The observation-based relationships between $PM_{2.5}$ and AOD over China

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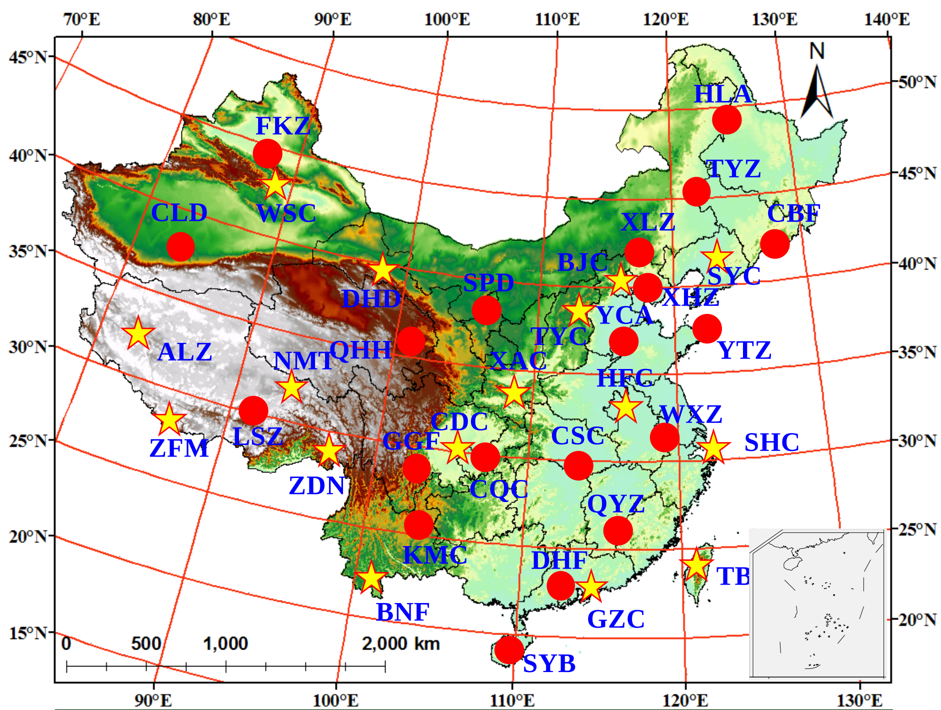
Outline

1. The network
2. Research results
3. Summary

1. CARE-China

The Campaign on atmospheric Aerosol REsearch network of China

- **Based on a network of field stations belonging to the Chinese Academy of Sciences (CAS) and some typical urban sites.**
- **Started since Sep 2011, Running from 2012 to 2015.**



The CARE-China network (36 sites)

● The first-order site ☆ The second-order site

The observation in the CARE-China network

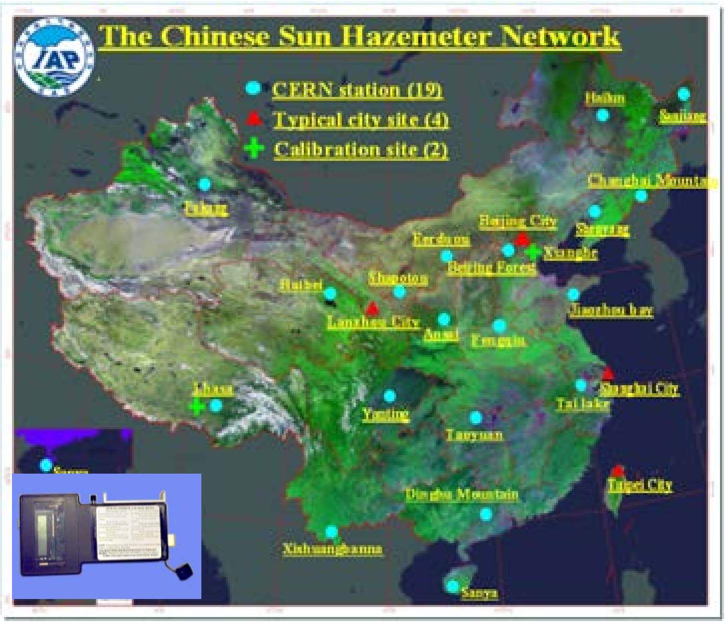
➢Observational elements, experimental methods and temporal resolutions across the network

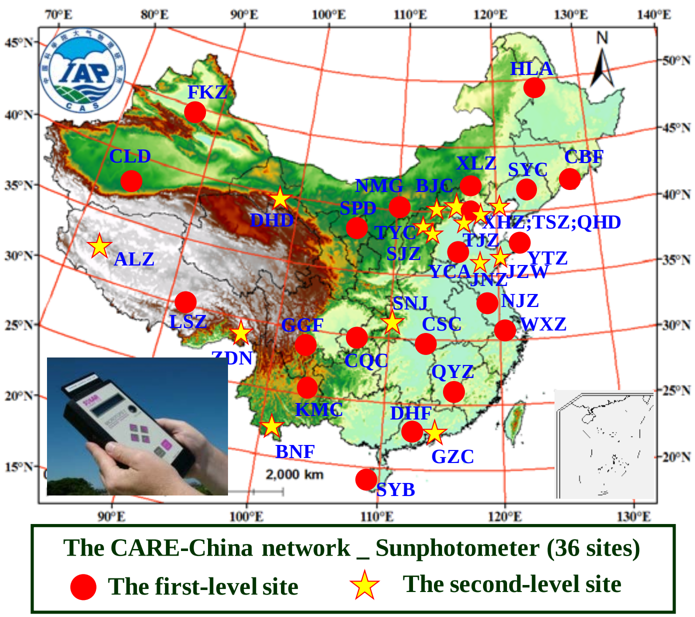
Research content	Observational element	Instrumentation	Frequency
1. Online aerosol concentration; nine-stage distribution of aerosol concentration	(1) $PM_{2.5}$ (2) Nine-size aerosol mass concentration	(1) TEOM RP1400 $PM_{2.5}$ (2) Nine-stage Anderson sampler*	Hourly Weekly
2. Online gaseous precursors (first-grade sites)	SO_2, NOx, CO, O_3	Thermo 42I, 43I, 45I, 49I analyzer	Hourly
3. Nine-stage distribution of EC/OC	Nine-size EC/OC concentration	Thermal optical carbon analyzer	Biweekly
4. Nine-stage inorganic salt	Ten soluble salts	IC	Biweekly
5. OC composition	(1) SOA (2) OC composition	(1) GC/MS (2) GC/MS, IC	Biweekly Biweekly
6. SOA precursors: VOCs	Greater than 60 VOCs	CCS-GC/MS	Weekly
7. Aerosol optical properties (first-grade sites)	(1) Aerosol optical depth (2) Angström exponent (3) Direct radiative forcing	Microtops II sunphotometer (five wavelengths) With MODIS	Hourly Daily

***The nine sizes of Anderson samplers: <0.43, 0.43–0.65, 0.65–1.1, 1.1–2.1, 2.1–3.3, 3.3–4.7, 4.7–5.8, 5.8–9.0, >9.0 µm.**

The network of aerosol optical properties

- The Chinese Sun Hazemeter Network, 2004-2007
- The CARE-China Network_Sunphotometer, 2011-now





2004-2007: 23 sites

Xin et al., JGR, 2007

Upgrade

2012-now: 36 sites

Xin et al., BAMS, 2015

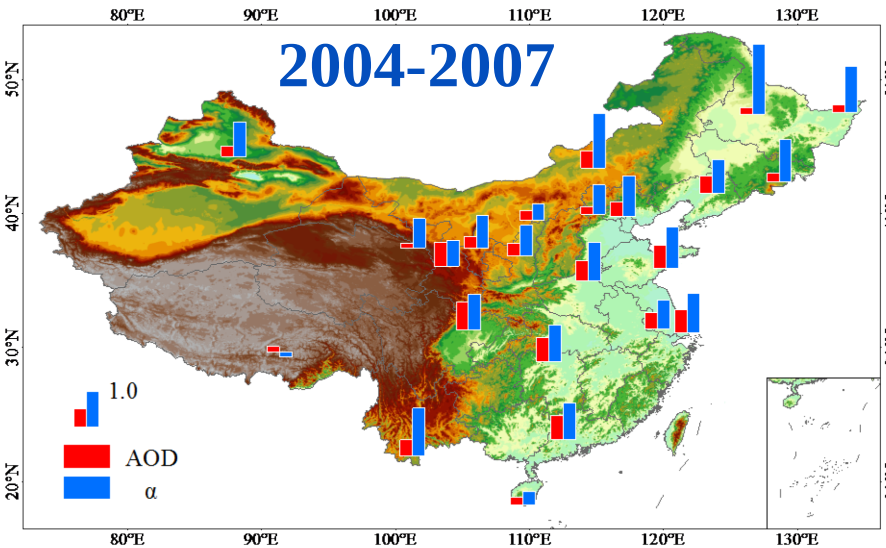
2. Research results

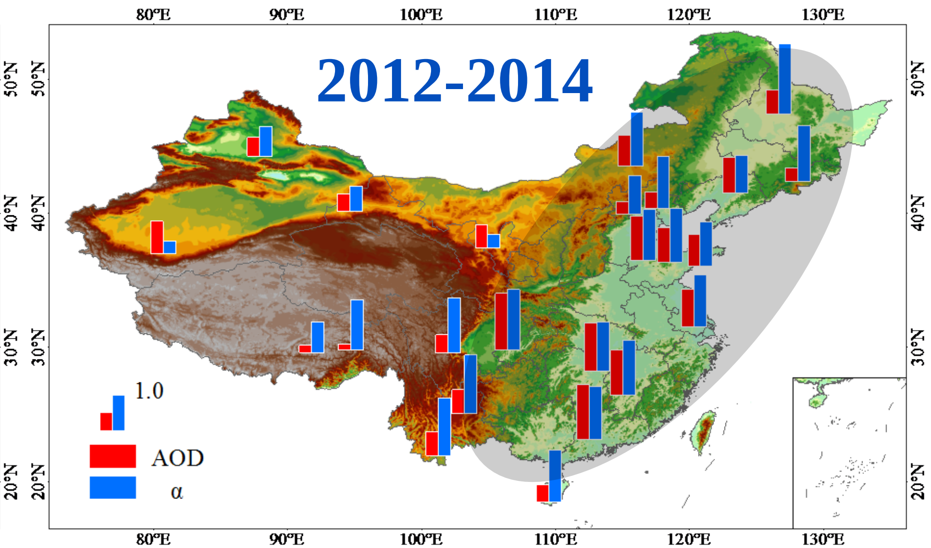
- 2.1 The trends of aerosol optical properties
- 2.2 The level of PM2.5 concentration
- 2.3 The relationship between PM2.5 and AOD
- 2.4 The distribution of PM2.5 retrieved by MODIS

The data and relationships are useful to verify the aerosol models and satellite remote sensing

Xin et al., JGR, 2016

2.1 The increasing trends of AOD and Angstrom exponent - α



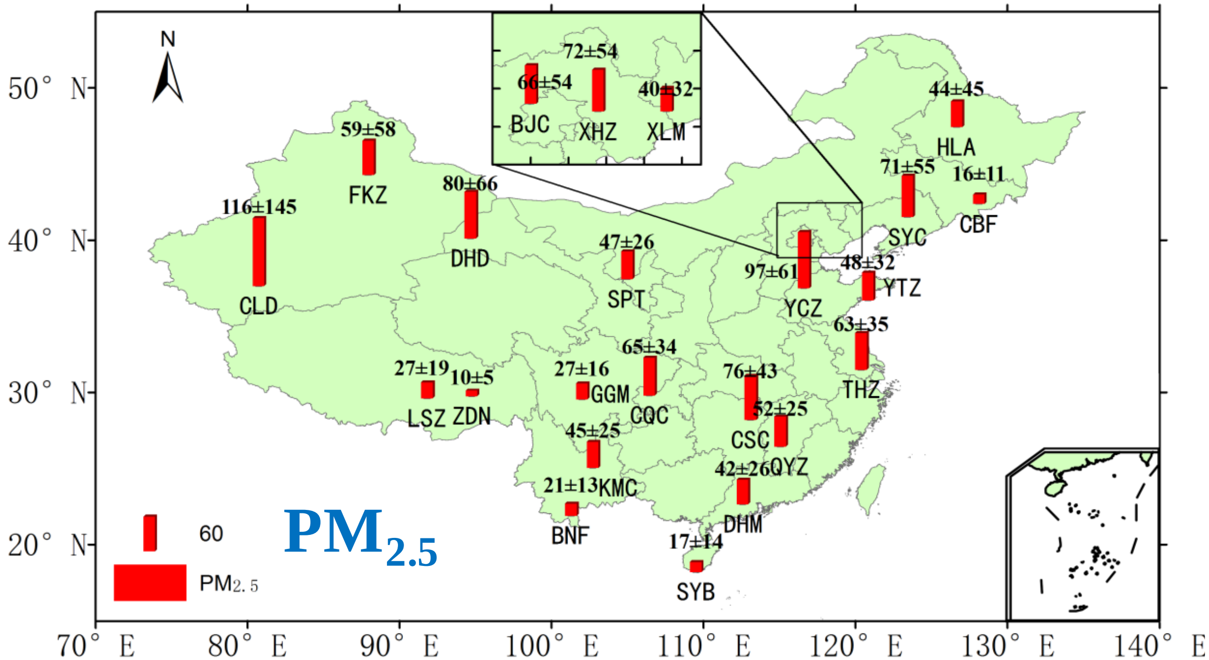


Xin et al., JGR, 2007
Wang et al., JGR, 2011

Xin et al., JGR, 2016

- **AOD rose by approximately 0.10-0.40 in the populated regions with the increasing Angstrom exponent. In the regional background of those regions, AOD rose by approximately 0.01-0.05.**
- **These results indicated that anthropogenic aerosols increased in recent years with the industrial and economic development not only in the polluted regions but also in the remotely clean areas**

