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VALIDATION OF THE SHORT TERM EMISSION APPROACH USED IN THE ATMOSPHERIC RADIONUCLIDE TRANSPORT MODEL ARTM

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Abstract: For regulatory purposes with respect to licensing and supervision of nuclear installations, the Gaussian plume model is still in use in Germany. However, for complex situations it is to be replaced by a Lagrangian particle model on medium terms. The Atmospheric Radionuclide Transportation Model (ARTM) is available already, which allows the simulation of the atmospheric dispersion of operational releases from nuclear installations. ARTM is based on the program package AUSTAL2000 which is designed for long term simulations of atmospheric dispersion of non-radioactive operational releases from industrial plants. In successive research projects ARTM and the accompanying program system were upgraded distinctively. Especially the capability to deal with short term emissions (lasting less than an hour) was introduced. This is needed to model the radiological consequences of so called design basis accidents, which potentially would lead to short time emissions. For dealing with short term emissions (down to 10% of the input data time step) in the model a simple power law is used to adjust the lateral standard deviation of wind speed components to shorter than an hour emission intervals. This adjustment has been validated utilizing the data set of the Near Roadway Tracer Study 2008.
The power law exponent derived from the experimental data of 0.19 nearly matches the used exponent in ARTM of 0.2. However, it becomes apparent that using a single exponent for all atmospheric stability classes may be a problematic approach.

Keywords: *atmospheric radionuclide transport model ARTM, short term emissions, turbulence parameters, validation, Near Road Tracer Study.*

THE ATMOSPHERIC RADIONUCLIDE TRANSPORT MODEL

As its parent code AUSTAL2000 (Janicke L. and Janicke U., 2003) the radionuclide transport model ARTM is an open source realization of the German regulatory guideline VDI 3945 Part 3 on particle models (Kommission Reinhaltung der Luft, 2000). Additional processes simulated by ARTM are e.g. radioactive decay of arbitrary nuclides, wet deposition, or the calculation of the gamma rays field out of a plume of radionuclides. The graphical user interface GO-ARTM is part of the free download package available at www.grs.de/en/artm-atmospheric-radionuclide-transport-model. The interface allows to easily set up and run a simulation as well as to create visualizations of the input parameters and simulation results.

To run a Lagrangian particle model of the VDI 3945 Part3 type, a meteorological input field for the whole simulation region has to be provided. To model the dispersion of the particles, this input field has to contain the mean wind speed, mean wind direction, the standard deviation of the wind speed components, and the Lagrangian time scales (denoted as meteorological field variables MFV in the following). The mean rain rate is needed to model the wet deposition additionally. ARTM derives the meteorological field from measurements of wind speed, wind direction, the stability class of the atmosphere, and the rain rate, which are given as time series or statistic compilations of hourly mean values at a single point within the simulation region.

In a horizontally homogeneous terrain (plain; no buildings or only “small”/“far away” buildings relative to the source location) the vertical profile of the MFV are calculated according to the VDI guideline 3783, Part 8 (Kommission Reinhaltung der Luft, 2002), which is currently being revised. The guideline utilizes the profile method to fit standard profiles of the boundary layer parameters to the measured input data. Additional assumptions needed to use the profile method are taken from specifications of the German requirements for dispersion calculations of non-radioactive operational releases from industrial plants, the so-called “TA Luft” (TA Luft 2002). These specifications concern the boundary layer height (depending on the Coriolis parameter and thus the geographical latitude) and the wind shear with height (depending on boundary layer height). Also, within the near surface region (below the zero displacement height d_0 plus six times the roughness length z_0) the whole set of the boundary layer parameters are approximated following TA Luft assumptions (simple linear interpolations or setting to constant values).

If the simulation region is not horizontally homogeneous (distinct topography; significant buildings), using the profile functions is not sufficient. The wind and turbulence field should not be modelled solely by introducing a (high) roughness length and a zero displacement to parameterize the lower boundary of the simulation region. ARTM uses the diagnostic wind and turbulence model TALdia then (Janicke U. and Janicke L., 2004). This model provides simple approximations of the wind field influenced by the topography (the slope the terrain should not exceed 0.2) or near buildings as well as of the additional turbulence induced by buildings.

To model short term emissions 0.1h < T < 1.0h, which are shorter than the input data time pattern T_0 of one hour, a reduction by the factor $(T/T_0)^{0.2}$ of the standard deviation of the horizontal lateral wind speed fluctuations σ_v was introduced (Martens et al. 2012), following the suggestion of Janicke L. and U. Janicke (2000).

