NCAR/ASP 2016 Summer Colloquium on Air Quality

Air Quality Forecast and Modeling over Asia

For a Bridge between Scientific Findings and Policy

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August 1, 2016

Outline

Preface

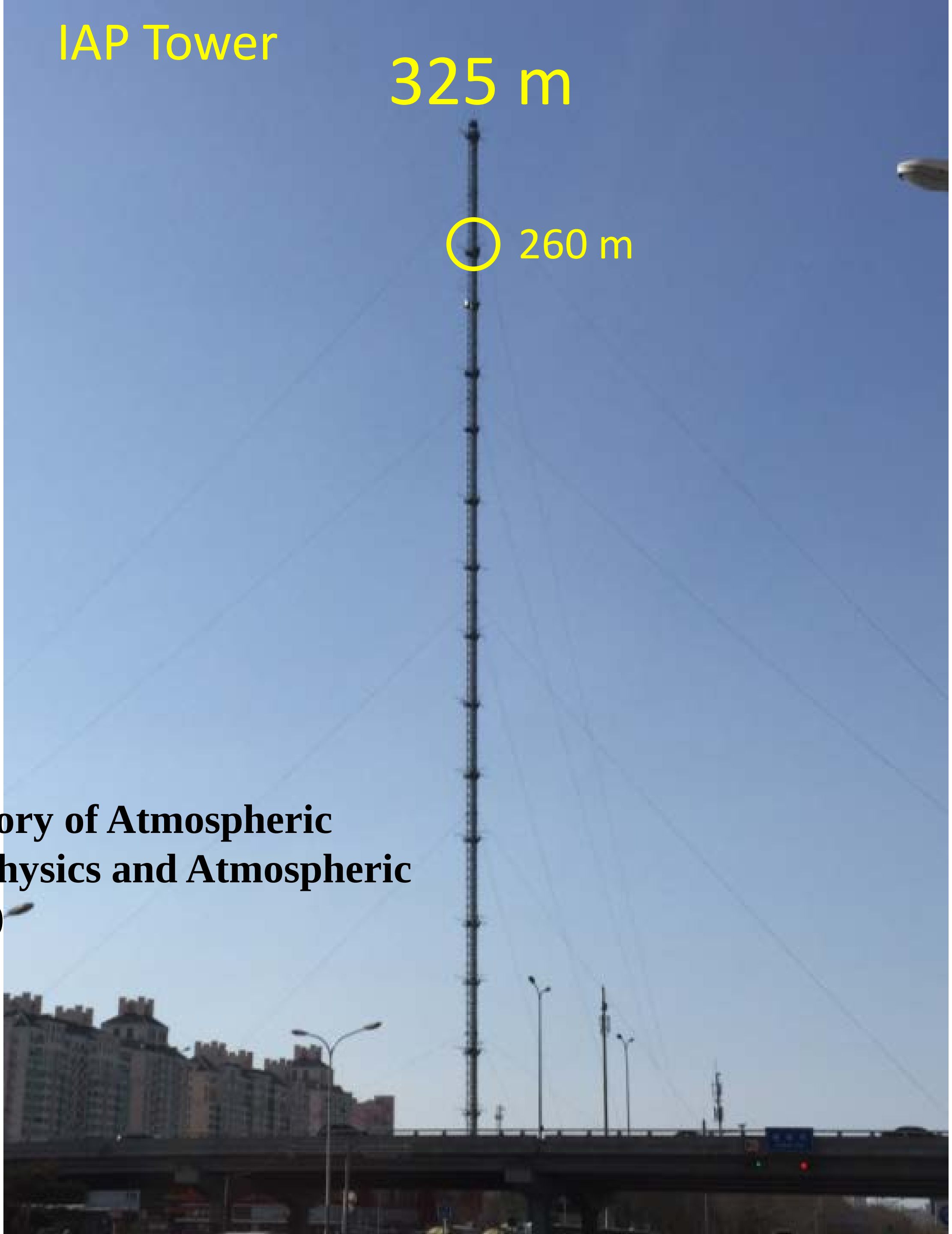
I. Program goals, research strategy and milestones

II. Scientific support and major achievements

III. International scientific and collaborative networks

IV. Contributions to capacity building and academic training

V. Strengths, Weaknesses, Opportunities, Threats



State Key Laboratory of Atmospheric Boundary Layer Physics and Atmospheric Chemistry (LAPC)

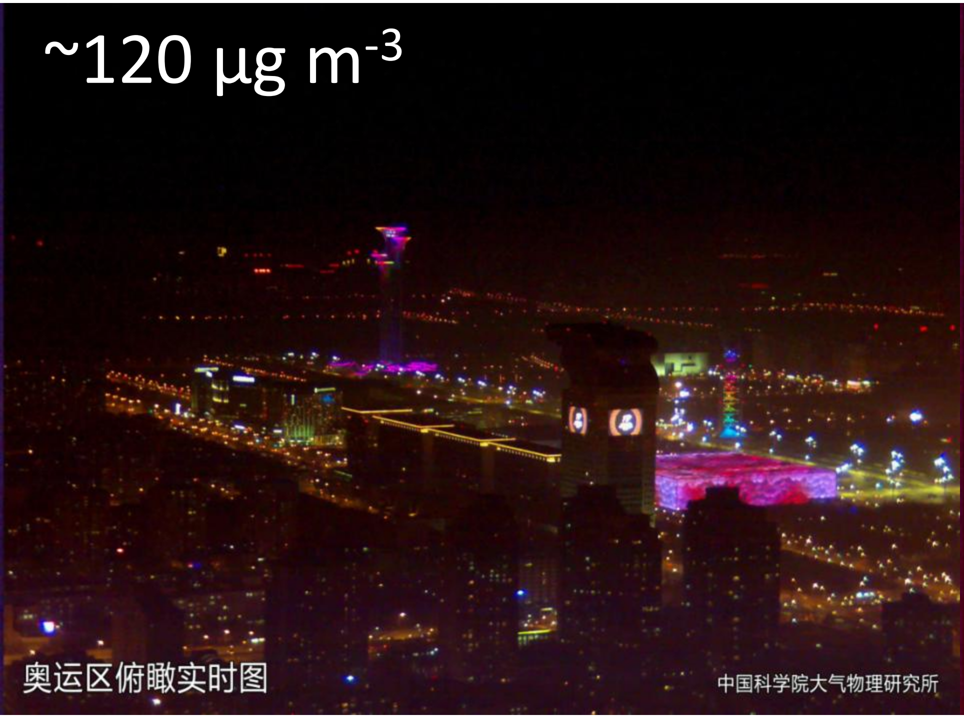

Clean Day
~15 μg m-3
奥运区俯瞰实时图
中国科学院大气物理研究所


Polluted Day
~200 μg m-3
奥运区俯瞰实时图
中国科学院大气物理研究所

Severely Polluted Day

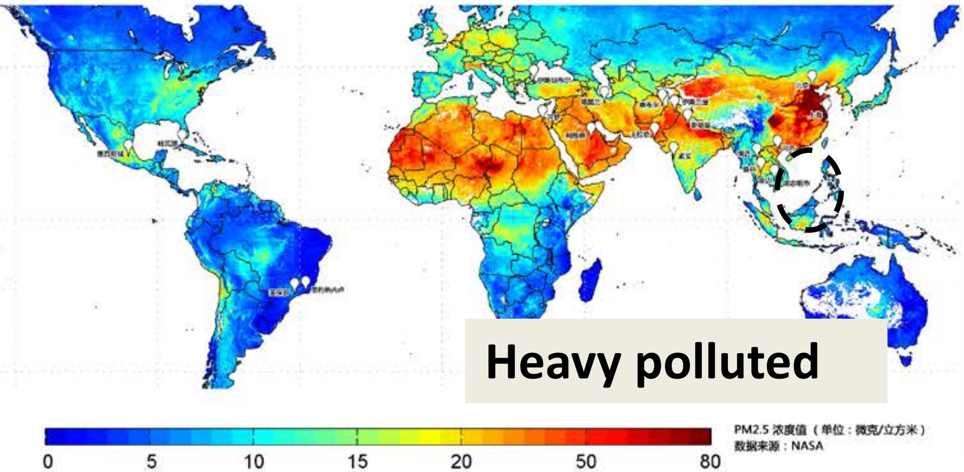
Light Polluted Day

Heavy Polluted Day

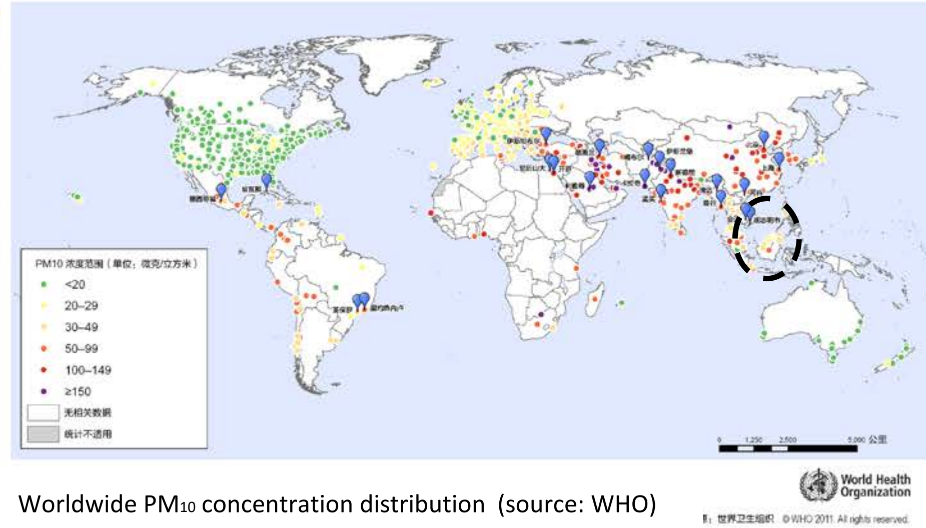



250 m

Facing Problems of Asia (China)



Worldwide $PM_{2.5}$ concentration distribution (source: NASA)



Worldwide PM_{10} concentration distribution (source: WHO)

Severe regional air pollution	Vs.	Limited information availability/ Confining control strategies
Increasing public needs for environmental information	Vs.	Under developing monitoring/forecasting techniques & public service capacity
Vast economic activities along with great ambient environmental changes	Vs.	Lack of timely evaluation and quantified estimation (obsolete emission inventory few risk assessment & cost-benefit analysis)

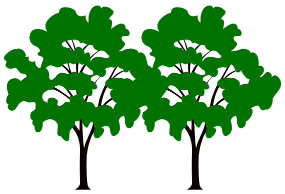
Program Background 建设背景

According to "The Action Plan for Air Pollution Prevention and Control", it is explicitly required to establish the air quality monitoring & warnings system, and manage the heavy air pollutions appropriately.

《大气污染防治行动计划》要求：建立监测预警应急体系，妥善应对重污染天气。

National Center for Environmental Quality Forecasting was established in CNEMC directed by MEP of China in the summer of 2013.

环境保护部2013年在中国环境监测总站成立"国家环境质量预报预警中心"。



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Ⅰ Program goals, research strategy and milestones

Development of a New-generation Atmospheric Environment Prediction System with

New modules: aerosol micro-physics dynamic module, secondary organic aerosol module, visibility module, toxicity module et al.

Advanced modeling techniques: emission inversion method, data assimilation, ensemble forecast, and source apportionment technique

Evolution and formation mechanisms of air pollutants in the atmospheric boundary layer, the nonlinear response relationship of emission and atmospheric pollutants, source apportionment and the key factors of regional haze formation

Integration of the regional air quality monitoring network, a real-time air quality forecasting system, and a technique to support decision making for air quality management

l Program goals, research strategy and milestones

Involving scientists from various labs of IAP and a large network of external collaborators, the program develops a modeling system perspective of the interactions between anthropogenic activities, emission control measures, their environmental and climate effects, and how they interact across different spatial and temporal scales.

A variety of prediction methods and tools are used to support the real-time air quality forecast over China.

These analyses are of immediate policy relevance and provide scientific guidance to the central and local governments of China.

Program Design 国家预报预警体系规划设计

- Diagram of Forecasting Organization： 4-levels

国家预报预警中心
National Forecast Center

中国环境监测总站
Head quarter, CNEMC

重点区域预报预警中心
Regional Forecast Centers

京津冀/长三角/珠三角
3 Regions

省级预报预警中心
Provincial Forecast Centers

31省/自治区/直辖市
31 Provinces

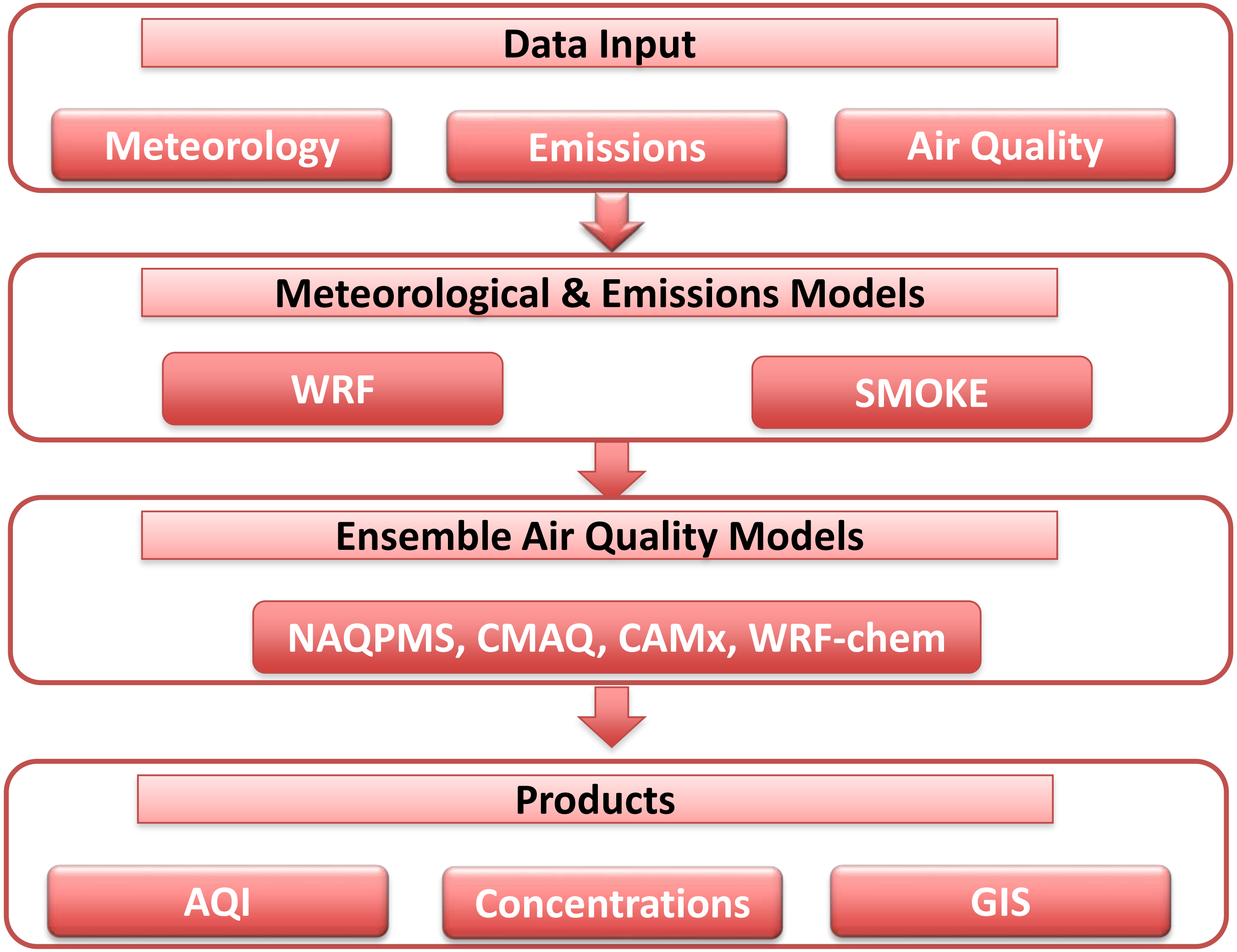
城市预报预警中心
City Forecast Centers

省会城市/计划单列市/等
Major Cities

Operational System Development in China

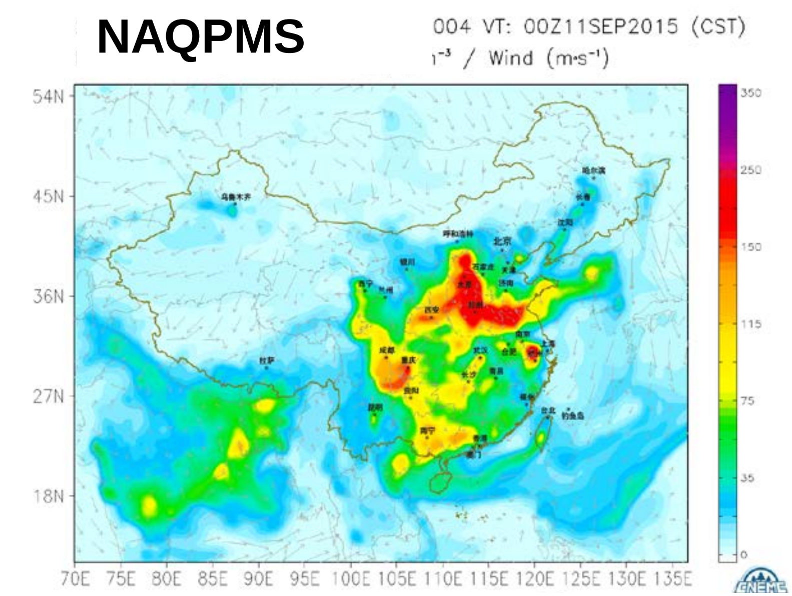
- **IAP of CAS (Institute of Atmospheric Physics, Chinese Academy of Sciences) has developed an ensemble air quality forecast modeling system combining NAQPMS, CMAQ, CAMx, WRF-chem, etc. for the system.**
- **The multiple-models system was successfully applied in the air quality forecasting operation for 2008 Beijing Olympic Games, 2010 Shanghai World Expo, and 2010 Guangzhou Asian Games.**
- **中科院大气所集成了NAQPMS、CMAQ、CAMx、WRF-chem等国际上先进空气质量数值预报模型，建立了中国第一套多模型空气质量数值集合预报系统，成功业务化应用于2008北京奥运会、2010上海世博会、2010广州亚运会的城市空气质量预报。**

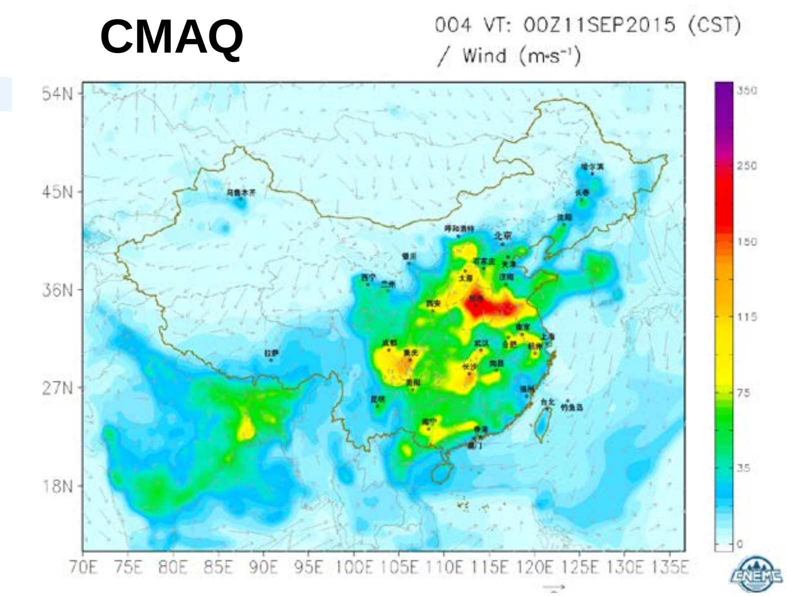
National Platform of Operational Air Quality Forecast
国家预报预警业务平台

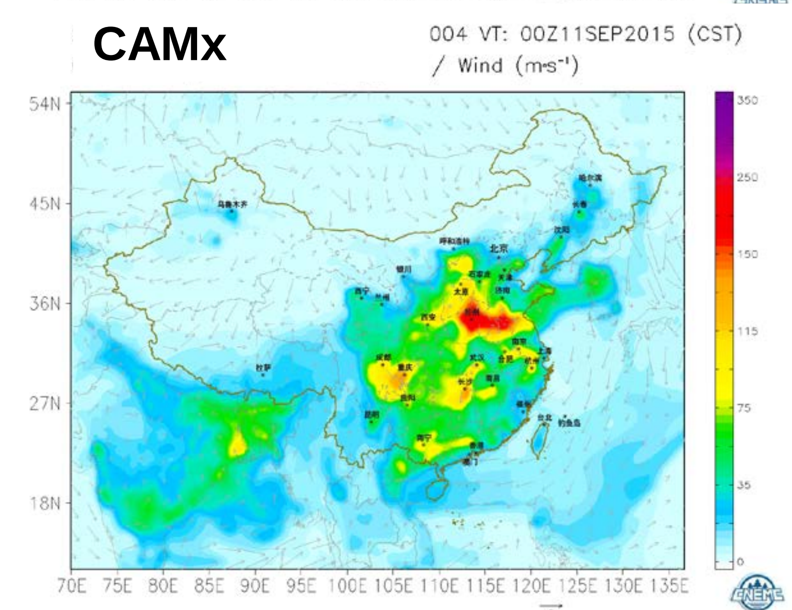


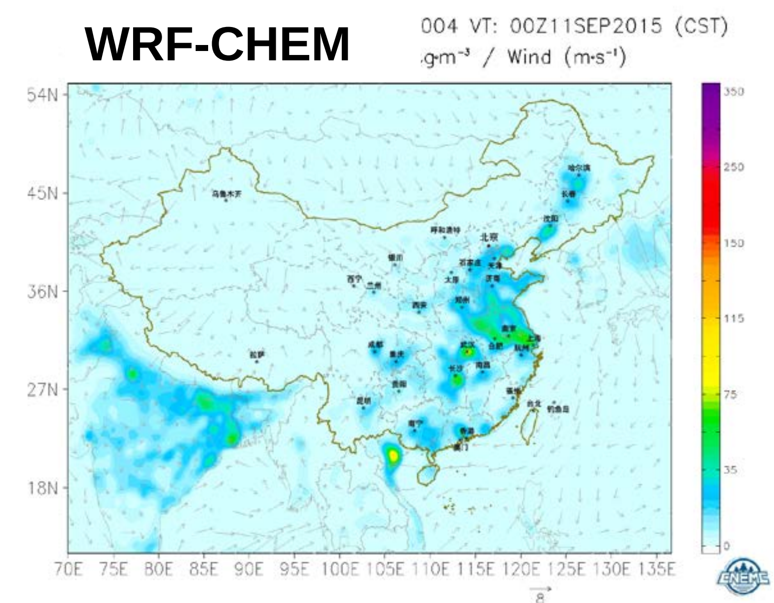
Super Computer (130 T flops) 计算能力

Regional forecast operation system

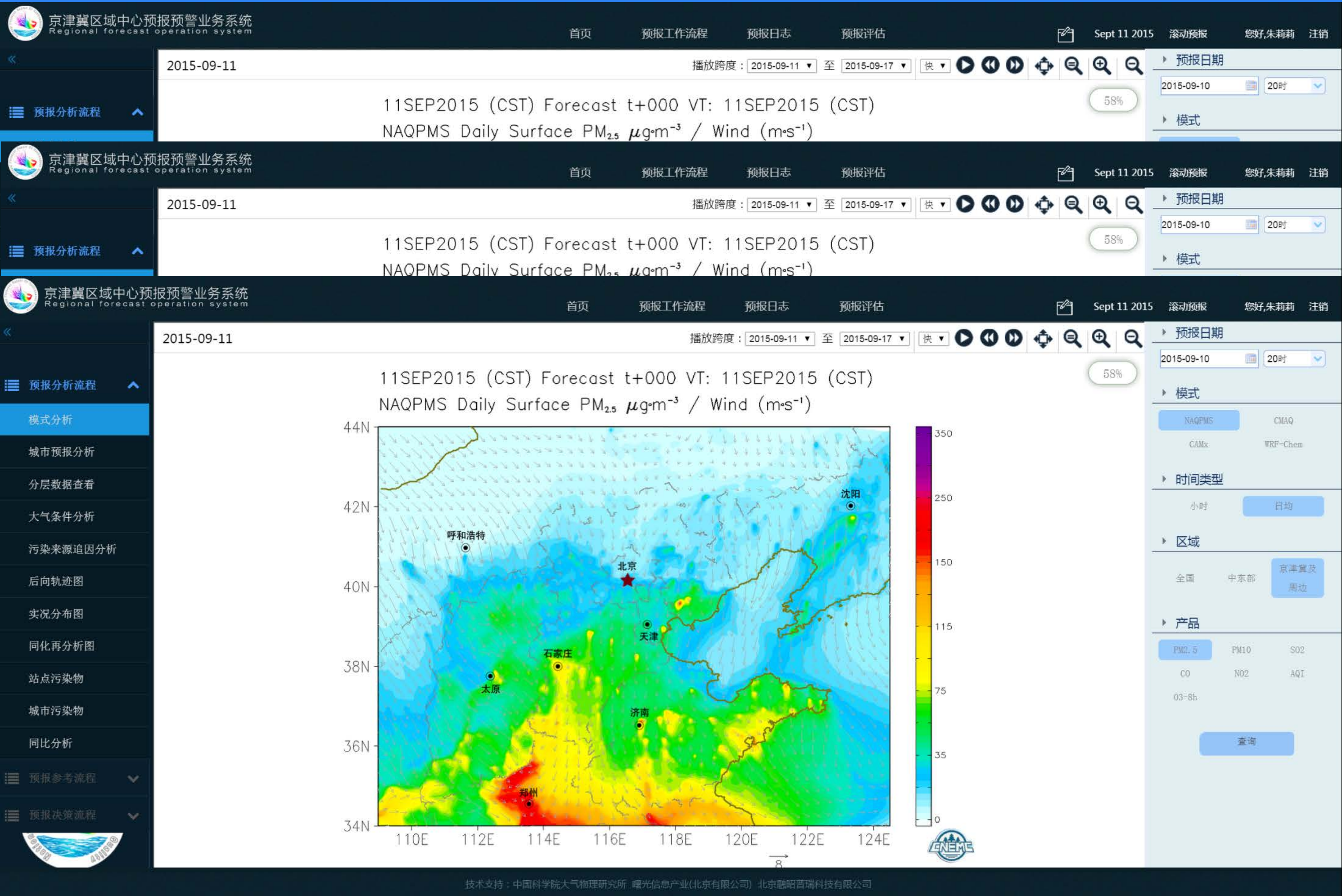








Regional forecast operation system



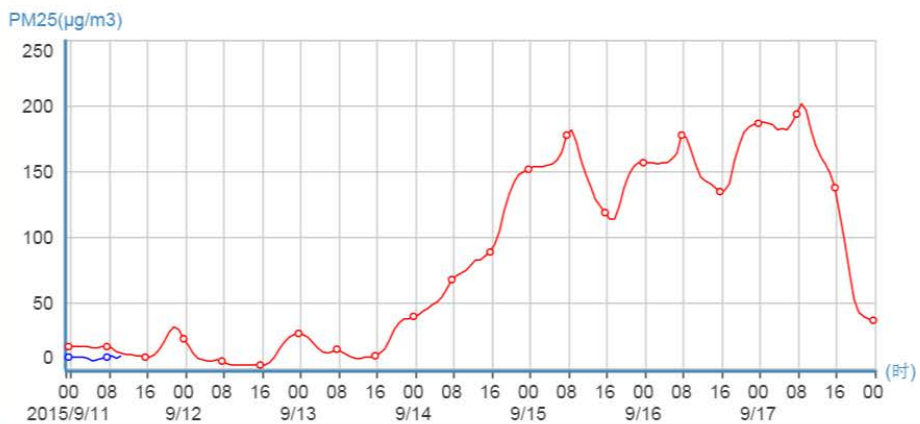
Regional forecast operation system

日期	SO2	IAQI	NO2	IAQI	PM10	IAQI	CO	IAQI	O3-1h	IAQI	O3-8h	IAQI	PM2.5	IAQI	AQI	首要污染物	指数级别
20150911	13	13	13	16	19	19	0.252	6	79	25	75	38	17	24	38		1
20150912	9	9	13	16	12	12	0.224	6	87	27	83	42	10	14	42		1
20150913	15	15	25	31	23	23	0.335	8	73	23	68	34	19	27	34		1
20150914	46	46	49	61	101	76	0.785	20	77	24	67	34	88	116	116	PM2.5	3
20150915	68	59	56	70	166	108	0.983	25	91	28	81	41	149	199	199	PM2.5	4
20150916	63	57	58	73	178	114	0.971	24	101	32	92	46	160	210	210	PM2.5	5
20150917	52	51	37	46	155	103	0.849	21	92	29	83	42	140	186	186	PM2.5	4

