VALIDATION OF THE LONG-RANGE DISPERSION MODEL BT ETEX DATA

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INTRODUCTION

Radiological emergency preparedness systems have been widely developed to predict and minimize the radiological damage to a surrounding environment after the Chernobyl accident *(Klug, W. e. al.,* 1992*)*. There are many nuclear power plants in the region of Northeast Asia. It is necessary to develop a long-range atmospheric dispersion model for the radiological emergency preparedness against a nuclear accident in the region of Northeast Asia. From these viewpoints, a long-range atmospheric dispersion model named LADAS(Long-range Accident Dose Assessment System) has been developed in Korea since 2001. The Monte Carlo method was used for the estimation of the concentration distribution of the radioactive materials released into the atmosphere. The model was designed to estimate air concentrations and a dry deposition as well as a wet deposition at distances of up to some thousands of kilometers from the source point in a horizontal direction. The turbulent motion is considered to separate the treatment of the particles within the mixing layer and those above the mixing layer.

For a validation study, the calculated concentration distributions were compared with the measured values by ETEX exercise *(Dop, H.V., e .al.,* 1998*)*. The determination of the mixing height is one of the most important factors for calculating the concentration in LADAS. Several numerical simulations using the variations of the mixing height were performed to obtain more accurate concentration distributions when compared with the measured ones from ETEX. The calculated concentration distributions agreed well with those by EXTX.

LONG-RANGE DISPERSION MODEL (LADAS)

The particles to depict the characteristics of a pollutant in the Lagrangian type model can be released to evaluate the transport and diffusion process of a pollutant in the atmosphere. The concentration is calculated by tracking the trajectory of a particle. Lagrangian type models can treat the rapid concentration gradient near a source point easily and don't cause a numerical dispersion. The particle is advected by the averaged wind components and dispersed by a turbulent motion in a three dimensional space. The movement of the particle is represented by the sum of the movements due to the advection and the turbulence. The new position of a particle after a time step Δt is represented as follows:

$$X_j(t+\Delta t) = X_j(t) + v_j(t)\Delta t + v_j^{'}(t)\Delta t \quad (1)$$

where v_j are the averaged wind components(*j=1,2,3*) and $v_j^{'}$ are the turbulent components of wind (*j=1,2,3*). The horizontal displacement due to a turbulence is computed by:

$$v_j^{'}(t)\Delta t = \sqrt{2K_j \Delta t}R \quad (2)$$

where K_j (*j=1,2*) are the horizontal diffusion coefficients and R is the random numbers picked up from a Gaussian distribution having a mean value and a standard deviation equal to 0 and 1 respectively. To calculate the vertical component of $v_3^{'}(t)\Delta t$, two situations have been distinguished such as within the mixing layer and above the mixing layer (*Anfossi, D., Sacchetti, D. and Catelli, S.T.,* 1995)

$$v_3^{'}(t)\Delta t = \sqrt{2K_3 \Delta t}R \quad \text{(above mixing layer)}$$
$$v_3^{'}(t)\Delta t = (h_{pbl} - Z_g)R \quad \text{(within mixing layer)} \quad (3)$$

where K_3 is the vertical diffusion coefficient, h_{pbl} is the mixing height and Z_g is the height of the topography. The concentration in the Lagrangian particle model is calculated in the domain of interest by counting the number of particles in an arbitrary control volume. The concentration is equal to the number of particles divided by the volume of the box. If the control volume has the dimensions Δx, Δy, Δz and contains N_p number of particles, then the concentration *c(x,y,z)* at the center of the box may be computed as follows.

$$c(x,y,z) = \frac{N_p}{\Delta x \Delta y \Delta z} \quad (4)$$

The mixing heights were calculated by the bulk Richardson number (*Vogelezang, D.H.P., and Holtslag, A.A.M.,* 1996). The mixing height is defined as the height where the bulk Richardson number reaches a critical value of $R_{ih}=0.25$

$$R_{ih} = \frac{(g/\theta_{vs})(\theta_{vh} - \theta_{vs})(h - z_s)}{(u_h - u_s) + (v_h - v_s)^2 + 100u_*^2} \quad (5)$$

where z_s and h are the heights of the surface and the h^{th} model level, θ_{vs} and θ_{vh} are the virtual potential temperature at z_s and h, (u_s, v_s) and (u_h, v_h) are the wind components at z_s and h, and u_* is the friction velocity.

