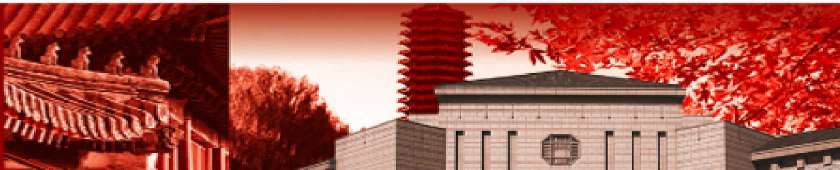
New particle formation in China: current knowledge and future directions

Min Hu, Zhibin Wang, Zhijun Wu, Dingli Yue, Dongjie Shang, Song Guo

State Key Joint Laboratory of Environmental Simulation and Pollution Control, College of Environmental Sciences and Engineering, Peking University



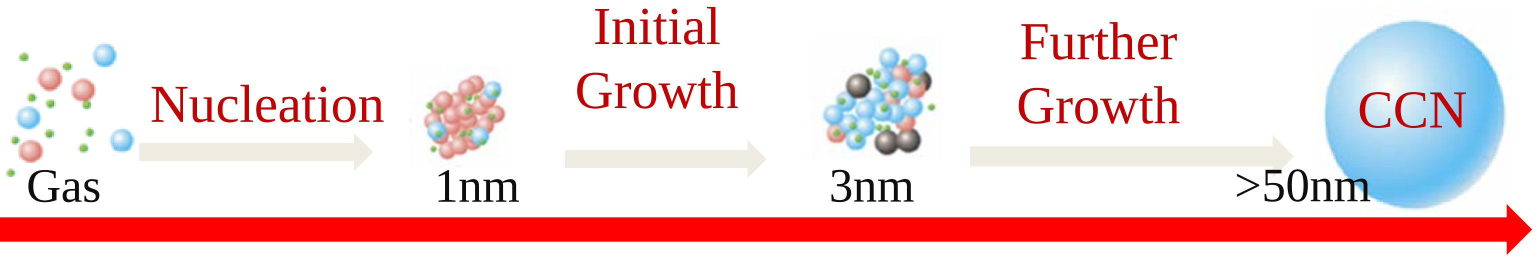
New particle formation (NPF)

- A **crucial secondary transformation process** in the atmosphere (Zhang et al., 2012). Generally, this process includes two distinct stages: (1) **nucleation** to form a critical molecular cluster from gaseous vapours, and (2) subsequent **growth** of these clusters to detectable sizes or even larger (Kulmala, 2003; Zhang, 2010).
- NPF is an **important source** of atmospheric aerosol particles on a global scale (Yu et al., 2008; Merikanto et al., 2009).
- The newly formed particles can grow into sizes where they may **act as** cloud condensation nuclei (**CCN**), thereby influencing cloud- and climate-relevant properties (Kerminen et al., 2012).
- Understanding of NPF secondary aerosol formation and evolution in the atmosphere has become critically important.

北京大學
PEKING UNIVERSITY

New Particle Formation and effects

Secondary formation



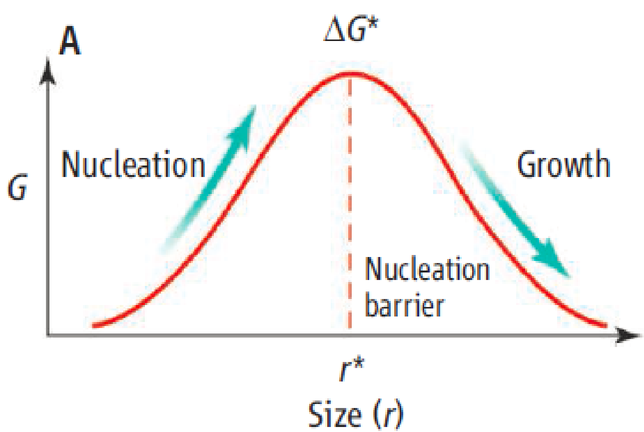
Parameters

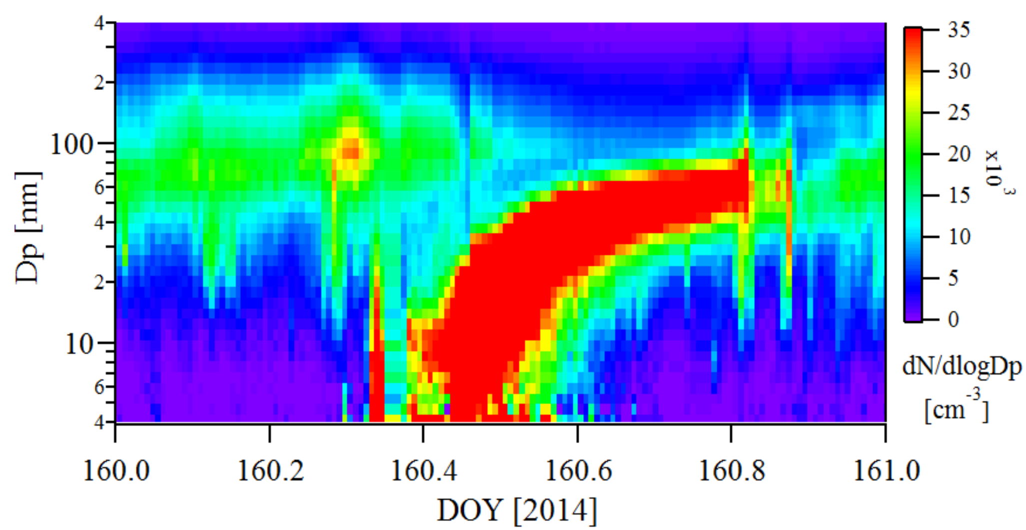
FR Formation rate ($cm^{-3}s^{-1}$)

GR Growth Rate (nmh^{-1})

CCN $PM_{2.5}$

CS Condensation Sink (s^{-1})

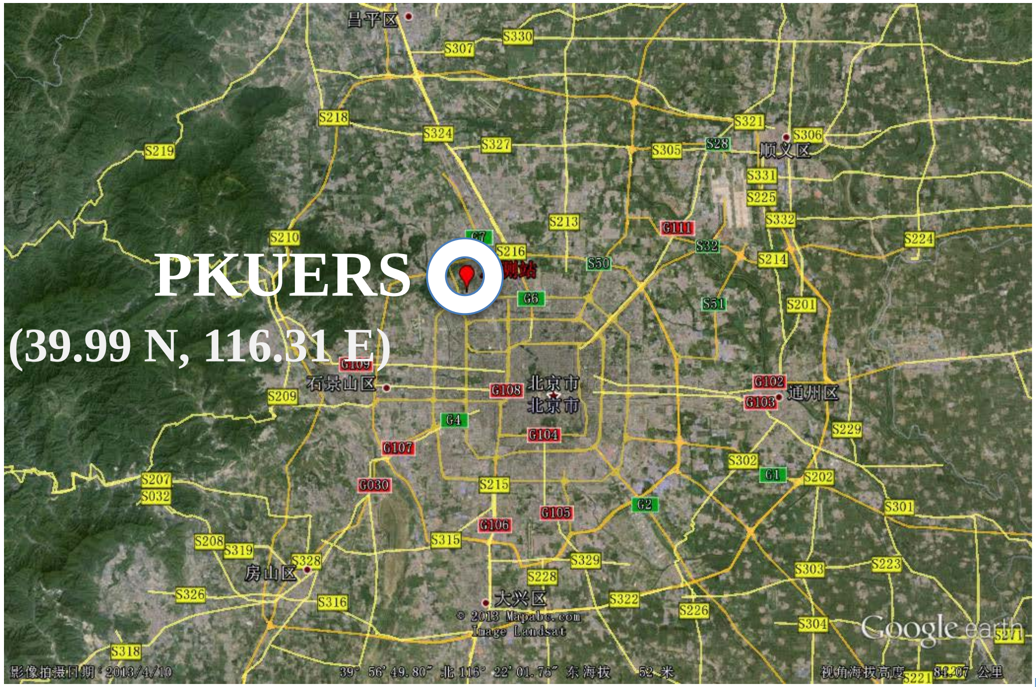




(Kulmala *et al.*, ***Science***, 2003; Zhang, et al., ***Science***, 2010)

北京大学

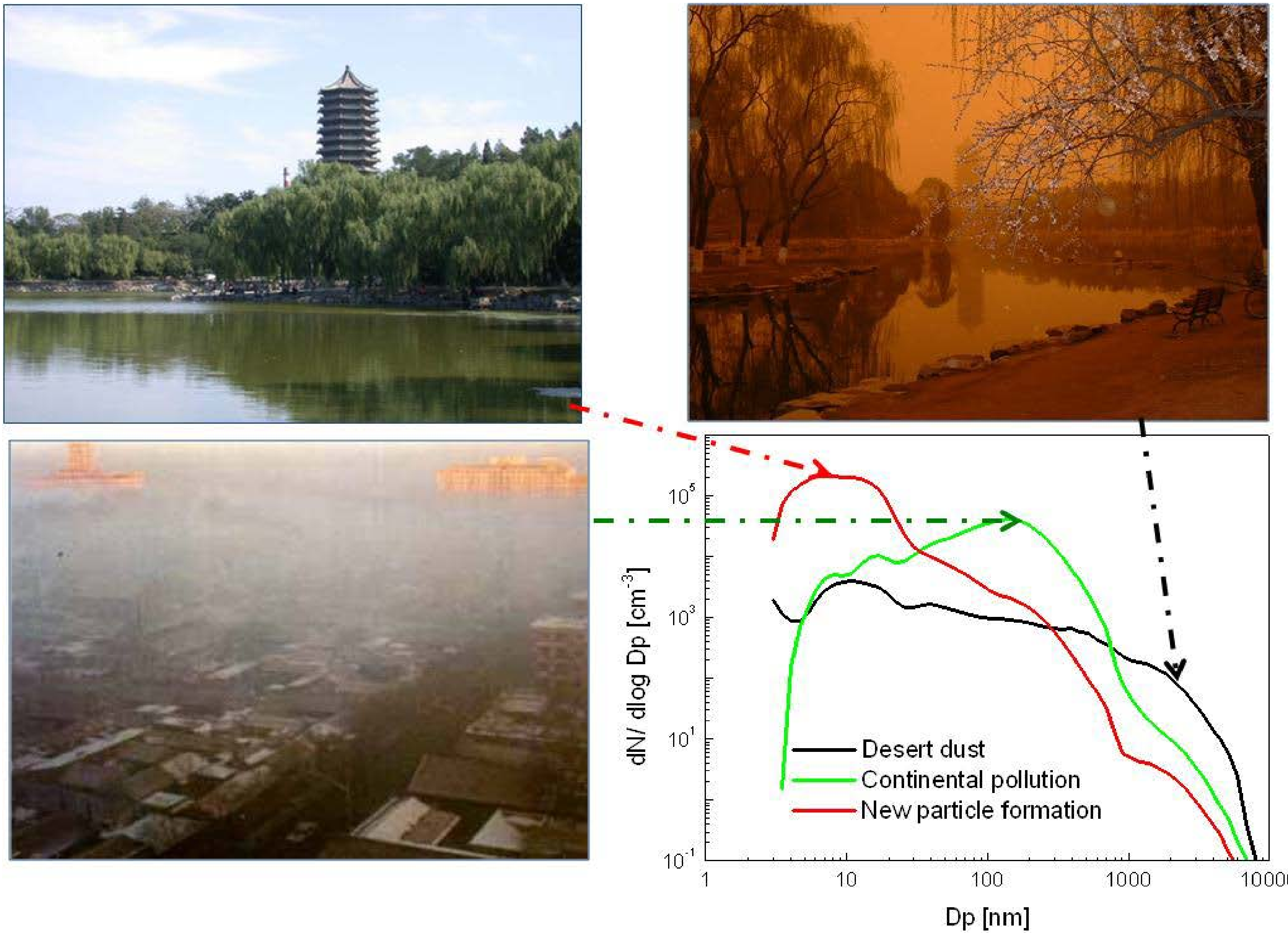
PKUERS: PKU Urban Atmosphere Environment MonitoRing Station



