Asian Journal of Water, Environment and Pollution, Vol. 19, No. 2 (2022), pp. 1-8.
DOI 10.3233/AJW220017

Simulating the Potential Impacts of Nuclear Power Plant Accident for Northern Vietnam

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Received January 5, 2022; revised and accepted February 17, 2022

Abstract: The Fangchenggang nuclear power plant has been built very close to the Vietnam boundary. This is done to generate potential impacts for Northern Vietnam if nuclear power plant accident occurs. This study applied the Weather Research and Forecasting (WRF) model to construct the meteorological data at horizontal mesh resolution of 1 km as input for the FLEXible PARTicle dispersion model (FLEXPART). The assumption of the nuclear accident at Fangchenggang Power Plant is considered with setup parameter of the Fukushima accident. The results show a similar in simulating the ^{137}Cs concentration from 03 out of 24 experiments configured with different parameterisation schemes of the WRF model. However, the dry and wet deposition of radioactive ^{137}Cs are significantly different. It is especially illustrated that if the accident occurs, then almost all provinces in northern Vietnam are affected. The high concentration of radioactive pollutants may be intensively transported from Fangchenggang nuclear power plant to Vietnam under the domination of wind fields in the wintertime. The maximum values of the total effective dose rate could reach up to over 10 mSvh^{-1} of dose rate during 50 to 100 hours. Importantly, the maximum effective dose continues to be observed during 145 to 205 hours.

Key words: Fangchenggang, nuclear power plant, WRF, FLEXPART.

Introduction

Numerical modelling of air dispersion plays a central role in studying the behaviours of air pollutants dispersed in the ambient atmosphere. Doing so, calculating programmes that contain models and algorithms are involved to solve mathematical equations that describe atmospheric physical processes (e.g., dispersion processes and atmospheric phenomena). Specific scenarios are assumed to simulate the consequences of air pollutants, hazardous chemical materials, or radionuclides released from industrial facilities, especially from nuclear power plants. Several typical software and/or model systems are used to evaluate the air quality (e.g., ModOdor of Yanjun et al. (2019) which is an Eulerian-based model for simulating the dispersion of gaseous contaminants; the READY web-based of Glenn et al. (2017) for running the HYSPLIT model). Fast (2006) applied the WRF model to evaluate the dispersion ability and calculate the trajectories of particles in the atmosphere for central Mexico. The WRF model was setup with three nested grids of different resolutions of 22.5 km, 7.5 and 2.5 km. The outputs were used as input for FLEXPART-

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WRF for simulating the dispersion of pollutants during the period from February 26, 1997 to March 4, 1997. The results showed that changes in parameterisation schemes of the planetary boundary layer could lead to changes in the fields of meteorological parameters like winds. Consequently, the density and spatial distribution of particles in the atmosphere are changed. de Foy et al. (2011) also applied the FLEXPART-WRF model to study the transport and metabolism of particles with the outputs of the WRF model in urban Mexico. The WRF model was configured with 27, 9, and 3 km and 41 vertical levels. In addition, the physical options within the model are configured with different schemes (e.g., the planetary boundary layer of Yonsei University (Hong et al., 2005), Kain-Fritsh cumulus scheme (Kain, 2004), WSM6 microphysics (Hong and Kim, 2006)). The results showed that the FLEXPART-WRF simulations could capture the main direction of aerosol particles. This model has also been used by Rakesh (2021) to simulate the dispersion of radioactive from a nuclear power plant in southeastern France. All things illustrated potential applications of combined WRF and FLEXPART-WRF for simulating the radioactive dispersion. Importantly, the physical configuration of the model defines the ability of obtained results.

