Recommendations when using the GRAL/GRAMM modelling system

Version 21.09

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1 Introduction

This document presents recommended methods and settings for the atmospheric dispersion modelling system GRAL and the non-hydrostatic mesoscale wind-field model GRAMM. These recommendations are based on experience and insights gained during the quality assurance procedure (see the GRAL/GRAMM documentation reports) and practical applications. This document aims to help users to obtain reasonable results for a wide range of applications.

This document supplements the detailed model descriptions found in the documents "Documentation of the Lagrangian Particle Model GRAL (Graz Lagrangian Model)" and "Documentation of the prognostic mesoscale model GRAMM (Graz Mesoscale Model)" and the documentation of the graphical user interface "GRAL Manual - GRAL Graphical User Interface".

2 Known limits and shortcomings

In the current version of GRAL the following physical processes are not implemented

- Chemistry

In the current version of GRAL the following shortcomings are known

- Sometimes unrealistically high concentrations occur at facades, probably because the reflexion and/or the well-mixed criterion are not treated well enough by the model. Thus, it is not recommended to use computed concentrations at facades of buildings/obstacles. At least one grid point shall be between the point of interest and the side wall of a building.
- Due to the stepped resolution of terrain in GRAL simulations, stepped patterns may occur in the resulting concentration maps (see chapt. 3.4.3 for advice).

3 Recommendations

3.1 General hints for using GRAMM/GRAL

3.1.1 Roughness length

Table 1 lists ranges for roughness lengths per land-use type.

If running GRAL without GRAMM, one of these values representing the model domain may be input into the graphical user interface (GUI). When running GRAL in this way, the roughness length as defined in the GUI is used for the entire model domain. Even if buildings are taken explicitly into account in GRAL simulations, it is necessary to set a mean roughness length in such cases, except the option "Adaptive Roughness" is used. If GRAL is coupled with GRAMM, the user-defined land-use file and therefore spatially varying surface roughness lengths are imported from the GRAMM model. The prescribed roughness value in the GUI is not used in this case.

If the Adaptive Roughness option is used, the GUI roughness length defines the minimum surface roughness in the domain area, the specified Adatpive Roughness value defines the maximum surface roughness. The surface roughness is estimated based on buildings and vegetation areas. For vegetation with a height of up to 1 m, the height is interpreted as roughness length.

The optional file "RoughnessLengthsGral.dat" overrules the adaptive surface roughness algorithm and the GRAMM rouhness and defines the spatially varying surface roughness based on the values defined in this file. This file must be an ESRI ASCii raster file and the file must match the flow field raster (cell number, cell size).

When running GRAMM, the user may create a CORINE-based land-use file containing spatially non-homogenous roughness lengths. If GRAMM is used with the Adaptive Roughness option, the Adaptive Roughness is only used if it is higher than the GRAMM Roughness. When coupling with GRAMM, the Adaptive Roughness option should be used carefully (small maximum values).

Table 1: Approximate roughness lengths according to the German-guideline VDI 3783-8

Z0 [m]	Description
0,00001 – 0,005	Ice-, Snow-, Water-surfaces
0,005 – 0,1	Arable land, Pastures
0,1 – 0,5	Parks, Sub-urban areas, Villages, Bushes
0,5 – 2,0 [1]	Forests, Cities, Downtown areas

3.1.2 Determination of stability classes

It is recommended to use a slightly modified form of the solar radiation delta-T (SRDT) method described in US-EPA (2000) to compute stability classes A-G (1 - 7). The method

[1] In city centres with extremely tall buildings, even larger values might be appropriate (e.g. Ling et al., 2017)

Table 2: Pasquill-Gifford (P-G) stability categories

DAYTIME (solar radiation ≥ 20 W/m²)				
	Solar radiation [W/m²]			
Wind speed [m/s]	≥925	925-675	675-175	<175
< 2	A	A	B	D
2 - 3	A	B	C	D
3 – 5	B	B	C	D
5 – 6	C	C	D	D
≥ 6	C	D	D	D

NIGHTTIME (solar radiation < 20 W/m²)		
	Vertical Temperature Gradient	
Wind speed [m/s]	< 0°C	>0°C
< 2	F	G
2 – 3	E	F
> 3	D	D

uses the surface layer wind speed (measured at or near 10 m) in combination with measurements of total solar radiation during the day and a low-level vertical temperature difference ΔT at night. In order to distinguish between 'DAYTIME' and 'NIGHTTIME', it is recommended to use a threshold for solar radiation of 20 W/m² (note that instruments sometimes have offsets, thus a threshold of 0 W/m² is not recommended). Note that GRAL uses figures instead of letters to assign stability classes (i.e. A = 1,. . . ,G = 7).

3.2 Mesoscale wind field simulations with GRAMM

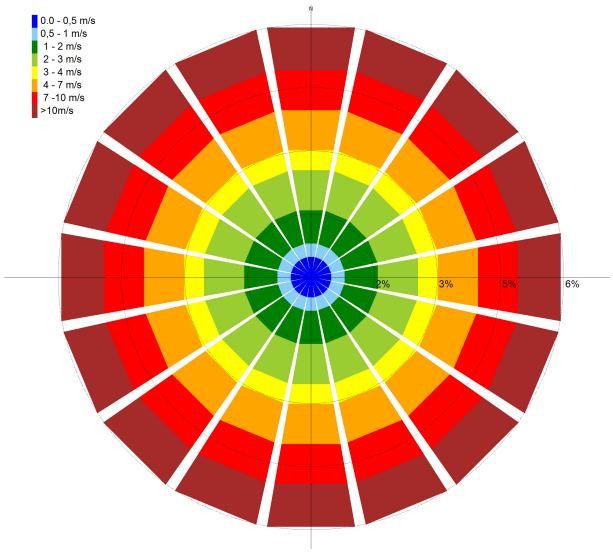
3.2.1 General remarks

Currently, the standard procedure is as follows: a meteorological time series is classed as defined by the user. For each binned situation GRAMM calculates quasi steady-state solutions for the flow field. Using such simple meteorological input data for a mesoscale model means that large uncertainties in computed flow fields evolve due to unknown surface temperatures, soil temperatures, soil moisture distributions, snow cover, etc. For this reason, the following the following procedure is recommended.

- Use an artificial wind rose (delivered with GRAMM) as meterological input (figure 1). The artificial wind rose contains a variety of wind speed, wind direction and stability classes.
- Use a sufficient number of wind speed and wind direction classes.
- In mountainous areas the variability of the wind fields can be increased by using the sunrise Option

  Post-processing procedures are provided by the GUI

Figure 1: Artificial wind rose



- *Re-order function:* This function can be applied to any existing GRAMM wind field simulation. The procedure looks up every computed flow situation discriminating between stable, neutral, and convective conditions, and selects the best-fitting simulation for each classed meteorological situation. The re-order function can be used but is not further developed anymore.
- *Match-to-observation function:* This function can be applied to any existing GRAMM wind field simulation. The procedure looks up every computed flow situation discriminating between stable, neutral, and convective conditions, and selects the best-fitting simulation for each classified meteorological situation. This function can be used for multiple meteorological observations at any location within the model domain. It enables the following modelling strategy: first, for a specific classification scheme of wind speed, and -direction defined by the user, all theoretically possible situations are simulated, using an artificial, equally distributed wind rose. In a second step, these simulations are matched to any observational site within the model domain. Whenever new observations are available or a detailled evaluation is needed for a part of the model domain, these existing wind fields can again be matched and need not to be simulated again.

