ON THE ORIGIN AND THE TREND OF ACID PRECIPITATION IN CHINA

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Abstract. The acidity of the precipitation in China as well as the area affected by acidic raimfalls have increased in the years, along with the rapid economic growth in china. Field observations indicate that acid precipitation often occur are the southern par, of china ,although the emissiors of the precursors are stronger in the North.In this paper,we explain the geographical distribution of acid precipitation in china, based on the content alkaline ions in soil ,soil acidity, atmospheric particulate concentration, aerosol buffering capacity and atmospheric dispersion. It is further anticipated that continuous increasing of sulfur emissions in the North will eventually result in acid rain in the northern part of China. On the basis of the projection of SO_2 and No emissions ,it is argued that the problem of acid precipitation may get worse towars the year 2020,if expenditure on emission control maintains at current level.

1. Introduction

Accompanying the rapid economic development and population growth in east Asia, the world third largest acid rain area emerged in this region, following Europe and North America (Dovland, 1993; Winstanley, 1993; Cheng, 1993; Han, 1993). The main part of this acid rain region is located in the southern part of China, and the area affected is estimated to exceed one million km^2 (Wang et al., 1993). High acidity of rainfall and elevated levels of atmospheric SO_2 have caused severe damage to crops, forests and building materials. In the early 1980's, China initiated a national program to systematically study the acid rain problem in China. This program consists of monitoring, atmospheric processes, studies of effects on natural environments, materials damage, and control technology and strategy. Since then, numerous studies have been conducted. For examples, field observations including those obtained from aircraft found that acid rain in Chongqing and Guiyang areas in southwestern China was mainly caused by local emissions (Huang et al., 1988; Zhao et al. 1988); whereas results on the seasonal variations of rain water acidity and meteorological conditions in the FuJian province in southeastern China indicate that acid rain found in the Jiamen area was primarily caused by long range transport (Yu et al., 1992). Model calculations based on wet deposition data in the Spring in the Guangdong Province in South China also suggest that acid rain there seems to be caused by meso-scale and long

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range transport of pollutants from the northern provinces (Wang et al., 1992a). However, most of the previous work tends to focus on acid precipitation in relatively small spatial scales and are often limited to one or two factors. In the present study, we try to address the acid rain issue on a national scale, and consider several factors that could affect this complex environmental problem. In particular, our attempt focuses on explaining the fact that acidic rainfalls often are observed in South China although the North tends to have stronger sources of precursor emission.

2. Current State of Acid Rain in China

In 1982, the National Acid Rain Monitoring Network was established by the Chinese National Environmental Protection Agency and managed by the National Environmental Monitoring Center. One of the objectives of this network is to collect rain samples nationwide and to analyze them for chemical composition. Mean pH values of rain water obtained from this network in 1982 and 1992 are summarized in figure 1 (Cheng et al., 1993). It is obvious that the acid rain region is located in the South. In addition, it is estimated that the acid rain area has increased by about 600,000 - 700,000 km^2 since 1982 (Wang et al., 1993).

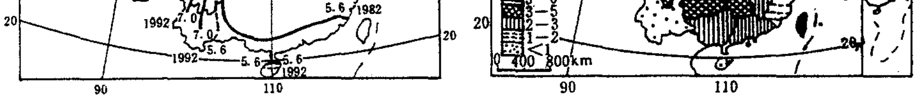

Fig. 1 Contours of annual volume weighted mean pH of rain water

3. Factors Affecting Acid Rain Formation

3.1 Emission intensity of precursors

As a part of the study of acid rain in China, emission intensities of SO_2 and NO_x were compiled for each economical sectors (Wang et al., 1993), based on the fuel consumption, sulfur content of the fuel and emission factors. The province-based SO_2 emission intensities are illustrated in Figure 2. Geographical distributions of NO_x emission intensities are similar to those of SO_2 and are not presented here. From figure 2, it can be seen that provinces with the strongest emission intensities are located in the coastal regions facing Bo Hai and the Yellow Sea. These provinces include: Jiansu, Shandong, Liaoning, Hebei and Shanxi, all with emission intensity larger than 7.4 ton SO_2/km^2. Although these five provinces combined account for only 9% of the nation's land area, their SO_2 emissions in 1990 were 40 % of total emissions in China. However, acidic rainfalls have not yet been observed in these provinces. On the contrary, southern provinces including Jianxi, Fujian, Guangdong and Guangxi have relatively smaller SO_2 emission intensity (less than 2.6 ton/km^2), and yet they have experienced serious acid precipitation. As will be discussed in the following sections, factors other than precursor emission intensity appear to play more dominant roles in the formation of acid precipitation in the South.

