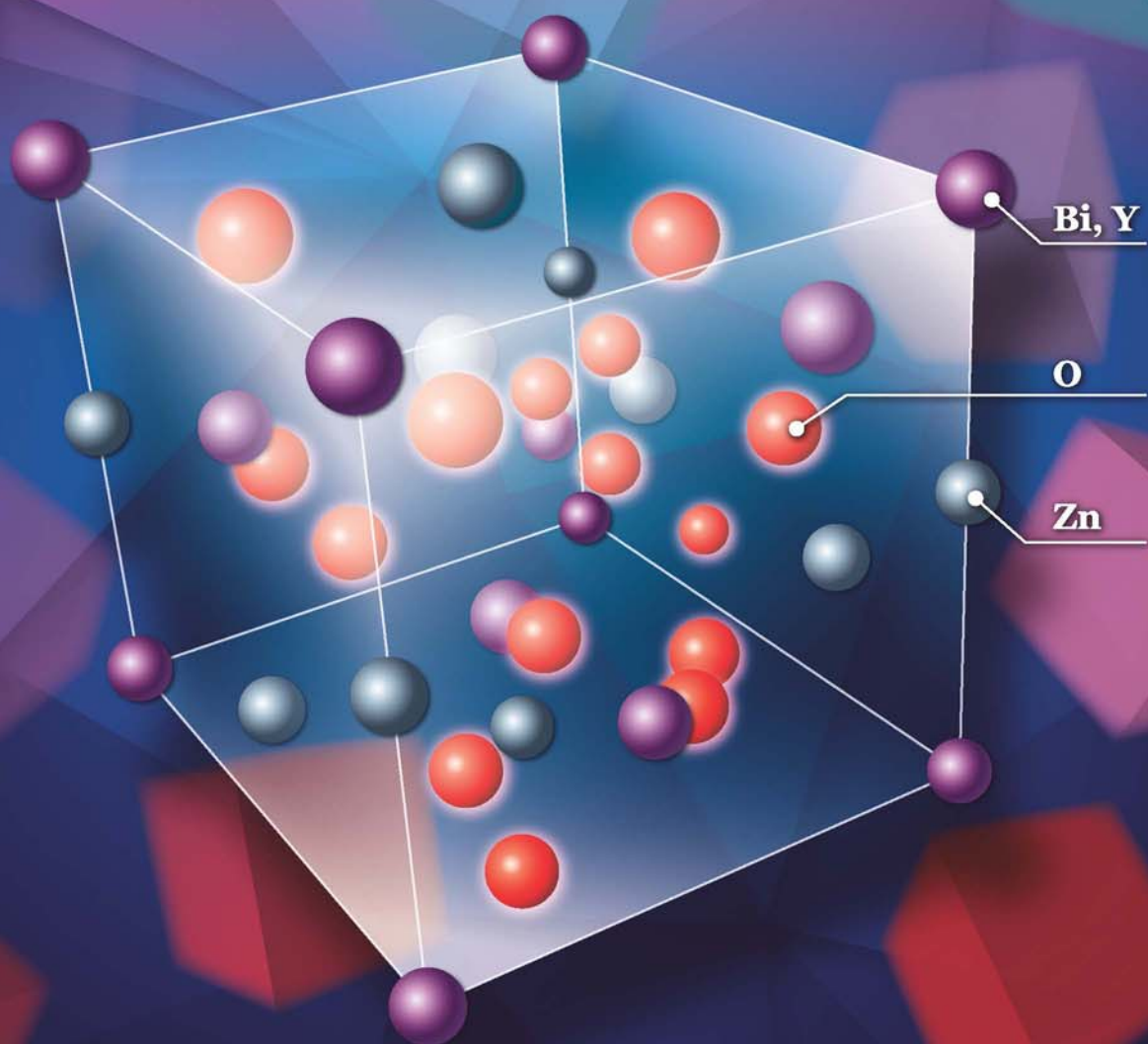


# JES

JOURNAL OF  
ENVIRONMENTAL  
SCIENCES

March 1, 2015 Volume 29  
www.jesc.ac.cn

ISSN 1001-0742  
CN 11-2629/X



Sponsored by  
Research Center for Eco-Environmental Sciences  
Chinese Academy of Sciences

- 1 A settling curve modeling method for quantitative description of the dispersion stability of carbon nanotubes in aquatic environments  
Lixia Zhou, Dunxue Zhu, Shujuan Zhang and Bingcai Pan
- 11 Antimony leaching release from brake pads: Effect of pH, temperature and organic acids  
Xingyun Hu, Mengchang He and Sisi Li
- 18 Molecular diversity of arbuscular mycorrhizal fungi at a large-scale antimony mining area in southern China  
Yuan Wei, Zhipeng Chen, Fengchang Wu, Hong Hou, Jining Li, Yuxian Shangguan, Juan Zhang, Fasheng Li and Qingru Zeng
- 27 Elevated CO<sub>2</sub> facilitates C and N accumulation in a rice paddy ecosystem  
Jia Guo, Mingqian Zhang, Xiaowen Wang and Weijian Zhang
- 34 Characterization of odorous charge and photochemical reactivity of VOC emissions from a full-scale food waste treatment plant in China  
Zhe Ni, Jianguo Liu, Mingying Song, Xiaowei Wang, Lianhai Ren and Xin Kong
- 45 Comparison between UV and VUV photolysis for the pre- and post-treatment of coking wastewater  
Rui Xing, Zhongyuan Zheng and Donghui Wen
- 51 Synthesis, crystal structure, photodegradation kinetics and photocatalytic activity of novel photocatalyst ZnBiYO<sub>4</sub>  
Yanbing Cui and Jingfei Luan
- 62 Sources and characteristics of fine particles over the Yellow Sea and Bohai Sea using online single particle aerosol mass spectrometer  
Huaiyu Fu, Mei Zheng, Caiqing Yan, Xiaoying Li, Huiwang Gao, Xiaohong Yao, Zhigang Guo and Yuanhang Zhang
- 71 Flower-, wire-, and sheet-like MnO<sub>2</sub>-deposited diatomites: Highly efficient absorbents for the removal of Cr(VI)  
Yucheng Du, Liping Wang, Jinshu Wang, Guangwei Zheng, Junshu Wu and Hongxing Dai
- 82 Methane and nitrous oxide emissions from a subtropical coastal embayment (Moreton Bay, Australia)  
Ronald S. Musenze, Ursula Werner, Alistair Grinham, James Udy and Zhiguo Yuan
- 97 Insights on the solubilization products after combined alkaline and ultrasonic pre-treatment of sewage sludge  
Xinbo Tian, Chong Wang, Antoine Prandota Trzcinski, Leonard Lin and Wun Jern Ng
- 106 Phosphorus recovery from biogas fermentation liquid by Ca-Mg loaded biochar  
Ci Fang, Tao Zhang, Ping Li, Rongfeng Jiang, Shubiao Wu, Haiyu Nie and Yingcai Wang
- 115 Characterization of the archaeal community fouling a membrane bioreactor  
Jinxue Luo, Jinsong Zhang, Xiaohui Tan, Diane McDougald, Guoqiang Zhuang, Anthony G. Fane, Staffan Kjelleberg, Yehuda Cohen and Scott A. Rice
- 124 Effect of six kinds of scale inhibitors on calcium carbonate precipitation in high salinity wastewater at high temperatures  
Xiaochen Li, Baoyu Gao, Qinyan Yue, Defang Ma, Hongyan Rong, Pin Zhao and Pengyou Teng
- 131 Experimental and molecular dynamic simulation study of perfluorooctane sulfonate adsorption on soil and sediment components  
Ruiming Zhang, Wei Yan and Chuanyong Jing
- 139 A fouling suppression system in submerged membrane bioreactors using dielectrophoretic forces  
Alaa H. Hawari, Fei Du, Michael Baune and Jorg Thöming

