VERIFICATION

UDM CHAPTER 7: FINITE-DURATION RELEASES

DATE: December 2023

Reference to part of this report which may lead to misinterpretation is not permissible.

No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
1	1999	PHAST 6.0	Witlox and Holt		
2	Oct 2005	SAFETI 6.5	Witlox and Harper		
3	May 2011	Phast 6.7; UDM v2	Harper		
4	Sep 2017	Phast 8.0; UDM v3	Witlox		
5	May 2021	Apply new template	D. Vatier		

Date: December 2023

Prepared by: Digital Solutions at DNV

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ABSTRACT

The UDM theory and solution algorithm for an finite-duration releases has been investigated in detail. The UDM allows for the quasi-instantaneous (QI) model or the finite-duration correction (FDC) model.

Quasi-instantaneous model
The QI model models the initial phase as a continuous source (neglect of downwind gravity spreading and downwind diffusion). When the cloud width becomes 'large' with respect to the cloud length, the cloud is replaced by an 'equivalent' circular cloud, and the subsequent phase is modelled as an 'instantaneous' circular cloud. The disadvantage of the QI model is the abrupt transition (sometimes resulting in severe discontinuities, e.g. erroneous significant increase in maximum concentration), and the inaccuracy in along-wind diffusion.

The QI model can be applied with or without the 'duration adjustment', where the duration adjustment applies the effect of averaging time because of time-dependency of the concentrations (for averaging times larger than release duration). The current duration adjustment over-estimates this effect downwind of the QI transition.

Finite-duration correction model
The FDC model is based on the HGSYSTEM formulation derived from that adopted in the SLAB dispersion model. It has a better scientific basis and is derived from an analytical solution of the Gaussian plume passive-dispersion equations. It takes the effects of downwind diffusion gradually into account including effects of both turbulent spread and vertical wind shear. A limitation of this model is however that it is strictly speaking only applicable to ground-level non-pressurised releases without significant rainout. Moreover it produces predictions of the maximum (centre-line ground-level) concentrations only. The finite-duration correction includes the effect of averaging time because of time-dependency of the concentrations.

The FDC module has been verified against the HGSYSTEM/SLAB steady-state results, and shown to lead to finite-duration results virtually identical to the latter programs.

First the UDM, HGSYSTEM and SLAB dispersion models have been compared for predictions in the far field for a steady-state release both without and with time averaging. For the chosen test case the UDM predictions have been shown to be below those predicted by HGSYSTEM and SLAB.

Secondly the models have been compared for predictions in the far field for a constant finite-duration release. The FDC finite-duration correction applied to the UDM steady-state results is shown to produce lower concentrations than the original UDM quasi-instantaneous approach. Moreover it also produces lower concentrations than the finite-duration concentrations obtained by HGSYSTEM and SLAB.

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7 FINITE-DURATION RELEASES

7.1 Introduction

This chapter documents the verification of the Unified Dispersion Model (UDM) for the case of a finite-duration release. The FDC finite-duration correction is applied to the UDM steady-state results and the results are compared with the original quasi-instantaneous finite-duration UDM results, for both cases of no time averaging and time averaging of 30 minutes. In addition the UDM results are compared with the SLAB and HGSYSTEM steady-state and finite-duration results. For additional verification of the FDC model refer to Section 8 of the UDM verification manual dealing with time-varying releases. Please note that instead of the FDC method now the new along-wind-diffusion method (AWD) is recommended.

The problem is considered of a ground-level release of chlorine vapour from a pool. The pollutant temperature is chosen equal to the ambient temperature and the ground temperature. Note that the problem is chosen such that 2-phase, non-isothermal, and jet effects do not occur.

The ambient data are given by stability class F, a wind speed of 1.5 m/s at 10-meter height, and an ambient temperature of 20^0C. The cloud disperses over terrain with a surface roughness of 0.1 m and a ground temperature of 20^0C.

The chlorine is released from a pool at ground level with a release rate of 10 kg/s and a temperature of 20^oC. For the HGSYSTEM/SLAB models a square pool is modelled of area of 0.04 m^2. Since the UDM does not allow for an initial pool, the pool is modelled by UDM as a low-speed jet release.

Four different cases are considered: no time averaging or time-averaging of 30 minutes, steady-state release or 10 minutes duration. In all simulations the core averaging time is chosen equal to the actual averaging time, thus assuming that the instantaneous cloud is circular.

7.2 UDM results using FDC module

The finite-duration correction program FDC has first been applied to the steady-state HGSYSTEM results. The FDC results were found to be identical to the HGSYSTEM finite-duration results, as should be the case[1]. Secondly FDC was applied to the steady-state SLAB results. The FDC results are found to be virtually identical to the finite-duration results obtained by SLAB

Figure 7.1 includes UDM results for each of the above 4 cases applying the finite-duration correction:

- The transition to passive dispersion is phased in for 642 m < x < 1284 m. Time-averaging for both the steady-state and finite-duration results includes the effects of wind meandering of the cloud by a factor of $(t_{av}/600)^{0.2}$ in the passive cross-wind dispersion coefficient. This effectively increases the plume width and reduces the peak concentrations (wider, more dilute cloud).
- In case of 10 minutes duration, the finite-duration correction multiplies the concentration with the factors F and D; see the UDM theory manual. Here F (0<F<1) represents the effect of the finite duration irrespective of averaging time, and D the additional finite-duration effect because of averaging time:
    * In the near-field $x \approx 0$, and it can be shown that $D \approx t_{dur}/t_{av}$ if $t_{dur} << t_{av}$. As a result the steady-state averaged pollutant mole fraction is multiplied with a extra factor $D = t_{dur}/t_{av}$ in the near-field. For the case of 10 minutes duration and 30 minutes time averaging, this leads to a multiplication factor of 1/3 (33% mol concentration).
    * At a downwind distance in the far-field the cloud is longer (because of larger downwind diffusion coefficient σ_x) and hence the observed cloud duration is longer. As a result the difference between the non-averaged and averaged finite-duration concentrations reduces ($D \rightarrow 1$), and the difference is mainly caused by wind meander (rather than by time-varying concentrations)

