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Air Pollution Monitoring in East Asia
— Japan's Role as an Environmentally Advanced Asian Country —

Hirokazu Fukushima
Environment and Energy Research Unit

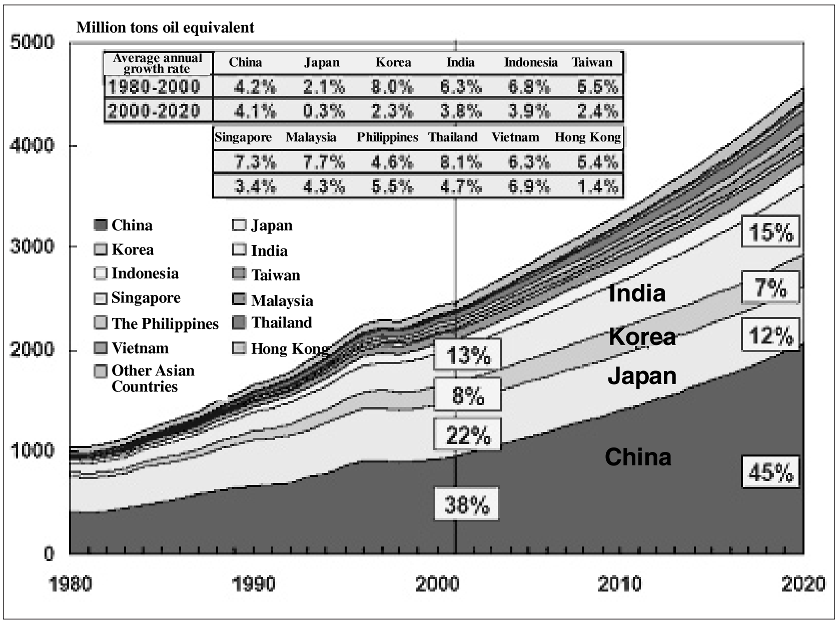
1 Introduction

As shown in Figure 1, primary energy consumption in East Asian countries -more than one third of the world's population live in- is surging with the rapidly growing regional economy. However, oil has yet to replace coal as the primary energy source in these countries, many of which are still dependent on coal with a high sulfur content. Meanwhile, with the rapid motorization in China and in the other emerging economies in the region, the atmospheric concentrations of sulfur oxides (SOx), nitrogen oxides (NOx), suspended particulate matter (SPM) and ozone (O_3) are on the rise, causing serious air pollution.

Air pollutants, once released into the atmosphere, are carried across borders through the general atmospheric circulation (seasonal winds, etc.), and this could have a serious impact on other countries. Given the ever-expanding economic activities in East Asia, transboundary air pollution is expected to pose a serious problem in the near future, necessitating immediate measures.

This article describes the role of monitoring of ambient air quality and pollutant emission sources in solving air pollution problems, while providing an overview of Japan's efforts to significantly reduce air pollutants, primarily through monitoring activities. The development of a regional monitoring network is critical in addressing transboundary air pollution in East Asia, where Japan, as an environmentally advanced country, has a role to play.

Figure 1 : Trends in primary energy consumption in Asian countries



Source: The Institute of Energy Economics, Japan[1]

2 Possible impact on Japan of air pollutants originating in the Asian Continent

2-1 Acid rain in the region along the Sea of Japan

According to a nationwide survey on acid rain conducted over the past two decades by the Ministry of the Environment (completed in 2002), the amounts of sulfate and nitrate ion deposits in acid rain vary both seasonally and regionally. Specifically, they peak during the winter months in the central and northern regions along the Sea of Japan and in the San-in region. This observation suggests that SOx and NOx originating in the Asian Continent were carried aloft by the winter winds to reach the region along the Sea of Japan[2].

Meanwhile, the results of a numerical model for the transport of transboundary air pollutants during the high wind period (from January 15 to February 14, 1999) indicate that 62% and 16% of the SOx deposits observed in Japan originate in China and Korea, respectively. The air pollutants released in the Asian Continent could therefore have a significant impact on Japan[3].

