19th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
3-6 June 2019, Bruges, Belgium

IDENTIFICATION OF ODOUR SOURCES IN THE ORE MOUNTAINS BY COSMO-MUSCAT SIMULATIONS

Ralf Wolke, Roland Schrödner, Matthias Faust

Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, 04318 Leipzig, Germany

Abstract. During the last years, the local authorities of the Ore Mountains region, Saxony, Germany have received an increasing number of complaints about malodour events in their localities. These events are mainly observed for specific weather situations with southerly wind. The origin of the malodour is presumably in the North Bohemian Basin. However, the malodour is not recognized in near-emission areas. Therefore, it is suspected that the fetid substance is formed by chemical transformations or mixing of different air masses. The search for the malodour sources using chemistry transport modelling is presented in the paper. The investigations are performed with the chemistry transport model system COSMO-MUSCAT and the Lagrangian particle model COSMO-LaPaSi. Horizontal grid resolutions up to 100 m are used for an appropriate description of the mountainous topography and the exact location of the emissions. Additionally, to usual dispersion calculations, a detailed analysis of forward and backward trajectories is performed. A result of the present study is the fact of the accumulation of air masses in the North Bohemian Basin, which occurs in most cases. Thus, many potential sources of malodorous substances can come into question. Those can be related to a larger industrial area at its best.

Key words. *Chemistry transport modelling, source appointment, Lagrangian particle model, inversion layer, stagnating weather conditions*

INTRODUCTION

The air flows in the Ore Mountains for three selected periods were analyzed and visualized with the aid of model calculations with high temporal and spatial resolution (with horizontal grid widths of up to 200 m). The aim of the investigations was to identify possible causes for the malodor events that occurred and to exclude industrial plants and areas as causes. In doing so, flow patterns and vertical exchange processes were investigated which lead to the accumulation of pollutants in the Bohemian Basin and/or the transport of air masses over the Ore Mountains ridge. Due to the high spatial resolution, the effect of the complex orography on ground-level air flow should be reproduced as realistically as possible.
Three different types of models were used for the investigations:

1. offline calculation of backward trajectories with the model LAGRANTO (Miltenberg et al., 2013),
2. derivation of source-receptor relationships and visualization of flow patterns using COSMO-MUSCAT (Wolke et al., 2012) for passive tracers from fictitious point sources at different heights above ground,
3. dispersion calculations with the Lagrangian particle model LaPaSi (Faust, 2017) coupled online to COSMO.

Three malodor episodes were selected for the investigations, which led to frequent complaints from citizens of the Ore Mountains region. In addition to the citizen reports, these episodes were also registered by trained probands as part of the EU project OdCom. Therefore, it can be assumed that the information provided here is more accurate and reliable. Here we analyze and discuss exemplarily only one of the three episodes, the 25/26 January 2018.

MODEL DESCRIPTIONS AND SETUP

The Chemistry Transport Model COSMO-MUSCAT

The simulations were performed with the multi-scale model system COSMO-MUSCAT (COnsortium for Small-scale Modeling – MUltiScale Chemistry Aerosol Transport), which has been developed at TROPOS for predicting the dispersion of air pollutants on the local and regional scale (Hinneburg et al., 2009; Stern et al.; 2008; Chen et al., 2018) and aerosol radiative feedback studies (Meier et al., 2012). Driven by the meteorological model COSMO, the online-coupled chemistry transport model MUSCAT treats the atmospheric transport as well as chemical transformations for several gas phase species and particle populations. The transport processes include advection, turbulent diffusion, sedimentation, dry and wet deposition. For a detailed description, we refer to Wolke et al. (2012) and the related model Web page (https://cosmo-muscat.tropos.de/). Different source appointment techniques have been implemented in COSMO-MUSCAT to describe transport and linear chemical turnover for selected emitters (Chen et al., 2018; Jähn et al., 2013). Thus, different source regions as well as different emitter groups can be investigated.