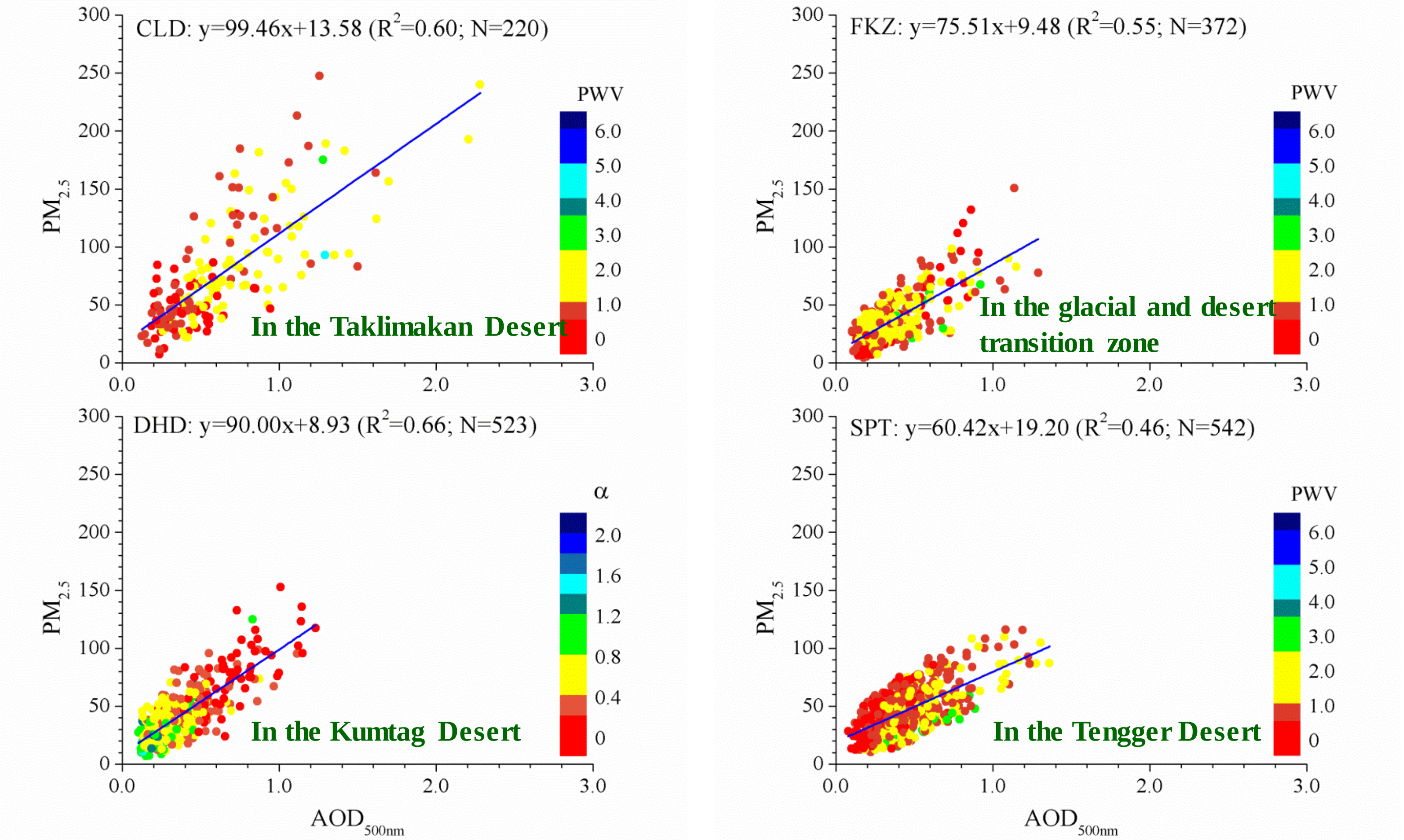
2.2 The level of the $PM_{2.5}$ concentration from 2012 to 2013



- In China, the low level of PM2.5 was only in the Tibet Plateau, in the primeval forest and the tropical rain forest, and in the Hainan Island from 10 to 27 μg/m^3, which was close to the level of Europe and America.
- But in the industrialized domains of China (eastern, northeastern, southeastern China), the annual-mean PM2.5 was from 40 to 100μg/m^3, which was approximately four to ten times higher than in the United States and in Europe.

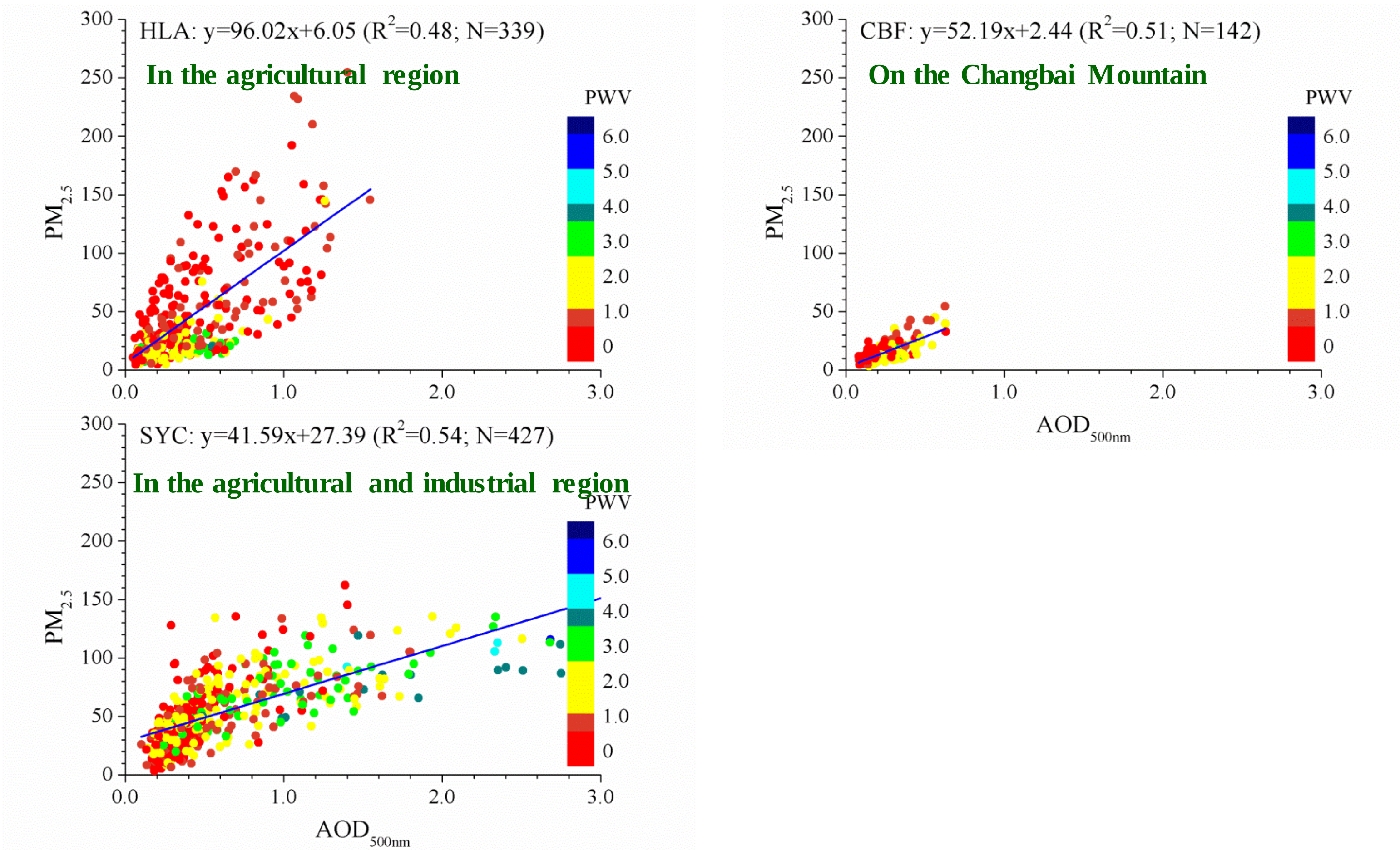
2.3 The relationship of PM2.5-AOD in northwestern China

- **SPT, FKZ have a certain anthropogenic impacts. The slopes of SPT and FKZ was lower than CLZ and DHD. The differences of the slopes indicated that the extinction efficiency of anthropogenic aerosol was higher than dust aerosol.**



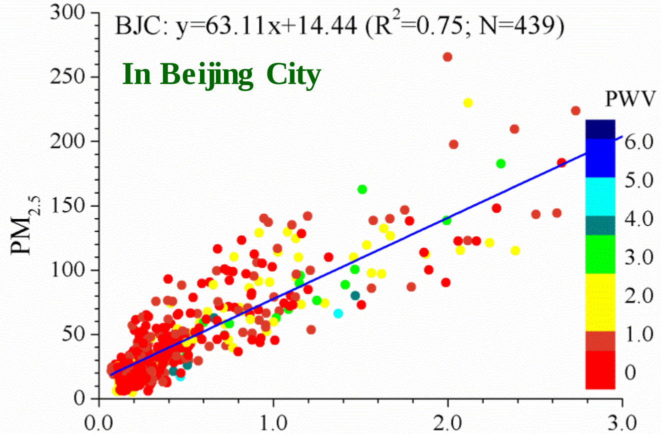
The relationship of PM2.5-AOD in northeastern China

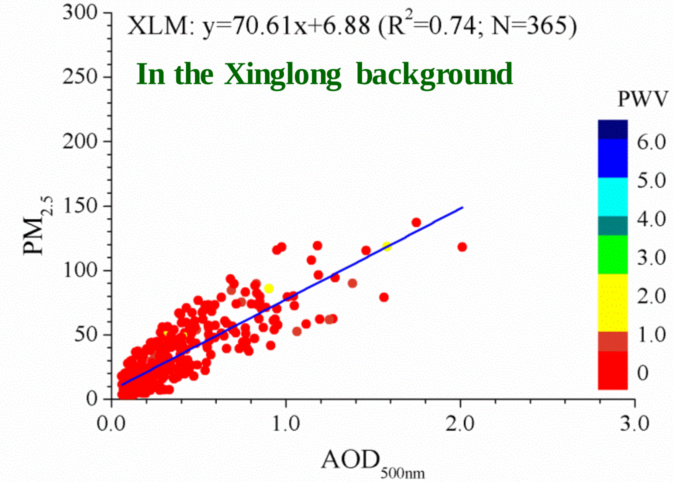
- Anthropogenic aerosol emissions was very high in the industrial and agricultural regions in northeastern China. The anthropogenic aerosols changed the aerosol optical properties in the region. But it is unclear why the slope of CBF was low.

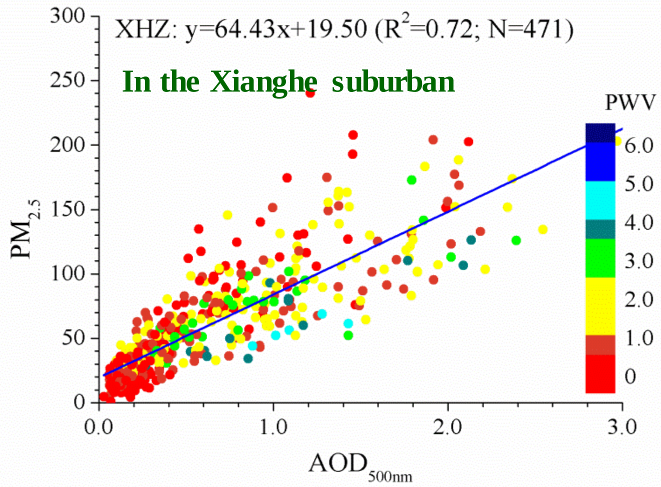


The relationship of PM2.5-AOD in north China

- Fine anthropogenic and industrial aerosols were the main contribution of aerosols in the region. Figures shows the similar in the background, urban and suburban areas. With increasing atmospheric humidity, the hygroscopic effect of aerosol increased the extinction efficiency.

