doc 2

OPS Test Report Falster and North Carolina

Comparing results of the OPS model with measurements around two pig farms in Falster and North Carolina

10.2.e [redacted], December 2014

Abstract

This test report describes the comparison between results of the models OPS-ST (version 3.0.2) and OPS-LT (OPS-Pro, version 2013), respectively modeling Short-Term and Long-Term dispersion, with field measurements of ammoniac concentrations around two pig farms in Falster (Denmark) and Green County, North Carolina (US). Results are ambiguous. The results of both tests on predicted and observed concentrations are inconclusive. In the Falster case, concentrations are underestimated at nearby locations and overestimated at more distant locations, while in the North Carolina case this finding is the opposite. OPS-ST has a better performance than OPS-LT in the Falster case, however, OPS-LT has a better performance in the North Carolina case. Final impression is that the accuracy of emission data has a major impact on model performance.

1. Introduction

The development of the OPS model started in the '80s with a Long-Term version (OPS-LT) and a Short-Term version (OPS-ST) followed in the '90s. Between then and nowadays, a number of improvements are applied. The last time OPS was validated was for a high source, the Kincaid case (Van Jaarsveld, 2004). In view of the growing demand for NH_3 concentrations and NH_4-deposition around agricultural sources, a repeat of a comparison of model and measured results is desired, this time for a low source. The two cases Falster and North Caroline are selected out of an inventory of cases concerning long-term measurements, see table in annex 1. These two cases describe the situation around an NH_3 source (a pig farm) with relatively long periods of available observations (3 months and one year respectively). Moreover, the data of those cases were inventoried already in a study on intercomparison of four dispersion models, among which OPS-ST (Theobald et al., 2010, 2012). The input data in that study was based on data obtained during the two measuring campaigns in Falster and North Carolina. The Pig Research Centre of the Danish Agriculture & Food Council supplied the monitoring and meteorological data on the Falster case (Pedersen et al., 2007). The study in North Carolina was performed on behalf of the US-EPA by Walker et al. (2008). The authors of this study made a set of data files available for the RIVM with permission of the investigators of both cases. Contact person in the Falster case was 10.2.e [redacted]@lf.dk) and in the North Carolina case 10.2.e [redacted] [to be contacted in case of official publication] 10.2.e [redacted]@epa.gov).

Aim of this study is to test the OPS model for low NH_3 sources. Both results of OPS-LT and OPS-ST are compared with results of the measuring campaigns. Furthermore the sensitivity for variations (and omissions) in meteorological input parameters is tested. Starting point is the set of input data compiled by Theobald et al. The OPS version used by Theobald was version OPS-ST 3.0.2. Possible improvements to the input data are the use of meteorological data with standardized wind velocity (at height of 10 meter and with roughness length of 0.03 meter) instead of the observed wind velocity at measuring height, and use of supplementary data like precipitation and snow cover. While the geographical location in OPS is restricted to co-ordinates in the Netherlands, an intervention in the software was made to run a calculation for the actual co-ordinates in the North Carolina case. In the Falster case, the emission input file is supplemented with emissions by the existing slurry tank. The model versions used in this test study are OPS-ST version 3.0.2 and OPS-LT version OPS-Pro 2013.

2. Description of the Falster case

2.1 Site description

The study site is a pig farm located on the island Falster in Denmark. The Dansk Svineproduktion inventoried information about NH_3 emission from a pig house and concentrations around the farm by a measuring campaign during summer 2006 (Pedersen et al., 2007). The pig farm is situated in the rural district Væggerløse in Denmark, coordinates are 54.707 N, 11.9425 E. The landscape is typical rural with arable lands and scattered farms, but no forests or wooded banks.

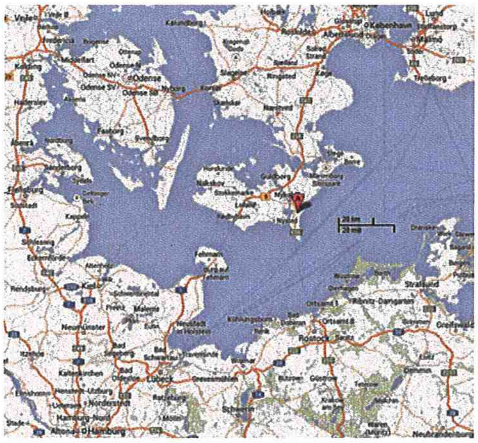


Figure 2.1. Location of site on Falster Island, DK (red marker A)

Figure 2.2. Site with pig farm (Google maps streetview).

2.2 Sources and emissions

The pig farm consists of an artificially ventilated pig house and an adjacent slurry tank. The dimensions of the pig house are 64 x 33 meter. The mechanical ventilation is performed by 11 extractor fans situated on the roof at a height of 6.4 meter. The livestock counts 1344 piglets and 1344 fattening pigs on average. During the campaign, concentrations, volume flow rate and temperature are measured in the outflow of each fan, resulting in hourly values of the emission rates, 0.0068 g/s per average fan. The annual emission of the pig house is estimated to be 2361 kg NH_3, proportional to the emissions measured during the sampling period (12 weeks).

