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THE OPS PLUME AND TRAJECTORY MODEL AND ITS APPLICATIONS

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Abstract: The OPS model has been used throughout the last few decades in various studies for policy support as well as in research projects. It is applied for pollutants such as particulate matter and compounds such as SO_2, NO_x and NH_3. Recently, the OPS short-term model has been extended to calculate the exposure of residents to other substances emitted by livestock farms. This includes firstly the dispersion of endotoxins and micro-organisms, which could potentially cause detrimental health effects (e.g. respiratory symptoms, influenza) and secondly the dispersion of odour, used in studies on odour nuisance. We will briefly introduce the model and present a number of applications with emphasis on the dispersion of substances released by livestock farms.

Key words: *Atmospheric dispersion model, OPS, livestock farms, particulate matter, ammonia, endotoxins, micro-organisms, odour, living environment, public health studies*

INTRODUCTION

The Operational Priority Substances (OPS) model is an atmospheric dispersion model for airborne pollutant substances. It is used in the Netherlands for a large number of environmental issues. This ranges from producing large-scale concentration and deposition maps to monitor the national air quality cooperation programme (NSL), to calculating nitrogen deposition on hectare scale in Natura 2000 areas to monitor the PAS (Programma Aanpak Stikstof: Integrated approach to nitrogen) and to support licencing for economic activities associated with nitrogen emissions as part of PAS.

Furthermore, OPS is used in various research studies, with recently more and more emphasis on substances released by livestock farms. For instance, the short-term version of the model is used to study the dispersion of bio-aerosols in health related studies (Van Leuken et al., 2015; Hagenaars et al., 2017). Hereafter, the model was extended for several other purposes, such as the dispersion of odour. The long-term model is used, for instance, to study the association between medication use for asthma and COPD and the primary particulate matter emissions from livestock farms.

By using the same model for new applications regarding health related problems (endotoxins, micro-organisms, odour), knowledge on the transport, dispersion and removal processes is reused. This guarantees consistency in how airborne substances are modelled and is therefore more efficient in terms of knowledge and budget. It also increases the acceptance of model results by peers, policy makers and the public.

THE ATMOSPHERIC DISPERSION MODEL OPS

The OPS model is a transport and deposition model that describes relations between individual sources and individual receptors by Gaussian plumes. It makes use of trajectories for the long-range transport. For a certain location, the contributions of the individual sources are summed to obtain the total concentration at that location. Besides dispersion and transport, the model takes into account chemical conversion and dry and wet deposition. For living micro-organisms, inactivation is included as they may die-off due to environmental and meteorological factors such as temperature (Hagenaars et al., 2017).

Primary meteorological data measured at 19 sites by the Royal Netherlands Meteorological Institute (KNMI) are provided to the model, being wind speed, wind direction, global radiation, temperature, relative humidity, precipitation duration and intensity. First, these are spatially interpolated over the Netherlands to a 10 km by 10 km grid using a weighting factor depending on the distance between the station and the grid point. In order to make the system less vulnerable to missing data from one station, district / regional averages are calculated (Figure 1). The primary meteorological data are used to determine a.o. the Obukhov length, friction velocity and sensible heat flux, which are used to determine the boundary layer height. These also serve as input to determine the amount of turbulence from which the dispersion lengths are calculated.

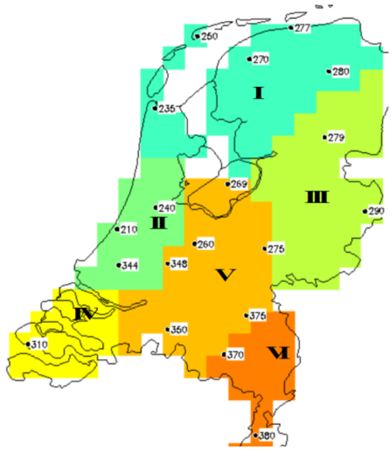

Figure 1. OPS meteorological districts and locations of KNMI stations (Source: Sauter et al., 2018).

Trajectories are applied to represent the long-range transport. To account for the real travel distance along the trajectory, the source is shifted to a virtual location after which the Gaussian plume formulation is applied. Two versions of OPS exist, being the long-term (OPS-LT) and short-term (OPS-ST) version. Most processes are modelled in the same way for both versions. The major differences are described below. More information on the OPS parameterizations can be found in Sauter et al. (2018).

OPS-LT uses statistics of 'long-term' meteorological data (e.g. monthly or yearly) and calculations are performed for a number of typical meteorological situations (classes) to include the effects of different stability regimes in the atmosphere. Three classes for stability (unstable, neutral and stable) and two classes for mixing height (relatively low and relatively high) were chosen. Furthermore, model parameters and average trajectories are computed for 12 wind direction sectors and for 4 representative distances (local, intermediate (100 km), long (300 km) and very long (1000 km and up). Concentrations and depositions are obtained by summing values per class, weighted according to their relative frequency of occurrence. To determine the contribution of an arbitrary source, inter- and extrapolation is used between wind directions and distances (Sauter et al., 2018).