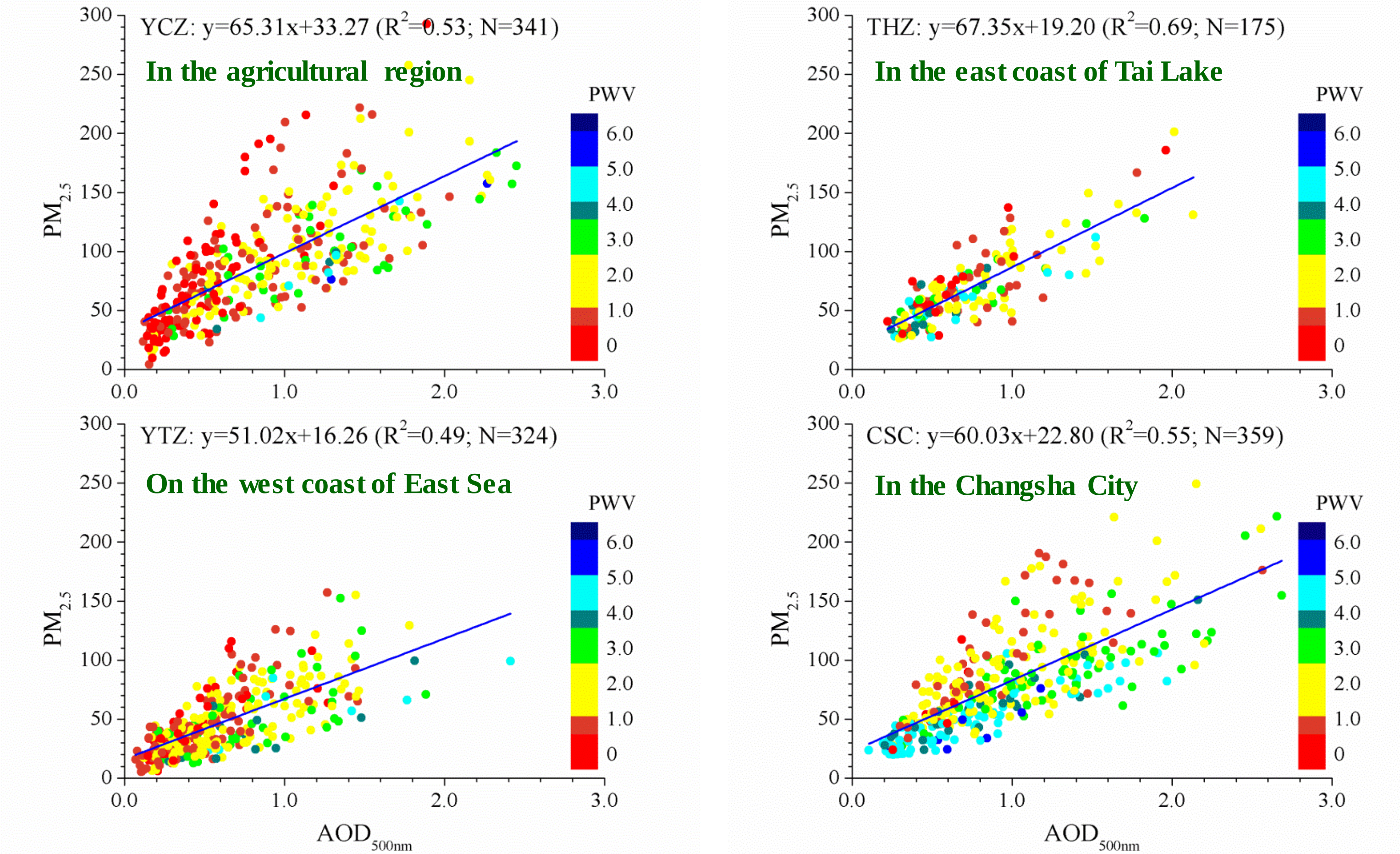






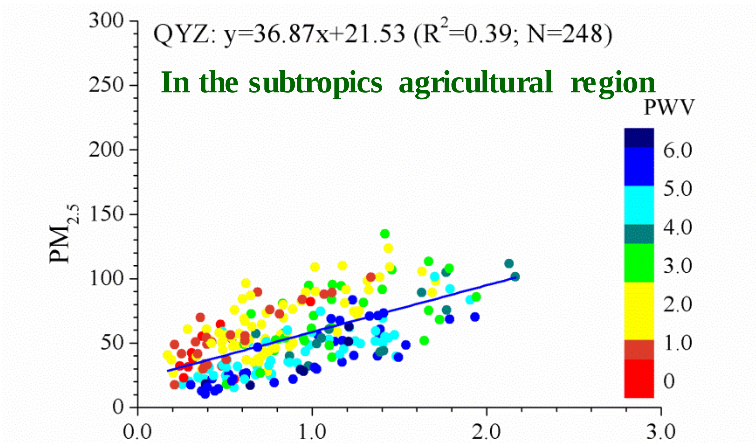
The relationship of PM2.5-AOD in eastern and central China

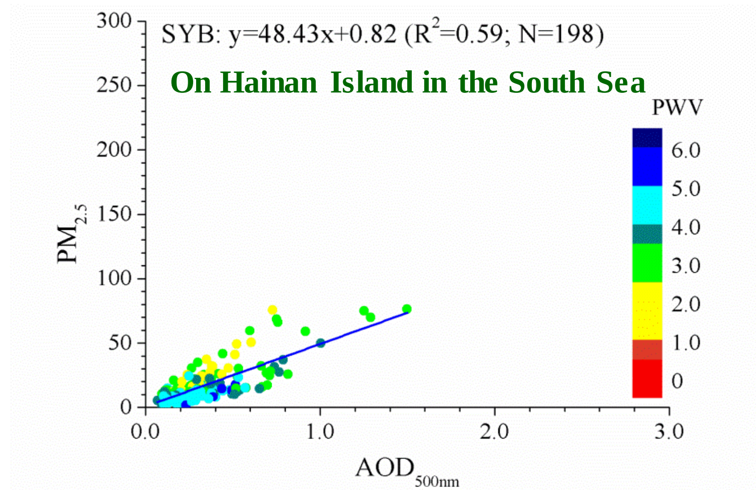
- Like north China, fine anthropogenic and industrial aerosol pollution was serious in the region. The relationships were similar in the agricultural region and the city. With increasing atmospheric humidity, the hygroscopic effect of aerosol increased the extinction efficiency.

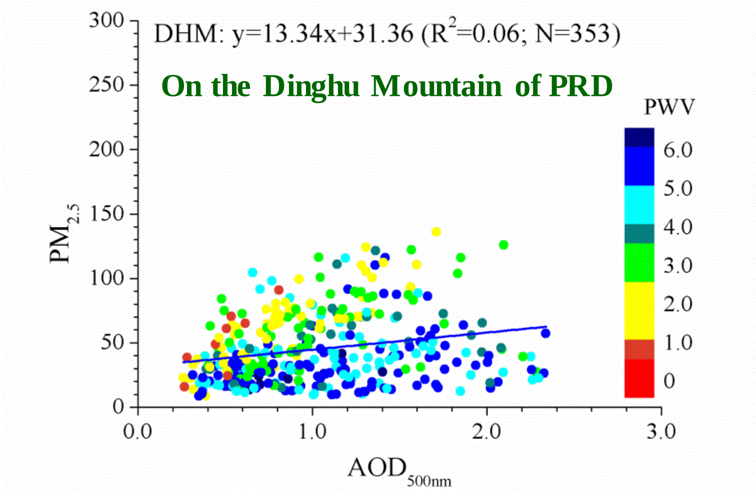


The relationship of PM2.5-AOD in south China

- **Due to the high atmospheric humidity and strong hygroscopic effect of the aerosol, the slopes of the regression functions were lower than in the other regions. The relationships also had obvious differences in the dry season and the wet season.**

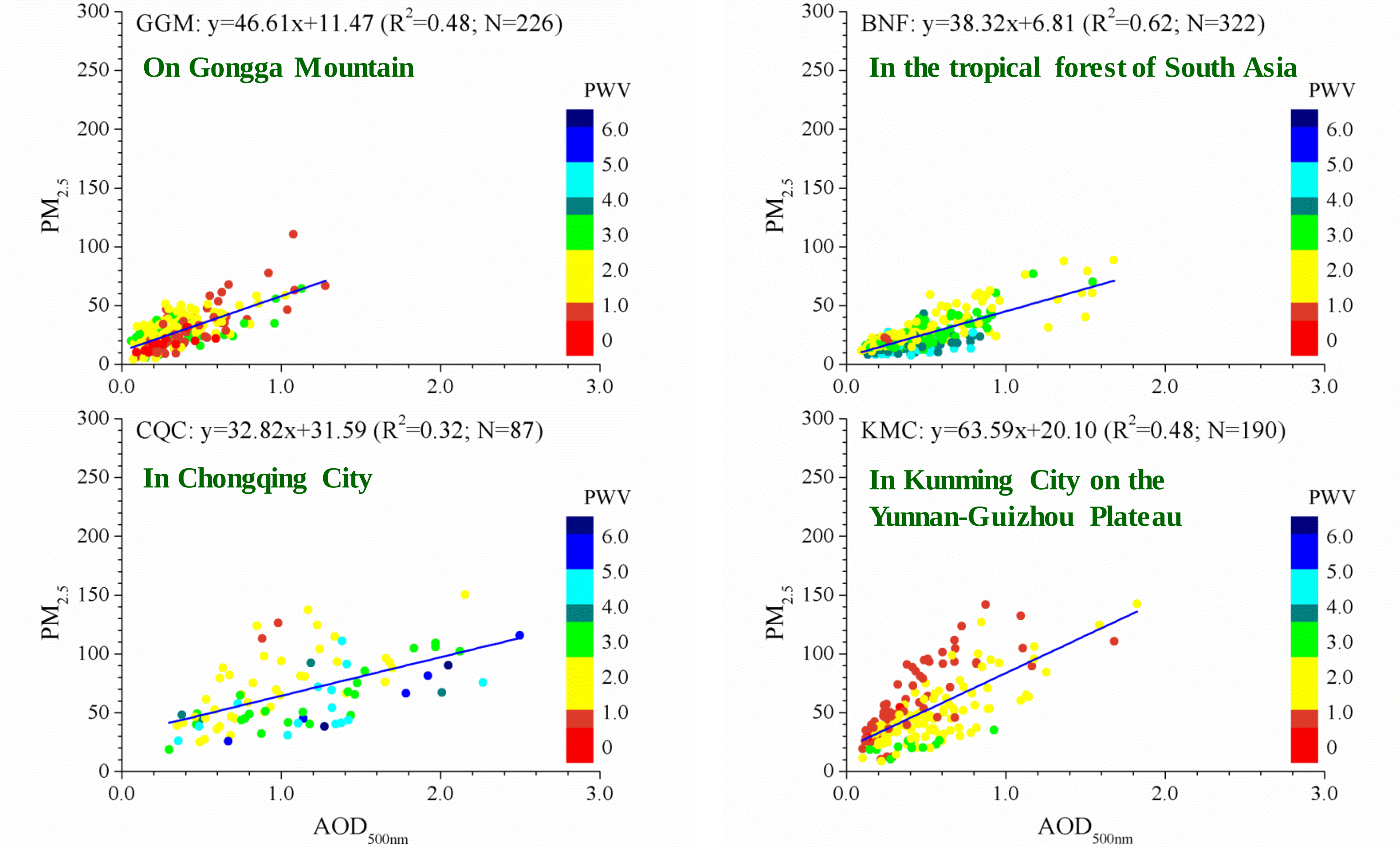






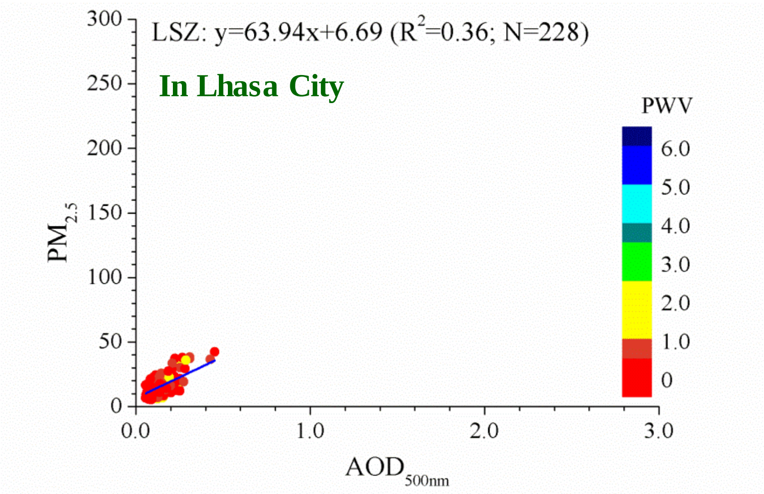
The relationship of PM2.5-AOD in southwestern China

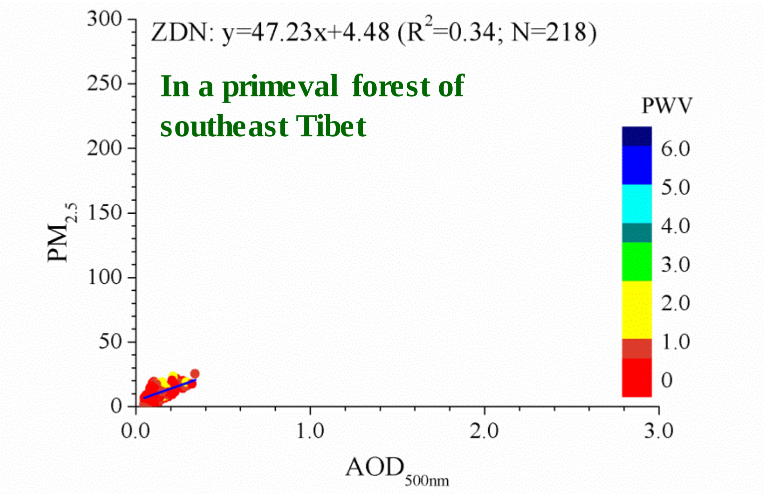
- In the wet season, the hygroscopic effect also strongly increased the extinction efficiency of aerosol in the region. Moreover, the relationship of KMC was similar to the relationships in north China because of regular subtropical monsoon climate controlling Yunnan-Guizhou Plateau.



The relationship of PM2.5-AOD on the Tibetan Plateau

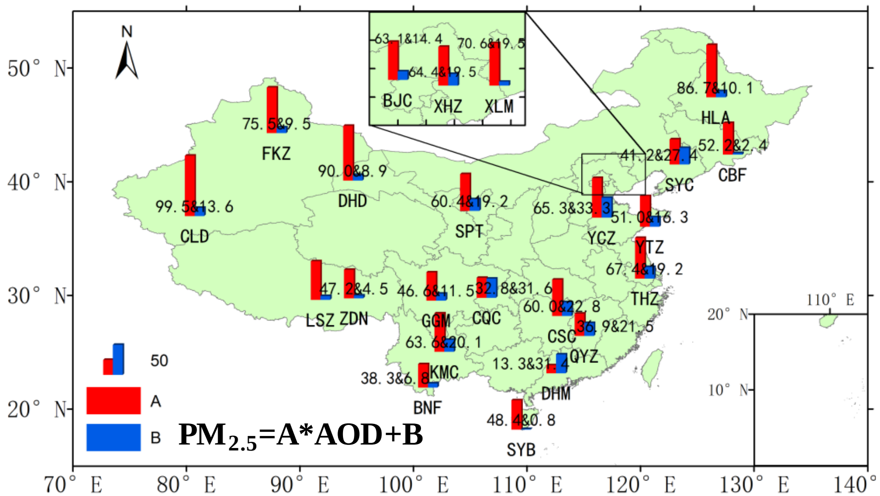
- The regression function of $PM_{2.5}$ and AOD was y=63.94x+6.69 (R^2=0.36) at the LSZ site, which was similar to the regression functions in north China, east and central China and on the Yunnan-Guizhou Plateau. The regression function was y=47.23x+4.48 (R^2=0.34) at the ZDN site, which was similar to the relationship of $PM_{2.5}$ and AOD in southwestern and south China.

