Digital comparative analysis of simulation results of radioactive deposition field of nuclear explosion

Yunlong Liu¹, Xiaobing Geng¹a*, Mei Xu¹

¹Institute of NBC defence of Army
ª136959005@qq.com

Abstract—The radioactive settlement of nuclear explosion is simulated by Lagrange particle diffusion model. The simulated settlement map and the measured data map are digitally extracted into the same format. The effectiveness measurement (MOE) method and normalized absolute difference (NAD) method are used to conduct numerical comparative analysis between each dose simulation area and the measured area.

1. Introduction
The nuclear explosion releases huge energy in a very short time and limited space, forming a fireball with high temperature and high pressure, vaporizing and ionizing a large number of fragments in the high-temperature area, and drawing in the surrounding air, dust and soil to melt, vaporize and ionize, forming a hot air mass, which is constantly expanding, expanding, rapidly rising and cooling, it gradually becomes a smoke cloud carrying most of the remaining radioactive material after nuclear fission. Radioactive sedimentation of nuclear explosion is that the particles formed after the condensation of fission fragments are lifted to the high altitude under the buoyancy of explosion fireball, diffused and settled to the ground under the action of atmosphere and gravity, forming a vast radioactive contamination area [1].

In this paper, by constructing a stable smoke cloud model, the mesoscale meteorological prediction model WRF is used to dynamically downscale the obtained meteorological data to obtain a high spatial-temporal resolution meteorological field. By constructing a stable smoke cloud model after nuclear explosion, the Lagrangian particle diffusion model wrf-flexpart is driven by the downscale meteorological field to simulate the diffusion and deposition of parameterized stable smoke clouds, The simulated settlement map and the measured data map are digitally extracted into the same format, and the effectiveness measurement (MOE) method and normalized absolute difference (NAD) method are used to conduct numerical comparative analysis between each dose simulation area and the measured area.

2. Experimental design and method

2.1. Experimental ideas
Firstly, the stable smoke cloud model is constructed, and the global reanalysis data are downscaled to obtain the high temporal and spatial resolution meteorological field. Then wrf-flexpart driven by meteorological field is used to simulate the diffusion and deposition of parameterized stable smoke cloud model in the atmosphere. Finally, the obtained data are converted into dose rate through calculation, and the radiation field distribution map is drawn. The simulated settlement map and the
measured data map are digitally extracted into the same format. The effectiveness measurement (MOE) method and normalized absolute difference (NAD) method are used to conduct numerical comparative analysis and Research on each dose simulation area and the measured area.

Fig.1 research ideas

2.2. Trinity nuclear explosion test
The Trinity test was detonated 57 miles northwest of Alamogordo, New Mexico at 12:29 (UTC) on July 16, 1945. The explosion center coordinate is (33.677°N, 106.475°W), the equivalent is 19kt, the explosion height is 30.48m, and the explosion type is tower explosion. After the explosion, the cloud height reaches 10668m, forming a 2.89m deep and 670.56m wide meteorite crater[2].

2.3. Source item construction
In this simulation, the NATO operation manual is used to define the top height and bottom height of stable smoke clouds. The radioactive share of radioactive particles in each cloud layer is described by hffte[3] and the particle size activity distribution of Glasstone and Dolan (1977)[4]. The total activity is simulated by using the empirical formula of equivalent and activity, the dose rate conversion is calculated by using the dose rate conversion factor, and the empirical formula of settlement rate is obtained by calculating Reynolds number by using Bridgman and Davies equations.

2.4. WRF-flexpart simulation scheme
According to the published literature, the diffusion of radioactive deposition of Trinity in the U.S. nuclear explosion test is simulated from 12:00 on July 16 to 0:00 on July 18, 1945.

