Application of a Refined Emergency Code System SPEEDI to Atmospheric Field Experiments Conducted over a Complex Terrain

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An environmental emergency code system SPEEDI consisting of a mass consistent wind field model and a lagrangian particle dispersion model is taken up for validation study using the benchmark data obtained from a series of field experiments conducted over a complex terrain. During the experiments extensive data on meteorological parameters were collected and in addition SF\textsubscript{6} tracer gas was released and sampled by thickly distributed samplers. An isolated hill placed on an otherwise flat terrain provides a special geometrical situation so that the data can be used for testing the model simulation of stream line deflections past an obstacle. An objective basis for relating the ratio of Gauss precision moduli which controls the horizontal to vertical adjustment of the wind components has been introduced in the wind field model and the results show great improvement particularly when the parameter is allowed to vary with height. Results of the tracer release experiments confirm the improvements. The modified wind field model is then coupled with the lagrangian particle dispersion model. Diffusion calculations are carried out using locally obtained empirical diffusion parameters similar to the traditional Pasquill-Gifford parameters and as well as the observed turbulence information. Better accuracy is seen in the calculation of tracer concentration distribution in the latter case. While the code retains the merit of quick and effective use of routine measurements, the general performance is expected to improve when these changes are incorporated in it.

KEYWORDS: atmospheric diffusion, complex terrain, emergency, environment, meteorology, modelling, SODAR, SPEEDI, wind, experimental data, benchmarks, tracer techniques, parametric analysis

I. INTRODUCTION

The need for immediate assessment and prognosis of radiation dose in the environment during an early phase of a nuclear accident has initiated the development of emergency modelling systems in which wind field and diffusion models assume the primary role. The wind field determines the trajectory of the emitted particles and also provides initial dilution to the plume. Therefore the accuracy of the calculated concentration essentially depends upon the proper simulation of the flow. In order to minimise the influence of modelling uncertainties on the estimation of the wind field and finally the ground level concentration (GLC) of the pollutants, the emergency preparedness programme always tries to rely upon the available measured values of the meteorological parameters. Diagnostic mass consistent wind models provide a quick and effective means of utilising the available data especially in a complex terrain. Based on this approach, the Japan Atomic Energy Research Institute (JAERI) has developed a computer code system SPEEDI\textsuperscript{(1)} (System for Prediction of Environmental Emergency Dose Information) for the purpose of immediate assessment of radiological consequences. The system is comprised of a mass consistent wind field code WIND04, a particle random walk diffusion and advection code PRWDA and a radiological dose estimation code CIDE. Details of these models can be found in the report by Imai et al.\textsuperscript{(1)}

The code WIND04 interpolates the observed wind data onto three dimensional grid points and adjusts them minimally to account for the orography subject to the constraint of mass consistency. A key parameter in adjusting the air flow is the ratio of the Gauss precision moduli which determines the adjustment to be made in the horizontal component of wind \((u, v)\) relative to the vertical component \((w)\). Ever since the development of a similar operational code MATHEW\textsuperscript{(2)} the value of this parameter has been generally assumed to represent the expected ratio of \(w/u\) and is varied from 0.2 to 0.01 in MATHEW corresponding to the unstable and stable con-
ditions of the atmosphere respectively. Thus the value of the ratio is pre-set in the wind model and assumed constant for the entire model domain. Although this works well for a level terrain (complexity introduced due to the terrain inhomogeneity such as coastal site, etc.), when modelling flows over hilly terrain it is reasonable to relate the value to the Froude number $F$ which indicates the relative strength of the inertial force to buoyancy. In fact it has been shown by simulating simple cases that the value varies from 1 (neutral) to 0.1 (stable). Moussiopoulos et al. extended this objective basis to unstable cases and provided a more general approach of relating the parameter to Strouhal number, the inverse of $F$. Some of the recent mass-consistent models use this approach and also allow variation of its value with height. Model verification studies generally focus on the gross features of the wind field and the improvement in the results due to this approach is not discussed probably because of the lack of data.