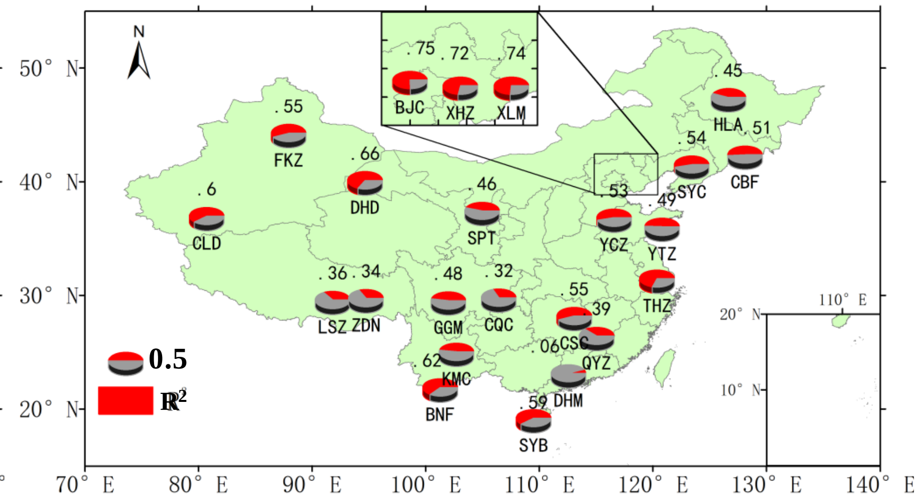




The linear regression functions ($PM_{2.5}$ = A*AOD + B)

- There were good regression correlations between $PM_{2.5}$ and AOD over the various ecosystems throughout China. However, there are large differences in the linear regression functions and correlation coefficients from the north to the south and from the west to the east.





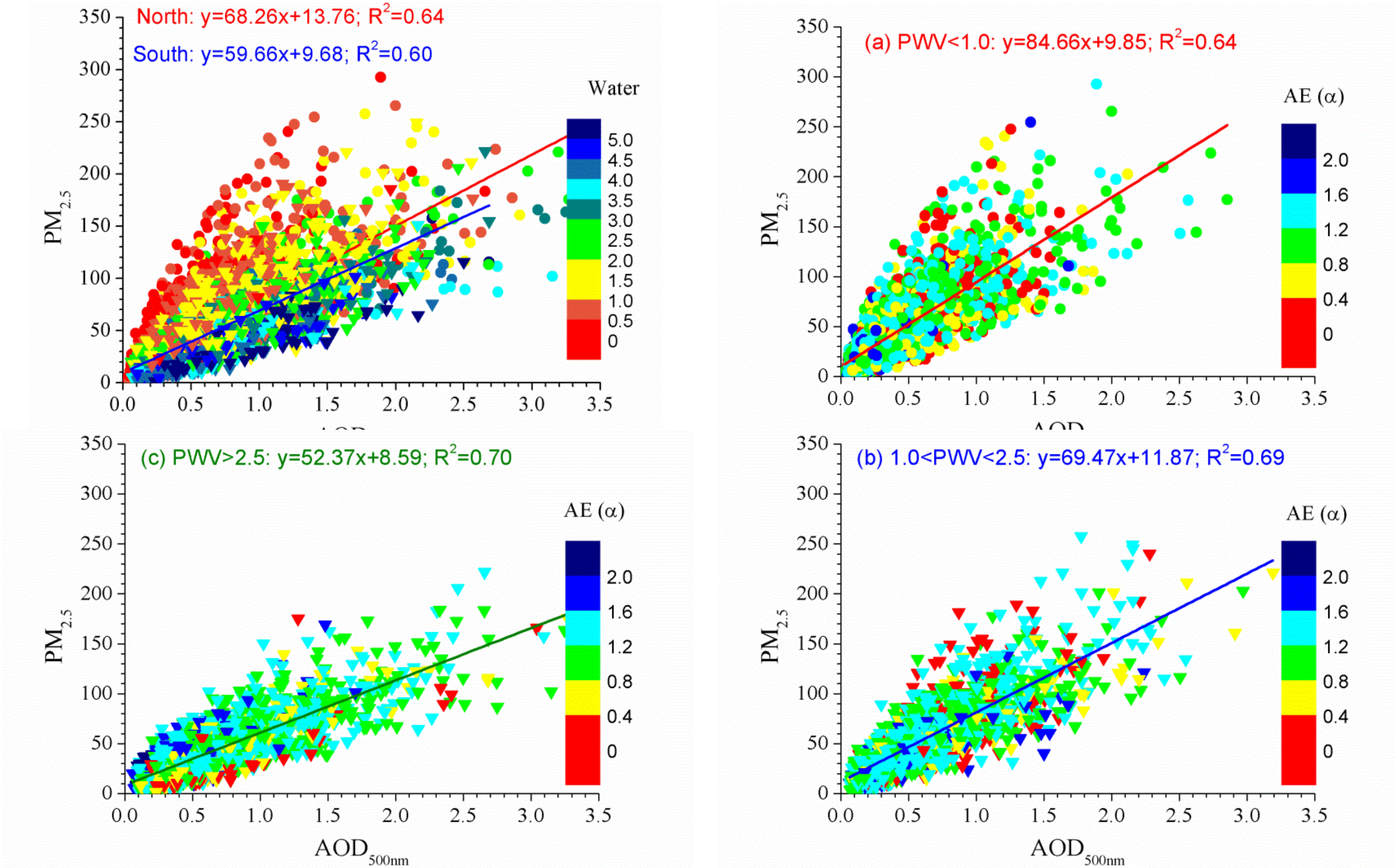
Slope A: 13-90; Intercepts B: 0.8-33

Correlation coefficient R^2: 0.06-0.75

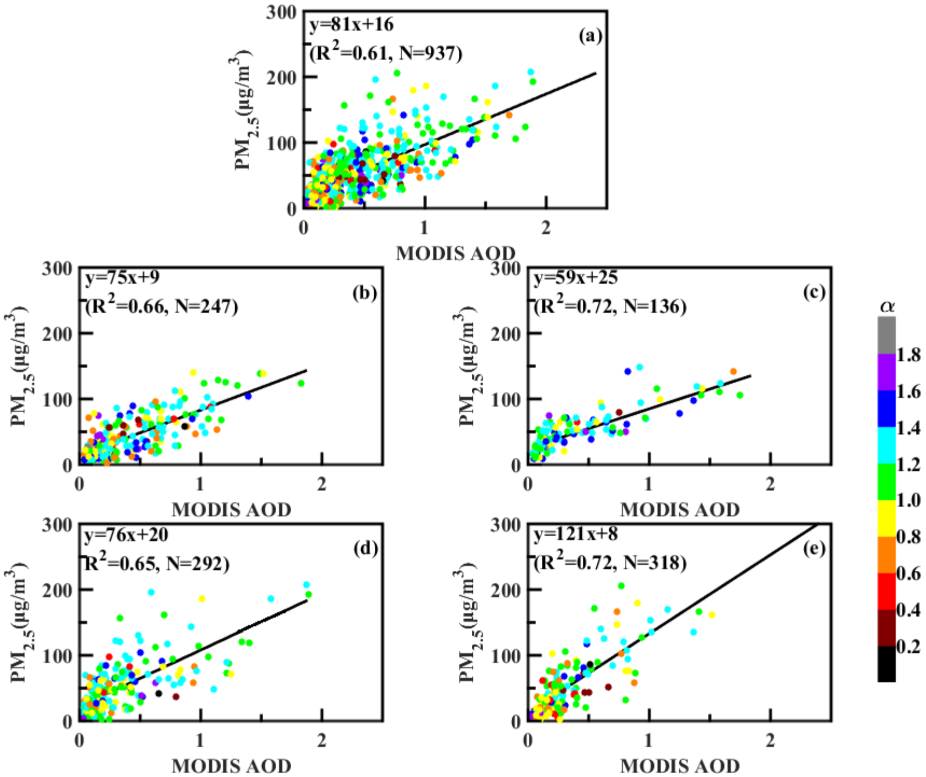
The slopes (A) were much higher in the north than in the south because the extinction efficiency of hygroscopic aerosol rapidly increased with increasing humidity from the dry north to the humid south.

The segmented linear regression functions of AOD&PM2.5

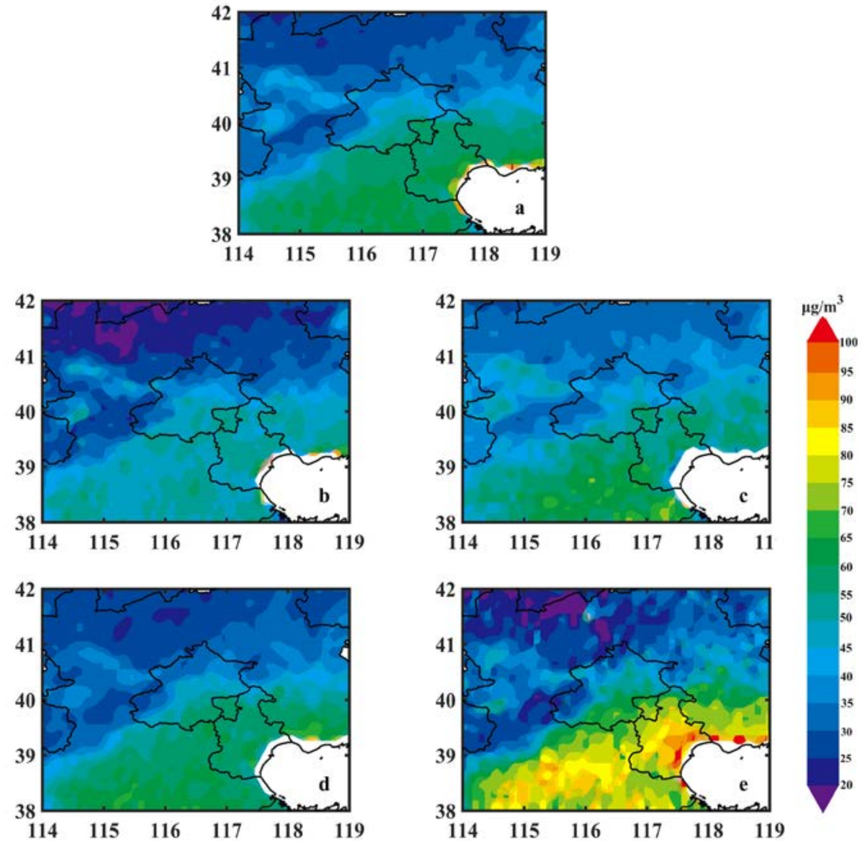
- There was high consistency of AOD vs $PM_{2.5}$ for all sites in three ranges of the atmospheric column precipitable water vapor (PWV). The correlation coefficients (R^2) were high from 0.64 to 0.70 across China.



2.4 PM2.5 retrieved by MODIS in Beijing-Tianjin-Hebei



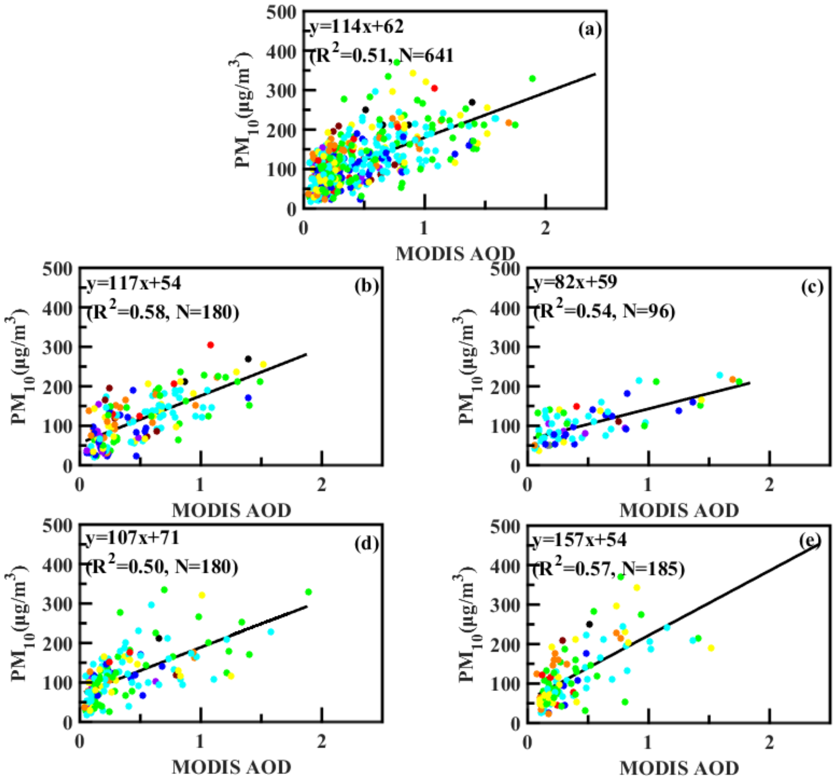
The relationships between PM2.5 and MODIS AOD