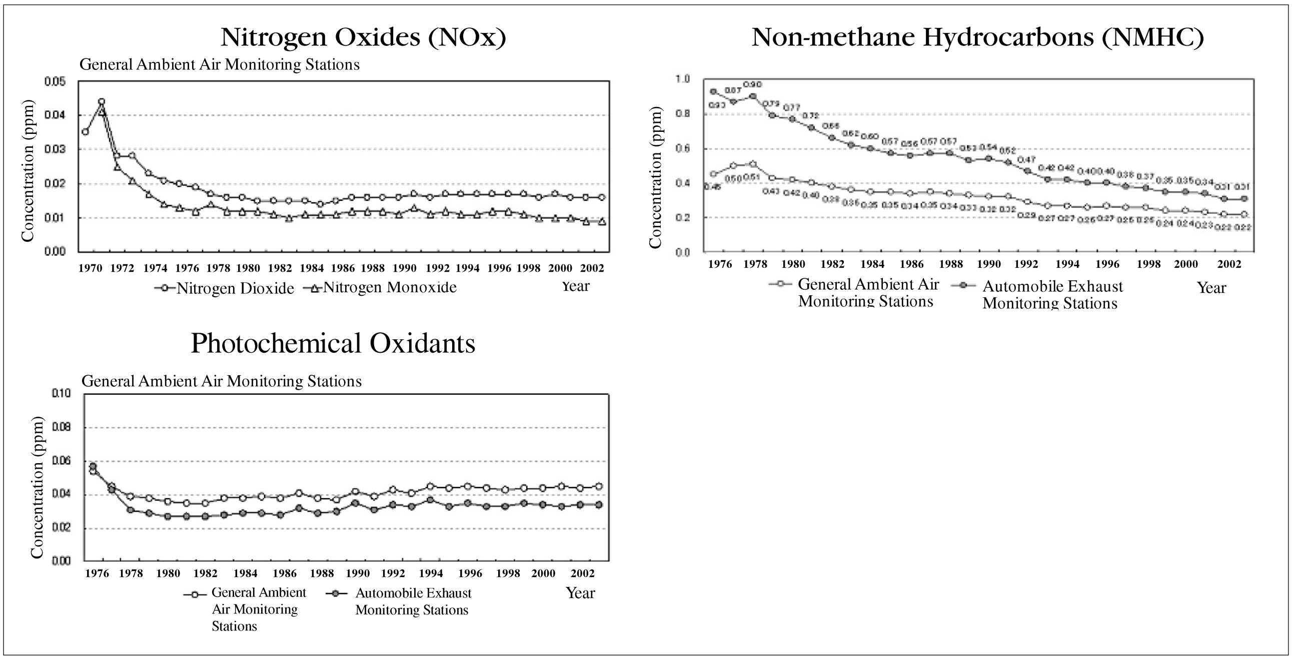
2-2 Tropospheric ozone concentrations over Japan

Figure 2 shows the concentrations of NOx, non-methane hydrocarbons (NMHC)*1 and photochemical oxidants*2 in Japan, while Figure 3 shows the number of days when photochemical oxidant warnings were issued in Tokyo. While NOx and NMHC concentrations have been stable or declining in recent years, photochemical oxidant concentrations are increasing across the country. As a result, environmental standards*3 for photochemical oxidant concentrations are not complied with in many areas, and the number of warnings shows no sign of abating in metropolitan areas. The Japan Agency for Marine-Earth Science and Technology analyzed data on tropospheric ozone concentrations using backward trajectory analysis*4 in an effort to explain this phenomenon. The results of this analysis indicate that NOx originating in East Asia contributes to increasing tropospheric ozone concentrations over Japan, which is located in the lee of East Asia, during the spring and summer months when photochemical reactions peak[4].

2-3 Brown clouds

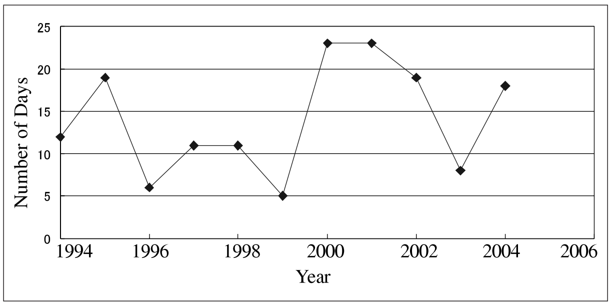
Brown clouds have been observed in recent

Figure 2 : Trends in the average concentrations of nitrogen oxides, non-methane hydrocarbons and photochemical oxidants in Japan



Source: Reference[5]

Figure 3 : Number of days where photochemical oxidant warnings were issued in Tokyo



Source: Reference[6]

years over the Asian region. Brown clouds, averaging about 3 kilometers in thickness, are made up of high concentrations of aerosols*5 and yellow sand. These airborne particulates block the sunlight, resulting in less sunlight reaching the earth's surface — a phenomenon that has a serious impact on crop production and may have been implicated in recent unusual monsoon weather patterns in Asia. The United Nations Environment Programme (UNEP) launched an international research project in 2003 to investigate brown clouds in Asia.

