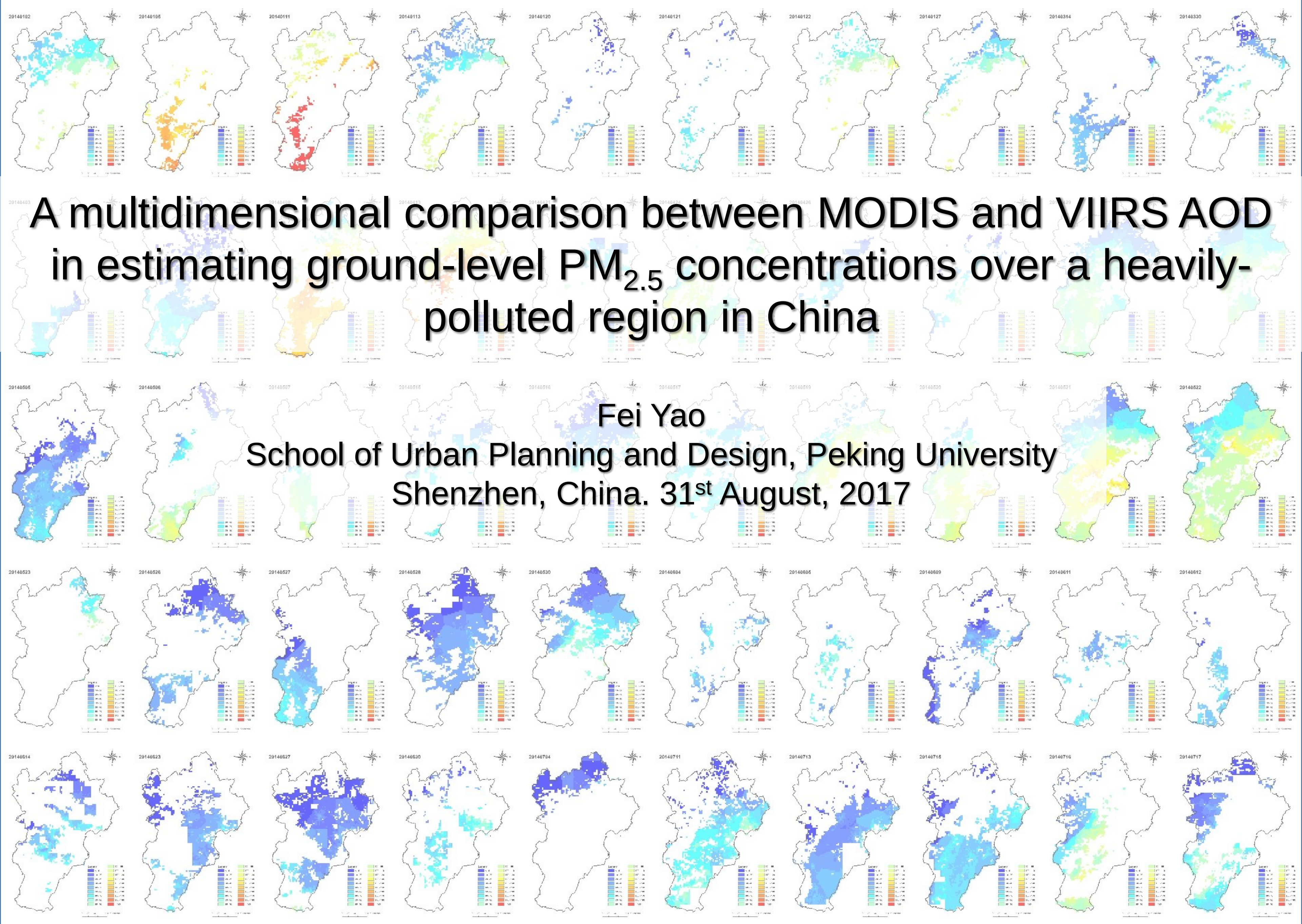

A multidimensional comparison between MODIS and VIIRS AOD in estimating ground-level $PM_{2.5}$ concentrations over a heavily-polluted region in China

Fei Yao
School of Urban Planning and Design, Peking University

Shenzhen, China. 31st August, 2017

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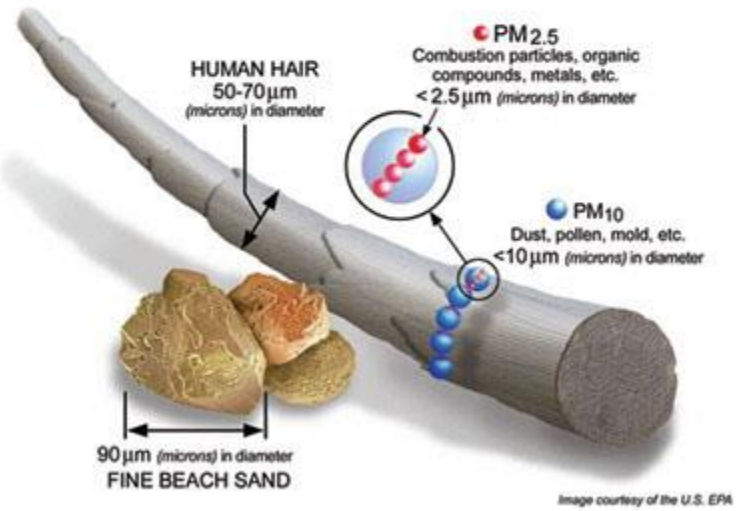
Part One
Introduction

What is $PM_{2.5}$?

- Particles with aerodynamic diameters of less than 2.5 μm.

