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P. Wittek
Institut für Meteorologie und Klimaforschung
Projekt Nukleare Sicherheit

Kernforschungszentrum Karlsruhe

KERNFORSCHUNGSZENTRUM KARLSRUHE
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Summary

Atmospheric dispersion models are reviewed with respect to their application to the consequence assessment within risk studies for nuclear power plants located in complex terrain. This review comprises

- seven straight-line Gaussian models, which have been modified in order to take into account in a crude way terrain elevations, enhanced turbulence and some other effects;

- three trajectory/puff-models, which can handle wind direction changes and the resulting plume or puff trajectories;

- five threedimensional windfield models, which calculate the windfield in complex terrain for the application in a grid model;

- three grid models;

- one Monte-Carlo-model.

The main features of the computer codes are described, along with some informations on the necessary computer time and storage capacity.

Übersicht über atmosphärische Ausbreitungsmodelle, anwendbar in Risikostudien für Nuklearanlagen in komplexem Terrain

Kurzfassung

Der Bericht enthält kurze Beschreibungen atmosphärischer Ausbreitungsmodelle im Hinblick auf die Anwendung zur Folgenabschätzung in Risikostudien für Kernkraftwerke in komplexem Terrain. Die Übersicht umfaßt

- sieben geradlinige Gauß-Modelle, welche modifiziert sind, um in einfacher Weise Geländeerhebungen und die durch die Geländestruktur bedingte verstärkte Turbulenz zu berücksichtigen;

- drei Trajektorien-/Puff-Modelle, welche die Änderung der Windrichtung und die resultierenden Trajektorien der Abluftfahne berücksichtigen;

- fünf dreidimensionale Windfeldmodelle, welche das Windfeld in komplexem Terrain für ein Gittermodell liefern;

- drei Gitter-Modelle;

- ein Monte-Carlo-Modell.

Es werden die wesentlichen Merkmale dieser numerischen Computer-Modelle beschrieben und einige Informationen über Rechenzeit und Speicherplatzbedarf mitgeteilt.

Contents

1. Introduction

Special demands are made to atmospheric dispersion models applied in nuclear reactor accident consequences codes. They are required to assess the activity concentration distribution for short term releases with a typical time scale of some hours as well as for long term releases with a time scale of several days or weeks. They also take into account plume rise, the vertical wind profile, mixing layer height and the variation of dispersion conditions during the travel of the plume. In addition they have to account for radioactive decay and removal processes of the effluents like dry and wet deposition. Dispersion of local, meso and large scale is frequently treated by the same atmospheric model. The majority among the atmospheric models currently used in reactor risk studies is of the straight-line Gaussian type. This was confirmed by an International Comparisom Study of reactor accident consequence models, performed by NEA in 1983 /NU83/. These models are not designed to take into acount complex terrain. This survey has been performed in order to review the currently available atmospheric dispersion models which account for orographic effects.

2. Atmospheric Dispersion in the Context of the Consequence Assessment for Risk Studies

A brief introduction to consequence assessment codes used for risk studies may be helpful for showing the position of the atmospheric dispersion model within the consequence assessment code. The representation is based mainly on the procedure applied to the German Reactor Risk Study /BA82/. Usually a reactor accident consequence analysis starts with the assumed release of radioactive material from nuclear power plants to the environment. The release is followed by the atmospheric transport, the diffusion and deposition of the radioactive effluents. The meteorological conditions affecting these processes determine the space and time dependent air concentration and ground contamination, calculated for each species of radionuclides in the atmospheric dispersion submodel.

From these intermediate results the potential radiation doses are calculated, which serve as a criterion for protective action and countermeasures proposed to reduce early or chronic damages. After taking into account these actions the expected doses are determined by the dosimetry submodel.

According to the expected doses the resultant averaged individual probabilities of damage are evaluated. Taking into account the local population density the number of collective fatalities and collective doses is calculated. In nearly all dispersion calculations for risk studies the meteorological parameters, measured at the site or associated to the site, are assumed to be the same at all distances at the time of measurement. This assumption can not be accepted for complex terrain. Especially the wind speed and direction have to be recorded at many stations in order to calculate the windfield. In complex terrain the knowledge of inversions is also relevant to the behaviour of an activity plume. From these considerations it can be recognised that the expenditure for modelling dispersion in complex terrain will increase considerably.

3. Atmospheric Dispersion Models for Complex Terrain

3.1 Semi-empirical Approaches

3.1.1 Gaussian Straight Line Models

The Gaussian model is based on the equation (1) for the pollutant concentration C in the plume.

$$C(x,y,z) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \left\{ \exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right] \right\} \tag{1}$$

The involved parameters are defined as follows:

C	Concentration of effluents in the plume
Q	Continuous point source strength
u	windspeed
σ_y	lateral dispersion parameter
σ_z	vertical dispersion parameter
x	axial distance from source point
y	lateral distance from plume centre line
z	height above ground
H	effective plume height above ground

Equation (1) is a solution of the steady-state diffusion equation:

$$u \frac{\partial C}{\partial x} = K_y(x) \frac{\partial^2 C}{\partial y^2} + K_z(x) \frac{\partial^2 C}{\partial z^2} \qquad (2)$$

if total reflection at the ground is assumed and the origin of the point source is at $x = 0$, $y = 0$, $z = H$.