*(continued on inside back cover)*

## CONTENTS

- 146 A 1-dodecanethiol-based phase transfer protocol for the highly efficient extraction of noble metal ions from aqueous phase  
Dong Chen, Penglei Cui, Hongbin Cao and Jun Yang
- 151 Intracellular biosynthesis of Au and Ag nanoparticles using ethanolic extract of *Brassica oleracea* L. and studies on their physicochemical and biological properties  
Palaniselvam Kuppusamy, Solachuddin J.A. Ichwan, Narasimha Reddy Parine, Mashitah M. Yusoff, Gaanty Pragas Maniam and Natanamurugaraj Govindan
- 158 Forecasting of dissolved oxygen in the Guanting reservoir using an optimized NGBM (1,1) model  
Yan An, Zhihong Zou and Yanfei Zhao
- 165 Individual particle analysis of aerosols collected at Lhasa City in the Tibetan Plateau  
Bu Duo, Yunchen Zhang, Lingdong Kong, Hongbo Fu, Yunjie Hu, Jianmin Chen, Lin Li and A. Qiong
- 178 Design and demonstration of a next-generation air quality attainment assessment system for PM<sub>2.5</sub> and O<sub>3</sub>  
Hua Wang, Yun Zhu, Carey Jang, Che-Jen Lin, Shuxiao Wang, Joshua S. Fu, Jian Gao, Shuang Deng, Junping Xie, Dian Ding, Xuezhen Qiu and Shicheng Long
- 189 Soil microbial response to waste potassium silicate drilling fluid  
Linjun Yao, M. Anne Naeth and Allen Jobson
- 199 Enhanced catalytic complete oxidation of 1,2-dichloroethane over mesoporous transition metal-doped  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>  
Abbas Khaleel and Muhammad Nawaz
- 210 Role of nitric oxide in the genotoxic response to chronic microcystin-LR exposure in human-hamster hybrid cells  
Xiaofei Wang, Pei Huang, Yun Liu, Hua Du, Xinan Wang, Meimei Wang, Yichen Wang, Tom K. Hei, Lijun Wu and An Xu

Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

ScienceDirect

[www.journals.elsevier.com/journal-of-environmental-sciences](http://www.journals.elsevier.com/journal-of-environmental-sciences)JOURNAL OF  
ENVIRONMENTAL  
SCIENCES[www.jesc.ac.cn](http://www.jesc.ac.cn)

## Sources and characteristics of fine particles over the Yellow Sea and Bohai Sea using online single particle aerosol mass spectrometer

Huaiyu Fu<sup>1,2</sup>, Mei Zheng<sup>2,\*</sup>, Caiqing Yan<sup>2</sup>, Xiaoying Li<sup>2</sup>, Huiwang Gao<sup>3</sup>, Xiaohong Yao<sup>3</sup>, Zhigang Guo<sup>1,\*</sup>, Yuanhang Zhang<sup>2</sup>

1. Shanghai Key Laboratory of Atmospheric Particle Pollution and Prevention, Department of Environmental Science and Engineering, Fudan University, Shanghai 200433, China. E-mail: [fuhuaiyu2006@163.com](mailto:fuhuaiyu2006@163.com)

2. State Key Joint Laboratory of Environmental Simulation and Pollution Control, College of Environmental Sciences and Engineering, Peking University, Beijing 100871, China

3. Key Laboratory of Marine Environment and Ecology, Ministry of Education, Ocean University of China, Qingdao 266100, China

### ARTICLE INFO

#### Article history:

Received 5 May 2014

Revised 10 September 2014

Accepted 16 September 2014

Available online 30 January 2015

#### Keywords:

Source apportionment

Marine aerosol

Size and chemical composition

SPAMS

East China Sea

### ABSTRACT

Marine aerosols over the East China Seas are heavily polluted by continental sources. During the Chinese Comprehensive Ocean Experiment in November 2012, size and mass spectra of individual atmospheric particles in the size range from 0.2 to 2.0  $\mu\text{m}$  were measured on board by a single particle aerosol mass spectrometer (SPAMS). The average hourly particle number (PN) was around  $4560 \pm 3240$  in the South Yellow Sea (SYS),  $2900 \pm 3970$  in the North Yellow Sea (NYS), and  $1700 \pm 2220$  in the Bohai Sea (BS). PN in NYS and BS varied greatly over 3 orders of magnitude, while that in SYS varied slightly. The size distributions were fitted with two log-normal modes. Accumulation mode dominated in NYS and BS, especially during episodic periods. Coarse mode particles played an important role in SYS. Particles were classified using an adaptive resonance theory based neural network algorithm (ART-2a). Six particle types were identified with secondary-containing, aged sea-salt, soot-like, biomass burning, fresh sea-salt, and lead-containing particles accounting for 32%, 21%, 18%, 16%, 4%, and 3% of total PN, respectively. Aerosols in BS were relatively enriched in particles from anthropogenic sources compared to SYS, probably due to emissions from more developed upwind regions and indicating stronger influence of continental outflow on marine environment. Variation of source types depended mainly on origins of transported air masses. This study examined rapid changes in PN, size distribution and source types of fine particles in marine atmospheres. It also demonstrated the effectiveness of high-time-resolution source apportionment by ART-2a.

© 2015 The Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences.

Published by Elsevier B.V.

### Introduction

Marine aerosols can affect climate directly, through scattering and absorbing solar radiation, and indirectly by acting as cloud

condensation nuclei. The marine atmosphere adjacent to large urban and industrial centers can be strongly impacted by continental emissions with high loading of pollutants (Arndt et al., 1997; Streets et al., 2001). Mixed marine aerosols can transport

\* Corresponding authors. E-mail: [mzheng@pku.edu.cn](mailto:mzheng@pku.edu.cn) (Mei Zheng), [guozgg@fudan.edu.cn](mailto:guozgg@fudan.edu.cn) (Zhigang Guo).



and deposit into the upper ocean, leading to changes in nutrient supply and marine primary productivity, such as Fe fertilization (Martin and Fitzwater, 1988), and toxic effects by Cu (Paytan et al., 2009) and polycyclic aromatic hydrocarbons (Murphy et al., 2009).

The East China Seas (ECSs), as one of the largest marginal seas in the world, are transitional zones through which pollutants can be transported from continent to ocean. There have been a number of studies on marine aerosols over ECSs including size distribution (Lin et al., 2007; Kim et al., 2009), spatial distribution (Hu et al., 2003), source identification of marine aerosols (Nakamura et al., 2006; Yang et al., 2009), effects of Asian dust (Zhang and Gao, 2007; Geng et al., 2009), as well as deposition fluxes of elements (Chen et al., 2010). However, previous studies were mostly conducted using offline filter sampling methods, which were limited by low time resolution. It is very common that sampling time is required to last for 12 hr or even 3 or 4 days to reach detection limits for offline filter analysis (Zhang et al., 2007), while the characteristics of marine aerosols can change rapidly within several hours. Therefore, high-time-resolution measurement is important and necessary to study quick changes of sources and compositions of aerosols over the ECSs.

In recent years, online aerosol time-of-flight mass spectrometry (ATOFMS) has been able to provide size and chemical information of single particles in marine environments (Sullivan and Prather, 2007; Spencer et al., 2008). There have been a few studies in China examining chemical composition (Zhang et al., 2012), aerosol sources (Bi et al., 2011), mixing state (Zhang et al., 2013), and source profile of urban aerosols (Li et al., 2012) using single particle mass spectrometry. However, to the best of our knowledge, this is the first work to study marine aerosols using a newly developed single particle aerosol mass spectrometer (SPAMS 0515, Guangzhou Hexin Analytical Instrument Co., Ltd., Guangzhou, China). This study aims to understand the rapid variation of fine particle compositions and sources and the influence of land emissions on the offshore marine atmosphere in the ECSs.

## 1. Experimental

### 1.1. Study area

During the Chinese Comprehensive Ocean Experiment in 2012 by R/V “Dong Fang Hong 2” of Ocean University of China, aerosol measurement using SPAMS on board was carried out in the Yellow Sea (YS) (N 31°98′04″–38°74′75″, E 120°30′44″–124°49′62″) and BS (N 37°72′05″–39°54′78″, E 118°95′41″–120°92′62″) during 2–20 November 2012. Ship tracks are shown in Fig. 1. The aerosol instrument was housed in a laboratory located on the third level and left side of the vessel with an inlet (approximately 10 m above sea level) connecting the instrument to the outside of the laboratory to sample marine aerosols.

### 1.2. Online aerosol sampling

#### 1.2.1. SPAMS

The method for particle collection by SPAMS has been described by Li et al. (2011). Briefly, particles were dried using a sequential 30-cm diffusion dryer filled with silica gel and introduced into SPAMS through a critical orifice. They were focused and accelerated to specific velocities, which were determined by their flight time through two continuous diode Nd:YAG (neodymium: yttrium aluminum garnet) laser beams (532 nm) in the sizing region. The particles were subsequently desorbed/ionized by a pulsed laser (266 nm) triggered exactly based on the

velocity of the specific particle. Particles were sampled with a flow rate of about 80 mL/min. Ionizing laser energy and the irradiance (power density) of the laser desorption/ionization (LDI) was kept at about 0.5–0.6 mJ and  $1.06 \times 10^8$  W/cm<sup>2</sup>, respectively. Polystyrene latex sphere (PSL) particles with aerodynamic diameter of 0.2, 0.3, 0.5, 0.72, 1.0, 1.3, and 2.0 μm were used for size calibration.