EUROPEAN TRACER EXPERIMENT(ETEX)

ETEX*(Dop, H.V., et al.,* 1998*).* essentially consisted of two releases to the atmosphere of tracers(perfluorocarbons) sampled for three days after the beginning of the emission using a sampling network spread over a large part of Europe. The sampling network consisted of 168 ground-level sampling stations in Western and Eastern Europe. To complement the meteorological measurements routinely gathered by the WMO network all over Europe, additional ground level and upper-air meteorological measurements at the release site were performed to obtain a comprehensive meteorological database.

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 at an average flow rate of 8.0 g/s. A SODAR was operating at the release site during the first experiment. Vertical profiles of the horizontal wind speed and direction and the vertical wind speed were measured from 30 to 600 m above ground. During the release the wind blew 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 between south and west during the rest of the period. The wind speed during the release ranged between 4 and 7 m/s. During the first release each of the 168 sampling stations collected 24 samples which accounted for a total of more than 4000 samples. All the tubes were sent to the JRC Ispra for a chemical analysis. The detailed results of all the analyses were collected in the ETEX data base. All the data consisted of the 3 hour average concentrations available at each site for 96 hours from the time of release.

NUMERICAL SIMULATION

For a validation study, the calculated concentration distributions were compared with the measured values by the ETEX exercise. The meteorological data with 6 hour time intervals is 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. The archived data for the operation of the dispersion model are the wind component, temperature, humidity, geopotential height, precipitation, surface pressure and others.

The particles were released about 115 particles per Δt. Several numerical simulations were performed to investigate the effects by the variations of the mixing height in LADAS(Table 1). The mixing heights in the case of run 3 in Table 1 were calculated using the Richardson number. All the runs were performed with fixed values of $K_h=2.5 \times 10^4\ m^2/s$, $K_v=1.0\ m^2/s$.

The determination of the mixing height is one of the most important factors for calculating the concentration of the released particles in the dispersion model. Numerical simulations in LADAS according to a variation of the mixing heights are performed in three runs (Table 1). The calculated results for several cases were compared with the measured ones using the statistical methods such as NMSE (Normalized Mean Square Error), RMSE (Root Mean Square Error), FB (Fractional Bias), and fractions FA2 and FA5 represent the proportion of the calculated values, which are within a factor of 2 and a factor of 5 of the observed values respectively (*Mosca, S., et. al.,* 1998). The results obtained by the three runs are summarized in Table 2.

Table 1. Several numerical simulations

Run no.	Conditions of the variation of the mixing height
1	Constant mixing height, h=1500 m
2	Constant mixing height, h=1000 m
3	Calculation of the mixing height using Richardson no

Table 2. Statistical results

Run no.	NMSE	Bias	RMSE	FB	FA2	FA5
1	8.6	-0.18	0.7	-0.7	30.0	57.2
2	7.6	-0.16	0.7	-0.6	29.8	59.7
3	7.6	-0.14	0.6	-0.5	30.2	60.5

The results of the three runs in Table 2 showed similar results. However, the result in the case of run 3 agreed well with the measured concentration. It means that the space and time varying mixing heights are considered as more realistic in LADAS. The concentration distributions of run 3 are shown in Fig. 1 which are plotted after 24, 36, 48 and 60 hours from the beginning of the release. The major part of the calculated concentrations moved over the east area from the release point due to the westerly winds. After 48 hours, the cloud moved over northern Germany and southern Scandinavia due to the south-westerly winds. The calculated results showed some agreement when compared with those of ETEX.

CONCLUSIONS

A three dimensional Lagrangian particle model named LADAS was developed to evaluate the characteristics of a long-range atmospheric dispersion. The developed model was used to estimate the radiological consequences from a nuclear accident. The calculated results of LADAS were validated by the measured values of ETEX. The calculated concentration distributions by several numerical experiments were compared with the measured ones using statistical methods. The results using the mixing height calculated by the Ricahrdson number showed a better agreement than those using the constant mixing height.

