2019 International Emission Inventory Conference

Top-down Estimate of Black Carbon Emissions for City Cluster Using Ground Observations: A Case Study in Southern Jiangsu, China

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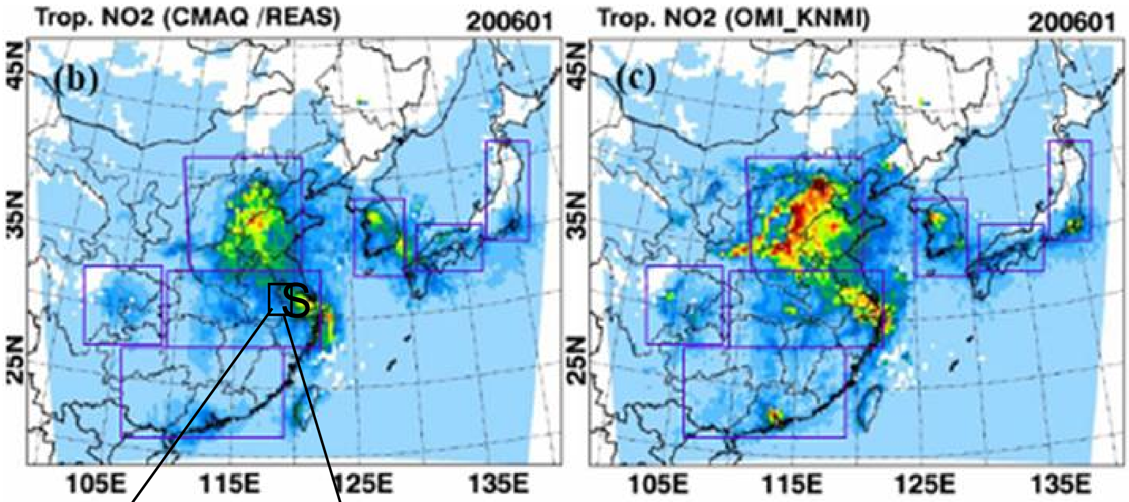
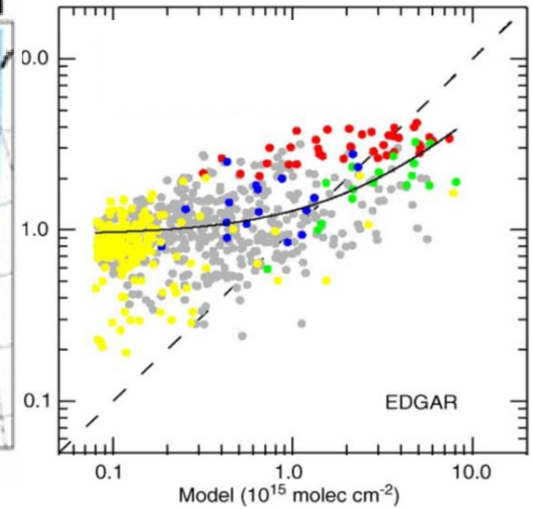
Outlines

- Motivation
  - Evaluation of local emission inventory
  - Black carbon: sources and uncertainty
- Methods: Model description
- Results and discussions
  - Result of the constrained top-down emissions
  - Impacts of sites, prior emissions and precipitation
- Conclusion

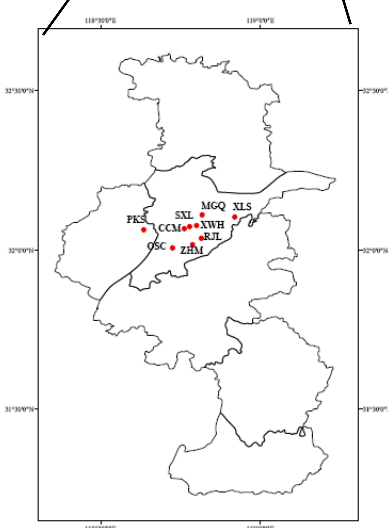
Motivation-Discrepancy between obs. and sim.

China

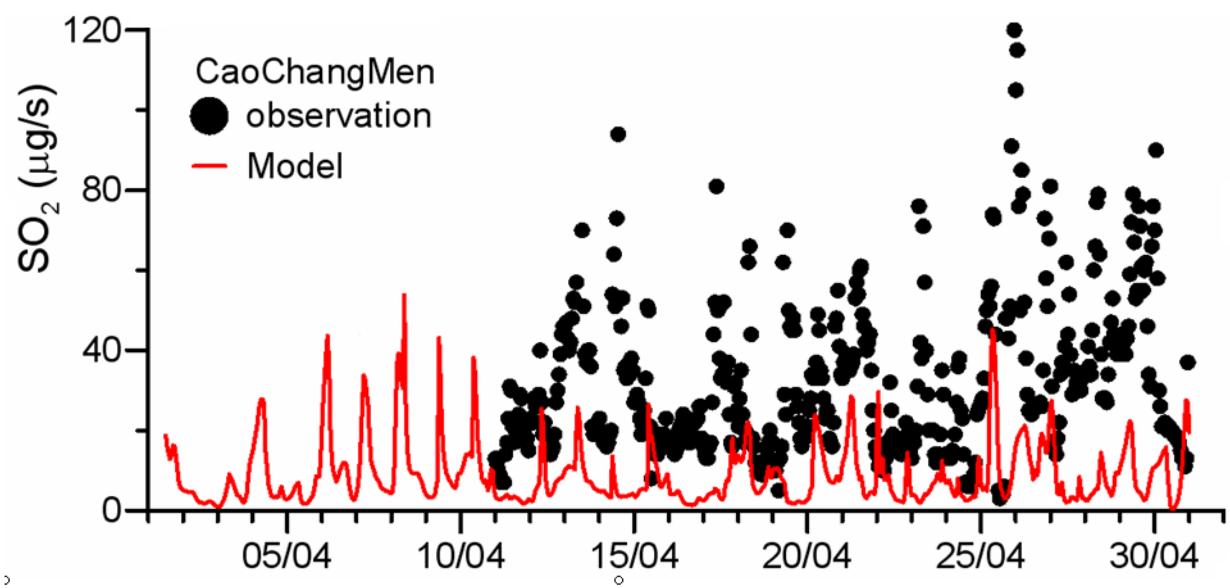




City



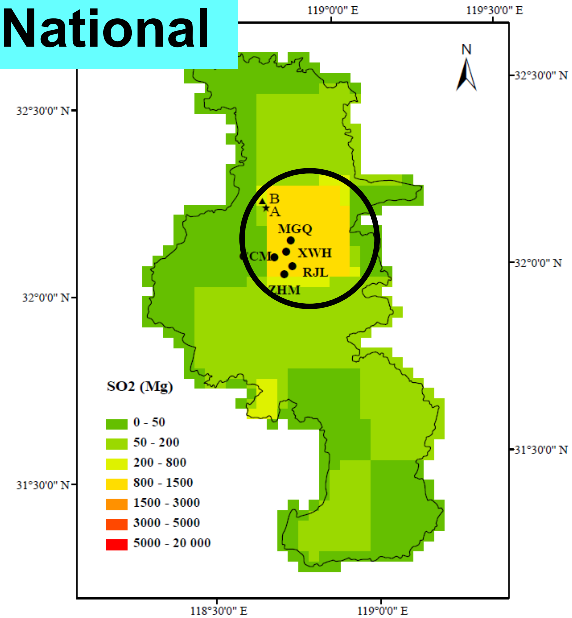
Nanjing



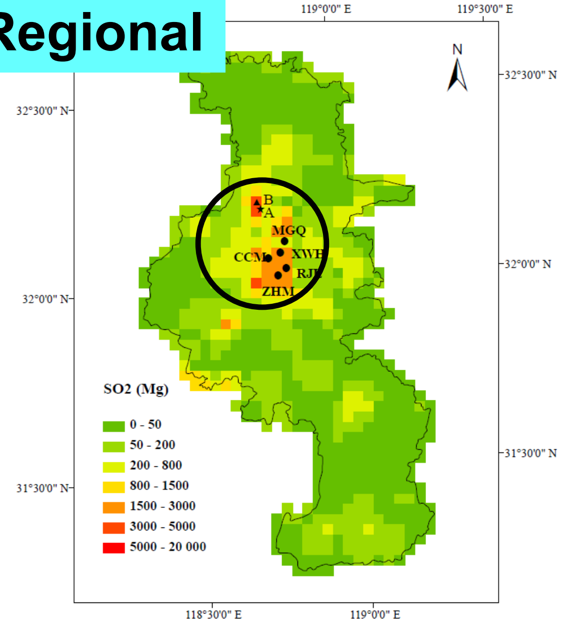
Ma et al., 2006; Han et al., 2015; Zhao et al., 2015