Research Focus:

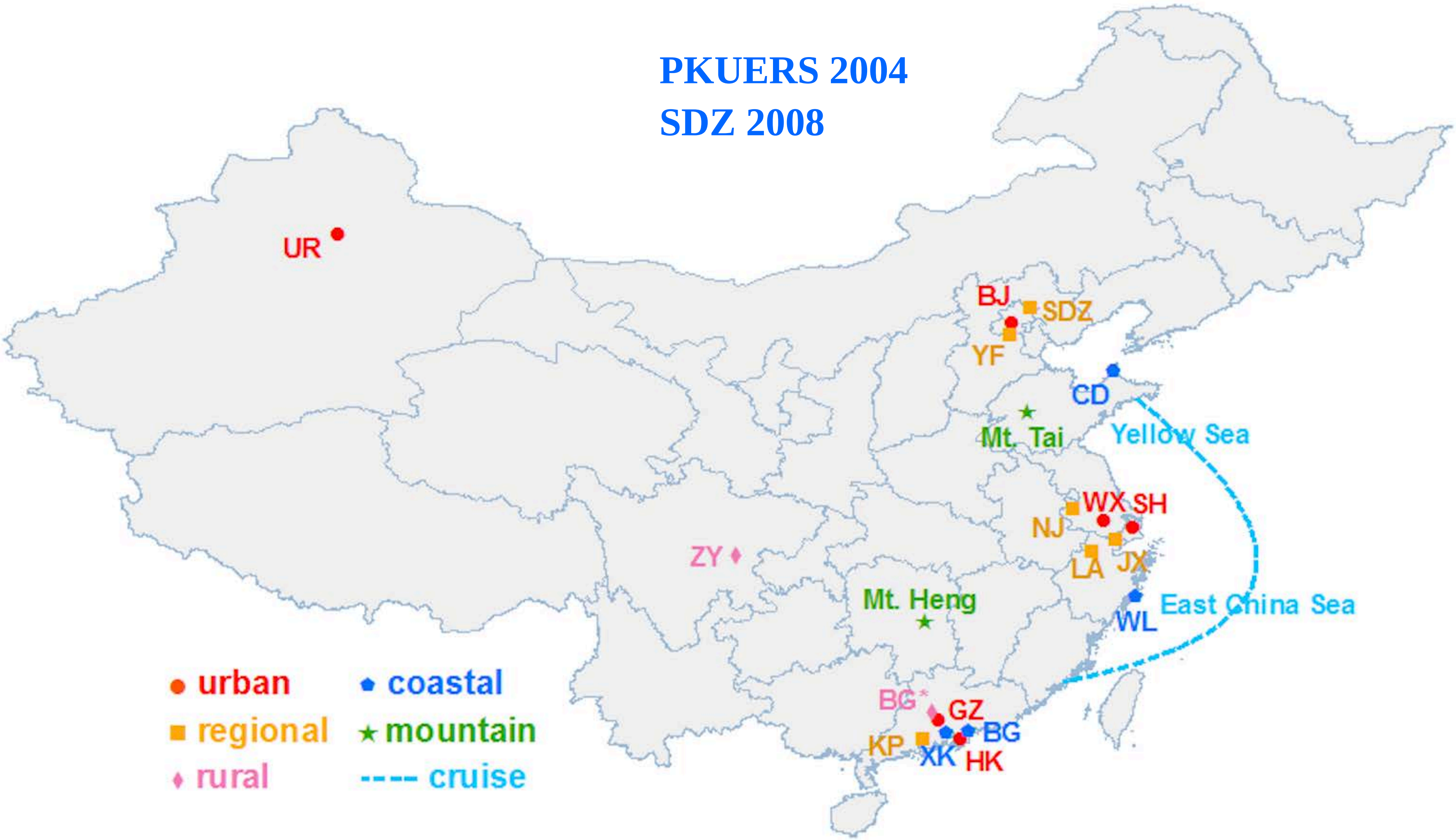
Ozone and Oxidant Chemistry
Aerosol Characteristics
Air Quality and Climate Change
Air Pollution and Human Health
Evaluation of the effectiveness of pollution control
Instrument Development

Typical Particle Number Distribution of NPF, dust storm and Haze days in Beijing

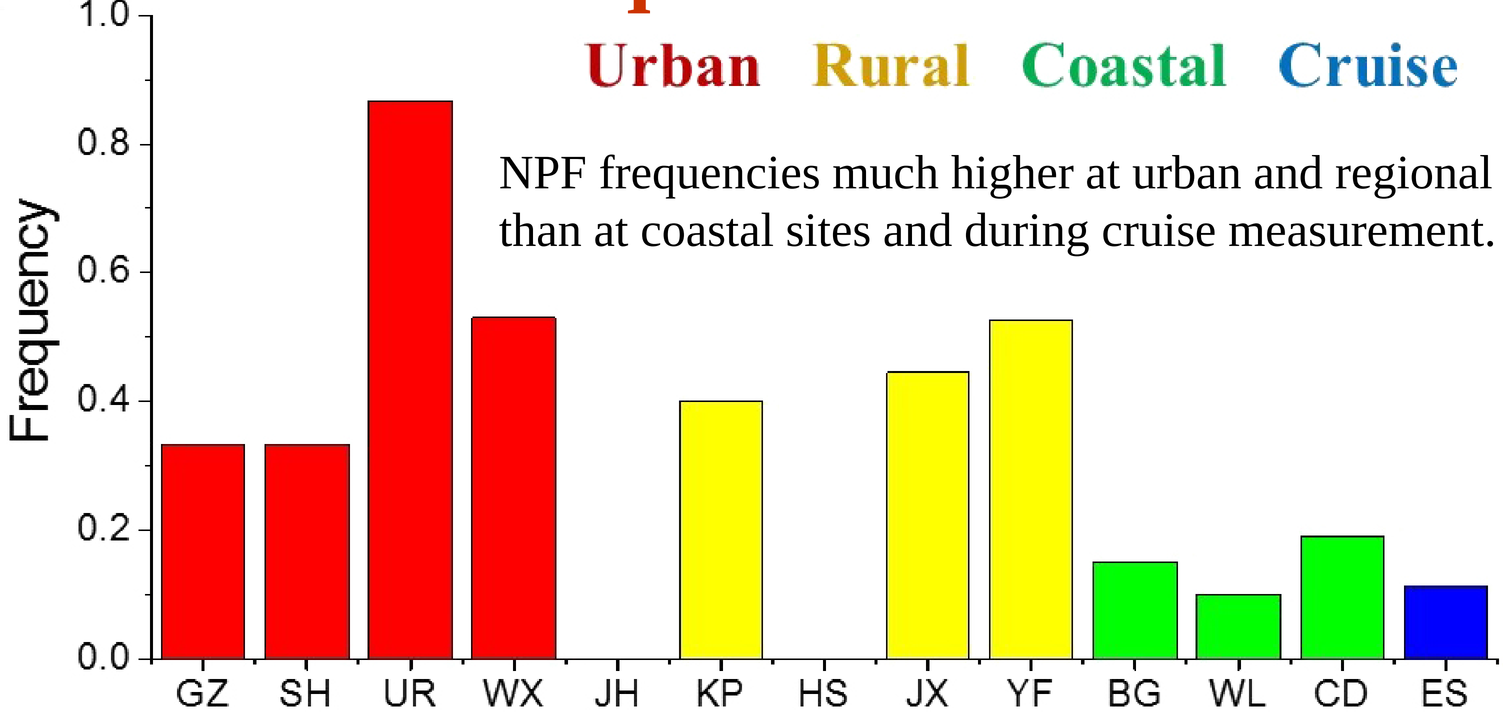


Geographic distribution of stations new particle formation events reported in China