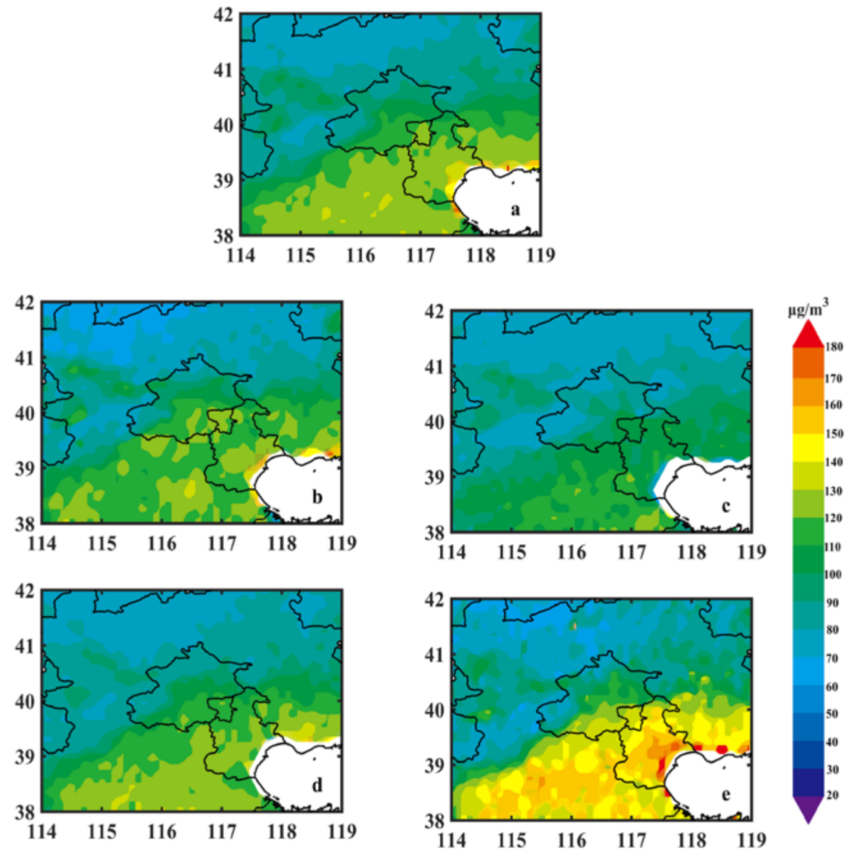
The PM2.5 on sunny days
(2009-2010: from 30 to 60μg/m³)

Kong and Xin et al., Environmental Pollution, 2016*

2.4 PM10 retrieved by MODIS in Beijing-Tianjin-Hebei



The relationships between PM10 and MODIS AOD



The PM10 on sunny days

(2009-2010: from 50 to 100 μg/m³)

Kong and Xin et al., Environmental Pollution, 2016*

Error Analysis in Beijing-Tianjin-Hebei

- **Triangle: Beijing, Xianghe and Xinglong for the function**
- **Cycle: Beijing Forest and Tangshan City for verification**

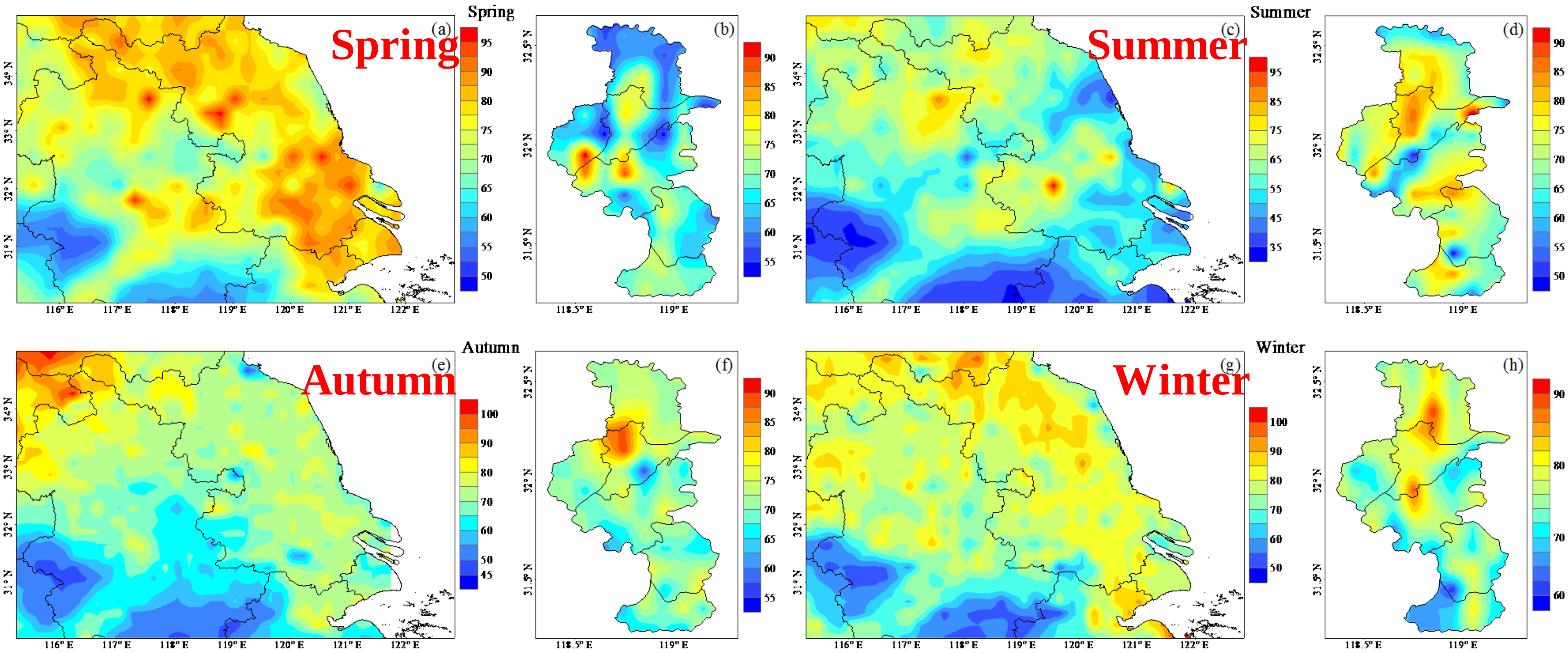
The relative errors of retrieved seasonal $PM_{2.5}$ were lower than 8% and 33% in the urban and suburban and the background.

Observed values and retrieved values of daily $PM_{2.5}$

Kong and Xin et al., Environmental Pollution, 2016*

2.4 PM2.5 retrieved by MODIS in Yangtze River Delta

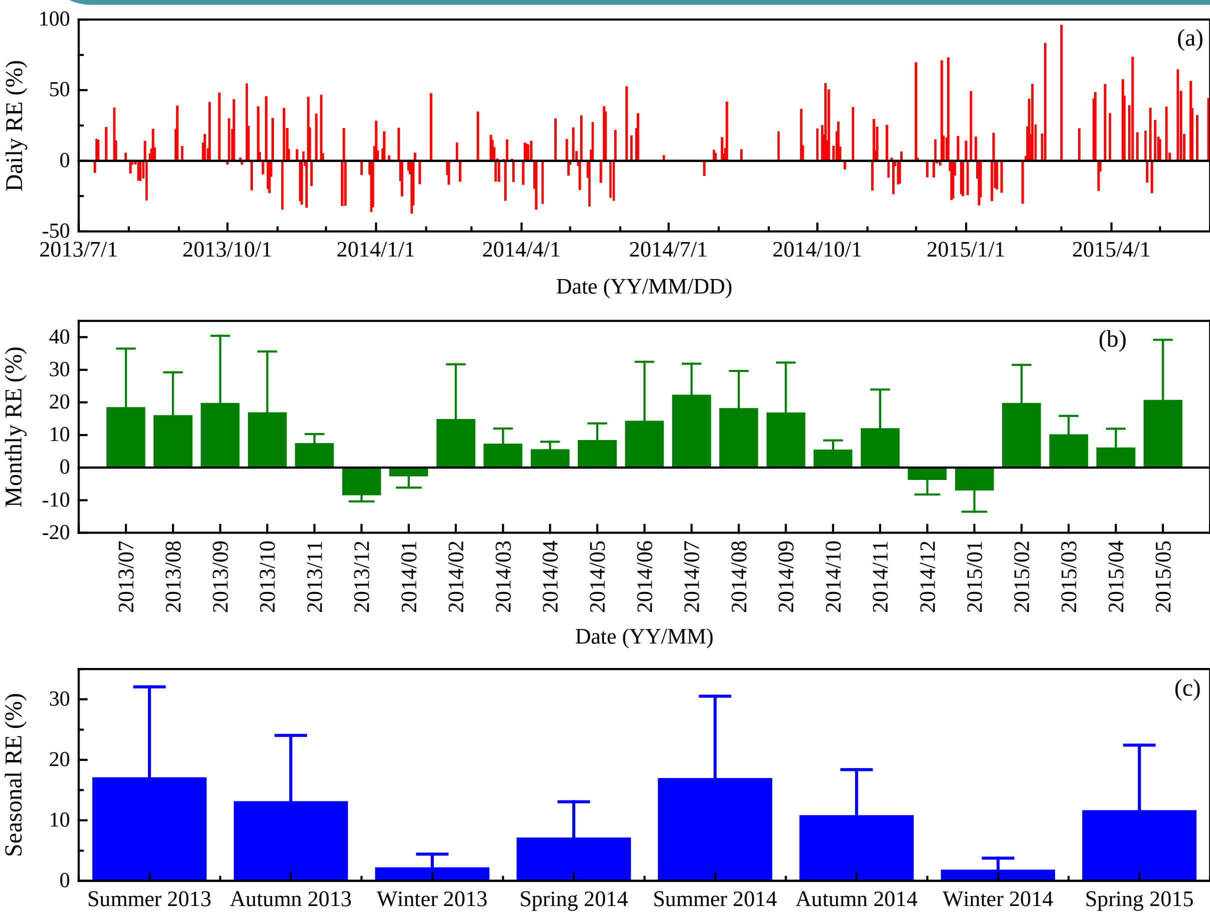
- The retrieved $PM_{2.5}$ concentrations were generally higher in northern YRD. The maximum $PM_{2.5}$ on sunny days (2013-2015): 75 μg/m^3
- There was a high-concentration area (>70 μg/m^3) of the retrieved $PM_{2.5}$ anchoring over the industrial area of Nanjing .

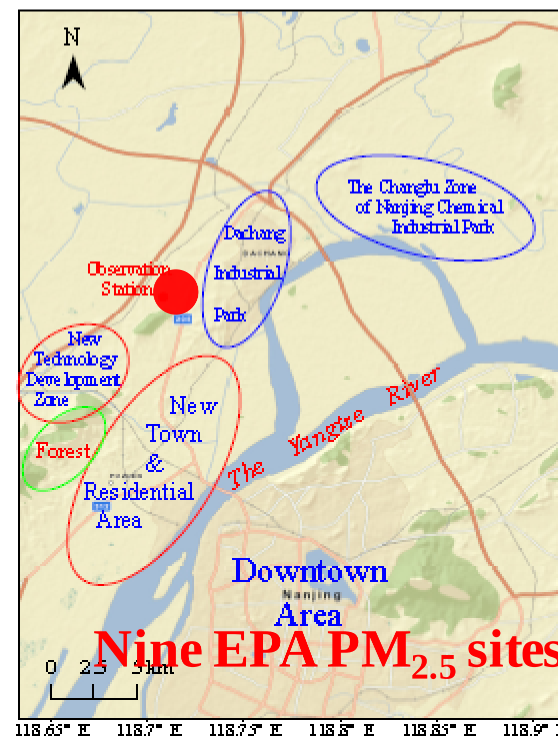


Shao and Xin et al., Atmospheric Pollution Research, 2016*

Error Analysis in Yangtze River Delta

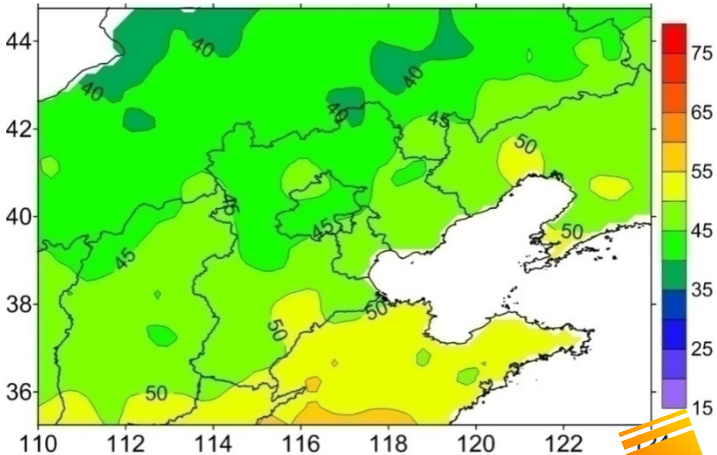
- **Retrieved $PM_{2.5}$ daily values had the highest absolute error (+17 μg·m^{-3}) in summer and the lowest (+2 μg·m^{-3}) in winter.**
- **Average relative error of the seasonal $PM_{2.5}$ concentration was 15%±10%.**



