An Analysis of the Air Parcel Trajectories of Long-Range Transport at Shanghai

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I. INTRODUCTION

Acid rain observations show that acid cloud water in Shanghai region appears not only in the lower part of clouds, but also in the upper part at the height of about 3000 m. (Fig.1). This fact indicates that in addition to the local pollution impact, the acid rain and sulphur dioxide pollution in Shanghai region are also related to the impact of external pollution along with upper air transport. In order to study the impact of the air parcel transport on air pollution and acid rain in Shanghai region, the analysis research is made for the air parcel transport trajectory affecting Shanghai region.

According to the hypothesis of Lagrangian trajectory model, air parcel containing pollutants is transported wholly by large-scale air flow in the medium-long distance transport of pollutants, i.e., the advection transport of large-scale air flow with time-space variation plays a leading role and the diffusion effect of small-scale air flow can be neglected.

Therefore, taking Shanghai region as the receiving point, we calculated and analyzed the backward trajectories to explore the coming-direction of pollutants influencing and arriving in Shanghai region. Also, taking Shanghai region as the initiated point, we calculated forward trajectories to analyze the going-direction of pollutants emitted from Shanghai.

II. CALCULATION EXTENT AND METHOD

The calculated grid region is the area of 20°N–45°N, 95°E–135°E, centred around the middle-lower reaches of the Changjiang (Yangtze) River and Shanghai region, which not only covers the middle-east part of China mainland, but also covers East China coast, Korean Peninsula and west part of Japan.

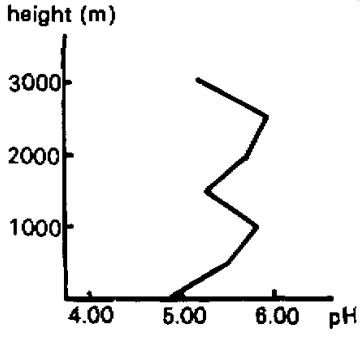

Fig.1. The vertical distribution of mean pH values in cloud water (Shanghai).

20×23 grid points with grid length about 150 km are established in the calculated region. The sounding data from 140 upper air sounding sites are chosen at the 850 hPa isobaric surface. The u,v components of wind at any point in the grid are derived by using interpolation weighted inversely by the square of the distance. The positions and trajectories of air parcel at 12, 24, 36, 48, 60 and 72 h are derived according to the time step of 12 h interval. The calculation time for each trajectory is 3 days. The distance error of trajectory approaching is less than 25 km.

III. THE ANNUAL AIR FLOW TRANSPORT TRAJECTORIES AFFECTING SHANGHAI REGION

358 backward trajectories in 1985 were calculated. It is shown from the 72 h backward trajectories that 34.8% of them are from southwest of Shanghai, 15.7% from northwest of Shanghai and 16.7% from northeast–east of Shanghai (Fig.2).

The coming directions of trajectories in each month are different (Fig.3).

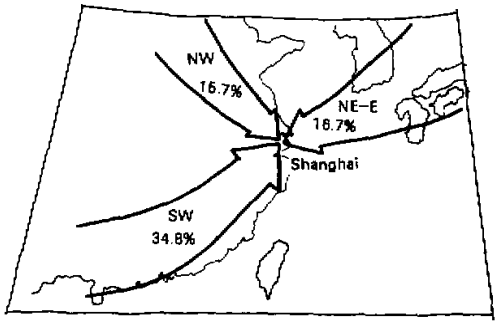

Fig.2. The annual air flow backward trajectories affecting Shanghai.

