9th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purpose

Development of Numerical Model for Dispersion over Complicated Terrain in the Convective Boundary Layer

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Background

(1) **The development of practical dispersion model which is able to take both the terrain and atmospheric stability into account is now undertaken by Japan Environmental Management Association for Industry (JEMAI) in collaboration with Mitsubishi Heavy Industries (MHI), National Institute of Advanced Industrial Science and Technology, Ryoken-tech LTD. and Kyusyu University.**

(2) Our first aim was to develop practical dispersion model for unstable conditions, because the unstable conditions causes fumigation and brings high ground level concentrations (GLC).

Aim

(1) To develop a numerical dispersion model for unstable atmospheric conditions for regulatory use.

- **Easy to use. It means this model is to be developed as an user-friendly software.**
- **Short calculation time.**

(2)To validate the performance of the model.

- **Date sets obtained from wind tunnel experiments.**
- **Date sets from field observation. (Model Validation Kit)**

Numerical dispersion model

- **Dispersion model which is applicable to dispersion around complicated terrain under unstable atmospheric condition.**
- **Easy to use and short calculation time.**

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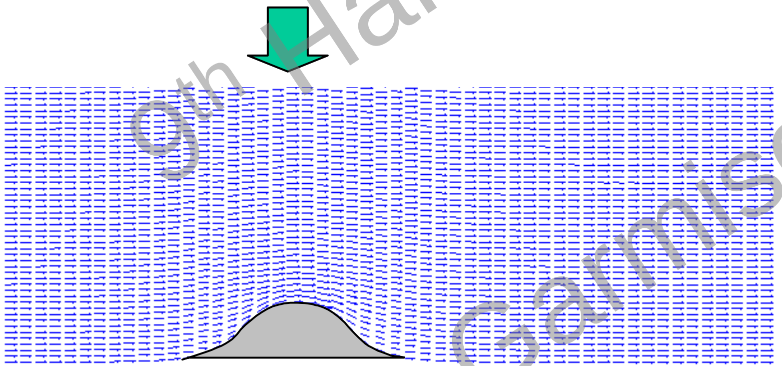
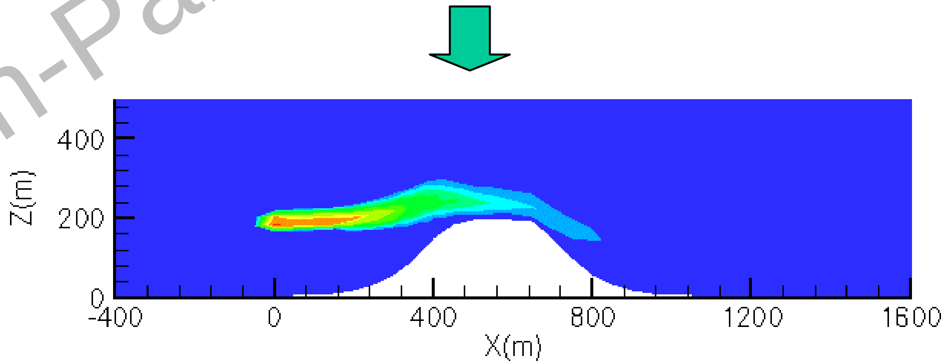
Potential flow model + Lagrangian stochastic dispersion model

(Ohba, Shao 1991)



Time-mean flow field



Concentration Field

Numerical dispersion model

- **Lagrangian stochastic dispersion model**

$$dU_i = a_i dt + \sqrt{C_0 \varepsilon}\, d\xi_i$$

$$dX_i = U_i dt$$

For movement of passive particle in turbulent flow

Drift coefficient a_i is determined by turbulent properties.

$$\sigma_{wc} = \sqrt{2}\, w_* \left(\frac{z}{z_i}\right)^{1/3} \left(1 - 0.8\frac{z}{z_i}\right)^{3/4}$$

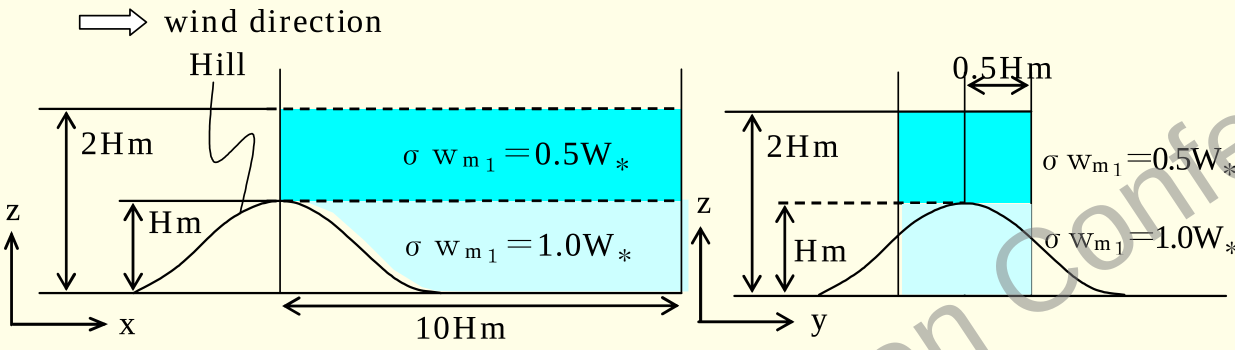
$$S_\kappa = 0.42\left(1 - \frac{z}{z_i}\right)\left(1 - 0.8\frac{z}{z_i}\right)^{-2}$$