OPS-ST uses hourly meteorological data such that hourly concentrations can be calculated, making it suitable to compare output with short measurement campaigns or to study diurnal variations. For the trajectories, so-called segmented Gaussian plumes are used. OPS-ST keeps track of a trajectory of each plume segment in a plume which is divided in 96 segments (4 days). The characteristics of this trajectory (e.g. wind speed, wind direction, temperature, Obukhov length, friction velocity) are updated hourly.

APPLICATIONS OF OPS

Concentration and Deposition maps (OPS-LT)

The OPS-model is used for a large number of environmental issues in the Netherlands. For example, the RIVM (National Institute for Public Health and the Environment) produces year-averaged maps showing airborne concentrations of several substances (e.g. NH_3, PM_{10}, NO_2, SO_2) and maps showing deposition (e.g. for nitrogen) (Velders et al., 2018). The resolution is 1 km × 1 km. These maps are based on a combination of model calculations with the OPS-LT model and calibration with measurements and as such provide a large scale picture of the air quality in the Netherlands.

These maps for both the current year as for future years up to 2030 are made yearly in order to monitor the NSL, a national air quality cooperation programme (Rutledge-Jonker et al., 2018). OPS is also used in the calculation tool AERIUS, which calculates deposition at hectare level for Natura 2000 areas. This is used for the monitoring of the PAS, an integrated approach to nitrogen (Marra et al., 2019). Both programmes check on how spatial planning affects airborne concentrations of pollutants (NSL) and nitrogen deposition (PAS).

Exposure to livestock related emissions

There has been interest in the impact of livestock farms on air quality issues for a long time. For instance, the deposition of ammonia emitted from animal housings and during manure application leads to eutrophication of soil and vegetation as well as acidification of the soil. This can have a detrimental effect on biodiversity. Livestock farms also emit particulate matter (PM) and chemical conversion of ammonia to secondary inorganic aerosol also contributes to higher PM levels, influencing the air quality.

Since several years, there is an increased interest in the health of residents living nearby livestock farms. Besides PM, livestock farms might emit endotoxins (cell wall substances of micro-organisms) and micro-organisms/zoonoses. PM and endotoxins are linked to respiratory health effects such as pneumonia, asthma and COPD (Smit and Heederik, 2017). Pathogenic micro-organisms could cause infectious diseases, such as Q fever and avian influenza (Van Leuken et al., 2015, Smit and Heederik, 2017). Odour from livestock farms may cause nuisance in the living environment and could indirectly pose a risk to public health.

Below, several studies are briefly presented in which the OPS model is applied for the above-mentioned substances related to exposure and health.

1. Effect of emission exit velocity on dispersal of odour, endotoxins, PM, and ammonia (OPS-ST)[1]

As part of the VGO study (Livestock Farming and the Health of Local Residents, Maassen et al., 2016; Hagenaars et al., 2017, Sterk et al., 2018), the OPS-ST model was applied to estimate exposure of local residents to endotoxins and micro-organisms. A follow-up study is started to investigate the effect of certain measures to reduce e.g. odour and PM_{10} exceedances in conjunction with the dispersal of substances such as endotoxins and ammonia. The reason for this is that it is possible that an intervention, such as heightening stack height or increasing exit velocity, reduces a nuisance or exceedance (e.g. malodour, PM_{10}) locally, but at the same time leads to a wider dispersion of e.g. endotoxins from livestock farms. Thus, more people might be exposed.

OPS-ST is used here, as the hourly values can be used to determine 98-percentiles needed for odour and to determine the number of exceedance hours of 8-hour average values of endotoxin concentrations > 30 EU m^{-3} (EU = Endotoxin Units). The latter is the health-based recommended exposure limit proposed for the general population (Health Council, 2012). Necessary model adjustments were:

- Implementing the option for odour dispersal (assuming no chemical conversion or deposition)
- Modelling plume rise due to momentum (according to Briggs (1969) and Turner (1986))

Calculations for PM_{100} were performed with output in 7 particle size classes. Particle size distributions were derived from measurements by Lai et al. (2014) and Winkel et al. (2015) by estimating the optimal underlying cumulative mass distribution using Bayesian statistics. The concentrations per PM class were multiplied with the endotoxin contents published in Ogink et al. (2016) to retrieve the endotoxin concentrations.

