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LOCAL-SCALE DISPERSION MODELLING FOR EMERGENCY RESPONSE IN THE CZECH REPUBLIC

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Abstract: Dispersion modelling can be used to provide timely information to emergency response providers in the event of an accidental release of hazardous gas. The model used is required to run quickly, have minimal data requirements and, provide reliable results given appropriate input data. The ALOHA software package has been designed for such circumstances however it is not appropriate for complex topography. The emergence of 'shallow layer' models and increases to personal computer processing speeds in the last decade have allowed accidental release simulations involving complex terrain to be completed with increasing speed. This paper presents the results of two dispersion models that could be used to predict heavy gas dispersion in the event of an accidental release; ALOHA, categorised as a similarity profile model and selected for its widespread use and regular maintenance and update cycles, and TWODEE-2, categorised as a shallow layer model and selected for its ability to accommodate complex terrain effects. The models were run a number of times under increasingly sloping terrain to judge how varying terrain slopes might contribute to misleading results should terrain be ignored. Results for flat topography from the two models were found to be different, but reasonably comparable within 1km. It was found that topography is important and does affect dispersion and furthermore, relatively minor slopes were found to influence dispersion from the flat topography scenarios. For the studied scenarios model run times of TWODEE-2, when compared to ALOHA, were longer but not unlikely to be excessive for emergency response situations.

Key words: *Accidental release, dispersion, dense gas, ALOHA, TWODEE-2*

INTRODUCTION

Predictions of concentrations and movement of hazardous gas after a chemical accident are valuable to emergency response teams. Released gases may form a buoyant plume, a neutrally buoyant plume, or denser-than-air cloud. Releases of pressurised gasses can cause a denser-than-air cloud to form due to its cold temperature (following expansion to ambient pressure) and, or, high molecular weight. Dense gas dispersion is the focus of this paper as pressurised gas accidents, which can cause large releases of gas, often disperse as a dense gas. Koopman and Ermak (2007) summarised the phenomenon of a dispersing dense gas cloud and in particular identified aspects of the cloud that differs from a neutrally buoyant or buoyant cloud. These aspects include a reduction in vertical turbulent mixing inside the gas cloud due to stable density stratification, horizontal gravity-spreading flow due to density gradients in the horizontal direction, and gas pooling and flowing downhill due to density gradients. These aspects prevent most models designed for neutrally-buoyant gas dispersion being appropriate for dense gas dispersion.

Dense gas dispersion models have been developed since the 1980's and are often categorised into three groups; Navier-Stokes models, similarity-profile models and modified Gaussian models. It has been noted (Koopman and Ermak, 2007) that the Navier-Stokes models, which allow the most complete representation of physical processes, also require extensive computer time, thus being impractical for emergency response situations. Similarity profile models, for example DEGADIS (Spicer and Havens 1989), and the less complex modified Gaussian models were noted to be computationally inexpensive but ignore the effects of topography. Avoiding the Navier-Stokes type of model because of computational time, two alternative approaches to include topography are; the use of a Lagrangian particle in-cell advection-diffusion model and the use of a two-dimensional shallow layer model such as TWODEE (Hankin and Britter, 1999a) or DISPLAY-2 (Venetsanos *et al.*, 2003) which extends the idea of one a dimensional similarity profile into two dimensions. While dense gas versions of Lagrangian particle models have been developed they are often applied to regional dispersion studies or tools (including those used for nuclear emergencies). For local scale dense gas dispersion requirements the two-dimensional shallow layer approach is established (Hankin and Britter, 1999c).

In the Czech Republic locations of non-flat terrain are common and could therefore be an important element in an emergency gas release situation. Dispersion modellers or emergency services operating in areas of non-flat terrain may find it desirable to use a model that therefore accounts for terrain effects. Consequently this study used, and presents results of, two models; a one-dimensional similarity profile model and a two-dimensional shallow layer model in order to account for terrain effects.