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

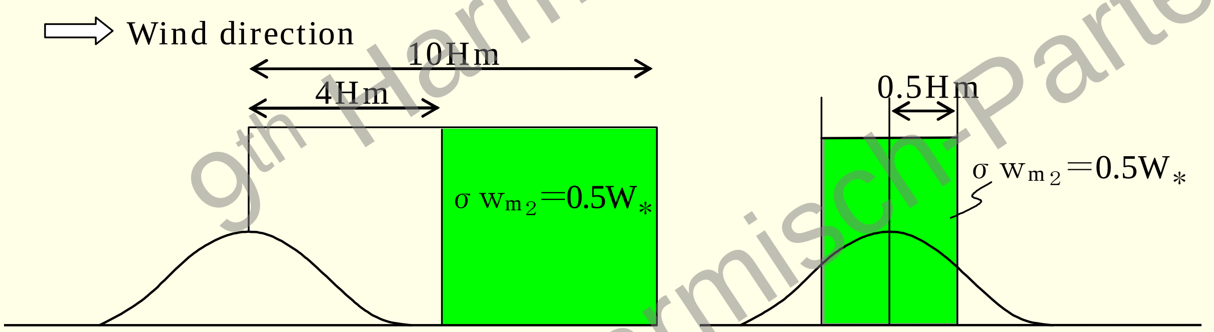
Turbulent properties in CBL are determined based on similarity relationship (derived from observation over flat land)

Strictly speaking, applying these relationships to complicated terrain is not adequate! It brings low performance on the concentration prediction.

Modification of the model to take into account of increase of turbulent strength behind the hill



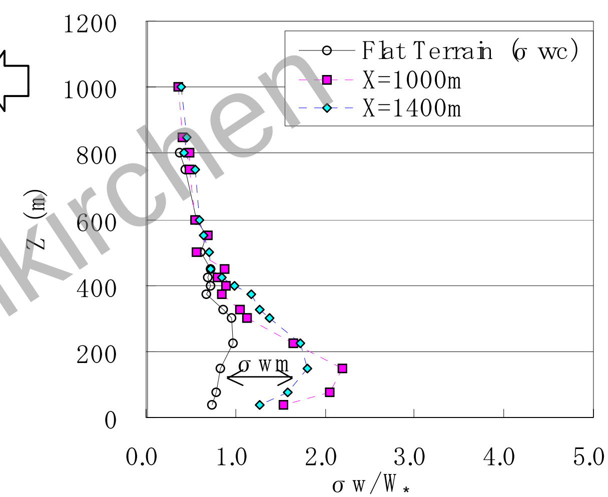
1st Step : σ m_1 is added to σ wc (from similarity relationship) .
→A particle is moved firstly in the manner as described before.



2nd Step : The particle is moved assuming the Gaussian turbulence which has a standard deviation of vertical velocity σ m_2.

Assumption of the domain and the strength of additional turbulence

Modification : Adding turbulent strength generated by hill σ wm1 and σ wm2.



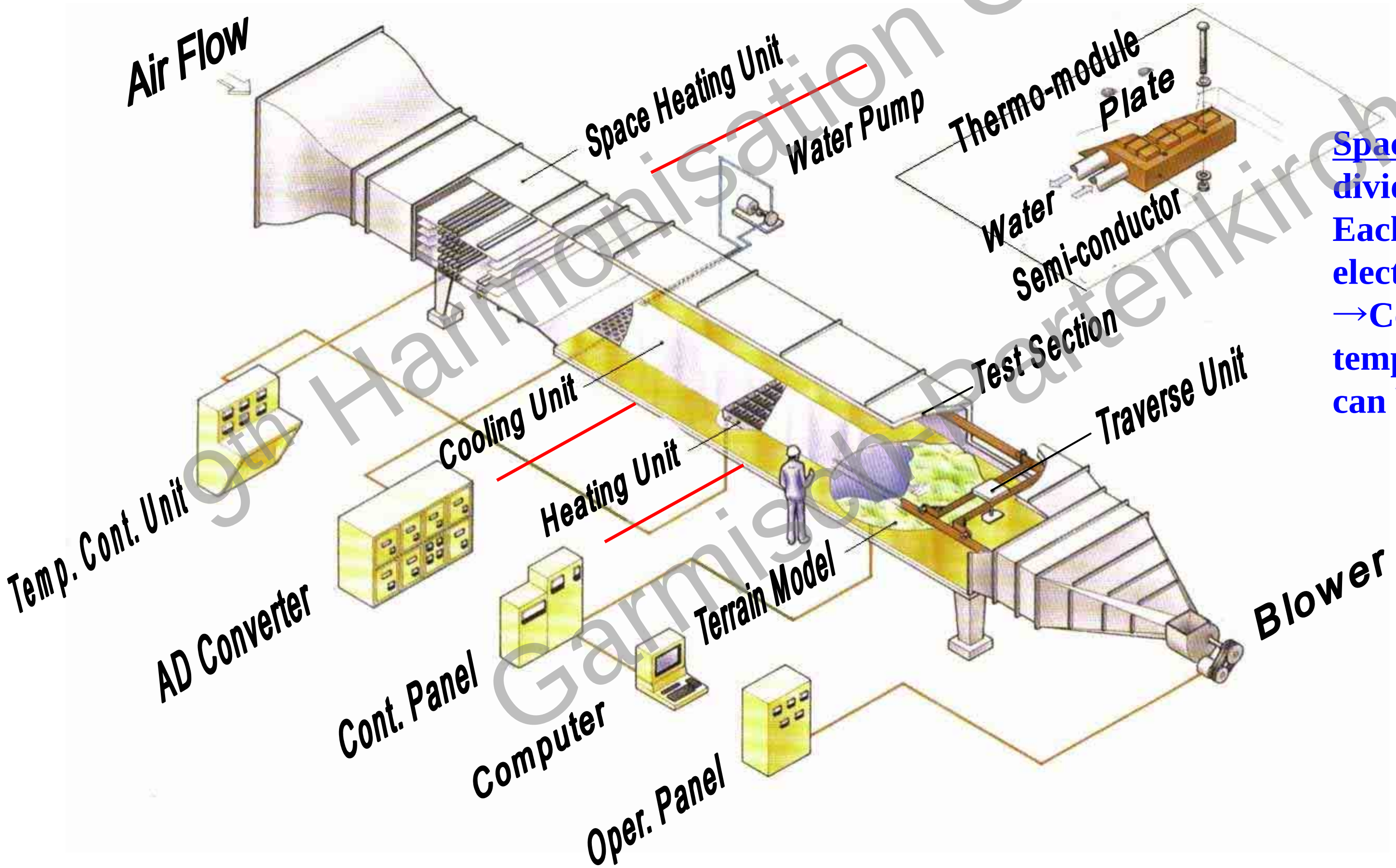
Assumption of the domain and the value of σ m was roughly estimated based on the data from wind tunnel experiments.