For two existing situations with either mostly poultry, or mostly fattening pigs, model calculations were

[1] This project was carried out on behalf of the Dutch ministry of I&W.

performed where for a single livestock farm the exit velocity or stack height was varied. An example for an increased exit velocity is given in Figure 2. As expected, in general a reduction of concentrations (here up to several hundreds of meters up to several km) is found. Hence, the exposure of the people in the vicinity of the source(s) to these substances decreases. However, concentrations increase at further distance from the source. The distance at which the decrease changes into an increase is generally smaller for coarser material and larger for fine dust and gases. In these particular cases, it was around 4.5-5.5 km or further for odour, PM_{10} and endotoxins, around 2-3 km for ammonia and a few hundred meters to ~2.5km for PM_{10-100}. The absolute decrease in concentration locally is many times greater than the absolute increase in concentration at further distance. Even though endotoxin contents are in general higher for the larger PM fractions, a concentration increase is still found relatively far away. Though indeed the switch in decrease/increase is located relatively close to the source for the coarser PM, this is apparently compensated by the lower endotoxin concentrations in the finer PM for which the switch is at a relatively large distance.

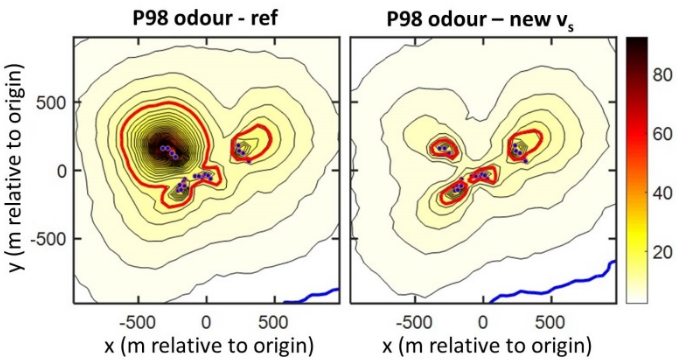

Figure 2. The 98-percentile of all 2015 hourly values for odour (Odour Units m^{-3}) for the poultry reference case ($v_s = 0.4\ ms^{-1}$) and case with new exit velocity ($v_s = 5.5\ ms^{-1}$). The red and blue contour lines represent 14 (standard rural area) and 3 OU m^{-3} (standard built-up area) respectively. The blue circles represent the included sources.

When compared with population density, we find for these cases that more people are exposed to lower concentration levels, while the amount of people being exposed to higher concentration levels decreases. Only for coarse PM (PM_{10-100}) more people are exposed to the highest concentration class. For ammonia, we also find increased deposition further away which could have consequences for the granting of permits under the PAS. The area with 8h-average 30 EU m^{-3} exceedances decreases, as does the number of hours for which this occurs.

Note that results strongly depend on the local situation: where sources are located and where people live. For substances for which certain standards need to be met, also the level of existing background concentration must be considered. An increase in concentration, however small, may lead to the standard being exceeded.

2. Associations between medication use for Asthma and COPD and proximity of livestock farms in the Netherlands (OPS-LT)[2]

The aim of this study was to analyse medication use for asthma or COPD in relation to the proximity of livestock farms containing specific animal species. One way to do this was to define exposure based on modelled livestock-related particulate matter concentration (PM_{10}). Separate maps were produced for the different animal groups using OPS-LT on a high resolution of 250 m × 250 m. Particle size distributions were derived similarly as for study "1" described above, for those animal types for which measurements were available. For the other animal types, a standard particle size distribution for agriculture is applied. An example for the PM_{10} concentration resulting from all cattle sources is given in Figure 3.

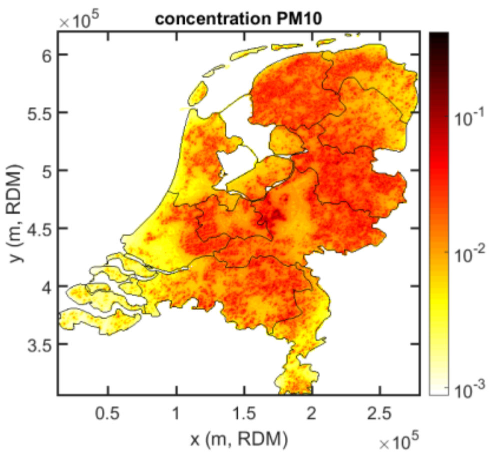

Figure 3. PM_{10} concentrations (μg m^{-3}) due to all cattle sources in the Netherlands.

[2] Part of this research was carried out in the framework of the RIVM Strategic Programme (SPR).

Subsequently, these livestock related PM_{10} exposures were coupled with data on medication dispenses for treatment of asthma/COPD in 2016 as well as data on several personal characteristics. Preliminary results show that the contribution of cattle farms to local PM_{10} concentrations was generally negatively associated with medication use after adjustment for PM from other sources. The pooled odds-ratio (factor by which change ratios (the odds) differ) for the Netherlands, for the increase in exposure by 10-90 percentile is 0.93, with a 95% confidence interval of 0.87-0.98. A negative odds ratio implies a negative association and hence in this case less medication dispense related to PM_{10} concentrations caused by cattle. Associations with exposure related to other animals than cattle were less evident.

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