MEASUREMENTS AND SIMULATIONS OF THE DISPERSION OF A PASSIVE TRACER IN A MOUNTAINOUS AREA

Karine Sartelet, Takeshi Saito, Masatoki Suzuki, Japan NUS Co. Ltd. Tokyo, JAPAN

and

Yoichi Ichikawa, Central Research Institute of Electric Power Industry. Tokyo, JAPAN
INTRODUCTION

Measured air concentrations of the field tracer experiments are compared to the atmospheric dispersion code, MERCURE.

- field tracer experiments done around Akagi Testing Center located at the mountain slope
- To apply atmospheric dispersion model in different meteorological conditions
# FIELD EXPERIMENTS

## 1. Outline of Experiments

<table>
<thead>
<tr>
<th></th>
<th>Site and Date</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Site</strong></td>
<td>Central Research Institute of Electric Power Industry (CRIEPI), Akagi Testing Center</td>
</tr>
<tr>
<td><strong>Date</strong></td>
<td>23 and 24 January 2001, 22, 23 and 24 January 2002</td>
</tr>
</tbody>
</table>

### Tracer Emission and Sampling

<table>
<thead>
<tr>
<th><strong>Tracer</strong></th>
<th>PMCH (C(<em>{7}F</em>{14}): Perfluoro-Methyl Cyclohexane)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Release height</strong></td>
<td>95 m ground level (GL)</td>
</tr>
<tr>
<td><strong>Air flow rate</strong></td>
<td>0.035 Nm(^3)/min</td>
</tr>
<tr>
<td><strong>Tracer’s flow rate</strong></td>
<td>90 g/h</td>
</tr>
<tr>
<td><strong>Sampling time and rate</strong></td>
<td>Every 30 minutes, 100 ml/min.</td>
</tr>
</tbody>
</table>

### Meteorological Measurement

<table>
<thead>
<tr>
<th><strong>Meteorological Conditions</strong></th>
<th>Weather: no precipitation; Wind direction: north (2001), north and west (2002); Atmospheric stability: neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ultrasonic anemometer</strong></td>
<td>Horizontal and vertical velocities at 100 m (GL). sampled at 20Hz</td>
</tr>
<tr>
<td><strong>Doppler-Sodar</strong></td>
<td>Observation heights: 11 ground levels between 30m and 250m; Measurements of standard deviation of vertical wind velocity (2001), and standard deviation of horizontal and vertical wind velocities (2002)</td>
</tr>
</tbody>
</table>
FIELD EXPERIMENTS
2. Test site & Topography

Mt. Akagi: 1828m ASL
Akagi Testing Center: 490m ASL

5 km
FIELD EXPERIMENTS

3. Release point & Sensors
MODELING

1. Description of MERCURE

- CFD code, adapted to the atmosphere
- Finite-difference and Finite-volume Method
- Standard k-ε closure scheme
- Terrain-following coordinate in vertical direction

Mass balance equation
\[
\frac{\partial \rho \tilde{v}_i}{\partial x_i} = 0
\]

Navier-Stokes equation
\[
\bar{p} \left( \frac{\partial \tilde{v}_i}{\partial t} + \tilde{v}_j \frac{\partial \tilde{v}_i}{\partial x_j} \right) = \frac{\partial \tilde{p}^*}{\partial x_i} + \left( \mu + \mu_t \right) \text{div} \, \tilde{v} + \frac{\partial}{\partial x_i} \left[ \mu + \mu_t \left( \frac{\partial \tilde{v}_i}{\partial x_j} + \frac{\partial \tilde{v}_j}{\partial x_i} \right) \right] \]

Energy balance equation
\[
\rho \left( \frac{\partial \theta}{\partial t} + u_j \frac{\partial \theta}{\partial x_j} \right) = T \left( \frac{p_x}{\rho} \right) \left( \frac{\lambda_c}{C_p} \right) \left( \frac{\partial \tilde{T}}{\partial x_j} \right) + \Phi
\]

Passive tracer transport equation
\[
\rho \left( \frac{\partial X_k}{\partial t} + \tilde{v}_j \frac{\partial X_k}{\partial x_j} \right) = \frac{\partial}{\partial x_j} \left( \frac{\lambda_c}{\sigma_t} \frac{\partial X_k}{\partial x_j} \right) + S_k
\]
MODELING

