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Atmospheric dispersion and ground deposition induced by the Fukushima Nuclear Power Plant accident: A local-scale simulation and sensitivity study

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HIGHLIGHTS

- ► We model atmospheric dispersion of the Fukushima accident at local scale (80 km).
- ► Comparisons to gamma dose rate measurements are within a factor 2–5.
- ► Comparisons to deposition measurements are within a factor 5–10.
- ► Source term is the most sensitive parameter.
- ► Gamma dose rate, especially peak values, are more sensitive than deposition.

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ABSTRACT

Following the Fukushima Daiichi Nuclear Power Plant (FNPP1) accident on March 2011, radioactive products were released in the atmosphere. Simulations at local scale (within 80 km of FNPP1) were carried out by the Institute of Radiation Protection and Nuclear Safety (IRSN) with the Gaussian Puff model pX, during the crisis and since then, to assess the radiological and environmental consequences. The evolution of atmospheric and ground activity simulated at local scale is presented with a “reference” simulation, whose performance is assessed through comparisons with environmental monitoring data (gamma dose rate and deposition). The results are within a factor of 2–5 of the observations for gamma dose rates (0.52 and 0.85 for FAC2 and FAC5), and 5–10 for deposition (0.31 for FAC2, 0.73 for FAC5 and 0.90 for FAC10). A sensitivity analysis is also made to highlight the most sensitive parameters. A source term comparison is made between IRSN's estimation, and those from Katata et al. (2012) and Stohl et al. (2011). Results are quite sensitive to the source term, but also to wind direction and dispersion parameters. Dry deposition budget is more sensitive than wet deposition. Gamma dose rates are more sensitive than deposition, in particular peak values.

1. Introduction

On March 11th 2011, an earthquake of magnitude 9.0 occurred off northeastern Japan, causing a tsunami and damaging the Fukushima Daiichi Nuclear Power Plant (FNPP1). As a result, radioactive products were released in the atmosphere. During the emergency phase, the Institute of Radiation Protection and Nuclear Safety (IRSN) was asked to provide its expertise in support of the French authorities. Since then, the institute has been working on improving its assessment of the terrestrial and marine contamination (Mathieu et al., 2012; Bailly du Bois et al., 2012). Understanding the formation process of highly contaminated areas cannot be achieved through measurements only. While several kinds of measurements are available, they only yield partial information: gamma dose rates devices have a high temporal resolution, but are integrated overall gamma-emitters, and are too scarce to provide a good spatial coverage. Soil samplings and airborne readings provide maps of the contamination, but no information on short-lived species, noble gases, and temporal variations. Thus, improving atmospheric dispersion simulations remains a key issue, especially for dose assessments.

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To this day, most numerical studies have focused on reconstructing the source term using environmental data, either at large scale (Stohl et al., 2011,Winiarek et al., 2012), or at local scale (Katata et al., 2012), and using it for dose assessments (e.g. Morino et al., 2011; Terada et al., 2012). Numerical simulations and model-to-data comparisons at local scale are scarce, partly because of the difficulty to produce satisfactory meteorological fields at that scale. Such studies (Chino et al., 2011 and following papers) use gamma dose rates, but not deposition measurements (except Terada et al., 2012 which is based on prefectural measurements at Japan scale). The existing studies were conducted with a given source term and set of deposition parameters, but no extensive sensitivity study has been carried out.

This paper presents the evolution of atmospheric and ground activity simulated at local scale (within 80 km of FNPP1). Simulations are made with pX, IRSN's Gaussian puff model. The pX model is part of the operational platform C3X, which is used by IRSN's Emergency Response Center in case of an accidental radioactive release. The aim of this study is to better understand the formation processes of the contaminated areas, but also to give new insights on the pertinence and limitations of model evaluation tools and indicators in accidental situations. Indeed, usual Gaussian model evaluations are made on simple, well-known dispersion experiments. The Fukushima accident provides an unprecedented case to evaluate atmospheric dispersion models devoted to radionuclides, with many environmental measurements. We try to highlight advantages and shortcomings of each kind of measurements and of statistical indicators used to evaluate a model's performance.

More than one year later, many uncertainties remain, especially on the source term (release kinetics, source height, and isotopic composition) and meteorology. Besides, uncertainties in simulation parameters such as dry deposition velocities and scavenging coefficients cannot be neglected. Our sensitivity study is aimed at identifying the most sensitive simulation parameters and input data.