For simulating atmosphere dispersion, normally, there are three ubiquitous types of mathematical models (e.g., Gaussian, Eulerian, and Lagrangian). In the Gaussian model, the pollutant concentration profile through the plume follows a Gaussian distribution in vertical and lateral directions. The Gaussian model is mostly recommended for applications that need fast calculation, such as online risk management (Leelossy et al., 2014). The Eulerian model tracks the movement of a large number of pollution plume parcels as they move away from their initial location by solving the Navier-Stoke equation, it uses a fixed three-dimensional Cartesian grid as a frame of reference (Grifoni and D'Onofrio, 2012). The Eulerian model is well suited for long-range dispersion applications, or high stability of boundary layers (Leelossy et al., 2014). The Lagrangian model followed moving air parcels (also called particles) along trajectories, it calculates the velocity of the particles as a stochastic process (Bluett et al., 2002). It is the most proposed model for applications that need to scrutinise accuracy and simulation time in mesoscale, such as free atmospheric dispersion and complex terrain (Leelossy et al., 2014). In particular, it is noticed that FLEXPART is flexible to directly use the output from meteorological fields. In other words, the advantages of the model involve atmospheric processes. Currently, China has been operating four nuclear power plants (e.g., Fangchenggang, Changjiang, Yangjiang and Guangxi Bailong) very close to the Vietnamese border. This could lead to very high risks if nuclear accidents occur like the Fukushima–Daiichi nuclear power plant incident in 2011. This event is the most severe nuclear accident followed by the event of Chernobyl in 1986, where over 150,000 people had to be evacuated and large amounts of water contaminated with radioactive isotopes were released into the Pacific Ocean during that event. Hence, it is very urgent to build assumption scenarios for responding and preventing their potential impacts on national security, socio-economic development. The aim of this study is to simulate the potential impacts of nuclear power plant accidents for Northern Vietnam if a nuclear accident occurs at the Fangchenggang power plant. It is located in Fangchenggang within the Guangxi Zhuang Autonomous Region in western China, approximately 50 km from the border of Vietnam. This power plant project involves the construction of six nuclear reactor units, with a total capacity of 6GW in multiple phases from 2010.

Method and Experiment Design

To simulate the dispersion of potential impacts of nuclear power plant accidents for Vietnam, the WRF model is used to generate the regional meteorological fields at high resolution (i.e., 1 km). The purpose of this is to properly resolve orographic effects and mesoscale processes from the spare resolution global data like ERA5 data (e.g., 0.25° × 0.25°). This is a numerical weather prediction model, which could be used for both research and operational applications. The WRF model is also considered to be a common tool for the research and operational communities to promote closer ties between them (Skamarock et al., 2008). Importantly, it is optimized for the analysis and forecast of meteorological fields from the microscale to the synoptic and event global scales. In this study, two domains are configured with labels of d01 and d02 (Figure 1) that have a spatial resolution of 5 km × 5 km and 1 km × 1 km, respectively. The d01 domain covers from 17ºN to 25ºN through 101ºE-110ºE.

Uncertainties of WRF simulations are different depending on dozens of parameterisations for boundary layer processes, convection, microphysics, radiation, land surface processes. It is especially noted that 24 experiments are investigated by Dzung et al. (2020) with the assessment of uncertainties dealing with these parameterisations. In this study, lists of parameterisation schemes are selected to simulate the potential impacts of the nuclear power plant accident (Table 1). The ERA5 data is used as the boundary and initial conditions to simulate the meteorological fields. The purpose of this is to evaluate the performance of WRF simulations before modeling the potential impacts of the nuclear power plant accident for Vietnam with the input data of the global forecast system. The WRF is run with 51 vertical levels and four soil layers.

It is noticed that the output from the WRF model is used as input for FLEXPART. This software is firstly released in 1998 and written in Fortran 90 code. Since the release of version 8.2 in 2010, the code is distributed under the GNU General Public License (GPL) Version 3 (Stohl et al., 2010). The FLEXPART, a Lagrangian dispersion model, is an open-source programme. This programme is mainly designed to calculate the long-range and mesoscale dispersion of air pollutants released from point sources often observed from an accident in a nuclear power plant. The performance of FLEXPART is also comprehensively validated with experiments by using controlled tracer in intercontinental air pollution transport studies (e.g., Stohl et al., 2003a, 2003b). In this study, an assumption of dispersion for the accident at Fangchenggang nuclear power plant (Figure 1) is selected to simulate the potential impacts on Vietnam

Table 1: Physics choices for sensitivity test of the FLEXPART-WRF model

No.	*Experiment name*	*Microphysics*	*Boundary-layer*	*Longwave/Shortwave radiation*
1	Exp01	WSM 6-class graupel scheme	Mellor-Yamada-Janjic (Eta) TKE scheme	Rapid Radiative Transfer Model (RRTM) scheme/Dudhia scheme
2	Exp02	Kessler scheme		
3	Exp03		MYNN 2.5 level TKE scheme	