AN ESTABLISHED DISPERSION MODEL FOR EMERGENCY RESPONSE PROVIDERS

ALOHA (Areal Locations Of Hazardous Atmospheres) has been developed jointly by the National Oceanic and Atmospheric Administration (NOAA) and the United States Environmental Protection Agency (EPA). The model, based on DEGADIS, can be used in accidental release situations to make useful predictions however it does not simulate topography effects which can affect winds and gas movement. It and its associated software package were established to provide emergency responders with information on the atmospheric dispersion of hazardous substances (EPA, 1999).

Some of the key aspects and capabilities of this dispersion model and its associated software package (CAMEO), which make it attractive for use in emergency response situations, are that it; calculates emissions for the user, has a short execution time, allows access to an extensive chemical database for model parameters and chemical information, has a graphical user interface (GUI), assists the user in plotting hazard areas and threat levels at specific locations, and links with a graphical information system (GIS). Using a different dispersion model, aspects other than runtime may be able to be implemented to an equivalent degree and therefore model run time presents itself as the potentially limiting factor when considering alternatives to ALOHA.

A POSSIBLE ALTERNATIVE DISPERSION MODEL FOR EMERGENCY RESPONSE PROVIDERS

The two-dimensional shallow layer approach to modelling dense gas dispersion has been described and demonstrated to be a useful model for predicting the dispersion of dense gasses (Hankin and Britter, 1999a, 1999b, 1999c), including for risk assessment in complex terrain (Hankin 2003b, 2003c). This study used the TWODEE-2 version of Fortran code, described by Folch *et al.* (2009) and used by Costa *et al.* (2008) for CO_2 releases from land. Of particular note, this version of the code includes a diagnostic wind model for a gridded, temporally and spatially varying, wind field. The dispersion model reads topography and surface roughness information, in addition to winds and emissions, to describe the gas cloud in terms of cloud height[1], u and v velocity, and depth-averaged cloud density. The code was not modified other than to allow time-varying emissions to be used.

CASE STUDY

Emissions

To investigate the effects of typical Czech terrain on dense gas cloud dispersion a case study based on a release of chlorine was prepared. The mass emission rate calculated by ALOHA (Table) was used in both the ALOHA dispersion calculation and in the TWODEE-2 dispersion calculation. The mass rate was calculated from an initial mass of 1000kg chlorine contained in a ground-level tank of volume $0.92m^3$ and released through a hole of 2cm diameter. The initial tank temperature was 15°C. The model estimated the release would initially be a two-phase flow and it was found that a high mass rate was calculated to occur initially, relative to rates after the first minute.

Table 1. Mass Emission Rate of Chlorine

Time since release start (seconds)	Mass Rate (kg.s-1)
0	6.27
63	0.32
135	0.20
250	0.13
390	0.05
790 - 3600	0

As ALOHA simulations are limited to one hour, this duration was set for both models.

Meteorology and Surface Roughness

Meteorological conditions were set as follows: wind, $1m.s^{-1}$ at 10m above ground; ambient temperature, 15^oC; air pressure, 1013.25hPa; atmospheric stability, neutral. The surface roughness was set to be 0.4m across the modelled domain.

Topography

An actual location in the Czech Republic with non-flat topography was selected for the study. A square area of 6km by 6km with a horizontal resolution of 50m (in east and north directions) was used and topography data from SRTM was processed for this grid. Nine separate adjustments were made to the original terrain elevations (including zero adjustment) to produce nine topography datasets. A summary of the topography adjustments and effect on slopes is provided in

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[1] Cloud height is the height below which 96% of the buoyancy is located (Hankin, 2003a).

Table .

An adjustment was performed by making an increase or decrease to each elevation on the grid. The elevation change (increase, or decrease) in meters (C) was calculated using Equation 1; where $e_{(i,j)}$ was the elevation in meters at the particular grid point referenced by the indices i and j, where p was the percentage change. The reference elevation (e_r) in meters was selected in this study to be the elevation at the source location. In this way, the topography was adjusted relative to the source location. With a positive value of p, points higher than e_r were increased further in elevation. With a negative value of p, points higher than e_r were lowered.

$$C = (e_{(i,j)} - e_r)\left(\frac{p}{100}\right) \tag{1}$$

While the unadjusted topography can be visually inspected in Figure 12, the adjusted topographies are shown using transects in Figure , and Figure . The source location (also the terrain reference elevation, e_r) is located at 4240m. It is apparent that the percentage adjustment effect had (as expected) little effect at elevations close to the reference elevation level. As such, terrain along the two transects is reasonably flat for all adjustment categories near to the source (relative to the extremes away from the source). Stronger elevation changes occurred away from the source at locations where the initial terrain elevation was further from the reference elevation level. It should be noted that these transects do not represent the other areas in the model domain.