3.2 Chemical composition of precipitation

The composition of rain water collected from 16 cites in the South and 11 cities in the North showed that the averaged concentrations of SO_4^{2-} and NO_3^- in the northern cities are 217.6 and 29.3 ueq/l, respectively. Their values in the South are 125.1 and 20.0 ueq/l, respectively. Total concentration of acidic ions in the North is about 1.7 times of that in the South. Meanwhile, the NH4- content in the rain samples from the South and North is comparable, but there is significant difference in the calcium and magnesium concentrations: total concentration of Ca^{2+} and Mg^{2+} in the North is approximately 3 times of that in the South. Therefore, acidity of rainfall in the North is significantly reduced due to abundant alkaline ions in the rain water. Thus, the acidity of rain water does not depend on absolute amount of acidic ions, but rather the amount of acidic ions relative to alkaline ions.

3.3 Atmospheric particulate matters and their buffering capacity

China has a large territory with distinct natural conditions across the nation. In the North, because of the relatively drier weather and less coverage of vegetation, concentration of atmospheric aerosols is higher than that in the South where it is typically moist and there is abundant plant coverage on soil.

In the non-acid rain region in the North, aerosols have high neutraling ability, thus have stronger buttering ability to acidic rain water. In the acid rain region in the South, however, aerosols tend to be of acidic nature, and thus they can hardly buffer the acidity of rain water.

3.4 The contents of alkaline matters in soil

Studies conducted in different regions in China indicate that 30-70% of urban airborne particulate matters originate from soils (Wang et al., 1992b). The distributions of alkaline matters in soils are closely correlated with the pH contour of rain samples shown in figure 3(Chen, 1995). Namely, regions with low calcium and sodium content are also those affected by acid rain. Therefore, chemical composition of aerosols and its subsequent impact on acidity of rain water may be largely determined by the nature of soils.

3.5 Meteorological Conditions

Meteorology can influence acidity of rain water in at least the following ways: it affects chemical reaction rates, dispersion, transport and deposition of air pollutants.

(1) Effects on photochemical reaction rates

The initial oxidation rate of SO_2 in China has been described by the following empirical formula (Wang et al., 1990)

$R= 0.175.RH + 2.03.lnIo + 0.0704.[SO_2] - 2.35$

where R is the oxidation rate of SO_2 (ppbv.h-1), RH is relative humidity (%), Io is sunlight intensity (kw/m2), and $[SO_2]$ is mixing ratio of SO_2 (ppbv). This formula shows that stronger intensity of sunlight and higher relative humidity will increase the photochemical conversion rate of SO_2 to sulfate. In general, sunlight intensity and relative humidity decrease with increase of latitude, and thus the South tends to favor faster photochemical production of sulfate.

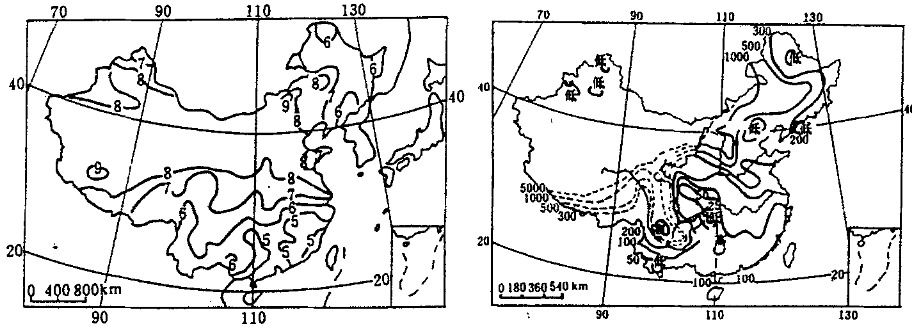

Fig. 2 Annual emission intensity of sulfur dioxide, t / km^2 1990

(2) Effect on transport and deposition

Transport and deposition of acidic species are strongly affected by meteorological conditions. Xu et al. (1989) calculated ventilation and rainout capacity in China using a steady-state box model. Figure 4 shows the half value of rainout region length (HRRL) defined as the downwind extent of a box in which air pollutants are rained out as much as carried out of the box by winds, that is