Wind tunnel experiments

(1) Experimental Facilities

・**Thermally stratified wind tunnel** in the Nagasaki Research & Development Center of Mitsubishi Heavy Industries was used.

→ **Working section : 1.7m wide, 1m high and 15m long**



Space heating unit: divided into 10 layers. Each temp is controlled by electric heater.
→Continuous temperature stratification can be simulated.

Wind tunnel experiments

(2) Measurements

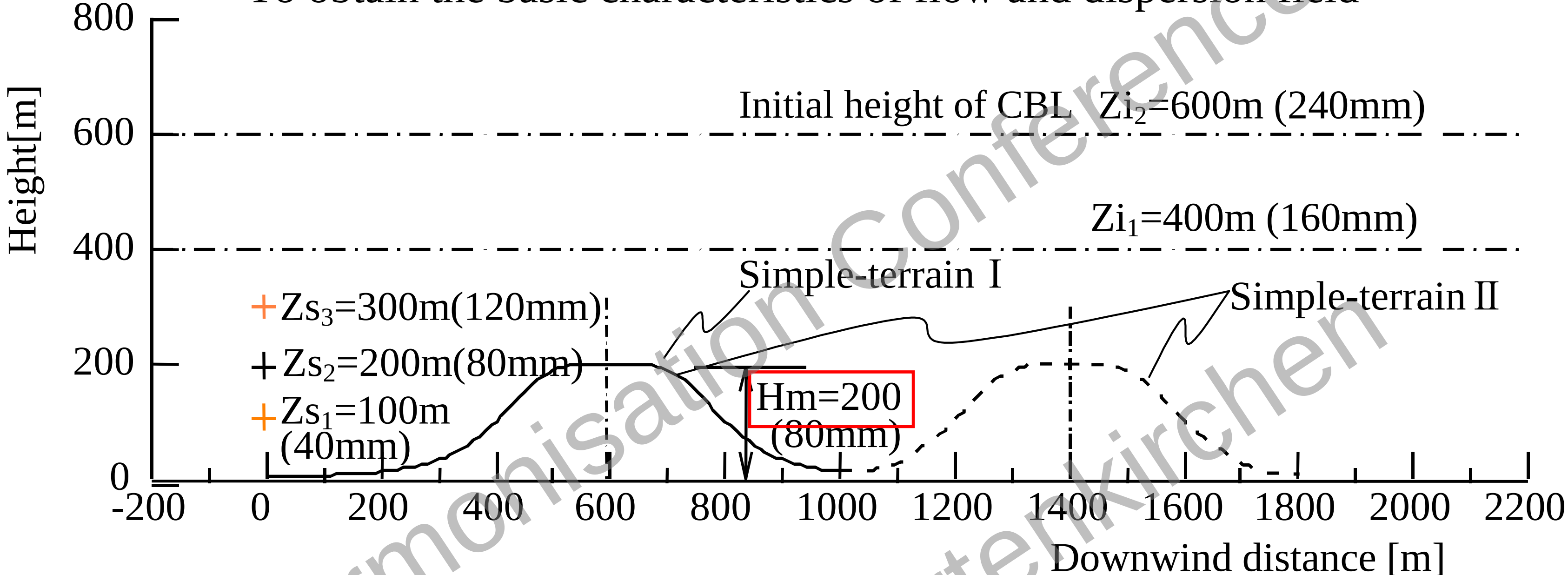
- Wind velocity components → FLV(Fiver Laser Velocimater)
- Temperature → Cold wire (Platinum resistance sensor)
- Sensible heat flux from tunnel floor → Heat flux sensor
- Gas concentration → Hydrocarbon gas analyzer (Tracer gas:methane)

(3) Terrain Model

- Scale = 1/2500
- 3 types of terrain models
  - Simple hills / Simple-terrain I, Simple-terrain II
  - Complicated-terrain