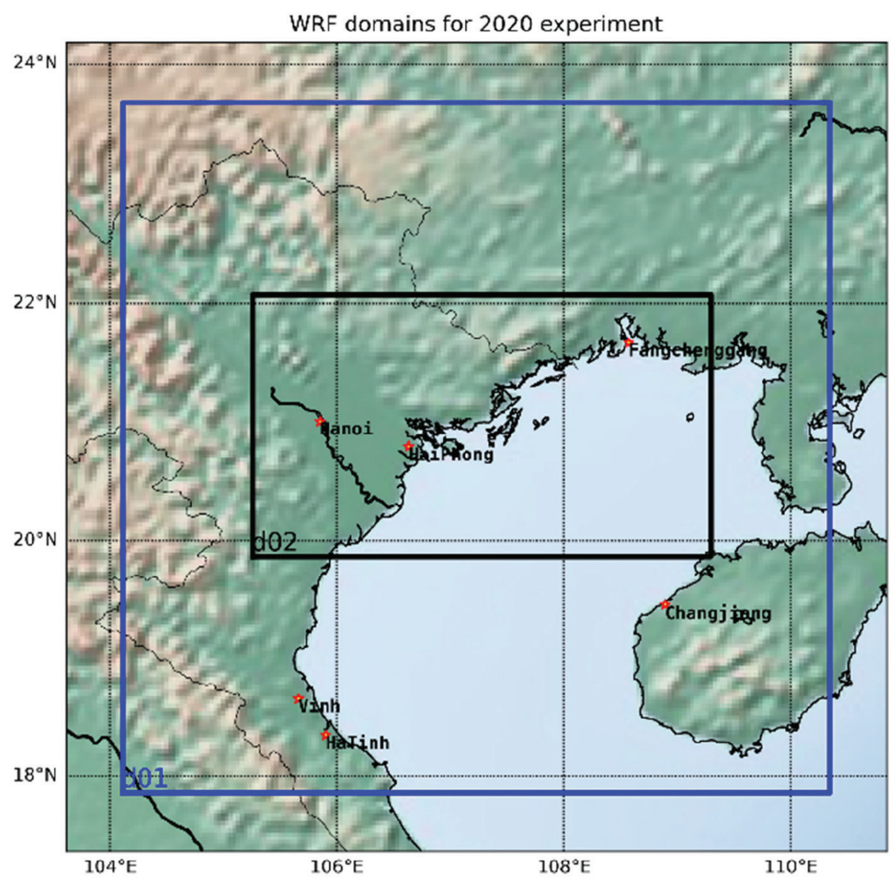

Figure 1: Sketch of study area.

from 00:00 UTC on March 12, 2020 to 00:00 UTC on March 17, 2020. Importantly, a specific emission source is required to identify. They are taken from the same value as the Fukushima incident. The source term of the ^{137}Cs radioactive nuclide released from the reactor area by time and position is determined based on the analysis report of Katata et al. (2015) and Terada et al. (2020). The total amount of ^{137}Cs emitted in the duration is 1.4×10^{16} Bq. This number is based on the estimation from Fukushima–Daiichi nuclear accident (United Nations, 2015) and converted in the year 2020. It is also hypothesised that total radioactivity is continuously and constantly emitted during the 2 hours of the accident. Additionally, the ability of the FLEXPART-WRF model in reproducing temporal and spatial distribution of radioactivity is successfully illustrated for the accident at Fukushima–Daiichi nuclear power plant (March 2011). So, the parameters of FLEXPART are adopted for these experiments.

Results and Discussions

Simulating of Potential Impacts of Nuclear Power Plant Accident for Northern Vietnam

First and foremost, there is a similarity in the obtained results of ^{137}Cs concentration from three experiments. Importantly, the Exp03 experiment has a noticeable difference compared to Exp01 and Exp02 that is radioactive emissions spread towards China with a wider cloud from Figures 2a to 2c, respectively. This difference continues to be observed as radioactive dispersion spreads towards the East Sea on March 13, 2020. On March 14-15, 2020, the radioactive dispersion is more visible over Northern Vietnam (Figures 3 and 5). This is well suitable with the cumulative wind and precipitation at the surface level (Figure 4). Furthermore, during the winter (usually from November until March), polar air masses originating from the Siberian High penetrate deeply into the low latitudes including Vietnam, facilitated by the eastern Tibetan Plateau that funnels the air southwards in a northeast direction. Hence, the dispersion of radioactive emissions is partly dominated by the wind direction of the northeast. It is also noticed that the main consideration in this study is to explore to what extent the assumed accident affects Vietnam, only winter monsoon condition is considered.

