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Study on the Relationship Between Meteorological Conditions and Acid Rain in Mid-Eastern Fujian

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Abstract Based on the acid rain observation data and the contemporaneous historical synoptic charts of Mid-Eastern Fujian during the period of 1991 to 2003, we analyzed the distribution characteristics of acid rain in different seasons, weather types, precipitation grades and wind directions. The results showed that the acid pollution in Mid-Eastern Fujian was still serious. In winter, the precipitation pH value was 4.79, and the acid rain frequency was 60.62% which was twice higher than that in summer. The pH value of warm shear-type precipitation at 850 hPa was 4.79. Nearly half of these precipitations had the problems of acid rain pollution. The acid rain frequency of the inverted trough type was only 26.11% which was the lowest one in all types. There was no marked difference of the acid rain distribution characteristics between ahead-of-trough and behind-the-trough. The precipitation pH values of the five grades were lower than 5.30 and the acid rain frequency changed as an inverted U shape with the increasing of the rainfall. The pH values of precipitations in the eight wind directions were generally below 5.20, and the acid rain frequencies were about 40%.

Keywords Mid-Eastern Fujian · Acid rain · Weather type

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At present, acid rain is recognized as one of the most serious global environment problems. China has become the third largest acid rain-plagued area following Europe and North America (Feng et al. 1999). Including Fujian Province, South China Region is one of the seriously-polluted regions in China. Acid rain not only has done great damage to the national economic construction of Fujian, but also given severe hazards to the ecological environment. Currently there have been six cities of Fujian province on the list of national acid rain control zones. In order to control the acid rain pollution and protect the ecological environment, in recent years both Fujian provincial government and the environmental protection departments have formulated laws and regulations to inhibit further expansion of harm by acid rain.

The results from the present investigation suggested that the occurrence of acid rain was reflected by the chemical property and the variation of source field of local air pollutants, and the precipitation acidity was obviously affected by the change of meteorological condition as well (Lin et al. 2005); Lin et al. (1999) analyzed the characteristics of acid precipitation collected in Taipei, Taiwan during 1991–1995 by performing cluster analysis, and identified that as the northeast flow prevailed during the northeast monsoon season, the concentrations of sea salt and sulfate ions in rainwater were significantly high; when the Pacific high dominated the region, nitrate concentration in rainwater was significantly elevated. Nam et al. (2001) found that the rainwater showed strong acidity in winter and weak in summer in the central part of Korean Peninsula, and the pH and ion concentrations were highly dependent on synoptic weather system. Balachandran and Khillare (2001) collected precipitation samples as wet-fall only and primarily on event basis in Delhi during the monsoon period of 1995, indicated that the pH of the rain water was found to be more than 5.6 during the early phase of monsoon but pH tendency was towards acidity during the late phase, neutralization was not only due to the local process but also due to the pre-monsoon ‘Andhi’. Singh et al. (2007) investigated the chemical composition of wet atmospheric precipitation over Dhanbad for three years and the pH of the rainwater was found well above the reference pH (5.6) during the non-monsoon and early phase of monsoon, but during the late phase pH tendency was towards acidity (<5.6 pH). They found that the acidity was greatly influenced by SO_4 and Ca, and NH_4 played an important role in the neutralization of acidic ions in the rainwater. Liu et al. (2007) made use of acid rain and synoptic data of south Fujian province, and the analysis proved that the cold-trough type, warm-shear type and cold-shear type at 850 hPa had the highest acid rain frequency while the inverted-trough type had the lowest one. The behind-trough southeaster of inverted-trough type had more than twice acid rain frequency as the ahead-of-trough northeaster; the acid rain frequency was high under the westerly while it was minimal with northeaster. Based on the observation of spring’s acid rain in GuangDong and GuangXi Province, Zhang and Meng (1992) found that in the cold front precipitation process, the average of pH value was lower than 5.00, which could be acidity precipitation.

Mid-Eastern Fujian locates in the downstream of Southern China. The industrial infrastructure construction is relatively backward, whereas similar with the south of Fujian province, there are various types of synoptic systems of seasonal precipitation, and the acid rain pollution has been becoming more and more obvious (Lin et al. 2006). The study on the relationship between synoptic system and acid rain has not been developed yet. Therefore, this paper made full use of acid rain observation data and the contemporaneous historical synoptic charts of Mid-Eastern Fujian from 1991 to 2003. Based on the objective analysis of the synoptic background for acid rain formation, we analyzed acid rain distribution characteristics in different seasons, weather types, precipitation grades and wind directions, deepened the understanding of the causes of acid rain formation in Mid-Eastern Fujian and provided objective evidences for the development of the acid rain forecasting in Fujian.