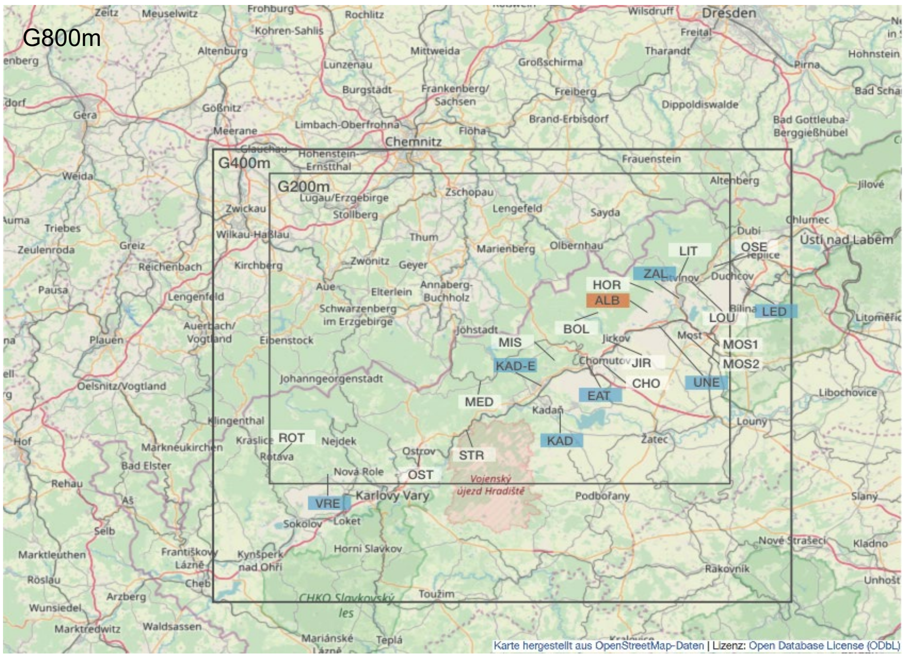

Figure 1. Overview of the model areas and tracer sources. Sources highlighted in blue are industrial sites or power plants. The white background contains additional hypothetical sources for a better differentiation of possible source regions. (Image source of the map: *OpenStreetMap.)*

COSMO-MUSCAT was used in the context of this work to limit or exclude source regions for the three investigation periods. For this purpose, the model was used to simulate the propagation of tracers from potential point sources of industrial plants and power plants as well as from purely hypothetical sources (to characterize a source region). Since a high temporal and spatial accuracy is aimed at for the localization of the pollutant sources and the area under consideration is characterized by a pronounced orography, the simulations were carried out with a horizontal grid resolution of about 200 x 200 m^2 and 50 vertical layers. A usual hierarchical grid nesting technique was applied for forcing the simulation in this finest inner domain. Figure 1 shows the spatial coverage of the three domains and the locations of the investigated sources. The simulations in the outer domain (G800m) were driven by COSMO reanalysis data with 2.7

km resolution provided by the German Weather Service. The model results with 400 m and 200 m horizontal resolution were used for the analysis. For most sources, the emission was considered at ground level (approximately 10 m above ground) and at approximately100 m above ground. For the sites ZAL, KAD-E and UNE tracers were also emitted 200 m above ground and for UNE 300 m above ground. The source ALB represents a brown coal opencast mining. In order to cover this large source, a total of 6 sources were distributed over the surface of the mine and combined for analysis, whereby only tracers close to the ground were emitted.

Backward trajectories with LAGRANTO and the Lagrangian particle model LaPaSi

Backward trajectories can be used to track the route taken by air parcels arriving at a specific destination at a specific altitude. The output data of the meteorological model COSMO were used (usually in hourly resolution) to reconstruct the route. Within the project, the trajectory model LAGRANTO (Miltenberg et al., 2013) was used. Backward trajectories were created for all test person reports, whereby trajectories were observed within a radius of 500 m to 1 km and up to 150 m above ground at the test person location. For the analysis, the trajectories were traced back up to 6 hours.