Importantly, the dry and wet deposition of radioactive ^{137}Cs from March 12-16, 2020 with three different experiments are constructed. On March 12, 2020, it was clearly seen that there is a difference in the simulation results from Exp03 (Figure 6c) in comparison with others (Figure 6a-b) in the spreading of radioactive

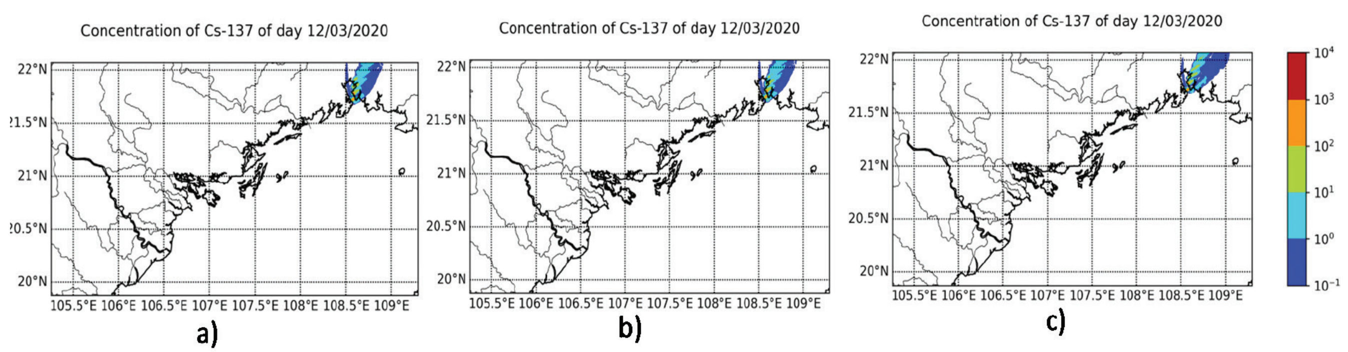

Figure 2: Spatial distribution of ^{137}Cs concentration on March 12, 2020 with Exp01(a), Exp02(b) and Exp03(c).

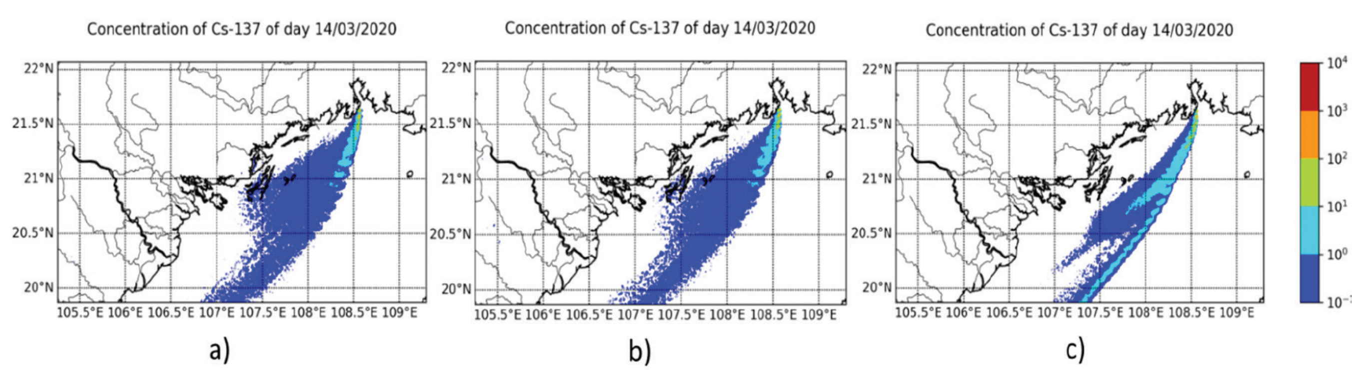

Figure 3: Similar to Figure 2 but on March 14, 2020.

areas. On March 14, 2021, Exp03 (Figure 7c) experiment shows a narrow and extension band of dry and wet deposition of radioactive ^{137}Cs. It is observed that Exp01 (Figure 7a) and Exp02 (Figure 7b) simulate the dry and wet deposition of radioactive ^{137}Cs with a shorter and wider band compared with the Exp03 experiment. All things illustrate that the WRF model with a scheme of a boundary layer is more sensitive than the WRF model with a scheme of microphysics. The reason for this comes from the effects of the planetary boundary layer on the thermo-dymamical structure and the flow fields in the atmosphere. The accuracy of the WRF model with different configurations was clearly depicted in Dzung et al. (2020). In the study, 24 experiments were designed and validated using the Taylor diagram with Pearson correlation coefficient and normalised standard deviation.