The code PRWDA uses diffusion parameters derived from Pasquill-Gifford chart or similar chart obtained from local experiments) which are related to the diffusion categories A to F. It is a gross simplification of turbulence effects, but has been justified in practice essentially for want of adequate data on turbulence condition. Since the turbulence data are readily available from measurements using instruments such as SODARs (acoustic sounding systems) and Sonic anemometers in these years, it will be realistic to use the observed turbulence information for diffusion calculations rather than using the empirical parameters.

In this paper we study the performance of the code SPEEDI with reformed parameterisation of the Gauss precision moduli for WINDO4 and improved diffusion scheme PRWDA using the meteorological and the tracer release field experiments conducted over an isolated hill.

II. OUTLINE OF THE FIELD EXPERIMENT

Figure 1 shows the positions of the meteorological devices over the site where the 185 m high hill Sophienhöhe covers an area of 4 km$^2$ in association with a large open air mining area of 5 km$^2$ and the 250 m depth at the south east. The tracer gas SF$_6$ was released continuously from the KFA tower at a height of 50 m and at the rate of 2 g/s. Around 140 samplers were distributed at positions varying from 0.1 to 11 km from the source and with an azimuthal distance of $5^\circ$ as seen from the release. The terrain around the emission point is rather rough relative to its surroundings due to the presence of tall trees of height 15 to 20 m and building structures. The roughness length has been estimated to be 1.7 m from the observed wind profiles. This value changes to 0.8 just about a few hundred metres downwind to the northeast and reduces to 0.2 over the surface of the hill. The locations of the meteorological instruments are indicated in the figure. Doppler SODAR systems were placed south-eastern, western and northern bases of the hill so that the flow around the hill could be observed. These systems give profiles of the three components of the wind and standard deviation of the vertical component of the wind at an interval of 20 m up to a height of approximately 300 m. Masts 1 to 6 were placed in steps around the hill to get the wind velocity near the surface at the north-western part and the top of the hill. Data were continuously collected from these instruments and the averaged data were stored every 10 minutes. Special launches of pilot balloons, tetroons and tethered sondes were also carried out during the field experiment. The complete details of the experiment can be found in the report of Zeuner. Table 1 shows the summary of the tracer experiments which provided the present study with data. The meteorological data shown in Table 1 are taken from KFA tower averaged over the sampling periods.

Before analysing the model results an examination of the concentration distribution will help in knowing certain characteristics observed during these experiments. The ground level concentration (GLC) distributions shown in Fig. 2 corresponding to the three sampling periods reveal the following features:

<table>
<thead>
<tr>
<th>Exp. No.</th>
<th>Release time</th>
<th>Sampling interval</th>
<th>Meteorological data (KFA-tower)</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 Aug. 1988</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III-2-1</td>
<td>18:00-</td>
<td>19:00-19:30</td>
<td>2.5</td>
<td>230</td>
</tr>
<tr>
<td></td>
<td>20:30-</td>
<td>19:30-20:00</td>
<td>2.1</td>
<td>216</td>
</tr>
<tr>
<td></td>
<td>20:00-20:30</td>
<td></td>
<td>1.6</td>
<td>193</td>
</tr>
</tbody>
</table>

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Exp. III-2-1
- The plume has passed over the hill, the lower part of the plume is slightly deflected northward.
- Width of the plume is broad contrary to what is expected for a Gaussian plume under stable stratification.
- GLC maximum is found much closer to the source than expected for a Gaussian plume under stable stratification.

Exp. III-2-2
- The plume has deflected further north.
- Width of the plume is still broader than the last case.
- Position of GLC maximum has shifted away from the source.

Exp. III-2-3
- Large part of the plume has flown around the western side of the hill.
- Some part of the plume is seen stagnant in front of the hill.
- The general level of the concentration has decreased.
- The position of the GLC maximum remains the same as earlier sampling times.

As the meteorological measurements show, the change in wind direction, strong wind shear and relatively high turbulence are the major reasons for the observed features in the first two cases. For the last sampling period the wind speed was low.

