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VALIDATION OF GAUSSIAN PLUME MODEL AEROPOL AGAINST CABAUW FIELD EXPERIMENT

Marko Kaasik[1] *, Gertie Geertsema*[2] *and Rinus Scheele*[2]

[1]Institute of Physics, University of Tartu, Tartu, Estonia
[2]Royal Netherlands Meteorological Institute, De Bilt, Netherlands

Abstract: The Gaussian dispersion model AEROPOL is validated against Cabauw (1977 – 1978) data set, applying the parameters and rules described in the Model Validation Kit. The purpose to revisit this classical experiment is preparation for fast response to elevated (buoyant) accidental releases. In AEROPOL model (Kaasik & Kimmel, 2003) two alternatives for dispersion parameterisations are used: (i) classical Pasquill-Gifford stability and (ii) a scheme based on Lagrangian time scales by Gryining *et al.* (1987). Validation is based on correlation, fractional bias, fractional sigma, NMSE and fraction in factor 2, applying these statistics to maximal arc-wise, near-centreline and cross-wind integrated concentrations. Both parameterisations are found fairly adequate. Pasquill-Gifford parameterisation performs somewhat better, except for correlations, which exceed even 0,9 with Gryning scheme. Gryning scheme results in too wide Gaussian spread and thus, lower maxima compared to measurements, whereas the Pasquill parameterisation gives sharper maxima, which makes the statistics more sensitive to the small discrepancies in plume position. The average wind speed and direction between the lowest measurement level and release level was found a good approximation for effective wind according to position of Gaussian plume.

Key words: *Gaussian plume, dispersion experiment, Cabauw, AEROPOL***,** *HARMONIE***,** *Model Validation Kit.*

INTRODUCTION

The purpose of revisiting the classical dispersion experiment in Cabauw (Agterberg et al., 1983) is a better understanding of dispersion from elevated (buoyant) accidental releases, such as 2011 in Moerdijk, and preparation for fast response.

A fire at the chemical plant Chemie-Pack on January the 5th of 2011 resulted in a large-scale accident with the release of many different hazardous materials. The accident lasted almost a day, though the fire was under control after some ten hours. Due to the enormous heat the hazardous material was ejected into the atmosphere at heights of several tens of meters to hundreds of meters, where the wind direction was more easterly (veered) with respect to the wind at lower heights. Moerdijk is about 40 km south of the port of Rotterdam and even closer to the cities Dordrecht and Rotterdam, which are part of the densely populated western parts of the Netherlands which include The Hague and Amsterdam, and the impact could have been disastrous. Luckily the weather situation was such that the hazardous material was dispersed at higher altitudes. Due to vertical shear the plume was essentially split over two heights. The lower plume moved towards the city of Dordrecht. Shipping traffic towards the Moerdijk area was halted and the motorway was closed. The upper plume was advected in the direction of Flevoland where much of the food for the citizens is grown, resulting in another concern for public health.

Extensive evaluation of the accident showed the need for mesoscale dispersion models capable of capturing vertical wind shear and precipitation. Dispersion models available to assist the emergency responders were either appropriate for short range and short-lived accidents or for long range accidents. The Moerdijk accident showed the need for high-resolution dispersion models using numerical weather forecasts up to a distance of several tens of kilometers. A project to implement a mesoscale dispersion model for the Dutch emergency response has since been launched. In this report we investigate the validation and verification of the dispersion model the experiments at the Cabauw mast. Two questions have to be answered: (1) is the quality of these older measurements up to par for the present state-of-art dispersion models and (2) is it possible to reconstruct the weather with the latest high-resolution numerical weather prediction models. The first question is tested using the dispersion model AEROPOL with two different parameter schemes. The second question is answered by a reconstruction of the weather in 1977 and 1978 using HARMONIE v.38 (http://www.hirlam.org) nested in ERA40 (http://www.ecmwf.int).