Simple-terrain I, II

→To obtain the basic characteristics of flow and dispersion field



Simple-terrain I

:Symmetrical shape

Shape of the hill

$$h(r) = \frac{Hm}{1 + \left(\frac{r}{200}\right)^4}$$

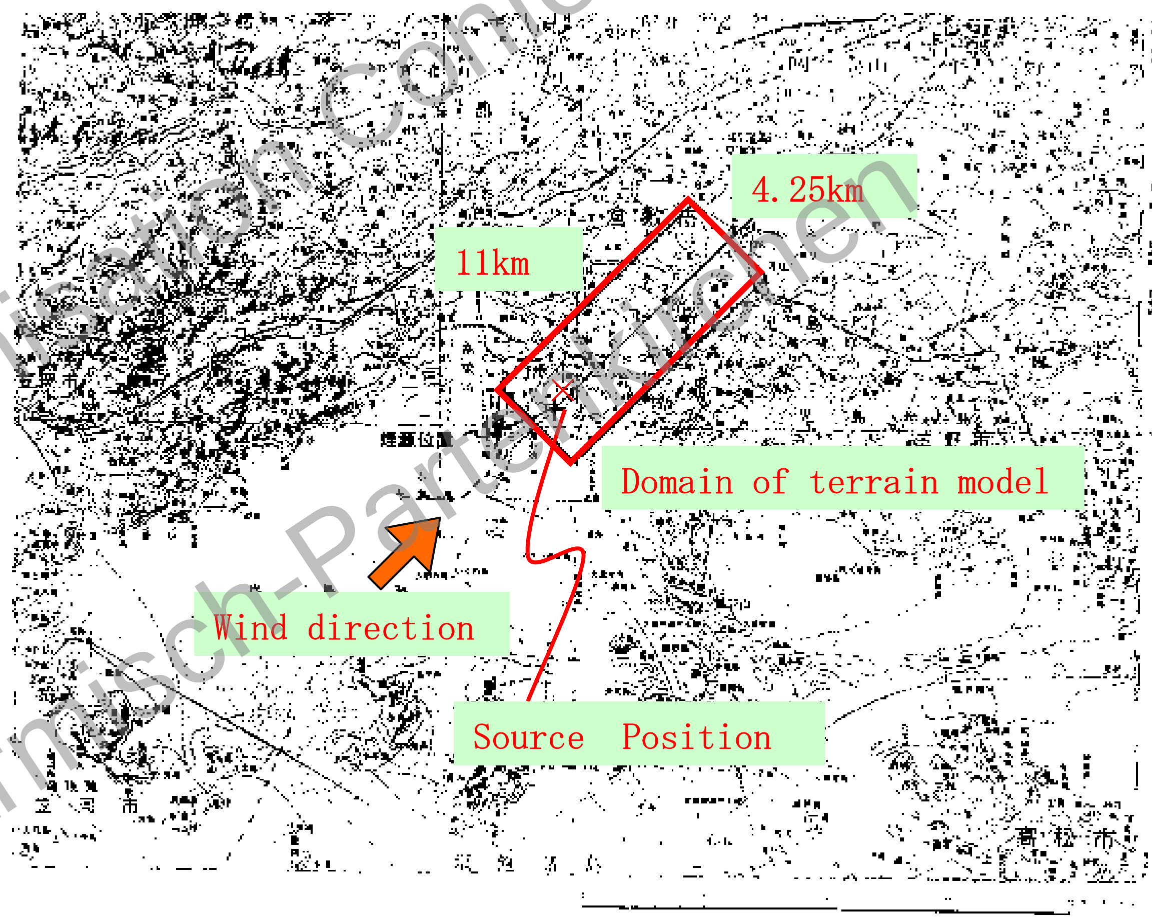
Hm :200m(Top height)

h(r) : Height of the terrain

r : Radius

Complicated-terrain

・A scale model of Mizushima region in Okayama prefecture in Japan.



Wind tunnel experiments

(4) Similarity rule

•*Bulk Richardson Number* : Ri_b

$$Ri_b = \frac{g \cdot L \cdot \Delta T}{T \cdot U^2}$$

$$\left(\begin{array}{l} \Delta T \ : Temperature\ Difference, \quad L \ : Length\ Scale \\ U \ : Wind\ Velocity \end{array} \right)$$

Experimental parameters in wind tunnel based on Rib

	Field scale	Wind tunnel scale
Flow velocity [m/s]	7.9	0.61
Temperature difference [K]	1	15
Length Scale [m] (= Hm)	200	0.08

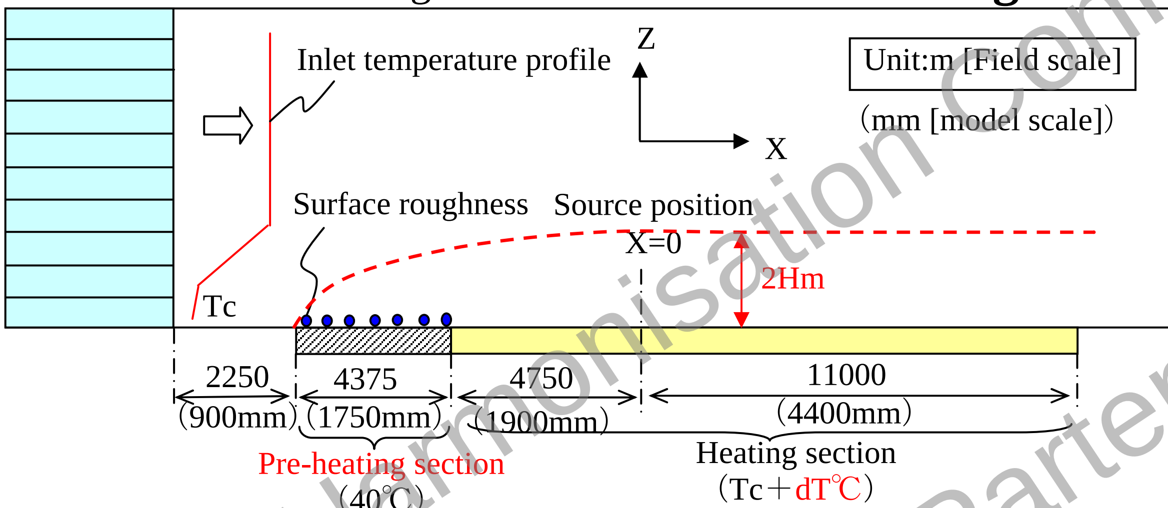
← Assumption: Temperature scale

(5) Experimental conditions -2 types of flow conditions-

- Inland type CBL/ Zi=2Hm (Zi: CBL height→almost const near source position)
- Coastal type CBL :TIBL-type (Thermal Internal boundary layer: Zi grows with distance from coast line.)