III. MODEL DESCRIPTION
1. Basic Concept of the Wind Field Model

The code WIND04 interpolates the available sparse meteorological data over a rectangular grid mesh horizontally using inverse square interpolation technique and vertically using power law of vertical wind profile. Following the method proposed by Sherman(2), the values are then adjusted minimally with the strong constraint of mass conservation to account for the topography under a Cartesian co-ordinate system. Details of the numerical interpolation schemes are already described elsewhere(1) and we now focus on the parameterisation of the adjustment coefficients. According to the concept, the functional

$$E(u, v, w) = \iiint \left\{ \alpha_1^2(u - u_0)^2 + \alpha_1^2(v - v_0)^2 + \alpha_2^2(w - w_0)^2 \right\} dV$$

is to be minimised subject to the constraint

$$\nabla U = 0,$$

where $U = (u, v, w)$ is the final wind after adjustment and $U_0 = (u_0, v_0, w_0)$ denotes the observed wind. $w_0$ is usually set zero. $\alpha_1$ and $\alpha_2$ are the Gauss precision moduli for horizontal and vertical wind respectively as introduced in the beginning. The larger the value of $\alpha$ the smaller the adjustment in that respective component of wind. Using Lagrange multiplier theory the minimisation functional is written as

$$E(u, v, w, \lambda) = \iiint \left[ \alpha_1^2(u - u_0)^2 + \alpha_2^2(v - v_0)^2 + \alpha_2^2(w - w_0)^2 + \lambda \nabla \cdot U \right] dV$$

$$\lambda(x, y, z)$$ is the Lagrangian multiplier. For $\alpha_1 = \alpha_2 = 1$, $\lambda$ represents the velocity potential of the adjustment. The condition for stationary value of $E$ leads to the following Euler-Lagrange equations.
to be solved subject to the boundary condition
\[ \lambda(u - u_0) = \lambda(v - v_0) = \lambda(w - w_0) = 0. \]

'Free flow' conditions (\( \lambda=0 \)) are assumed at the lateral boundaries allowing adjustment in the normal component of the wind speed and 'no flow-through' condition (\( w-w_0=\partial\lambda/\partial z=0 \)) is assumed at the surface ensuring no change in the initial vertical velocity (\( w_0=0 \)). Rearranging the four equations, (3a)-(3d), the Poisson's equation for \( \lambda \) can be derived as follows,

\[ \frac{\partial^2\lambda}{\partial x^2} + \frac{\partial^2\lambda}{\partial y^2} + \frac{\alpha_1^2}{\alpha_2^2} \cdot \frac{\partial^2\lambda}{\partial z^2} = -2\alpha_1^2 \nabla \cdot U_0. \]  

The equation is solved iteratively using successive over relaxation method with the above boundary conditions. Once \( \lambda \) is obtained, the adjusted wind can be computed from the Euler-Lagrange equations (3a)-(3c).

2. Parameterisation of \( \alpha \)

The ratio \( \alpha (\alpha_1/\alpha_2) \) of the Gauss precision moduli is important for the relative adjustment of the vertical velocity. An objective method of parameterisation based on a physically more meaningful scheme is introduced in the original code SPEEDI in order to simulate the streamlines over the hill. Using the energy arguments of Snyder \(^{18} \) to calculate the dividing streamline height for stably stratified flow, Ross et al. \(^{19} \) have developed an argument to relate the \( \alpha \) and the Froude number \( F \) characterising the domain of interest and an empirical relation was obtained by comparing the fluid tank experiments of Hunt and Snyder \(^{12} \). Details about the scheme can be found in these references. Since \( F \) approaches infinity under neutral stratification, Moussiopoulos \(^{14} \) uses Strouhal number \( Str_\alpha \), the inverse of \( F \), and the final relation for \( \alpha \) is given as

\[ \alpha^2 = 1 - \frac{Str_\alpha^4}{2} \left( \sqrt{1 + \frac{4}{Str_\alpha^4}} - 1 \right). \]  

For a linearly stratified atmosphere with uniform vertical wind profile, constant value of \( \alpha \) derived from the above relation can be used. However, the real atmosphere seldom satisfies this condition particularly under nocturnal stable conditions and hence vertical variation of the coefficient would be realistic.

