Rosenthal, Eberhard; Lodomez, Philipp;
Henseler, Jessica; Hartmann, Julia; Büscher, Wolfgang and Diekmann, Bernd

Validation of a dynamic dispersion model concerning dust emitted by agricultural facilities

Immission prediction is necessary to give detailled and site-specific information on aerosol exposure due to animal husbandry facilities. In order to reproduce natural conditions, algorithms used in propagation modelling have become more and more complex. A verification technique, based on a fluorescent tracer aerosol and a corresponding tracer system, was developed and allows to validate a dynamic propagation model that was earlier developed in our work group.

Keywords
Dispersion modeling, validation, UPMS, dust, transmission, immission, exhaust air velocity

Abstract
Landtechnik 64 (2009), no. 2, pp. 98 - 101, 3 figures, 4 references

Especially in structured, agricultural areas propagation modelling often reaches its limits. Dynamic propagation models are used to take circulation around buildings and landscape components into consideration [Lodomez]. In order to validate new models, measurements under natural conditions are unavoidable. Dealing with the propagation of dust the usage of conventional measuring systems based on tracer gases is not possible. The reason is that aerosol specific physical properties can not be validated with this technique. This is why the work group Energy and Environmental Physics at the Institute of Physics at the University of Bonn, in cooperation with the Institute of Agricultural Engineering, developed both a dynamic propagation model called STAR3D and a technique to validate aerosol propagation models.

The dynamic propagation model STAR3D

STAR3D (Simulated transmission of aerosols in 3 dimensions) allows for a dynamic examination of aerosol propagation characteristics. This program is based on the earlier at the Institute of Applied Mathematics at University of Bonn developed software Nast3DGP [Griebel]. It solves the incompressible Navier-Stokes-equations for a freely adjustable volume via numeric approximation.

$$\frac{\partial \vec{u}}{\partial t} + \vec{u} \cdot \nabla \vec{u} = \frac{\vec{g}}{Fr} - \nabla p + \frac{1}{\mathrm{Re}} \Delta \vec{u} \qquad \text{[Eq.1]}$$

$$\nabla \vec{u} = 0 \qquad \text{[Eq.2]} \quad \text{(Navier-Stokes-equations)}$$

($\vec{u}$ = Wind velocity, $\vec{g}$ = external forces, p = pressure, Re = Reynolds number and Fr = Froude number)

Hereby it is possible to compute the wind field in a test volume under consideration of obstacles (buildings, trees etc.), as well as define the inflow unrestrictedly which allows to take the influx of exhaust air from chimneys into consideration.

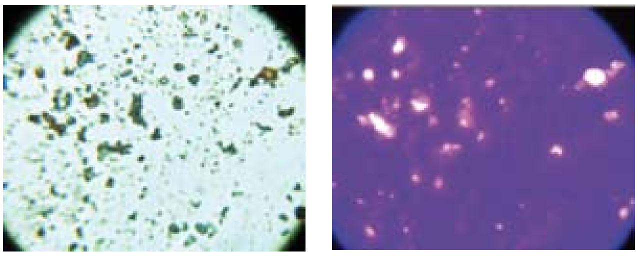
The simulated wind velocity field can be implemented into STAR3D to compute the particle trajectories following the equation

$$\frac{\partial \vec{x}_p}{\partial t} = \alpha_w \cdot \vec{u} + \lambda \cdot \vec{e} + \vec{v}_{sed} \qquad \text{[Eq.3]}$$

Here $\vec{x}_p$ denotes the particle position, α_w the coupling between the particle and the external wind velocity field, $\vec{u}$ the wind velocity at the particle's position, λ the diffusion constant, $\vec{e}$ a unity vector denoting the direction of diffusion and $\vec{v}_{sed}$ the particle's sedimentation velocity [Rosenthal]. Via the so computed particle distribution the total immission can be calculated for every time step using integration methods.

In order to validate such a method it is therefore useful to measure the aerosol concentration or the amount of deposed

Fig. 1



Sample, illuminated with transmitted white light (left) respectively incident ultraviolet light (right)

aerosol particles in regard to the spatial distance from the source with a suitable measuring procedure and to compare it to the simulation results.

The validation system

A general problem while investigating the propagation of aerosols under natural conditions is the relative high background aerosol concentration. Adding another source, e.g. another exhaust chimney or barn, does not increase the backgroud concentration significantly, respectively it is not possible to assign the particles to a distinct source. Therefore it is not possible to make reliable predictions about the transmission of aerosols.

This is why a suitable tracer must be found, that on one hand has similar properties to the dust under investigation and on the other hand holds distinct features that allow to identify the tracer efficiently and without mix-up. Furthermore the tracer must not be dangerous towards the health of man or animal, nor harm the environment.