A slurry tank, situated in the northeast part of the farm, was in use during the measuring campaign. The Danish researchers estimated the NH_3 emission of this slurry tank by use of concentrations observed at four measuring points situated around the tank. The emission from the slurry tank starts at a level of 0.0066 g/s at 2006-06-07, declines via 0.0044 g/s at 2006-07-11 to the minimum level of 0.00088 g/s at 2006-08-05, as shown in Figure 9 in the Danish report.

No information is available on emissions by manure appliance on surrounding fields or by animal houses at neighboring farms. Emissions by these sources are neglected in the model calculations.

The OPS-ST emission file, based on the input file used by Theobald, describes the hourly emissions of the 11 extractor fans at the roof. The horizontal dimensions are 1x1 meter (surface source). The vertical initial dispersion and a possible heat flux are neglected in the model calculations. Supplementary, hourly emissions from the slurry tank are interpolated between the three points given in the Danish report and added to the emission file. The diameter of the slurry tank is 22 meter. While not mentioned in the report, the source height is estimated at 2 meter.

Input files for the OPS-LT model emission rates are described by long-term averages, optionally supplemented with a diurnal profile. In this case, the average emission per fan is derived from the hourly values. The time average emission from the slurry tank is 0.00316 g/s during the measuring period. No use is made of the option of a diurnal profile. The input file with average emissions is used in a run with OPS-ST also.

The data in the input files are based on the Dutch co-ordinate system (RD coordinates). The OPS program does accept coordinates situated in the Netherlands only. For this reason, the geographical coordinates of emissions and receptors are transformed from Falster to a location situated in the Netherlands, still using land use and meteo data of the Falster site. After the relocation, the RD-coordinates of the center of the farm are (100000; 400000).

2.3 Meteorological data

Hourly measurements of wind speed, wind direction, air temperature and dew-point are made during the measuring campaign. The observation height was 7.2 meter. Additional data for cloud cover were obtained from the MM5 model and used by Theobald to calculate solar radiation conform the method described by Holtslag and Van Ulden. No precipitation was measured at the site and no alternative sources of observational data were found. The meteorological station Beldringe airport, near Odense at the mainland, showed precipitation at 36 of the 87 campaign days, but was assumed not to be representative for Falster Island. The option no-data for precipitation is used in the OPS-ST input file with meteorological data.

The OPS-ST model requires standardized observation conditions for wind velocity, meaning the observation height (h_{obs}) and roughness length (z_0) has to be h_{obs} = 10 meter respectively z_0 = 0.03 meter. The conversion into standardized wind velocity is according to an exponential profile for the wind velocity, as assumed in the OPS model and described by Benschop (1996). The conversion is done in two steps: first the wind velocity at observation height is converted, under original roughness conditions, to a height of 60 meter and next back down, using standard z_0 = 0.03 meter, to the standard height of 10 meter (see Annex 2). However, the input files for OPS are not clear on this point. Values of h_{obs} and z_0 are required input parameters, but the used versions of OPS do not standardize the wind velocity in the model calculations. For this reason, a new input file has been created by replacing the wind velocity in the meteo file of Theobald by the standardized wind velocity. In this conversion the original observation height is 7.2 meter, the roughness length in the study area has been estimated to be z_0 = 0.11 meter.

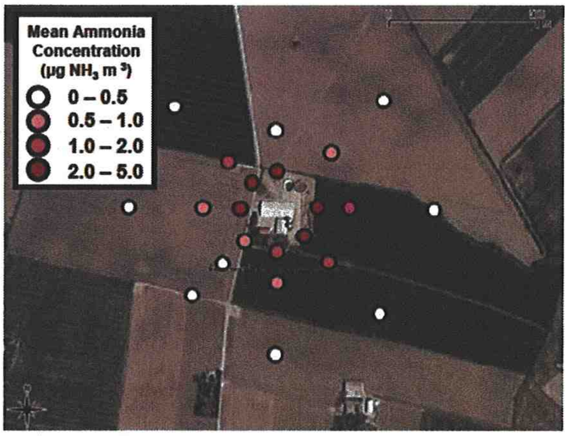
Input files with meteorological data used for OPS-ST are the file compiled by Theobald et al. and a file with the same meteorology data but with standardized wind velocities.

Data-preprocessing is necessary to make the meteorological input file useable to the OPS-LT model. The program METPRO version 2.2 processes the hourly data for OPS-ST to a file with meteorological statistics as input for OPS-LT.

2.4 Measurements and receptor points

The measurement campaign was between 2006-07-06 – 2006-09-01. Measurements of ammonia concentrations in the air were performed using passive diffusion tubes. Concentrations at 27 locations were determined during 12 sample periods of 7 days. The sampling height was 2.0 meter. The distances to receptor points were up to 300 meter. The sampling points are drawn in Figure 2.3, except the northernmost point while this observation was negative. The figure does not show the 4 points located near the slurry tank (NE of the pig house) used for assessment of emission by this source.