Motivation-Simulations from different inventories

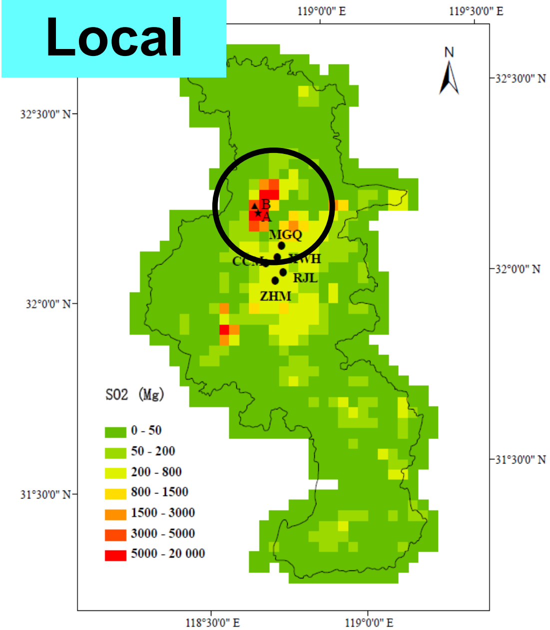
National



Regional



Local

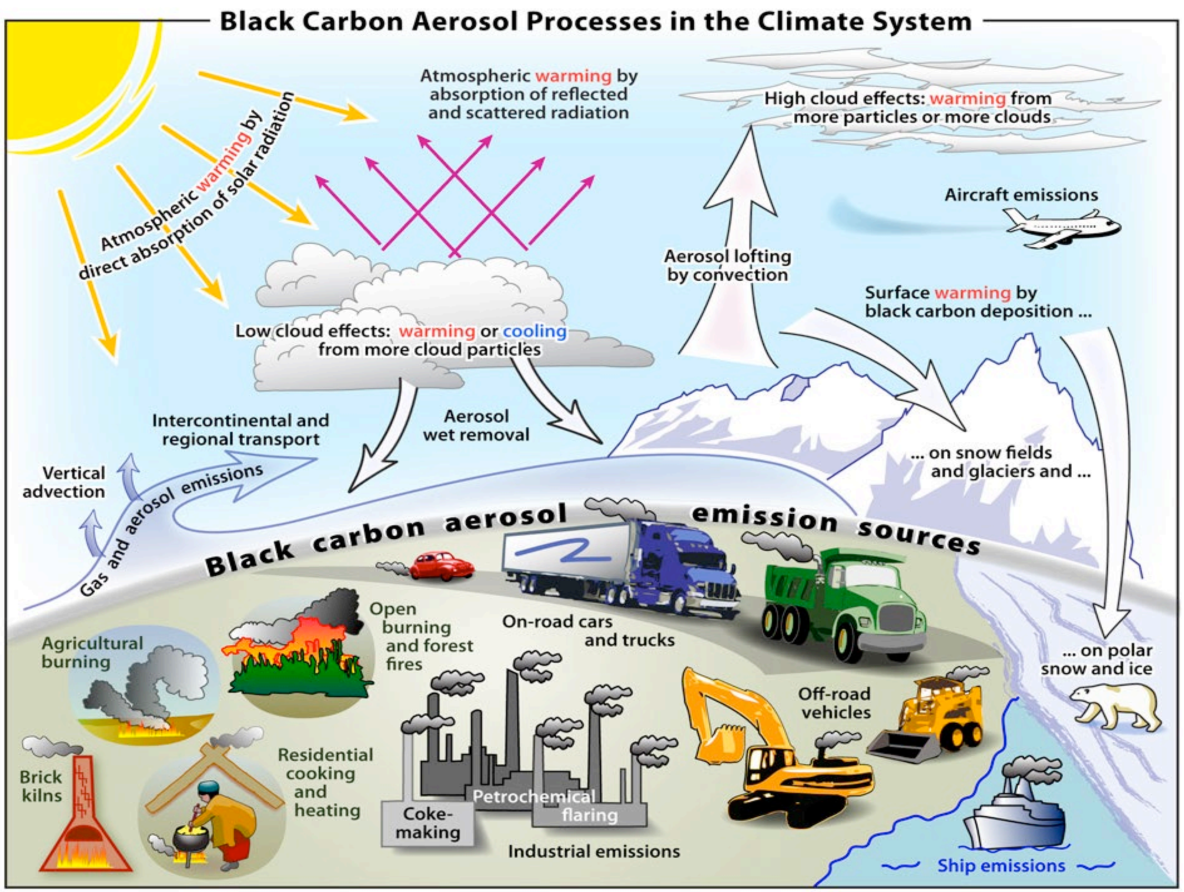


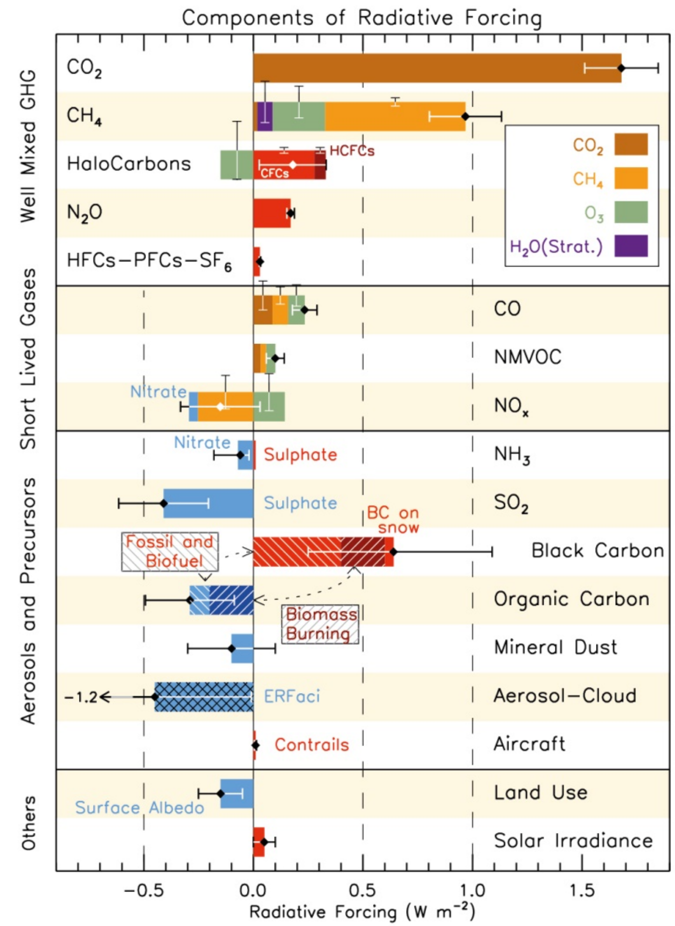
Pollutants	National (MEIC)		Regional (Fu et al., 2013)		Provincial (this work)	
	NMB	NME	NMB	NME	NMB	NME
SO_2	48.45 %	76.53 %	74.08 %	95.04 %	−9.97 %	47.49 %
NO_2	21.02 %	35.99 %	29.84 %	43.45 %	−14.47 %	33.22 %
O_3	−65.55 %	68.57 %	−53.93 %	61.59 %	−24.98 %	44.29 %
$PM_{2.5}$	−51.63 %	55.32 %	−49.16 %	56.00 %	−43.64 %	51.81 %

Zhou et al., *ACP*, 2017

Black carbon/elemental carbon

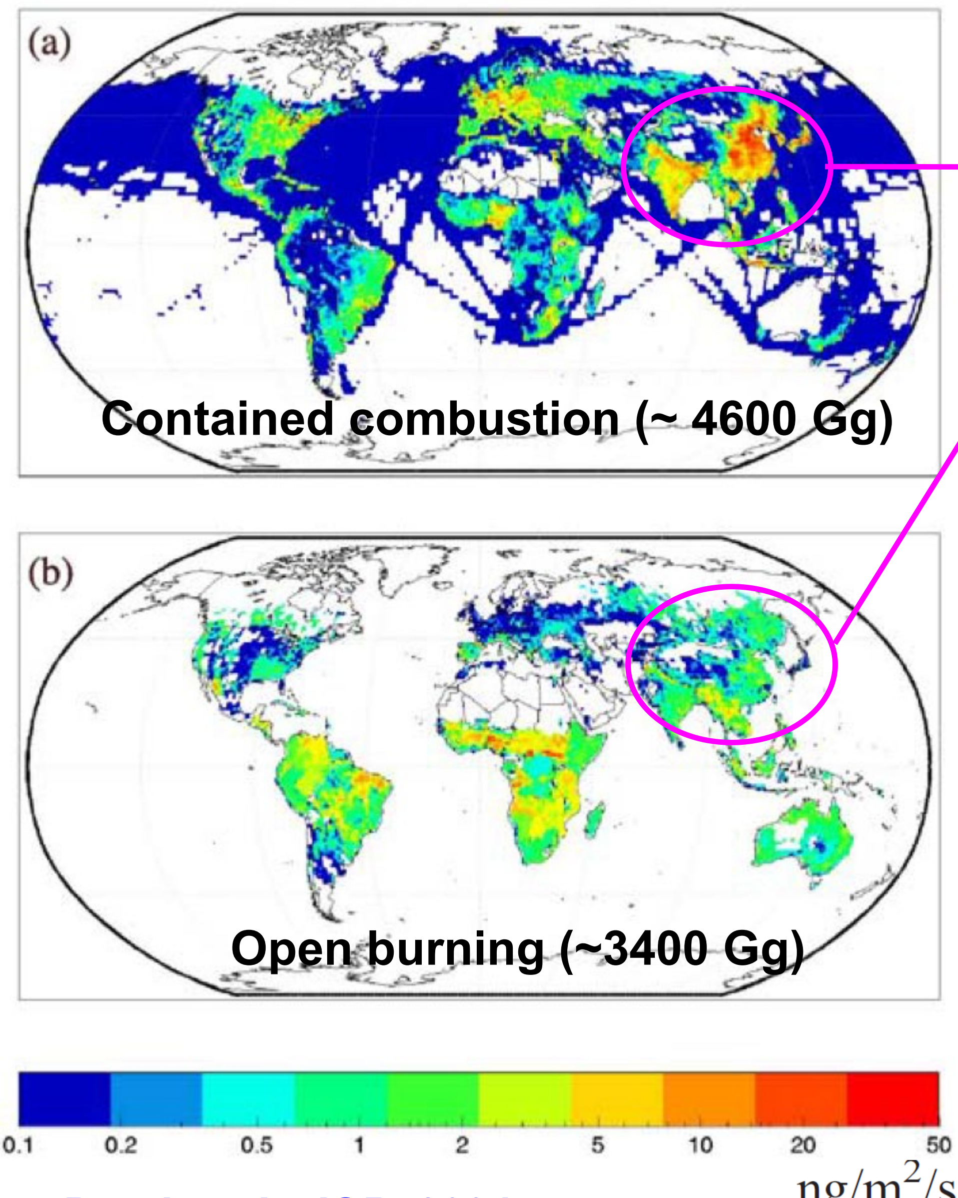
- Complicated sources (Industry, transportation, household)
- Significant climate (and health) impacts