CABAUW DATASET

The dispersion experiment was carried out in Cabauw atmospheric measurement site in 1977-1978, using the facilities of a 213 m high mast (http://www.cesar-observatory.nl). The data set consists of 28 half-hourly runs – two sequential half hours per day, thus 14 days in total. The SF_6 tracer was released from the height either at 80 or 200 m depending on pre-estimated dispersion conditions, and measured at surface level on an arc 2 – 5 km downwind. As during two half-hours the arc-wise maximal concentration was obviously out of the arc, these experiments were excluded from the comparison. The comparison is made on hourly basis, except these two days, when one of half-hours was excluded. Thus, number of valid cases is 14. The data set includes on-site evaluated meteorological parameters, which were used for modelling: temperature, wind speed and direction at different heights in the mast, surface turbulent heat flux. More detail parameters included in the data, such as standard deviations of wind speed and direction, are not used, as the minimalistic application-oriented AEROPOL model does not need them.

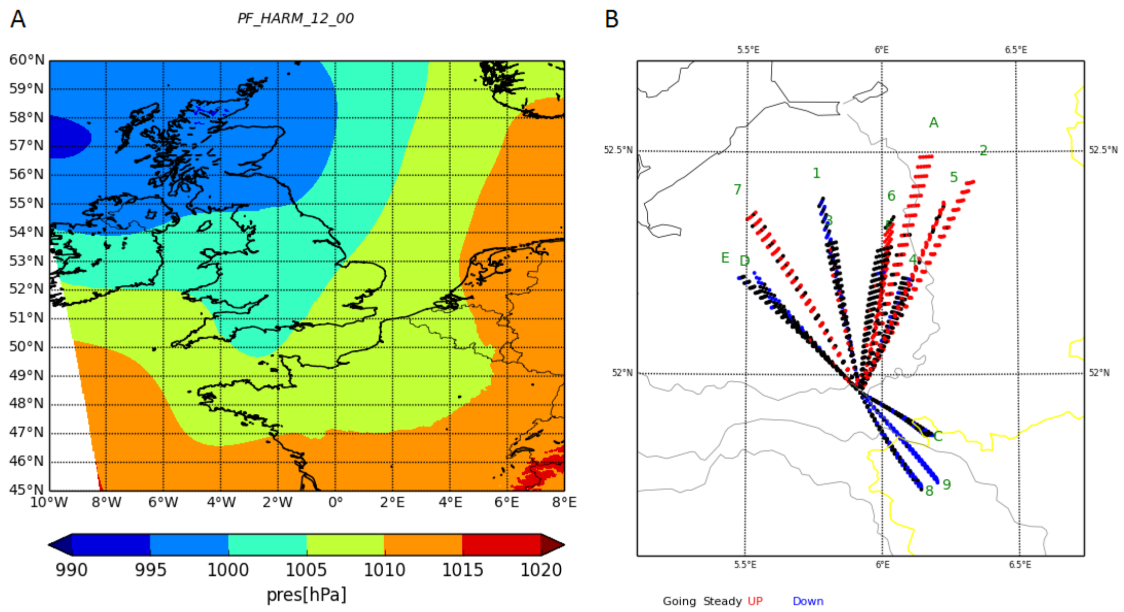

Figure 1. The panel A shows the pressure at mean sea level at 1977042812 UTC calculated by HARMONIE. The panel B shows trajectories with a colour code for a constant height (black), an upward movement (red) or a downward movement (blue) for all experiments. For each experiment a trajectory is calculated every 15 minutes and the location is plotted every 5 minutes. A vertical displacement upward larger than 1 meter per 5 minutes is defined as an ascending trajectory (red). Descending is defined as a vertical displacement downward of more than 1 meter per 5 minutes. The numbers denote the experiments 1-9, the letters represent experiments 10-15, with A for the 10th experiment.

