



Max-Planck-Institut  
für Meteorologie



# Multi-Model Ensemble Forecasts of Regional Air Quality in China

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# Outline

- ❑ Background
- ❑ Ensemble Model Forecasting System
- ❑ Results
- ❑ Improving Model Performance
- ❑ Next Steps



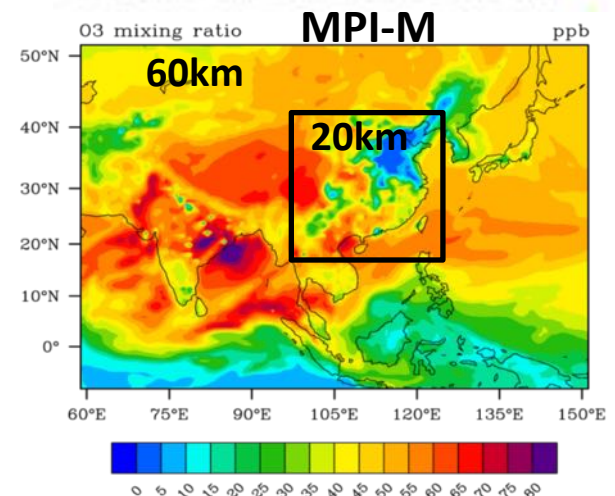
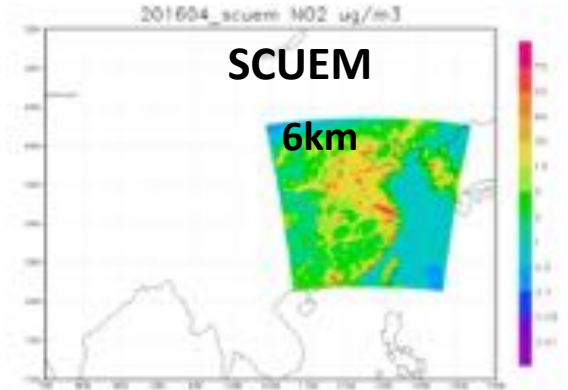
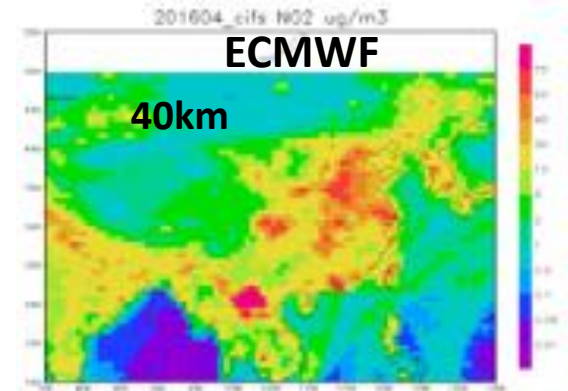
# Forecasting Air Quality in China: A Challenging Task

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- Air quality forecast systems rely also on meteorological models which still contain some inaccuracies in the formulation of physical processes
- Chemical (and Physical) processes are not always carefully formulated: simplified assumptions are sometimes adopted
- Large uncertainties in current emissions inventories
- Urban environment “every where!": - 9 megacities of 10-25 Million inhabitants  
- 37 Cities over 3 Million inhabitants
- The formation mechanisms leading to severe haze episodes remain uncertain
- Complex landscape and conditions in some cities: e.g. Beijing is prone to develop stagnant conditions, because of surrounding mountains to the north of the city
- Coupling interactions between complex meteorological conditions, pollution sources, and atmospheric transformation processes
- ...

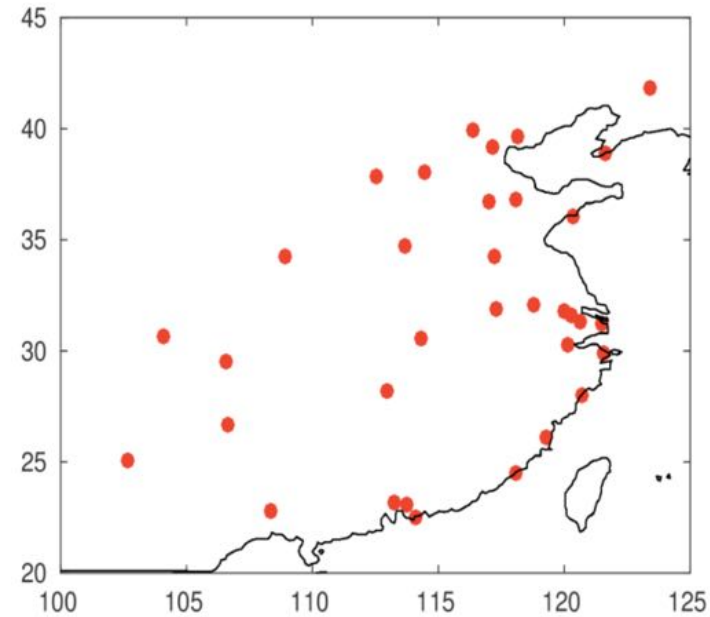
# An Ensemble of 7 Models to Forecast Air Quality in China

Institute	Model	Emissions	Domain	Res.
KNMI (NL)	CHIMERE v2013	MEIC INTEX-B MEGAN	E. China: 18-50N, 102-132E	0.25
ECMWF (UK)	C-IFS	MACCity	China: 10-49N, 75-135E	0.4
SCUEM (CN)	WRF-Chem	MEIC2010	East China: 21-44N, 104-132E	6km
FMI (FI)	SILAM	MACCity GFAS MEGAN	E. Asia: 7-54N, 67-147E	0.25
MPI-M (DE)	WRF-Chem	HTAPv2 FINN MEGAN	E. China: 18-45N, 95-125E	0.2
Met.NO (NO)	EMEP	HTAP+MEI C (PanHam)	China: 15-55N, 90	0.125
TNO (NL)	LOTOS-Euros	MEIC Edgar	E. China: 20-45N, 105-130E	0.125



# Selected cities

北京 – Beijing	哈尔滨 – Harbin	合肥 – Hefei
上海 – Shanghai	苏州 – Suzhou	常州 – Changzhou
广州 – Guangzhou	青岛 – Qingdao	唐山 – Tangshan
深圳 – Shenzhen	济南 – Jinan	长沙 – Changsha
杭州 – Hangzhou	郑州 – Zhengzhou	徐州 – Xuzhou
天津 – Tianjin	大连 – Dalian	温州 – Wenzhou
成都 – Chengdu	昆明 – Kunming	贵阳 – Guiyang
南京 – Nanjing	无锡 – Wuxi	乌鲁木齐 – Ürümqi
西安 – Xi'an	厦门 – Xiamen	淄博 – Zibo
武汉 – Wuhan	长春 – Changchun	福州 – Fuzhou
沈阳 – Shenyang	宁波 – Ningbo	石家庄 – Shijiazhuang
东莞 – Dongguan	南宁 – Nanning	
重庆 – Chongqing	太原 – Taiyuan	



- Cities with over 3 million inhabitants (37), according to 2010 census
- Most cities are covered by all models



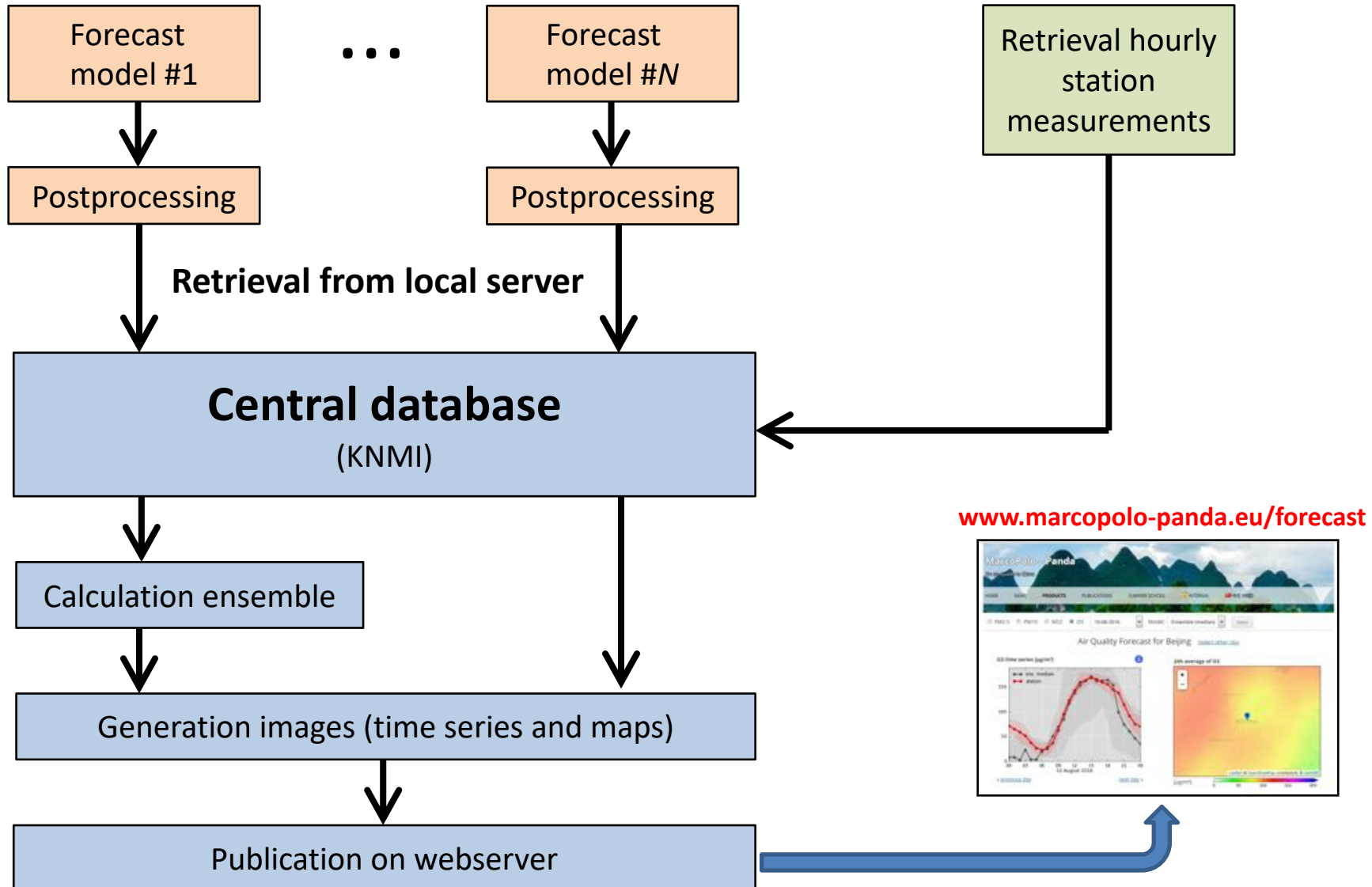
# Surface Observations

- Currently, collected from websites (e.g. [www.pm25.in](http://www.pm25.in)):
  - 367 different cities
  - 1526 stations
- Species: O<sub>3</sub>, NO<sub>2</sub>, PM<sub>2.5</sub>, PM<sub>10</sub> (soon CO, NO, SO<sub>2</sub>?)
- Hourly data automatically copied to KNMI database, starting from April 2015
- Ground value given is an area average, typically based on 5-12 stations