2-4 Transboundary air pollution problems

As mentioned earlier, acid rain, photochemical oxidants and suspended particulate matter have all proved to be transboundary air pollution problems. Keeping track of the atmospheric concentrations of SOx, NOx, ozone and SPM in the whole of East Asia is considered a critical first step towards solving these problems.

3 The role of monitoring in addressing air pollution problems

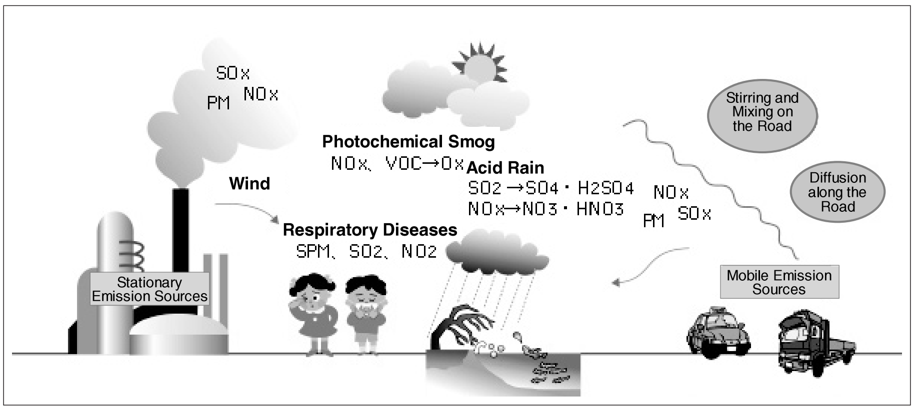
3-1 Mechanisms of air pollution

As shown in Figure 4, emissions from stationary sources (fossil fuel combustion gases) and mobile sources (tailpipe emissions) contain pollutants such as SOx, NOx, particulate matter (PM) and volatile organic compounds (VOCs). SOx and NOx, when inhaled, cause respiratory disease. They are converted to sulfuric acid and nitric acid in the atmosphere, causing acid rain. In addition, NOx and some VOCs (non-methane hydrocarbons), when exposed to strong ultraviolet radiation, are converted to photochemical oxidants, irritating the eyes and respiratory organs. Very fine particulate matter is suspended in the air, and hence is called "suspended particulate matter (SPM)". It is considered to cause respiratory disease and climate change.

3-2 The role of air pollution monitoring

The first step in instituting measures against air pollution is to have a clear picture of the current pollution situation through ambient air monitoring. Such measurement values are a basis for setting emission standards for environmental measures. Ambient air monitoring plays a vital role in assessing and reviewing environmental measures, which are implemented by repeating the cycle of (1) understanding the current situation (through ambient air monitoring), (2)

Figure 4 : Mechanisms of air pollution



Source: 2004 Energy White Paper[7]

formulating and implementing specific measures, and (3) reviewing achievements (through ambient air monitoring), as shown in Figure 5.

(1) Ambient air monitoring

Ambient air monitoring can be broadly categorized into (1) regional monitoring, which keeps track of local pollution, and (2) broad-based monitoring, which is not influenced directly by air pollution sources, and provides background measurements.

Regional monitoring is conducted by monitoring stations around the world, each of which provides representative data for the region in which it operates. In Japan, two types of monitoring stations are in operation: general ambient air monitoring stations (continuous monitoring of general air pollution), and automobile exhaust monitoring stations (continuous monitoring of air pollution caused by automobile exhaust).

Broad-based monitoring, meanwhile, is designed to keep track of the medium to long-range transport of air pollutants (several hundred to several thousand kilometers). It is conducted in locations away from pollution sources such as Oki (Shimane Prefecture) and Hedo Cape (Okinawa Prefecture).