The match-to-observation functional should be the preferred method in most GRAMM applications as it has the potential to improve simulation results enormously. Note that as wind-fields change after the match, stability classes will do so, too. Based on our experience, it might happen in less complex terrain, that the frequencies of each stability class throughout the model domain will deviate substantially from observed ones. Setting the weighting factors for each station used in the match function to a very low value, e.g. 0.05 instead of the default value 1, increases the influence of stability classes compared to wind direction and wind speed. Weighting factors >1 lower the influence of the stability classes and increase the weigthing of wind speed and wind direction. Using the latest GRAMM and GUI (20.01 or later) version, the vectorial optimization method is preferred.

3.2.2 Complex terrain

In the presence of complex terrain it is strongly recommended to apply GRAMM to get 3D wind fields as input for GRAL. GRAMM can take into account effects of drainage flows, slope winds, blocking-, channeling of flows, and re-circulation behind topographical elevations.

For regulatory purposes, GRAMM is driven by the same meteorological data as GRAL, i.e. a time series of wind speed, wind direction, and stability class at a certain height. It should be stressed that the interpretation of the meteorological input data depends on the size of the GRAMM modelling domain. Generally, the meteorological input data represents the so-called 'large-scale forcing', i.e. the forcing originating outside of the modelling domain. For instance, for areas ranging a few tens of kilometres, the large-scale forcing consists of synoptic-scale pressure systems and pressure gradients generated by for example, mountain ridges and their respective low-lands or between land surfaces and large water bodies. Typically, mountain-valley or land-see breeze systems have pressure gradients with length scales of more than 100 km. Therefore, if the model domain is larger than this, these pressure differences can be captured by the model. In this case, synoptic-scale pressure differences remain as the only large-scale force.

The topography file used for GRAMM simulations *should not be smoothed* at the boundaries for GRAMM versions 19.1. and higher.

It is recommended to use the online functionality of the GUI, which helps to track the modelled flow fields.

In the case of numerical problems, one could try to reduce the *relaxation factors* and/or the *maximum allowed time step*. By default, these values are 0.15 and 10 s regardless of the horizontal grid size. GRAMM automatically adjusts both factors to keep simulations numerically stable as far as possible.

The *integration time* should be set in dependence on the size of the modelling domain and the intended physical phenomena to be simulated. For instance, if one attempts to simulate local phenomena such as slope winds or flow channelling, an integration time of one hour will be sufficient in most applications. However, if a user wishes to simulate mountain-valley wind systems or land-sea breezes, the integration time needs to be higher as the characteristic time scale of these phenomena are larger. An integration time of about 3 - 4 hours may often be suitable. Further, it is highly recommended that when simulating mountain-valley and land-sea winds, that the 'sunrise option' in the GUI is selected. This option invokes a transient computation of the sun's incoming radiation.

GRAMM adjusts the user-defined integration time in dependence on wind speed and stability in order to minimize the computational time. Table 3 provides an overview of the automatically adjusted integration times in GRAMM. As shown, when the sunrise option is selected by the user, the simulation time in convective conditions is always set to 6 hours regardless of the integration time chosen by the user. As already mentioned, the sunrise option should only be selected when simulating mountain-valley or land-sea winds with very large model domains. In the case of stability classes 6 and 7, integration times in GRAMM are extended for low-wind-speed situations. In this model set-up cold-air drainage flows are expected to develop.

Table 3: Integration times [t] in GRAMM in [s] in dependence on wind speed and stability class. The numbers in brackets apply when the sunrise option is invoked

SC 1 – 3	**SC 4**	**SC 5**	**SC 6**	**SC 7**
$u \leq 3$ m/s	$t \leq 600$ s	$t = t_{user}$	$u \leq 2$ m/s	$u \leq 0.5$ m/s
$t = t_{user}$($t = 21600$ s)			$t = \text{Min}[1.5\ t_{user}, 3600]$ ($t = 3\ t_{user}$)	$t = \text{Min}[2\ t_{user}, 3600]$
$3 < u \leq 5$ m/s			($t = 3\ t_{user}$)	($t = \text{Min}[2\ t_{user}, 7200]$)
$t = 0.5\ t_{user}$ ($t = 21600$ s)			$u > 2$ m/s	$0.5 < u \leq 1$ m/s
$5 < u \leq 6$ m/s			$t = t_{user}$	$t = \text{Min}[1.5\ t_{user}, 3600]$
$t = 0.3\ t_{user}$ ($t = 21600$ s)				($t = \text{Min}[1.5\ t_{user}, 7200]$)
6 m/s $< u$				1 m/s $< u$
$t = 0.17\ t_{user}$ ($t = 21600$ s)				$t = \text{Min}[t_{user}, 3600]$

3.2.3 Flat terrain applications of GRAMM

There are also several reasons to apply GRAMM in relatively flat terrain:

- To consider land-use changes in subsequent GRAL dispersion simulations
- To consider a wind-direction shift in the lower boundary layer due to surface roughness (Ekman shift)
- To include a proper transition between flat and complex terrain

In flat terrain, small forces introduced by the boundary conditions or numerical algorithms can have a large effect on simulated flow fields. Numerous tests (e.g. Wilhelm, 2017) have shown that the standard GRAMM set-up is not appropriate for simulations in very flat terrain. Therefore, the 'flat terrain option' is available in the GUI, where some settings in GRAMM are changed to better represent flat-terrain conditions. In particular, different boundary conditions at the lateral boundaries for momentum (homogenous von Neuman BC) is used. In addition, the numerical computation of air temperature and radiation is neglected. It is highly recommended to use the flat terrain option for the aforementioned modelling objectives.

3.2.4 General issues

It is recommended to use a minimum of 15 vertical layers in GRAMM simulations, and a cell height of about 10 m for the first layer above ground level. Horizontal grid sizes can range from a few tens of metres up to several kilometres. The finer the horizontal resolution, the more prone GRAMM is to numerical instabilities.

How to check if GRAMM results are numerically stable?

There are several options to track numerical stability of the model:

1. Once GRAMM is launched, the user can inspect the numerical values on the screen in the CMD-window (see Figure 2). If these values increase constantly, numerical instability is likely.
2. The online functionality of the GUI can be used to inspect simulated flow fields for every time step of the simulation.
3. When the computed wind speeds exceed 55 m/s and 20 m/s in the horizontal and vertical directions respectively, a 'Problemreport.txt' will be written into the 'Computation' folder. The report is a simple text file, which can be viewed by any text editor.
4. Mass divergence may increase during the simulation causing it to be larger at the end of the simulation than at the beginning. In this case, the 'Problemreport.txt' will include the following error message: 'Final mass divergence is larger than initial mass divergence. Possible numerical instabilities detected for flow field: xx',