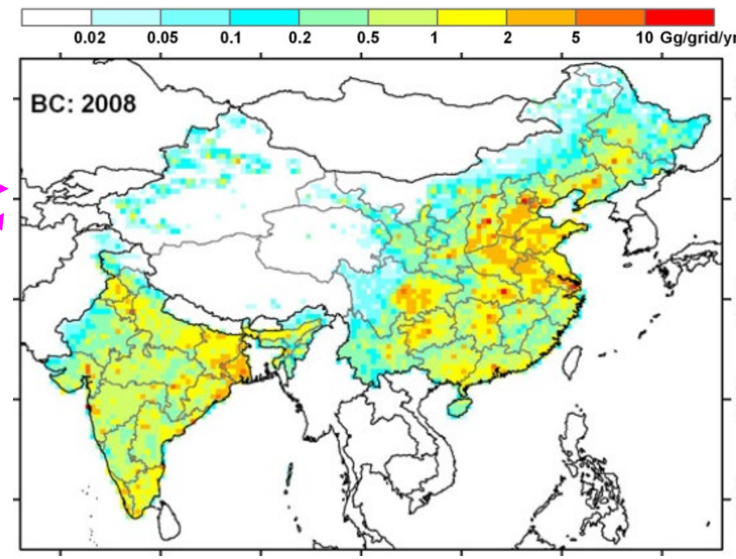


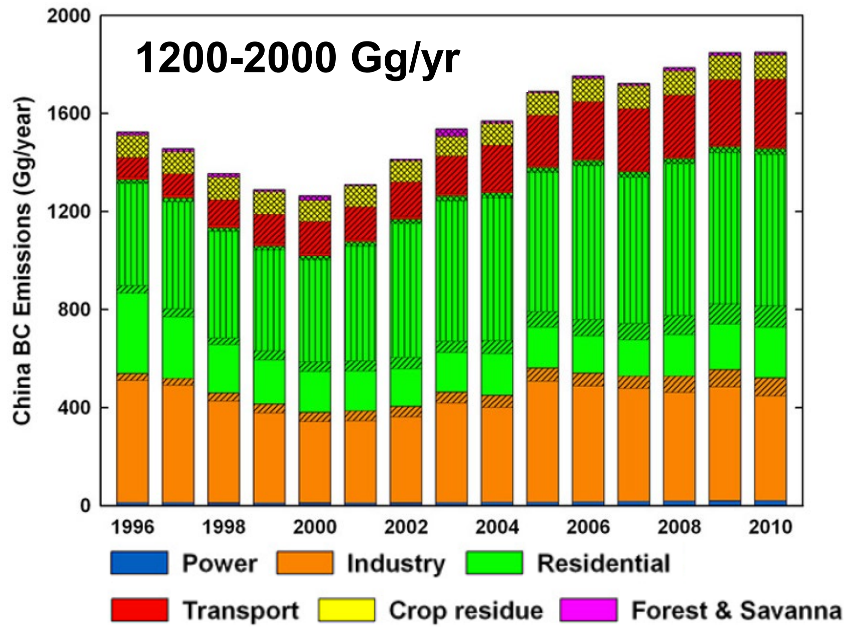
IPCC 5th Report 2013

Emissions of black carbon



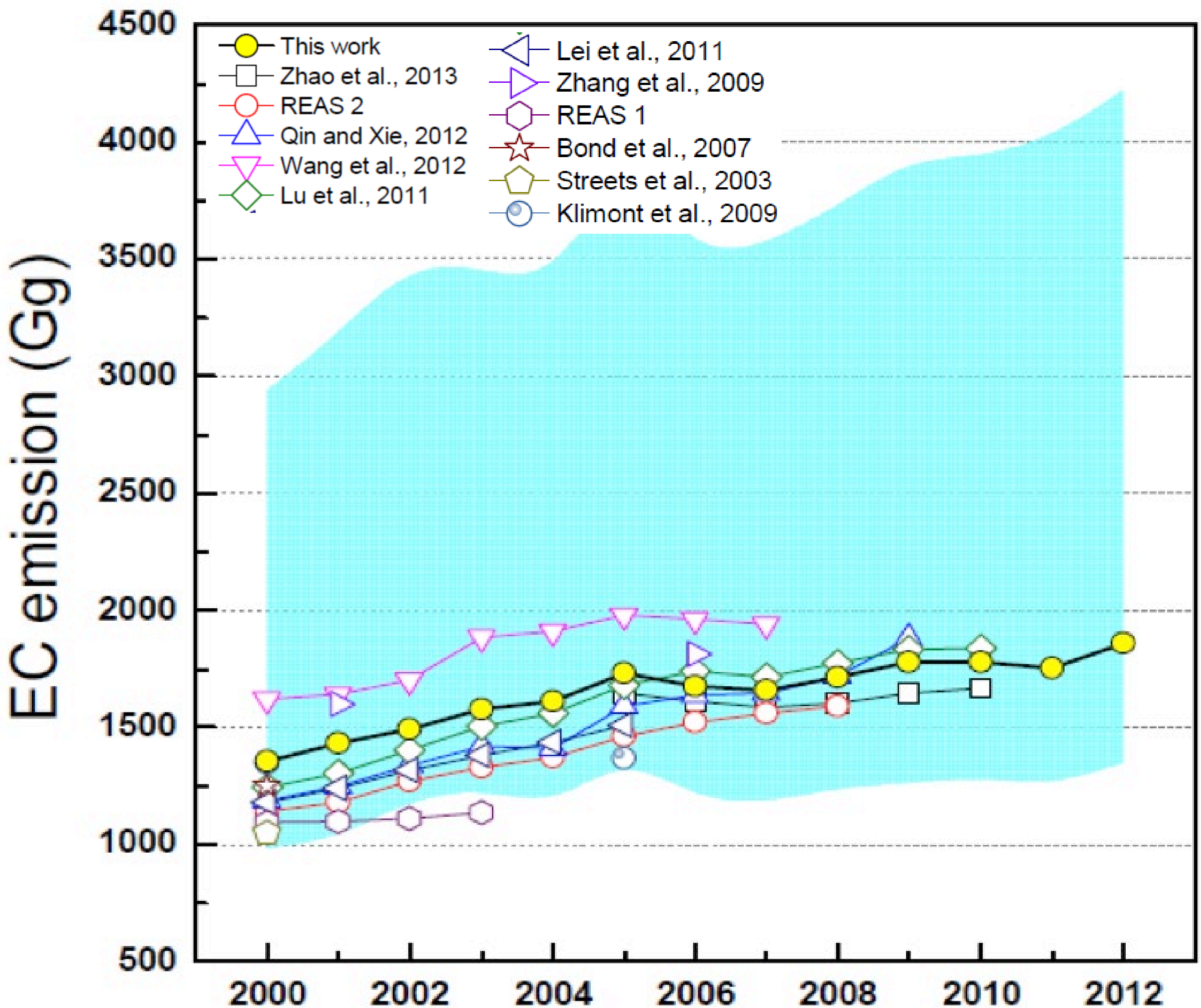
Bond et al., JGR, 2004





Lu et al., ACP, 2011

Inter-annual trends and uncertainty



Inter-annual trends in China's BC emissions ***Cui et al., ACP, 2015***

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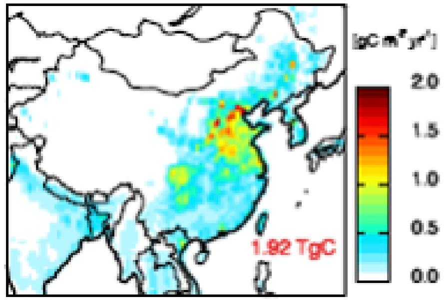
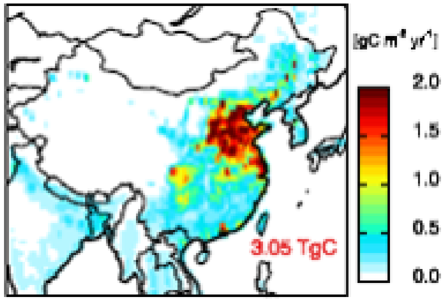
Method Linear regression + transport model

Whole country Fu et al., ACP, 2012

Bottom-up emissions



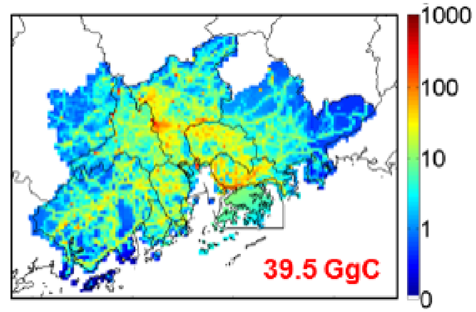
Top-down emissions



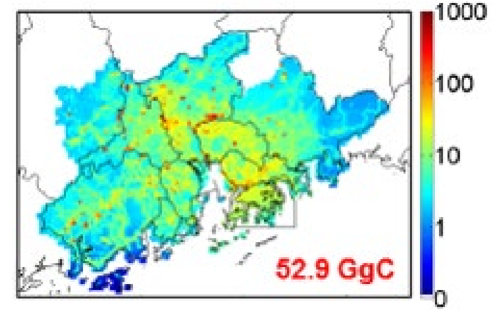
$$c_{obs} - c_{background} = \beta_1 c_{residential} + \beta_2 c_{non-residential} + \beta_3 c_{biomass} + \epsilon$$

Pearl river delta Li et al., ACP, 2015

Bottom-up emissions(× 10^{-3}GgC y^{-1})



Top-down emissions(× 10^{-3}GgC y^{-1})



$$c_{obs} - c_{background} = \beta_1 c_{transportation} + \beta_2 c_{non-transportation} + \beta_3 c_{biomass} + \epsilon$$