Background concentrations were supposed to be equal to the lowest observed concentration within each sampling period. The reported concentrations are aggregated over all sampling periods and adjusted for the assumed background concentrations.



2.5 Results

The version of OPS-ST used for model calculations is version 3.0.2. This version was used in the study of Theobald et al. in 2010. First, it was tested to reproduce the results of Theobald et al. Next, input files are used with adaptions to standardized wind velocity and to the slurry tank emissions.

The long-term-version of OPS used is OPS-Pro 2013. The LT-version calculates annual average concentrations. In this case, the "year" has been reduced to a period of 12 weeks, while meteorological data and emissions refer to the sampling period of 12 weeks.

The contributions of the local sources are calculated as period average concentrations, both for OPS-ST and OPS-LT. The model results are compared with the observed concentrations including a correction for the background concentration. Next two figures show the effect of standardized wind velocities, respectively the effect of modelling the slurry tank as a supplement to the NH_3-sources. In both figures calculated contributions, using OPS-ST and OPS-LT, are plotted versus observed concentrations.

In Figure 2.4 results are plotted of the run by Theobald et al. (2010), the reproduction run, both with h_{obs} = 7.2 m and z_0 = 0.11 m, and results of the runs with standardized wind velocities with OPS-ST respectively OPS-LT. Shown are concentrations at 23 sampling points (see Figure 2.3).

Figure 2.5 shows the effect of the slurry tank emissions in runs with and without slurry tank, for OPS-ST and OPS-LT. In Figure 2.6, the differences between model results and observations are plotted as function of distance. Plotted are the concentrations at 27 sampling points plus the sampling points around the slurry tank used for assessing its emission. Figure 2.6 shows the difference between model results and observations as a function of the distance to the center point in the pig house.

Table 2.1 shows an overview of statistical indicators, among which the indicators suggested by Hanna et al. (2004) to evaluate model performance, see annex 3. Determination of indicator values for 23 receptor points.

Table 2.1. Performance indicators

Run	Performance indicators Hanna (2004) FB	MG	NMSE	VG	FAC2	Regression model Slope	Inter-cept	ρ	RMSE
Short-Term (OPS-ST)									
Theobald	-0.09	0.58	0.24	2.34	0.61	0.67	0.57	0.90	0.69
Reproduction	-0.09	0.58	0.24	2.34	0.61	0.67	0.57	0.90	0.69
Standardized Wind	-0.08	0.58	0.26	2.39	0.61	0.65	0.58	0.90	0.71
Average emissions	-0.13	0.54	0.25	2.76	0.52	0.65	0.66	0.90	0.72
Em. incl. slurry tank*	-0.21	0.51	0.18	2.62	0.57	0.77	0.62	0.93	0.63
Long-Term (OPS-LT)									
Standardized wind	-0.23	0.47	0.28	3.71	0.43	0.61	0.87	0.91	0.79
Em. incl. slurry tank*	-0.35	0.42	0.23	4.14	0.39	0.77	0.90	0.95	0.77

Green background: acceptable model performance. The ranges indicating acceptable model performance, suggested by Chang and Hanna (2005), are fractional bias (FB): |FB| < 0.3, geometric mean bias (MG): 0.7 < MG < 1.3, normalized mean square error (NMSE): NMSE < 1.5, geometric variance (VG): VG < 4 and prediction within a factor two (FAC2): FAC2 > 50%.
* Run with emissions including the slurry tank.