优 良 轻 中 重 严重

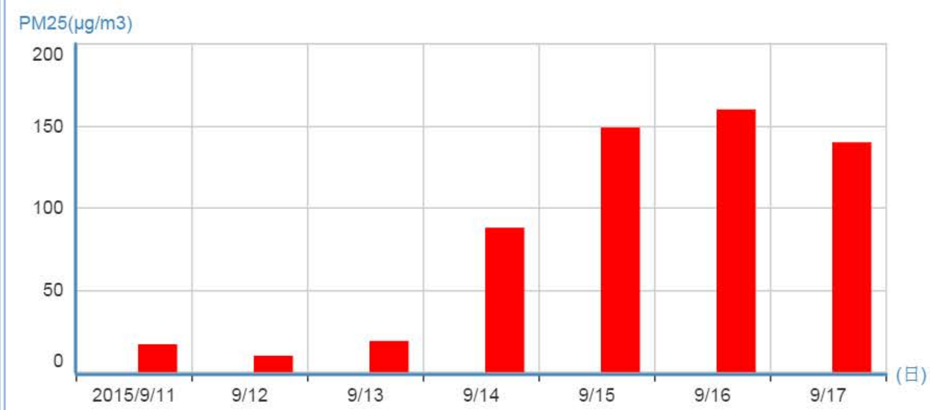
PM2.5 SO2 NO2 PM10 CO O3

PM2.5模式与监测对比



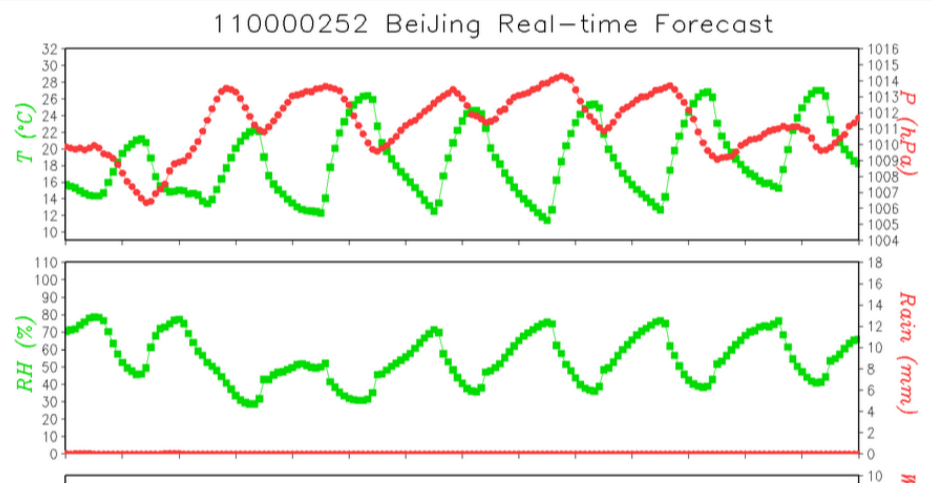
PM2.5 SO2 NO2 PM10 CO O3

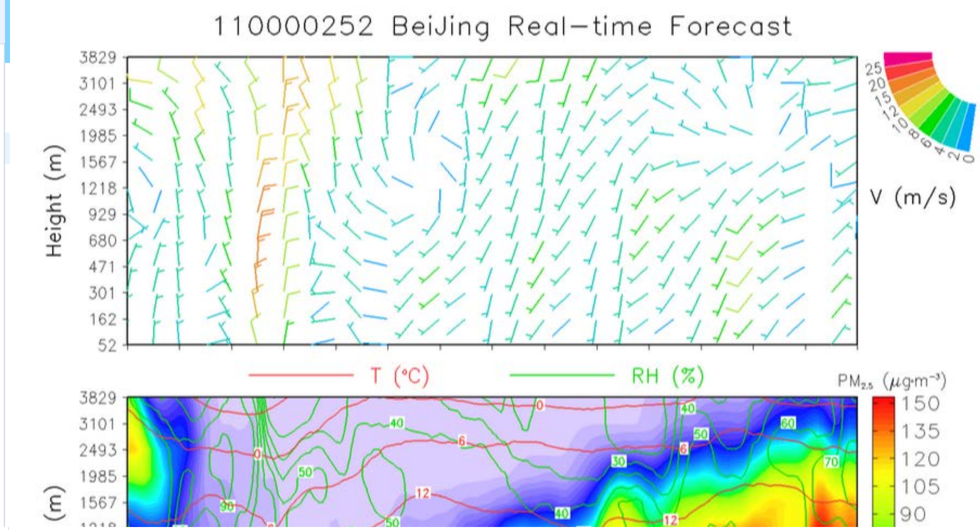
PM2.5模式与监测对比

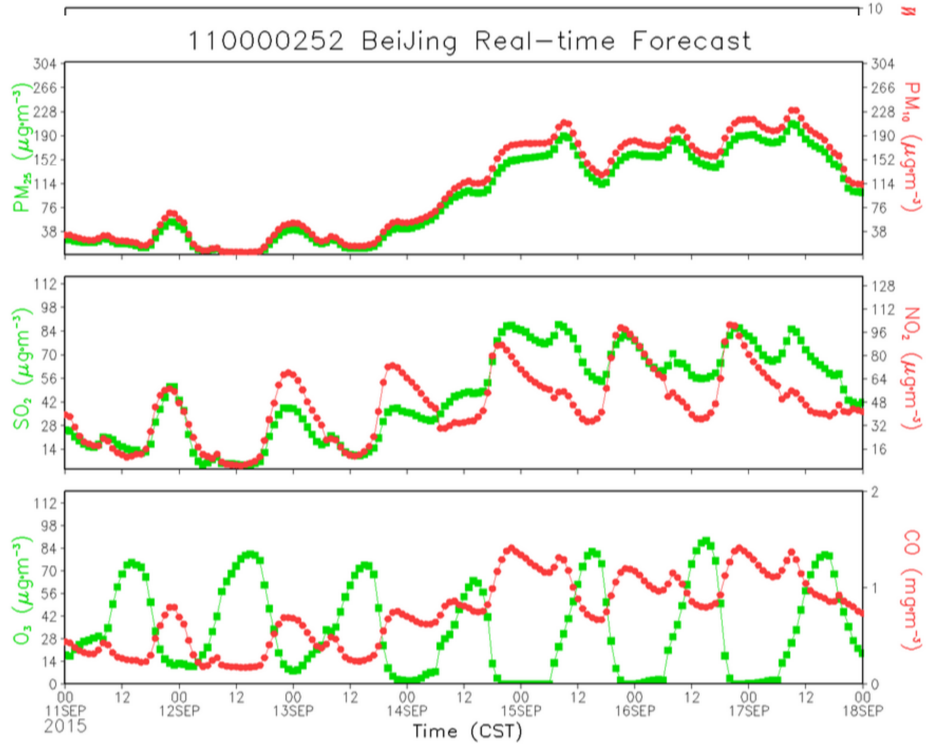


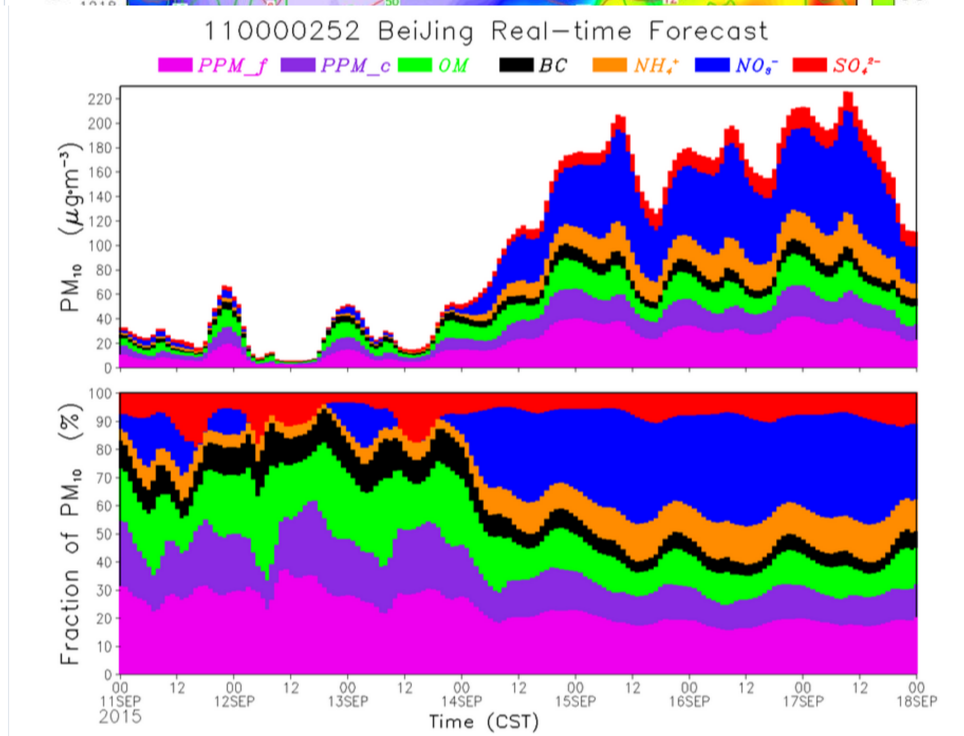
Regional forecast operation system

气象与污染预报

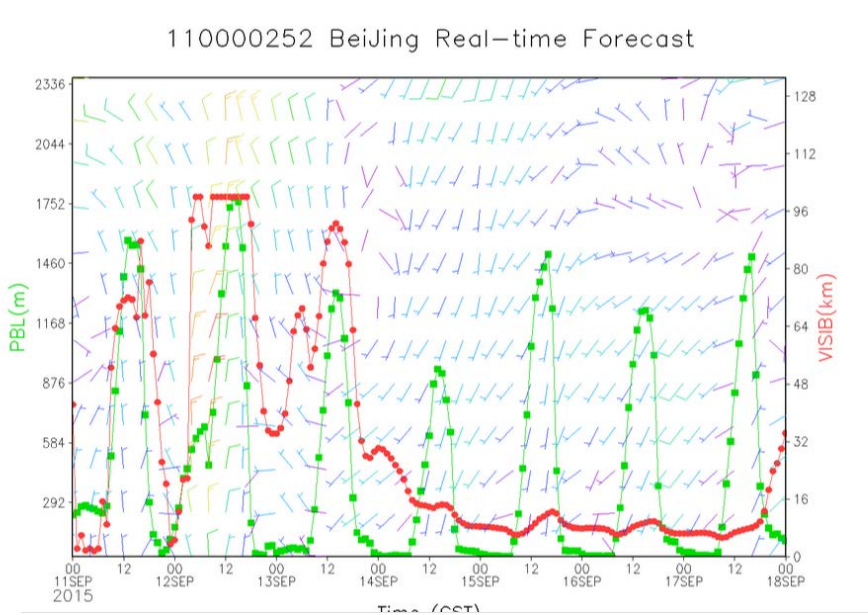


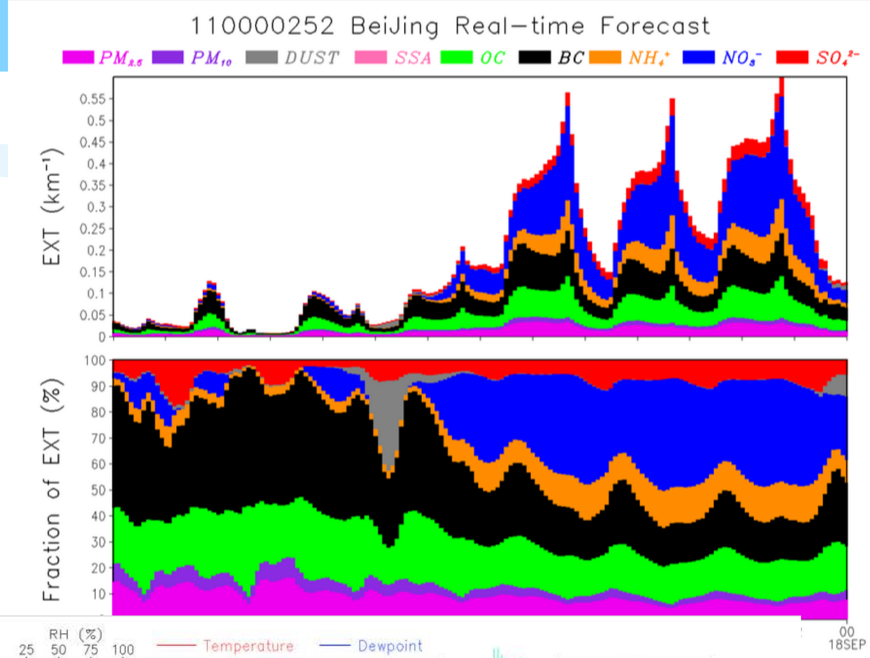


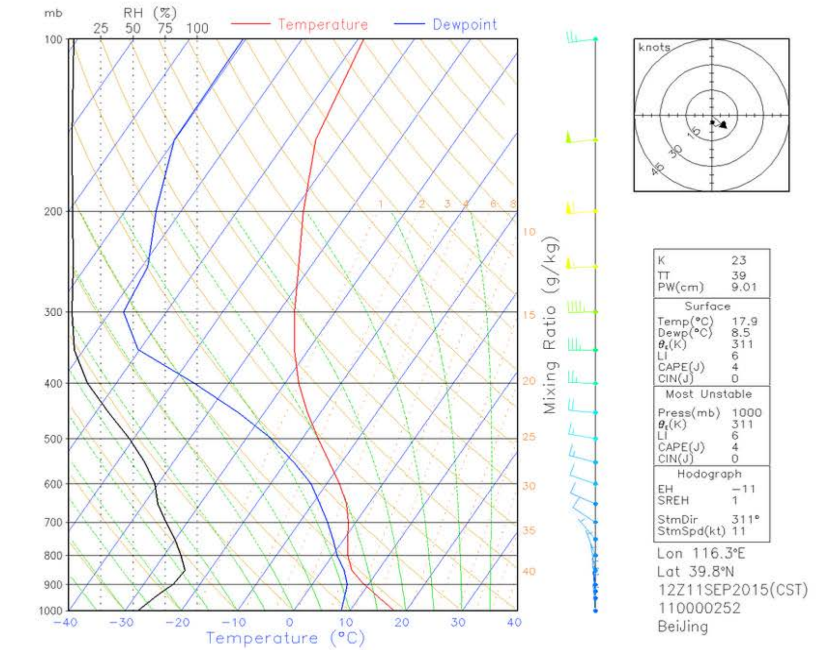


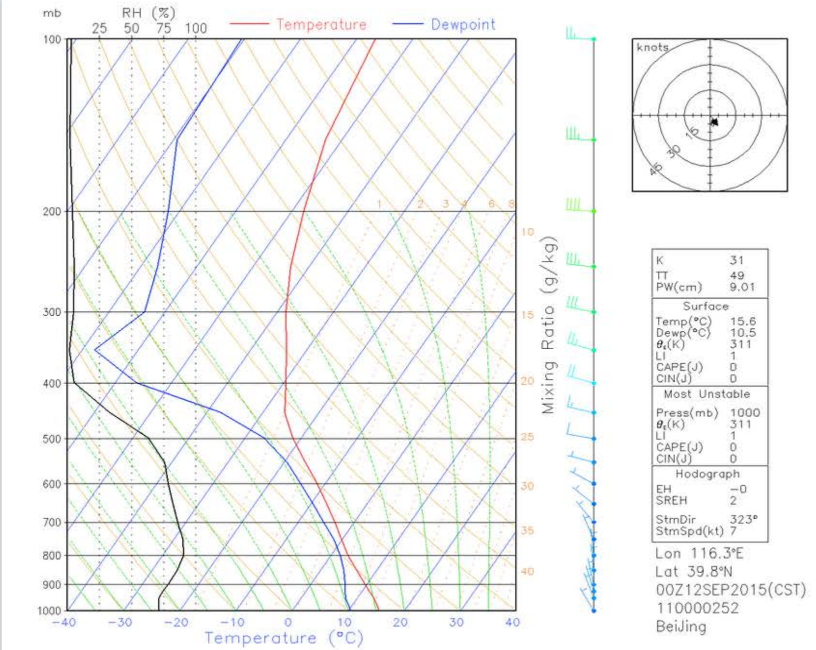


Regional forecast operation system

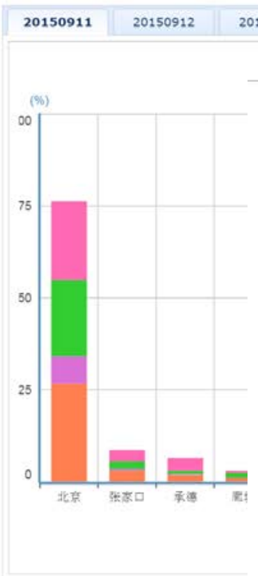


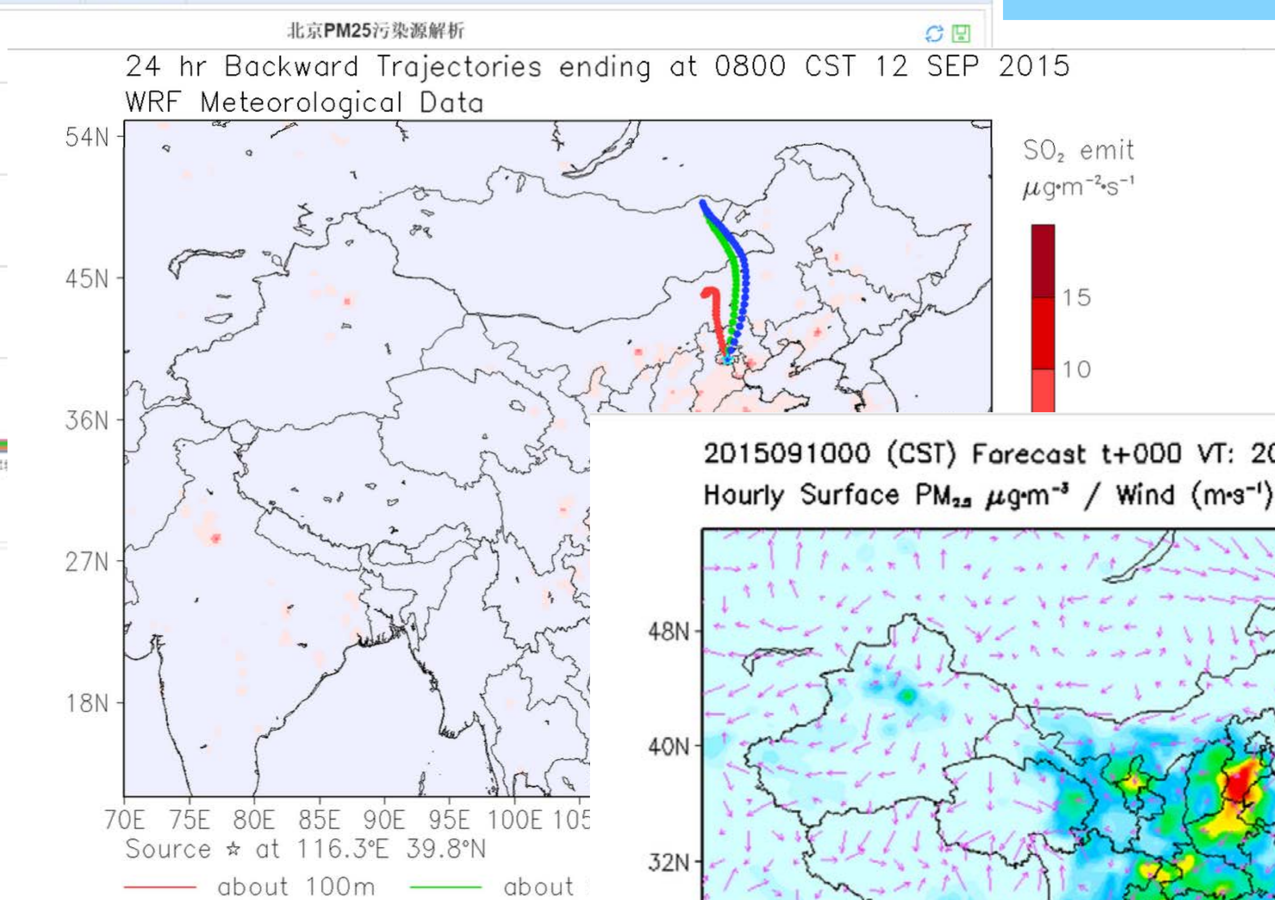


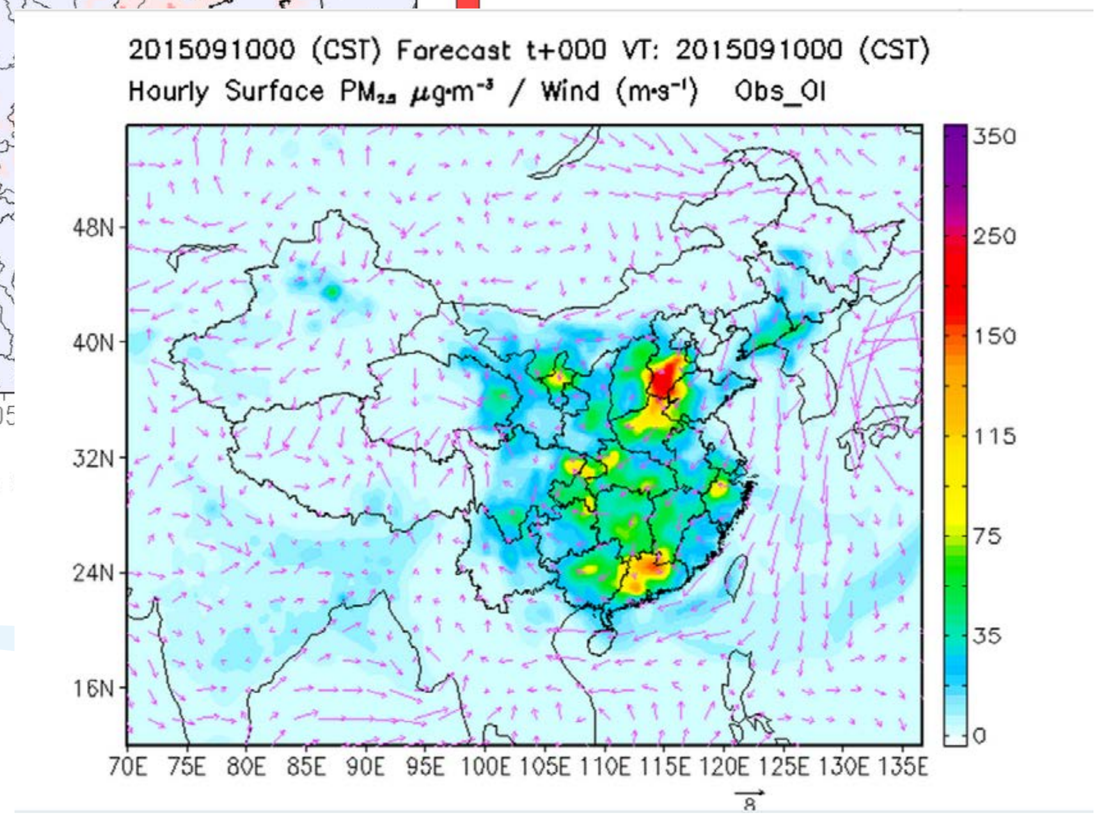




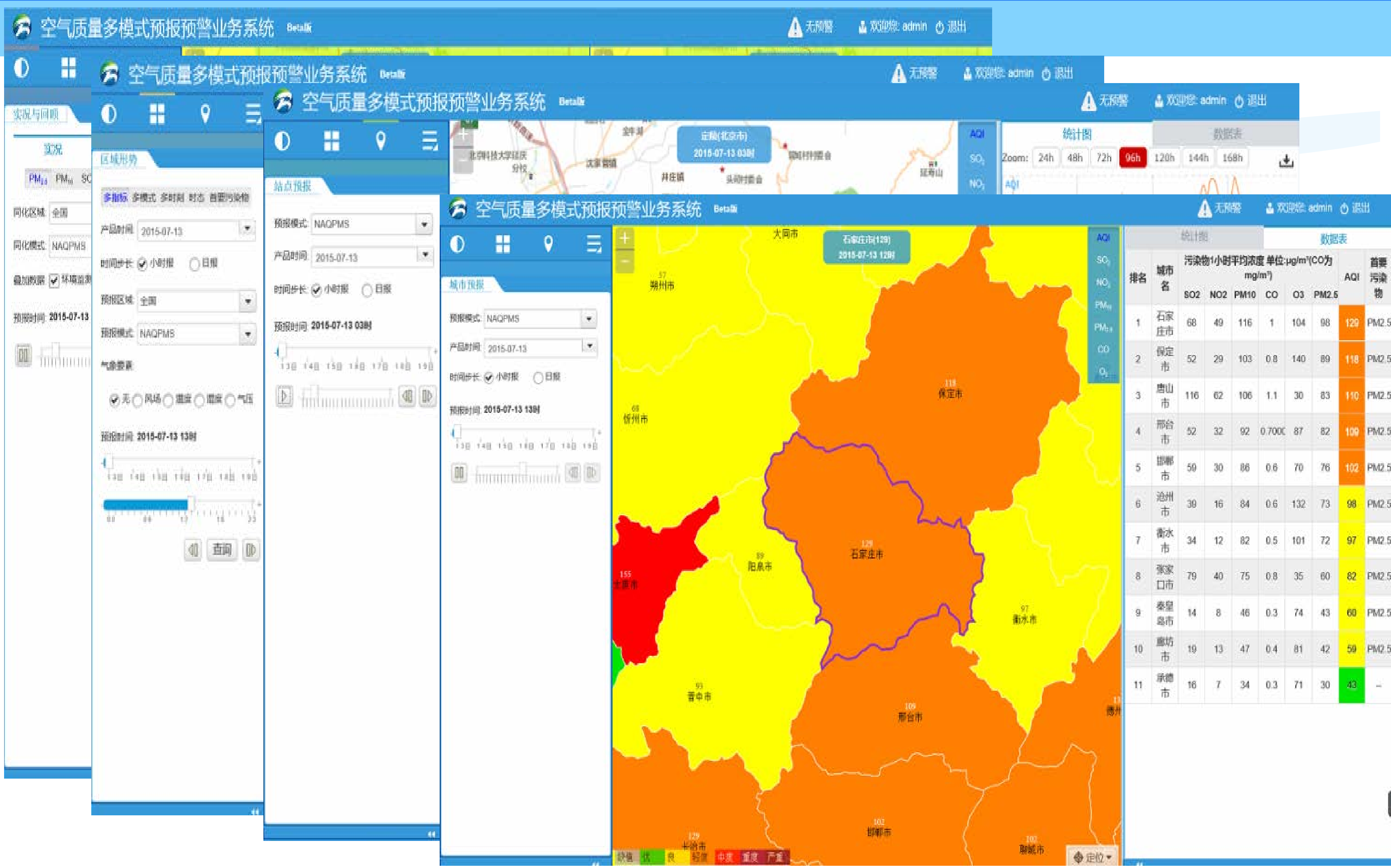
Regional forecast operation system





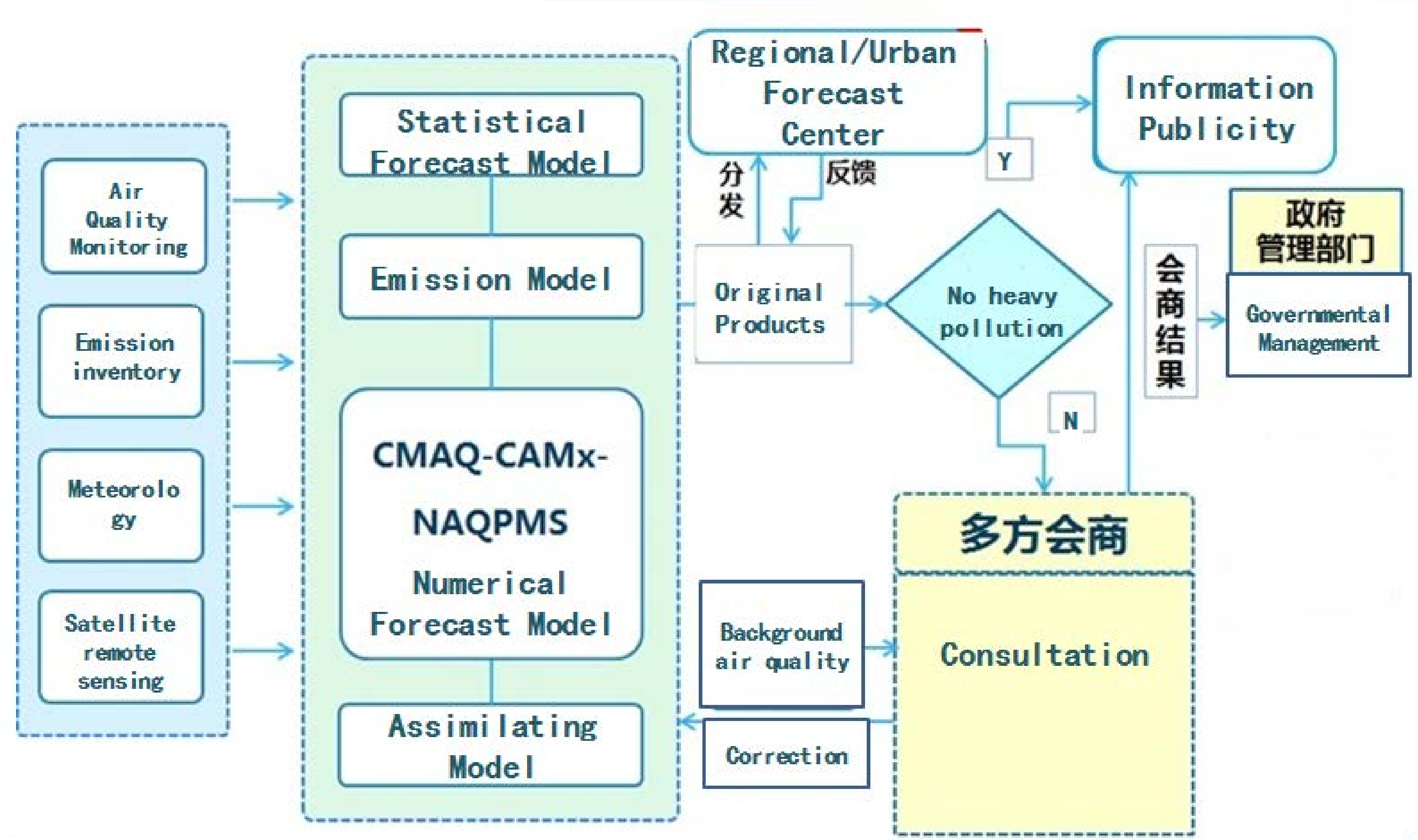


Comparative analysis system



国家预报预警工作机制 Working Procedures

Operational Procedure



（Source：总站、中科院大气所、广东、上海监测中心，2013）

预报信息服务 Air quality information service

中华人民共和国环境保护部

Ministry of Environmental Protection of the People's Republic of China

您现在的位置：首页 -> 专题报道 -> 热点专栏 -> 重点区域环境空气质量预报

京津冀、长三角和珠三角区域环境空气质量形势预报

日期：2015-09-10 来源：中国环境监测总站

根据京津冀、长三角和珠三角区域预报中心基于现有污染源监测、环境空气质量新标准实时监测、大气污染过程模拟分析以及与相关监测成员单位会商预报结果，预计：

（一）京津冀区域

11～13日，扩散条件有利，全境优良。

14～15日，扩散条件一般，北部优良，中南部以良至轻度污染为主，首要污染物主要为PM2.5。

（二）长三角区域

11日，长三角处于高低压之间，沿海以良为主，其它地区良到轻度污染。

12日，长三角受冷空气影响，总体以良为主，短时轻度污染。

13日，长三角中南部处于高压底部，总体以良为主；北部处于高压中心附近，良到轻度污染。

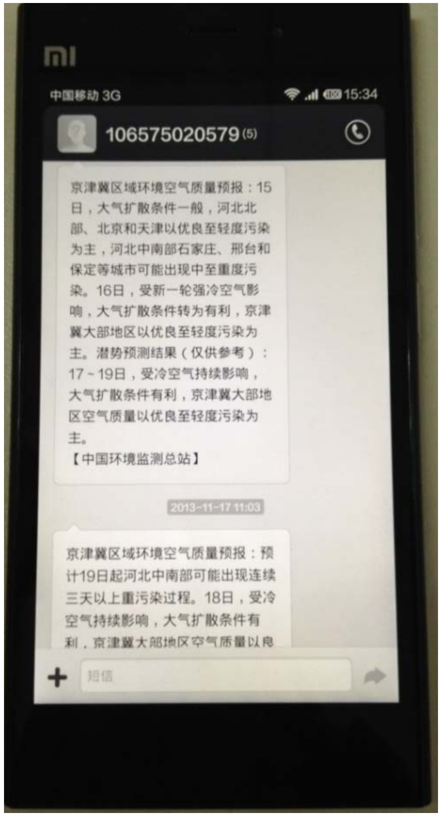
14日，长三角处于高压后部，总体以良为主。

15日，长三角处于入海高压后部，总体以良为主。

（三）珠三角区域

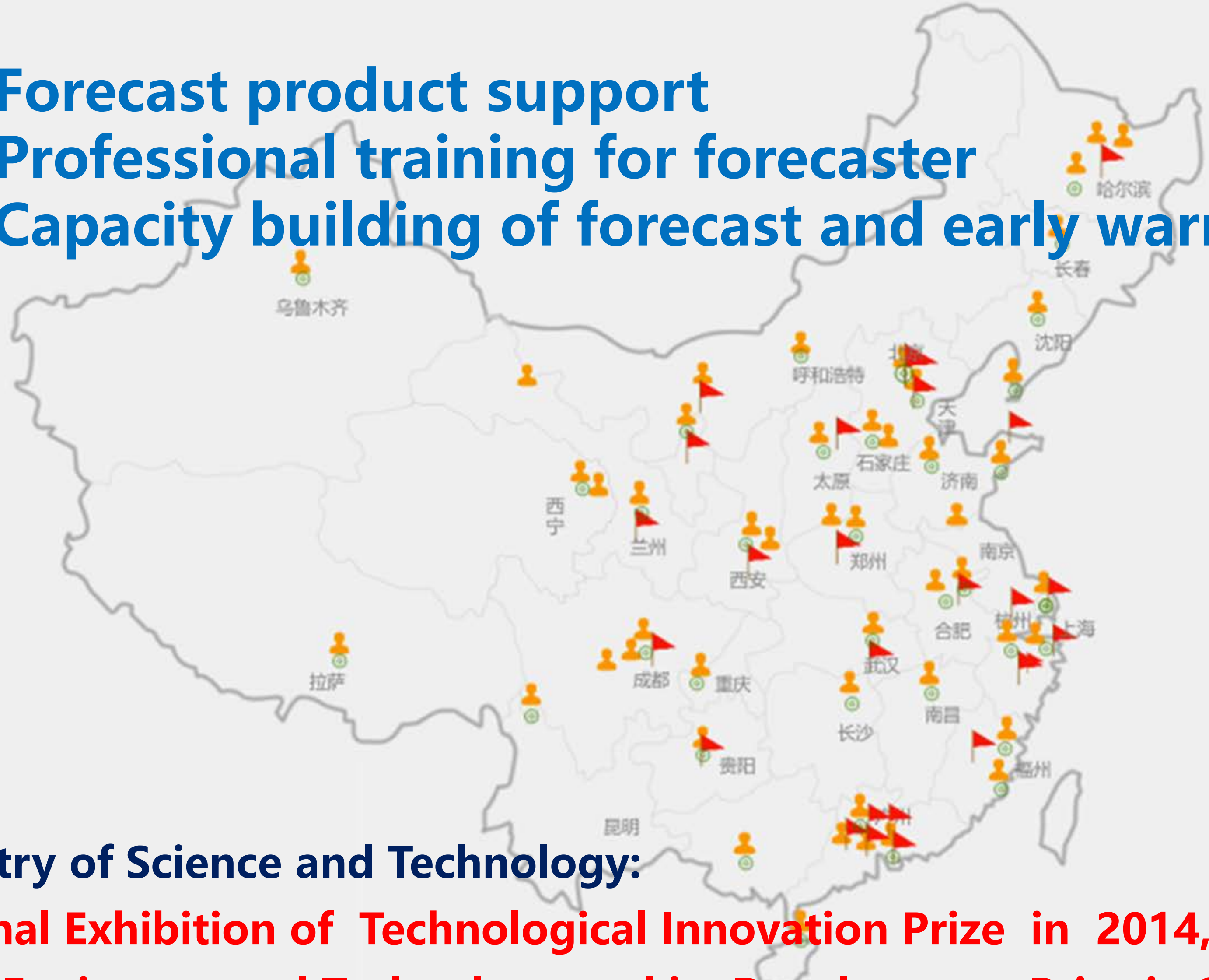
11日，珠三角地区空气质量以良至轻度污染为主，局部中度污染，首要污染物为O_3。

12～13日，珠三角地区空气质量以良至轻度污染为主，首要污染物为O_3。



Application and Performance

- Forecast product support
- Professional training for forecaster
- Capacity building of forecast and early warning



Ministry of Science and Technology:

National Exhibition of Technological Innovation Prize in 2014, 2016

China Environmental Technology and its Development Prize in 2014"

Air Quality Assurance in the National Major Activities

Beijing 2008

EXPO 2010 SHANGHAI CHINA

16TH ASIAN GAMES Guangzhou2010

NANJING 2014 YOUTH OLYMPIC GAMES

YOG DNA

APEC CHINA 2014

The 60th National Day

The 70th National Day

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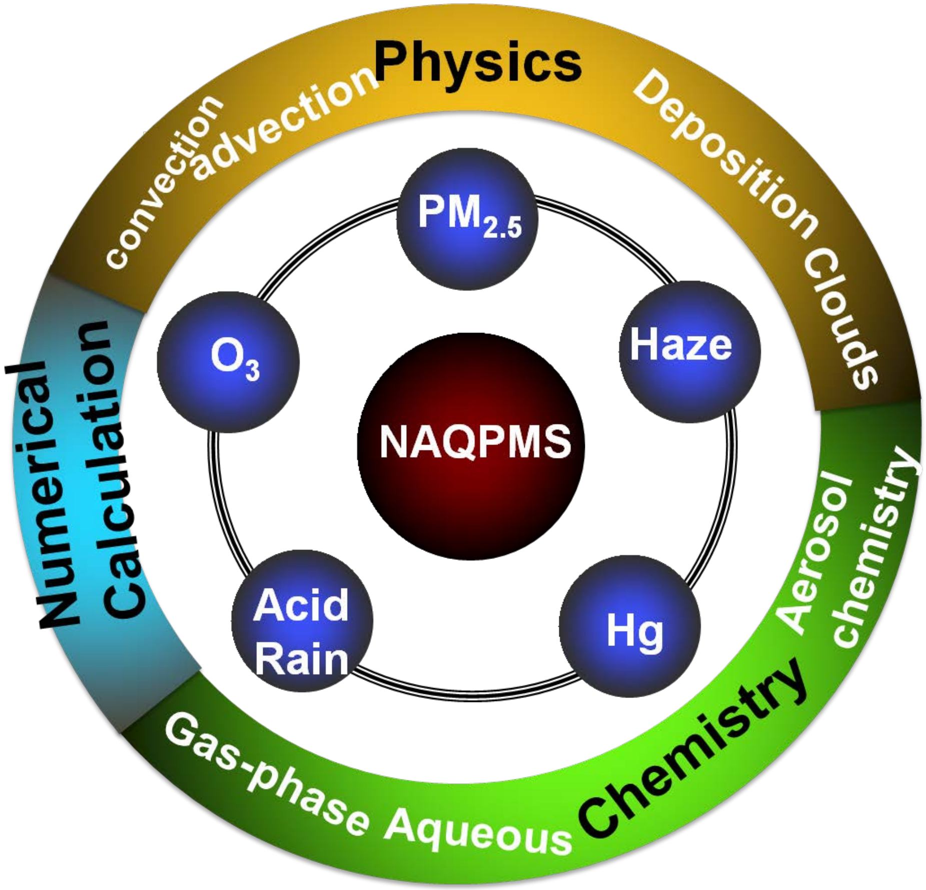
Development of Nested Air Quality Prediction Modeling System (NAQPMS)

Nested Air Quality Prediction Modeling System (NAQPMS)



1.Updated gas-chemistry mechanism

67 species and 176 reactions

2.On-line source appointment scheme based on air quality model

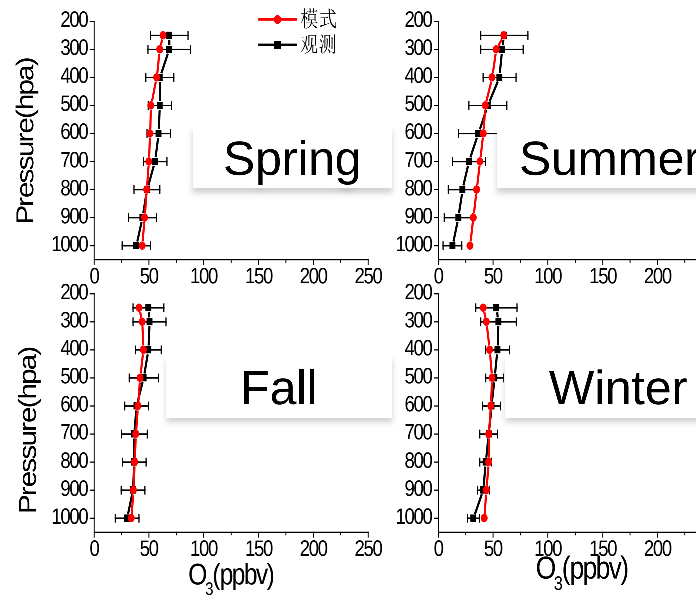
3. Model uncertainty analysis scheme

JAC 2006; JGR, 2007; ACP 2008, 2010, 2013; SOLA 2008, 2010, 2012；GRL 2009；AE 2011; Tellus –B 2013；ACP 2014;EP 2014; AE 2014; SC 2014

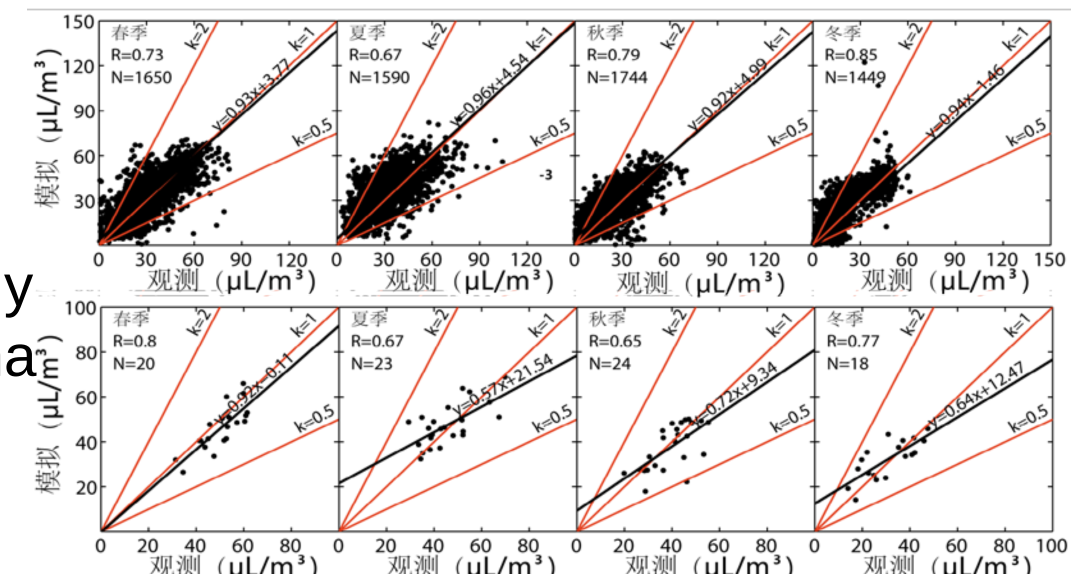
Uptaked gas-chemistry mechanism

RA->CBN-IV->CBMZ

	RA	CBM-IV	CBM-Z
Species	31	34	67
Reactions	52	81	176
Rates	Look-up tables	On-line	On-line
Scales	regional	urban	Global-region-urban

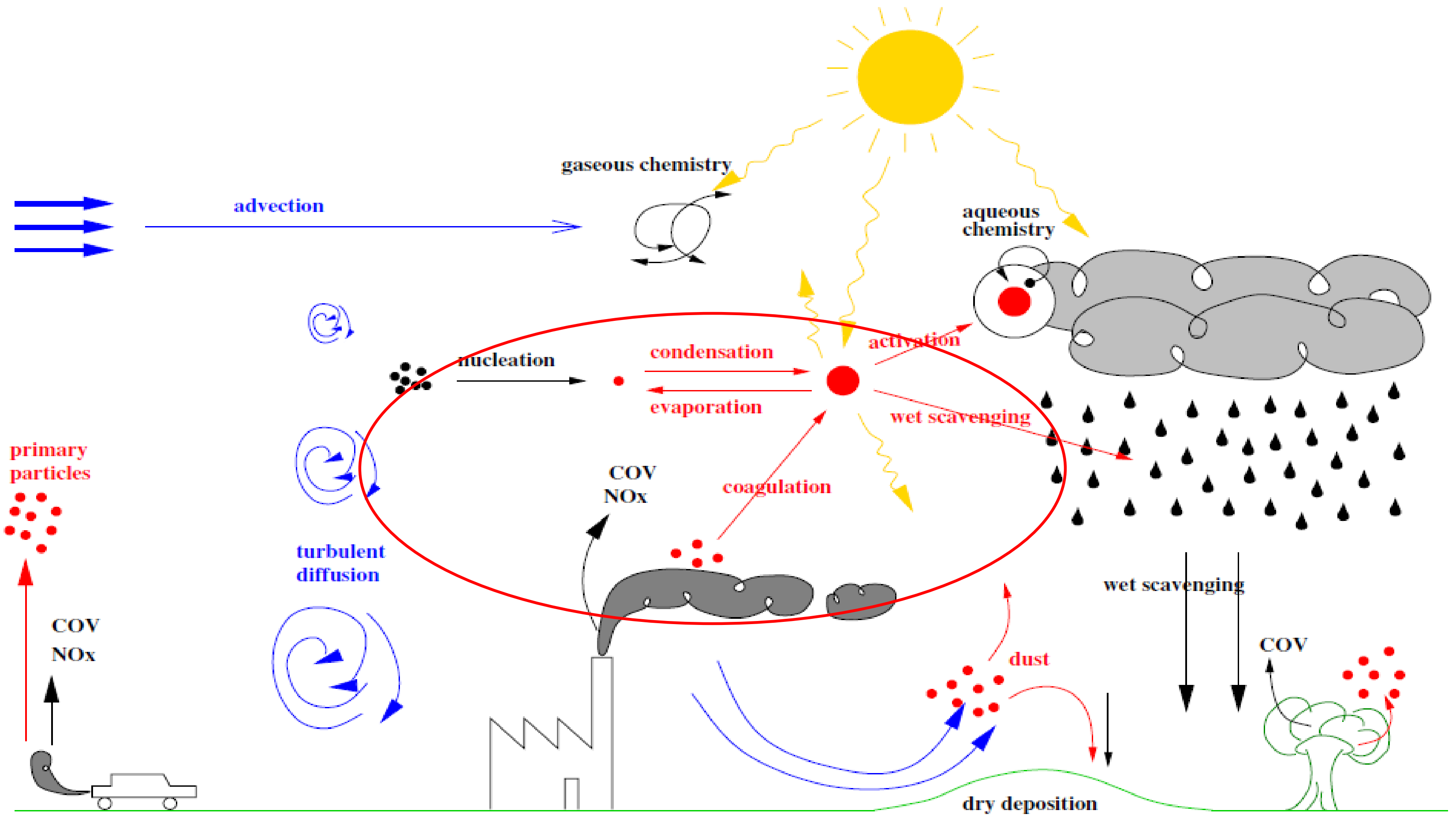


Vertical profiles of ozone



Scatters of observed and simulated daily ozone in China in 2010

NAQPMS+APM



NAQPMS+APM describes nucleation, condensation/evaporation, coagulation and size-resolved deposition.