#### 1.2.2. Data analysis

The data collected when the research vessel was anchored for other research activities were excluded from analysis to avoid self-contamination. SPAMS can provide size and mass spectral information of individual particles with aerodynamic diameter ranging from 0.2 to 2.0 μm at the same time, however, not all particles that are sized can have mass spectra collected. Overall, approximately 1 million particles with size information and 162,000 particles with mass spectral information were collected. “Particle number” in the following text refers to the number of particles with size information every hour. Particle mass spectral information was imported into MATLAB (The Mathworks Inc.) and analyzed using YAADA (V2.1, <http://www.yaada.org>). Individual particles were classified into different groups or clusters using ART-2a based on the similarity of mass spectra (presence and intensity of ions) with a vigilance factor of 0.7, learning rate of 0.05, and 20 iterations (Hopke and Song, 1997; Song et al., 1999). A total of 195 clusters representing more than 97% of all particles were clustered by ART-2a, and then six particle types were manually grouped based on spectral similarities. It should be noted that SPAMS in this study gives apportionment by particle number instead of particle mass. Particle number provides an indication of their relative abundance rather than the absolute mass concentration, as the laser-desorption ionization technique is a non-quantitative method (Gross et al., 2000). However, a good linear correlation between particle number from SPAMS and particle mass concentration has been found for particles collected in Beijing (Fu et al., 2014).

#### 1.2.3. Identification of particle types

The major marker ions used to identify different particle types were shown in Table 1. The rules used are as follows: (1) sodium-containing particles were classified as sea-salt particles. The ratio of the relative intensities of  $m/z$  (mass to charge ratio) 23[Na]<sup>+</sup> and  $m/z$  39[K]<sup>+</sup> in the spectra was compared to that of seawater using the empirical relative sensitivity factor to confirm the sea-salt particle designation (Gross et al., 2000; Gard et al., 1998). These particles were then subdivided into fresh and aged sea-salt particles depending on the extent of mixing with secondary inorganic ions; (2) particles containing elemental carbon chain ions (extending from  $m/z$  12[C]<sup>+</sup> to  $m/z$  144[C<sub>12</sub>]<sup>+</sup> in the positive ion spectrum and  $m/z$  12[C]<sup>-</sup> to  $m/z$  156[C<sub>13</sub>]<sup>-</sup> in the negative ion spectrum) and fewer organic ions were classified as soot-like particles; (3) particles with clear ions of potassium, organic matter, ammonium, and fewer elemental carbon ions were classified as biomass burning particles; (4) particles with abundant secondary ions ( $m/z$  -80[SO<sub>3</sub>]<sup>-</sup>, -97[HSO<sub>4</sub>]<sup>-</sup>, -46[NO<sub>2</sub>]<sup>-</sup>, -62[NO<sub>3</sub>]<sup>-</sup>, 18[NH<sub>4</sub>]<sup>+</sup>) were classified as secondary-containing particles; (5) particles with ions of [Pb]<sup>+</sup> ( $m/z$  206 or 207 or 208) were classified as lead-containing particles; and (6) particles other than the above types were classified as “other particles”; only about 4%

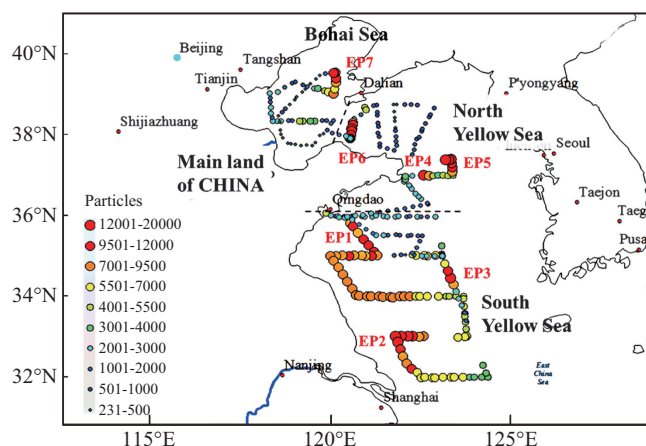


Fig. 1 – Spatial distribution of measured hourly particle number (0.2–2.0  $\mu\text{m}$ ).

of total particles were present in this type. Therefore, particle types in this study include fresh sea-salt, aged sea-salt, soot-like, biomass burning, secondary-containing, lead-containing and other particles.

### 1.3. Meteorological data

One-second resolution data for wind speed and wind direction were recorded during the cruise by the automatic weather station on board. Air mass back-trajectories were calculated using the NOAA HYSPLIT4 model (<http://www.arl.noaa.gov/ready/hysplit4.html>). Meteorological data in the model were obtained from the NOAA FNL archives.

## 2. Results and discussion

### 2.1. Spatial and size distribution of fine particles

Total particle number (in the size range of 0.2–2.0  $\mu\text{m}$ , 1 hr resolution) measured by SPAMS during this study is shown in Fig. 1. A total of seven episodes (episode: EP1–7) were

observed during the observation. The highest average hourly particle number was found in SYS (4560  $\pm$  3240), followed by NYS (2900  $\pm$  3970) and BS (1730  $\pm$  2220). Hourly particle number in SYS varied over 2 orders of magnitude, ranging from 270 to 14,000. When hourly particle number is higher than 9000 over a period of 6 hr, it is defined as an episode. Three particle episodes (EP1–3) were observed in SYS. Hourly particle number during three episodes ranged from 9200 to 14,000, which were about 4–6 fold that during non-episodic periods (3700) in open ocean regions. Hourly particle number in coastal regions during non-episodic periods remained at a level of 7700  $\pm$  2560, suggesting a strong influence on coastal marine aerosols from continental sources. Hourly particle number over NYS and BS ranged from 80 to 19,800, varying over 3 orders of magnitude. A total of four episodes (EP4–7) were observed in NYS and BS. Hourly particle numbers during four episodes ranged from 6030 to 19,800, which were about 5–16 fold that during non-episodic periods (1157). These episodes were all associated with strong wind speed (13  $\pm$  1, 16  $\pm$  1, 11  $\pm$  1, 13  $\pm$  2 m/sec in EP4–7, respectively). Under high wind speed, long-range transport of continental emissions and marine sources can

Table 1 – Major marker ions for each particle type.

Particle type	Characteristic mass spectral marker ions	References
Fresh sea-salt	$m/z$ 23[Na] <sup>+</sup> , 81/83[Na <sub>2</sub> Cl] <sup>+</sup> , –35/37[Cl] <sup>–</sup> , 24[Mg] <sup>+</sup> , 46[K <sub>2</sub> ] <sup>+</sup> , 55[KO] <sup>+</sup> , 62[Na <sub>2</sub> O] <sup>+</sup> , 63[Na <sub>2</sub> OH] <sup>+</sup> , 97[Na <sub>2</sub> ClO] <sup>+</sup> , –16[O] <sup>–</sup> , –17[OH] <sup>–</sup> , –26[CN] <sup>–</sup> , –42[CNO] <sup>–</sup> , –58[NaCl] <sup>–</sup> , –93[NaCl <sub>2</sub> ] <sup>–</sup> , and no nitrate as well as sulfate ions.	Dall'Osto et al. (2004), Guazzotti et al. (2001), Gaston et al. (2011), Pratt et al. (2010)
Aged sea-salt	$m/z$ 23[Na] <sup>+</sup> with nitrate or sulfate ions (e.g., $m/z$ –46[NO <sub>2</sub> ] <sup>–</sup> , –62[NO <sub>3</sub> ] <sup>–</sup> , –97[HSO <sub>4</sub> ] <sup>–</sup> ).	Suess and Prather (2002)
Soot-like	Elemental carbon chain ions (extending from $m/z$ 12[C] <sup>+</sup> to $m/z$ 144[C <sub>12</sub> ] <sup>+</sup> in the positive ion spectrum and $m/z$ 12[C] <sup>–</sup> to $m/z$ 156[C <sub>13</sub> ] <sup>–</sup> in the negative ion spectrum), often mixed with potassium and sulfate. A fraction contains organic carbon ions as well.	Suess and Prather (2002)
Biomass burning	Dominated by potassium ( $m/z$ 39[K] <sup>+</sup> ) and levoglucosan ions with less intense carbonaceous positive ions. Most contain sulfate ( $m/z$ –97[HSO <sub>4</sub> ] <sup>–</sup> ), and to a lesser extent nitrate ( $m/z$ –62[NO <sub>3</sub> ] <sup>–</sup> ).	Silva et al. (1999), Ault et al. (2010), Pratt et al. (2011)
Lead-containing	$m/z$ 206[Pb] <sup>+</sup> , 207[Pb] <sup>+</sup> , 208[Pb] <sup>+</sup> mixed with other ions.	Bi et al. (2011), Li et al. (2011), Pratt et al. (2011), Creamean et al. (2011), Zhang et al. (2009)
Secondary-containing	Intensive $m/z$ –97[HSO <sub>4</sub> ] <sup>–</sup> , –46[NO <sub>2</sub> ] <sup>–</sup> , –62[NO <sub>3</sub> ] <sup>–</sup> and minor other ions.	Sullivan et al. (2007)
Other	Other than the above types.	\

both contribute to high particle numbers during these episodes. It can be seen that particle numbers in NYS and BS were lower than SYS. However, it should be noted that samplings at NYS, BS, and SYS were not performed simultaneously; therefore, this factor should be considered when relative comparisons in different seas are made. In general, it was found that air masses in SYS were often from the east (sea) with higher wind speed, which might contribute to higher particle number, as high wind speed can enhance the production of particles from sea water through the bubble-bursting process.

