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SENSITIVITY STUDY ON ATMOSPHERIC RADIONUCLIDE TRANSPORT MODEL (ARTM)

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Abstract: In the past decades several different atmospheric dispersion models have been developed and used all over the world at meteorological meso and micro scales for regulatory purposes. In this work the Lagrangian particle dispersion model ARTM is analysed. For its user it is essential to understand the model's behavior. A sensitivity study has been performed in order to get a better understanding in how the results of a simulation react on the given input parameters. Within this study meteorological, environmental as well as source specific parameters were altered and their influence on the results analysed. We show that some parameters have a massive effect on the simulation results. They affect not only concentration values but the complete three dimensional spread of particles. Contrary to this there are some parameters which play a minor role and have only a week influence on the simulation results.

Key words: *atmospheric dispersion, ARTM, Atmospheric Radionuclide Transport Model, Lagrangian particle dispersion model, sensitivity study*

INTRODUCTION

In the past decades several different atmospheric dispersion models have been developed for regulatory purposes (Mayall, 2003). The Gaussian plume model become very popular to simulate dispersion within the atmospheric boundary layer in the 1960s and 1970s due to its simple analytical solution (Mayall, 2003; Huber, 1991; Miller and Hively, 1987). However there are disadvantages concerning the performance of this model in the case of calm wind conditions or complex structured topography (Mayall, 2003; Walter, 2004). To overcome these disadvantages and due to the rise of computational capacity more complex models have been developed like the Lagrangian particle dispersion models among others (Leelőssy et al., 2018). The Lagrangian particle dispersion models are a twofold system where the particle dispersion is simulated on a flow field. Such models simulate closer to reality compared to the Gaussian plume models and are able to produce reliable results at conditions where Gaussian models are not suitable. (Leelőssy et al., 2018; Walter, 2004).

In this work the Lagrangian dispersion model Atmospheric Radionuclide Transport Model (ARTM) was investigated. It is essential for any user to understand the behaviour of their simulation tool in order to correctly interpret the calculated results. Therefore a sensitivity analysis on variations of ARTMs input parameters was performed on its 3-dimensional results.

THE MODEL

In this study the Atmospheric Radionuclide Transport Model (ARTM) was investigated. ARTM was developed by the "Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH" (GRS, 2007). It is a Lagrangian particle dispersion model which uses the diagnostic wind field model TALdia (GRS, 2007; Martens et al., 2012) in order to simulate a 3D flow field of the domain of interest in which single particles propagate in place and time. For this purpose advection and diffusion were taken into account. The turbulence parameterization is performed via Monin-Obukhov Similarity Theory (GRS, 2007).

PERFORMING THE SIMULATIONS

All simulations were performed using plain surface and constant wind speed of 1 m/s from the west. The anemometer is located at 10 m height in a horizontal distance of 32.5 m from the source of emission. The emission source is a point like source at 20 m height. The simulation area has rectangle shape with dimensions of 10 000 m from west to east and 1 500 m from north to south. The horizontal resolution is 50 m in both directions. The height of the boundary layer is assumed to be 1 500 m. For simulation purpose it is divided into 15 separate vertical layers of non-uniform heights. In order to make the simulations comparable a standard set of input parameters is defined in Table 1.

Table 1. Standard input parameters.

Parameter	Value
Wind speed	1 m/s
Wind direction	west
Roughness length z_0	0.5 m
Zero displacement height d_0	$6 \cdot z_0$
Source height	20 m

RESULTS

To get a better insight how the simulation tool reacts on variations of certain input parameters the dispersion category (stability class), the roughness length, the zero displacement height and the source position were altered, respectively. The occurrence of maximum concentrations, concentration distributions, the volume of the plume and other key values were analysed.

Dispersion category

The standard set of input parameters was used to investigate the sole effects of the dispersion categories. The variation ranges from very stable to very instable boundary layer conditions in six categories. Since this parameter reflects the turbulence intensity the volume of the resulting plume is an indicator of the mixing strength. The plume covers from less than 1 % to 71 % of the total volume of the simulated domain while the dispersion category varies from very stable to very instable. This is in agreement with the increasing contribution of diffusion in the different dispersion categories. With increasing instability the plume reaches higher altitudes inside the boundary layer. Interestingly the size of horizontal cross-sections of the plume in the layers close to the ground show a maximum at neutral conditions. The horizontal distance between the source and the point of maximum concentration of each horizontal layer of the plume decreases with increasing instability at ground level.

