IOSR Journal Of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 12, Issue 6 Ser. II (Nov. – Dec. 2020), PP 51-63
www.Iosrjournals.Org

Study on numerical models to evaluate atmospheric dispersion of radioactive materials on Vietnam territory

Kieu Ngoc Dung[1*], Nguyen Hao Quang[2], Hoang Huu Duc[3], NguyenQuang Trung[4]Nguyen Thị Hang[1], Nguyen Thi Thoa[3]
[1] *National Committee for Search and Rescue of Vietnam, Long Bien, Ha Noi, Vietnam*
[2] *Vietnam Atomic Energy Institute, 59 Ly ThuongKiet, Ha Noi, Vietnam*
[3]*Military Environmental Chemistry Institute, AnKhanh, Hoai Duc, Ha Noi, Vietnam*
[4]*Vietnam Institute of Meteorology, Hydrology and Climate change, Ha Noi, Vietnam*

Abstract*: Atmospheric dispersion modeling is a challenging problem not only for environmental management, but also for predict the dispersion of radioactive materials. The key priority to promote an effective model for emergency response is making a balance between the accuracy and the computational cost. This research has made a brief review about the properties of several dispersion models as Gaussian, Eulerian, Lagrangian, and CFD (Computational Flux Dynamic). We also discussed their performance in parallel computing and proposed an approach for predict and fast nuclear accident response by using the WRF model (Weather Research and Forecasting) and the FLEXPART-WRF. For demonstration, we presented two examples by using FLEXPART-WRF for simulation of the dispersion of ^{137}Cs from the Fangchenggang nuclear power plant.*

Keywords: *Air dispersion modelling, Gaussian, Eulerian, Lagrangian, CFD, WRF, FLEXPART, FLEXPART-WRF.*

Date of Submission: 27-11-2020 Date of Acceptance: 11-12-2020

I. Introduction

Among lessons learned from the Fukushima Daiichi nuclear accident, emergency response planning plays a crucial role in preventing scenarios resulted after the accident. Vietnam is developing a national warning system for predicting the potential dispersion of nuclear accidents, in which the atmospheric dispersion modelling is aimed to be the main objective of this project. Choosing appropriate models is necessary and needs careful study.

Atmospheric pollution diffusion can be numerically simulated by several techniques, which are mainly divided into two categories:[1]

II. Lagrangian models

The basic differencebetweenthese two approaches is illustrated in Figure 1, in which the Eulerian coordinateis fixed in spaceand the concentration of the pollutantthrough a lattice is calculated by solving the mass conservation equation[2][3][4]. While the Lagrangiancoordinatefollows the motion of each individual species, the fluid flow of pollutants is assumed to be composed of a huge number of single particles, the total concentration is calculated by solving the motion of each individual particles. The Gaussian models are a consequence of the Lagrangianapproach by normalize the probability density function.

This paper presents the pros and cons of each model to apply for simulating the dispersion of radioactive materials in mesoscale, we discussed their accuracy in calculation and their computational performance to make time-effective in emergency cases. The criteria to propose a model to be the most suitable for Vietnam is defined as has simulation time under 30 minutes and the model must has been validated with experimental results.

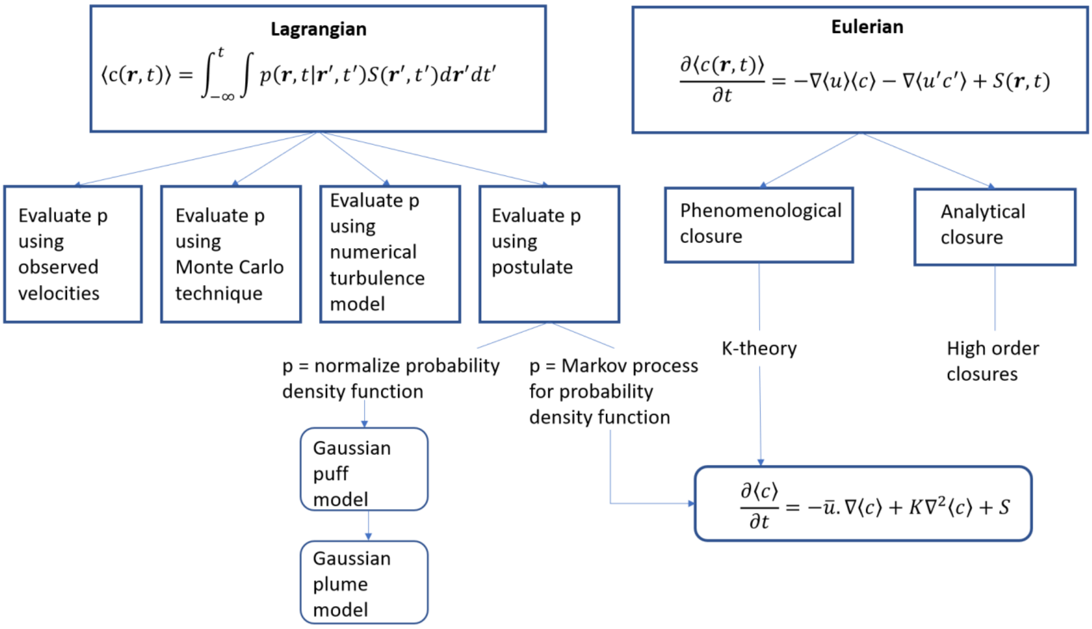


Fig. 1: Comparision of Lagrangian and Eulerian approach for atmospheric dispersion modelling. [1]

III. Gaussian dispersion models

The Gaussian dispersion modelsarethe most simple and common model for air dispersion modeling. It assumes a homogeneous, steady-state emissionrate,and under a stationary meteorologicalcondition: wind speed and wind direction are constant in space and time[2][5][6].Assume the plume is advected toward the positive x-axis, the concentration of the plume can be expressed by the Gaussian plumeformula [5]:

$$c(x,y,z) = \frac{Q}{2\pi\sigma_y\sigma_z u} exp\left[-\frac{y^2}{2\sigma_y^2}\right]\left\{exp\left[-\frac{(z-h)^2}{2\sigma_z^2}\right] + exp\left[-\frac{(z+h)^2}{2\sigma_z^2}\right]\right\}$$

where $c(x,y,z)$ is the concentration at point(x,y,z), (g/m^3)
Q is emission rate, (g/s)
u is wind speed, (m/s)
σ_y is dispersion parameter in the horizontal direction, (m)
σ_z is dispersion parameter in the vertical direction, (m)

In general, there are two types of Gaussian dispersion models: the plume model, and the puff model[5]. Fig. 1 shows the schematic of the Gaussian plume model, which is pollutant concentration profiles in y-axis and z-axis are results in a Gaussian distribution, centered at the plume centerline[1][5]. The terms σ_y and σ_z represent the affection of the weather conditions at the emission site to the dispersion of plume. These terms are semi-empirically calculatedunder stability classes based on Pasquill and Gifford criteria[5].

Gaussian models have the fastest calculation time by solving only one single formula, but theysacrificing accuracy for simplicity. It is widely applied for online risk managementapplications require fast response time[2].