PKUERS 2004
SDZ 2008



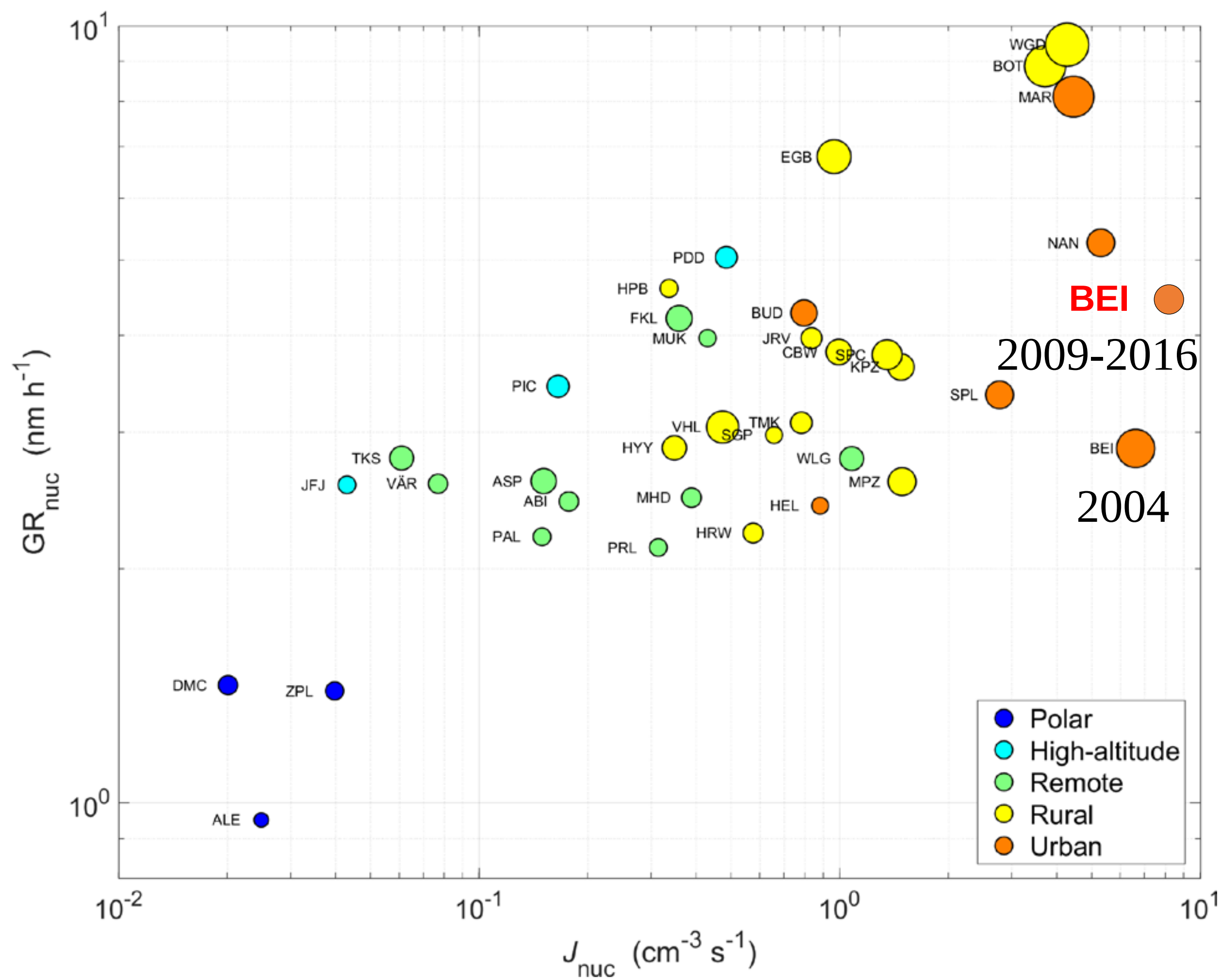
Frequencies of NPF events



- The average growth rates of nucleation mode particles were 8.0–10.9 nm h^{-1} at urban, 7.4–13.6 nm h^{-1} at regional and 2.8–7.5 nm h^{-1} at coastal and cruise.
- The high gaseous precursors and strong oxidation at urban and regional sites not only favored the formation of particles, but also accelerated the growth rate of the nucleation mode particles.
- No significant difference in condensation sink during NPF days was observed among different site types, suggesting that the NPF events in background areas were more influenced by the pollutant transport.

Nucleation rate higher and growth rate lower compared with those in the world

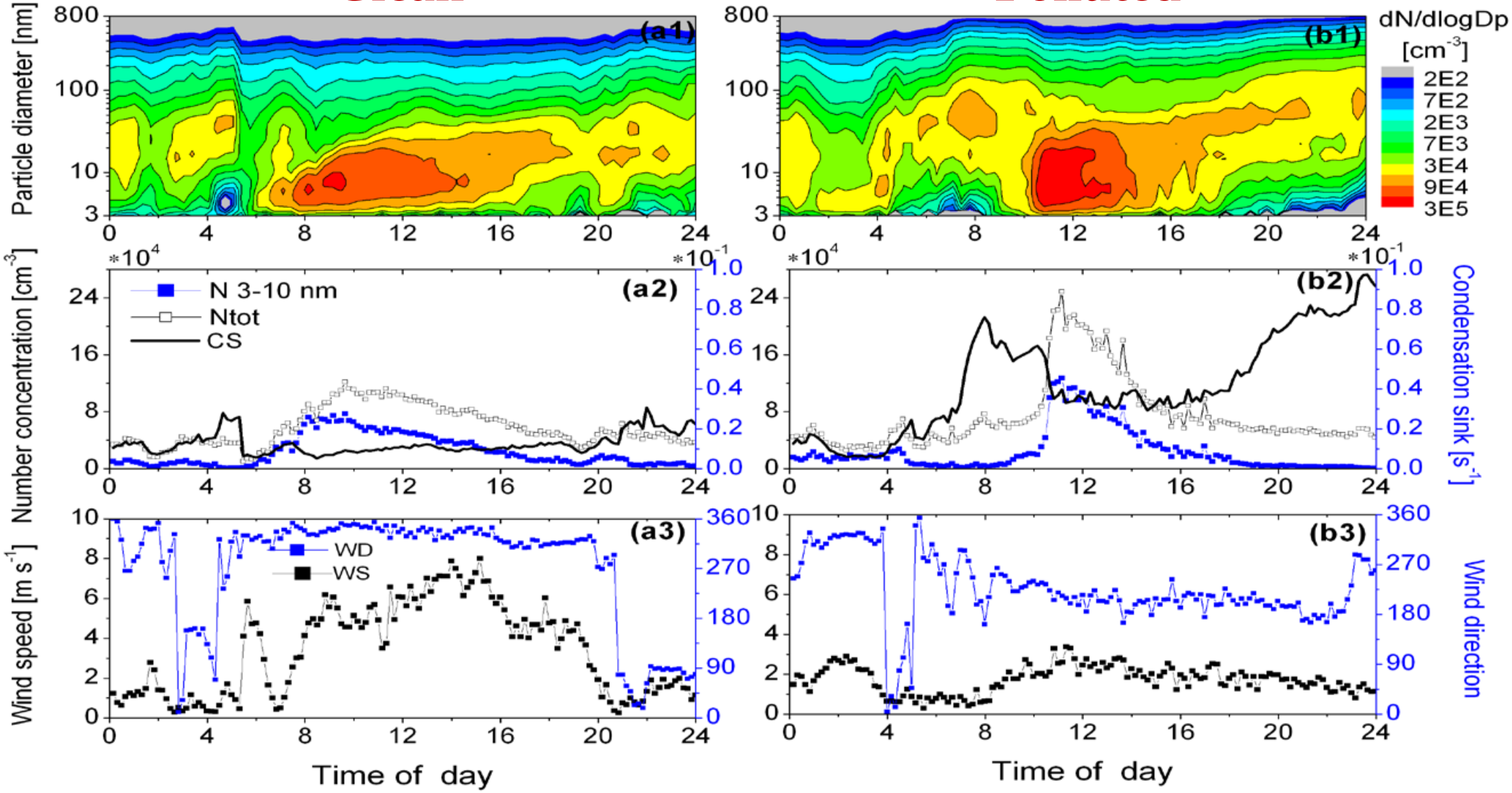
	Station name and abbreviation	
1	Mt. Zeppelin	ZPL
2	Dome-C	DMC
3	Alert	ALE
4	Jungfraujoch	JFJ
5	Puy de Dome	PDD
6	Pico Espejo	PIC
7	Aspvreten	ASP
8	Preila	PRL
9	Finokalia	FKL
10	Mace Head	MHD
11	Värriö	VÄR
12	Pallas	PAL
13	Abisko	ABI
14	Tiksi	TKS
15	Mt. Waliguan	WLG
16	Mukteshwar	MUK
17	Hyytiälä	HYY
18	Tomsk	TMK
19	Järvselja	JRV
20	Hohenpeissenberg	HPB
21	Vavihill	VHL
22	K-Puszta	KPZ
23	Melpitz	MPZ
24	San Pietro Capofiume	SPC
25	Cabauw	CBW
26	Harwell	HRW
27	Egbert	EGB
28	Southern Great Plains	SGP
29	Botsalano	BOT
30	Welgegund	WGD
31	Marikana	MAR
32	Helsinki	HEL
33	Beijing	BEI
34	Nanjing	NAN
35	Budapest	BUD
36	Sao Paulo	SPL



（Tuomo Nieminen, ACPD，2017）

Two types of NPF in Beijing

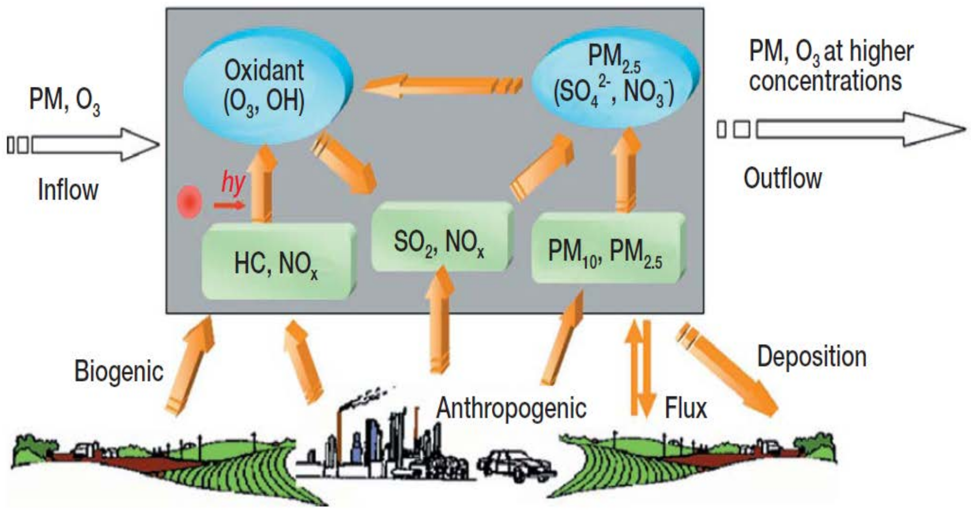
Clean | **Polluted**

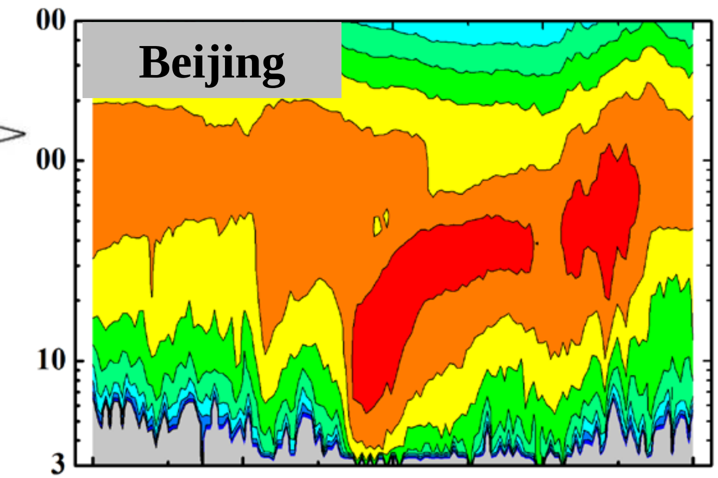


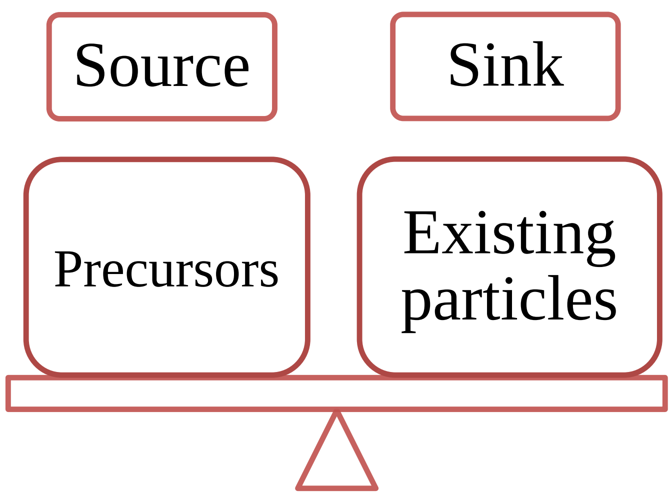
Clean	Polluted
FR: **16.4 ±13.2** $cm^{-3}s^{-1}$	FR: **15.9 ±13.4** $cm^{-3}s^{-1}$
GR**: 2.2±1.9** nm h^{-1}	GR: **5.5 ±3.4** nm h^{-1}
CS: (**1.3 ±0.5**) $\times 10^{-2}$ s^{-1}	CS: (**3.1 ±1.3**) $\times 10^{-2}$ s^{-1}

