4.12 DEVELOPMENT OF NUMERICAL MODEL FOR DISPERSION OVER COMPLICATED TERRAIN IN THE CONVECTIVE BOUNDARY LAYER

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INTRODUCTION

Complicated terrain and atmospheric stability are important factors in the prediction of dispersion of air pollutants. However, so far in Japan, it is rare that the effect of terrain is taken into account in the prediction of environmental impact of air pollutants. One of these reasons is the lack of practical regulatory dispersion model which can take the terrain effect due into account. To overcome this problem, the development of practical dispersion model which is able to take both the terrain and atmospheric stability into account was undertaken by Japan Environmental Management Association for Industry in collaboration with Mitsubishi Heavy Industries, National Institute of Advanced Industrial Science and Technology, Ryoken-tech LTD. and Kyusyu University.

Our first aim was to develop practical dispersion model for unstable conditions, because the unstable conditions causes fumigation and brings high ground level concentrations. Based on this dispersion model, the next aim was to develop user-friendly software which is able to calculate not only 1-hr average concentration but also long-term averaged concentrations.

The numerical model for unstable condition we want to develop was to be easy to use and it takes short calculation time because we expect that this model will be used as a regulatory model. So we adopted the combination of the potential flow model and Lagrangian stochastic dispersion model. Wind tunnel experiments simulating gas dispersion in the convective boundary layer were also done. The data sets of turbulent properties and concentrations obtained in the wind tunnel were used for the modification of dispersion model and model validation.

MODEL DESCRIPTION

The numerical model we developed for dispersion in unstable layer is the combination of the potential flow model and Lagrangian stochastic dispersion model. In this model, time-mean flow field is predicted by the potential flow model and concentration field is calculated by Lagrangian stochastic dispersion model using the time-mean flow field. The reason why we chose the potential flow model is to shorten the calculation time for practical use. The Boundary Element Method (BEM) is used as solver of the potential flow theory (*Ohba, R. and K. Okabayashi, 1989*).

The Lagrangian stochastic dispersion model was applied to prediction for dispersion in CBL. This model was originally developed by the CANCES (Center for Advanced Numerical Computation in Engineering and Science), University of New South Wales, Australia. The well mixed condition and Kolmogorov's local similarity theory are applied to determine the advection and diffusion coefficients in the model (*Ohba. R, Y. Shao and A.Kouchi, 1998*) .

In the model, the movement of passive particle in a turbulent flow is described by a equation system below.

$$dU_i = a_i dt + \sqrt{C_0 \varepsilon}\, d\xi_i \quad (1) \qquad dX_i = U_i dt \quad (2)$$

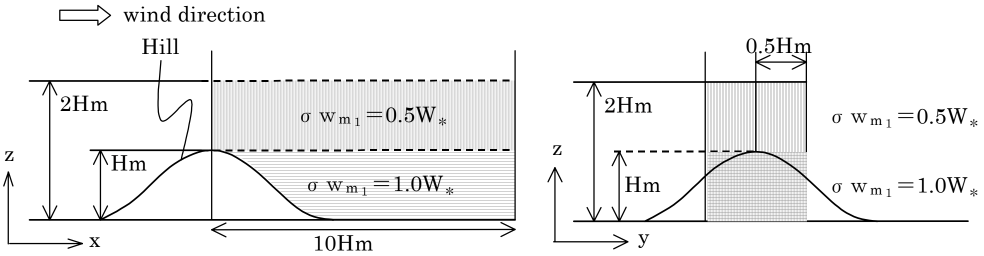
The drift coefficient ai is determined by solving the Fokker-Planck equation assuming the well mixed condition. The turbulent parameters required in determination of a_i such as velocity variance, skewness, and dissipation rate of turbulent kinetic energy are calculated by the similarity relationship of convective layer as shown in formulas below. The similarity relationship is based on the airbone observations (*Shao, Y., J. M. Hacker and P. Schwerdtfeger, 1991*).

$$\sigma_w = \sqrt{2}\, w_* \left(\frac{z}{z_i}\right)^{1/3} \left(1 - 0.8\frac{z}{z_i}\right)^{3/4} \quad (3) \qquad S_K = 0.42\left(1 - \frac{z}{z_i}\right)\left(1 - 0.8\frac{z}{z_i}\right)^{-2} \quad (4)$$