Introduction to APM

■Mixing state: semi-external

•Secondary particles

•Primary particles + coating

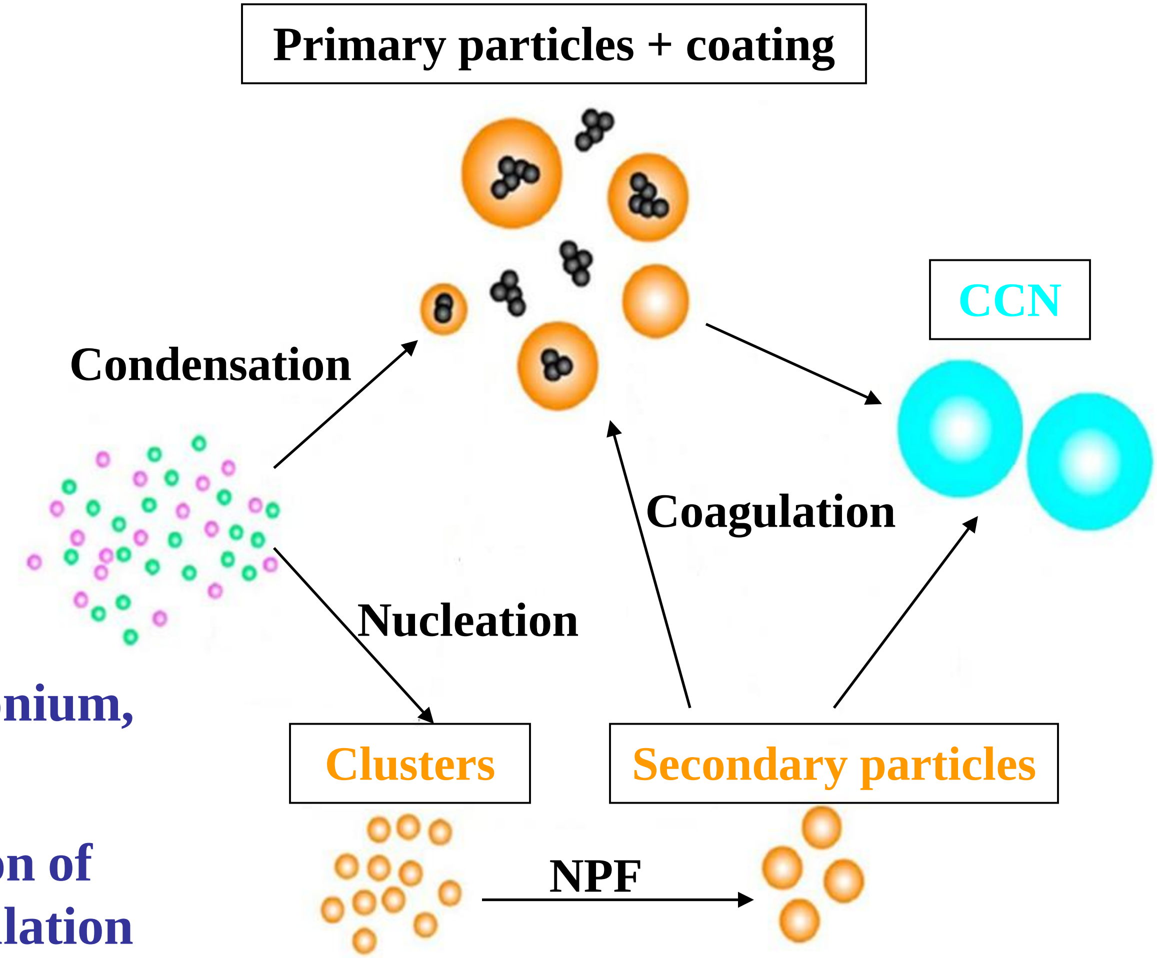
■Micro-physical process

•Nucleation： IMN or other

•Condensation： sulfuric acid

•Equilibrium： Nitrate, ammonium, SOA

•Coagulation： Self-coagulation of secondary particles and coagulation scavenging by other particles



Yu Fangqun, et al, 2012, 2013, 2014

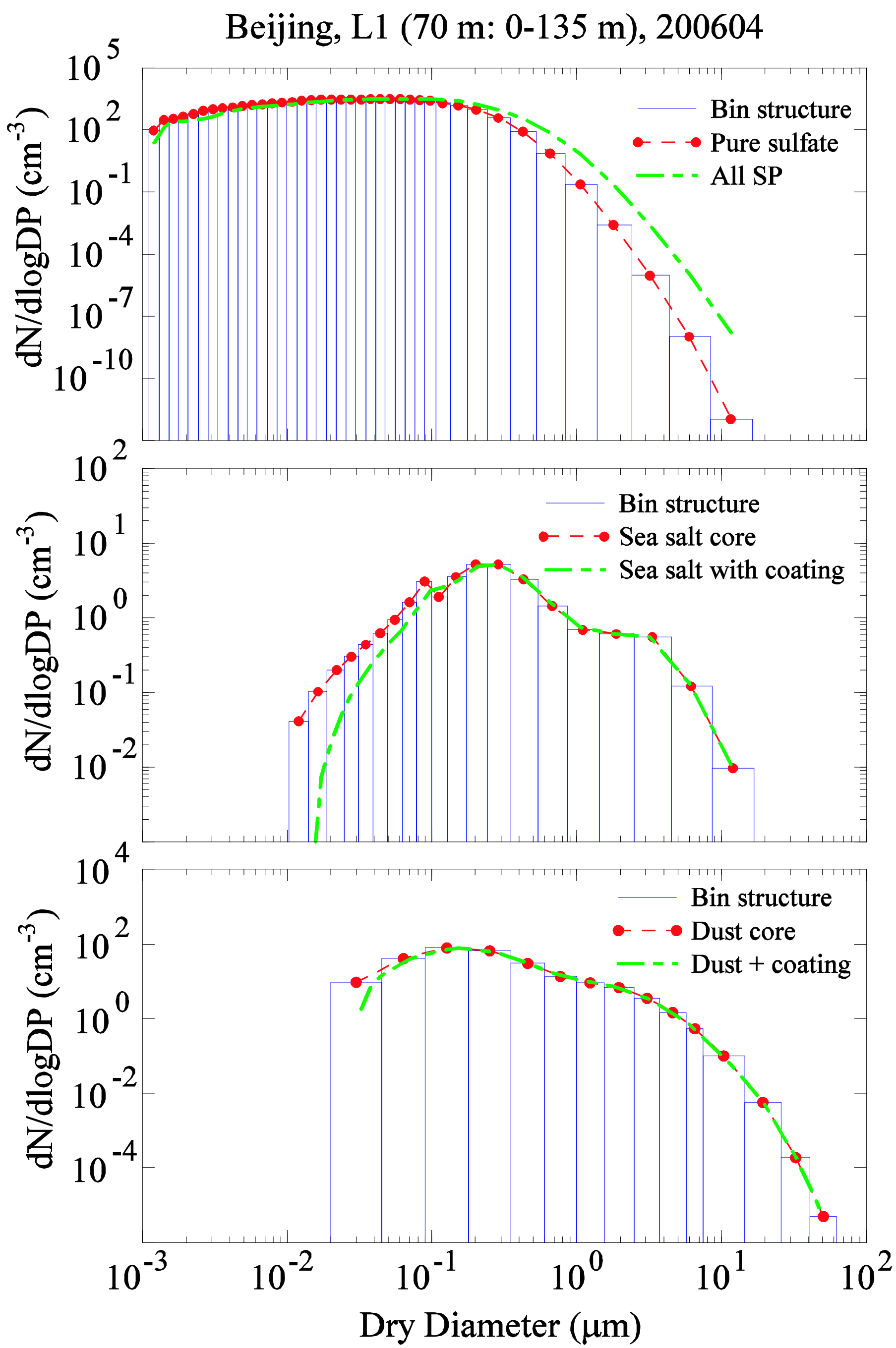
Particles representation

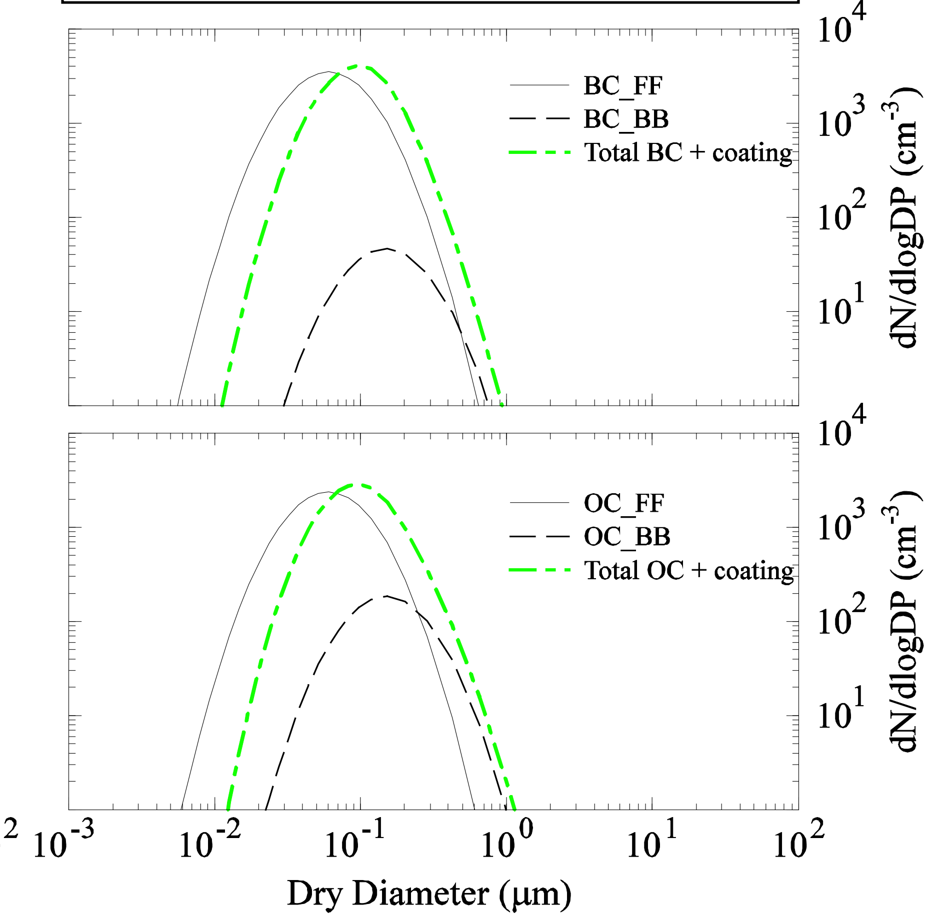
Secondary particles: 40 bins

Sea salt: 20 bins

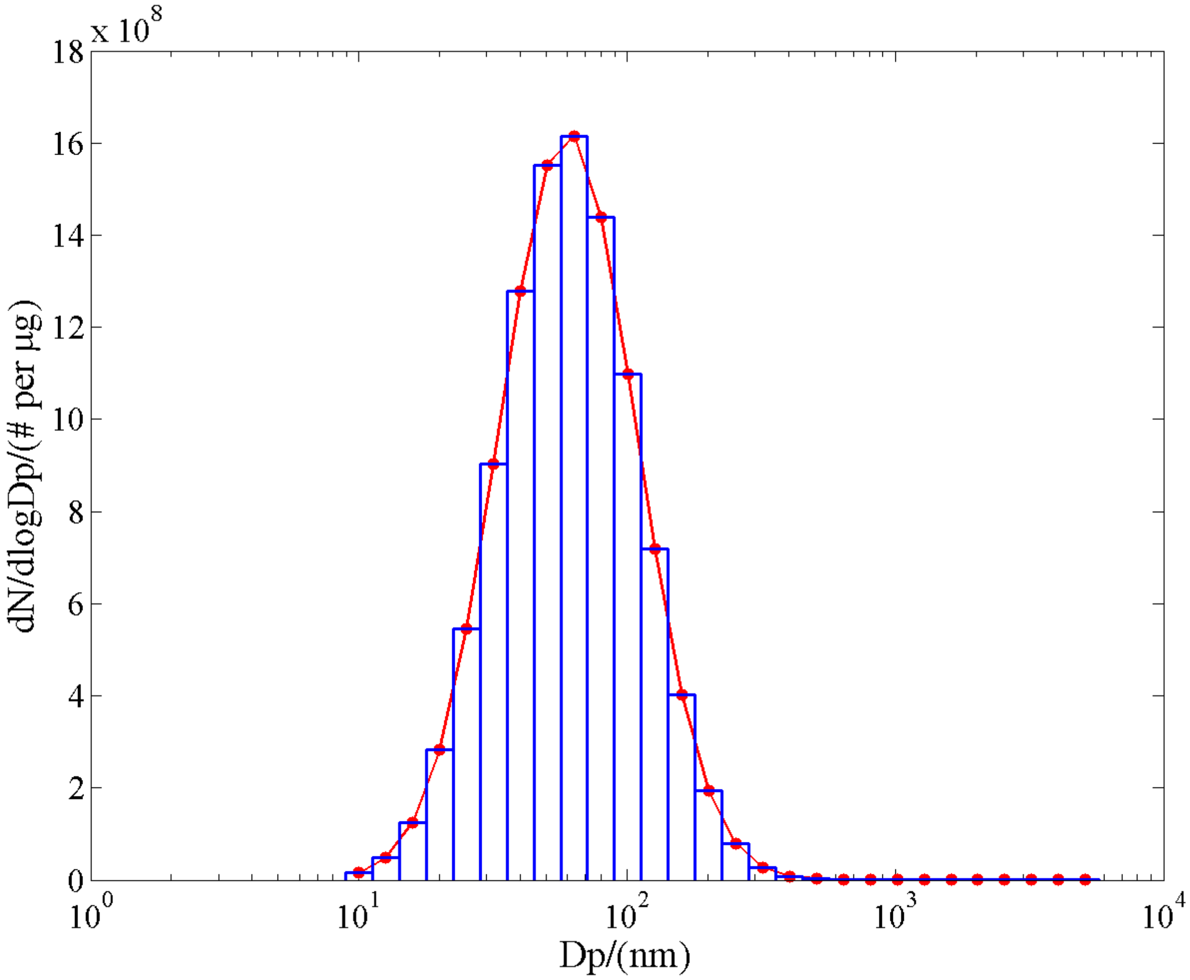
Dust: 4 bins or 15 bins

BC/OC: lognomal/28 bins





Carbonaceous particles size bins



- **Size bins:**

  10nm-10µm, 28 bins

- **Coagulation:**

  Jacobson（1994）

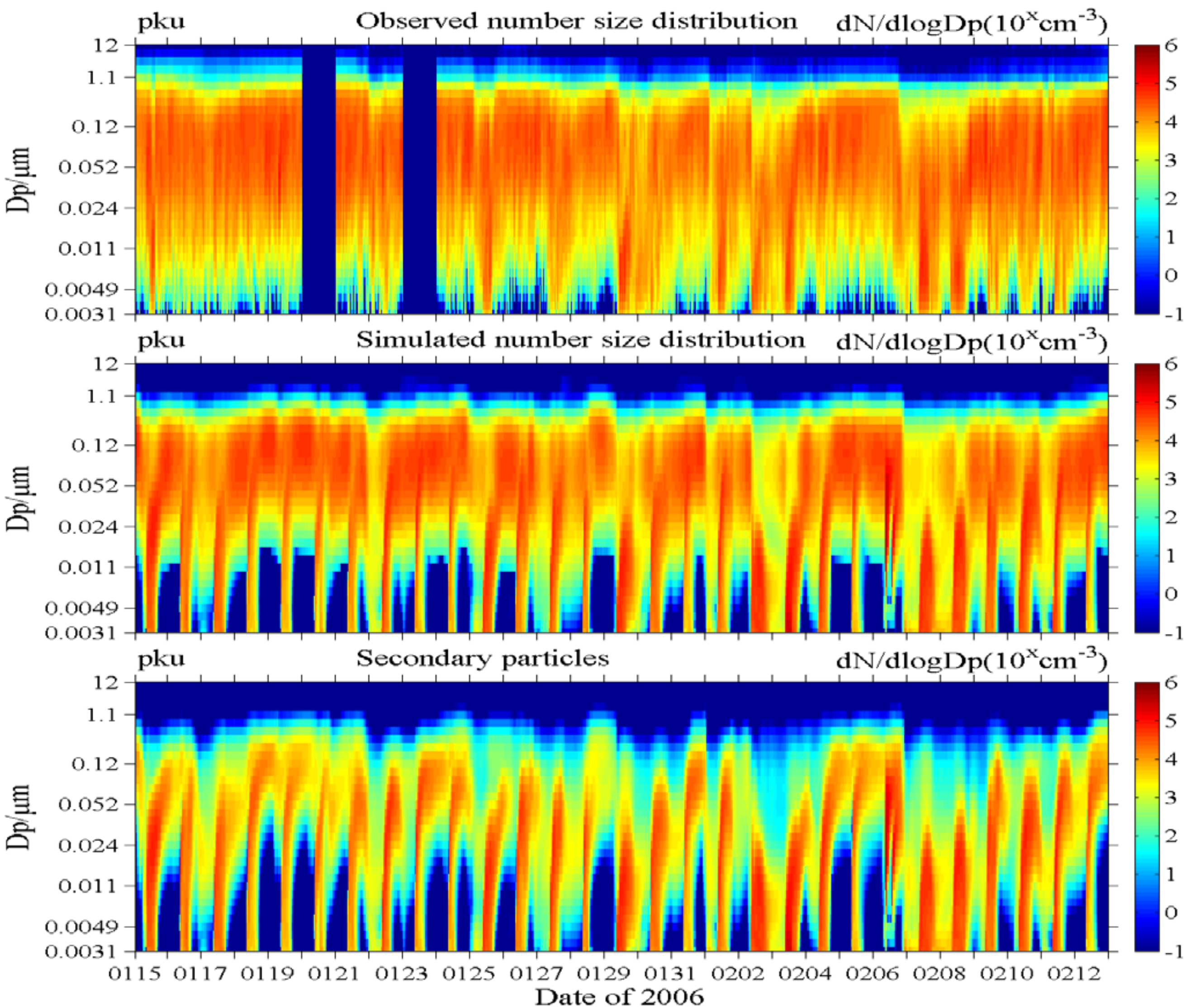
- **Ageing**

  e-folding time: 1.2 day

✓ **Coagulation can be considered;**

✓ **Model can be constrained by observed BC size distribution.**

Particles number size distribution in Beijing

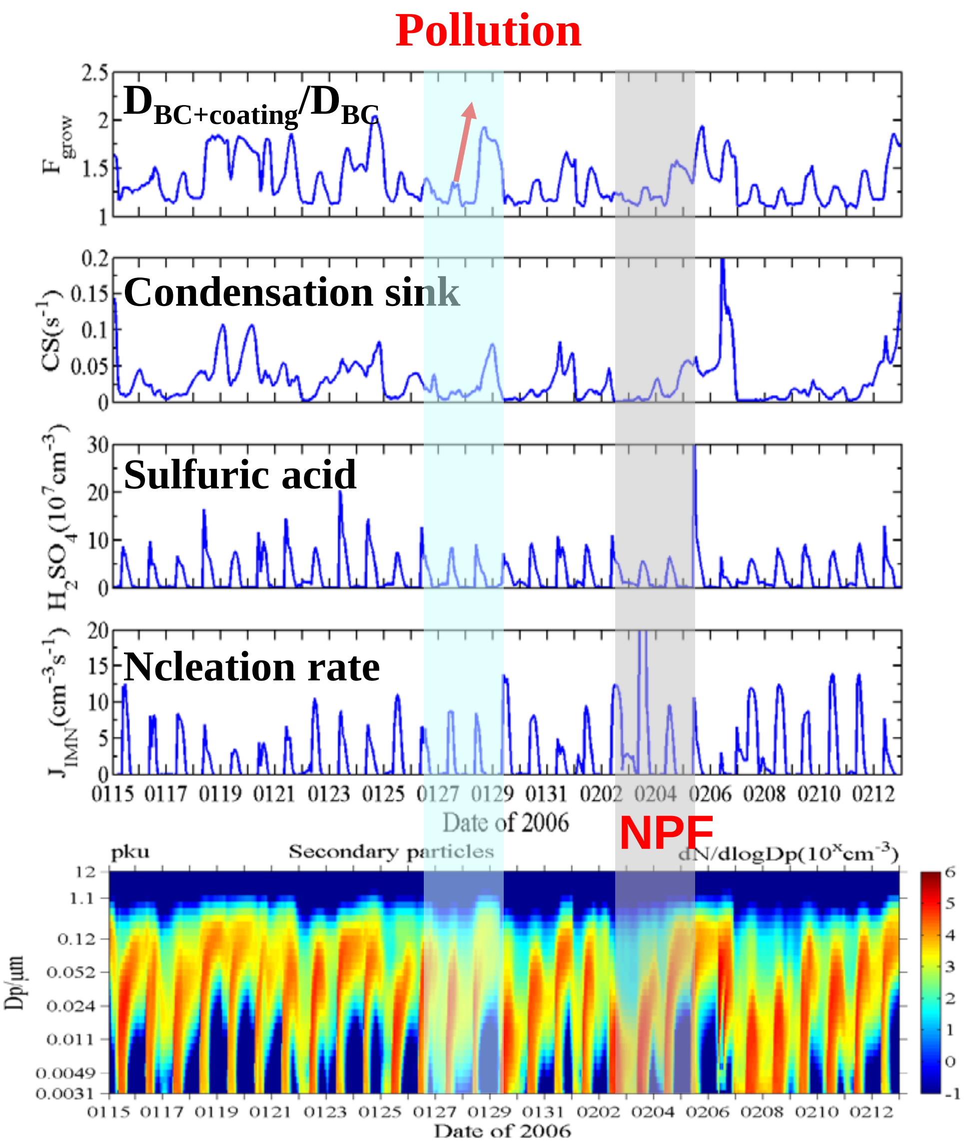


Observed

Simulated

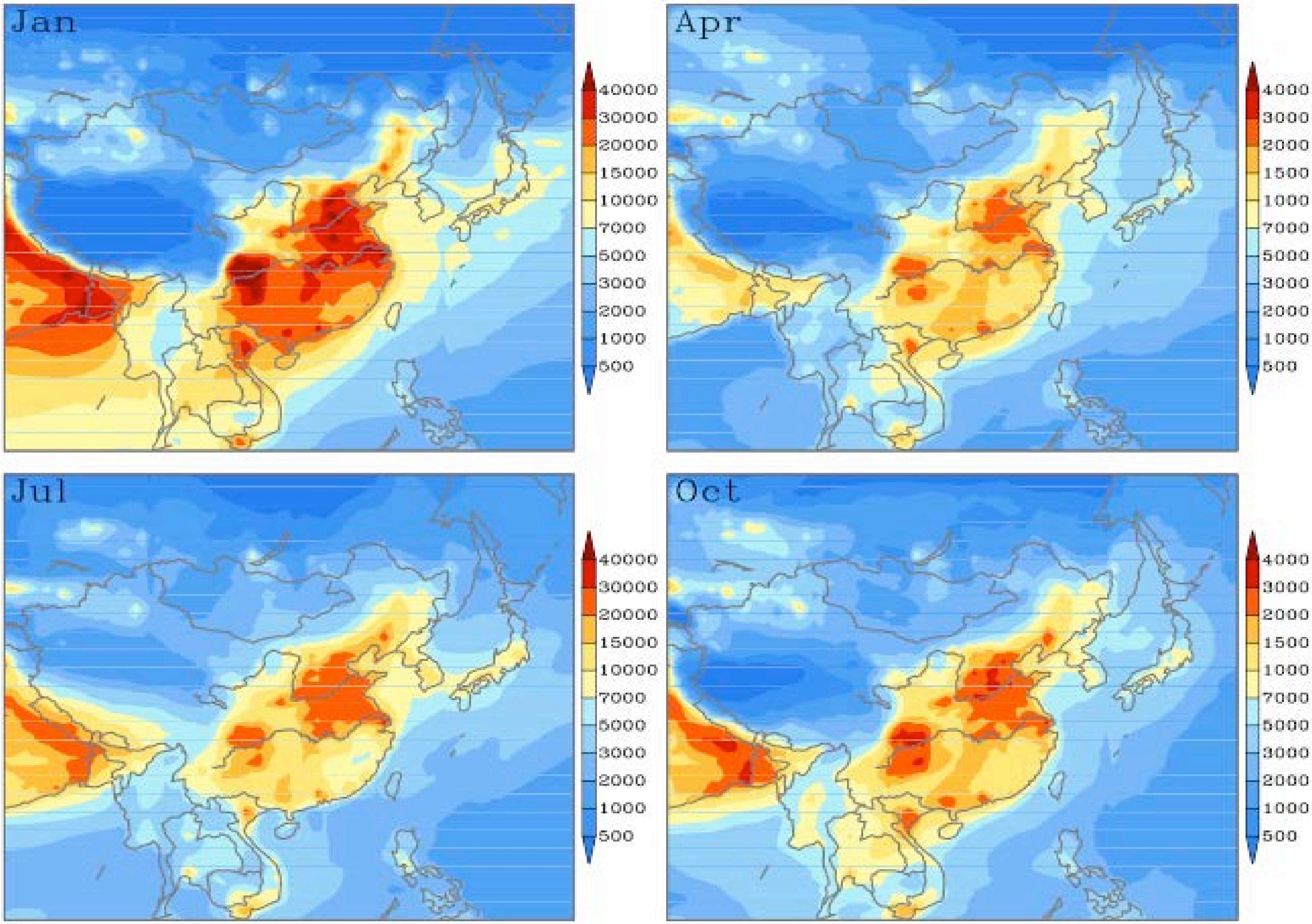
Secondary particles

Evolution of microphysics parameters



- $D_{BC+coating}/D_{BC}$ can be as high as 1.5 or above, BC mixing state was changed;
- Condensational sink was higher in pollution episodes;
- Sulfuric aid concentration showed a evident diurnal variation;
- Nucleation rate was higher in NPF event;
- NPF can be identified and reproduced by NAQPMS+APM.

The APM was coupled with a recently developed version of NAQPMS in order to study the spatial and seasonal variations of aerosol number concentration over China



Simulated ground-level monthly mean number concentration of CN10nm (cm^{-3})

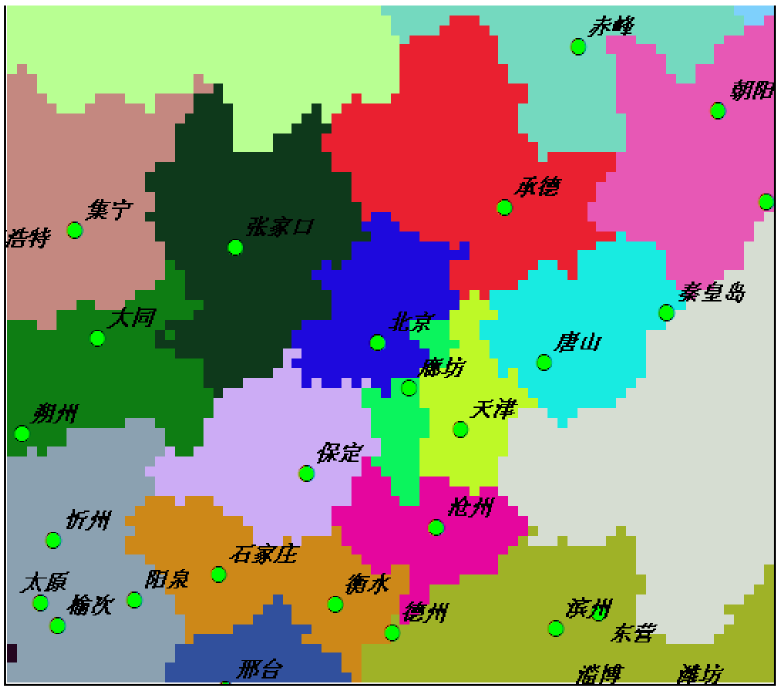
Chen et al., SOLA,10,83-87

On-line source appointment scheme

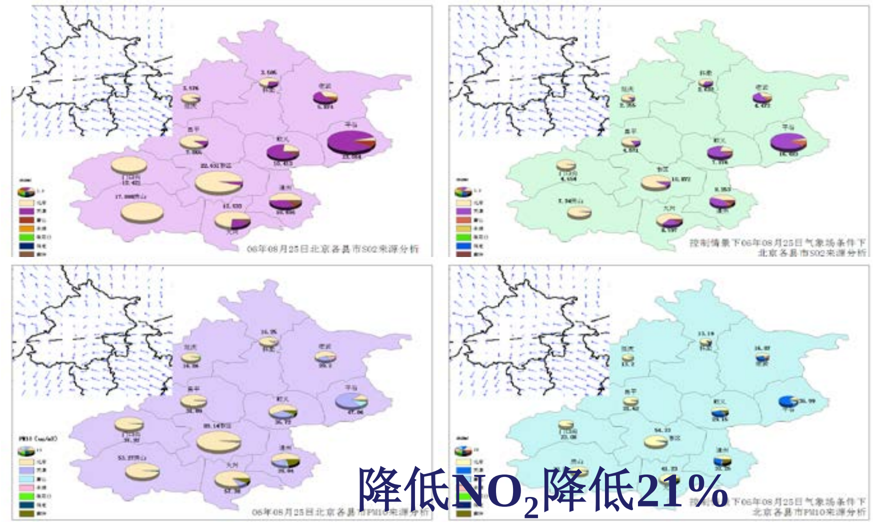
$$\overline{Fr_i^{'}} = \frac{1 - Fr_1 - Fr_2 - Fr_3}{\sum \overline{Fr_{.}}}\,\overline{Fr_i}$$

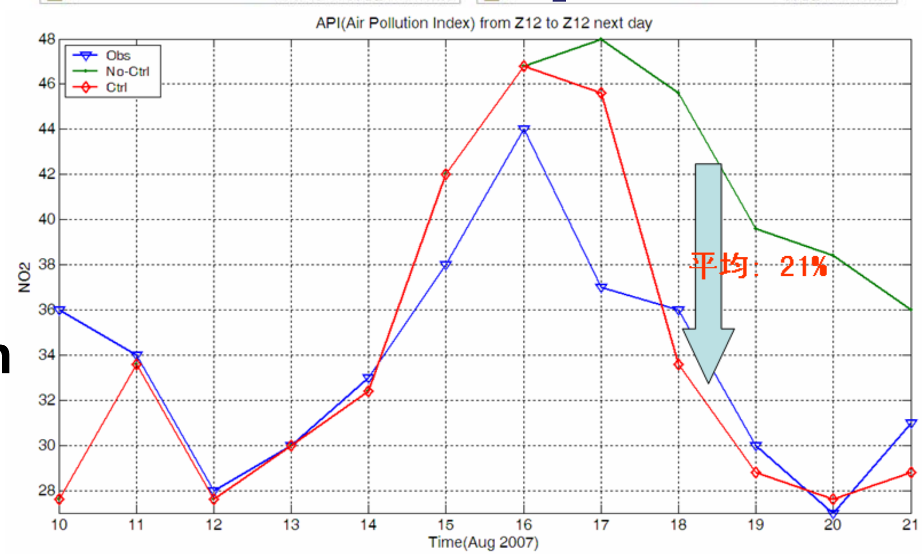
$$\frac{d(C \bullet Fr_i)}{dt} = (Fi_{(adv+conv+diff)} \bullet Fr_i^{'} + P^{i}{}_{chem}$$

$$- (Fo_{(adv+conv+diff)} - L_{chem} - L_{dry+wet}) \bullet Fr_i$$



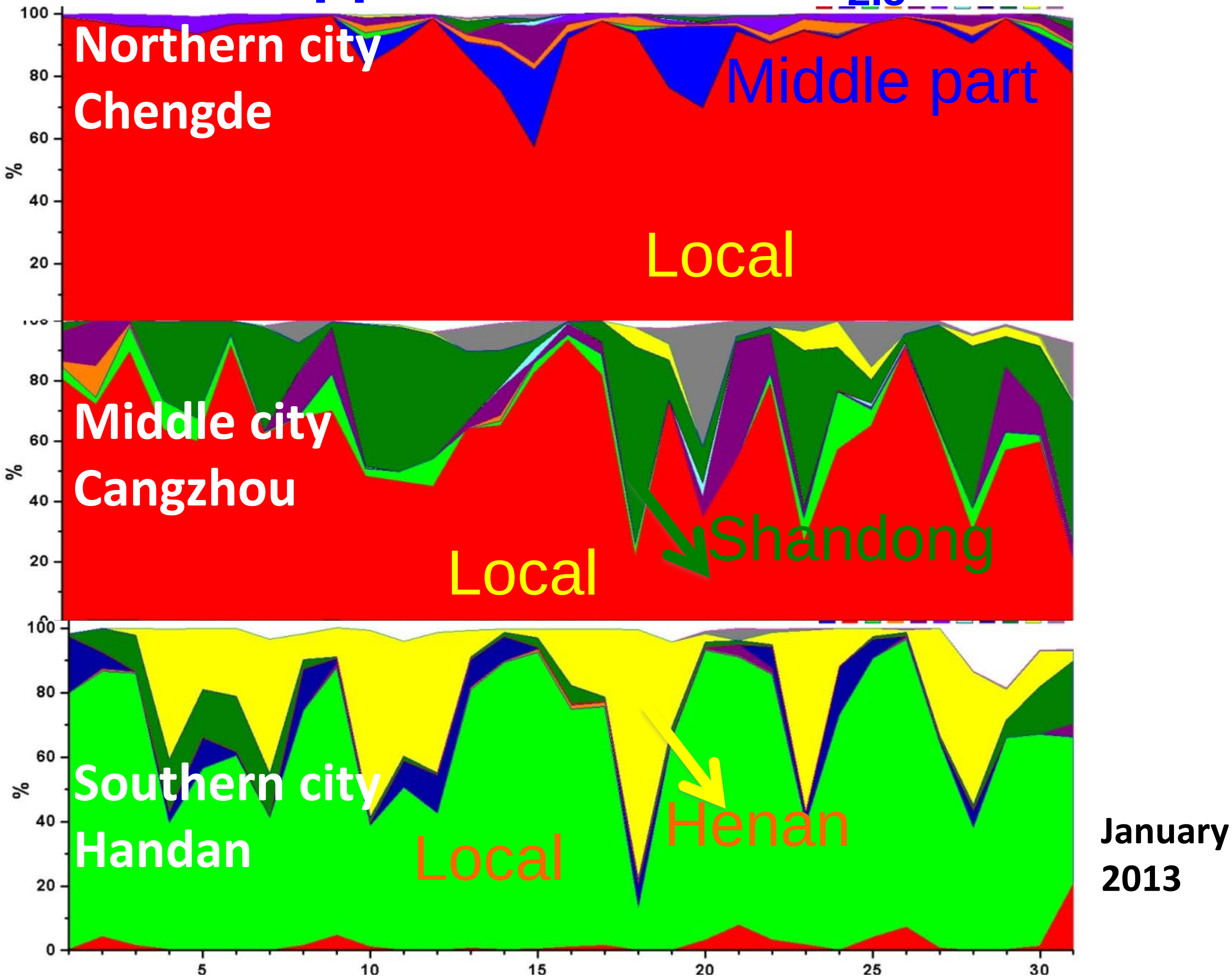
Sources of SO_2,NO2,PM_{10} and O_3 at Beijing in 2008 Beijing Olympics