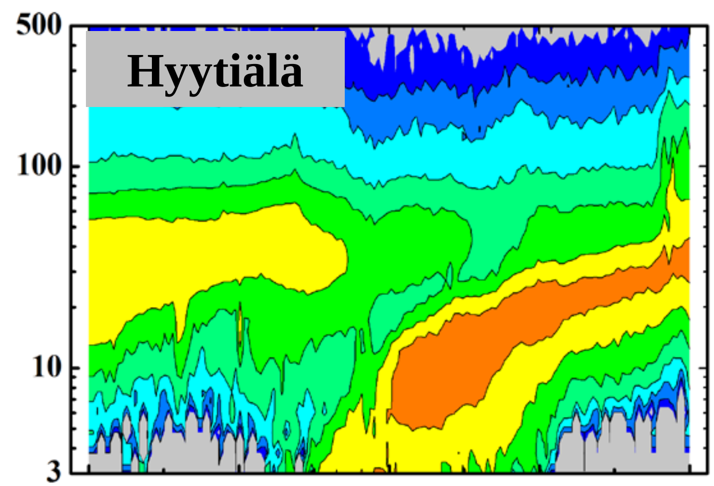
Wu Z J, Hu M* *et al*, *J. Geophys. Res.*, 2007

NPF under high aerosol loading in China





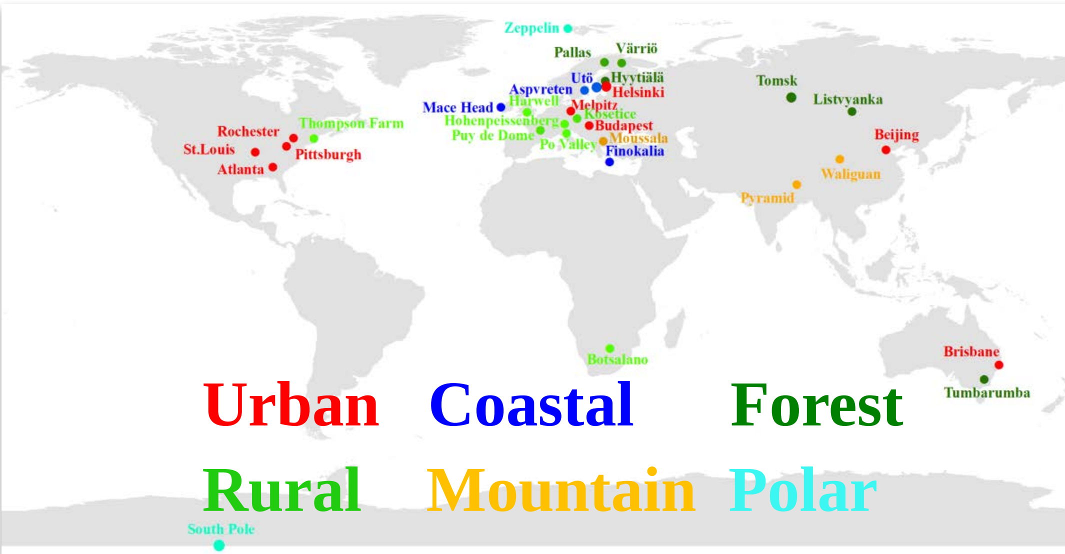




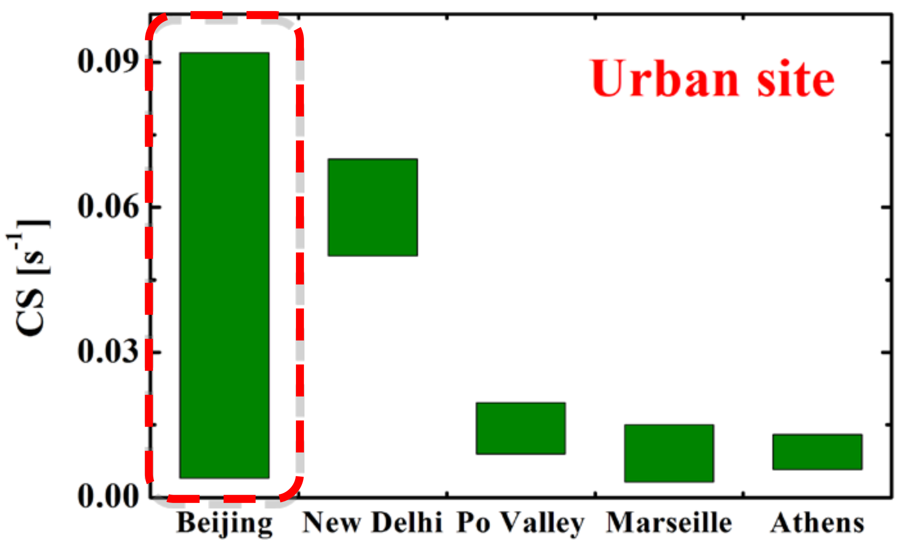
(Shao et al., *FEE*, 2006)

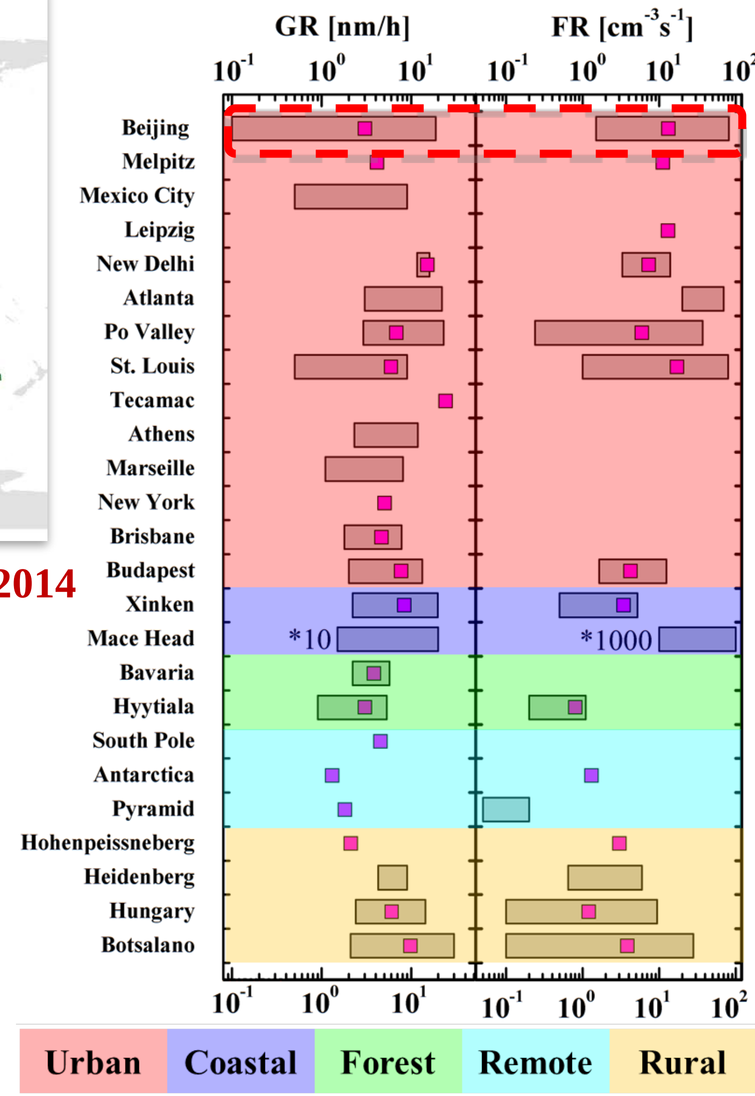
PEKING UNIVERSITY

Beijing: typical NPF at polluted region



Beijing urban @ PKU for 10 years measurements 2004-2014

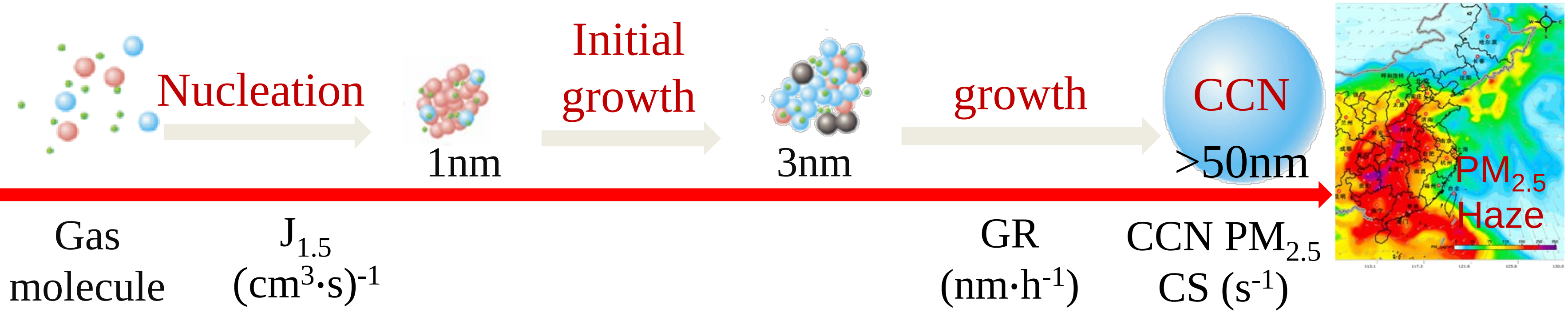




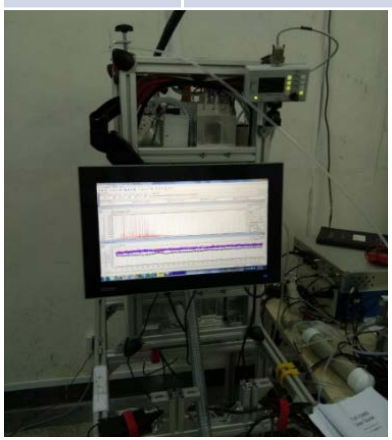
Wang ZB, **Hu M***, *et al*, *Acta Chimica Sinica*, 2013