Further assumptions are:

- The advection of the airborne material is essentially greater than the diffusion in x-direction.
- Horizontal and vertical wind shear is not being considered.

Modified forms of the equation (1) are often used for special effects like plume trapping, fumigation or inversion-break-up fumigation /LI82/. To account for complex terrain several modifications have been applied to Gaussian models from plume centerline corrections up to the selection of special diffusion parameters. The major disadvantage of this type of model however is that it does not take into account horizontal deflection of the plume. For dispersion in complex terrain this means an essential restriction even in distances up to 10 km.

VALLEY

One of the earlier models, called the VALLEY-model, is described by Burt /BU77/. This steady-state plume dispersion model is designed for multiple point and area source application. The plume height is assumed to be constant for stable atmospheric conditions. Thus if terrain rises the plume will approach the elevated surface. According to the variation of the terrain height an effective plume height must be recalculated at each receptor. In case the terrain height exceeds the original plume height, the plume centerline is adjusted so that it remains 10 m above ground. Deflection of the plume out of the sector of concern for stable conditions is simulated by applying a concentration reduction factor F = (401-D)/400 where D is the receptor elevation minus the effective plume height both related to level terrain (Fig. 3.1). The deflected parts of the plume are not regarded furtheron, so that mass conservation is not accomplished. The argument for using a maximum height of 400 m is given in /BU77/ as following: Evaluations of weather conditions in the Western part of the US show that the height of the plumes in stable air calculated according to G. A. Briggs would not exceed 400 m above stack base. For unstable and neutral atmospheric conditions the plume is assumed to remain at a constant height above terrain. The model has been designed to estimate the long term as well as the maximum 24-hour concentration. This explains why lateral spread is considered using cross-sector concentration averaging over a 22.5°-sector. The values of σ_z are calculated according to Pasquill-Gifford, but the σ_z of the stability classes E and F (night time conditions) is replaced by σ_z of D if the "urban" option of the model is used.

The VALLEY code does not simulate lee effects like a down wash of plume pollutants when the plume is passing over a crest or if the source might be placed directly in the lee of mountains. Curvature of the plume due to pressure gradients induced by topographical features is not simulated.

COMPLEX I and II

An analysis of dispersion models /FA80/ comprises the codes COMPLEX I and II which are slightly modified versions of the VALLEY - code. COMPLEX I is designed to use hourly meteorological data and to model the plume centerline following one-half of the terrain height variation. COMPLEX II calculates a horizontal Gaussian concentration distribution instead of the sector averaged concentration in VALLEY.

MPTER

Hourly air pollutant concentration can be estimated by the MPTER - code (multiple point source model with terrain adjustments) for slight terrain variations /PI80/. This means that the code is intended to consider terrain heights less than the effective plume height. The terrain adjusted effective plume height H_A is being varied according to the stability category as follows:

$$H_A = H - \Delta E + F_T \, \Delta E \qquad \text{with}$$

H = effective height site level related
$\Delta E = E_R - E_S$
E_R = ground level elevation of receptor
E_S = ground level elevation of source

The effect of terrain adjustment factor F_T is shown in Fig. 3.2. Further assumptions to account for structured terrain are not made.

CPS

In the CPS-code (Continuous Point Source Computer Code) topography is handled as "a function of distance from the source by changing the vertical distance between the plume centerline and the ground" /PE76/. 10 x 16 height values are the input corresponding to 10 distances and 16 sectors (of 22.5°). No further assumptions for complex terrain are made.

CTDM

The behaviour of a plume approaching a terrain obstacle in stable stratified flow can be characterised by the concept of the dividing streamline.
As can be seen in Fig. 3.3 there is made a distinction between two regions of the flow encompassing the hill. The regions are divided by a boundary line at the critical height H_c. Above H_c the flow has sufficient energy to pass up and over the hill while the part of the plume below H_c is forced to go around the hill. H_c is defined by the following formula /SN82/:

$$\frac{1}{2}\,\rho\, U^2(H_c) \doteq g \int_{H_c}^{H} (H - z) \left(\frac{-\partial\rho}{\partial z}\right) dz$$

with

U: wind speed of flow approaching the hill at H_c

$\frac{\partial\rho}{\partial z}$: local density gradient

g: gravity acceleration

The term at left is the kinetic energy of a fluid parcel at H_c. A fluid parcel will pass over a hill of the height H if the kinetic energy equals at least the potential energy (right term) gained by the parcel when rising from H_c up to the height H.