2. Computational Domain & Simulated Cases

North wind cases

RUN1: 15:30-16:00 23 January 2001
RUN2: 16:00-16:30 23 January 2001

West wind cases

RUN3: 17:00-17:30 23 January 2002
RUN4: 17:30-18:00 23 January 2002
MODELING

4. Input data (Inlet boundary condition)

Vertical profile of following data needed at Inlet condition

- Velocities (Vx, Vy, Vz=0)
  - From the wind measurements at 100m GL
    \[ V(z) = V_0(z/z_0)^p \]

- Potential temperature (derived from temperature, pressure)
  - From the measurements at ground surface (RUN1-2: 5°C, RUN3-4: 3°C)
    \[ T(z) = T_0 - z\Gamma \]

- Relative humidity
  - No measurement assumed to be constant (80%)

- Turbulent energy & Dissipation of turbulent energy
  - From the wind measurements at 100m GL
    \[ k(z) = U_m^2 / \sqrt{C_m} \]
    \[ \varepsilon(z) = U_m^3 / (K_m z) \]
    where \( U_m = V_0 K_m / \log(z_0 / z_r) \)
RESULT

1. Wind field

Time series of wind velocity at 100m (GL) on the release point
RESULT

2. Tracer concentrations

Tracer concentration on the ground surface: North wind cases

RUN1

RUN2
RESULT

2. Tracer concentrations

Tracer concentration on the ground surface: West wind cases

RUN3

RUN4
RESULT

2. Tracer concentrations

RUN 1 - ARC A
RUN 2 - ARC A
RUN 3 - ARC A
RUN 4 - ARC A

RUN 1 - ARC B
RUN 2 - ARC B
RUN 3 - ARC B
RUN 4 - ARC B

RUN 1 - ARC C
RUN 2 - ARC C
RUN 3 - ARC C
RUN 4 - ARC C

Japan NUS Co. Ltd.
RESULT

2. Tracer concentrations

Quantitative Comparison

<table>
<thead>
<tr>
<th></th>
<th>RUN 1</th>
<th>RUN 2</th>
<th>RUN 3</th>
<th>RUN 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma )</td>
<td>0.54</td>
<td>0.71</td>
<td>0.85</td>
<td>2.31</td>
</tr>
<tr>
<td>( \tau )</td>
<td>0.10</td>
<td>0.44</td>
<td>0.12</td>
<td>1.70</td>
</tr>
</tbody>
</table>

Mean-square root \( \sigma \)

\[
\sigma^2 = \frac{1}{3} \sum_{j=1}^{3} \frac{\sum_j (M_{i,j} - C_{i,j})^2}{\sum_i M_{i,j}^2}
\]

Peak accuracy prediction \( \tau \)

\[
\tau = \frac{1}{3} \sum_{j=1}^{3} \frac{\left| \text{Max}_i M_{i,j} - \text{Max}_i C_{i,j} \right|}{\text{Max}_i M_{i,j}}
\]
RESULT

3. Turbulent kinetic energy

Vertical profile of turbulent kinetic energy at the release point

Calculated turbulent kinetic energy in North wind case (RUN1-RUN2) are about 2.5 times larger than West wind case (RUN3-RUN4)
CONCLUSION

- Field experiments at Akagi Testing Center,
  - dispersion of tracer in the presence of topography
- Using a CFD code, Mercure,
  - good agreements with measured tracer concentrations
  - good agreements with measured kinetic turbulent energy in west wind case
- Further studies
  - more precise wind boundary conditions,
  - other turbulence scheme
MODELING

3. Mesh discretization & Boundary condition

Inlet

Outlet

Absorbing Layer
RESULT

1. Wind field

Wind speed averaged over 30 min. at 100m (GL) on the release point

<table>
<thead>
<tr>
<th></th>
<th>Measured</th>
<th>Computed</th>
<th>Relative Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUN1</td>
<td>10.7m/s</td>
<td>7.2m/s</td>
<td>-33.1%</td>
</tr>
<tr>
<td>RUN2</td>
<td>6.3m/s</td>
<td>5.9m/s</td>
<td>-5.6%</td>
</tr>
<tr>
<td>RUN3</td>
<td>6.8m/s</td>
<td>7.2m/s</td>
<td>+6.4%</td>
</tr>
<tr>
<td>RUN4</td>
<td>6.7m/s</td>
<td>7.7m/s</td>
<td>+15.3%</td>
</tr>
</tbody>
</table>

Note: wind speeds in RUN2, RUN3 and RUN4 are almost same values (differences are less than 10% in measurements, less than 15% in simulations).