Atmospheric Environment 95 (2014) 165–174

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

The contribution of site to washout and rainout: Precipitation chemistry based on sample analysis from 0.5 mm precipitation increments and numerical simulation

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HIGHLIGHTS

- Precipitation was studied from the viewpoint of washout and rainout mechanisms.
- Precipitation was collected at 0.5 mm basis at three sites (urban, suburban, rural).
- Rainout and washout contribution was estimated for NO_3^- and SO_4^{2-}.
- The contribution of site difference was also discussed.
- The above estimation was compared and verified by a chemical transport model.

ARTICLE INFO

Article history:
Received 3 April 2014
Received in revised form
4 June 2014
Accepted 5 June 2014
Available online 12 June 2014

Keywords:
Acid rain
Nitrate
Sulfate
Washout
Rainout
Site classification
Numerical simulation

ABSTRACT

Datasets of precipitation chemistry at a precipitation resolution of 0.5 mm from three sites were studied to determine whether the washout and rainout mechanisms differed with site type (urban, suburban, rural). Rainout accounted for approximately one-third of the total NO_3^- deposition and washout contributed two-thirds, irrespective of the site type, although the washout contribution at the urban site (over 70%) was larger than that at the other two sites. The rainout mechanism and the washout mechanism both accounted for about half the total SO_4^{2-} deposition at the suburban and rural sites, whereas at the urban site the rainout contribution was over 80%. A chemical transport model produced similar levels of washout and rainout contributions as the precipitation chemistry data.

1. Introduction

Precipitation removes air pollutants from the atmosphere via two mechanisms: the rainout mechanism (in-cloud scavenging) and the washout mechanism (below-cloud scavenging). Many studies have been conducted to elucidate the mechanisms involved (e.g., Harrison and Pio, 1983; Kitada and Lee, 1993; Kitada and Lee, 1993; Seto et al., 1995; Okita et al., 1996; Tanner et al., 1997; Chate and Prannesha, 2004; Hicks, 2005; Fukuzaki et al., 2005). Aikawa et al. (2008a) and Aikawa and Hiraki (2009) intensively measured and sampled precipitation at a resolution of 0.5 mm increments, revealing insights into the washout and rainout mechanisms. From a year-round dataset of precipitation obtained at a suburban site, they estimated that about one-third of NO_3^- deposition from the atmosphere occurred via the rainout mechanism and two-thirds via the washout mechanism; in the case of SO_4^{2-}, they found that the rainout mechanism and washout mechanism each accounted for about half the deposition (Aikawa and Hiraki, 2009).

The dataset Aikawa et al. (2008a) and Aikawa and Hiraki (2009) studied was collected by the Hyogo Prefectural Government, which sampled and analyzed precipitation at a resolution of 0.5 mm

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http://dx.doi.org/10.1016/j.atmosenv.2014.06.015
1352-2310/

precipitation; this fine resolution enabled the washout and rainout mechanisms to be discriminated and analyzed in detail. The studies by Aikawa et al. (2008a) and Aikawa and Hiraki (2009) were based on a dataset obtained at a suburban site located in Toyo-oka City, Hyogo Prefecture, Japan. The Hyogo Prefectural Government conducted sampling and analysis at a 0.5 mm precipitation resolution at three sites in Hyogo Prefecture, including the above-mentioned Toyo-oka site. Of the other two sites, one was located in an urban area, and the other in a rural area.

The aim of the present study was to examine the washout and rainout mechanisms with respect to the predominant character of the site, i.e., urban, suburban, or rural. We compared the washout and rainout contributions simulated by a regional air quality model with observed values to evaluate the performance of the wet scavenging process modeling.

2. Experimental

2.1. Survey site

Precipitation samples were collected at three sites of different character: Kobe City (an urban area), Toyo-oka City (a suburban area), and Tamba City (a rural area). All sites are located in Hyogo Prefecture, Japan (Fig. 1). The areas surrounding the sites have been described in previous manuscripts (Aikawa et al., 2003, 2004). Tamba City is referred to as Kaibara in the earlier manuscripts. The annual mean concentrations of air pollutants around the survey sites were obtained at air pollution monitoring stations near each survey site (Table 1). The concentrations of air pollutants were generally higher in Kobe than in Toyo-oka and Tamba, with the latter two displaying few differences from each other.

Table 1
Annual mean concentrations of air pollutants, NO_2/NO_x and wind speed around survey sites in 2007.

	SO_2	NO_x[a]		SPM[b]
	ppb	ppb	NO_2/NO_x	μg/m³
Kobe	–	38	0.67	29
Toyo-oka	2	10	0.70	17
Tamba	2	6	0.90	21

[a] $NO_x = NO + NO_2$.
[b] SPM is suspended particulate matter (10 μm diameter 100% cutoff).

2.2. Collection and analysis

2.2.1. Equipment

The precipitation samples were analyzed with an acid rain monitor (model AR-107SNA, Kimoto Electric Co., Ltd., Osaka). A schematic diagram of the acid rain monitor has been provided in Tamaki et al. (2000) and Aikawa et al. (2003). Aliquots of the collected precipitation were automatically analyzed for pH and electrical conductivity (EC) for every 0.5 mm of precipitation and for NO_3^- and SO_4^{2-} concentrations (both by absorption spectrophotometry) for every 1 mm of precipitation. The analyzed data were stored on floppy disk with a time stamp for when the

Fig. 1. Location of Hyogo Prefecture and the three survey sites within it.