According to the discrete layers the Complex Terrain Dispersion Model (CTDM) has two components termed the "Wrap" and the "Lift" Model /EG84/:

The Wrap component describes the up-wind concentration at an elevated receptor if the flow passes horizontally around the hill in region 1. The model allows the incorporation of an observed wind direction distribution. The plume material below H_c is treated as a source distribution and the response function (Green's function) is integrated from the hill base to H_c in order to get the receptor concentration.

The Lift model has the following extensions and modifications as compared to the Wrap component: The concentration of material in region 2, which is also reflected from the hill surface, is calculated by integrating the response function from H_c to infinity.

PSDM

Egan /EG75/ reports on the ERT/PSDM (Point Source Diffusion Model) which provides an improved estimate of the impact of plume in elevated terrain. According to Fig. 3.4 the plume centerline describes an intermediate course between a terrain following trajectory and a constant height trajectory. In the model it is distinguished between receptors located on terrain above the effective plume height H_o, as related to the level of the original stack base, and below H_o. In the first case the terrain modified plume centerline height is calculated being one half of the effective plume height H_o. If the receptor is located below H_o this height is reduced by the semi-terrain height. The model has been used for neutral and unstable as well as stable conditions. As cited by Fabrich /FA77/ test data recorded at Garfield under unstable conditions confirm the assumptions made because the prediction comes closest to the actual trajectory.

Egan/Lavery

A Gaussian formula parameterised to take into account some futher modifications is reported by Egan /EG75/ and more extended by Lavery /LA82/.

$$C(x,y) = \frac{2\,Q}{(2\,\pi\,\sigma_y\,\sigma_z\,u)_f\,(D_y\,D_z)}\;\exp\left(-\frac{\eta^2\,z_o^2}{\zeta^2\,2\sigma_{zf}^2\,D_z^2}\right)\;\exp\left(-\frac{(\beta\,y)^2}{2\,D_y^2\,\sigma_{yf}^2}\right)$$

when the subsript f denotes "flat terrain" values.

D_y, D_z — are the ratios of the complex terrain versus flat terrain plume spread σ_y/σ_{yf} and σ_z/σ_{zf} taking into account the different turbulence levels.

y = $(z - h)/z_o$

z_o = effective source height
z = local height of the plume centerline
h = local height of the terrain

$\left.\begin{array}{l} z_o \\ z \\ h \end{array}\right\}$ related to the stack base

$\zeta = (\partial\psi/\partial_z)_o/(\partial\psi/\partial_z)$ — the ratio of the average vertical gradient of the stream function ψ at the effective stack height to the gradient at the plume centerline over the surface at a given distance. ζ is derived from the potential flow theory for some typical geometrical formations in /EG75/.

β — horizontal distortion factor /LA82/

The model is regarded to be valid in moderate or high Froude number flow because potential flow solutions are involved.

3.1.2 Trajectory/Puff Models for Homogeneous Windfields

The main feature of these models is their ability to take into account temporarily (but not spatially) varying wind directions. The windfield is assumed to be homogeneous at any time. A continuous release is approximated by a series of plume segments or puffs. The plume elements are released at specified time intervals and tracked along a trajectory evaluated from the variable wind direction. The concentration contributions of the plume segments are superposed at selected grid points. A series of trajectory /puff - models currently available for risk studies is given in Tab. 3.1. In general they do not consider the vertical variation of a trajectory in irregular terrain and are restricted to run only with source meteorological data.
No information is given in literature about the computational expenditure of these models, but it must be assumed that the CPU time and the required storage capacity exceed those of straight-line Gaussian models considerably because of a relatively small time increment between the puff releases in order to obtain a good approximation of the real plume dispersion.

3.2 Grid Models

3.2.1 Windfield Models

The models discussed in the previous chapters use source meteorological data in order to describe the atmospheric dispersion of effluents. In complex terrain meteorological information from a single station cannot be assumed to be representative for a region of some 100 km^2.

By use of wind data observed all over the region of interest windfield models are able to predict major flow fields. They provide an input for pollutant transport calculations by numerical grid models.

Numerical grid models depend generally on a certain type of more or less complex air flow models. Advanced air flow models include thermodynamics (i. e. mountain-valley-windsystems) as well as dynamic effects (i. e. wake effects) and provide data of velocity, pressure, temperature and density.
This chapter is referred to models which provide a windfield according to the following steps:

- Supply of observed wind data usually being limited and sparsely distributed over the area of interest.
- Estimation of an initial windfield by interpolation and extrapolation of the measured values.
- Construction of a final windfield with respect to orography and mass consistency.

Common to all is the fundamental scheme of the adjustment procedure in order to come from the initial to the final windfield.