$\Delta Xw = 53V_E/R$

where Δ Xw is half value of rainout region length (km), V_E is ventilation (m^2/s), and

R is precipitation (mm/year). It can be seen that Δ Xw is proportional to ventilation and inversely proportional to precipitation and it is a measure of relative intensity of transport versus deposition of acidic species. From figure 4, it can be seen that areas with short HRRL overlap the acid rain regions. HRRLs are shorter than 100 km in the Sichuan Basin in South China, and are also short in the southern part of Yunan Province as well as in some parts of northeastern China. On the other hand, in northern- and large portions of northeastern China, HRRLs are general long and are between 300 to 500 km, suggesting that air pollutants may be easily transported to other regions as opposed to being washed out and removed from the atmosphere.

As discussed above, the distribution of acid precipitation in China can be explained according to precursor distribution, total suspended particulate matters and their buffering capability, alkaline matter contents in soils and meteorological conditions. Based on our current understanding, the future trend of acid rain in China can be speculated.

4. The Trend of Acid Rain in China

4.1 Projection of precursor emissions

From the increase of energy consumption and available desulfurization investment, SO_2 emissions in the year 2020 were projected by Han (1993) that SO_2 emissions in China would continue to increase through the year 2000, 2010 and 2020, reaching 20.98, 27.67 and 31.28 million tons, respectively. SO_2 emissions in the year 2020 would increase by 80% over that in 1990. At that time, China would probably be the largest SO_2 emitter among the three acid rain regions in the world. NO_x emissions are also projected to increase and probably at faster rates since NO_x emission control is more difficult and more expensive.

4.2 Historical trends of acid rain in typical areas in China

Historical trends of pH of rain water from five typical cities in China are shown that pH of rain water showed consistent decrease in all five places from 1982 to 1990. In the Wudu area of the Gansu Province in the Northwest, pH value decreased by 1.5 units in 8 years. The pH of rain water in all other cities have decreased about 0.4-1.0 pH unit in the same time.

4.3 Future trend of acid rain in China

Since the quantitative relationship between acidity of rain water and precursor emissions has not yet been fully established, it will be difficult for us to give a quantitative prediction about the acidity in rain water in China. However, on the basis of the acid rain formation mechanism, historical trends of rain water acidity and the projection of future precursor emissions, we argue that towards the year 2020 the acidity in rain water in China may continue to increase, the area affected by acid rain may continue to expand and may move toward the northern- and western parts of China.

5. Conclusion

5.1 In northern China, five provinces along the coast of Bo Hai and Yellow Sea account for only 9% of total national area, but 40% of total SO_2 emissions. Acid rain has not been observed in the region. It is believed that this due to alkaline nature of atmospheric particulate matters that exert strong buffer to acidity of rain water in the North.

5.2 Atmospheric particulate matters in northern China have very different characteristics than those in the South. Total suspended particulate concentration in the North is nearly twice of that in the South is about one order of magnitude higher than that in the South. Thus the aerosols in the North have stronger buffering ability to acidity of rain water. The difference in composition of airborne particulate matters is attributed to the difference in soil property: alkaline in the North, and acidic in the South.

5.3 Meteorological conditions are also different in the North than in the South: In the South, weaker atmospheric dispersion, higher humidity and more sunlight favor the formation of acidic species there.

5.4 It is projected that SO_2 emission in China will reach 31.78 million tons in the year 2020, or 80% increase from 1990. It is argued that acid rain pollution in China may get worse toward the year 2020. The acidity of rain water may continue to increase, the acid rain area may continue to expend, and new acid regions may emerge.

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