc	Mobile sources

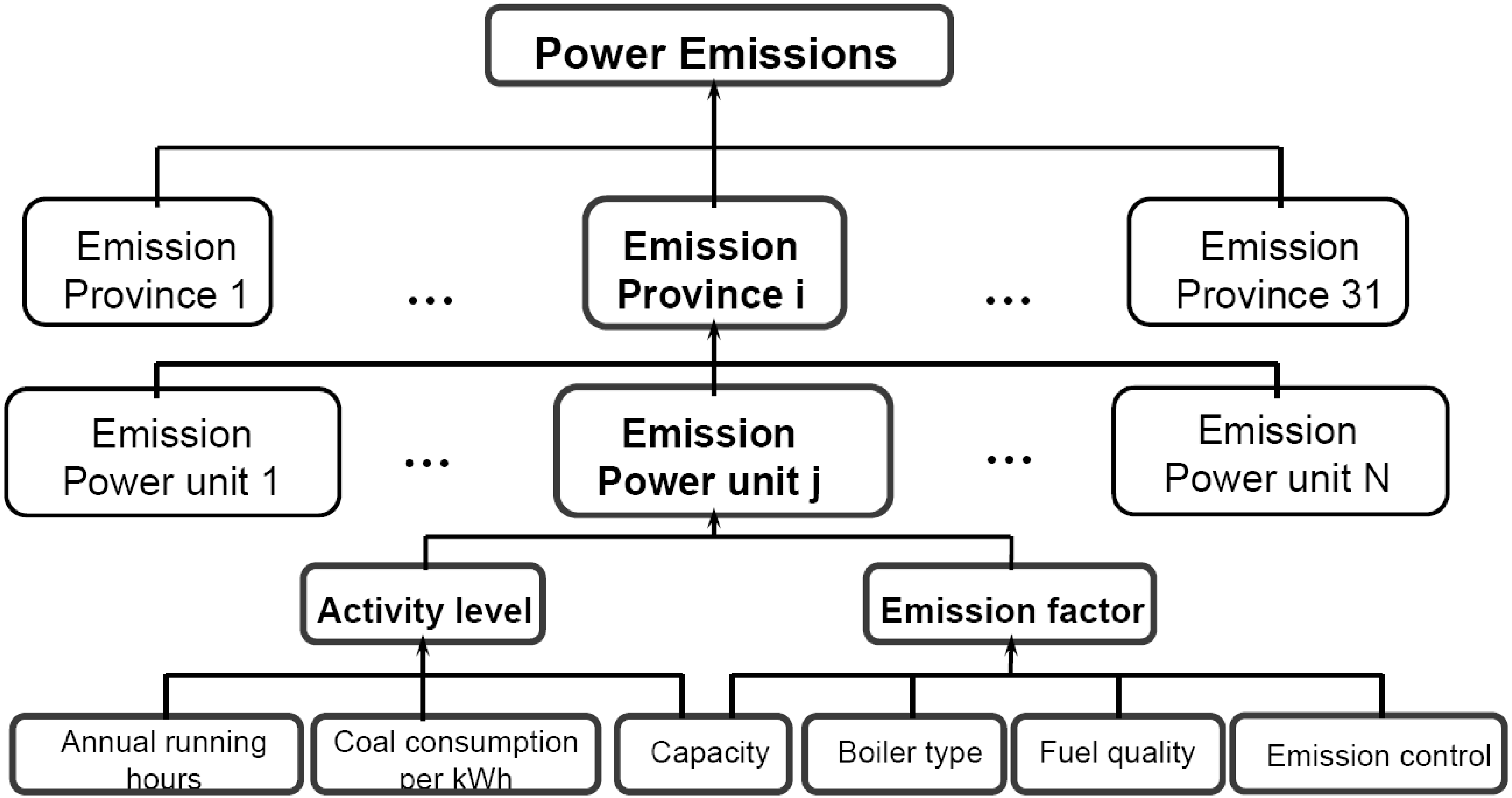
Monte-Carlo simulation-conceptual approach



$$E_{i,j,k,m} = \sum_{n} AL_{j,k,m,n} \times EF_{i,j,k,m} \times R_{i,j,k,m,n} \times (1-\eta_{i,n})$$

Uncertainties of every parameters will be determined and put in Monte-Carlo simulation.

Unit-based methodology for power units



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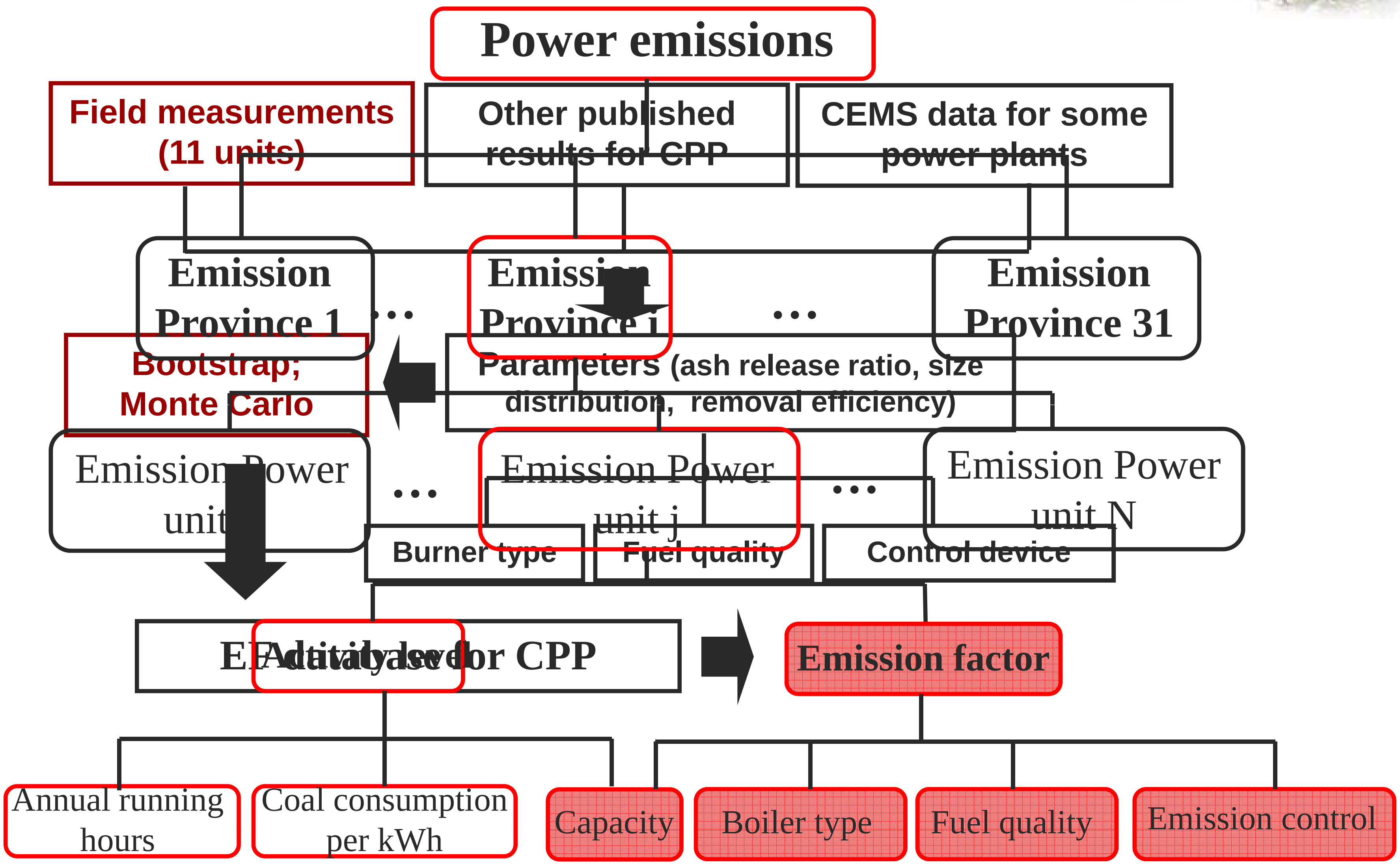
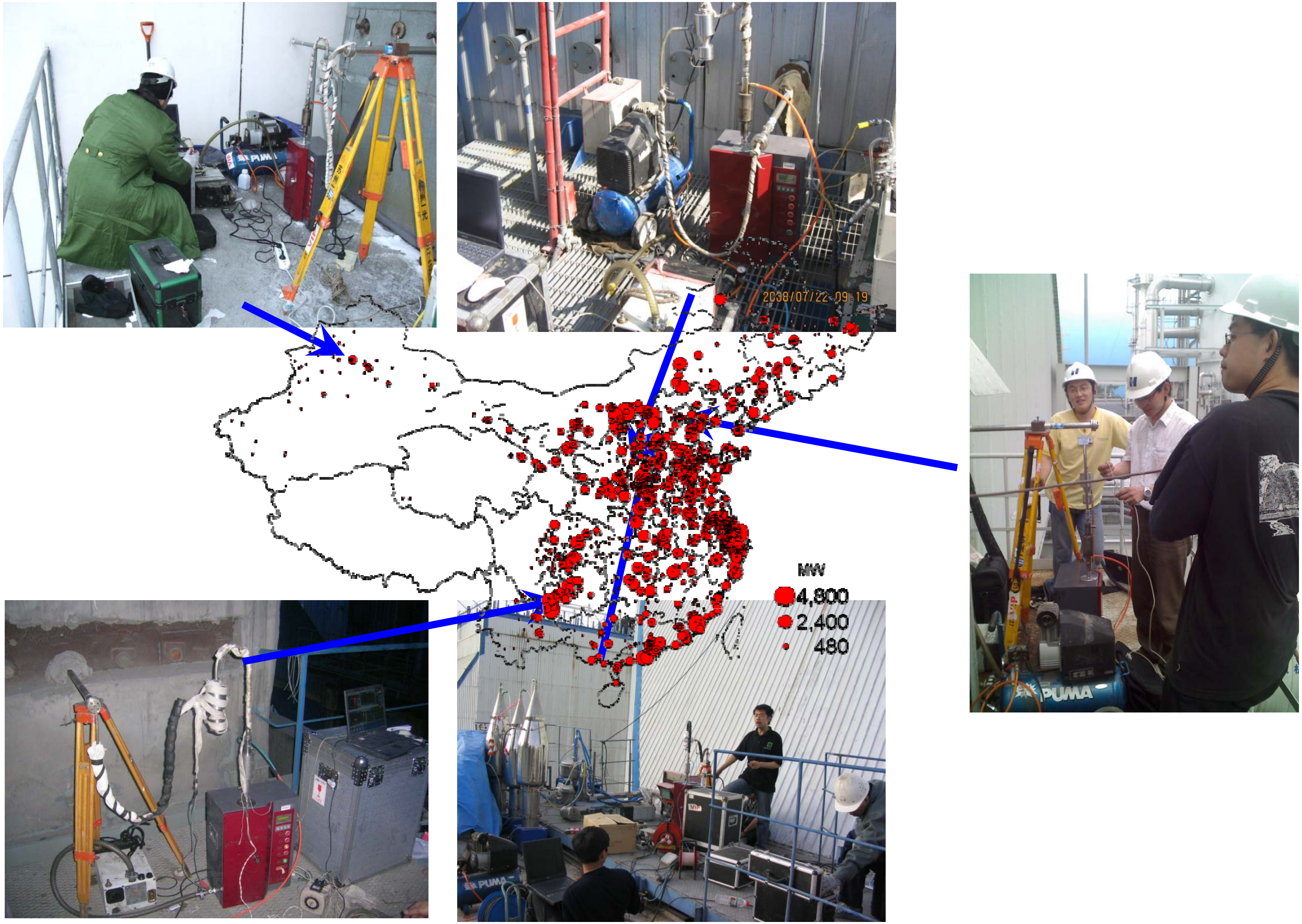
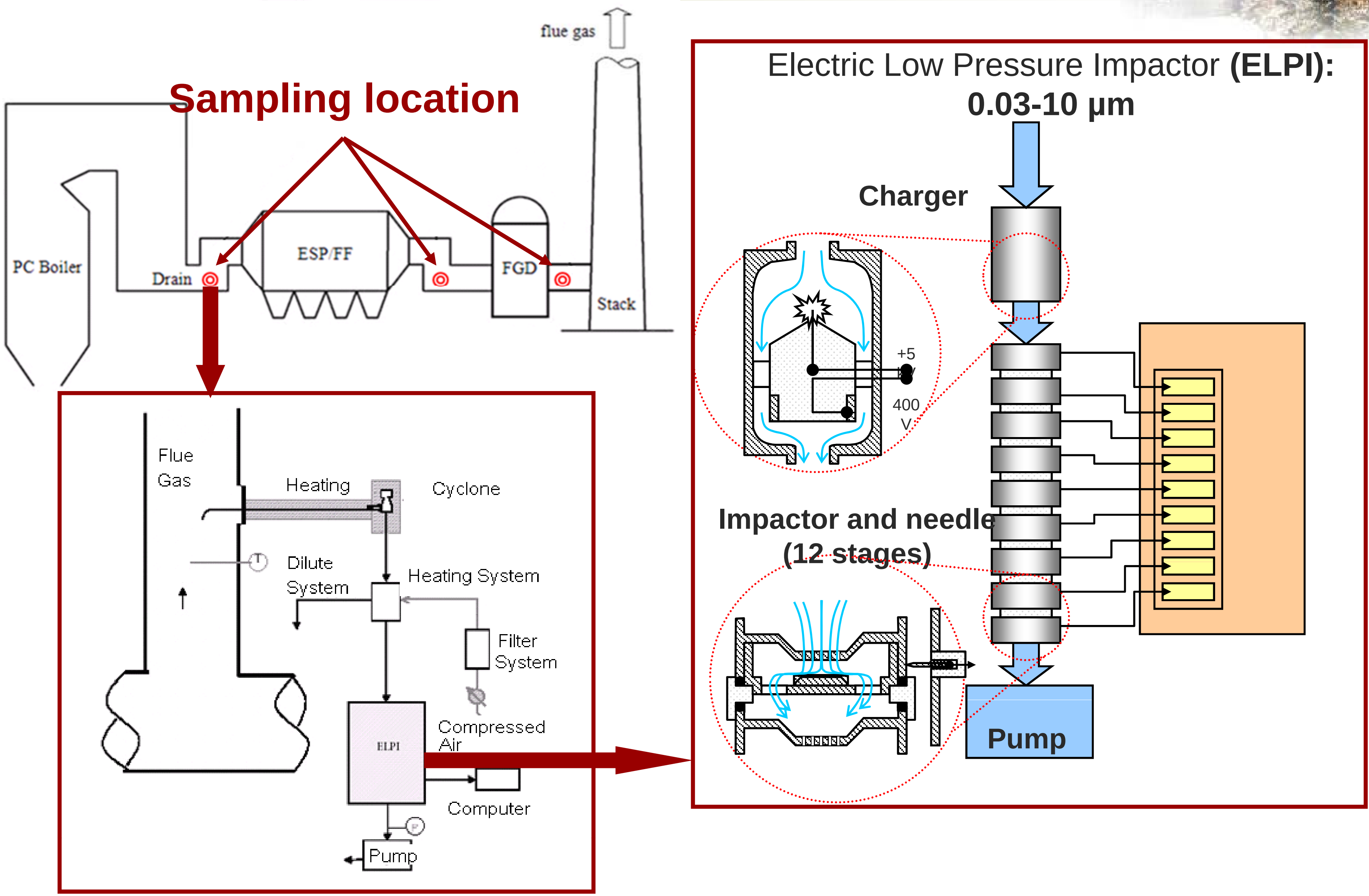
EF database for coal-fired power plants (CPP)