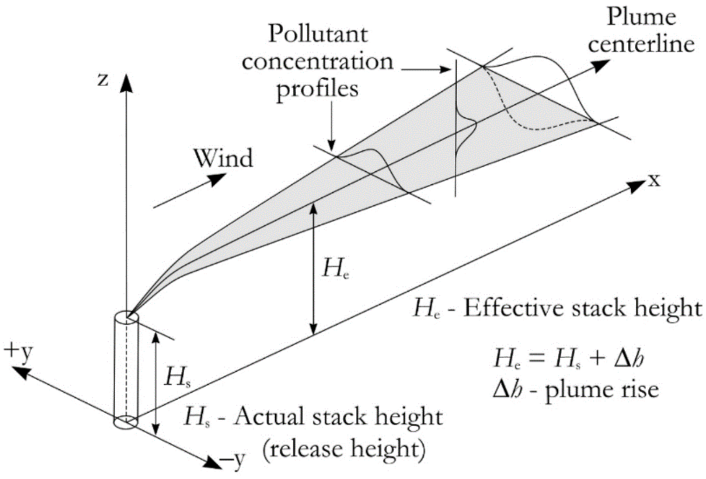


Fig. 2: Schematic of the Gaussian plume model.[2]

IV. Eulerian dispersion models

The Eulerian approach tracks the movement of pollution parcels in a fixed three-dimensionalcoordinate grid. The dispersion of the pollution parcels is solved numerically by the atmospheric transportequation[2][5][7]:

$$\frac{\partial c}{\partial t} = -\nabla.(c\vec{v}) + S_c + \nabla.(D_c \nabla c)$$

Where $\frac{\partial c}{\partial t}$ is the change of the local concentration in time.

$-\nabla.(c\vec{v})$ is the transport term, $\vec{v}$ is the wind vector.

S_c is the source termlocated in the given grid, including chemical production and loss, radioactive decay, dry and wet deposition.

D_c is the diffusion coefficient.

By considering a large number of particles as a pollution parcel, so Eulerian models can nottrack the movement of each individual particle. The accuracy of Eulerian models is largely depends on the resolution of the computation domain, the computational cost increases very rapidly with increasing resolution[2][1].The main advantage of this type of model is able to handle complex chemical processes. Eulerian models are usually used for long-range applications (ranging from 100-1000km), such as long-term average loads, stable boundary layer, or reactive materials[2]. A typical model is the CMAQ (The Community Multi-scale Air Quality) used for predictingchemical and physical processes that are important intropospheric ozone, toxics and acid deposition,and visibility degradation[2][4][5].However,the computational cost of Eulerian models rapidly increases when increasing grid resolution.

V. Computational Fluid Dynamics (CFD) models

Similar to the approach of Eulerian models, CFD models calculate the motion of air packageson a computational grid (usually refer as the mesh) by solving the Navier-Stokes equation[2]:

$$\rho\left(\frac{\partial \vec{v}}{\partial t} + (\vec{v}.\nabla)\vec{v}\right) = -\nabla P + \mu \nabla^2 \vec{v} + \vec{f}$$

Where $\frac{\partial \vec{v}}{\partial t}$ is the local acceleration.

$(\vec{v}.\nabla)\vec{v}$ is the acceleration of convective term

∇P is the pressure gradient

$\mu \nabla^2 \vec{v}$ is the viscous term

$\vec{f}$ is the body force term, including internal forces and external forces.

Obviously, the Navier-Stokes equation does not include the turbulence term[2][5], the only way to modelling the turbulence using Navier–Stokes equationdirectly calculates the turbulent kinetic energyon each scale where the energy is dissipated by viscous forces[2][5]. This requires the computational mesh cell must have 1mm-size to calculate atmospheric turbulence with acceptable accuracy, which results to need extremely high computational costs. Therefore, the turbulence has to be estimated by two common approaches: the $k-\varepsilon$ approach, or Large Eddy Simulation (LES) approach[2][5]. The $k-\varepsilon$ model uses the Reynolds-averagedNavier–Stokes(RANS)which gives more efficient than the LES, but least accurate[2][5]. The LES is a state-of-the-art tool for turbulence modeling but requires high computational cost, its results are often used as a standard dataset for other models[2][5].

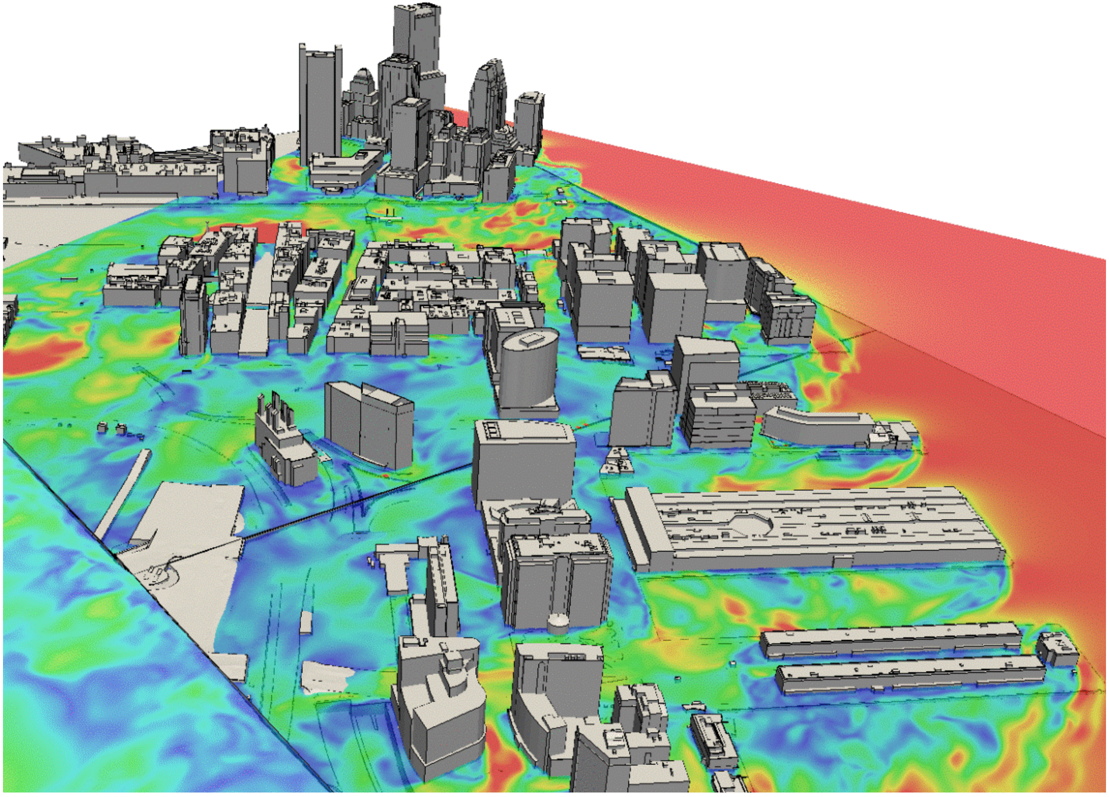


Fig. 3: An example of wind velocitysimulation based CFDat Boston Seaport District using theSimScalesoftware.[8]

Computational fluid dynamic is an intensive technique and costs extremely high performance computing, beside, it is required to constructall the buildings geometry,determine boundaryconditions. The computational fluid dynamic is only feasible at small scales, ranging around 1-10 km[2].

VI. Lagrangian dispersion models

Unlike the approach of Eulerian models and CFD models, Lagrangian models solve the motion of each single particleas it moves away in the atmosphere (or also refer as air parcel)[2][4][5][6].Over time, the position and characteristicof this air parcel are calculated by solving ordinary differential equations (ODEs) according to the mean wind field data[2]. In the Lagrangian particle models, thecoordinate system of each particle is moving follow with its position. The keyparameter of Lagrangian models is the probability density function $p(\boldsymbol{r}, t|\boldsymbol{r}', t')$ that an air parcel moves from $\boldsymbol{r}'$ at $t'$to $\boldsymbol{r}$ at$t$, where t>t', this probability density functiondepends on thesite-specific meteorology, particle size distribution, and particle density[2][5]. The velocity of the particle is calculated based on the Langevin stochastic differential equation[2]:

$$dw = -\left(\frac{w}{T_L}\right)dt + Xd\mu$$

where w is any component of particle velocity, T_L is the Lagrangian time scale, $\frac{w}{T_L}$ is the deterministic term, $Xd\mu$ is the stochastic term. By take into account for stochastic term in particle velocity calculation, therefore Lagrangian particle models is the better way for modelling thestochasticturbulence motion of particles.