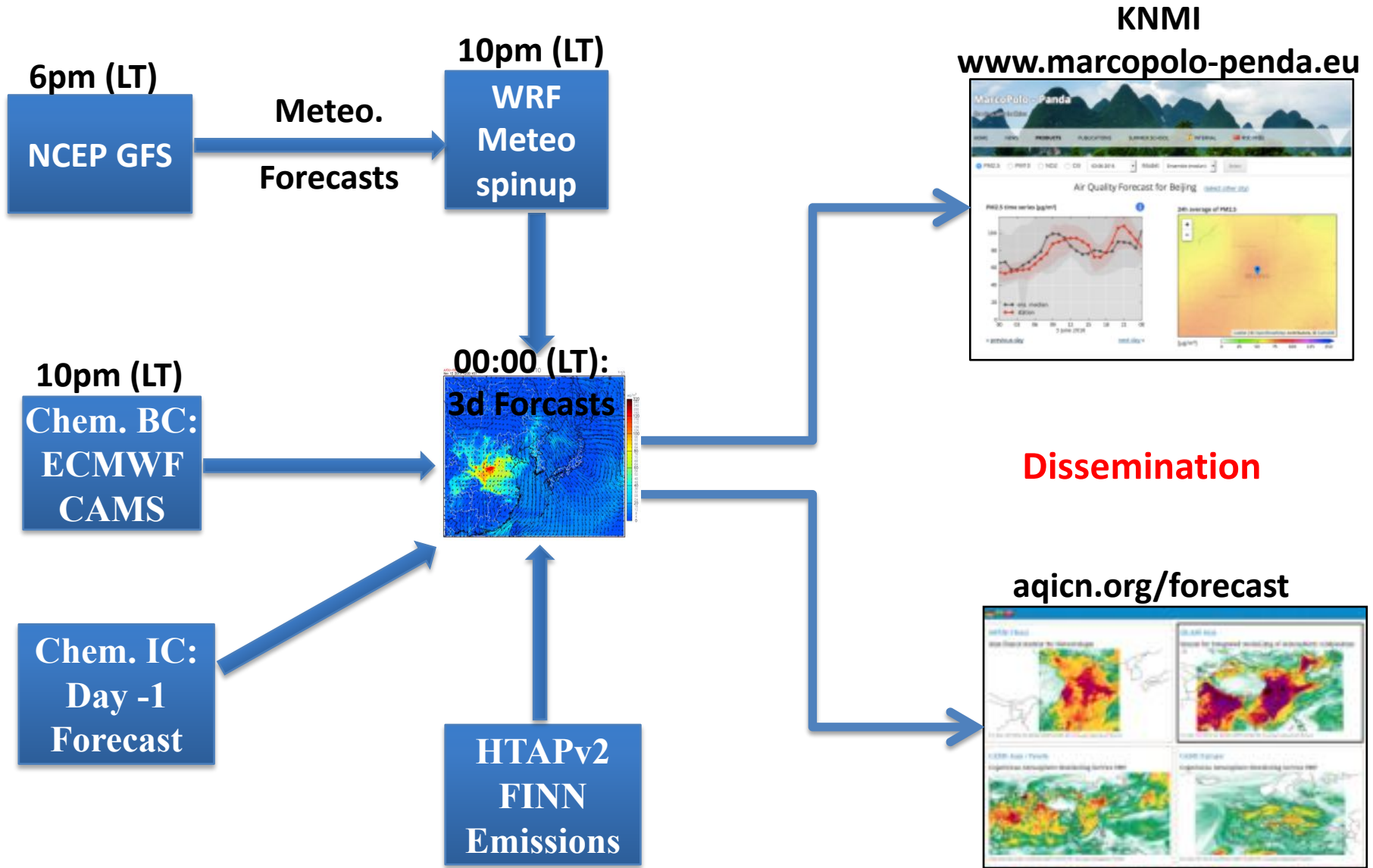


# Schematic Overview Data Flow

Courtesy B. Meijling

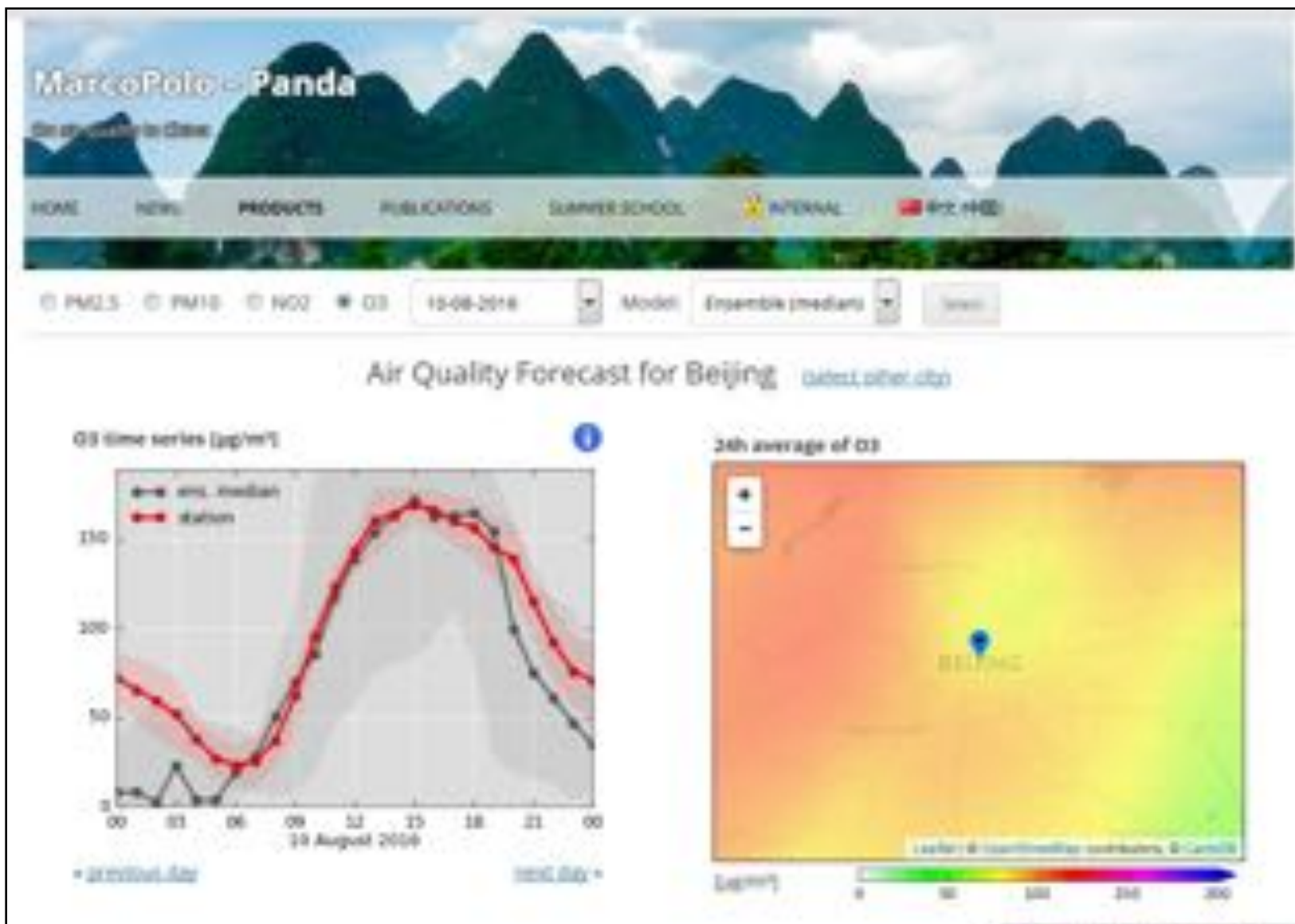


# Operational Forecasting System at MPI-M with WRF-Chem (DKRZ, Hamburg, Germany)





[www.marcopolo-panda.eu/forecast](http://www.marcopolo-panda.eu/forecast)



# Results

## □ **Cases:**

1. *All/Most Models Agree*
2. *All/Most Models Fail*
3. *Models Show Substantial Differences*

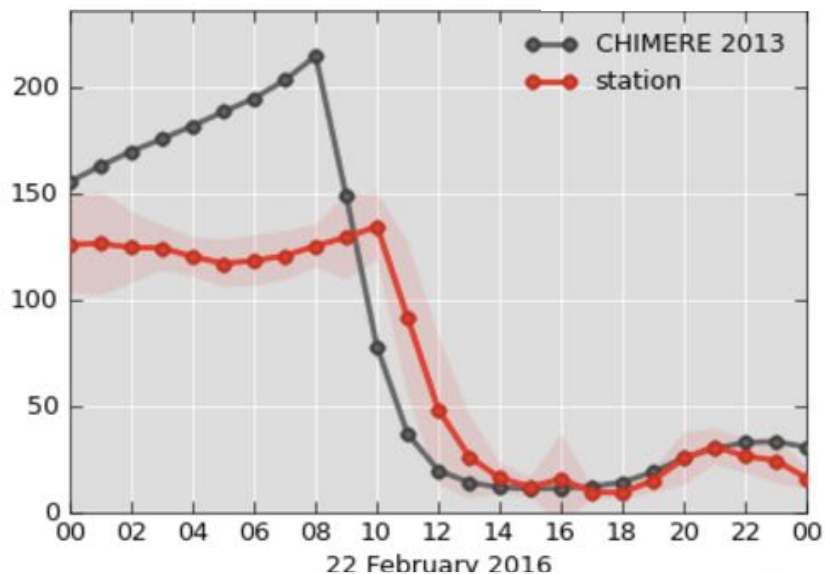
## □ **Ensemble Model Performance**



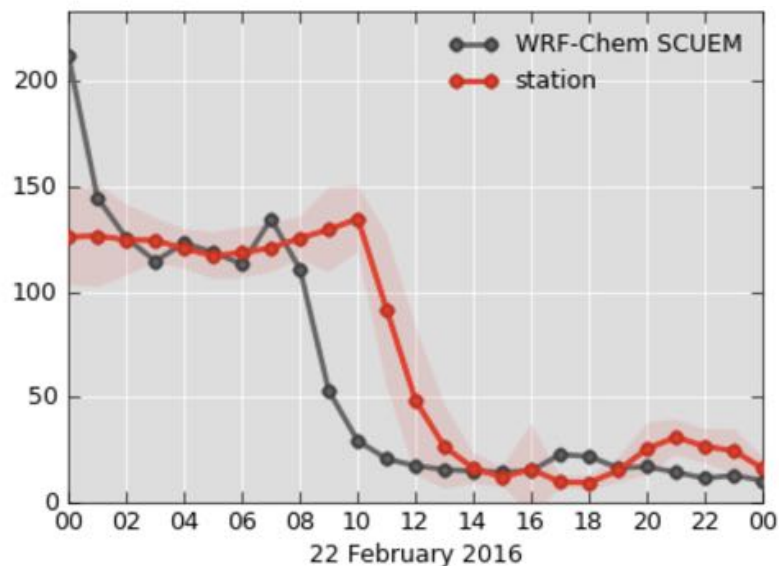
# Case 1: All/Most Models Agree

PM2.5 time series [ $\mu\text{g}/\text{m}^3$ ]

**CHIMERE**

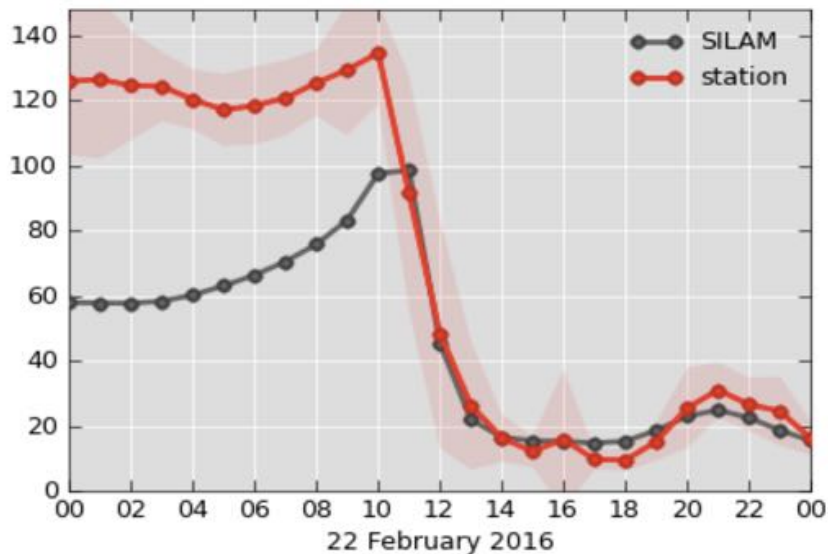


PM2.5 time series [ $\mu\text{g}/\text{m}^3$ ] **WRF-Chem/SCUEM**

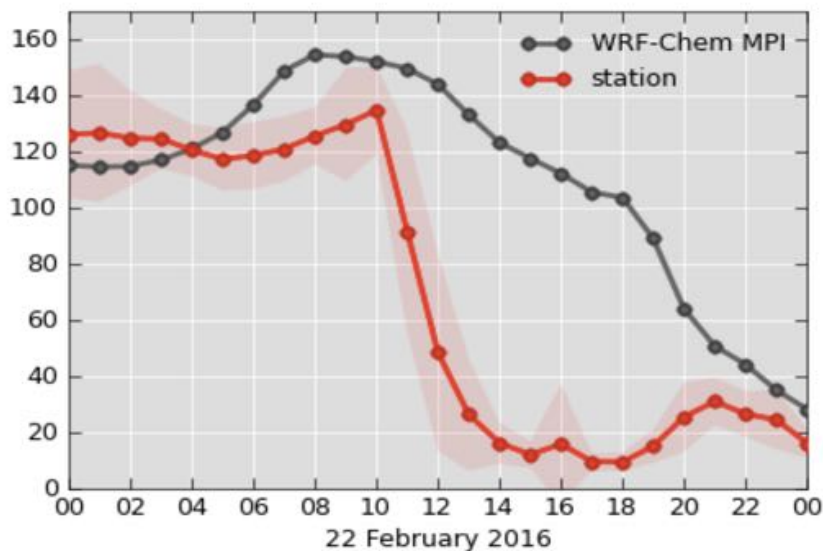


PM2.5 time series [ $\mu\text{g}/\text{m}^3$ ]

**SILAM**



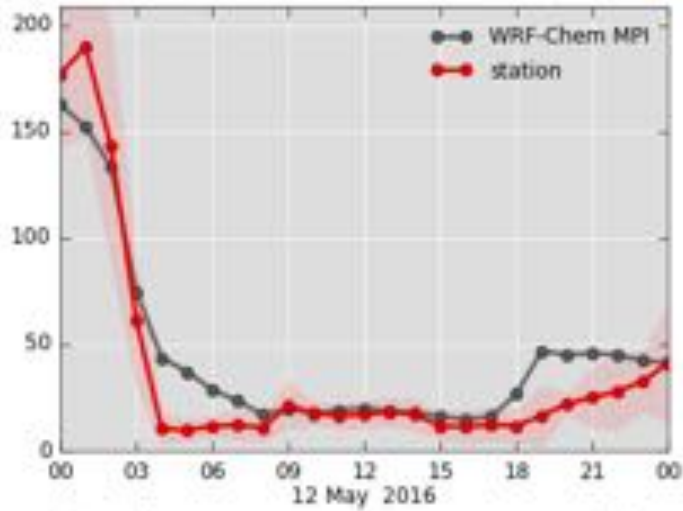
PM2.5 time series [ $\mu\text{g}/\text{m}^3$ ] **WRF-Chem /MPI**



# Case 1

## WRF-Chem

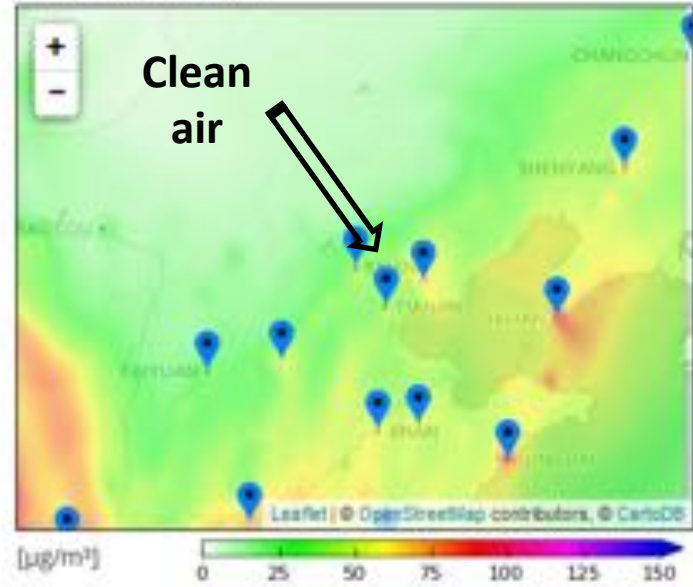
PM2.5 time series [ $\mu\text{g}/\text{m}^3$ ]



◀ previous day

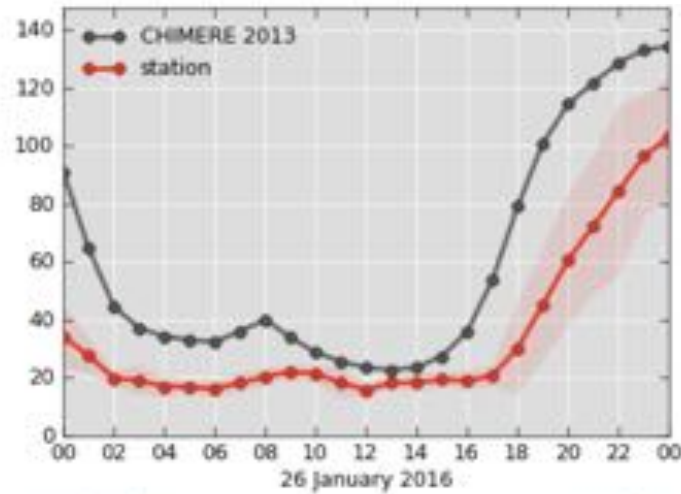
next day ▶

24h average of PM2.5



## CHIMERE

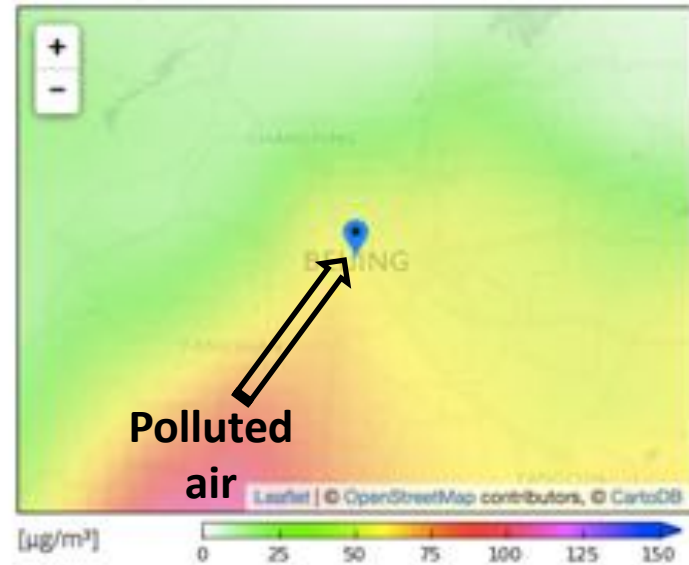
PM2.5 time series [ $\mu\text{g}/\text{m}^3$ ]