[1] The along-wind diffusion coefficient $\sigma_x = (\sigma_{xs}+\sigma_{xt})^{1/2}$ was adopted, with σ_{xs} along-wind diffusion because of wind shear and σ_{xt} the along-wind diffusion because of turbulent spread. In HGSYSTEM $\sigma_{xt} = \sigma_{yt}$ is adopted with σ_{yt} the averaged cross-wind diffusion coefficient. Using this choice in FDC lead to identical comparison. In the final version in FDC the unaveraged value is adopted, since time meander is believed not to affect σ_{xt}.

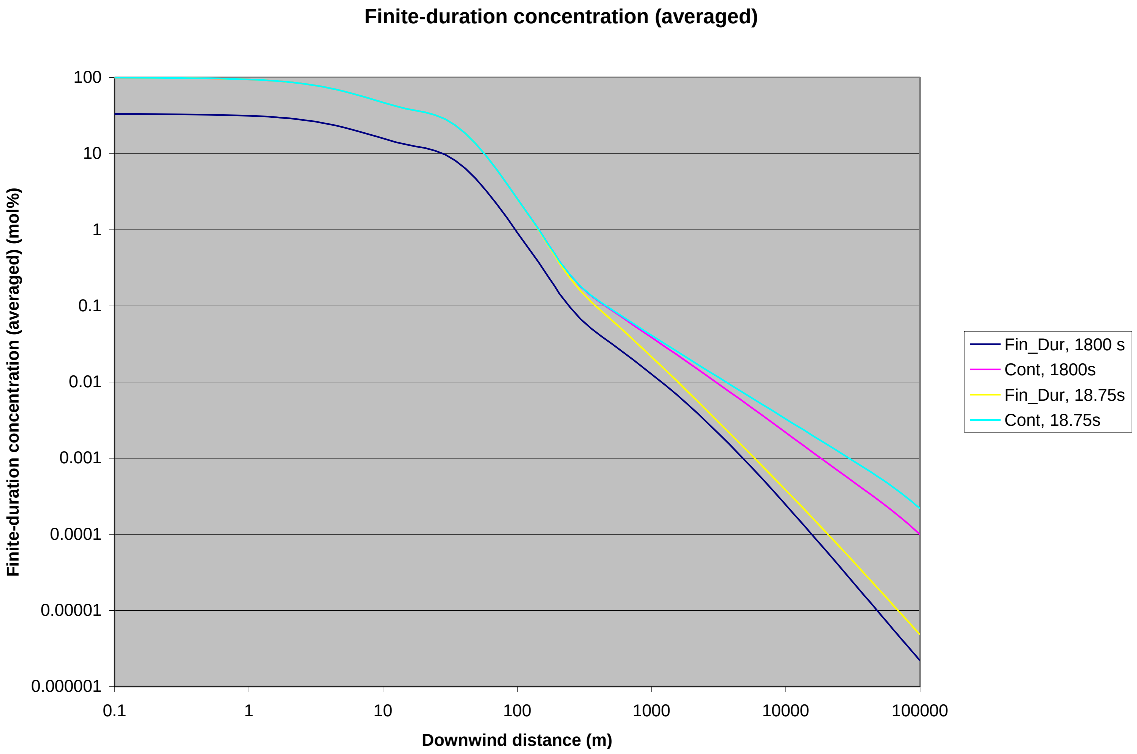

Figure 7.1. **UDM predictions for steady-state release and 10 minutes finite-duration release (simulations using finite-duration correction module); no time-averaging or 30 minutes averaging time**

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7.3 UDM results using quasi-instantaneous transition

In case of the quasi-instantaneous finite-duration model, the quasi-instantaneous transition was investigated in detail for the case of no time averaging (t_{av} = 18.75 seconds). The following data represents the conditions of the cloud at the transition point:

x_{dw} = the downwind distance to the front edge of the cloud = 342 m
x_{uw} = the downwind distance to the trailing edge of the cloud = 22 m
L_{cld} = cloud length = $x_{dw} - x_{uw}$ = 320 m
W_{eff} = effective cloud half width = = 358 m.

The transition occurred since $2W_{eff}/L_{cld}$ exceeded the quasi-instantaneous transition parameter r_{quasi} = 0.8[2].

The following data presents the cloud variable representing the instantaneous cloud "matched" to those of the truncated continuous plume:

Variable	*truncated continuous plume*	*equivalent instantaneous cloud*
m_{cld} = cloud mass	10 kg/s	6000 kg
m_{wa} = mass of moist air	3475 kg/s	590394 kg
m_{wv}^{gnd} = mass of substrate water	0	0 kg
I_{x2} = excess horizontal momentum	3.9E-08 kg m/s^2	2.21 kg m / s
I_z = vertical momentum	0 kg m/ s^2	0 kg m/s
H_{cld} = cloud enthalpy	-1.911E+07 J/s	-3.28E+09 J
x_{cld} = downwind distance	342 m	269 m
z_{cld} = centre-line height	0 m	0 m
A_{cld} = cloud "area"	7,930003 m^2	165023 m^2
q_{gnd} = 'heat transfer from substrate'[3]	0 J	-9.00E+06 J

The cloud depth was found by dividing the instantaneous cloud volume V_{cld} (calculated from the thermodynamics module) by the instantaneous cloud area A_{cld}:

$$H_{eff} = 494171 / 165023 = 3 \text{ m},$$

and from this, the cloud width

$$W_{eff} = [494171 / (\pi * 3 * (1+h_d))]^{1/2} = 229 \text{ m}$$

Downwind of the quasi-instantaneous transition, the downwind dispersion coefficient is set equal to the cross-wind dispersion coefficient and the UDM instantaneous model is used to evaluate the concentrations.