The log-normal fit of aerosol number size distribution showed two modes: an accumulation mode (particle mean diameter: 0.2–0.6  $\mu\text{m}$ ) and a coarse mode (0.6–2.0  $\mu\text{m}$ ) (Fig. 2). Accumulation mode particle was the dominant mode. The average hourly particle numbers of accumulation mode particles were  $3090 \pm 2180$ ,  $2530 \pm 3560$ , and  $1360 \pm 1710$  in SYS, NYS, and BS, respectively, which accounted for 50%–80%, 80%–95%, 70%–95% of total particle numbers in the three sea areas. Compared to SYS, accumulation mode particle numbers accounted for a larger fraction and varied more greatly in NYS and BS especially during episodic periods. During some episodic periods in NYS and BS such as during 13:00–21:00 p.m. on November 13th, accumulation mode particles even accounted for 91%–96% of total particle number. A study on fine aerosol size distributions by Lin et al. (2007) showed that long-range transport was a major source for accumulation mode particles over China seas. The residence time is about several days for 0.2–0.6  $\mu\text{m}$  particles (Shan, 2010), allowing enough time for anthropogenic accumulation mode particles to be transported from the continent to the sampling locations in the marine atmosphere.

The average hourly particle number of coarse mode particles was  $1360 \pm 1130$  in SYS, the highest among the three sea areas and about 4 times the average in NYS ( $370 \pm 500$ ) and BS ( $360 \pm 510$ ). It accounted for 20%–50%, 5%–20%, 5%–30% of total particle number in SYS, NYS, and BS, respectively. In SYS, coarse mode particle numbers in episodic periods ( $3850 \pm 1050$ ) such as at 16:00–24:00 on November 7th and at 3:00–4:00 on November 9th, 2012 were about 8-fold that in non-episodic periods ( $460 \pm 350$ , on November 2–3, 2012). Therefore, coarse mode particles play a more important role in SYS than in NYS and BS, especially during episodic periods. The major reason might be due to the wind direction and sources of air masses. Easterly wind (wind from the sea) was the prevailing wind during sampling in SYS, therefore, marine aerosols generated from bursting bubbles or wind-induced wave breaking dominated in SYS. In NYS and BS, air masses were mainly from northwest, passing by the heavily polluted Beijing–Tianjin–Hebei region with a great deal of coal-fired pollutants in November. Taking the EP1 in SYS (Episode 1, 9:00–16:00 on November 5th, 2012) as an example, the prevailing wind was from the east (sea) and the average wind speed was as high as  $11.1 \pm 1.4$  m/sec. Unsteady weather conditions and stronger wind speed resulted in more particles generated from seawater, which are often in the coarse mode. Previous studies have shown that aerosol concentrations increase with the increase of wind speed (Zielinski et al., 1997). The episodes in NYS and BS (such as 18:00–24:00 p.m. 13th and 7:00 a.m.–20:00 p.m. 16th Nov., 2012) were influenced by air masses from the northwest and were mainly contributed by continental sources, especially

coal burning. Coal-fired particles are mainly distributed in fine mode (between 0.01–0.6  $\mu\text{m}$ ) (Hu, 2009).

## 2.2. Characteristics of different particle types

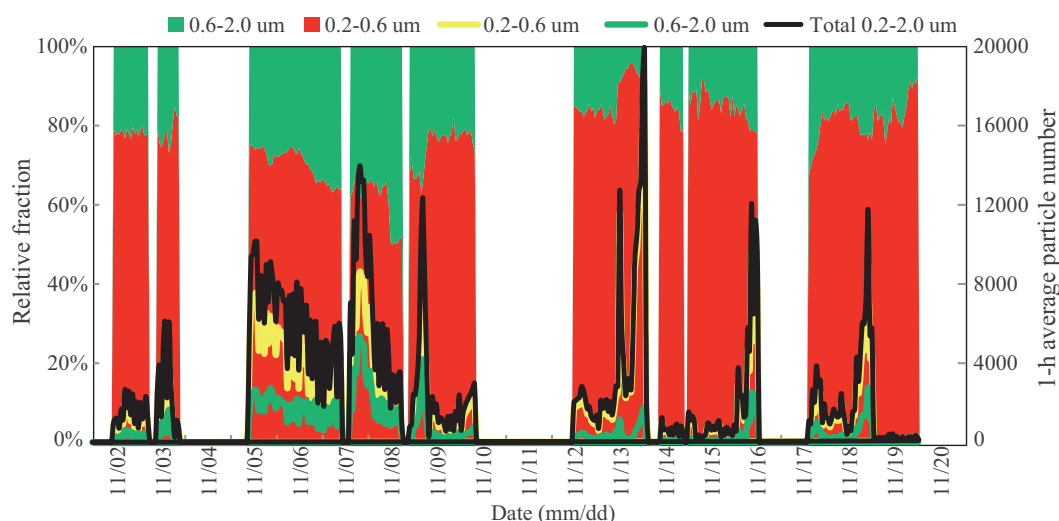
As discussed in Section 1.2.3, six particle types were determined in this study. Mass spectra for each particle type are presented in Fig. S1. Spatial distribution of the six particle types in SYS, NYS, and BS is shown in Fig. 3, respectively.

The hourly particle number of sea-salt particles during the campaign varied from 15 to 3732, accounting for  $25\% \pm 10\%$  of total particles. The average hourly sea-salt particle numbers (fresh plus aged) in SYS, NYS, and BS were  $1000 \pm 630$ ,  $770 \pm 800$ , and  $370 \pm 360$ , respectively, accounting for  $26\% \pm 10\%$ ,  $27\% \pm 10\%$ , and  $20\% \pm 6\%$  of total particle number, respectively. In this study, sea-salt particles were mainly coarser particles, distributing at 0.6–2.0  $\mu\text{m}$ . Compared to BS, a larger contribution from sea-salt particles was found in SYS, and this was consistent with the finding on size distribution in SYS, which was dominated by coarse particles as discussed earlier. Secondary inorganics were chosen as tracer species for aged sea-salt particles (Gard et al., 1998; Song and Carmichael, 1999; Guazzotti et al., 2001). About  $85\% \pm 5\%$  of total sea-salt particles were aged sea-salt particles. The high ratio of aged sea-salt particles suggested that fresh sea-salt particles reacted and mixed with continental emissions.

The particles of secondary-containing type contained typical secondary species, mainly from continental sources. Sulfates were mostly found coupled with dust and organic species (Liu et al., 2003). Nitrogen oxides, the main precursors of tropospheric particulate nitrate, were mostly emitted by fossil fuel combustion (Sakamaki et al., 1983). Ammonia underwent acid/base reaction with the acids in ambient air, mostly nitric acid and sulfuric acid, forming the respective ammonium salts, and thus played a major role in determining particle acidity. The average hourly secondary-containing particle numbers in SYS, NYS, and BS were  $1860 \pm 2180$ ,  $1280 \pm 1920$ , and  $890 \pm 1450$ , respectively, accounting for  $32\% \pm 14\%$ ,  $33\% \pm 9\%$ , and  $29\% \pm 14\%$  of total particle number, respectively.

In SYS, higher secondary-containing particle numbers were mainly distributed in coastal regions (about 55–150 km away from land), suggesting direct influence from continental emissions. In NYS and BS, high relative proportions of secondary-containing particles ( $44 \pm 11\%$ ) were commonly observed during episodic periods. In BS, the relative fraction of secondary-containing particles in the northernmost part could be as high as  $54\% \pm 7\%$  of the total particle number. The hourly particle number of soot-like particles varied from 28 to 3908, accounting for  $18\% \pm 9\%$  of total particles. The presence of elemental carbon, sulfate, and organic carbon ions indicated that continental sources, especially combustion sources, were major contributors to soot-like particles. The hourly particle numbers of soot-like particles in SYS, NYS, and BS were  $590 \pm 410$ ,  $700 \pm 866$ , and  $430 \pm 500$ , respectively, with the average fractions of total particle number  $14\% \pm 6\%$ ,  $22\% \pm 8\%$ , and  $25\% \pm 10\%$ . Soot-like particles have a relatively even distribution in most sampling locations in YS and BS. Although the soot-like particle number in NYS and BS was less than that in SYS, the relative fraction of soot-like particles was higher in NYS and BS compared to SYS.