Lagrangian particle models handle physics aspects that lay behind the air dispersion better than any other modeland be more accurate at long distances (thousands of kilometers)[5].The computational cost of Lagrangian models only depends on the number of particles, not dependson the output grid resolution, thereforeLagrangian models areexceptionally efficient for mesoscale simulation to compare to Eulerian gridded simulation with very fine resolution.Table 1 demonstrates recommended applications of several dispersion models by Leelossy et al.[2], therefore we proposed the Lagrangian models for atmospheric dispersion modelling that is suitable for the Vietnam territory scale.

Table 1: Recommended applications of numerical models for atmospheric dispersionmodelling[2]

Application	**< 1 km**	**1-10 km**	**10-100 km**	**100-1000 km**
Online risk management	-	Gaussian	Puff	Eulerian
Complex terrain	CFD	Lagrangian	Lagrangian	Eulerian
Reactive materials	CFD	Eulerian	Eulerian	Eulerian
Source-receptor sensitivity	-	Lagrangian	Lagrangian	Lagrangian
Long-term average loads	-	Gaussian	Gaussian	Eulerian
Free atmosphere dispersion	-	Lagrangian	Lagrangian	Lagrangian
Convective boundary layer	CFD	Lagrangian	Eulerian	Eulerian
Stable boundary layer	CFD	Lagrangian	Eulerian	Eulerian
Urban areas, street canyon	CFD	CFD	Eulerian	Eulerian

VII. Proposed simulationmodels for Vietnam

There are several simulation programs based on Lagrangian models, such as AUSTAL2000 (Janicke,http://www.austal2000.de/en/home.html), FLEXPART (Stohl, https://www.flexpart.eu/), GRAL (The Graz Lagrangian Model), HYSPLIT (https://www.ready.noaa.gov/HYSPLIT.php). Especially with FLEXPART by Andreas Stohl, this program is good for simulation at the local and global scale, it contains advanced algorithms to describe particle transport and diffusion, dry/wet deposition, radioactive decay, OH reaction. FLEXPART has been comprehensively validated with experiments by using controlled tracer in intercontinental air pollution transport studies[9][10][11][12][13][14]. The study of Long et al. [15]showed good abilitíesof FLEXPART to be applied for simulation of long-range radioactive materials dispersion and good to deal with fast nuclear incident response on the whole Vietnam territory. FLEXPART takes data from the GFS (Global Forecast System) or the ECMWF (European Centre for Medium-Range Weather Forecasts) as meteorological input[16], however, the highest resolution of the GFS data is0.25 degree resolution, which is grid resolution about 27km×27km, may need to ameliorate to higher resolution to get better accuracy. As far as our opinion, to improve the accuracy of the dispersion simulation, a meteorological module should be implemented to be used as an intermediary preprocessor. The intermediary meteorological module is expected to give better accuracyin terms of treating the coarse meteorological data for getting initial and boundary conditions. Here, we promoted the WRF-ARW (Weather Research and Forecasting) to be a meteorological preprocessor for this problem.

The ARWis a non-hydrostatic mesoscale model that is the most commonly used for weather prediction and atmospheric research, we simply invoke it as WRF. The WRF contains dozens of parameterization schemes for modelling in-depth all processes in the atmosphere, including microphysics, cumulus, short/long-wave radiation, planetary boundary layer, and surface layer. WRF has always been a free program ever since it was released, it is the most prestigious and powerful computational model for simulating atmospheric aspect, lots of institution are using WRF for research and operational. Beside, WRF is flexible for nesting computational domains, define geographical projection, and set the grid resolution. Users can increase time-resolution or grid resolution in order to get higher accuracy. For running WRF require initial and boundary conditions from GFS or ECMWF data[17]. The ECMWF dataset requires pay charges for license, but the GFS is provided for free by NCEP and user can freely access and download from NCEP server, therefore we proposed an approach for atmospheric dispersion simulation of radioactive material is that by using the WRF/GFS for meteorological simulation.

Besides the original version, FLEXPART has several branches which are bespoke for limited-area models, such as FLEXPART-WRF, FLEXPART-MM5, FLEXPART-AROME, FLEXPART-COSMO. These branches take input from meteorological module (WRF, MM5, AROME, COSMO) and use them as initial and boundary conditions. FLEXPART has always been a powerful tool for atmospheric dispersion modelling, but it is require for further development to be more comprehensive at small-scale, therefore the FLEXPART-WRF is developed and inherit the quintessence of FLEXPART. Some new highlight features are implemented into FLEXPART-WRF while keeping the strength of FLEXPART, which include new options for interpolating wind field data (instantaneous or time-averaged winds), parallelization computational (MPI, OMP, SERIAL), and improvement on skewed turbulence modelling based on the studyCassiani et al.[17]. By new development, FLEXPART-WRF is expected to give insight into small-scale than FLEXPART can present[17].

VIII. Demonstration runs

We present two example runs in two different climate patterns in Vietnam by using the FLEXPART-WRF Langragian model for forwarding simulation of the dispersion of 137Cs aerosol from the Fanchengang NPP. The first case took at the time when the winter northwesterly winds were striking the northern of Vietnam, and the second case was performed under heavy rainfall event from the Mun tropical storm. Both of two simulation runs are conducted on a High-Performance Computer (HPC) which has two Intel Xeon E5-2699 processors (44 cores, 88 threads, 2.2 GHz base frequency), 1 TB of RAM.

The WRF configuration for meteorological simulation and release properties in both two case are given in Table 2. The schemes used for WRF simulation are referenced based on the study ofTien et. al[18],that is tested on 32 different configurations for heavy rainfall forecast for the North Vietnam.

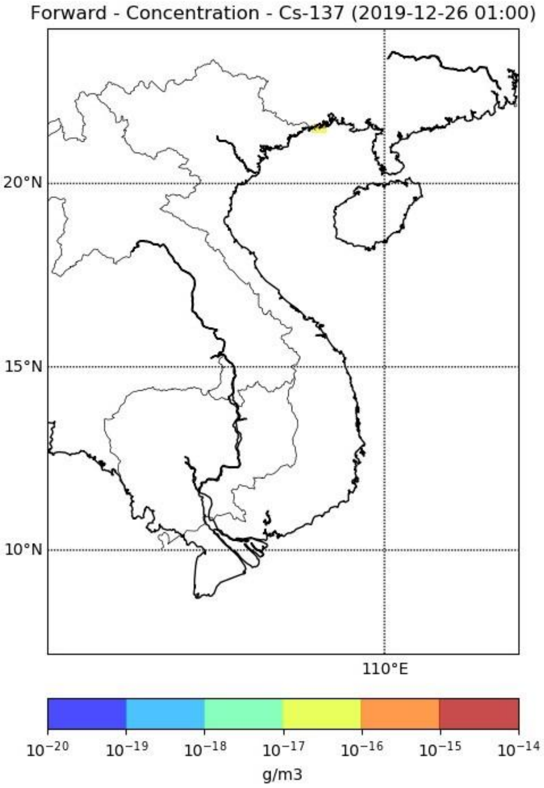
Table 2: Details on WRF schemes and release properties using for two demonstration runs