Impact of traffic restriction on NO_2 concentrations

Source appointment of $PM_{2.5}$ in Hebei



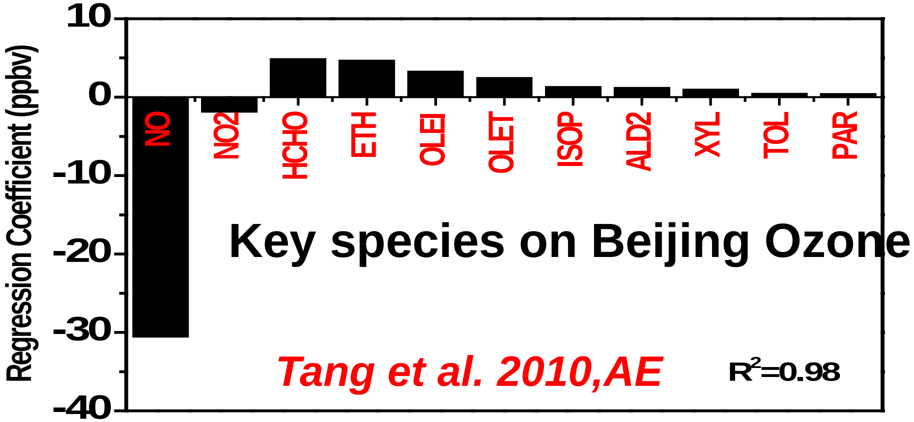
Uncertainty analysis scheme

Monte Carlo Sensitivity Analysis method

Advantages

✓ no tangent-linear and adjoint model

✓ easy to deal with a set of about 100 or more input parameters



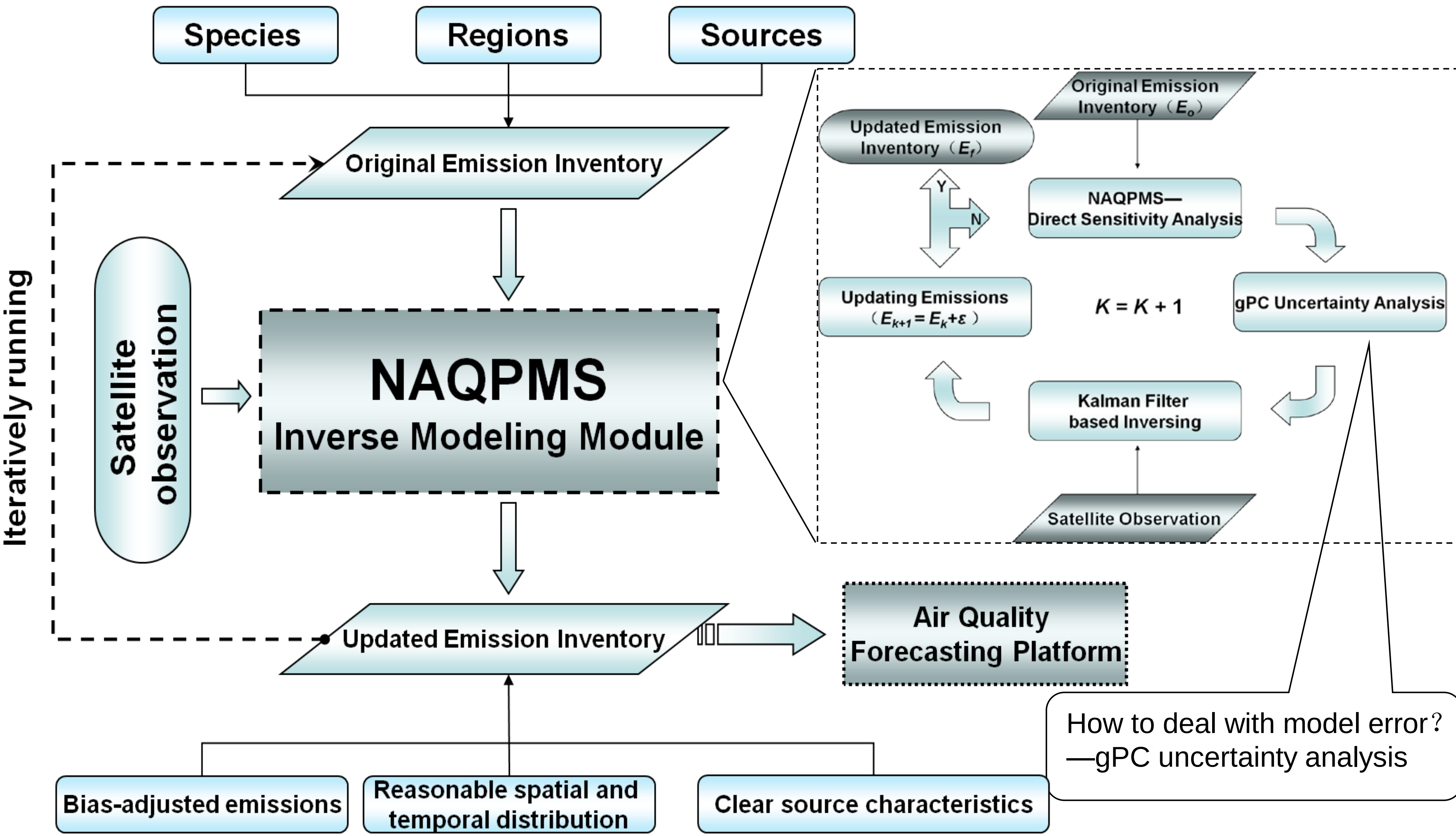
Importance ranking of uncertainty sources

Sites	importance ranking of uncertainty sources in ozone simulation			
	1	2	3	4
Urban Beijing	Local VOC emissions	NO_2 Photolysis constant	Local NO_x Emissions	Wind direction
Tianjin	Local VOC Emissions	Local NO_x Emission	NO_2 Photolysis constant	Wind speed
Tangshan	Local VOC Emissions	Wind direction	NO_2 Photolysis constant	R（$NO+O_3$）
Baoding	Local NO_x Emissions	Local VOC Emissions	Wind direction	R（$NO+O_3$）

Major achievements 2

Inverse Modeling & Data Assimilation System for air quality forecast

Inverse Modeling for air quality forecast

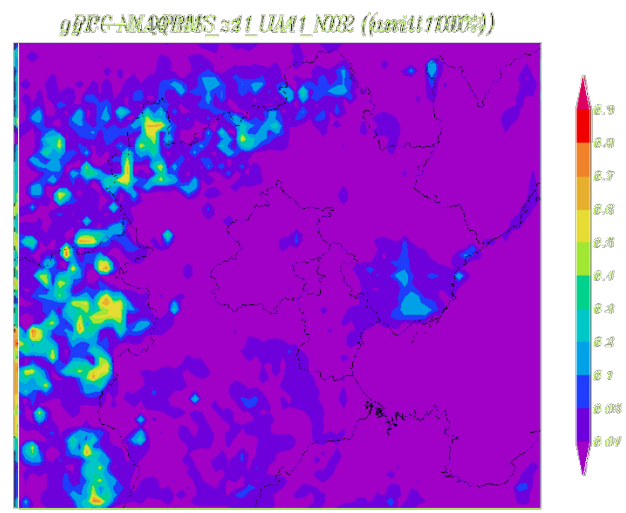


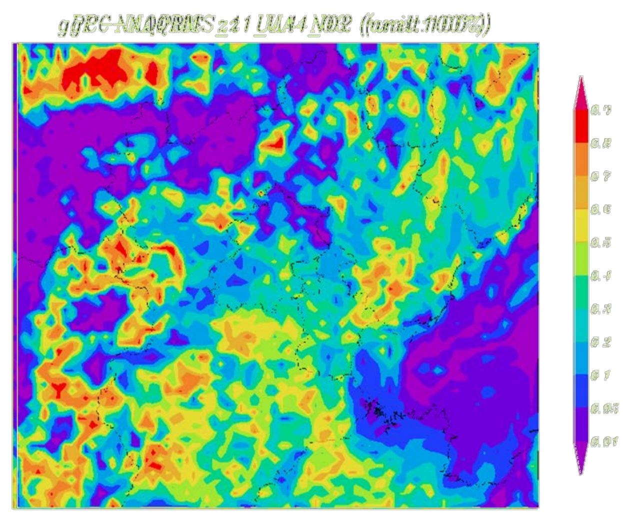
（Hartley et al., 1992;1993;1996; S.L.Napelenok et al., 2008 ）

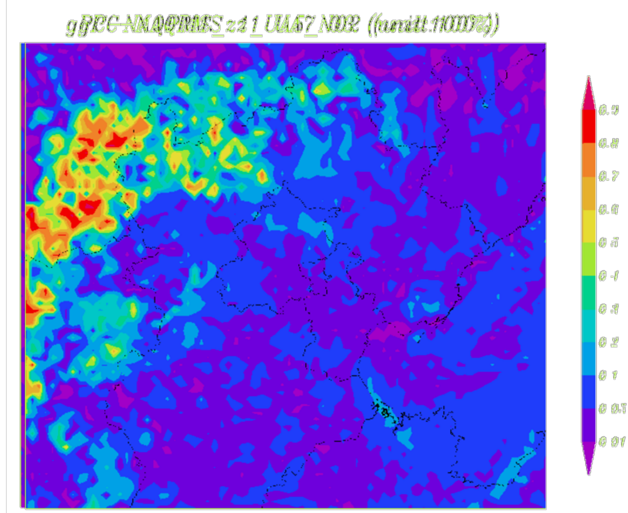
Model Uncertainty Analysis

Source of bias between mod and obs:
$$\overline{(C_o - C_p)^2} = \underbrace{\overline{(\delta C_p)^2}}_{(a-1)} + \underbrace{\overline{(\delta C_o)^2}}_{(a-2)} + \underbrace{(\bar{d})^2}_{(b)} + \underbrace{\sigma_c{}^2}_{(c)}$$

	Uncertainty factors	Distribution	Perturbation	Polynomial basis
ζ_1	NO_x emission	Beta	[-10%,+10%]	Jacobi
ζ_2	u	Beta	[-10%,+10%]	Jacobi
ζ_3	v	Beta	[-10%,+10%]	Jacobi
ζ_4	t	Beta	[-10%,+10%]	Jacobi
ζ_5	NO_2 Dry Deposition velocity	Beta	[-10%,+10%]	Jacobi
ζ_6	NO_2 Vertical Diffusion coeff	Beta	[-10%,+10%]	Jacobi
ζ_7	NO_2 Photolysis coeff	Beta	[-10%,+10%]	Jacobi







Kalman Filter Inversion

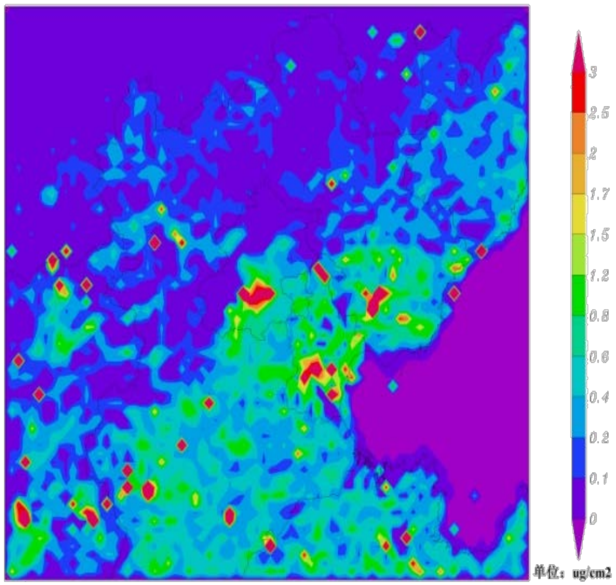
Basic formula:

$$E_{i+1} = E_i + G_i\left(obs_i - mod_i\right)$$

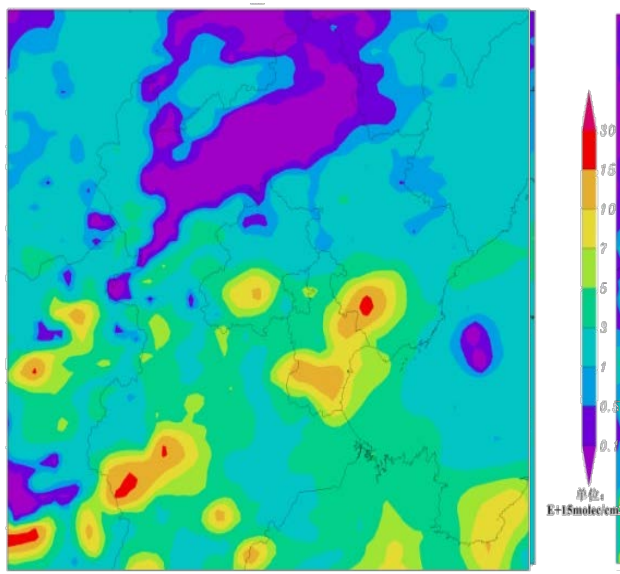
E—emission field:

obs—observation:

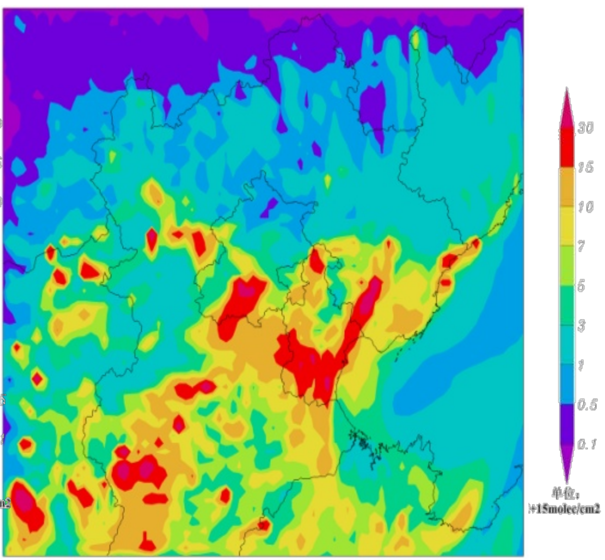
mod—chemical field:



(2008-08-02 original NOx emission field)



(2008-08-02 13:00 OMI NO_2 VCD)



(2008-08-02 13:00 model NO_2 VCD with original EI)

G—Kalman Filter gain matrix:

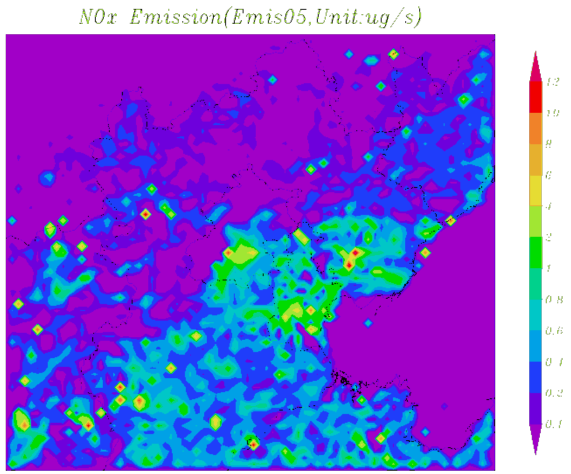
$$G_i = C_i P_i^T \left[P_i C_i P_i^T + N_i\right]^{-1}$$

C—covariance of error in emission field:

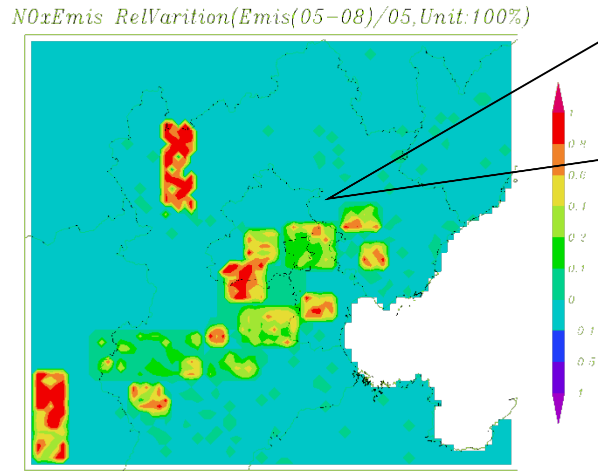
$$C_{i+1} = C_i - G_i P_i C_i$$

Result——Updated Emission Inventory

Original NOx EI（Emis05）：

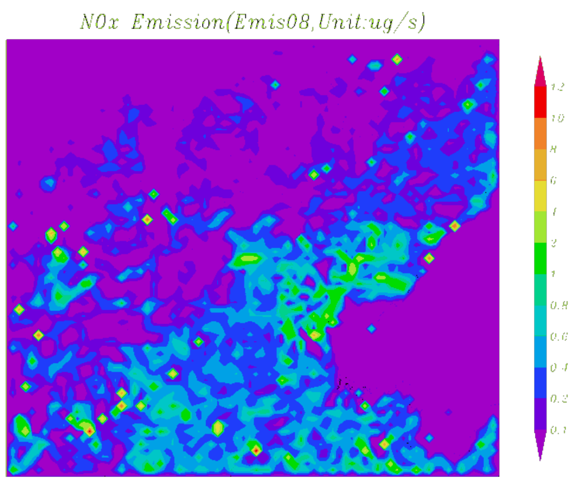


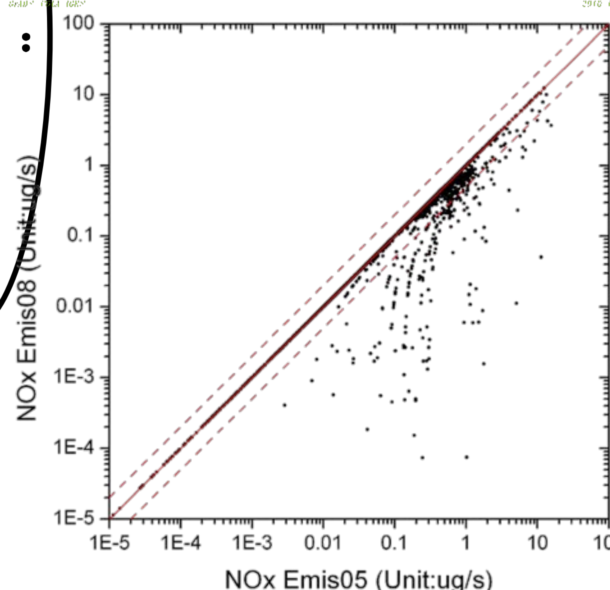
Differences between 2 EIs：



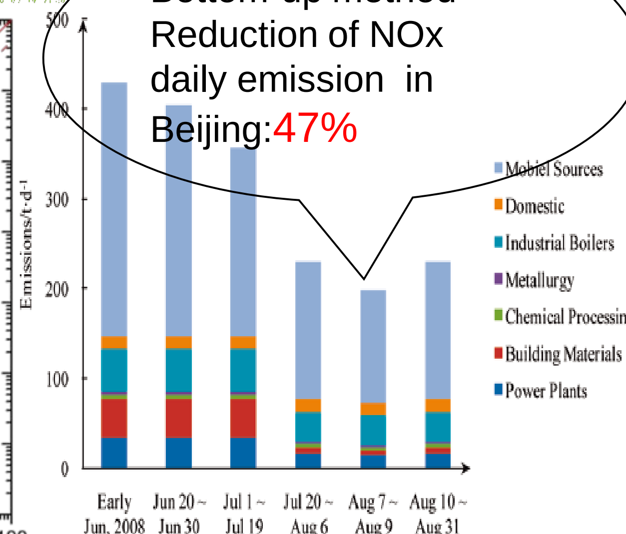
Top-down method—
Reduction of Emis08 vs. Emis05 on average：↓39.5% ！
Reduction in Beijing: ↓47.5%！
Computation Costs: 4 Iterations on average

Updated NOx EI（Emis08）：





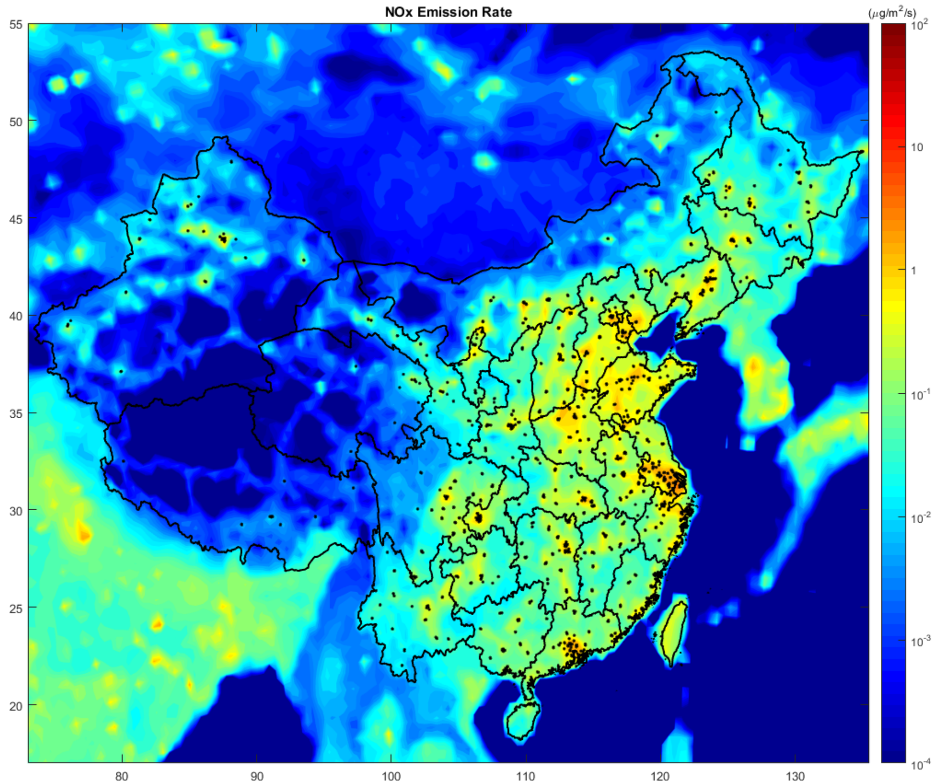
Bottom-up method—
Reduction of NOx daily emission in Beijing:47%



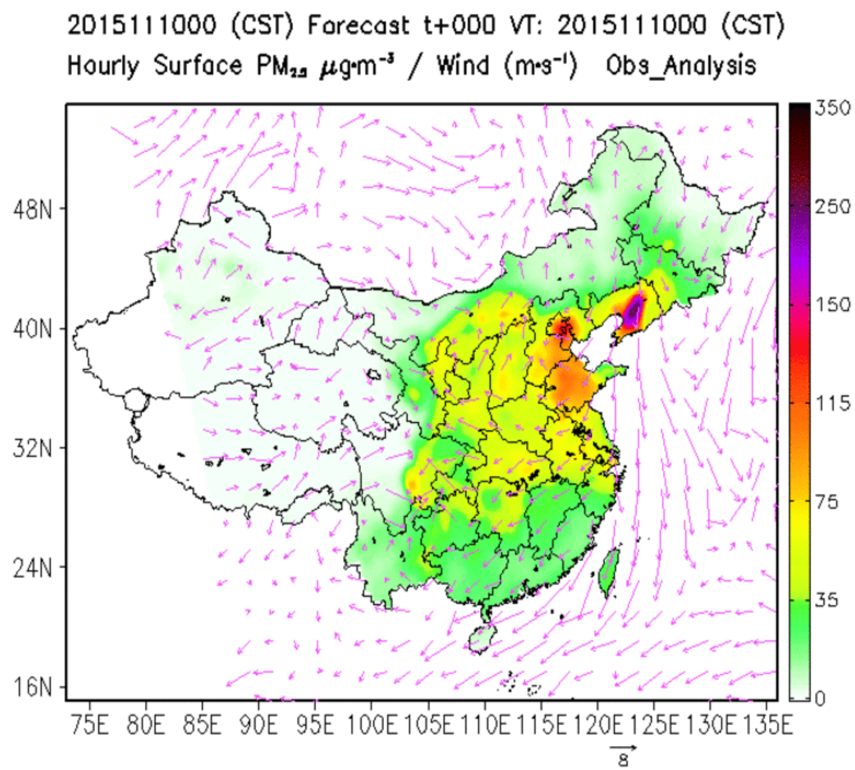
（Wang et al., 2010 ）

Using ChemDAS for Routine data assimilation at China National Environment Monitoring Center

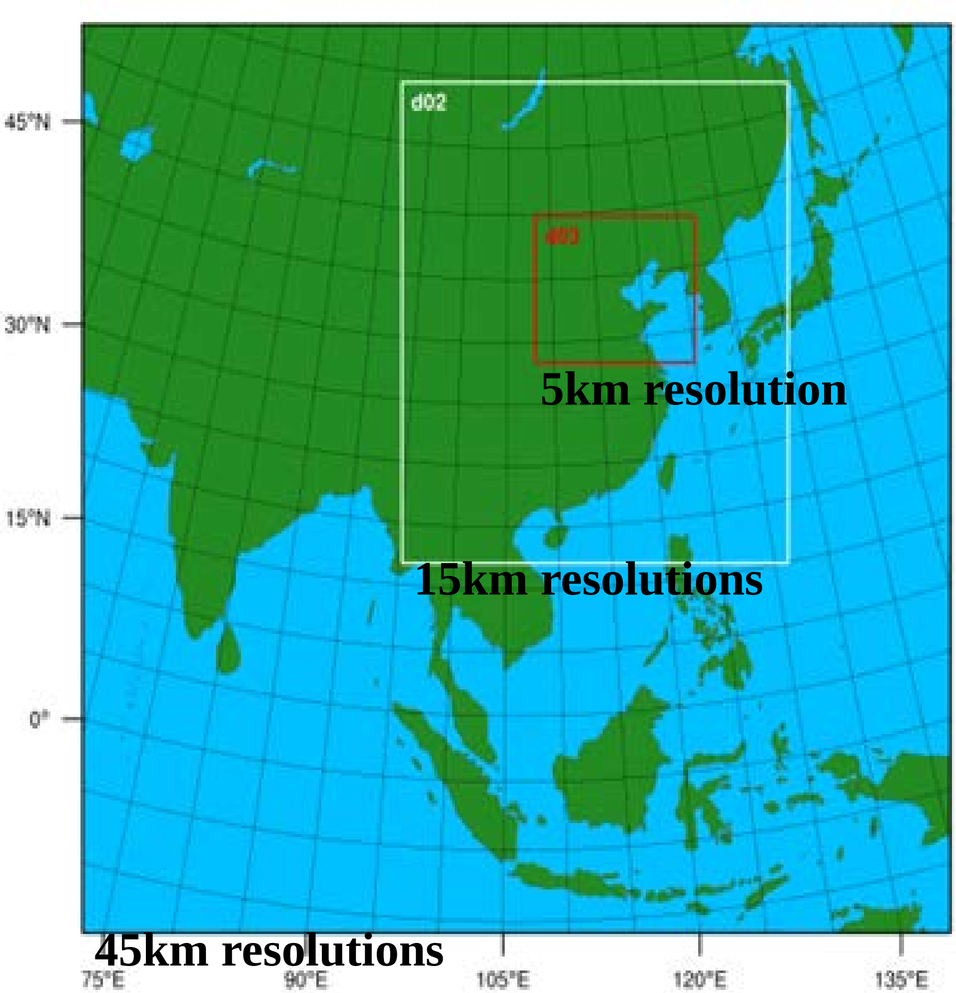
National Air Quality Monitoring Network (>1500 stations)

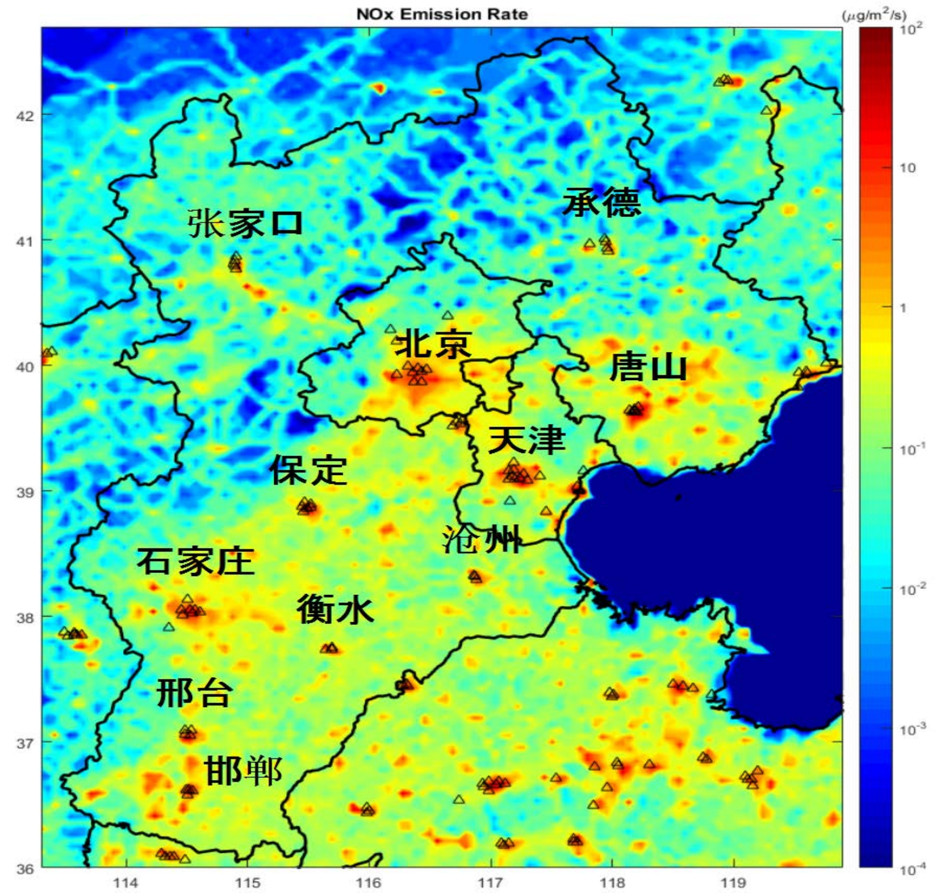


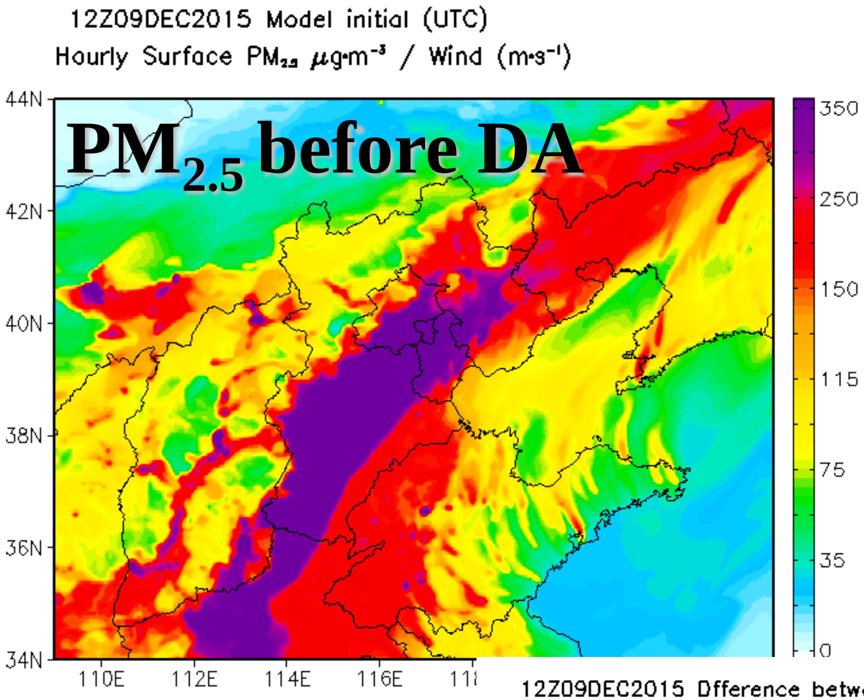
Near real data assimilation

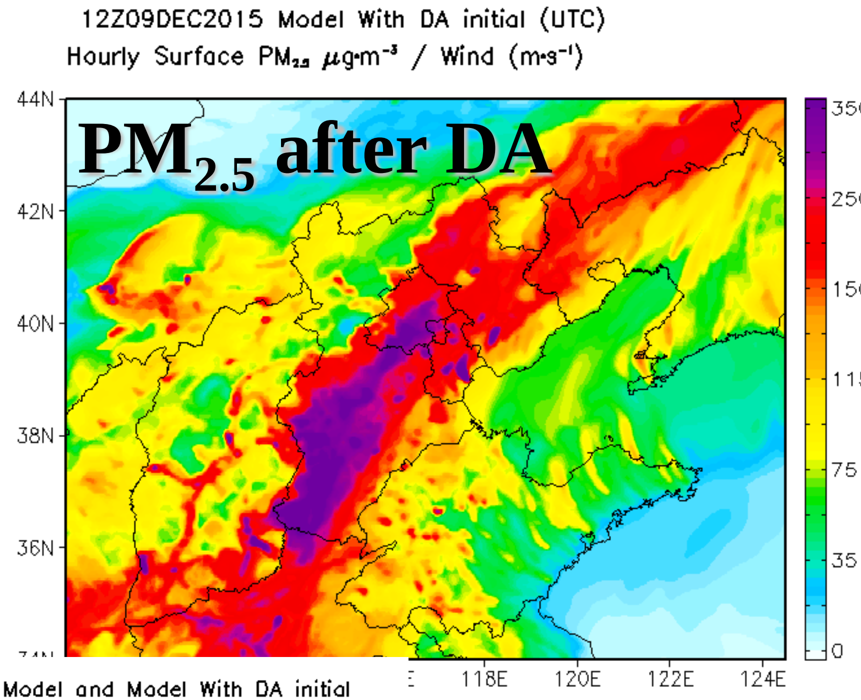


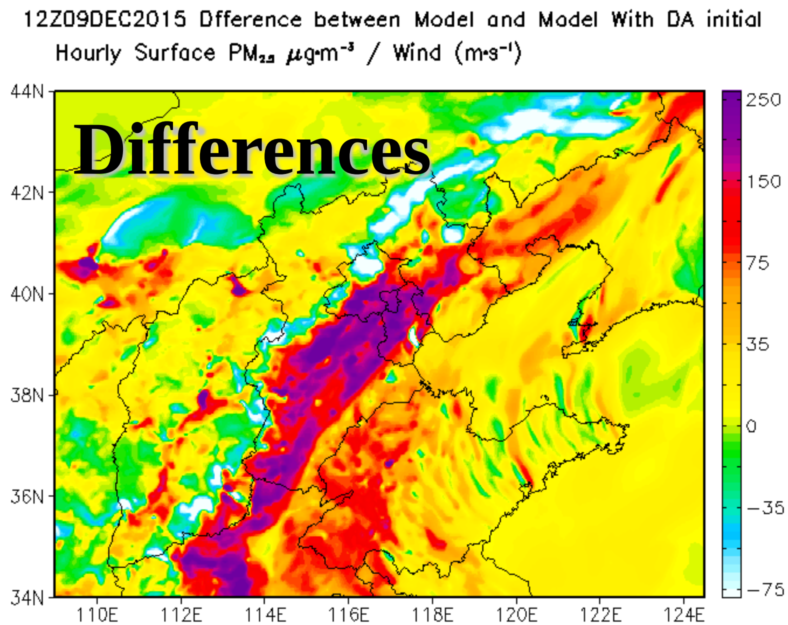
Assimilating surface observations of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone(O_3), fine particulate matter ($PM_{2.5}$) into the model with three nested domains