MODELS AND METHODS

The data from this dispersion experiment is downloaded from http://www.jsirwin.com/. The synoptic weather charts for the 14 different cases are provided in Agterberg et al (1983). We analysed the synoptic weather using the ERA40 reanalysis dataset. Based on the 3D-wind information from the ERA40 reanalysis dataset, the trajectory model TRAJKS (Stohl et al., 2001) calculated the advection of the centre of the plume. Figure 1 shows whether the trajectories are ascending (in red), descending (in blue) or move at a constant height (in black). In experiments 1 and 3 the trajectories coincide, in both experiments the centre of the plume is advected towards NNW. In experiment 1 the centre of the plume ascends in the first kilometres and descends afterwards. Trajectories are calculated starting at the source location every 15 minutes and from the spread in the trajectories it can be seen that the wind direction did not change significantly during the release period. In the third experiment the spread in the horizontal location of the plume is larger whereas the spread in the vertical is small and the trajectories stay at the same height.

AEROPOL (basic features, see Kaasik & Kimmel, 2003) is a stationary Gaussian plume model developed in University of Tartu, Estonia. AEROPOL 5.2, applied in this study, enables two alternative parameterisations for dispersion parameters:

- classical Pasquill-Gifford stability classification (further referred as Pasquill scheme);
- a scheme based on Lagrangian time scales, developed by Gryning et al. (1987) and validated against the Copenhagen dispersion experiment (further referred as Gryning scheme).

Both the parametrisation schemes apply the wind speed and surface heat flux as key input parameters, whereas Pasquill classes are evaluated as a discrete empirical function of surface roughness and Monin-Obukhov length, applying the approach by Myrup & Ranzieri (1976). The detail description of the method is given by Kaasik & Kerner (2010).

The model *vs*. measurement intercomparison follows the standard of the Model Validation Kit of the HARMO initiative. The validated output parameters are cross-wind integrated, maximal arc-wise and near-centreline concentrations. Validation is based on correlation (COR), fractional bias (FB), fractional sigma (FS), normalised mean square error (NMSE) and fraction of measured vs. modelled values in factor of two (FA2). The near-centreline concentration is defined as average of concentrations between $-0.67\sigma_y$ and $0.67\sigma_y$, where σ_y is the horizontal standard deviation of the plume in Gaussian approximation (Olesen, 2000).

RESULTS

Wind correction

As the AEROPOL model can use only single-point meteorological data and wind from maximum two levels (standard 10 m height and another arbitrarily chosen level higher up), the most straightforward way would be to take the higher level exactly at source height, thus giving to the plume the direction and speed at the release level. However, comparison of these initial results gave unsatisfactory match of modelled plumes with measured ones – too high wind speeds and wrong directions were obvious in vast majority of runs. Then, repeating the model runs with average wind speed between the standard level and the source height, the consistent results were achieved. Keeping in mind that the downward-dispersed tracer starts to move with local wind, the gradual dispersion in line with downwind transport should result in an intermediate transport speed and direction – thus, this approach is theoretically sound as a first approximation. All the model results presented this point forward, are computed with wind data averaged between the estimated (extrapolated, when needed) 10 m level and actual wind at release height.

Summary statistics

The summary statistics for cross-wind integrated, arc-wise maximum and near-centreline concentrations is given in Table 1.

Table 1. summary statistics for cross-wind integrated, arc-wise maximum and near-centreline concentrations. Statistics are given separately for model runs with the Pasquill and the Gyning parameterisation schemes (see Models and Methods).

	Cross-wind integrated		Maximum arc-wise		Near-centreline	
	Gryning	**Pasquill**	**Gryning**	**Pasquill**	**Gryning**	**Pasquill**
CORR	0,92	0,79	0,94	0,74	0,83	0,79
FB	-0,13	-0,25	0,65	0,03	0,46	-0,12
FS	-0,03	-0,07	0,83	0,06	0,75	0,05
NMSE	0,08	0,22	0,65	0,22	0,51	0,18

FA2	0,86	0,86	0,50	0,71	0,71	0,79

As seen from Table 1, the conservative Pasquill-Gifford parameterisation performs somewhat better, except for correlations, which exceed even 0,9 with Gryning scheme for cross-wind integrated and maximal arc-wise concentrations. In most cases, the Gryning scheme results in too wide spread and thus, lower maxima compared to measurements, whereas the Pasquill parameterisation gives sharper maxima, which makes the statistics more sensitive to the small discrepancies in plume position.