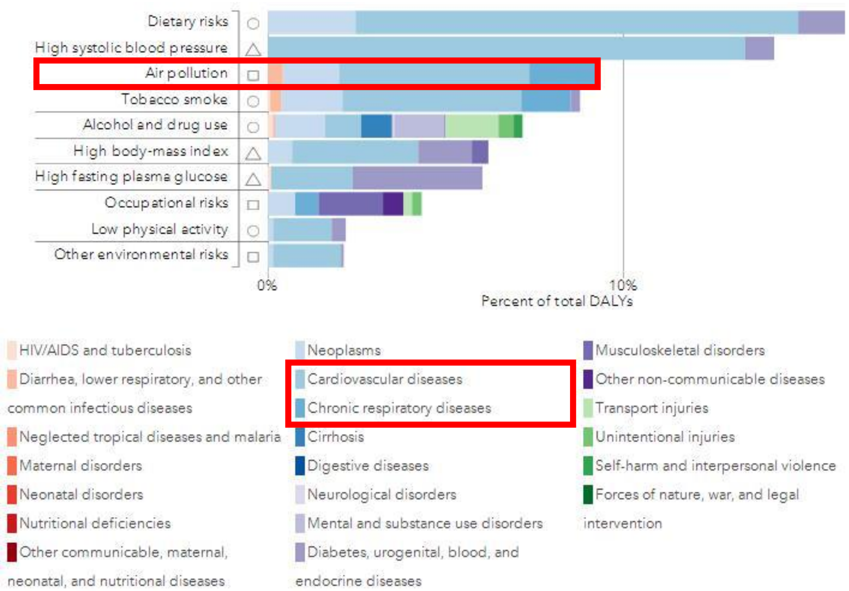


Source: US MA

Part One
Introduction

Adverse outcomes associated with $PM_{2.5}$

- Increasing cardiovascular- and respiratory-related morbidity and mortality according to plentiful epidemiological studies abroad (Pope et al. 2002; Dominici et al. 2006; Pope and Dockery 2006).



Source: http://www.healthdata.org/china

Part One

Introduction

The significance of obtaining high accuracy, resolution and spatiotemporal coverage $PM_{2.5}$ data

- Conducting environmental epidemiologic studies
- Design and perfect environmental management policies and standards.

Part One
Introduction

Ground monitoring cannot achieve the goal

- Expensive operating costs -> Limited ground monitoring sites with uneven spatial distribution -> Hard to obtain high accuracy, resolution and spatiotemporal coverage $PM_{2.5}$ data

Source: http://113.108.142.147:20035/emcpublish/

Part One
Introduction

Satellite remote sensing technology provides the possibility

- Aerosol optical depth (AOD) is the most commonly used remote sensing parameter in satellite-based $PM_{2.5}$ estimation models.
- A series of AOD products have been explored.

Sensor	Satellite	Retrieval algorithm	Spatial resolution	Lastest version	Remarks
MODIS	Terra/Aqua	DT	10km 3km(C6)	C6	C5 has been applied mostly
		DB	10km	C6	The accuracy of C6 is much higher than C5
		MAIAC	1km	trial version	Not yet global coverage
MISR	Terra	EOF	17.6km	V22	High prediction accuracy, however, long revisit period.
SeaWiFS	SeaStar	DB	13.5km	V004	Ended in Octobor, 2010 because of a mechanical trouble
VIIRS	Suomi-NPP	DT	6km/750m	beta version	An expansion and improvement of AVHRR and MODIS

Part One
Introduction

The necessity of comparing new VIIRS to MODIS

- MODIS AOD has been explored mostly due to its long time series of archived data (Chu et al., 2016).
- The VIIRS was designed and launched to address the issue that the MODIS is already working beyond its expected operation period.
- Despite previous studies have showed that both the MODIS and VIIRS AOD are suitable for estimating ground-level $PM_{2.5}$ concentrations, few compared have compared their capacities.

Part One
Introduction

Satellite remote sensing provides the possibility

- Thus, the objective of this paper was to compare the capability of 3 km MODIS AOD and 6 km VIIRS AOD in ground-level $PM_{2.5}$ estimating from a multidimensional perspective.

Sensor	Satellite	Retrieval algorithm	Spatial resolution	Lastest version	Remarks
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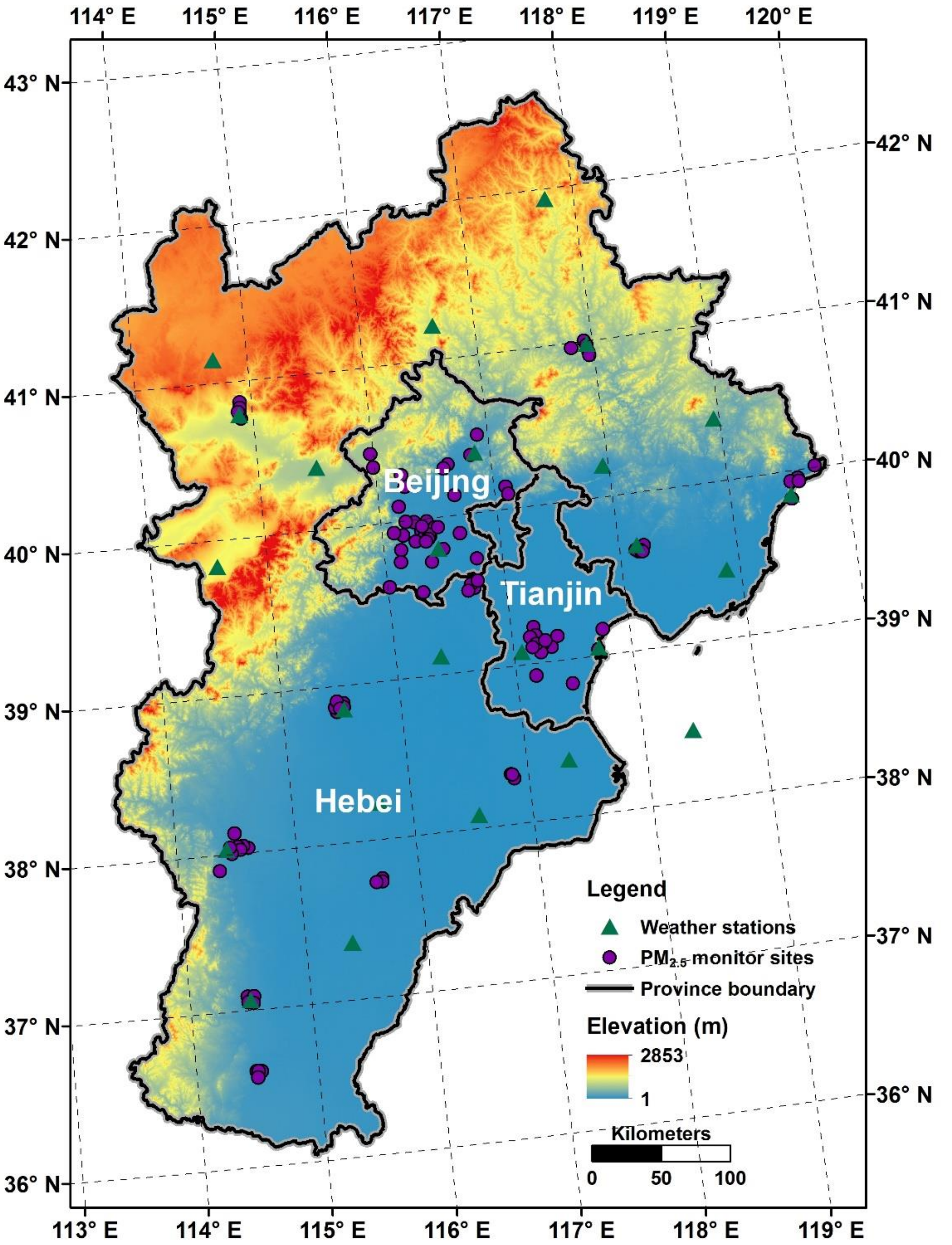
Part Two
Data & Methods