Materials and Methods

Source materials were obtained from 13-year acid rain observation data with contemporaneous historical synoptic charts and rain data of 7 coastal cities including Fuzhou, Putian, Fuqing, Changle, Ningde, Fu’an and Fuding. If precipitation occurred during the period of 8 am to 19 pm, we chose the synoptic chart at intraday 8 am to analyze. If it occurred at the time interval from 20 pm to 7 am, the intraday synoptic chart at 20 pm was taken for reference.

The precipitation samples were tested whenever it happened. 24-h was taken as a time quantum for sample observation. If there was no precipitation within 2 h, the precipitation samples were immediately collected and one sample monitoring was completed. When there were acid rain data of several monitoring points simultaneously in the day in one city, the precipitation pH value was represented as a weighted average of the multipoint rainfall. The precipitation with pH value lower than 5.60 was acid rain, and the acid rain frequency equaled to the percentage of the observation samples with pH value lower than 5.60 in total observation samples. The pH potentiometer method was used to analyze acidity. The pH value less than 4.50 was high acidity and the pH between 4.50 and 5.60 was acidity. The rain water samples were calculated by rainfall weighted average method.

Precipitation Grade: Drizzle: $0.1 \leq R < 2$; Light rain: $2 \leq R < 0$; Moderate rain: $10 \leq R < 25$; Heavy rain: $25 \leq R < 50$; Storm rain: $R \geq 50$ (R stands for rainfall, Unit: mm).

The division standard of wind directions at 850 hPa: there are eight wind directions including E, NE, N, NW, W, SW, S and SE.

The division of Weather Types: Based solely on upper-air chart of 850 hPa, it was separated according to the wind directions at 850 hPa of 10 radiosonde stations including Xia’men, Fuzhou, Shaowu, Nanchang, Ganzhou, Dachen, Quzhou, Shantou, TaiBei and Hualian. The concrete results were shown in Table 1.

Results and Discussion

From 1991 to 2003, there were 2926 acid rain observation samples totally obtained in seven costal cities of mid-eastern Fujian, the annual average precipitation pH value was 4.96 and the acid rain frequency was 43.88%. Comparing with 46.3% of south Fujian, both areas basically reached the same level of the acid rain frequency. Using Daniel’s trend test method to analyze the annual change of precipitation pH value and the acid rain frequency of mid-eastern Fujian, the annual change of precipitation pH value showed a marked increasing trend($r_s > w_{p(0.05)}$), while the downward tendency of the acid rain frequency was not significant ($|r_s| < w_{p(0.05)}$), so the situation of the acid rain pollution in Mid-Eastern Fujian was not optimistic, and the result that the annual average acid rain frequency is above 40% should be paid enough attention.

Table 2 showed the statistical results of seasonal acid rain in Mid-Eastern Fujian from 1991 to 2003. As shown in the table, spring had the most precipitation opportunities

Table 1 Weather types

No.	Weather types	Characters of wind direction
1	Warm shear	Angle between southwester and southeaster
2	Cold shear	Angle between northeaster and southwester or southeaster and northwester
3	Cold trough	Angle between northwester and southwester
4	Warm sectors convergence	Identical southwester, southern wind or southeaster
5	Low-pressure inverted trough	Angle between southeaster and northeaster
6	Low-pressure cyclone	Wind direction proves cyclonic circulation
7	High pressure	Wind direction proves anti-cyclonic circulation

Table 2 Annual and seasonal acid rain distribution in Mid-Eastern Fujian (Acid rain frequency: %, the same below)