◀ previous day

next day ▶

24h average of PM2.5

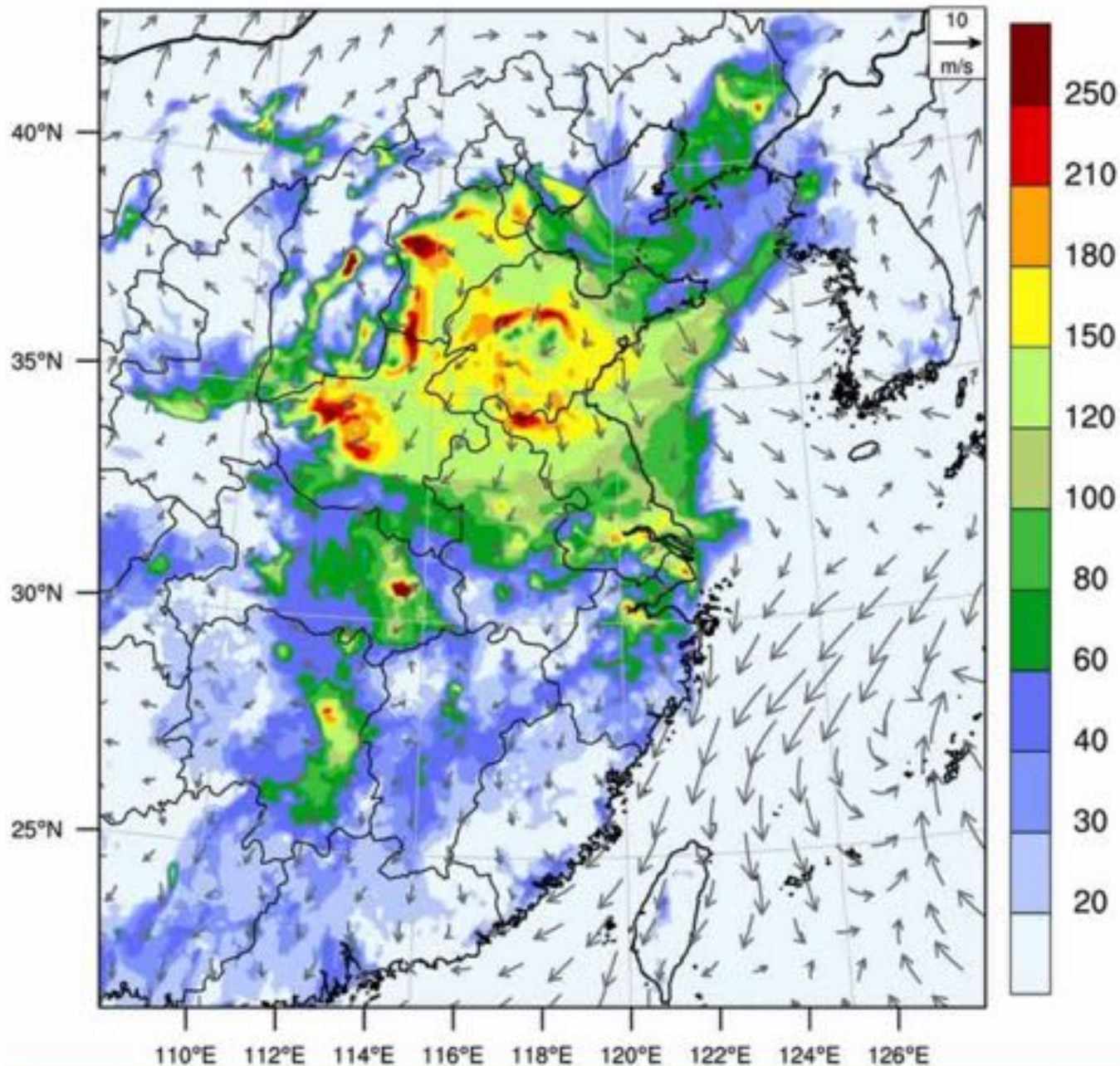




# WRF/CHEM Prediction

Init: 2015-11-29\_12:00:00  
Valid: 2015-11-29\_12:00:00

Surface PM2.5 Concentration (ug/m3)  
Wind at 10m



Case 1

WRF-Chem PM2.5  
Prediction

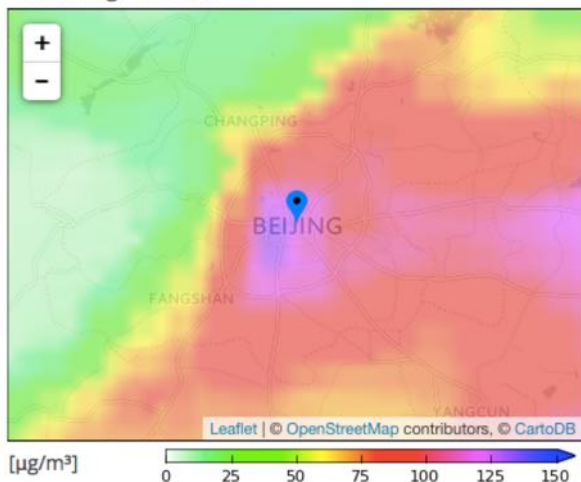
28Nov.-02Dec. 2015

# Case 2: All/Most Models Fail

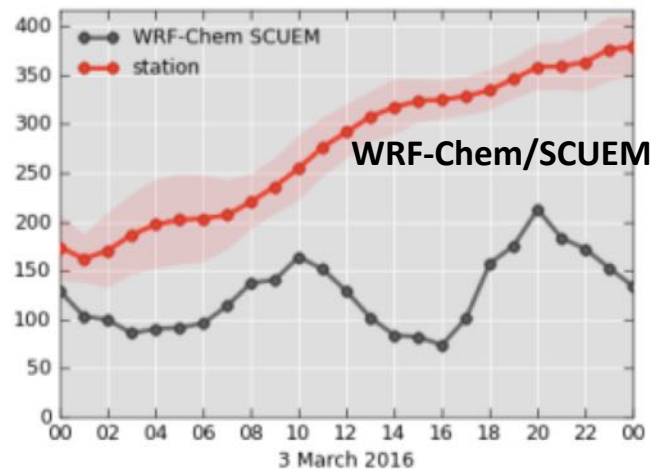
## Special Haze Events in N. China

### PM2.5 Beijing 3 March 2016

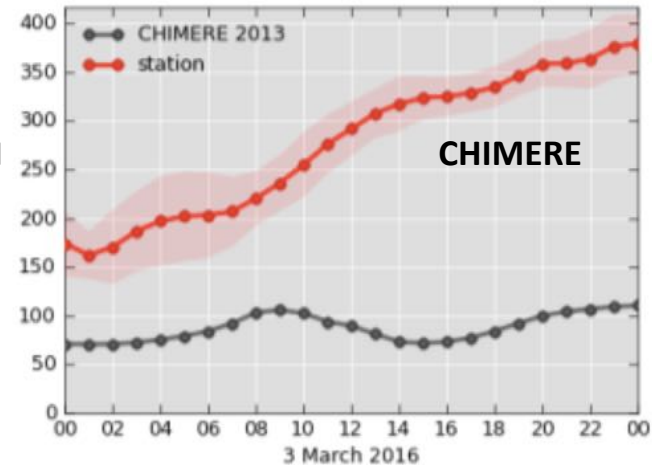
24h average of PM2.5



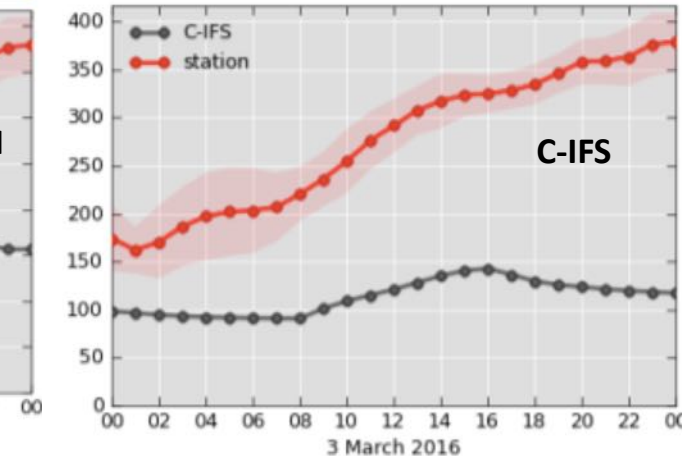
PM2.5 time series [ $\mu\text{g}/\text{m}^3$ ]



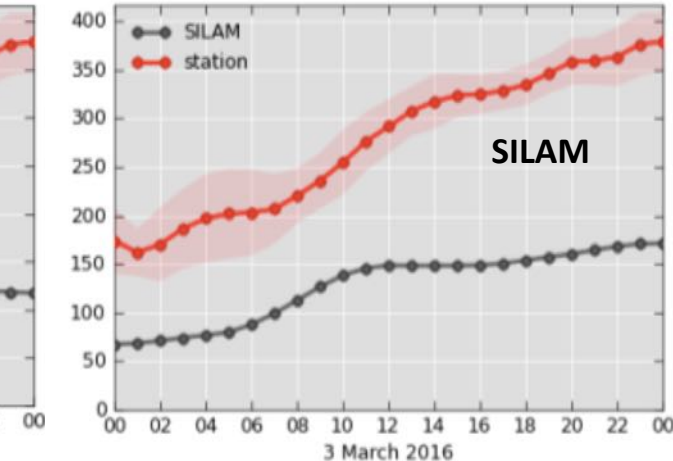
PM2.5 time series [ $\mu\text{g}/\text{m}^3$ ]



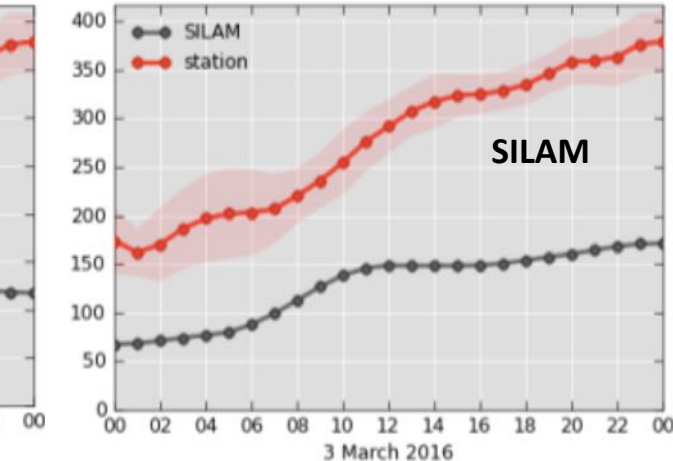
PM2.5 time series [ $\mu\text{g}/\text{m}^3$ ]



PM2.5 time series [ $\mu\text{g}/\text{m}^3$ ]

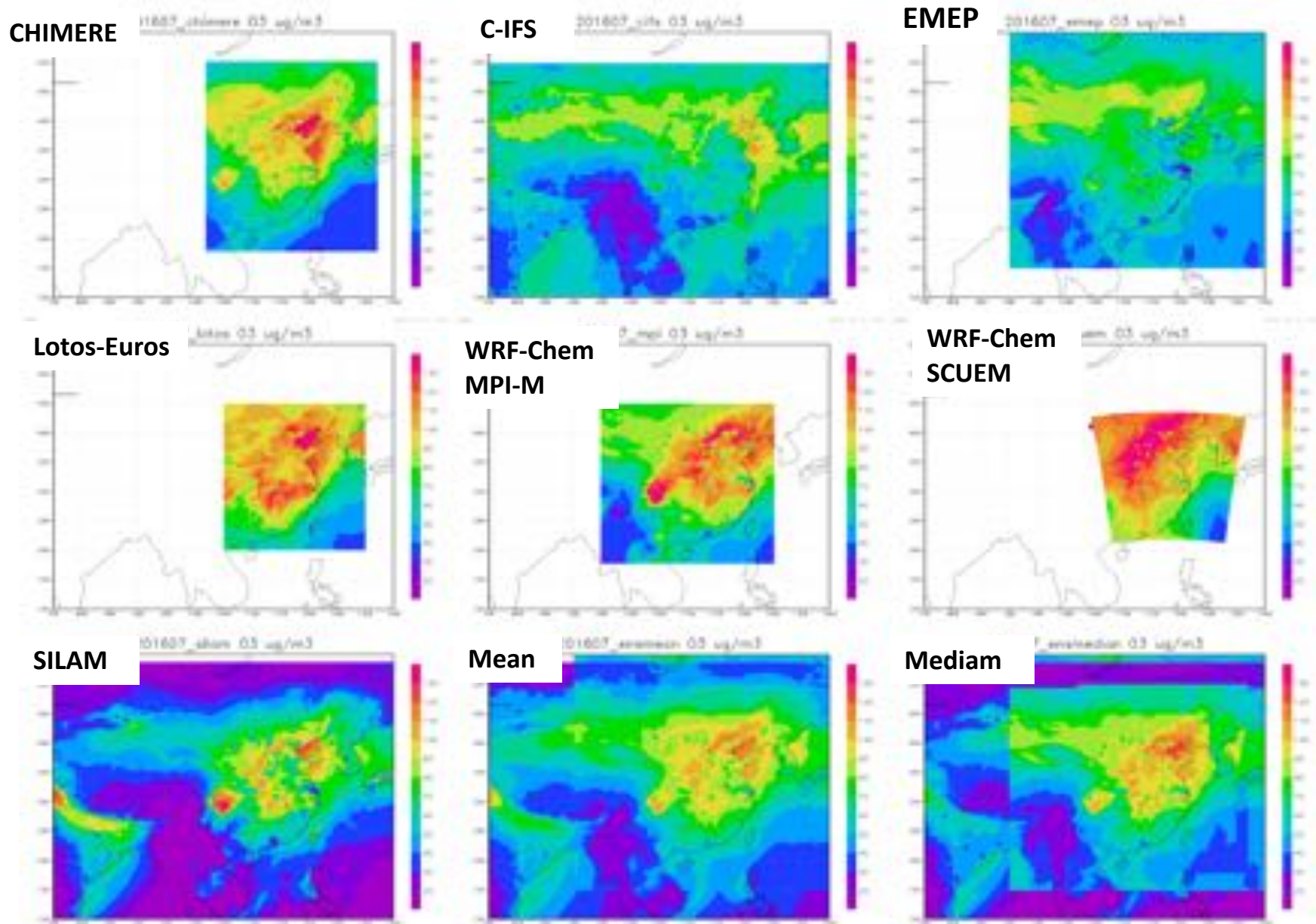


PM2.5 time series [ $\mu\text{g}/\text{m}^3$ ]



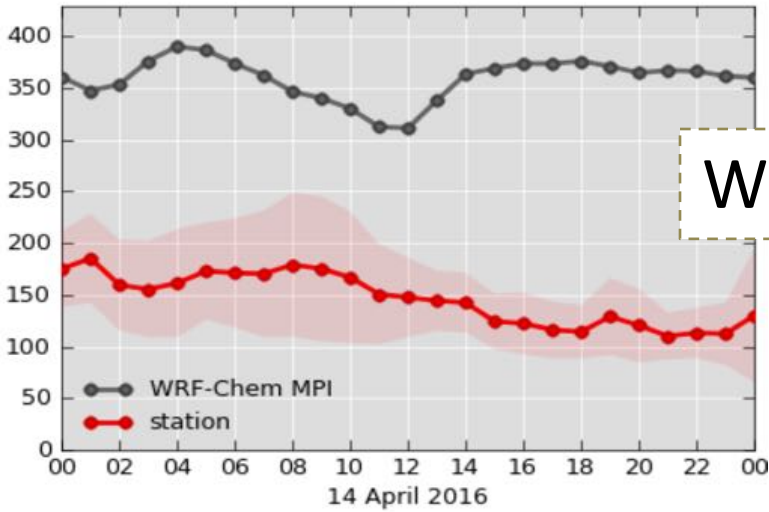


# Case 3: Models Show Substantial Differences

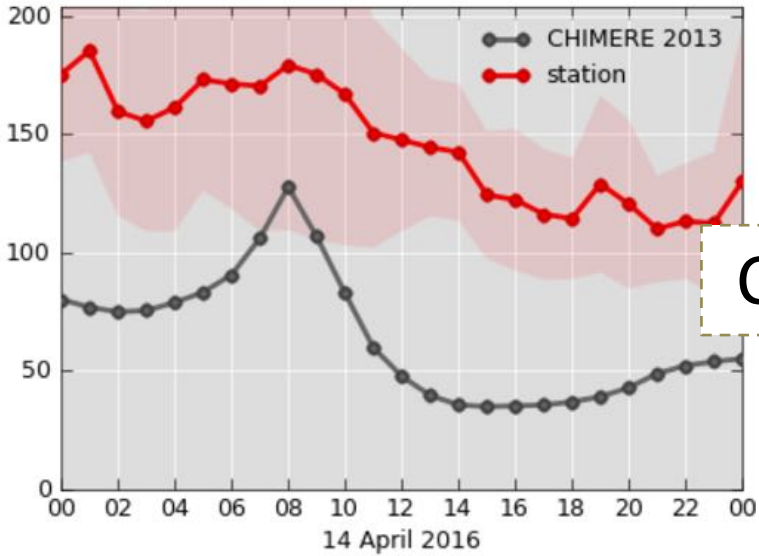
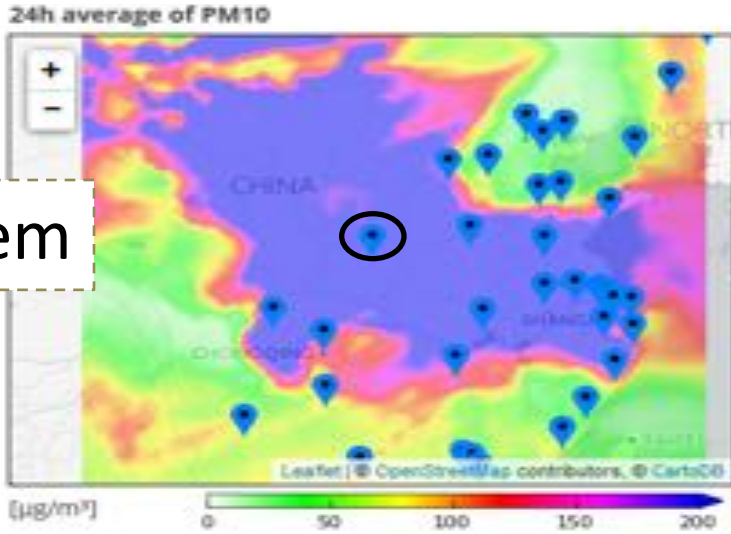