Figure 7.2 and Figure 7.3 include UDM predictions fur non-averaged and 30-minutes averaged concentrations. Results are included for the following runs:

- steady-state simulation
- 10 minute duration simulation using FDC module
- 10 minute duration simulation using QI transition without duration adjustment
- 10 minute duration simulation using QI transition with duration adjustment. In case of 10 minutes duration and 30 minutes time averaging, the finite-duration results produced by UDM correspond to the duration-corrected results of the quasi-instantaneous model. This implies a multiplication of the centre-line ground-level concentrations with a factor of t_{dur}/t_{av}, in case of $t_{av} > t_{dur}$ (= 1/3 for the present case).

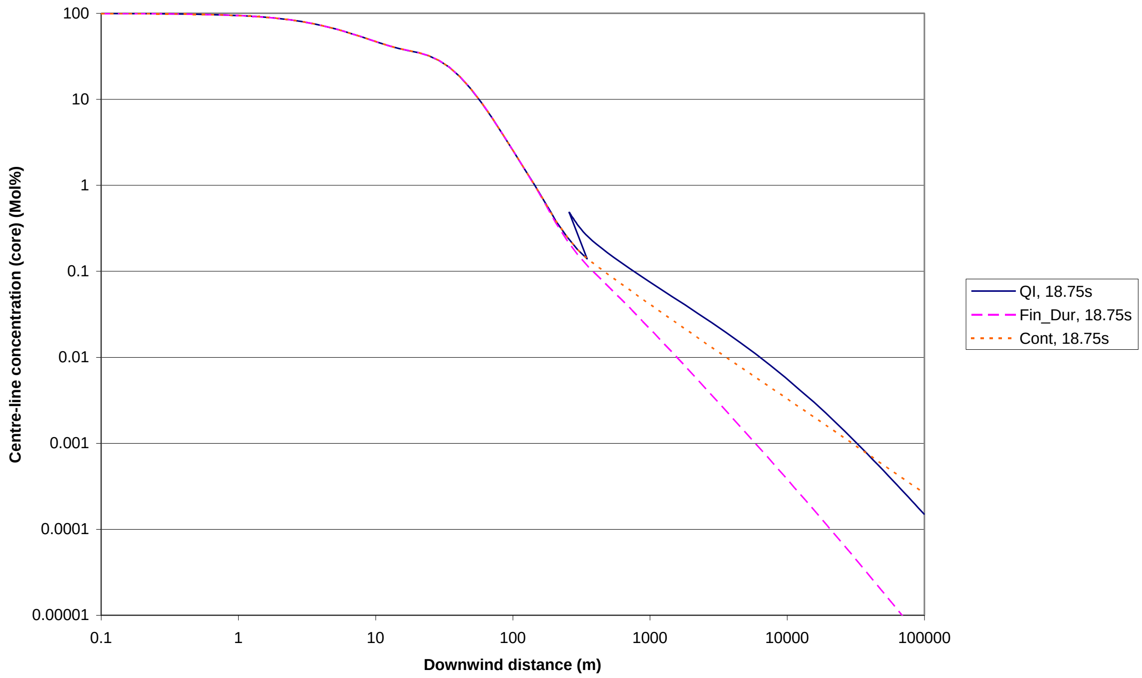
The figures include results for the maximum centre-line concentration, the cloud half-width R_y and the cloud height R_z. It is observed that the quasi instantaneous transition is not very smooth. It leads to large discontinuities in the cloud concentration and a large period over which the concentrations for the QI cloud are larger than those for the continuous cloud. This is clearly not satisfactory

The transition is made much earlier than in previous versions. This is related to modifications in the heavy gas dispersion model which lead to much wider clouds. Note that the transition to passive for the QI simulations is earlier than the steady-state simulations resulting in a longer distance for which the concentrations are higher. Also note that for F1.5, σ_{xs} is usually significantly larger than $\sigma_{xt}=\sigma_{yt}$. As a result the QI simulations (adopting $\sigma_x = \sigma_{yt}$) assume a too short cloud (see