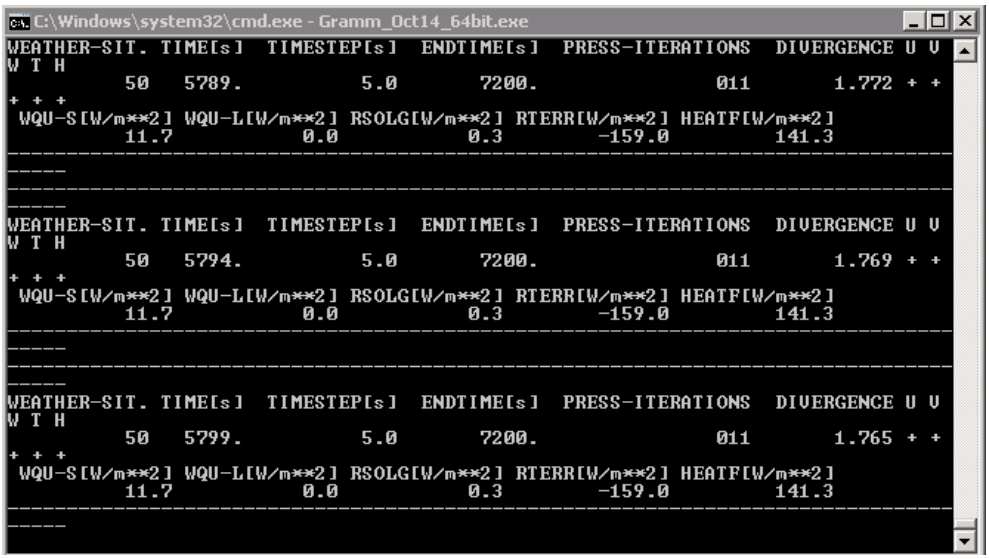
Whenever GRAMM becomes numerically unstable, the computation core repeats the simulation with reduced maximum time steps and in the case of continuing instabilities, relaxation factors will be reduced. If the simulation is forced to repeat a weather situation (up to four attempts), the number right to the one indicating the weather situation is increased (e.g. 28/2 is the second attempt of simulating weather situation 28).

If the simulation is still unstable, the following recommendations may help to solve the problem:

- Decrease the maximum allowed time step
- Decrease the relaxation factors
- Increase the number of cells at the boundaries over which topography is smoothed
- Increase the horizontal and/or the vertical grid spacing

In some cases, the user may require a small modelling domain. Consequently, drainage flows might be underestimated or not simulated at all. This is because some of the hilly terrain causing drainage flows may be located outside of the model domain. The 'catabatic forcing' option may help to obtain better representation of drainage flows in such situations. In addition, the catabatic forcing can save CPU time in order to represent catabatic processes with smaller integration times. If possible however, it is recommended that the model domain is selected large enough to contain all important terrain characteristics playing a role in the development of drainage flows instead of using the 'catabatic forcing' option.

Figure 2: Controlling convergence and numerical stability of mesoscale flow simulations with GRAMM



3.3 Microscale flow field simulations with GRAL

3.3.1 Prognostic flow field model

The microscale flow field model in GRAL is a fully prognostic, non-hydrostatic model that takes into account the effects of buildings on dispersion. Thus, it is a very powerful tool to simulate flow around obstacles. However, the model can also be prone to numerical instabilities due to the complex, iterative-solution algorithm applied.

In order to resolve obstacles with some accuracy, it is recommended to use a horizontal grid resolution below 10 m. Best results are seen with grid sizes in the range of 2 – 4 m. The vertical grid size for the first layer above ground should be in the range of 1 – 2 m. Vertical grid spacing below 1 m may lead to numerical instabilities. In addition, it is recommended to use the online functionality of the GUI to inspect flow fields during the simulation process. Alternatively, the user can analyse the GRAL flow fields when available.

Generally, it can be stated that numerical instabilities can be avoided in most cases by increasing the vertical grid spacing or by decreasing the horizontal resolution. From experience, cubic-like grid cells (i.e. horizontal and vertical grid spacing are more or less equal) appear to ensure best numerical stability of the model.

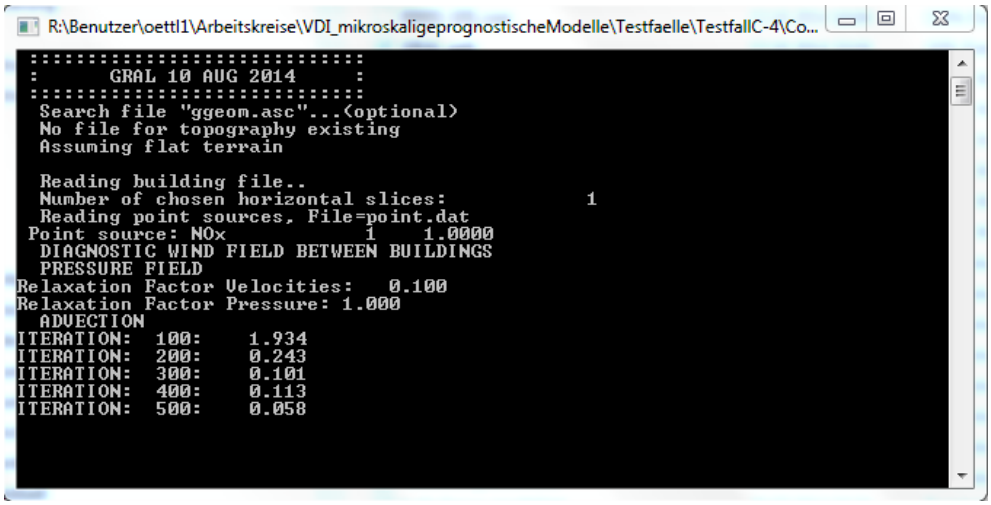
In many cases, problems can be avoided by keeping the model domain boundaries free of any obstacles. It is highly recommended that no obstacles are placed near the boundaries of the model within an area of approximately 10 times the horizontal grid size.

As GRAL has been thoroughly tested with the below set of parameter values prescribed in the GUI, it is not recommended to change these, as the model may become numerically unstable.

The recommended set of parameter values is as follows:

- Number of vertical cells: 25 – 40 (depending on the max. height of obstacles)

Figure 3: Controlling convergence and numerical stability for microscale flow simulations with GRAL, respectively



- Minimum iterations: 100 Maximum iterations: 500
- Roughness of building walls: 0.001 m

All other parameters related to the microscale flow field model are freely adjustable by the user.

How is numerical instability identifiable by a user?

There are several ways for detecting numerical instabilities:

- Once GRAL is launched, the user can inspect the numerical values printed to the screen in the CMD-window right to the iteration number (see Figure 3). If these figures increase, then numerical instability is very likely, and one of the remedies as described above should be tried out.
- Another way is to use the online functionality of the GUI, which allows for inspecting simulated flow fields every time step of the simulation.
- GRAL itself writes a file named 'Problemreport_GRAL.txt' in the subdirectory 'Computation' whenever implausible wind speeds or non-convergence of the flow computation is detected.

How to retrieve information about simulated flows with the microscale flow field model?

In some cases, it may be of interest for users to retrieve information about the simulated microscale flow field. For instance, simulated wind speeds behind walls may be needed to compute the effect on fugitive dust emissions due to wind erosion.

As outlined in the GRAL manual, once receptor points are defined by the user, the time series of simulated flows at these receptor points is stored in the file named 'GRAL_*NameOfReceptorPoint*.met'.