Configurations of wind tunnel

Inland CBL

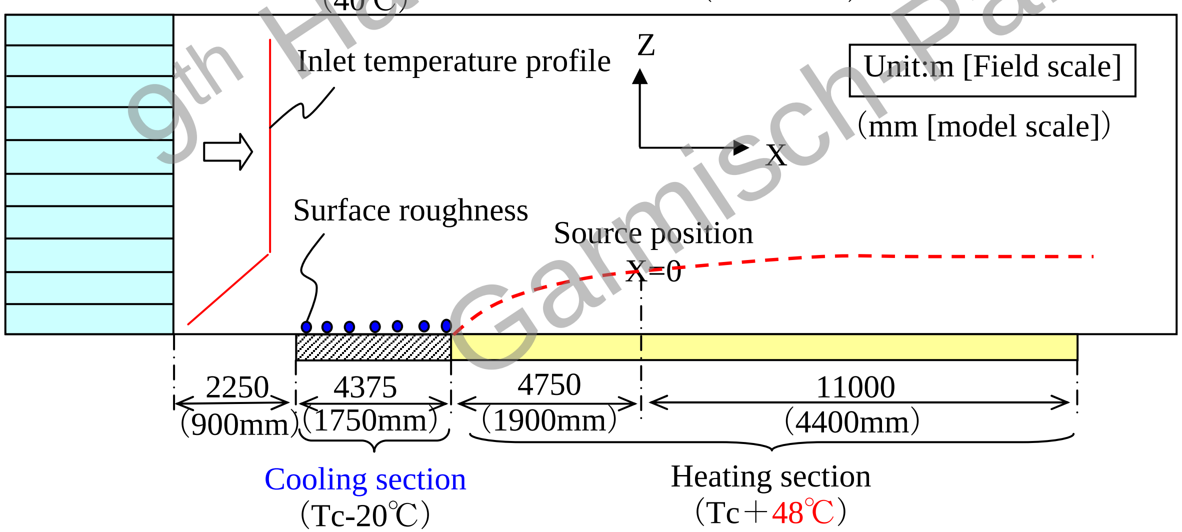


Coastal CBL (TIBL)

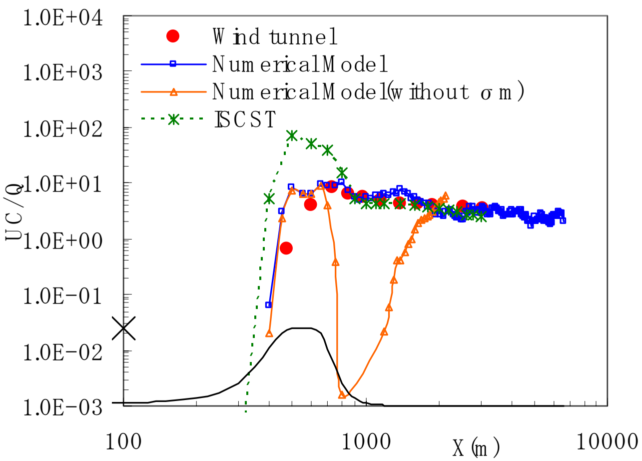
↓

Tracer gas from source is emitted into stable layer firstly and next it goes into CBL.

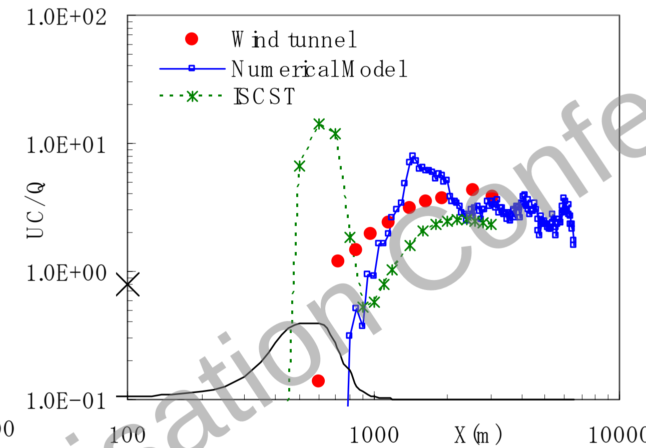
Fumigation is to be observed.