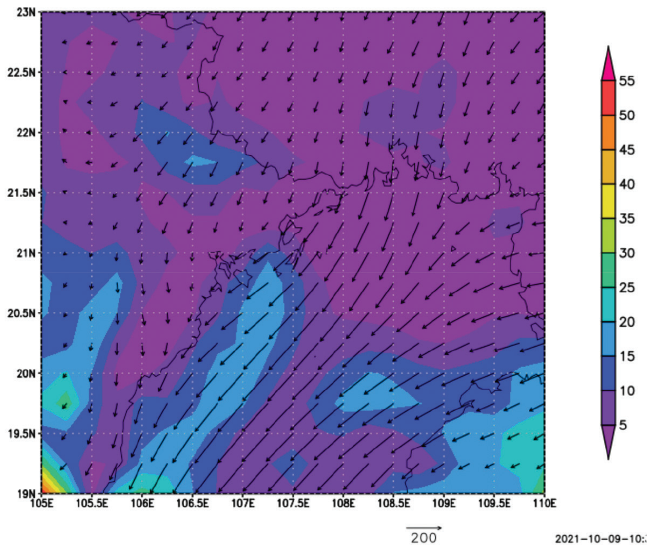

Figure 4: Cumulative wind and precipitation at surface level on March 14, 2020.

Calculation of Effective Dose Rate

Calculation of the effective dose rate due to human breathing in a hypothetical nuclear accident is performed using the method proposed by the International Atomic Energy Agency (2004). The amount of ^{137}Cs that can be inhaled by a person is calculated using the empirical coefficient with measured data after two days if an incident occurs. The conversation coefficient from the radioactivity concentration and deposition density to a dose rate of radionuclides of ^{137}Cs is 6.7×10^{-9} Sv/Bq. Figures 8 and 9 show the calculation of the effective

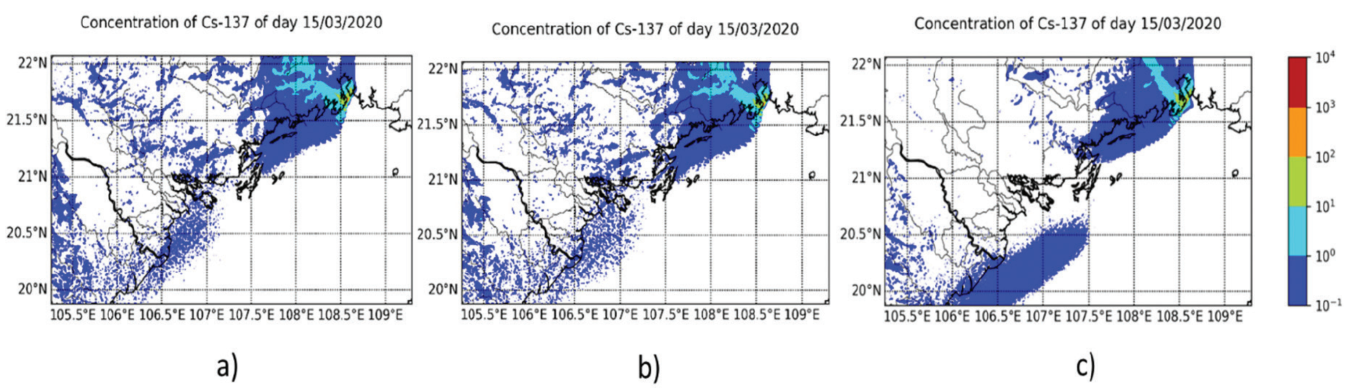

Figure 5: Similar to Figure 2 but on March 15, 2020.