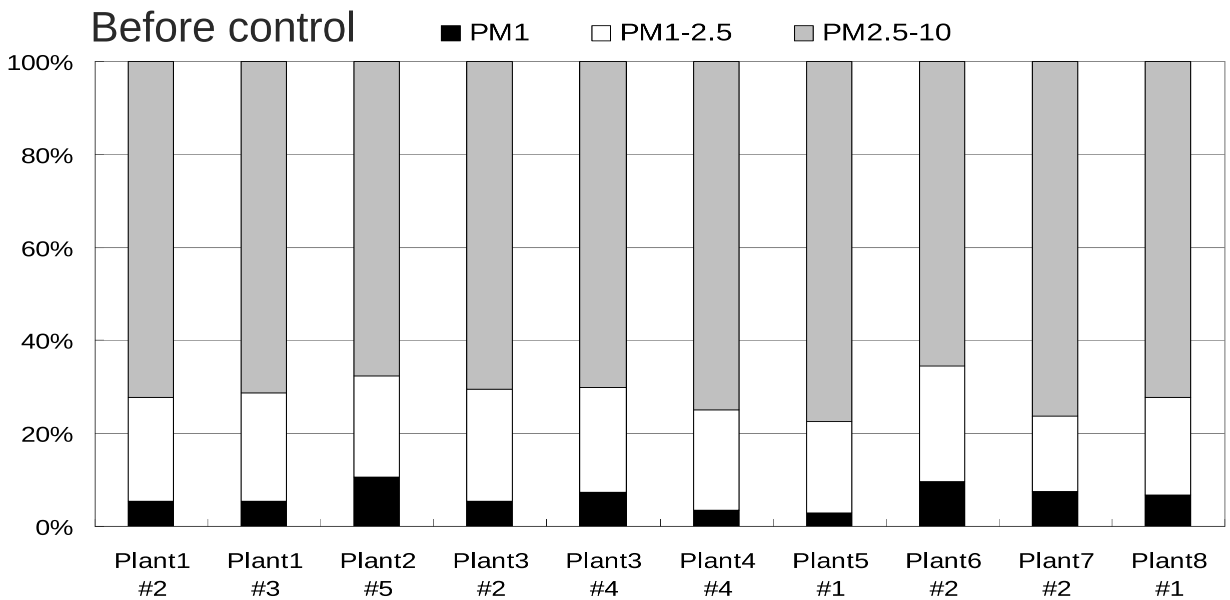


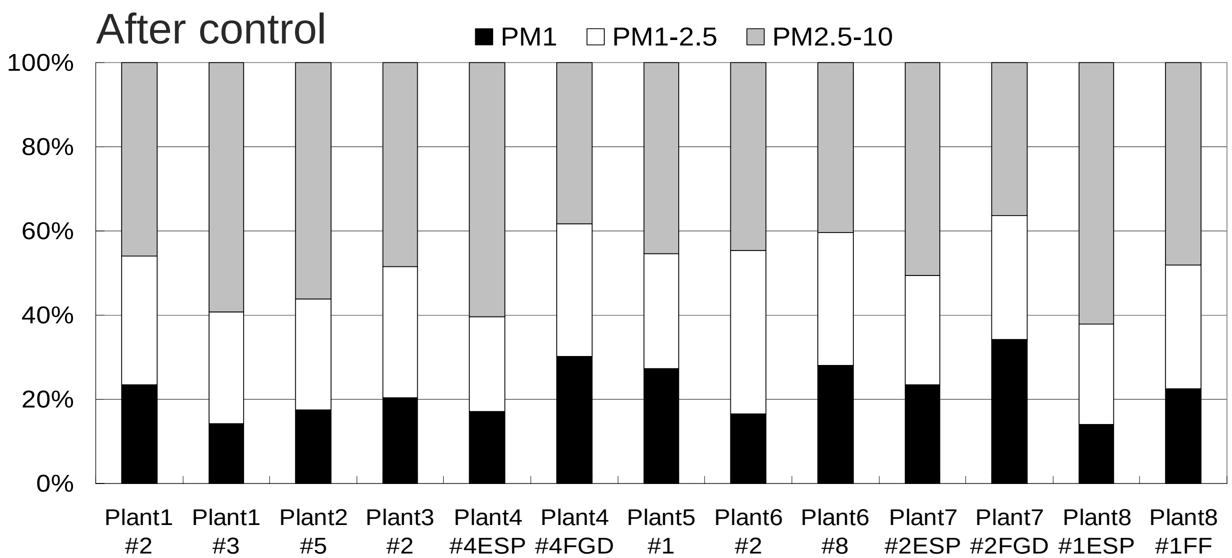

MW
4,800
2,400
480

Sampling methods



PM_{10} mass fraction before and after control





- Before ESP, PM_1 accounts for less than 10% of PM_{10}, coarse fraction ($PM_{2.5-10}$) accounts for more than 65%.
- After ESP, the share of fine particles largely increases. PM_1 accounts for about 14%-28% of PM_{10}, and the course fraction decreases to 40%-62%.
- After the Wet FGD, PM_1 accounts for more than 30% mass fraction of PM_{10}.

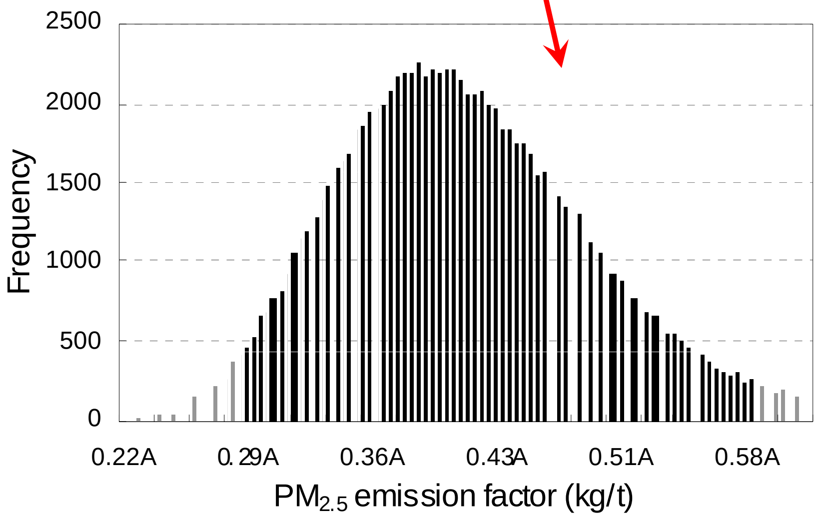
Results of field measurements

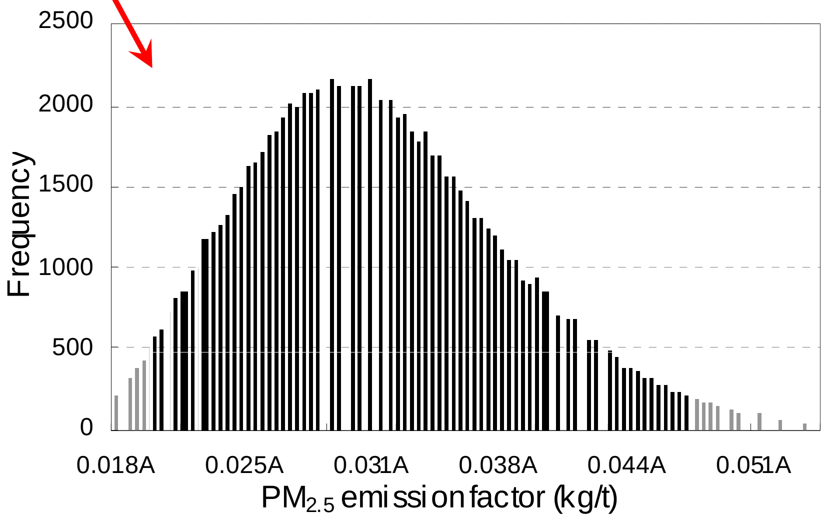
$$EF_{PM,y} = A \times (1 - ar) \times f_y \times (1 - \eta_y)$$

Boiler	Size (MWe)	Dust collector	1-ar	Size fraction			Efficiency (%)		
				>PM_{10}	$PM_{2.5-10}$	$PM_{2.5}$	>PM_{10}	$PM_{2.5-10}$	$PM_{2.5}$
Grate	29	Wet	0.15	0.72	0.18	0.1	98.65	87.98	71.73
PC	50	ESP	0.5	0.80	0.14	0.06	99.53	94.39	90.88
PC	50	ESP	-	0.77	0.16	0.07	99.61	99.16	97.86
PC	100	ESP	0.66	0.86	0.1	0.04	–	–	–
PC	100	FF	0.58	0.90	0.07	0.03	–	–	–
PC	125	ESP	0.75	0.90	0.08	0.02	99.37	98.7	94.62
PC	165	ESP	0.71	0.80	0.15	0.05	99.54	98.22	94.44
		Wet-FGD					92.82	73.03	52.7
PC	200	ESP	0.84	0.85	0.11	0.04	99.79	98.81	96.24
PC	200	ESP	0.89	0.83	0.12	0.05	99.11	95.71	92.65
PC	200	ESP	0.65	0.85	0.11	0.04	99.74	98.39	96.84
		Wet-FGD					90.46	78.22	46.34

PM emission factor database for CPP (kg/t)

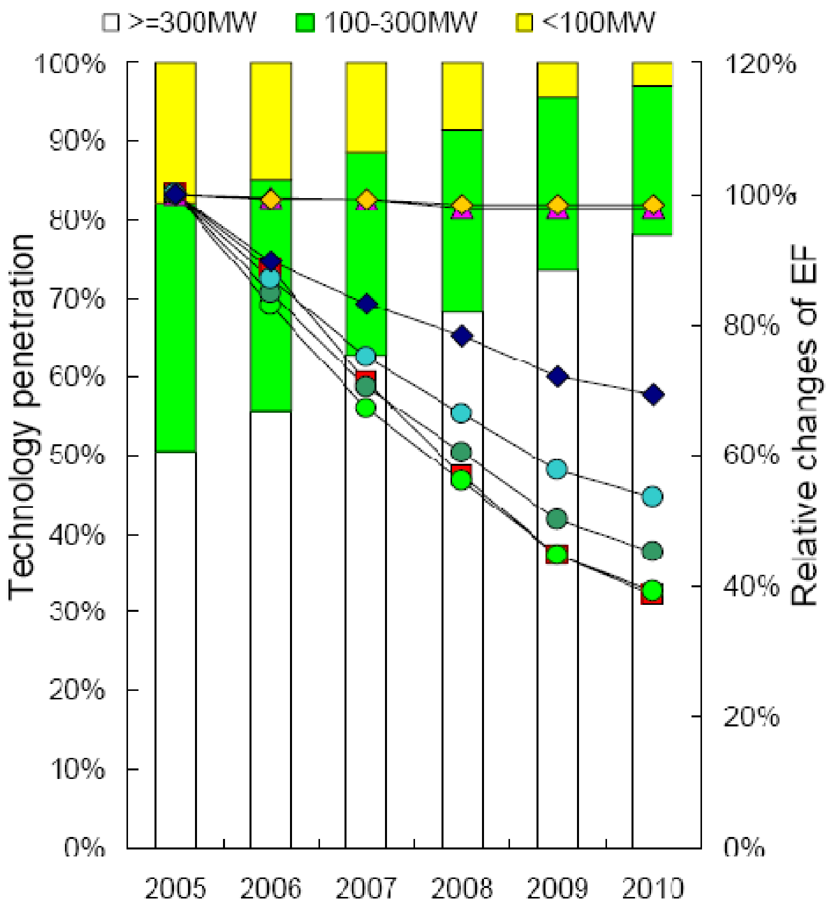
		Uncontrolled	Controlled			
			ESP	Wet scrubber	FF	ESP + wet-FGD
PC	$PM_{2.5}$	0.4A [1] (0.3A-0.5A)	0.032A (0.021A-0.046A)	0.135A	0.0019A	0.0147A (0.0092A-0.0225A)
	PM_{10}	1.5A (1.1A-1.9A)	0.065A (0.039A-0.092A)	0.291A	0.0034A	0.0210A (0.0129A-0.0317A)
	PM	6.9A (5.8A-7.9A)	0.094A (0.065A-0.132A)	0.479A	0.0042A	0.0231A (0.0142A-0.0348A)