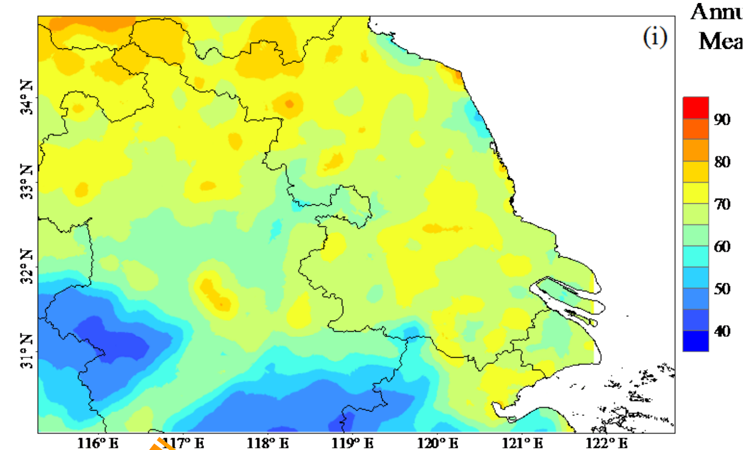


Shao and Xin et al., Atmospheric Pollution Research, 2016*

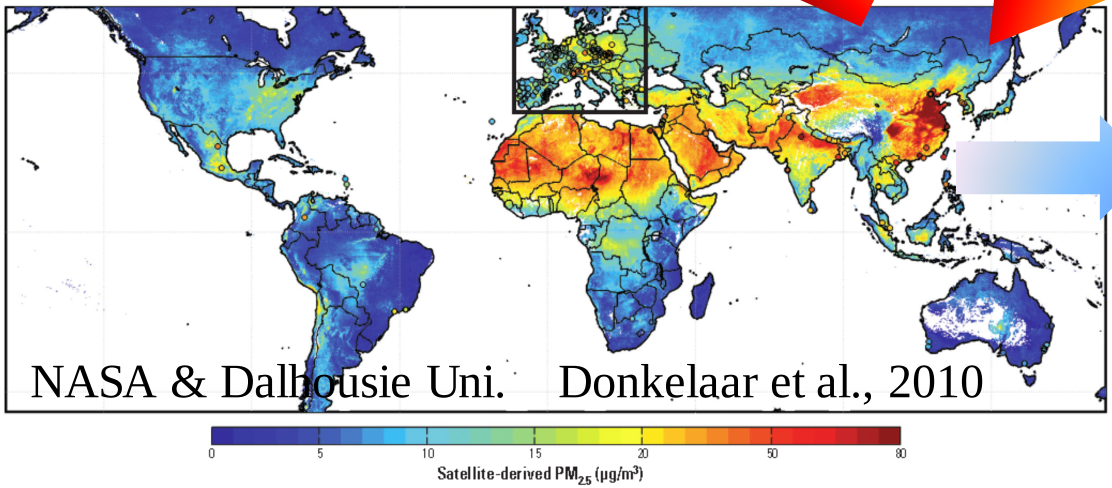
The previous result maybe overestimate PM2.5 in China



The annual $PM_{2.5}$ on sunny days (2009-2011): 40-55 μg/m^3



$PM_{2.5}$ over Yangtze River Delta (2012-2013): 50-75 μg/m^3



The annual PM2.5 (2001-2006): 60-80 μg/m^3

There may be large error, if without the local revisal.

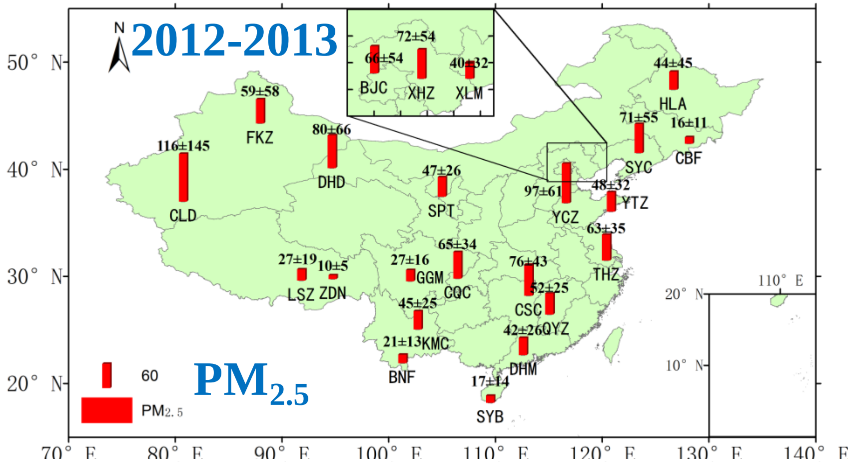
Shao and Xin et al., 2016*

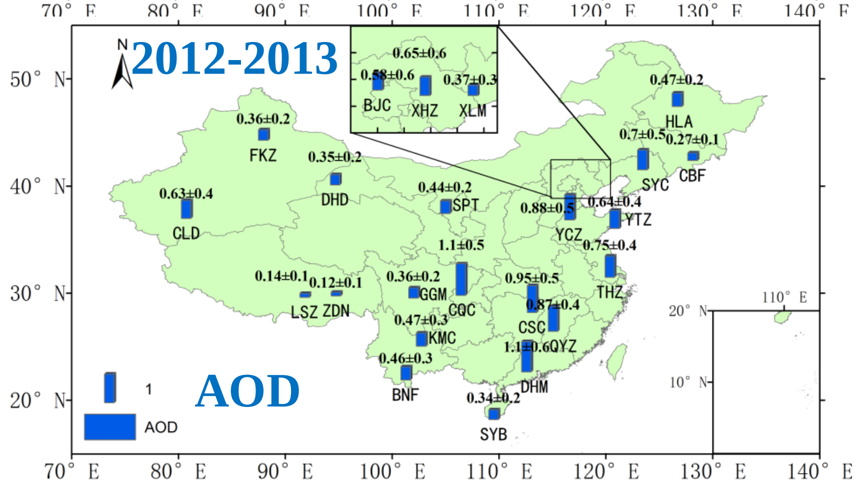
Kong and Xin et al., 2016*

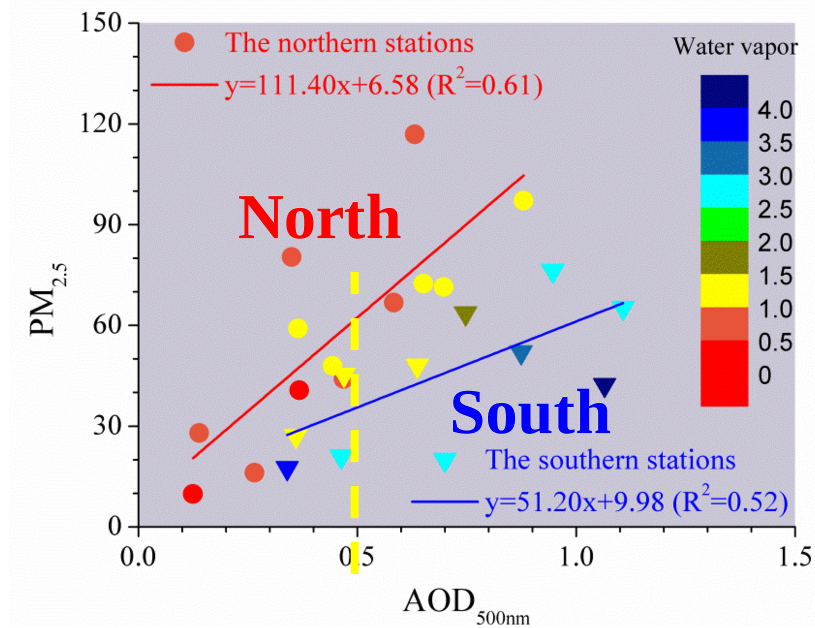
Xin, et al., Atmos Res., 2014

How far for the north and south to realize the blue sky?

- There is large difference in the relationships of the annual-mean PM2.5 and AOD from South to North, the slopes (A) from 51 to 111. The extinction efficiency of hygroscopic aerosol rapidly increased with increasing humidity from the dry north to the humid south.







If AOD decreases to realize the blue sky, it is more difficult to cut PM2.5 emission in the south than in the north.

3. Summary

1. $PM_{2.5}$ and AOD has large spatial differences in China. Fine particle pollution is very serious. AOD has increasing trends in the recent decade with the sky dimming, fine anthropogenic aerosol increasing.

2. There were significant spatial agreements and correlations between the $PM_{2.5}$ and AOD. But, the linear regression functions ($PM_{2.5}$ = A*AOD + B) exhibited large differences in different regions and seasons.

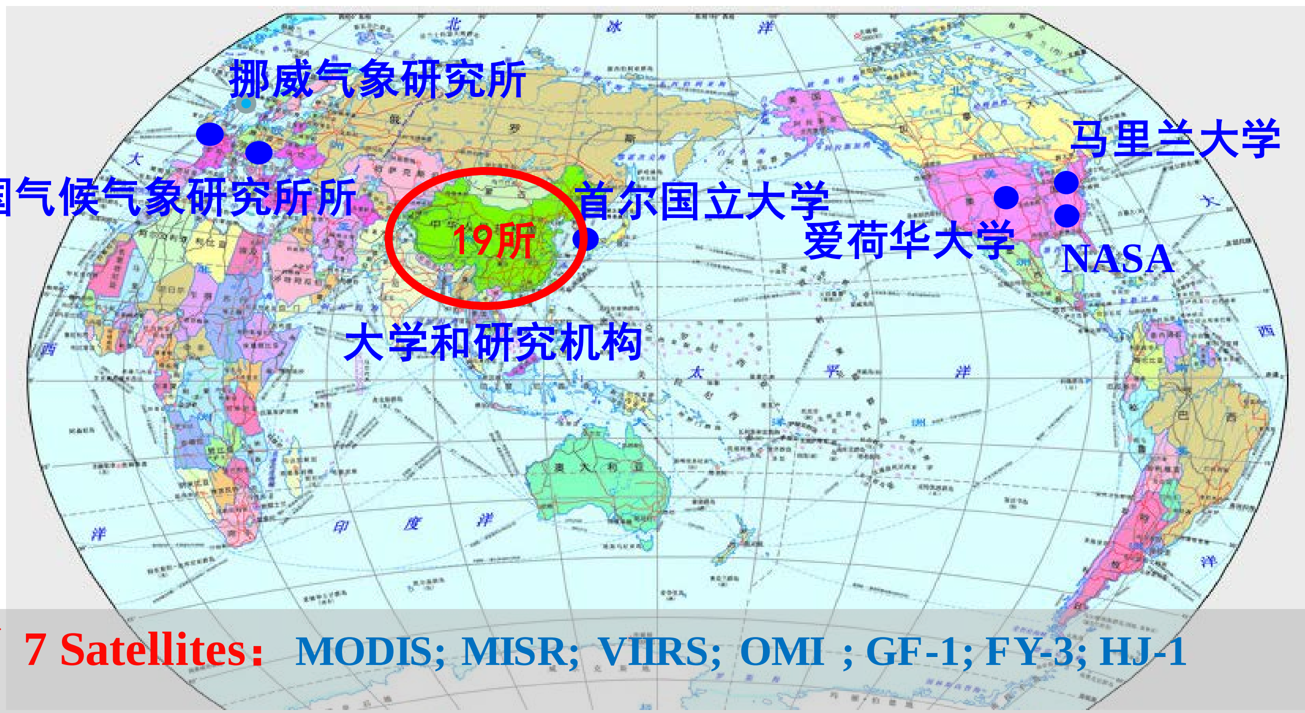
3. The extinction efficiency of hygroscopic aerosol was rapidly increasing with the increasing humidity from the dry north to the humid south. So the segmented linear regression functions were built in three ranges of PWV (precipitable water vapor) across China.

4. The network data and the function of PM&AOD are useful to verify the aerosol models and satellite remote sensing.

Cooperation

✓The network is open for cooperation, to realize the value in the research directions.

✓Email: xjy@mail.iap.ac.cn; Dr. Jinyuan Xin



✓ **7 Satellites：** MODIS; MISR; VIIRS; OMI；GF-1; FY-3; HJ-1

✓ **9 models：** NAQPMS; GEOS-Chem; WRF-Chem; RegCM; RAMS-CMAC; NICAM; MATCH; GOCART; AeroCom

	共享单位（26个）
1	University of Maryland
2	U.S. Department of Agriculture
3	Karlsruhe Institute of Technology
4	Seoul National University
5	University of Iowa
6	Norvegian Meteorological Institute
7	NASA-GSFC
8	中科院遥感与数字地球研究所
9	国家气象局气候中心
10	中科院寒区旱区环境研究所
11	中国地质大学
12	南京大学国际地球研究所
13	成都信息工程大学
14	南京信息工程大学
15	中国环境保护部卫星中心
16	北京大学公共卫生学院
17	北京大学物理学院
18	北京师范大学
19	兰州大学大气科学学院
20	北京市气象局
21	江苏省环境保护局
22	济南市环境监测中心站
23	山东建筑工程大学
24	河南理工大学
25	中科院东北地理与农业生态研究所
26	天津市气象局
27	大气物理研究所

Thank you！

Dr. Jinyuan Xin

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Calibration and Quality Control

- ✓ To build the observation and instrument calibration standard
- ✓ To build the data quality control procedure for the network

Langley plot

↓

CIMEL Com.

↓

Transfer Cal.