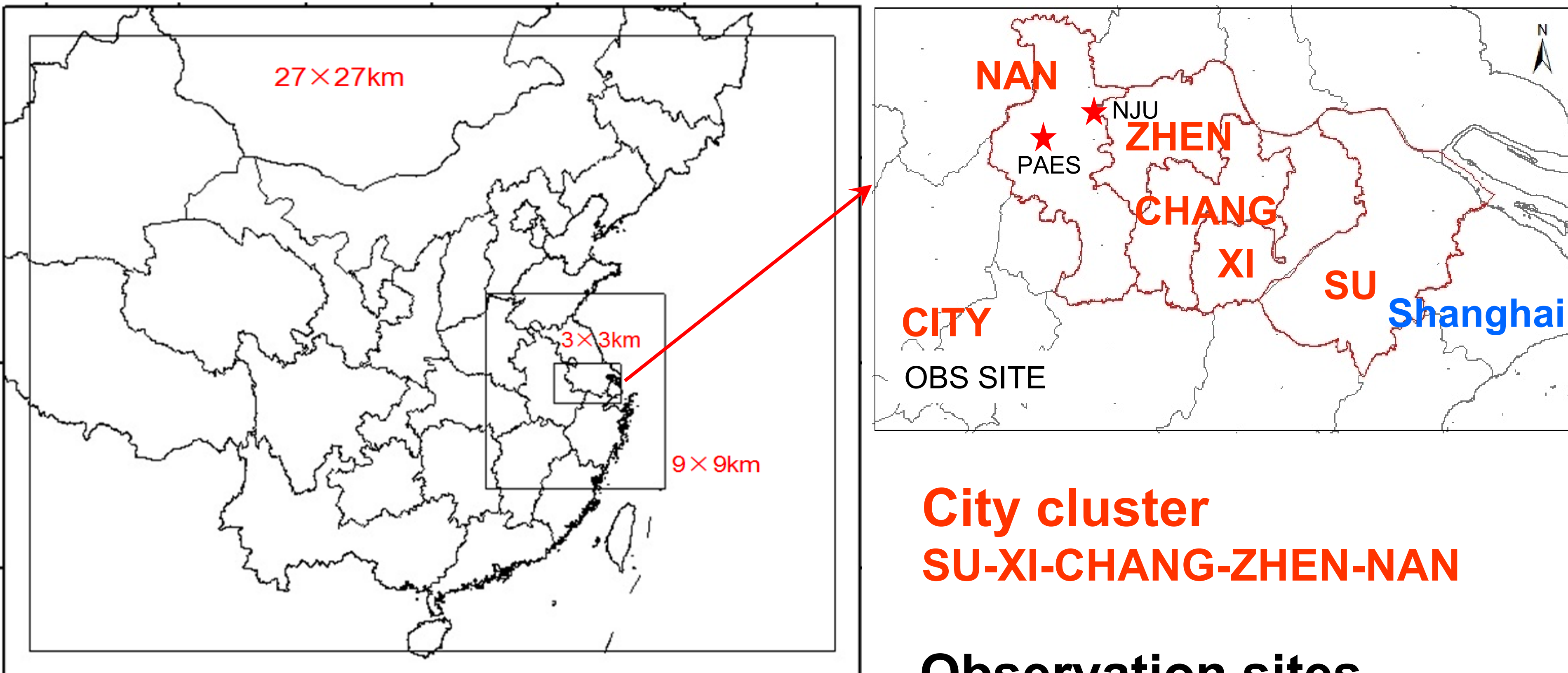
Application in southern Jiangsu city cluster

- ☐ **Constraining emissions from hourly on-line ground measurements**
- ☐ **Revising emissions by sector from detailed categories of emissions**

$$c_{obs} = \beta_1 c_{industry} + \beta_2 c_{residential} + \beta_3 c_{transportation} + \beta_4 c_{power} + \varepsilon$$

$$E_{top-down} = \beta_1 E_{industry} + \beta_2 E_{residential} + \beta_3 E_{transportation} + \beta_4 E_{power} + \varepsilon$$

Method – Modeling domain and site location



WRF-CMAQ modeling domain

City cluster

SU-XI-CHANG-ZHEN-NAN

Observation sites

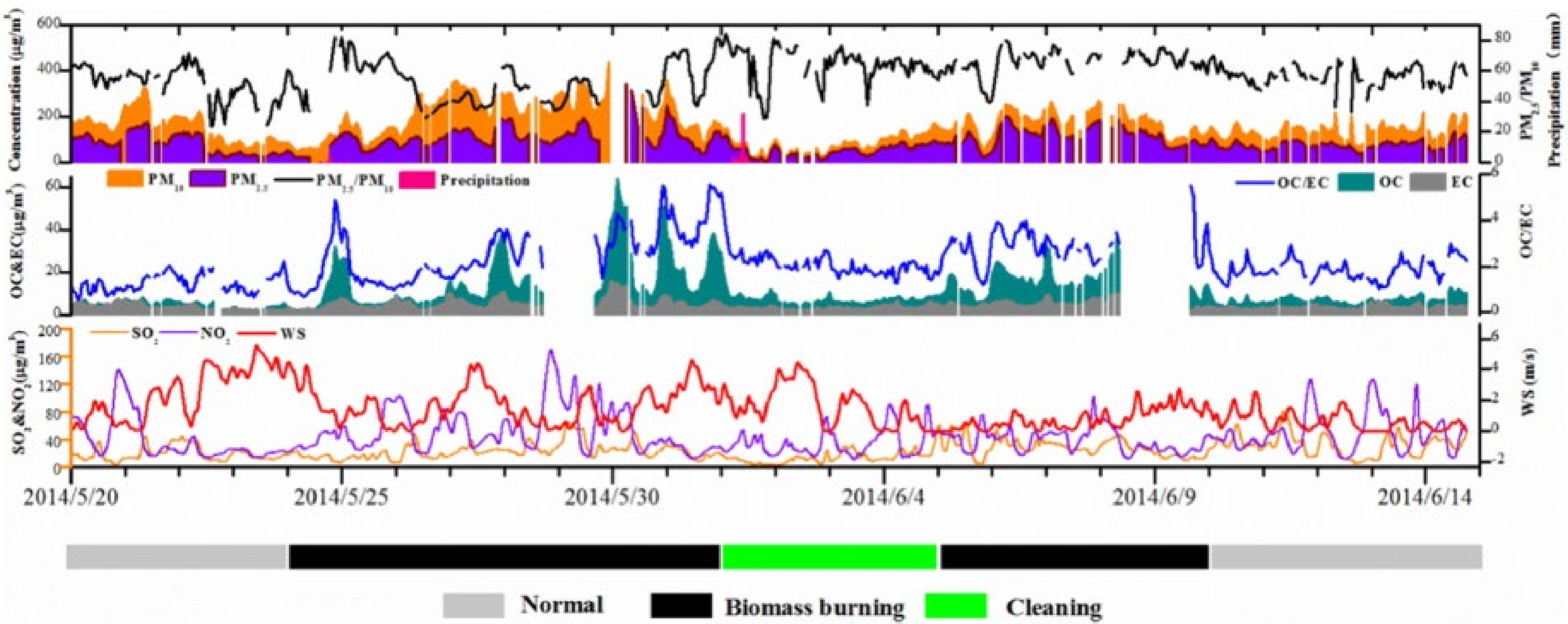
NJU Suburban site (upwind)

PAES Urban (downwind)

Method – Ground measurements

$$c_{obs} = \beta_1 c_{industry} + \beta_2 c_{residential} + \beta_3 c_{transportation} + \beta_4 c_{power} + \varepsilon$$

$$E_{top-down} = \beta_1 E_{industry} + \beta_2 E_{residential} + \beta_3 E_{transportation} + \beta_4 E_{power} + \varepsilon$$

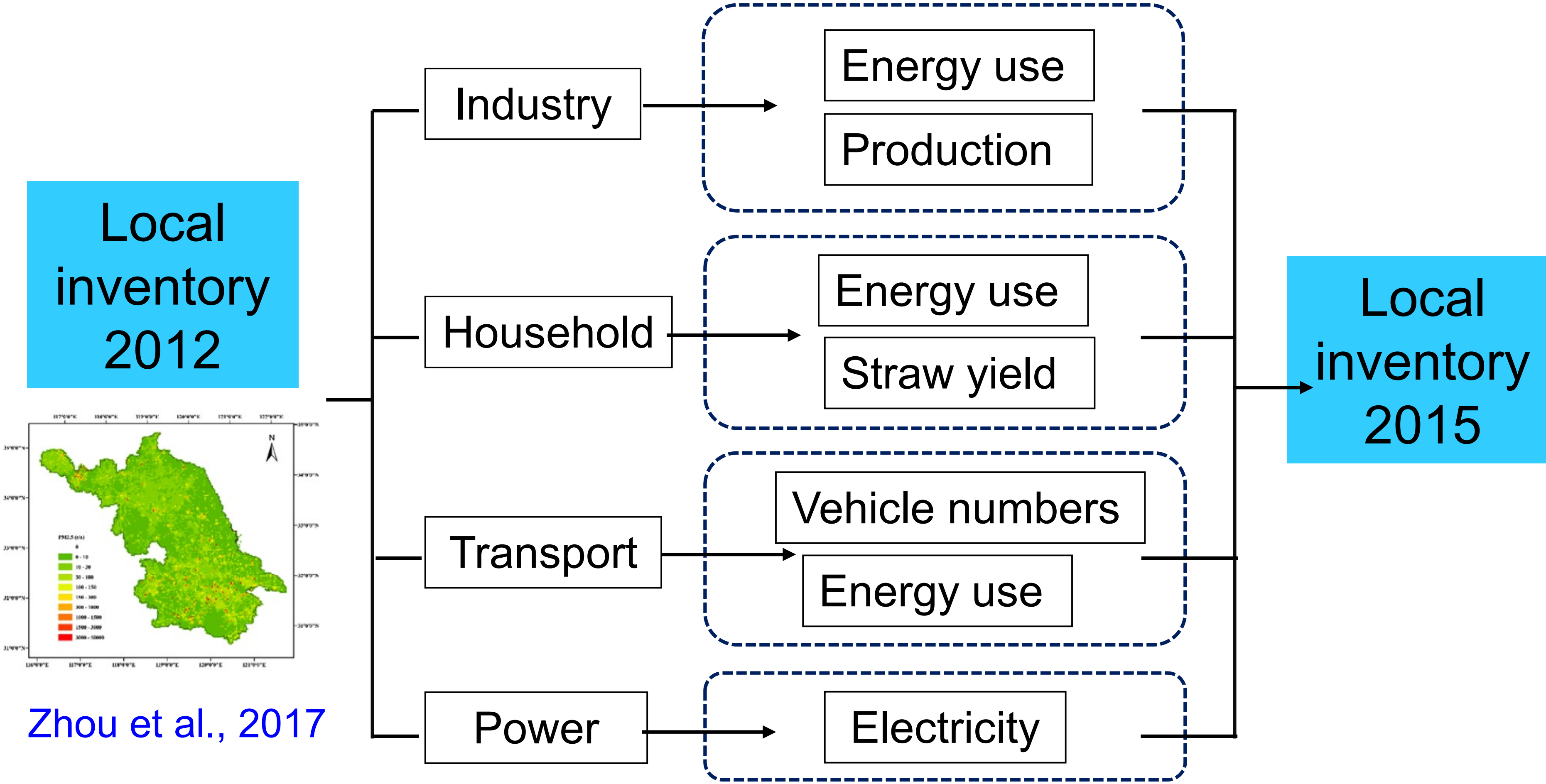


NJU: Suburban site (upwind); PAES Urban (downwind)