In contrast to the "classical" trajectory model, the Lagrangian particle model calculates the trajectories for "many emitted particles". In order to take the turbulence of the atmosphere into account, the individual trajectories are stochastically disturbed. This leads to a crowd of trajectories, which on average correspond to the direction of motion of the wind field. The scattering of the trajectories represents the turbulence and illustrates the uncertainties of the calculated trajectories. The Lagrangian particle model LaPaSi (Lagrangian Particle Simulation; Faust, 2017) was developed as a module within the weather forecast model COSMO at TROPOS and is thus coupled online to COSMO. This means that LaPaSi is supplied with new meteorological fields with every time step (usually in the order of a few 10 seconds). Thus, the particle transport can be mapped more realistically than with offline driven particle models (time resolution of forcing ~0.5 - 1 h).

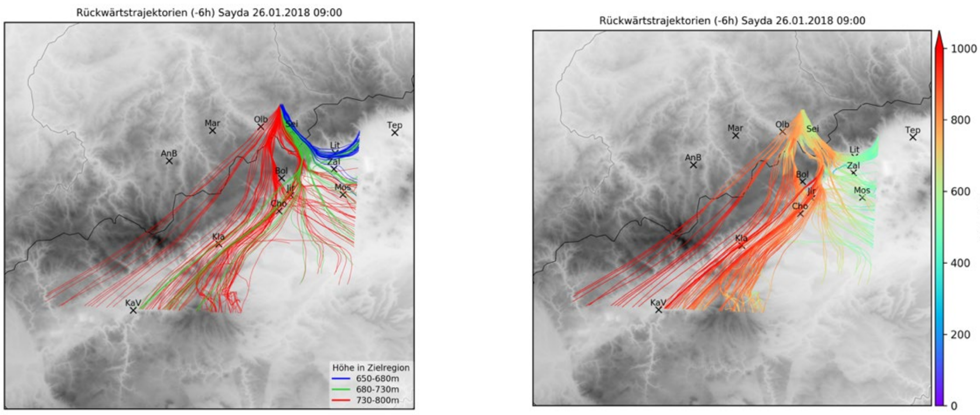

Figure 2: Backward trajectories (6 hours back) for Sayda, Germany, on 26/01/2018 09:00. Left: Coloured according to height at the target area (blue: low, green: medium-high, red: high). Right: Coloured by absolute altitude. (Orography data: *NASA SRTM v4.1.)*

ANALYSIS OF THE SELECTED PERIOD (25/26 January 2018)

Meteorological characterization. On both days, temperatures were slightly above zero during the day and slightly below zero at night. The stratification in the lower layers of the atmosphere was stable. The altitude of temperature inversion was about 1200 m on both days. On 25/01/ the vertical mixing was severely restricted with near-ground mixing layer heights partly below 100 m in the North Bohemian Basin. On 26/01/, the vertical mixing was much stronger with mixing layer heights of more than 300 m. The vertical mixing of the two layers was also much more pronounced. On both days, it was often foggy in the North Bohemian Basin and on the ridge of the Ore Mountains. In the Bohemian Basin spray rain was occasionally observed. Both days are again characterized by low wind speeds in the valleys on the Czech side of the Ore

Mountain (max. 10 km h^{-1}). In the high altitudes, especially 26/01/ strong wind was observed (> 40 km h^{-1}). In the North Bohemian Basin, the wind blew on 25/01/ first from Southwest directions. From approximately 18:00 the wind turned towards Southeast and in the further process of 26/01/ towards North (from about 14:00).

Source appointment modelling. The trajectory analyses show that no transport from the East and Southeast to the observation sites took place until around 18:00 on 25 January. During this period, low trajectories point west along the northern edge of the North Bohemian Basin via Jirkov, Chomutov, Kadan to Karlovy Vary and run close to the ground (within the lowest 100 m above ground). Air parcels in higher layers at the destination (50 to 150 m) were transported along the main ridge of the Ore Mountains in higher layers at high wind speeds. Lower backward trajectories in Litvínov point to the area around Zaluzi and Most and somewhat west of them. After 18:00 low trajectories at all locations point to the area between Litvínov, Most and south of it. At Litvínov, all air parcels arrive from the east at 21:00. On 26/01/, the trajectories for the investigated sites fan out strongly and point to a catchment area extending from Jirkov via Most and Litvínov to Teplice. Low trajectories point more to the east (blue), while medium trajectories point to the area around Litvínov and Most (green, see Figure 2). Air parcels along both trajectory categories cover the area near the ground. In the afternoon, the wind turns to northern directions, so that hardly any backward trajectories point to the south.