Results - Comparisons of GLC with wind tunnel experiments : Inland type CBL -



(a) Simple-terrain Ⅰ,Zs=200



(b) Simple-terrain Ⅰ,Zs=300

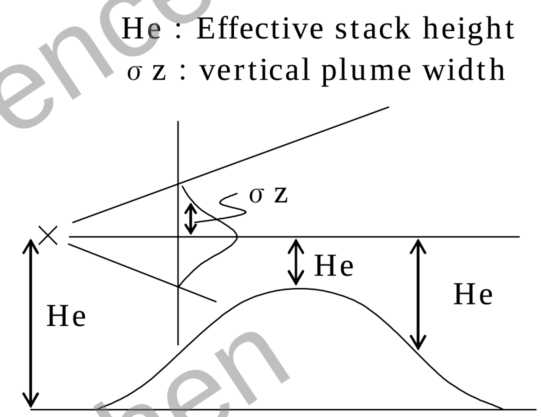
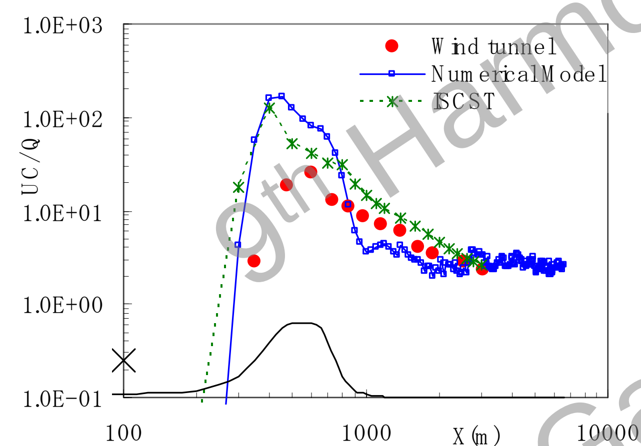
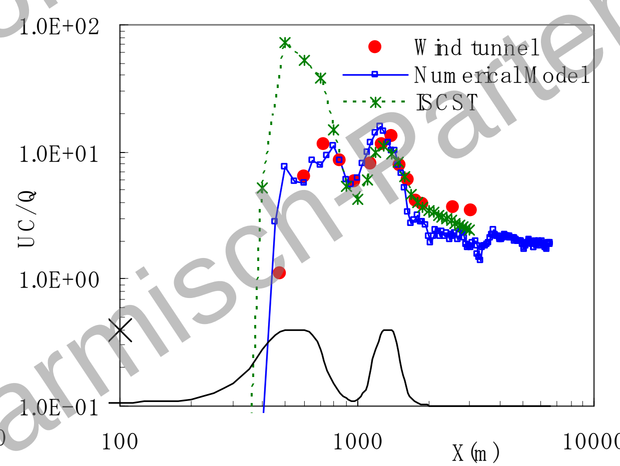


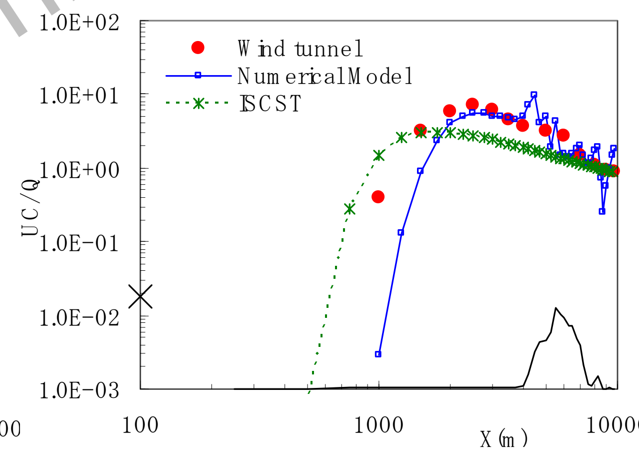
Illustration of plume behavior assumed by the ISCST model