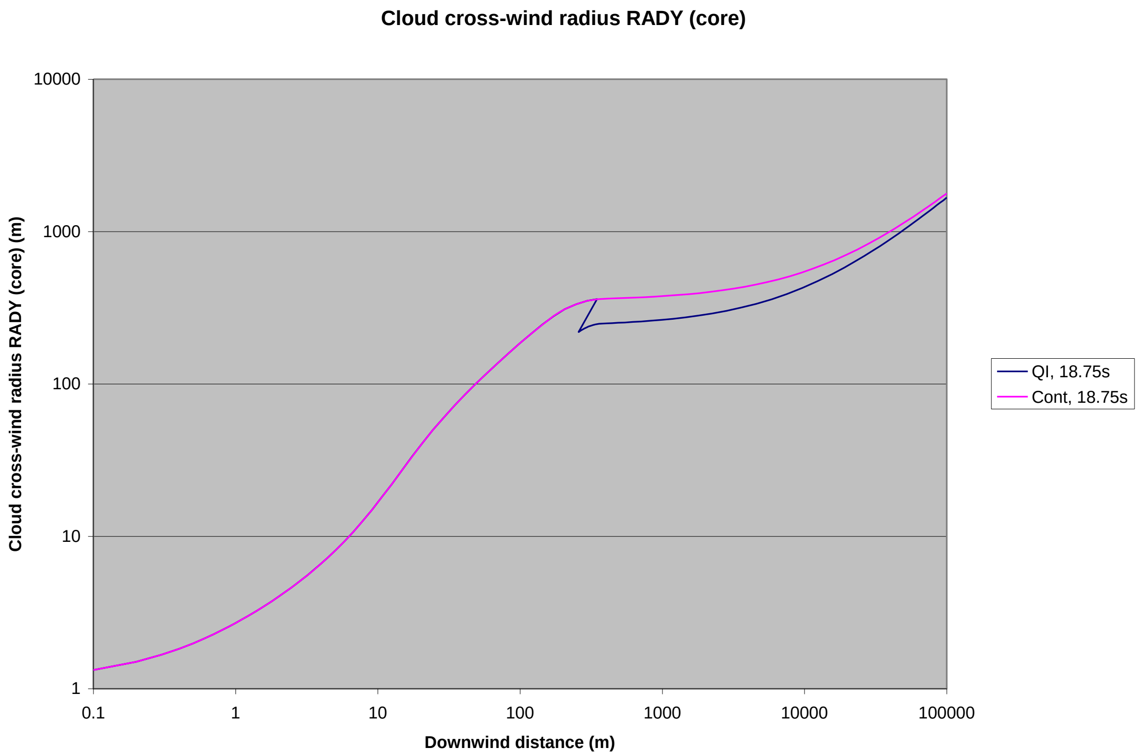
[2] Note that this criterion was satisfied immediately after the end of the 10-minute release as a result of large heavy-gas spreading, limited entrainment and slow windspeed!

[3] Rounding error 'q_{gnd}' is indeed small compared to total cloud enthalpy, as expected.

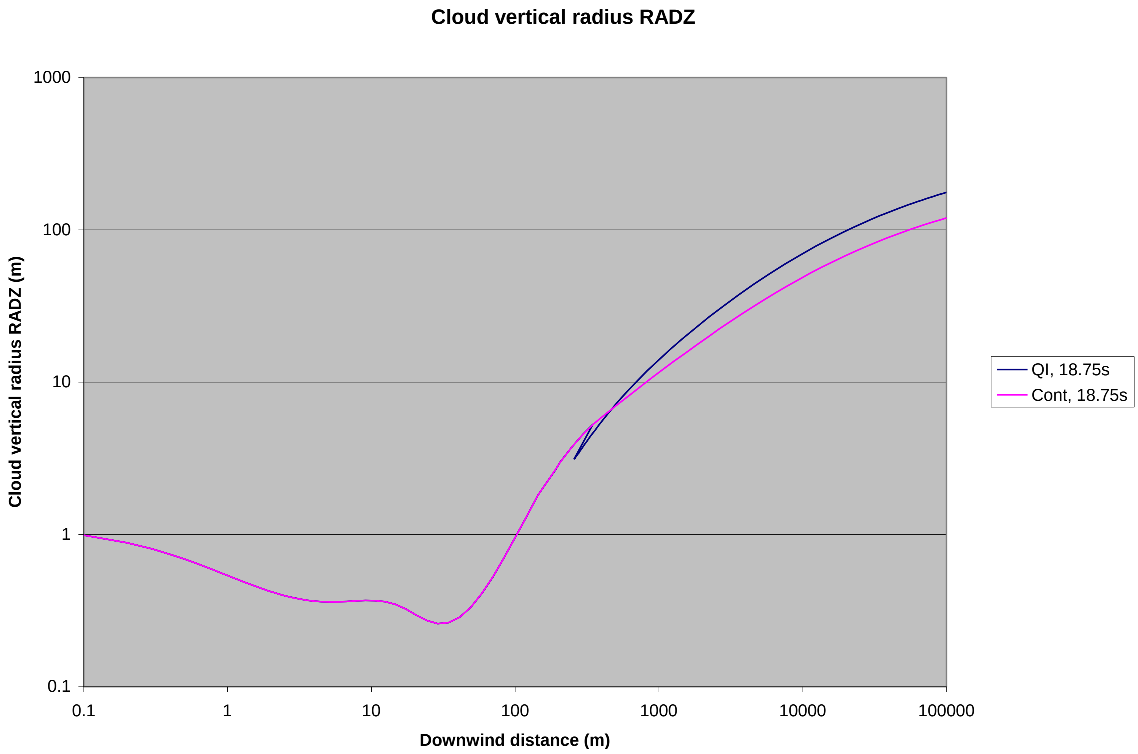
also Figure 7.4) and therefore too high concentrations. Also note that the QI predictions can be changed by modifying the transition criteria (e.g. transition at lower rate of cloud width to cloud length).