Figure 4: Location of the air quality observation site “Deutschlandsberg-A15“

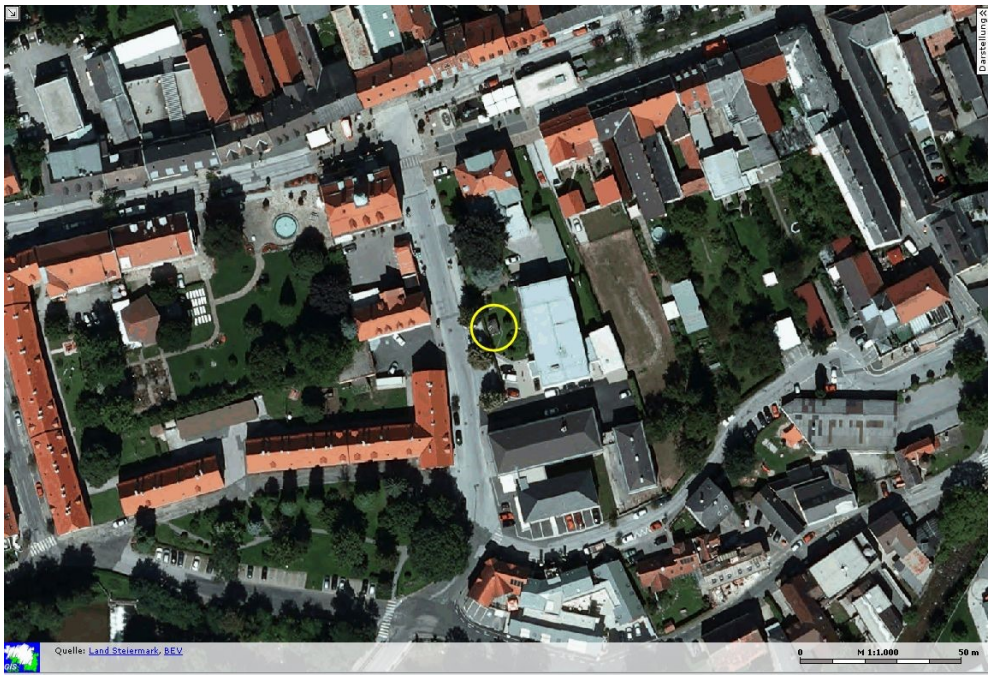
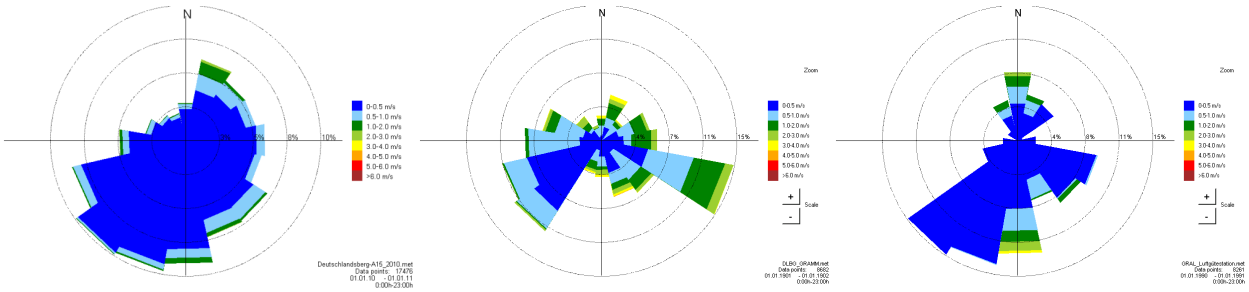


Figure 5: Observed (left) and simulated (GRAMM: middle; GRAL: right) mean wind-roses at the site Deutschlandsberg-A15 for 2010



This file is saved in the sub-directory ‘Metfiles’ after invoking the ‘Receptor points’ function (button) in the ‘Computation’ menu.

The below figures show a comparison between simulated flows by GRAMM in complex terrain at a specific point within a built-up area compared to subsequent GRAL simulations. Figure 4 shows the location of the air quality observations (Deutschlandsberg-A15) and Figure 5 shows the observed and simulated wind-roses extracted from GRAMM and GRAL.

It is noted that the GRAMM simulations were carried out with a rather coarse horizontal resolution (300 m), and cannot not take buildings into account. The GRAL simulations were performed with a resolution of 5 m and included buildings.

Figure 5 shows that while GRAMM overestimates wind speeds at this site, GRAL is able to reproduce wind speeds well. In addition, wind directions are better captured by the GRAL microscale simulations.

3.3.2 Diagnostic flow field model

When running the model using the diagnostic option, the microscale flow around obstacles is computed on the bases of mass conservation only. GRAL evaluations clearly indicate that this approach is inferior to the prognostic option. Thus, it is not recommended to use this approach unless the size of the model domain prohibits the use of the prognostic flow field model or the prognostic model cannot be operated to get numerically stable results.

3.4 Pollutant dispersion simulations with GRAL

3.4.1 General

Due to the turbulence parameterisations used in the model it is not recommended to apply GRAL for averaging times smaller than 300 seconds.

Due to the nature of Lagrangian particle models, computed pollutant concentrations are prone to a sampling error. This error can be kept small when the number of particles is set high enough. A rough guide can be found in the user manual of the graphical user interface. However, it is recommended that the user checks the file 'Logfile_GRALCore.txt', which can be found the folder directory where GRAL has been launched. In the case of large model domains with a large numbers of sources, there may not be enough particles defined by the user to adequately represent all sources in the simulation. In these cases, GRAL automatically increases the number of released particles. However, if the total number of particles (as documented in the logfile) is more than 20 % higher than initially defined by the user, it is highly recommended to increase the total number of particles in the simulations and to re-run the simulations from the beginning. The following table 4 lists the minimum number of particles that are automatically assigned by GRAL, if the total initial number of particles is too low. As of GRAL version 20.01 a file "Receptor_Timeseries_Transient.txt" is written at the end of a calculation. This file contains the estimated statistical error for each receptor point in the last line. High error values indicate that too few particles were used in the simulation. A value NA (not available) means that no concentration at this receptor (no particle) has been counted.

Table 4: Minimum number of particles automatically assigned by GRAL in cases, where the total number of particles is too low for a good representation of all sources within the model domain

	Point sources	**Tunnel portals**	**Area sources** per subarea	**Line sources** per line segment
< 2,000 sources	20 particles/source	20 particles/source	5 particles/source	5 particles/source
2,000 – 30,000 sources	10 particles/source	10 particles/source	3 particles/source	3 particles/source
> 30,000 sources	5 particles/source	5 particles/source	1 particles/source	3 particles/source

3.4.2 Complex terrain

If terrain needs to be taken into account, GRAMM simulations must first be completed. These simulations – due to computational reasons – can generally be performed with a rather coarse horizontal resolution (e.g. 50 - 1000 m). For some applications, however, it might be necessary to capture important topographical details at a higher resolution. This can be achieved through the GUI, and by running GRAL after the GRAMM simulations have been completed. This approach is explained below.

The user will need to prepare a topography file in ASCII format. If specific topographical features are important, the use of a high-resolution terrain dataset (e.g. 1 m to 25 m, depending on the application) is recommended.

Once the GRAMM wind fields have been imported into the project, and the GRAL domain has been defined, the user can import the high-resolution topography file using the menu entry 'File – Import – Original GRAL topography' in the GIS window. The GIS window indicates the topography height at the top right of the menu bar. The topography file must be larger than the chosen GRAL domain.

Alternatively, the user may tick the corresponding check box in the menu 'Computation' of the GUI before starting the GRAL simulation. Once the topography file has been selected, the GUI automatically generates a new topography file for use in GRAL. This functionality is illustrated in the example below.

