

Hourly variations of water-soluble ions under different sand and dust weather processes in Lanzhou, China

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Abstract. In this paper we aimed to collect water-soluble anion and cationic through rapid capturing system of atmospheric fine particles in order to analyze the source of water-soluble ions of atmospheric PM_{2.5} in Lanzhou city, and the characteristics of hourly concentration changes in different sand and dust weather processes. The author also applied Hysplit4.8 to conduct backward trajectory analysis. The results showed that the correlation between water-soluble ions is instrumental to infer the forms of water-soluble ions in Lanzhou, such as (NH₄)₂ SO₄, NH₄NO₃, CaSO₄, and NH₄Cl. Lanzhou has been severely polluted by sand and dust apart from the increasing amount of Ca²⁺ under different dust sources and transmission paths. Na⁺ was also elevated in March, resulted from the dust going through the Hexi Corridor from the Taklimakan. Furthermore, in April Cl⁻ also increased due to the dust being derived from Outer Mongolia then passing Qaidam Basin. In addition, Na⁺ dramatically went up in the process of precipitation.

1. Introduction

Water-soluble ions are the major chemical components of atmospheric fine particles (PM_{2.5}). Their slow sedimentation rate, strong hygroscopicity, and content variation will have strong impact on atmospheric visibility^[1], atmospheric precipitation and cloud mist acidity^[2]. In addition, they also promote the dissolution of toxic and harmful substances into human body^[3]. Therefore, it is of great necessity to study water-soluble components in PM_{2.5}. In the past, artificial sampling was used to detect and analyze water-soluble inorganic ions in atmospheric aerosol or sand-dust samples by ion chromatography (IC). Up till now, detection of water-soluble ions in aerosol and sand-dust have been carried out in few cities in China. In this paper, URG-9000D atmospheric/aerosol cation-anion of on-line monitoring equipment (hereafter URG) was used for the first time in collection of water-soluble ion samples. The whole course was continuously monitored and analyzed from March 19 to May 30, 2010. Via the usage of URG, the whole course of automatic sampling, analysis, data processing and research was easily achieved.

2. Material and methods

2.1. Site description and sampling

The sampling site was located approximately 30 m above the ground in Tongban building No. 2 (36°03'06" N, 103°50'20" E) of the Atmospheric Laboratory at Gansu Province Environmental Monitoring Center, located in Dongfanghong Squares at the center of urban Lanzhou. URG



atmospheric/aerosol ($\text{PM}_{2.5}$) cation-anion of on-line monitoring equipment (USA) was employed to continuously obtain 1440 valid data from March 19 to May 30, 2010. The atmospheric/aerosol samples were collected at an interval of 1 h. With a Dionex ICS 2000 IC analyzer (USA) and a Dionex ICS 1100 IC analyzer (USA), 10 types of inorganic ions were analyzed. A Dionex IonPac AS14A separation column and an AG14A protection column were used for the analysis of the 5 anions (F^- , Cl^- , NO_2^- , NO_3^- , and SO_4^{2-}) whereas a Dionex IonPacCS 12A separation column and a CG12A protection column were used for the 5 cations (Na^+ , NH_4^+ , K^+ , Mg^{2+} , and Ca^{2+}). Relevant weather data were also collected. In order match them with water-soluble inorganic ions, we set the start of measuring time at 0:00 each day, with an interval of 1 h. In addition, the meteorological factors included air temperature, relative humidity, precipitation, wind speed, wind direction, and visibility (Ren et al., 2010).

2.2 .Methods

Air trajectory estimation was analyzed by utilizing air resources laboratory of National Oceanic and Atmospheric Administration (NOAA) in U.S.A. and software Hysplit 4.8 was developed by the Australian Meteorology Bureau.