Case 3

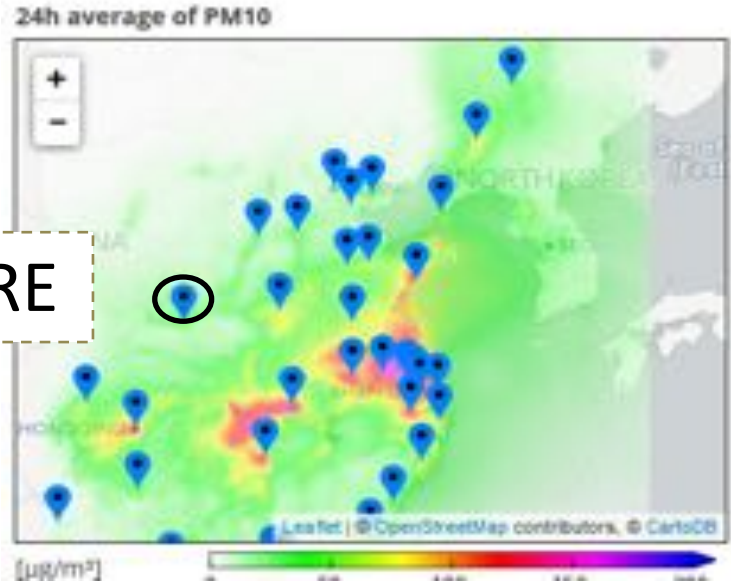
PM10 14 Apr. 2016 X'ian



WRF-Chem



CHIMERE





# Case 3

## 05-06 May 2016

## 13 April 2016

**Observations**

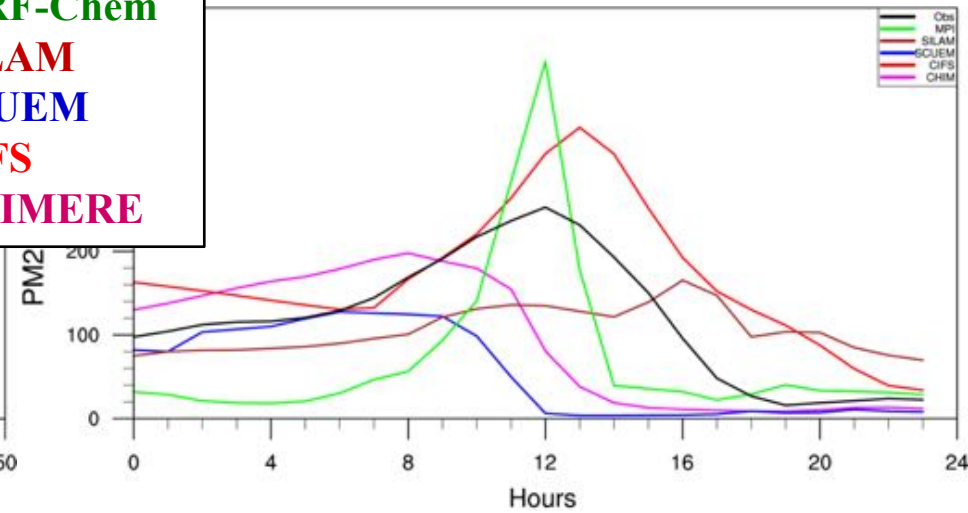
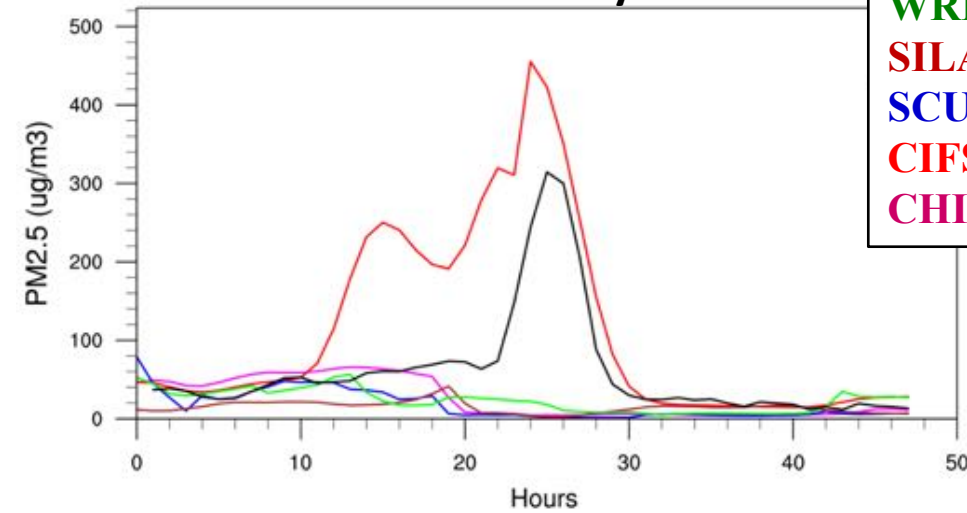
**WRF-Chem**

**SILAM**

**SCUEM**

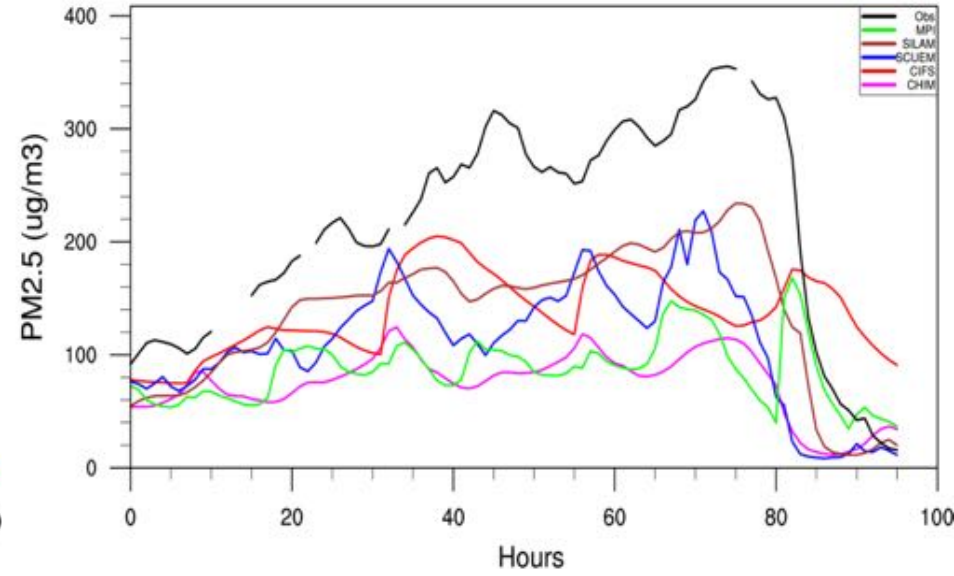
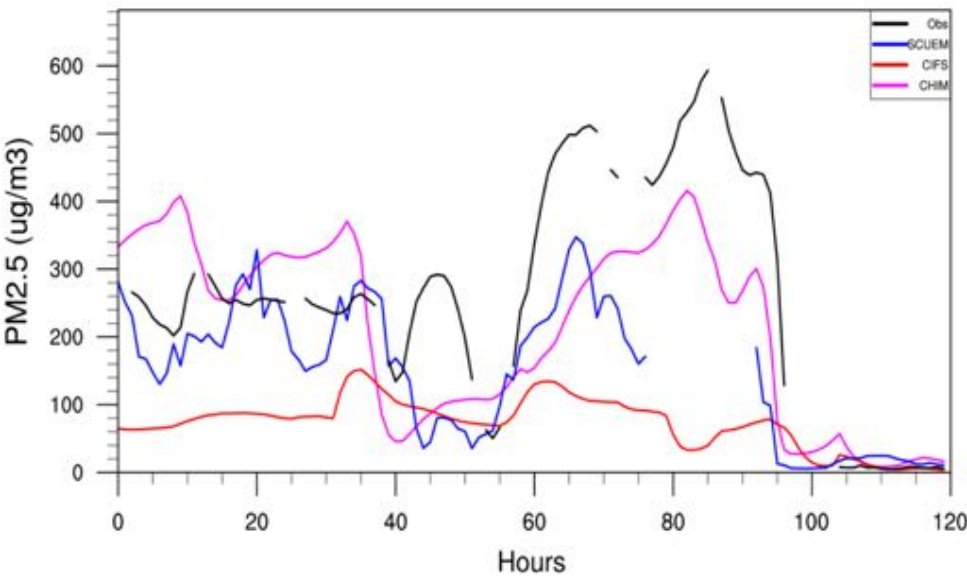
**CIFS**

**CHIMERE**

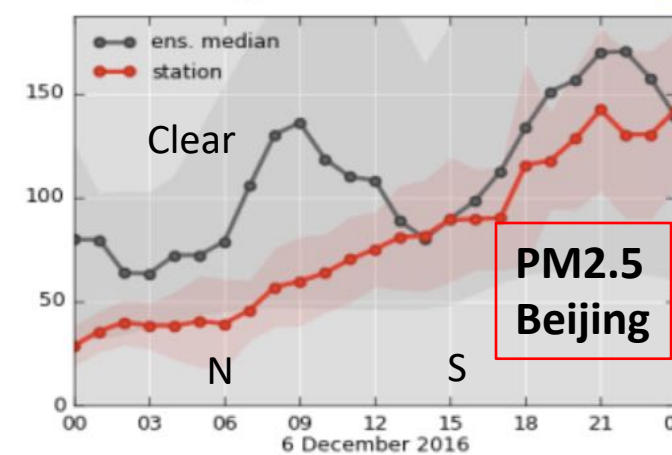


## 28Nov.-02Dec. 2015

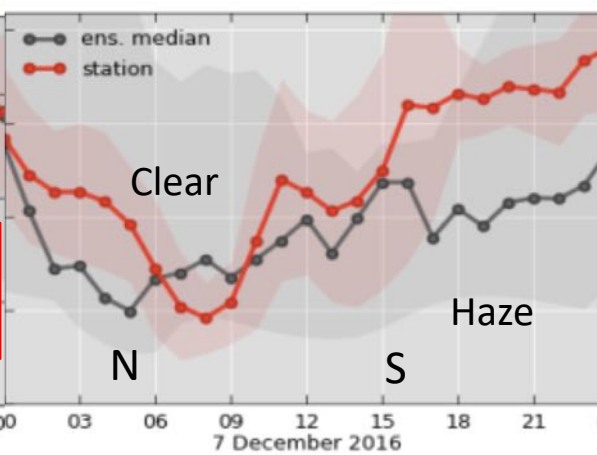
## 15-18 March 2016



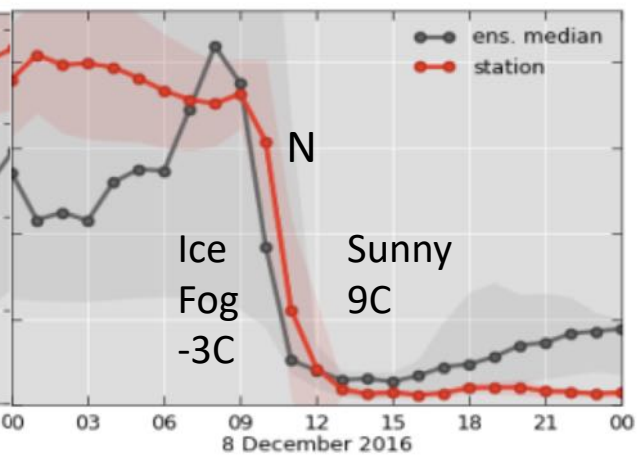
PM2.5 time series [ $\mu\text{g}/\text{m}^3$ ]



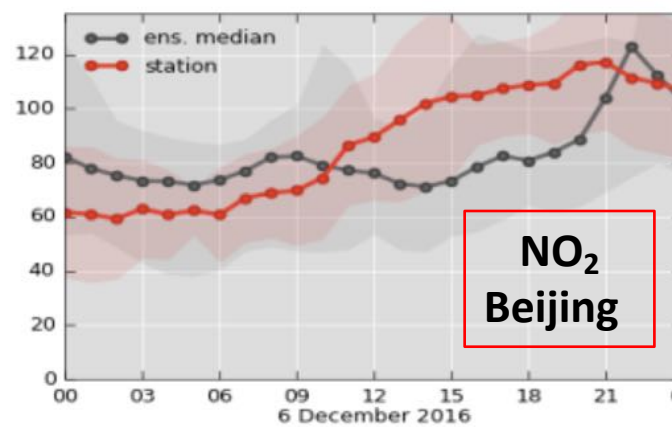
5 time series [ $\mu\text{g}/\text{m}^3$ ]



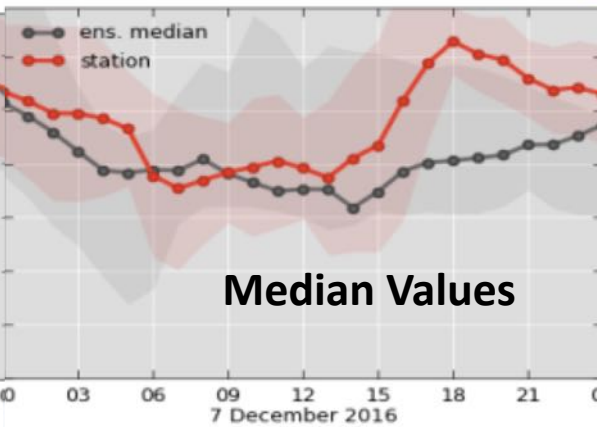
5 time series [ $\mu\text{g}/\text{m}^3$ ]



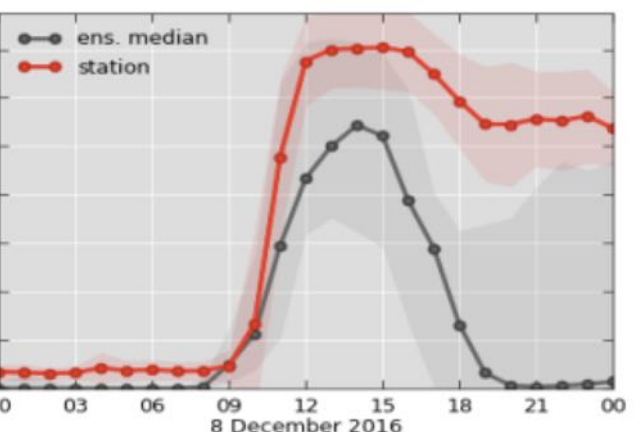
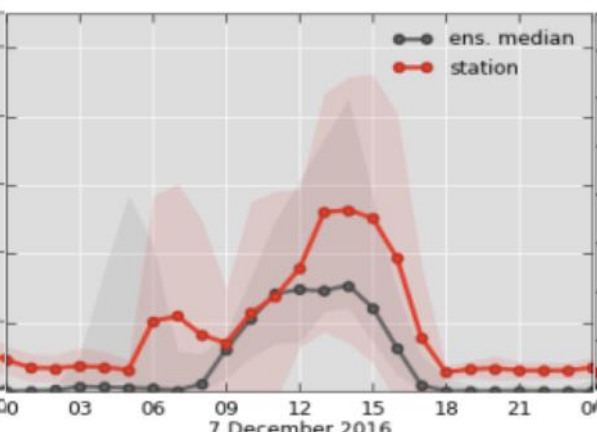
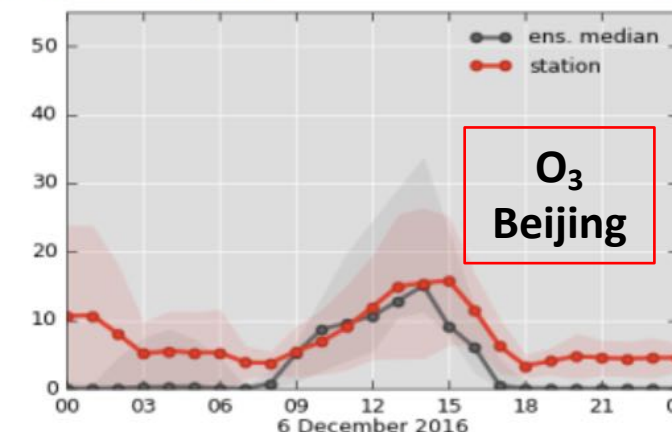
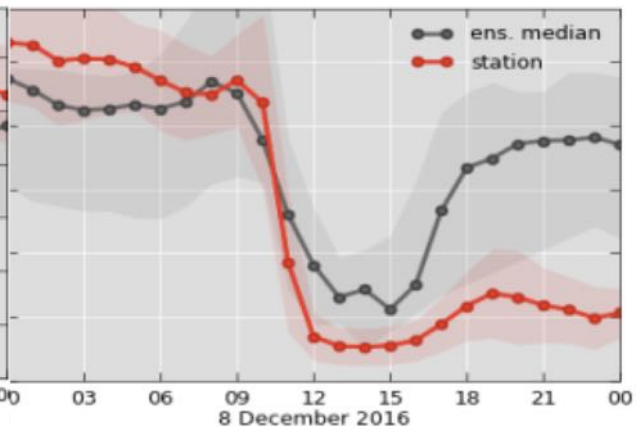
NO2 time series [ $\mu\text{g}/\text{m}^3$ ]



time series [ $\mu\text{g}/\text{m}^3$ ]