**Fig. 2 – Temporal variation of accumulation (0.2–0.6  $\mu\text{m}$ ) and coarse (0.6–2.0  $\mu\text{m}$ ) mode particle during 1st–10th November in South Yellow Sea, 1st–16th November in North Yellow Sea, and 17th–20th November in Bohai Sea.**

Hourly particle numbers of biomass burning particles ranged from 15 to 2991 and accounted for  $16\% \pm 5\%$  of total particles. The presence of potassium, organic carbon, and secondary species such as sulfate and nitrate ions indicated that the observed biomass burning particles were mainly contributed by continental sources (Silva et al., 1999; Pratt et al., 2011). Hourly particle numbers of biomass burning particles in SYS, NYS, and BS were respectively  $850 \pm 700$ ,  $450 \pm 600$ , and  $360 \pm 460$ , with the average fractions in total particle number  $17\% \pm 4\%$ ,  $14\% \pm 5\%$ , and  $16\% \pm 5\%$ , respectively.

The hourly particle number of lead-containing particles ranged from 0 to 1163, accounting for  $3\% \pm 4\%$  of total particles. Carbonaceous ions were present in this particle type, and the aerodynamic diameters were generally smaller than  $1.0 \mu\text{m}$  and peaked at  $0.55 \mu\text{m}$ , indicating combustion-related sources for this particle type. The average hourly particle numbers of lead-containing particles in SYS, NYS, and BS were  $72 \pm 69$ ,  $107 \pm 222$ , and  $102 \pm 165$ , respectively, accounting for  $2\% \pm 1\%$ ,  $2\% \pm 3\%$ , and  $6\% \pm 7\%$  of total particle number. The relative fraction of lead-containing particles in BS was about 3 fold that in SYS. Lead-containing particles were distributed relatively evenly in SYS. In NYS, they were mainly distributed in the southern coastal part near Shandong Province. In this region, the relative fraction of lead-containing particles could be as high as 11%–13% of total particle number. In BS, this percentage could be as high as 26%, indicating that BS was more polluted by continental lead-related combustion sources.

In conclusion, abundant secondary-containing, biomass burning, soot-like, and lead-containing particles were all found in the three sea areas, indicating strong anthropogenic influence on marine aerosols. Lead-containing and soot-like particles in BS were relatively enriched compared to SYS, indicating that BS was more heavily polluted by anthropogenic sources from northern China. This is probably because BS is adjacent to the Beijing–Tianjin–Hebei region, which is known to have a high population density and significant emissions of fine particulate matter and gaseous precursors (van Donkelaar et al., 2010).

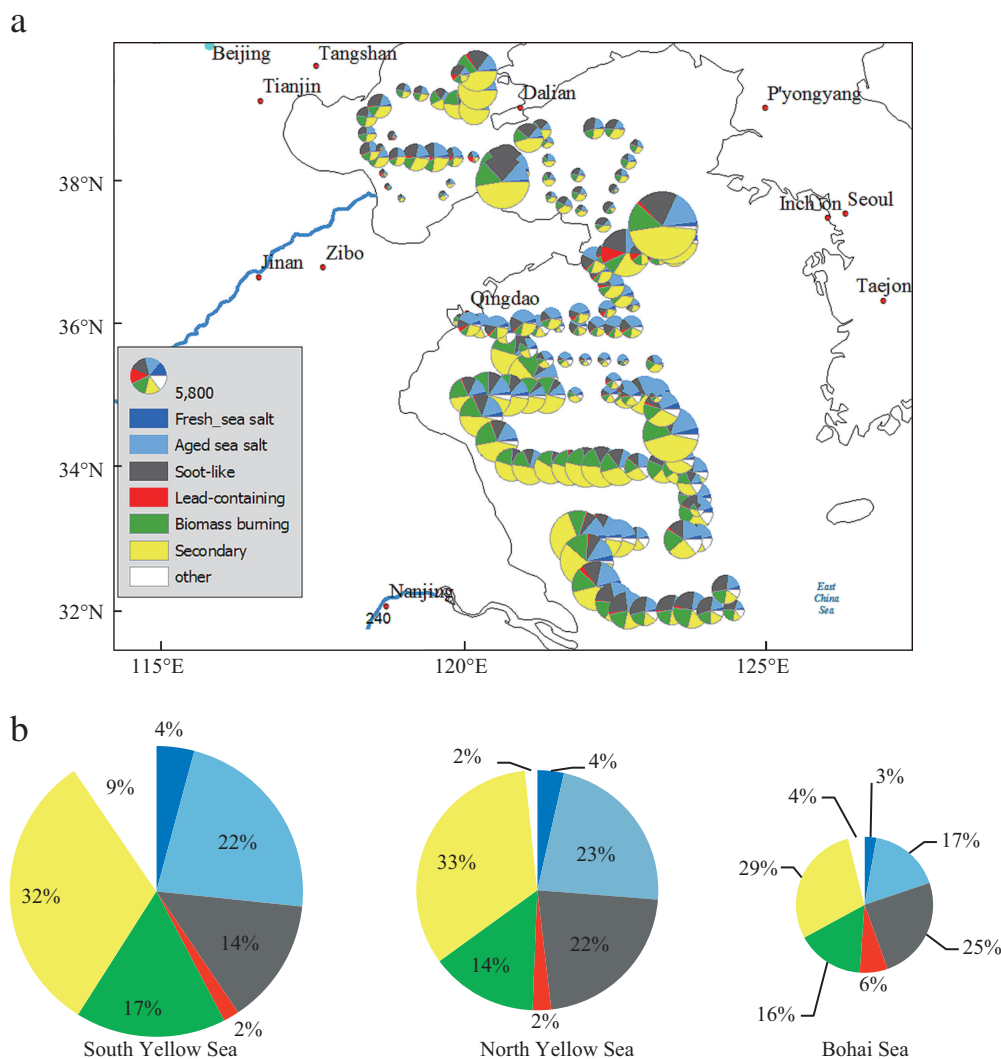
### 2.3. Relationship between particle types and origin of air masses

Temporal variation of relative fractions of identified particle types is shown in Fig. 4. Based on the different origins of air masses, a total of six periods (SYS-1, SYS-2, SYS-3, SYS-4, NYS, and BS) was selected for analysis. Twenty-four-hour air mass back trajectories during six periods are shown in Fig. S2. Air masses at sampling locations during SYS-1, SYS-3, and SYS-4 periods mainly originated from the southeast or east (oceanic air masses), while for SYS-2, NYS, and BS periods, the origin was from the northwest or west (continental air masses). Particle types between oceanic and continental air masses were compared.

As shown in Fig. 4, sea-salt particle was the major particle type during SYS-1, SYS-3, and SYS-4 periods, when the origin of air masses was from the ocean. The relative fraction of sea-salt particles during SYS-1 (42%–70%) and SYS-4 (25%–50%) was much higher than in other periods (10%–30%). Although SYS-3 was also influenced by oceanic air masses, the relative fraction of sea-salt particles only ranged from 15% to 25%, half during SYS-1 and SYS-4. The difference might be due to the influence of wind speed. Wind speeds during SYS-1, SYS-3, and SYS-4 were  $5.4 \pm 0.9$ ,  $2.1 \pm 1.6$ ,  $7.2 \pm 1.7$  m/sec, respectively. High wind speed during SYS-1 and SYS-4 enhanced wave breaking and consequent whitecaps, resulting in more sea-salt particles in the atmosphere (Nair et al., 2005).