Study Area

- A heavily polluted region in China (Ma et al. 2014, 2016; Wang et al. 2015).
- The southeast area had lower terrain and concentrated the main human activities.



Part Two
Data & Methods

Data collecting

- All the data were collected from the Internet.

Data		Type	Spatial resolutions	Source
$PM_{2.5}$		Point	\	http://113.108.142.147:20035/emcpublish/ http://zx.bjmemc.com.cn/
Suomi-NPP VIIRS 6 km AOD		Raster	6 km	http://www.class.ngdc.noaa.gov/saa/products/welcome
Terra/Aqua MODIS 3 km AOD		Raster	3 km	https://ladsweb.nascom.nasa.gov/
Surface meteorolgical data		Point	\	http://www.escience.gov.cn/metdata/page/index.html
Aerological data	RH	Raster	1.25° × 1.25°	http://disc.sci.gsfc.nasa.gov/
	PBLH		0.5° × 0.5°	
Satellite-derived NDVI		Raster	250 m	https://ladsweb.nascom.nasa.gov/
Satellite derived NO_2		Raster	0.25° × 0.25°	http://www.temis.nl/index.php

Part Two

Data & Methods

Quality Assurance

- Comparison of MODIS and VIIRS QA data

MODIS		VIIRS	
Flag	Quality	Flag	Quality
0	Bad or No Confidence	0	Not Produced
1	Marginal	1	Low
2	Good	2	Medium
3	Very Good	3	High

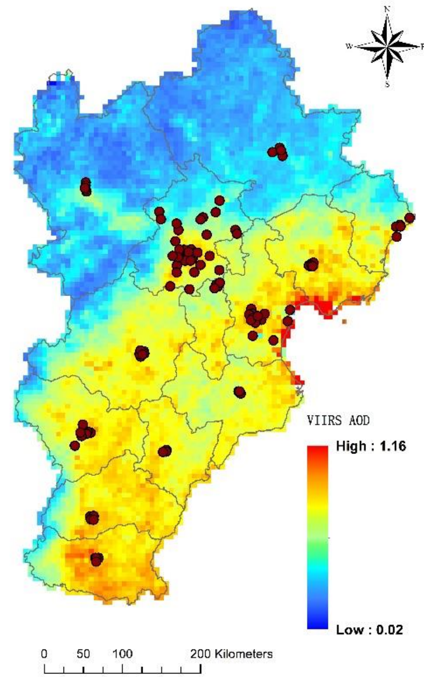
- Model I: Terra/Aqua fused MODIS AOD with QA = 2, 3
- Model II: VIIRS AOD with QA = 3
- Model III: VIIRS AOD with QA =2, 3

Part Two

Data & Methods

Data integration

- Nearest neighbor approach



Y	X													
PM2.5	AOD	PBLH	RH_PBL	TEMP	SRH	PRCP	EWS	SWS	WWS	NWS	NDVI	NO2_Lag	seq	site

- MODIS AOD VS VIIRS AOD
- Four wind vectors derived from wind speed and direction data
- Spatial unbalanced panel dataset

Time

Space

Part Two
Data & Methods

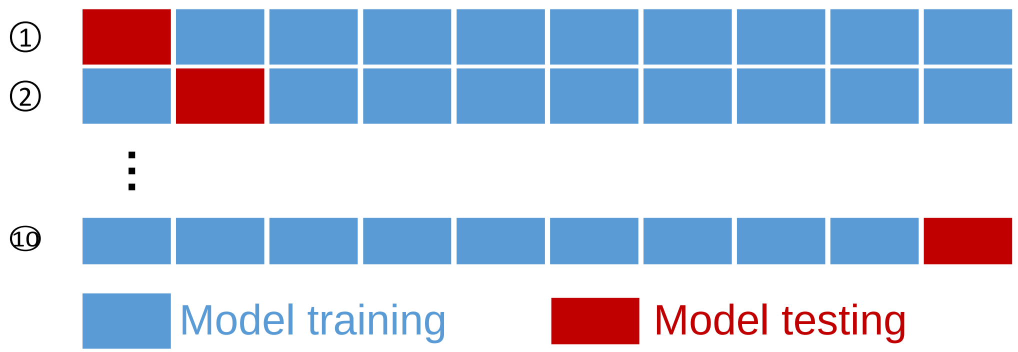
Model development

- Time fixed effects regression model
  - $PM_{2.5,st} = \lambda_t + \beta_{AOD} * AOD_{st} + \beta_{PBLH} * PBLH_{st} + \beta_{RH\_PBL} * RH\_PBL_{st} + \beta_{TEMP} * TEMP_{st} + \beta_{SRH} * SRH_{st} + \beta_{PRCP} * PRCP_{st} + \beta_{EWS} * EWS_{st} + \beta_{SWS} * SWS_{st} + \beta_{WWS} * WWS_{st} + \beta_{NWS} * NWS_{st} + \beta_{NDVI} * NDVI_{st} + \beta_{NO_2\_Lag} * NO_2\_Lag_{st} + \varepsilon_{st}$

Part Two
Data & Methods

Model validation

- Statistical indicators
  - Coefficient of determination (R^2)
  - Mean predication error (MPE)
  - Root-mean-square error (RMSE)
- Ten-folder cross validation