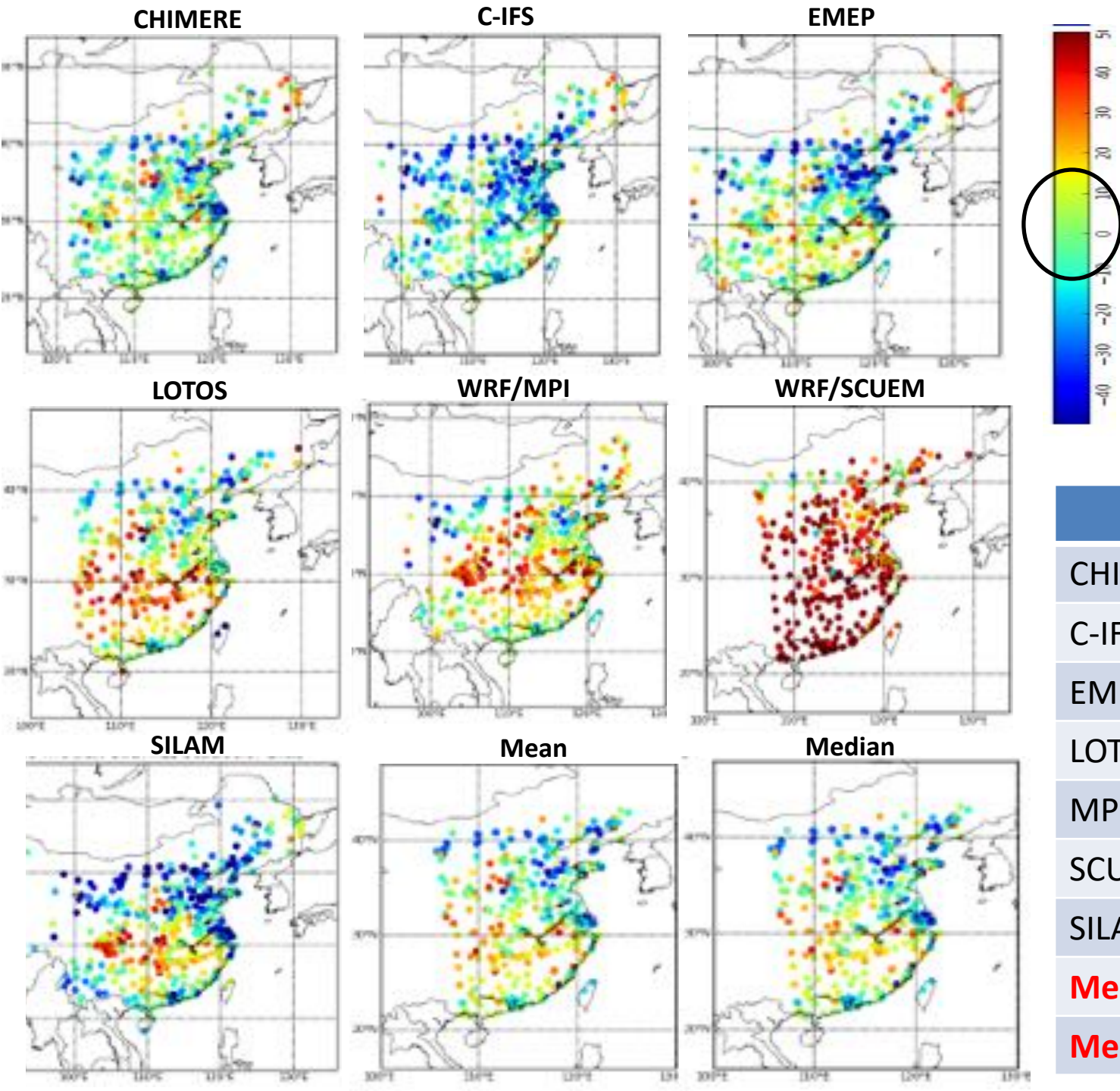


time series [ $\mu\text{g}/\text{m}^3$ ]



Courtesy  
K. Rostislav

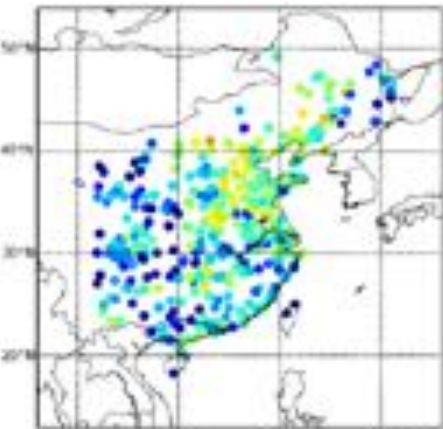
**03**  
**June 2016**



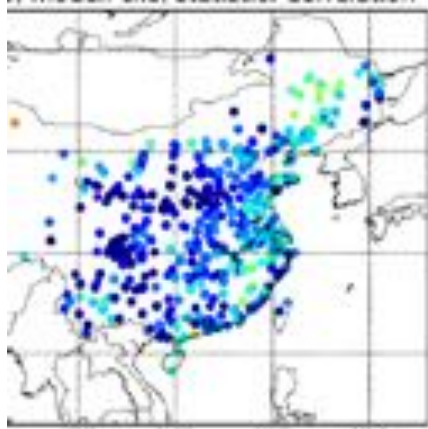
	Bias	r
CHIMERE	25.8	0.83
C-IFS	19.1	0.79
EMEP	25.1	0.71
LOTOS	44.1	0.74
MPI	45.5	0.72
SCUEM	74.7	0.78
SILAM	36.1	0.73
<b>Mean</b>	<b>30.5</b>	<b>0.84</b>
<b>Median</b>	<b>29.2</b>	<b>0.83</b>



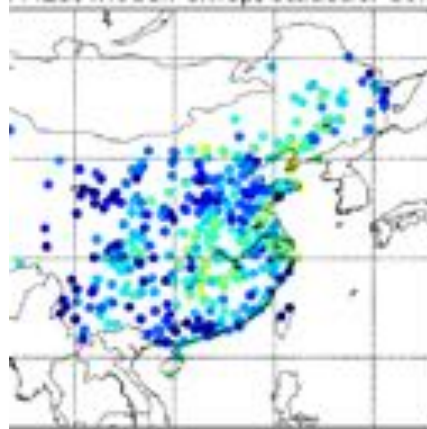
CHIMERE



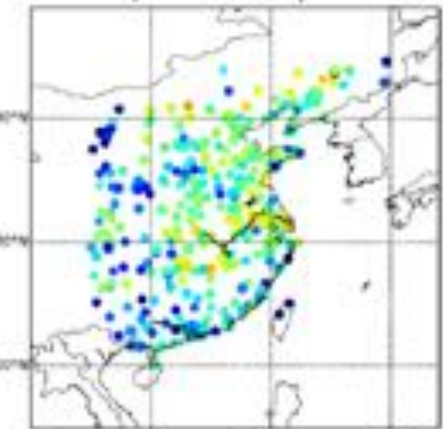
C-IFS



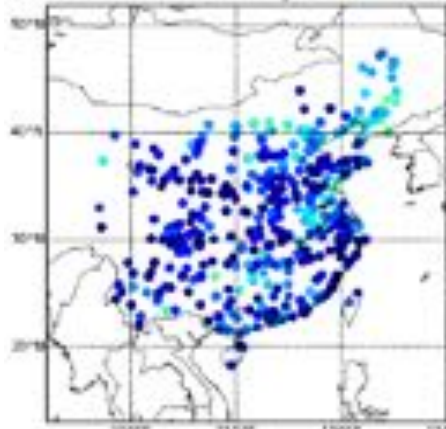
EMEP



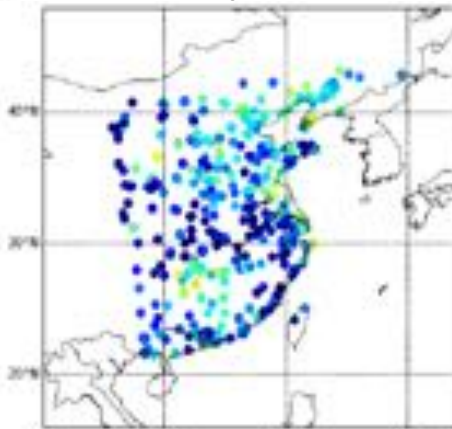
LOTOS



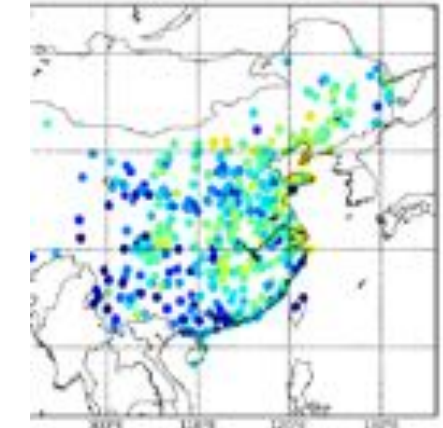
WRF/MPI



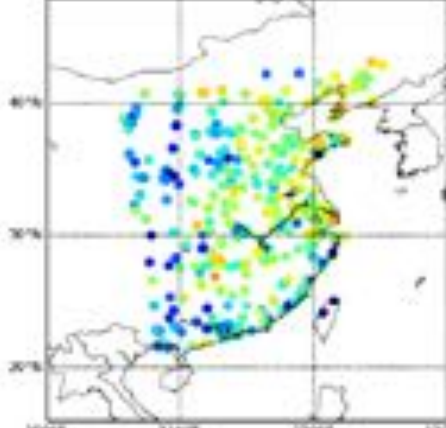
WRF/SCUEM



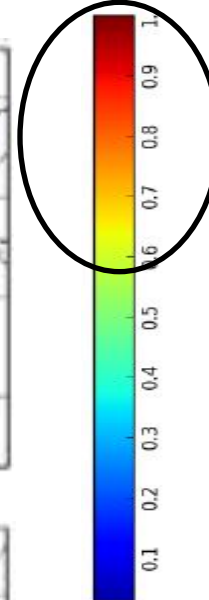
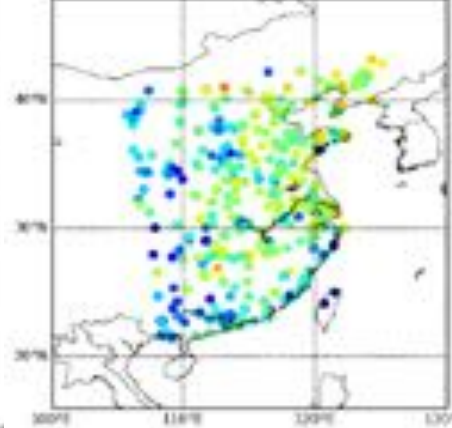
SILAM



Mean



Median

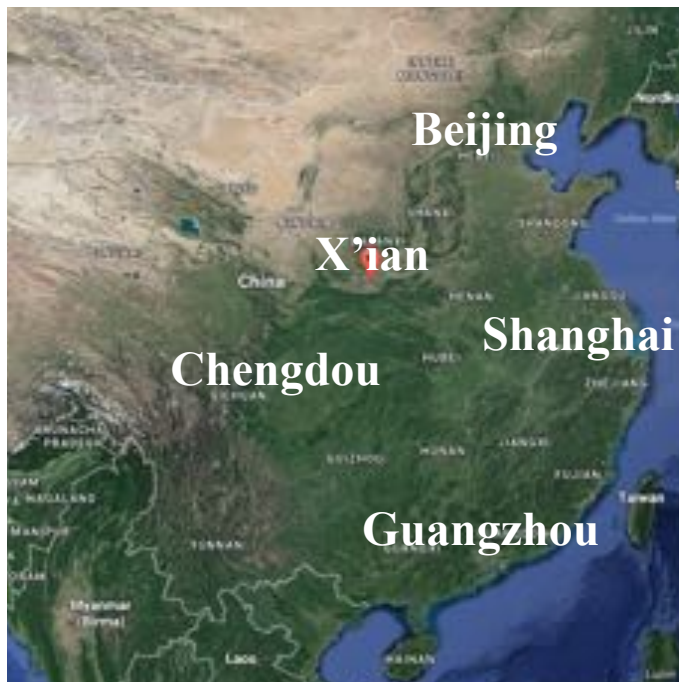


Courtesy  
K. Rostislav

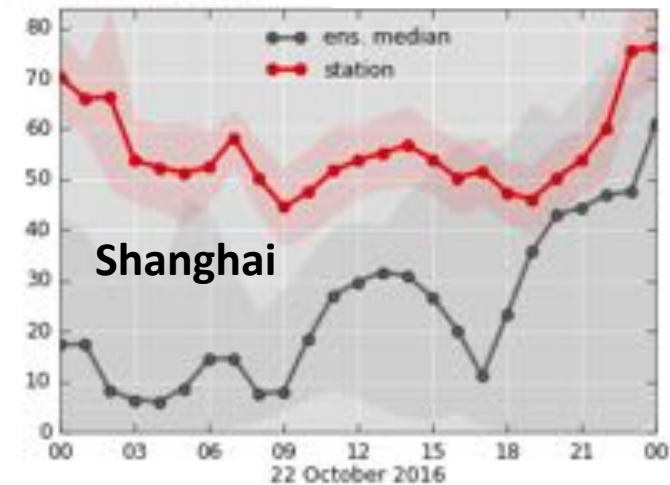
**PM2.5**  
**June 2016**

	Bias	r
CHIMERE	37	0.63
C-IFS	74	0.47
EMEP	41	0.53
LOTOS	20.8	0.65
MPI	28.8	0.4
SCUEM	14.7	0.54
SILAM	41.6	0.63
<b>Mean</b>	<b>33.3</b>	<b>0.67</b>
<b>Median</b>	<b>25</b>	<b>0.64</b>