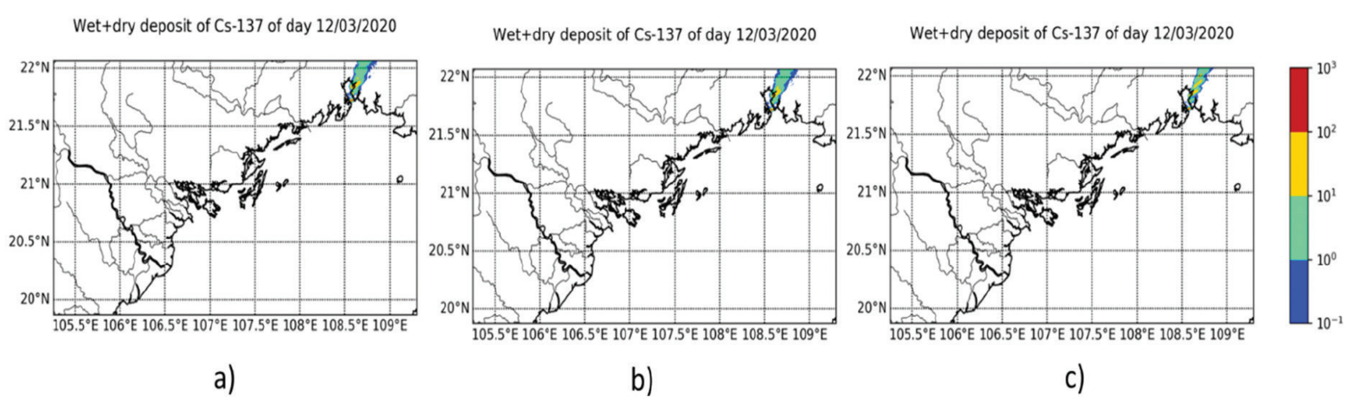

Figure 6: Dry and wet deposition of radioactive ^{137}Cs on March 12, 2020.

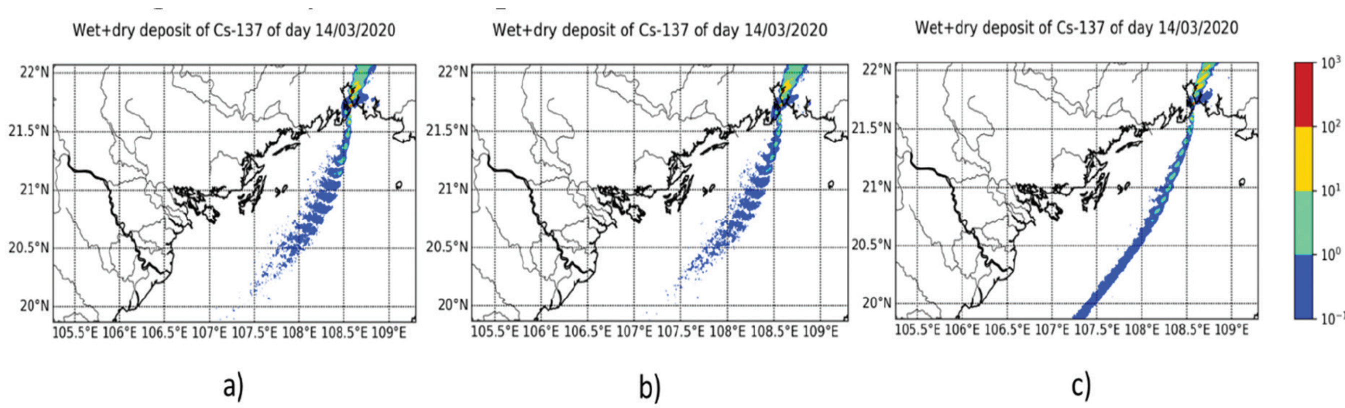

Figure 7: Similar to Figure 5 but on March 14, 2020.