The developed Lagrangian particle model for a long-range atmospheric dispersion will be provided as a basic tool to evaluate the atmospheric diffusion and the radiological dose assessment in the national emergency preparedness system in Korea (*Cho, J.W., Nam, K.W., Chun, I.Y., et al., 1999).*

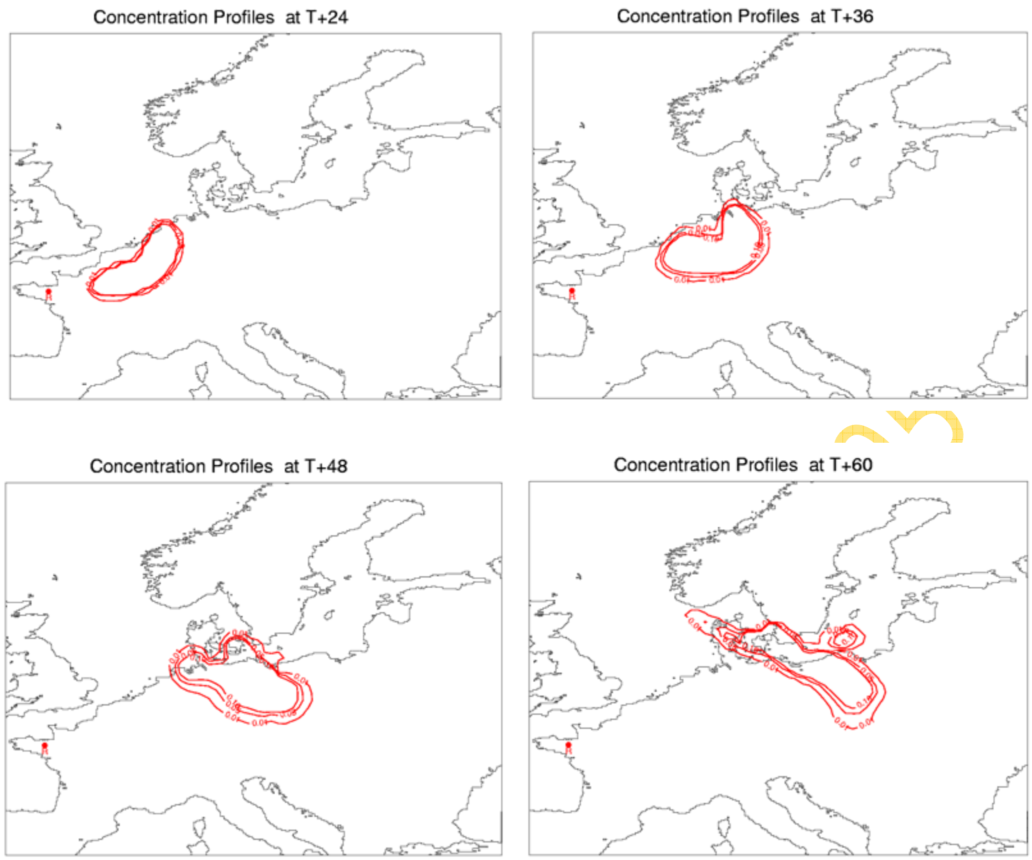

Fig. 1 ; Contours of air concentration calculated by LADAS.
Contour levels are 0.01, 0.05 and 0.1 ng/m3.

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REFERENCES

Anfossi, D. Sacchetti, D. and Catelli, S.T., 1995: Development and sensitivity analysis of a Lagrangian particle model for long range dispersion, Environmental Software, ***10(4)****, 263-287.*

Dop, H.V. et al., 1998: ETEX: A European tracer experiment observations, dispersion modeling and emergency response. Atmospheric Environ., ***32(24)****, 4089-4094.*

Klug, W. Graziani, G. Grippa, G. Pierce, D. and Tassone, C., 1992: Evaluation of long range atmospheric transport models using environmental radioactivity data from the Chernobyl accident, Elservier Applied Science, London and New York.

Mosca, S. et al., 1998: A statistical methodology for the evaluation of long-range dispersion models : an application to the ETEX exercise, Atmospheric Environ., ***32(24)****, 4307-4324.*

Vogelezang, D.H.P. and Holtslag, A.A.M., 1996: Evaluation and model impacts of alternative boundary-layer height fromulation, Boundary-Layer Meteo., ***81,*** *245-269.*

Cho, J.W. Nam, K.W. Chun, I.Y. et al., 1999: Development and operation of the network system for nuclear safety. KINS/AR-704, Daejeon (in Korean).