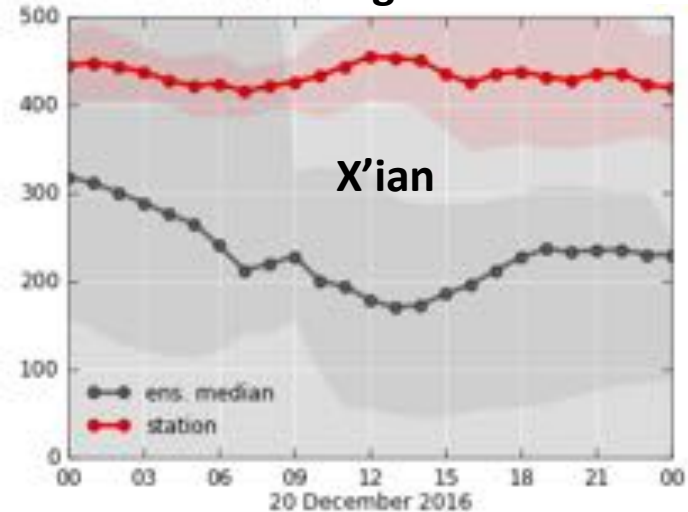
# Other challenging cases



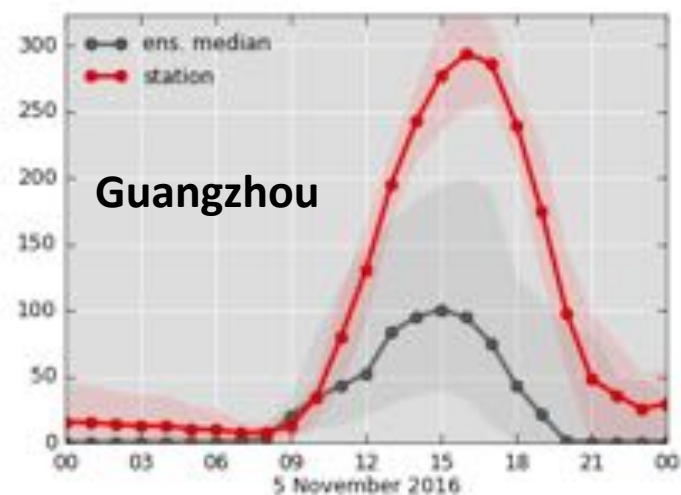
### O3 time series [ $\mu\text{g}/\text{m}^3$ ] Coastal Cases



### PM2.5 time series [ $\mu\text{g}/\text{m}^3$ ] Regional + Urban Dust



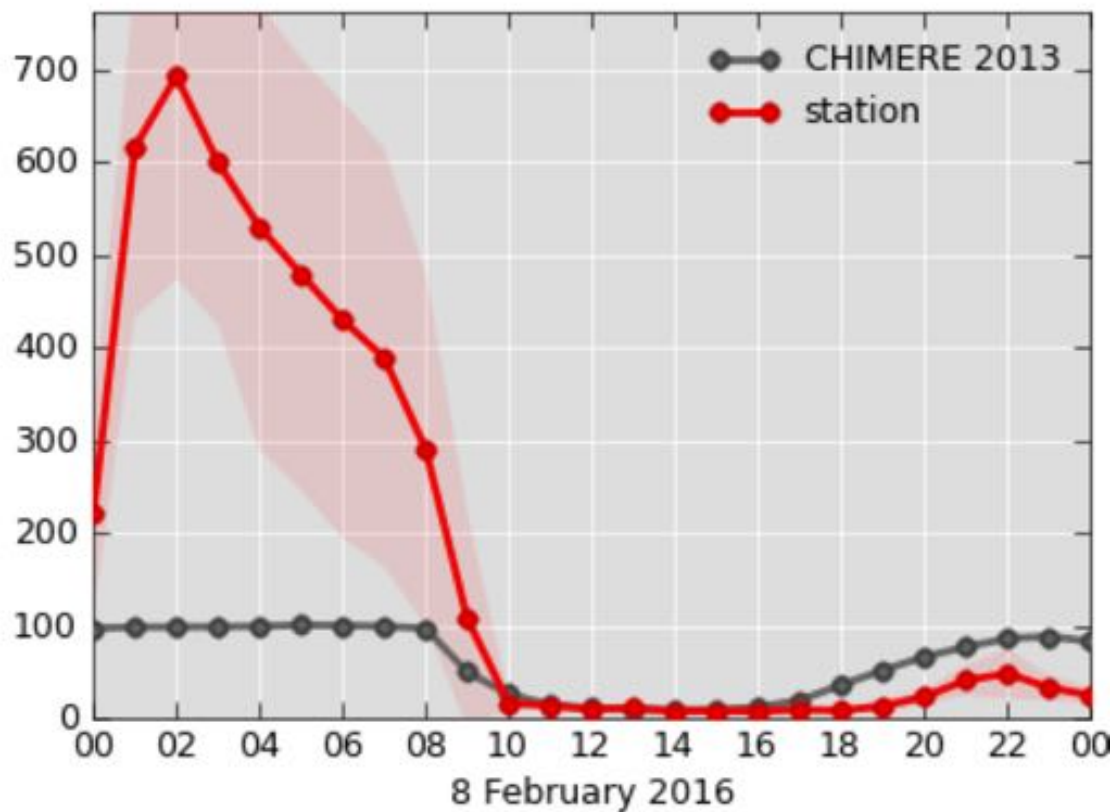
### O3 time series [ $\mu\text{g}/\text{m}^3$ ] Complex Terrain





# Chinese new year! (Coincidence?)

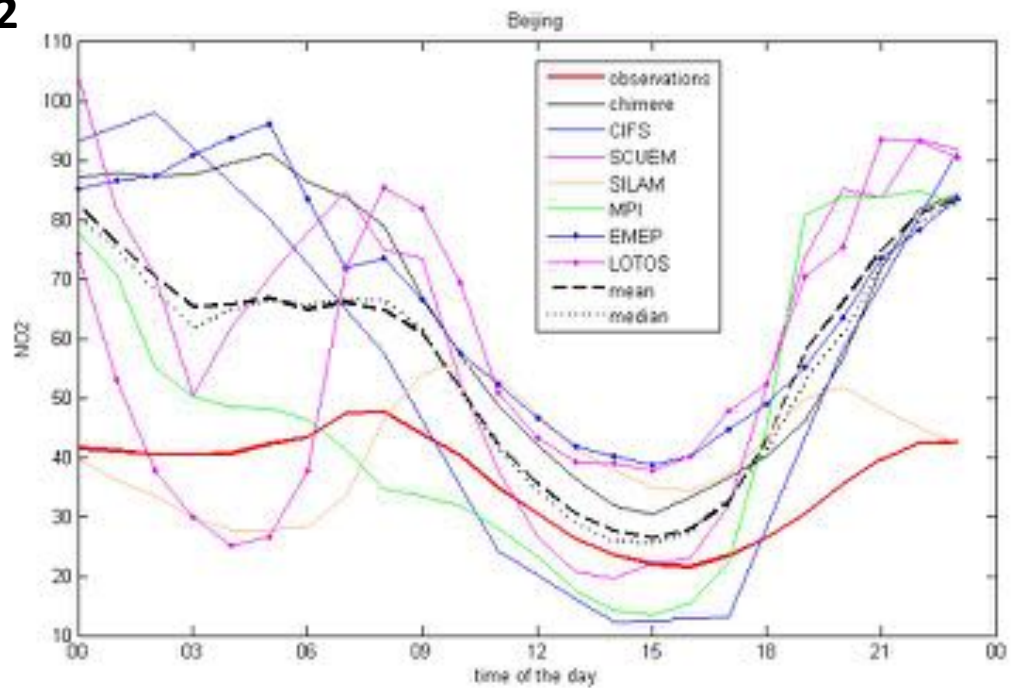
PM2.5 in Beijing [ $\mu\text{g}/\text{m}^3$ ], 8 February 2016



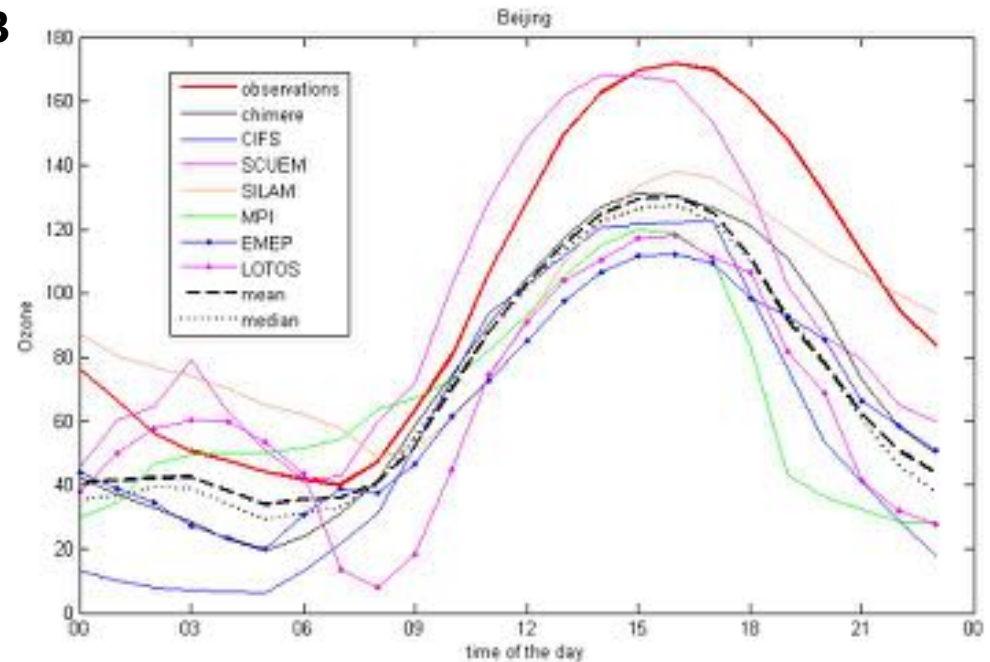
# Diurnal Variability

- Significant differences among models
- Increased bias at nighttime
- Mean/median ensemble forecast affected by individual model skills

**NO2**

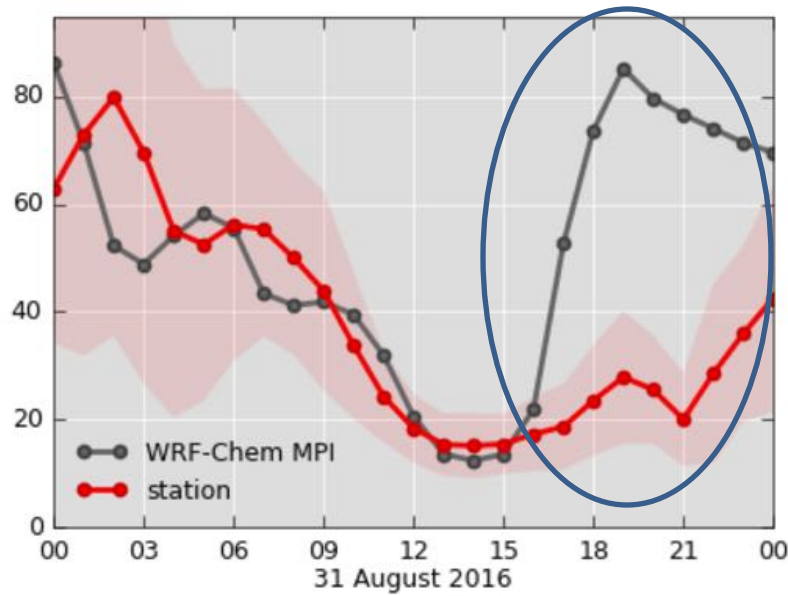


**O3**

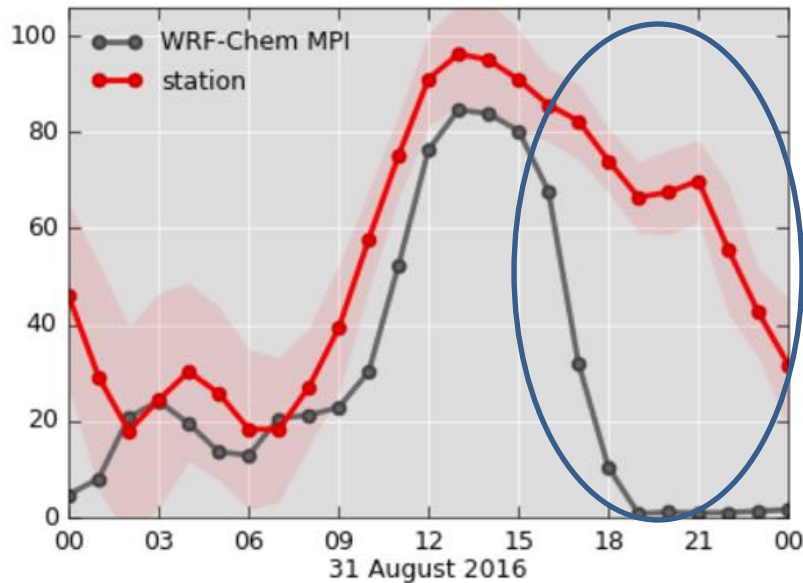


# Nighttime Boundary Layer in Urban Environments

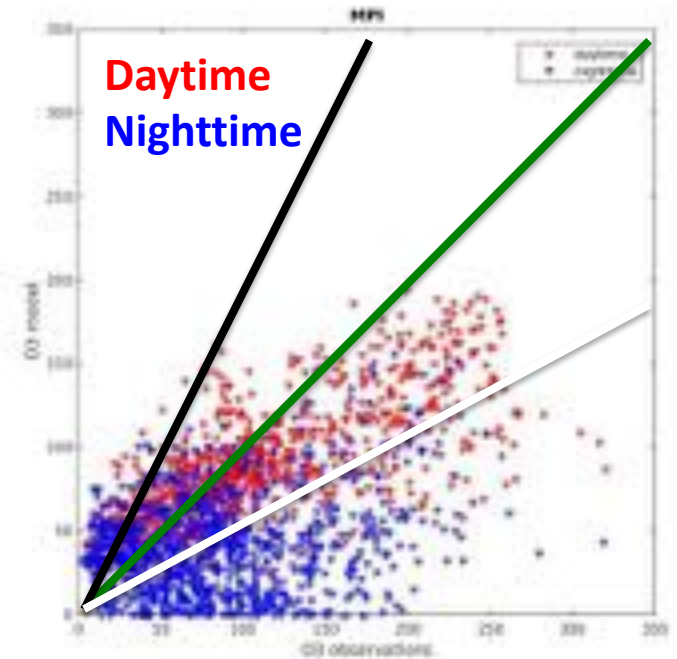
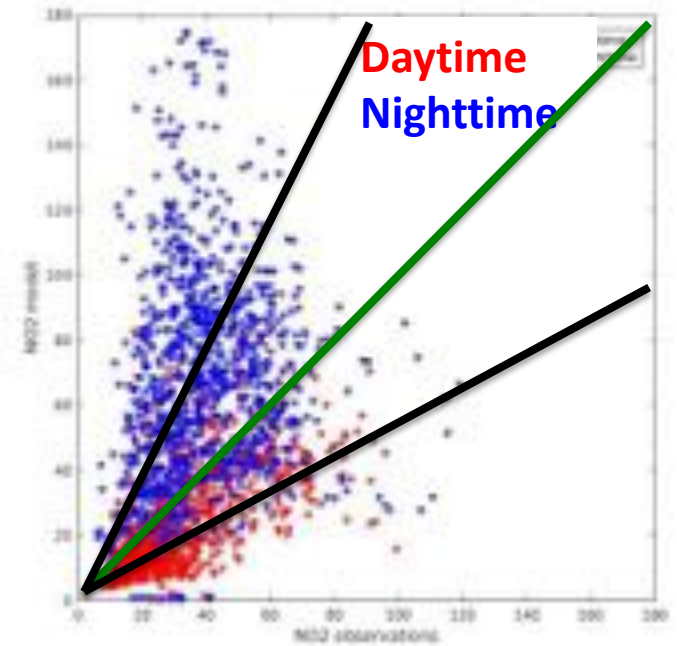
$\text{NO}_2$