Parameter	Configuration scheme	Properties
Initial boundary data file	GFS final analysis.	Provide by NCEP for free.
Meteorological domain	214 grid point in West-East 316 grid pont in South-North Centered at lat:16.17, long: 106.61	Cover all Vietnam territory and site of the Fangchenggang NPP.
Grid resolution	7 km	
Map projection	Mercator	Highly accurate for areas within tropical region.
Microphysics	WSM5	Replacement of the old version –NCEP5. Contains five categories of hydrometrics: water vapor, cloud vapor, cloud ice, rain and snow. [19]
Longwave radiation	Rapid Radiative Transfer Model scheme	A spectral-band scheme using the correlated-k method. Ituses pre-set tables to accurately represent longwave processes due to water vapor, ozone, CO_2, and trace gases.Accounting for cloud optical depth in calculation.[19]
Shortwave radiation	Dudhia scheme	Contains simple downward integration of solar flux, accounting for clear-air scattering, water vapor absorption. account for terrain slope and shadowing effects on the surface solar flux. [19]
Surface layer	MM5 similarity scheme	Uses stability functions to compute surface exchange coefficients for heat, moisture, and momentum. [19]
Land surface	Noah Land-Surface Model	Developed jointly by NCAR and NCEP. Uses 4-layer soil temperature and moisture model with canopy moisture and snow cover prediction. Includes root zone, evapotranspiration, soil drainage, and runoff, taking into account vegetation categories, monthly vegetation fraction, and soil texture.[19]
Planetary boundary layer	Yonsei University scheme (YSU scheme)	First-order closure, non-local scheme, uses a parabolic K-profile in an unstable mixed layer. More accurately in simulation of buoyancy-driven PBLs with shallower mixing in strong-wind regimes. [20][21]
Cumulus Parameterization	Kain-Fritsch scheme	A simple cloud model with moist updrafts and downdrafts, including the effects of detrainment, entrainment, and relatively simple microphysics. [20]
Release location	Latitude: 21.64 Longitude: 108.50	At the Fangchenggang NPP.

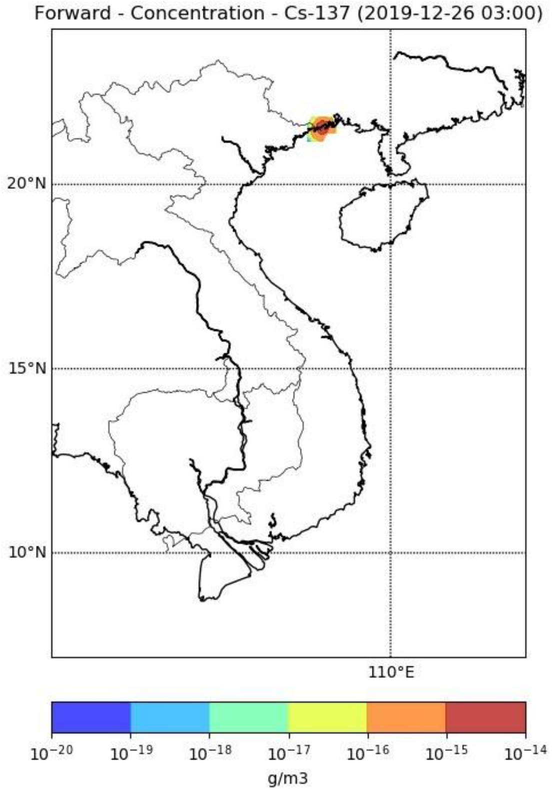
8.1. Winter northwesterly winds

The trajectory of the plume is shown in Figure 4.This simulation took 23 minutes for running and about 9 Gb on disk storage. The simulation time wasmet our definition for fast nuclear response, which is under 30 minutes for running.

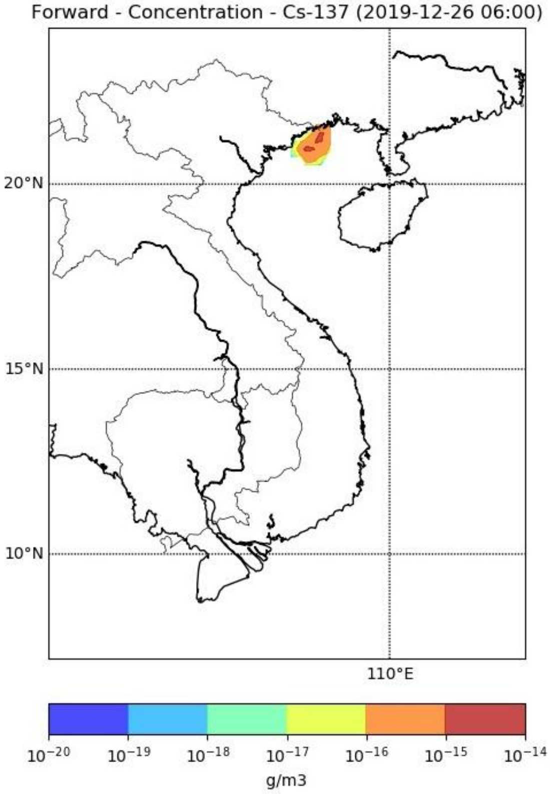
The simulation results showed that 3 hours after released (Fig. 4b), the radioactive material was beginning entered to the Vietnam territory, the main fraction of radioactive was remains stayed nearby the plant site. The dispersion direction towardedthe South-West (Fig. 4c, 4d, 4e) led the radioactive material drifted to the North Central of Vietnam. After 12 hours (Fig. 4f), some province in the North Central of Vietnam was beginning affected by radioactive material. At 12 o'clock the next day (Fig. 4i), the impact area of radioactive material was including the whole North Central of Vietnam, some provinces in North-West of Vietnam, and Laos territory.


Forward - Concentration - Cs-137 (2019-12-26 01:00)
20°N
15°N
10°N
110°E
10^{-20}
10^{-19}
10^{-18}
10^{-17}
10^{-16}
10^{-15}
10^{-14}
g/m3

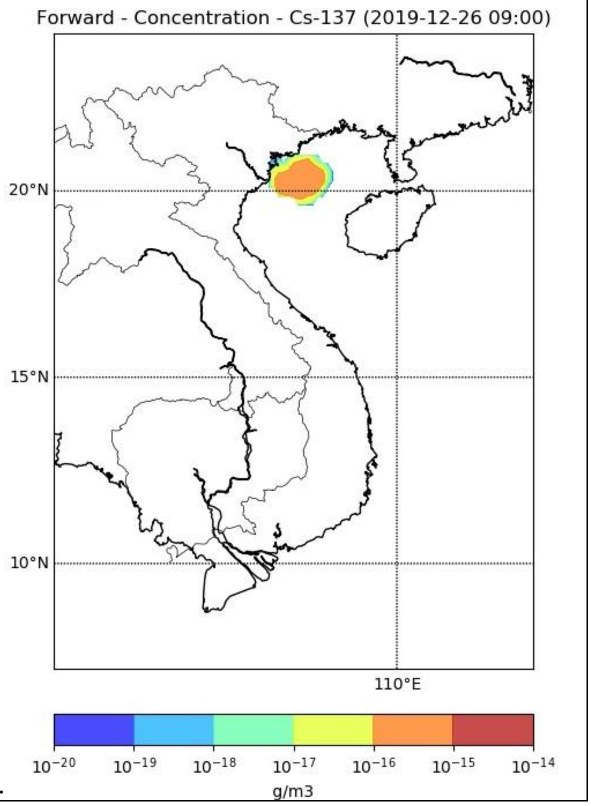
a.