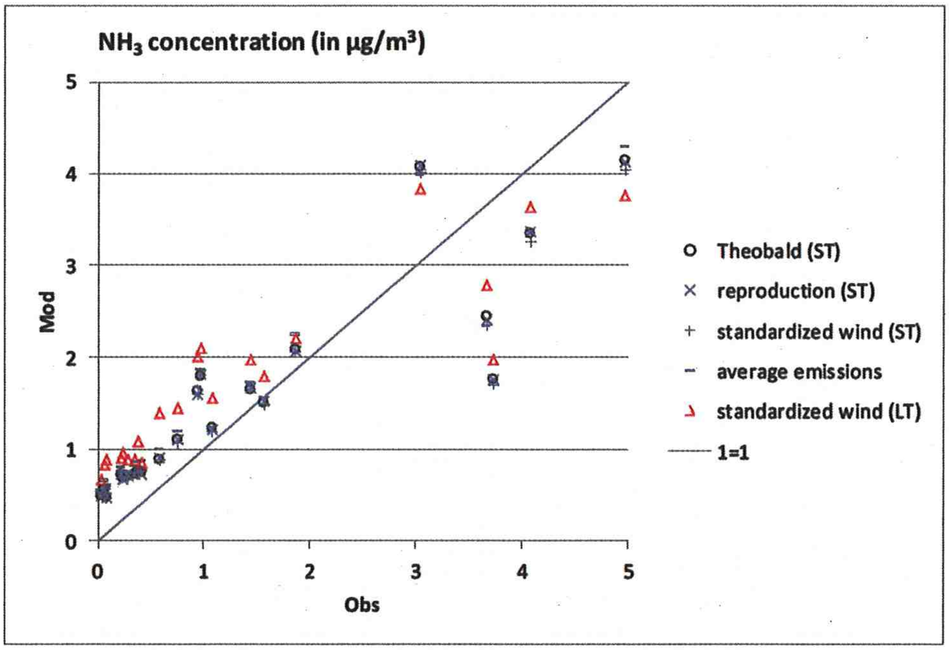


Figure 2.4. NH_3 concentrations calculated with OPS-ST and OPS-LT for the pig house emissions only and compared with observations. Calculations by Theobald et al. (2010) and reproduction run with wind data as observed (h_{obs} = 7.2 m and z_0 = 0.11 m) and supplementary ST- and LT-runs with standardized wind data (h_{obs} = 10 m and z_0 = 0.03 m).

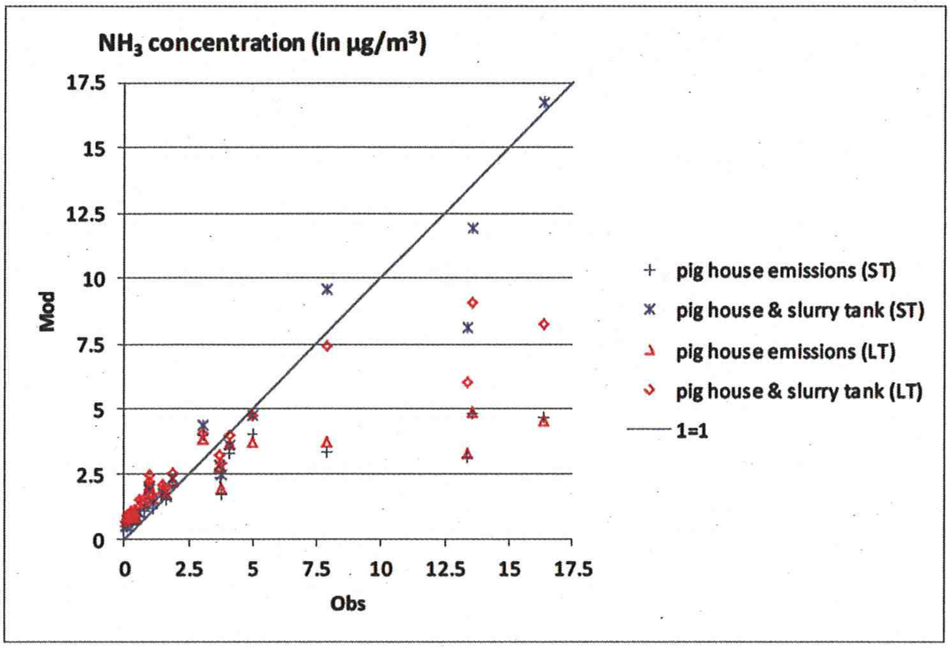


Figure 2.5. NH_3 concentrations calculated with OPS-ST and OPS-LT with emissions by the pig house only and including the slurry tank (all with standardized wind data). Besides the 23 receptor-points, this figure shows also concentrations at the 4 point around the slurry tank used to estimate the emission.

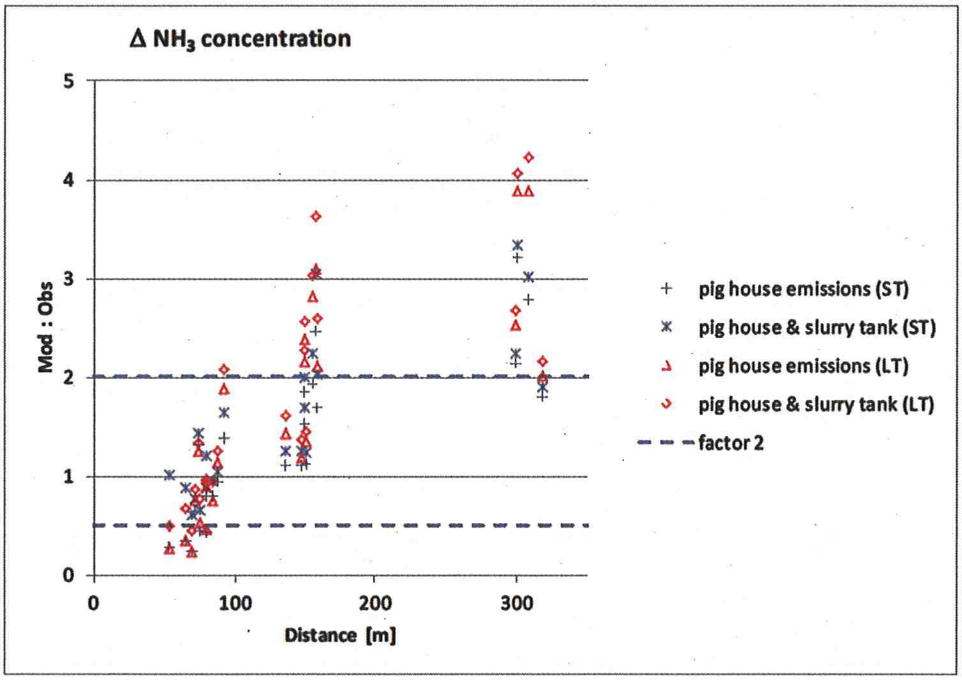


Figure 2.6. Difference between model result and observation as a ratio (Mod:Obs), plotted as a function of distance between pig house (center point) and receptor point.

