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ScienceDirect

Energy Procedia 131 (2017) 208–215

Energy Procedia

www.elsevier.com/locate/procedia

5th International Symposium on Innovative Nuclear Energy Systems, INES-5, 31 October – 2 November, 2016, Ookayama Campus, Tokyo Institute of Technology, JAPAN

Improvement of atmospheric dispersion simulation using an advanced meteorological data assimilation method to reconstruct the spatiotemporal distribution of radioactive materials released during the Fukushima Daiichi Nuclear Power Station accident

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Abstract

To improve the atmospheric dispersion simulations of radioactive materials released due to the Fukushima Daiichi Nuclear Power Station (FNPS1) accident, we adopted four-dimensional variational data assimilation (4D-Var) of the data assimilation system (WRFDA) and confirmed the effectiveness of the existing 4D-Var technique for the reproducibility of dispersion simulation during the FNPS1 accident. The simulation was performed by the community meteorological model (WRF) and our atmospheric dispersion model (GEARN). The accuracy of simulated ^{137}Cs deposition patterns in the area closed to FNPS1 and the Ibaraki, Tochigi, and Fukushima Prefectures was increased due to improvements in wind and rain fields in 4D-Var calculations. The results demonstrated that 4D-Var was effective for improving local- and regional-scale atmospheric dispersion simulations.

Peer-review under responsibility of the organizing committee of the 5th International Symposium on Innovative Nuclear Energy Systems.

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Peer-review under responsibility of the organizing committee of the 5th International Symposium on Innovative Nuclear Energy Systems.
10.1016/j.egypro.2017.09.465

Keywords: Atmospheric dispersion; meteorological data assimilation; emergency response; radiological dose assessment; Fukushima Daiichi Nuclear Power Station accident

1. Introduction

A significant amount of radioactive material was accidentally emitted into the atmosphere from the Fukushima Daiichi Nuclear Power Station (hereafter referred to as FNPS1) due to the earthquake and resulting tsunami that occurred on March 11, 2011. As a result, radiological contamination has occurred over eastern Japan [1]. Atmospheric dispersion models, which can simulate spatiotemporal distributions of radioactive material, have been utilized to estimate source term and to reveal the atmospheric dispersion processes during the FNPS1 accident. The simulation result strongly depends on input meteorological field to drive an atmospheric dispersion model. Thus, the problem needed to reduce uncertainty of input meteorological field has already been frequently pointed out. In the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) for evaluating radiation risk and for establishing protective measures based on scientific knowledge, atmospheric dispersion simulations have been used to assess radiological doses to the public; demonstrating that the accuracy of simulated meteorological fields has room to be improved for better atmospheric dispersion estimates [2]. To increase the accuracy of the meteorological data, four-dimensional variational data assimilation (4D-Var) is one of widely accepted method in communities of weather research and forecasting [3-5].

In our previous study, the detailed source term was estimated by using WSPEEDI (Worldwide version of System for Prediction of Environmental Emergency Dose Information) [6] including new deposition scheme [7]. By using the estimated source term and WSPEEDI with new deposition scheme, the local and regional deposition patterns of ^{131}I and ^{137}Cs were successfully reproduced. For further improvement of WSPEEDI simulation, we attempted to update the meteorological field by adopting the up-to-date meteorological calculation model, the Weather Research and Forecasting Model (WRF [8]), instead of the former atmospheric model MM5 [9] in the original WSPEEDI. Furthermore, we introduced the 4D-Var technique to calculate more reliable meteorological field by effectively assimilating meteorological observation data. As the result, the reproducibility of local and regional deposition patterns of ^{137}Cs derived from airborne monitoring was improved.

The present study aims to demonstrate the effectiveness of the existing 4D-Var technique for the reproducibility of dispersion simulation during the FNPS1 accident in comparison of results from WRF simulations with and without 4D-Var. Then, its impact on modelled plume movements and deposition patterns of ^{137}Cs during the FNPS1 accident is evaluated by comparing simulation results with airborne monitoring surveys.

2. Models and experimental designs

In this study, we used our Lagrangian particle dispersion model GEARN and the community meteorological model WRF. To improve the meteorological fields calculated by WRF, an advanced meteorological data assimilation system (WRFDA) was utilized to assimilate available meteorological input data obtained in eastern Japan (section 2.4) based on the 4D-Var technique.

2.1. WRF

To obtain the meteorological variables to drive GEARN, we used the WRF model version 3.6.1, which is a non-hydrostatic, fully compressible model developed by the National Center for Atmospheric Research [8]. The model predicts three-dimensional meteorological fields by solving several governing equations of the atmospheric dynamics. This model has various physics options applied to the processes of microphysics, cumulus clouds, land surface, boundary layer and radiation.

2.2. WRFDA

In order to increase accuracy of meteorological fields, 4D-Var was conducted using WRF data assimilation system (WRFDA) [10]. WRFDA deals with the process to combine observational datasets with meteorological model output. Assimilated observational datasets are shown in section 2.4.