Forward - Concentration - Cs-137 (2019-12-26 03:00)
20°N
15°N
10°N
110°E
10^{-20}
10^{-19}
10^{-18}
10^{-17}
10^{-16}
10^{-15}
10^{-14}
g/m3

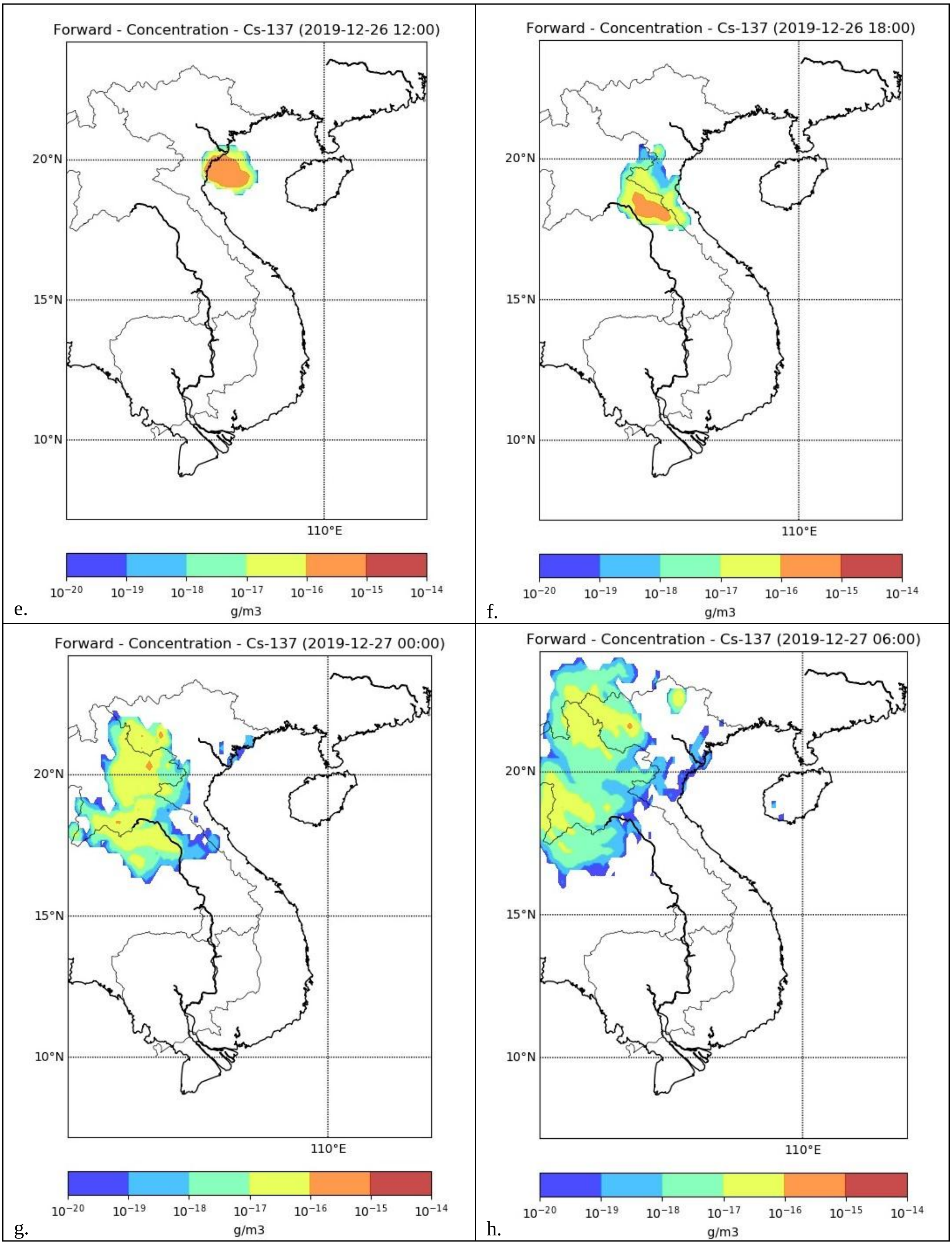
b.

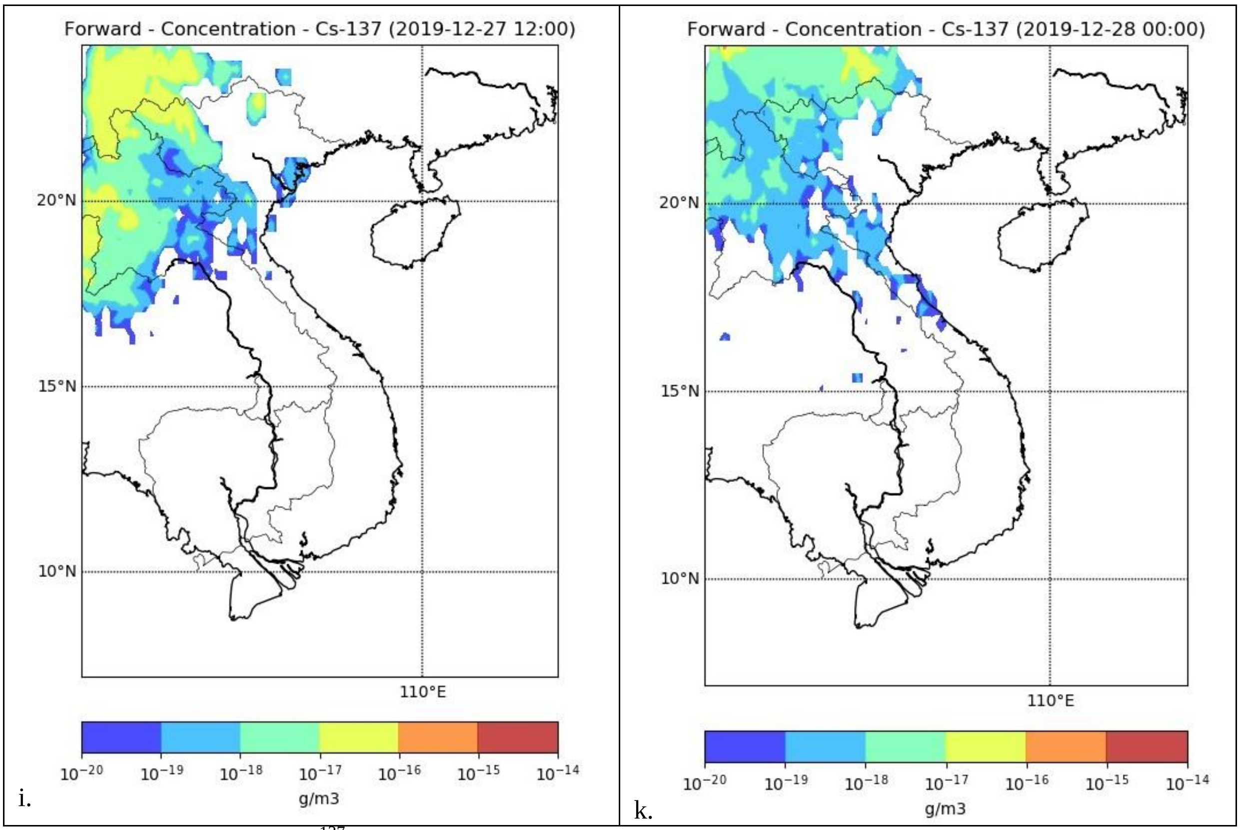

Forward - Concentration - Cs-137 (2019-12-26 06:00)
20°N
15°N
10°N
110°E
10^{-20}
10^{-19}
10^{-18}
10^{-17}
10^{-16}
10^{-15}
10^{-14}
g/m3

c.


Forward - Concentration - Cs-137 (2019-12-26 09:00)
20°N
15°N
10°N
110°E
10^{-20}
10^{-19}
10^{-18}
10^{-17}
10^{-16}
10^{-15}
10^{-14}
g/m3

d.


Forward - Concentration - Cs-137 (2019-12-26 12:00)
20°N
15°N
10°N
110°E
10^{-20} 10^{-19} 10^{-18} 10^{-17} 10^{-16} 10^{-15} 10^{-14}
g/m3
e.
Forward - Concentration - Cs-137 (2019-12-26 18:00)
20°N
15°N
10°N
110°E
10^{-20} 10^{-19} 10^{-18} 10^{-17} 10^{-16} 10^{-15} 10^{-14}
g/m3
f.
Forward - Concentration - Cs-137 (2019-12-27 00:00)
20°N
15°N
10°N
110°E
10^{-20} 10^{-19} 10^{-18} 10^{-17} 10^{-16} 10^{-15} 10^{-14}
g/m3
g.
Forward - Concentration - Cs-137 (2019-12-27 06:00)
20°N
15°N
10°N
110°E
10^{-20} 10^{-19} 10^{-18} 10^{-17} 10^{-16} 10^{-15} 10^{-14}
g/m3
h.



i.

