Journal of Environmental Radioactivity 164 (2016) 1–12

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

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

Inverse modeling of the ^{137}Cs source term of the Fukushima Dai-ichi Nuclear Power Plant accident constrained by a deposition map monitored by aircraft

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ARTICLE INFO

Article history:
Received 28 February 2016
Received in revised form
21 June 2016
Accepted 21 June 2016

Keywords:
Fukushima Daiichi Nuclear Power Plant accident
Inverse modeling
Surface deposition
Source term
Atmospheric dispersion

ABSTRACT

The amount of ^{137}Cs released by the Fukushima Dai-ichi Nuclear Power Plant accident of 11 March 2011 was inversely estimated by integrating an atmospheric dispersion model, an a priori source term, and map of deposition recorded by aircraft. An a posteriori source term refined finer (hourly) variations comparing with the a priori term, and estimated ^{137}Cs released 11 March to 2 April to be 8.12 PBq. Although time series of the a posteriori source term was generally similar to those of the a priori source term, notable modifications were found in the periods when the a posteriori source term was well-constrained by the observations. Spatial pattern of ^{137}Cs deposition with the a posteriori source term showed better agreement with the ^{137}Cs deposition monitored by aircraft. The a posteriori source term increased ^{137}Cs deposition in the Naka-dori region (the central part of Fukushima Prefecture) by 32.9%, and considerably improved the underestimated a priori ^{137}Cs deposition. Observed values of deposition measured at 16 stations and surface atmospheric concentrations collected on a filter tape of suspended particulate matter were used for validation of the a posteriori results. A great improvement was found in surface atmospheric concentration on 15 March; the a posteriori source term reduced root mean square error, normalized mean error, and normalized mean bias by 13.4, 22.3, and 92.0% for the hourly values, respectively. However, limited improvements were observed in some periods and areas due to the difficulty in simulating accurate wind fields and the lack of the observational constraints.

1. Introduction

The Fukushima Dai-ichi Nuclear Power Plant (FNPP1) accident subsequent to the great earthquake and tsunami of 11 March 2011 released large amount of radionuclides into the atmosphere. The discharged radionuclides were transported, dispersed, and deposited worldwide. To understand the spatiotemporal characteristics of atmospheric transport and deposition, various studies have been conducted with atmospheric dispersion models (ADMs) in regional (Morino et al., 2013, 2011; Park et al., 2013; Yasunari et al., 2011) and global (Christoudias and Lelieveld, 2013; Stohl et al., 2012; Takemura et al., 2011; Ten Hoeve and Jacobson, 2012) scales. In addition, a study comparing the models assesses the current status of and uncertainties associated with radionuclide simulations (Science Council of Japan (2014)).

ADMs include various processes (e.g., advection, dispersion, chemical reaction, and wet and dry deposition), and use the source term and meteorological fields as inputs. Although each process and input contains errors, one of the largest contributors to uncertainty is the source term because bias in the source term can directly affect atmospheric concentrations and deposition

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http://dx.doi.org/10.1016/j.jenvrad.2016.06.018
0265-931X/

amounts. Inverse modeling, which optimizes the source term by integrating ADMs and observations, is one way to reduce uncertainty and obtain better simulation results. Several simple methods for source estimations studies have been performed for the FNPP1 accident with different ADMs and observational dataset. Researchers in the Japan Atomic Energy Agency (JAEA) performed source estimations with a regional model and data consisting of daily and monthly surface deposition amounts and air concentrations measured in Japan (Chino et al., 2011; Katata et al., 2012; Terada et al., 2012). More recently, Katata et al. (2015) revised the source terms estimated by Terada et al. (2012). Researchers in the Institut de Radioprotection et de Sûreté Nucléaire (IRSN) assessed emission peaks and the quantities with the facility events and ambient measurements (Korsakissok et al., 2013; Mathieu et al., 2012). Stohl et al. (2012) and Winiarek et al. (2012) performed inverse modeling studies on a global scale with atmospheric activity concentrations measured by a global International Monitoring System operated by the Comprehensive Nuclear Test Ban Treaty Organization. They also demonstrated that using a priori knowledge of the source term (an a priori source term or first guess) can compensate for the lack of observed data, and their inverse modeling successfully improved a priori source term. Saunier et al. (2013) estimated emissions of radionuclides with dose rate measurements. More recently, Winiarek et al. (2014) developed an inversion method using cumulated deposition and air activity concentration simultaneously. However, the range of emissions estimates was wide even in the inverse modeling results.