$\text{O}_3$

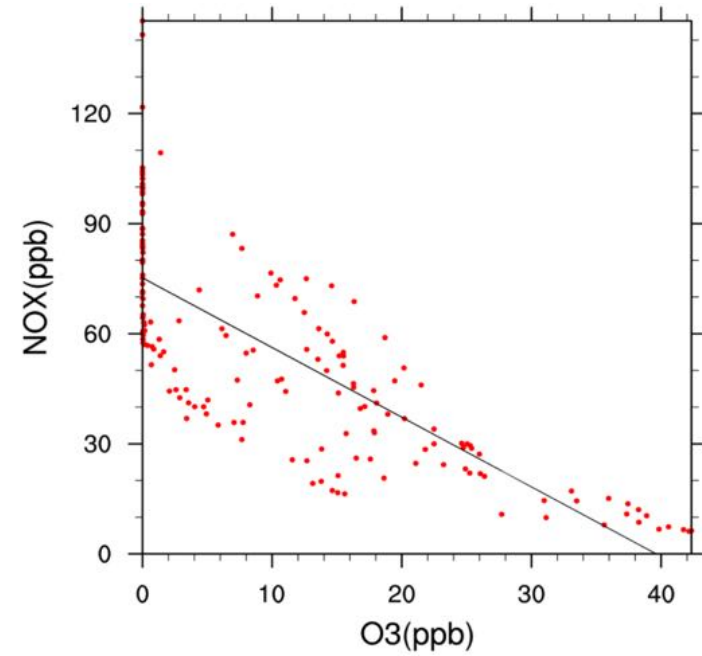
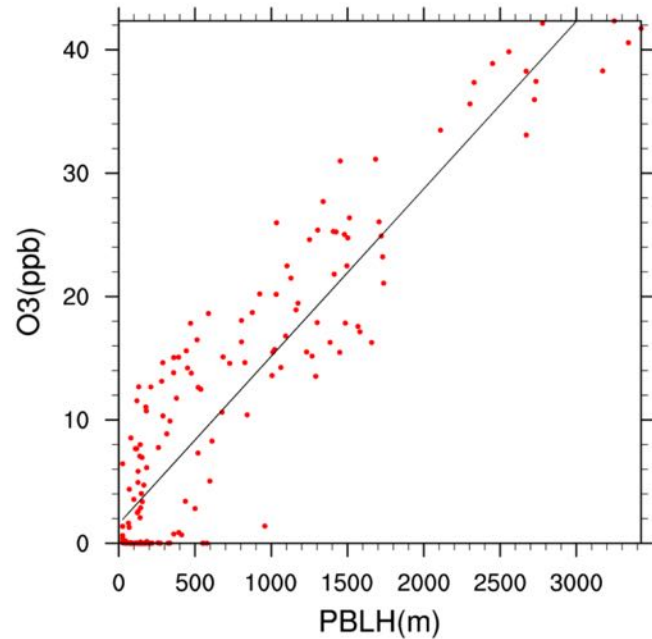
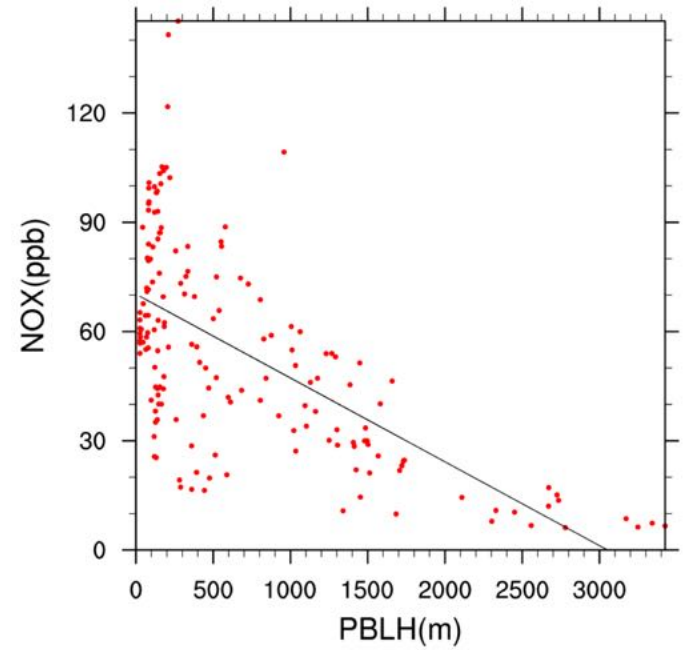
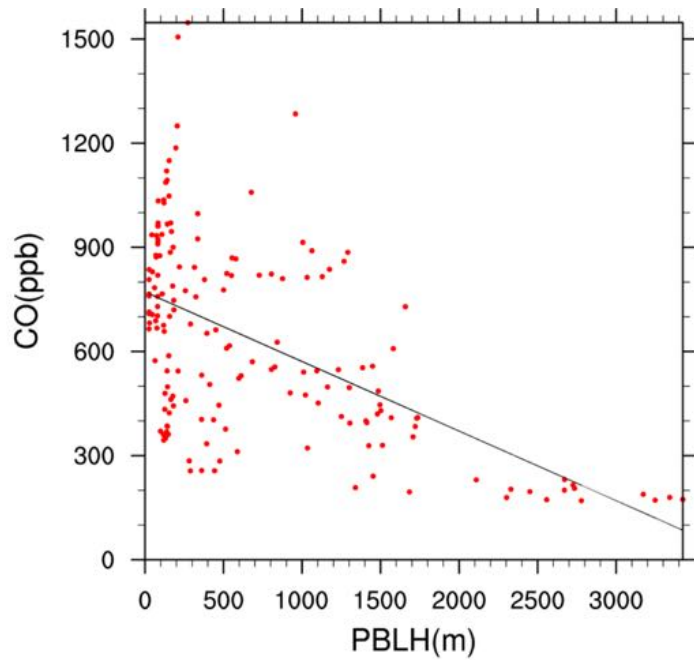


WRF-Chem  
Beijing

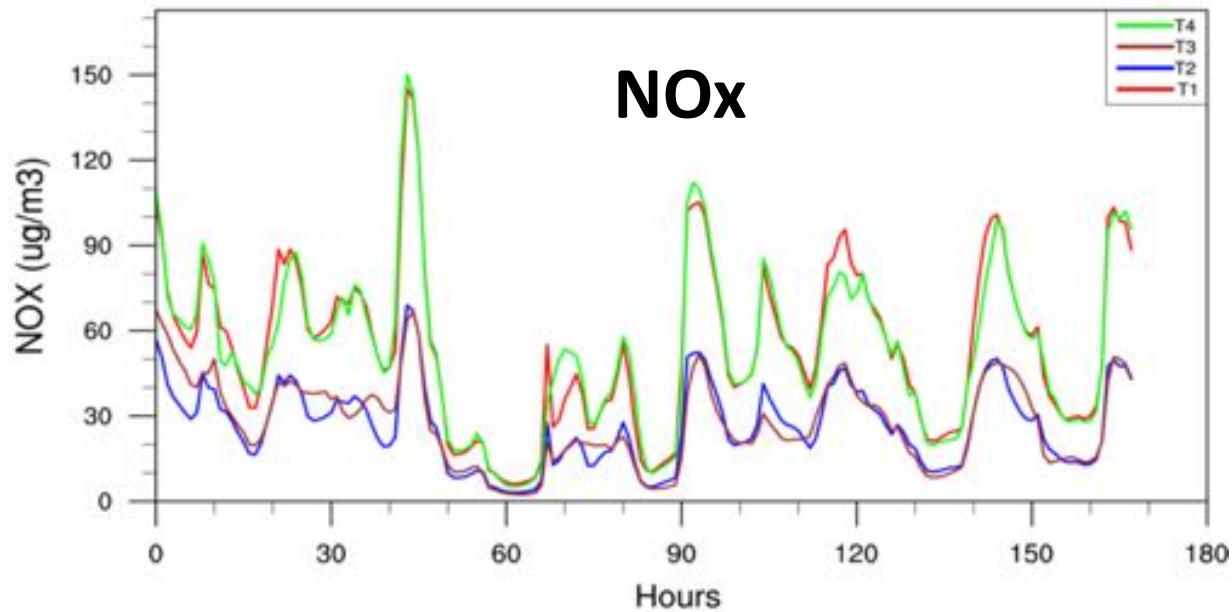




# Boundary Layer Effect in Urban Environments



# Sensitivity to Emissions

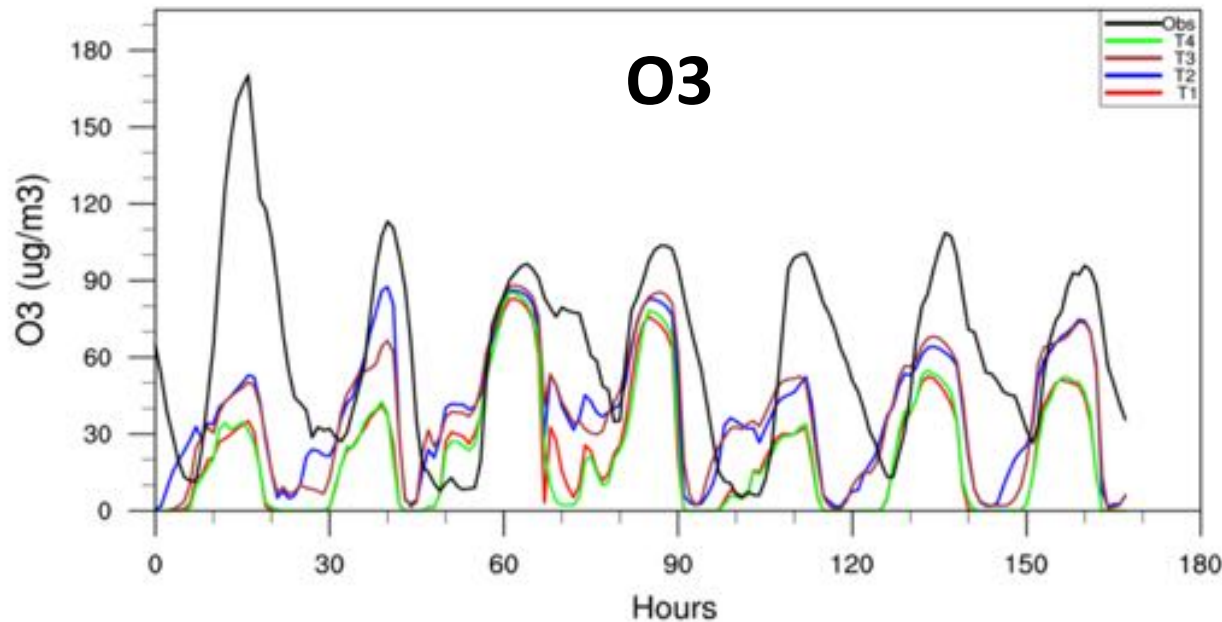


**T1: CONTROL**

**T2: -50% NOx**

**T3: MACC City  
Emissions (0.5x0.5)**

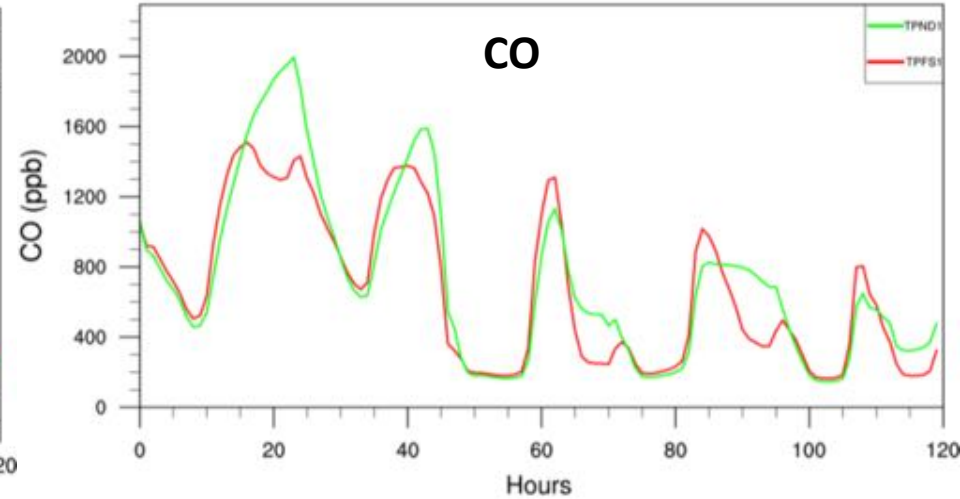
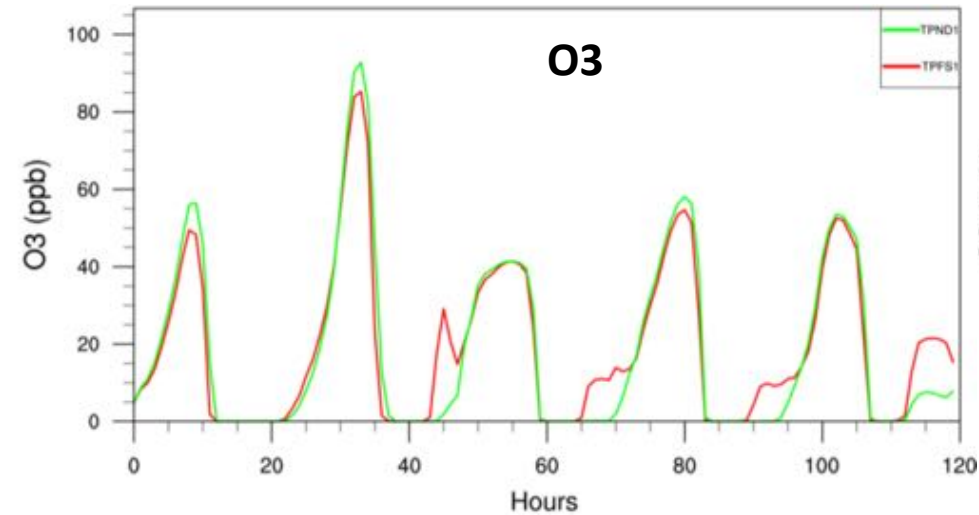
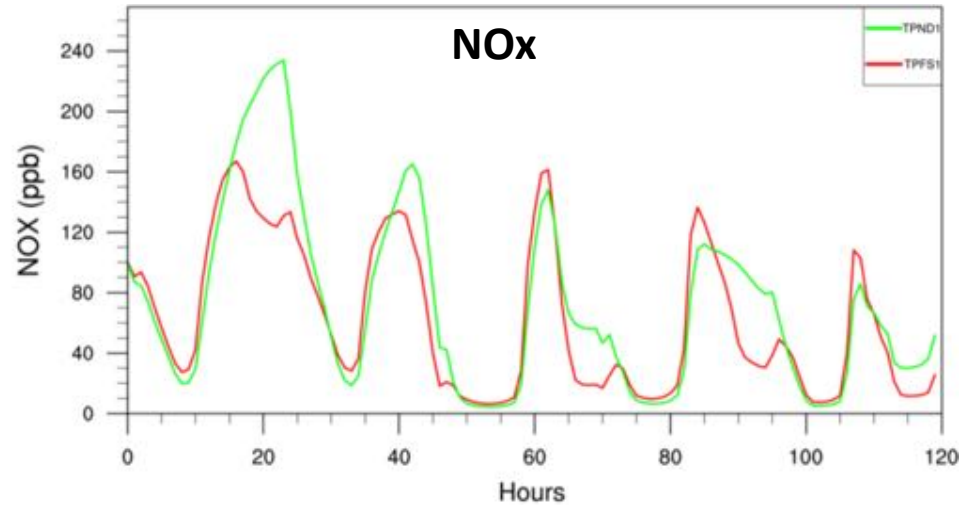
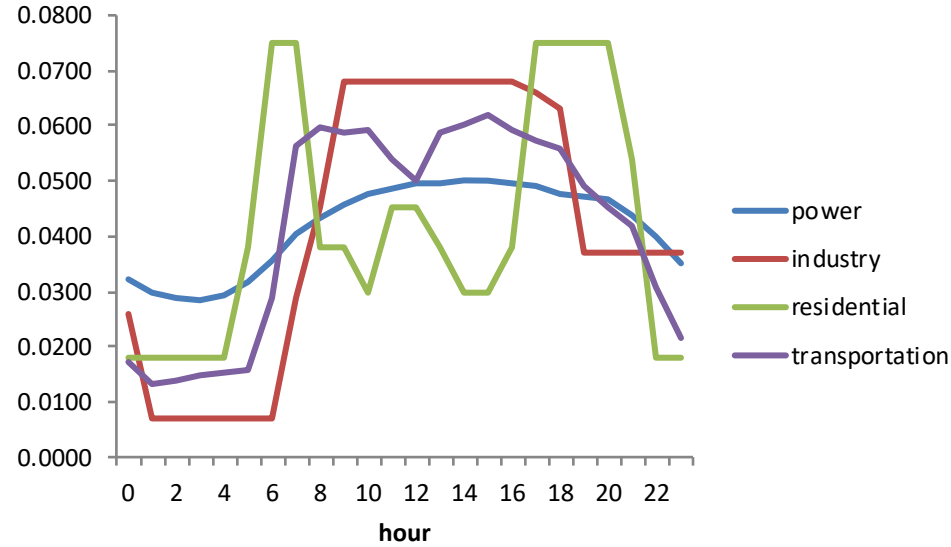
**T4: Other PBL**