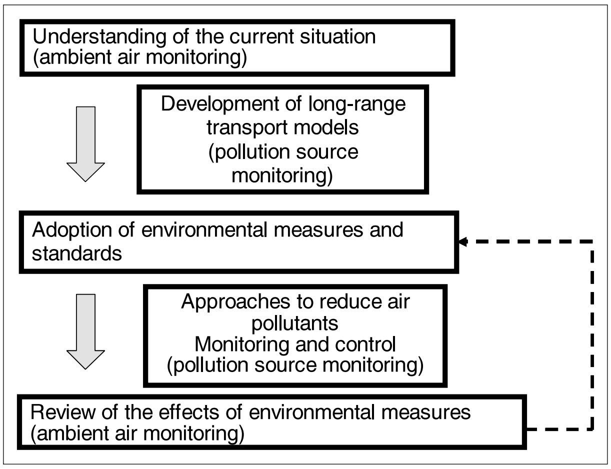
These monitoring systems, both essential in keeping track of air pollution levels, should be integrated to establish a monitoring network.

(2) Pollution source monitoring

Long-range transport models are quite effective in shedding light on how air pollutants are transported over thousands of kilometers.

The development of such accurate transport models involves the identification of pollution sources (factories, facilities, etc.) along with the types and amount of pollutants released into the atmosphere. This can be done by monitoring air pollution sources. In a situation where environmental measures are in place — with factories, facilites, etc. implementing measures to reduce air pollutants — there is a need to monitor pollution sources to ensure that emission standards are observed. Such pollution source monitoring is also needed to measure emissions in real time, as a means of controlling combustion processes and the operation of desulfurization/de nitrification facilities.

Figure 5 : Measures against air pollution



Source: Prepared by STFC

3-3 Controlling the accuracy of ambient air monitoring

Measurement values obtained from ambient air monitoring should be accurate in order to keep track of the pollution situation in the region concerned. In other words, certain standards should be set for measuring instruments, and measurements should be conducted in accordance with prescribed procedures. It is therefore essential that operating procedures for the entire monitoring process (including calibration procedures using standard samples) be established and accuracy assurance/control be implemented at each monitoring station. Specific approaches to ensure the accuracy of measurement values include:

(1) Preparation of high accuracy standard samples
(2) Establishment of a calibration system
(3) Regular cross-checking among monitoring networks
(4) Establishment of a data management system
(5) Improvement of technical training for monitoring activities
(6) Development of standard operating procedures (SOPs) for monitoring site selection, sampling, sample preservation, pretreatment and analysis
(7) Establishment of a reference center to put the above approaches into practice

Table 1 : History of air pollution in Japan

Year	Description
Early 1960s	Air pollution in Yokkaichi City became an object of public concern
1968	The Air Pollution Control Law was enforced
1969	SO_2 environmental standards were set
1970	Photochemical smog occurred frequently
1974	Total volume control was introduced for sulfur oxides (SOx)
1978	Automobile emissions control was introduced
1978	NO_2 environmental standards were revised
1981	Total volume control was introduced for nitrogen oxides (NOx)
1992	The Automobile NOx Law was enforced
2001	The Automobile NOx Law was revised to control particulate matter (the Automobile NOx and PM Law)

Source: Reference[10]

Each of these is essential in developing an ambient air monitoring network.

3-4 Japan's ambient air monitoring network

Japan's rapid economic growth in the post-war period took its toll, with serious air pollution in large cities and areas surrounding industrial districts. With the combustion of heavy oil containing about 3% sulfur, for example, a massive amount of SOx was released into the atmosphere in Yokkaichi City (an industrial city in Mie Prefecture) around 1960, causing serious air pollution known as the Yokkaichi Pollution (see Table 1). As a result, local residents suffered bronchial asthma, pulmonary disease and respiratory disease. Against this background, continuous air pollution monitoring was launched in 1962 in large cities (Tokyo, Osaka, etc.) and areas surrounding industrial districts (Yokkaichi, etc.), followed by the enactment of the Air Pollution Control Law in 1968. In the same year, the Osaka Prefecture Government established an online, real-time air pollution monitoring system, connecting 15 local monitoring stations through radio transmission. Other municipalities followed suit, setting up similar systems[8]. As of 2004, sulfur dioxide is monitored at 1,487 stations, nitrogen dioxide at 1,880 stations, photochemical oxidants at 1,193 stations, suspended particulate matter at 1,910 stations, and carbon monoxide at 401 stations. This nationwide monitoring network is designed to keep track of air pollutant concentrations and appropriate measures are taken immediately when these concentrations exceed environmental standards. The Air Pollution Control Law, meanwhile, mandates prefectural governors to monitor the air environment around the clock and report the results. Each governor is authorized to take emergency measures when air pollution is severe enough to damage human health and the living environment.