In Figure , and Figure the effect of -150% and -200% adjustment can also be seen and summarised as a reversal of the original topography to the extent that hills were turned into valleys. Results of dispersion modelling using these topographies are not included in this paper.

Table 2. Terrain Adjustments

Adjustment Category	**Source Elevation (m)**	**Maximum Elevation (m)**	**Minimum Elevation (m)**	**Average Elevation (m)**	**Qualitative Effect Of Adjustment**
-100% Adjusted	174	174	174	174	Flat topography
-50% Adjusted	174	225	169	186	Increasingly flattened topography
-25% Adjusted	174	251	167	193	Slightly flattened topography
0% Adjusted	174	276	164	199	No change (unadjusted topography)
25% Adjusted	174	302	162	205	Slight increase to slopes
50% Adjusted	174	327	159	211	Further increase to slopes
100% Adjusted	174	378	154	223	Increased slopes
150% Adjusted	174	429	149	236	Increased slopes
200% Adjusted	174	480	144	248	Increased slopes

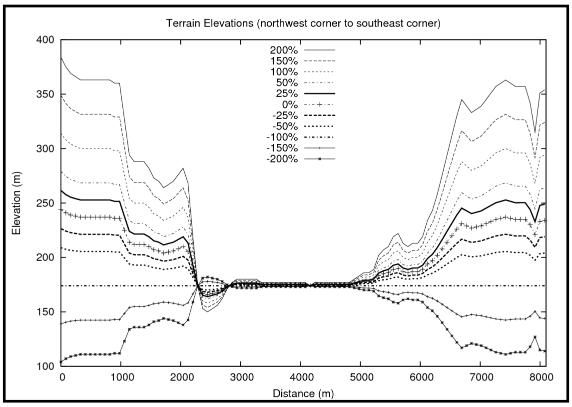

Figure 1 Terrain elevation transects (cross sections) from northwest corner to southeast corner Different topography sets are identified by percentage adjustment.

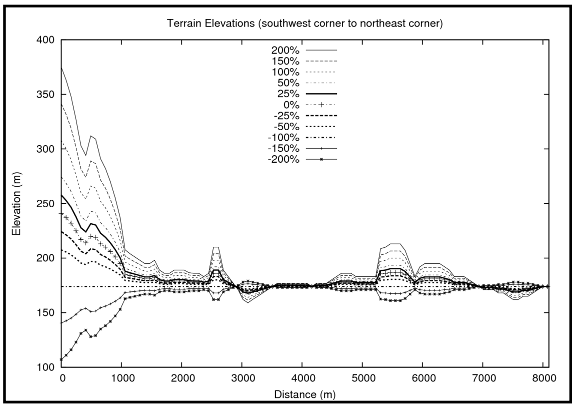

Figure 2 Terrain elevation transects (cross sections) from southwest corner to northeast corner (, right). Cross sections for different topography sets are identified by percentage adjustment..

Selection of indicators

Two indicators were selected to determine the effect of topography changes on dispersion. They were; cloud arrival time – as the cloud's movement could either be sped-up, slowed-down or undergo a direction change due to topography, the cloud arrival time was investigated, and, cloud footprint – the cloud's movement could undergo a directional change meaning that the impact zone in complex terrain could be different than in flat terrain.