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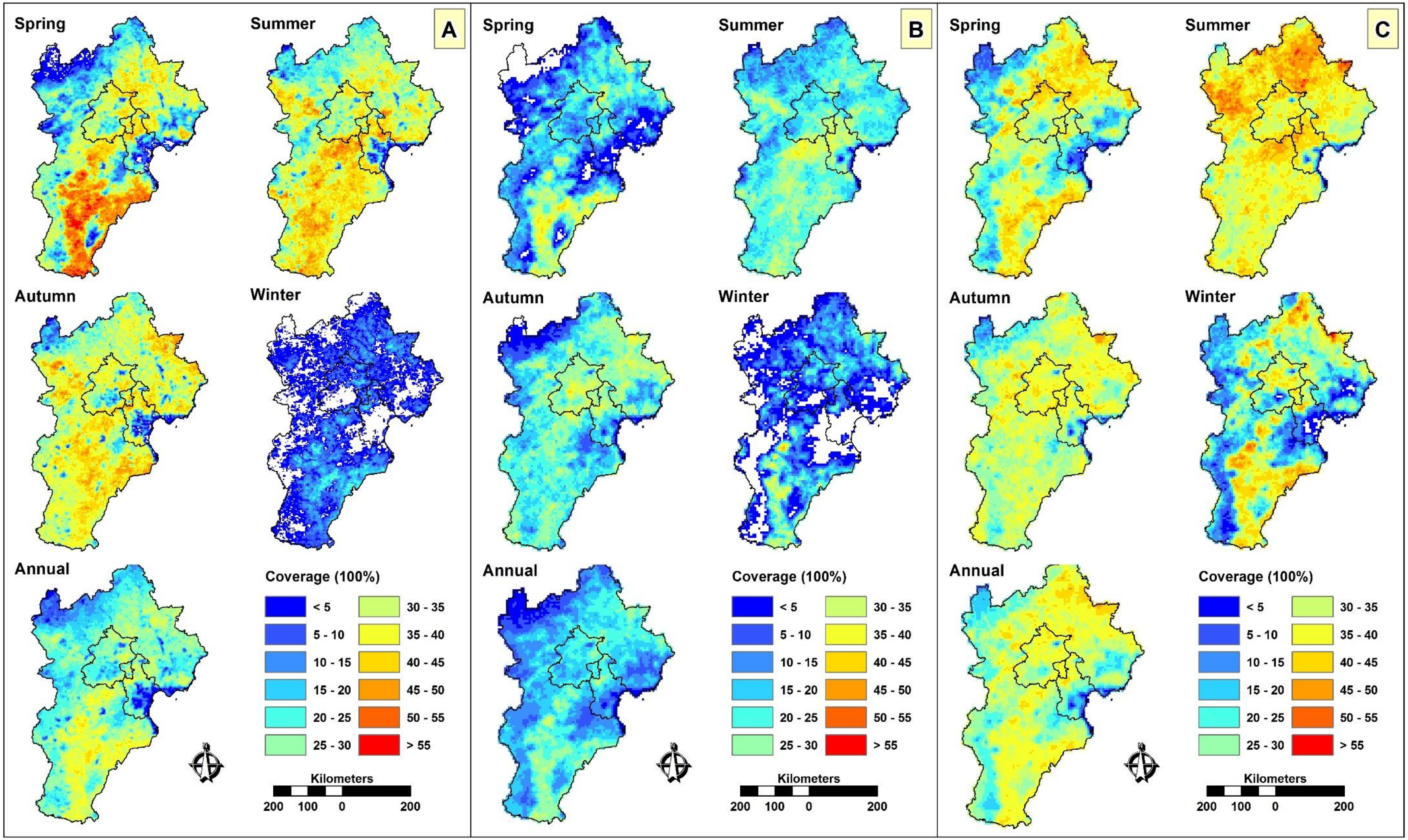
Part Three
Results

Descriptive analysis

- Three aspects should be noted
  - The maximum value and standard deviation of $PM_{2.5}$ concentrations
  - The ranges of MODIS and VIIRS AOD
  - The size of MODIS and VIIRS modelling data set

Variable	Model I (N = 3584, days = 162)				Model II (N = 2847, days = 144)				Model III (N = 4790, days = 188)			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
$PM_{2.5}$ (μg/m³)	2.33	327.22	65.45	38.17	2.33	417.74	61.45	41.58	2.00	429.59	61.45	43.59
AOD (Unitless)	0.00	3.98	0.83	0.55	0.01	1.92	0.56	0.43	0.00	1.93	0.53	0.44
TEMP (0.1 ° C)	-65.00	355.00	219.63	68.90	-101.00	318.00	203.35	85.17	-101.00	320.00	173.61	107.97
SRH (%)	12.00	90.00	50.81	14.90	12.00	90.00	51.84	14.07	9.00	90.00	48.72	15.73
PRCP (0.1 mm)	0.00	700.00	6.38	38.24	0.00	451.00	5.16	25.65	0.00	700.00	5.02	29.63
PBLH (m)	65.36	4661.76	1972.85	566.14	65.36	3634.31	1876.15	553.46	65.36	3682.31	1825.48	589.67
RH_PBL (Unitless)	0.09	0.86	0.37	0.16	0.09	0.85	0.37	0.15	0.09	0.86	0.35	0.15
NDVI (Unitless)	0.02	0.88	0.35	0.14	0.02	0.88	0.36	0.14	-0.03	0.88	0.32	0.15
NO_2_Lag (10^{15} molec/cm^2)	0.14	53.43	11.77	7.57	0.56	83.47	11.96	8.70	0.56	83.47	12.71	10.50
WWS (0.1 m/s)	0.00	51.74	7.43	9.19	0.00	60.98	7.09	8.47	0.00	76.68	7.64	9.91
NWS (0.1 m/s)	0.00	47.12	4.82	8.98	0.00	57.00	5.28	9.38	0.00	64.35	6.74	10.63
EWS (0.1 m/s)	0.00	46.19	4.64	7.59	0.00	39.73	4.22	6.91	0.00	46.19	4.56	7.47
SWS (0.1 m/s)	0.00	39.73	8.95	9.14	0.00	39.73	8.17	8.53	0.00	54.51	7.24	8.73