In 2001, the Atmospheric Environmental Regional Observation System dubbed "Soramame-kun"[9] was introduced, with real-time monitoring results provided by each monitoring station being made public through the Internet. This system is unique in that it allows proactive measures to be taken to counter unusually high atmospheric concentrations of photochemical oxidants. It is expected to contribute to raising public awareness of air pollution. Table 2 outlines Japan's air quality standards and the number of monitoring stations.

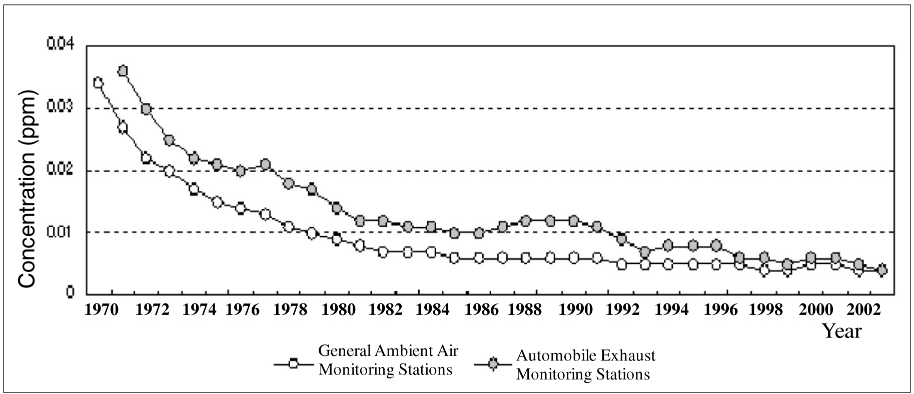
Figure 6 shows the trends in the average SO_2 concentrations measured by general ambient air monitoring stations and automobile exhaust monitoring stations. The annual average decreased dramatically in the fourth and fifth decades of the Showa Era (1965-1984). They have been stable or declining in recent years. As these results suggest, SO_2 emissions (a major cause of acid rain) are now significantly reduced in Japan. This achievement is due, in large part, to a series of environmental measures based on the advanced ambient air monitoring network and pollution source monitoring, which together,

Table 2 : Air quality standards and the number of monitoring stations

Subject	Standards	Number of Monitoring Stations (2004)
Sulfur Dioxide (SO_2)	0.04 ppm (Daily average) 0.1 ppm (Hourly average)	1,487
Carbon Monoxide (CO)	10 ppm (Daily average) 20 ppm (8-hour average)	401
Suspended Particulate Matter (SPM)	0.10 mg/m^3 (Daily average) 0.20 mg/m^3 (Hourly average)	1,910
Nitrogen Dioxide (NO_2)	0.04 ppm - 0.06 ppm (Daily average)	1,880
Photochemical Oxidants (Ox)	0.06 ppm (Hourly average)	1,193

Source: Prepared by STFC based on Reference[11]

Figure 6 : Trends in the average SO_2 concentrations



Source: Reference[6]

encourage factories, facilities, etc. to take emission reduction measures.

4 Approaches to transboundary air pollution in the West and Asia

4-1 Measures in Europe

In the latter half of the 1960s, environmental problems such as lake acidification (resulting in the extinction of fish and aquatic organisms) and the death of forests began to become apparent in the Scandinavian Peninsula and other parts of Northeastern Europe. The cause was considered to be transboundary air pollutants (SO_2, etc.) originating in Western Europe. An international, continent-wide monitoring system was immediately put in place to address these problems. Subsequently, in 1972, 11 OECD member countries jointly launched a monitoring network in compliance with the "OECD Programme on Long-range Transport of Air Pollutants."