The findings are:

- *The results of Theobald et al. were reproduced successfully with OPS-ST. Only marginal differences occur because of the use of different compilations of the program.*
- *At the receptor points situated relatively close to the source and with high concentrations, four out of five points are underestimated by both OPS-ST and OPS-LT.*
- *The predicted concentrations at the more distant points are systematically higher than the observations; the overestimation by OPS-LT is stronger.*
- *The use of standardized wind velocities in the meteorological data does not result in a significant improvement of the performance of OPS-ST.*
- *The use of an input file with long-term emission instead of hourly values does result in a lower performance of OPS-ST.*
- *Addition of the slurry tank as a source of emission does not improve the model performance, the performance indicators become even slightly worse for the LT-version.*
- *Overall, the performance of OPS-ST is better than that of OPS-LT. Partly the better performance is due to used hourly emissions instead of the average emissions in OPS-LT.*

3. Description of the North Carolina case

3.1 Site description

The study site is a pig farm located in Greenfield County, North Carolina (USA). The farm was subject in a study of emissions and concentration at a pig farm by US-EPA (Walker et al, 2008). The coordinates of the farm are 35.523 N, 77.561 W. The pig farm is situated in a wooded area alternated with arable lands and scattered farms. The site is located eastward of a wooded bank.

Figure 3.1. Location of site in North Carolina (red marker)

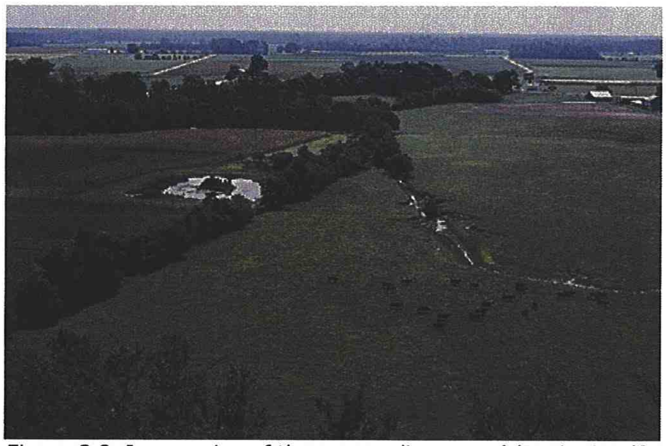


Figure 3.2. Impression of the surrounding area (the site itself is not shown) (picture: Google Panoramio)

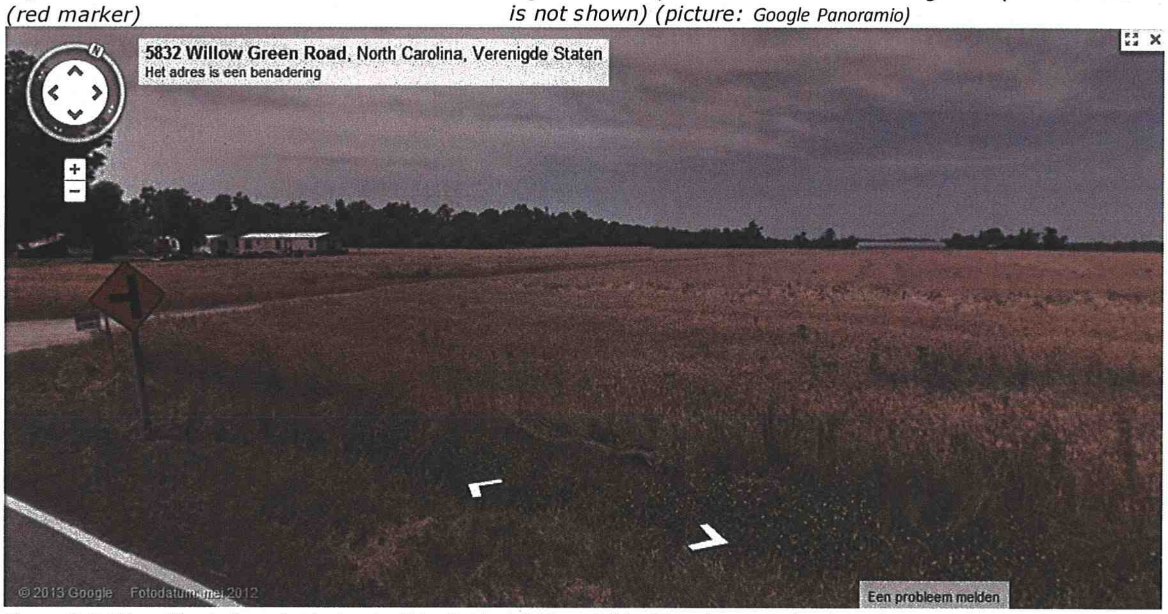


Figure 3.3. Site with pig farm in the back of the field, right hand side (Google maps streetview).

