Retrospective Analysis of 2015-2017 Winter-time $PM_{2.5}$ In China: Response to Emission Regulations and The Role of Meteorology

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NCAR

China applied strict pollution control strategies since 2010, especially for power and industry sectors

China's clean air policies implemented during 2010-2017

Regular Periods

Source sector	Emission source	2010	2011	2012	2013	2014	2015	2016	2017
Power	Thermal power plants	GB 13223-2003		GB 13223-2011				"Ultra-low" emission standard	
Industry	Flat glass	GB 9078-1996	GB 26453-2011						
	Sinter	GB 9078-1996		GB 28662-2012					
	Coking	GB 16171-1996		GB 16171-2012					
	Iron	GB 9078-1996		GB 28663-2012					
	Steel making	GB 9078-1996		GB 28664-2012					
	Steel rolling	GB 9078-1996		GB 28665-2012					
	Electronic glass	GB 9078-1996			GB 29495-2013				
	Brick	GB 9078-1996				GB 29620-2013			
	Cement	GB 4915-2004				GB 4915-2013			
	Industrial boiler	GB 13271-2001				GB 13271-2014; Eliminate small coal-fired boilers.			
	All	/			Phase out outdated industrial capacity; strengthen emissions standards; phase out small, high-emitting factories; install VOC emission control facilities				
Residential	All	No specific regulations			Replace coal with electricity and natural gas				
Transportation	Light duty gasoline vehicle	Euro 3	Euro 4						Euro 5
	Heavy duty gasoline vehicle	Euro 3			Euro 4				
	Diesel vehicle	Euro 3				Euro 4			Euro 5
	All	/			Strengthen emissions standards; retire old vehicles; improve fuel quality				

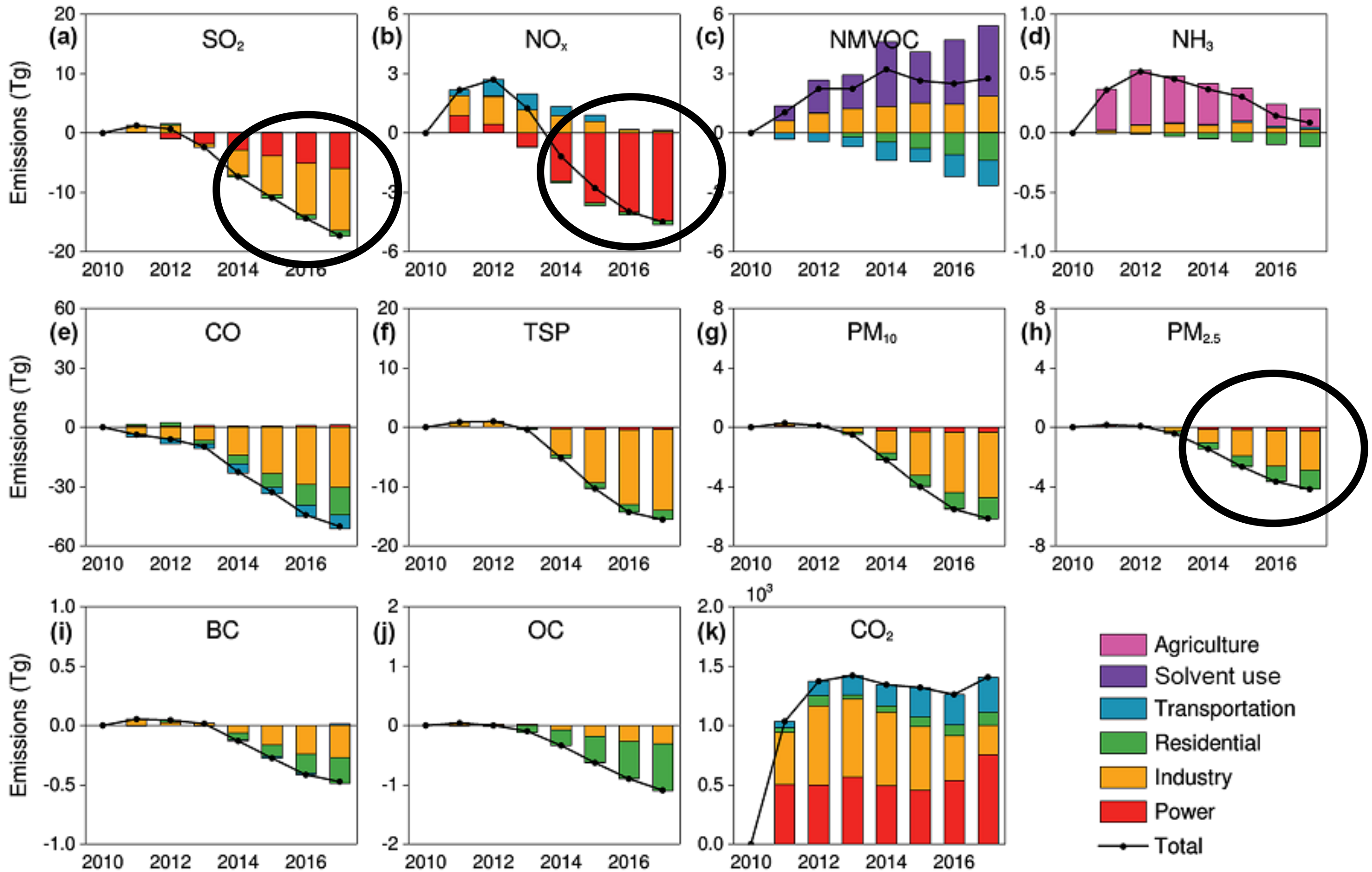
Pollution Events

Stricter temporary control measurements

(Zheng et al. ACP, 2017)