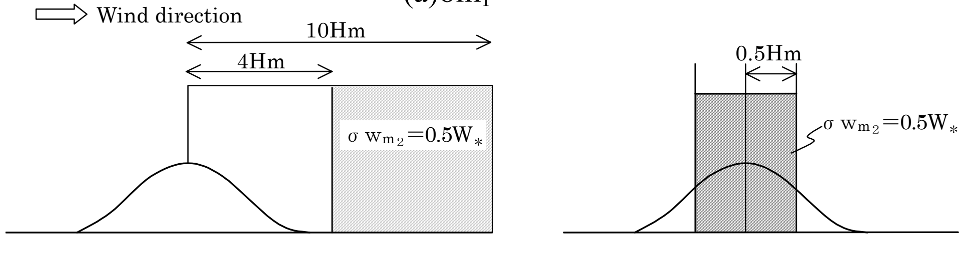
$$\varepsilon = \frac{1}{\sqrt{8}}\left(1.3 + 0.1\frac{z}{z_i}\right)^{3/2} \frac{w_*^3}{z_i} \quad (5)$$

However, strictly speaking, these relationships above are only adequate for in case of flat terrain. In case terrain exists the turbulent strength increases behind the hills when compared with flat land. And this phenomena has strong influence on gas dispersion behind the terrain. Therefore we tried to modify the model simply to take the increase of turbulent strength behind the mountain into account.

The modification is as follows. In a some domain behind the hill, we added the turbulent strength increased by hill, σm_1 and σm_2. The σm_1 is added to the turbulent strength expressed as Equation(3) and a particle is moved firstly in the manner as described above. And then, additionally, the particle is moved assuming the Gaussian turbulence which has a standard deviation of vertical velocity σm_2. Assumption of the domain and the value of σm was roughly estimated based on the experimental data described later and fixed as shown in Figure1.



(a)σm_1



(b)σm_2

Figure 1. Assumption of the domain and the value of σm_1 and σm_2

WIND TUNNEL EXPERIMENTS

For the purpose of obtaining the data sets of turbulent properties and concentration field to be used for the model development and model validation, wind tunnel experiments simulating gas dispersion in the convective boundary layer were conducted in the thermally stratified wind tunnel of Nagasaki Research & Development Center, Mitsubishi Heavy Industries, Ltd..

In the wind tunnel experiments, simple terrain models (Figure2) and complicated terrain model ware prepared. The scale of all these models is 1/2500. The similarity rule of bulk Richardson number, Ri_b, was applied to determine the relationships between the wind tunnel scale and field scale. The details of these wind tunnel experiments can be found in *Kouchi, A. et. al., 2003*.

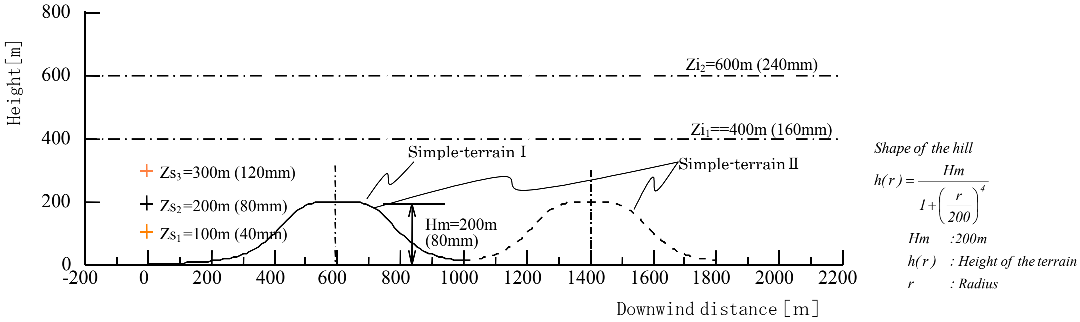


Figure 2 Simple-terrain model and height of point source

MODEL VALIDATION

Data sets obtained from the wind tunnel experiments were used for model validation. Comparisons of axial ground level concentration (GLC) between the numerical model and the wind tunnel experiments are shown In Figure3, whereY-axis in these graphs represent GLC normalized with wind speed, U, and source strength, Q. The conditions of the simulations are summarized in Table1 In the graphs, calculation results from ISCST (*U. S. EPA, 1995*) model are also plotted. As can be seen, ISCST model tends to overestimate GLC near the hill when compared with experimental results. The reason of the overestimation is that the ISCST model does not take the plume-axis movement into account, in other words, the plume-axis remains at the plume stabilization height above mean sea level in the ISCST model.