↓

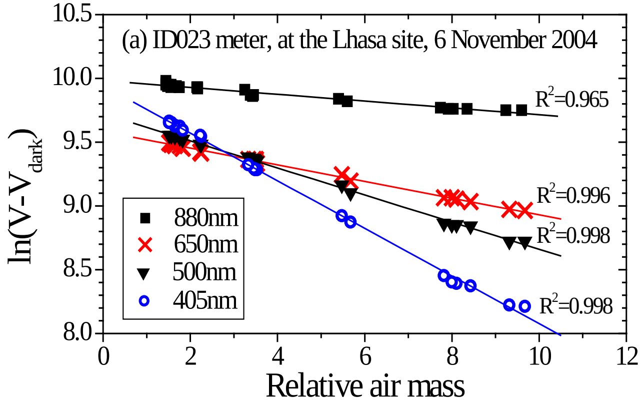
Test Stability

↓

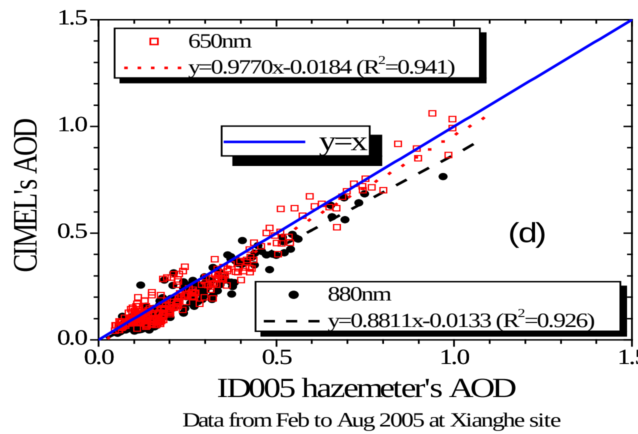
In Rotation

Calibration Process

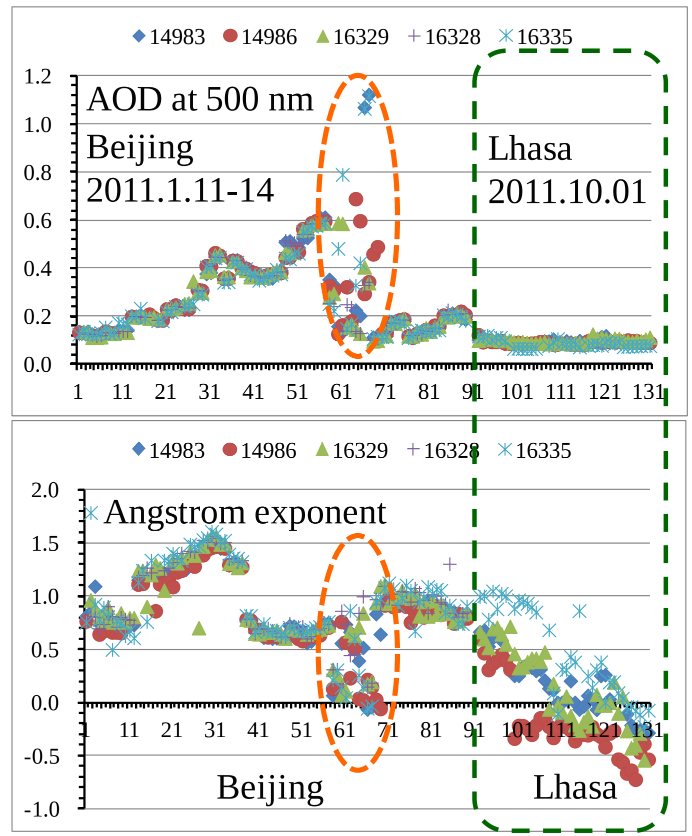
Xin et al. JGR, 2007



Langley plot at the Lhasa site

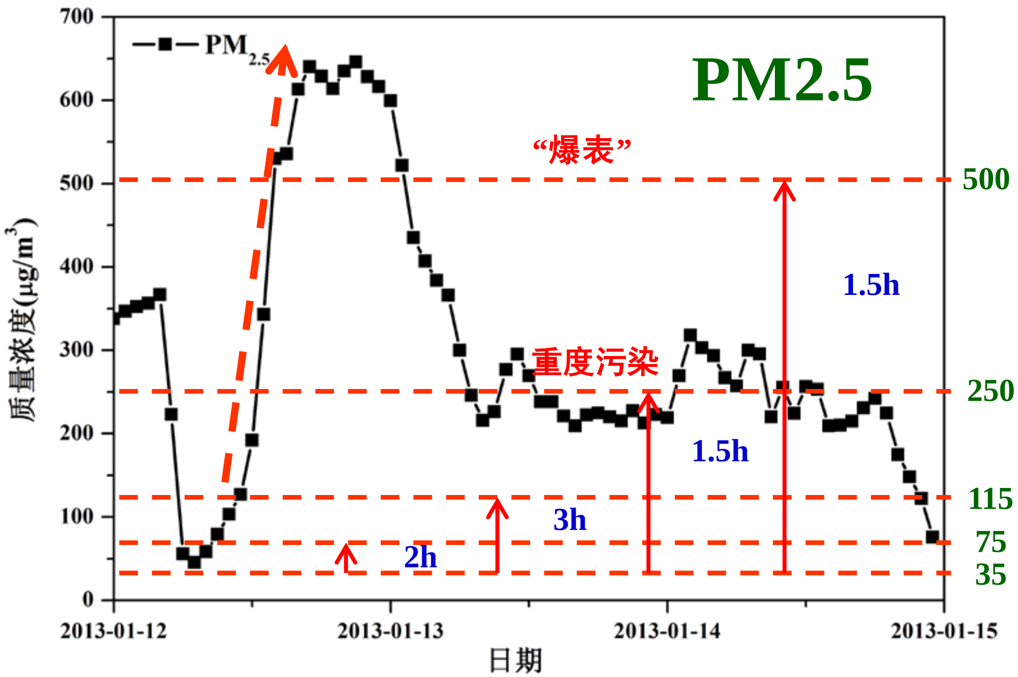


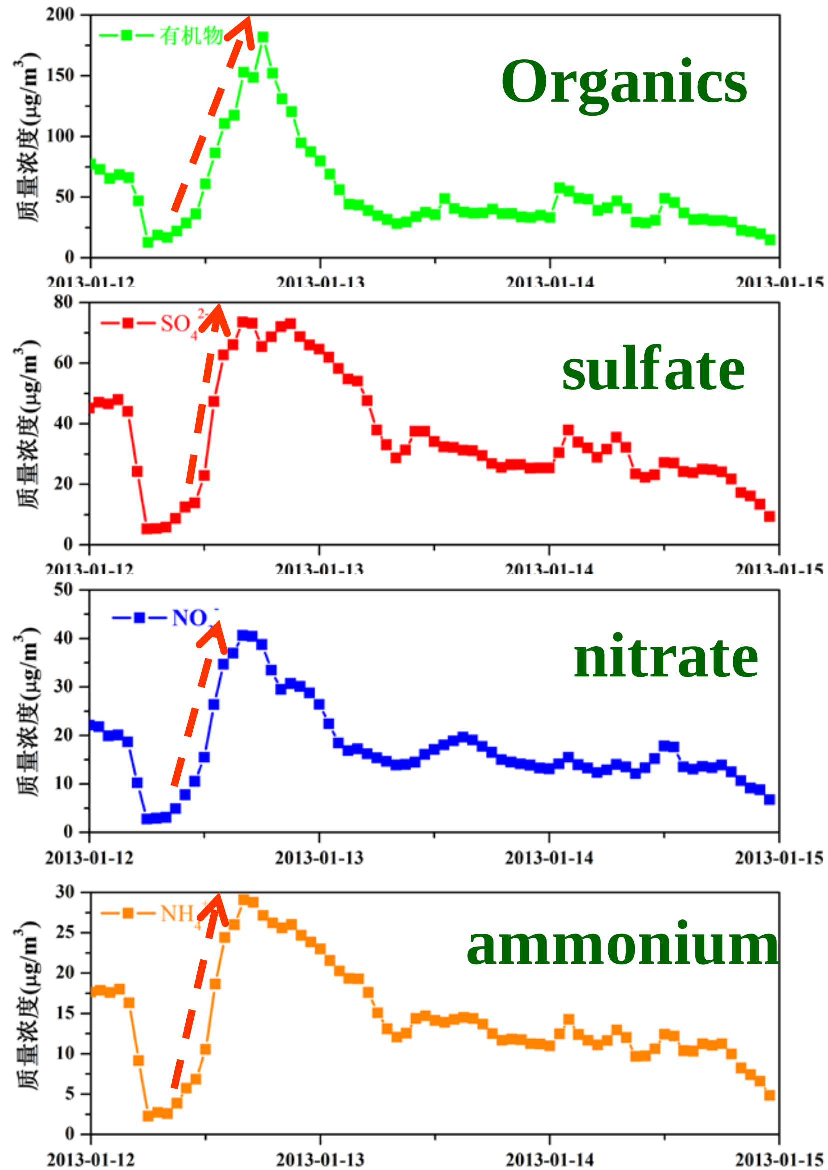
Comparison with AERONET site



Transfer calibration, test stability; deal with the cloud pollution

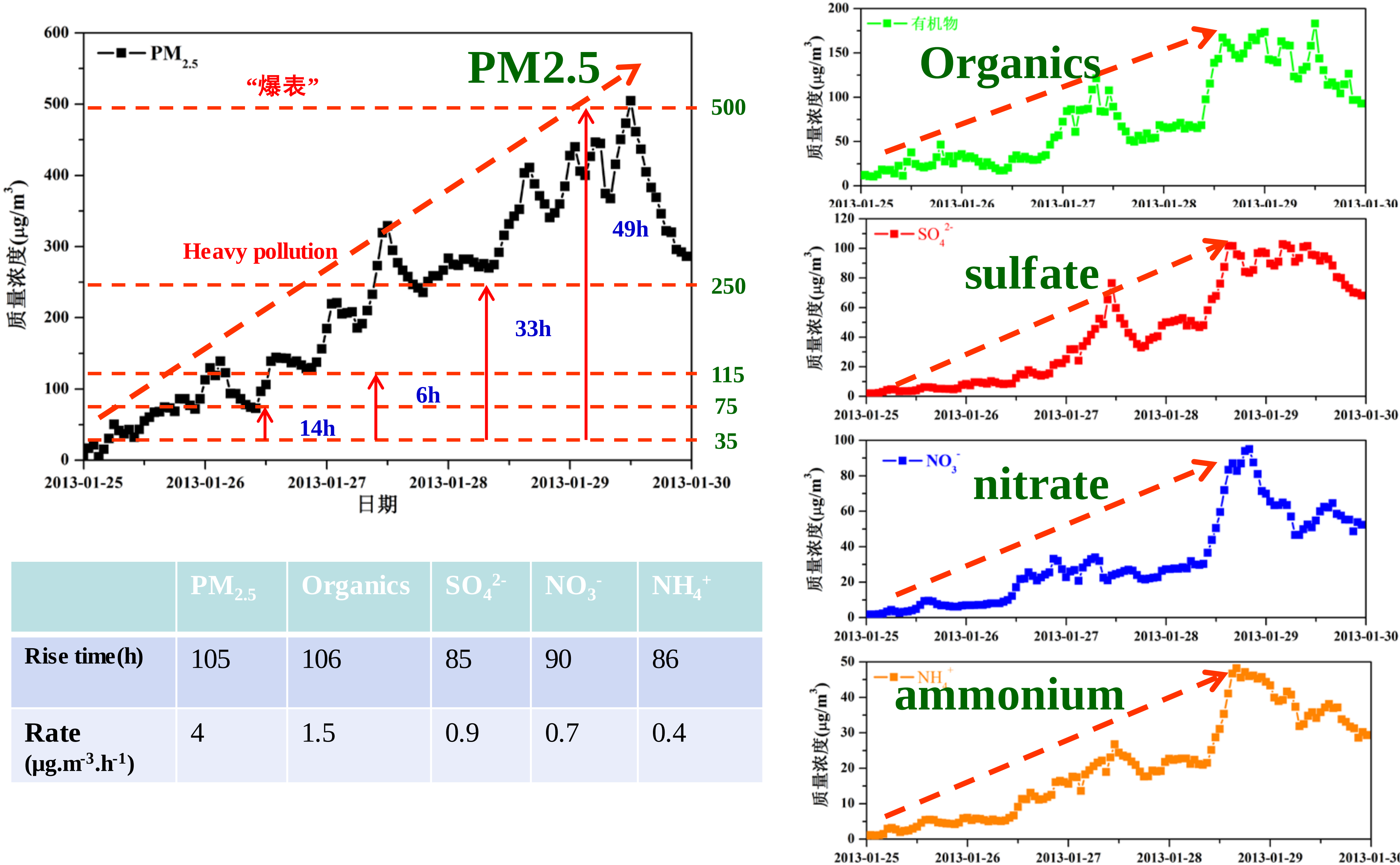
10.1 "Explosive growth" - Episode in Jan. 2013





	$PM_{2.5}$	Organics	SO_4^{2-}	NO_3^-	NH_4^+
Rise time(h)	8	9	7	7	7
Rate ($\mu g.m^{-3}.h^{-1}$)	88	20	12	6	4.5

10.2 "Strong presence"- Episode in Jan. 2013



	$PM_{2.5}$	Organics	SO_4^{2-}	NO_3^-	NH_4^+
Rise time(h)	105	106	85	90	86
Rate ($\mu g.m^{-3}.h^{-1}$)	4	1.5	0.9	0.7	0.4