Chen et al., AR, 2017

Method - Emission data

$$E_{top-down} = \beta_1 E_{industry} + \beta_2 E_{residential} + \beta_3 E_{transportation} + \beta_4 E_{power} + \varepsilon$$



Zhou et al., 2017

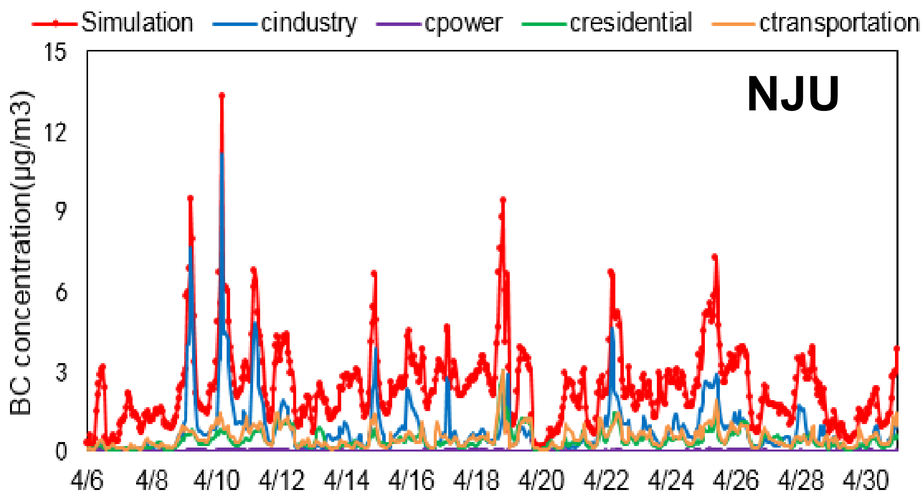
Scaling from activity levels without emission control progress

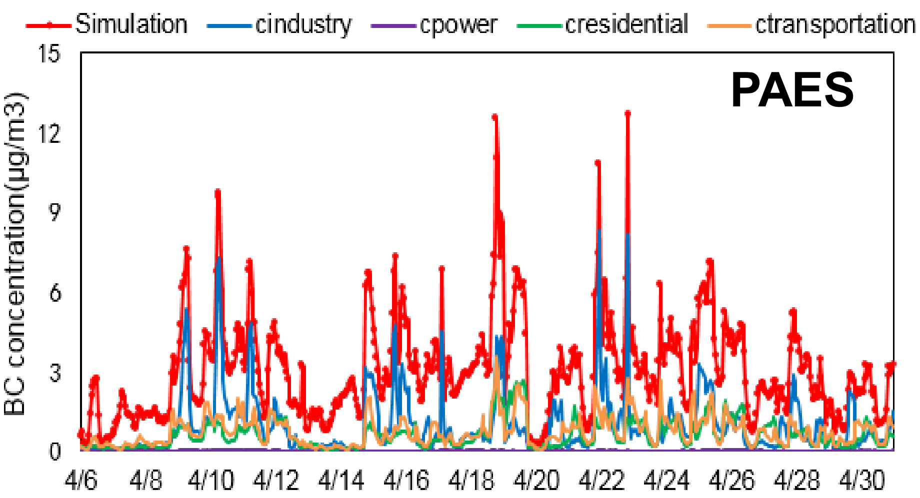
Method - Contribution by sector

$$c_{obs} = \beta_1 c_{industry} + \beta_2 c_{residential} + \beta_3 c_{transportation} + \beta_4 c_{power} + \varepsilon$$

Brute Force Method□ WRF-CMAQ□

	industry	residential	transportation	power
Base	√	√	√	√
Case1		√	√	√
Case2	√		√	√
Case3	√	√		√
Case4	√	√	√	





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Results and discussion - Linear egression

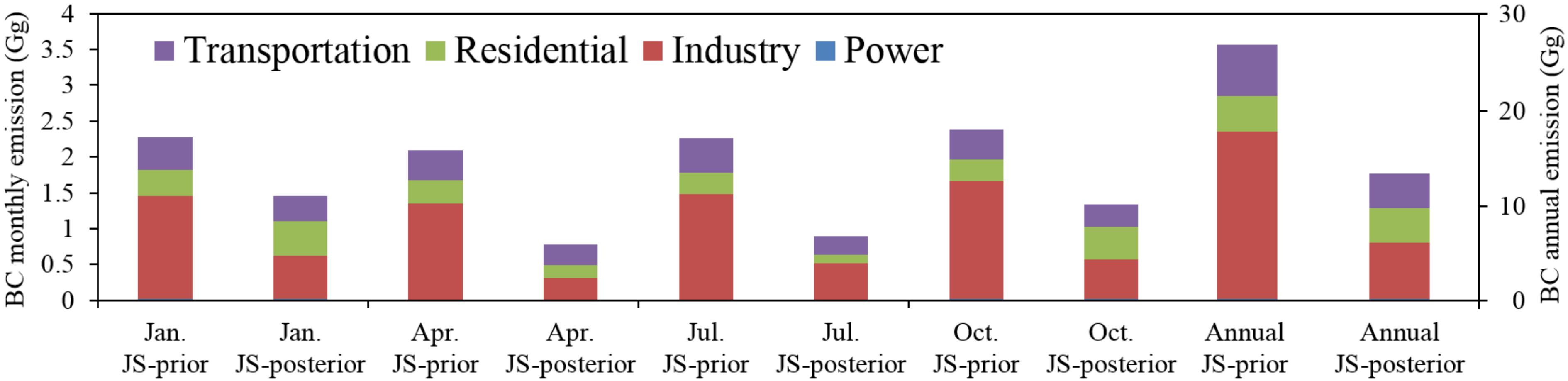
$$c_{obs} = \beta_1 c_{industry} + \beta_2 c_{residential} + \beta_3 c_{transportation} + \beta_4 c_{power} + \varepsilon$$

		factor	t[a]	Sig.[b]	VIF[c]
Jan.	β_1	0.421	2.649	0.008	1.755
	β_2	1.313	3.667	0.000	2.367
	β_3	0.790	2.226	0.026	2.715
Apr.	β_1	0.221	0.960	0.338	2.653
	β_2	0.582	1.625	0.105	4.616
	β_3	0.673	2.205	0.028	4.186
Jul.	β_1	0.346	3.092	0.002	2.088
	β_2	0.393	0.948	0.344	2.949
	β_3	0.550	2.201	0.028	3.463
Oct.	β_1	0.335	1.924	0.055	1.529
	β_2	1.516	4.123	0.000	2.198
	β_3	0.744	2.801	0.005	2.649

Criteria: $t>2$ b: $Sig.<0.05$ c: $VIF<10$

Results and discussion – Emission levels

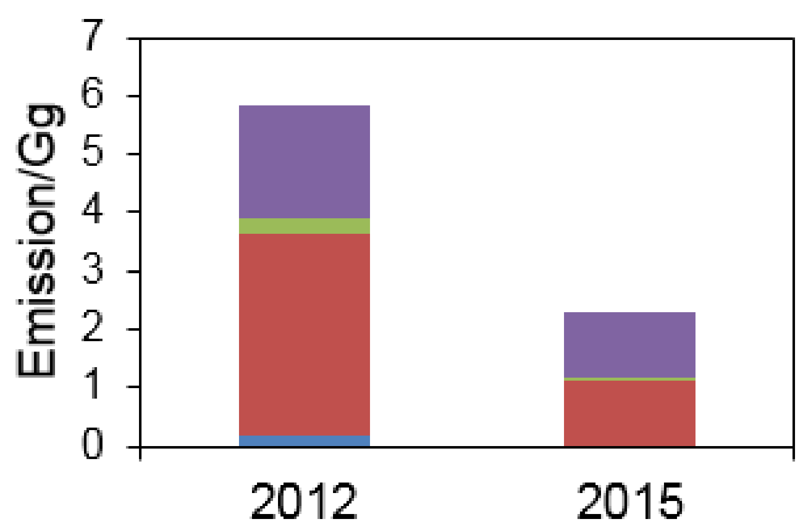
Emissions largely reduced from Top-down constraining