(a) maximum centre-line concentration (mol %)

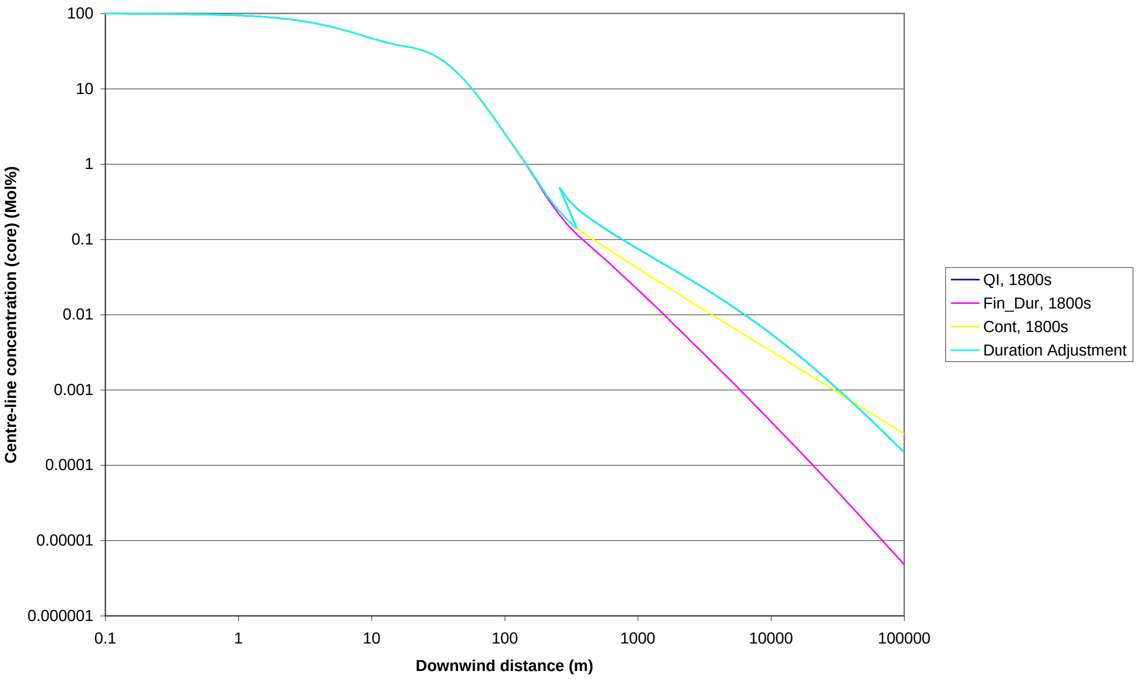


(b) cloud half-width R_y

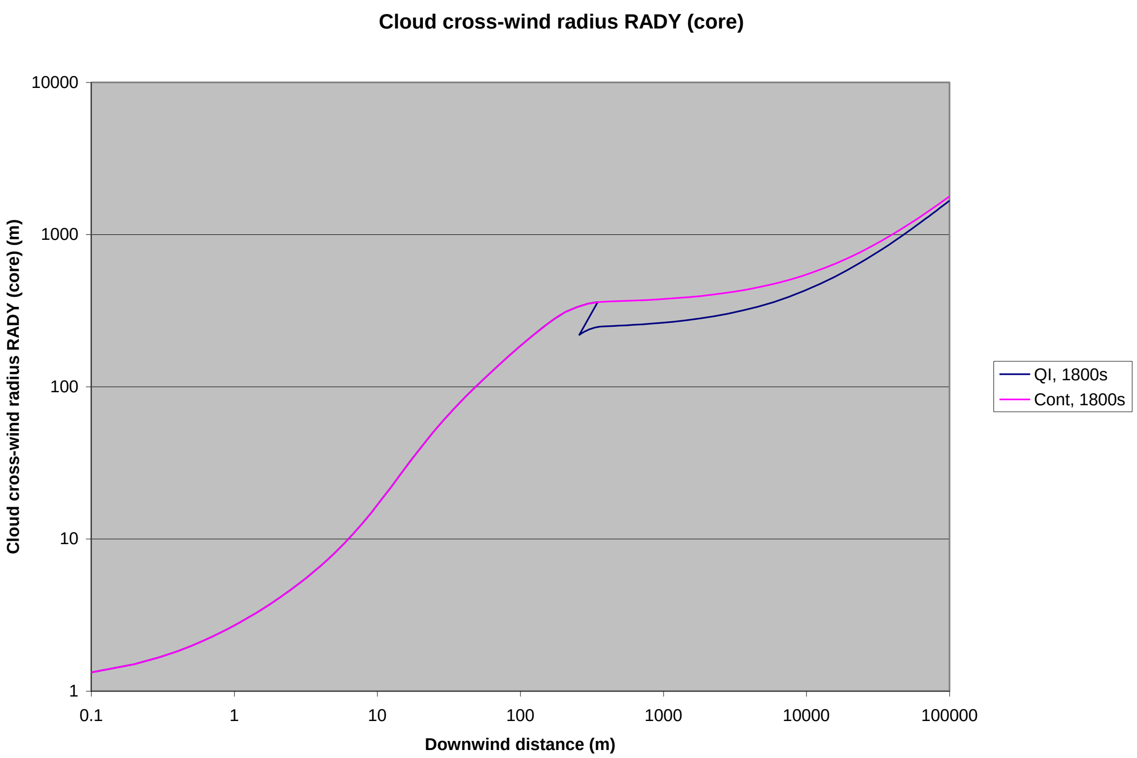


(c) cloud height R_z

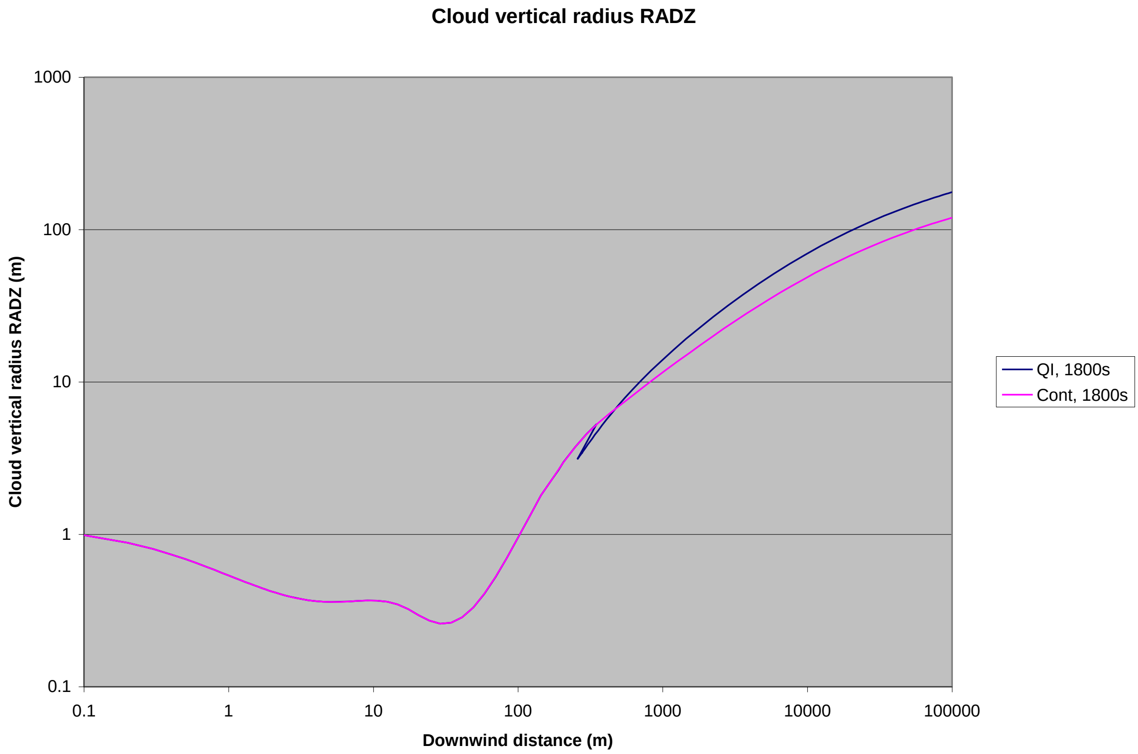
Figure 7.2. UDM predictions for steady-state release and 10 minutes finite-duration release (simulations using FDC module or quasi-instantaneous transition); no time-averaging



(a) maximum centre-line concentration (mol %)



(b) cloud half-width R_y



(c) cloud height R_z

Figure 7.3. **UDM predictions for steady-state release and 10 minutes finite-duration release (simulations using FDC module or quasi-instantaneous transition with/without duration adjustment); 30 minutes averaging time**