"Bottom-up" EI show significantly decreases since 2010 for most pollutants

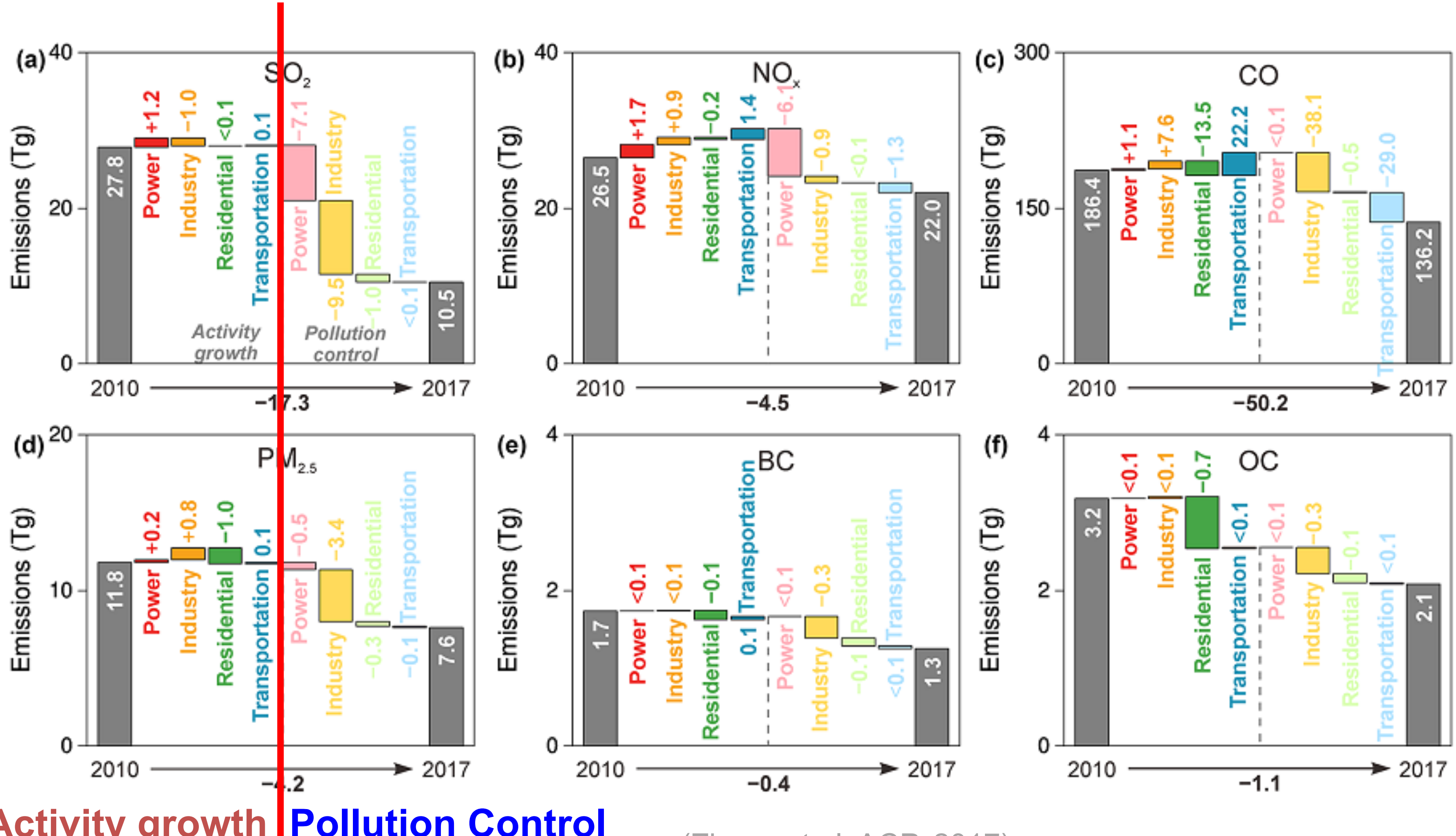
National total emission changes compared to 2010 from "Bottom-up" EI



(Zheng et al. ACP, 2017)

Pollution control strategies are the main driver of recent emission decreases

Drivers of emission changes for different emission species

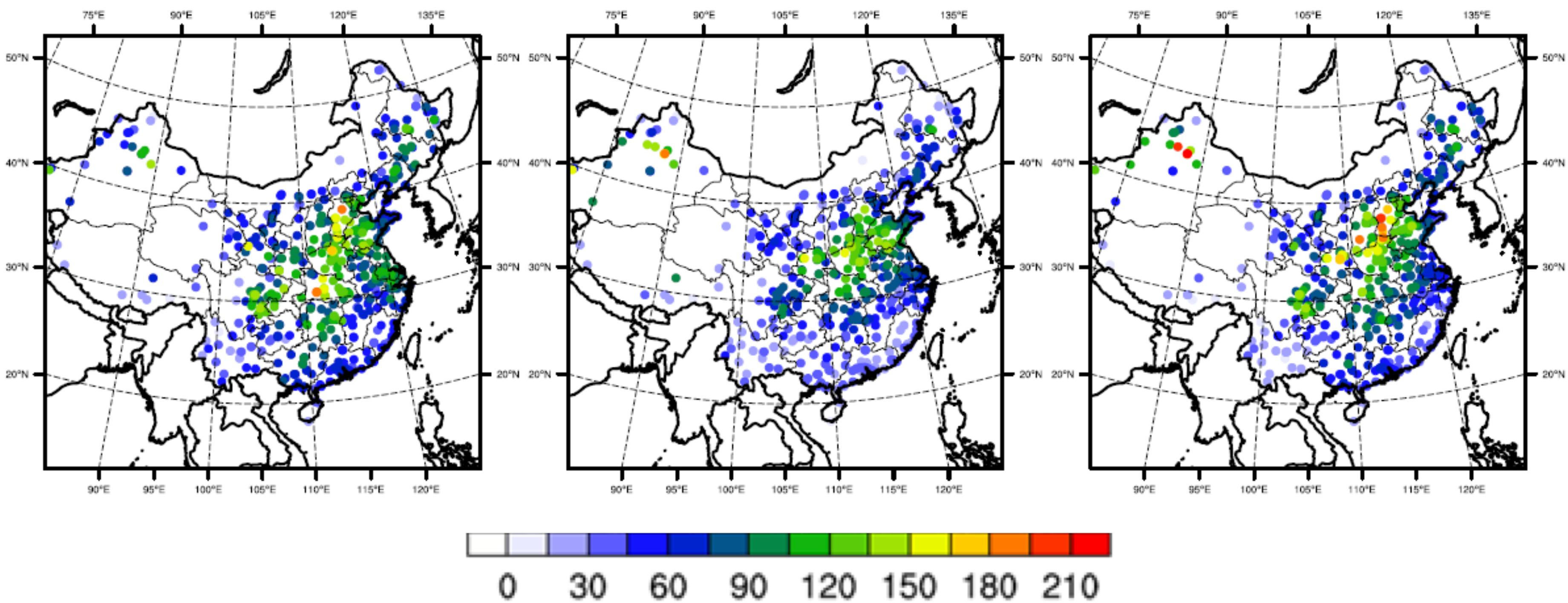


Activity growth | **Pollution Control**

(Zheng et al. ACP, 2017)