(c) Simple-terrain Ⅰ,Zs=100



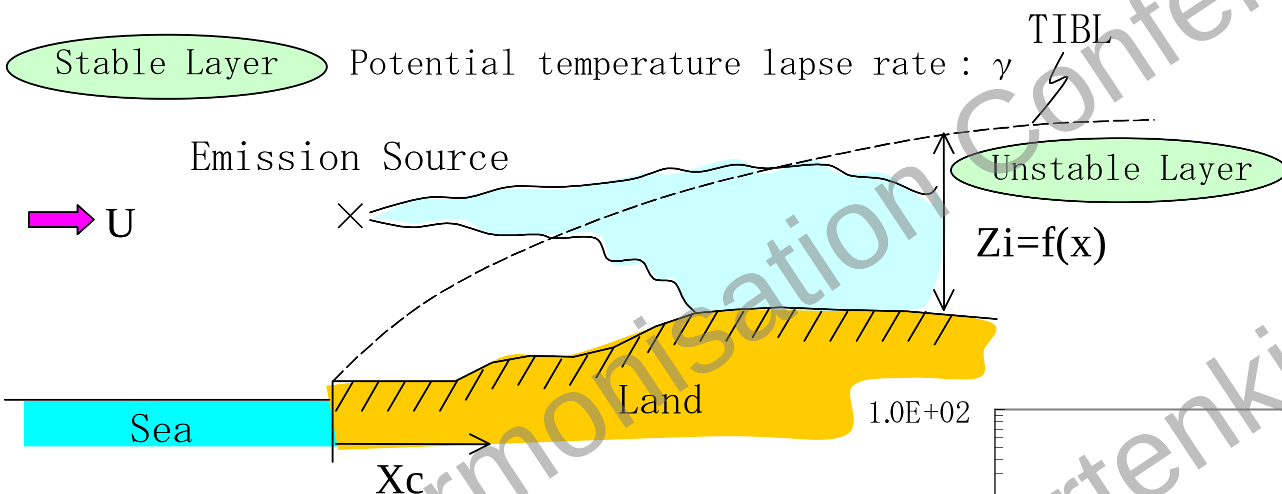
(d) Simple-terrain Ⅱ,Zs=200



(e) Complicated Terrain

Comparison of numerical model with the wind tunnel results

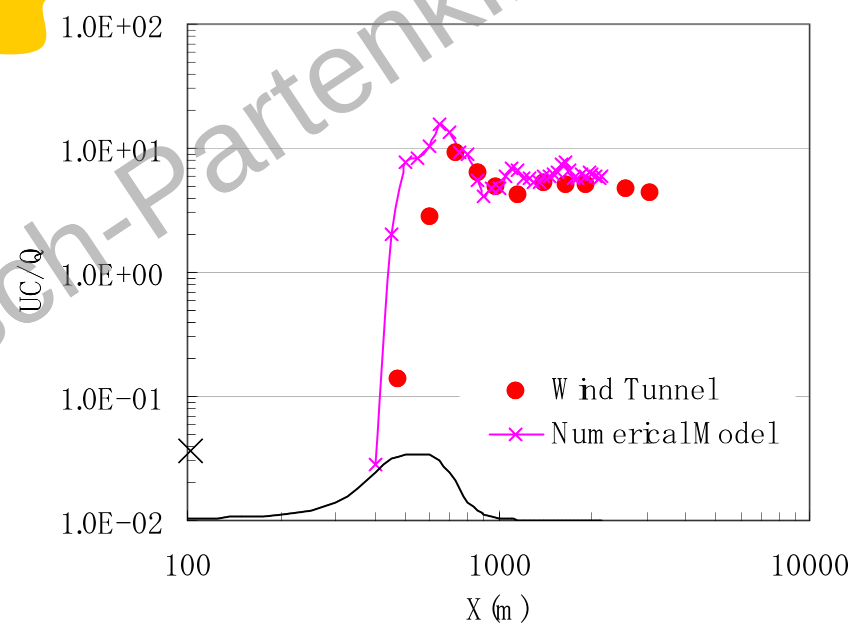
Results - Comparisons of GLC with wind tunnel experiments : Coastal fumigation-



$$Zi = \left(\frac{2H_0 Xc}{\rho Cp \gamma U} \right)$$

Xc: Distance from coast line

H_0: Heat flux from land surface



Simple Terrain I, Zs=200m

Results -Comparisons with Kincaid data set

● Field observation in Kincaid (*Olsesen, H. R., 1995*)

Table 1(1). Conditions of Kincaid field observation

Case	Wind speed (m/s) (at 100m)	Heat flux, H_0 (W/m^2)	Height of Convective layer, Z_i(m)
80/7/13 13:00	2.0	364.1	396
14:00	2.0	399.0	554
15:00	1.7	333.3	600
81/5/28 13:00	3.2	307.5	1250
14:00	3.4	276.3	1353

Kincaid field data : experiment over flat land. It includes several data under unstable conditions.

4 tests were chosen and categorized into 2 groups. The numerical simulations ware done for these two cases.

Table 2. Conditions of model calculation for Model Validation Kit

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

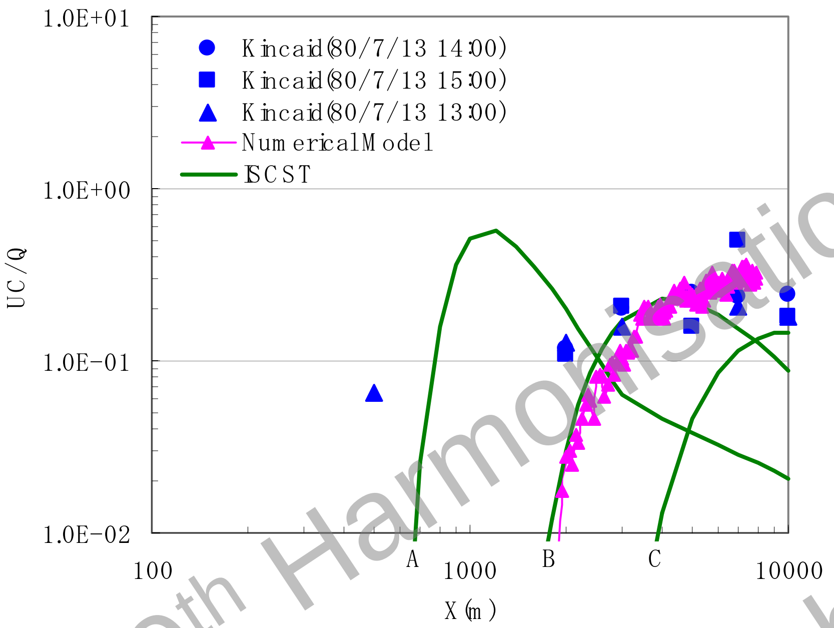
←Source heights are determined by CONCAWE formula.

$$\Delta Zs = 0.175 Q^{1/2} U^{-3/4}$$

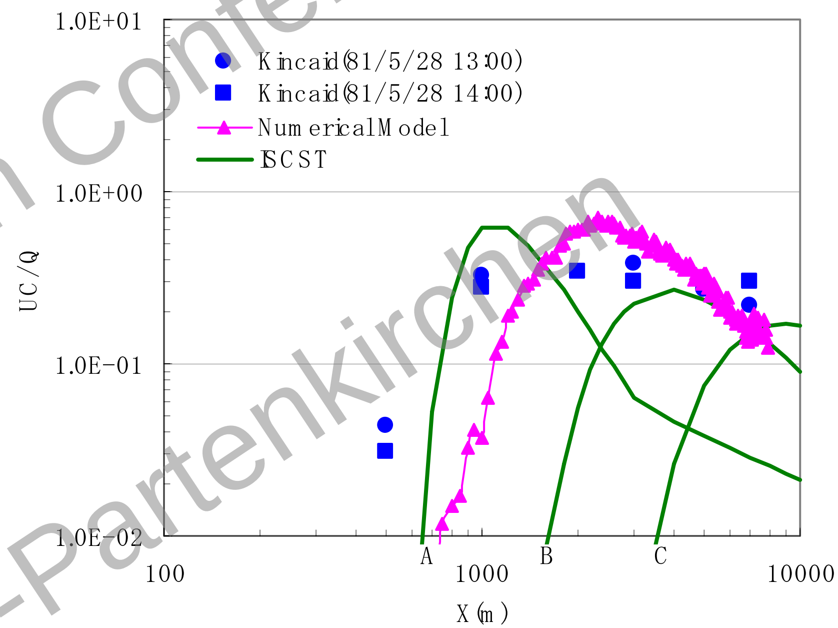
Table 1(2). Conditions of Kincaid field observation