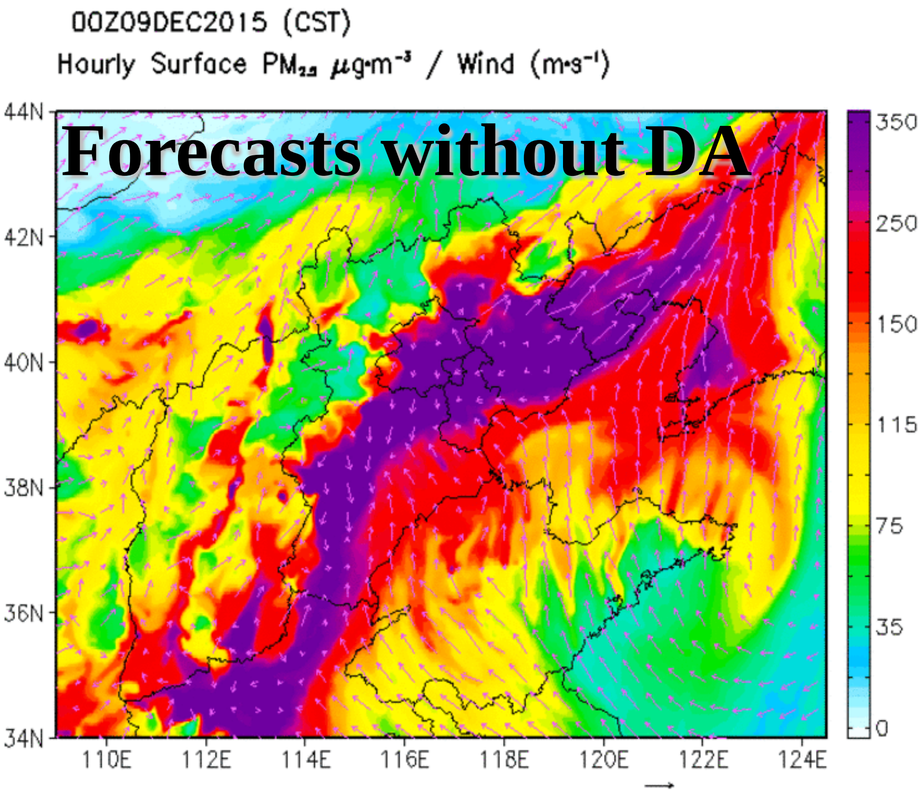


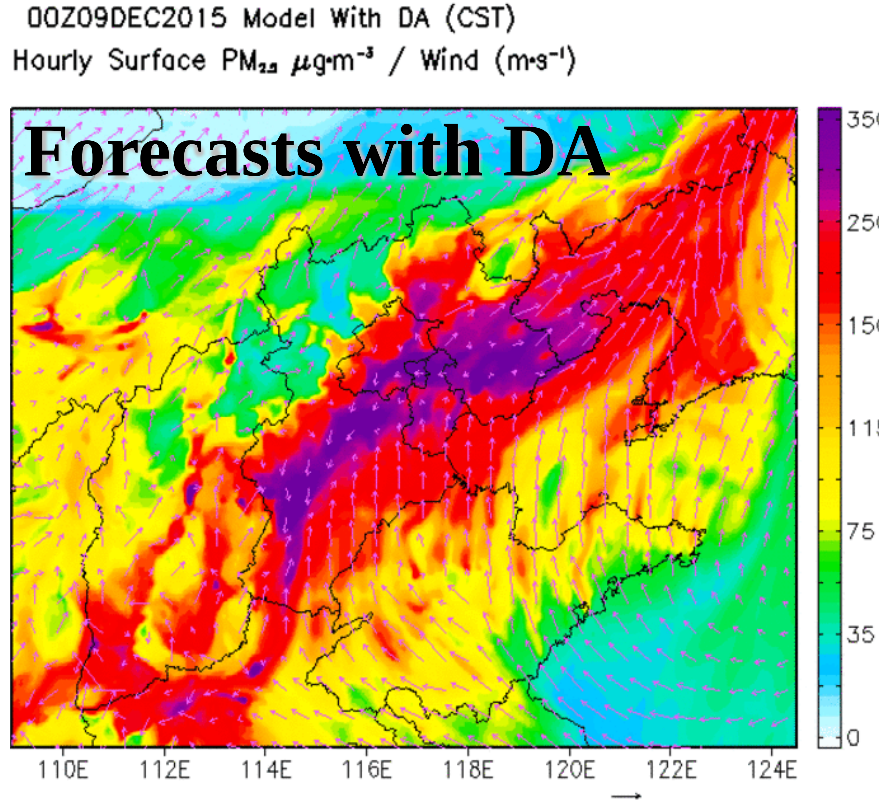


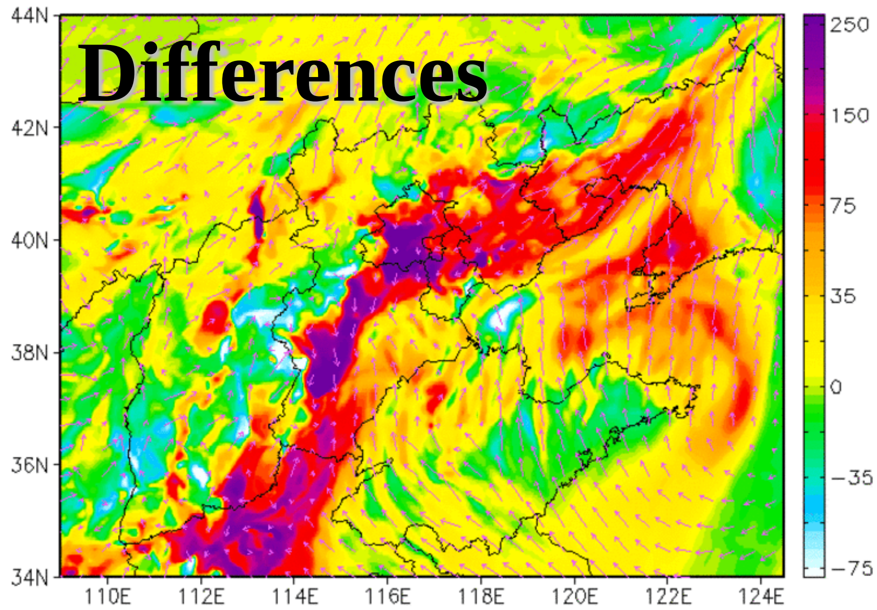


Sources: CNEMC

中国环境监测总站

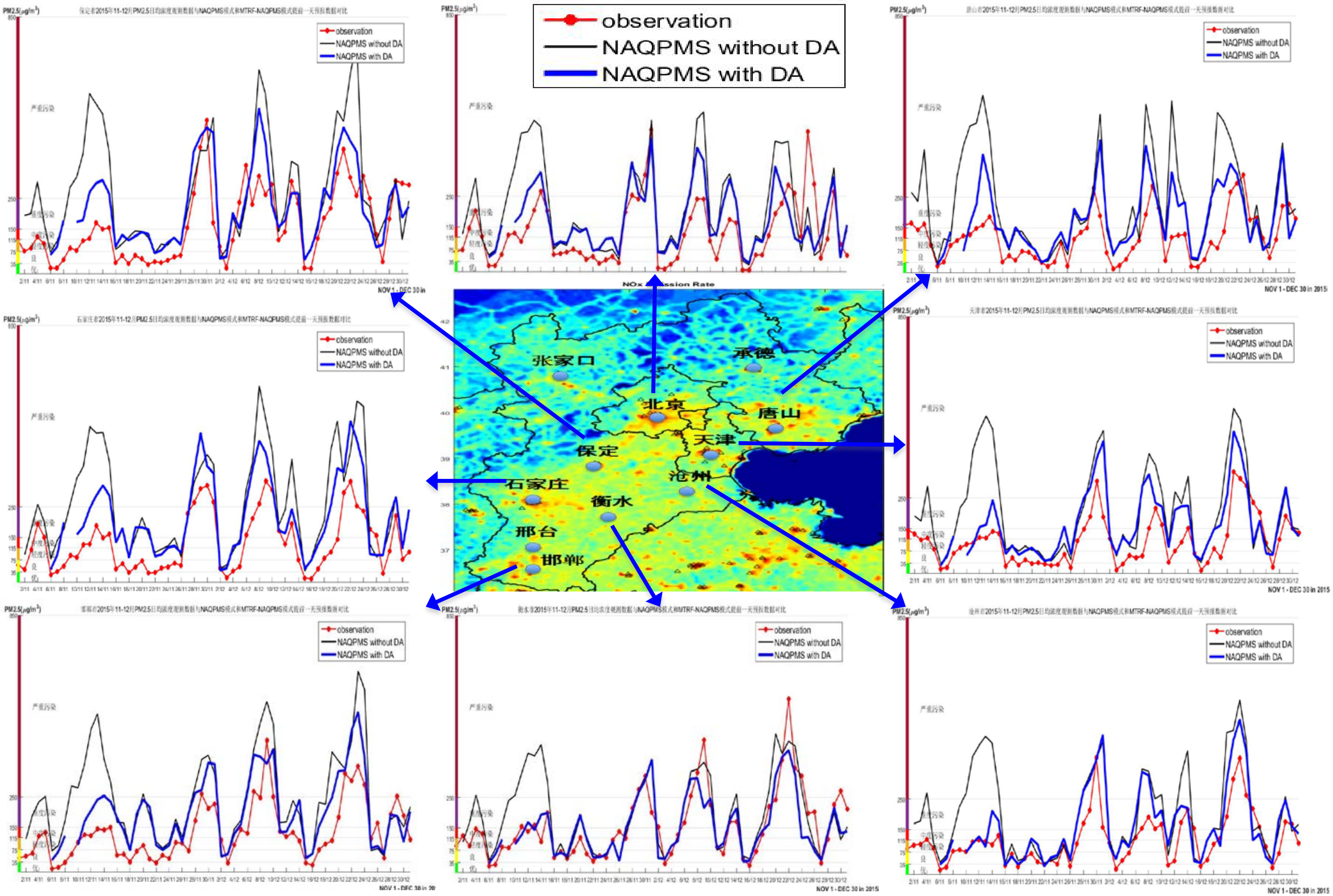






Sources: CNEMC
中国环境监测总站

Routine air quality forecast with and without DA



24-hour $PM_{2.5}$ forecast at CNEMC during Nov 1 - Dec 30, 2015

Comparison of root mean square errors ($\mu g/m^3$) of the forecasts

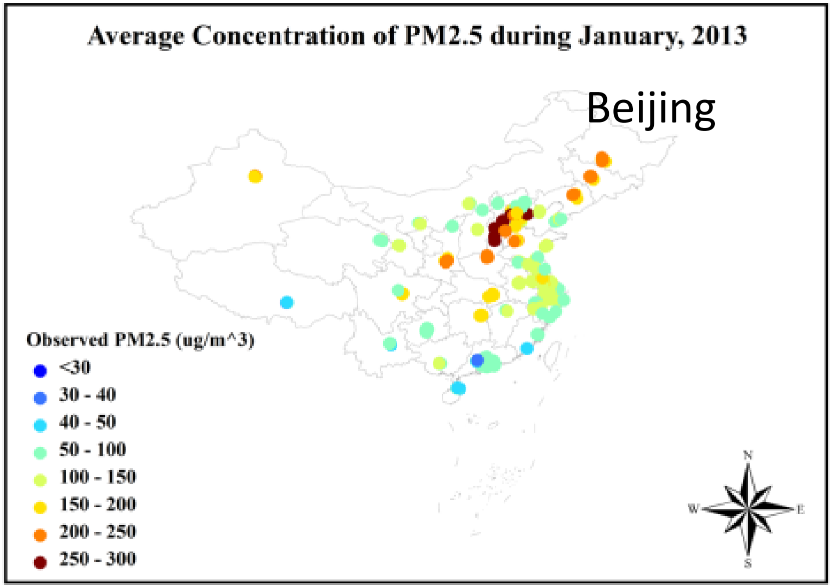
	NAQPMS without DA	NAQPMS with DA	Improved by
24-h forecast	124.7	77.4	38%
48-h forecast	125.2	84.2	33%
72-h forecast	133.7	94.1	30%

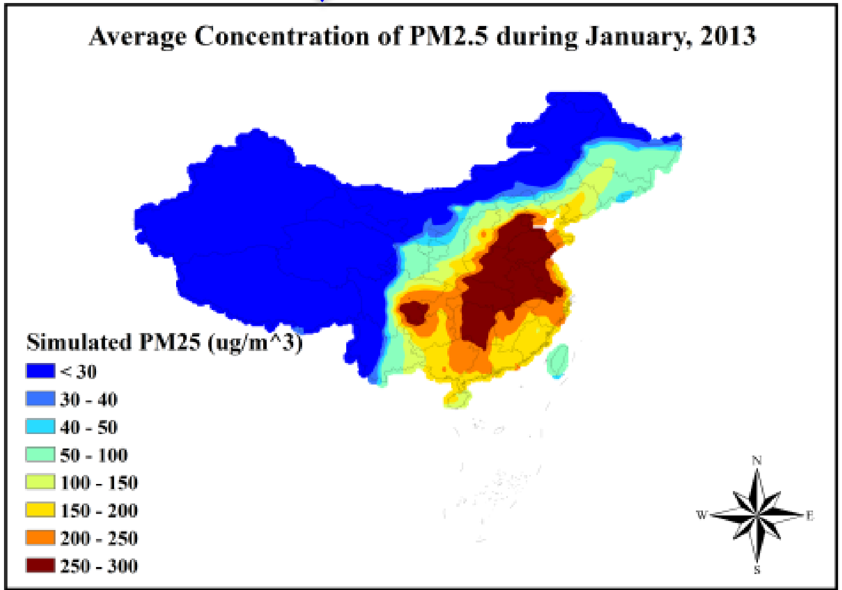
Comparison of biases ($\mu g/m^3$) of the forecasts

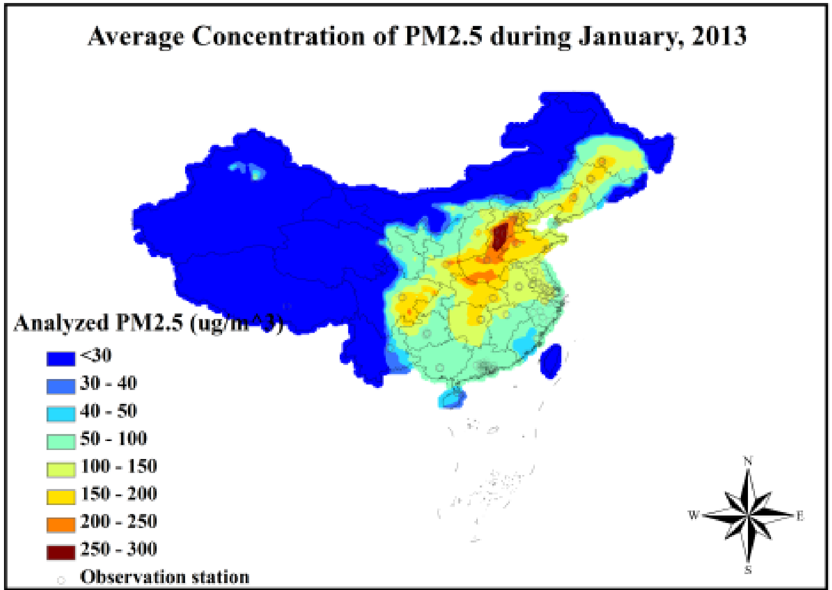
	NAQPMS without DA	NAQPMS with DA	Improved by
24-h forecast	76.3	37.6	51%
48-h forecast	78.1	46.8	40%
72-h forecast	91.1	57.3	37%

Using ChemDAS to estimate air pollution state

Observed data
VS
Analyzed data
VS
Simulated data







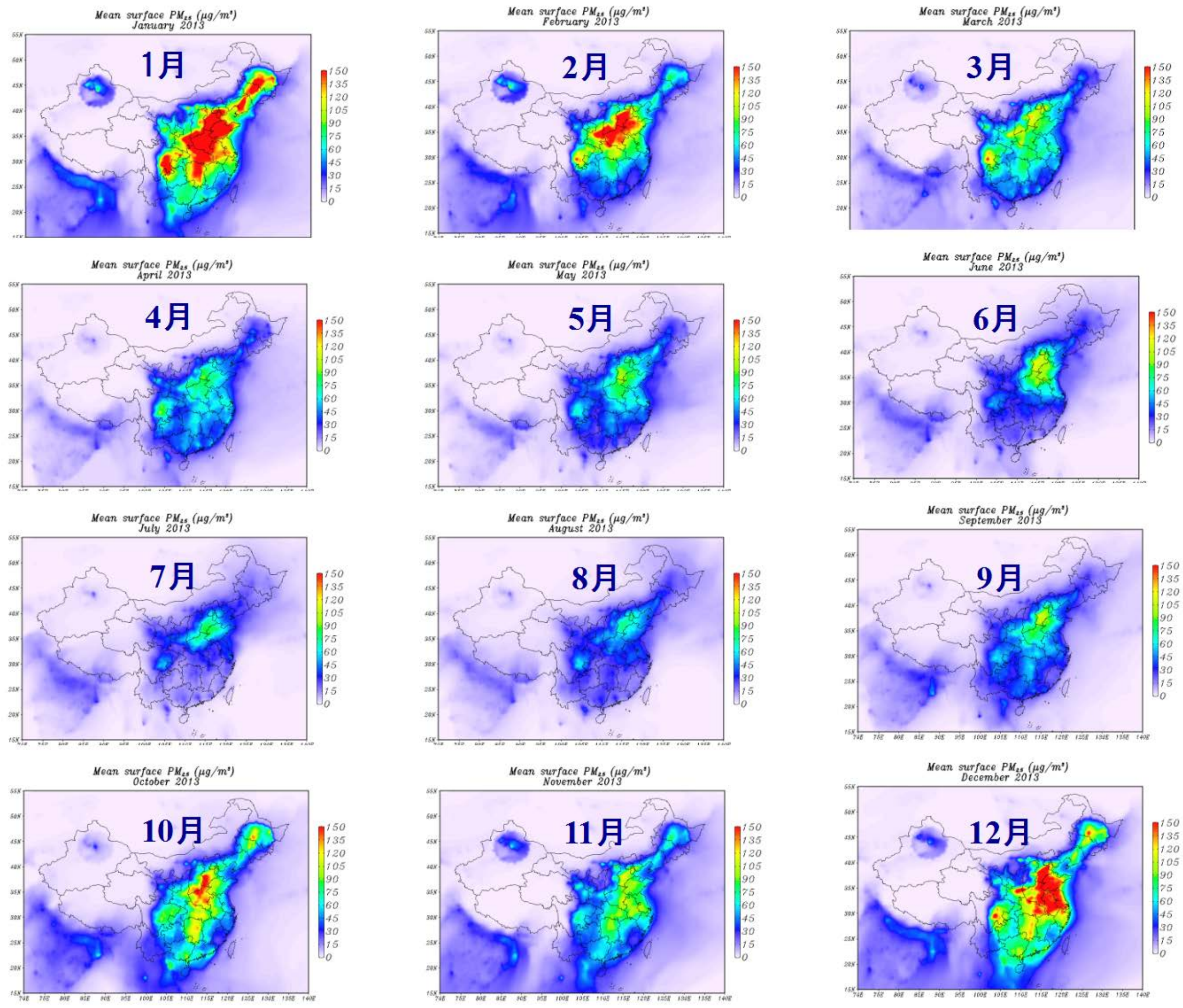
DA significantly improved $PM_{2.5}$ estimation

Cross Validation (CV) Experiments

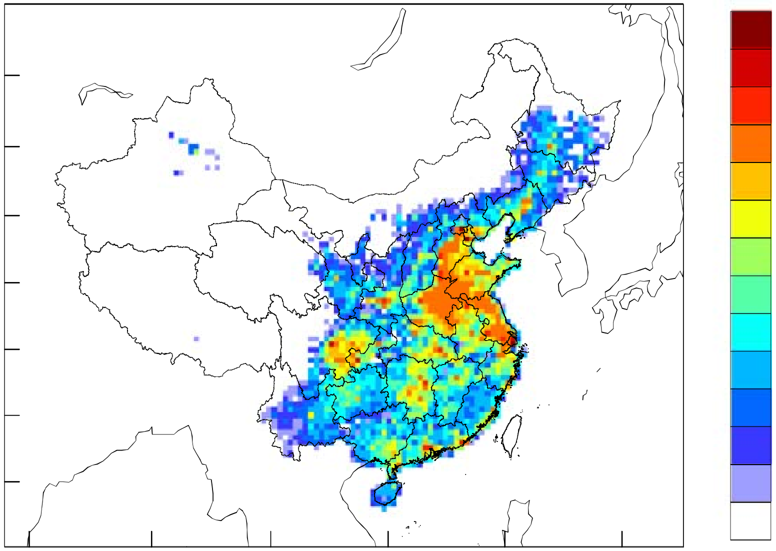
CV experiments	Simulated PM2.5		Analyzed PM2.5	
	RMSE (μg/m^3)	Relative errors	RMSE (μg/m^3)	Relative errors
CV01	139.0	56%	28.5	20%
CV02	131.6	57%	25.6	19%
CV03	144.9	66%	27.1	19%
CV04	139.2	68%	36.1	21%
CV05	141.6	64%	27.4	16%

Observation stations were divided into 5 subsets.
In each experiment, one subset of observations was withheld for validation

Hourly $PM_{2.5}$ Reanalysis dataset in 2013



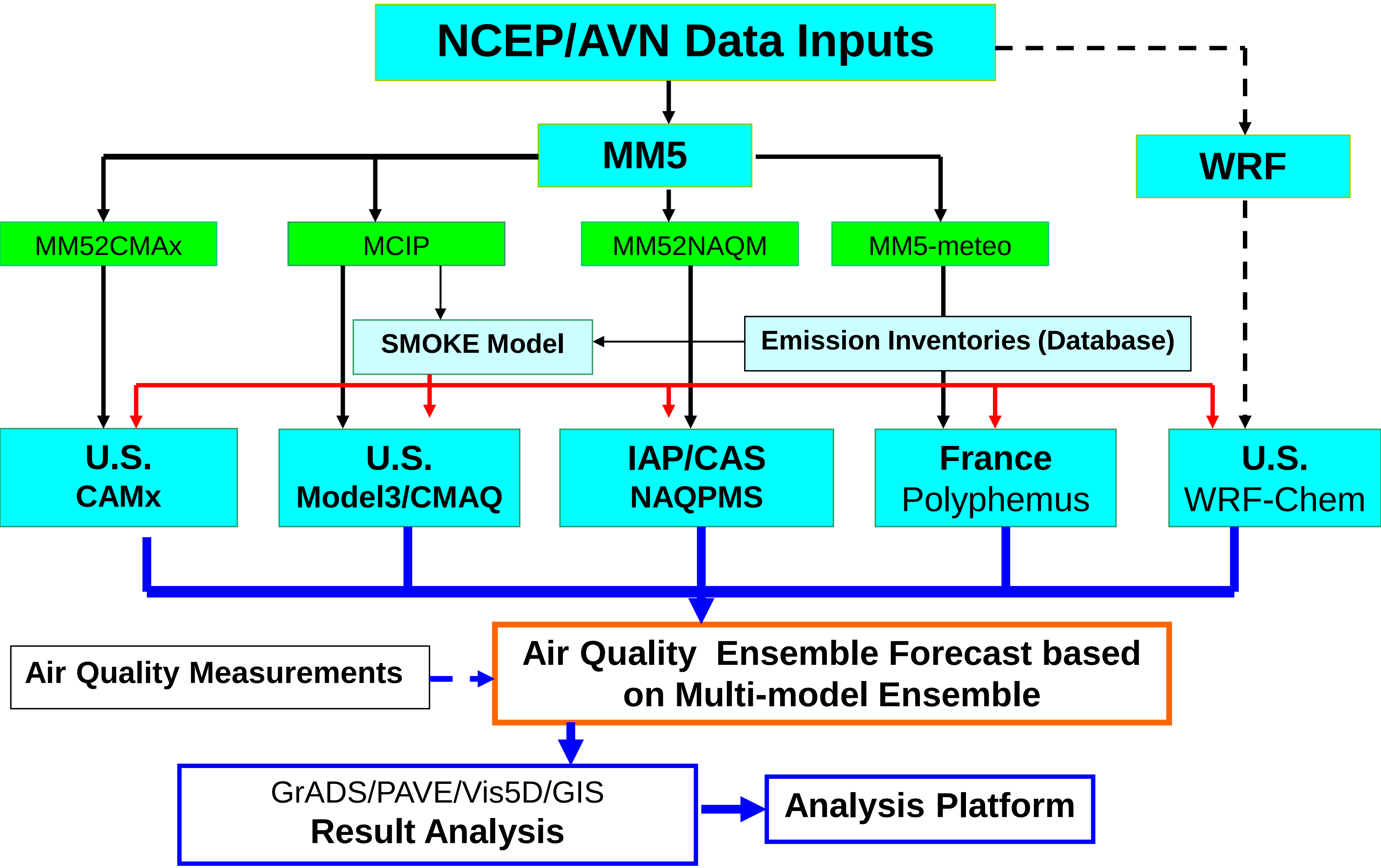
Estimating adult mortality attributable to $PM_{2.5}$ exposure in China with assimilated $PM_{2.5}$ concentrations based on a ground monitoring network



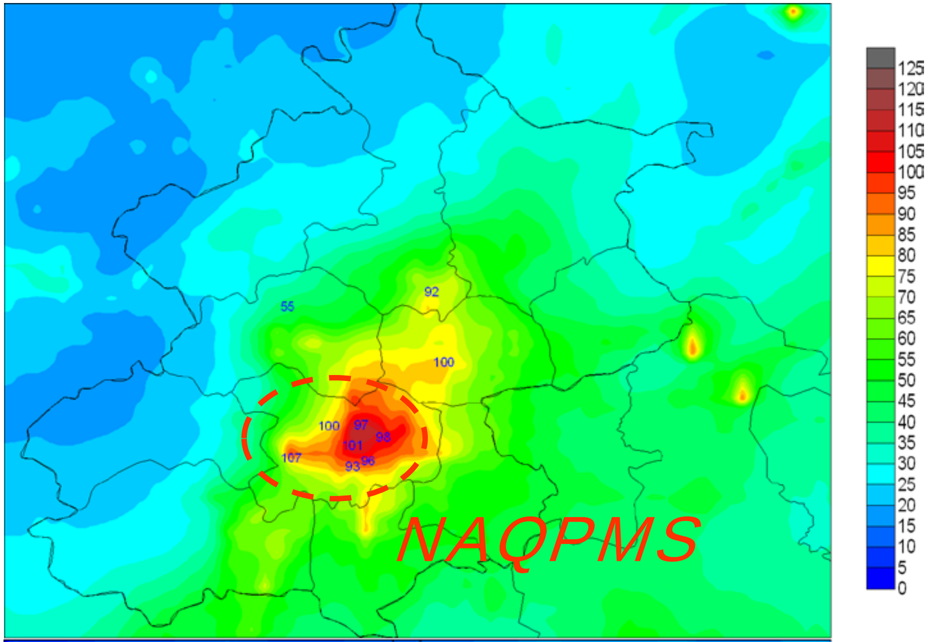
Liu et al., STOTEN , 2016

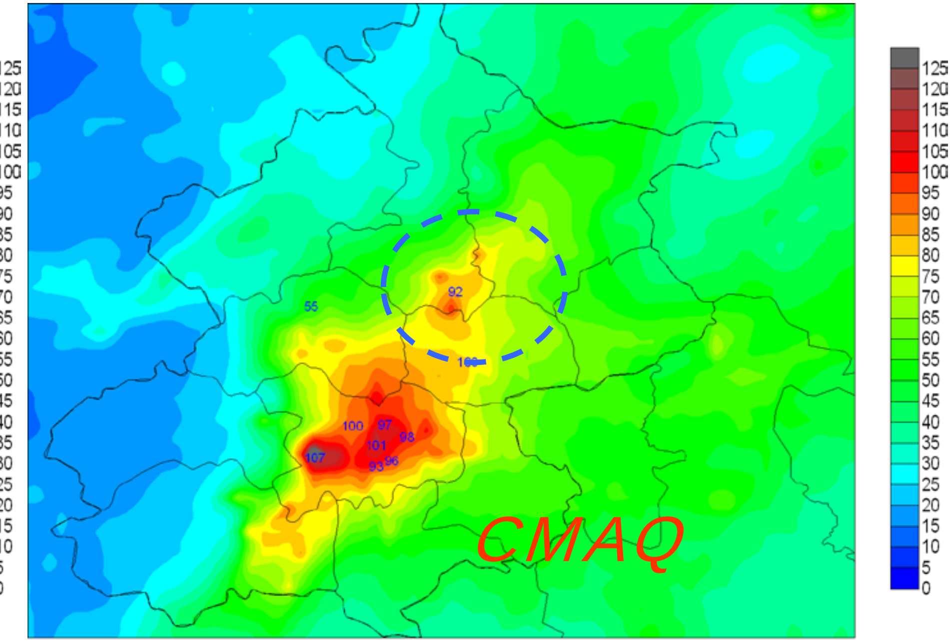
Ensemble Model System for air quality forecast

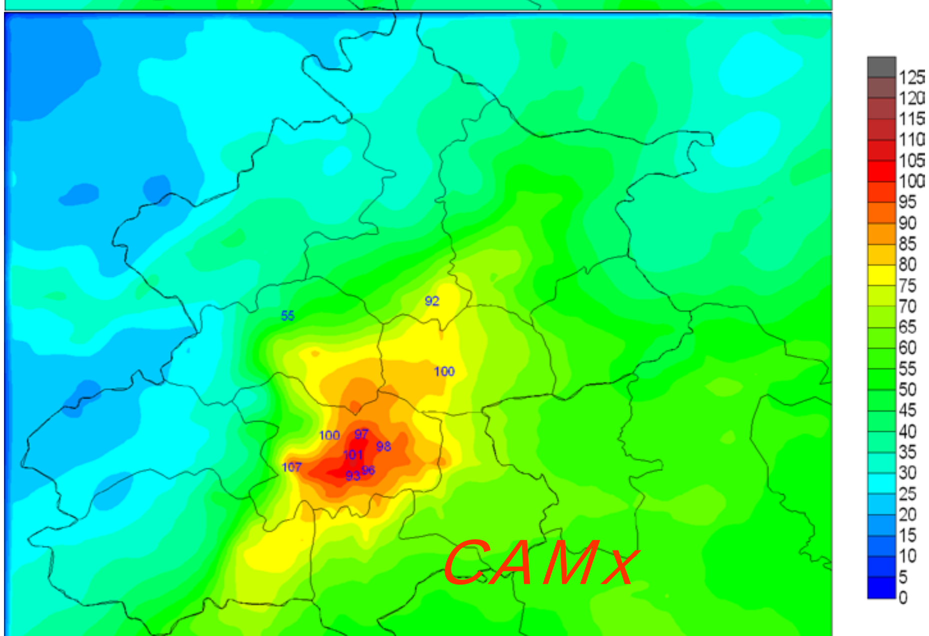
Design of Emsemble Model System



The spatial distribution of PM10 concentration

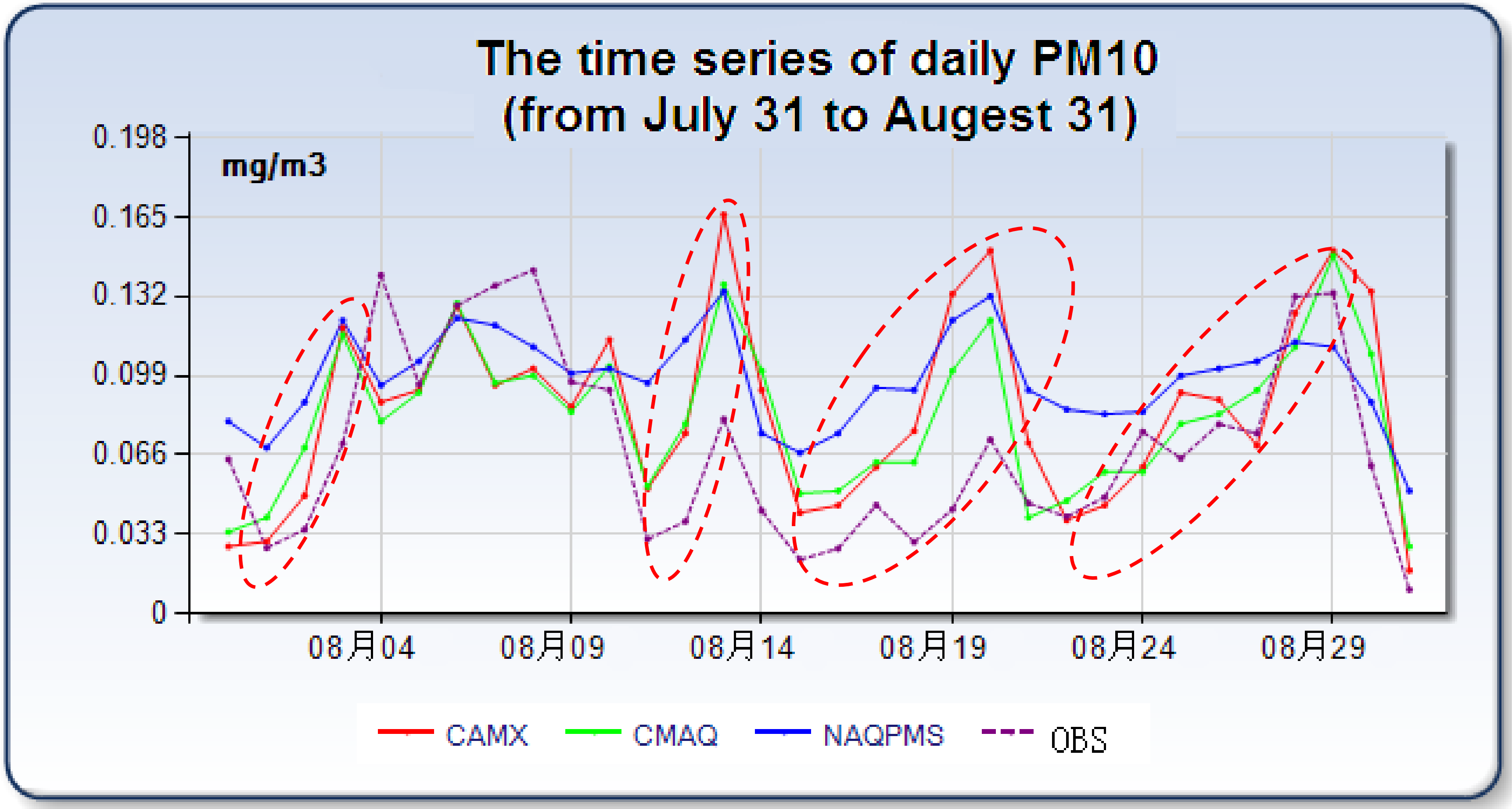






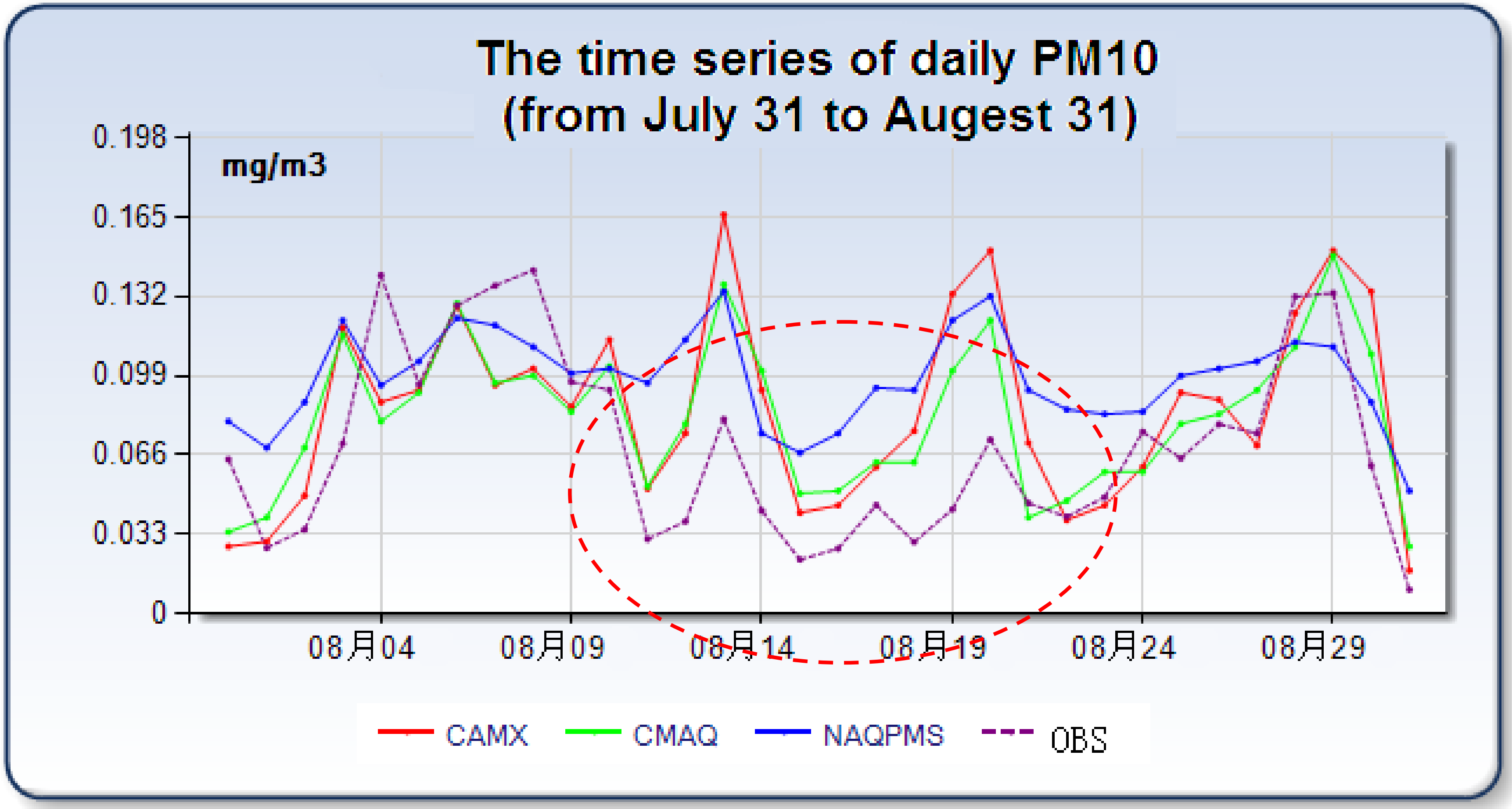
- **Forecast the spatial distribution of PM10 concentration**
- **In red region, NAQPMS match to the observation better than the other two**
- **But in blue region, CMAQ is better**
- **No best single model, thus, multi-models ensemble is necessary**

PM10 simulation in Beijing



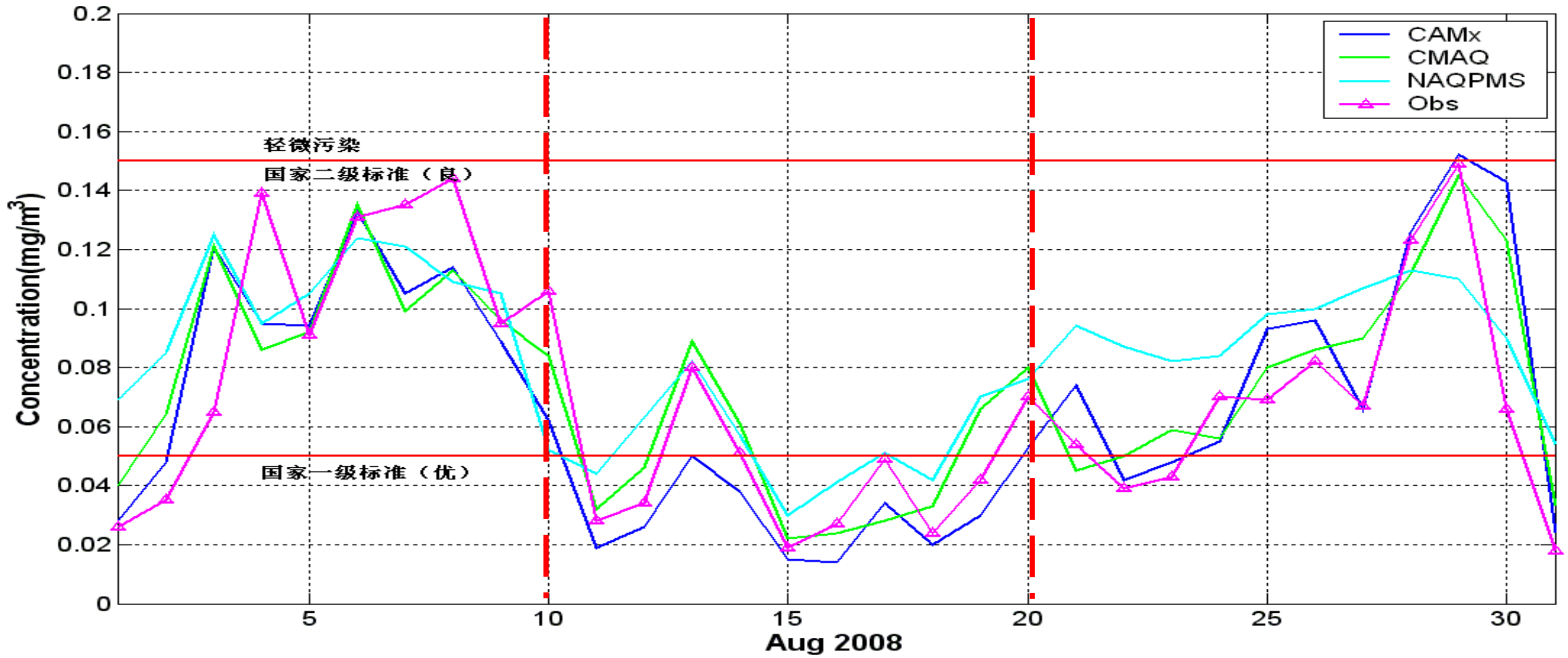
- The models have good skill in PM10 simulation. The four processes of air pollution accumulation are simulated well in Augest 2008.