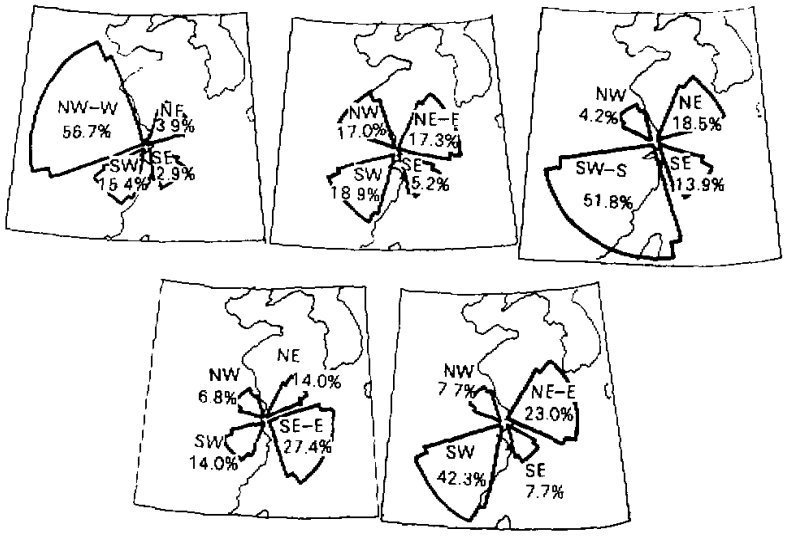

Fig.3. The coming–directions of trajectories in each month at Shanghai in 1985.

November, December, January and February in Shanghai region are the winter half year when the cold air dominates and Shanghai is often controlled by the cold high pressure. Most of the air parcels arriving in Shanghai are from northwest–west with occurrence frequency more than 50%.

March, April and May are the transformation period from winter season to summer season, weather is changeable and the air parcel trajectories affecting Shanghai are relatively scattered. The frequencies of trajectories from NE–E, NW and SW are almost equal, but in March the trajectories come from northeast–east of Shanghai amount to about 30%.

June and July are the plum rain season in Shanghai, rainy days associated with stationary frout systems are dominant. The trajectories affecting Shanghai are mainly from southwest–south of Shanghai with frequencies up to 50–70%. In July the trajectories from southwest with frequencies are more than 60%, but in June the trajectories from northeast–east are about 35%.

August and September are the midsummer season, Shanghai is often controlled by the subtropical high. During this period tropical storms are active. Therefore, most fo the trajectories are from southeast–east with frequencies 40%, but trajectories coming from northeast–east also amount to 30%.

In October autumn rainy days associated with stationary front and low pressure system dominate in Shanghai, parcel trajectories are mainly from southwest with frequencies 40%.

IV. THE RELATIONSHIP BETWEEN AIR PARCEL TRAJECTORY AND SYNOPTIC SYSTEM

The parcel trajectory is closely related to the movement and variation of synoptic system. The synoptic system influencing Shanghai can be classified into five types of stationary front system, low pressure system, cold front system, tropical storm (typhoon) and high pressure system.

Precipitation often occurs when stationary front, low pressure or cold front infuences Shanghai. In this period, more than 60% of trajectories affecting Shanghai are from southwest–west, among which the most occurrence frequency of about 35% is the trajectories from southwest associated with stationary frontal system. But at the same time, trajectories from northeast–east are also more than 20% (Fig.4).

Tropical storms (typhoon) are mainly from the sea of southeast of Shanghai. During this period trajectories are mainly from east–southeast–south with frequency of more than 75%.

When high pressure (including the verge of high pressure) influences Shanghai, trajectories are mainly from west–northwest with frequency of more than 40%, but trajectories coming from northeast also amount to 12% and more.

V. THE COMING–DIRECTION OF TRAJECTORIES AND ACID RAIN IN THE RAINY DAYS OF SHANGHAI

In 1985 annual rainy days in Shanghai are 167 days with annual rainfall 1627.8 mm. About 108 days (65% of annual rainy days) pH mean values of rainwater are less than 5.60. When stationary front, low pressure or cold front synoptic system influences Shanghai, a vast extent of precipitation tends to occur in Shanghai region. Precipitation associated with stationary frontal system occurs most frequently (38% of annual precipitation) with the maximum both in the daily mean rainfall and the event total precipitation, but the pH value of rainwater is the minimum. More than half of trajectories are from southwest–west, among which trajectories from southwest occur most frequently with frequency about 45%. Meanwhile, trajectories from northeast–east also amount to about 20%.