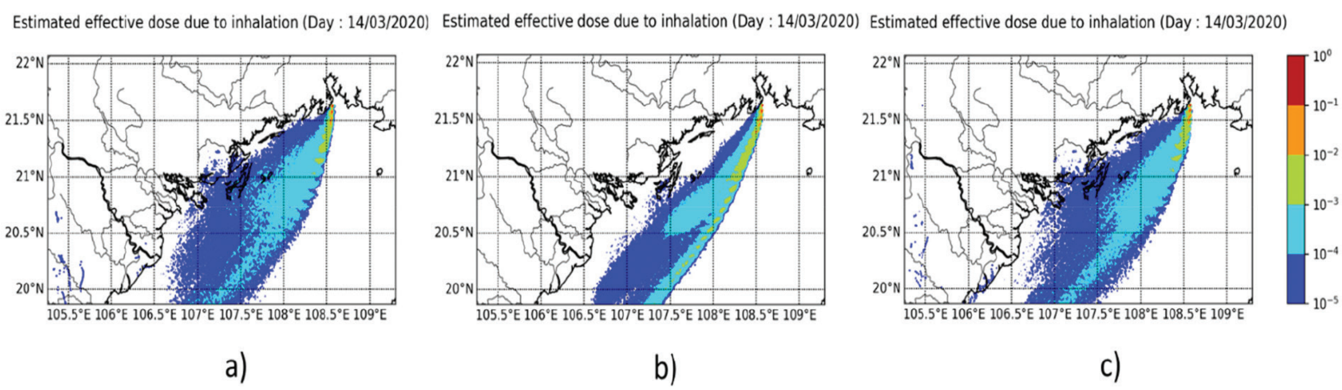

Figure 8: Spatial distribution of effective dose rate on March 14, 2020 with Exp01 (a), Exp02 (b) and Exp03 (c).

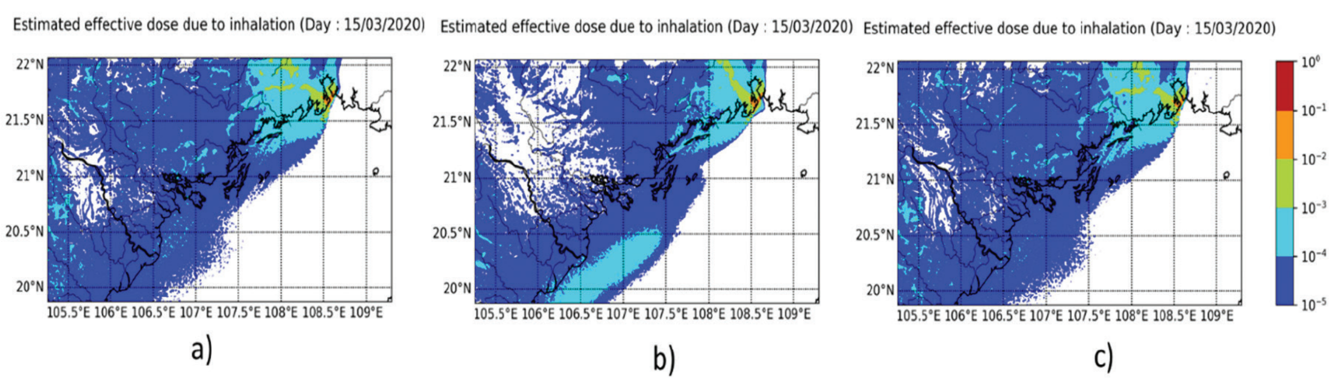

Figure 9: Similar to Figure 8 but on March 15, 2020.

dose rate during March 14-15, 2020, respectively. It can be seen that the effective dose rate is high on the mainland of northern Vietnam on March 15, 2020 due to the high radiation concentration of ^{137}Cs.

With three different sets of microphysical and boundary layer configurations, the obtained results are different, especially Exp03 (Figure 10c) is compared with others (Exp01, Exp02) in simulating ^{137}Cs concentration and dry and wet deposition. Figure 10 shows the temporal distribution of the total effective dose rate caused by radionuclides after 217 hours that nuclear accident occurred. It displays that maximum values could reach up to over 10 mSv h^{-1} of dose rate during 50 to 100 hours. The provinces having values between 0.2 and 3mSv include Quang Ninh, Hai Phong, Hai Duong, Thai Binh, Hanoi, Bac Giang, Bac Ninh, Cao Bang. Especially, the maximum effective dose continues to be observed during 145 to 205 hours in these provinces for Exp01 (Figure 10a) and Exp02 (Figure 10b). This is useful reference data to setup the