Given the interpolated initial windfield $V_o = (u_o, v_o, w_o)$, the final windfield $V = (v, u, w)$ is being achieved under the requirement of a minimal adjustment of the initial field.

$$
\begin{aligned}
u &= u_o + \frac{1}{2\alpha_1^2}\frac{\partial\lambda}{\partial x}\\
v &= v_o + \frac{1}{2\alpha_2^2}\frac{\partial\lambda}{\partial y} \qquad (1)\\
w &= w_o + \frac{1}{2\alpha_3^2}\frac{\partial\lambda}{\partial z}
\end{aligned}
$$

with the Lagrange multiplier λ and the tunable parameters α_1, α_2, α_3, which describe the relation between the variations of horizontal and vertical motion.

The only constraint to the final windfield is that is has to satisfy the mass conservation equation.

$$\mathrm{div}(V) = 0 \qquad (2)$$

because the density of the lower part of the atmosphere is assumed to be constant.

Differentiation of the equation (1) and substitution into the continuity equation (2) gives a second order differential equation in λ.

$$\frac{\partial^2\lambda}{\partial x^2} + \frac{\partial^2\lambda}{\partial y^2} + \frac{\alpha_1}{\alpha_3}\frac{\partial^2\lambda}{\partial z^2} = - 2\alpha_1 \left(\frac{\partial u_o}{\partial x} + \frac{\partial v_o}{\partial y} + \frac{\partial w_o}{\partial z}\right) \qquad (4)$$

where $\alpha_1 = \alpha_2$

Equation (4) is solved for λ using boundary conditions like $\lambda = 0$ for flow through boundaries and $\frac{\partial\lambda}{\partial\eta} = 0$ for solid boundaries. (For η see equ. (5)). λ substituted back into equation (1) yields the final windfield.
Differences between the regarded mass-consistent windfield models result mainly from handling of orography, interpolation/extrapolation schemes estimating the initial windfield and calculation techniques solving the Poisson equation (4) for λ.
Orography can be taken into account by a terrain following coordinate system with the transformation equation as follows:

$$x = x, \quad y = y \qquad \eta(x,y,z) = \frac{z - H}{h(x,y) - H} \qquad (5)$$

where $h(x,y)$ is the orographic height and H the domain height of the model.
The cartesian z-coordinate is replaced by the vertical component η such that η = const. for the irregular terrain surface. The simplification of the model domain yields a more complex formulation of the differential equations. Terrain following coordinates are used for example in the windfield models of Davis et al /DA84/ named <u>ATMOS</u> and Nester /KI84/ named <u>MAKOS</u>.

MATHEW

A 3-d-model which considers orography in a relatively crude way is described by Sherman /SH78/. The solid bottom boundary is determined by grid cells being either completely part of the ground or part of the atmospheric domain. According to this the terrain surface is reproduced in a block structure. The choice of the grid intervals is therefore codetermined by the requirement to resolve the major topographic features of the site. The model named MATHEW (mass-adjusted, three-dimensional wind field model) was developed to provide windfields for the ADPIC pollutant transport model (see chapter 3.2.2). The informations needed are hourly wind data of several surface stations, wind data taken from a synoptic analysis, stability data and a vertical profile of horizontal wind speed and direction. The interpolation of the wind data is carried out by inverse-sqaere distance weighting for the surface winds of the nearest 3 observation stations, the vertical variation of the winds is determined by a stability determined power law up to the surface layer height and by measured vertical profile from the surface layer height up to the top of the grid.

WEST

Another windfield model (WEST) /FA77/,, is used to provide a windfield for the numerical pollutant transport model IMPACT. The philosophy behind WEST /SK79/ is that locally measured winds are the most relevant wind data for an area and that these, together with the local terrain, atmospheric stability and a requirement for mass conservation, define a reasonable wind field. Atmospheric stability is simulated introducing transmission coefficients, which control the horizontal and vertical fluxes through the wall faces. They have been developed on the basis of numerical simulations of idealized problems and empirical data and are formulated as follows:

Stability category	A	B	C	D	E	F	G
horizontal transmission coefficient	1	1	1	1	200	500	1000
vertical transmission coefficient	1.6	1.4	1.2	1	0.8	0.6	0.4

These conditions imply according to the Froude number concept that air parcels tend to flow around a hill under stable conditions rather than over it. Orography is modelled identically to MATHEW.

WAFT

Compared to MATHEW the WAFT model (Wind fields Adjusted For Topography) presented by Apsimon /AP84/ is provided by a refined handling of orography. Instead of block orography occupying a grid cell either totally or not at all, the grid cells in WAFT may be partially intersected by ground surface at the bottom boundary of the calculational domain. The flow throught an irregular cell is determined by weighting coefficients similar to those given in the equations (1). Each weighting coefficient used in WAFT is a product of one which accounts for the geometry of a cell wall partially blocked by terrain while the other one is used to enforce or suppress the velocity adjustment across the same cell wall.

$$\alpha_i = \frac{A_{total}}{A_{open}} \alpha_i^*$$

where i = x,y,z

A_{total}: total area of the cell wall

A_{open} : area of the open portion of the cell wall.