A: Model I; B: Model II; C: Model III

Part Three
Results

Spatiotemporal coverage of AOD

- Two aspects should be noted
  - The spatiotemporal coverage of high-quality AOD data
  - The improvement brought by the practice of including medium-quality AOD data

AOD Parameter	Spring Coverage	Summer Coverage	Autumn Coverage	Winter Coverage	Annual Coverage
MODIS	29.16	33.06	32.89	4.78	25.06
VIIRS (QA = 3)	15.54	22.3	21.61	8.51	17.02
VIIRS (QA = 2, 3)	30.23	38.06	31.77	24.88	31.27

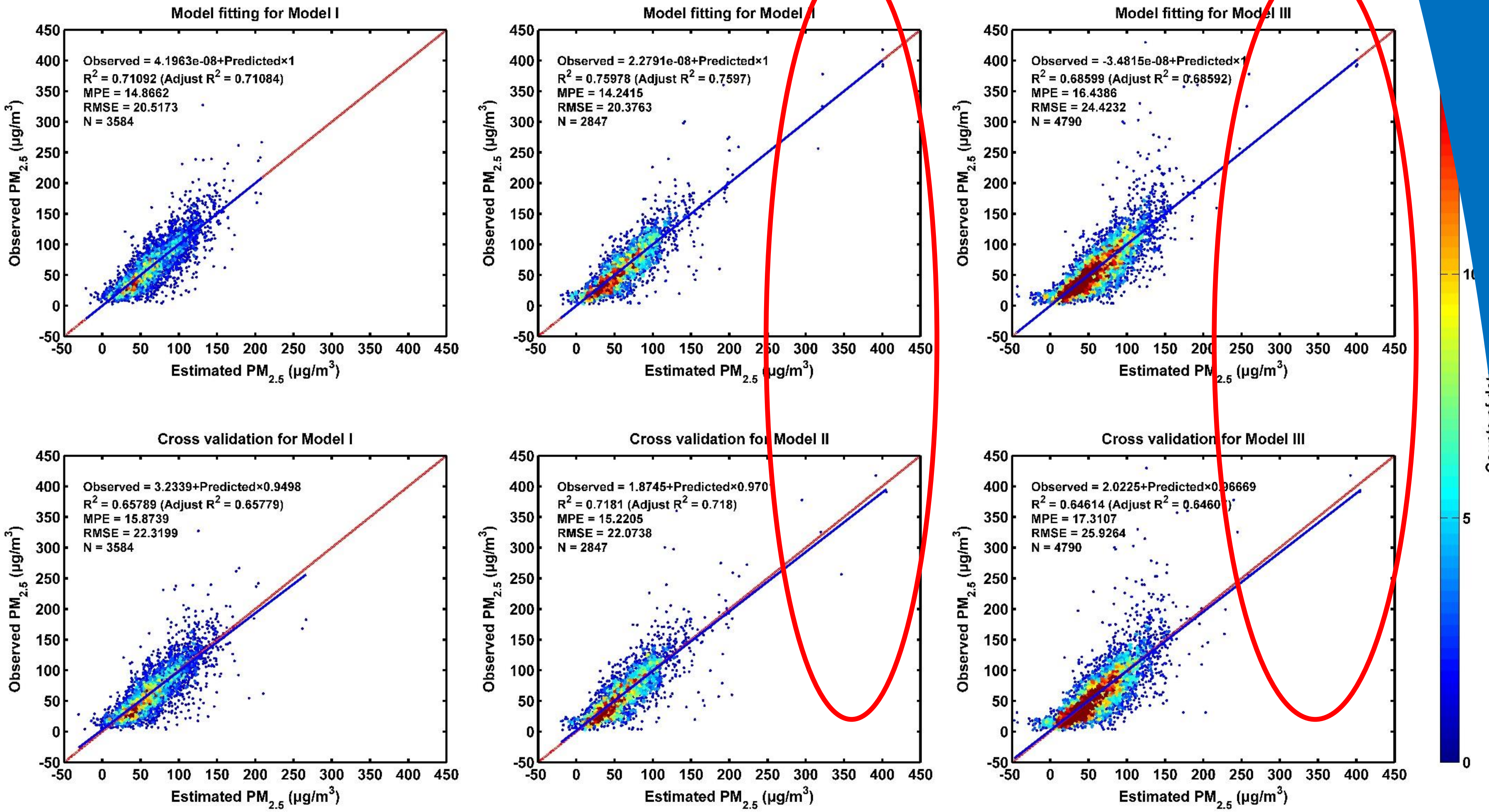
Part Three
Results

Model fitting

- The VIIRS model performed better than the MODIS model
  - Signs and p-values of PBLH and NDVI variables
  - Significance test of four wind vectors

Variable	Model I				Model II				Model III			
	β	p	5%	95%	β	p	5%	95%	β	p	5%	95%
AOD (Unitless)	26.513	0.000	24.014	29.011	23.880	0.000	20.800	26.959	26.591	0.000	23.756	29.427
TEMP (0.1 °C)	0.460	0.000	0.407	0.514	0.542	0.000	0.484	0.600	0.495	0.000	0.448	0.542
SRH (%)	0.798	0.000	0.687	0.910	1.077	0.000	0.951	1.203	1.218	0.000	1.112	1.324
PRCP (0.1 mm)	-0.035	0.003	-0.058	-0.012	-0.054	0.011	-0.096	-0.012	-0.044	0.004	-0.073	-0.014
PBLH (m)	0.001	0.602	-0.002	0.003	-0.002	0.110	-0.005	0.001	-0.001	0.498	-0.003	0.002
RH_PBL (Unitless)	-23.688	0.000	-34.584	-12.792	-26.147	0.000	-39.593	-12.701	-27.001	0.000	-38.857	-15.145
NDVI (Unitless)	1.812	0.521	-3.727	7.350	-5.756	0.059	-11.725	0.214	-5.206	0.081	-11.051	0.639
NO_2_Lag (10^{15} molec/cm^2)	0.376	0.000	0.251	0.501	0.127	0.079	-0.015	0.269	0.512	0.000	0.395	0.629
WWS (0.1 m/s)	0.060	0.308	-0.055	0.175	-0.079	0.270	-0.221	0.062	0.070	0.212	-0.040	0.180
NWS (0.1 m/s)	-0.122	0.057	-0.248	0.004	-0.342	0.000	-0.494	-0.191	-0.208	0.000	-0.321	-0.095
EWS (0.1 m/s)	-0.044	0.510	-0.177	0.088	-0.291	0.001	-0.465	-0.117	-0.048	0.492	-0.186	0.090
SWS (0.1 m/s)	-0.316	0.000	-0.432	-0.200	-0.242	0.002	-0.395	-0.089	-0.134	0.048	-0.267	-0.001

