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Modeling of atmospheric dispersion of mercury from coal–fired power plants in Japan

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ABSTRACT

The Air Quality Management Division of Ministry of the Environment in Japan selected the maximum level of annual mean air quality standard for mercury as 0.04 μg/m^3. The yearly average atmospheric emissions of mercury from two nearly located point sources, background concentrations of mercury in the atmosphere and one–year meteorological data was used to predict the ambient concentrations of mercury at ground level by atmospheric dispersion modeling. To estimate the mercury concentration in the air of the local area, two different models have been used. The first one is AIST–ADMER model that estimates regional atmospheric distribution of mercury concentration. The second one is METI–LIS model that estimates the atmospheric distribution of mercury concentration in the vicinity of industrial facilities. The annual mean concentration of mercury in the atmosphere was calculated for the central Honshu Island of Japan using the AIST–ADMER model, which served as a background data for the METI–LIS model to calculate atmospheric mercury concentration in the vicinity of industrial facilities. Maximum annual mean atmospheric concentrations of mercury in the vicinity of the two hypothetical coal–fired power plants were calculated as 0.0118 μg/m^3 that was lower than the Japanese annual mean air quality standard for mercury.

Keywords:
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1. Introduction

In Japan, mercury was categorized as a hazardous air pollutant (HAP) in 1996 and is on the list of "Substances Requiring Priority Action" published by the Central Environmental Council of Japan (Kida, 2005). The Central Environmental Council prepared the second report "Future direction of measures against hazardous air pollutants" in October 1996, which also proposed that the voluntary action to reduce emissions, as well as an investigation of hazards, atmospheric concentration and pollution sources should be promoted. Although the industrial emissions of mercury in Japan have decreased in recent years (Ito et al., 2006), primarily due to the voluntary reduction of mercury emissions from industrial sources, the concentration distribution of these pollutants in the local atmospheric environment has remained largely unknown (Shirane, 2007).

Mercury is a natural trace component in the environment. Notwithstanding, the bioaccumulation of methylmercury (MeHg) via the food chain, especially through fish, concentrates mercury and poses serious toxicity hazards to the biosphere (Harada, 1995). For that reason, natural and anthropogenic emissions of mercury in the environment (Nriagu and Pacyna, 1988), its transportation and fate (Schroeder and Munthe, 1998; Boening, 2000), and its adverse effects on human health and the ecosystem (Ditri, 1991) have all attracted great attention as facets of a major environmental problem. Stack emissions from coal–combustion power industry includes both vapor and particle–bound phases. Reactive gaseous mercury [RMG or Hg(II)] (Schroeder and Munthe, 1998) can be inorganic (e.g., mercuric chloride, $HgCl_2$) or organic [e.g., methylmercury (MeHg)]. It can also be present as particulate mercury (e.g, mercuric oxide, HgO, or mercury sulfide, HgS). In the global atmosphere, gaseous elemental mercury [GEM or Hg(0)] is the dominant form. Hg(II) typically constitutes a small percentage of total mercury and is predominantly in the gas phase. MeHg concentration in the atmosphere is relatively low, about 10% – 30% lower than total Hg(II) concentrations, according to analysis of precipitation samples (Seigneur et al., 1998). However, Hg(II) becomes methylated in water bodies, where it can bioaccumulate in the food chain. Hg(0) is sparingly soluble in cloud particles and is not removed significantly by wet deposition, and its dry deposition velocity is also believed to be low. As a result, Hg(0) has a long atmospheric lifetime. On the other hand, Hg(II) is quite soluble with cloud particles, so is removed rapidly by wet and dry deposition processes, and has much shorter atmospheric lifetimes (Hedgecock and Pirrone, 2004). Particulate mercury [PM or Hg(p)] is mostly present in the fine fraction of particulate matter ($PM_{2.5}$), although some Hg(p) may be present in coarse PM (Landis and Keeler, 2002).

The concentration of mercury should be estimated both on a regional scale as well as on a local scale, because not only the concentration of mercury in the general environment is important (i.e. the area which includes most of the total population), but also those in the vicinity of industrial sources (i.e. areas of high concentration) should be considered carefully, as particular industrial sources are expected to be associated with relatively high–risk areas. In this study, two different models have been

selected, which were used to assess the extent of exposure: the AIST–ADMER (National Institute of Advanced Science and Technology–Atmospheric Dispersion Model for Exposure and Risk Assessment) estimates regional concentration distribution of hazardous chemical substances (Higashino et al., 2003; Higashino et al., 2004), and the METI–LIS (Ministry of Economy, Trade and Industry–Low–Rise Industrial Source Dispersion Model) estimates the concentration distribution in the vicinity of particular industrial facilities (Kouchi et al., 2004).