THE NEAR ROADWAY TRACER STUDY 2008

The Near Roadway Tracer Study 2008 (NRTS) is a dispersion study conducted by the Field Research Division of the Air Resources Laboratory of the National Oceanic Atmospheric Administration (NOAA) sponsored by the Atmospheric Modelling and Analysis Division of the U.S. Environmental Protection Agency. It took place at the Idaho National Laboratory in October 2008. The study was designed to quantify the effects of roadside sound barriers on downwind air pollutant concentrations stemming from roadway sources. The aim of the study was to compile a data set covering diverse atmospheric conditions with minimized factors that would complicate the data interpretation. Finally, the data should be useful for further model development (Finn et al. 2010).

Figure 1 Aerial view of the mock sound barrier (build of 300 1-ton straw bales, 6m in height, 90m in length) test site. In the upper left of the picture, the command center and the release trailer are visible (Source: Figure 5 of Clawson et al. 2009)

Roadway emissions were simulated by the release of SF6 as an atmospheric tracer from two 54 m long line sources, one for an experiment with a mock noise barrier (see Figure 1) and one for a control experiment without a barrier. Among other surveying near-surface tracer concentrations were measured with bag samplers simultaneously on identical sampling grids downwind from the line sources and six 3-d sonic anemometers measured the approaching wind and turbulence as well as the barrier-induced turbulence (Clawson et al. 2009). A detailed description of this comprehensive study can be found in the just given reference.

VALIDATION

For the validation, the NRTS sonic wind speed measurements of the approaching wind were utilized. For each of the 5 experiments, about 300,000 raw data points are available (3 hours of measurements, sampling interval of 0.1 s, wind speed in x, y and z direction of the stationary coordinate system). The raw data were used to calculate moving means of the horizontal wind speed u, the wind direction and the fluctuations σ_u, σ_v and σ_w for increasing averaging intervals between 360s and 3600s. An example is shown in Figure 2. Subsequently, the standard deviations of the horizontal lateral wind speed fluctuations were plotted against the averaging time (see an example in Figure 3). Assuming a power law dependence of the kind used in ARTM: $\sigma_v(T) = \sigma_v(T_0)\ (T/T_0)^X$, a least square fits were used to find experimental approximations for the exponent X (lines in Figure 3).

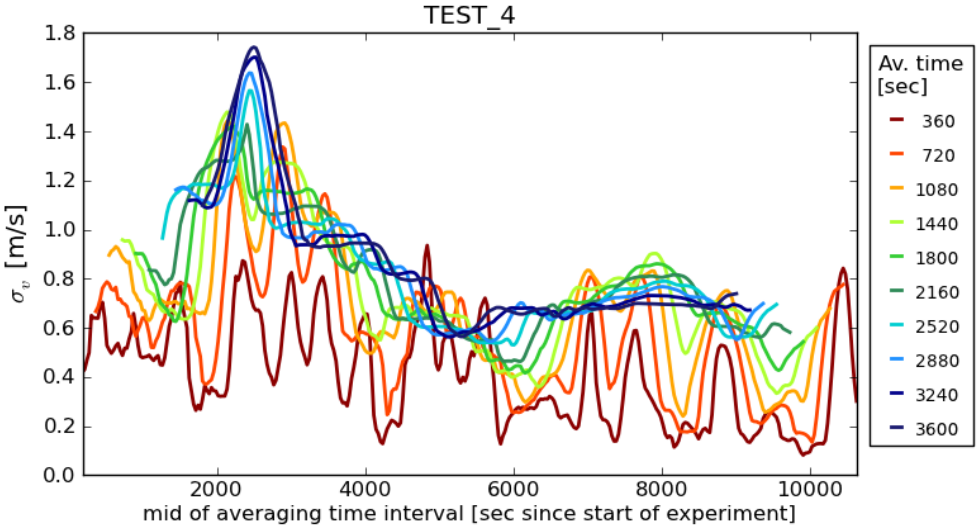

Figure 2 Moving means of horizontal lateral wind speed fluctuations for Test 4 of NTRS.