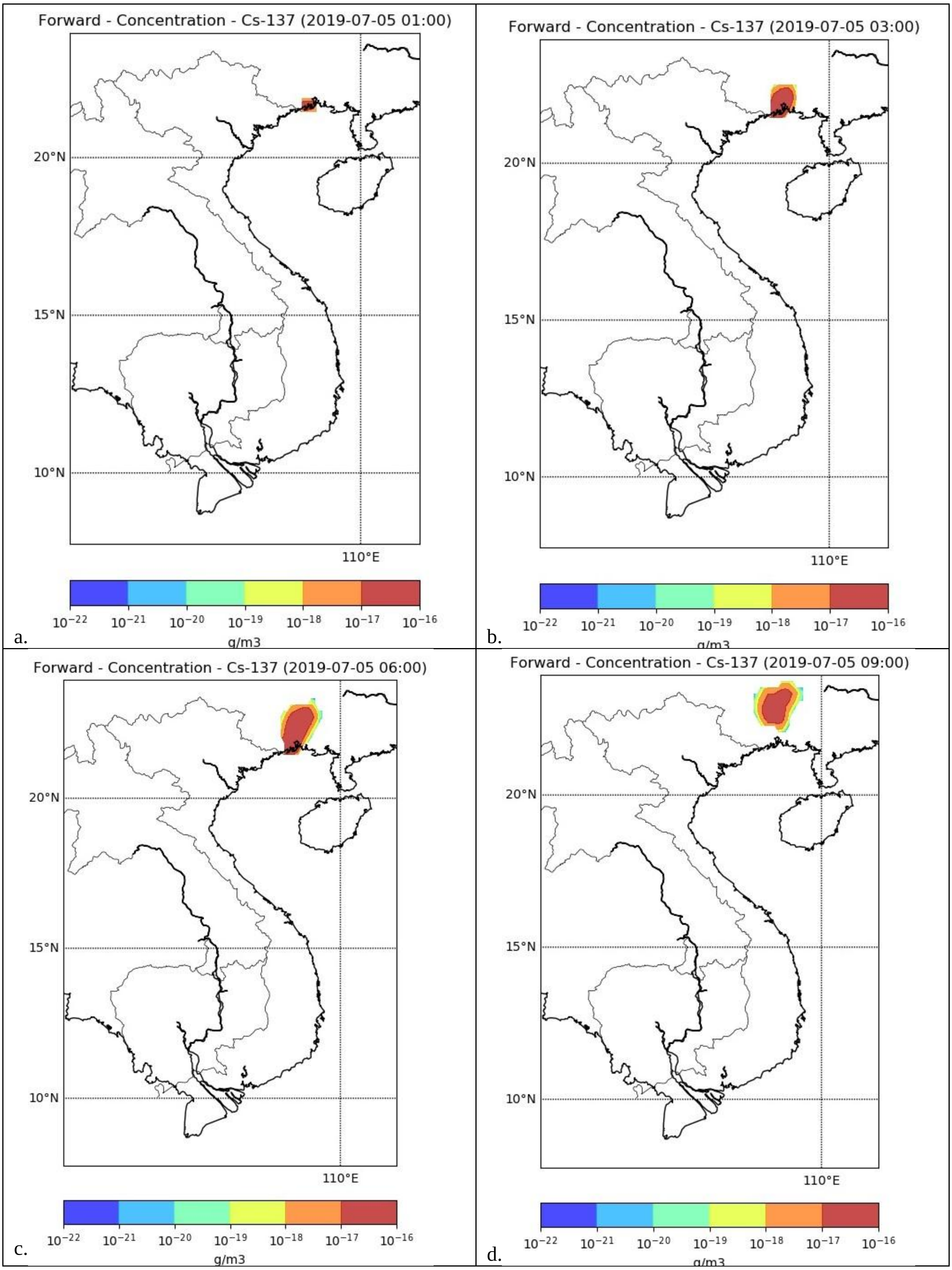
k.

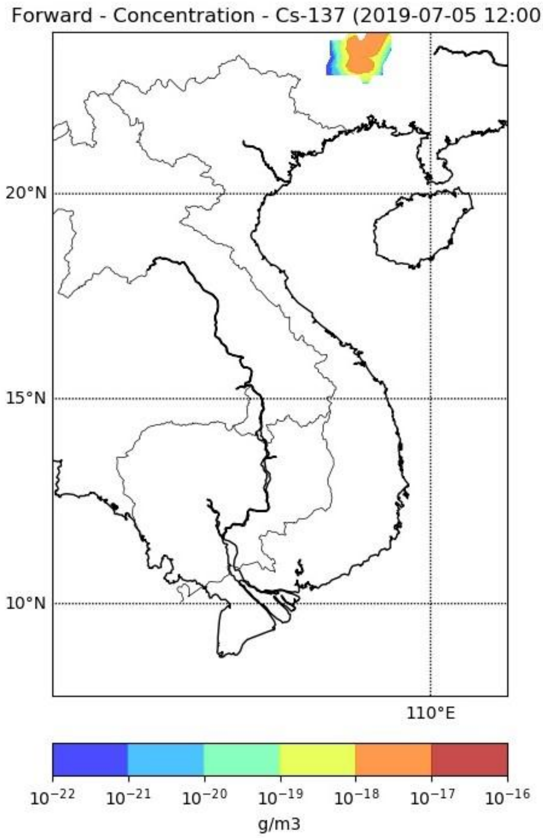
Figure 4: Trajectory of ^{137}Cs released from the Fangchenggang NPP from 26/12/2019 00:00:00 GMT to 28/12/2019 00:00:00 GMT.

8.2. Summer heavy rainfall

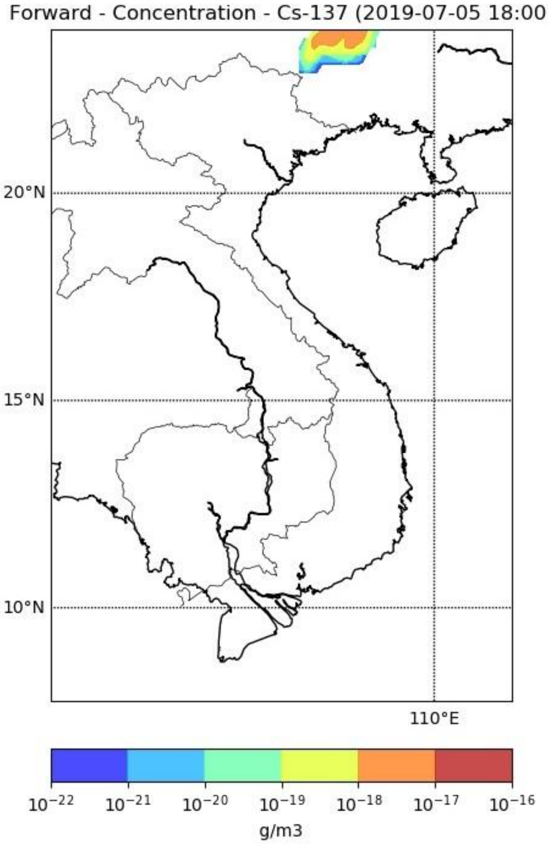
The trajectory of the plume is shown in Figure 5. This simulation took 19 minutes for running and about 7 Gb on disk storage. The simulation time was faster than the first demonstration run due tothere was a large amount of the radioactive material dispersed to the out of bounds of the simulation domain after a short time from release.