PM10 simulation in Beijing



- **During the Beijing Olympic Games, all of the three models PM10 simulation concentration overestimate. Emission control and rainfall may be the most important reasons**

Hindcast for Beijing Olympic Games



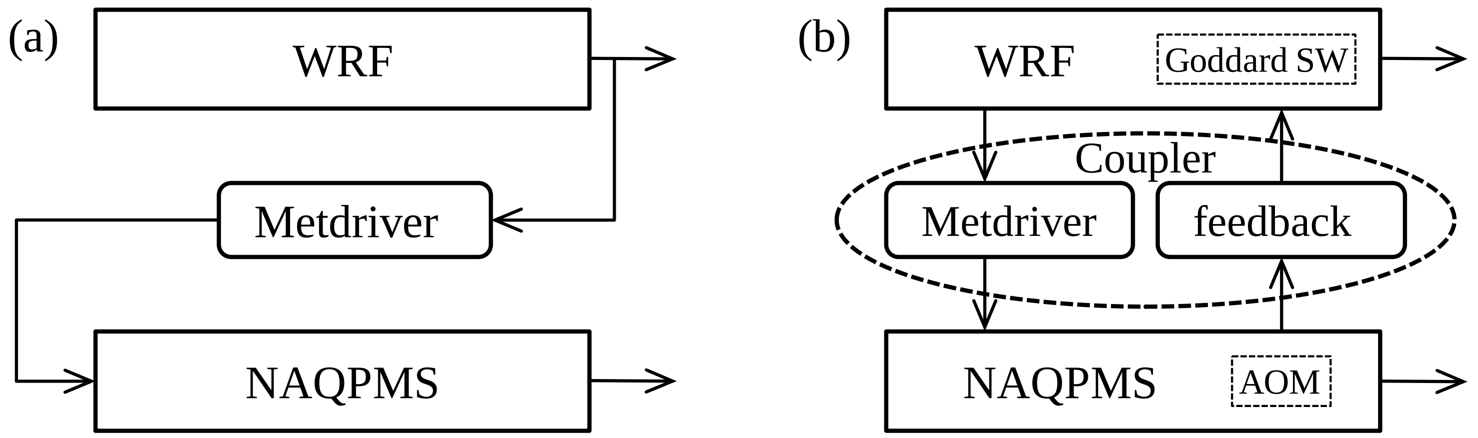
- **Hindcast for PM10 during Beijing Olympic Games shows that PM10 emission may be cut off 200 tons/day.**

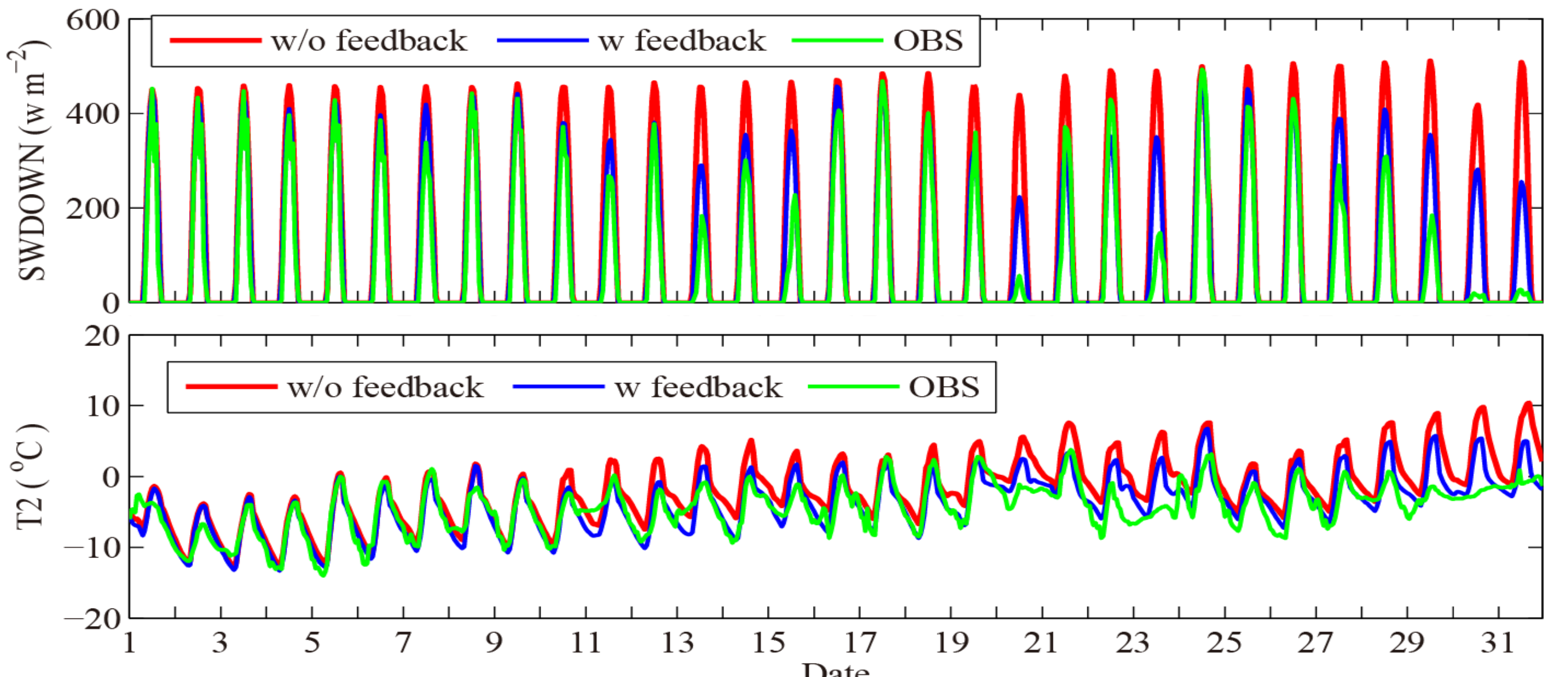
Wang et al. 2010

Major achievements 4

Enhanced air pollution by aerosol direct effect using a two-way coupled model: WRF-NAQPMS

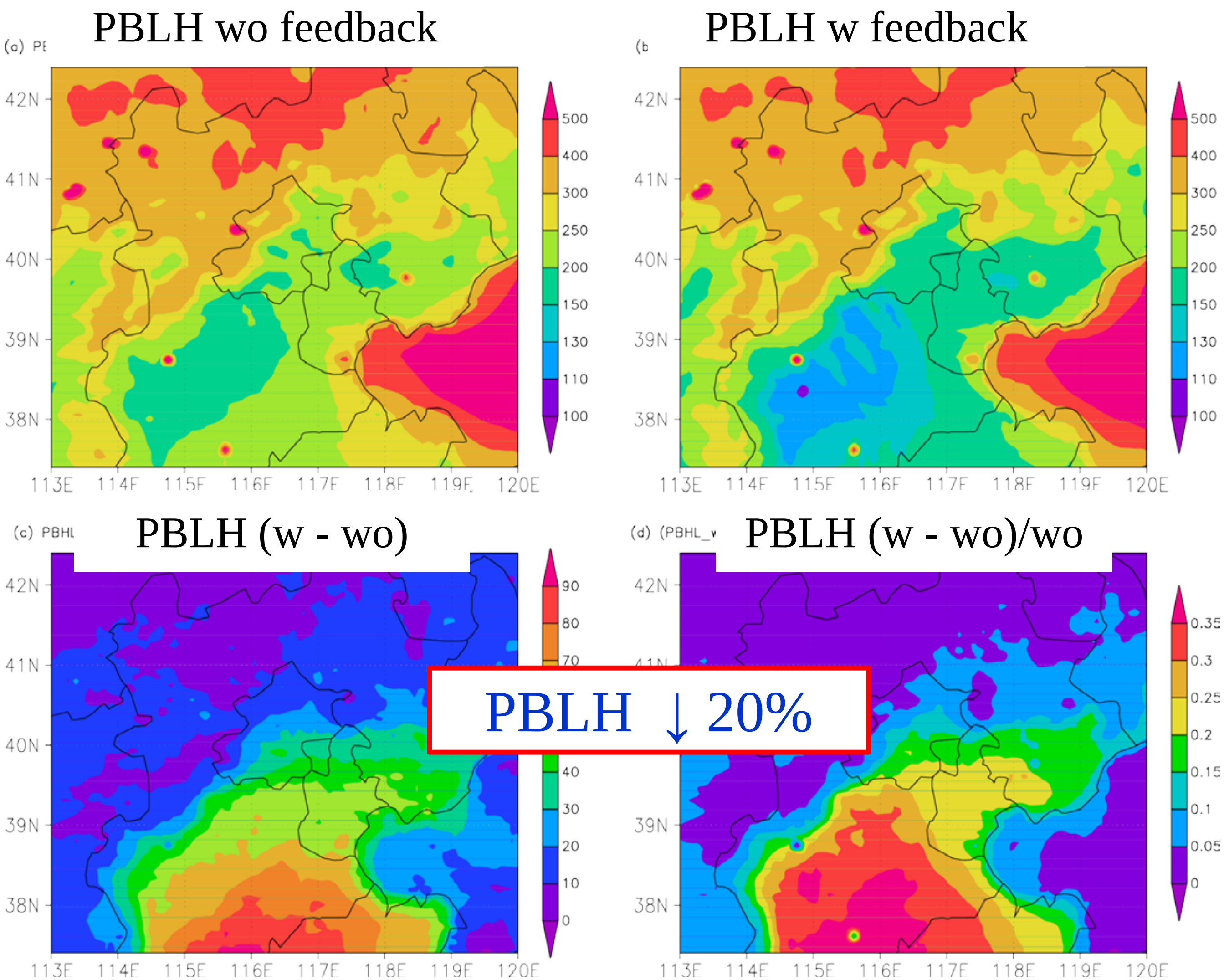
Schematic of (a) offline and (b) two-way coupled WRF-NAQPMS





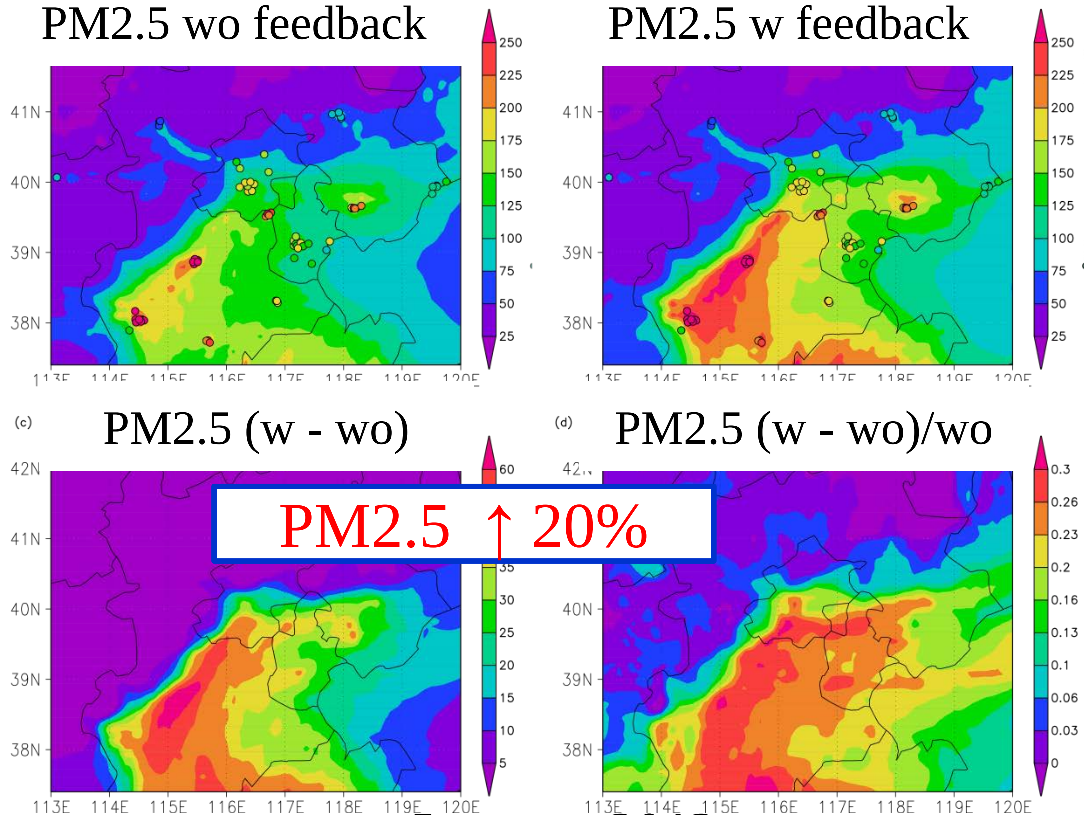
January 2013

Impact of Aerosol radiative feedback on PBLH



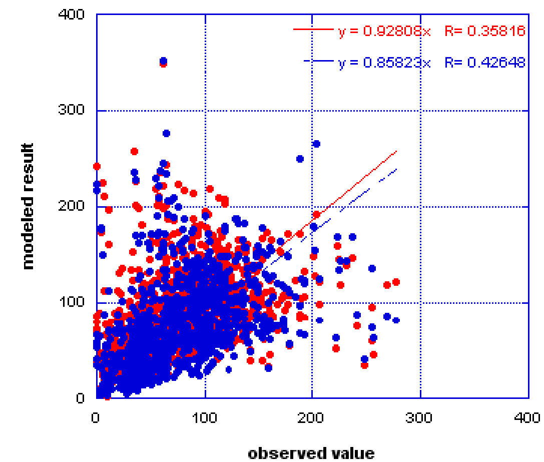
January 2013

Impact of Aerosol radiative feedback on PM2.5 concentration

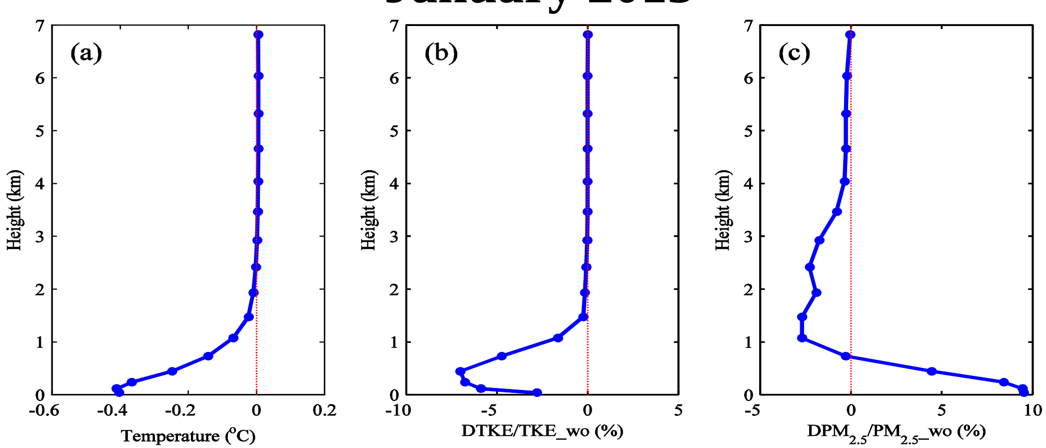


January 2013

WRF-CMAQ Wong et al. 2011



PM2.5 Relative change
~ 8.2 %



WRF-NAQPMS

Vertical distribution of Temperature, TKE and PM2.5 difference

Outline

Preface

I. Program goals, research strategy and milestones

II. Major achievements

III. International scientific and collaborative networks

IV. Contributions to capacity building and academic training

V. Strengths, Weaknesses, Opportunities, Threats

III. International scientific and collaborative networks

Established a network of external collaborators from around the world.

Host the "Joint International Center on Air Quality Modeling Studies (JICAM)" founded by IAP and Asia Center for Air Pollution Research (ACAP).

Contributes to the MICS-Asia (Model Intercomparison Study for Asia)
Co-Coordinating the activity, making scientific and working plan, organizing workshops and provides advanced modeling analysis tools, meteorological model results, dust emissions, observations network as input to the joint model calculations.

MICS-Asia Phase I and II

- To obtain common understanding of model performance and uncertainties in Asia.
- MICS-Asia Phase I (1998-2000), long-range transport and deposition of sulfur.
- MICS-Asia Phase II (2004-2009), taking into account more species than Phase I.

sulfur, nitrogen compounds, ozone and aerosols

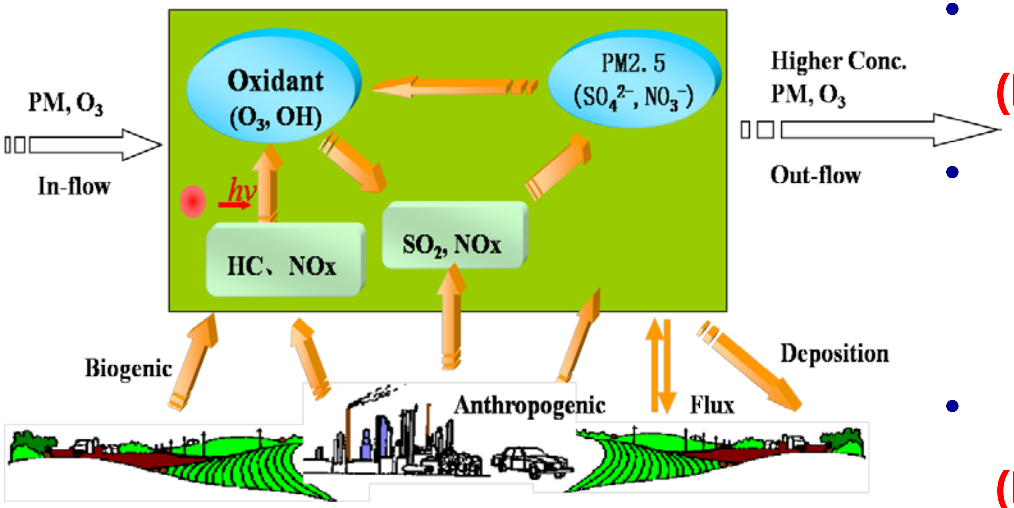
Achievement of MICS-Asia II were published in AE in 2008

MICS-Asia III

February 2008, Austria the 10th MICS-Asia Workshop	Discussing the prospect of Phase III
March 2010, Dalian the 1st International Workshop on Atmospheric Modeling in East Asia	giving an opportunity for more Asian scientists to participate
December 2010, Sanya the 2nd Workshop on Atmospheric Modeling in East Asia	Determining three topics of MICS-Asia Phase III and leaders
September 2011, Chengdu the Third Workshop on Atmospheric Modeling in East Asia	materializing more concrete work plan for each of the three topics
July 2012, Beijing the International Workshop on MICS-Asia III	further discussing work plans for MICS-Asia Phase III
March 2013, Kumming the International Workshop on MICS-Asia III	Progress of MICS-Asia Phase III

FOCUS in MICS-Asia III

Air Pollution Complex in Asia: Regional Haze and High Ozone



- *Topic 1:* Model Intercomparison (Leaders: Z. Wang, K. Yamaji and J. Fu)
- *Topic 2:* Development of reliable emission inventories in Asia (Leaders: J. Woo, T. Ohara, Q. Zhang)
- *Topic 3:* Air Quality/Climate Change (Leaders: G.Carmichael, ZW Han, Y.F Cheng)

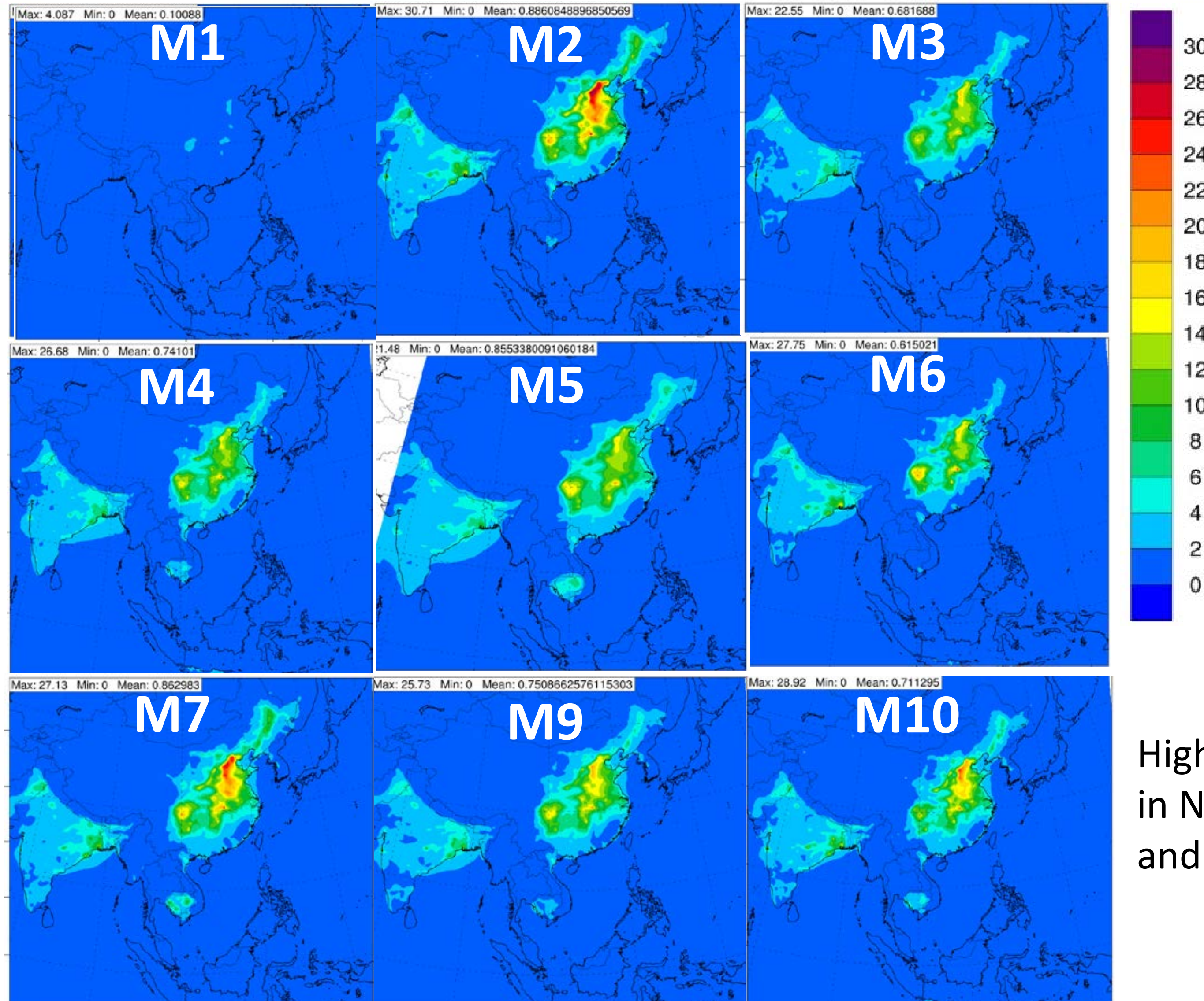
To understand and improve air quality models, we need to

I. Assessing the ability of models to reproduce pollutant concentrations under highly polluted conditions (Regional Haze and High Ozone);

II. Quantifying uncertainties of each process (phys and chem), model resolutions (hori and vert) and key boundary layer parameters.

III. Investigating the air quality responses to specific emissions perturbations in a common case.

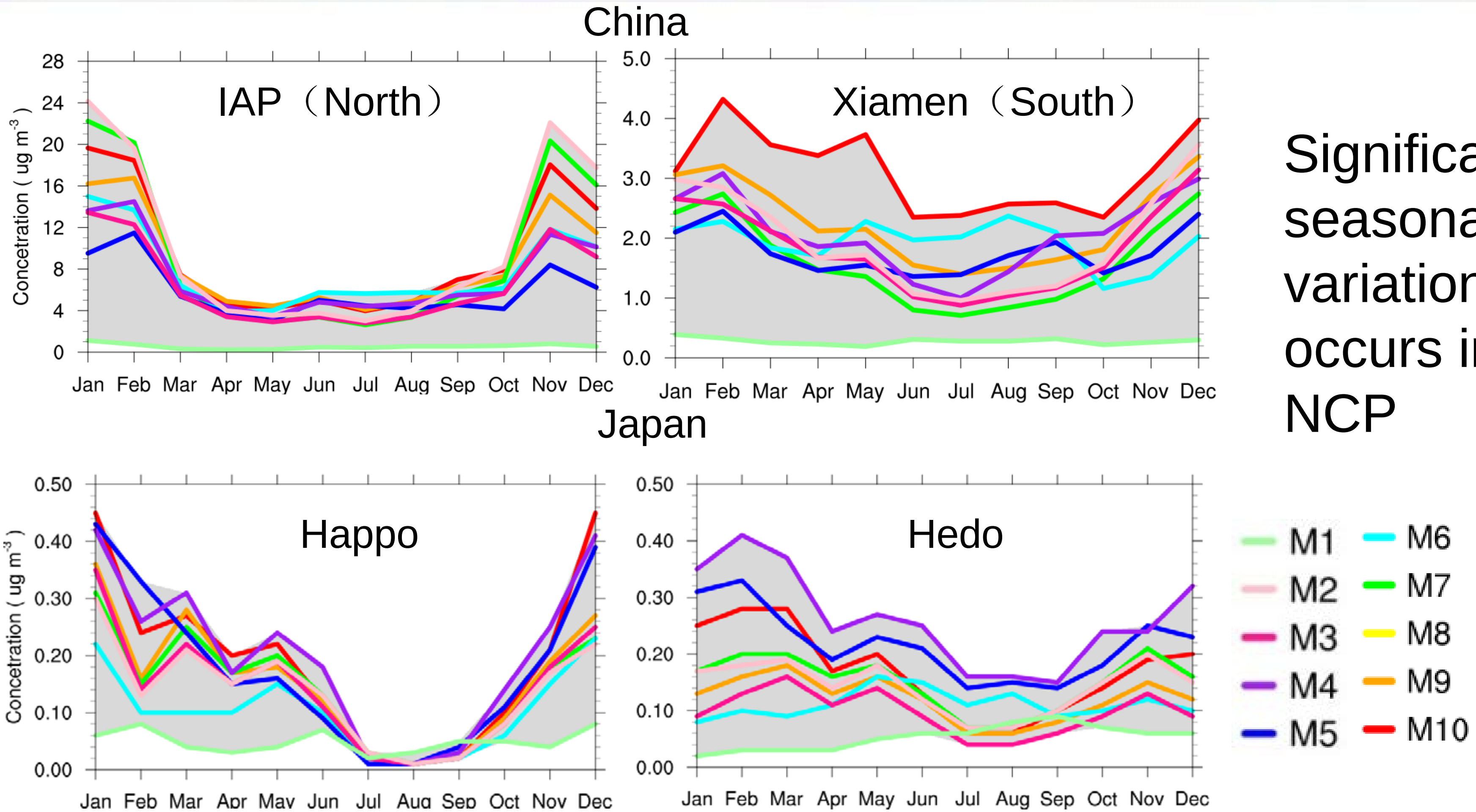
Multi-Model comparison of BC (Jan.2010)



The simulation performance on BC are almost the same except M1 in Jan.,2010.

Higher BC concentration in North China Plain (NCP) and South Tibetan Plateau

BC simulation in different regions



Significant seasonal variation occurs in NCP

Higher concentration distributes over China, especially in the north

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V. Strengths, Weaknesses, Opportunities, Threats

IV. Contributions to capacity building and academic training

Super-Computer System Platform.

Regional air quality monitoring network.

Organized a number of NAQPMS training sessions.

Hosted 57 students as parts of IAP summer school program and provided supervision to 37 PhD and mater students.

Lecture of “Atmospheric Environment ” in the Master Program of University of Chinese Academy of Sciences.

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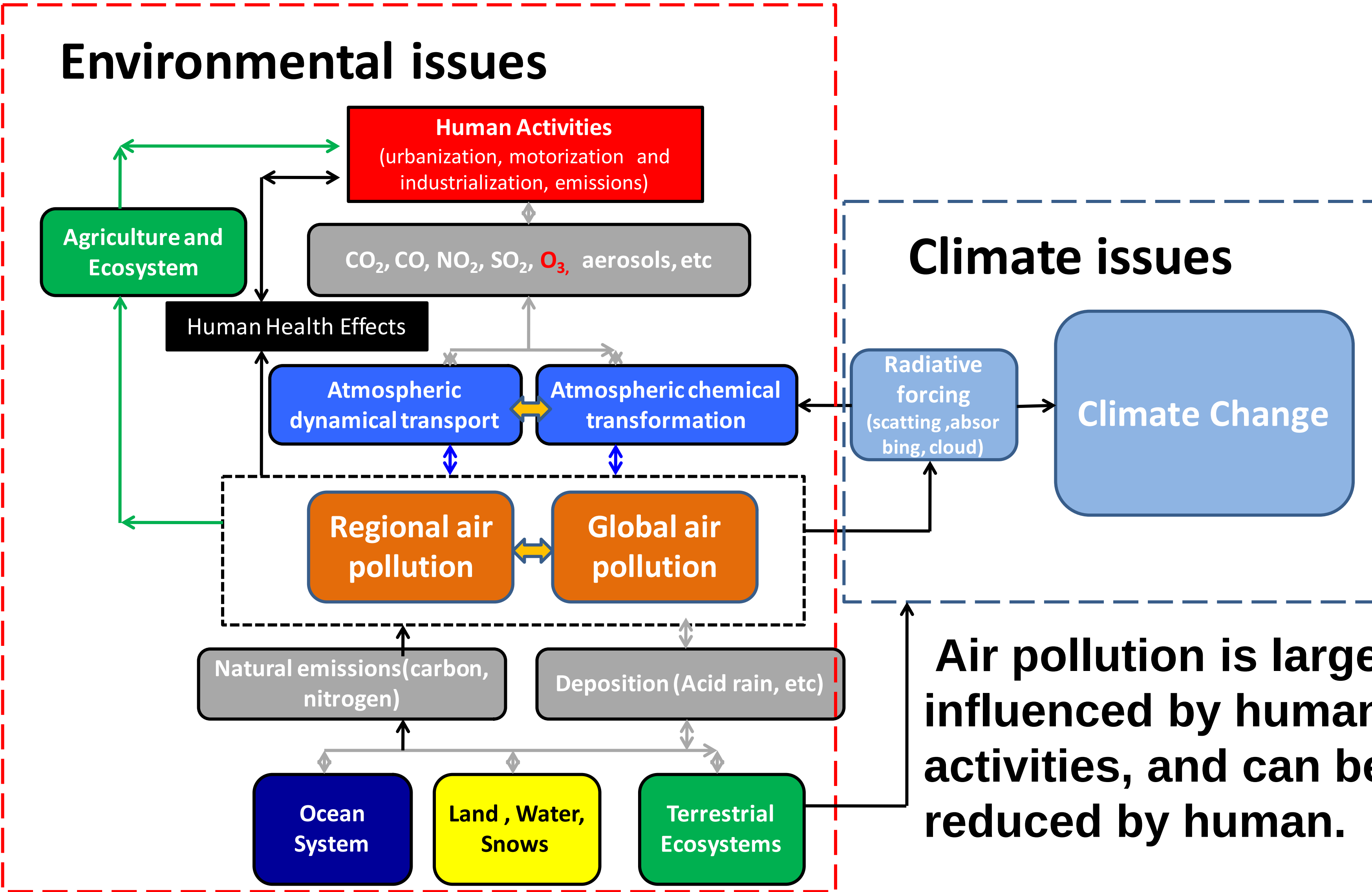
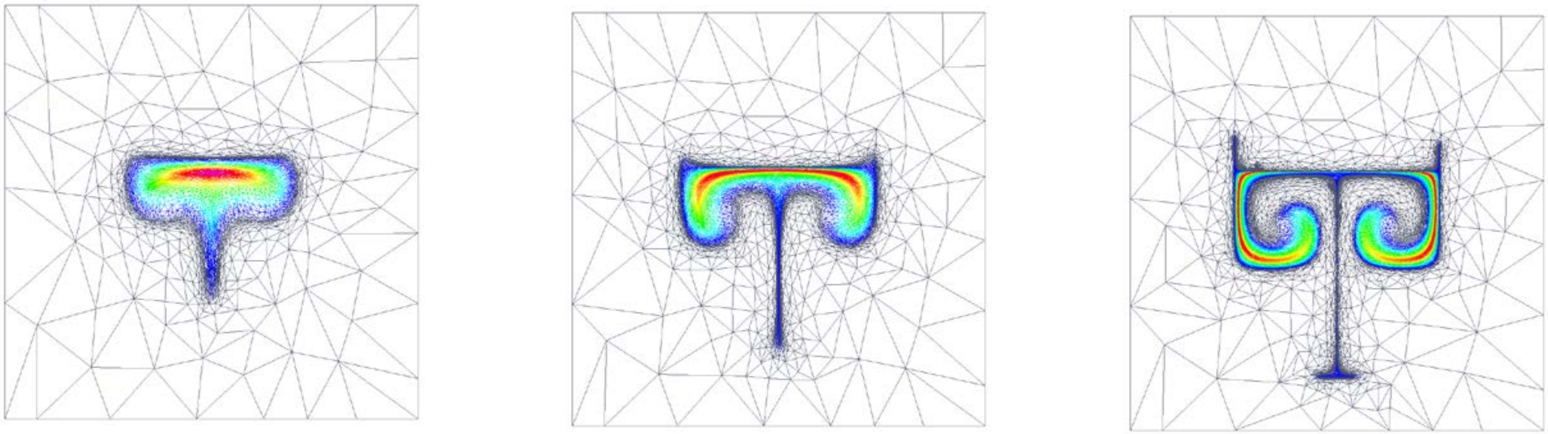
Atmospheric Environmental Model: Critical bridge between human activities and environmental change

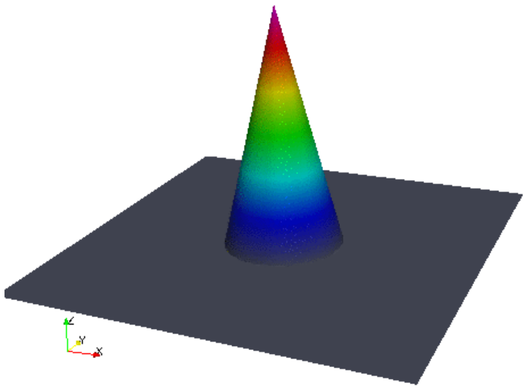


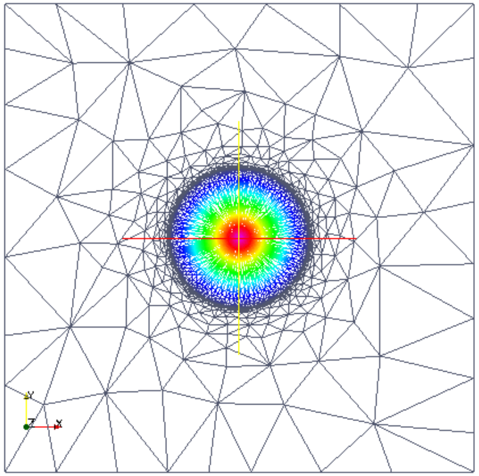
Air pollution is largely influenced by human activities, and can be reduced by human.