Item	Spring (March–June)	Summer (July–September)	Autumn (October–November)	Winter (December–February)	Annual average
Sample amounts	1416	728	236	546	2926
The mean value of pH	4.82	5.41	5.21	4.79	4.96
Acid rain frequency	49.93	20.05	42.37	60.62	43.88

followed by summer and winter, and autumn had the least. Among four seasons, the precipitation pH value of winter was the lowest one which was followed by spring and autumn, and that of summer was as the highest as 5.41. So does the seasonal statistical results of the acid rain frequency, hereinto, the occurrence rate of acid rain in winter is more than twice as many as that in summer. Compared with the documents by Liu et al. (2007), both were costal cities, the occurrence rate of acid rain in summer in Mid-Eastern Fujian is nearly 20% less than that in the south of Fujian, however, in autumn, it was 20% more than that in the south of Fujian. The reason for such regional differences might be that summer and autumn precipitation were mainly local convective precipitations, which was beneficial to vertical diffusion and horizontal convergence of local atmospheric pollutants, therefore the alkalinity–acidity property of precipitation in the two areas chiefly depended on the chemical property of local pollution sources. The precipitations in both winter and spring were mainly storm precipitations, during the process the driving southwester was helpful to transport the atmospheric pollutants outside the southwest Fujian to the costal areas, which influenced the local precipitation acidity. This might be the reason why winter and spring acid rain pollution in Mid-Eastern was more or less similar with that in South Fujian.

Besides the chemical property and field-of-sources transformation of local atmospheric pollutants as the factors influencing the precipitation acidity, the meteorological condition was also an indispensable one. Because various synoptic systems would influence both vertical and horizontal diffusion of local atmospheric pollutants and the external pollutants transportation to some extent. Table 3 showed the acid rain distribution results of different weather types in Mid-Eastern Fujian.

Seen from Table 3:

1. The mean pH values of precipitation on the warm-shear type, the cold-trough type and the cold-shear type were respectively 4.79, 4.79 and 5.00, and all the acid rain frequencies exceed 47%, which were respectively 53.15%, 47.72% and 47.52%, basically reaching the same level of statistical results of the south of Fujian. That was because the common characteristic of the warm-shear type, the cold-trough type and the cold-shear type was that all of them were accompanied by meteorological fronts on the ground. When Mid-Eastern Fujian was situated ahead of front, relatively

Table 3 Acid rain distribution results of different weather types in Mid-Eastern Fujian

Weather types	Warm shear	Cold shear	Cold trough	Warm sectors convergence	Inverted trough	Low-pressure (cyclone)	High pressure
Sample amounts	333	444	725	648	203	165	408
The mean value of pH	4.79	5.00	4.79	4.99	5.53	5.24	5.03
Acid rain frequency	53.15	47.52	47.72	40.28	26.11	41.82	40.93

strong southwester always existed at 850 hPa. In addition, the upper atmospheric stratification was comparatively steady before precipitation, which was favorable to the stacking of local pollutants ahead of front, simultaneously with the southwest warm–moist current at 850 hPa, local and external pollutants were entrained into clouds along the frontal lifting, and then cleaned up by cloud water as freezing nucleus or condensation nucleus. When raindrop fell outside the clouds, the local pollutant which was affected by the below-cloud erosion made its acidity change, then reflected on the change of ground precipitation acidity. Compared with the warm-shear type and the cold-shear type, the moving speed of cold front based on the cold-trough type was more rapid, and the entrainment effect was more distinct. Due to that the chemical property of atmospheric pollutant influencing the precipitation acidity of Mid-Eastern Fujian was relatively complex, the speed of front and the strength of entrainment effect might influence on precipitation acidity under these three weather types to different degrees.

2. The precipitation pH value and acid rain frequency of the inverted-trough type was the lowest one in the seven weather types, its mean pH value of precipitation was 5.53 and acid rain frequency was only 26.11%. That was because under the control of the inverted-trough type, there were always tropical cyclones in eastern South China Sea or Taiwan Strait. Mid-Eastern Fujian was in the northeast current ahead of trough or southeast current behind trough. The east flow came from relatively clean warm–moist air on the sea and it had weaker effect on precipitation acidity of Mid-Eastern Fujian. However, compared with the results based on analysis of the south of Fujian, the acid rain frequency under the control of the inverted-trough type in Mid-Eastern Fujian was nearly 10% less than that in the south of Fujian. It was obvious that the acid rain frequencies of different areas under the same weather type were still different.
3. The acid rain frequencies of warm-sector-convergence type, low-pressure (cyclone) type and high-pressure type were basically similar, respectively 40.28%, 41.82% and 40.93%, and their mean pH values of precipitation were respectively 4.99, 5.24 and 5.03. Under the control of the warm-sector-convergence type, there were accordant southwestern flows over Mid-Eastern Fujian, its precipitation chiefly caused by wind-speed convergence and was mainly intermittent precipitation. Simultaneously, the southwestern warm-moist flow could easily make temperature inversion appear, in the low-layer atmosphere, which was adverse to the diffusion of local pollutants and the occurrence rate of acid rain increased relatively. When the low-pressure (cyclone) type occurred, it not only uplifted the local pollutants into the clouds, but also prompted the horizontal diffusion of local pollutants, so it was obvious that precipitation acidity was affected by the strength of the system itself. The characteristic of the high-pressure type was that it was under the control of anti-cyclonic circulation at 850 hPa, at this time the east wind prevailed in Mid-Eastern Fujian. The external pollutants from the sea were relatively less; moreover, the high-pressure type was mainly accompanied with intermittent thermal thunderstorm, so it had less occurrences of acid rain.