The simulation results showed that Vietnam was not affected by radioactive material due to the southwestern monsoon from the South China Sea offered wind-action driving radioactive material away from the Vietnam territory, towarded the North of the plant site and entered to China mainland.

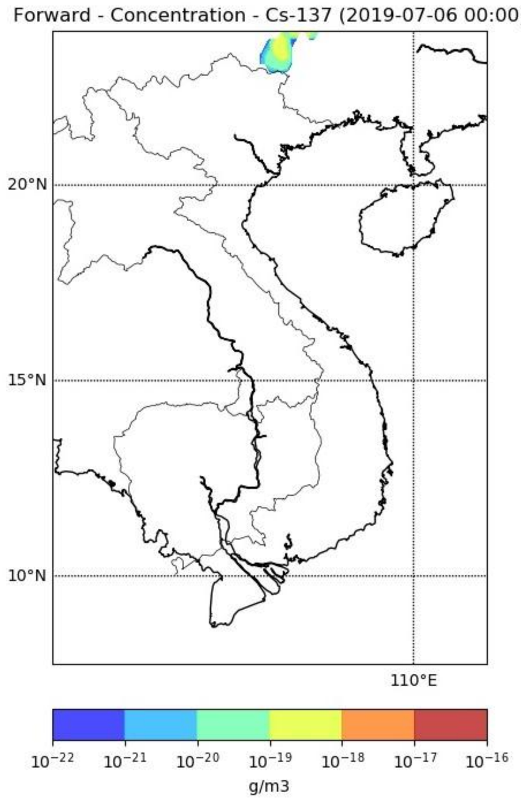

Forward - Concentration - Cs-137 (2019-07-05 01:00)
Forward - Concentration - Cs-137 (2019-07-05 03:00)
Forward - Concentration - Cs-137 (2019-07-05 06:00)
Forward - Concentration - Cs-137 (2019-07-05 09:00)
20°N
15°N
10°N
110°E
10^{-22}
10^{-21}
10^{-20}
10^{-19}
10^{-18}
10^{-17}
10^{-16}
g/m3
a.
b.
c.
d.


Forward - Concentration - Cs-137 (2019-07-05 12:00)
20°N
15°N
10°N
110°E
10^{-22}
10^{-21}
10^{-20}
10^{-19}
10^{-18}
10^{-17}
10^{-16}
g/m3

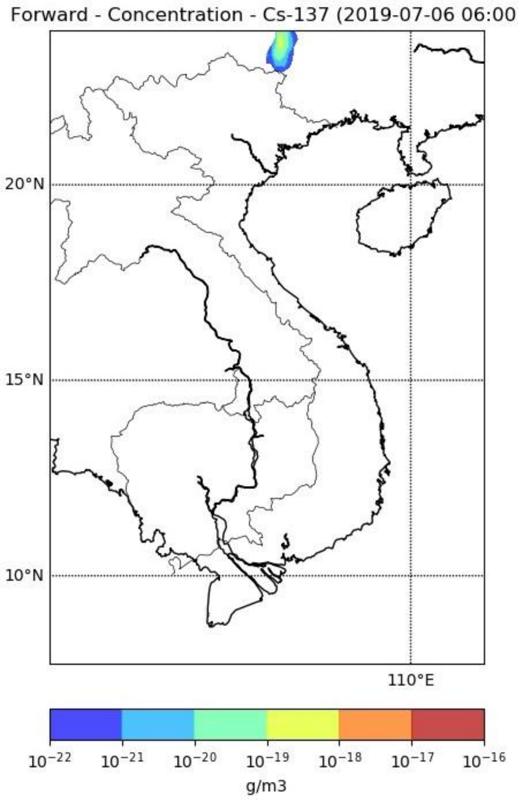
e.


Forward - Concentration - Cs-137 (2019-07-05 18:00)
20°N
15°N
10°N
110°E
10^{-22}
10^{-21}
10^{-20}
10^{-19}
10^{-18}
10^{-17}
10^{-16}
g/m3

f.


Forward - Concentration - Cs-137 (2019-07-06 00:00)
20°N
15°N
10°N
110°E
10^{-22}
10^{-21}
10^{-20}
10^{-19}
10^{-18}
10^{-17}
10^{-16}
g/m3

g.


Forward - Concentration - Cs-137 (2019-07-06 06:00)
20°N
15°N
10°N
110°E
10^{-22}
10^{-21}
10^{-20}
10^{-19}
10^{-18}
10^{-17}
10^{-16}
g/m3

h.

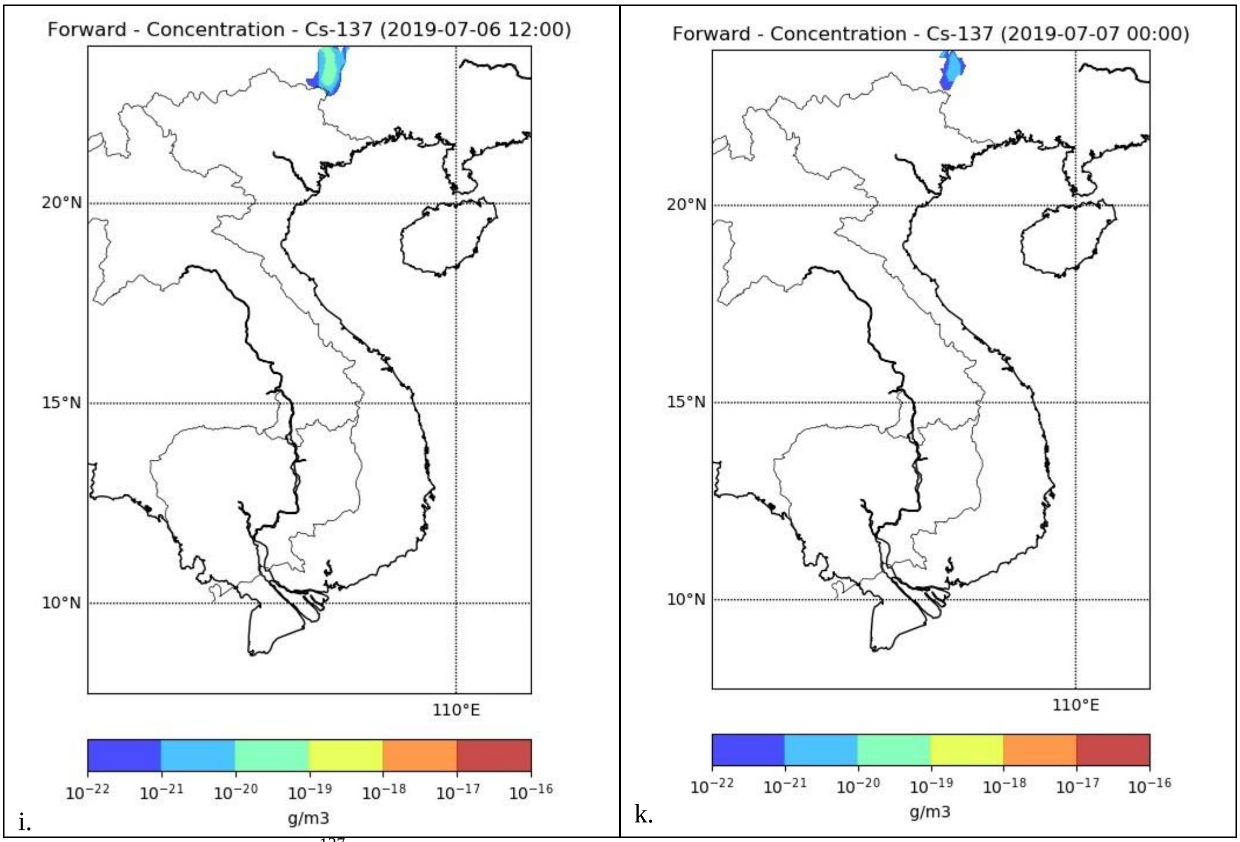


Figure 5: Trajectory of ^{137}Cs released from the Fangchenggang NPP from 05/07/2019 00:00:00 GMT to 07/07/2019 00:00:00 GMT.