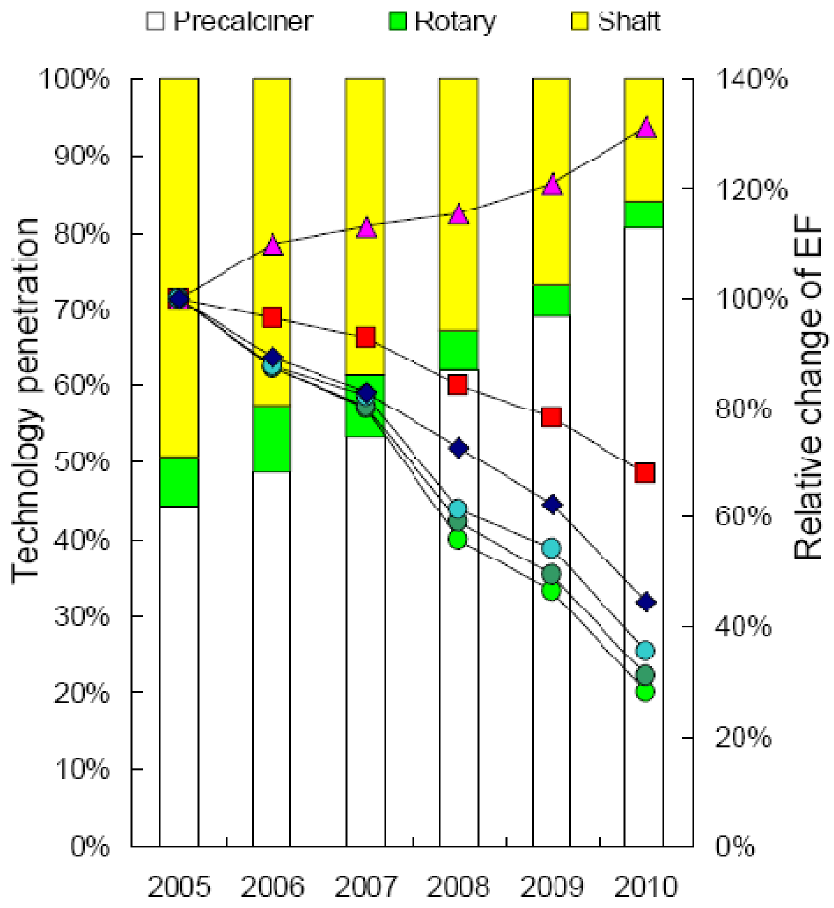


[1] In all cases, A is the ash content, in percent, of the coal as fired.

Emission factor change for stationary sources

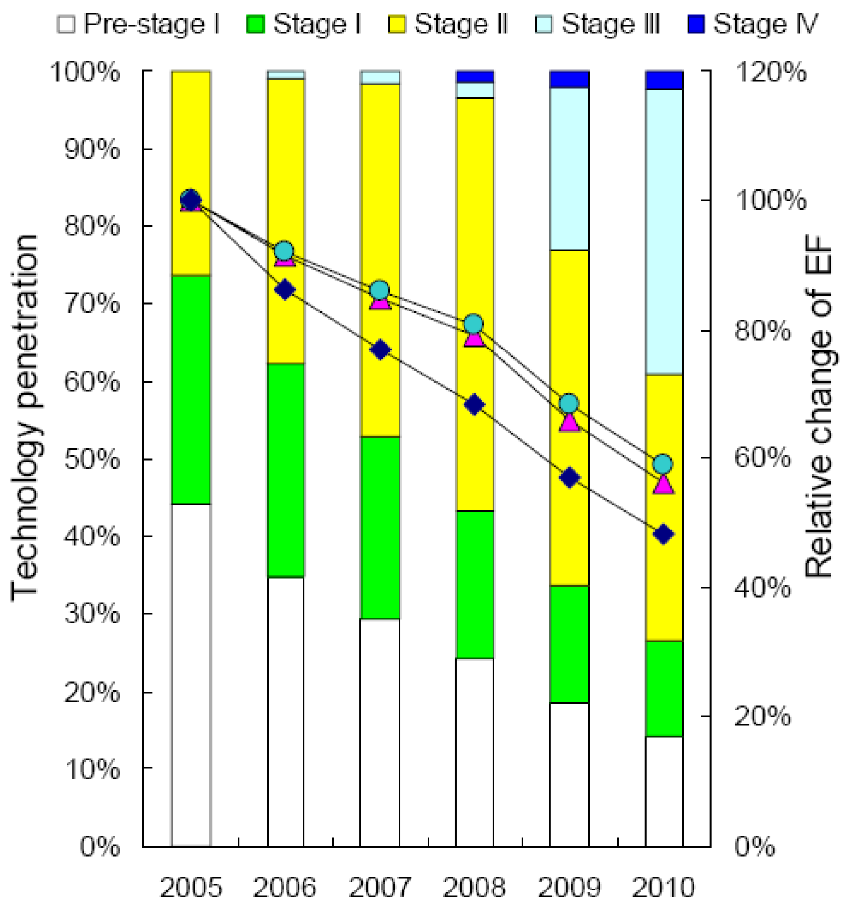


(a) Coal-fired power plants

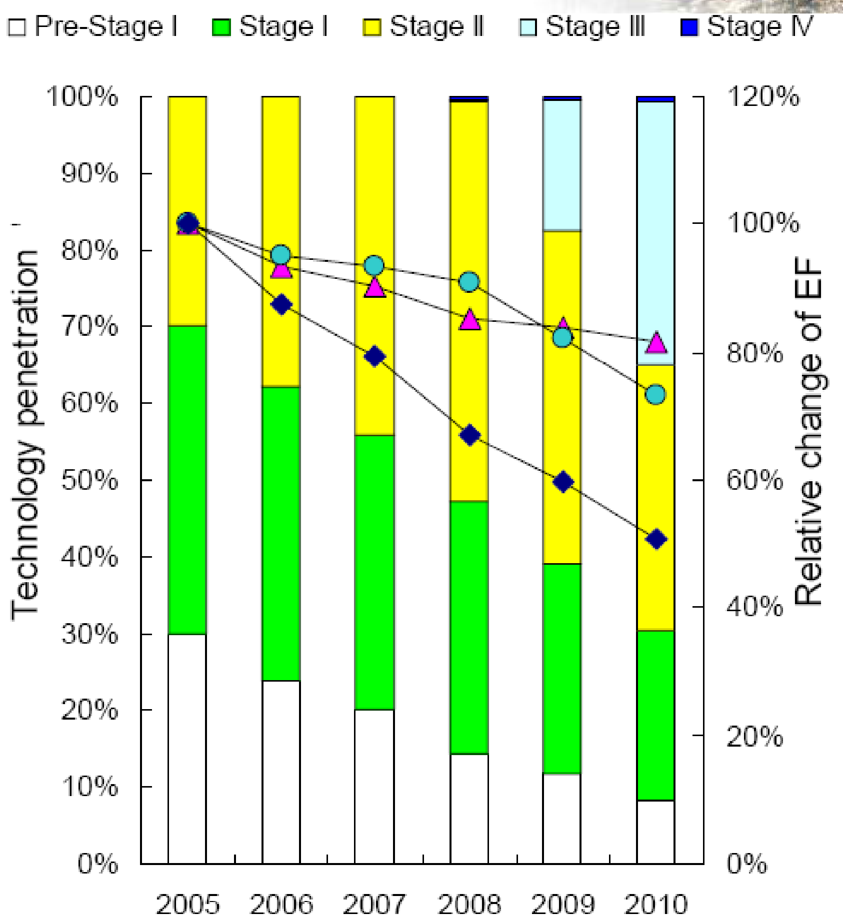


(b) Cement production

Emission factor change for mobile sources



(d) Light-duty gasoline vehicles



(e) Heavy-duty diesel vehicles

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China's emissions 2005-2010

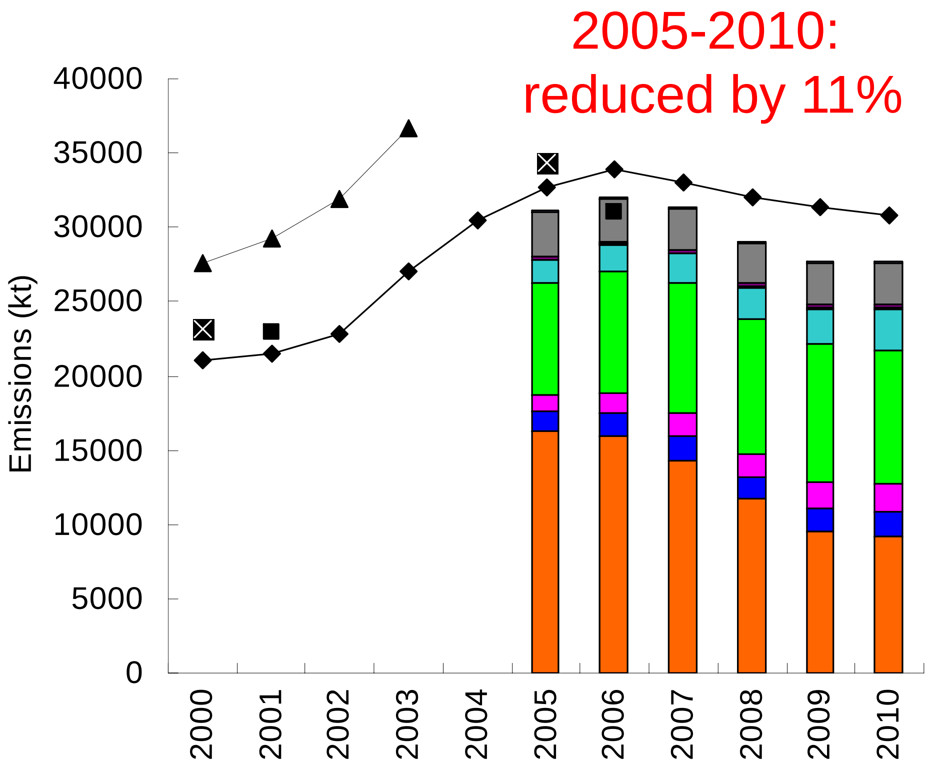
	2005	2006	2007	2008	2009	2010
SO2	31085 (-14%, 13%)	32058	31376	29019	27715	27714 (-15%, 26%)
NOx	19645 (-13%, 37%)	21550	23621	24082	26016	28815 (-15%, 35%)
CO	172871 (-20%, 45%)	178678	179337	177194	183017	187900 (-18%, 42%)
TSP	33197(-11%, 38%)	32401	32457	30217	30367	28746 (-22%, 54%)
PM10	18906 (-14%,45%)	18837	18876	17680	17834	16990 (-15%, 54%)
PM25	12981 (-17%, 54%)	12921	12951	12293	12508	12212 (-15%, 63%)
BC	1690 (-25%, 136%)	1752	1733	1790	1848	1667 (-28%, 126%)
OC	3153 (-40%, 121%)	2907	2791	2782	2829	2848 (-42%, 114%)
Ca	5653	5652	5706	4866	4873	4253 (-75%, 77%)
Mg	375	367	373	357	367	356 (-46%, 152%)
CO2	7126 (-9%,11%)	7733	8476	8706	9386	10176 (-10%, 9%)

Unit: Million metric tons (Mt) for CO_2 and kilo metric tons (kt) for other species