Total emissions reduced by 50.6%

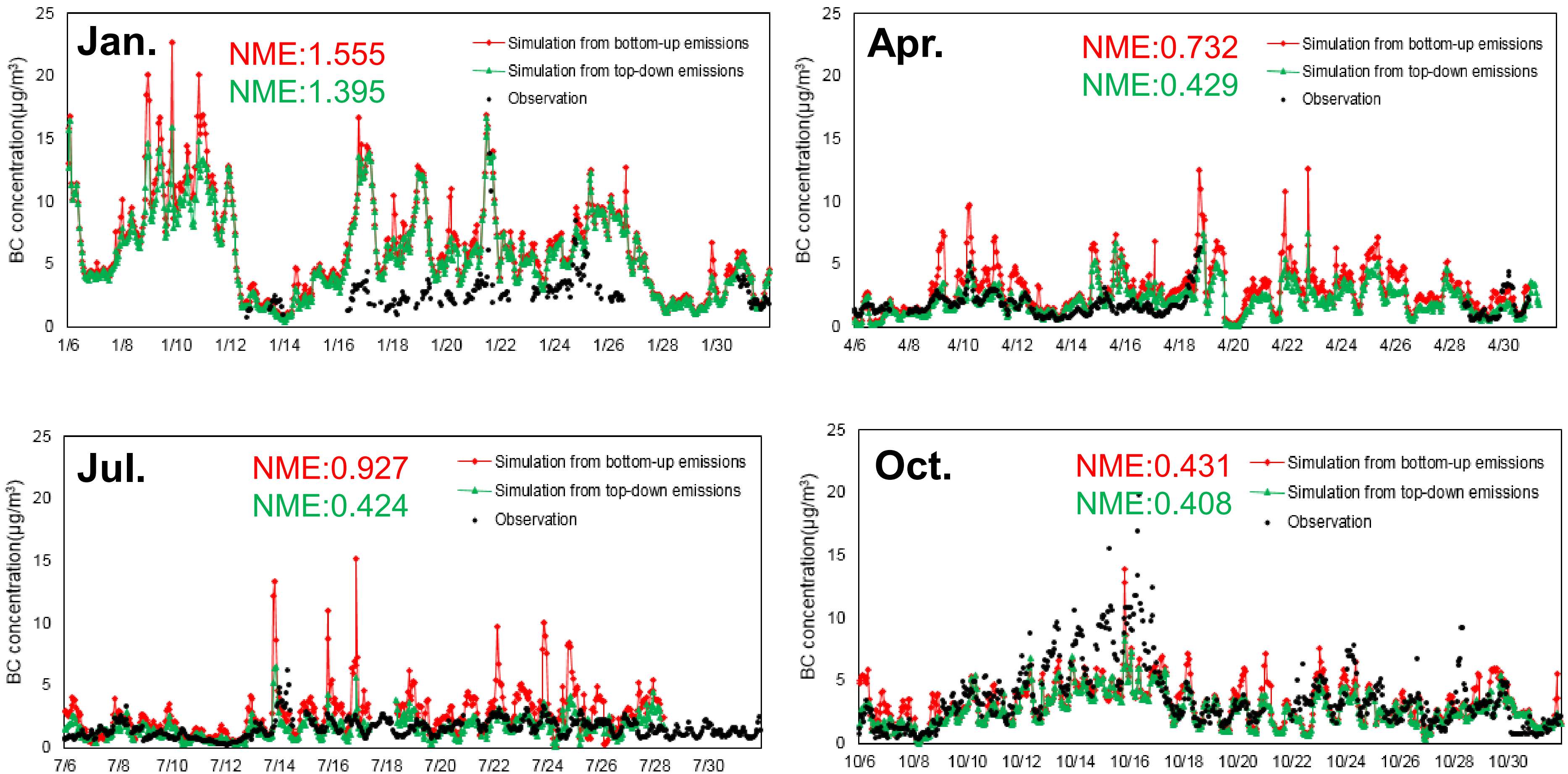
Industry	66.6%
Residential	2.9%
Transportation	31.9%

Nanjing emissions (bottom-up method)



Results and discussion – Model performance

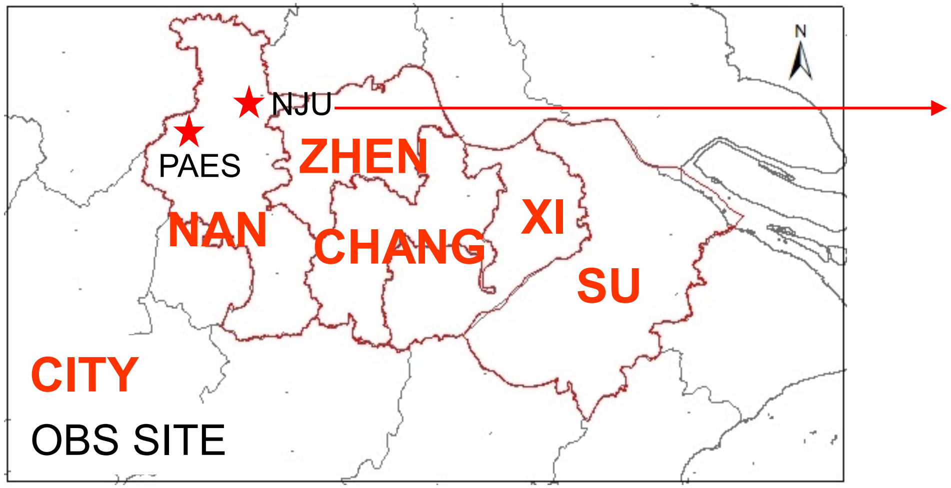
Top-down emissions reduced overestimation

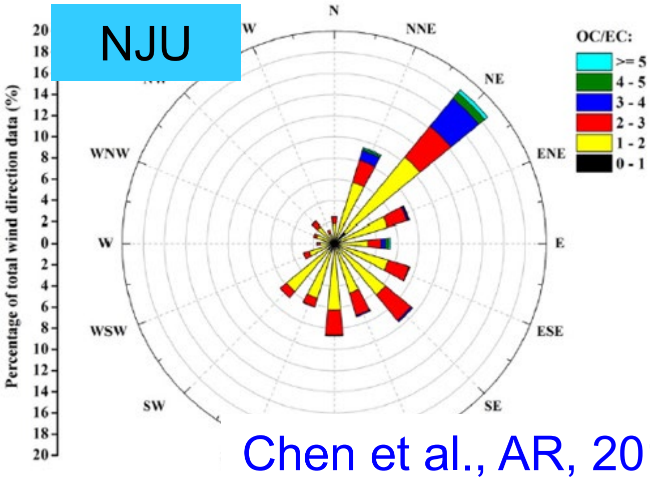


PAES

$$\mathrm{NME} = \frac{\sum_{i=1}^{n} |P_i - O_i|}{\sum_{i=1}^{n} O_i} \times 100\%$$ (P: prediction; O: observation)

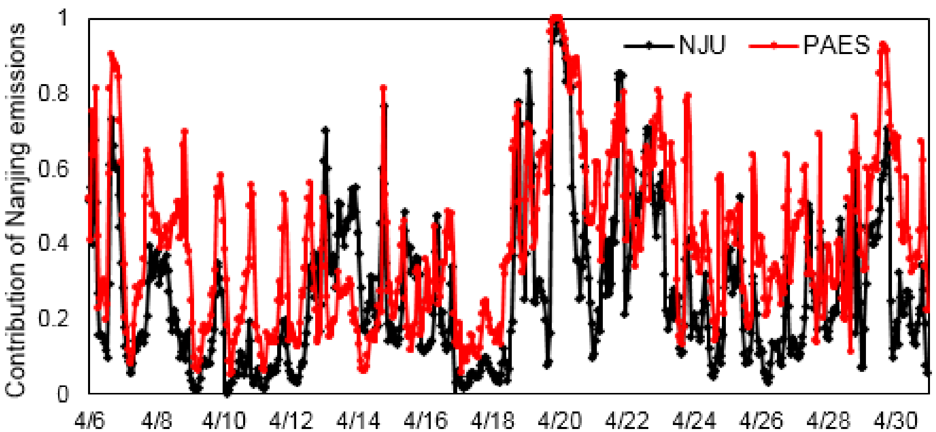
Results and discussion – Impacts of sites

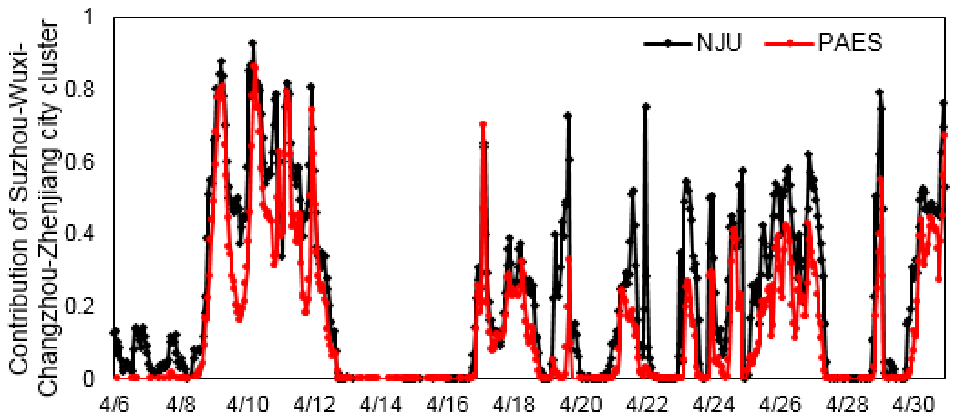




Chen et al., AR, 2017

Contribution from Nanjing (NAN)	Contribution from other cities
PAES>NJU□ 81.8%	**NJU**>PAES□ 81.3%





Results and discussion – Impacts of sites

Consideration of different spatial representativeness of the two sites

$$c_{obs-NJU} = \beta_1 c_{industry} + \beta_2 c_{residential} + \beta_3 c_{transportation} + \beta_4 c_{power} + \varepsilon$$
$$c_{obs-PAES} = \alpha_1 c'_{industry} + \alpha_2 c'_{residenial} + \alpha_3 c'_{transportation} + \alpha_4 c'_{power} + \varepsilon$$

	sector	factor	t[a]	Sig.[b]	VIF[c]
NJU (other cities)	β_1	**0.416**	1.711	0.088	2.025
	β_2	**0.947**	2.498	0.013	2.520
	β_3	**0.651**	2.134	0.034	2.655
PAES (Nanjing)	α_1	**0.193**	3.464	0.001	1.436
	α_2	**0.360**	1.889	0.061	1.436
	α_3	**0.651**[d]			

More stringent emission control policies in Nanjing were implied compared to other southern Jiangsu cities

Results and discussion – Impacts of sites

More improvement when spatial representativeness considered

$$\mathrm{NME} = \frac{\sum_{i=1}^{n} |P_i - O_i|}{\sum_{i=1}^{n} O_i} \times 100\%$$ (P: prediction; O: observation)

		Result1	Result2	Result3	Result4
NJU	NME	0.423	0.386	0.326	0.325
	R	0.341	0.427	0.489	0.494
PAES	NME	0.732	0.429	0.396	0.616
	R	0.637	0.530	0.658	0.629

Result1 Original bottom-up inventory

Result2 Emissions constrained with two sites (representativeness not considered)

Result3 Emissions constrained with two sites (representativeness considered)