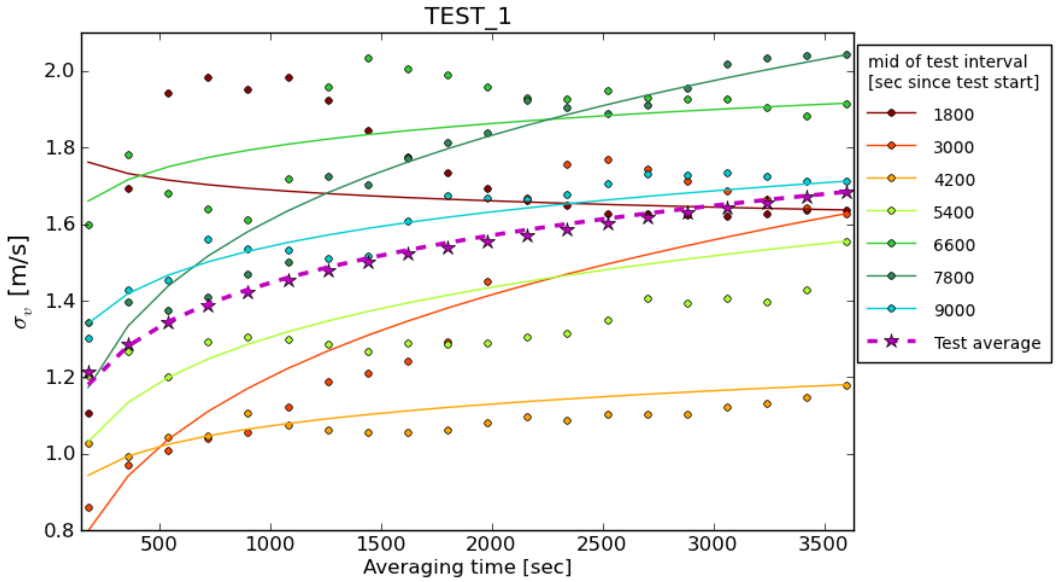

Figure 3 Experimentally derived σ_v (bullets) and fit (solid line) over averaging time. Individual time slices show no evidence for a power law dependence. However, looking at the test's average (stars), the power law fits the data well (dashed line).

Although the individual time slices do not show the assumed power law dependence, the test means approximately do. However, the exponents show a high variance within each test and from test to test as documented in Table 1 and exemplarily shown in Figure 4.

Neutral to unstable atmospheric conditions (test 1, test 2, beginning of test 3) tend to lower values. This means that σ_v depends on the averaging period only slightly. For neutral to stable conditions (second half of test 3, test 4 and test 5) the exponents tend to higher values. In these cases, smaller averaging periods show a considerably lower σ_v (compare again Figure 2).

Table 1. Mean fitted exponents ($\pm$ σ) for the power law dependence of σ_v on the averaging time and stability class (derived with two different methods) as given in Clawson et al. (2009).

Test number	**1**	**2**	**3**	**4**	**5**
Fitted exponent average	0.13 ± 0.09	0.08 ± 0.09	0.15 ± 0.18	0.23 ± 0.15	0.38 ± 0.20
Pasquille-Gifford stability class	D / D	A / D	D / D	E–F / E-F	D-E / E-F

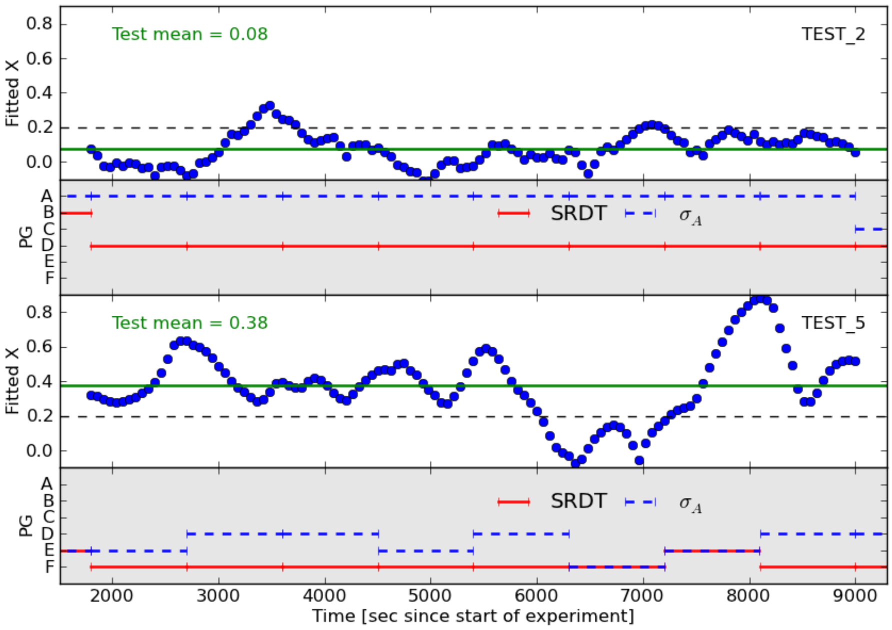

Figure 4 Fitted exponent X (blue dots) and Pasquill-Gifford stability class (PG) over time for tests 2 (top) and 5 (bottom). The test's average fitted exponent is represented by the green line. The dotted black line shows the value used in ARTM.