Because the seven weather types would occur in four seasons, then what about the corresponding acid rain distribution results of the seven weather types in different seasons? Thus we analyzed the acid rain distribution of different weather types in the four seasons in Mid-Eastern Fujian, and the results were shown in Table 4.

Seen from Table 4, the warm-shear type in Mid-Eastern Fujian mainly occurred in spring and winter, and more often in spring. In both spring and winter, the mean pH values of precipitation were below 5.00 and the acid rain frequencies were more than 50%, and it could reach the highest value of 67.14% during winter. The mean pH value of precipitation in summer was the highest of 5.48 among the four seasons, and its acid rain frequency was the lowest of 17.07%. Although there was less opportunity that the warm-shear type occurred in autumn, its acid rain frequency reached to 60%. The cold-shear type, cold-trough type and warm-sector-convergence type chiefly appeared in spring, summer and winter, and appeared most in spring. The acid rain frequencies of these three weather types in winter were the highest ones, and all were above 58%, the precipitation of the cold-shear type and the warm-sector-convergence type was the most acid in winter, while the cold-trough type was in spring. The acid rain frequency of these three weather types in summer was lower, below 30%, and the warm-sector-convergence type had the lowest one, only 14.10%. The acid rain of the inverted-trough type occurred most in summer, but its mean precipitation pH value was as high as 5.53, the acid rain frequency was only 20.83%. Although the occurrence rate of inverted-trough type was equivalent in spring, autumn and winter, but their mean precipitation pH values and the acid rain frequency had very wide differences. The acid rain frequency in winter was as high as 60.0%, while in spring it was only 21.74%, and the mean precipitation pH value in winter was 5.27, while in spring it rose to 5.71 and its precipitation indicated alkaline. The low-pressure (cyclone) type mainly appeared in spring and summer, and the acid rain frequency in spring was the highest one, reaching 70.69%,

Table 4 Acid rain distribution results of different weather types in seasons in Mid-Eastern Fujian

Item	Weather types	Warm shear	Cold shear	Cold trough	Warm sectors convergence	Inverted trough	Low-pressure (cyclone)	High pressure
Spring	Sample amounts	197	248	434	380	23	58	76
	The mean value of pH	4.72	4.94	4.69	4.9	5.71	5.01	4.86
	Acid rain frequency	54.82	50	50	45.53	21.74	70.69	51.32
Summer	Sample amounts	41	84	95	156	144	77	131
	The mean value of pH	5.48	5.3	5.36	5.6	5.53	5.52	5.16
	Acid rain frequency	17.07	29.76	15.79	14.1	20.83	23.38	22.14
Autumn	Sample amounts	25	31	38	16	21	10	95
	The mean value of pH	4.89	5.22	5.11	5.08	5.55	5.79	5.14
	Acid rain frequency	60	48.39	42.11	37.5	42.86	10	40
Winter	Sample amounts	70	81	158	96	15	20	106
	The mean value of pH	4.7	4.82	4.81	4.66	5.27	4.9	4.87
	Acid rain frequency	67.14	58.02	62.03	62.5	60	45	57.55

while in summer it was only 23.38%. The mean pH value of precipitation in winter was the lowest one. In autumn there was not only little occurrence of the low-pressure (cyclone) type but also little acid rain, the mean precipitation pH value was above 5.60. The high-pressure type was common in four seasons. In spring and winter, the mean precipitation pH values were low and the acid rain frequencies were both above 50%. Although the precipitation was acid when the high-pressure type appear in summer, the acid rain frequency was only 22.14%.