RESULTS

Cloud Arrival Time

Table presents the time in minutes since the start of the release when the gas cloud first arrives at a receptor location. The receptor locations (height 1m) were located downwind from the source at distances of 100m, 500m, 1000m, and 2000m. Regarding flat terrain, ALOHA and TWODEE-2 predicted similar cloud arrival times up to 1km down wind. At 2km downwind TWODEE-2's cloud took 20 minutes longer to arrive. Changes to topography did influence the cloud arrival times, both by prolonging and hastening the cloud's arrival (depending on the topography). With wind directions 225° and 315° the cloud did not reach the 2km downwind receptor, and it was noted that this occurred in all topography adjustment scenarios except -100% – flat topography.

Table 3. Cloud arrival time in minutes since release start

Downwind distance	**Topography adjustment category**							
	200%	**150%**	**100%**	**50%**	**25%**	**0%**	**-25%**	**-50%**	**-100% (flat)**
Wind 45° 100	3	3	3	3	3	3	3	3	3 (ALOHA 3)
500	19	17	20	15	19	14	17	15	7 (ALOHA 13)
1000	19	19	21	20	22	21	24	24	21 (ALOHA 21)
2000	58	44	40	48	53	49	52	59	56 (ALOHA 36)
Wind 135° 100	3	3	3	3	3	3	3	3	3
500	11	8	10	11	11	9	6	9	7
1000	22	20	20	23	22	23	16	24	21
2000	48	48	48	43	50	44	40	49	56

Table 3. Cloud arrival time in minutes since release start

Downwind distance	**Topography adjustment category**								
	200%	**150%**	**100%**	**50%**	**25%**	**0%**	**-25%**	**-50%**	**-100% (flat)**
Wind 225° 100	4	3	3	3	3	3	3	3	3
500	17	15	12	24	18	11	15	7	7
1000	41	39	31	38	38	31	30	26	21
2000	-	-	-	-	-	-	-	-	56
Wind 315° 100	3	3	3	3	3	3	3	3	3
500	17	8	9	8	7	7	8	7	7
1000	51	32	33	25	37	25	26	22	21
2000	-	-	-	-	-	-	-	-	56

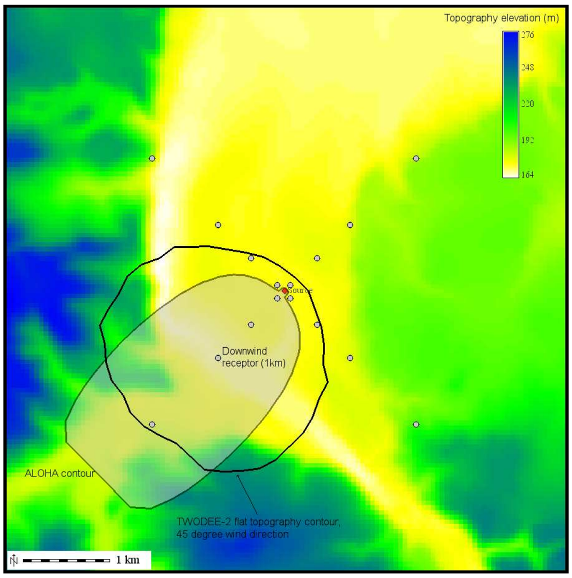

Figure 3 Maximum gas concentration (1ppm contours) predicted by ALOHA and TWODEE-2 over flat topography.

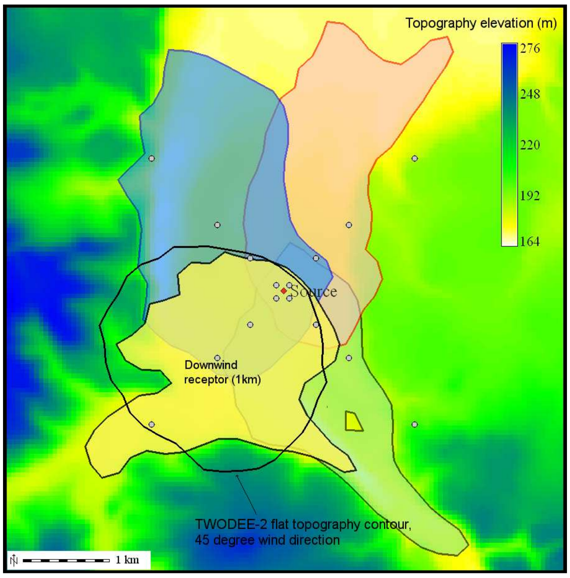

Figure 12 Maximum gas concentration (1ppm contours) predicted by TWODEE-2 over flat topography in wind direction 45° and over unadjusted topography in wind directions 45°, 135°, 225°, and 315°.

