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Prediction of health effects of cross-border atmospheric pollutants using an aerosol forecast model

Kazunari Onishi[a,*], Tsuyoshi Thomas Sekiyama[b,d], Masanori Nojima[c], Yasunori Kurosaki[d], Yusuke Fujitani[e], Shinji Otani[f], Takashi Maki[b], Masato Shinoda[g], Youichi Kurozawa[e], Zentaro Yamagata[a,h]

[a] Center for Birth Cohort Studies, Interdisciplinary Graduate School of Medicine, University of Yamanashi, 1110 Shimokato, Chuo, Yamanashi 409-3898, Japan
[b] Meteorological Research Institute, 1-1 Nagamine, Tsukuba 305-0052, Japan
[c] Center for Translational Research, The Institute of Medical Science Hospital, The University of Tokyo, 4-6-1 Shirokanedai, Minato-ku 108-8639, Japan
[d] Arid Land Research Center, Tottori University, 1390 Hamasaka, Tottori 680-0001, Japan
[e] Division of Health Administration and Promotion, Department of Social Medicine, Faculty of Medicine, Tottori University, 86 Nishi-cho, Yonago 683-8503, Japan
[f] International Platform for Dryland Research and Education, Tottori University, 1390 Hamasaka, Tottori 680-0001, Japan
[g] Graduate School of Environmental Studies, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan
[h] Department of Health Sciences, School of Medicine, University of Yamanashi, 1110 Shimokato, Chuo, Yamanashi 409-3898, Japan

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A B S T R A C T

Health effects of cross-border air pollutants and Asian dust are of significant concern in Japan. Currently, models predicting the arrival of aerosols have not investigated the association between arrival predictions and health effects. We investigated the association between subjective health symptoms and unreleased aerosol data from the Model of Aerosol Species in the Global Atmosphere (MASINGAR) acquired from the Japan Meteorological Agency, with the objective of ascertaining if these data could be applied to predicting health effects. Subjective symptom scores were collected via self-administered questionnaires and, along with modeled surface aerosol concentration data, were used to conduct a risk evaluation using generalized estimating equations between October and November 2011. Altogether, 29 individuals provided 1670 responses. Spearman's correlation coefficients were determined for the relationship between the proportion of the participants reporting the maximum score of two or more for each symptom and the surface concentrations for each considered aerosol species calculated using MASINGAR; the coefficients showed significant intermediate correlations between surface sulfate aerosol concentration and respiratory, throat, and fever symptoms ($R = 0.557$, 0.454, and 0.470, respectively; $p < 0.01$). In the general estimation equation (logit link) analyses, a significant linear association of surface sulfate aerosol concentration, with an endpoint determined by reported respiratory symptom scores of two or more, was observed (P trend = 0.001, odds ratio [OR] of the highest quartile [Q4] vs. the lowest [Q1] = 5.31, 95% CI = 2.18 to 12.96), with adjustment for potential confounding. The surface sulfate aerosol concentration was also associated with throat and fever symptoms. In conclusion, our findings suggest that modeled data are potentially useful for predicting health risks of cross-border aerosol arrivals.

1. Introduction

Air pollution originates from a variety of sources, including anthropogenic and phenomenal causes; in addition, it can present from across borders or be locally generated. In Japan, a country downwind from the Asian continent, there is great concern about cross-border air pollution. In western Japan, in particular, cross-border pollution might contribute more to pollution levels than does local pollution (Ministry of the Environment, 2014).

Asian dust events generate large amounts of cross-border air pollutants that originate from the arid and semiarid areas of China and Mongolia when strong winds pick up and transport dust with the urban or industrial pollution to downwind countries, including Korea (Chun et al., 2001; Chung and Yoon, 1996), Japan (Mori et al., 1999; Onishi et al., 2012), and the United States (Husar et al., 2001; Tratt et al., 2001; Uematsu et al., 1983).

Recent evidence reveals that among several possible negative effects on human health, Asian dust events are associated with an increased

* Corresponding author.
E-mail address: kohnishi@yamanashi.ac.jp (K. Onishi).

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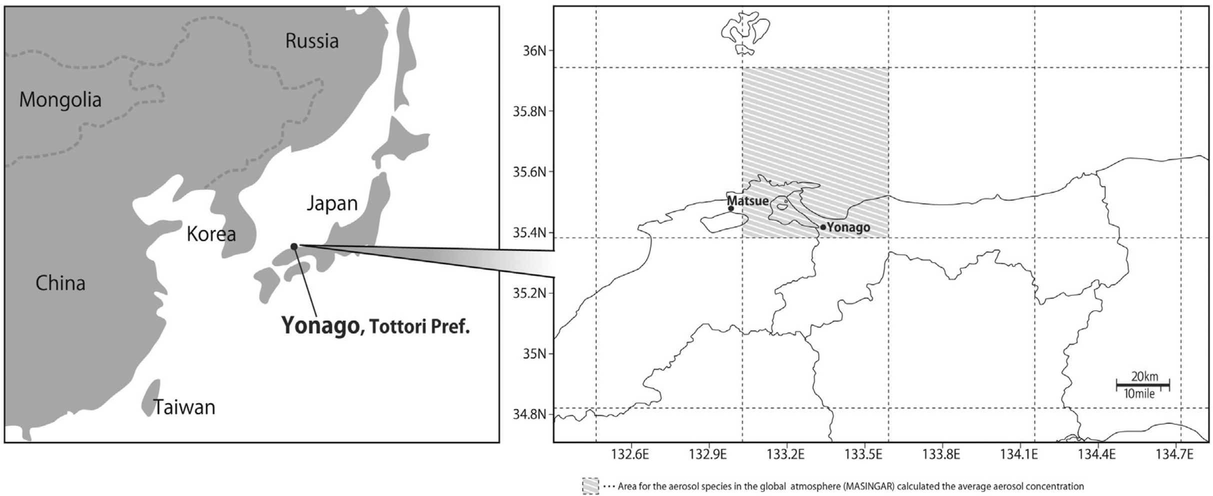