From Table 4, we could further obtain there were distinct differences on acid rain distribution under the control of different weather types in the same season in Mid-Eastern Fujian, including:

(1) The main weather types appearing in spring precipitation process were the cold-trough type, the warm-sector-convergence type, the cold-shear type and the warm-shear type, among which the mean precipitation pH values of cold-trough type and warm-sector-convergence type were the lowest ones followed by the cold-shear type and the warm-shear type, and the acid rain frequencies of these four types were about 50%. Although the high-pressure type and the low-pressure (cyclone) type had less chance to occur, their acid rain frequencies also exceeded 50%, and that of the low-pressure (cyclone) type reached to 70.69%, and both of the mean precipitation pH values were about 5.00. The inverted-trough type occurred least in spring, and its mean precipitation pH value was also the lowest, and the precipitation was generally alkaline.

(2) The main weather types appearing in summer precipitation process were the warm-sector-convergence type, the inverted-trough type and the high-pressure type. The warm-sector-convergence type had the lowest occurrence rates. Compared with spring, the mean precipitation pH values of the seven weather types in summer were generally increasing. All of the acid rain frequencies fell below 30%, and that of the warm-sector-convergence type was the lowest one, only 14.10%.

(3) There were few precipitation occurrences in autumn, the high-pressure type was dominant in the precipitation process. When Mid-Eastern Fujian was controlled by subtropical high pressure, the acid rain frequency was only 40%, but the precipitation indicated partially acid. The low-pressure (cyclone) type had the least chance to occur in autumn, and its acid rain frequency was only 10%, and the precipitation indicated alkaline. The warm-sector-convergence type had less chance to occur, but it had the highest acid rain frequency which reached to 60%, and its mean precipitation pH value was also as the lowest one among the seven weather types. The precipitation of other weather types indicated acid, but their acid rain frequencies were all about 40%.

(4) The precipitation processes of the seven weather types in winter all indicated acid, the chief precipitation processes were of the cold-trough type, the high-pressure type and the warm-sector-convergence type, the acid rain frequencies of the three were all above 55%, and the warm-sector-convergence type

had the lowest mean precipitation pH value among them. Although the inverted-trough type and the low-pressure (cyclone) type had the least chance to occur, the acid rain frequency of the inverted-trough type was up to 60%, and that of the low-pressure (cyclone) type was also not lower than 45%. The acid rain frequency of the warm-shear type was the highest of 67.14% among the seven weather types in winter.

When Mid-Eastern Fujian was under the control of the warm-shear type, the cold-shear type, the cold-trough type and the inverted-trough type, there was usually trough line at 850 hPa height field, accompanied by frontal interface system on the ground. In view of the significant differences between ahead-of-trough and behind-trough precipitation properties, whether the distributions of acid rain corresponding to the various areas of trough line had differences should be paid attention. Table 5 showed the acid rain distribution results of the four weather types at different parts of trough line at 850 hPa in Mid-Eastern Fujian.

Seen from Table 5, the warm-shear type had the highest acid rain frequency ahead of trough among the four weather types, and next comes the cold-shear type, the cold-trough type and the inverted-trough type, and the acid rain frequency of the inverted-trough type was only 22.83% among them, nearly once less than the former three types. The mean ahead-of-through precipitation pH values of the cold-shear type, the warm-shear type and the cold-trough type were below 5.60, whereas that of the inverted-trough type exceeded 5.60, which showed the majority of its precipitation indicated alkaline. The mean precipitation pH values of the four weather types behind trough were all below 5.60, and the acid rain frequency of the warm-shear type, the cold-shear type and the cold-trough type were all about 50% when these three controlled Mid-Eastern Fujian, only that of the inverted-trough type was the lowest of 28.83%. According to the acid rain distribution results of the four weather types ahead of and behind trough, there was not any significant difference. The result was quite different from the analysis result that when the south of Fujian was under the control of the warm-shear type and the inverted-trough type, the acid rain frequency of behind-trough was as twice as that of ahead-of-trough. It was estimated that before the trough line leaped over Wuyi mountain range in northern Fujian, the Mid-Eastern Fujian kept the ahead-of-trough acid rain distribution characteristic. Once the trough line strided across Wuyi mountain range and was eastward down to the sea rapidly, the ahead-of-trough acid rain distribution characteristic was still the primary one because of the very short time maintained by behind-trough, so the differences between them were not distinct.