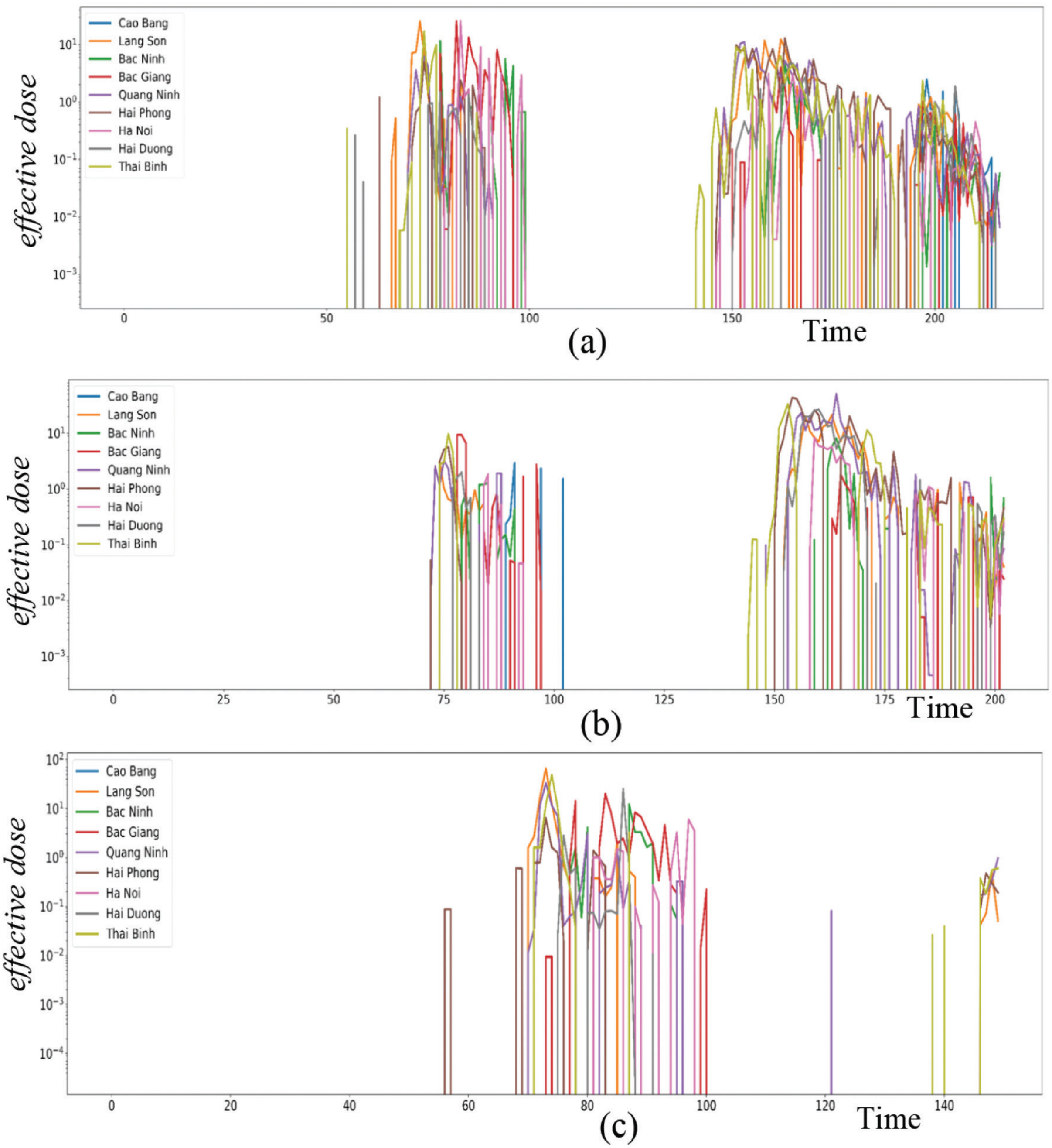

Figure 10: The spatial distribution of effective dose rate after 217 hours from the time of the accident occurred with Exp01 (a), Exp02 (b) and Exp03 (c).

location of the systems warning system, monitoring and early detection of radiation in the environment.

Conclusions

In this study, the Weather Research and Forecasting (WRF) model is applied to construct the meteorological data at 1 km and 5 km for the FLEXPART. The potential impacts of the nuclear power plant accident from Fangchenggang are investigated with three experiments of parameterization schemes of the WRF model. It is illustrated that there is little difference between these experiments. The second domain nested first domain with the highest resolution of 1 km covers a part of Northern Vietnam and the Fangchenggang Nuclear Power Plant. For the Vietnam area, in case the nuclear accident occurs at the Fangchenggang nuclear power plant, the pollutants will be mostly transported to provinces located in the northern of Vietnam. This could come from the strong effects of cold air with the predominant northeast wind in the time of winter. The information is useful for policy makers to setup action plans for protecting human and food security if a nuclear accident occurs at the Fangchenggang nuclear power plant.

Conflict of Interest

The author declares no conflict of interest.

Acknowledgement

This article is supported by the project titled "Study the effects of the floating nuclear power plant on the sea and the nuclear power plants on Hainan Island on Vietnam's marine environment by modelling and developing response plans for a nuclear accident occurred over the sea", project code: KC.AT 2016–2020.

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