To refine estimates of ^{137}Cs emissions from the FNPP1 accident, we performed an inverse modeling study with a regional ADM, an a priori source term, and ^{137}Cs depositions measured by aircraft. The aircraft observation yielded a detailed map of ^{137}Cs deposition over the eastern part of Japan's main island. More than 16,000 data points were used in the inverse modeling, much larger than the number of observational constraints used in previous studies. We used an a posteriori source term to validate various observation datasets including a set of measurements of atmospheric ^{137}Cs concentration, and to revisit the analysis of episodic deposition patterns over Japan.

2. Methodologies

2.1. Atmospheric dispersion model and the a priori source term

We used Weather Forecast and Research Model version 3.1

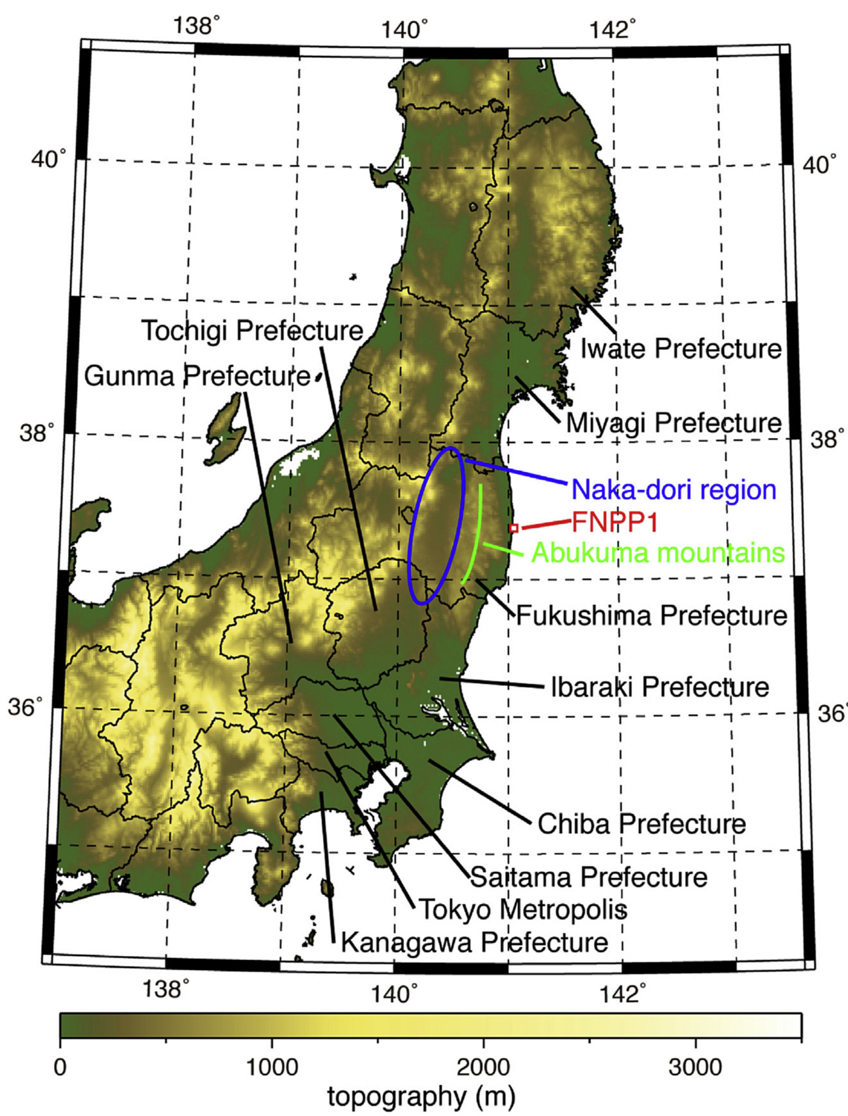

Fig. 1. The model domain and topography.