Modelled *vs.* measured data plots

The plots of cross-wind integrated, maximum arc-wise and near-centreline concentrations are given in Figures 2, 3 and 4 respectively. All these concentrations are normalised with source release rate.

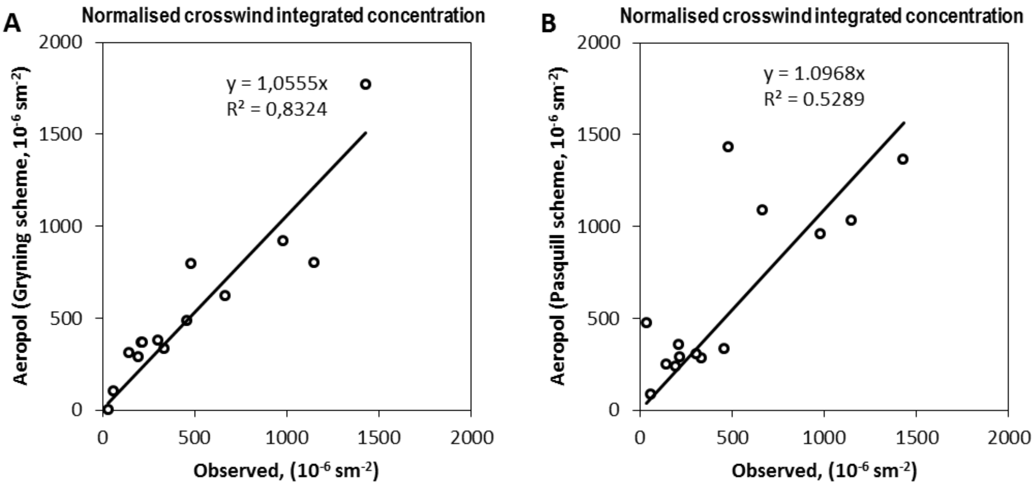

Figure 2. Plots of modelled *versus* measured normalised cross-wind integrated concentrations. Modelled concentrations are computed with the Gryning (A) and the Pasquill-Gifford (B) parameterisations.

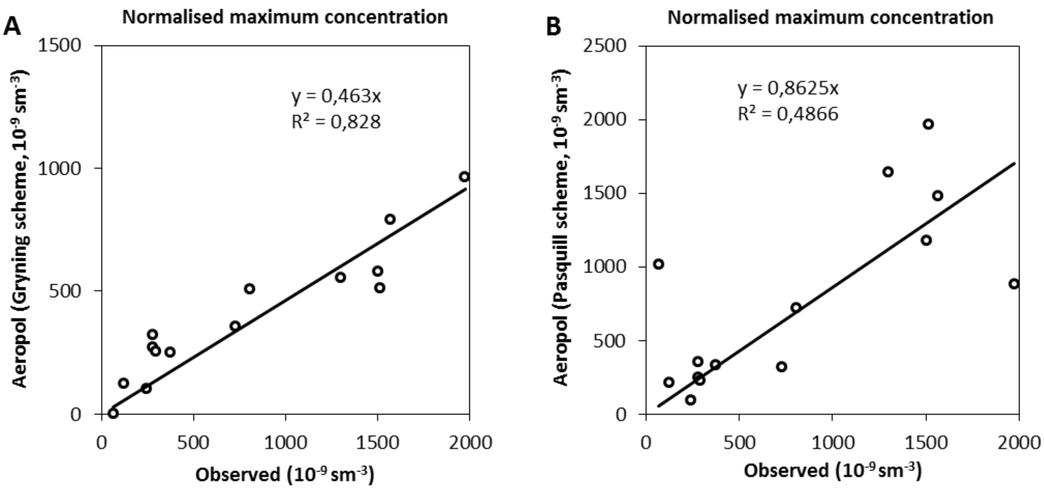

Figure 3. Plots of modelled *versus* measured normalised arc-wise maximum concentrations. Modelled concentrations are computed with the Gryning (A) and the Pasquill-Gifford (B) parameterisations.