Advection scheme for Adaptive Grids



(a) $t=T/20$ (b) $t=T/10$ (c) $t=T/5$

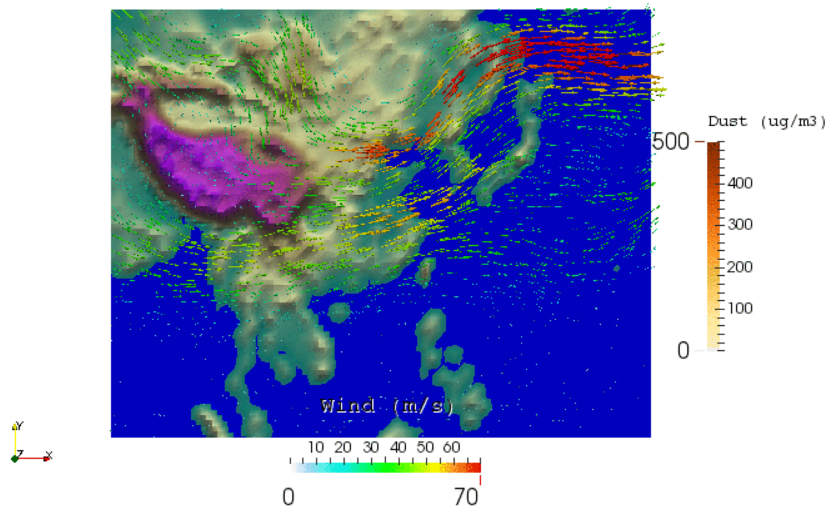


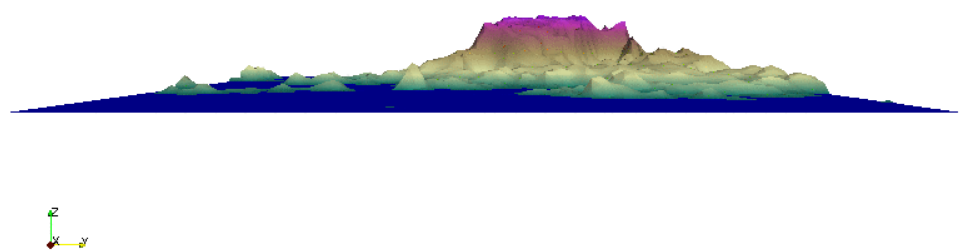


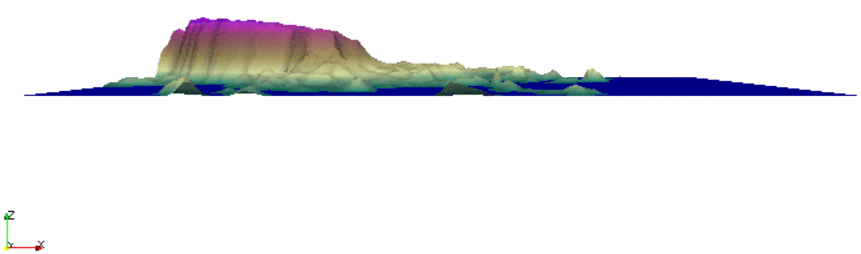
Zheng et al., 2015, GMD

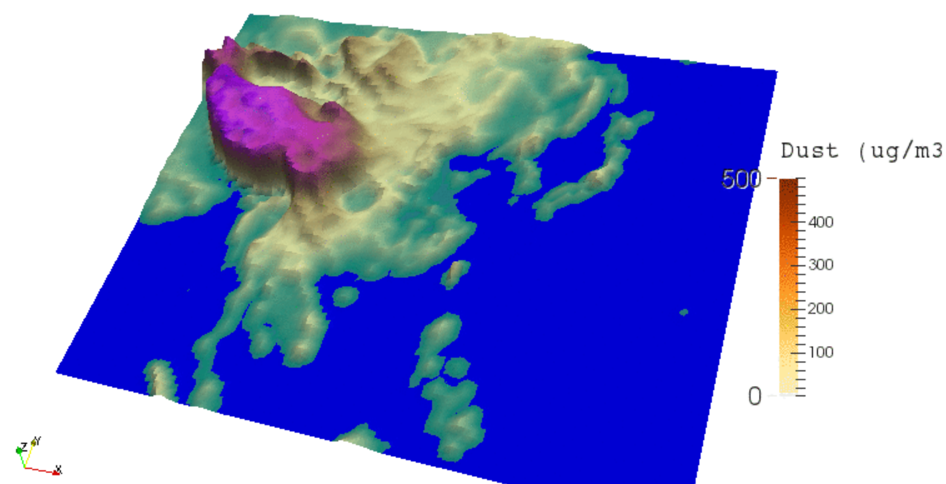
Fluidity

Mineral Dust Transport Model with Adaptive Grids



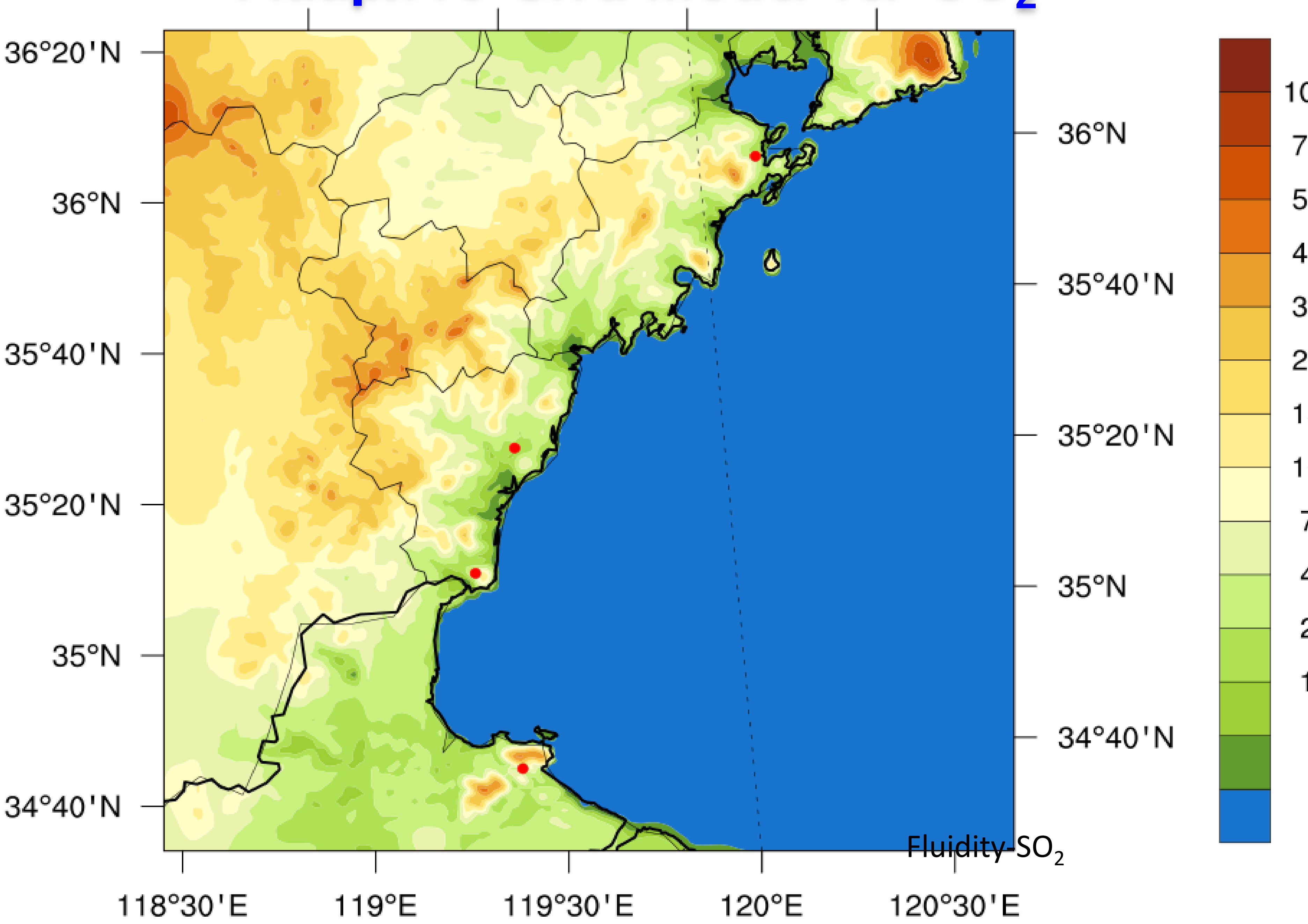






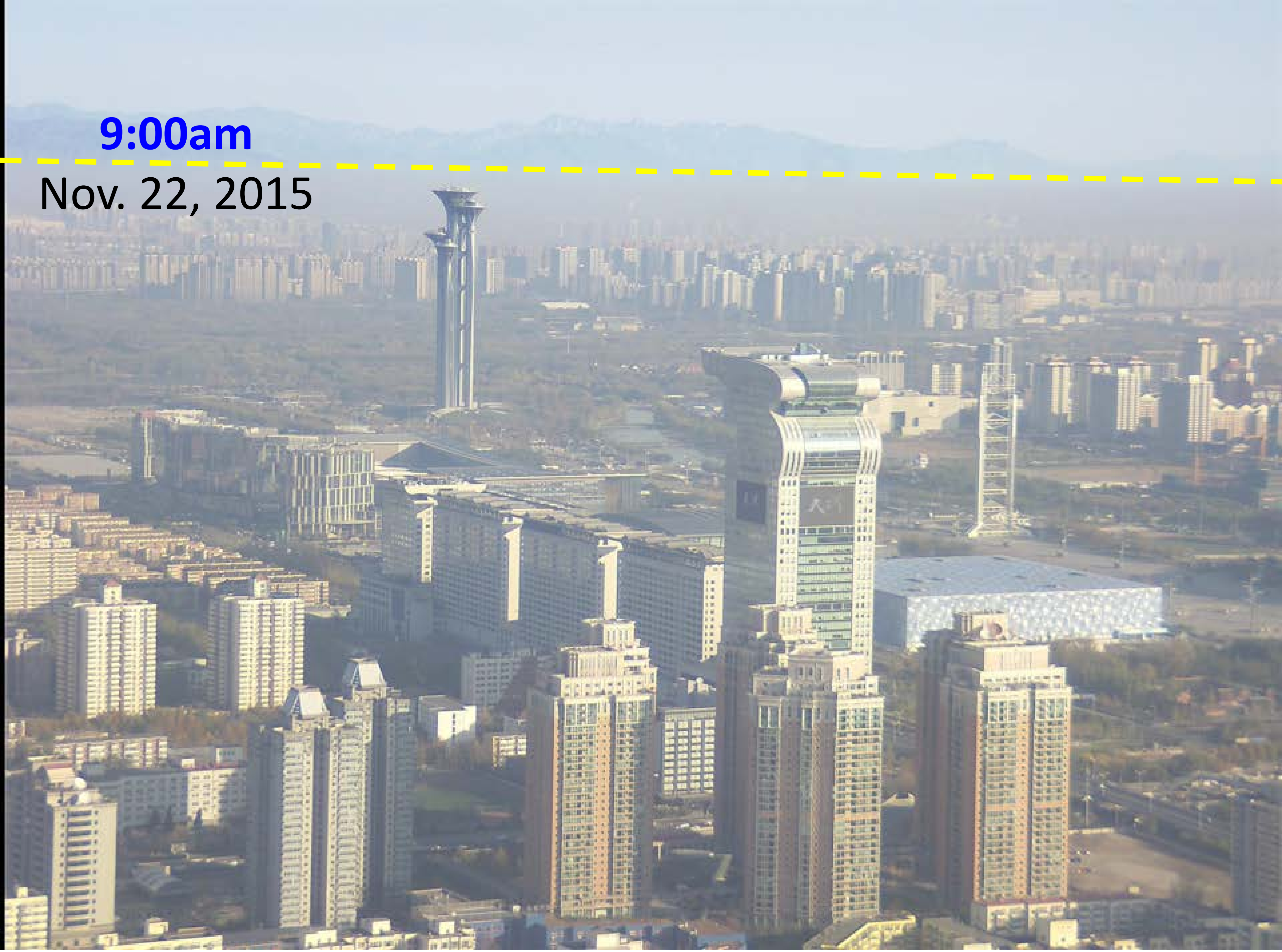
Fluidity-dust

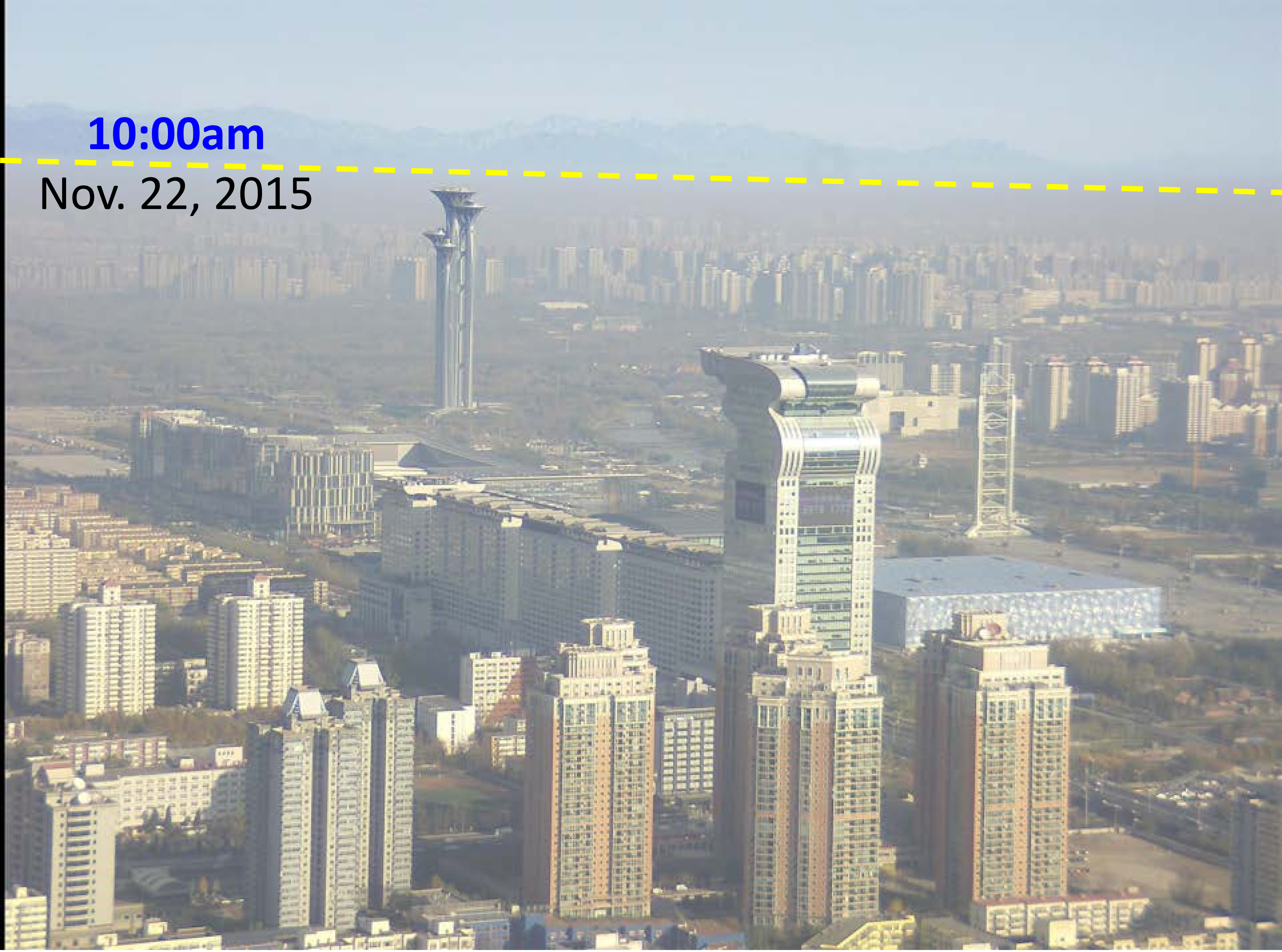
Adaptive Grid Model for SO_2

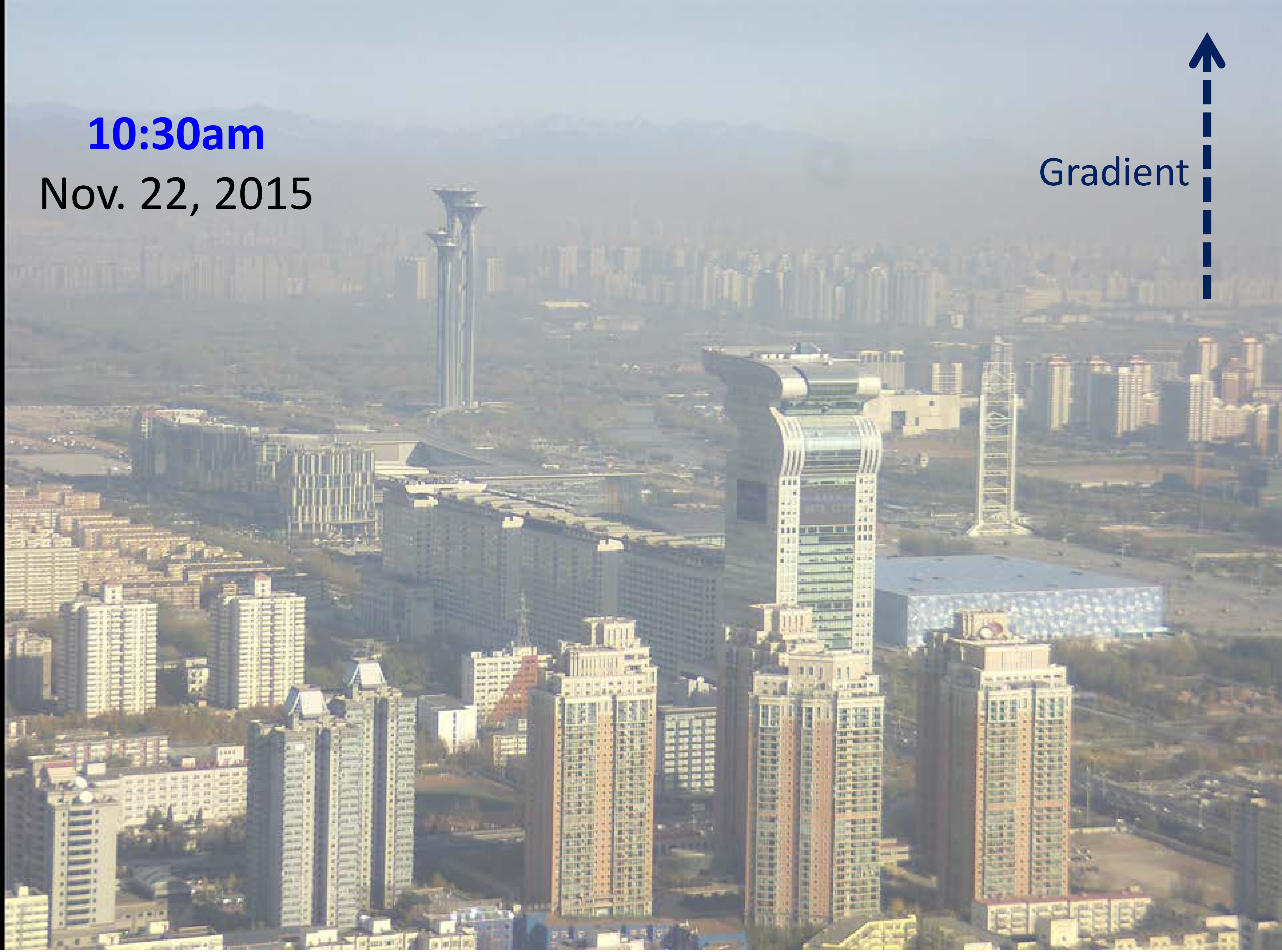


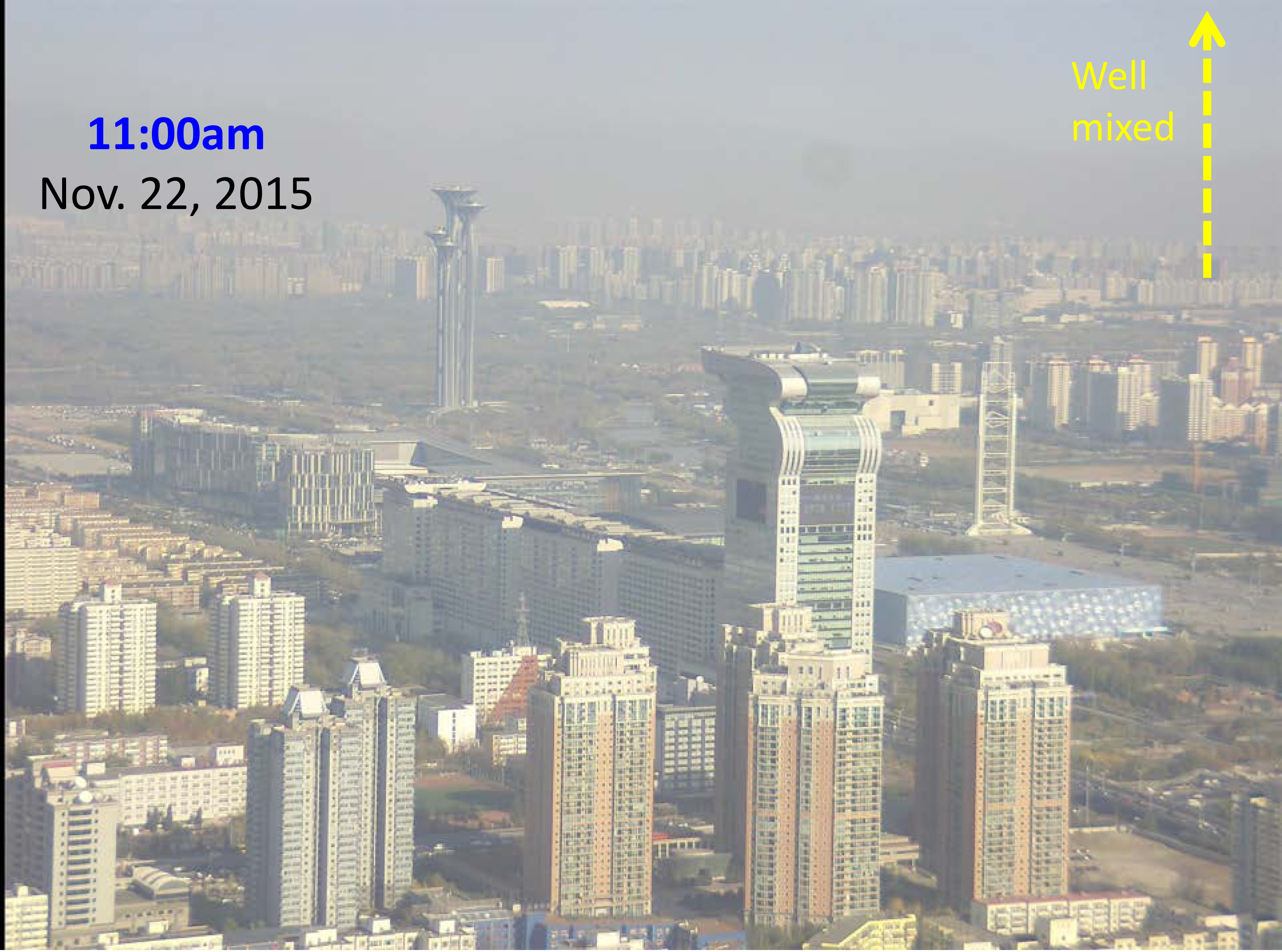

Thank you!

Evolution of Air Pollution and Boundary Layer


9:00am
Nov. 22, 2015


10:00am
Nov. 22, 2015


10:30am
Nov. 22, 2015
Gradient


11:00am
Nov. 22, 2015
Well
mixed

Major achievements 5

Modeling study of regional severe hazes over North China Plain and its implications on emergency pollution control

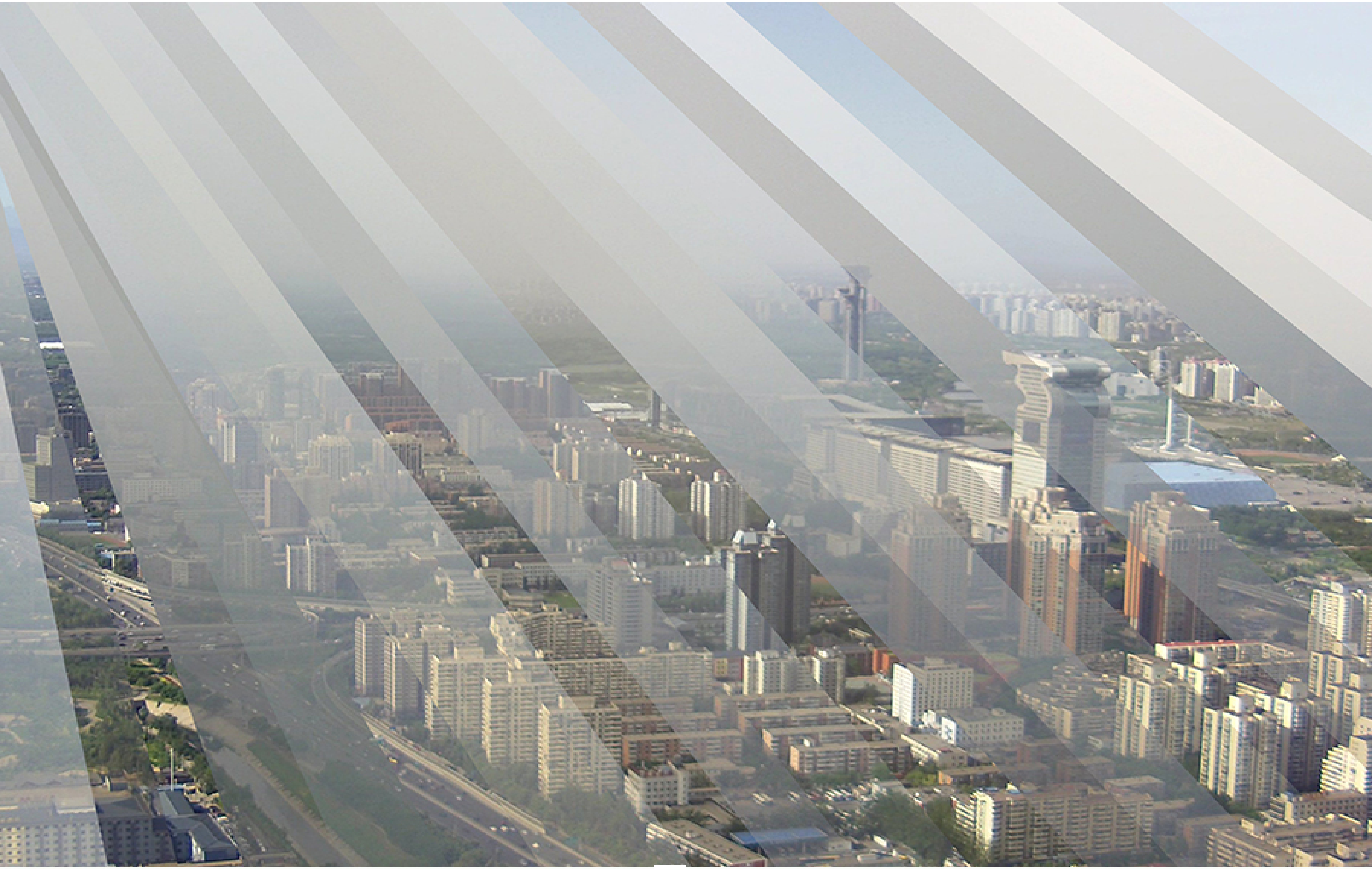
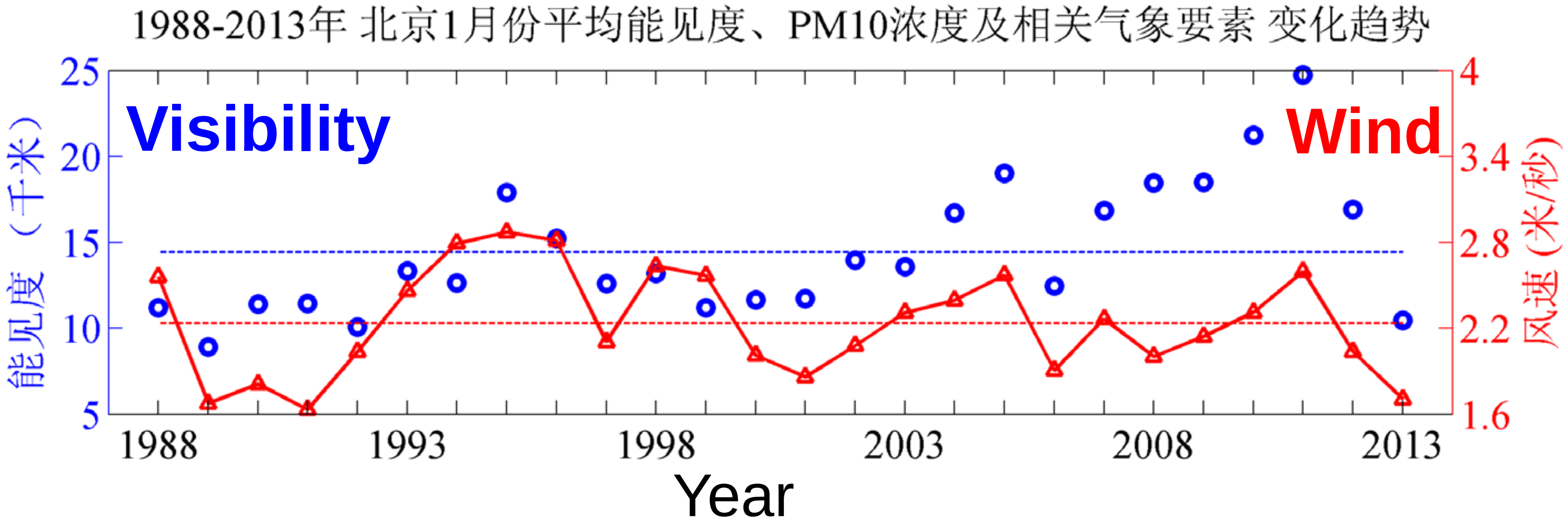


Photo taken from
300 m tower

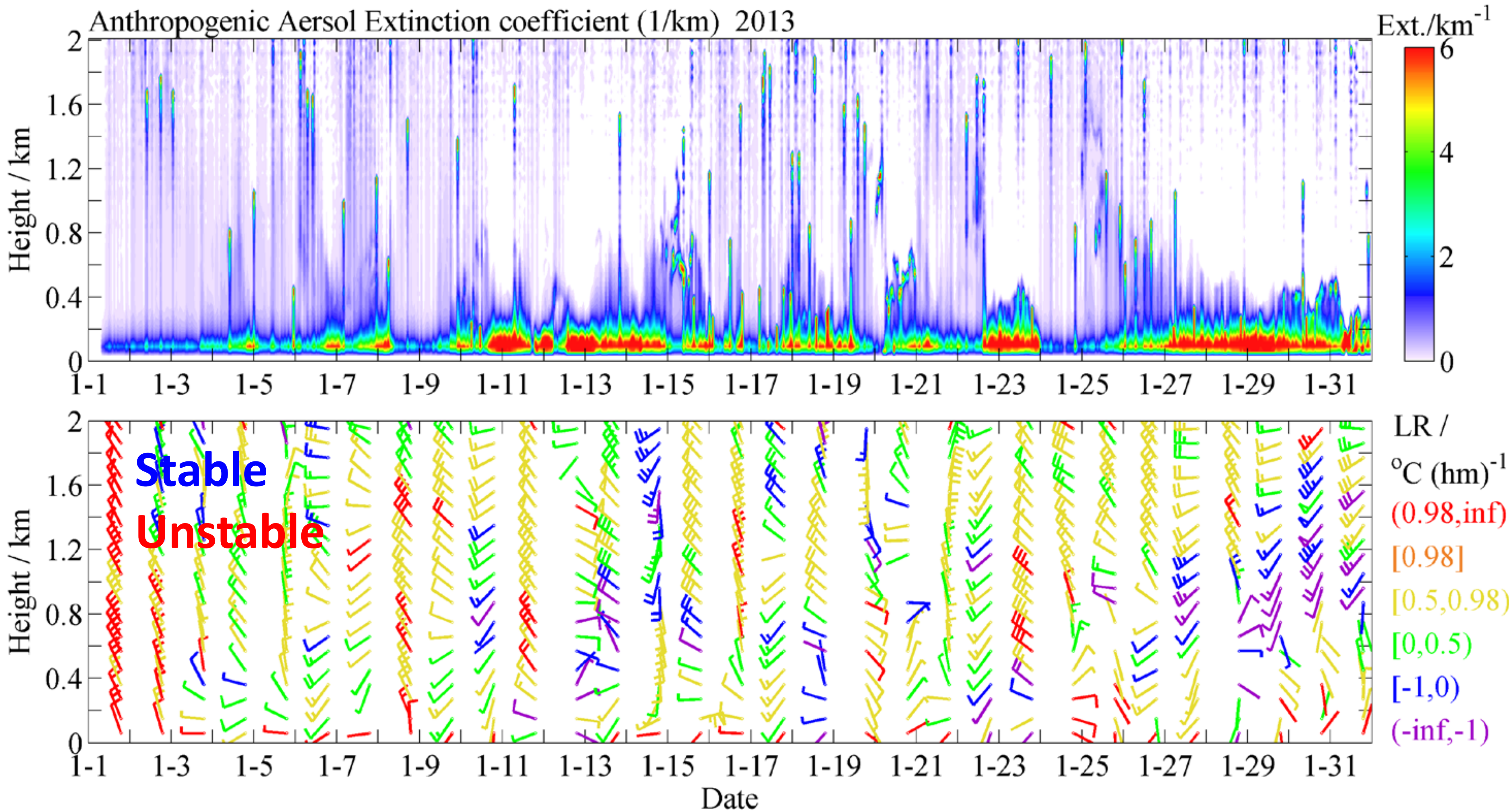
2013年 1月的北京

从300米的高空每天同一时间拍摄同一场景的照片，
这些照片分割后合成为一张，一条代表一天的景色。

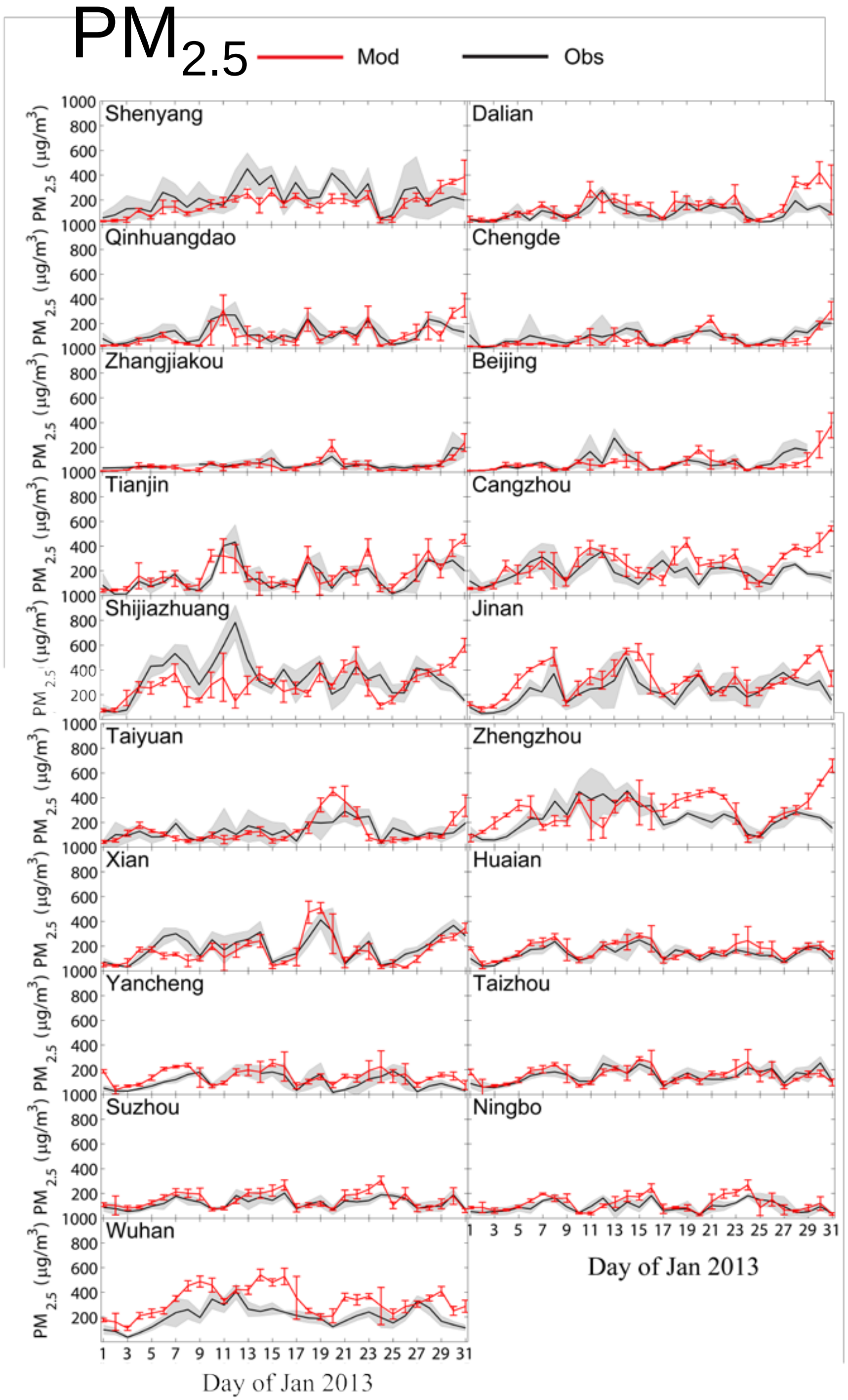
The worst air quality at Beijing since 1998