Table 1. Brief overview of probands reports

Time period (25/01/2018)	Location	Time period (26/01/2018)	Location
25/01/2018, 06:00 – 24:00	Seiffen	26/01/2018, 00:00 – 10:00	Olbernhau
25/01/2018, 07:40 – 10:00	Steinhübel	26/01/2018, 17:00 – 24:00	Olbernhau
25/01/2018, 09:00 – 21:00	Litvínov	26/01/2018, 05:00 – 15:00	Seiffen
25/01/2018, 17:00 – 22:00	Olbernhau	26/01/2018, 06:00 – 10:00	Sayda
25/01/2018, 18:00 – 23:00	Sayda	26/01/2018, 07:00 – 08:00	Steinhübel

The reports in Litvínov, Olbernhau and Sayda can only be explained by the sources ZAL and ALB for the entire period reported (see Table 1). Partial matches were found at the three locations with resulting tracer concentrations from the sources MOS2, BOL, LIT, HOR, LOU, OSE, JIR and UNE. The reports in Steinhübel only agree completely with the concentration curves of the sources BOL, MED and MIS.

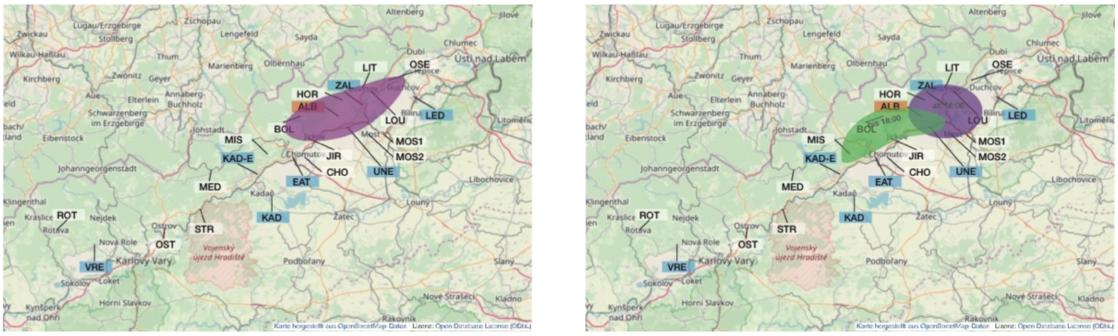

Figure 3: Source regions for 25/01/ (green: until 18:00 h, purple: from 18:00 h, left) and 26/01/2018 (purple, right) that best match the respondent reports. (Image source of the map: *OpenStreetMap*.)

None of the investigated sources can explain the total time period reported at Seiffen. No sources west of HOR do reach this site after 18:00 on 25/01/ (time of the wind turn). Air parcels from locations east of HOR as well as HOR itself will only be transported to Seiffen from this time on. The sources ALB and UNE show the longest period with agreement. On 26/01/ most reported periods can be explained by the sources OSE, ZAL, ALB, UNE and BOL. There is no agreement with one of the investigated sources for the reporting in Olbernhau in the afternoon (17:00 to 24:00). Since the wind at that time was blowing from northern directions, the sources considered are out of the question. Also, the backward trajectories from 19:00 point to the northeast. Between 17:00 and 19:00 the backward trajectories indicate transport within the valley and the neighbouring valleys from directions Seiffen and Sayda. In summary (see Figure 3) all sources southwest of Chomutov can be excluded. Likewise, on 25/01/ before 18:00 sources east and northeast of Most do not contribute. For the evening of 25/01/ sources southwest of Most can be excluded.