Example: Pollutant dispersion in the vicinity of a stone quarry

Three simulations (tests) were performed with different settings, as summarised in Table 5. The same GRAMM wind fields for the area were imported for all three tests. The GRAMM domain had a horizontal resolution of 300 m.

The topography and predicted concentrations for Test 1, Test 2 and Test 3 are presented in Figure 6, Figure 7, and Figure 8, respectively.

The three figures show that the use of highly-resolved terrain data has a significant impact on modelled concentrations. The Test 1 plot (see Figure 6) show simplified terrain patterns compared to the other tests.

The Test 2 results (see Figure 7) show a significant improvement in the representation of terrain in GRAL. It is important to note here that in the case of Test 2, there was almost no increase in the simulation time.

Due to the 'stepped' sides of the stone quarry, recirculation zones and rather complex microscale flow patterns would probably occur. Thus, invoking the prognostic microscale flow field model in GRAL was the preferred choice and was included in Test 3.

As the prognostic option can only be invoked in the presence of buildings, which are not of interest in this case, a work-around is necessary to force GRAL to perform microscale flow simulations around the stone quarry. Up to the GRAL version 20.01, a single building could be placed in the GRAL model domain with a height of 0.1 m (indicated by the black rectangle in Figure 8). Clearly, such a low building has no effect on the flow itself, but simply

Table 5: Test configurations

Test no.	**GRAMM configuration**	**GRAL configuration**	**Topography used**
1	GRAMM run with a coarse grid (300 m horizontal resolution) and imported into GRAL	GRAL run with a fine grid (5 m horizontal resolution)	Topography file with a horizontal resolution of 300 m included in GRAMM only
2	GRAMM run with a coarse grid (300 m horizontal resolution) and imported into GRAL	GRAL run with a fine grid (5 m horizontal resolution)	A high-resolution (3 m) topography file was created using GIS and imported into GRAL using the 'Use original topographical data for GRAL' check box
3	GRAMM run with a coarse grid (300 m horizontal resolution) and imported into GRAL	GRAL run with a fine grid (5 m horizontal resolution) Prognostic microscale flow field invoked in the 'GRAL settings' window	Test 2 method applied

invokes the prognostic flow model of GRAL in the area, where the building is placed. This resulted in complex flow fields within the quarry, as shown in Figure 9.

Since the roughness of the ground may be changed by such a building, this method is no longer recommended!

Rather, as of version 20.01, a large sub-domain factor up to 1000 can be selected to force GRAL to calculate a large area prognostically. If you simply enter a building with a height of 2 m and a sub domain factor of 1000, a surrounding area of 2000 m around the building is calculated prognostically.

The corresponding concentration map is shown in Figure 8. Note, that the microscale flow field model in GRAL uses the roughness length of the building, so it may be necessary to adjust this value in the 'GRAL Settings' screen to represent the conditions of the area of interest. It is noted that simulation times increased in this case by about a factor of 10 relative to Tests 1 and 2.

Figure 6: Test 1 – Computed pollutant dispersion using GRAMM wind fields and GRAMM topography (300 m horizontal resolution) as input for GRAL simulations

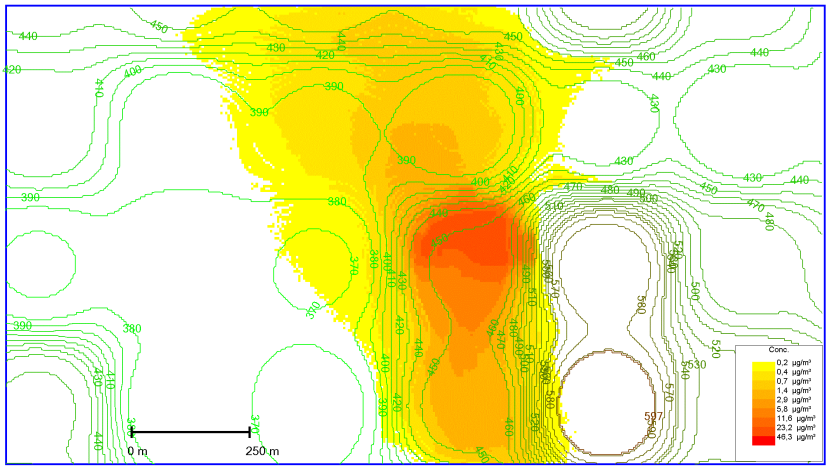


Figure 7: Test 2 - Computed pollutant dispersion using GRAMM wind fields and highly-resolved terrain data (5 m) as input for GRAL simulations

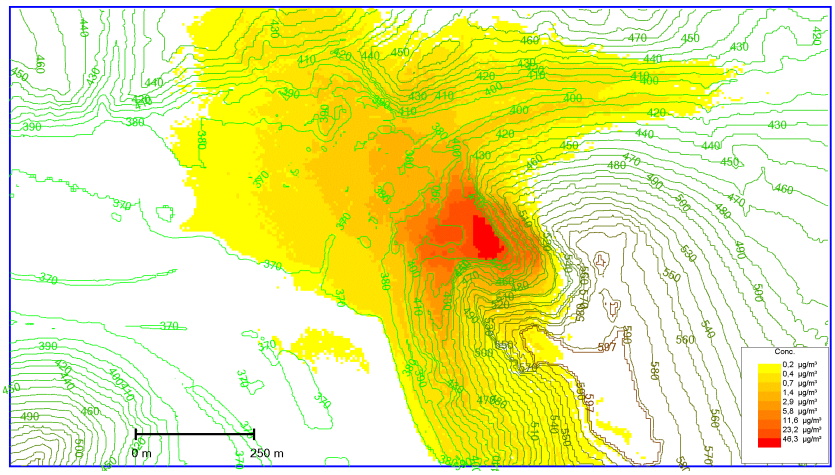


Figure 8: Test 3 - Computed pollutant dispersion using GRAMM wind fields, highly-resolved terrain data (5 m) as input for GRAL simulations, and invoked microscale prognostic flow field model of GRAL by placing a virtual building (black rectangle) in the domain of interest (not recommendend anymore since GRAL version 20.01)