3. Results and discussion

3.1. The change of water-soluble ions under typical weather

Typically, in spring, Lanzhou usually goes through precipitation and wind along with weather phenomena, such as floating dust, blowing sand and sandstorm. Based on monitoring, the average concentration of main water-soluble ions under typical weather is shown in Table 1. It showed that the high value of Ca^{2+} concentration appeared on dust day and the average concentration of Ca^{2+} was $4.25\mu\text{g}/\text{m}^3$, which coincided with the common view that Ca^{2+} derives from soil dust. Table 1 reflects the characteristics of Cl^- , NO_3^{2-} and SO_4^{2-} under different weather conditions during non-heating period. In sand and dust days or windy days, the amount of Cl^- , NO_3^{2-} and SO_4^{2-} is higher than rainy days or sunny days. The reason why precipitation removes three kinds of ions efficiently is that they perform as secondary particles converge in fine particles. As for NH_4^+ , due to underperformance of air diffusion, rainy days enjoy most of NH_4^+ , while sunny days enjoy less of it than windy days and sand and dust days do, inferring that the influence of pollution and air dry sedimentation is larger than precipitation. The amount of NO_3^- which keeps unchanged during heating period under diverse weather conditions in sand and dust day is the highest of all weathers. However, in the spring and summer, it mainly comes from NO_x in the exhaust of motor vehicles.

Table 1. The changing characteristics of average concentration of main ions under typical weather ($\mu\text{g}/\text{m}^3$)

major ions	windy day	dust day	rainy day	sunny day
Ca^{2+}	0.610801	4.258054	0.503914	0.432576
NH_4^+	0.568448	0.42273	0.947619	0.630713
Na^+	0.718058	0.362487	0.506907	0.492672
SO_4^{2-}	2.25619	4.132337	2.180914	1.968421
NO_3^-	0.186534	0.410089	0.258257	0.212957
Cl^-	0.406109	1.448941	0.564219	0.452589

3.2. The concentration comparison of water soluble ions between two dust weather processes.

3.2.1. Sand and dust from March 19 to 20. The storm rehearsed at 1 o'clock, on 19th March, 2010, started at 14 o'clock, and ended at 2 o'clock in the morning of the 20th. The data of hourly changes for 48 hours before, during and after the storm were well collected. The violent evaluation of Mongolia cyclone was the major cause for this sandstorm, deriving from the south of Mongolia, the south and the east of Xinjiang in China, and the central and western regions of Inner Mongolia. The vorticity

moved forward and at the same time advanced deeply with the combination of heat and power. Upper trough, due to deepened cold advection, moves forward with vorticity advection. Strengthened cold frontogenesis was produced high winds, which was the power factors causing dust storms and promoting dust long-distance conveying.

Figure 1 illustrates hourly changes of six ions' concentration (Cl^- , SO_4^{2-} , NH_4^+ , Ca^{2+} , Na^+ and NO_3^{2-}) before, during and after dust transit. Before dust transit, Figures 1.a and c show that $\rho(\text{Na}^+)$, $\rho(\text{NO}_3^{2-})$, $\rho(\text{Cl}^-)$ and $\rho(\text{SO}_4^{2-})$ all suddenly appeared a peak value at 11 o'clock on March 19, Figure 1.b shows $\rho(\text{NH}_4^+)$ bearing a stepwise increase, also peaked with $8.739\mu\text{g}/\text{m}^3$ at 11am. The peak values were attributed to the strong inversion along boundary layer before dust crossing, which was not conducive to the spread of pollutants, together with the increase of man-made pollution emissions. Thus, the concentration of atmospheric pollutants was enhanced. $\rho(\text{Ca}^{2+})$ remained stable without big fluctuations. As the inversion layer was destroyed and mixing layer rapidly developed during dust transit, the vertical gradient of lower temperature and humidity from boundary layer decreased whereas the vertical gradient of wind speed increased.