The effect of too wide Gaussian spread of Gryning scheme is seen in plots of the arc-wise maximum and the near-centreline concentrations, as the reason of serious underestimation. On the other hand, the wider spread makes the fit less sensitive to the exact position of the Gaussian peak and thus, the scatter of data points is much lower than with Pasquill-Gifford scheme. In contrary, the fit of arc-wise integrated concentrations is almost perfect with Gryning scheme and much looser with Pasquill-Gifford scheme, i.e. the latter one is not that precise to reproduce the vertical transport of the tracer.

Considering the cross-wind integrated concentrations (see Figure 2), both schemes are within 10% range from one-to-one relation by trendline, thus handling the vertical dispersion rather well.

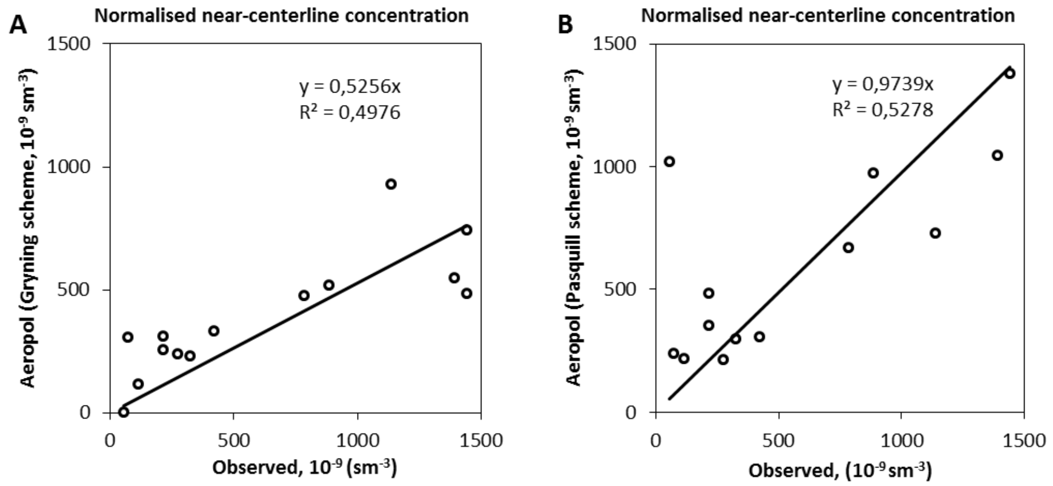

Figure 4. Plots of modelled *versus* measured normalised near-centreline concentrations. Modelled concentrations are computed with Gryning (A) and Pasquill-Gifford (B) parameterisation.

CONCLUSIONS

The first question posed in Introduction above got a positive answer: the AEROPOL model reproduced the measured concentrations rather consistently, thus both *Cabauw* data set is still useful for model validation, and *vice versa*: AEROPOL is a useful tool for predicting the dispersion of pollutants from elevated releases. As a supplement to earlier validation studies (e.g. Kaasik & Kimmel, 2003), the advantages and disadvantages of newer Gryning parameterisation scheme are clarified. Based on this validation study the Pasquill-Gifford scheme seems better for predicting the highest concentrations near the surface, but the key issue for exact matching is the proper wind direction. On the other hand, the Gryning scheme is somewhat more accurate in predicting the cross-wind integrated concentrations. To match these two advantages together, more research is needed.

To answer the second question, the next stage of research consisting of the AEROPOL runs based on HARMONIE meteorological re-analysis, is in progress.

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