Roughness length

The roughness length z_0 represents the surface roughness and influences the wind profile close above the ground. Based on the standard parameter set z_0 was altered. From a global point of view it can be seen, that the roughness length plays a smaller role compared to the dispersion categories. The maximum growth of the covered volume of the plume was found at neutral layer conditions as 22 % of the volume. For other conditions the growth is less than 7 %. Concerning the expansion of the plume to higher altitudes the variation of the roughness length has only a small effect. However, below the source height of 20 m and for stable boundary layer conditions the distance between the source and the occurrence of the maximum concentration is strongly influenced by the roughness length as depicted in Figure 1. Large roughness lengths lead to a better mixing close to the ground and within shorter distances.

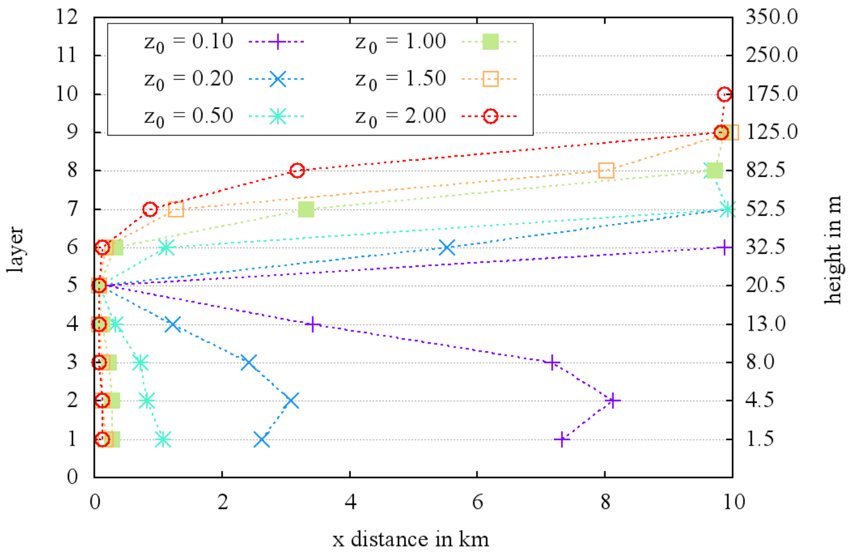

Figure 1. Points of maximum concentration for separate layers over the distance in x direction from the source for varying roughness lengths. The dispersion category is hold at very stable conditions for the shown roughness lengths.

Zero displacement height

The zero displacement height d_0 was varied gradually from $3{\cdot}z_0$ to $15{\cdot}z_0$ in four steps. This parameter controls an additional displacement of the wind profile in its lowest section just above the ground. Within the d_0 the wind profile is changed from its logarithmic shape to a straight line shape. This leads to a constant and continuous rise in wind speed with increasing height. It was found that the zero displacement height has only a very week influence on the total extend of the plume. For any simulated conditions no set of parameters could be found where the d_0 plays a dominant role.

Source height

The effects of the height of the source was investigated for several heights from 10 m to 120 m. Within this range only a marginal effect on the size of the volume of the plume was observed when the height variation was performed for a constant dispersion category. However, the distance between the source and the occurrence of the maximum concentration was influenced depending on the dispersion category. For neutral and even more stable categories an increasing source height leads to an increasing distance between the source and the point of maximum concentration for levels below the source level. For very stable boundary layer conditions the plume does not even reach the ground level within 10 km for source heights above 50 m.

CONCLUSION

The sensitivity analysis of ARTM shows – within the scope of this investigation – that there are some parameters which dominate the simulation results while others have only week effects. It was clearly observed that the dispersion category is one of the most important input parameters to perform such simulations. Since it is connected to the turbulence within the boundary layer the dispersion category is the most important parameter to control the dispersion of the plume to all of the three dimensions. The roughness length is able to influence the dispersion as well. Nevertheless the magnitude on dispersion effects is much smaller. However, when observing the distances between the source and the occurrence of maximum concentrations, the roughness length play an important role at the lowest levels above the ground. Since the zero displacement height - as well as the roughness length - influences the shape of the wind profile near the ground it has a similar but attenuated effect on the simulation result compared to the roughness length. Similar to the previous parameters the source height affects the lowest layers of the boundary layer most. The location of each layer's concentration maximum and the extent of the plume to the ground is influenced strongly by the source height in the case of neutral to very stable dispersion categories.

This sensitivity study shows the complexity of this atmospheric dispersion model. Several parameters affect the result in different magnitudes. Keeping the mentioned observations in mind the user is able to give a quick estimate on the model's uncertainty and it is possible to evaluate the obtained results with respect to their reliability.

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