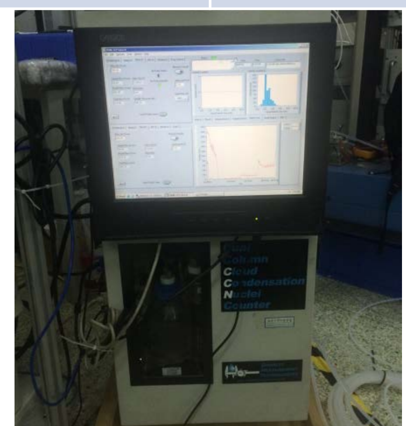
Kulmala *et al*., *ACP*, 2005; Hamed *et al*., *ACP*, 2007

Evolution from NPF to Haze



Parameters	NH_3, Amine	H_2SO_4, HOMs	Particles 1-3 nm	Particles 3nm-10μm	Chemical compositions	CCN
Instruments	C_2H_5OH-CIMS	Nitrate-CIMS	PSM	SMPS	HR-TOF-AMS, ACSM	CCNc-200



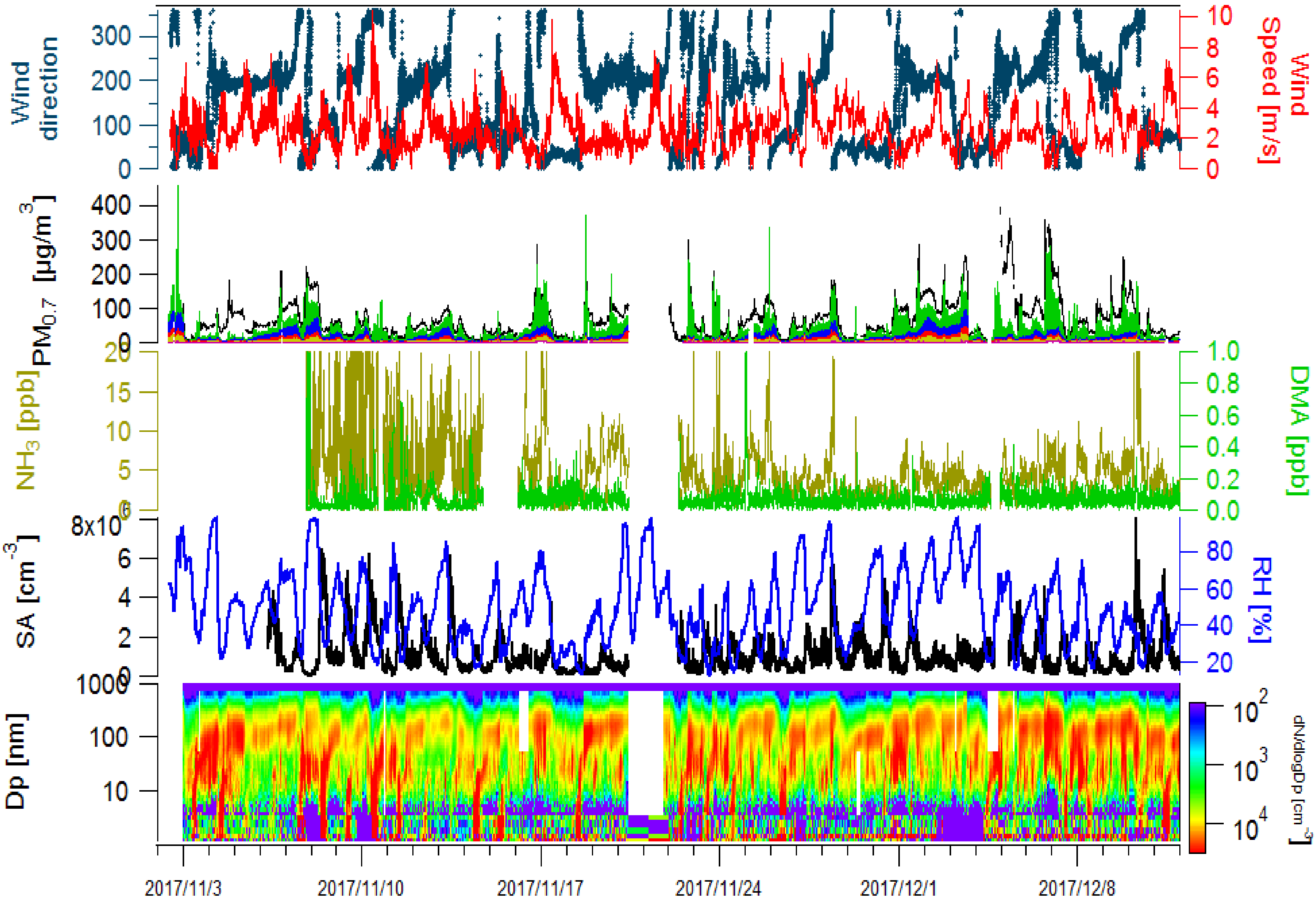
Current techniques for atmospheric nucleation studies in China

Instruments and measurement parameters in field observation

Instrument	Measurement parameter	Size range (nm)	Application in China	Reference*
ID-CIMS	Sulfuric acid	——	Beijing	(Zheng et al., 2011)
HRToF-CIMS	Ammonia and amine	——	Nanjing	(Zheng et al., 2015)
APi-TOF-MS	Ion and cluster	——	——	——
Cluster-CIMS	Neutral molecular cluster	~ 1	——	——
NAIS	Particle and ion number size distribution	0.8-42	Xianghe	(Wang et al., in preparation)
AIS	Ion number size distribution	0.8-42	Nanjing	(Herrmann et al., 2014)
PSM	Particle number concentration	1-1000	Shanghai	(Xiao et al., 2015)
SMPS/DMPS	Particle number size distribution	3-800	Beijing	(Wehner et al., 2004)
DEG-SMPS	Particle number size distribution	1-50	——	(Jiang et al., 2011b)
Nano-CCNC	Hygroscopicity	2-10	——	——
CPCB	Water / butanol affinity	2-10	——	——
Nano-H/V-TDMA	Hygroscopicity / volatility	4-10	——	——
TD-CIMS	Size-resolved chemical composition	6-20	——	——
HR-ToF-AMS	Size-resolved chemical composition	Submicron	Beijing	(Huang et al., 2010)
Q-AMS	Size-resolved chemical composition	Submicron	Beijing	(Zhang et al., 2011)

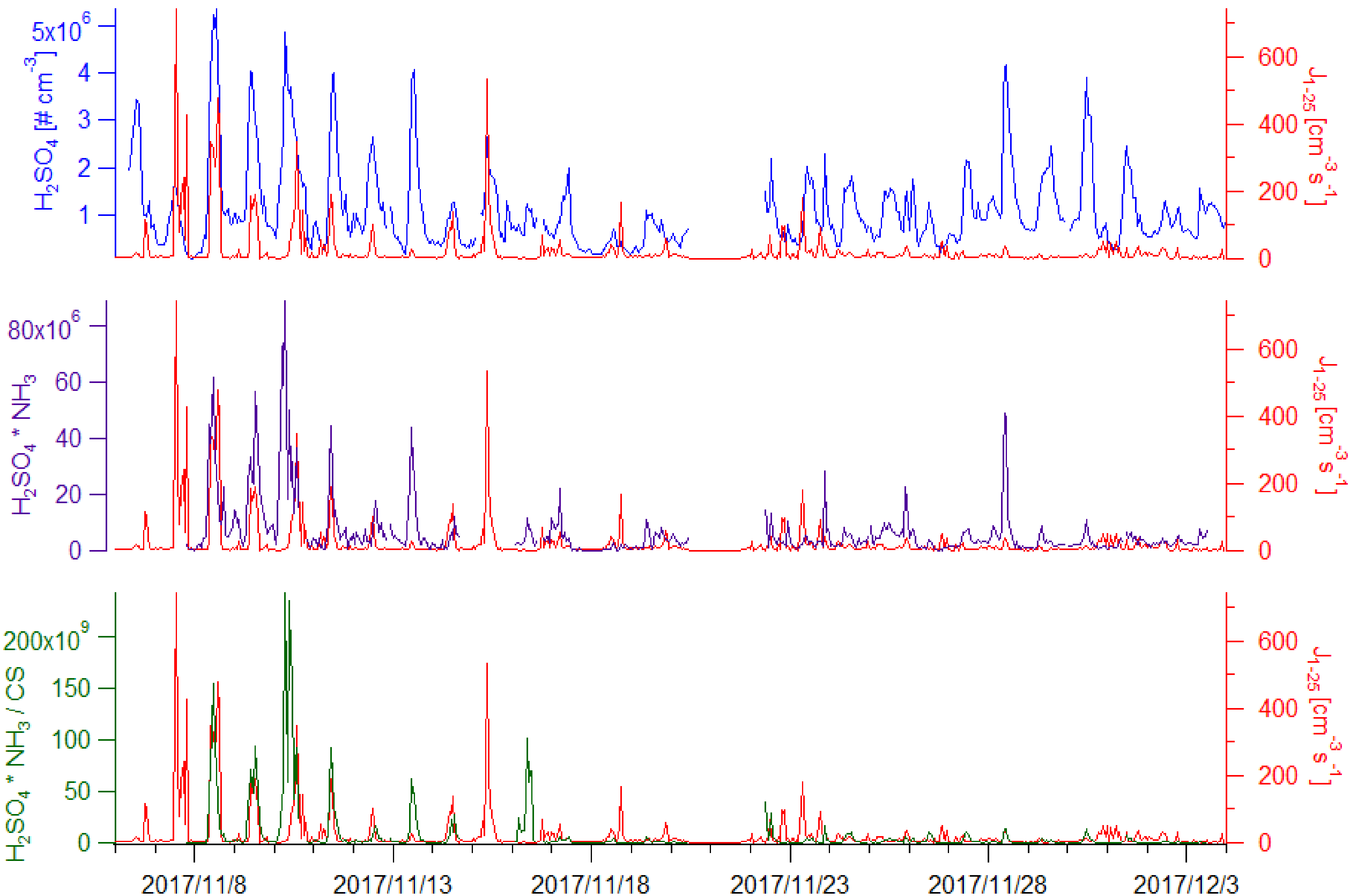
*Note the reference is only referred to the first application in China.