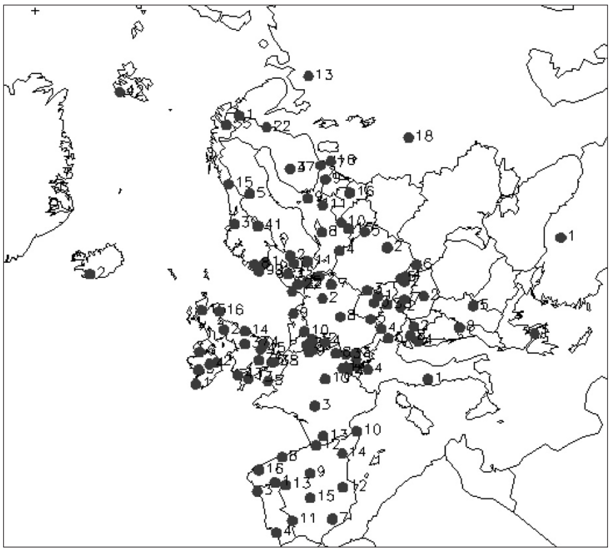
In addition, the OECD conducted a research study between 1973 and 1975 on the long-range transport and deposition of airborne sulfur in Eastern and Western Europe, the results of which showed that acid deposition had spread across Northwestern Europe. The United Nations Economic Commission for Europe (ECE), meanwhile, launched the "European Monitoring and Evaluation Programme" (EMEP) in 1977 to create a long-range transport model for air pollutants. A network of 60 monitoring stations located in 16 countries is now in place. Data collected by each station are fed for analysis to the Chemical Coordination Centre (CCC) of Norwegian Institute for Air Research. Figure 7 shows the locations of the EMEP monitoring stations for acidic substances.

In Europe, the accumulation of scientific data through the monitoring networks shed light as early as the 1970s on the mechanisms of acid deposition - i.e., acid fallout originates not only from domestic sources but also from overseas sources located hundreds to thousands of kilometers away from monitoring stations. As a result, in order to address a broad range of problems, measures against air pollution in Europe evolved further, from the initial stage of using ambient air monitoring and long-range transport modeling, to the next stage which saw the development of international environmental measures.

In 1979, the ECE took the lead in concluding a groundbreaking international treaty on transboundary air pollution, the Convention on Long-range Transboundary Air Pollution (Geneva Convention), in which a total of 35 countries, including the former Soviet Union, the U.S. and Canada, participated. Following the signing of the treaty, the Helsinki Protocol was ratified in 1985 by 25 countries, with the 1993 goal of reducing sulfur emissions and their transboundary fluxes to 30% below their 1980 levels. With these measures in place, Europe has achieved a breakthrough in reducing SO_2 emissions, a major cause of acid rain. Figure 8 shows the trends in SO_2 emissions in Europe (the EMEP member countries). Annual emissions were reduced by 56% between 1980 and 1998.

About 100 monitoring stations are in operation under the EMEP, with each of them monitoring SO_2, NO_2, SPM and ozone. Another network is in place to monitor transboundary air pollutants other than acidic substances. EMEP monitoring stations for SPM and ozone are shown in Figures 9 and 10.

Figure 7 : EMEP monitoring stations for acidic substances (2001)



Source: Reference[12]

4-2 Measures in North America

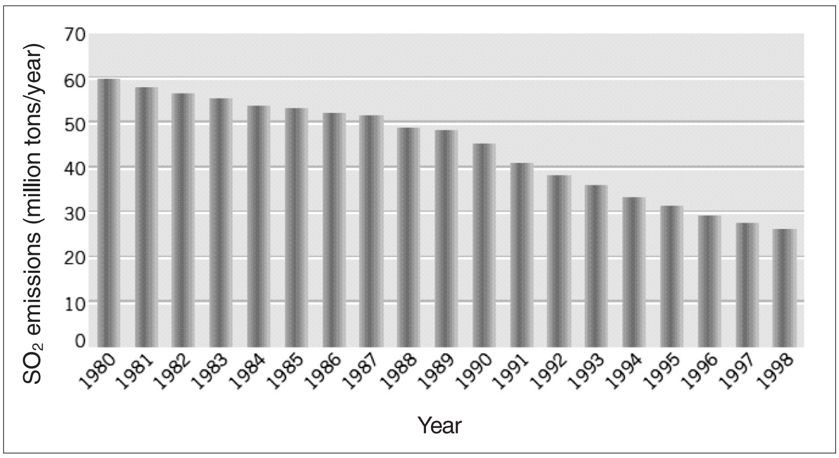
Acid rain and snow, which had begun to cause serious damage to trees (maples, etc.) and freshwater fish in North America, subsequently emerged as public concerns.

The U.S. and Canadian governments launched a bilateral research convention in 1973 on the long-range transport of air pollutants in order to exchange information regarding acid fallout, and signed a memorandum on transboundary air pollution in 1980 to elucidate the mechanisms of acid rain through monitoring networks, etc. In addition, the U.S. government announced a major revision of the Clean Air Act in 1990. As a result, SO_2 emissions in the U.S. were reduced from 20 million tons in 1990 to 15 million tons in 2000[14].