Winter-time $PM_{2.5}$ still fluctuate in North China Plain

Jan. 2015 **Jan. 2016** **Jan. 2017**



(Unit: μg m^{-3}, http://www.cnemc.cn >1600 sites）

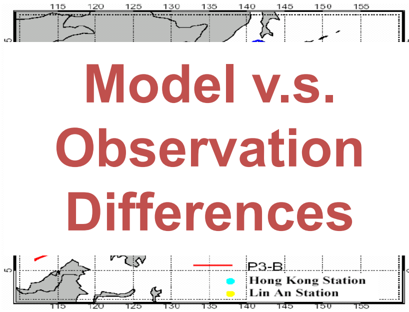
Why ?

Control measurements not executed? -> uncertainties in EI

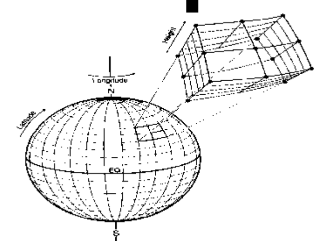
The role of meteorology v.s. emission changes?

Limitations of air quality model

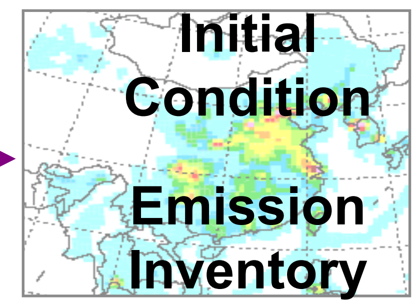
Observation Constrain



Air Quality Model



DA



C1 （Simulated Conc.）

=

C0（Initial Condition）+

E（Emission input） +

T（Meteorology） +

C（Chemistry）-

D（Scavenging）

How to make use of DA Technique?

Goals of this study

Technique

- **Update of GSI-WRF/Chem 3D-Var for heavily polluted region**

Science Purposes

- **Reproduce 2015-2016-2017 winter-time PM2.5**
- **Separate the roles of meteorology and emission**

2.1 GSI-WRF/Chem Aerosol DA system-basic framework

$$J(x)=\frac{1}{2}(x-x^b)^T\mathbf{B}^{-1}(x-x^b)+\frac{1}{2}[\mathbf{H}x-y]^T\mathbf{R}^{-1}[\mathbf{H}x-y]$$

Background Error

Model. VS. OBS

Analysis

$$x=\begin{bmatrix}x_1\\x_2\\\vdots\\x_m\end{bmatrix}$$

T、UV、 P、Q

SO_2、NO_x、 CO、 O3、

BC， OC，SO_4，NO_3，NH_4， OIN……

BE

$$\mathbf{B}=\begin{bmatrix}\sigma_1^2 & c_{12}\sigma_1\sigma_2 & \cdots & \cdots\\ c_{12}\sigma_1\sigma_2 & \sigma_2^2 & \cdots & \cdots\\ \cdots & \cdots & \ddots & \cdots\\ \cdots & \cdots & \cdots & \sigma_m^2\end{bmatrix}$$

GEN-BE

Control Variables Transform

Horizontal Length-scale

Vertical Length scale

OBS

$$y=\begin{bmatrix}y_1\\y_2\\\vdots\\y_n\end{bmatrix}$$

Observation input：

Surface SO_2、NO_2、CO、 O_3、$PM_{2.5}$， PM_{10}

Forward Operator

$$PM_{2.5}=\sum_{Bin=1}^{3}\begin{pmatrix}\text{BC+OC+SO4+NO3+}\\ \text{Na+Cl+OIN+NH4}\end{pmatrix}$$

> 1600 sites from http://www.cnemc.cn

2.1 GSI-WRF/Chem Aerosol DA system-update for application in China

GOCART

$$\prod PM2.5 = \mathrm{P} + D1 + 0.286D2 + 1.8(O1 + O2) + B1 + B2 + S1 + 0.942S2 + 1.375U$$