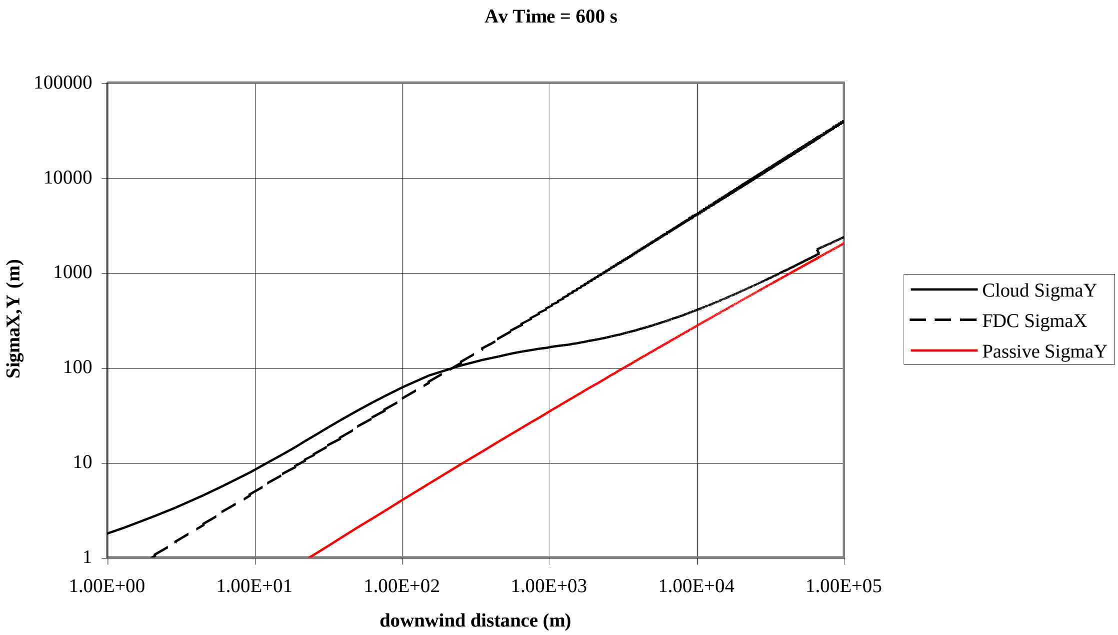


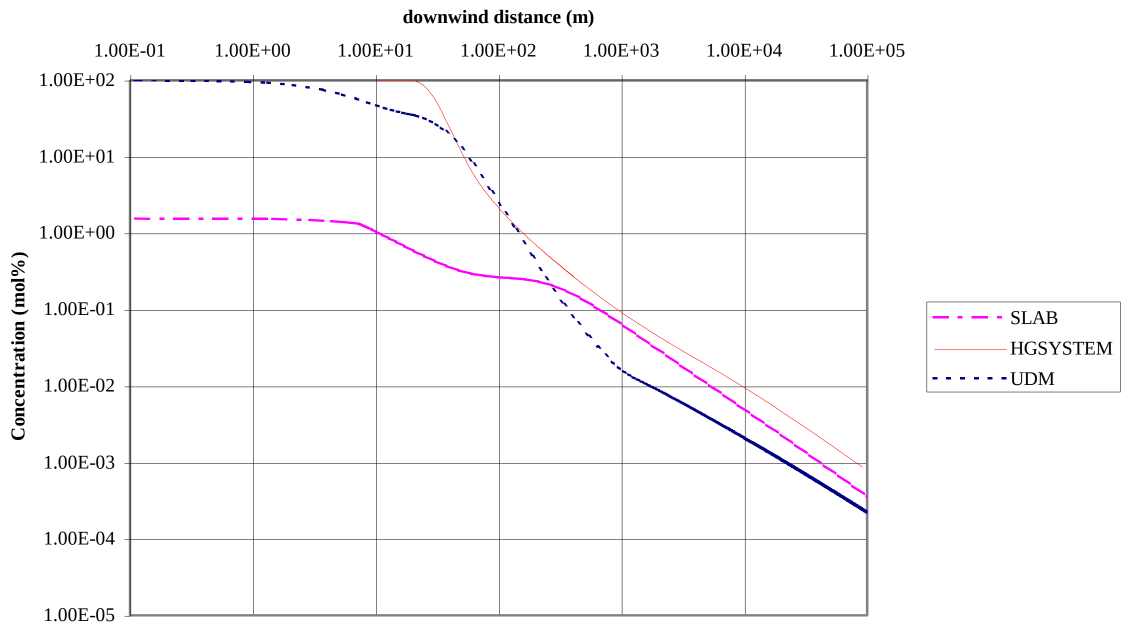
Figure 7.4. **Comparison of FDC value of along-wind diffusion coefficient σ_x, and the QI value of along wind-diffusion coefficient which is taken to be equal to the cloud cross-wind dispersion coefficient σ_y. As a result the FDC predictions result in lower predictions of the concentrations in the far field. Also note that σ_y approaches the passive cross-wind dispersion coefficient σ_{ya} in the far-field.**

7.4 Comparison between UDM, HGSYSTEM and SLAB models

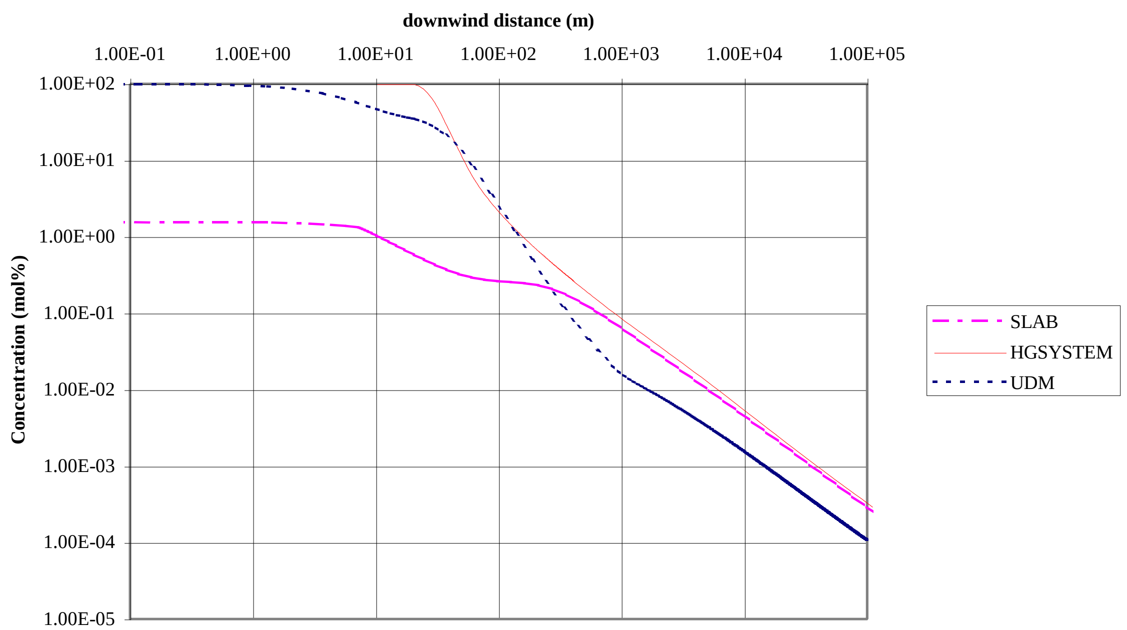
Figure 7.5 compares the steady-state concentrations calculated by UDM, SLAB and HGSYSTEM:

1. The differences in the near-field between UDM/SLAB/HGSYSTEM result from different source assumptions (UDM – jet release, HGSYSTEM – gas blanket, SLAB ??)
2. It can be seen that the steady-state passive-dispersion concentrations by the current UDM model in the far field are below those predicted by HGSYSTEM and SLAB. The precise results in the far-field are determined by the assumptions in the far-field:
   - HGSYSTEM prescribes the passive vertical entrainment and calculates σ_z.
   - UDM prescribes the passive formula for the vertical dispersion coefficient σ_z (prescription of the entrainment in heavy-gas phase prior to passive-dispersion transition only). It should be noted that the UDM results, in the far field, are totally determined by the adopted formulas for σ_x, σ_y, σ_z [and could be compared to the corresponding analytical Gaussian plume equation!].
   - Precise formulas adopted by SLAB have not been checked.