α_i^* reflects the physical conditions of the flow like vertical stability independently of the grid.

An option is also included in WAFT to account for flow over hill in stable conditions. Then α_z^* is chosen according to the hill height and slope, incident windspeed and atmospheric stability. Atmospheric stratification is introduced via the Brunt-Vaisala-frequency, which can be estimated from the additional information about the vertical profile of the potential temperature.

In order to decide about the specification of α_z^* a mean Froude number for a single hill is calculated. For Froude numbers $F > 0.5$ the flow over the hill is approximated by potential flow. For $F < 0.5$ a critical height is calculated above which potential flow is assumed while quasi-horizontal flow is assumed below. Although derived only for a single hill this procedure is also applied to regions of complex terrain.
In order to obtain the Langrangian parameters λ WAFT employs either the successive-over-relaxation method, which has been used also in MATHEW, or the Incomplete Cholesky Conjugate Gradient Method /AP83/.

Little information is given in the literature about the need of computer capacity and computing time on a comparative basis. From the information available it has to be expected that for a number of 30 000 - 40 000 grid points corresponding to a 1 km horizontal and 200 m vertical resolution of an area of 60 x 60 x 2 km a few minutes of CPU-time are needed on a large computer.

3.2.2 First Order Closure Models

IMPACT

The Integrated Model of Plumes and Atmospherics in Complex Terrain is an Eulerian grid model. The model is intended to serve as an advanced point source air quality model. It is based on five submodels: windfield development, pollutant transport, diffusivity field development, plume rise calculation and chemical tranformations. The pollutant transport model is based on a second-order flux-corrected algorithm of Crowley /FA77/, which uses the technique of fractional steps /YA71/. For the diffusivities several algorithms are discussed in /FA77/. The simplest one is a function of the local wind speed and local atmospheric stability. The plume rise is calculated optionally by the formulae of Briggs. Concerning computer requirements an extrapolation for a reference area of 60 km x 60 km x 1 km (according to the information given in /FA77/) yields a minimum computer storage of 1280 kBytes (grid resolution: 1000 m x 1000 m x 100 m). In this case the CPU-time may amount to about 1 hour.

ADPIC

The 3-dimensional particle-in-cell model ADPIC simulates the pollutant transport in a mass-consistent windfield provided by MATHEW and computes the time varying concentration field of radioactive pollutants. ADPIC is a hybrid Lagrangian-Eulerian diffusion model /LA78/. Lagrangian marker particles are transported through the grid by a pseudo velocity, being composed of the advective windfield and the diffusivity velocity. The concentration is associated to each cell of the Eulerian grid by the number of particles. The diffusion velocity is evaluated from the concentration gradients. The particles can be tagged with its age, activity, mass, size and species, in order to simulate the removal processes and radioactive decay. Accuracy and resolution are influenced by the cell size and the number of particles tracked.
As an indication to computer capacity requirements Lange /LA78/ describes a 100 km x 100 km complex terrain study, where ADPIC uses 24 000 cells (40 x 40 x 15) and tracks 30 000 particles simultaneously. In this mode the ADPIC-code runs about 50 times faster than real time on a CDC 7600 computer and takes about 90% of the large-core memory. If twice the grid cell length is regarded as the minimum extension of the plume width in order to apply the finite-difference approximation then the grid resolution has to be refined considerably because ADPIC employes for the subgrid representation a Gaussian diffusion algorithm /LE82/.
An increase of the number of particles by an order of magnitude results in an increase of computer time by one order of magnetitude /LE82/. Because the atmospheric diffusion parameterization in ADPIC is essentially the same as that used in a Gaussian puff model /LA78/, the only real advantage may be seen according to /LE82/ in its ability to simulate the spatial wind shearing on dispersion. But this requires an accurate calculation of the windfield by MATHEW.

Although ADPIC has been used to calculate doses from released radioactive material /KN80/ it has not currently been linked to a probabilistic risk assessment code.

CRACIT

The CRACIT-code (Calculation of Reactor Accident Consequences Including Trajectories)/WO79/is the only grid dispersion model in current consequence codes. The model has been used for the Zion Probabilistic Safety Study /ZI81/, but nevertheless only rare information about the code CRACIT is available. The atmospheric dispersion model in CRACIT consists of a modified potential flow (MPF) and a turbulent diffusion model. The MPF model utilises digitised site terrain data to provide a wind flow field. The model considers the large scale deformation of flow in mountainous terrain like channeling. Local effects like flow separation are not regarded. The potential flow model was enabled to account for viscous effects by varying empirical coefficients with the height above surface. The eddy diffusivities applied in the turbulent diffusion model are parameterised by power law related to atmospheric stability. The numerical procedures for solving the modified potential flow equation emerged from the continuity equation. The solution of the advection/diffusion equation is described in /LA74/.