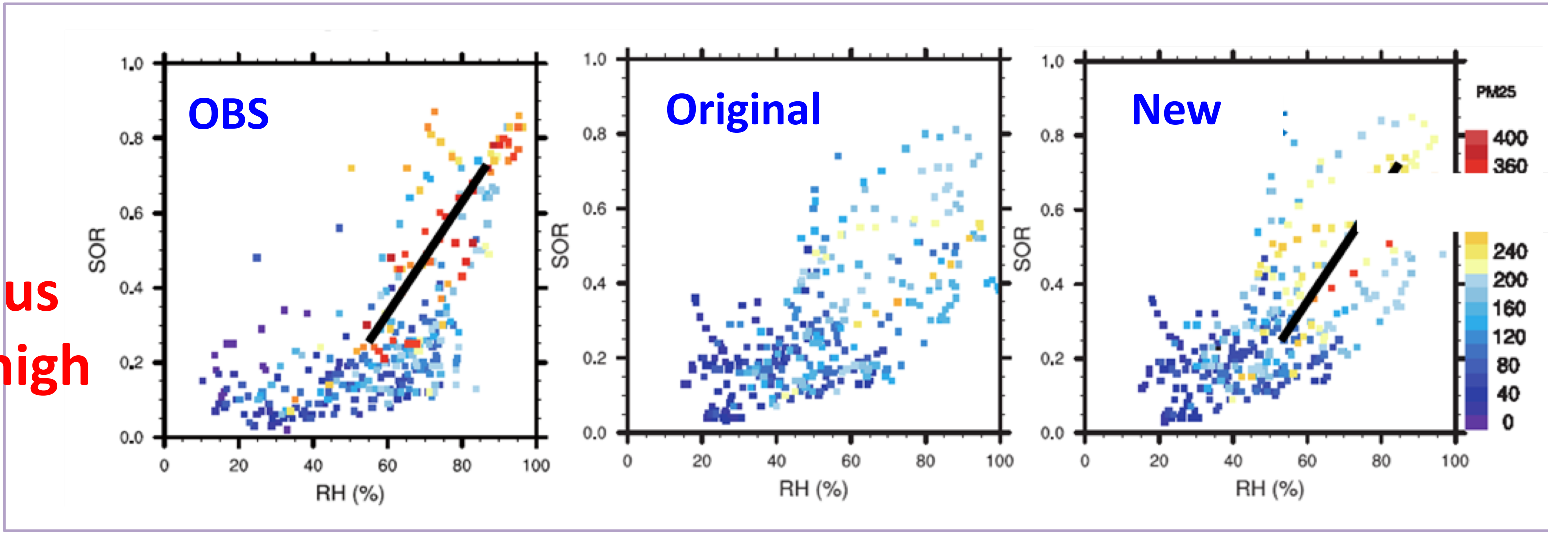
13 species (dust, sea-salt etc.)

32 species (secondary species included)

MOSAIC

$$\prod PM2.5 = \sum_{i=1}^{3}[BC\_i + OC\_i + SO4\_i + NO3\_i + NH4\_i + CL\_i + NA\_i + OIN\_i]$$

SO_2/NO_2 Heterogeneous reactions in high RH cases



(Chen et al. 2016)

2.2 Experiments Design

Simulation period: Dec. 20- Jan.31 of 2015, 2016 and 2017

MET IC/BC: GFS analysis every 6-hr

EI: MEIC_2010 (keep the same)

Scenarios:
NO_DA (WRF-Chem run with 2010 EI)
CONC_DA (GSI hourly DA)

Assimilated Obs.: hourly surface PM2.5

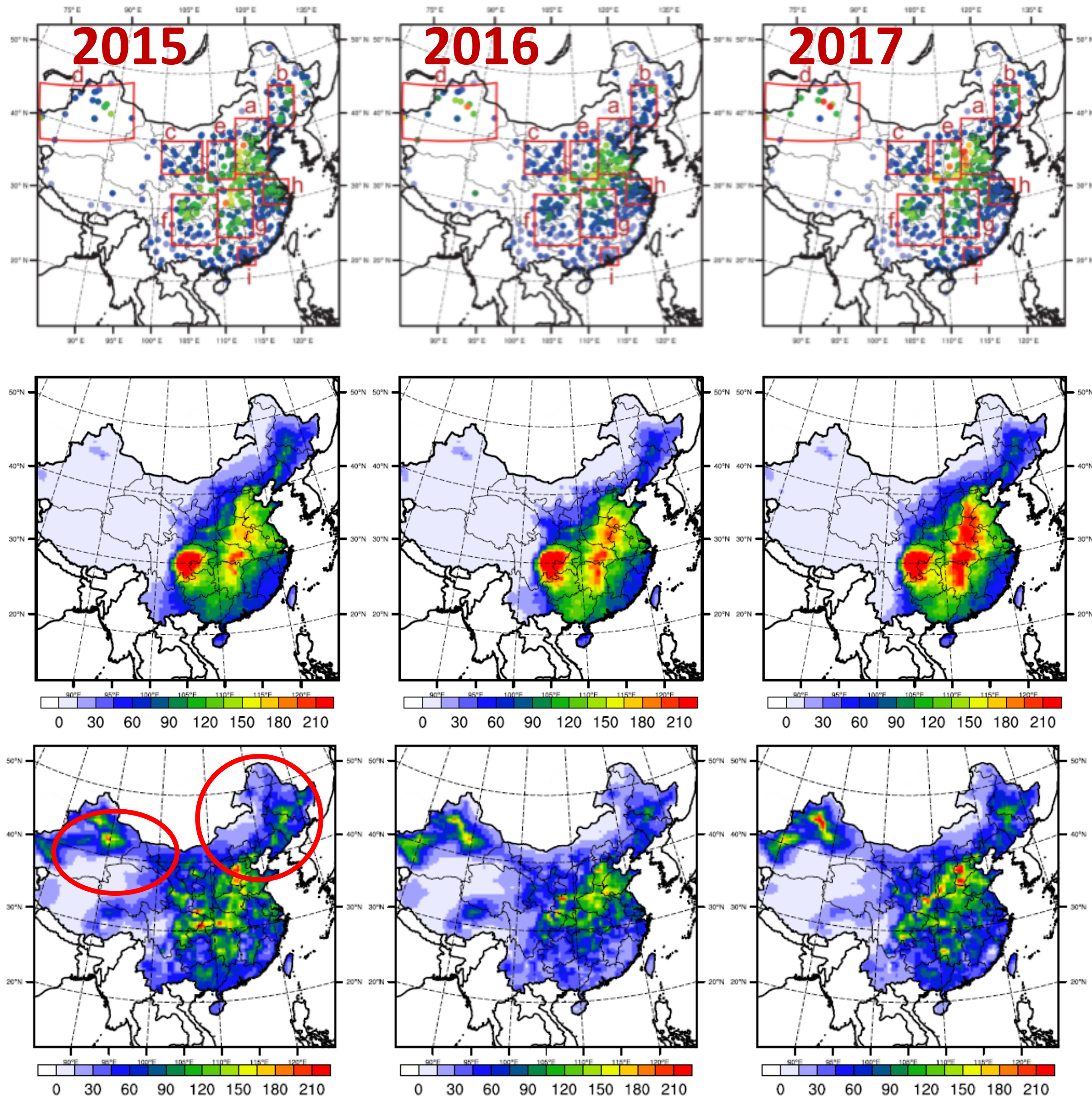
BE: NMC method

2.3 Verification

OBS.