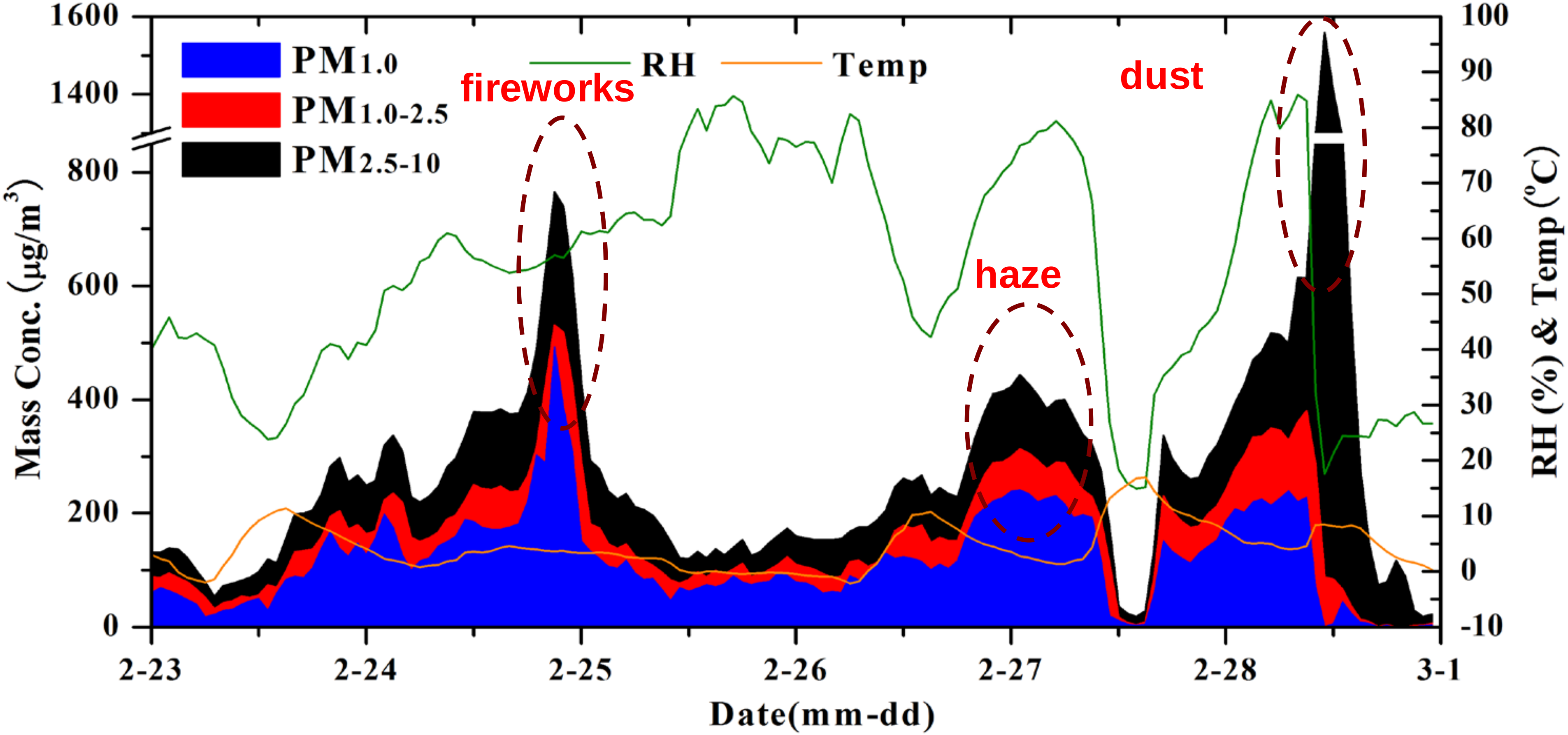
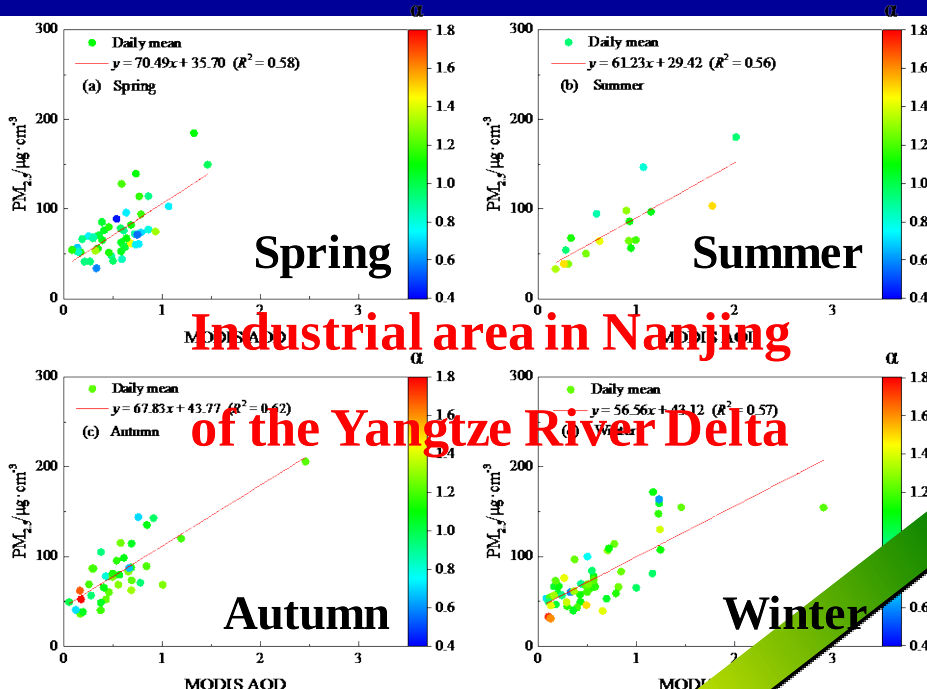


Table1 Average particle mass concentrations in three kinds of pollution events

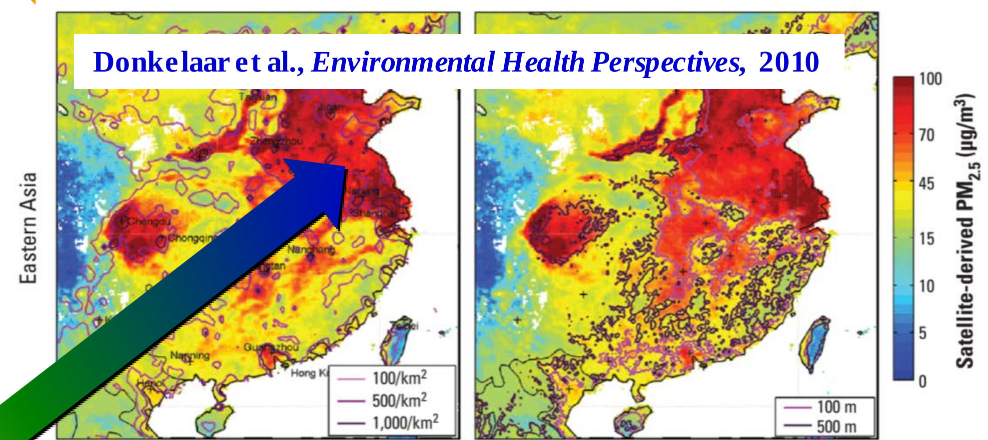
type	$PM_{1.0}$(μg/m^3)	$PM_{2.5}$(μg/m^3)	PM_{10}(μg/m^3)	$PM_{1.0}/PM_{2.5}$	$PM_{2.5}/PM_{10}$	$PM_{1.0}/PM_{10}$
haze	240	310	445	0.77	0.70	0.54
fireworks	490	530	765	0.92	0.69	0.64
dust	2	90	1560	0.02	0.06	0.001

2.4 PM2.5 retrieved by MODIS in Yangtze River Delta



Industrial area in Nanjing of the Yangtze River Delta

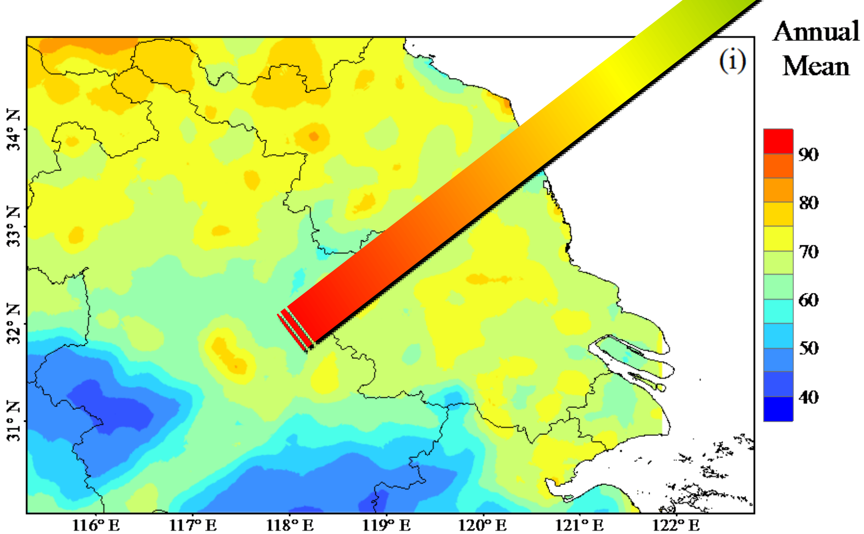
Relationships between $PM_{2.5}$ and MODIS AOD

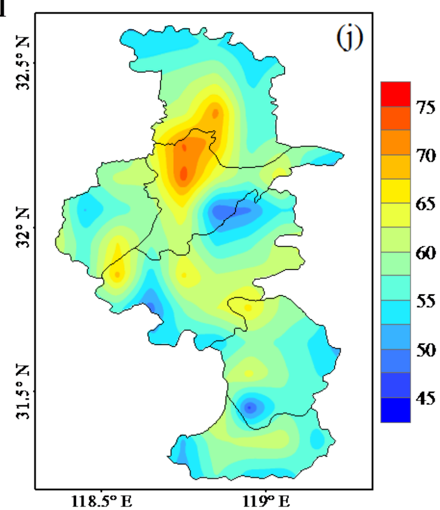


Donkelaar et al., *Environmental Health Perspectives*, 2010

The maximum $PM_{2.5}$ (2001-2006): 100 μg/m^3

There may be large error, if without the local revisal, especially heavily polluted areas.

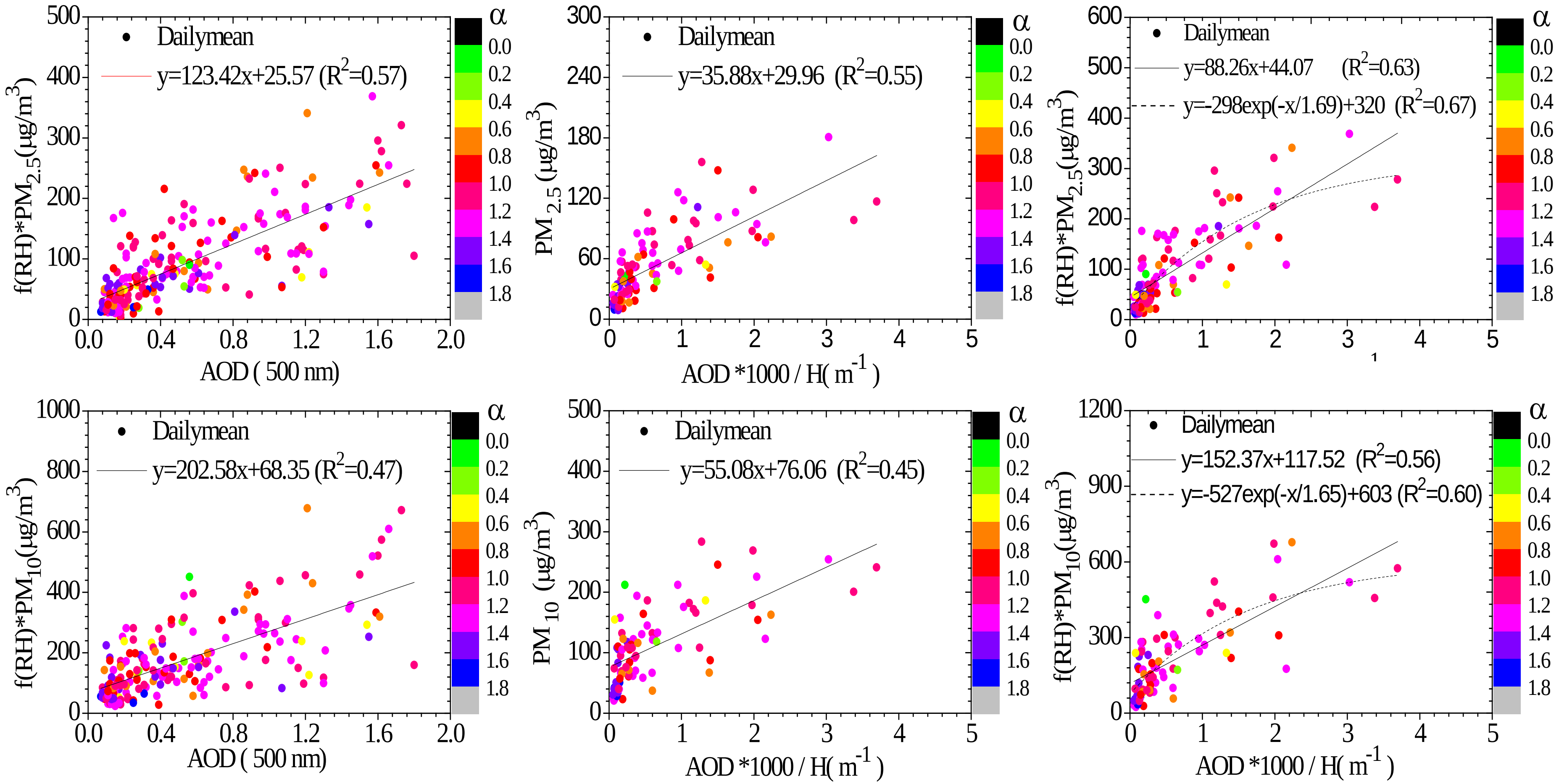




The maximum $PM_{2.5}$ on sunny days (2013-2015): 75 μg/m^3

Shao and Xin et al., Atmospheric Pollution Research, 2016*

The relationships modified by the humidity and the mixing layer



The modified relationships of AOD/PM was not better than before, in Beijing; The results was same in the wet south because of high aerosol concentration.

*林海峰, 辛金元*等, 环境科学, 2013.*

Chen and Xin et al., atmospheric research, 2014.*