3.2 Sources and emissions

The pig farm consists of five naturally ventilated pig houses and an adjacent slurry lagoon. The dimensions of a pig house are 84 x 11 meter each. The roof height is 3 meter. The slurry lagoon is a basin with a trapezoidal shape with two right angles at one side. The length is 135 to 155 meter and the width is 60 meter, the surface area is 10175 m^2.

The annual emission was estimated to be 34300 kg NH_3, caused by 4900 animals with a mean weight per animal of 61 kg and an estimated emission of 7.0 kg NH_3 per animal per year (EPA, 2002). The total emission is split up in 59% housing (20365 kg), 26% slurry storage (8842 kg) and 15% slurry application (5091 kg) (Walker, 2008).

No information is available neither about location and time of emissions from manure appliance on surrounding fields nor about emissions by animal houses at neighboring farms.

The input files for OPS describe emissions from the pig houses and from the slurry lagoon. Emissions from manure appliance and neighboring farms are neglected. The emission factors are listed as long-term average values, because emissions are not measured but assessed. The option of a diurnal emission profile is not used. Each pig house is configured by 8 surface sources of 11 x 11 m^2 at a height of 1.5 meter and a vertical initial spread of 1.16 meter. The last value is obtained by the method in the AERMOD user guide: mean vertical dimension of the source divided by 2.15, being 2.5/2.15 = 1.16 [m] (Cimorelli, 2002). The slurry lagoon emission is made up of 407 surface sources of 5 x5 m^2 at ground level (h = 0 m) and with no vertical spread.

The data in the input files are based on the Dutch co-ordinate system (RD coordinates). The OPS program does accept coordinates situated in the Netherlands only. For this reason, the geographical coordinates of emissions and receptors are transformed from North Carolina to a location situated in the Netherlands, still retaining the land use and meteo data from North Caroline. After the relocation, the RD-coordinates of the center of the farm are (100000; 400000).

3.3 Meteorological data

Meteorological data represent observations at the site during the sampling period. Wind velocity and wind direction are measured at a height of 4.5 meter. The roughness length in this area is estimated to be z_0 = 0.11 meter. Other measured indicators are standard deviation of wind direction, temperature, relative humidity and global radiation. The data have been converted to metric units.

Precipitation and snow cover were not measured at the site. In addition to the indicators measured on the site, precipitation and snow cover observed at the airport at Greenville (NC), 20 km NE of the site, are available. The data is obtained from the NOAA-NCDC (http://www.ncdc.noaa.gov/cdo-web/search).

The OPS-ST model requires standardized observation conditions for wind velocity, meaning the observation height (h_{obs}) and roughness length (z_0) has to be h_{obs} = 10 meter respectively z_0 = 0.03 meter. The conversion into standardized wind velocity is according to an exponential profile for the wind velocity, as assumed in the OPS model and described by Benschop (1996). The conversion is done in two steps: first the wind velocity at observation height is converted, under original roughness conditions, to a height of 60 meter and next back down, using standard z_0 = 0.03 meter, to the standard height of 10 meter (see Annex 2). However, the input files for OPS are not clear on this point. Values of h_{obs} and z_0 are required input parameters, but the used versions of OPS do not standardize the wind velocity in the model calculations. For this reason, a new input file has been created by replacing the wind velocity in the meteo file of Theobald by the standardized wind velocity. In this conversion the original observation height is 4.5 meter, the roughness length in the study area has been estimated to be z_0 = 0.11 meter.

Input files with meteorological data used for OPS-ST are the file compiled by Theobald et al, a file with the same meteorology data but with standardized wind velocities, and a file with additional precipitation and snow cover data.

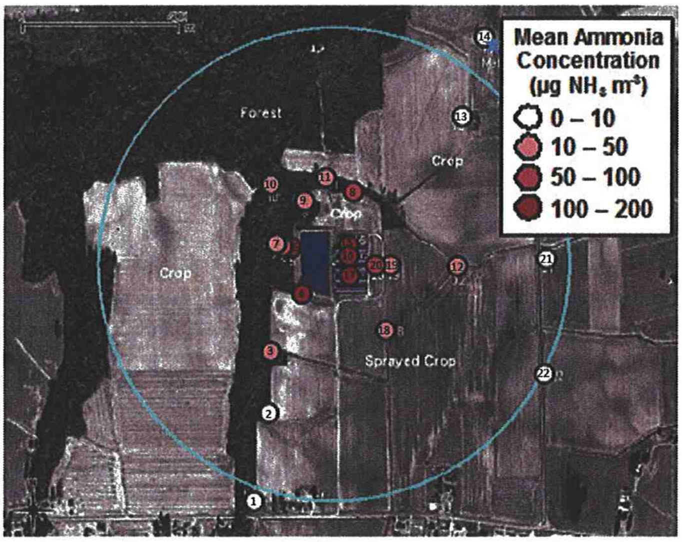
Data-preprocessing is necessary to make the meteorological input file useable to the OPS-LT model. The program METPRO version 2.2 processes the hourly data for OPS-ST to a file with meteorological statistics as input for OPS-LT.