In order to save computation time the MPF-model is applied in a categorised way to each of 16 wind direction sectors and is used for plumes to be released at 10 m, 100 m, 200 m and 300 m levels, for each of three stability categories and up to a distance of 14.5 km from the source. The precalculated results are stored on files and can be read back for appropriate weather sequences. Beyond 14.5 km and if there occurs a sudden wind direction change of more than 45°, CRACIT uses a segmented Gaussian plume model. According to /WO79/ CRACIT requires about 50% more computer time in this version than the CRAC-model of WASH-1400.

A CRACIT run needs a continuous series of hourly meteorological data measured at a number of towers in the site area.

An hourly dat set includes windspeed, stability, rain, wind direction and lid height. The set is assumed to be representative for the meteorological region passed by the activity plume /ZI81/.

3.2.3 A Statistical (Monte Carlo) Model

TOMCAT

Apsimon /AP84/ reports on a statistical approach to the simulation of pollutant dispersion called TOMCAT (Topography Oriented Monte-Carlo Atmospheric Transport Simulation). Many particles (5000 and more) are released and their atmospheric transport is treated using Monte-Carlo techniques. The trajectory of a particle is determined in TOMCAT by displacements through successive time steps. The displacements are composed of a translation along a streamline (advection with the flow field), a semi-random displacement due to turbulence and a horizontal displacement due to large horizontal eddies in the atmosphere. Large horizontal eddies of a scale comparable with hill dimensions and spacings are regarded to be one of the sources of enhanced turbulence in complex terrain. Because for short releases large horizontal eddies cannot be subsumed under the term fluctuations of statistical occurrence, the effect of this phenomenon is regarded separately. Thus in TOMCAT three independent components contribute to each particle velocity: the advective velocity, the small scale turbulence induced velocity and the perturbation velocity due to horizontal eddies.
The first component is supplied by the advective flow field. As the intensity of turbulence and the Lagrangean time scale determine the second component, semi-empirical approaches are adapted to different stability conditions and to the surface roughness. The 3rd component is provided by the "inpinging eddy model" where the particle motion is affected by assemblies of eddies. The density of subsequent eddies and the size spectrum is chosen so as to conform with the observed level of enhanced turbulence in hilly terrain.

The computer requirements seem to be considerable for this statistical transport model. A CDC 6600 computer takes about 300 sec CPU time to follow 2000 particles across a region of 30 x 24 horizontal grid points. Regarding the number of particles, the grid size and the possible options of the TOMCAT model this computer requirement represents a lower limit.

4. Conclusions

Straight-line Gaussian models, although frequently used in risk assessment, should be applied to complex terrain only with some modifications, which take account of the elevated terrain and the enhanced turbulence in a crude way. Some examples are discribed. Nevertheless Gaussian straight line models in some cases may be inadequate in complex terrain; therefore a trajectory model, which treats the dispersion via a segmented plume or subsequent puffs, is expected to be the next step towards an advanced atmospheric dispersion model for accident consequence assessment in complex terrain. Some of the models presently available take account only of the time variation (not of spatial variation) of the wind direction. The more realistic models depend of the knowledge of the 3-dimensional time varying windfield. The relatively complex Eulerian, Quasi-Lagrangian or Monte-Carlo models in principle are capable to consider some important orographic effects on plume behaviour like channeled and deflected flow, shearing and enhanced diffusion. These models however require meteorological data in sufficient quantity and quality. In addition the need of CPU-time and computer storage requirement restricts their application to special investigations within risk studies. But the use of these more realistic approaches may not be justified for overall consequence analysis because of the incertainties in the meteorological input parameters and because of possible uncertainties of the same order of magnitude in other components of the consequence code. Therefore several arguments still support the application of the Gaussian straight line models with the before mentioned modifications to accident consequence assessment.

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	MUSEMET	Riso	AVACTA
model type: segmented plume puff plume	 x	 x	 x
plume rise	x	x	x
removal processes: dry deposition wet deposition radioactive decay	 x x x	 x x has to be assumed	?
Consideration of complex terrain besides channeled flow	-	-	Horizontal diffusion coefficients consider terrain roughness, wind fluctuations and meander of the wind
Reference	/GE83, VO81, ST81/	/MI83/	/CH78, CH79/