NO_DA

CONC_DA

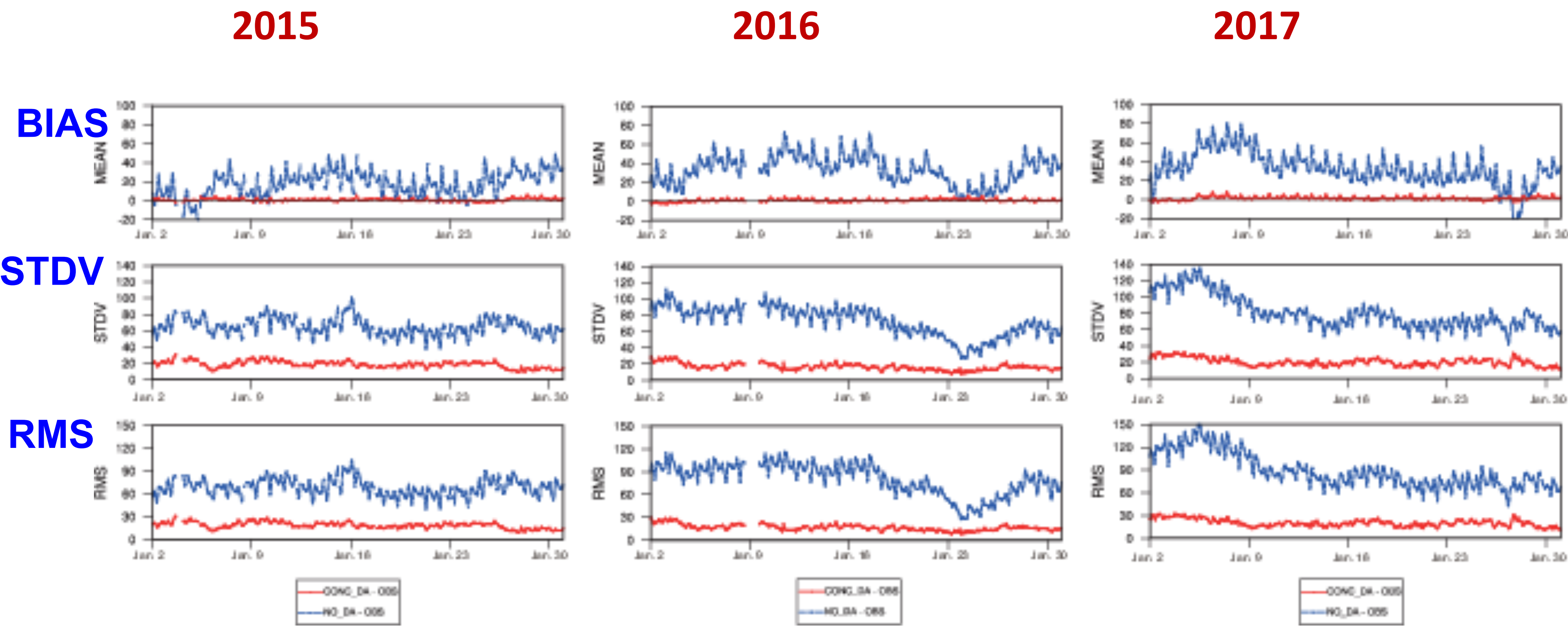


a. NCP
b. NEC
c. EGT
d. XJ
e. FWP
f. SB
g. CC
h. YRD
i. PRD

Inter-annual changes

New source regions

2.3 Verification-surface observation



NO_DA **MEAN BIAS、STDV、RMS increases from 2015-2017**

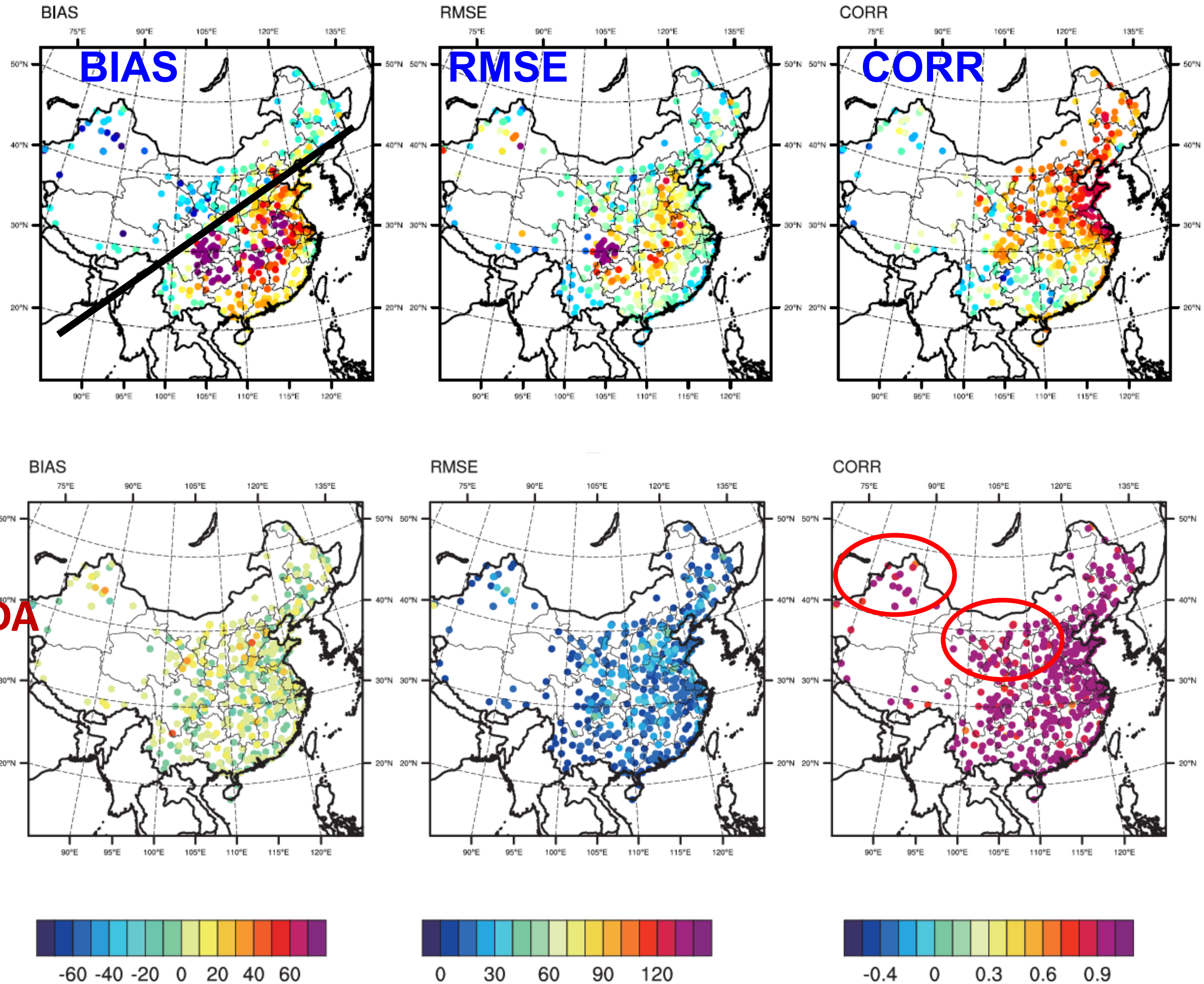
CONC_DA **Improved and much stable**

2.3 Verification-surface observation

Jan. 2015

NO_DA

CONC_DA

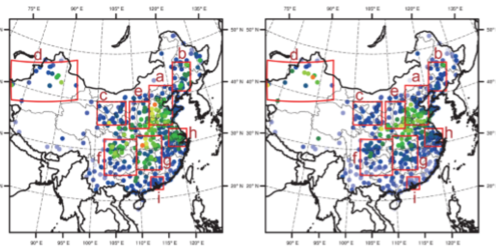


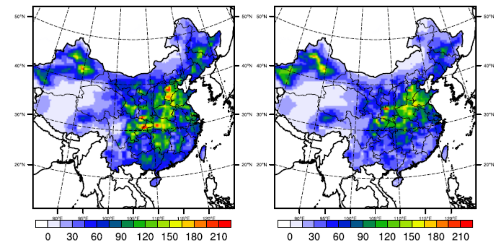