# Diurnal Variability of Emissions

With diurnal variation

Without diurnal variation

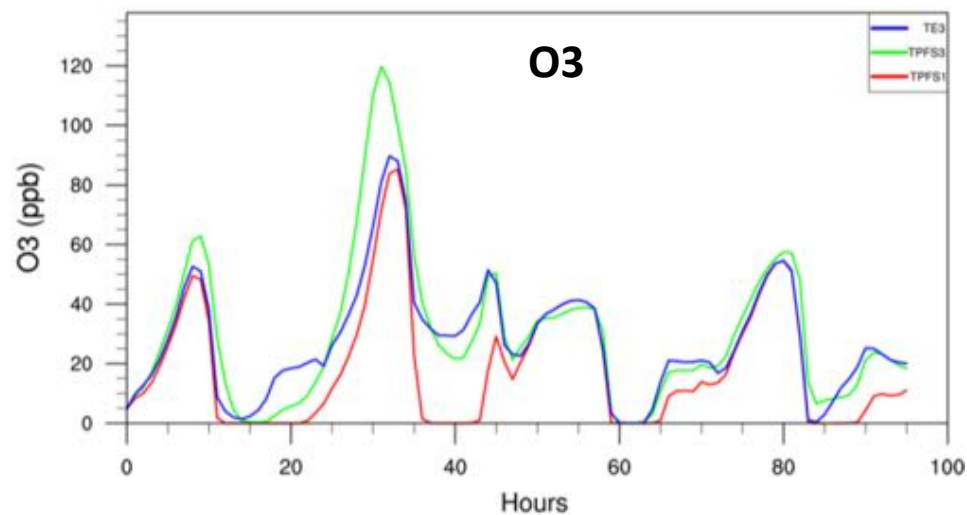
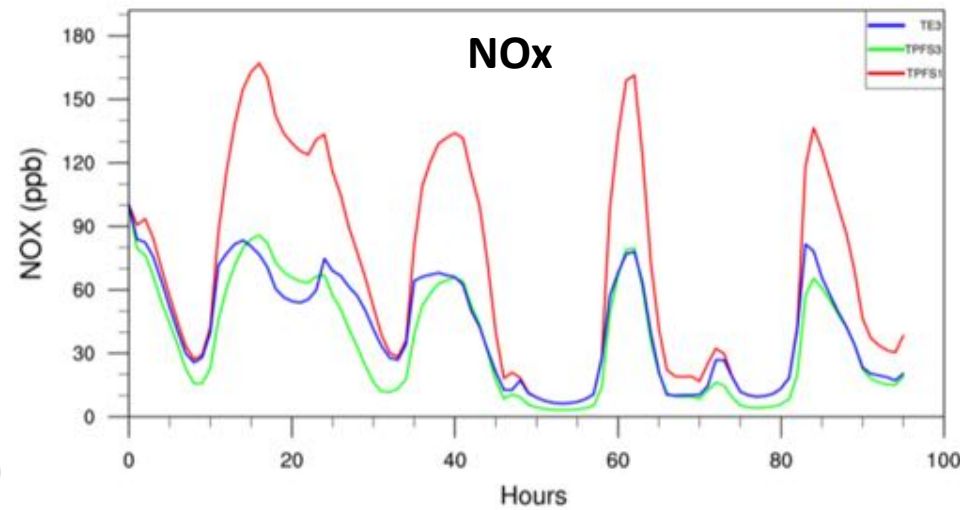
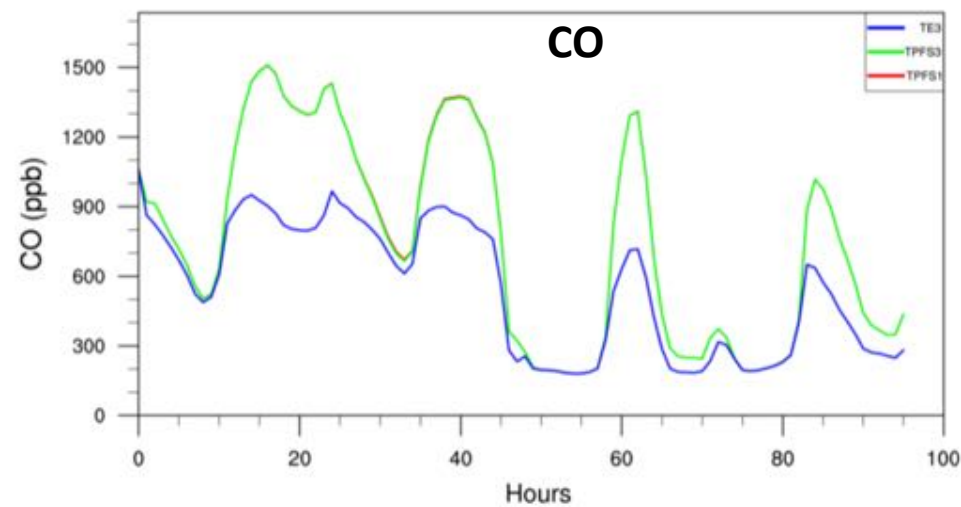


# Effect of Vertical Diffusion

**CONTROL**

**-50% NO<sub>x</sub>**

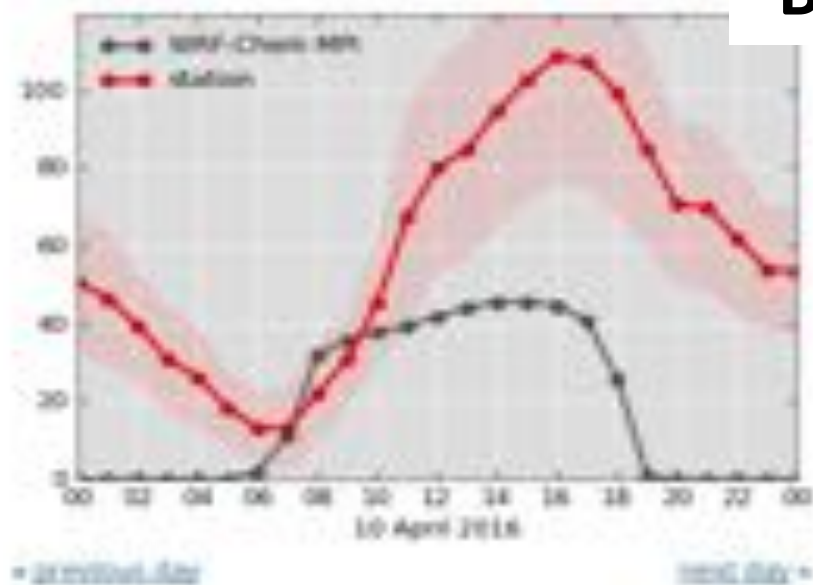
**K<sub>z</sub> >=10**



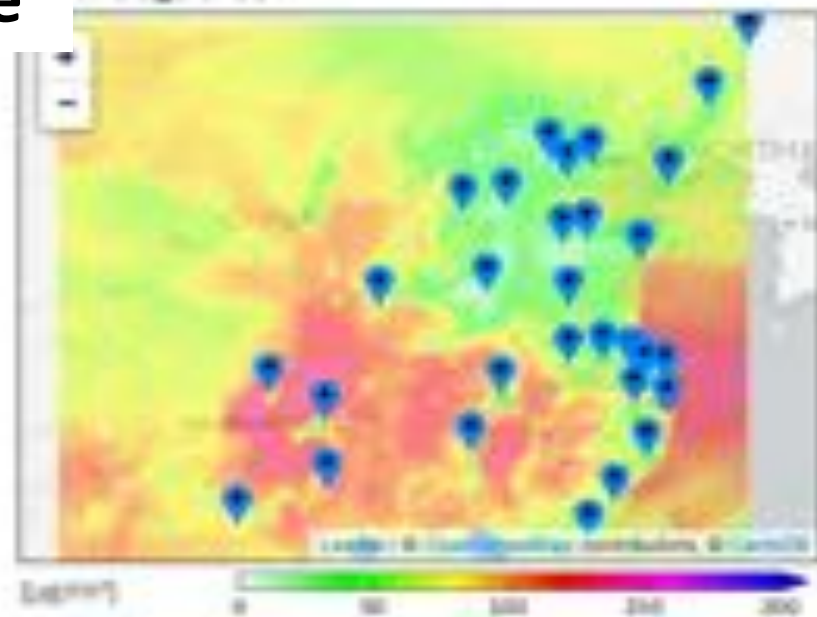
# Beijing O3 forecast

## Before

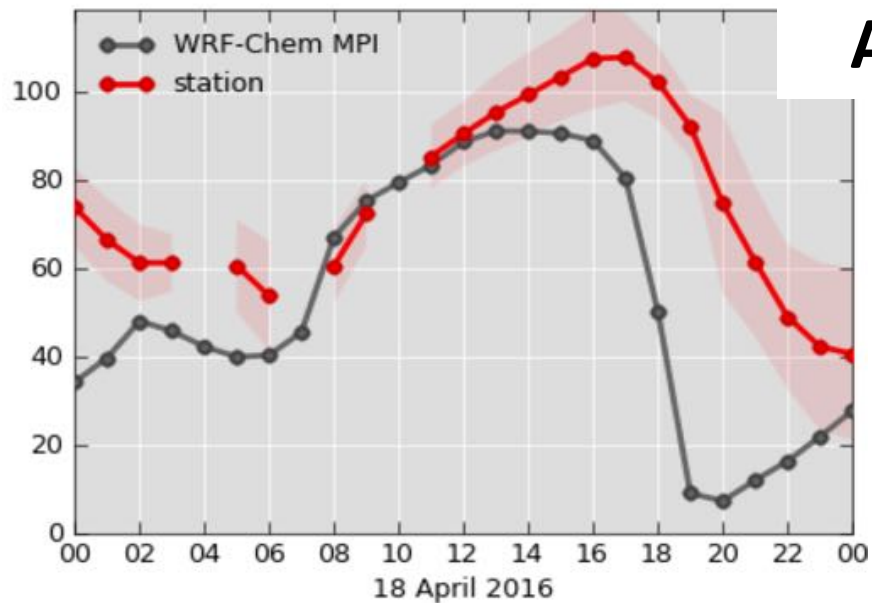
O3 time series (ppm)



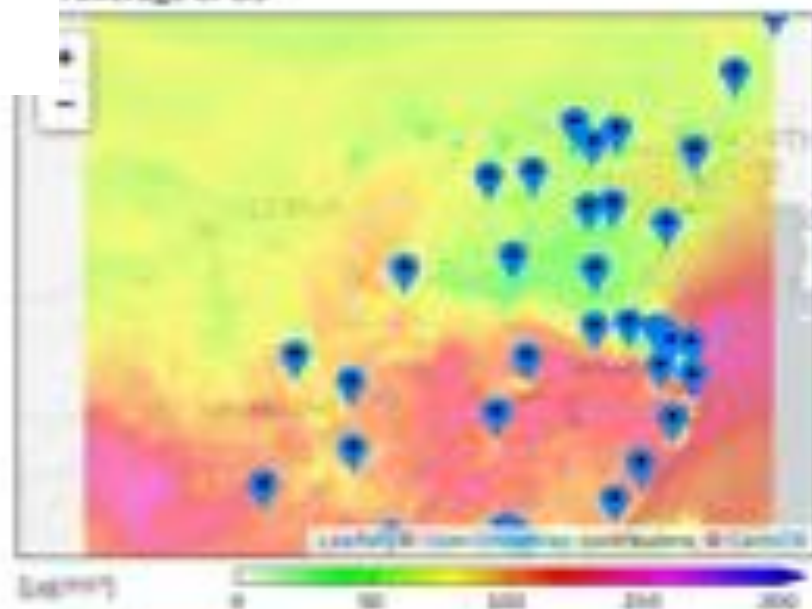
average of O3



## After



average of O3

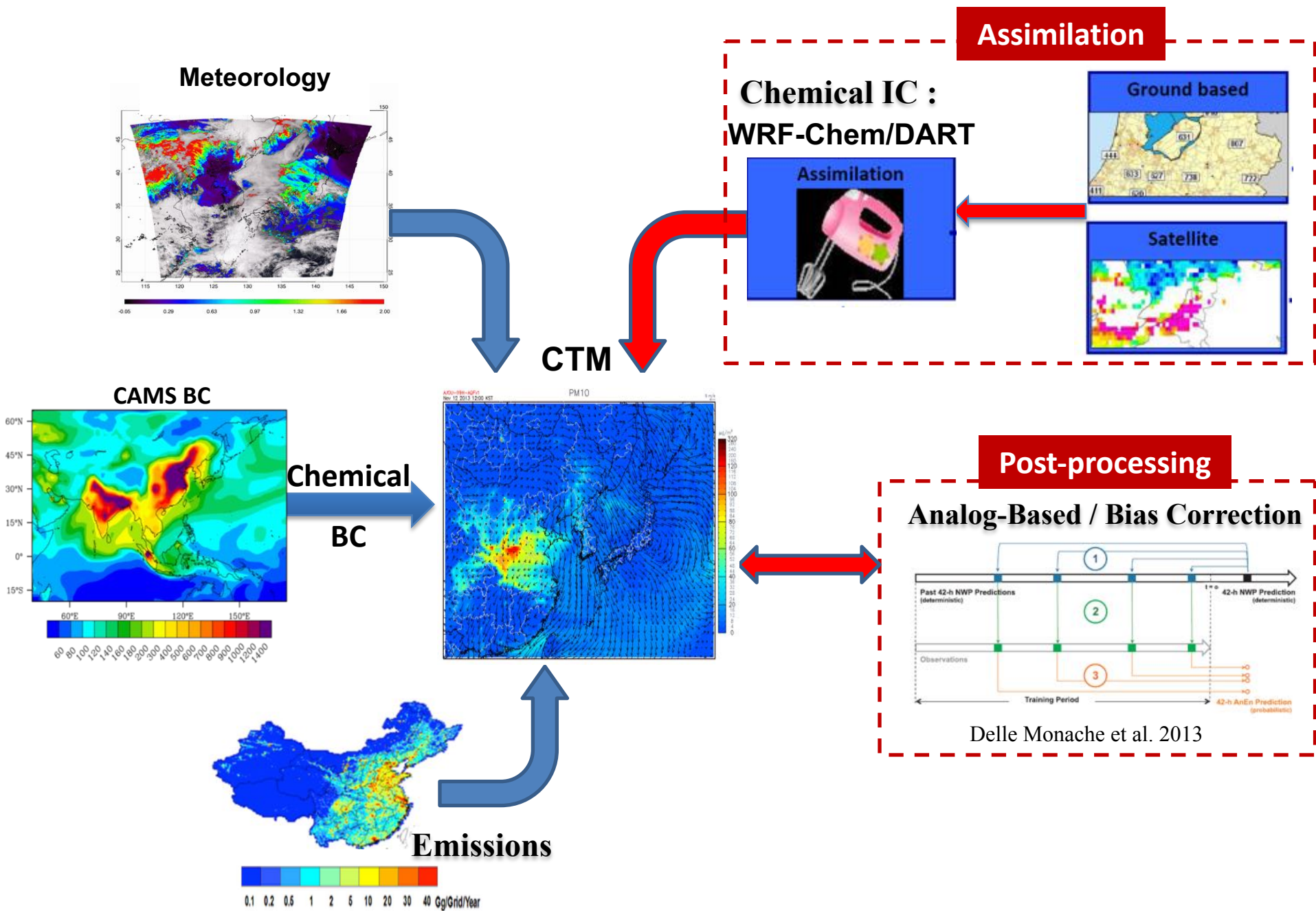




# Perspectives

- Keep Running the Systems : see, in long-term, how current measures to reduce emissions are efficient
- Consistent Scientific Evaluation: **Model-Intercomparison Exercise**
- Get Access to Monitoring Stations and Other Observations
- Provide Other Products/Information: AQI, Other Chemical Species, Visibility, Haze
- Further Investigate Boundary Layer Impact on Pollution in Urban Environment
- Improve key model processes (e.g. SOA formation, key Met. Parameters...)
- Update anthropogenic emissions (e.g. with satellite inversions)
- Downscale to City-level
- .....

# Improving Model Predictions



# Thank you!

Life must go on ...



Dancing at a park blanketed by snow along in Fuyang, China, on Tuesday.