The foregoing research showed the change of rainfall in Fuzhou city influenced the acid rain pollution to some extent; the analysis results of Minnan area also confirmed this point (Feng et al. 1999). And then whether such kind of relation existed in Mid-Eastern Fujian was shown in Table 6, which was the analysis result of the relation between precipitation grades and acid rain in Mid-Eastern Fujian.

Table 5 Acid rain distribution results of the four weather types at different parts of trough line at 850 hPa in Mid-Eastern Fujian

Item	Weather types	Warm shear	Cold shear	Cold trough	Inverted trough
Ahead of trough	Sample amounts	206	265	331	92
	The mean value of pH	4.77	5.04	4.68	5.67
	Acid rain frequency	53.4	46.04	44.41	22.83
Behind trough	Sample amounts	127	179	394	111
	The mean value of pH	4.83	4.95	4.92	5.45
	Acid rain frequency	52.76	49.72	50.51	28.83

Table 6 Acid rain distribution results of different precipitation grades in Mid-Eastern Fujian

Item	Sample amounts	The mean value of pH	Acid rain frequency	Spring		Summer		Autumn		Winter	
				The mean value of pH	Acid rain frequency	The mean value of pH	Acid rain frequency	The mean value of pH	Acid rain frequency	The mean value of pH	Acid rain frequency
Drizzle	148	4.86	41.22	4.86	47.06	5.17	16	4.81	45.45	4.75	45.45
Light rain	1119	4.91	40.93	4.87	45.21	5.59	14.06	4.93	37.07	4.69	60.67
Moderate rain	925	4.87	48.76	4.78	54.99	5.27	21.61	5.03	52.11	4.82	61.59
Heavy rain	481	4.84	43.87	4.69	50	5.60	19.7	5.47	36.84	4.73	70.97
Storm rain	253	5.22	40.71	5.05	49.54	5.38	31.9	5.58	42.11	5.33	44.44

Seen from Table 6, the precipitation in Mid-Eastern Fujian was dominated by light rain and moderate rain, the mean precipitation pH values of the five precipitation grades were below 5.60, and those precipitation grades under heavy rain were all below 5.00. The acid rain frequency of the five grades were above 40% and changed as an inverted "U" type, which was different from the analysis of Minnan area that the acid rain frequency increased with the rainfall rising. Further analysis according to seasons revealed that there were notable differences among the acid rain distribution results of the same precipitation grade in different seasons. For example, when drizzle occurred in spring, autumn and winter, the mean precipitation pH values were below 5.00 and the acid rain frequency maintained above 45%, however, the mean precipitation pH value in summer was above 5.00 and the acid rain frequency was only 16%. When light rain fell, the mean precipitation pH value in winter was the lowest one, only 4.69, then followed by spring, autumn and summer. And the acid rain frequency in winter rose to 60.67%, and the next was spring with 45.21%, and that of summer was the lowest of 14.06%. When moderate rain fell, the change trends of acid rain were similar to those of light rain, but the acid rain frequencies were a litter higher than those of light rain, especially in spring and autumn they surpassed 50%. So was the heavy rain, but it was different that the occurrence rate of acid rain in winter was as high as 70.97%. When it came to the storm grade, the mean precipitation pH values in four seasons were all above 5.00, and the acid rain frequencies in spring, winter and autumn were below 50%. On the contrary, there was an addition to that of summer, increasing to 31.90%.

But from the analysis of different precipitation grades in the same season, the mean precipitation pH values of those grades under heavy rain in spring were below 5.00, the acid rain frequency of the precipitation grade between moderate rain and heavy rain was 50% and distributed as an inverted "U" type, along with the rainfall increasing. The mean precipitation pH values of the five grades in summer all rose to beyond 5.00, and the acid rain frequencies dropped markedly. Even if storm rain appeared, the acid rain frequency was only 31.90%, and others were below 22%. Compared with summer, there was a widespread decline in the mean values of precipitation pH in autumn but a rise in the acid rain frequency. The mean precipitation pH values rose with the increasing of rainfall, only the acid rain frequency of moderate rain exceeded 50%. In winter, the mean precipitation pH value of each precipitation grade continued to decline, and those of the precipitation grades under the heavy rain were below 5.00, which was similar to spring. It was different that all the acid rain frequencies between light rain and heavy rain grade in winter were above 60%, and that of heavy rain was as high as 70.97%. The acid rain frequency also distributed as an inverted "U" type with the rainfall increasing, which was different from the analysis of the south of Fujian.