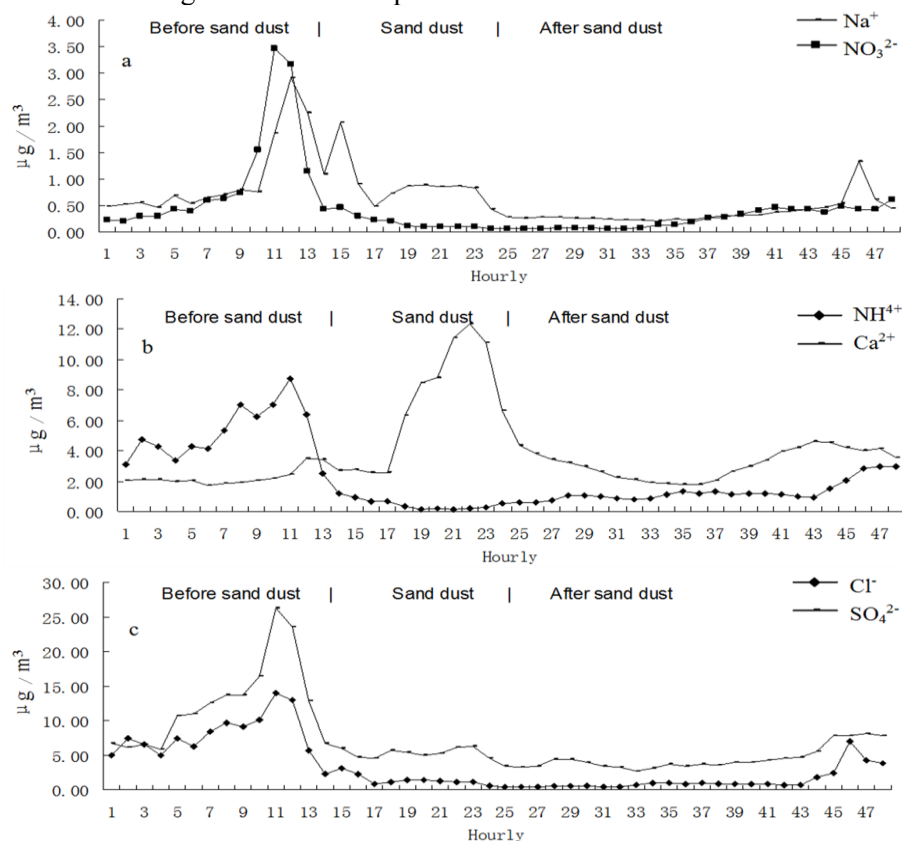


Figure 1. Hourly variation of $\rho(\text{Cl}^-)$, $\rho(\text{SO}_4^{2-})$, $\rho(\text{NH}_4^+)$, $\rho(\text{Ca}^{2+})$, $\rho(\text{Na}^+)$ and $\rho(\text{NO}_3^{2-})$ when the sand-dust passed.

3.2.2. The process of sand and dust occurring from April 25 to 26. The sand process rehearsed at one o'clock on April 25, 2010, started at 17 o'clock and ended at 18 o'clock on 26th April. This paper has selected 48-hour changes of concentration before, during and after dust transit. The slanting north wind carried strong polar cold air from Sino-Siberia and the north of Xinjiang invaded on April 24. There existed a westerly jet center over the dust area with the height between 200-250hpa. When sandstorms broke out, the wind speeded up to $40\text{m} \cdot \text{s}^{-1}$, therefore, height reduced and scope expanded. The maximum wind speed extending from jet center to the ground will make high momentum spread down, causing sandstorms in Hexi Corridor.

Figure 2 expresses the hourly changes of six ions of Cl^- , SO_4^{2-} , NH_4^+ , Ca^{2+} , Na^+ and NO_3^{2-} before, during and after dust crossing. From Figure 2.a, it could be seen that $p(\text{Na}^+)$ was in stable state and $p(\text{Ca}^{2+})$ changed from high to low. From Figure 2.b, $p(\text{SO}_4^{2-})$ and $p(\text{NH}_4^+)$, concentration changed to some extent, reaching the peak at 11am, and then quickly fell back as wind speed increased. From Figure 2.c, $p(\text{Cl}^-)$ changed dramatically whereas $p(\text{NO}_3^{2-})$ kept relatively stable. During dust functioning, $p(\text{Ca}^{2+})$ increased significantly, reaching its peak in the morning on April 26, and then began to decline at 15 o'clock. At the beginning of the dust transiting, $p(\text{Cl}^-)$ was relatively stable, at the speed of $0.937\mu\text{g}/\text{m}^3$ at 23 o'clock on 25th April. At 5 o'clock on 26th April, along with the advent of dust, $p(\text{Cl}^-)$ rose sharply, gradually rising to a maximum of $2.799\mu\text{g}/\text{m}^3$. However, $p(\text{Na}^+)$, $p(\text{NO}_3^{2-})$, $p(\text{SO}_4^{2-})$ and $p(\text{NH}_4^+)$ tended to embrace no obvious changes. After dust crossing, various ions fell.