4-3 Measures in Asia

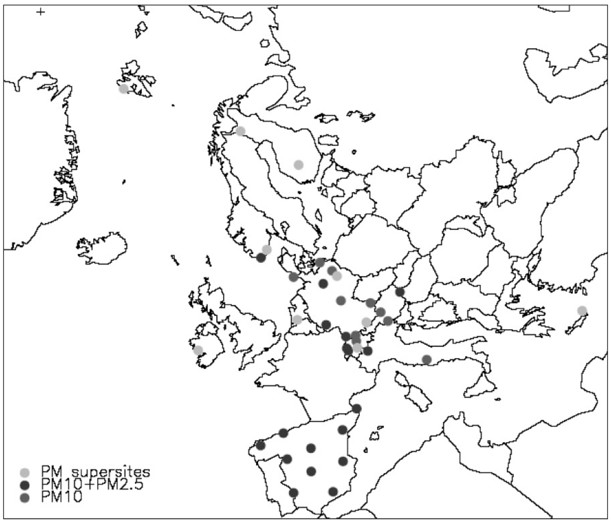
Measures against transboundary air pollution start in the 1990s.

Figure 8 : Trends in SO_2 emissions in Europe (EMEP member countries)



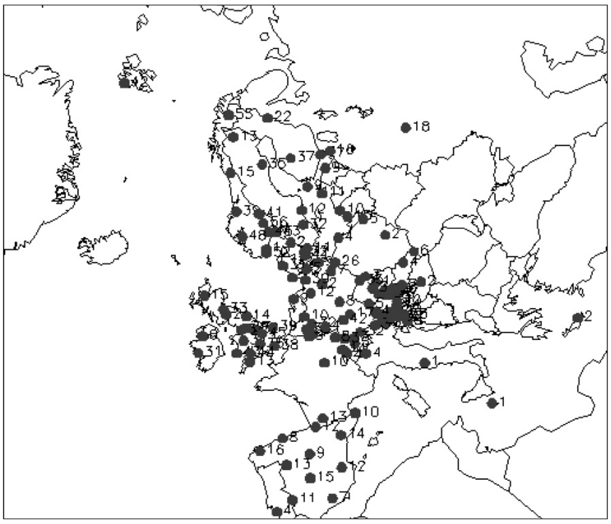
Source: Reference[13]

Figure 9 : EMEP monitoring stations for suspended particulate matter (2001)



Source: Reference[12]

Figure 10 : EMEP monitoring stations for ozone (2001)



Source: Reference[12]

In 1991, the Environment Agency of Japan (now the Ministry of the Environment) proposed the concept of an "Acid Deposition Monitoring Network in East Asia" (EANET), with the aim of preventing the effects of acid rain in the East Asian region. As a result of this initiative, since 1993, Japan has played a leading role in giving expert advice on acid rain monitoring networks in East Asia. The acid rain problem involves a variety of factors such as the acidity of rain, snow, gas and aerosols, as well as their chemical composition, and the tolerance which soil exhibits to them. In monitoring acid rain, therefore, not only should the pH of the rain be monitored, but also its ion concentrations, as well as dry deposition. As mentioned in Section 3-3, monitoring methods and accuracy should be standardized internationally for data comparison purposes. In 1997, consultation by experts highlighted the need to develop a regional monitoring network where each country performs acid rain monitoring using a standardized methodology. In response to this, EANET was test launched in April 1998, and began fully fledged operations in January 2001, based on an intergovernmental agreement. The secretariat of EANET is located at UNEP RRC.AP (Regional Resource Centre for Asia and the Pacific) in Bangkok, while the Acid Deposition and Oxidant Research Center in Niigata Prefecture serves as a network center in which a total of 12 countries (China, Indonesia, Japan, Malaysia, Mongolia, the Philippines, Korea, Russia, Thailand, Vietnam, Cambodia and Laos) participate. Figure 11 shows the locations of the EANET monitoring stations.

Figure 11 : EANET monitoring stations for acidic substances

Source: Reference[15]

A monitoring network is designed primarily to disseminate information that is useful in developing national and regional policies for the prevention of the negative impacts of air pollution on the environment. Both broad-based monitoring of background pollution levels and regional monitoring of local pollution levels need to be improved for this purpose, as mentioned in Section 3-2 (1). EANET monitoring stations, however, are located in areas mainly for background monitoring (broad-based monitoring). More stations are needed to keep track of regional pollution levels. In addition, technical training should be provided for the staff members of new monitoring stations to ensure the reliability of the data they supply.