Part Three
Results



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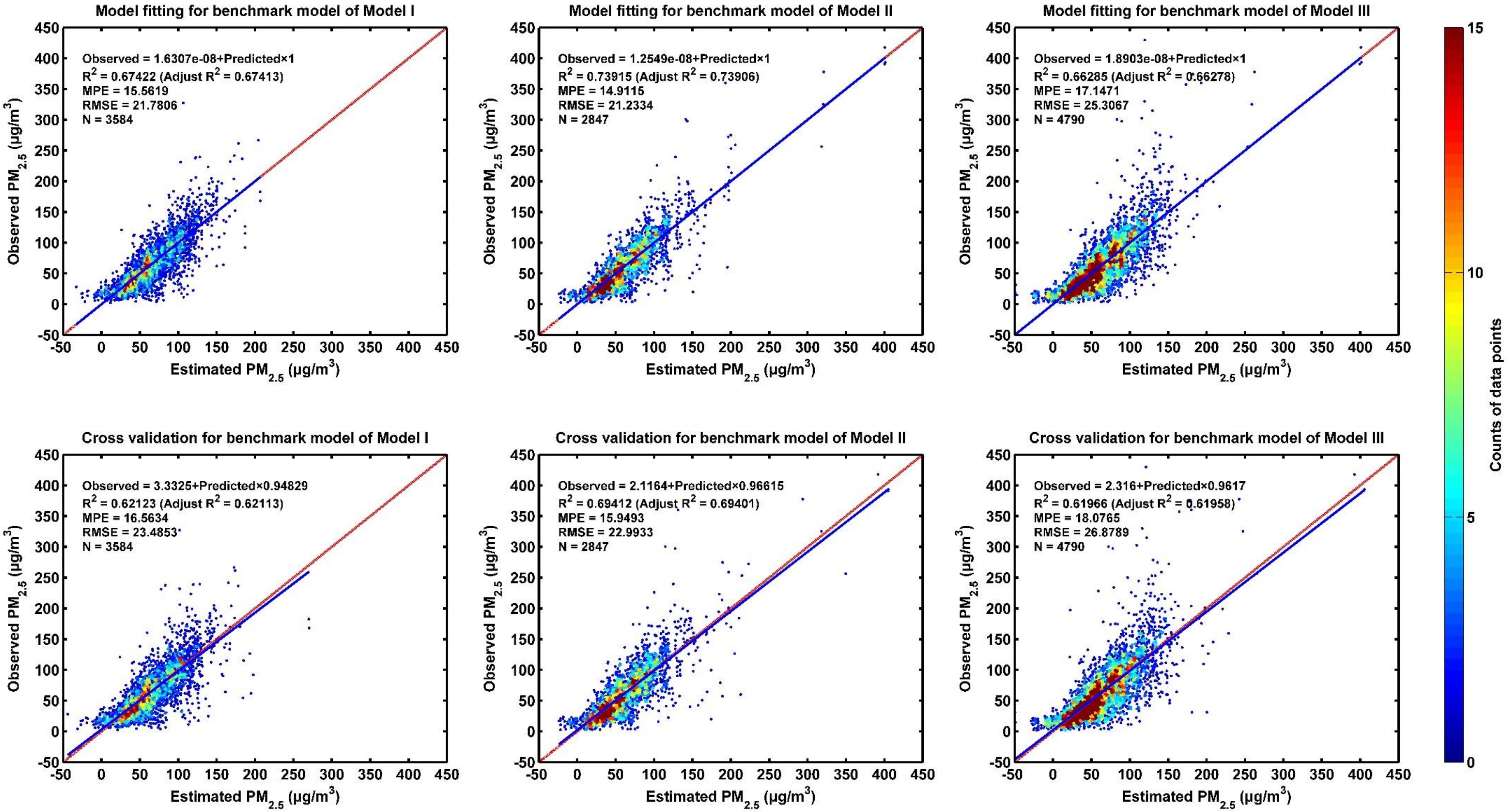
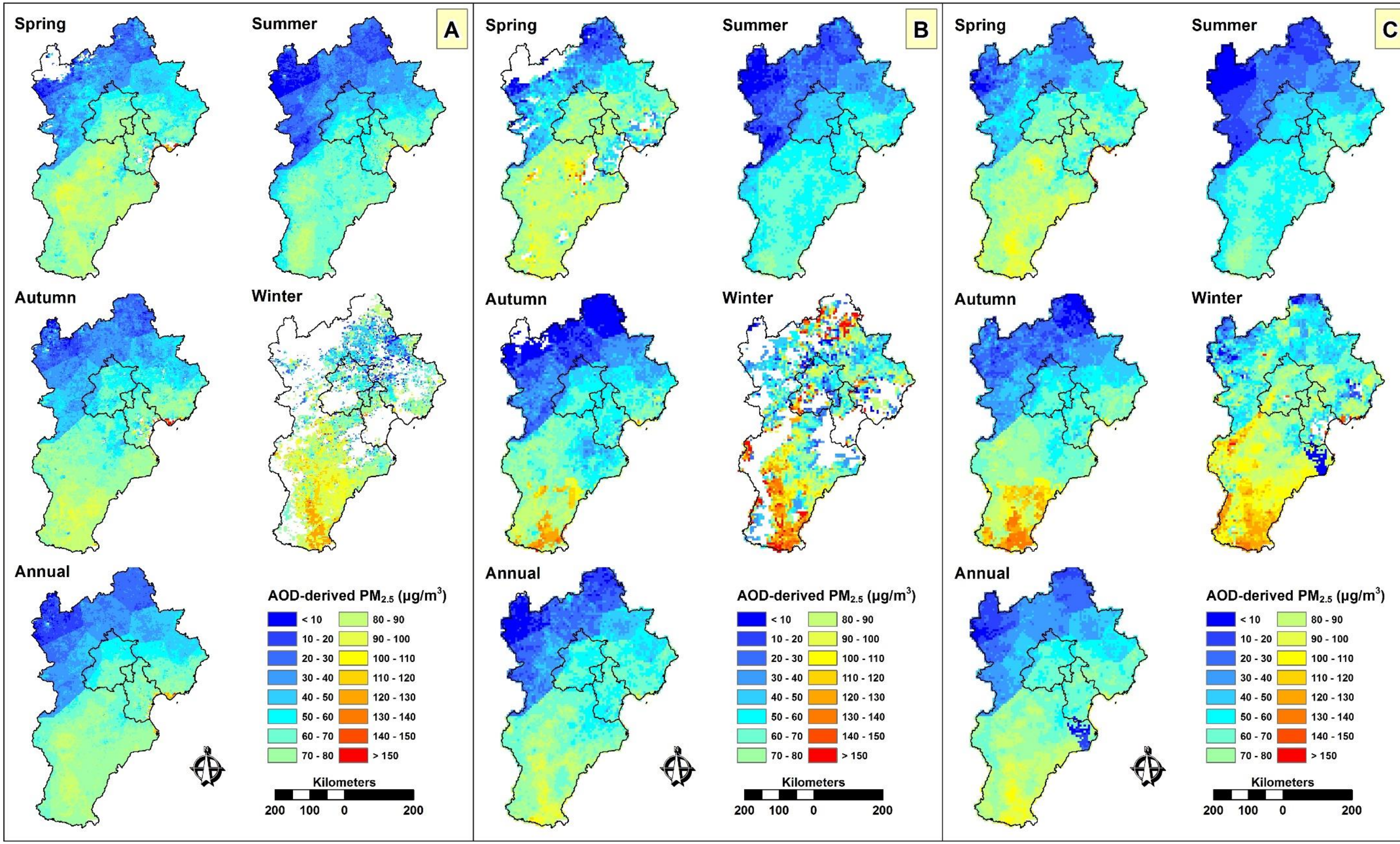