RESULT AND DISCUSSION

The analysis of the experimental data shows, that the standard deviation of the horizontal lateral wind speed fluctuations doesn't show a uniform dependence on the averaging period. In fact, an indication has been found, that the atmospheric stability class influences the dependence on averaging time. Further analysis (of additional data sets) in this regard has to be performed, however.

Using a single exponent in a power law to adjust the horizontal lateral wind speed fluctuations in the model to shorter than 3600s emission intervals, thus is a questionable approach. Especially an underestimation of the model exponent will lead to lower maximum concentrations calculated in the model for short term emissions compared to results calculated with a proposed higher value. To illustrate this, Figure 5 shows a qualitative comparison of two ARTM simulations for a simple test case: emission time 360 seconds, point source at (x=0, y=0, z=10m; black bullet), stable atmospheric conditions, flat terrain. Shown are the hourly mean ground level airborne concentrations of the emitted radionuclide (aerosols with aerodynamic diameters less than 2.5µm). The top figure shows the calculation using X=0.2, the bottom figure the calculation using X=0.3. The locations (white x) and the magnitudes of the simulated maximum concentrations differ clearly, with higher concentrations calculated by using the bigger exponent.

As the potential maximum concentration is the crucial parameter for the assessment of design basis events, the model results need to be appropriately conservative in this respect. Whether the used exponent of 0.2 fulfils this requirement (due to ARTM being ample conservative in other model assumptions), has to be evaluated further.

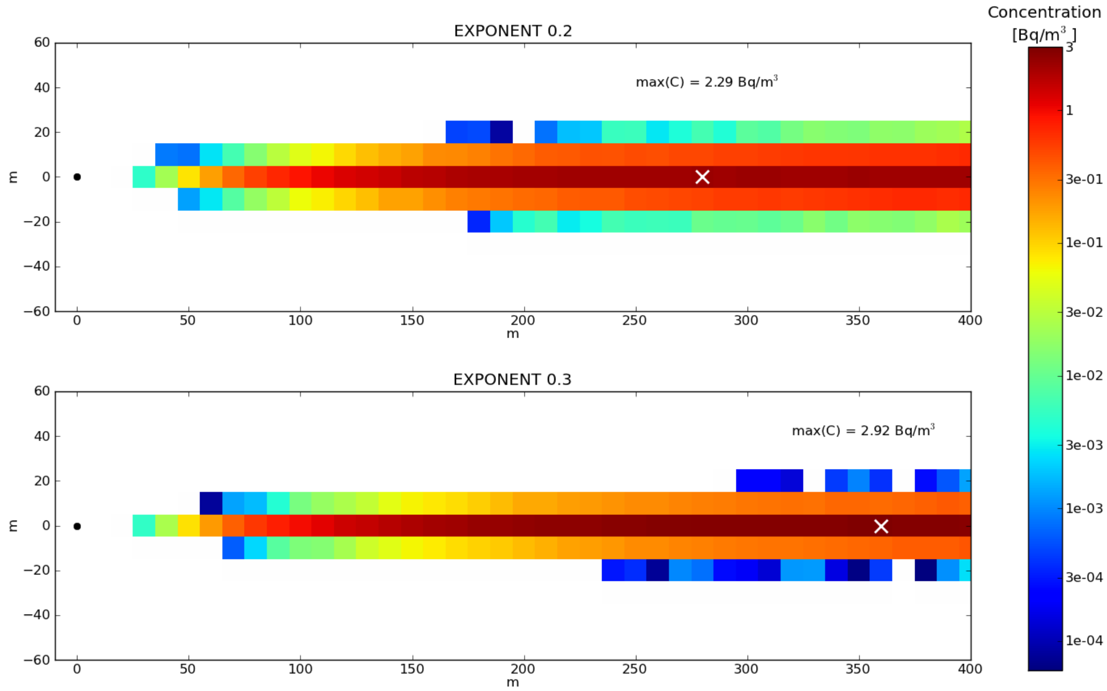

Figure 5 Qualitative comparison of two ARTM simulations (compare text).

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