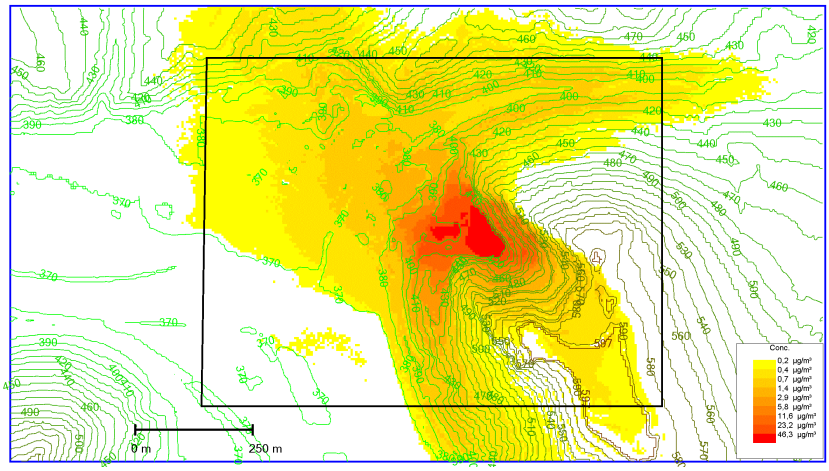
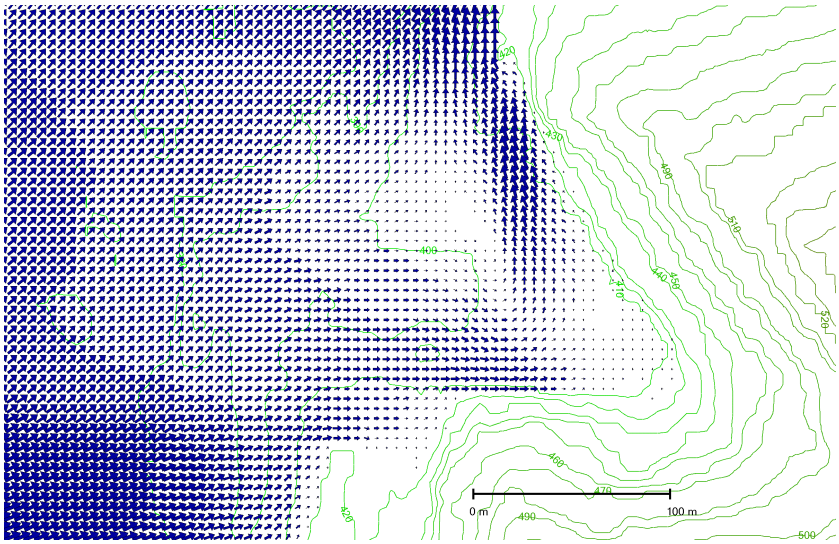


Figure 9: Example of a computed microscale flow field within the stone quarry for Test 3



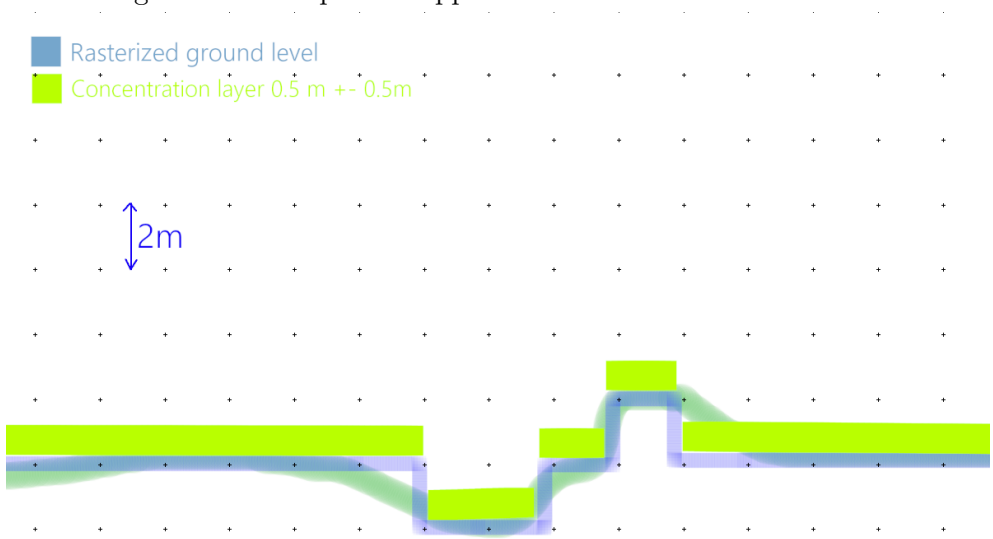
3.4.3 Stepped horizontal concentration patterns in complex terrain

Due to the resolution of terrain in GRAL simulations (see Figure 10), stepped patterns may occur in the resulting concentration maps.

This problem can be mitigated in the GRAL configuration using the following approaches:

- Avoiding setting the concentration grids at a height close to the ground. For example, in the 'GRAL Settings' screen, ensure that the first 'heights above ground' value is set to 2 m or higher.
- Increasing the vertical dimension of concentration layers (in the 'GRAL Settings' tab). This will create a smoothing effect.

Figure 10: Example of stepped resolution of terrain in GRAL



- Reducing the vertical grid size of the microscale flow-field grid (e.g. setting the vertical thickness of the first layer to 1 m and using a low vertical stretching factor (e.g. 1.0). With the new 'Flexible stretching factor' functionality, acceptable computing times can be maintained using small stretching factors for low heights and higher factors for greater heights above the ground
- Setting the horizontal grid resolution of the GRAL concentration grid to be larger (e.g. twice as much) than the horizontal grid resolution of the GRAL internal flow-field grid.

Using one or more of the above approaches should result in a smoothing of the stepped concentration patterns. When visualising contours in the GUI, it is recommended that the low-pass filter option for concentration maps is applied. This option is available in the GUI 'Layout Manager' for contour maps and should be activated by default.

Another (additional) option is to use the function 'Low pass filter GRAL topography' (and to save the filtered terrain afterwards) before the calculation is started. This smoothes the terrain and helps to avoid isolated holes in the topography.

It is generally advised that, when using terrain and evaluating concentration layers, the height of evaluation should be above the value set for 'Vertical thickness of first layer'.

3.4.4 Dispersion calculation for high stack sources

Especially for dispersion calculations with high stacks, special attention must be paid to a sufficient number of particles. Otherwise, unrealistic concentration fields with strong concentration fluctuations can occur near the ground. If you ask what defines a high stack: it depends - on the height, the exit velocity and the exit temperature of the exhaust gases and the distance to the receptor points. The higher the stack compared to the distance to the receptor points, the more important is the number of particles. From a stack height of 40 m, special attention should be paid to the following points.

The following procedure is proposed for estimating the particle number:

In any case, you need some receptor points which are located in the plume direction of the first dispersion situations.

Steady state mode Copy the file meteopgt.all and edit the original file. Keep only a few situations within this file. Then start the calculation and wait until it is finished. You will find the estimated statistical uncertainty for each receptor point in the file "Receptor_Timeseries_Transient.txt". The error should be below 20 % even after the calculation of only a few situations. If you like to analyze the concentration in certain weather conditions, the uncertainty (for a plume direction towards the receptor point) should be below 5 %. If a receptor point lies within the plume direction and the error value is NA or above 25 %, the number of particles should be increased. Once the uncertainties are low enough, replace the meteogt.all file with the previously created copy and start the final calculation.

Transient mode Copy the file mettimeseries.dat and edit the original file. Keep only a few weather situations within this file. Then start the calculation, wait until it is finished and check the file "Receptor_Timeseries_Transient.txt" like in the steady state mode. Afterwards replace the mettimeseries.dat file with the previously created copy and start the final calculation.

Using the transient mode, the grid size of the concentration grid should not exceed 25x25 m^2, because otherwise very high concentrations of the transient particles and thus additional numerical uncertainties will occur, especially when calculationg the dispersion of very high stack sources (above 80 m). This is somewhat contradictory to the fact that large concentration grids should be used for high stack sources. If necessary, a higher particle number must be used in such cases.