On 26/01/ only sources within a large area stretching from Jirkov to Osek do contribute. A possible source region for the observations in Olbernhau in the evening cannot be determined.

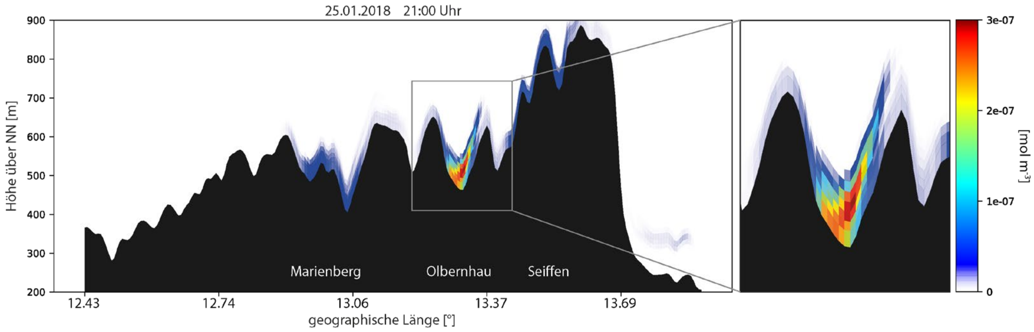

Figure 4: Vertical sections through the model area on a line from Marienberg via Olbernhau to Seiffen on 25/01/2018 21:00 (left, cf. Figure 5) and the section enlarged by Olbernhau (right). The height of the concentration refers to an assumed constant source strength of the point sources of 1mol s^{-1}.

Vertical exchange. In addition to the analysis of the air flow and the source-receptor relationship, the vertical distribution of the emitted tracers was also investigated. Figure 4 shows the concentration of the tracers (sum of the sources CHO, BOL, ZAL) along a line Marienberg-Olbernhau-Seiffen (see line in Figure 5). The tracer was transported along the valleys (i.e. into the diagram). It can be seen that the tracers emitted into the atmosphere in the Bohemian Basin are still concentrated in the lowest atmospheric layers (lowest approximately 100-200 m). This fact was observed in all episodes. In addition, it can be seen that the different tracers, due to the complex orography of the mountainous landscape, can spread from their source on different paths (cf. Figure 5). In the valley of Olbernhau (see section on the right in Figure 4), it can be seen that for the specific time and the tracers shown on the western side of the valley the highest concentrations occur directly on the ground and on the eastern side of the valley at about 50-100 m above ground. However, for other cases different concentration distributions were found in the valley cross-section, so that no generally valid conclusions can be derived from these observations. Rather, it shows the frequently observed high small-scale variability of tracer concentrations.

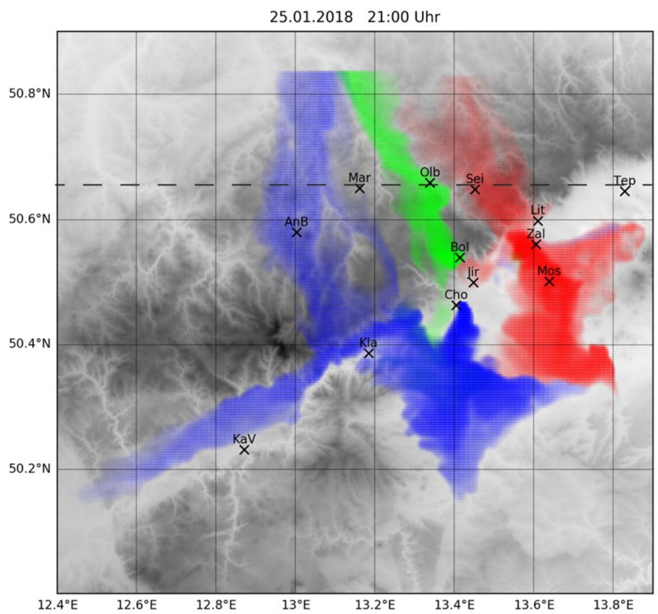

Figure 5: Concentration of the tracers from the sources CHO (blue), BOL (green) and ZAL (red) on 25/01/2018 21:00. Low concentrations are shown transparent, high concentrations opaque. The dashed line marks the position of the vertical profile in Figure 4.