Secondary-containing particles were identified by sulfate-, nitrate-, and ammonium-containing particles, which were mainly contributed by continental sources. This was the major particle type during SYS-2, NYS, and BS periods when the origin of air masses was dominated by continental air masses from the Asian continent. The relative fractions of secondary-containing particles during SYS-2, NYS, and BS were  $41\% \pm 13\%$ ,  $33\% \pm 9\%$ ,  $29\% \pm 14\%$ , respectively, and were even as high as 50%–70% in total particle number during episodic periods (5th, 7th, 16th, and 18th November 2012). The above analysis suggests that particle types in marine atmospheres are closely correlated with the origin of air masses and wind speed. From this study, it was found when a





**Fig. 3 – (a) Source apportionment of marine particles and its spatial distribution including fresh sea-salt, aged sea-salt, soot-like, lead-containing, biomass burning, secondary-containing, and other particle types (one-hour resolution) over South Yellow Sea, North Yellow Sea, and Bohai Sea, (b) average percentage of seven particle types in three sea areas. The size of pie represents hourly total particle number.**

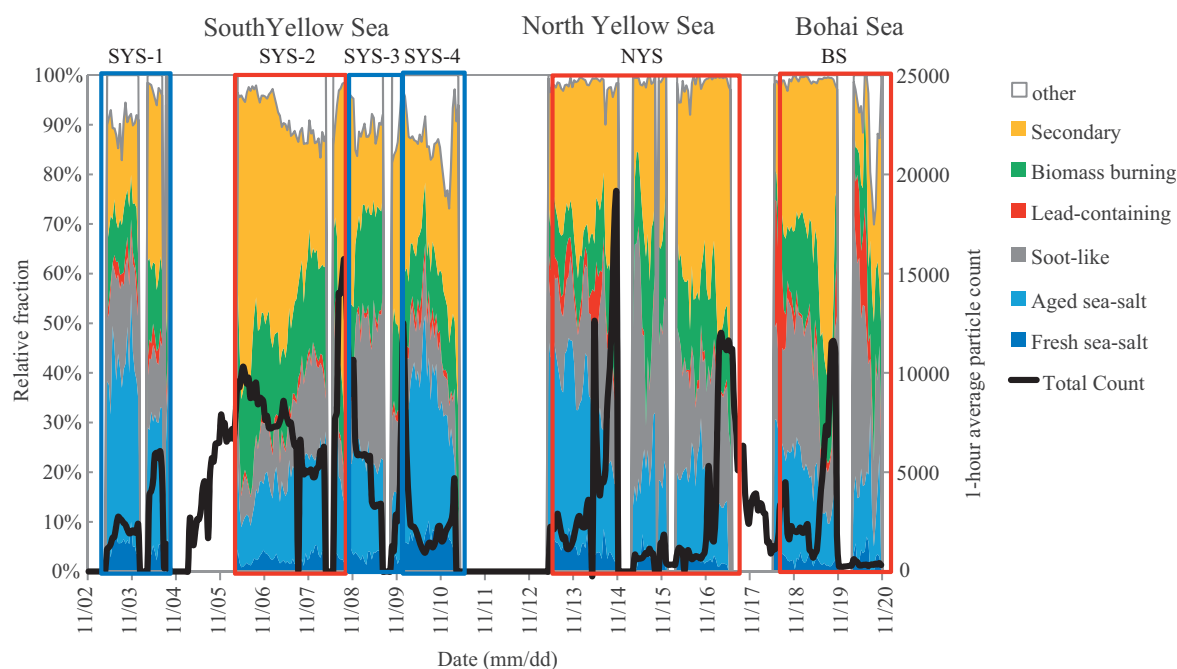
specific sampling location was influenced by strong oceanic air masses, sea-salt particle was the major particle type, especially under high wind speed. However, when it was influenced by continental air masses, secondary-containing particle was the major particle type, clearly showing strong influence from continental emissions with particles characterized by secondary and aged species such as sulfate, nitrate and ammonium.

### 3. Conclusions

This study applied an online technique to provide high-time-resolution (about 1 hr) source apportionment results for marine aerosols (0.2 to 2  $\mu\text{m}$ ) as well as size distributions at the same time, using SPAMS over the East China Seas including SYS, NYS and BS. The average hourly particle number was the highest in SYS ( $4560 \pm 3240$ ), followed by NYS ( $2900 \pm 3970$ ) and BS ( $1730 \pm 2220$ ). Particle number in

SYS exhibited relatively smaller spatial variation compared to NYS and BS, where particle episodes were found more frequently. Accumulation mode (particle mean diameter: 0.2–0.6  $\mu\text{m}$ ) and coarse mode (0.6–2.0  $\mu\text{m}$ ) were the two major modes in this study, with accumulation mode as the dominant one. Coarse mode particles played a more important role in SYS, especially during particle episodic periods.

In this study, six particle types were identified based on mass spectra from SPAMS and clustered by ART-2a, including secondary-containing, aged sea-salt, soot-like, biomass burning, fresh sea-salt, and lead-containing particles, accounting for 32%, 21%, 18%, 16%, 4%, and 3% of total particles, respectively. Abundant secondary-containing, biomass burning, soot-like, and lead-containing particles were all found in SYS, NYS, and BS, indicating strong anthropogenic influence on marine aerosols in YS and BS. Anthropogenic particles were more enriched in BS, with higher relative contribution from lead-containing and soot-like particles than SYS.



**Fig. 4 – Based on origin of air masses, source types of a total of six periods are shown. Three out of six periods (SYS-1, SYS-3, and SYS-4 in blue boxes) are mainly influenced by east or southeast (oceanic) air masses from East China Seas. SYS-2, NYS, and BS in red boxes are mainly influenced by northwest or west (continental) air masses from Asian continent (Fig. S1). (Note: "SYS" denote South Yellow Sea, and "NYS" denote North Yellow Sea).**

Variation of particle types over the marine area was closely correlated with the origin of air masses rather than the sampling locations. The dominance of oceanic air masses coupling with strong wind speed favored production of sea-salt particles. When marine aerosols were mainly originated from continental air masses, secondary-containing particle was the major type among all particles.

Compared to traditional filter measurement methods, SPAMS was a high-time-resolution measurement method giving both size and mass information of single particles, which can provide source information and form the basis for formulating atmospheric control measures, especially when SPAMS becomes more quantitative in the future. This could be achieved through calibration or together with other instruments such as the micro-orifice uniform deposit impactor and aerodynamic particle sizer (Allen et al., 2000; Qin et al., 2006; Spencer et al., 2008).

### Acknowledgments

This work was supported by the National Natural Science Foundation of China (Nos. 41121004, 21190050) and by the National Basic Research Program of China (No. 2014CB953701). The authors would like to express their gratitude to the Guangzhou Hexin Analytical Instrument Co., Ltd. (GHAICL) for providing SPAMS in this campaign. The authors are also indebted to Ms. Yanru Bi from GHAICL for her assistance with the SPAMS measurement before and during the cruise. Finally, the authors gratefully acknowledge the NOAA Air

Resources Laboratory (ARL) for providing results from the HYSPLIT transport and dispersion model.

### Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at <http://dx.doi.org/10.1016/j.jes.2014.09.031>.

### REFERENCES

- Allen, J.O., Fergenson, D.P., Gard, E.E., Hughes, L.S., Morrical, B.D., Kleeman, M.J., et al., 2000. Particle detection efficiencies of aerosol time of flight mass spectrometers under ambient sampling conditions. *Environ. Sci. Technol.* 34 (1), 211–217.
- Arndt, R.L., Carmichael, G.R., Streets, D.G., Bhatti, N., 1997. Sulfur dioxide emissions and sectorial contributions to sulfur deposition in Asia. *Atmos. Environ.* 31 (10), 1553–1572.
- Ault, A.P., Gaston, C.J., Wang, Y., Dominguez, G., Thiemens, M.H., Prather, K.A., 2010. Characterization of the single particle mixing state of individual ship plume events measured at the port of Los Angeles. *Environ. Sci. Technol.* 44 (6), 1954–1961.
- Bi, X.H., Zhang, G.H., Li, L., Wang, X.M., Li, M., Sheng, G.Y., et al., 2011. Mixing state of biomass burning particles by single particle aerosol mass spectrometer in the urban area of PRD, China. *Atmos. Environ.* 45 (20), 3447–3453.
- Chen, Y., Zhuang, G.S., Guo, Z.G., 2010. Atmospheric deposition of nutrients and trace elements to the coastal oceans: a review. *Adv. Earth Sci.* 25 (7), 682–689.