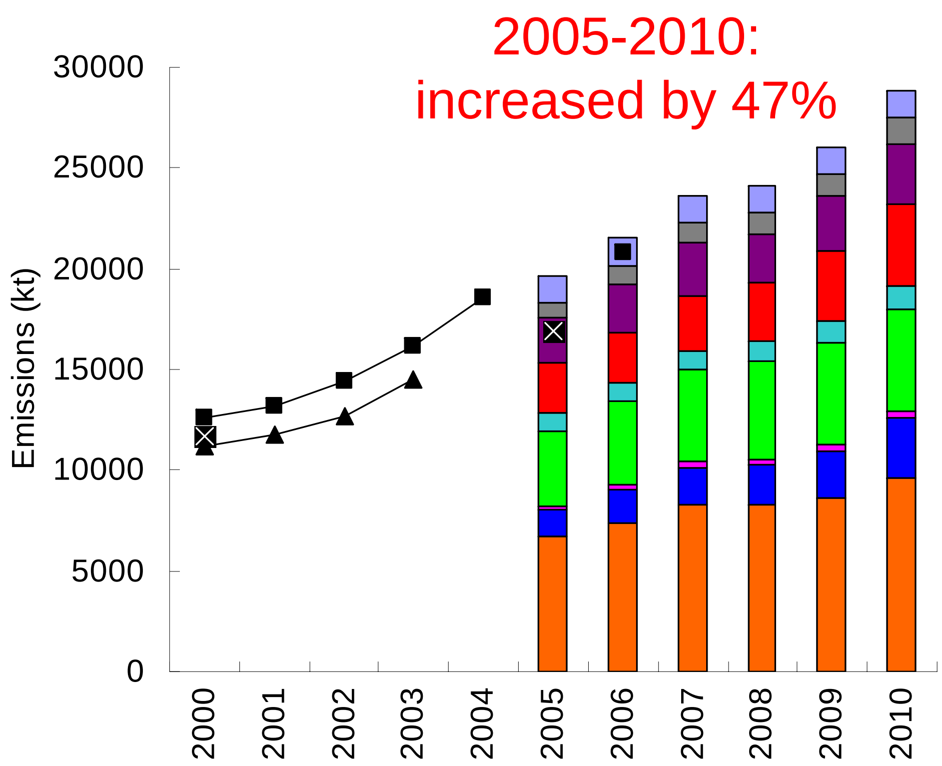
SO_2 and NO_X emission trends

This work
- Coal-fired power plants
- Cement production
- Iron & steel production
- Other industrial boilers
- Other industrial processes
- On-road transportation
- Non-road transportation
- Residential & commercial (fossil fuel)
- Residential & commercial (Biofuel/biomass)

Other studies
- Klimont et al.(2009); GAINS
- Zhang et al.(2007; 2009)
- Ohara et al.(2007)
- Lei et al.(2011a)
- Lu et al.(2011)



SO_2 emissions



NO_X emissions

PM emission trends

This work

- Coal-fired power plants
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- Non-road transportation
- Residential & commercial (fossil fuel)
- Residential & commercial (Biofuel/biomass)

Other studies

- Klimont et al.(2009); GAINS
- Zhang et al.(2007; 2009)
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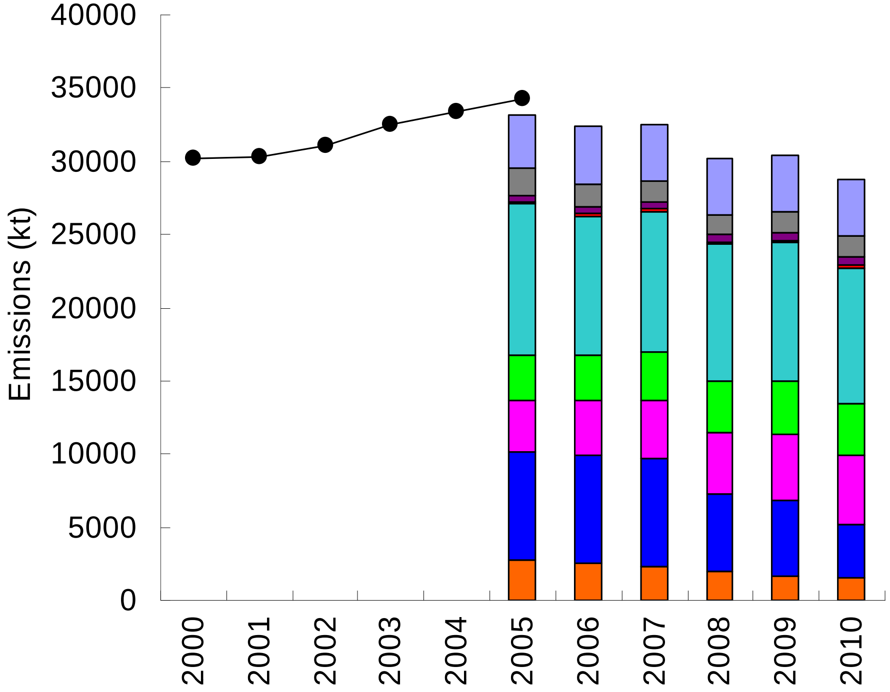
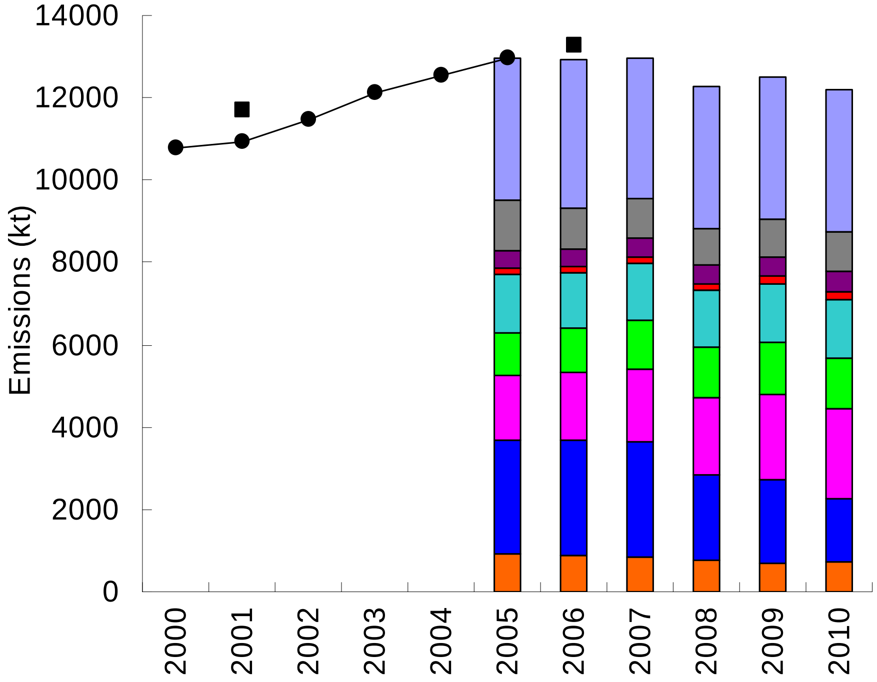
- Lei et al.(2011a)
- Lu et al.(2011)

Less benefits have been achieved for finer particle emissions



Total PM emissions



$PM_{2.5}$ emissions

Carbonaceous emission trends

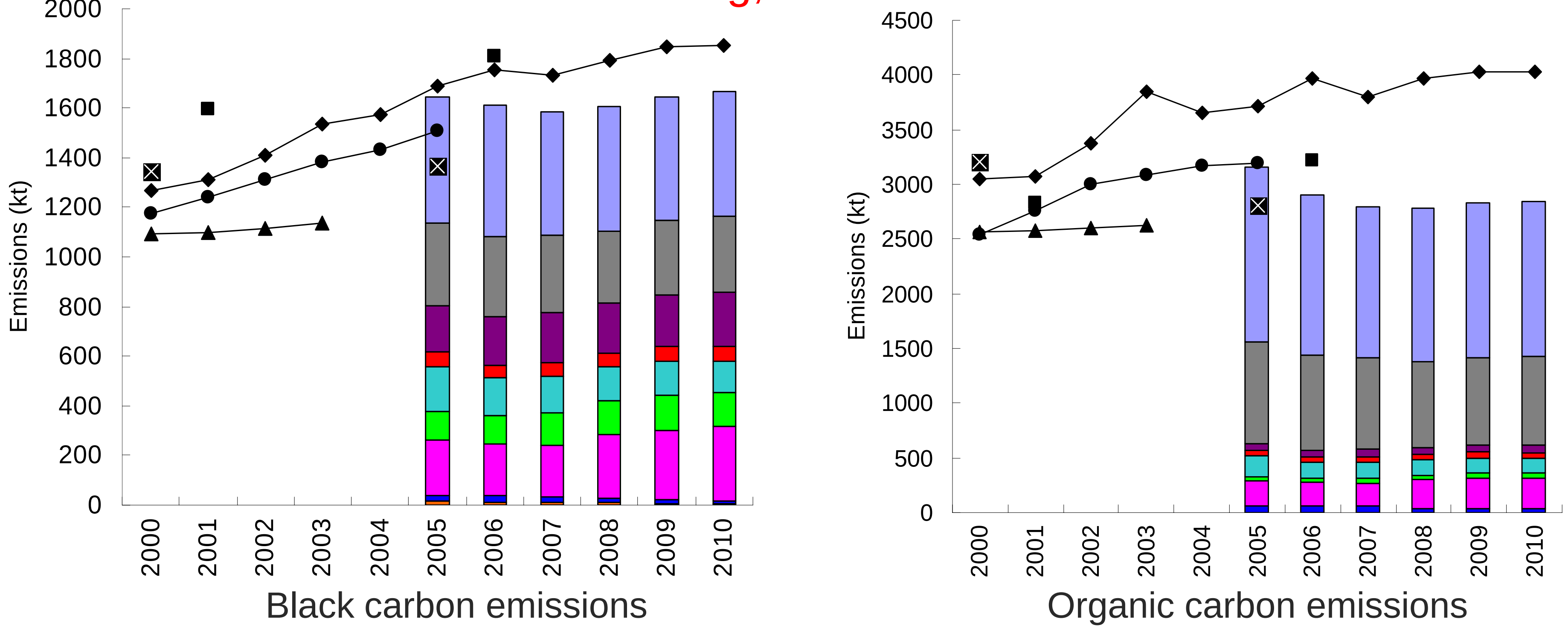
This work

- Coal-fired power plants
- Cement production
- Iron & steel production
- Other industrial boilers
- Other industrial processes
- On-road transportation
- Non-road transportation
- Residential & commercial (fossil fuel)
- Residential & commercial (Biofuel/biomass)

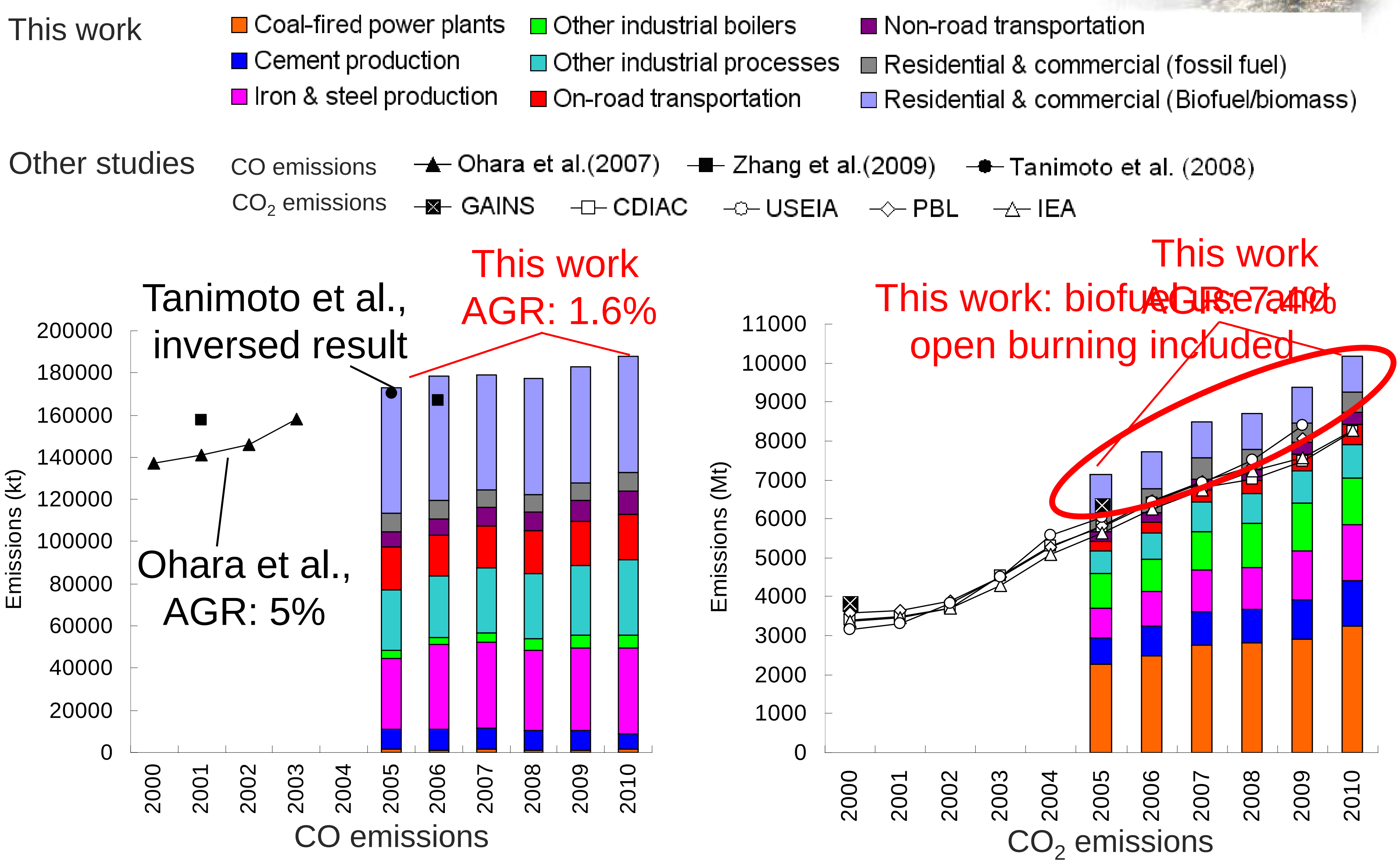
Other studies

- Klimont et al.(2009); GAINS
- Zhang et al.(2007; 2009)
- Ohara et al.(2007)
- Lei et al.(2011a)
- Lu et al.(2011)