Explanations:

x = yes

- = no

? = cannot be identified

Tab. 3.1 Main features of the Trajectory/Puff Models

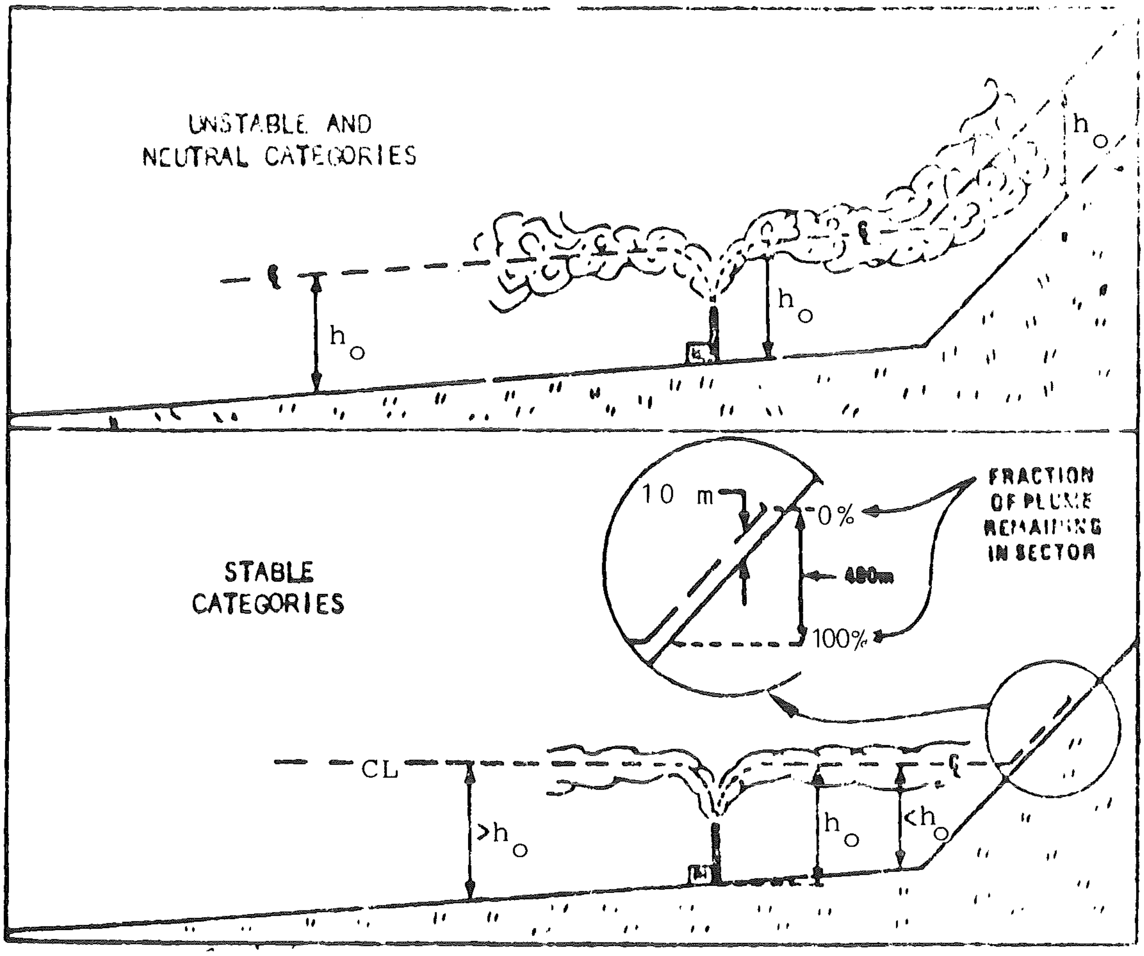


Fig. 3.1: Depiction of plume height in complex terrain, as in the VALLEY model. h_o is the height of the plume at final rise above ground for the unstable and neutral cases and above stack base for the stable cases. Plumes are shown for flows toward and away from elevated terrain /BU77/