The existing ambient air monitoring system of EANET, meanwhile, is designed mainly to monitor air pollutants causing acid rain (NO_2 and SO_2). A monitoring network for other transboundary air pollutants such as SPM and ozone - like the one run by EMEP - has yet to be developed in Asia.

5 Conclusion : Japan's role and responsibilities

It was in Europe that acid rain was first recognized as being a manifestation of transboundary pollution. A monitoring network encompassing the entire European continent is in place to keep track of transboundary air pollutants, in line with the European Monitoring and Evaluation Programme (EMEP). In addition, the promotion of international environmental measures has contributed dramatically to reductions in SO_2 emissions (a major cause of acid rain). Under EMEP, a further network is in operation to monitor SPM and ozone in addition to acidic substances.

An immediate improvement in the air pollution monitoring network covering the entire East Asian region should be the first step towards addressing transboundary air pollution involving acid rain, SPM and ozone - each of which poses a great threat to the region. The Acid Deposition Monitoring Network in East Asia (EANET) began fully fledged operations in 2001 based on an intergovernmental agreement, with 12 East Asian countries taking part as of 2005. This network, however, requires more monitoring stations in order to be on a par with EMEP in terms of the scope of monitoring. It should also keep track of air pollutants other than acidic substances.

Japan, as an environmentally advanced Asian country, should take the lead in improving and expanding the scope of EANET. Specifically, the following should be put into practice.

(1) Expansion of the monitoring network

EANET monitoring stations for acid rain are located in areas mainly for the purpose of background monitoring (broad-based monitoring). More stations are needed to keep track of regional pollution levels. The following two issues are critical in expanding the monitoring network:

1) Technical training to ensure the accuracy of monitored values

For data comparison purposes, each monitoring station should perform monitoring in accordance with standard operating procedures. In addition, theoretical training should be complemented with on-the-job training in the use of measuring instruments to ensure the accuracy of data provided by new monitoring stations. In addition, a system should be implemented whereby local technical experts and staff members manage technical training on a continuous basis. As part of its international cooperation, Japan, which has expertise and years of experience in measurement technology, should offer technical support to other East Asian countries to assist them in managing their own technical training independently.

2) Development of low-cost analytical instruments

Budgets should be increased and, in addition, low-cost analytical instruments should be developed to improve the monitoring network. Japan, which has extensive technical expertise in such instrumentation, should therefore strive to lower the cost of ambient air monitoring instruments (continuous monitoring). Increasing the number of monitoring stations by introducing simple measurement methods (batch measurement) would also be effective.

(2) Creation of a monitoring network for suspended particulate matter and ozone

There has been a growing need to create a monitoring network encompassing the East Asian region in order to keep track of SPM (including yellow sand, and particulate matter in automobile exhaust and plant emissions), and ozone (a major cause of photochemical smog) in the regional atmosphere. Such a network could be created quickly by improving the existing EANET monitoring system. In other words, it is recommended that a network be put in place to monitor not only acidic substances such as SO_2 and NO_2, but also SPM and ozone. The issues described above - technical training to ensure the accuracy of monitored values, and development of low-cost analytical instruments - should also be addressed in this instance. As far as technical training to ensure the accuracy of monitored values is concerned, however, standard operating procedures should be tailor-made to meet the needs of East Asian countries.

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Glossary

*1 Non-methane hydrocarbons
Hydrocarbons excluding methane - they are precursors of photochemical oxidants.

*2 Photochemical oxidants
Atmospheric oxidants (powerful oxidants) causing photochemical smog - they are comprised primarily of ozone.

*3 Environmental standards
Administrative objectives that should be complied with in order to protect human health and the living environment - they are based on as many scientific findings as are available.

*4 Backward trajectory analysis
An analytical method that keeps track of the past route of the atmosphere using meteorological models.

*5 Aerosols
Solid or liquid airborne particulates - they diffuse or absorb sunlight and alter the properties of clouds by serving as condensation nuclei, thereby having a complex impact on the climate system.

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Hirokazu FUKUSHIMA
Environment and Energy Research Unit, Science and Technology Foresight Center

Engaged in the research and development of analytical instruments (for engine emissions, particulate matter, etc.) at Horiba, Ltd. His area of interest includes environmental purification technology and its trends, and environmental policies aimed at the creation of a sustainable society.

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