On the other hand, the results of the numerical model we developed agree well with the experiments. In the graphs, additionally, the numerical results in case turbulent strength σm is not added (i.e. turbulent strength is determined from only Eq(3)) are also shown in Figure3(a). In these cases, the model does not take the turbulent effect into account. Consequently the dispersion behind the hill was smaller and it led to underestimation of the GLC.

As reference, data sets of Kincaid field observations from the Model Validation Kit (*Olesen, H. R., 1995*) were also used for the validation. However the data sets from 4 fields experiments included in the model validation kit are results from dispersion experiments over flat land and strictly speaking, these data are not adequate to validate this numerical model. The reason why Kincaid data was chosen is that Kincaid's data sets include many unstable conditions and in many case, maximum axial concentration could be obtained. The comparison with Kincaid data sets are shown in Figure 4 and the conditions of calculation are shown in Table2. As can be seen, in case of dispersion over flat land, the results of numerical model agree well with the experiments.

Table 1. Conditions of model calculations

Terrain shape	Height of the hill (m)	Source height Zs(m)	Wind speed (m/s)	Heat flux H_0 (W/m^2)	Height of Convective layer Z_i(m)
Simple-terrain I	200	100, 200, 300	7.9	230	400
Simple-terrain II	200	200	7.9	230	400