Figure shows the cloud footprint as predicted by ALOHA and TWODEE-2 for flat terrain and a 45° wind direction. The original topography is underlaid. It demonstrates that the two models do not produce identical results, that aloha predicted a longer downwind impact and TWODEE-2 predicted a wider impact.

Figure 12 (cloud footprints as predicted by TWODEE-2 over unadjusted topography) indicated that, as expected, topography will alter the dispersion of the gas from a flat topography scenario. It also indicated the cloud was limited to dispersion into areas of near or lower terrain elevation as steep positive terrain gradients caused a distinctive barrier to dispersion.

Figure (a summary of the effects of terrain adjustment on dispersion) indicates that even relatively minor terrain slopes, when compared to the original topography, can alter the path of the dispersing cloud. Positive increases in terrain elevation, where the adjustments increased the elevation further above the source location, did not substantially affect the dispersing cloud. At locations where the adjustment caused a lowering of the topography (for example Figure c, south of the source), the cloud was predicted to disperse further into these areas.

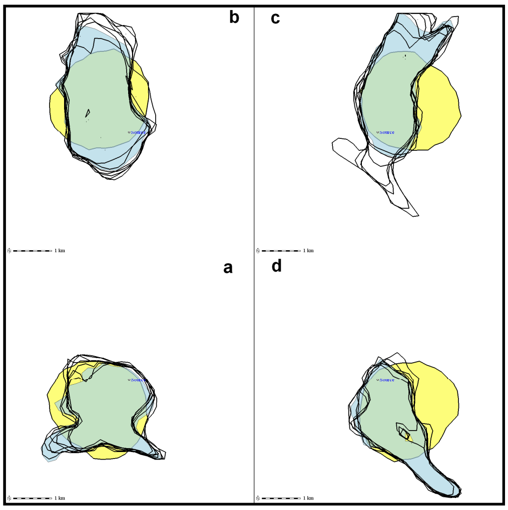

Figure 5 Maximum gas concentration (1ppm contours) for wind directions (a) 45°, (b) 135°, (c) 225°, (d) 315°. Flat topography is shown in yellow, original in blue. Topography adjustment scenarios 200%, 150%, 100%, 50%, 25%, -25%, -50% marked with black lines

TIMING

Table provides a summary of the time taken to run each model on an x86-64 Intel computer with 2GB RAM and a 2.33 Ghz processor. Only model runtime was included in the timing experiment. Other stages required to produce results (model configuration and results plotting) could presumably be somewhat automated and aided by a GUI to reduce time spent on these tasks to a reasonable duration. The results indicate that runtime for the TWODEE-2 model is strongly related to the number of grid points although other parameters may also be important (emissions, cloud area, and topography). Model runtime for TWODEE was between 0.5 and 3.5 minutes. Therefore, increases to domain size or a finer resolution (among other parameters) can dramatically increase computation time.

Table 4. Approximate model runtime in seconds.

Model	**Winds**	**Dispersion**	**Total**
ALOHA	0	1	1
TWODEE-2 (121x121 grid points)	3	30	33
TWODEE-2 (240x240 grid points)	10	200	210

SUMMARY AND CONCLUSIONS

The study used a release of chlorine and varied topography datasets to test the sensitivity of dispersion in the TWODEE-2 model. ALOHA's prediction of dispersion over flat terrain was compared to that produced by TWODEE-2. It was found that the models did not produce the same results. However, predicted cloud arrival times at down wind locations were reasonably comparable up to 1km. At 2km, ALOHA’s cloud arrived 20 minutes earlier than TWODEE-2’s.

Topography did affect dispersion of the gas. However, the most noticeable changes (from flat terrain) occurred as soon as the topography was non-flat, and especially when lowered to cause a downhill slope. Therefore terrain, even that which may have minor changes in elevation, should be considered for its influence on dense gas dispersion.