3.5 Pollutant dispersion from road tunnels in GRAL

3.5.1 Effect of air being sucked in by the tunnel entrance of the opposite lane

Oettl et al. (2002) found that large amounts (up to 50 %) of tracer emitted from a tunnel portal were sucked in via the tunnel portal of the opposite lane. In GRAL it is recommended to define an area around tunnel portals were traffic enters a tunnel, to take this effect into account. Normally such areas are not very large (see example in Figure 11) and extend more in the direction of traffic flowing into the tunnel portal rather than in the opposite direction. In order to account for this effect, the following steps are necessary

1. Define the area around the tunnel portal by digitizing a building (the height of the 'building' doesn't matter) using the GIS functionality of the GUI (see Figure 11).
2. Select the prognostic mode in the GUI's 'Project' menu and then press the button 'Building file' in the 'Computation' menu (see Figure 12). A file named 'buildings.dat' will be generated in the subdirectory 'Computation'. Rename this file to 'tunnel_entrance.txt'. Ensure that no other real buildings have already been digitized with the GUI, as all coordinates in the file 'tunnel_entrance.txt' will be used by GRAL

Figure 11: Defining the area around a tunnel entrance of the opposite lane

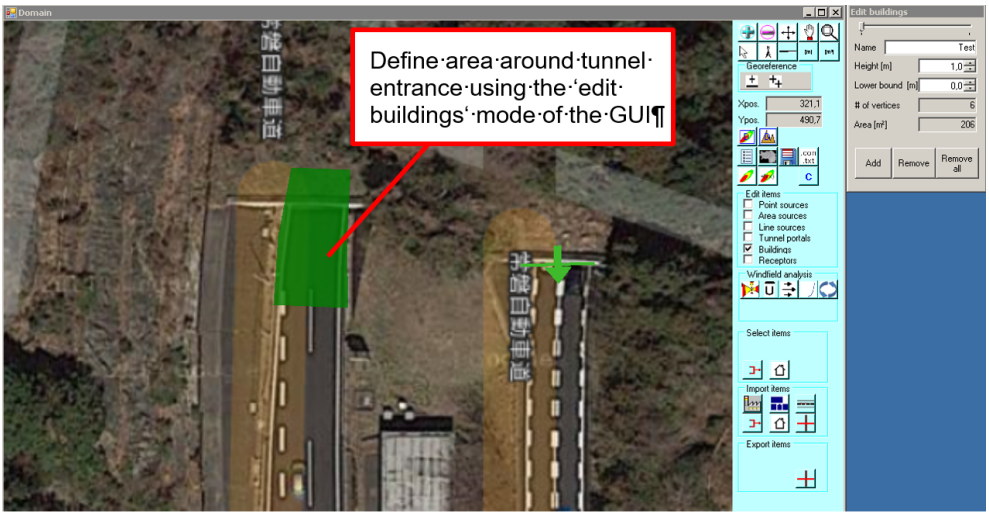
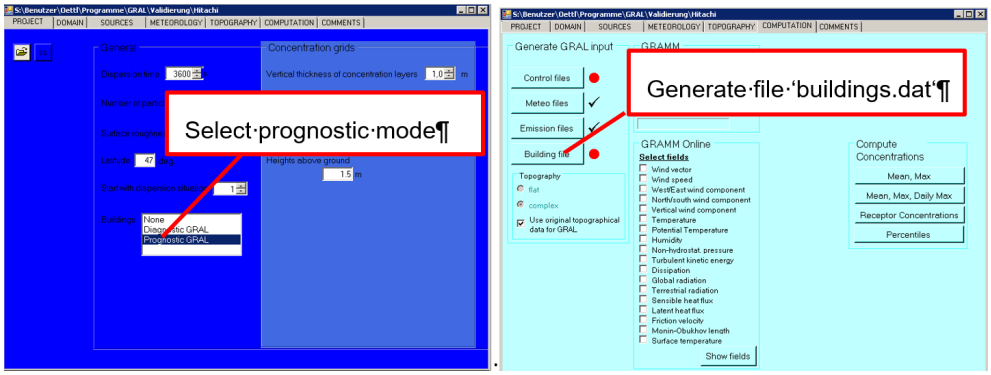


Figure 12: Generating the 'buildings.dat' file using the GUI



to remove particles up to a height of 5 m. Other buildings may be digitized following this step.

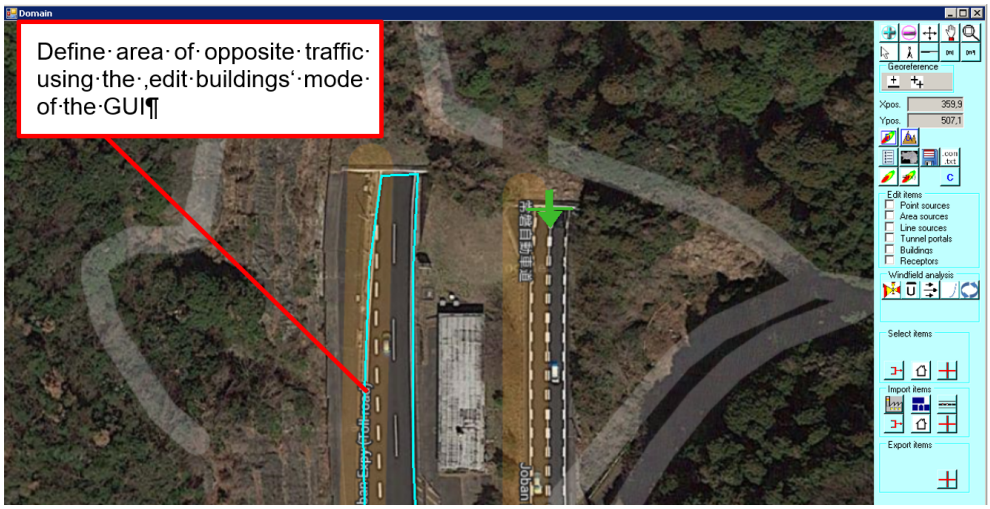
3.5.2 Effect of traffic at the opposite lane on the tunnel jet

It can be assumed that whenever a tunnel jet stream crosses the opposite lane it will be destroyed by the vehicle's induced turbulence. In the GRAL model it is possible to define the areas of traffic at the opposite lanes as described in the following:

1. Define the area of the opposite lane by digitizing a building (the height of the 'building' doesn't matter) using the GIS functionality of the GUI (see Figure 13). It is reasonable to limit the length of the area to about 100 - 200 m as tunnel jets typically do not exceed this length.

2. Select the prognostic mode in the GUI in the 'Project' menu, then press the button 'Building file' in the menu 'Computation' (see Figure 12). The 'buildings.dat' file will be generated in the 'Computation' subdirectory. Rename this file to 'opposite_lane.txt'. Make sure that no other real buildings have already been digitized with the GUI, as all

Figure 13: Defining the area of the opposite lane (make sure no other buildings have been digitized yet)



coordinates in the file ‘opposite_lane.txt’ will be used by GRAL to remove particles up to a height of 4 m. Other buildings may be digitized following this step.