Figure 7.6 compares the predictions in the far field for a constant finite-duration release. Note that the effect of the FDC correction is comparable for HGSYSTEM and FDC.

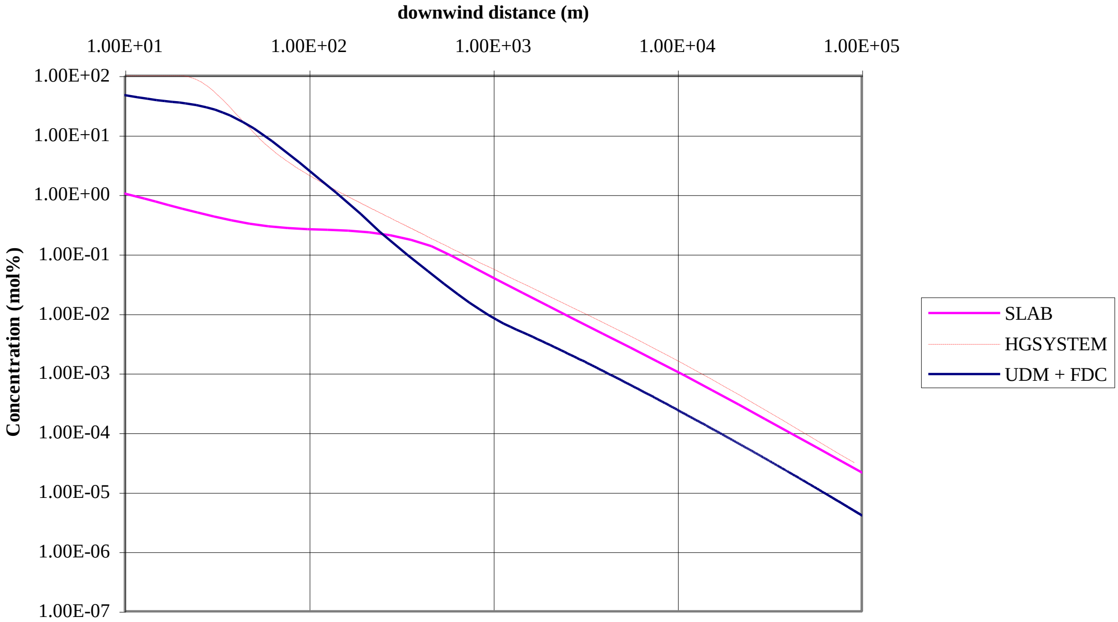


(a) no time averaging (t_{av} = 18.75 s)

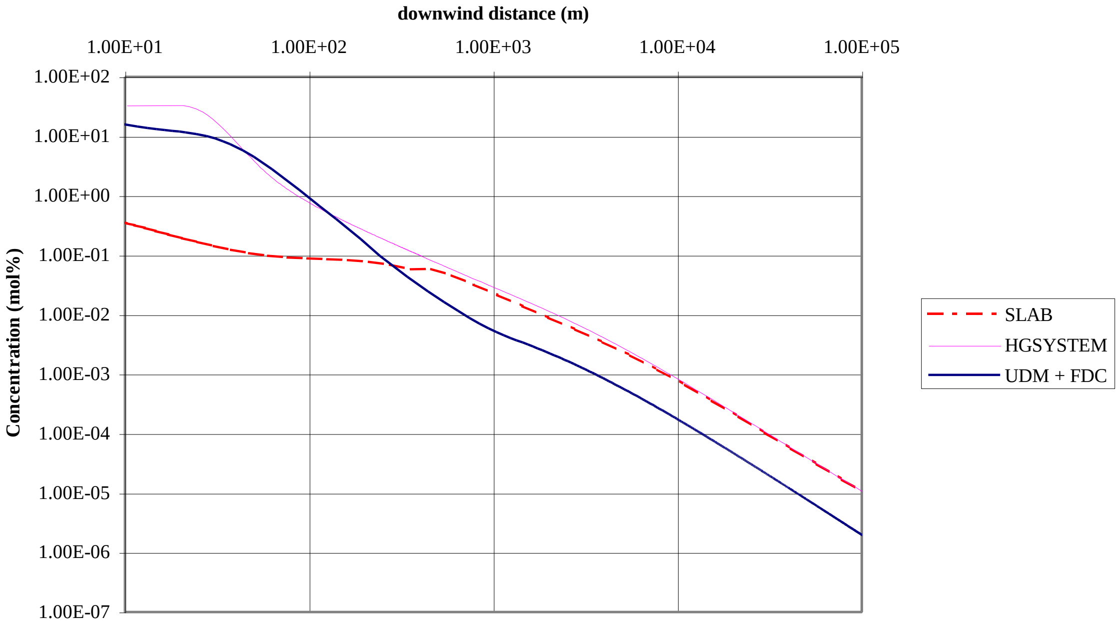


(b) averaging time t_{av} = 1800 s

Figure 7.5. Steady-state predictions by UDM, SLAB and HGSYSTEM



(a) no time averaging (t_{av} = 18.75 s)



(b) averaging time t_{av} = 1800 s

Figure 7.6. FDC (10 minutes duration) predictions by UDM, SLAB and HGSYSTEM

SPREADSHEETS

Figure 7.1	FDC_18.75_3600_Av_Time.xls
Figure 7.2	FDC_QI_18.75_Av_Time
Figure 7.3	FDC_QI_1800_Av_Time.xls
Figure 7.4	(Findur_sigmax)
Figure 7.5	(Findur_comp)
Figure 7.6	(Findur_comp)ous

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