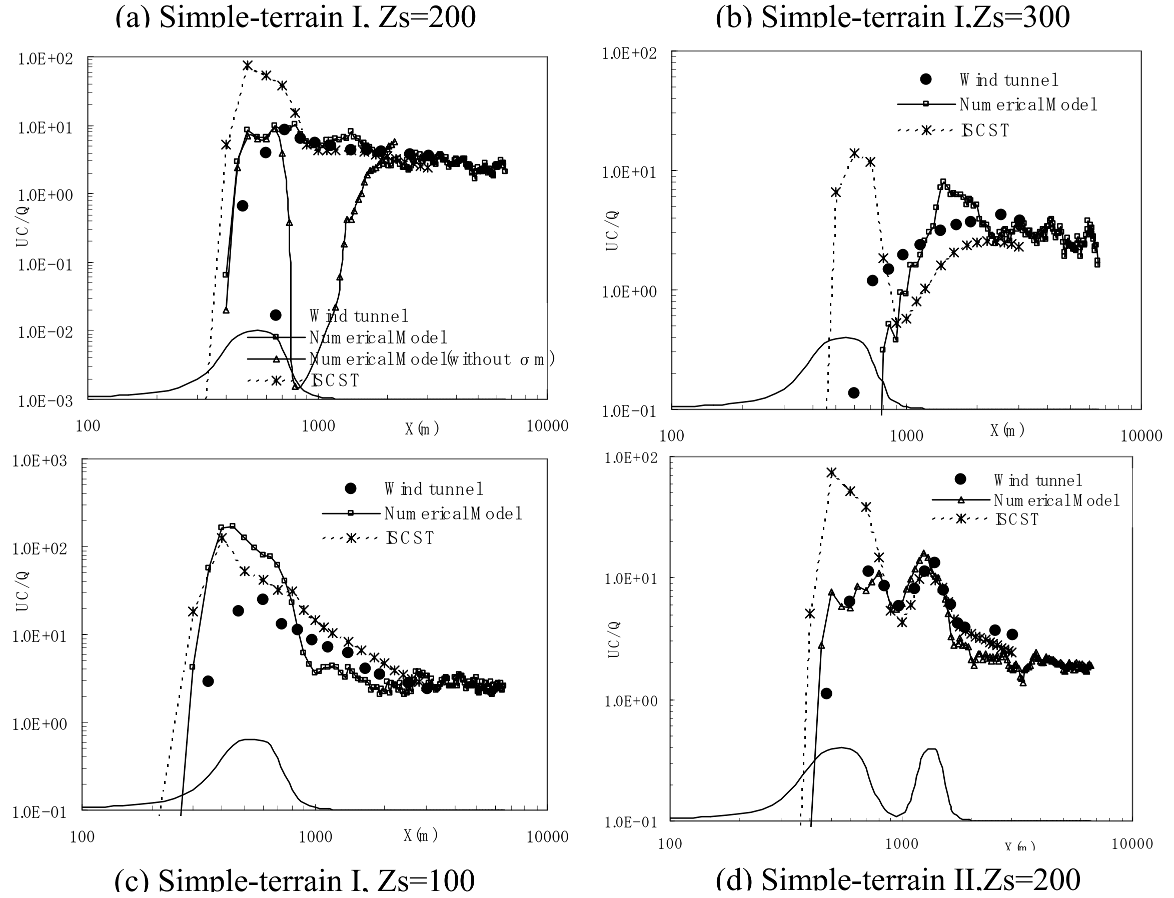

(a) Simple-terrain I. Zs=200
(b) Simple-terrain I.Zs=300
(c) Simple-terrain I. Zs=100
(d) Simple-terrain II.Zs=200

Figure 3. Comparison of numerical model with the wind tunnel results

Table 2. Conditions of model calculation for Model Validation Kit

Case	Source height, Zs(m)	Wind speed (m/s)	Heat flux, H_0 (W/m^2)	Height of Convective layer, Z_i(m)
80/7/13 13:00, 14:00, 15:00	565	2.2	350	550
81/5/28 13:00, 14:00	534	3.6	300	1250

USER-FRIENDLY SOFTWARE

Including the dispersion model for unstable layer, we developed an user-friendly PC software which is able to calculate not only 1-hr average concentration but also long-term averaged concentrations. This software uses GUI (Graphical User Interface) based on Windows and we can easily handle the input and output data on the windows screens. The main features and tools included in the software are as follows.

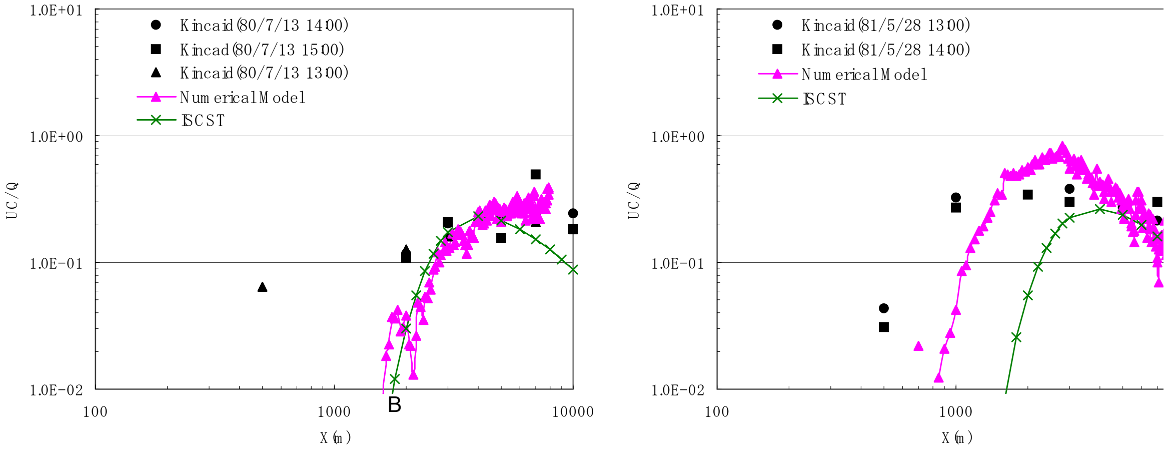
(a) The software can predict both 1hr-average concentrations and long-term averaged concentrations.

(b) The software can predict fumigation phenomena caused by TIBL (Thermal Internal Boundary Layer) in coastal area. In this software, TIBL depth is estimated by a following formula, where z_i, H_0, x_c and γ are TIBL depth, heat flux from land surface, distance from coast line and temperature gradient in the stable layer respectively.

$$z_i = \left(\frac{2H_0 x_C}{\rho C_P \gamma U} \right)^{1/2} \tag{6}$$

(c) The digital maps (CD-ROM) published by Japan Geographical Survey Institute is applicable to the software and we can easily handle topographical data.
(d) AMeDAS (Automated Meteorological Data Acquisition System) data published by Japan Meteorological Business Support Center in CD-ROM is available as meteorological input data.
(e) Lgrangian dispersion models for neutral and stable atmospheric conditions are also included.

We also developed internet web service system for predicting atmospheric impacts by using this software. This service will be available soon.



(a) Comparison with Data of 13/7/80 (b) Comparison of Data of 28/5/81

Figure 4. Comparison of numerical model with the Model Validation Kit (Kincaid)

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