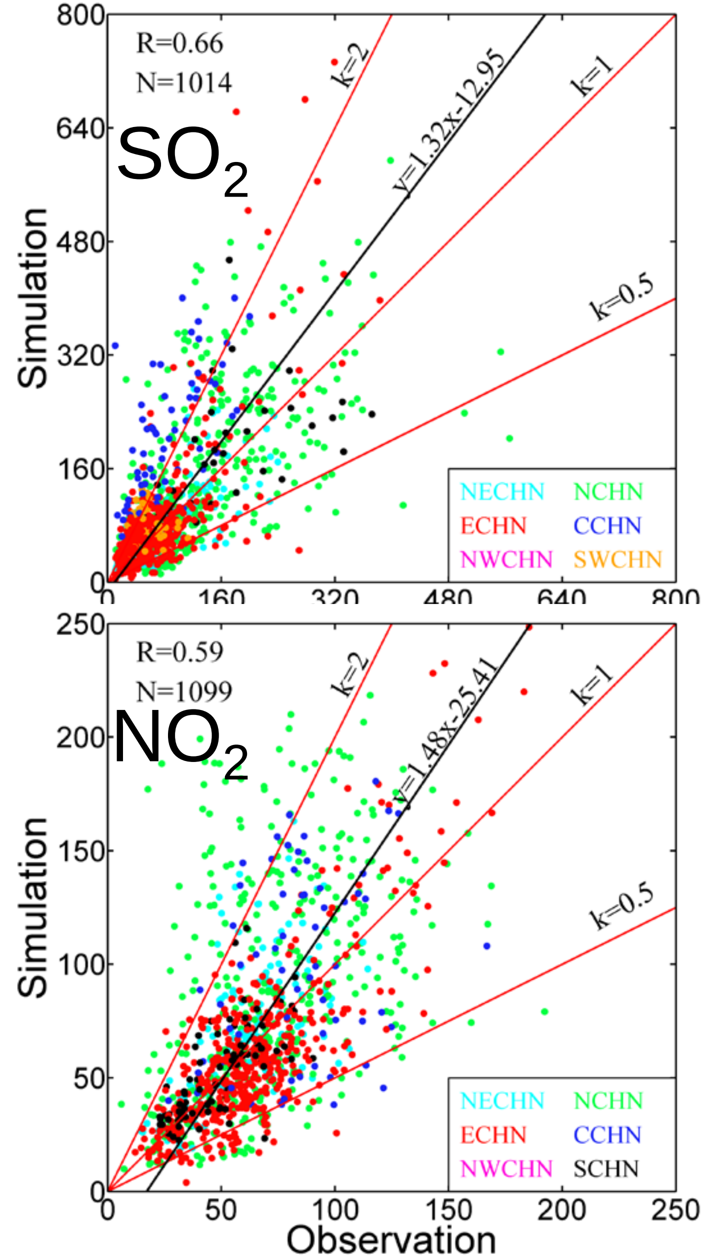


Vertical Observations at IAP 325 m Tower Site, Beijing

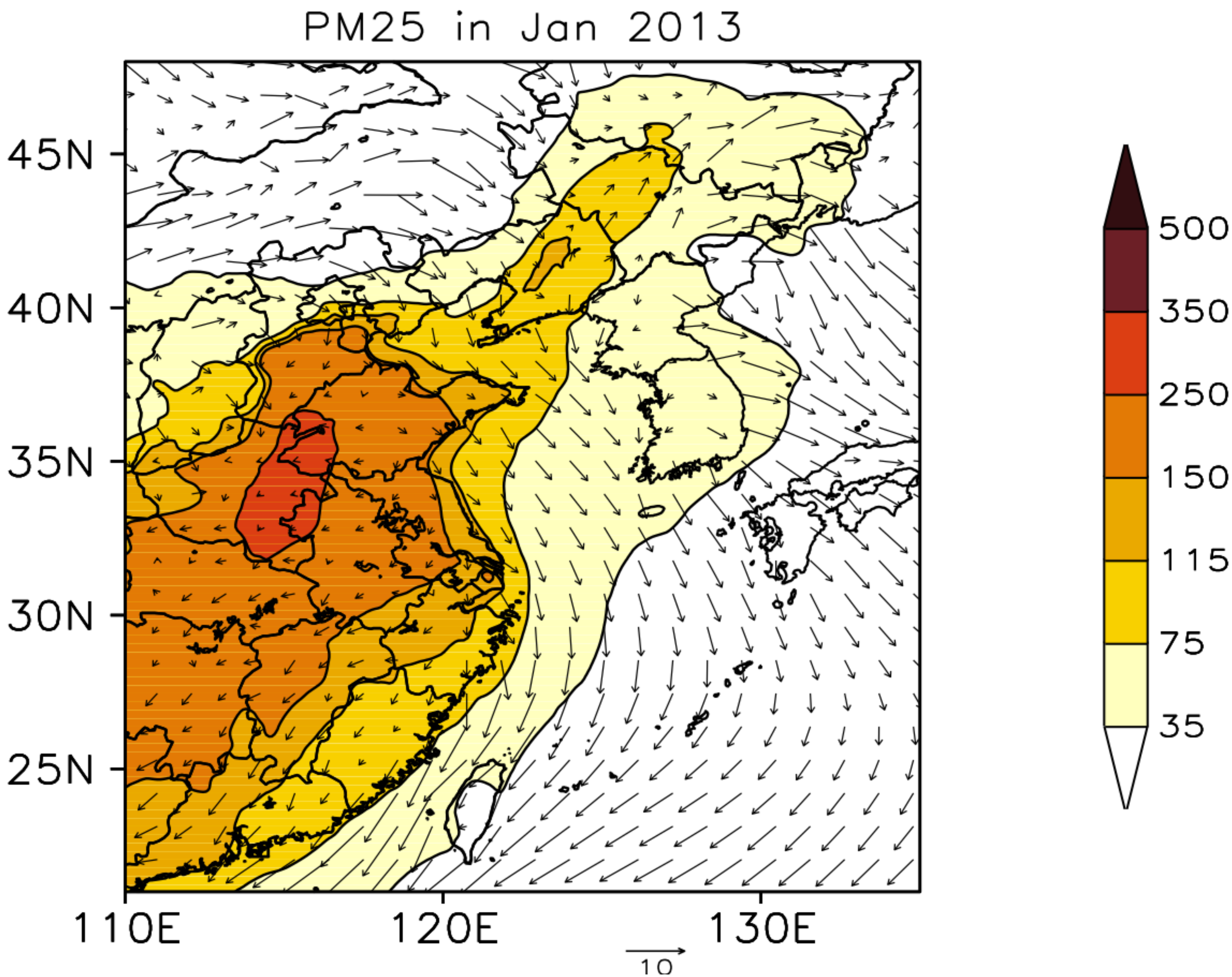


Aerosol was mostly constrained below 400m by stable conditions in Jan. 2013,different from previous years

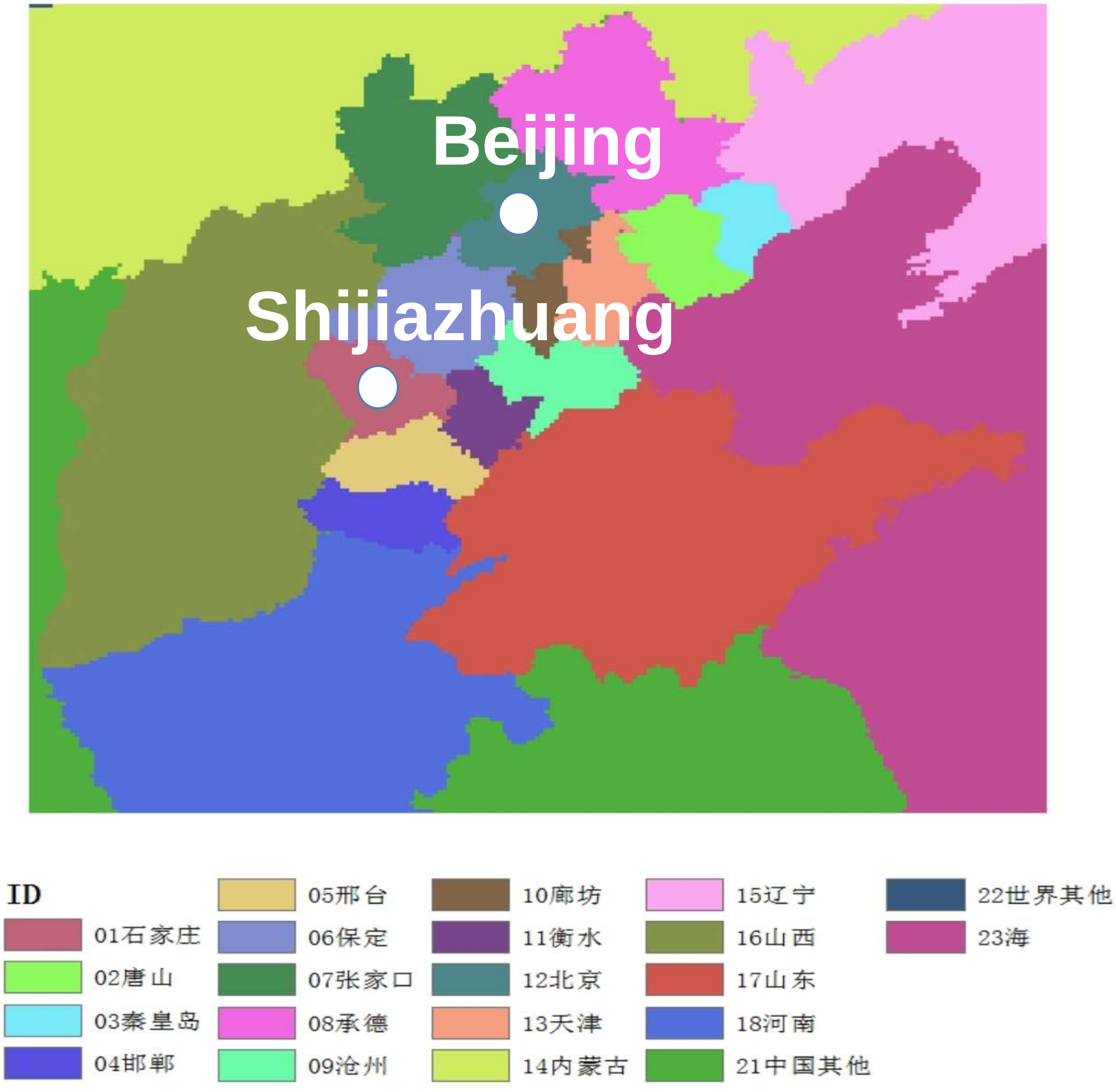

PM2.5
Mod
Obs
Shenyang
Dalian
Qinhuangdao
Chengde
Zhangjiakou
Beijing
Tianjin
Cangzhou
Shijiazhuang
Jinan
Taiyuan
Zhengzhou
Xian
Huaian
Yancheng
Taizhou
Suzhou
Ningbo
Wuhan
PM2.5 (μg/m3)
Day of Jan 2013


SO2
R=0.66
N=1014
k=2
y=1.32x-12.95
k=1
k=0.5
Simulation
NECHN
NCHN
ECHN
CCHN
NWCHN
SWCHN
NO2
R=0.59
N=1099
y=1.48x-25.41
SCHN
Observation

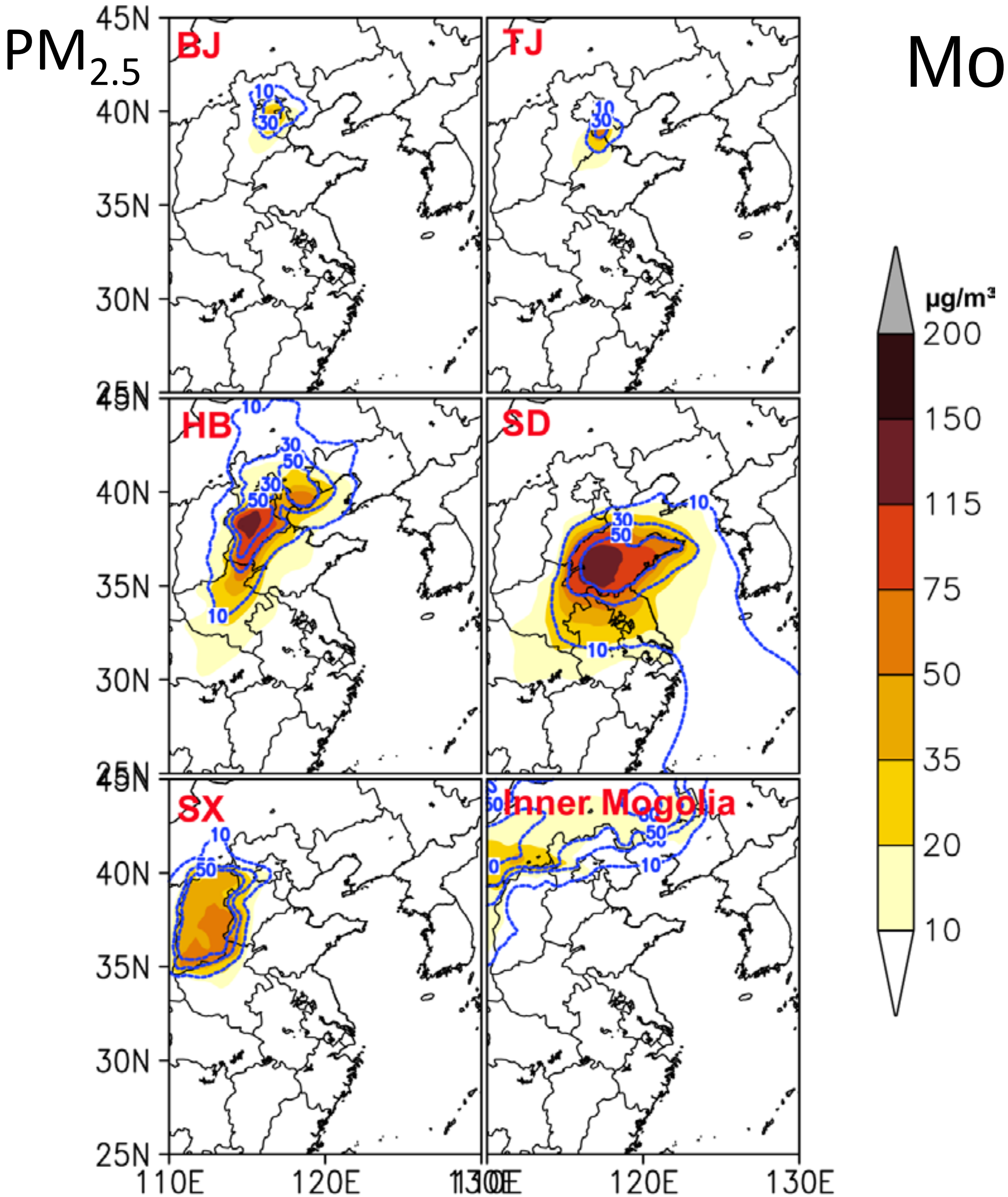
Simulated monthly average concentrations of $PM_{2.5}$ and surface wind fields (m s^{-1}) in East China in January 2013



21 regions was tagged to estimate contributions from regional transport



Regional transport in haze



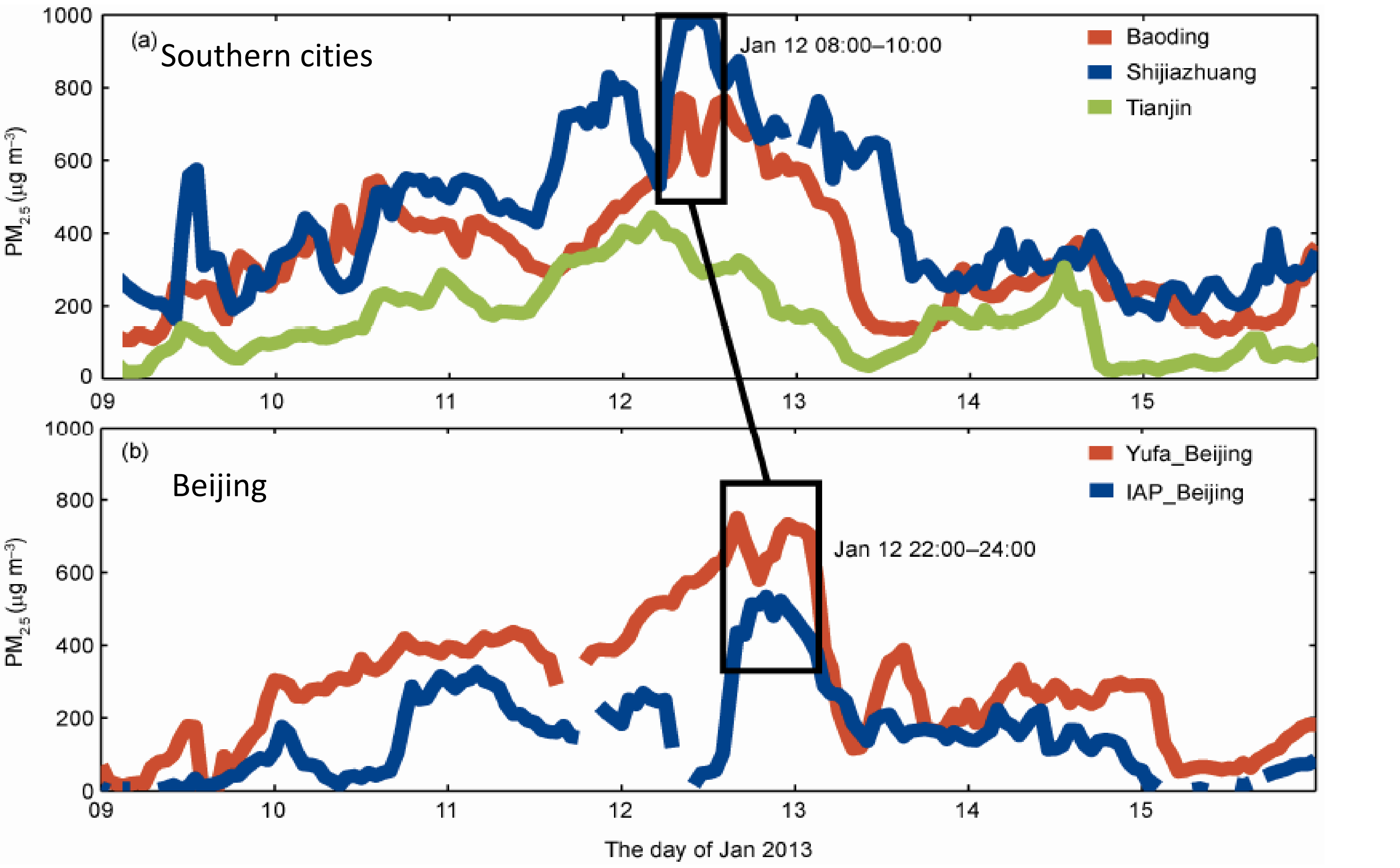
Monthly mean $PM_{2.5}$

Site	Local	Transport
Beijing	**48.3%**	**51.7%**
Tianjin	**32.6%**	**68.4%**
Qinghuangdao	**54.2%**	**46.8%**
Cangzhou	**47.2%**	**52.8%**

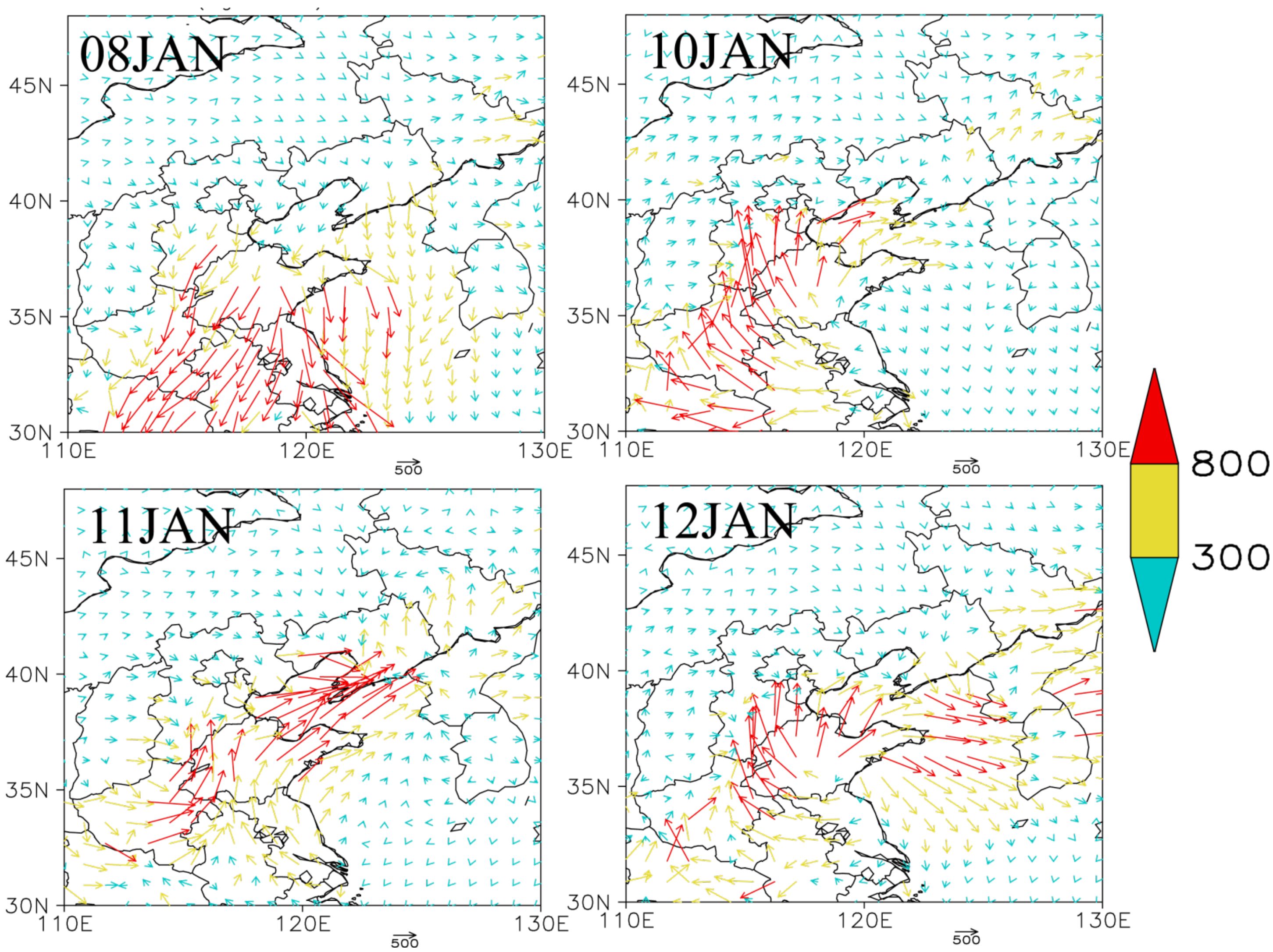
Regional transport was significant in regional hazes

A transport case: in 10-12th Jan. 2013 from south to north

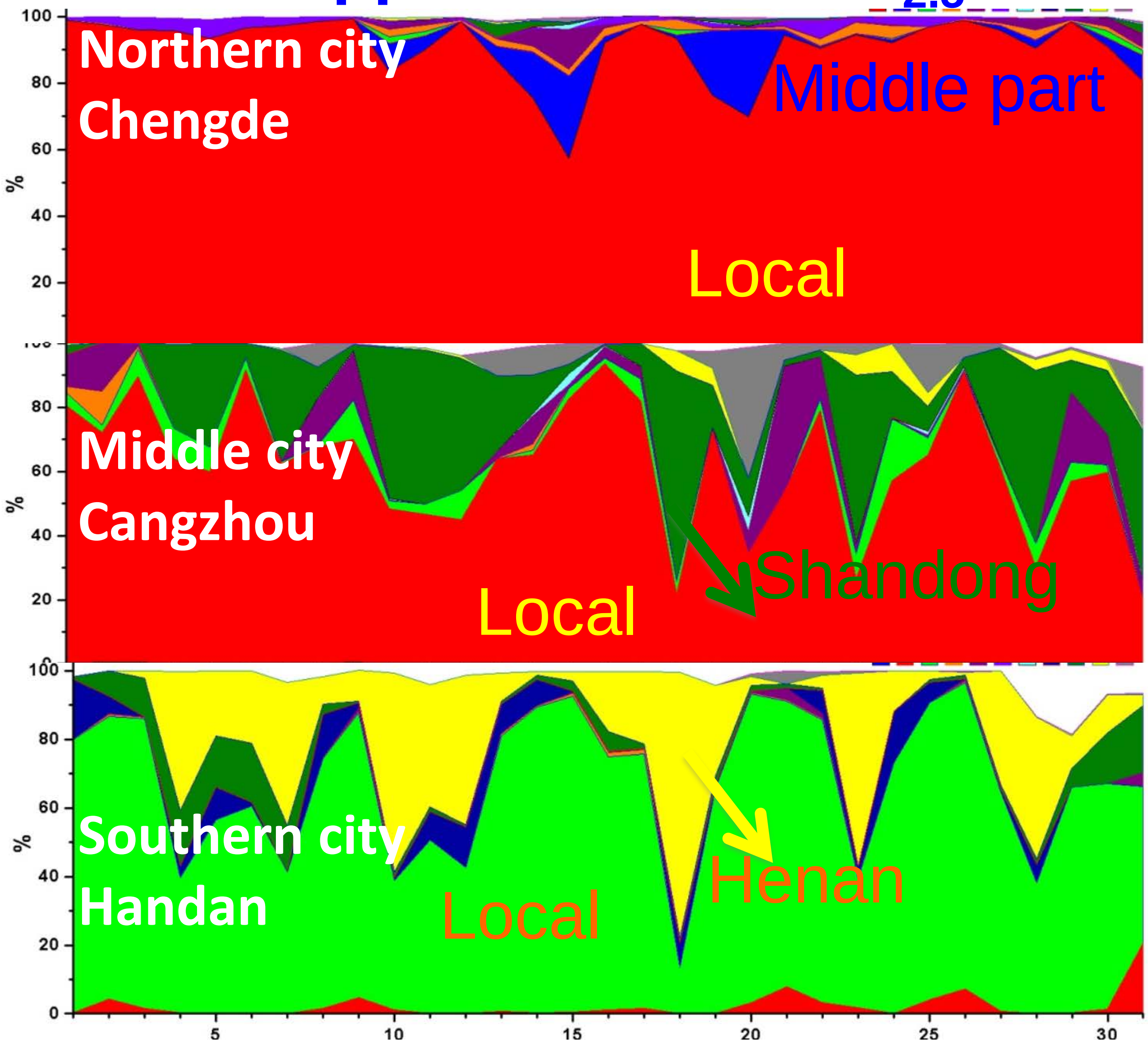
A time lag of $PM_{2.5}$ concentration peak from south to north



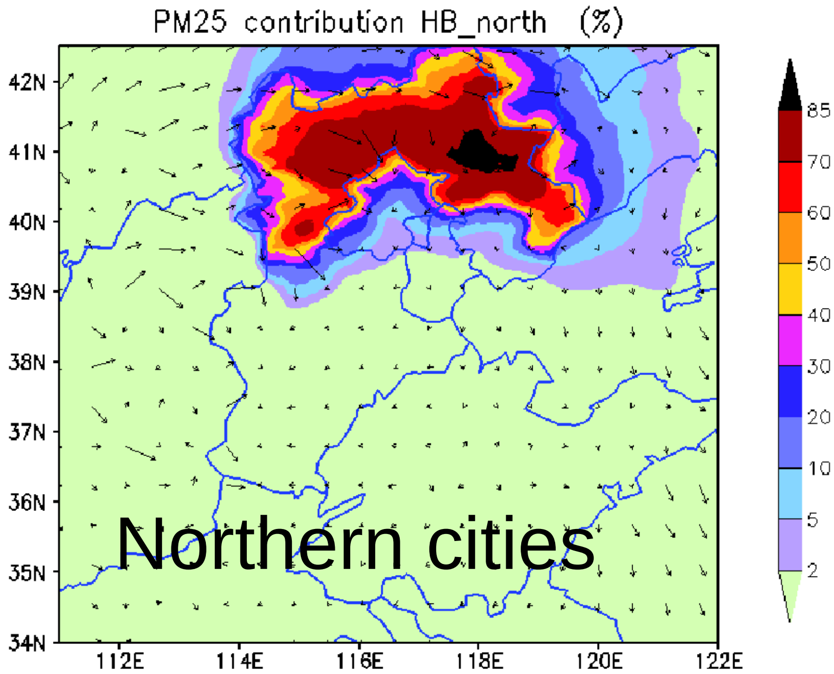
Transport fluxes of $PM_{2.5}$ in North China Plain

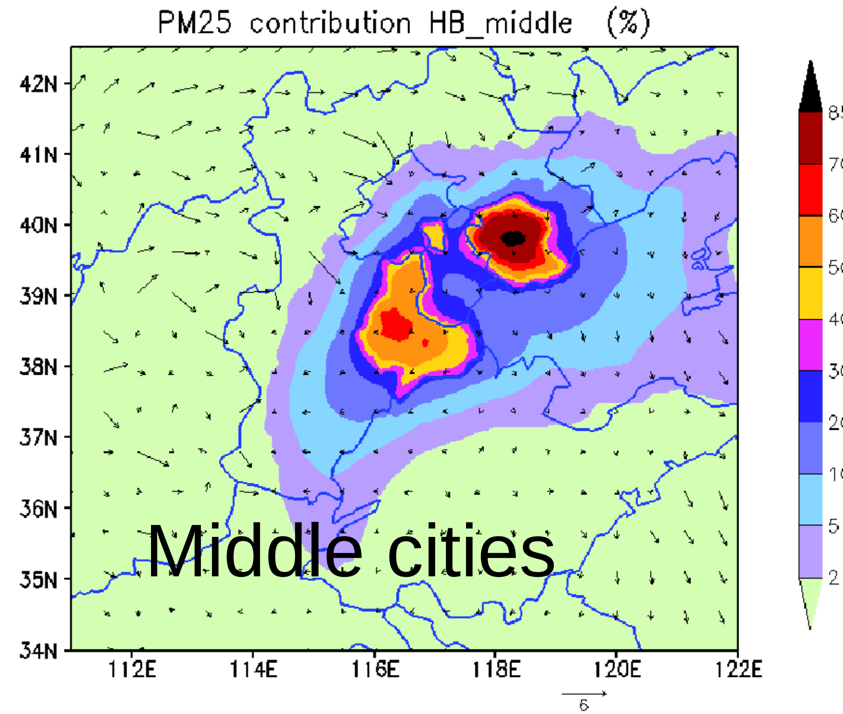


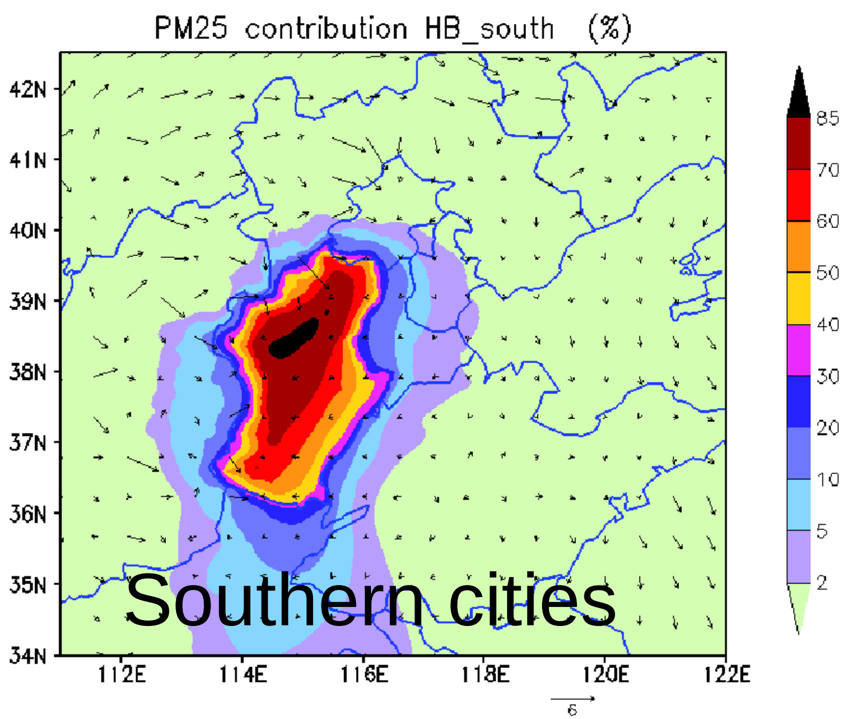
Source appointment of $PM_{2.5}$ in Hebei



January
2013







Contributions of emissions in three Hebei sub-regions to surface $PM_{2.5}$(%)

Hebei province emergency plans

1. Depending on source regions and sectors in hazes, **three sub-regions** was divided: northern cities, middle cities and southern cities
2. Calculating **efficiency of each emission to receptor** $PM_{2.5}$ concentrations(gm^{-3}/ton) , source regions and sectors with high efficiency is designed to reduce more.
3. Calculating **response of secondary pollutants** to their precursors emissions.
4. Two grade measures: III: heavily to moderate

   II: severely to moderate;

Considering the coupled impact of meteorological fields , distribution of emissions and chemistry.

III grade alert

Target: reduction $PM_{2.5}$ from heavy level to moderate level

Sub-region I: Southern city

III 级预警响应减排量（t/d）

政区划	工业			机动车		扬尘
	SO_2	NO_x	烟/粉尘	NO_x	颗粒物	颗粒物
家庄市	88.0	106.2	73.2	30.1	3.2	28.2
郸市	90.2	74.7	94.4	27.1	10.4	17.9
台市	39.2	37.6	38.3	15.3	9.8	15.0
定市	29.5	18.9	9.0	29.5	29.8	45.3
水市	15.2	17.6	7.5	6.8	3.9	10.1

Sub-region II: Middle city

III 级预警响应减排量（t/d）

政区划	工业			机动车		扬尘
	SO_2	NO_x	烟/粉尘	NO_x	颗粒物	颗粒物
唐山市	165.6	171.4	220.8	37.7	2.8	14.2
沧州市	22.3	25.4	9.3	30.9	6.4	9
廊坊市	23.2	15.3	3.7	23.2	4.1	3.3

Sub-region III: Northern city

III 级预警响应减排量（t/d）

政区划	工业			机动车		扬尘
	SO_2	NO_x	烟/粉尘	NO_x	颗粒物	颗粒物
皇岛市	23.5	21.9	28.8	16.4	4	3
家口市	27.6	30.2	86	5.3	0.8	7.1
承德市	27.1	15.3	6.8	7.5	1.4	5.5

$PM_{2.5}$ concentrations reduction from each control measure μgm^{-3}

行政区划		工业		机动车		扬尘
	SO_2 减排	NO_x 减排	烟尘减排	NO_x 减排	颗粒减排	颗粒减排
石家庄市	2.74	3.35	0.59	0.95	0.16	5.08
唐山市	0.10	0.10	0.30	0.00	0.10	0.20
秦皇岛市	0.00	0.00	0.00	0.00	0.00	0.00
邯郸市	1.92	1.59	0.16	0.58	0.07	1.35
邢台市	1.71	1.23	0.14	0.67	0.08	1.51
保定市	1.96	1.32	0.39	2.06	0.23	13.15
张家口市	0.00	0.00	0.00	0.00	0.00	0.01
承德市	0.00	0.00	0.00	0.00	0.00	0.00
沧州市	0.11	0.13	0.01	0.16	0.02	0.23
廊坊市	0.08	0.05	0.00	0.08	0.01	0.04
衡水市	1.44	1.66	0.07	0.64	0.08	1.36
合计	10.07	9.45	1.67	5.14	0.75	22.92

II grade alert

Target: reduction $PM_{2.5}$ from severely level to moderate level

行政区划	II 级预警响应减排量（t/d）					
	工业			机动车		扬尘
	SO_2	NO_x	烟/粉尘	NO_x	颗粒物	颗粒物
石家庄市	352.1	424.9	292.7	120.6	12.7	112.8
邯郸市	360.8	298.8	377.4	108.2	41.8	71.6
邢台市	156.9	150.3	153.3	61.3	39.1	60.1
保定市	117.8	75.5	36	117.8	119.2	181.1
衡水市	60.8	70.3	30	27.1	15.6	40.3

Sub-region I: Southern city

行政区划	II 级预警响应减排量（t/d）					
	工业			机动车		扬尘
	SO_2	NO_x	烟/粉尘	NO_x	颗粒物	颗粒物
唐山市	538.2	557	717.6	122.7	9.2	46.2
沧州市	72.5	82.5	30.2	100.5	20.8	29.1
廊坊市	75.5	49.8	12.1	75.2	13.4	10.6

Sub-region II: Middle city

行政区划	II 级预警响应减排量（t/d）					
	工业			机动车		扬尘
	SO_2	NO_x	烟/粉尘	NO_x	颗粒物	颗粒物
秦皇岛市	93.8	87.6	115	65.6	15.8	11.8
张家口市	110.4	120.8	344.1	21	3.3	28.5
承德市	108.4	61.3	27.2	29.8	5.4	22.1

Sub-region III: Northern city

Emission reductions of each city when all sub-regions exceeded alter levels

II 级预警响应减排量 （区域一）（t/d）						
行政区划	工业			机动车		扬尘
	SO_2	NO_x	烟/粉尘	NO_x	颗粒物	颗粒物
石家庄市	343.4	414.4	289	117.6	12.5	111.3
唐山市	359.3	371.5	753.1	20.4	8.9	12.2
秦皇岛市	7.9	19.2	13.9	10.2	4	6.3
邯郸市	351.9	291.4	372.7	105.5	41.2	70.7
邢台市	153	146.6	151.4	59.8	38.6	59.3
保定市	114.9	73.6	35.5	114.9	93.2	132
张家口市	11.3	25.9	93.6	6.9	3.9	10
承德市	8.5	12.6	7.9	3.9	3.6	10.4
沧州市	34.3	39	34.4	47.5	23.7	33.2
廊坊市	30.1	19.8	11.6	30	12.9	10.2
衡水市	59.3	68.6	29.7	26.4	15.4	39.8

$PM_{2.5}$ concentrations reduction from each control measure μgm^{-3}

行政区划	工业			机动车		扬尘
	SO_2减排	NO_x减排	烟尘减排	NO_x减排	颗粒减排	颗粒减排
石家庄市	10.3	13.4	2.4	3.8	0.7	21.3
唐山市	0.5	0.5	0.8	0.3	0.4	6.2
秦皇岛市	0.0	0.0	0.1	0.0	0.0	0.0
邯郸市	7.7	6.4	0.7	2.3	0.3	9.4
邢台市	6.8	6.5	0.6	2.7	0.3	6.0
保定市	10.3	7.3	4.6	8.3	0.9	31.3
张家口市	0.0	0.0	0.0	0.0	0.0	0.1
承德市	0.0	0.0	0.0	0.0	0.0	0.1
沧州市	0.5	0.5	0.0	0.6	0.2	1.9
廊坊市	0.3	0.2	0.0	0.3	0.0	1.2
衡水市	5.8	6.7	0.3	2.6	0.3	5.4
合计	42.1	41.5	9.4	20.9	3.1	83.0

- **NAQPMS model reproduced temporal and distribution of pollutants in hazes in Jan 2013, reasonably.**
- **Regional transport played a key role although a weak wind prevailed in heavy haze episodes.**
- **The coupled effect of meteorological field, emission distribution and atmospheric chemistry should be considered in emergency plan.**
- **Emissions control in emergency plan can efficiently decrease $PM_{2.5}$ pollution grade, but not disappear haze.**