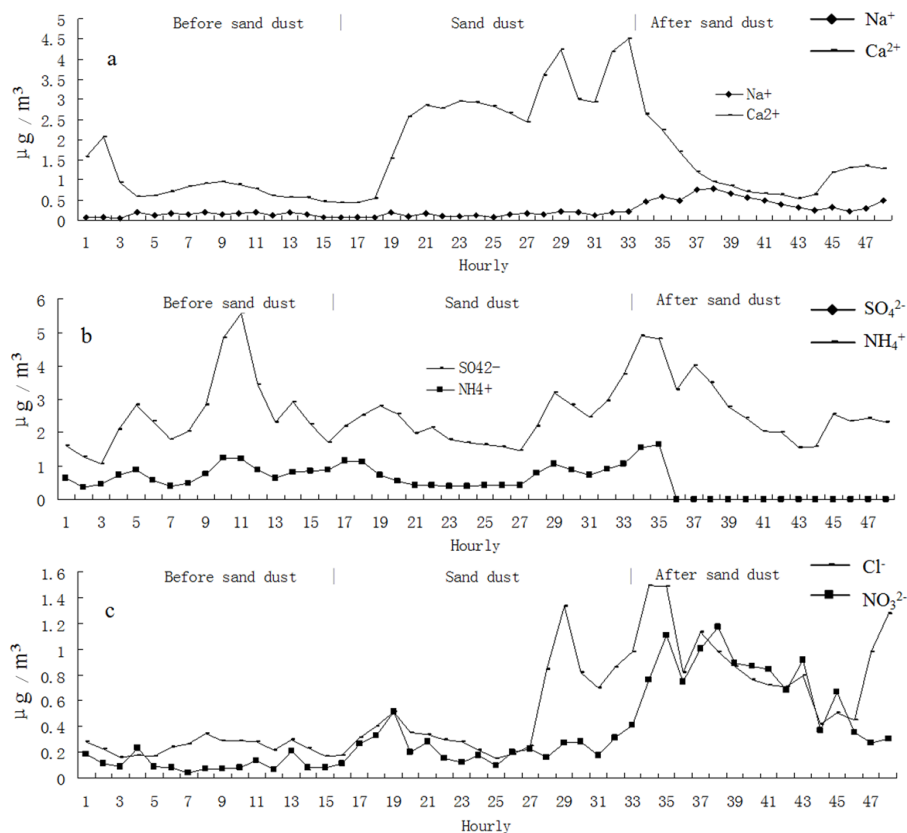


Figure 2. Hourly variation of $p(\text{Cl}^-)$, $p(\text{NO}_3^-)$, $p(\text{SO}_4^{2-})$, $p(\text{NH}_4^+)$, $p(\text{Na}^+)$ and $p(\text{Ca}^{2+})$ when the sand-dust passed.

3.3. Analysis of typical airflow trajectory

Hysplit 4.8 was used to explore the effects of sand-dust sources under different sand-dust weather processes on concentrations of water-soluble ions. Hysplit 4.8 could simulate the air current moving trajectory, at a precision of 6 hours. This mode was used to analyze the air trajectory and pollution source^[4]. Figure 3 reveals that on 19 March and 25 April 2010, Lanzhou was attacked by sand-dusts, and the 48-hour trajectories of air were reversed. The above analysis showed that these two sand-dust events caused severe air pollution to Lanzhou. However, Fig. 3 indicates that the invasion paths and sources of these two events were different. Figure 3.a shows that the sand-dust in 19 March originating from Taklimakan desert, as well as two air streams at 500 m and 1500 m high respectively passed along the northern foot of Altun Mountains, went through Hexi Corridor and finally reached Lanzhou. In this process, two air streams carried sand-dust supplementary materials from Badain Jaran Desert and Tengger Desert, and thus two air streams contributed to the strong sand-dust in 19 March in