This paper is organized as follows: first, input data and simulation set-up are described for a "reference" configuration (Section 2). Then, this reference simulation is compared to gamma dose rate and deposition measurements (Section 3). Finally, the sensitivity simulations are presented and discussed based on total deposition budget and model-to-data comparisons (Section 4).

2. "Reference" simulation set-up and input data

2.1. Meteorological data

2.1.1. Wind

Operational forecasts from the European Center for Medium-Range Weather Forecasts (ECMWF) with a spatial resolution of $0.125^\circ \times 0.125^\circ$ and a time resolution of 3 h were used. The model does not resolve the complex topography of the Fukushima area, which is located close to the sea and within 10 km of a mountainous area. The dataset was therefore analyzed and compared with available meteorological data at several monitoring stations in the Fukushima prefecture.

Fig. 1 shows the comparison between the wind at FNPP1 forecast by ECMWF model, and observed by a monitoring car. The modeled wind speed is often higher than the observed values, which is consistent with the difference in heights between observations (monitoring car) and simulation (10 m). Besides, the cell containing FNPP1 is partly over the ocean, where wind speeds are globally higher. The wind direction comparison shows a rather good model-to-data agreement except for some events, especially during March 15 in the evening. During this period, observations clearly indicate a north–northwest plume travel direction, whereas the modeled direction is mostly west. Accuracy in the wind direction is an issue of prime importance at that time since it coincides with heavy rainfalls (cf. Section 2.1.2) and large releases. Therefore, the simulations used in this study were carried out using homogeneous wind fields built with observations at FNPP1 during March 15, between 18 h and midnight, with a 10-min frequency. This solution had its own limitations, since the wind observed at Daiichi was used on a larger domain than its representativity scale, and did not take into account vertical wind shear. For the rest of the simulation, three-dimensional ECMWF data were preferred, to account for the heterogeneity of the flow.

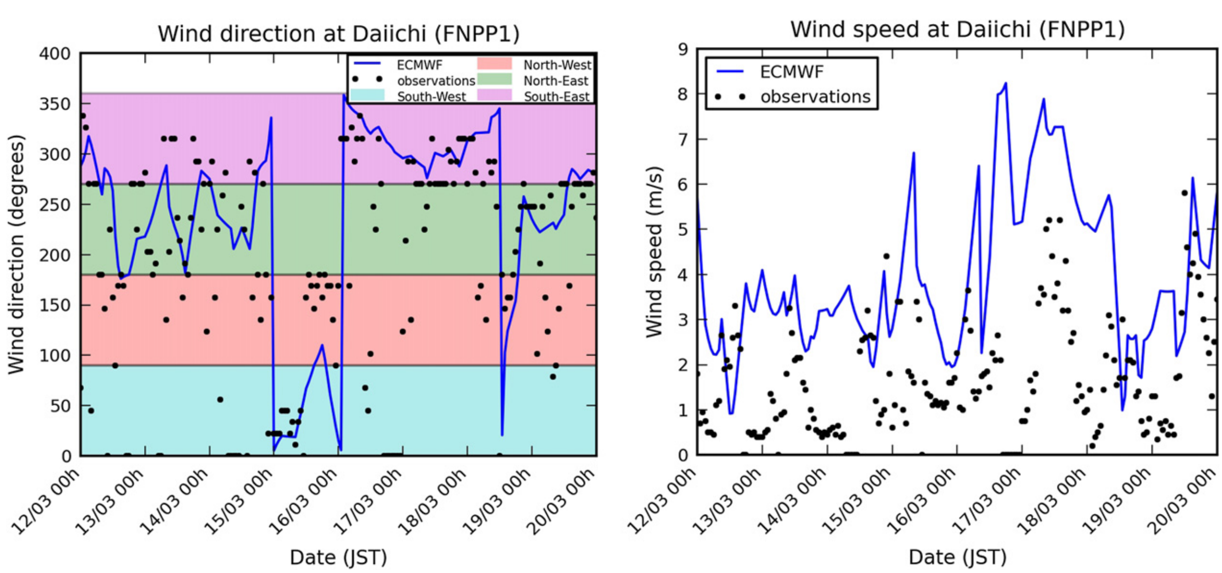

Fig. 1. Comparison of wind observations (1-h median) at FNPP1 and wind given by ECMWF model, between March 12th and 20th. Left: wind direction (the bands of color indicate the plume travel direction), right: wind speed. The ECMWF wind is taken in the cell of FNPP1 (without spatial interpolation), at 10 m. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)