3. The Dispersion Code PRWDA

The code PRWDA uses simple random walk displacement method to move each fictitious particle indepen-

dently. A deterministic approach based on \( K \) theory of diffusion is used for diffusion calculations. The eddy diffusivities (\( K_x, K_y, K_z \)) are related to the standard deviations of the plume (\( \sigma_y \) and \( \sigma_z \)) which are derived from the Pasquill-Gifford (PG) chart as a function of distance and stability. It may be noted that the PG chart was originally obtained using a ground source under the condition of a rather smooth terrain and smaller sampling times. Therefore it is not universally applicable and hence similar relations obtained from the field experiments \(^{11} \) conducted in this local terrain using an elevated (50 m) point source and a larger sampling period (1 h) has been used in the present calculation. The difference between these two relations for \( \sigma_y \) and \( \sigma_z \) are shown in Fig. 3. \( \sigma_z \) values from the local experiment are greater than those from the PG chart. Therefore, decrease in the plume touch-down distance and increase in the GLC values close to the source are expected when these values are used.

From the observations it is found that the turbulent intensity was rather high during the first two sampling periods compared with the recommended values for the diffusion category \( F \). For example the recommended \( \sigma_u \) for stable condition is less than or equal to 0.25 ms\(^{-1} \). The observed values of turbulent intensities from a sonic anemometer mounted on the KFA tower at the 50 m height are listed in Table 2. The values are found to decrease with time although the stability class remains the same. To be accurate the observed turbulence data should be used in the diffusion scheme and the best way to do this is by treating the particle movements in a Markov chain process. Hence the scheme is modified as follows. The original model describes advection and diffusion of the particles in time steps as follows.

\[ x_{i+1}^t = x_i^t + u_i(t) \Delta t(t) + \Delta x_i^t, \]

Fig. 3 Dispersion parameters as a function of distance for stability category \( F \)
where $\mathbf{x}_i = (x, y, z)$ is the position in the Cartesian coordinate system and $\mathbf{u}_i = (u, v, w)$ is the wind component supplied by the wind model. $\Delta x_i^*$ is the diffusion due to turbulence and due to random nature, this step is represented by random numbers generated with a uniform probability density function in a range determined by the deterministic values for diffusion i.e., the eddy diffusivities (1).

In order to use the observed turbulence the diffusion component in Eq. (6) can be rewritten as

$$\Delta x_i = u_i' \Delta t,$$

where $u_i'$ is the turbulent velocity expressed as the sum of two components—a correlated and a random (stochastic) component. Thus,

$$u_i'(t + \Delta t) = u_i'(t) + \tau_i,$$

where $\rho_{L,i}(\Delta t)$ is the Lagrangian auto-correlation coefficient assumed to have an exponential form given by

$$\rho_{L,i}(\Delta t) = \exp\left(-\frac{\Delta t}{T_{L,i}}\right)$$

and $\tau_i$ is the Monte Carlo component picked randomly from a Gaussian distribution with mean zero and standard deviation given by

$$\sigma_{\tau_i} = \sigma_i \sqrt{1 - [\rho_{L,i}(\Delta t)]^2}^{1/2},$$

where $\sigma_i = \sigma_u, \sigma_v, \sigma_w$.

$T_{L,i}$ is the Lagrangian time scale whose value is determined from the formulations recommended by Hanna (10). The following relations are used for $T_{L,i}$. This needs only the boundary layer height $h$ as additional input which is normally available from SODAR measurements.

$$T_{L,u} = 0.15 h / \sigma_u(z/h)^{0.5},$$

$$T_{L,v} = 0.07 h / \sigma_v(z/h)^{0.5},$$

$$T_{L,w} = 0.1 h / \sigma_w(z/h)^{0.8}.$$

Equation (9) is applied for all the three directions and PIC method is used for the vertical diffusion after the plume grows twice the vertical grid size. A correction term is generally added to the vertical diffusion velocity $w'$ in cases of inhomogeneous turbulence such as would occur during day time convective conditions. However we have considered it as insignificant in stable cases and as the PIC method is followed, the correction term is not included in our calculation.