- Creamean, J.M., Ault, A.P., Ten Hoeve, J.E., Jacobson, M.Z., Roberts, G.C., Prather, K.A., 2011. Measurements of aerosol chemistry during new particle formation events at a remote rural mountain site. *Environ. Sci. Technol.* 45 (19), 8208–8216.
- Dall'Osto, M., Beddows, D.C.S., Kinnersley, R.P., Harrison, R.M., Donovan, R.J., Heal, M.R., 2004. Characterisation of individual airborne particles by using aerosol time-of-flight mass spectrometry at Mace Head, Ireland. *J. Geophys. Res.* 109, D21302. <http://dx.doi.org/10.1029/2004JD004747>.
- van Donkelaar, A., Martin, R.V., Brauer, M., Kahn, R., Levy, R., Verduzco, C., et al., 2010. Global estimates of ambient fine particulate matter concentrations from satellite-based aerosol optical depth: development and application. *Environ. Health Perspect.* 118 (6), 847–855.
- Fu, H.Y., Yan, C.Q., Zheng, M., Cai, J., Li, X.Y., Zhang, Y.J., et al., 2014. Application of on-line single particle aerosol mass spectrometry (SPAMS) for studying major components in fine particulate matter. *Environ. Sci.* 35 (11), 4070–4077.
- Gard, E.E., Kleeman, M.J., Gross, D.S., Hughes, L.S., Allen, J.O., Morrical, B.D., et al., 1998. Direct observation of heterogeneous chemistry in the atmosphere. *Science* 279 (5354), 1184–1187.
- Gaston, C.J., Furutani, H., Guazzotti, S.A., Coffee, K.R., Bates, T.S., Quinn, P.K., et al., 2011. Unique ocean-derived particles serve as a proxy for changes in ocean chemistry. *J. Geophys. Res.* 116, D18310. <http://dx.doi.org/10.1029/2010JD015289>.
- Geng, H., Park, Y., Hwang, H., Kang, S., Ro, C.U., 2009. Elevated nitrogen-containing particles observed in Asian dust aerosol samples collected at the marine boundary layer of the Bohai Sea and the Yellow Sea. *Atmos. Chem. Phys.* 9 (18), 6933–6947.
- Gross, D.S., Gälli, M.E., Silva, P.J., Prather, K.A., 2000. Relative sensitivity factors for alkali metal and ammonium cations in single-particle aerosol time-of-flight mass spectra. *Anal. Chem.* 72 (2), 416–422.
- Guazzotti, S.A., Coffee, K.R., Prather, K.A., 2001. Continuous measurements of size-resolved particle chemistry during INDOEX-Intensive Field Phase 99. *J. Geophys. Res.* 106 (D22), 28607–28628.
- Hopke, P.K., Song, X.H., 1997. Classification of single particles by neural networks based on the computer-controlled scanning electron microscopy data. *Anal. Chim. Acta.* 348 (1–3), 375–388.
- Hu, M., Tang, X.Y., Li, J.L., Ma, Q.J., 2003. Distributions of dimethylsulfide in the Bohai Sea and Yellow Sea of China. *J. Environ. Sci.* 15 (6), 762–767.
- Hu, M., 2009. *Physicochemical Characteristics, Sources, Formation Mechanism of Atmospheric Fine and Ultrafine Particulate in Beijing*. Science Press, Beijing.
- Kim, J.H., Yum, S.S., Lee, Y.G., Choi, B.C., 2009. Ship measurements of submicron aerosol size distributions over the Yellow Sea and the East China Sea. *Atmos. Res.* 93 (4), 700–714.
- Li, L., Huang, Z.X., Dong, J.G., Li, M., Gao, W., Nian, H.Q., et al., 2011. Real time bipolar time-of-flight mass spectrometer for analyzing single aerosol particles. *Int. J. Mass Spectrom.* 303 (2–3), 118–124.
- Li, M., Dong, J.G., Huang, Z.X., Li, L., Gao, W., Nian, H.Q., et al., 2012. Analysis of cigarette smoke aerosol by single particle aerosol mass spectrometer. *Chin. J. Anal. Chem.* 40 (6), 936–939.
- Lin, P., Hu, M., Wu, Z.J., Niu, Y.W., Zhu, T., 2007. Marine aerosol size distributions in the springtime over China adjacent seas. *Atmos. Environ.* 41 (32), 6784–6796.
- Liu, D.Y., Wenzel, R.J., Prather, K.A., 2003. Aerosol time-of-flight mass spectrometry during the Atlanta Supersite Experiment: 1. Measurements. *J. Geophys. Res.* 108, 8426. <http://dx.doi.org/10.1029/2001JD001562>.
- Martin, J.H., Fitzwater, S.E., 1988. Iron deficiency limits phytoplankton growth in the north-east Pacific subarctic. *Nature* 331 (6154), 341–343.
- Murphy, S.M., Agrawal, H., Sorooshian, A., Padró, L.T., Gates, H., Hersey, S., et al., 2009. Comprehensive simultaneous shipboard and airborne characterization of exhaust from a modern container ship at sea. *Environ. Sci. Technol.* 43 (13), 4626–4640.
- Nair, P.R., Parameswaran, K., Abraham, A., Jacob, S., 2005. Wind-dependence of sea-salt and non-sea-salt aerosols over the oceanic environment. *J. Atmos. Sol. Terr. Phys.* 67 (10), 884–898.
- Nakamura, T., Ogawa, H., Maripi, D.K., Uematsu, M., 2006. Contribution of water soluble organic nitrogen to total nitrogen in marine aerosols over the East China Sea and western North Pacific. *Atmos. Environ.* 40 (37), 7259–7264.
- Paytan, A., Mackey, K.R.M., Chen, Y., Lima, I.D., Doney, S.C., Mahowald, N., et al., 2009. Toxicity of atmospheric aerosols on marine phytoplankton. *Proc. Natl. Acad. Sci. U. S. A.* 106 (12), 4601–4605.
- Pratt, K.A., Twohy, C.H., Murphy, S.M., Moffet, R.C., Heymsfield, A.J., Gaston, C.J., et al., 2010. Observation of playa salts as nuclei in orographic wave clouds. *J. Geophys. Res.* 115, D15301. <http://dx.doi.org/10.1029/2009JD013606>.
- Pratt, K.A., Murphy, S.M., Subramanian, R., DeMott, P.J., Kok, G.L., Campos, T., et al., 2011. Flight-based chemical characterization of biomass burning aerosols within two prescribed burn smoke plumes. *Atmos. Chem. Phys.* 11 (24), 12549–12565.
- Qin, Y., Bhawe, P.V., Prather, K.A., 2006. Comparison of two methods for obtaining quantitative mass concentrations from aerosol time-of-flight mass spectrometry measurements. *Anal. Chem.* 78, 6169–6178.
- Sakamaki, F., Hatakeyama, S., Akimoto, H., 1983. Formation of nitrous acid and nitric oxide in the heterogeneous dark reaction of nitrogen dioxide and water vapor in a smog chamber. *In: J. Chem. Kinet.* 15 (10), 1013–1029.
- Shan, J., 2010. *Study on Measurement Method and Its Application to Determining the Residence Time of Atmospheric Aerosol*. (PhD thesis). Nanhua University, Shanghai.
- Silva, P.J., Liu, D.Y., Noble, C.A., Prather, K.A., 1999. Size and chemical characterization of individual particles resulting from biomass burning of local Southern California species. *Environ. Sci. Technol.* 33 (18), 3068–3076.
- Song, C.H., Carmichael, G.R., 1999. The aging process of naturally emitted aerosol (sea-salt and mineral aerosol) during long range transport. *Atmos. Environ.* 33 (14), 2203–2218.
- Song, X.H., Hopke, P.K., Fergenson, D.P., Prather, K.A., 1999. Classification of single particles analyzed by ATOFMS using an artificial neural network, ART-2A. *Anal. Chem.* 71 (4), 860–865.
- Spencer, M.T., Holecek, J.C., Corrigan, C.E., Ramanathan, V., Prather, K.A., 2008. Size-resolved chemical composition of aerosol particles during a monsoonal transition period over the Indian Ocean. *J. Geophys. Res.* 113, D16305. <http://dx.doi.org/10.1029/2007JD008657>.
- Streets, D.G., Gupta, S., Waldhoff, S.T., Wang, M.Q., Bond, T.C., Yiyun, B., 2001. Black carbon emissions in China. *Atmos. Environ.* 35 (25), 4281–4296.
- Suess, D.T., Prather, K.A., 2002. Reproducibility of single particle chemical composition during a heavy duty diesel truck dynamometer study. *Aerosol Sci. Technol.* 36 (12), 1139–1141.
- Sullivan, R.C., Guazzotti, S.A., Sodeman, D.A., Prather, K.A., 2007. Direct observations of the atmospheric processing of Asian mineral dust. *Atmos. Chem. Phys.* 7 (5), 1213–1236.
- Sullivan, R.C., Prather, K.A., 2007. Investigations of the diurnal cycle and mixing state of oxalic acid in individual particles in Asian aerosol outflow. *Environ. Sci. Technol.* 41 (23), 8062–8069.
- Yang, G.P., Zhang, H.H., Su, L.P., Zhou, L.M., 2009. Biogenic emission of dimethylsulfide (DMS) from the North Yellow Sea, China and its contribution to sulfate in aerosol during summer. *Atmos. Environ.* 43 (13), 2196–2203.
- Zhang, K., Gao, H.W., 2007. The characteristics of Asian-dust storms during 2000–2002: from the source to the sea. *Atmos. Environ.* 41 (39), 9136–9145.
- Zhang, X.Y., Zhuang, G.S., Guo, J.H., Yin, K.D., Zhang, P., 2007. Characterization of aerosol over the Northern South China Sea during two cruises in 2003. *Atmos. Environ.* 41 (36), 7821–7836.