Fig. 1. Location of Yonago City, Japan, and the survey and grid areas for simulations calculated by the Model of Aerosol Species in the Global Atmosphere.

risk of mortality (Chan and Ng, 2011; Chen et al., 2004; Hwang et al., 2005; Kim et al., 2012; Kwon et al., 2002; Lee et al., 2007), cardiovascular disease (Cui et al., 2016; Kim et al., 2012; Liu et al., 2017), and respiratory disease (Yu et al., 2012; Yu et al., 2013) in countries that are close to the origin of Asian dust. Epidemiological studies in humans in Japan have also reported the health risk of mortality (Kashima et al., 2012), acute myocardial infarction (Kojima et al., 2017), respiratory symptoms (Kanatani et al., 2010; Nakamura et al., 2016), and allergic symptoms (Kanatani et al., 2016; Onishi et al., 2015).

However, Asian cross-border pollution is composed of soil dust particles and anthropogenic pollutants. These pollutants are transported together, and humans are exposed to them simultaneously. Soil may be less pathogenic than are anthropogenic pollutants, and anthropogenic pollutants may have a possible effect on the onset of diseases (Sadakane et al., 2016). We reported that different compositions of pollutants due to atmospheric transport routes are closely associated (Onishi et al., 2012).

Therefore, anthropogenic cross-border pollution, even without Asian dust, has also been recognized as a serious problem in Japan (Yoshino et al., 2016). Nevertheless, there have been limited reports of studies investigating the health effects of anthropogenic cross-border pollution in Japan.

Numerical aerosol simulation models can calculate the dispersion and distribution of natural/anthropogenic cross-border pollution or aerosol particles, based on geophysical equations. Numerical aerosol predictions have already been used, and some are available to the public (Takemura, 2012; Uno et al., 2003). The Model of Aerosol Species in the Global Atmosphere (MASINGAR) of the Japan Meteorological Agency (JMA) is one of the numerical aerosol simulation models (Sekiyama et al., 2016; Tanaka and Chiba, 2005). MASINGAR has been operationally used by the JMA as a part of the weather prediction system. The aerosol forecast product of MASINGAR is compared daily with other governmental aerosol forecasts (e.g., the National Aeronautics and Space Administration, the US Naval Research Laboratory, the European Centre for Medium-Range Weather Forecasting), which are sufficiently reliable for operational use (Sessions et al., 2015). However, most operational aerosol forecast products are unavailable for public health purposes. Therefore, the association between aerosol prediction data and health effects is not yet well known.

In the current study, we surveyed the health effects of atmospheric pollutants among residents of Yonago city, in the western part of Tottori Prefecture. Tottori is the most sparsely populated prefecture in Japan, and the region does not have heavy industrial zones. This region faces the Sea of Japan and has no relevant sources of pollution within a short distance upwind. However, downwind of mainland China, it is subject to the arrival of frequent long-distance Asian dust and cross-border pollutants carried by westerly winds blowing off the mainland, especially during spring and autumn. Consequently, the average yearly values for atmospheric particulate matter with diameter < 2.5 μm (PM2.5) did not meet Japanese environmental standards (< 15 μg/m^3/year) in 2011–2014 (Tottori Prefectural Institute of Public Health and Environmental Science, 2015; Ministry of the Environment, 2015). As mentioned, this region's local anthropogenic pollutant emission level is quite low compared with cross-border pollution levels (Ikeda et al., 2014). Accordingly, residents of Tottori are expected to be affected by cross-border pollution. MASINGAR does not deal with low-level dust/industrial emissions such as rural local life pollution in Tottori. Thus, in this study, MASINGAR simulations account for cross-border pollutants and not for local emission pollutants.

Cross-border air pollution that is aerosol-generated in mainland China reaches Japan after several hours depending on climate and wind conditions. Therefore, predicting when aerosols reach Japan and instituting preventive behavior beforehand is expected to yield significant health benefits. Therefore, this study aimed to explore the association between numerical aerosol simulation model data and subjective symptoms.

2. Material and methods

2.1. Study period and site

The survey was conducted during autumn, between October and November 2011. Fig. 1 shows the location of Yonago, where study participants were recruited, the Yonago Meteorological Observatory and Public Health Institute, and the Matsue site for light detection and ranging (LIDAR) observation. The diagonally-hatched grid square represents the area for which MASINGAR calculated the average aerosol concentration.

2.2. Air pollution and environmental data (observed concentration)

The observed surface concentration data were used as confounding factors in this study. Data were obtained hourly from the Public Health Institute of Yonago. Data collected included levels of suspended particulate matter (SPM, particle size < 10 μm, 100% at the 10-μm cutoff; > 10 μm in aerodynamic diameter were removed entirely; this represents the generally-used standard in Japan), NO_2 (nitrogen dioxide), SO_2 (sulfur dioxide), and Ox (oxidants). SPM data were measured by the beta-ray absorption method; NO_2 data, by ultraviolet fluorescence (GFS-327, TOADKK); SO_2 data, by the chemiluminescence method

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