3.5.3 Tunnel portals at depressed level

Naturally the effects of the ambient wind on the tunnel jet are weaker given that the tunnel portal is situated below surface level. In principle there are two ways to simulate this in GRAL:

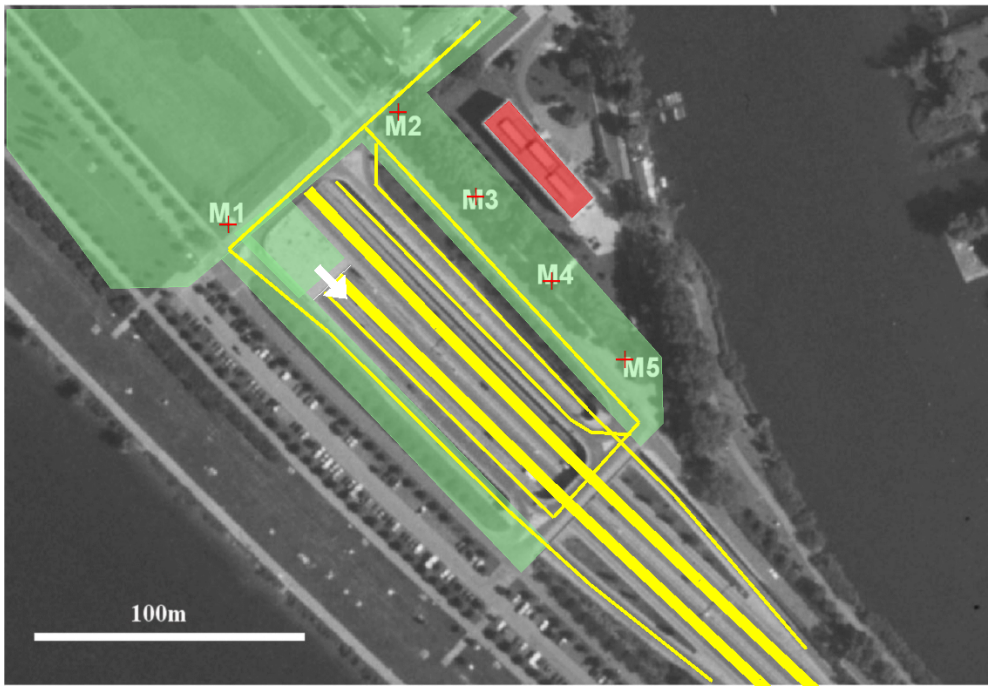
1. Obstacles (buildings) can be defined with heights equal to the depth of the depressed level where the tunnel portal is situated. An example (Kaisermuehlentunnel in Vienna) is given in Figure 14. In this case the heights of the receptor points M1 – M5 were set to 7.5 m above ground, as they were placed 2.5 m above ground in reality and the tunnel portal is situated 5 m below surface level.

2. Use of high-resolution topographical data. Firstly, GRAMM simulations must be carried out using these data. Note that the horizontal resolution of GRAMM can be rather coarse. In the case of the Kaisermuehlentunnel, a horizontal resolution of 25 m was chosen. Subsequently, when running GRAL, the option to use high resolution original topographical data must be selected in the GUI (as described in sect. 3.4.2). Figure 15 depicts topography (purple shading) and buildings (green contours) around the Kaisermuehlentunnel, Vienna. An additional, building with a height of 0.1 m has been defined (large green square) to invoke the microscale, prognostic wind-field model of GRAL as outlined in sect. 3.4.2. Receptors were placed as they were in the real world at 2.5 m above ground.

Both, options 1) and 2) resulted in quite similar results for the Kaisermuehlentunnel. How-

ever, the recommended method is the utilization of high-resolution terrain but with a caveat that the terrain must be of good quality and checked/filtered first before use.

Figure 14: Using obstacles (green) to account for the fact that a tunnel portal is below the surface; traffic lanes are in yellow



3.6 Odour dispersion simulations using GRAL

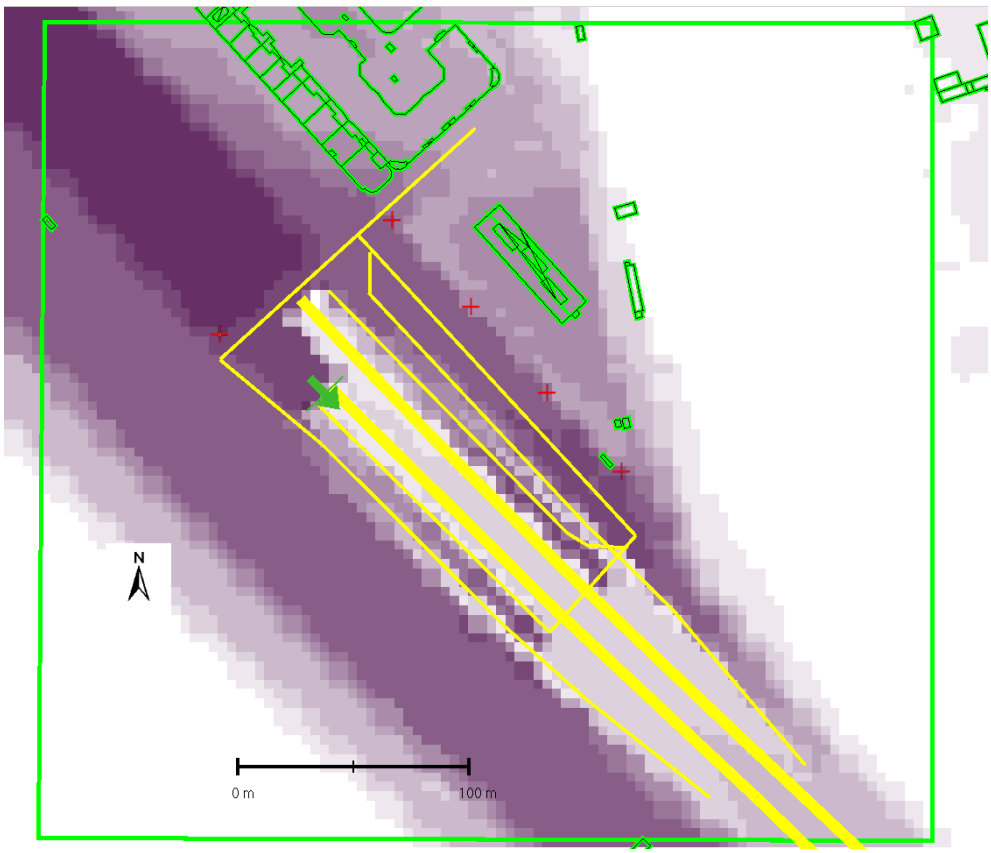
Odour dispersion simulations using GRAL aim to provide 'odour-hours frequencies', which form the basis for judging annoyance or nuisance in an area (for the exact definition of an odour hour read for instance Oettl et al., 2018). In addition, the GUI supports the computation of percentiles of mean-hourly odour concentrations.

It is recommended to use the 'concentration-variance' model (Oettl and Ferrero, 2017) for assessing odour-hours instead of a constant-factor model.

Based on comprehensive investigations (Oettl et al., 2014) the following guidance is provided to ensure traceability and sensible results when predicting odour from animal husbandry operations using GRAL:

- Odour emissions from natural ventilated animal stables should be considered an area source close to the building facade (where the windows are situated), 1.5 m above ground and with a vertical extension of 1.0 m.
- Horizontal grid spacing should be in the range of 2 – 3 m when modelling building downwash effects.
- The vertical grid spacing of the first cell above ground should not exceed 3 m, and the vertical stretching factor should not be larger than 1.05.

Figure 15: Using topographical data (ViennaGIS - www.wien.gv.at/viennagis/) to account for the fact that a tunnel portal is below the surface; traffic lanes are in yellow; building contours are in green



- The elevation for the concentration grid should be 1.5 m above ground and its vertical extension should be 1.0 m.

- For computing annual odour hours, odour thresholds of 1 OU/m³ should be used.
- It is recommended that odours from different species (pigs, poultry etc.) are not considered cumulative due to the different nature of the odours.
- For all-in / all-out systems it is recommended to take into account the saw-tooth cycle of emissions. Otherwise constant odour emissions in time may be adequate.

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