The here described method uses BHA Visolite® by General Electrics as a tracer. This is a fluorescent powder based on Natriumcarbonat. To induce fluorescence the sample is enlightened with light of wavelength between 390nm – 400nm. The tracer's emmission spectrum lies in the range between 590nm and 650nm.

A validation method may be divided into several parts:

1. First of all the tracer must be transformed into an aerosol and released via a suitable exhaust air system. This is why a mobile exhaust chimney consisting of exhaust pipes with a diameter of 920mm was constructed at the Institute of Agricultural Engineering. A fan was installed inside the chimney and creates an exhaust air flow into which the tracer particles were dosed. The chimney was mounted onto a 1.5m high truck trailer, resulting in an exhaust height of 6.50m. The resulting exhaust air speed alternated around an average of 10m/s. This corresponds to a typical summer situation in a barn housing 200 pigs [Jungbluth]. With the help of an optical particle detector number and size of the particles contained in the exhaust air were measured.

2. The most important point in determining the quantities that govern propagation is weather measurement technology. In our case an ultrasonic anemometer of type USA-1 manufactured by METEK was used to measure the three component wind velocity, this means for every Euclidean direction in space a wind speed component is measured. Furthermore a stationary weather station next to the simulation area was used to measure wind direction, wind speed, air pressure, temperature and relative air humidity.

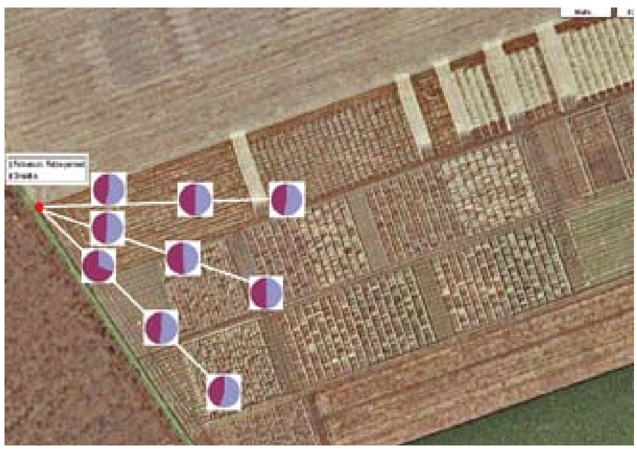
In order to detect the emitted tracer particles there must be measuring points in the propagation area. One has to distinguish if amount or concentration of aerosols is to be measured. In this case special deposition measuring devices were used. They consist of one meter high upright columns, carrying a holder for two glass slides. Every column is surrounded by a wind shelter that prevents the deposed particles from being stirred up again. Polysine® slides with a size of 76mm length and a width of 26 mm were used. The slides are coated in a way that particles are bound both electrostatically and chemically to the surface. In order to analyse the size and shape of the particles one needs a technique that can on one hand analyse the dust and on the other hand distinguish between tracer particles and dust.

The Universal Particle Measurement System (UPMS)

The UPMS is a measuring system that allows to analyse particles adhering to surfaces and contains an optical system that can be moved mechanically over any given surface in three dimensions. Particles adhering on the surface are pictured and later analysed. To distinguish between the collected dust in general and the tracer particles the surface is illuminated alternatingly with a transmitting white light source and an incident ultraviolet light source.

While the first method pictures all particles, the second shoot takes advantage of the tracer's fluorescent properties. One can easily see the according to their fluorescence spectrum glowing tracer particles while other particles remain dark **(Fig. 1)**. The surface is analysed step by step, taking two pictures of every spot. In order to stay in focus the distance between surface and objective must be held constant while deviations of only a few micrometers are already unacceptable. Therefore the position of the object is optimized mechatronically.

Fig. 2



Onview on the experimental area. The red point marks the point of emission, while the pie charts mark the points of dust collecting

For this reason the distance is varied for every position and the sum of the gradients of brightness of two adjacent pixel in the picture taken as an indicator for the picture's quality. This results in a huge amount of data that has to be proceeded. This is why a basic focussing process is implemented, but this so called Guided-Focus can be used only on planar surfaces. On the basis of reference data the objective is moved on a virtual focus layer in a constant distance to the surface. In this way the complexity of the focussing process can be reduced and the scanning process is accelerated. The image files are analysed using the graphic library OpenCV [OpenCV]. The evaluation process can be divided into several parts. First the sample is segmented. Afterwards connected pixel areas are identified as particles and their equivalent area is determined. Finally the UPMS provides an overview on number and size distribution of both dust in general and tracer particles. This way one can compare the simulation results to experimental data.