Gaseous mercury, including both Hg(0) and Hg(II), were considered as total mercury emissions in the atmosphere, which served as input emission data for these two air pollutant dispersion models. More than 99.5% of mercury in the stack emissions was in the gaseous form (Lindqvist and Rodhe, 1985) and the proportion in particulate form was extremely low in Japan (Yokoyama et al., 2000). Since mercury treatment systems of the coal combustion facilities are very advanced in Japan, Hg(II) emission from the stack is also very low (Takahashi et al., 2008).

The objective of this study was to estimate the concentration of mercury in Japan, whereas the above mentioned two models were used for the assessment of the atmospheric concentration of mercury.

2. Method

2.1. AIST–ADMER model

The AIST–ADMER (Higashino et al., 2003; Higashino et al., 2004) version 1.5e is a series of models and systems designed for estimating the regional atmospheric level of chemicals, developed by the National Institute of Advanced Industrial Science and Technology. The functions of the AIST–ADMER model provide the following calculations and simulations:

- Generation and confirmation of meteorological data
- Generation and confirmation of chemical substance emission data
- Calculation of atmospheric concentrations and deposition of chemicals
- Graphical images of calculation results
- Calculation of resulting histogram
- Population exposure assessment

The purpose of this model is to estimate a long–term, average distribution of chemical concentration in a relatively wide region, such as the Kanto and Kansai areas of Japan. Atmospheric concentration distribution of chemical substances of a 5 km × 5 km square spatial grid for an average of one month to one year can be calculated by this model. Generally, use of models requires preparation of various data, such as meteorological data, creating target substance emission data, and setting calculation param–eters, in order to estimate the atmospheric concentration of chemicals and assess their exposure.

In this study, meteorological input data, calculated monthly for a year, i.e., from January to December 2006, have been used for the AIST–ADMER model calculation. Meteorological input data were produced from AMeDAS (Automated Meteorological Data Acquisition System) (Akasaka and Nimiya, 1986) data, whereas the solar radiation and cloud cover were obtained from individual weather stations.

Simulations calculated from the AIST–ADMER model need information on target substances, such as the amount and geographical location (i.e., latitude, longitude) of emission etc. The AIST–ADMER contains a function for creating the gridded emission data required for the calculation. The methods used for creating gridded emission data can be classified mainly into two types, i.e., point sources, which specify a location using latitude and longitude, and enter the emissions generated from the location, and area sources, which specify emissions for each region or city, and allocate the emissions to calculation grids according to indices such as population, area, industrial statistics, and traffic volume.

The AIST–ADMER model calculation range consists of a number of calculation grids. Total 11 calculation ranges are pre–registered in ADMER in order to cover overall Japanese region (Table 1). Before starting the simulation, it is recommended to select a calculation range that includes target ranges.

***Table 1**. ADMER Calculation range*

Name	Range	Number of grids	Regions
Hokkaido	E 139° 15' 00" – 145° 56' 15" N 41° 17' 30" – 45° 35' 00"	107 × 103	Hokkaido
Tohoku	E 139° 07' 30" – 142° 11' 15" N 36° 45' 00" – 41° 37' 30"	49 × 117	Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima
Hokuriku	E 136° 07' 30" – 139° 56' 15" N 36° 02' 30" – 38° 35' 00"	61 × 61	Niigata, Toyama, Ishikawa
Kanto	E 138° 18' 45" – 140° 56' 15" N 34° 50' 00" – 37° 12' 30"	42 × 57	Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, Kanagawa
Chubu	E 135° 22' 30" – 139° 11' 15" N 35° 07' 30" – 37° 05' 00"	61 × 47	Fukui, Yamanashi, Nagano, Gifu
Tokai	E 135° 48' 45" – 139° 15' 00" N 33° 40' 00" – 35° 40' 00"	55 × 48	Shizuoka, Aichi, Mie
Kinki	E 134° 11' 15" – 136° 30' 00" N 33° 22' 30" – 35° 50' 00"	37 × 59	Shiga, Kyoto, Osaka, Hyogo, Nara, Wakayama
Chugoku	E 130° 41' 15" – 134° 33' 45" N 33° 40' 00" – 35° 40' 00"	62 × 48	Tottori, Shimane, Okayama, Hiroshima, Yamaguchi
Shikoku	E 131° 56' 15" – 134° 56' 15" N 32° 37' 30" – 34° 37' 30"	48 × 48	Tokushima, Kagawa, Ehime, Kochi
Kyushu	E 128° 15' 00" – 132° 11' 15" N 30° 55' 00" – 34° 17' 30"	63 × 81	Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki,
Okinawa	E 122° 48' 45" – 131° 26' 15" N 24° 00' 00" – 27° 57' 30"	138 × 95	Okinawa