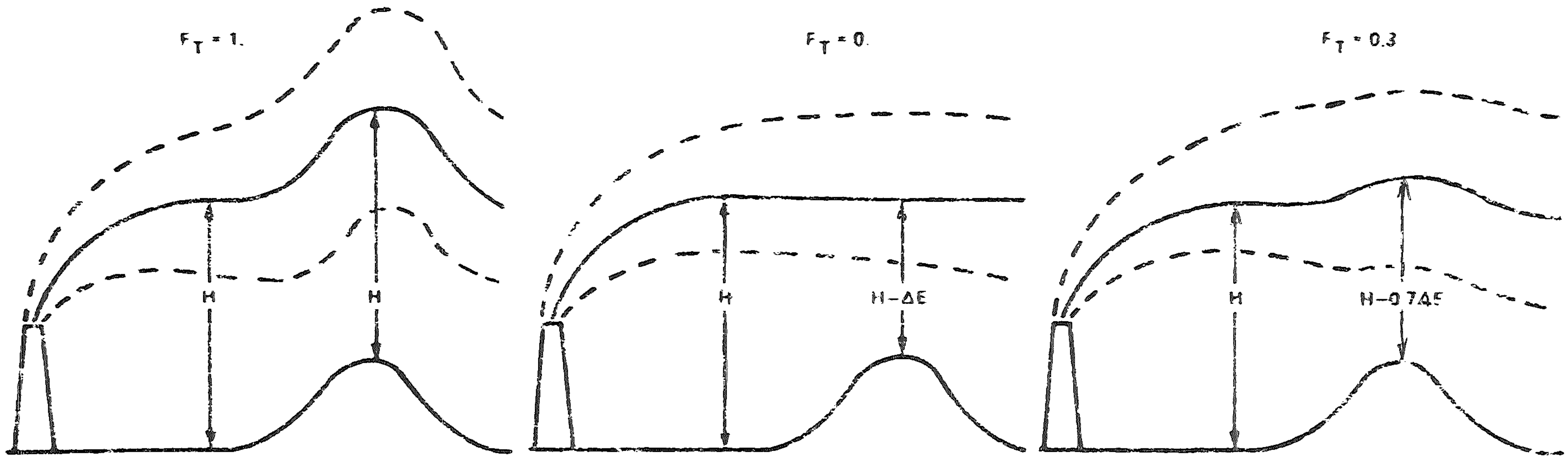


Fig. 3.2: Adjustment of plume height due to terrain/PI80/

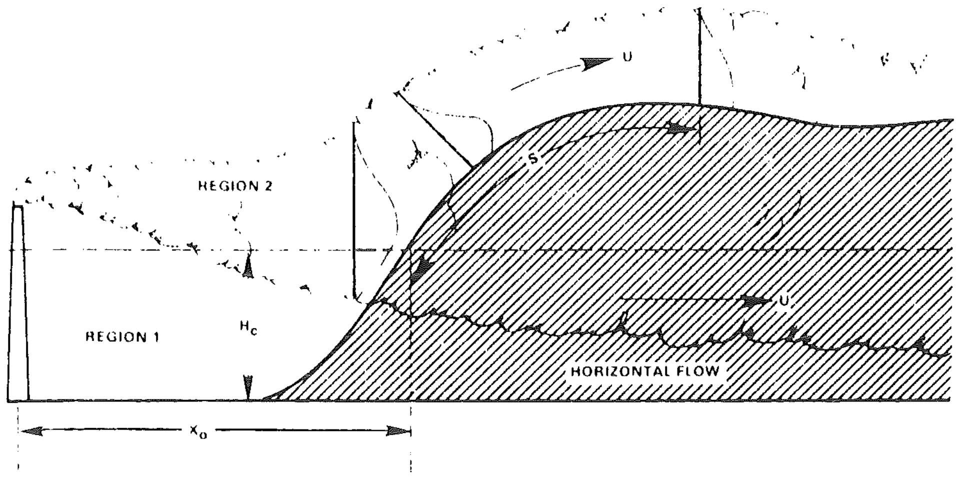
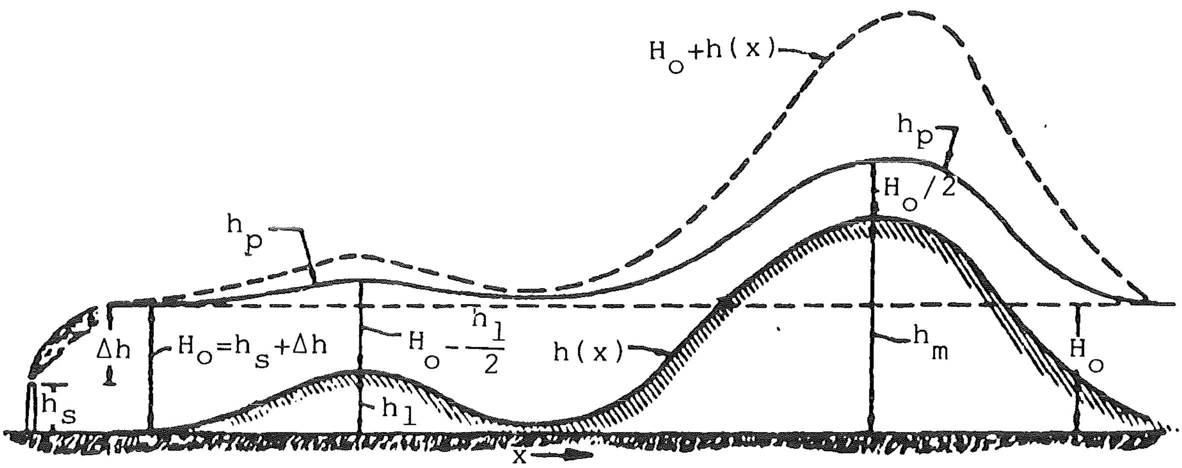


Fig. 3.3: Dispersion and flow regions for stratified flow around hills /EG84/



h_s	physical stack height
Δh	plume rise
H_o	effective stack height (physical stack height plus plume rise)
$h(x)$	terrain height above stack base elevation
h_p	plume centerline height above stack base elevation

Fig. 3.4: Treatment of terrain influence upon plume height used for neutral and unstable conditions /EG75/