3.4 Measurements and receptor points

The measurement campaign was between 2003-06-23 – 2005-07-25. In this study a period of one calendar year, 2004-01-06 – 2004-12-28, is used. Measurements of ammonia concentrations in the air were performed using calibrated diffusion tubes (Gradko International Ltd). Concentrations at 22 locations were determined during 46 sample periods of 7 days. The sampling height was 1.5 meter. The distances to sampling points were up to 700 meter. The sampling points are drawn in Figure 3.4. Three points are located in the passages between the pig houses (points 15-17). These three points are excluded in the comparison of model and sampling results, because locations within an area source are outside the scope of application of OPS. A number of sample points are situated in or at the border of the wood bank westward of the site, where roughness lengths differ significantly from the area average value.

Background concentrations were supposed to be equal to the lowest observed concentration within each sampling period. The reported concentrations were adjusted for the assumed background concentrations.

The OPS model uses geographical coordinates as a parameter in some routines, for example to model cloud cover or heat radiation when not available in the input files. The coordinates of De Bilt in the Netherlands are the standard coordinates in OPS program. The coordinates of the site in North Carolina are quite different, especially the difference in latitude could have consequences for the modelled results. To test the impact of change of latitude, an experimental version of OPS-ST is compiled with coordinates of the site in North Carolina (run NC coordinates).



3.5 Results

The version of OPS-ST used for model calculations is version 3.0.2. This version was used in the study of Theobald et al. in 2010. First, it was tested to reproduce the results of Theobald et al. Next, input files are used with adaptions to standardized wind velocity and with additional precipitation and snow cover data.

The long-term-version of OPS used is OPS-Pro 2013. Runs with this version cover the calendar year 2004.

The contribution of the local sources are calculated as period average concentrations, both for OPS-ST and OPS-LT. The model results are compared with the observed concentrations including a correction for the background concentration. Figure 3.5 shows the effect of standardized wind velocities, and the effect of additive data on precipitation and snow cover. Calculated contributions, using OPS-ST and OPS-LT, are plotted versus observed concentrations at 22 receptor points. Shown are results of the run by Theobald et al. (2010), the reproduction run, both with h_{obs} = 4.5 m and z_0 = 0.11 m, and results of the runs with standardized wind velocities with OPS-ST respectively OPS-LT. Furthermore, results are shown for a run using precipitation data and a run with the adapted version of the OPS-ST allowing actual coordinates of the site in North Carolina. Figure 3.6 shows the difference between model results and observations as a function of the distance to the center point.

Table 3.1 shows an overview of statistical indicators, among which the indicators suggested by Hanna et al. (2004) to evaluate model performance, see annex 3.

Table 3.1. Performance indicators

	Performance indicators Hanna (2004)					Regression model			
Run	FB	MG	NMSE	VG	FAC2	Slope	Inter-cept	ρ	RMSE
Short-Term (OPS-ST)									
Theobald	-0.43	0.70	0.42	1.31	0.84	1.24	12.13	0.78	39.8
Reproduction	-0.43	0.70	0.43	1.32	0.84	1.25	12.09	0.77	40.3
Standardized Wind	-0.56	0.58	0.58	1.53	0.68	1.34	17.65	0.76	49.7
NC-coordinates	-0.59	0.57	0.61	1.58	0.68	1.39	17.82	0.76	51.6
Precipitation	-0.57	0.58	0.59	1.54	0.68	1.35	17.56	0.76	50.0
Long-Term (OPS-LT)									
Standardized wind	-0.35	0.86	0.50	1.23	0.89	1.32	3.98	0.75	42.6

Green background: acceptable model performance. The ranges indicating acceptable model performance, suggested by Chang and Hanna (2005), are fractional bias (FB): |FB| < 0.3, geometric mean bias (MG): 0.7 < MG < 1.3, normalized mean square error (NMSE): NMSE < 1.5, geometric variance (VG): VG < 4 and prediction within a factor two (FAC2): FAC2 > 50%.