CONCLUSIONS

It is already known from earlier studies that malodor events occur mainly in high-pressure and inversion weather conditions, with weak wind, as well as an inflow from southern directions (Jähn et al., 2013). The air masses accumulate at the Ore Mountains in the North Bohemian Basin. When the inversion is broken up or the wind is increased, the emission mix is transported over the ridge and leads to increased odor nuisances in the Ore Mountains region. This mechanism is also confirmed by the present study for the selected periods. In addition to the typical weather situation, the three episodes analyzed were partly characterized by snow on the ground and fog. The flow patterns occurring during the overflow of the Ore Mountains ridge depend very strongly on the fine structure of the orography (e.g. mountains and valleys, incisions at the ridge). In earlier simulations with horizontal grid resolutions of more than 1 km, these could not be resolved accurately. In the now performed high-resolution model calculations (with grid spacing of 200 m) also fine flow patterns could be visualized and analyzed. This made it possible to investigate individual transport routes through the valleys and circulations within the valleys in more detail and also to map the vertical transport better.

After considering the three time periods, no clear allocation to a source or region can be made that could explain all the malodor complaints considered. With certainty, only the sources in the west of the investigated area (west and south of Chomutov) can be excluded as causes of the malodorous substances. For each of the periods studied, source regions can also be narrowed down and others excluded, but different from those on other days. In particular, none of the sources studied can explain all the reports made by volunteers. In the trajectory and tracer propagation analyses, the most frequent source region is the area around the Albrechtice opencast brown coal mine.

ACKNOWLEDGMENT

The authors would like to thank the Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie (LfULG) for funding of this project and good cooperation. Furthermore, we gratefully acknowledge the ZIH Dresden, the JSC Jülich and the DWD Offenbach for the support of this work.

REFERENCES

Chen, Y., R. Wolke, L. Ran, et al., 2018: A parameterization of the heterogeneous hydrolysis of N2O5 for mass-based aerosol models: improvement of particulate nitrate prediction. Atmos. Chem. Phys., **18**, 673-689, doi:10.5194/acp-18-673-2018.

Faust, M., 2017: Entwicklung eines Lagrangeschen Partikel Dispersions Modells zur Identifizierung von Geruchsquellen im Erzgebirge. Master Thesis, University of Leipzig, Germany.

Hinneburg, D., E. Renner, R. Wolke, 2009: Formation of secondary inorganic aerosols by power plant emissions exhausted through cooling towers in Saxony. *Environ. Sci. Pollut. Res.*, **16** (1), 25-35 (doi:10.1007/s11356-11008-10081-11355).

Jähn, M, R. Wolke, B.Sändig, 2013: Detection of odor sources and high concentrations of pollutants in the Ore Mountains by modeling of air mass paths. *Meteorologische Zeitschrift,* **22** (2), 213–220.

Miltenberger, A.K., Pfahl S., and Wernli H., 2013: An online trajectory module (version 1.0) for the nonhydrostatic numerical weather prediction model COSMO. *Geosci. Model Dev.,* **6**, 1989–2004, doi:10.5194/gmd-6-1989-2013.

Stern, R., P. Builtjes, M. Schaap, R. Timmermans, R. Vautard, A. Hodzic, M. Memmesheimer, H. Feldmann, E. Renner, R. Wolke and A. Kerschbaumer, 2008: A model intercomparison study focussing on episodes with elevated PM10 concentrations. *Atmos. Environ*., **42** (19), 4567-4588.

Wolke, R., W. Schröder, R. Schrödner, E. Renner (2012): Influence of grid resolution and meteorological forcing on simulated European air quality: A sensitivity study with the modeling system COSMO–MUSCAT, *Atmos. Environ*., **53**, 110-130.