Part Three
Results

Model validation

- Comparison of Model I, II, III and their benchmark models
  - Employing AOD decreases the model over fitting degree by 5.16%, 10.05%, and 21.37% for Model I, II, and III.

Model	Model overfitting degree % (full model)	Model overfitting degree % (full model)
I	7.46	7.86
II	5.49	6.1
III	5.82	7.4

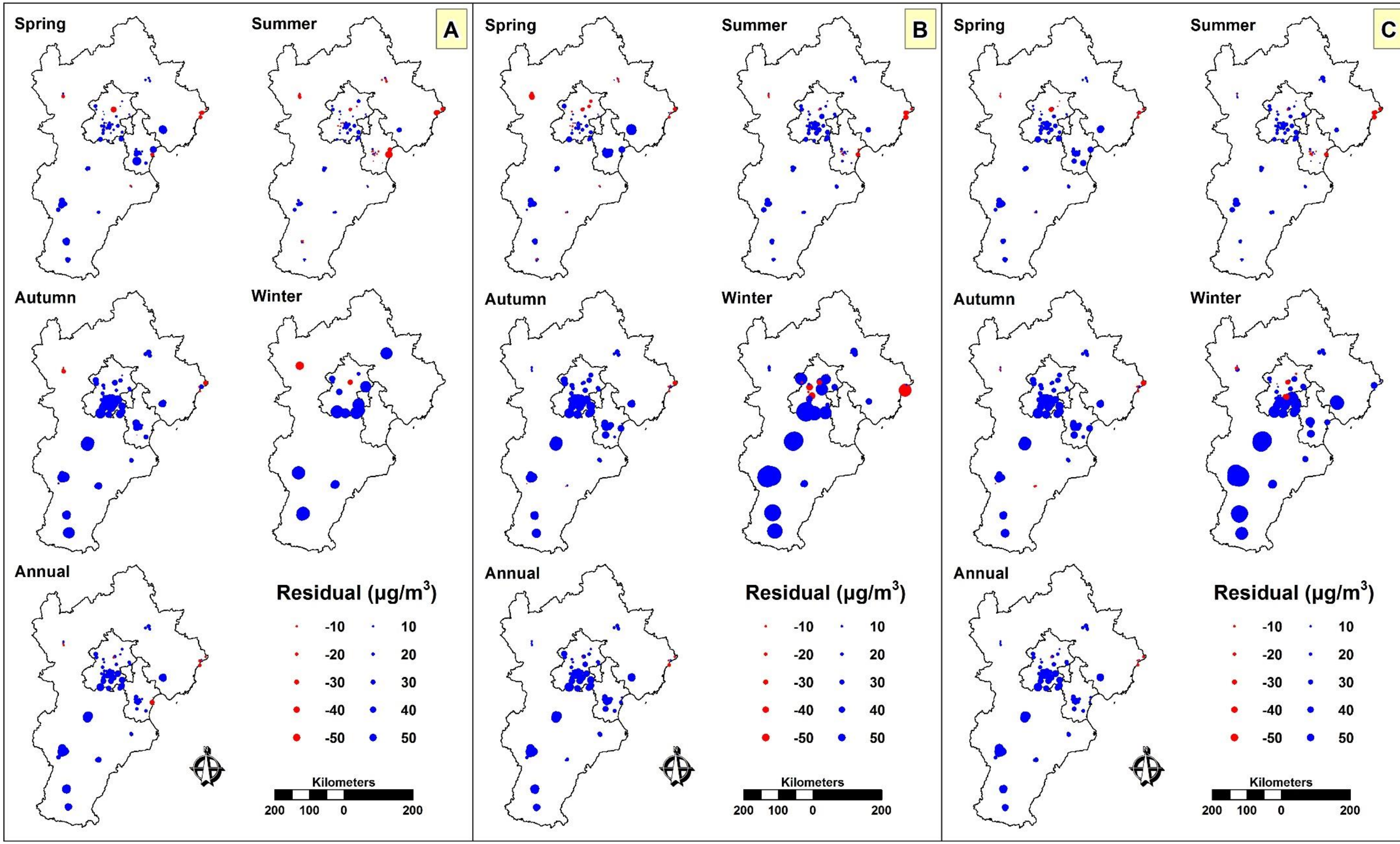


A: Model I; B: Model II; C: Model III

Part Three
Results

Ground-level $PM_{2.5}$ mapping and evaluation

- Temporally, high in winter, low in summer, medium in spring and autumn; spatially, high in the southeastern area, low in the northwestern area.
- The spatiotemporal coverage $PM_{2.5}$ estimates.
- The value size of $PM_{2.5}$ estimates.



