Development of the trajectory model for tracking release area of the radioactive materials

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1. Introduction

The detection and analysis of radionuclides have been conducted in Korea since 2006, when the first nuclear bomb-test was conducted by North Korea. The detection systems have been operated by KINS and CTBTO near the Korean Peninsula, and some radioisotopes were measured in 2010 [1]. It is important to investigate the origin of the radioisotopes to be measured at the detection places for evaluating the covert nuclear activities near neighboring countries. The backward trajectory method has been generally used to investigate the source area that the covert nuclear activities may conduct, and the HYSPLIT code has been widely used to understand the above things [2]. In this study, a forward and backward trajectory model has been developed to investigate the origin and release area of the radionuclides when they detected at the measurement locations. The calculated results using the developed trajectory model are also compared with the measurements of the ETEX exercise [3].

2. Trajectory Model

The trajectory model assumes that a single particle has a specific infinitesimally small air parcel, and its trajectory is defined by the differential trajectory equation [4].

$$\frac{dX}{dt} = V[X(t)] \quad (1)$$

Where t is time, X is the position vector and V is the wind vector. Equation (1) is solved using a finite difference approximation and can be expanded like a constant acceleration scheme [4].

$$X(t_1) \approx X(t_0) + \frac{1}{2}(\Delta t)[V(t_0) + V(t_1)] \quad (2)$$

If we obtain the solutions of the trajectory at $t=t_1$ in equation (2), it can be a forward trajectory. Otherwise, if we obtain the solutions of the trajectory at $t=t_0$ in equation (2), it can be a backward trajectory. Equation (2) has to be solved by iterative calculations, because it has unknown variables such as $V(t_1)$. The solution of equation (2) provides a higher accuracy at the cost of increased computing time, but it has the disadvantages in that the accelerations must be evaluated twice [4].

3. Numerical Simulations

Long-range tracer experimental data in ETEX (European Tracer Experiment) were used to validate the developed trajectory model. The ETEX consisted of two releases into the atmosphere of the tracers (perfluorocarbons) sampled for three days after the beginning of the emission using a sampling network spread over a large part of Europe [3,5]. The sampling network consisted of 168 ground-level sampling stations in Western and Eastern Europe. The first release started at 16:00 UTC on October 23, 1994 and lasted 11 hours and 50 minutes. A total of 340 kg PMCH (perfluoromethycyclohexane) were released in Montefil (2^o W, 48^o 03' N) at an average flow rate of 8.0 g/s. During the release the wind blew at between 240 and 290 degrees, i.e. from a west-south west to west-north west. The wind was westerly at the start of the release with a tendency to be from a west-north west until midnight and from a west-south west direction at the end of the release. The wind direction changed from between south and west during the rest of the period. During the first release, each of the 168 sampling stations collected 24 samples which accounted for a total of more than 4000 samples. All data consisted of the 3 hour average concentrations available at each site for 96 hours from the time of the release. The plume initially moved in a north-easterly direction. After 12 hours, the tracer could be detected in France and at a few German sites. Then, the plume moved eastward and traversed Germany, 36 hours after the release, and stretched from the west coast of Sweden in the north to Hungary in the south. About 60 hours after the release, owing to the wind convergence line evaluated by most of the flow models, the eastwardly movement of the cloud was blocked and the cloud stretched as a broad band from Bulgaria to Norway.

For the validation study, the trajectories calculated by the developed model were compared with the data of the ETEX exercise. The meteorological data with 6 hour time intervals were supplied by ECMWF. The computational area covered extends from 4.5^o W to 31.5^o E and from 40.0^o N to 67.0^o N. The spatial resolution is about 0.5^o and the grids are composed of 73 x 55 points in a horizontal direction. Simulations were performed from 16:00 UTC on October 23 to

18:00 UTC on October 26, and ten positions with relatively higher concentrations were selected to compare with the calculations and measurements. The backward trajectories were computed by releasing the particles with a one hour time interval at ten positions, which have higher measured concentrations. The calculated results for the backward trajectories are shown in Fig.1 and Fig. 2. The backward trajectories were approximately tracked at the source point (Montefil) from DK01 and DK10. The DK01 and DK10 are points where the tracer concentrations have higher values from the ETEX exercise. It is inferred from the results that the calculation accuracy of the backward trajectory will be better if the particles are released at the point where there is has a relatively high concentration.

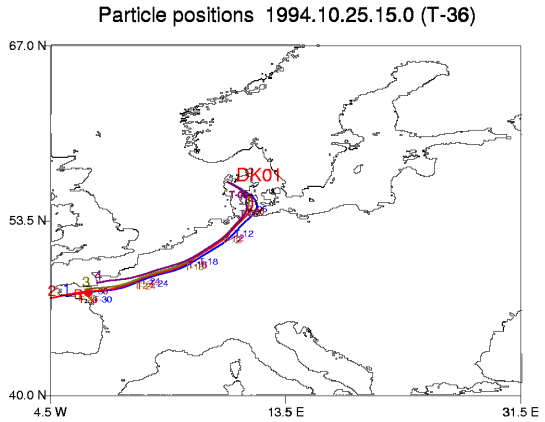

Fig.1. Calculated backward trajectory from release at DK01.

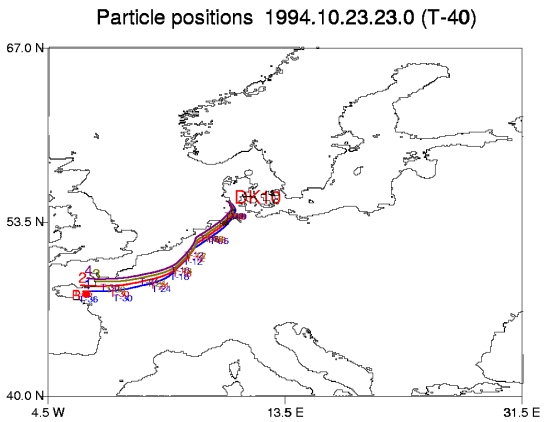

Fig.2. Calculated backward trajectory from release at DK10.

3. Conclusions

The trajectory model has been developed to estimate the unknown release area of radionuclides. This model is clearly connected with the measurements of the radionuclides by the detection instruments. The model was compared with measurements of the ETEX exercise and the calculated results agree with the observations. The trajectory model can be used as a basic tool to investigate the covert nuclear activities near neighboring countries including North Korea.

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