NPF observation at Dezhou

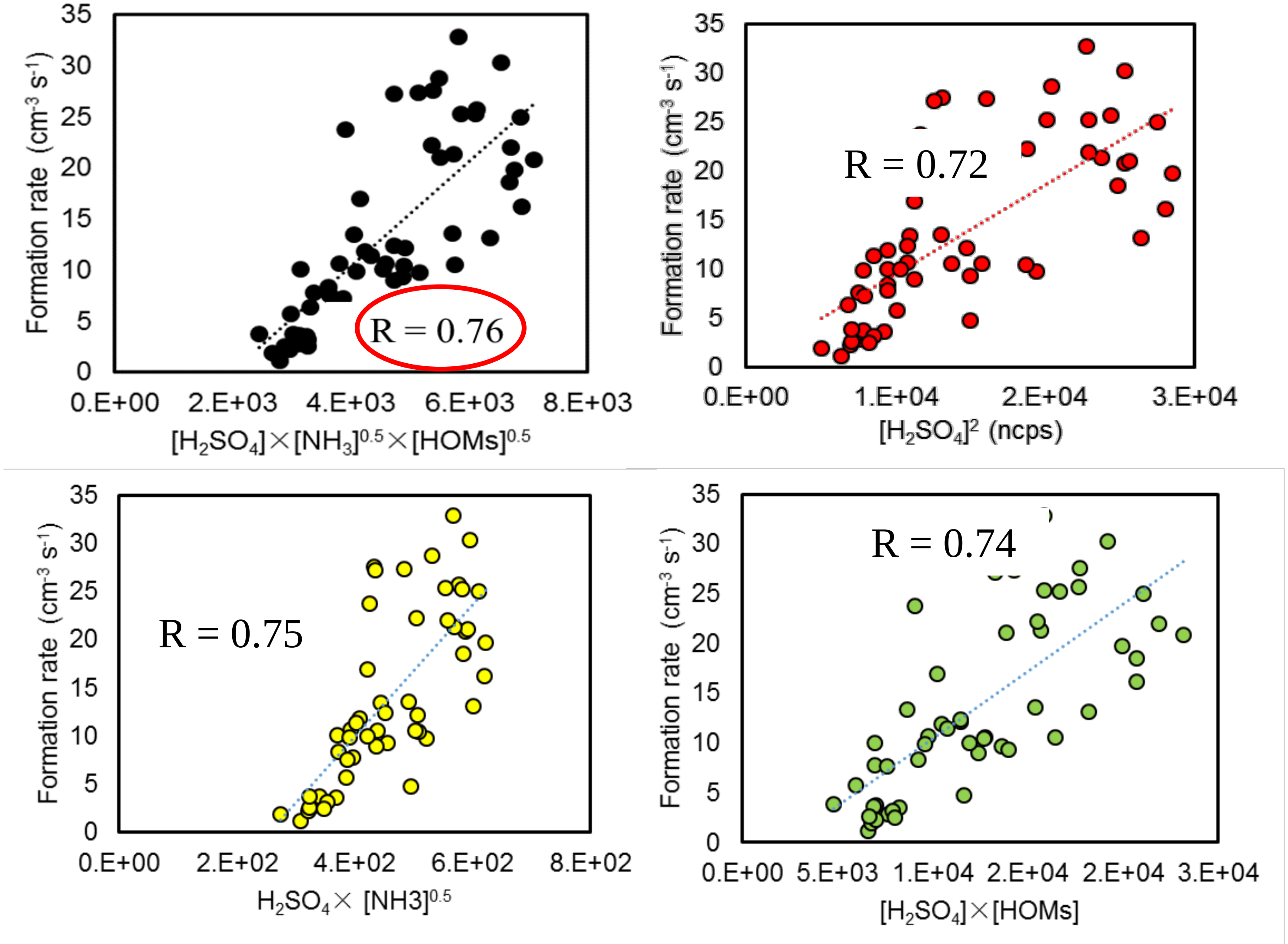


北京大學
PEKING UNIVERSITY

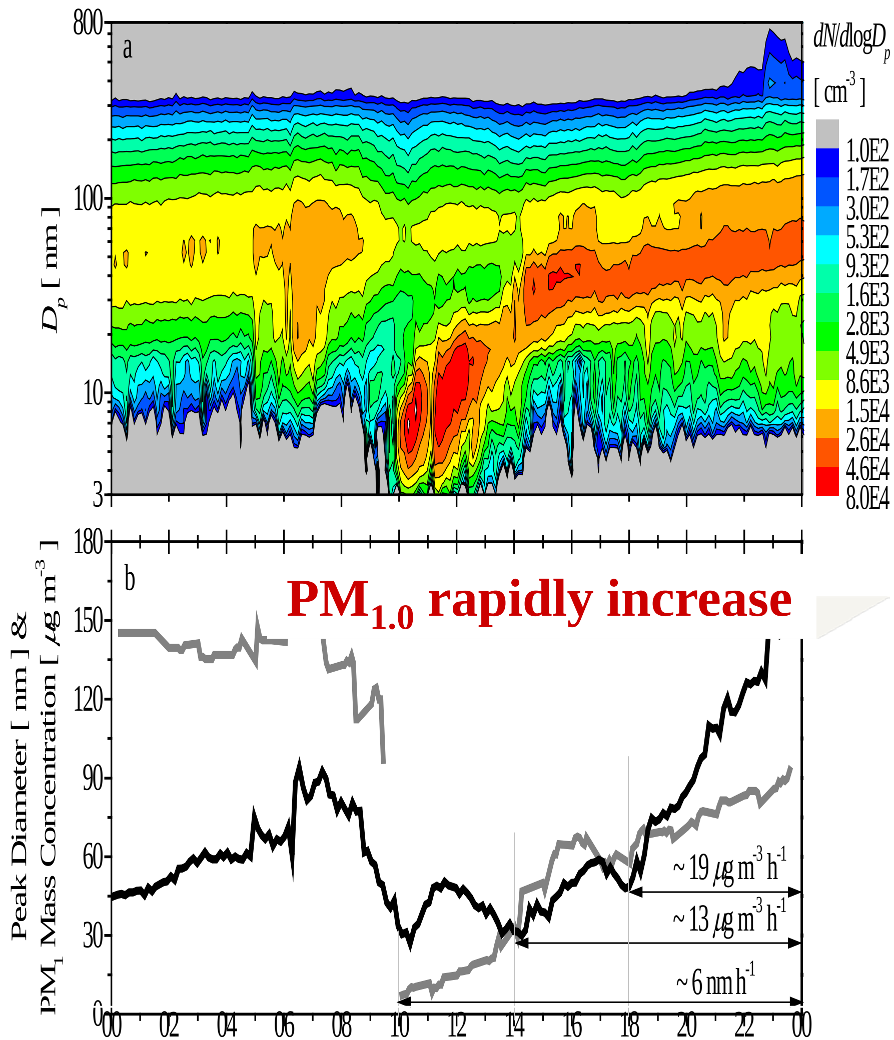
Rich NH_3 and high SA cause NPF



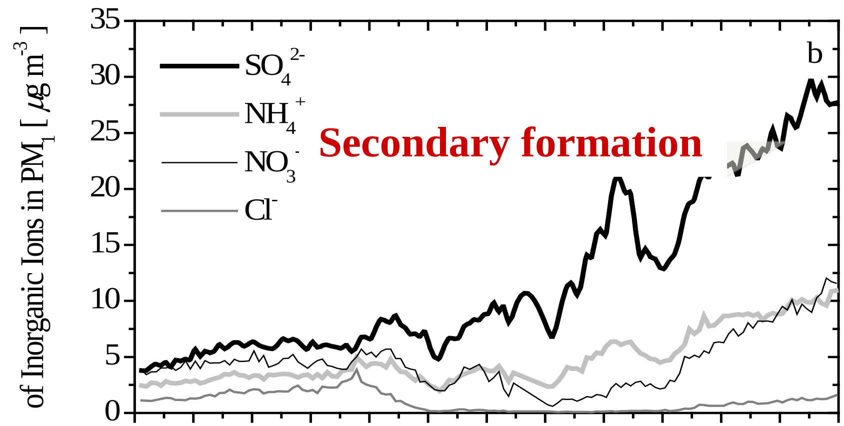
Both NH_3 and HOMs Participate Nucleation