Case	Stack Height (m)	Diameter (m)	Exit velocity Vg(m/s)	Gas temperature (℃)
80/7/13 13:00, 14:00, 15:00	187	9	12	121～124
81/5/28 13:00, 14:00	187	9	16.4～16.9	155

Results - Comparisons with Kincaid data set -



(a) Comparison with Data of 13/7/80

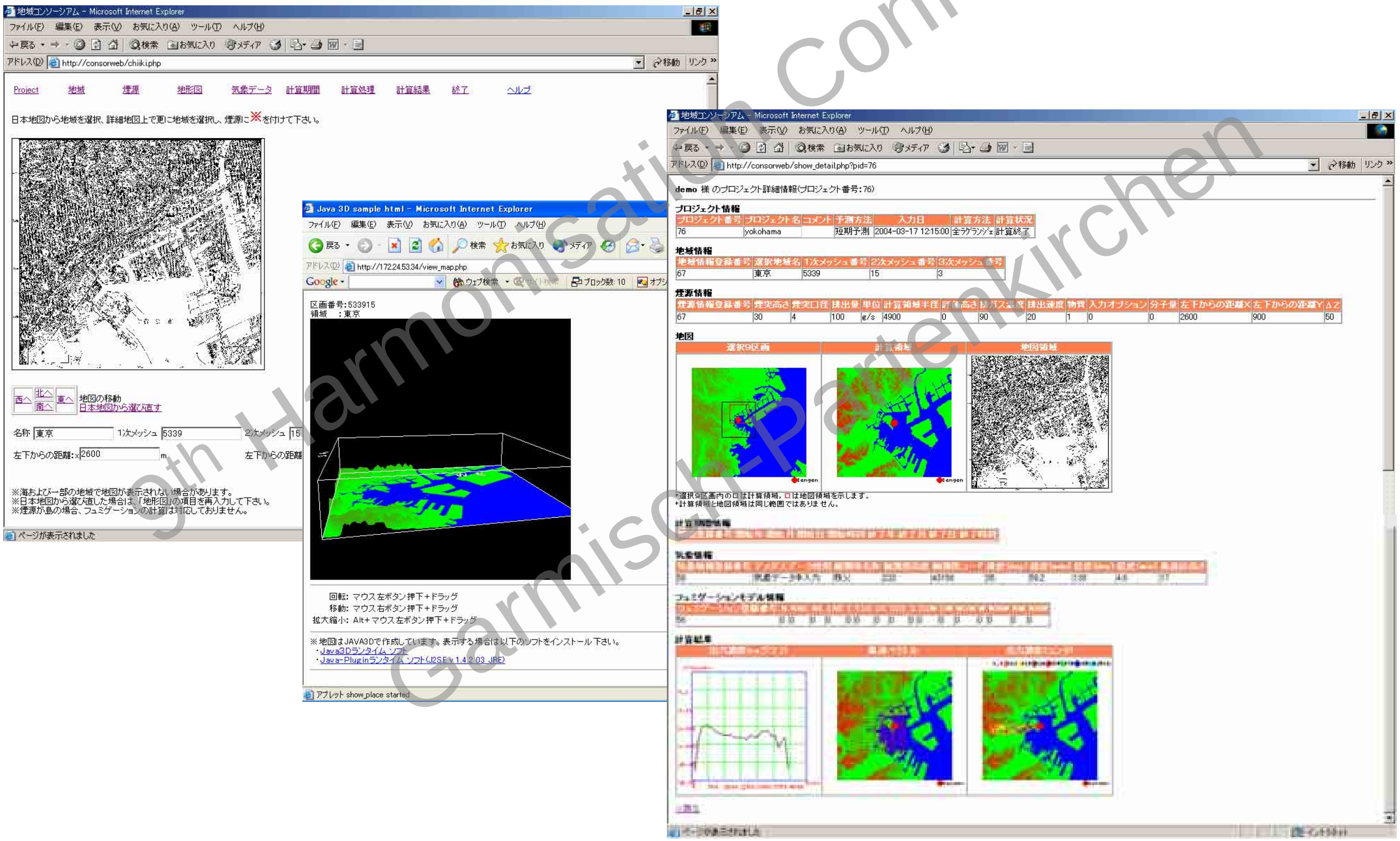


(b) Comparison of Data of 28/5/81

Comparison of numerical model with the Model Validation Kit (Kincaid) :
In case of dispersion over flat land, the results of numerical model agree well with the experiments.

User-friendly software

- User-friendly software using GUI (Graphical User Interface) is also developed based on the numerical model.
- By using GUI, we can easily handle the input and output data on the windows screens.



User-friendly software

- The software is able to calculate not only 1-hr average concentration but also long-term averaged concentrations.
- The software can predict fumigation phenomena caused by TIBL (Thermal Internal Boundary Layer) in coastal area.
- The digital maps published by Japan Geographical Survey Institute is applicable to the software and we can easily handle topographical data.
- AMeDAS (Automated Meteorological Data Acquisition System) data published by Japan Meteorological Business Support Center is available as meteorological input data.
- The software will be available in the web-site soon. (It will be charged.)

Summary

- We developed practical dispersion model for unstable conditions. The model we adopted was the combination of the potential flow model and Lagrangian stochastic dispersion model.
- The model was tested using wind tunnel experiments and several field experiments and proved to have better performances than conventional plume model.
- Based on the model, the user-friendly software was also developed and this software will be available in the web-site soon

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