BIAS/RMSE correction

CORR improvement

Northern v.s. Southern Differences uncertainties in EI spatial allocation

3.1 Separate the roles of meteorology and emission – methodology





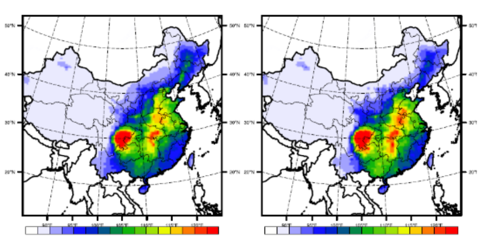
CONC_DA_2016 – CONC_DA_2015

Scattered Observation → Conc. diff= MET+EMIS

−

Control Simulations → Conc. diff= MET

= EMIS



NO_DA_2016 – NO_DA_2015

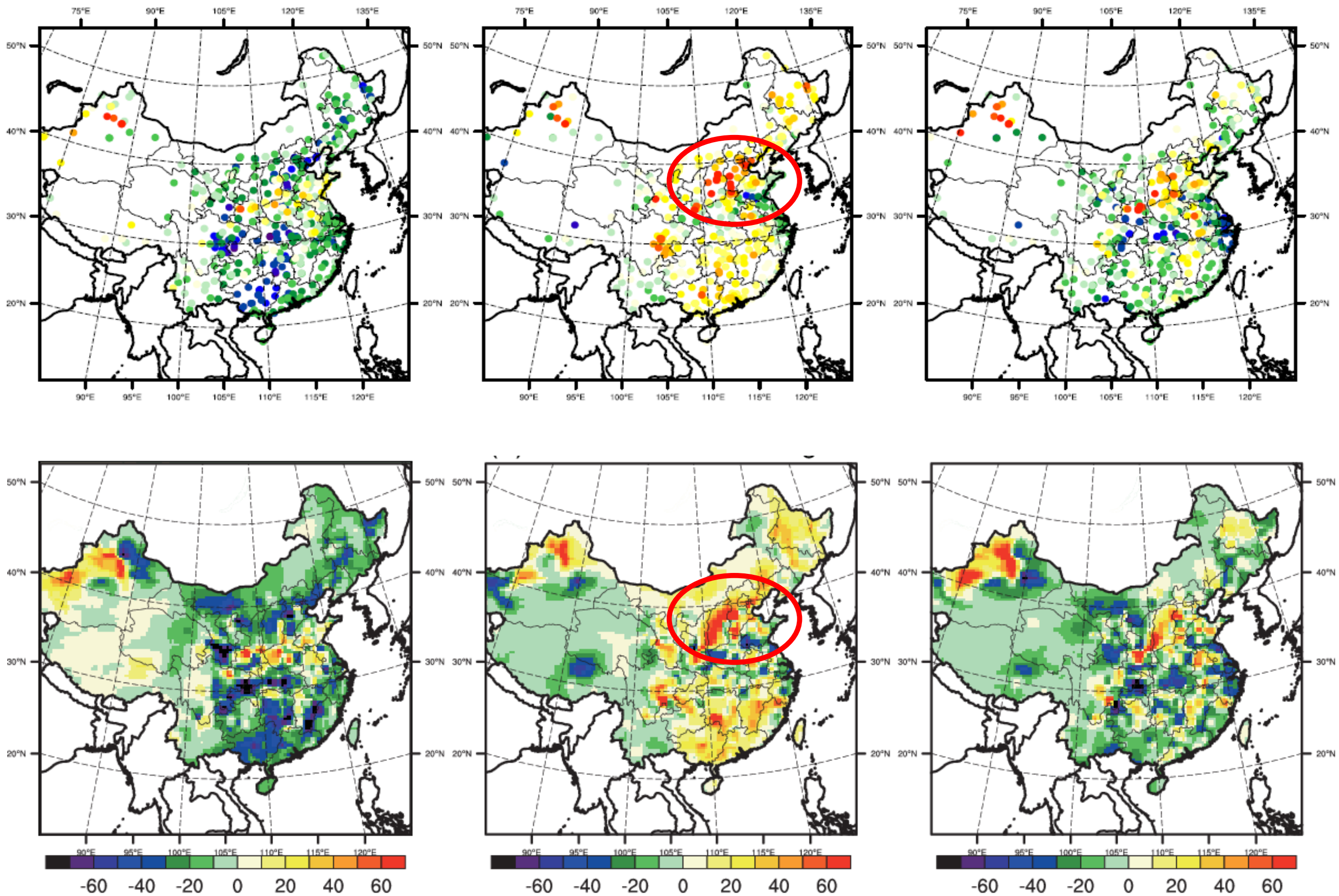
(Same EMIS but different MET)