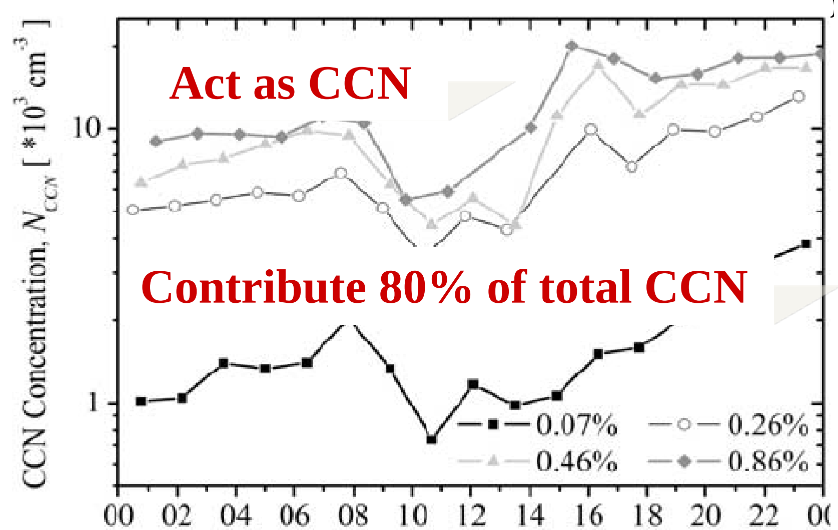


NPF enhanced increase of mass conc. Secondary formation and CCN activity



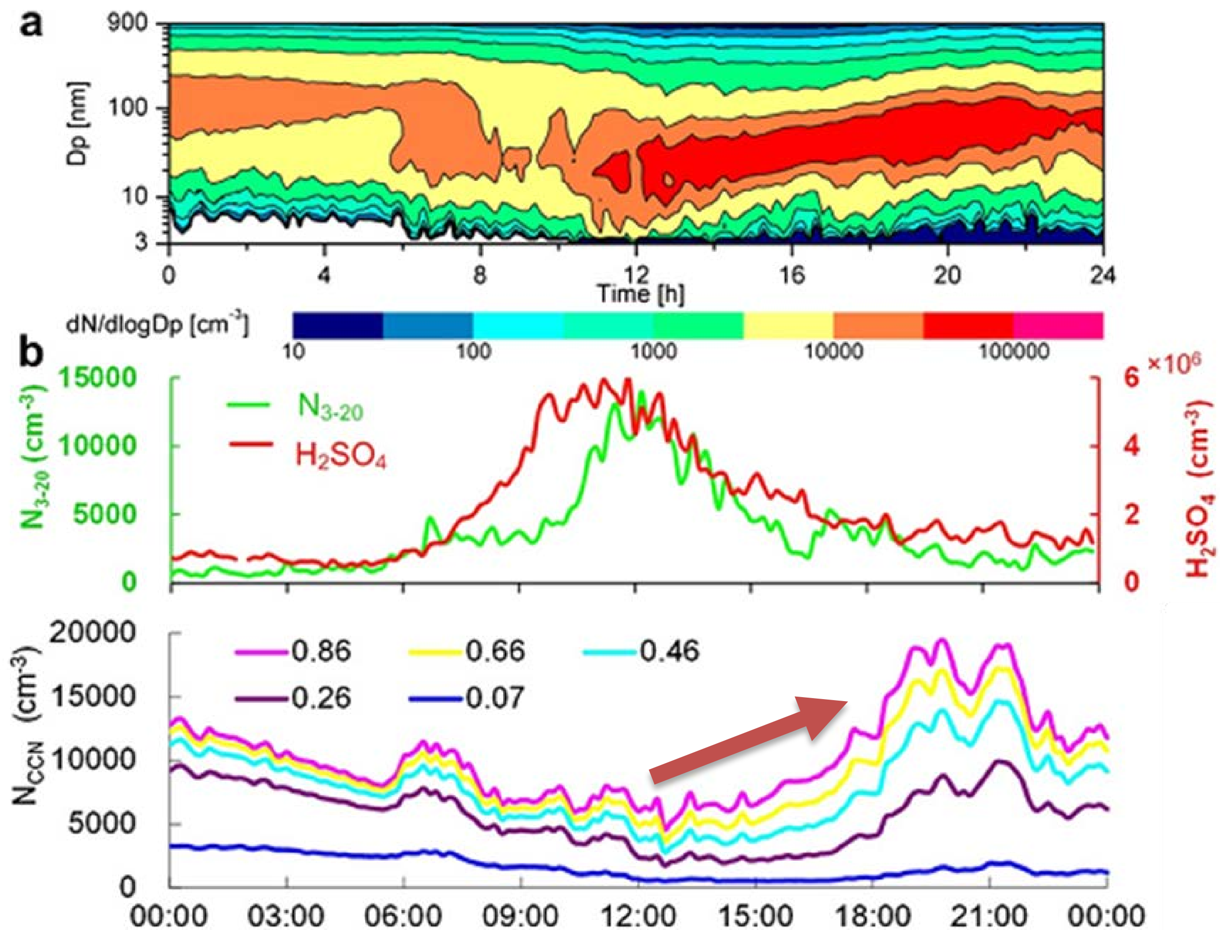
Carebeijing 2006





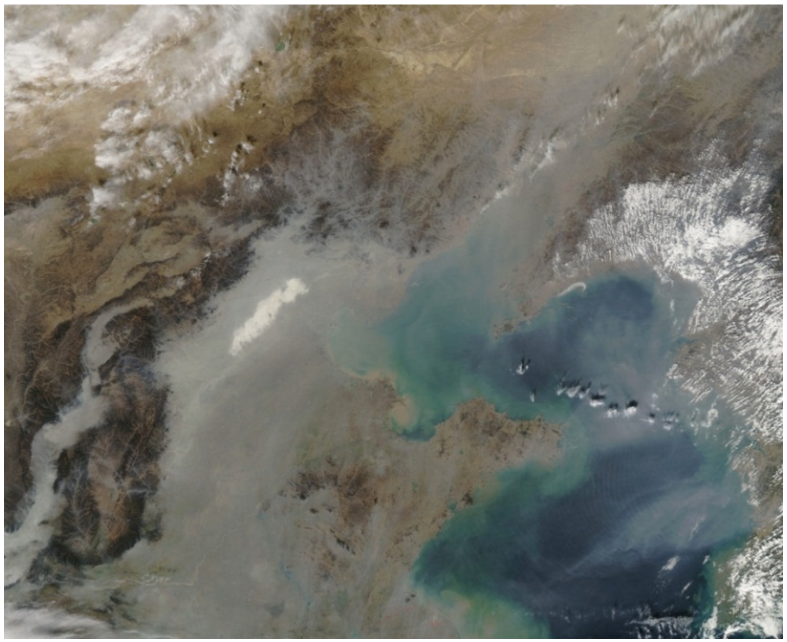
Wiedensohler A *et al*, *J. Geophys. Res.*, 2009

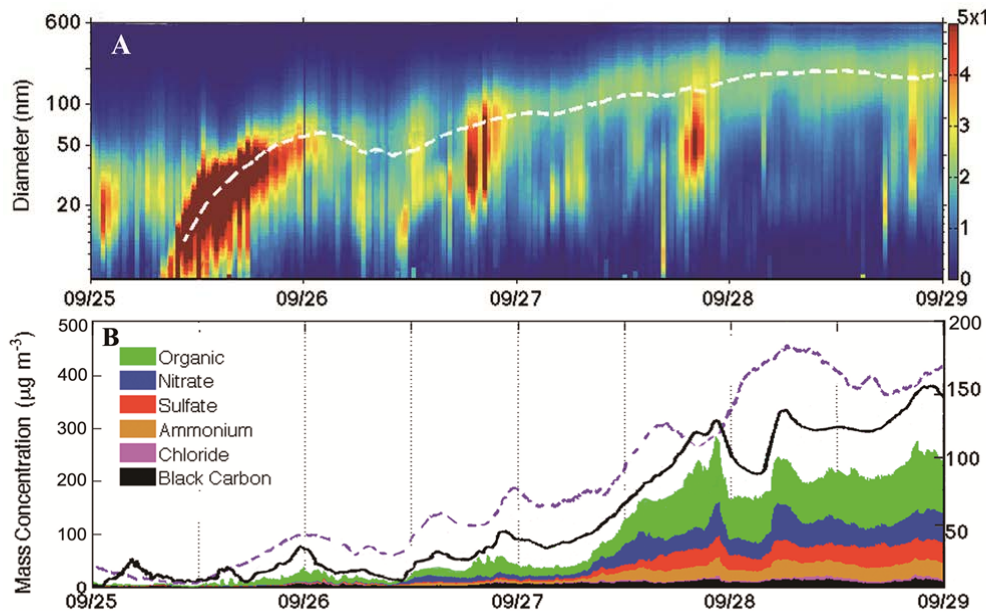
NPF contributes to CCN



- **NPF and growth increased CCN concentration 0.4~6 times in Beijing, 0.3~0.9 in Shanghai (Leng et al., 2014)**
- **NPF contributions to CCN te related with NPF growth** (Yue et al., 2011)

Regional Complex Air Pollution in China



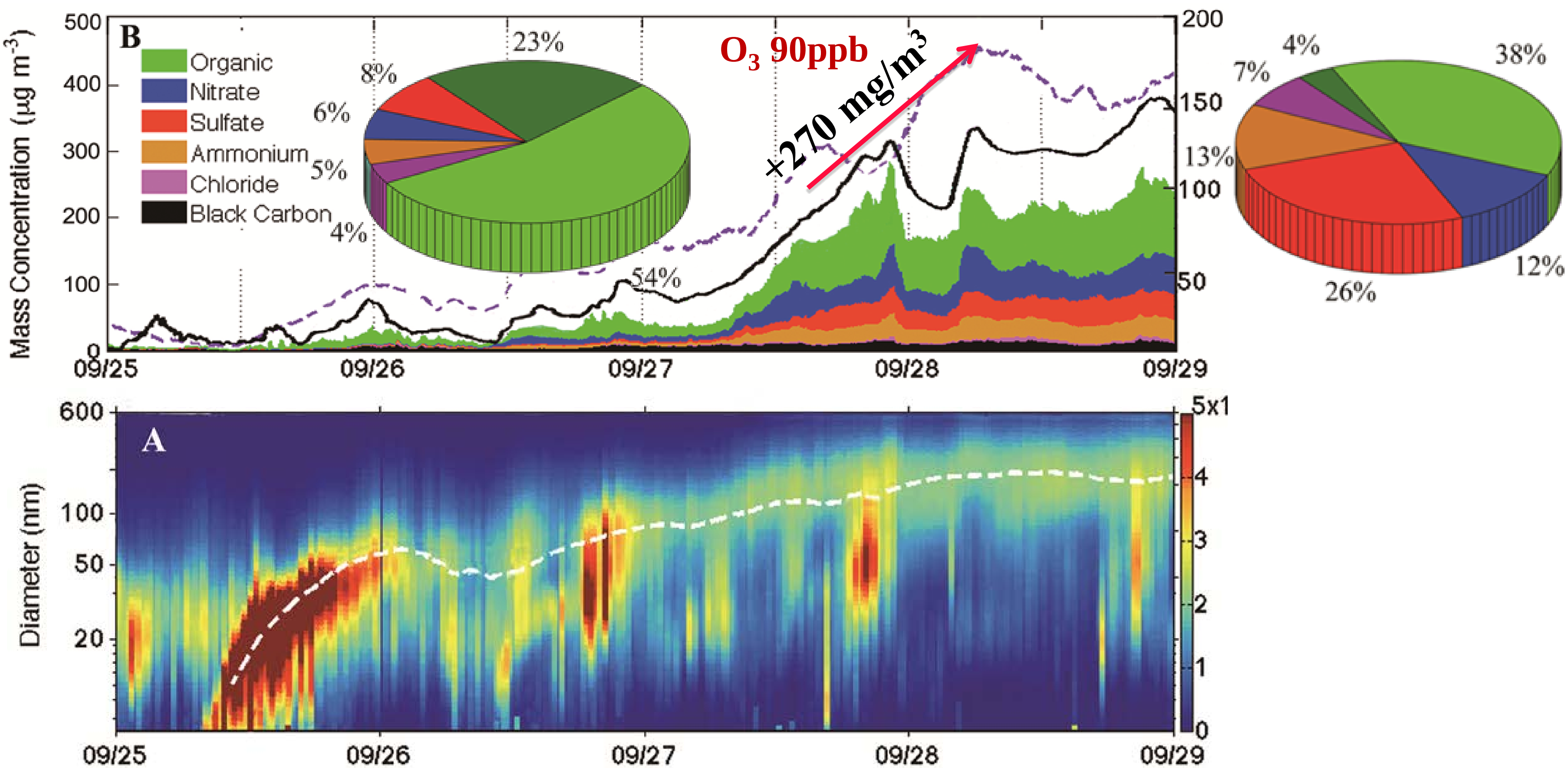


It has the characteristics of wide range of **$PM_{2.5}$** pollution, long duration, serious air pollution and rapid accumulation of pollutants.