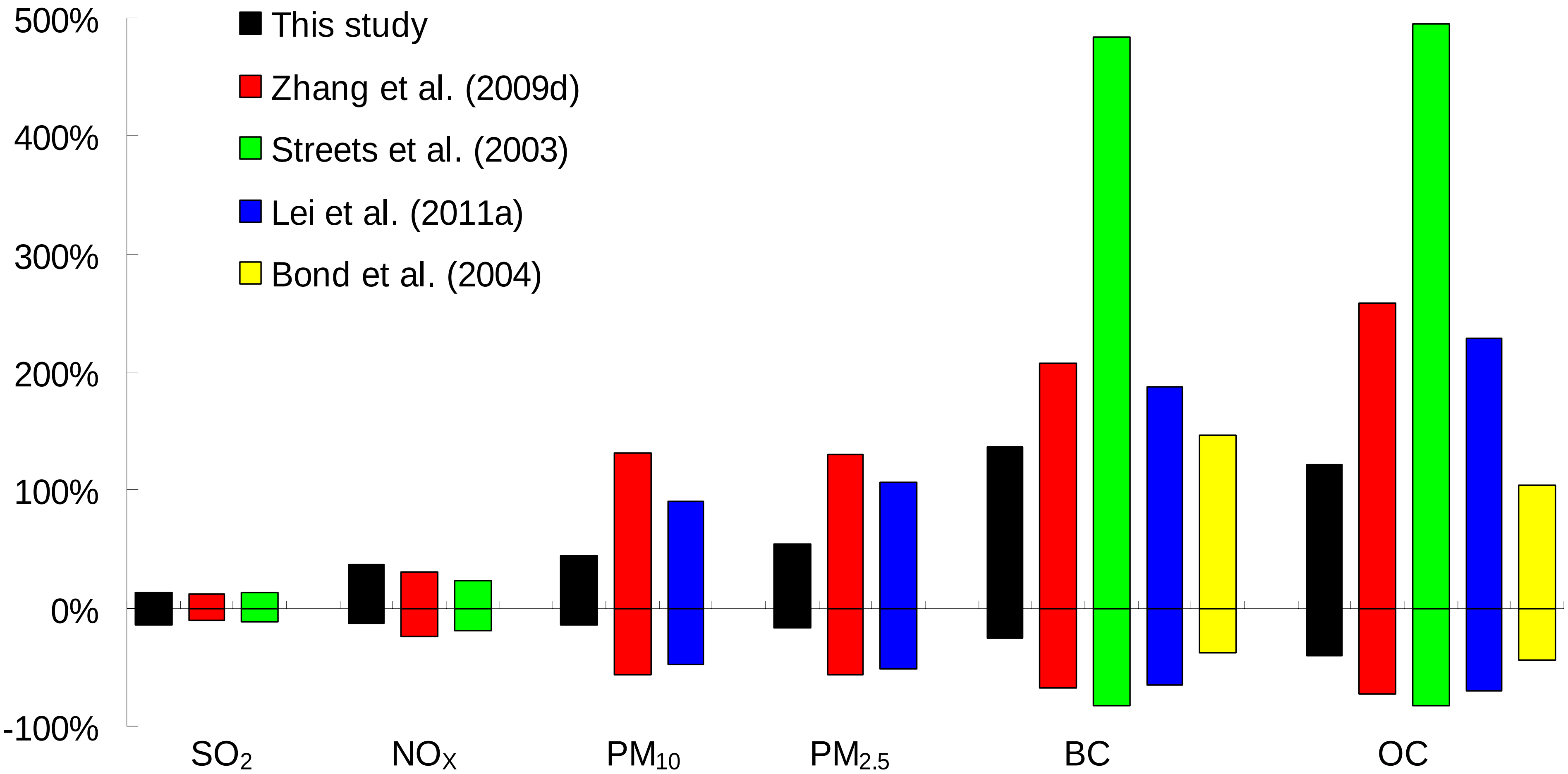
Most uncertain among all the species, due to unclear biofuel and biomass burning, as well as emission factors



CO and CO_2 emission trends



Reduced uncertainty through Monte-Carlo simulation



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Comparison with ground observations-SO_2