3.2 Separate the roles of meteorology and emission

2016-2015 | 2017-2016 | 2017-2015

OBS.

Assimilated inter-annual differences

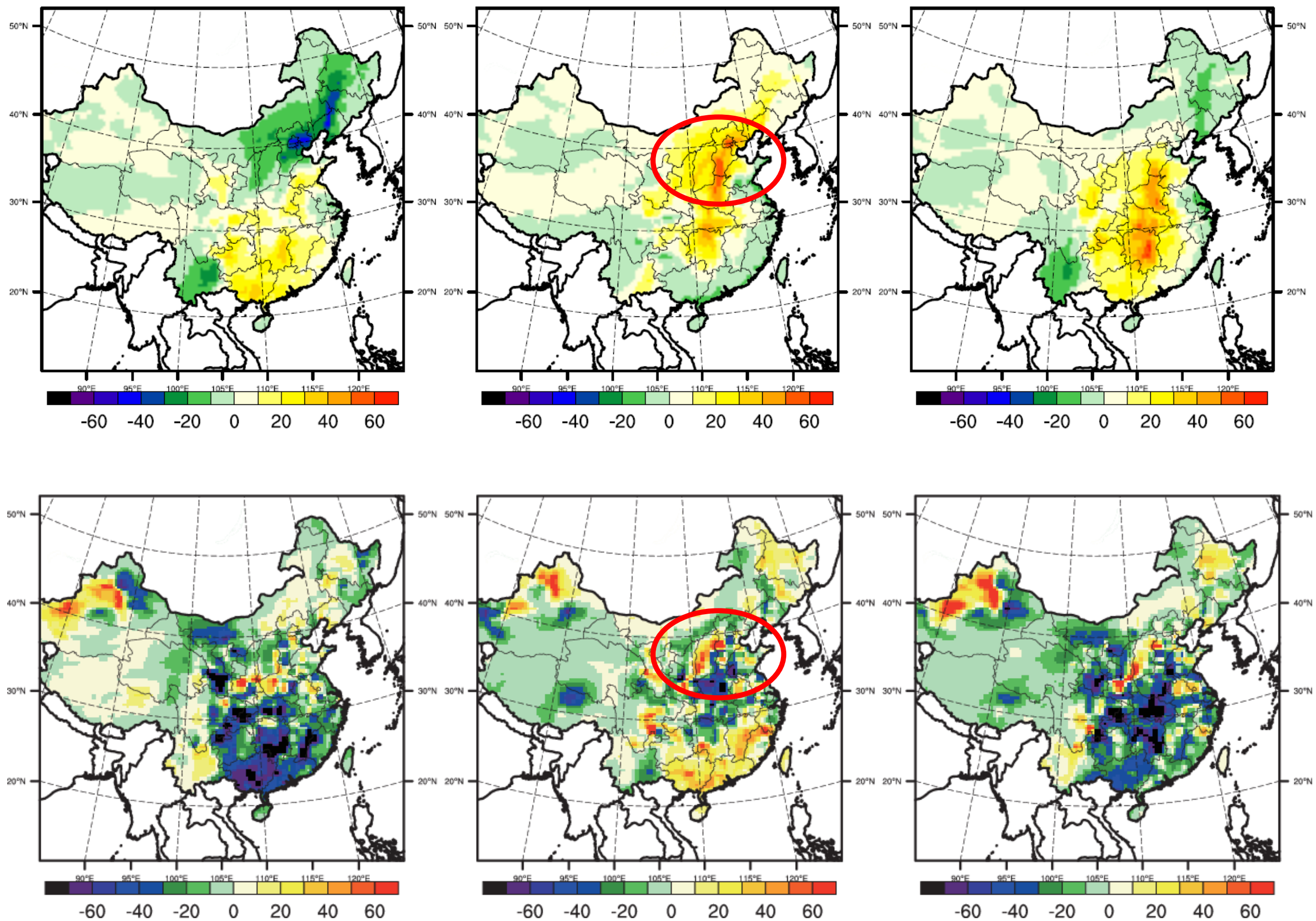


3.2 Separate the roles of meteorology and emission

2016-2015 | **2017-2016** | **2017-2015**

MET roles from NO_DA

EMIS roles Calculated



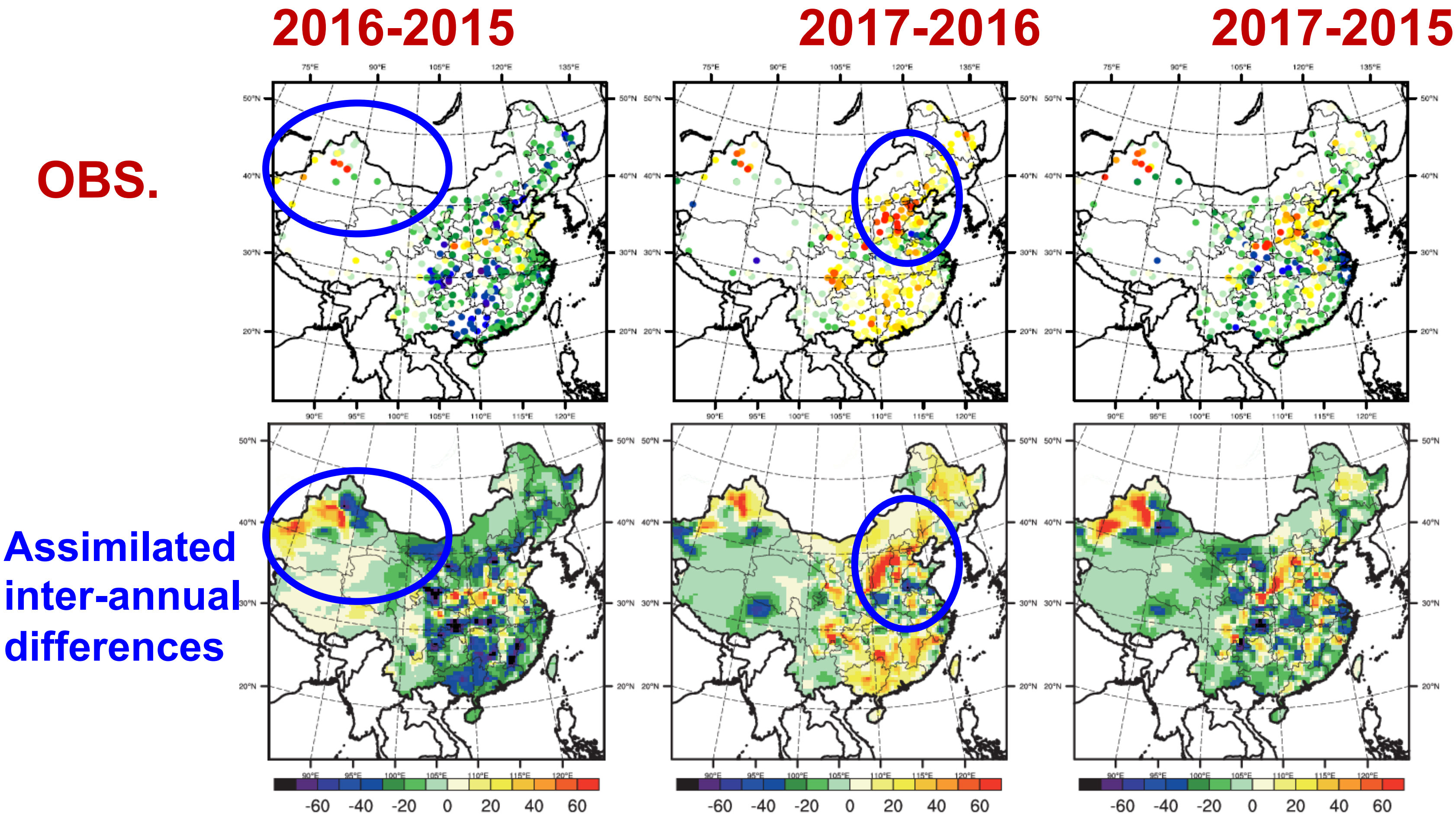
3.2 Separate the roles of meteorology and emission

Regional results (μg m^{-3})

	2016–2015			2017–2016			2017–2015		
	Total	MET	EMIS	Total	MET	EMIS	Total	MET	EMIS
NCP	−15.23	−12.52	−2.71	+14.91	+23.16	−8.25	−0.31	+10.65	−10.96
NEC	−20.09	−21.23	+1.14	+11.44	+12.61	−1.18	−8.66	−8.62	−0.04
EGT	−21.69	1.68	−23.37	+4.86	+3.81	+1.05	−16.83	+5.48	−22.31
XJ	+3.69	+0.07	+3.63	+1.85	+0.28	+1.57	+5.54	+0.34	+5.20
FWP	−7.05	−10.19	+3.13	+22.95	+25.62	−2.66	+15.90	+15.43	+0.47
SB	−18.75	+8.72	−27.48	+10.31	+4.02	+6.29	−8.45	+12.74	−21.19
CC	−21.80	+14.73	−36.54	+9.35	+19.36	−10.01	−12.45	+34.09	−46.54
YRD	−10.43	−3.03	−7.40	−11.45	−2.93	−8.52	−21.88	−5.96	−15.92
PRD	−23.48	13.02	−36.50	+12.71	−6.12	+18.83	−10.77	+6.90	−17.67

- **MET played different roles from 2016-2017**
- **For 2017, although surface observation increase, the emission control strategies are still archived.**
- **New emissions in western China should be noted.**

3.2 Separate the roles of meteorology and emission -uncertainties



A. NO_DA simulations (MET, EMIS)