Based on these results and depending on the grid resolution or domain size (among other parameters) TWODEE-2 runtime should be expected to be a matter of minutes. However, this is longer than the near-instantaneous results of ALOHA. A maximum allowable runtime should be identified to objectively determine whether a dispersion model is fast enough for emergency response applications. However, runtimes of one to two minutes should cause a negligible delay in provision of results. Possibilities to decrease the runtime of TWODEE-2 could include compilation optimisations and code parallelisation for multi-processor computers. This would allow longer simulations to be run, and wider model domains and finer grid resolution to be used. The modelling domain was set at 50m resolution due to lack of published guidance on an appropriate grid resolution. It would be prudent in a future study to ensure that 50m grid point spacing is not unreasonable, when results are compared to those from more detailed grids.

It seems clear that, as the shallow layer equations are appropriate while negative buoyancy controls the cloud (often defined as when the density contrast is greater than $0.001 kg/m^3$) algorithms accommodating gasses that are only initially dense could be included to simulate non-dense gas dispersion also. This may be done in similar fashion to the model used by Brambilla *et al.* (2009) however the effect on runtime would need to be re-evaluated for time critical applications.

REFERENCES

Brambilla, S., Manca, D., Williams, M.D., Gowardhan, A., and Brown, M.J., 2009: A Shallow Water Model for Dense Gas Simulation in Urban Areas, 8th Symposium on the Urban Environment, AMS, Paper 14.6, 5 pp.

Costa, A., G. Chiodini, D. Granieri, A. Folch, R. Hankin, S Caliro, R. Avino, C. Cardellini, 2008: A shallow layer model for heavy gas dispersion from natural sources: application and hazard assessment at Caldara di Manziana, Italy, Geochemistry Geosystems Geophysics, **9.**

EPA, 2007: ALOHA User's Manual, U.S Environmental Protection Agency, Office of Energy Management, USA.

Folch, A., A. Costa, R.K.S. Hankin, 2009: twodee-2: A shallow layer model for dense gas dispersion on complex topography, *Computers & Geosciences*, **35**, 667-674.

Hankin, R. K. S. and R. E. Britter, 1999a: The Health and Safety Laboratory's shallow layer model for heavy gas dispersion Part 1. Mathematical basis and physical assumptions, *Journal of Hazardous Materials*, **66**, 211-226.

Hankin, R. K. S. and R. E. Britter, 1999b: The Health and Safety Laboratory's shallow layer model for heavy gas dispersion Part 2: Outline and validation of the computational scheme, *Journal of Hazardous Materials*, **66**, 227-237.

Hankin, R. K. S. and R. E. Britter, 1999c: The Health and Safety Laboratory's shallow layer model for heavy gas dispersion Part 3: Experimental validation (Thorney Island), *Journal of Hazardous Materials*, **66**, 239-261.

Hankin, R. K. S., 2003a: Heavy Gas Dispersion: Integral models and shallow layer models, *Journal of Hazardous Materials*, **103**, 1-10.

Hankin, R. K. S., 2003b: Shallow layer simulation of heavy gas released on a slope in a calm ambient: Part I. Continuous releases, *Journal of Hazardous Materials*, **103**, 205-215.

Hankin, R. K. S., 2003c: Shallow layer simulation of heavy gas released on a slope in a calm ambient: Part II. Instantaneous releases, *Journal of Hazardous Materials*, **103**, 217-229.

Koopman R. P. and D. L. Ermak, 2007: Lessons learned from LNG safety research, *Journal of Hazardous Materials*, **140,** Issue 3**,** 412-428.

Spicer, T. and G. Havens, 1989: User's guide for the DEGADIS 2.1 dense gas dispersion model, **EPA-450/4-89-019**, Office of Air Quality Planning And Standards, Office if Air and Radiation, U.S Environmental Protection Agency, USA.

Venetsanos A. G. V., J. G. Bartzis, J. Wurtz and D. D. Papailiou, 2003: DISPLAY-2: a two-dimensional shallow layer model for dense gas dispersion including complex features, *Journal of Hazardous Materials*, **99**, 111-144.