The Characterization and Distribution of Aerosol and Gaseous Species in the Winter Monsoon over the Western Pacific Ocean

II The Residence Time of Aerosols and \( \text{SO}_2 \) in the Long-Range Transport over the Ocean

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Abstract. In order to obtain a better understanding of the behavior of aerosols and \( \text{SO}_2 \) in the long-range transport through a marine boundary layer, a simple box-model is applied to the evaluation of the residence times of the species from the concentrations of gases and aerosols measured simultaneously on two islands in the West Pacific Ocean in the north-west monsoon. For Aitken and large particles, the residence time is varied from 3.7 to 7.4 days depending on the particle size, and their flux to the sea is equal to or slightly smaller than that of the free atmosphere. The residence time of giant particles is about one day and their flux to the sea is three times larger than that of the free atmosphere. The residence time of \( \text{SO}_2 \) is 15 hr, and the relative \( \text{SO}_2 \) mass flows of the deposition to the sea, of the diffusion to the free atmosphere and of the transformation to \( \text{SO}_4^{2-} \) are approximately 4, 1 and 1, respectively.

Key words. Aerosol, sulfur dioxide, long-range transport, transport model, residence time, deposition rate.

1. Introduction

The background concentration of Aitken particles in the Pacific region around Chichijima Is. (27°05'N, 142°11'E) and Minami-torishima Is. (24°18'N, 153°58'E), more than 1000 km from the main islands of Japan, is about 250 cm\(^{-3}\). In this oceanic region, high concentrations of more than 1000 cm\(^{-3}\) are occasionally observed, especially in the north-westerly monsoon. According to the analysis of the airmass trajectory, the high concentrations are caused by the long-range transport of urban pollutants from the main islands (Ito, 1980). The importance of particles of land origin in the maritime background aerosol is also demonstrated by a chart showing the climatological aerosol distribution in the global maritime atmosphere presented by Podzimek (1980). The chart suggests the influence of species of land origin on the aerosol distribution in the marine boundary layer by showing that the Aitken particle concentration increases toward the land and decreases toward the mid-oceanic region. In order to clarify the
mechanism of background aerosol pollution on a global scale, a detailed knowledge of aerosol processes in the long-range transport of particles and gases of land origin over the ocean is needed.

Considerable efforts to tackle the problem of the long-range transport of airborne substances over the European and American continents were reviewed by Fisher (1983). The long-range transport of Asian dust over the ocean was the main subject in the SEAREX program (Uematsu, 1985). Arctic air pollution was also studied as a problem of the long-range transport of anthropogenic pollutants emitted from the European, Asian and American continents (Rahn, 1985). A recent review on the sulfur and nitrogen cycling (including the emission, transport, transformation, and deposition) in the remote atmosphere is given by Galloway et al. (1985).

During their long-range transport, the aerosol and gaseous species change their concentration through various processes such as dilution due to eddy diffusion, decay due to coagulation, deposition and chemical conversion. A key to the problem is to know the relative significance of these effects on the concentration reduction during the long-range transport of the species. To determine the relative significance, a well-designed observation, conducted in the oceanic region leeward of land, seems to have some advantages because there is no complex distribution of pollution sources on the sea and the air flow is rather simple as compared with that over the land, both enable us to treat the problem with a simple model.

Misaki and Takeuti (1970) measured atmospheric electric conductivity on a cruise along the shore off the Japan islands. The atmospheric electric conductivity is known as a good indicator of the atmospheric concentration of Aitken particles. They found that the Aitken particles originating from anthropogenic sources were transported over the ocean, and their concentration was decreased almost exponentially as a function of the distance from the land. Morita (1973) pointed out on the basis of observations on cruises that the age of the relevant air mass is a principal factor which controls the concentration reduction of aerosol dispersing from land. Misaki et al. (1975) determined the residence time of aerosols as a function of particle size, subtracting the dilution effect from the concentration reduction rate of aerosol of land origin dispersing over the ocean.

In the winters of 1981 and 1982, extensive observations were made of gaseous and aerosol species which had been carried in the north-westerly monsoon over the Pacific Ocean on two islands, Hachijo-jima and Chichi-jima, and on board a ferry-boat. The distances from the main islands of Japan are about 300 km to Hachijo-jima Is. (33°05′N, 139°45′E) and about 800 km to Chichi-jima Is, respectively. The data obtained in these observations were given in Part I, of this series of papers (Okita et al., 1986). In this paper, using the data presented in Part I, we try to determine the time constant of concentration reduction of aerosol and SO2 due to deposition loss (i.e. residence time), and dilution (mainly caused by the exchange of air between the boundary layer and free atmosphere), and also the time constant of the reduction of SO2 concentration due to conversion to SO2−. In other words, the present work aims to determine the relative significance of the