B. CONC_DA (DA performances)
C. Aerosol-Meteorology feedback

4 Summary

- **The observations and the reanalysis data from assimilation experiment were used to investigate the year-to-year changes.**
- **The important roles of emission and meteorology in driving the changes in the three years can be distinguished and analyzed quantitatively.**
- **The uncertainties from three aspects, including the inaccurate emission assumption in the control scenario, the DA performance and the ignorance of other processes.**

- **Papers :**
  - Chen D., Liu, Z., Fast, J., Ban, J.: Simulations of Sulfate-Nitrate-Ammonium (SNA) aerosols during the extreme haze events over Northern China, Atmos Chem Phys, 16, 10707–10724, doi:10.5194/acp-16-10707-2016.
  - Chen, D., Liu, Z., Ban, J., Zhao, P., and Chen, M.: Retrospective analysis of 2015–2017 wintertime PM2.5 in China: response to emission regulations and the role of meteorology, Atmos. Chem. Phys., 19, 7409-7427, https://doi.org/10.5194/acp-19-7409-2019, 2019.
  - Poster 10 (Wed.) : Chen, D., Liu, Z., Ban, J., and Chen, M.: 2015 and 2016 winter-time air pollution in China: SO2 emission changes derived from a WRF/Chem-EnKF coupled data assimilation system, Atmos. Chem. Phys., https://doi.org/10.5194/acp-2018-1152, in review (accepted), 2019.

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Thanks for your attention!