Because acid rain pollution was not only caused by the local pollution sources, the results from the present investigations suggested that the remote atmospheric-pollutant transportation also played a great role in the acid rain pollution of downstream area. The analysis result that '850 hPa was the chief transport height for atmospheric pollutant' was put forward (Zhang and Meng 1992). Therefore, we analyzed the acid rain distribution in eight wind directions in Mid-Eastern Fujian based on the wind field information from the synoptic chart at 850 hPa, at the same time we made a further study on the influence of the seasonal wind field change on the acid rain pollution in Mid-Eastern Fujian. The statistical results could be seen at Table 7.

From Table 7, it was clear that whatever the wind direction was, the precipitation in Mid-Eastern Fujian was generally meta-acid. The southwester at 850 hPa took the leading position in all precipitation occurrences, and the

Table 7 Acid rain distribution results in different wind directions at the height of 850 hPa in Mid-Eastern Fujian

Item		E	NE	N	NW	W	SW	S	SE
Spring	The mean value of pH	4.97	4.92	4.81	4.88	4.92	4.8	4.71	4.71
	Acid rain frequency	48.39	50.5	50.91	49.29	51.15	47.89	55.56	54.4
Summer	The mean value of pH	5.29	5.42	5.45	5.28	5.8	5.48	5.29	5.48
	Acid rain frequency	21.65	21.19	12	18.92	15.25	20.55	17.33	23.47
Autumn	The mean value of pH	5.12	5.27	5.49	5.11	5.09	5.26	4.44	5.25
	Acid rain frequency	42.86	41.67	30	31.82	44.44	41.67	50	55.88
Winter	The mean value of pH	4.93	4.99	5.18	4.76	4.63	4.7	4.84	4.83
	Acid rain frequency	54	54.35	48.48	60.22	76.92	65.41	49.06	62.79
Total sample numbers		258	325	133	292	294	1029	251	343
The mean value of pH		5.10	5.17	5.07	4.89	4.95	4.91	4.87	4.99
Acid rain frequency		38.37	38.77	39.85	47.6	48.3	44.12	42.63	47.81

precipitation pH mean value was 4.91 under the influence of the southwester, and the acid rain frequency reached 44.12%. When Mid-Eastern Fujian was controlled by the eastern wind, the northeaster and the north wind, the precipitation pH mean values were higher than 5.00, and the acid rain frequencies were lower than 40%. While all the precipitation pH mean values of the rest wind directions were lower than 5.00, the corresponding acid rain frequencies were 40%.

To make further analysis according to seasons, the precipitation pH mean values in spring in Mid-Eastern Fujian were below 5.00, and the acid rain frequencies were about 50%, and wind direction had unnoticeable effect on precipitation acidity. Compared with spring, the precipitation pH mean values in each wind direction in summer were increasing distinctly, and the acid rain frequencies declined to nearly half. Except that the precipitation pH mean value was above 5.60 under the influence of west wind, the precipitation in other wind directions generally indicated meta-acid, the acid rain frequencies only maintained from 12% to 24%. In autumn, there was a common fallback of the precipitation pH mean values in all wind directions and the precipitation appeared acid. When the south wind or the southeaster blew, the acid rain frequency rose to more than 50%, while when the north wind or the northwester blew, it was below 32%, and those in other wind directions changed from 41% to 45%. In winter, except the north and the south wind, the acid rain frequencies in other wind directions all exceeded 50%, and that of the west wind was the highest of 76.92%, and then followed by the southwester 65.41% and the southeaster 62.79%. The precipitation pH mean value of the north wind direction was above 5.00, while those of other wind directions were all below 5.00, and that of the west wind direction was the lowest of 4.63 among them.

According to the seasonal change of each wind direction, usually the precipitation of Mid-Eastern Fujian in spring and winter was easy to appear acid rain. Except that the occurrences of acid rain in the north and the south wind direction in spring were more than those in winter, the acid rain frequencies in other wind directions in winter were all higher than those in spring. Summer was the season that had the fewest acid rain occurrences, which was greatly different from the analysis results of the south of Fujian. It was estimated as a result of the differences of geographical positions, the development and scales of local economic construction of the two areas, especially that Mid-Eastern Fujian located northeast of the south of Fujian, with the transportation of the strong southwest flow, the pollutants of the south of Fujian might more or less influence the acid rain pollution in Mid-Eastern Fujian to some extent.

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