- Zhang, Y.P., Wang, X.F., Chen, H., Yang, X., Chen, J.M., Allen, J.O., 2009. Source apportionment of lead-containing aerosol particles in Shanghai using single particle mass spectrometry. *Chemosphere* 74 (4), 501–507.
- Zhang, G.H., Bi, X.H., Chan, L.Y., Li, L., Wang, X.M., Feng, J.L., et al., 2012. Enhanced trimethylamine-containing particles during fog events detected by single particle aerosol mass spectrometry in urban Guangzhou, China. *Atmos. Environ.* 55, 121–126.
- Zhang, G.H., Bi, X.H., Li, L., Chan, L.Y., Li, M., Wang, X.M., et al., 2013. Mixing state of individual submicron carbon-containing particles during spring and fall seasons in urban Guangzhou, China: a case study. *Atmos. Chem. Phys.* 13 (9), 4723–4735.
- Zielinski, A., Zielinski, T., Piskozub, J., 1997. Aerosol size distribution function in the coastal area. *J. Aerosol Sci.* 28, 41–42.





## Editorial Board of Journal of Environmental Sciences

### Editor-in-Chief

**X. Chris Le** University of Alberta, Canada

### Associate Editors-in-Chief

**Jiuhui Qu** Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China  
**Shu Tao** Peking University, China  
**Nigel Bell** Imperial College London, UK  
**Po-Keung Wong** The Chinese University of Hong Kong, Hong Kong, China

### Editorial Board

#### Aquatic environment

**Baoyu Gao**  
Shandong University, China  
**Maohong Fan**  
University of Wyoming, USA  
**Chihpin Huang**  
National Chiao Tung University  
Taiwan, China  
**Ng Wun Jern**  
Nanyang Environment &  
Water Research Institute, Singapore  
**Clark C. K. Liu**  
University of Hawaii at Manoa, USA  
**Hokyong Shon**  
University of Technology, Sydney, Australia  
**Zijian Wang**  
Research Center for Eco-Environmental Sciences,  
Chinese Academy of Sciences, China  
**Zhiwu Wang**  
The Ohio State University, USA  
**Yuxiang Wang**  
Queen's University, Canada  
**Min Yang**  
Research Center for Eco-Environmental Sciences,  
Chinese Academy of Sciences, China  
**Zhifeng Yang**  
Beijing Normal University, China  
**Han-Qing Yu**  
University of Science & Technology of China,  
China

#### Terrestrial environment

**Christopher Anderson**  
Massey University, New Zealand  
**Zucong Cai**  
Nanjing Normal University, China  
**Xinbin Feng**  
Institute of Geochemistry,  
Chinese Academy of Sciences, China  
**Hongqing Hu**  
Huazhong Agricultural University, China  
**Kin-Che Lam**  
The Chinese University of Hong Kong  
Hong Kong, China  
**Erwin Klumpp**  
Research Centre Juelich, Agrosphere Institute  
Germany

#### Peijun Li

Institute of Applied Ecology,  
Chinese Academy of Sciences, China  
**Michael Schloter**  
German Research Center for Environmental Health  
Germany  
**Xuejun Wang**  
Peking University, China  
**Lizhong Zhu**  
Zhejiang University, China

#### Atmospheric environment

**Jianmin Chen**  
Fudan University, China  
**Abdelwahid Mellouki**  
Centre National de la Recherche Scientifique  
France  
**Yujing Mu**  
Research Center for Eco-Environmental Sciences,  
Chinese Academy of Sciences, China  
**Min Shao**  
Peking University, China  
**James Jay Schauer**  
University of Wisconsin-Madison, USA  
**Yuesi Wang**  
Institute of Atmospheric Physics,  
Chinese Academy of Sciences, China  
**Xin Yang**  
University of Cambridge, UK

#### Environmental biology

**Yong Cai**  
Florida International University, USA  
**Henner Hollert**  
RWTH Aachen University, Germany  
**Jaeseong Lee**  
Sungkyunkwan University, South Korea  
**Christopher Rensing**  
University of Copenhagen, Denmark  
**Bojan Sedmak**  
National Institute of Biology, Slovenia  
**Lirong Song**  
Institute of Hydrobiology,  
Chinese Academy of Sciences, China  
**Chunxia Wang**  
National Natural Science Foundation of China  
**Gehong Wei**  
Northwest A & F University, China

#### Daqiang Yin

Tongji University, China  
**Zhongtang Yu**  
The Ohio State University, USA

#### Environmental toxicology and health

**Jingwen Chen**  
Dalian University of Technology, China  
**Jianning Hu**  
Peking University, China  
**Guibin Jiang**  
Research Center for Eco-Environmental Sciences,  
Chinese Academy of Sciences, China  
**Sijin Liu**  
Research Center for Eco-Environmental Sciences,  
Chinese Academy of Sciences, China  
**Tsuyoshi Nakanishi**  
Gifu Pharmaceutical University, Japan  
**Willie Peijnenburg**  
University of Leiden, The Netherlands  
**Bingsheng Zhou**  
Institute of Hydrobiology,  
Chinese Academy of Sciences, China

#### Environmental catalysis and materials

**Hong He**  
Research Center for Eco-Environmental Sciences,  
Chinese Academy of Sciences, China  
**Junhua Li**  
Tsinghua University, China  
**Wenfeng Shangguan**  
Shanghai Jiao Tong University, China  
**Ralph T. Yang**  
University of Michigan, USA

#### Environmental analysis and method

**Zongwei Cai**  
Hong Kong Baptist University,  
Hong Kong, China  
**Jiping Chen**  
Dalian Institute of Chemical Physics,  
Chinese Academy of Sciences, China  
**Minghui Zheng**  
Research Center for Eco-Environmental Sciences,  
Chinese Academy of Sciences, China  
**Municipal solid waste and green chemistry**  
**Pinjing He**  
Tongji University, China

### Editorial office staff

**Managing editor** Qingcai Feng  
**Editors** Zixuan Wang Suqin Liu Kuo Liu Zhengang Mao  
**English editor** Catherine Rice (USA)

# JOURNAL OF ENVIRONMENTAL SCIENCES

环境科学学报(英文版)

[www.jesc.ac.cn](http://www.jesc.ac.cn)

## Aims and scope

*Journal of Environmental Sciences* is an international academic journal supervised by Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. The journal publishes original, peer-reviewed innovative research and valuable findings in environmental sciences. The types of articles published are research article, critical review, rapid communications, and special issues.

The scope of the journal embraces the treatment processes for natural groundwater, municipal, agricultural and industrial water and wastewaters; physical and chemical methods for limitation of pollutants emission into the atmospheric environment; chemical and biological and phytoremediation of contaminated soil; fate and transport of pollutants in environments; toxicological effects of terrorist chemical release on the natural environment and human health; development of environmental catalysts and materials.

## For subscription to electronic edition

Elsevier is responsible for subscription of the journal. Please subscribe to the journal via <http://www.elsevier.com/locate/jes>.

## For subscription to print edition

China: Please contact the customer service, Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China. Tel: +86-10-64017032; E-mail: [journal@mail.sciencep.com](mailto:journal@mail.sciencep.com), or the local post office throughout China (domestic postcode: 2-580).

Outside China: Please order the journal from the Elsevier Customer Service Department at the Regional Sales Office nearest you.

## Submission declaration

Submission of the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The publication should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

## Editorial

Authors should submit manuscript online at <http://www.jesc.ac.cn>. In case of queries, please contact editorial office, Tel: +86-10-62920553, E-mail: [jesc@rcees.ac.cn](mailto:jesc@rcees.ac.cn). Instruction to authors is available at <http://www.jesc.ac.cn>.

**Journal of Environmental Sciences (Established in 1989)**

**Volume 29 2015**

<b>Supervised by</b>	Chinese Academy of Sciences	<b>Published by</b>	Science Press, Beijing, China
<b>Sponsored by</b>	Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences		Elsevier Limited, The Netherlands
<b>Edited by</b>	Editorial Office of Journal of Environmental Sciences P. O. Box 2871, Beijing 100085, China Tel: 86-10-62920553; <a href="http://www.jesc.ac.cn">http://www.jesc.ac.cn</a> E-mail: <a href="mailto:jesc@rcees.ac.cn">jesc@rcees.ac.cn</a>	<b>Distributed by</b>	Domestic Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China Local Post Offices through China Foreign Elsevier Limited <a href="http://www.elsevier.com/locate/jes">http://www.elsevier.com/locate/jes</a>
<b>Editor-in-chief</b>	X. Chris Le	<b>Printed by</b>	Beijing Beilin Printing House, 100083, China

CN 11-2629/X

Domestic postcode: 2-580

Domestic price per issue RMB ¥ 110.00

ISSN 1001-0742