A: Model I; B: Model II; C: Model III

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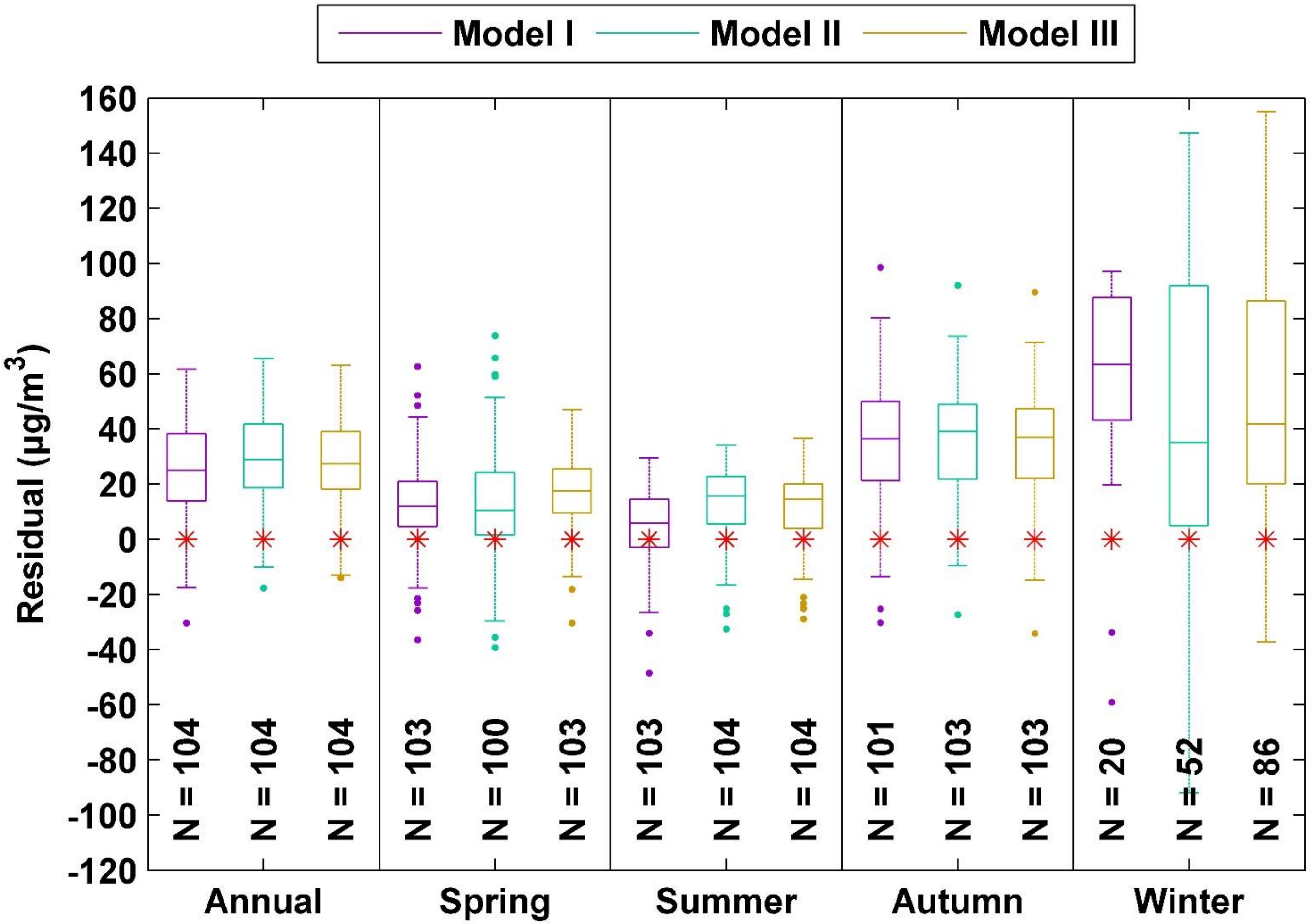
Results



Part Three
Results

Ground-level $PM_{2.5}$ mapping and evaluation

- Satellite-based annual or seasonal $PM_{2.5}$ estimates underestimates the actual levels during the whole year and almost all seasons.
- We could infer that the VIIRS models outperformed the MODIS model with respect to annual and seasonal deviations to some degree.
- We should realize that the MODIS model outperforms the two VIIRS models in summer with respect to lower residuals.

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Part Four
Discussion

Comparison between MODIS and VIIRS

- The VIIRS model had better model performances
  - The Model II performed best during model fitting and cross-validation with respect to significant variable numbers, signs and p values of variables, and model accuracy.
  - The seasonal estimates of ground-level $PM_{2.5}$ from the Model III had the highest spatiotemporal coverage especially in winter.
  - Both the Model II and III could retrieve high $PM_{2.5}$ concentrations and have lower model overfitting degrees, while the Model I did not.
- Two possible reasons
  - Different instrumental degradation
  - The design of the VIIRS

Part Four
Discussion

Assessment of employing medium-quality VIIRS AOD

- The benefits of the AOD spatiotemporal coverage improvement outweighs the model accuracy decline significantly.
- the VIIRS model with medium-quality AOD performed comparably or even better than the MODIS model with respect to variable significance test, model overfitting degree, and annual and seasonal deviations.

Part Four
Discussion

Deficiency of this study

- Failure to obtain the daily intercepts of $PM_{2.5}$-AOD relationships in those days without $PM_{2.5}$-ADO data matchups.
- No account for the spatial heterogeneity of the $PM_{2.5}$-AOD relationship.

Possible solutions

- Employment of nested time fixed effects regression model.
- Employment of spatiotemporal statistical regression model.

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Part Five

Conclusions

Listed as below

- From the perspective of the accuracy and capacity of the model, the VIIRS models outperform the MODIS model.
- From the perspective of annual and seasonal $PM_{2.5}$ estimates, the VIIRS models provide more estimates closer to actual levels.
- The VIIRS AOD is more suitable for epidemiological and urban studies, while the MODIS AOD could still have a role in regional source and transport studies.

Thanks

FAQ