NC: North-central

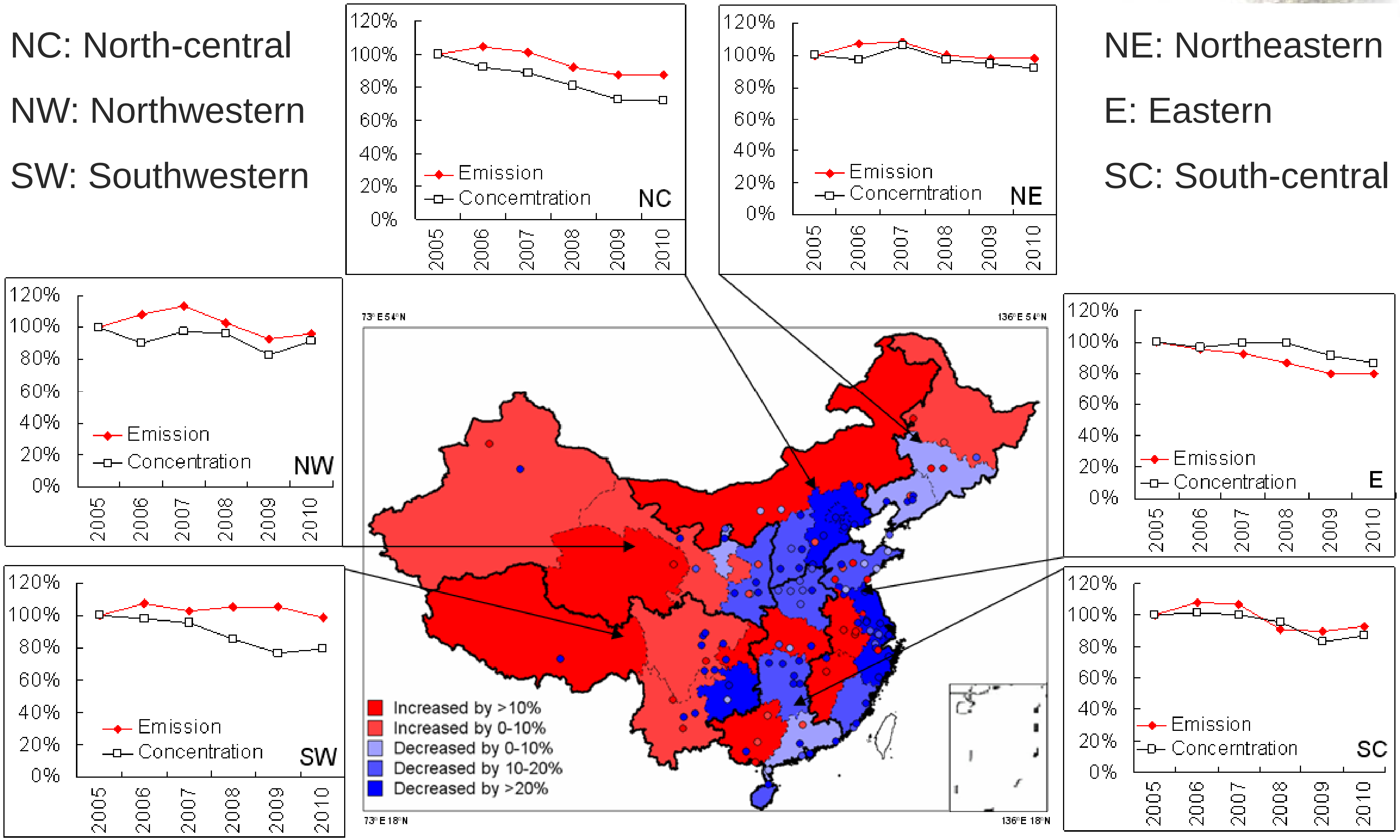
NW: Northwestern

SW: Southwestern

NE: Northeastern

E: Eastern

SC: South-central



Comparison with ground observations-PM_{10}

NC: North-central

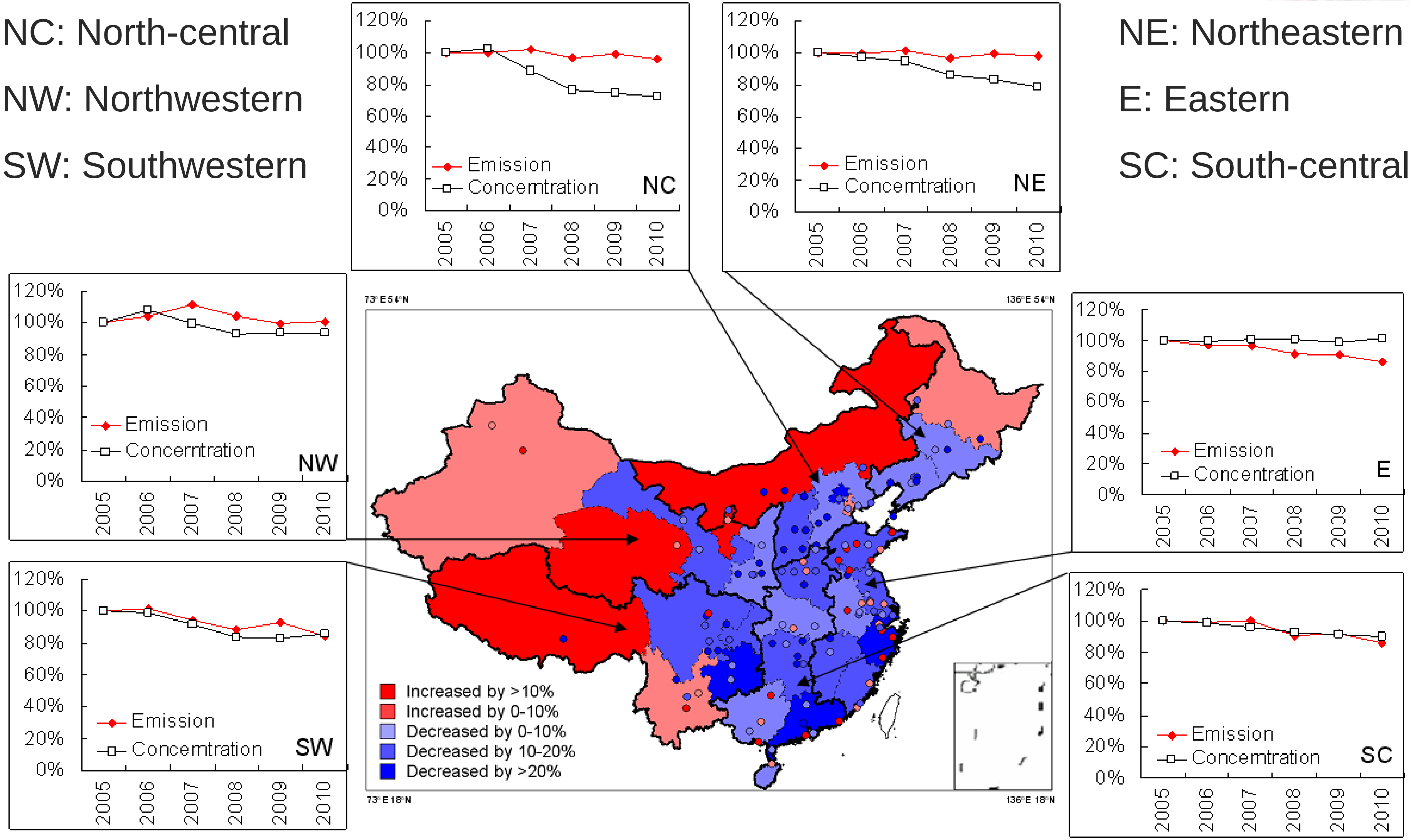
NW: Northwestern

SW: Southwestern

NE: Northeastern

E: Eastern

SC: South-central



Comparison with ground observations-NO_x

NC: North-central

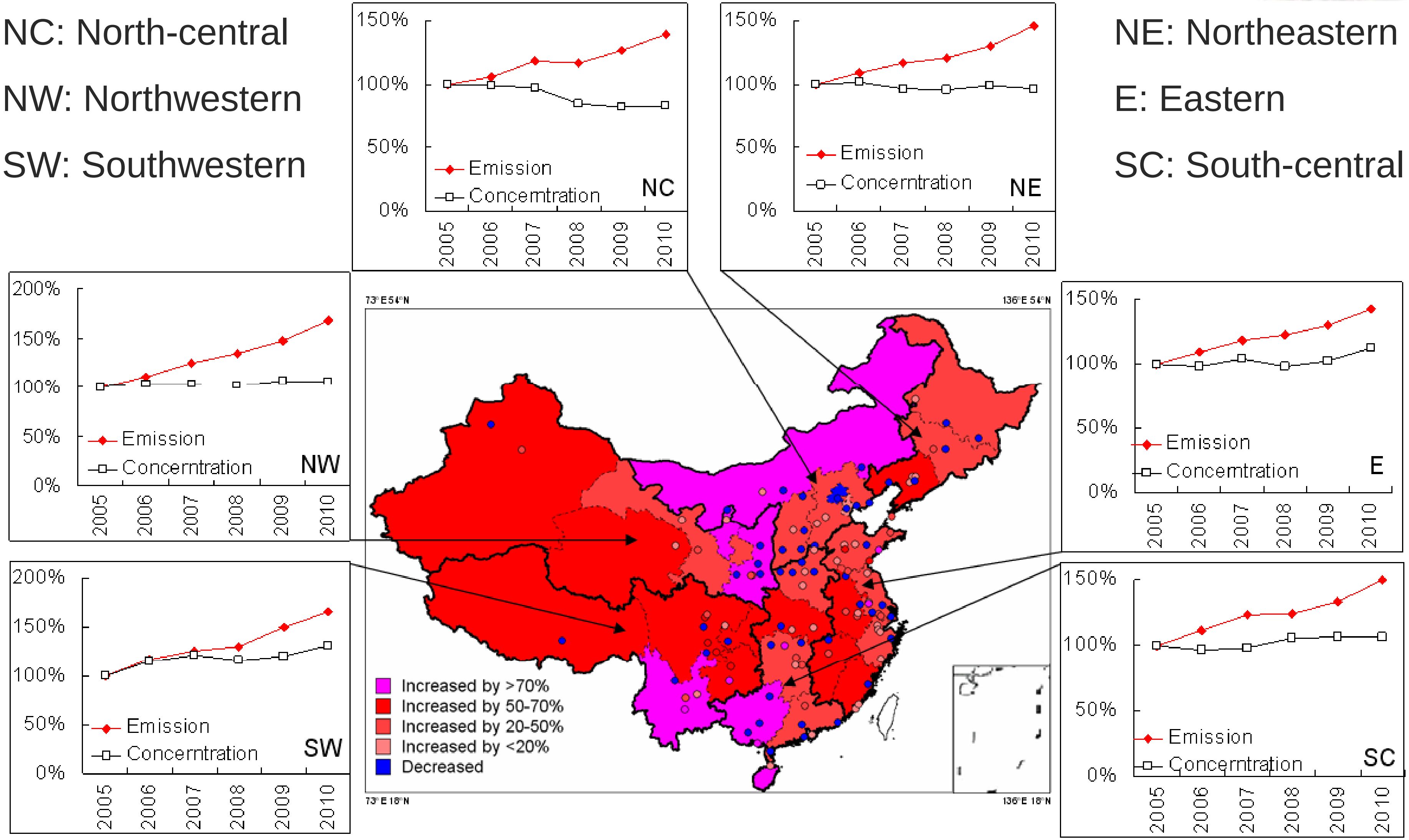
NW: Northwestern

SW: Southwestern

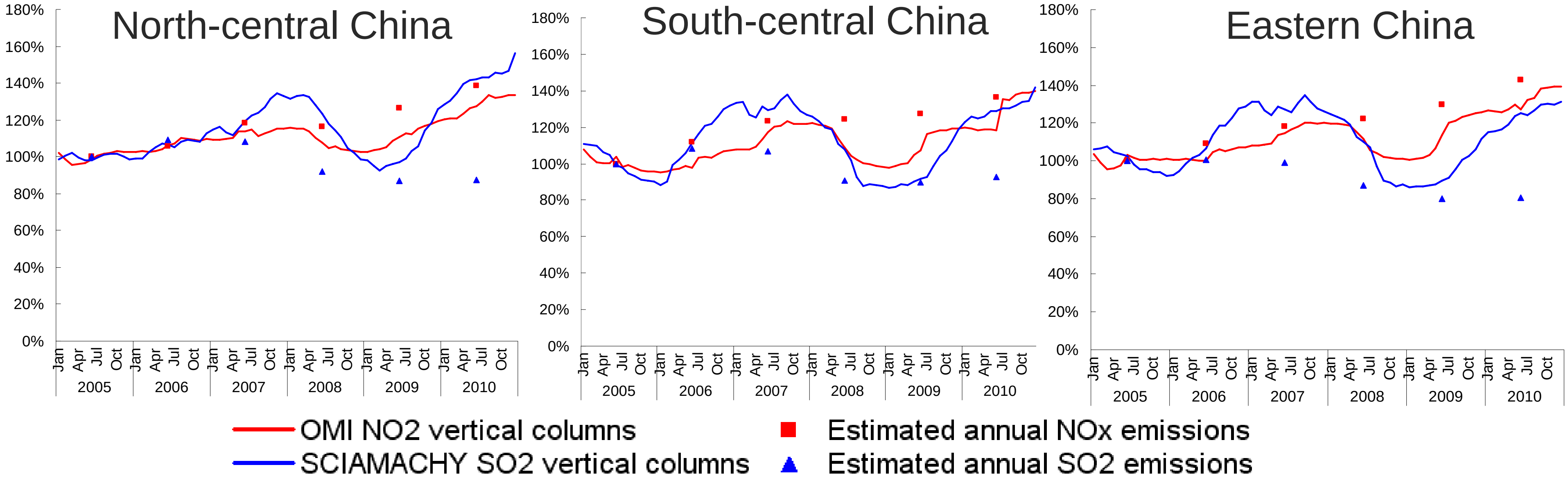
NE: Northeastern

E: Eastern

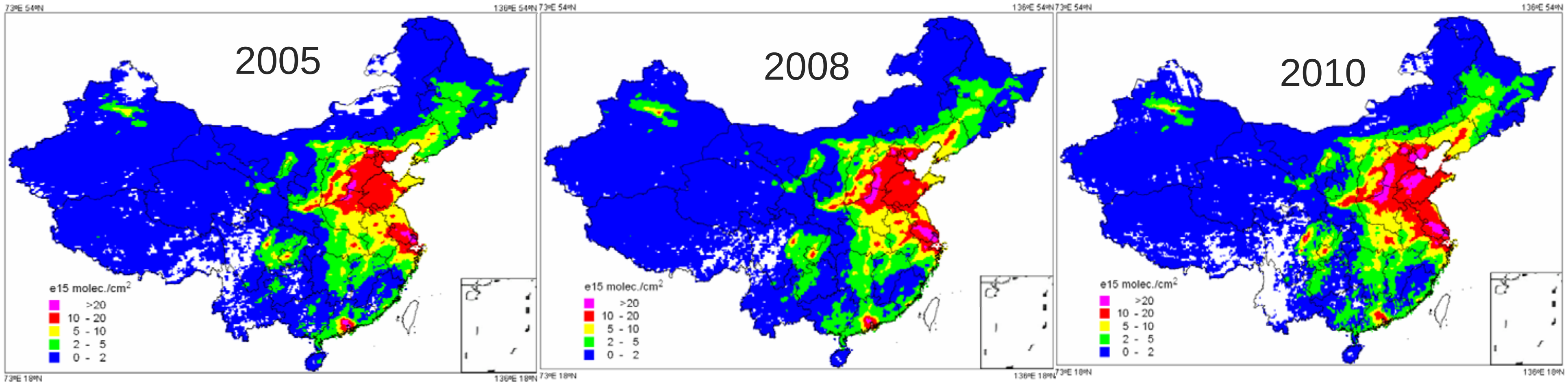
SC: South-central



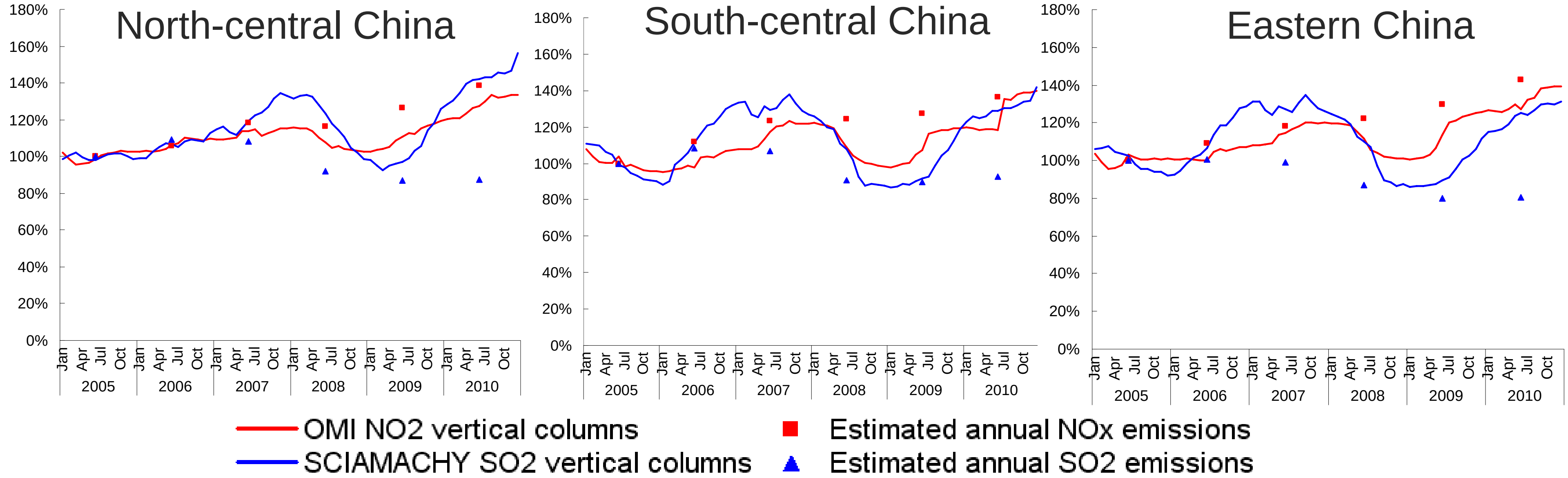
Comparison with satellite observations-NO_X



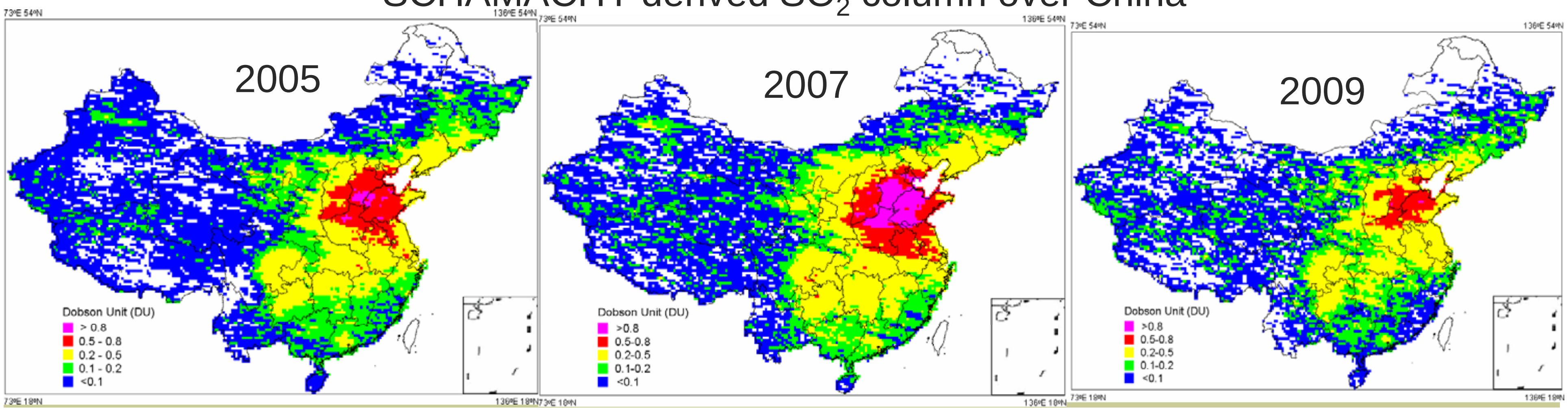
OMI-derived NO_2 column over China



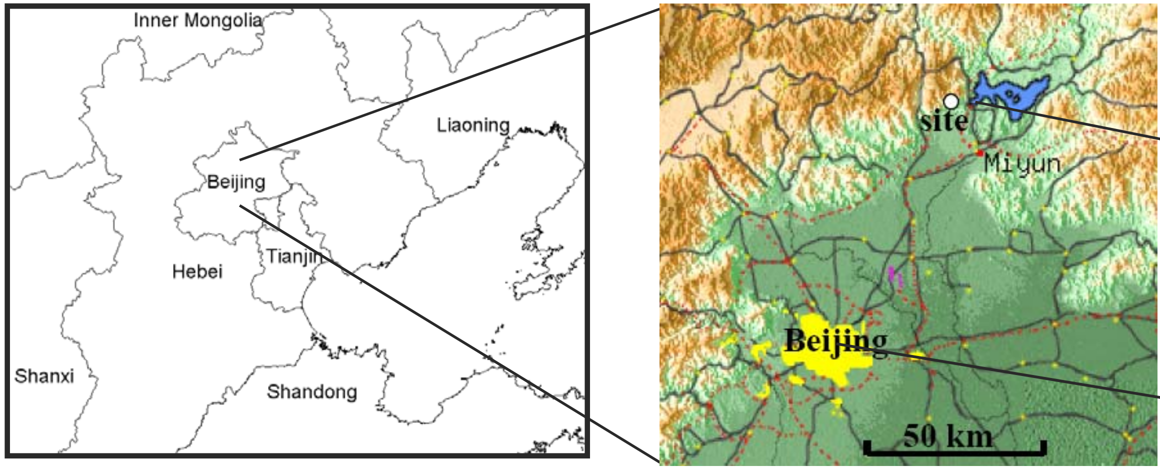
Comparison with satellite observations-SO_2