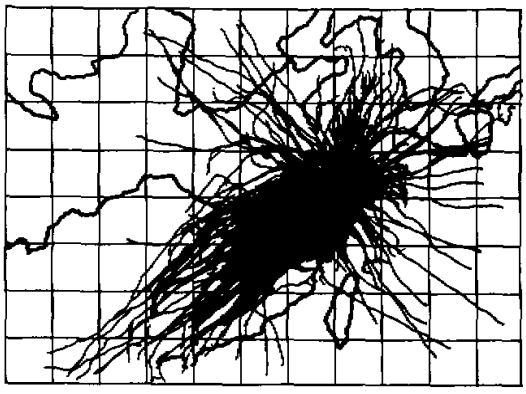

Fig.4. The coming-directions of air parcel trajectories for stationary front, low pressure and cold front system in Shanghai (1985).

In rainy days when trajectories are from southwest, the rainwater is more acidic with mean pH value 5.04; when trajectories are from northeast, rainwater is the most acidic with mean pH value 5.02. Generally speaking, the mean track of trajectory from southwest originates in Gulf Tonkin, via Chaoqing, Nanning, Guilin, Ganzhou, Nanchang, Hangzhou, and then arrives at Shanghai. Trajectories from northeast originate in South Korea and West Japan.

VI. THE TRANSPORT DISTANCE OF PARCEL TRAJECTORY AFFECTING SHANGHAI

Generally speaking, the transport distance of parcel trajectory affecting Shanghai is far. Only 19.1% of air parcels transport less than 600 km / 72 h., 28.7% of them can transfer more than 1200 km / 72 h. The most trajectories affecting Shanghai are from southwest with the farthest distance. 60.4% of them can transfer 1200 km / 72 h (Table 1).

Table 1. Transport distance of Air Parcel Trajectories during 72 h and pH Value of Rian Water in Rainy Days (Shanghai)

Trajectory	Fre. & pH	< 600 km / 72 h	600–1200 km / 72 h	> 1200 km / 72 h
Total	Fre.(%)	19.1	52.2	28.7
	pH	5.25	5.15	5.04
from SW	Fre.(%)	8.6	31.0	60.4
	pH	5.33	5.30	4.94
from S–SE	Fre.(%)	27.0	54.1	18.9
	pH	5.26	5.21	5.16

The pH mean value of rainwater decreases with increase of transport distance, i.e. the rainwater affected by far-distance transport is more acidic. It indicates that the acid rain in Shanghai region is affected by external pollutants transported from far away.

The coming-directions trajectories affecting Shanghai are analyzed according to three kinds of precipitation in Shanghai, (1) a vast extent of acid rain; (2) local acid rain and (3) no acid rain. The obtained results are as follows:

When there is no acid rain in Shanghai region, trajectories are mostly from southeast coastal area and the sea, with the mean transport distance 347 km / 72 h and the mean transport speed 1.3 m / s.

When there is acid rain in a part of Shanghai region, the coming-directions of trajectories are scattered. Some are from southeast Fujian Province, Zhejiang Province and the sea, with the mean transport distance about 697 km / 72 h and the mean transport speed 2.7 m / s.

When there is a vast extent of acid rain with low pH value, trajectories are mainly from southwest with the mean transport distance 1312 km / 72 h and the mean transport speed 5.1 m / s.

VII. THE ANALYSIS OF FORWARD TRAJECTORIES ORIGINATING IN SHANGHAI

Taking Shanghai as the initiated point, we analyzed the going-directions of forward trajectories. It is shown that in the whole year, about 40% of them transport outside to northeast-east-southeast; about 30% of them to southwest-west. In the rainy days, most of forward trajectories transport outside to southwest and northeast. In general, the going-directions of air parcels initiated from Shanghai are relatively scattered, and are not concentrated as that of coming trajectories.

VIII. CONCLUSION

The analysis of air parcel trajectories affecting Shanghai indicates that the coming-direction of air parcel is different in various months. The transport track of trajectory (backward and forward) is closely related to the synoptic system, and also related to acid rain occurring in Shanghai region.

Air pollution and acid rain in Shanghai region have relationship with both the influence of local pollutants and the influence of external pollutants from southwest and northeast.

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