Lanzhou. Figure 3.b indicates that the sand-dust in 25 April originated from Gobi in north Mongolia. The air stream from 500 m high travelled to the south. However, with the obstruction of Qilian Mountains, it passed via Hexi Corridor to Lanzhou. On April 25, air flow from 1500 m high altitude reached Lanzhou through the Qaidam Basin and Qinghai Lake. Due to sun radiation and transpiration, Cl^- released into the air, produced from the bubble burst on the salt lakes and carried by the air into Lanzhou. It resulted in the increase of $\rho(\text{Cl}^-)$ during dust. According to Someone's^[5] research on single particle analysis, it is known that when Asian sands went across the sea, 79% of all particles underwent the influence of sea salt. The interaction between sea salt and dust aerosol played a key part in the process of conveying long-distance dust^[6]. Through the analysis of air backward, trajectory confirmed that the Cl^- concentration of abnormal height in the North dust affecting Hong Kong was relevant to the path passing through the East Sea. As a result, the Cl^- content during the dust time significantly increased, as the dust passes over the salt lakes in Qaidam Basin. The two streams converged at Lanzhou and jointly caused the sand-dust weather. The above analysis indicates that during the two sand-dust events, except $\rho(\text{Ca}^{2+})$, the $\rho(\text{Cl}^-)$ and $\rho(\text{Na}^+)$ changed largely, since $\rho(\text{Na}^+)$ increased in the March 19 event and meanwhile, $\rho(\text{Cl}^-)$ increased in the April 25 event. The reason for that is the March sand-dust came from Hexi Corridor, and its strong air streams carried soils from large-area plowlands in west Yellow river to Lanzhou, thereby evidently increasing $\rho(\text{Na}^+)$ in sand-dusts. In the April event, the air stream at 1500 m high passed through Qaidam Basin and Qinghai Lake to Lanzhou. The Qinghai Lake and the lakes in Qaidam Basin were all salt water lakes. Due to solar radiation and transpiration, Cl^- was discharged from lakes to the air. Only 200 miles away from Lanzhou, Qinghai Lake was at higher altitude. Thus, air streams carried Cl^- to Lanzhou, increasing $\rho(\text{Cl}^-)$ at late stage of this event. Though another air stream at 500 m high passed Gansu Corridor, it was at late April that the farms and large-area plowlands in Hexi Corridor all turned green. The vegetations strongly fixed the dusts and soils. Therefore, in this event, no obvious change was seen in $\rho(\text{Na}^+)$ of the sand-dusts.

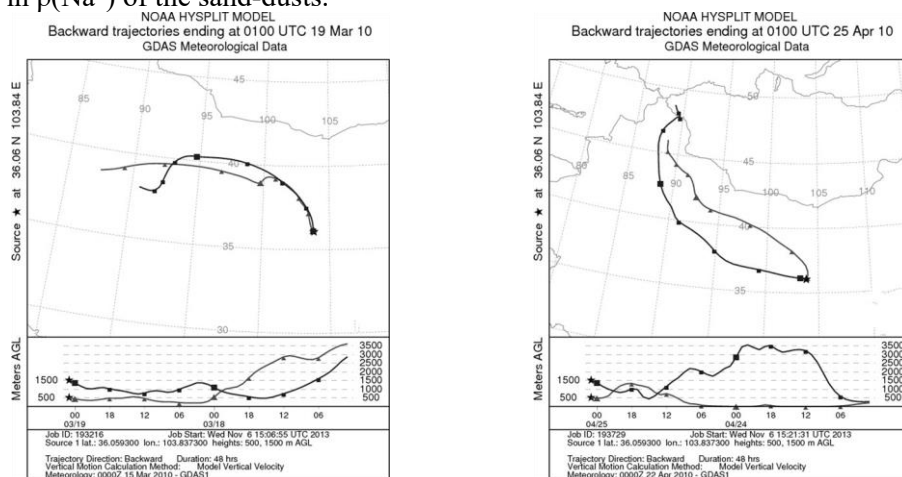


Figure 3. The 48-hour air mass trajectories reversed from two sand-dust events from 500 m and 1500 m high in Lanzhou (a. Event in 19 March 2010; b. Event in 25 April 2010). UTC time is used.

4. Conclusions

Under the typical weather process, apart from the increase of Ca^{2+} , SO_4^{2-} and Cl^- have increased significantly. The NH_4^+ concentration increased under the influence of rainy weather and weak air diffusion. However, rainfall and strong wind would low water-soluble ions in Lanzhou city. In sunny days with supreme condition, the concentration of various ions was lower than any other whether conditions. Both dust sources and dust conveying paths affected the concentrations of water-soluble ions in Lanzhou differently. The dust-storm in spring came from Mongolia through Gansu Corridor, leading to increased $\rho(\text{Na}^+)$ in Lanzhou. The sand-dust from Taklimakan desert passed through Qaidam Basin and Qinghai Lake. Under the action of salt water lakes, $\rho(\text{Cl}^-)$ increased.

Acknowledgements

This work was partially supported by grants from the China Postdoctoral Science Foundation (2016M600827), Specific Subjects of National Scientific Data Sharing Platform for Population and Health (2016NCMIZX09), National Natural Science Foundation of China(71472079), Key Project of China Ministry of Education for Philosophy and Social Science(16JZD023). Also, the authors would like to thank anonymous reviewers and editors for their useful comments which have helped to improve the quality of this manuscript.

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