SCHAMACHY-derived SO_2 column over China



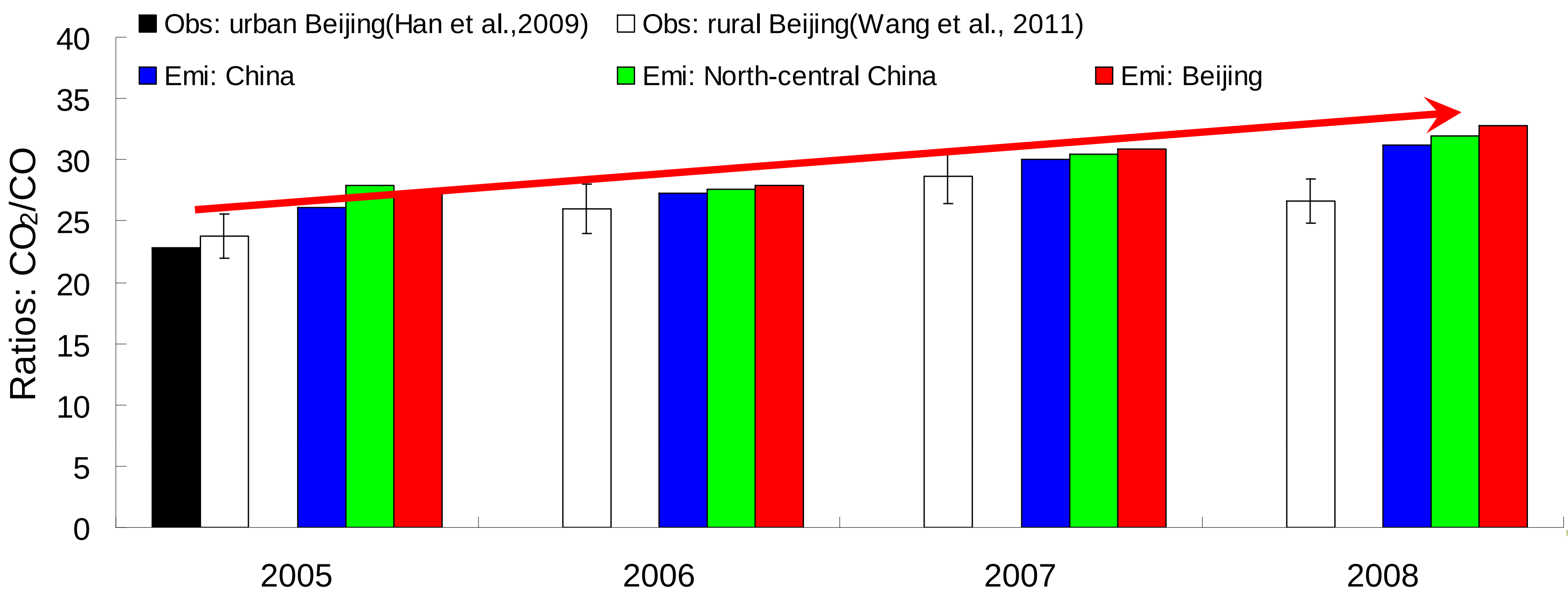
Comparisons for CO_2/CO ratios with observation



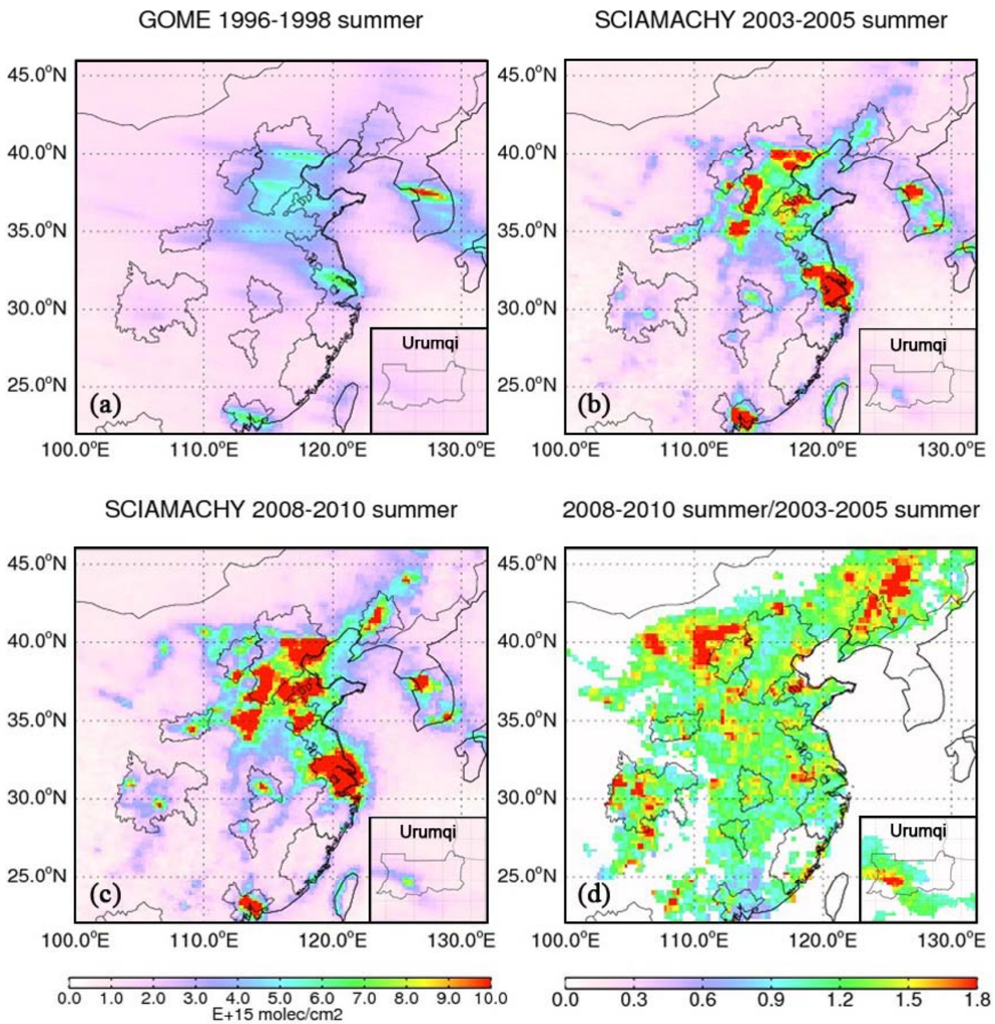
Obs site: Miyun, rural Beijing
Wang et al., *ACP*, 2010

Obs site: PKU, urban Beijing
Han et al., *JGR*, 2009

Revised figures from Wang et al., *ACP*, 2010



Pollution extends from developed to broader regions

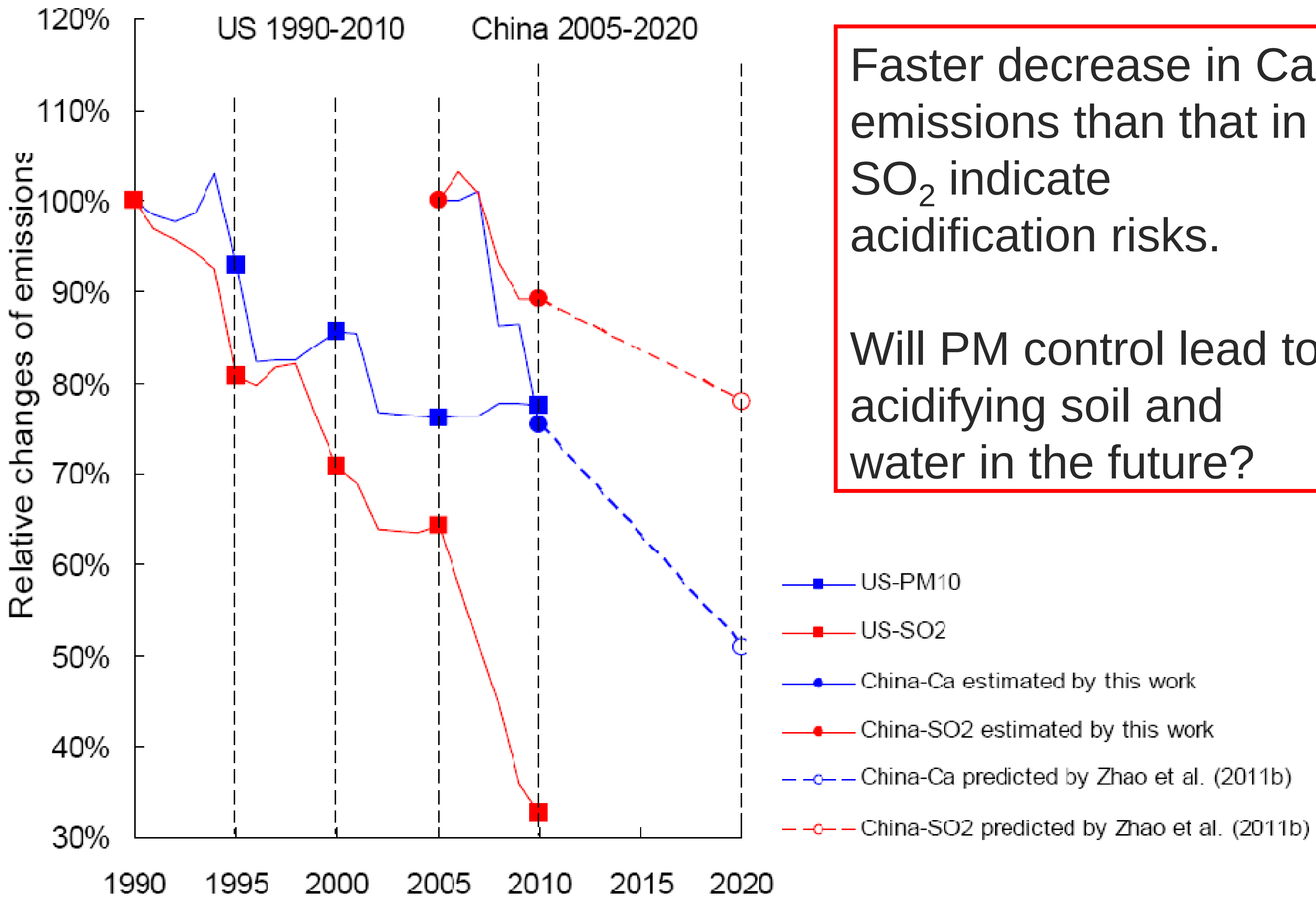


Zhang et al., *Chin. Sci. Bull.*, 2012

	The fractions of developed provinces to total country	
	2005	2010
Activity levels		
Capacity of coal-fired power plants	28 %	24 %
Cement production	28 %	22 %
Steel production	30 %	28 %
Coal consumption	18 %	17 %
On-road vehicle population	36 %	34 %
Emissions		
SO_2	22 %	17 %
NO_x	28 %	24 %
CO	21 %	18 %
PM	19 %	16 %
CO_2	23 %	21 %

The fractions of emissions from developed provinces reduced from 2005 to 2010

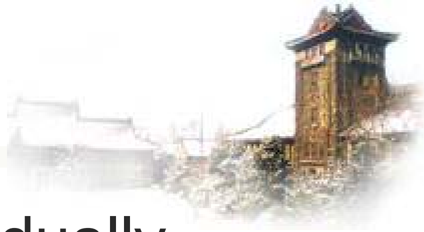
Potential risks for heavier acidification in future?



Faster decrease in Ca emissions than that in SO_2 indicate acidification risks.

Will PM control lead to acidifying soil and water in the future?

Conclusions



- China's current program of emission controls gradually reduces SO_2 and PM but fails to restrain NO_X. Less benefits are achieved for finer particles.
- Air pollution is spreading from mega cities to undeveloped areas, due to relatively strict control in developed urban regions.
- While observations reflect inter-annual trends of emissions, discrepancies exist for given regions and seasons, indicating the needs of research with higher time/spatial resolution.
- Faster decrease in PM emissions than that in SO_2 indicates potential risks for ecosystem acidification, reflecting the necessity of comprehensive multi-pollutant control.

Thank you

Comments and Questions?