### IV. MODEL APPLICATION

The computational domain of an area of $12.5 \times 12.5$ km and a height of 500 m is constructed using $50 \times 50 \times 20$ grid cells with horizontal intervals of 250 m and vertical intervals of 25 m. Topographical data with the same horizontal resolution is given as input. The input data of wind speed and direction are taken from the KFA tower measurements, SODARs (KFA, Köln and Essen). Surface stations include the lowest measurement level of SODARs and tower. All the other higher level measurements are treated as upper wind stations. The mast data represents highly localised measurements and cannot be resolved by the grid size considered for the present calculations. On the other hand, increasing the model grid resolution demands topographical data with the same resolution as input and consumes more computational time. Hence for the present version of the model, the mast data are not included in the input data. Since the power coefficient used in the vertical interpolation is pre-set as a function of stability category, the latter derived from the tower measurements of mean wind and temperature profile has been used as another input in the model. Wind field calculations are performed by using two types of parameter $\alpha$, i.e., constant and variable $\alpha$.

In the case of constant $\alpha$, the bulk Froude number, the inverse of Str in Eq. (5) is given by

$$F = \frac{U}{NH_c},$$

where $U$ is the characteristic wind speed, $H_c$ the length scale of the obstacle blocking the stream line and $N$ the Brunt-Väisälä frequency given by

$$N = \sqrt{\frac{g}{\bar{\theta}}} \frac{d\bar{\theta}}{dz}$$

for stable atmosphere. $\bar{\theta}$ is the representative potential temperature of the layer of the air under consideration.

Estimation of $U$ involves judgement (i.e., it should be representative of the upstream flow where the influence of the hill is less) because in the experiments considered for present study, simple averaging of the SODAR and tower data results in over estimation of the wind. Considering that the SODARs are located close to the obstacle and since our interest lies in studying the trajectory of the plume which is released from the tower, wind speed and potential temperature observed at the point of release (50 m height) are used to compute $N$. The temperature profile $\Delta \theta(z)/\Delta z$ is taken from the 20 m and 120 m level values of $\theta$ from the KFA tower.

In order to account for the effect of stratification and wind shear on the relative importance of the horizon-

**Table 2** Turbulence intensities in m s$^{-1}$ at the release height (50 m)

<table>
<thead>
<tr>
<th>Time</th>
<th>$\sigma_u$</th>
<th>$\sigma_v$</th>
<th>$\sigma_w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.40</td>
<td>0.93</td>
<td>0.76</td>
<td>0.53</td>
</tr>
<tr>
<td>18.50</td>
<td>0.92</td>
<td>0.69</td>
<td>0.49</td>
</tr>
<tr>
<td>19.00</td>
<td>0.93</td>
<td>0.61</td>
<td>0.46</td>
</tr>
<tr>
<td>19.10</td>
<td>0.69</td>
<td>0.46</td>
<td>0.41</td>
</tr>
<tr>
<td>19.20</td>
<td>0.51</td>
<td>0.47</td>
<td>0.31</td>
</tr>
<tr>
<td>19.30</td>
<td>0.55</td>
<td>0.42</td>
<td>0.34</td>
</tr>
<tr>
<td>19.40</td>
<td>0.47</td>
<td>0.35</td>
<td>0.28</td>
</tr>
<tr>
<td>19.50</td>
<td>0.39</td>
<td>0.37</td>
<td>0.23</td>
</tr>
<tr>
<td>20.00</td>
<td>0.32</td>
<td>0.35</td>
<td>0.20</td>
</tr>
</tbody>
</table>
tal to vertical adjustment, \( \alpha \) value should be allowed to vary with height rather than assumed as constant. For calculating variable \( \alpha \), \( \Delta \theta / \Delta z \) is obtained from 20 m, 50 m and 120 m level temperature measurements from the KFA tower and the profile is assumed to have different shapes below 50 m and above 50 m. \( \theta \) and \( U \) are averaged for each vertical interval of 25 m thickness and thus the vertical profile of \( \alpha \) is calculated from Eq.(5). Beyond the tower height, the data is taken from tethered sonde and KFA SODAR. The \( \alpha \) profile is considered horizontally homogeneous which is a valid assumption for most practical cases.