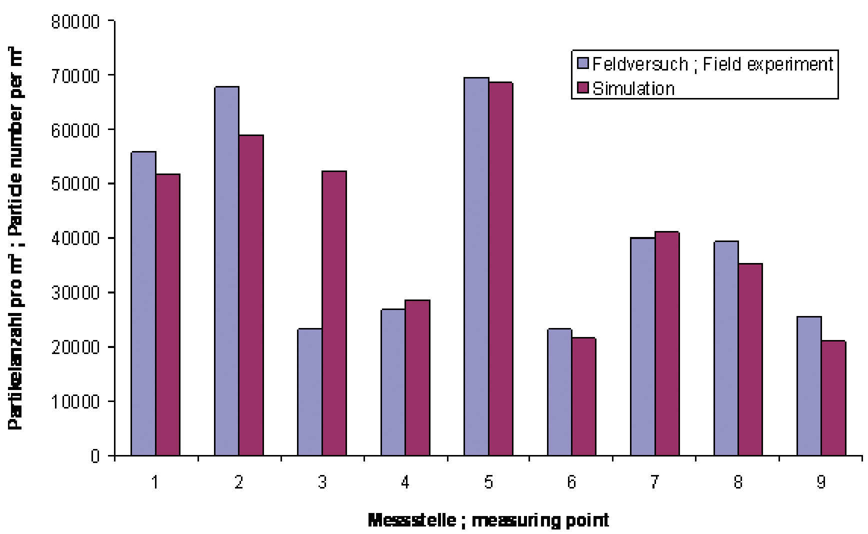
Results

In order to validate STAR3D and to test the validation system field tests were performed at the model and research farm Dikopshof. Beginning at the earlier described chimney 9 measuring points were installed on 3 rays **(see Fig. 2)**. The central ray headed north west, following the main wind direction. Two additional rays ran left and right from the central ray under an angle of 20°. The measuring points are aligned on the rays in a distance of 50m each. The emission point, located in the origin of the three rays, could be flown against freely. The average wind velocity that day was arout 3.5m/s.

Within an hour 140mg/s of tracer dust were emitted. Afterwards the glass slides were analysed in the lab using the UPMS. Meanwhile the progress of propagation was simulated with the help of STAR3D, using the wind velocity, emission data and average exhaust air velocity, that were measured every second during the test run, and tracer particle properties determined earlier in the lab. Here a simulation area of 200m width, 200m length and 40m height was chosen. The grid length was 1m, resulting in 1.6 million cells that had to be calculated for every time step. This results in a simulation time of three months.

Figure 2 and **figure 3** show measured (red) and simulated (blue) results compared in regard to the number of particles per square meter. One sees clearly that there is a good accordance between simulation and test run. It has to be taken into consideration that in the simulation a reduction depending on the particle size fraction was chosen. The simulation result was rescaled with a constant factor to allow for a comparison between results. Taking whole of the simulation area into consideration, a difference of about 14% can be found.

Fig. 3



Shown is the number of tracer particles per square meter for each of the nine deposition points. Experimental data is shown in red, while blue shows the simulation results.

Conclusion

In a test run it could be shown that our system can be used to validate propagation simulation. The UPMS was constructed and could proof its functionality under natural conditions. STAR3D can be used to simulate propagation sceneries. In a first test run a deflection of only 14% compared to the measurement results was found. However, one has to take into consideration that in our test run the area was planar and the emission source could be flown against freely. STAR3D in contrast was developed to simulate propagation in complex, cropped areas. Therefore the test run can be seen as a very simple case, for which also less complex propagation models with less computing time give good results. In spite of everything the results are promising and both UPMS and STAR3D provide the possibility for new methods of both simulating particle propagation and validating it.

Literature

[Lodomez] P. Lodomez, ; E. Rosenthal, J. Henseler; W. Büscher; B. Diekmann (2008): Dynamic Dispersion Modelling of Odours and Aerosols. 12th International Conference on Harmonization within Atmospheric Modelling for Regulatory Purposes. Proceedings, Zagreb, Vol. 43, ISSN 1330-0083

[Jungbluth] Jungbluth, Büscher, Krause, Technik Tierhaltung – Grundwissen Bachelor, Uni Taschenbücher GmbH, Stuttgart 2005

[Griebel] M. Griebel, T. Dornseifer and T. Neunhoeffer, Numerical Simulations in Fluid Dynamics, a Practical Introduction, SIAM, Philadelphia, (1998)

[OpenCV] Garry Bradski, Adrian Kaehler, OpenCV, O`Reilly, Beijing 2008

Authors

Dipl.-Phys. Eberhard Rosenthal and **Dipl.-Phys. Philipp Lodomez** are research assistants, **cand. Phys. Julia Hartmann** is graduand student, **Dr. Bernd Diekmann** is senior reasearcher of the work group Energy and environmental physics, is associate professor at the Institute of Physics at University of Bonn, Nussallee 12, 53115 Bonn. **Dipl.-Ing. Agr. Jessica Henseler** is reasearch assistant, **Prof. Dr. Wolfgang Büscher** is head of „Livestock Technology“ at the Institute of Agricultural Engineering, University of Bonn, Nussallee 5, 53115 Bonn; e-mail: rosenthal@uni-bonn.de