(Guo S, Hu M, Zamroa, M.L, Peng J. et al. ***PNAS***, 2014)

北京大学
PEKING UNIVERSITY

$PM_{2.5}$ increased from 10 μg/m^3 to 360 μg/m^3



Guo S, Hu M*,… Zhang R Y*, *PNAS*, 2014

Focus on haze in Beijing areas

PNAS PNAS PNAS PNAS

Elucidating severe urban haze formation in China

Song Guo[a,b], Min Hu[a,1], Misti L. Zamora[b], Jianfei Peng[a], Dongjie Shang[a], Jing Zheng[a], Zhuofei Du[a], Zhijun Wu[a], Min Shao[a], Limin Zeng[a], Mario J. Molina[c,1], and Renyi Zhang[a,b,1]

[a]State Key Joint Laboratory of Environmental Simulation and Pollution Control, College of Environmental Sciences and Engineering, Peking University, Beijing 100871, China; [b]Departments of Atmospheric Sciences and Chemistry, Center for the Atmospheric Chemistry and the Environment, Texas A&M University, College Station, TX 77843; and [c]Department of Chemistry and Biochemistry, University of California, San Diego, La Jolla, CA 92093

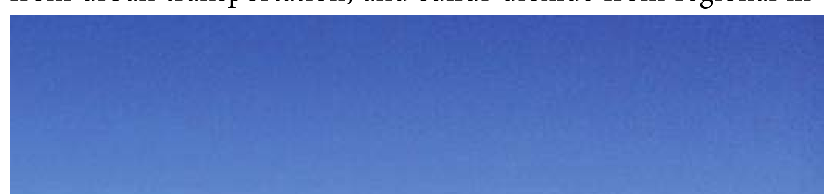
Contributed by Mario J. Molina, October 13, 2014 (sent for review September 9, 2014)

As the world's second largest economy, China has experienced severe haze pollution, with fine particulate matter (PM) recently reaching unprecedentedly high levels across many cities, and an understanding of the PM formation mechanism is critical in the development of efficient mediation policies to minimize its regional to global impacts. We demonstrate a periodic cycle of PM episodes in Beijing that is governed by meteorological conditions and characterized by two distinct aerosol formation processes of nucleation and growth, but with a small contribution from primary emissions and regional transport of particles. Nucleation consistently precedes a polluted period, producing a high number concentration of nano-sized particles under clean conditions. Accumulation of the particle mass concentration exceeding several hundred micrograms per cubic meter is accompanied by a continuous size growth from the nucleation-mode particles over multiple days to yield numerous larger particles, distinctive from the aerosol formation typically observed in other regions worldwide. The particle compositions in Beijing, on the other hand, exhibit a similarity to those commonly measured in many global areas, consistent with the chemical constituents dominated by secondary aerosol formation. Our results highlight that regulatory controls of gaseous emissions for volatile organic compounds and nitrogen oxides from local transportation and sulfur dioxide from regional industrial sources represent the key steps to reduce the urban PM level in China.

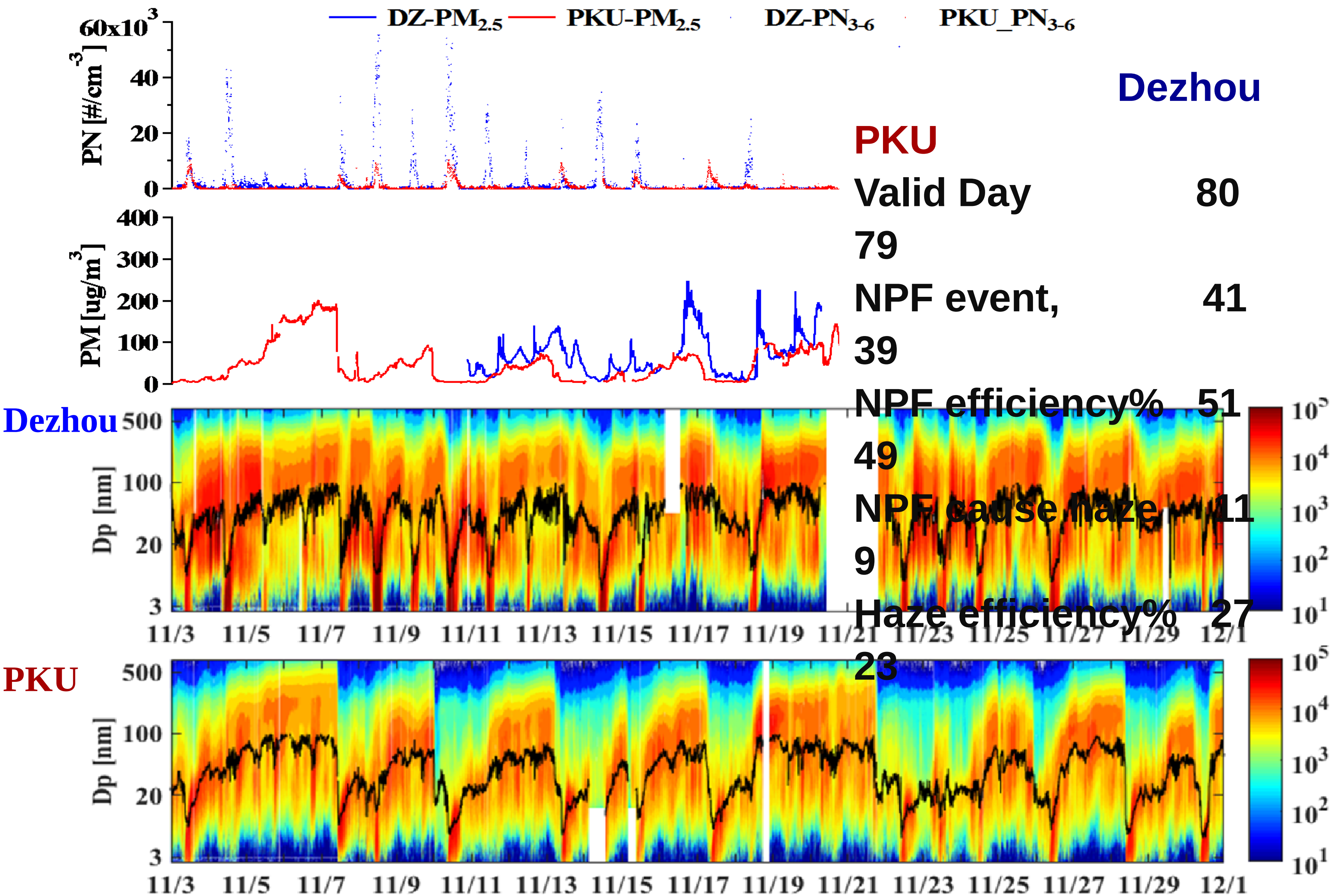
pollution | $PM_{2.5}$ | China | nucleation | secondary aerosols

Factors tied to extreme Beijing haze

China has recently experienced severe increases in urban haze pollution due to fine particulate matter (PM), which has reached unprecedented levels in many of its cities. Researchers seek to better understand the mechanisms of PM formation, a critical public health threat, and devise mitigation strategies to reduce its regional and global impacts. Focusing on the nation's capital, Song Guo et al. (pp. 17373–17378) found that meteorological conditions in Beijing drive a periodic cycle of PM episodes characterized by two distinct processes of aerosol nucleation and growth. According to the authors, Beijing's meteorology, local and surrounding emissions, and aerosol processes combine to produce extremely polluted conditions, although the chemical composition of airborne particles in the city is similar to many other population centers worldwide. Volatile organic compounds, nitrogen oxides from urban transportation, and sulfur dioxide from regional in-



NPF in the winter of Beijing and surrounding areas



Dezhou

PKU

Valid Day 80
79

NPF event, 41
39

NPF efficiency% 51
49

NPF cause haze 11
9

Haze efficiency% 27
23

Future directions

- For depth understanding of particle nucleation long-term continuous measurements and comprehensive observations utilizing the full capacity of the highly selective instruments are required.
- Integrating field campaign, laboratory experiments and model simulations is enable a more comprehensive view of chemical and physical processes of secondary aerosol formation.
- we should also focus attention on their impacts on the environment and climate. Such complete evaluation would be extremely important to address the actual environmental problems.

北京大學
PEKING UNIVERSITY

Science of the Total Environment 577 (2017) 258–266

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

ELSEVIER

New particle formation in China: Current knowledge and further directions

CrossMark

Zhibin Wang [a,1], Zhijun Wu [a], Dingli Yue [a,2], Dongjie Shang [a], Song Guo [a], Junying Sun [b], Aijun Ding [c], Lin Wang [d], Jingkun Jiang [e], Hai Guo [f], Jian Gao [g], Hing Cho Cheung [h], Lidia Morawska [i], Melita Keywood [j], Min Hu [a,*]

[a] *State Key Joint Laboratory of Environmental Simulation and Pollution Control, College of Environmental Sciences and Engineering, Peking University, Beijing 100871, China*
[b] *State Key Laboratory of Severe Weather, Key Laboratory of Atmospheric Chemistry of CMA, Chinese Academy of Meteorological Sciences, Beijing 100081, China*
[c] *Joint International Research Laboratory of Atmospheric and Earth System Sciences, School of Atmospheric Sciences, Nanjing University, Nanjing 210023, China*
[d] *Shanghai Key Laboratory of Atmospheric Particle Pollution and Prevention (LAP^3), Department of Environmental Science and Engineering, Fudan University, Shanghai 200433, China*
[e] *State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, China*
[f] *Air Quality Studies, Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China*
[g] *State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Science, Beijing 100012, China*
[h] *Research Center for Environmental Changes, Academia Sinica, Taipei 11529, Taiwan*
[i] *International Laboratory for Air Quality and Health, Institute of Future Environments, Queensland University of Technology, Brisbane, QLD 4001, Australia*
[j] *CSIRO Oceans & Atmosphere, PMB1, Aspendale, VIC 3195, Australia*

HIGHLIGHTS

- New particle formation has been frequently observed in diverse environments of China, even in a heavily-polluted atmosphere.
- The distinct profiles of particle formation and subsequent growth suggest the nucleation mechanisms should be reconsidered.
- This paper systematically summarizes the recent advances, current bottleneck and future directions in studying NPF in China.

环境科学与工程学院
College of Environmental Sciences and Engineering

北京大學
PEKING UNIVERSITY

Thank you for your attentions

Your comments are welcome!

Min HU 胡 敏
Peking University

Email:
minhu@pku.edu.cn