V. RESULTS AND DISCUSSION

1. Wind Field Simulation with Constant \( \alpha \)

The general flow field simulated using constant \( \alpha \) profile is depicted in Fig. 4 for the last sampling period. The streamlines at the height intervals of 30 m are shown along with their projections on the surface. The value of the Froude number \( F \) decreased from 2 to 1 for the period 18 to 19 h and fell to 0.4 at the end of the last sampling period due to increase in stability and reduction in wind speed. Introducing the concept of dividing streamline for a stably stratified flow Snyder(8) has given a simple relation for dividing streamline height as

\[
H_c = h(1 - F),
\]

where \( h \) is the height of the obstacle which is 185 m in our case. This means that the plume must have been below the dividing streamline height, which is about 100 m during the last sampling period and is expected to flow around the hill. From the results of the calculation, it is seen that the wind flows over the hill in all the cases although the speed reduces with time. Flow around the hill is seen feebly in the figure for the last sampling period. The change in wind direction during the experimental period bears importance in dispersion calculation but this has not been properly simulated.

2. Wind Field Simulation with Variable \( \alpha \)

Calculated \( \alpha \) profile up to 120 m height is shown in Fig. 5 along with the observed temperature profile. The value of Brunt-Väisälä frequency \( (N) \), which appears in the denominator of the relation for \( F \), did not change much with height. Variation of \( F \) and therefore \( \alpha \) with height was mainly due to the strong wind shear. Figure also indicates the decrease in \( \alpha \) value with increasing stability. The layer close to the surface has too low a value of \( \alpha \) since the wind speed measured by the KFA tower at this level was extremely low (0 m/s up to 10 m height). This is because of the presence of tall trees surrounding the tower. Such a low value of \( \alpha \) is not representative of the whole area covering the hill. To avoid unrealistic simulation, \( \alpha \) value extrapolated linearly from other levels had to be used to get proper wind field. The flow pattern is shown in Fig. 6 in the same way as Fig. 4. The stream lines can be seen turning around the western flank of the hill. Initially (not shown here) the lower most stream lines flow around the hill while those at higher altitudes flow over the hill. In the last sampling period, stream lines up to 90 m are seen flowing around the hill. This is in close agreement with the observed plume trajectory.

3. Comparison of the Concentration Distribution

Simulation of the concentration distribution may provide additional test of the wind field and dispersion models. The particle random walk model PRWDA is supplied with the adjusted wind field (with constant \( \alpha \)) every ten minutes interval from the beginning of the release. In the first case, diffusion parameters derived from the field experiments conducted over this site are used in the calculation. The results of the tracer distributions (GLC) are shown in Fig. 7 on the same scale as observed (Fig. 2). Even with the locally derived values
of $\sigma_z$ the high values of concentration close to the release point are not simulated. Simulation is some what better over the upslope of the hill. In the next case, the observed turbulence data collected at three vertical levels from KFA tower are used in the same manner as discussed earlier. The data at 50 m level are already shown in Table 2. The results are shown in Fig. 8. A general increase in the calculated GLC values are seen, as well as a shift in the position of GLC maximum towards the source can be noticed. For a more quantitative comparison, the calculated and observed values are shown for both cases as a scatter plot normalised to their maximum in Fig. 9. A diagonal line in the figure indicates perfect agreement and two lines on either side of this show the range of agreement within a factor of two. The clustering around the origin indicates that the agreement is better for lower values of the predicted concentration than the higher values. Values in less than one order of agreement are not shown to avoid crowding. The agreement is better (0.4 to 1.0) for higher values of GLC in the later case using observed turbulence data than using the empirical parameters. Cumulative frequency distribution (CFD) of the ratio of measured and calculated concentration is shown in Fig. 10. Around 20% of the calculation fall within a factor of 2, 50 to 60% within a factor of 5 and 65% within an order of 1 for the first two sampling periods and 70% for the third.