IX. Conclusion

This research has made a discussion on atmospheric dispersion models and proposed a simulation approach by using the FLEXPART-WRF tool. Moreover, we demonstrated two case runs of two different climate patterns in Vietnam, the simulation time of each is fast sufficient for nuclear accident response.

Acknowledgements

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, in the framework of technical research program, nuclear safety to ensure combat readiness for the Army in the 2016-2020 period. This article is also supported by the project titled "Study and calculating the spread of atmospheric radionuclides and modernization of stations for radioactive analysis" (PACT-1).The authors would like to give special thanks to the NCAR for WRF development and Prof. Andreas Stohl for FLEXPART-WRF development.

References

[1]. P. Zannetti, Air pollution modelling - Theories, Computational Methods and Available Software, Springer Science & Business Media, 2013.

[2]. Adam Leelossy, Ferenc Molnar, Ferenc Izsak, Agnes Havasi, István Lagzi, Robert Meszaros, "Dispersion modeling of air pollutants in the atmosphere: a review," Central European Journal of Geosciences, vol. 6, no. 3, pp. 257-278, 2014.

[3]. D.J. Hall, A.M. Spanton, M. Bennett, F. Dunkerley, R.F. Griffiths, B.E.A. Fisher, R.J. Timmis, "Evaluation of new generation atmospheric dispersion models," International Journal of Environment and Pollution, vol. 18, pp. 22-32, 2003.

[4]. Irwin, John S., "A Historical Look at the Development of Regulatory Air Quality Models for the United States Environmental Protection Agency," in AIR QUALITY MODELING - Theories, Methodologies, Computational Techniques, and Available Databases and Software. Vol. II, – Advanced Topics, The EnviroComp Institute, Air & Waste Management Association., 2014, pp. 557-598.

[5]. A. D. Visscher, Air Dispersion Modeling, Wiley, 2014.

[6]. Roberta Cocci Grifoni and R. D'Onofrio, "Fundamentals of Air Pollution Mathematical Modeling," in Atmospheric Flow Fields: Theory, Numerical Methods and Software Tools, Bentham, 2012, pp. 134-152.

[7]. Markiewicz, "Modelling of the air pollution dispersion," in Models and techniques for health and environmental hazard assessment and management. Part 2 Air quality modelling., Otwock-Swierk, Institute of Atomic Energy, 2006, pp. 303-348.

[8]. Meg Jenkins, "Boston Waterfront Weather & Pedestrian Wind Comfort," SIMSCALE, [Online]. Available: https://www.simscale.com/blog/2019/06/boston-pedestrian-wind-comfort/. [Accessed 20 06 2020].

[9]. A. Stohl, M.Hittenberger, G.Wotawa, "Validation of the Lagrangian particle dispersion model Flexpart against large-scale," Atmospheric Environment, vol. 32, pp. 4245-4264, 1998.

[10]. Andreas Stohl, Thomas Trickl, "A textbook example of long-range transport: Simultaneous observation of ozone maxima of stratospheric and North American origin in the free troposphere over Europe," JOURNAL OF GEOPHYSICAL RESEARCH, , vol. 104, pp. 30445-30462, 1999.

[11]. Caroline Forster Ulla Wandinger Gerhard Wotawa Paul James Ina Mattis Dietrich Althausen Peter Simmonds S. O'Doherty S. Gerard Jennings Christoph Kleefeld Johannes Schneider Thomas Trickl Stephan Kreipl Horst Jäger Andreas Stohl, "Transport of boreal forest fire emissions from Canada to Europe," JOURNAL OF GEOPHYSICAL RESEARCH, vol. 106, pp. 22887-22906, 2001.

[12]. N. Spichtinger M. Wenig P. James T. Wagner U. Platt A. Stohl, "Satellite detection of a continental-scale plume of nitrogen oxides from boreal forest fires," GEOPHYSICAL RESEARCH LETTERS, vol. 28, pp. 4579-4582, 2001.

[13]. Andreas Stohl, Sabine Eckhardt, Caroline Forster, Paul James, Nicole Spichtinger, Petra Seibert, "A replacement for simple back trajectory calculations in the interpretation of atmospheric trace substance measurements," Atmospheric Environment, vol. 36, p. 4635–4648, 2002.

[14]. A. Stohl, C. Forster S. Eckhardt N. Spichtinger H. Huntrieser J. Heland H. Schlager S. Wilhelm F. Arnold O. Cooper, "A backward modeling study of intercontinental pollution transport using aircraft measurements," JOURNAL OF GEOPHYSICAL RESEARCH, vol. 108, p. 4370, 2003.

[15]. Pham Kim Long, Pham Duy Hien, Nguyen Hao Quang, Do Xuan Anh, Duong Duc Thang, Doan Quang Tuyen, "The ability to use FLEXPART in simulation of the long-range radioactive materials dispersed from nuclear power plants near Vietnam border," Nuclear Science and Technology, vol. 6, pp. 40-48, 2016.

[16]. Ignacio Pisso, Espen Sollum, Henrik Grythe, Nina I. Kristiansen, Massimo Cassiani, Sabine Eckhardt, Delia Arnold, Don Morton, Rona L. Thompson, Christine D. Groot Zwaaftink, Nikolaos Evangeliou, Harald Sodemann, Andreas Stohl, "The Lagrangian particle dispersion model FLEXPART version 10.4," Geoscientific Model Development, vol. 12, pp. 4955-4977, 2019.

[17]. J. Brioude, D. Arnold, A. Stohl, M. Cassiani, D. Morton, P. Seibert, W. Angevine, S. Evan, A. Dingwell, "The Lagrangian particle dispersion model FLEXPART-WRF version 3.1," Geoscientific Model Development, vol. 6, pp. 1889-1904, 2013.

[18]. Tien Du Duc, Cuong Hoang Duc, Lars Robert Hole, Lam Hoang, Huyen Luong Thi Thanh, Hung Mai Khanh, "Impacts of Different Physical Parameterization Configurations on Widespread Heavy Rain Forecast over the Northern Area of Vietnam in WRF-ARW Model," Advances in Meteorology, 2019.

[19]. William C. Skamarock, Joseph B. Klemp, Jimy Dudhia, Da-vid O. Gill, Dale M. Barker, Michael G. Duda, Xiang-Yu Huang, Wei Wang, Jordan G. Powers, A Description of the Advanced Research WRF Version 3, Colorado, USA: National Center for Atmospheric Research, 2008.

[20]. ARIEL E. COHEN, STEVEN M. CAVALLO, MICHAEL C. CONIGLIO, HAROLD E. BROOKS, "A Review of Planetary Boundary Layer Parameterization Schemes and Their Sensitivity in Simulating Southeastern U.S. Cold Season Severe Weather Environments," American Meteorological Society, vol. 30, pp. 591-612, 2015.

[21]. Bhishma Tyagi, Vincenzo Magliulo, Sandro Finardi, Daniele Gasbarra, Pantaleone Carlucci, Piero Toscano, Alessandro Zaldei, Angelo Riccio, Giuseppe Calori, Alessio D'Allura, Beniamino Gioli , "Performance Analysis of Planetary Boundary Layer Parameterization Schemes in WRF Modeling Set Up over Southern Italy," Atmosphere, vol. 9, p. 272, 2018.

Kieu Ngoc Dung, et. al. "Study on numerical models to evaluate atmospheric dispersion of radioactive materials on Vietnam territory." *IOSR Journal of Applied Physics (IOSR-JAP),* 12(6), 2020, pp. 51-63.