The simulated horizontal resolution is the same as WRF, i.e. 3km × 3km, the time resolution is 1 hour, the release time of simulated radioactive particles is from 12:29 to 12:30 on July 16, 10000 particles are released in each particle size range, and the release source term is 3000m × 3000m × The center point of the release position is located at the explosion center (33.677°N, 106.475°W). Settlement related parameters: density ρ (2.5×10³kg/m³), the sampling time is 180s, and the average sampling time is 3600s.
3. Comparative analysis method

3.1. Effectiveness measurement (MOE) method and normalized absolute difference (NAD) method

The effectiveness measurement method is to identify and compare the overlapping area (AOV), observation data non-overlapping area (AFN) and prediction data non-overlapping area (AFP) between models, and the observation data and prediction data have at least one thing in common [5]. When the two data are the same: AOV = APR = AOB, APR is the prediction data and AOB is the observation data, as shown in Figure 2:

$$MOE = (x, y) = \left( \frac{AOV}{AOB}, \frac{AOV}{APR} \right) = \left( \frac{AOB - AFN}{AOB}, \frac{APR - AFP}{APR} \right)$$ (1)

However, when the AFP of one model is equal to the AFN of another model, it is not easy to determine which model is more effective by using MOE method. Therefore, the normalized absolute difference (NAD) method is introduced. When the model is closer to the predictor, the distance between MOE and the predictor will be smaller. The normalized distance is NAD. The more nad is, the closer the predicted data is to the observed data.

$$NAD = \frac{AFN + AFP}{2AOV + AFN + AFP} = \frac{x + y - 2xy}{x + y}$$ (2)

3.2. Digitization and matlab implementation process

Use canvas software to track the image on each dose rate contour line until the complete dose rate contour line is tracked. Then, each dose rate contour is filled with a continuous darker gray color each time the dose rate increases. Then insert a grid above the document according to the proportion, and import the digitized file into Matlab as a gray image.

Matlab needs to compare the graphics to read, display the gray scale, determine the gray scale corresponding to different dose rates, and determine the size of the picture. Set the contrast gray value, read the coordinates corresponding to the gray value, set the value of the blank matrix coordinates to 1, read the coordinates of the second picture, set the value of the blank matrix coordinates to 1, and compare with the black dot as the coordinate base point. The overlapping area is 1, predicted to be 1, measured to be 0 is AFP, predicted to be 0, measured to be 1 is AFN, and MOE and NAD are obtained in the form of points.
4. Results and analysis

| dose rate (r/hr) | MOE   | NAD   |
|-----------------|-------|-------|
| 0.0100          | 0.0127 | 0.2615 | 0.9757 |
| 0.0500          | 0.0337 | 0.3527 | 0.9385 |
| 0.1000          | 0.0953 | 0.1721 | 0.8773 |
| 0.5000          | 0.3312 | 0.1194 | 0.8245 |
| 2.0000          | 0.1464 | 0.3166 | 0.7998 |
| 5.0000          | 0.0028 | 0.2992 | 0.9944 |
| 7.5000          | 0.0000 | 0.0000 | nothing |
| 10.0000         | 0.0000 | 0.0000 | nothing |
| whole           | 0.3032 | 0.9694 | 0.5381 |

Fig.3 Digitized analog map (left) and Trinity measured data map (right) (grid unit: 30 miles)
Through the comparative analysis of Figure 3, it is found that WRF-flexpart uses meteorological data to simulate the outline of radioactive deposition distribution after nuclear explosion and the general square of radioactive deposition. Through the numerical value in Table 1, it is found that the simulated value for the area with dose rate of 2r/hr is the best, and its nad is 0.7998. Unfortunately, the simulated deposition does not simulate the range of dose rate of 7.5 r/hr and 10 r/hr. The analysis may be caused by the small particle size and particle range used in the simulation.

5. Conclusion

Based on the above results and discussion, the following conclusions are drawn:

(1) Wrf-flexpart can use meteorological data to simulate the distribution of radioactive deposition after nuclear explosion.

(2) At present, because there is less particle size distribution in stable smoke clouds, more particle size scales need to be selected to simulate the particle distribution in stable smoke clouds, so as to better reflect the vertical mass distribution of particles in stable smoke clouds and improve the simulation accuracy.

(3) For the realization of dose rate, it is necessary to adopt more accurate conversion coefficient and consider the radiation caused by the presence of radioactive particles in the air.

References

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