In general the model using empirical diffusion parameters underestimates the concentration values and fails to show the position of maximum concentration as revealed in the experiment. Using observed turbulence information has shown a significant improvement of 10 to 20% in general and in particular the higher values of GLC agree within a factor of 2 with the measurements.

Wind field obtained with variable $\alpha$ is used in the next case and the concentration is calculated in the same manner. Quantitative comparison of the calculations are shown in Figs. 11, 12 and 13 similar to earlier cases. The scatter plot and CFD are very similar to the constant $\alpha$ case. But the distribution pattern looks broader and the plume turning to the western side can be seen which is in agreement with the observation (Fig. 2).
Fig. 10 Observed and calculated values of the three sampling periods in the form of a cumulative frequency distribution (CFD)
Dashed lines indicate the calculation using diffusion parameters, solid lines show the results using observed turbulence data.

Fig. 11 Same as Fig. 8 but using variable $\alpha$

Fig. 12 Same as Fig. 9 but using variable $\alpha$

Fig. 13 Same as Fig. 10 but using variable $\alpha$

Table 3 Model performance for different cases

<table>
<thead>
<tr>
<th>Case</th>
<th>Sampling period</th>
<th>Percentage of agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Const. $\alpha$ and empirical diffusion</td>
<td>I</td>
<td>16 in fact. 2 30 in fact. 5 50 in fact. 10</td>
</tr>
<tr>
<td>(using parameters estimated for local terrain)</td>
<td>II</td>
<td>18 50 58</td>
</tr>
<tr>
<td>Const. $\alpha$ and revised diffusion</td>
<td>I</td>
<td>18 40 65</td>
</tr>
<tr>
<td>(using observed turbulence data)</td>
<td>II</td>
<td>21 50 62</td>
</tr>
<tr>
<td>Variable $\alpha$ and revised diffusion</td>
<td>I</td>
<td>18 40 58</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>21 50 62</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>30 60 70</td>
</tr>
</tbody>
</table>
general performance of all these cases are compared in Table 3.

VI. CONCLUSION

The performance of the mass consistent wind field model WIND04 of the emergency modelling system SPEEDI has been examined using the meteorological data collected during a series of field experiments conducted over a complex terrain. The adjustment coefficient $\alpha$ was parameterised objectively in terms of the Froude number. Model results with constant $\alpha$ showed stream lines flowing over the hill, whereas use of variable $\alpha$ with height showed some of the stream lines flowing around the hill at lower levels. The measured concentration distribution confirmed more or less the same behaviour of the wind field.

The lateral and vertical standard deviations of the plume obtained from the PG chart and used in the original code PRWDA were replaced by similar values derived from the field experiment conducted over the local terrain. The present values are greater than those given by the PG chart. The observed maximum concentration could not be simulated even with these new values. When modified to account of the observed turbulence intensity, the code showed good agreement with the measurements. The influence of wind field simulated using constant and variable $\alpha$ profile was examined in the GLC distribution but difference was hardly seen. Perhaps the difference could be seen on the shadow region of the hill where unfortunately few samplings were taken.

It should be noted that the effect of atmospheric stability is inherently taken into consideration by using stability dependent $\alpha$. Calculation of $\alpha$ profile needs temperature profile measurement which is routinely available from the meteorological tower. When observed turbulence is available, those values should be used in the diffusion code for accurate estimation. Greater improvement can thus be achieved using diagnostic models without increasing the computer time.

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