For More Information

Zhao et al., *Atmos Chem Phys*, 13, 487-508, 2013

Zhao et al., *Atmos Environ*, 59, 214-223, 2012

Zhao et al., *Atmos Environ*, 49, 103-213, 2012

Zhao et al., *Atmos Environ*, 44, 1515-1523, 2010

http://chinaproject.harvard.edu

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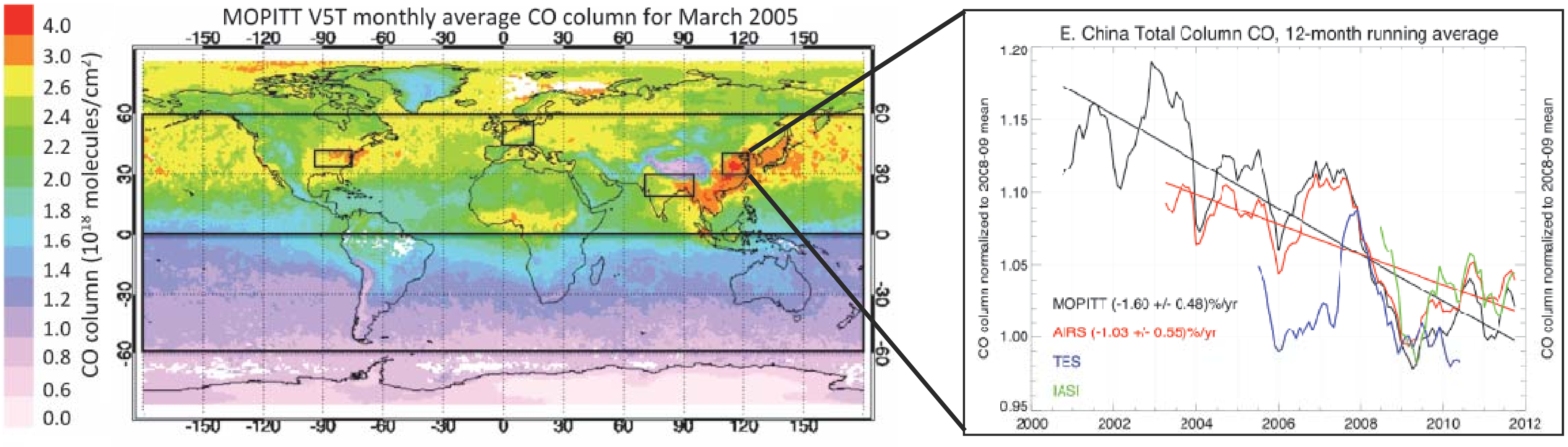
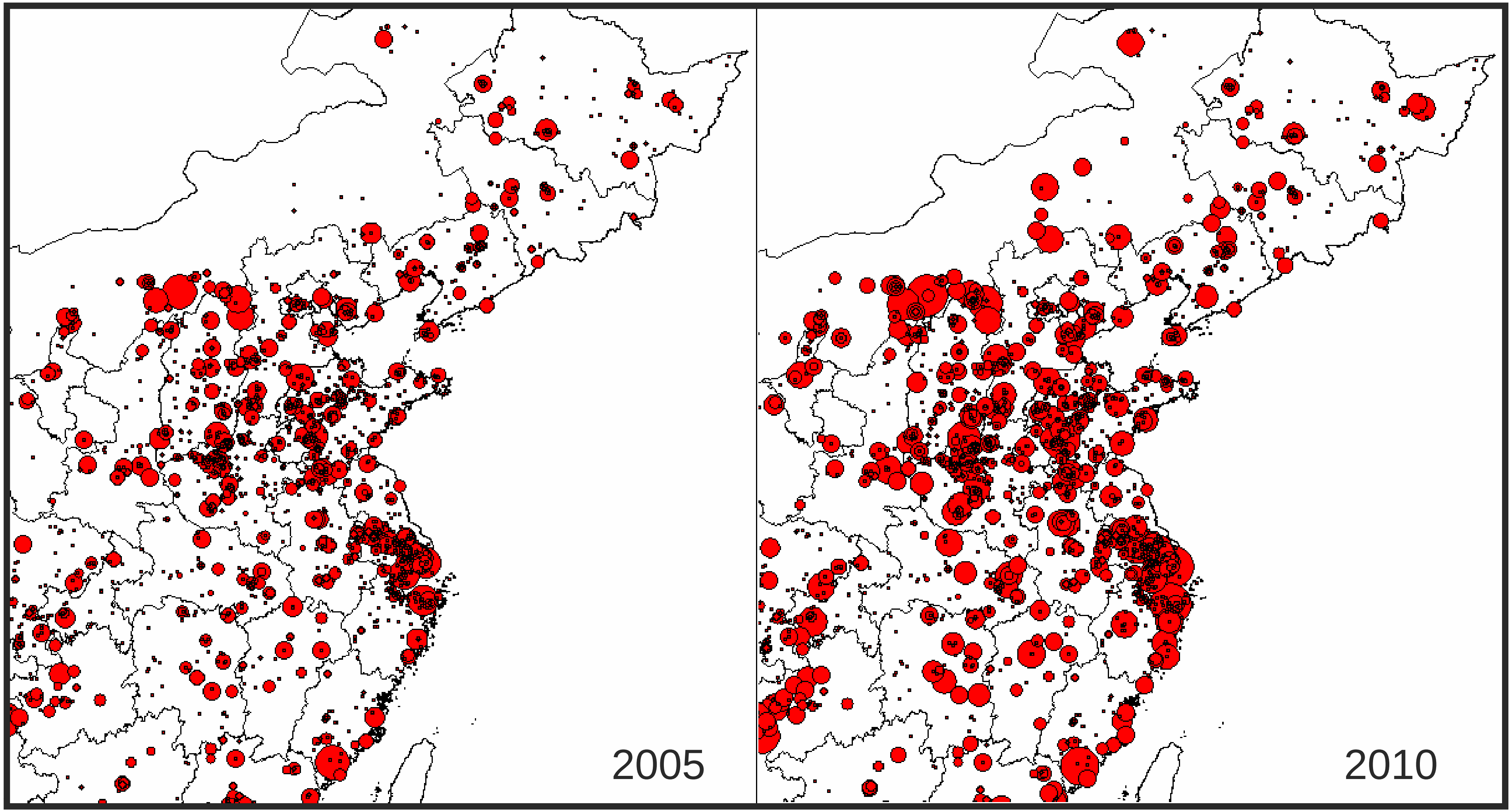
Satellite observation of CO (carbon monoxide) column

- Satellite observation indicates East China as hotspot of CO column
- The trend in East China total column CO has decreased since 2000

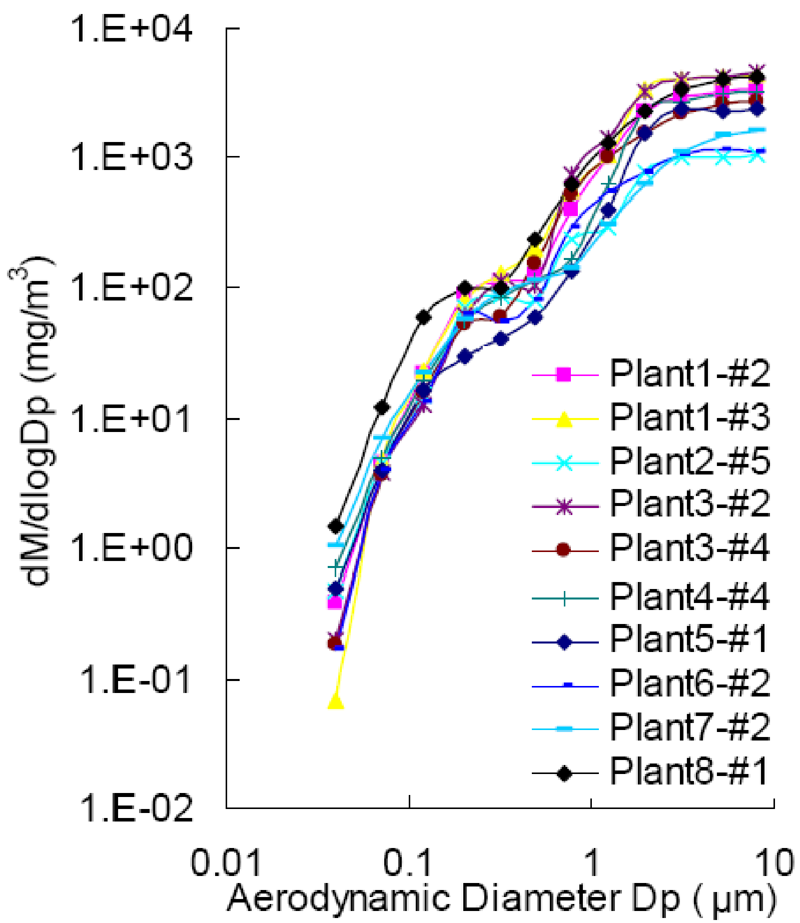


Revised figures from
Worden et al., *Atmos Chem Phys Discuss*, 12, 25703, 2012

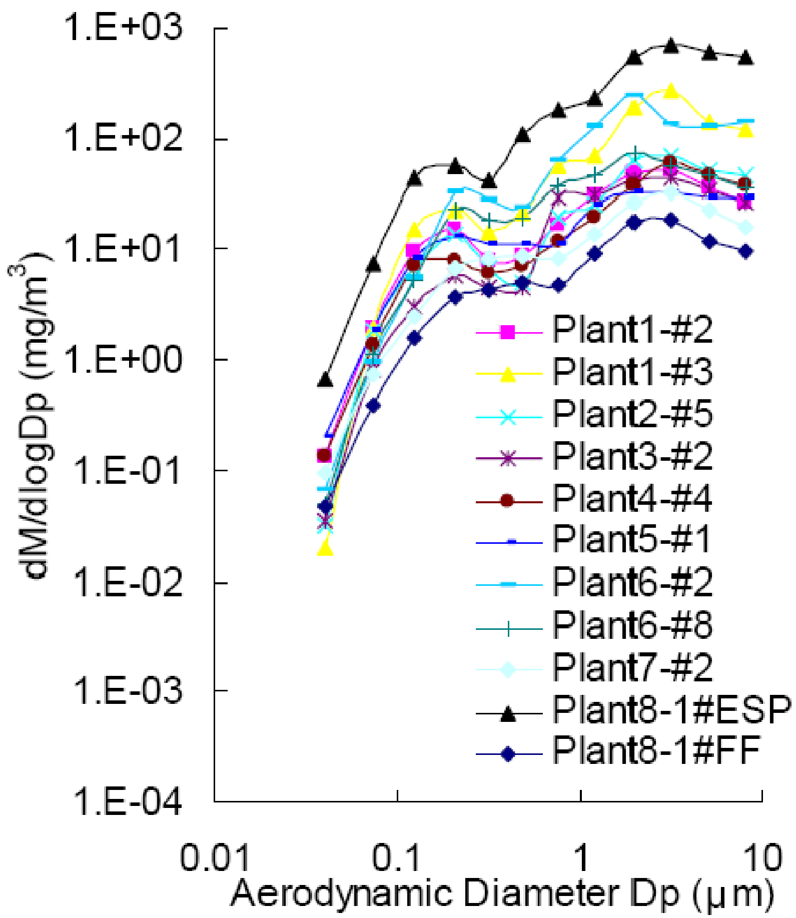
Coal-fired power units for 2005 and 2010



Size distribution of PM_{10}



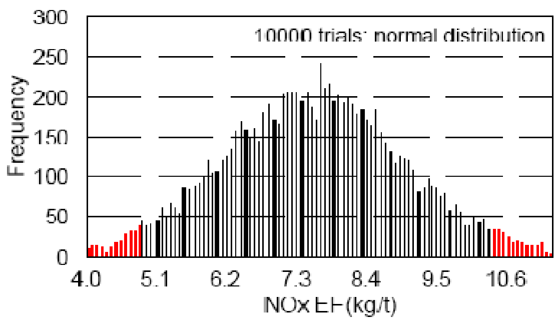
Before control

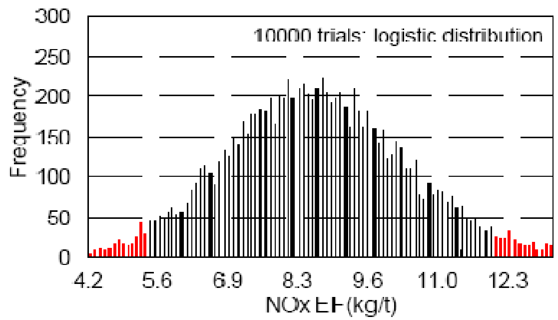


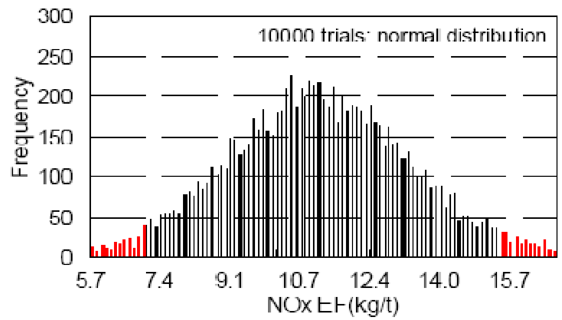
After control

NO_X emission factor database for CPP (kg/t)

Boiler	Capacity	Coal	Control	Burner	Emission factor
PC and grate boiler	<300MW	Bituminous and lignite	No	All types	6.1 (5.3-7.1)
		Anthracite	No	All types	9.0 (8.1-9.9)
		Bituminous and lignite	LNB	All types	4.0 (3.5-4.6)
		Anthracite	LNB	All types	5.5 (4.3-6.8)
		Bituminous and lignite	LNB	Tangential	4.7 (4.1-5.4)
		Bituminous and lignite	LNB	Wall-fired	5.2 (4.4-6.1)
	≥300MW	Anthracite	LNB	Tangential	7.6 (7.1-8.1)
		Anthracite	LNB	Wall-fired	8.6 (7.4-9.9)
		Anthracite	LNB	W-flame	11.2 (9.9-12.5)
CFBC	All	All types	No	CFBC	1.5







Comparison with other studies for CO_2