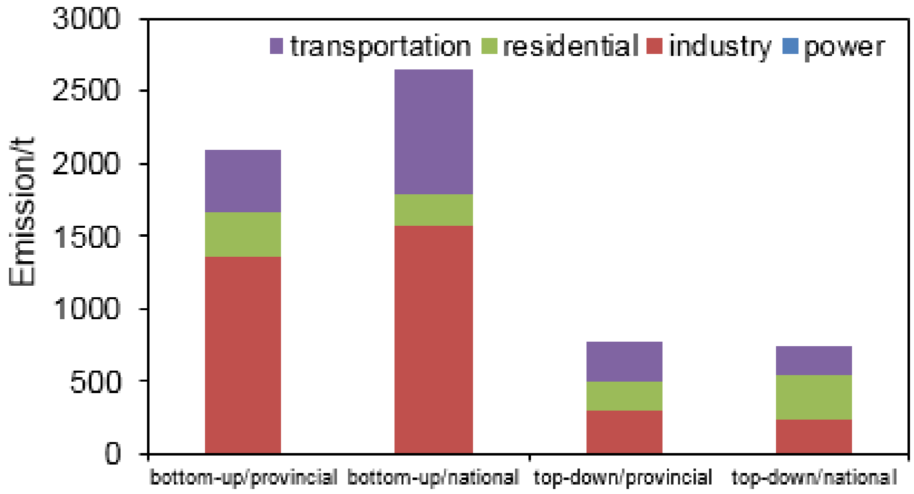
Result4 Emissions constrained with only one site (NJU)

Results and discussion – Impacts of emissions

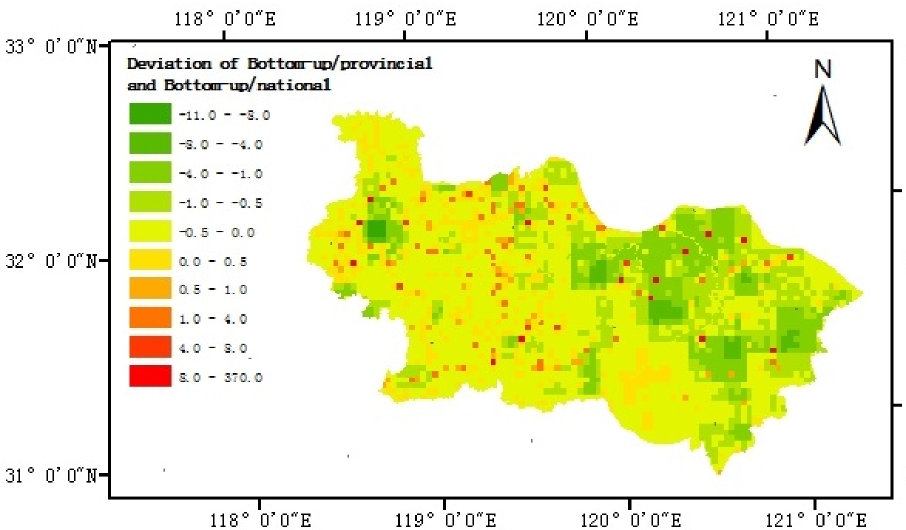
The a prior emission data:

Local inventory
Zhou et al., 2017 （Nanjing Univ.）

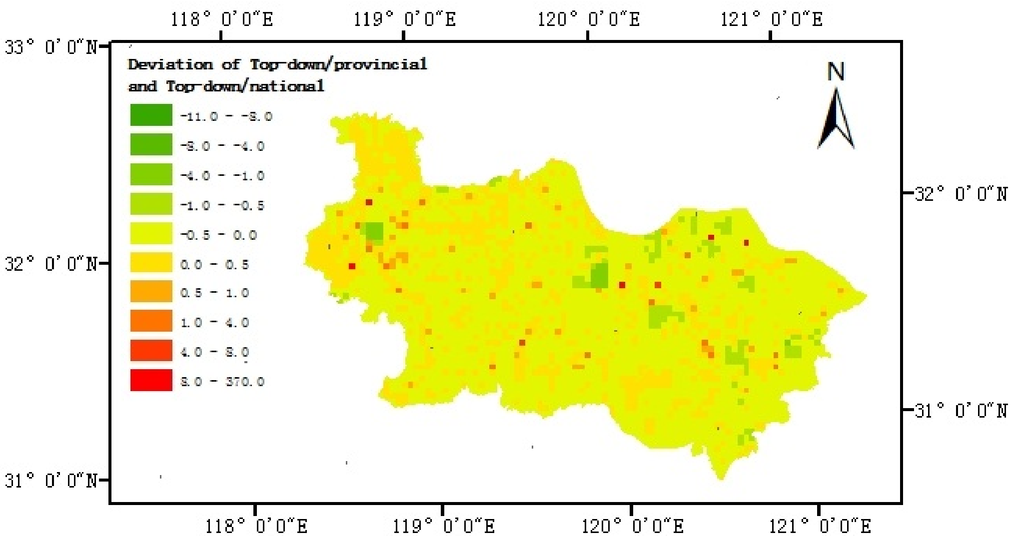
National inventory
MEIC（Tsinghua Univ.）



Discrepancies largely decreased with emission constraining



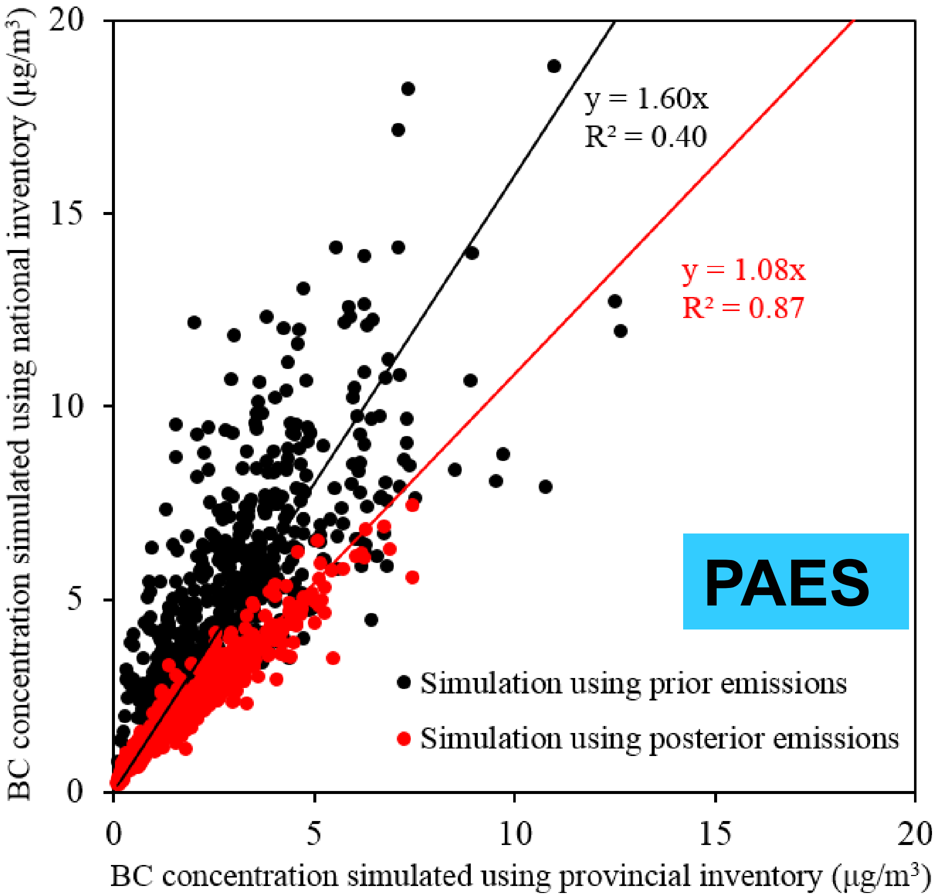
Discrepancies in prior emissions

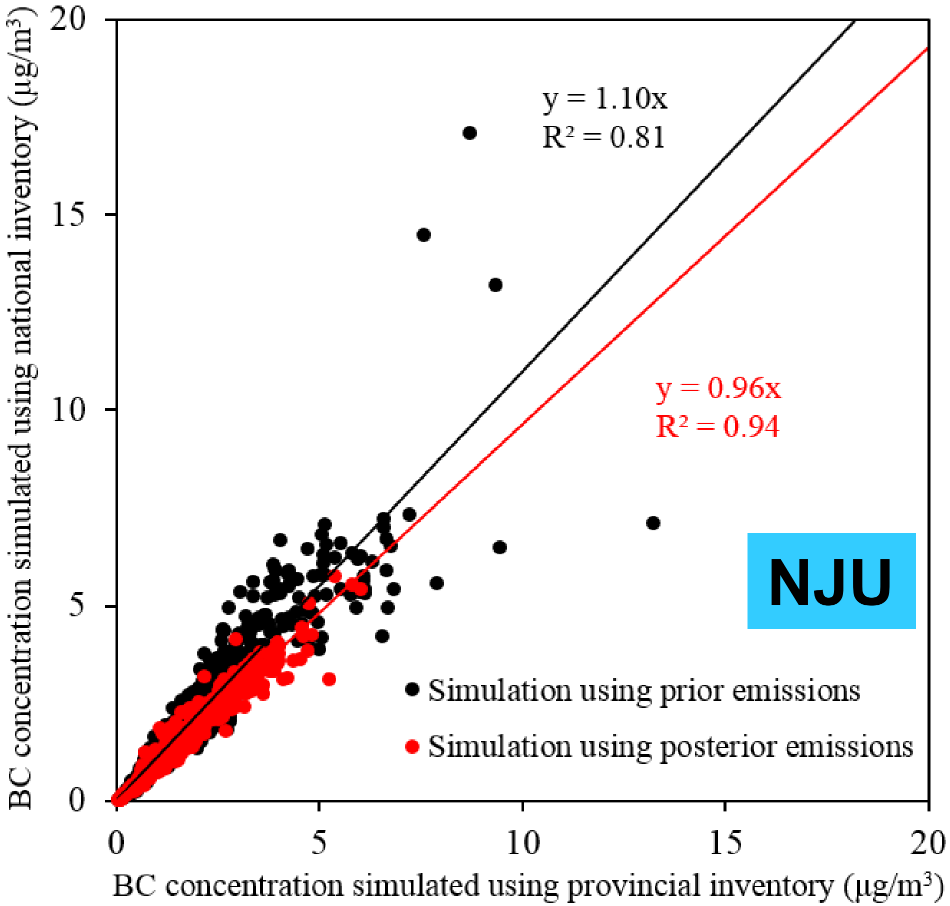


Discrepancies in posterior emissions

Results and discussion – Impacts of emissions

The impacts of prior emissions were limited

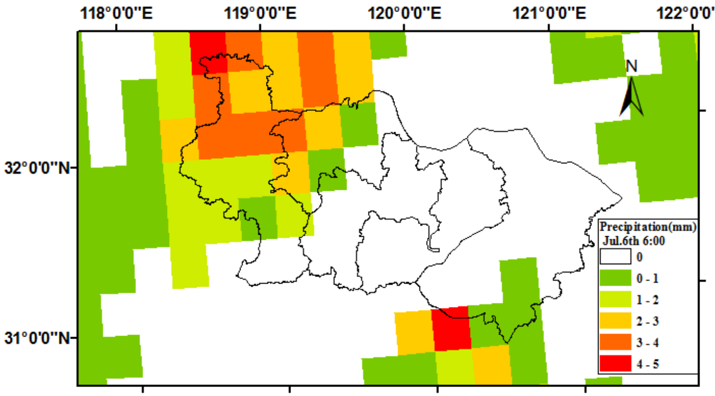




Modelling results of posterior inventories were closer than those of prior ones

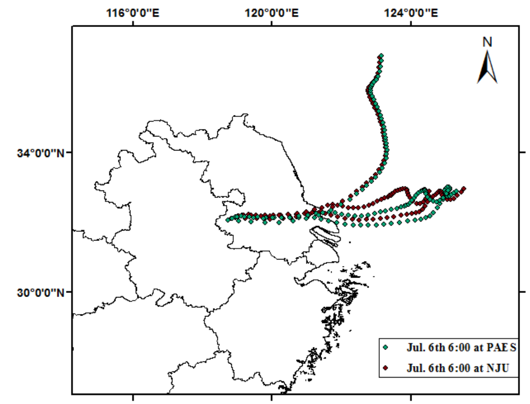
Results and discussion - Impacts of precipitation

TRMM (Tropical Rainfall Measuring Mission)

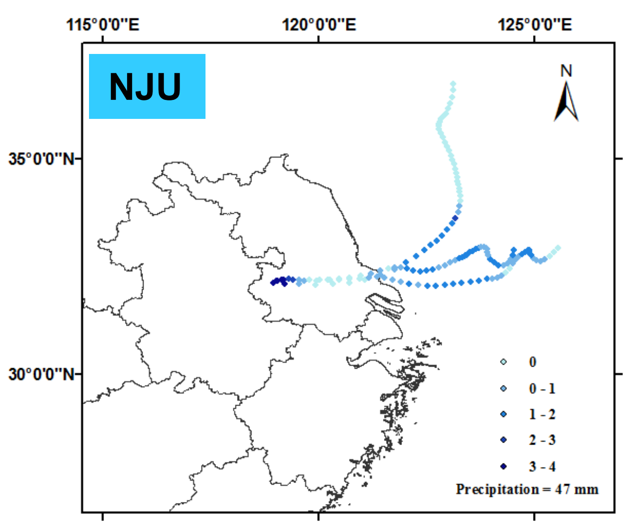


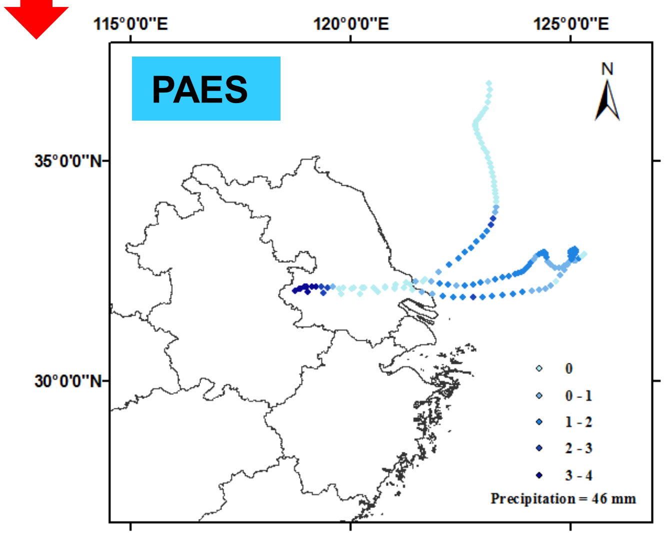
Precipitation with a temporal resolution of 3 h

HYSPLIT



48 h back trajectories at NJU and PAES

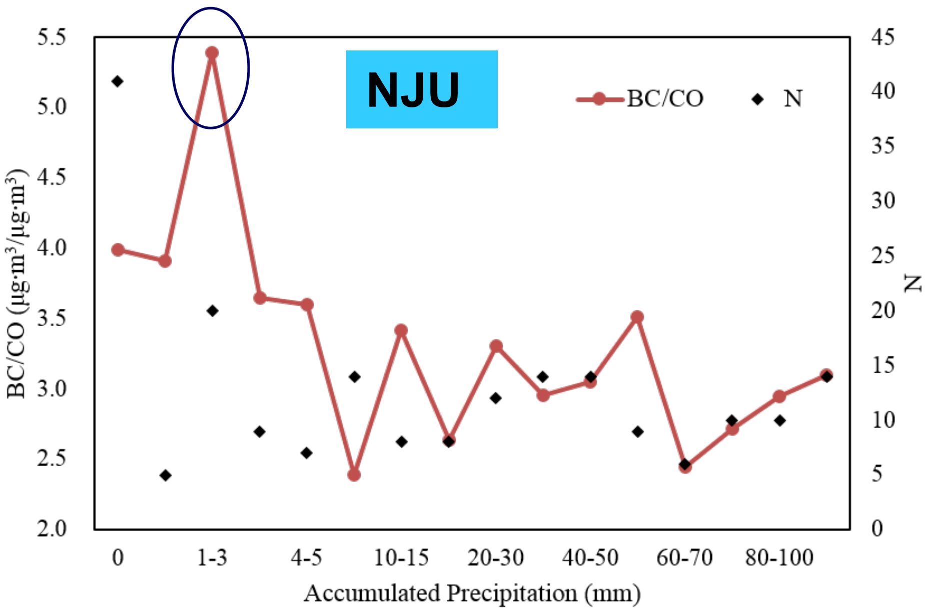


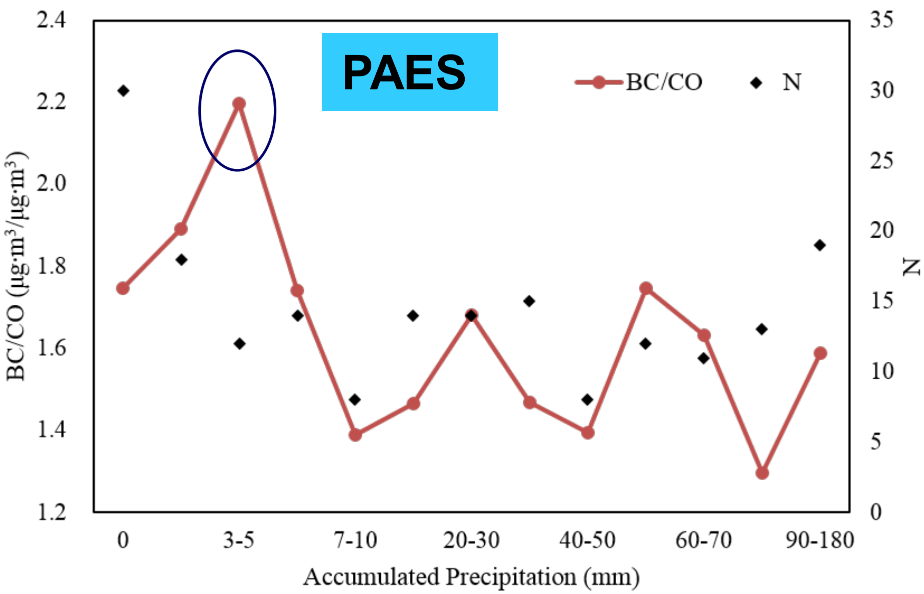


Hourly accumulative precipitation along the 48 h back trajectories

Results and discussion - Impacts of precipitation

The⊿BC/⊿CO ratio at the two sites separated by different accumulated precipitation along the back trajectories during 48 h





Data screening: **We exclude BC-CO data pairs receiving more than 3 mm (NJU) and 5 mm (PAES) to minimize the effect of wet deposition and to retain sufficient data points for statistical significance**

Results and discussion - Impacts of precipitation

$$c_{obs} = \beta_1 c_{industry} + \beta_2 c_{residential} + \beta_3 c_{transportation} + \beta_4 c_{power} + \varepsilon$$

$$E_{top-down} = \beta_1 E_{industry} + \beta_2 E_{residential} + \beta_3 E_{transportation} + \beta_4 E_{power} + \varepsilon$$

	Factor (β)	t	*RD* (%)
Power			0.0
Industry	0.38	2.38	9.5
Residential	0.31	0.31	-20.6
Transportation	0.75	1.8	36.4
Sum			**13.4**

RD: relative difference from the estimates without data screening

The impact of precipitation was moderate;

More effects on emission sources of relatively large uncertainty

Conclusions

● Black carbon emissions in southern Jiangsu city cluster were constrained combining chemistry transport model and available ground measurements with a multiple regression model.

● The modeling performance was improved with the constrained emissions. Reduced emissions from constraint implied the effectiveness of emission control in recent years.

● Uncertainty from the a prior inventory and non-linearity between emissions and concentrations was limited. Emissions could be better constrained if more available measurements are included.

Thanks for attention!

中华人民共和国科学技术部
Ministry of Science and Technology of the People´s Republic of China

For More Information:

http://www.airqualitynju.com/

Zhao et al., Atmos Chem Phys, 19, 2095, 2019

Zhou et al., *Atmos Chem Phys,* 17, 211, 2017

Cui et al., *Atmos Chem Phys*, 15, 8657, 2015

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