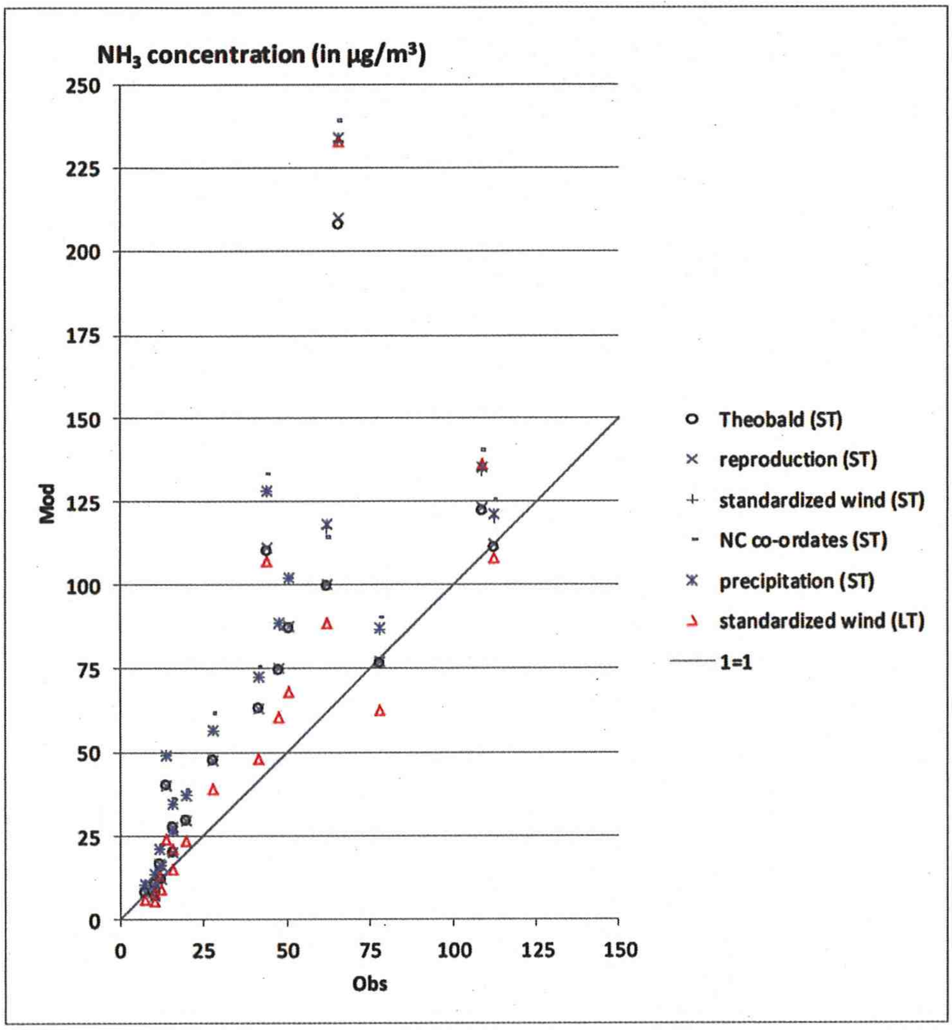


Figure 3.5. NH_3 concentrations calculated with OPS-ST and OPS-LT, compared with observations.

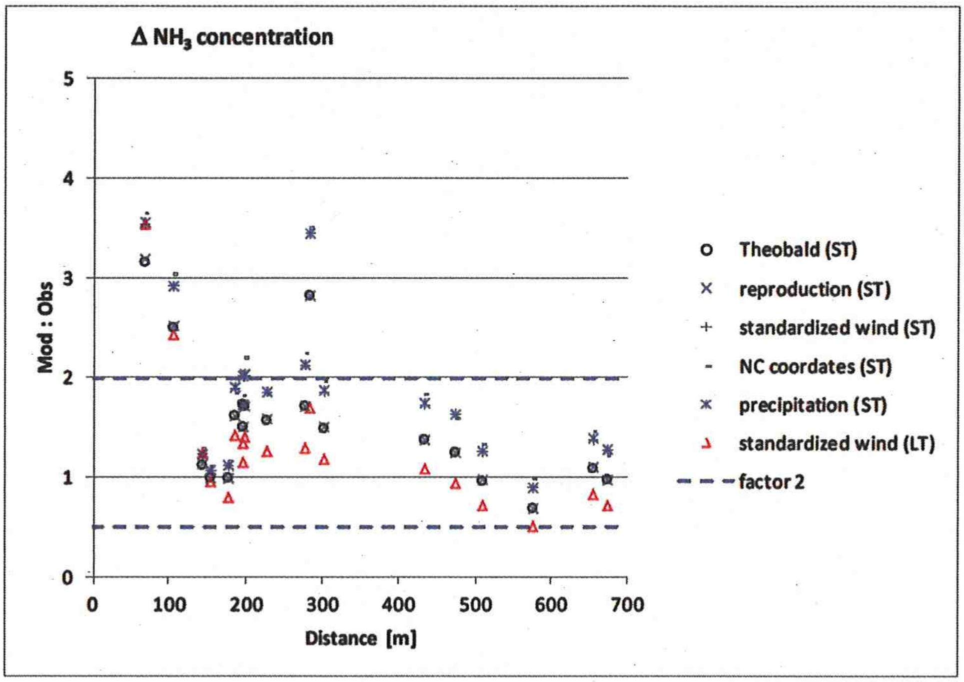


Figure 3.6. Difference between model result and observation as ratio (Mod:Obs), plotted as a function of distance between center point and receptor point.

The findings are:

- *The results of Theobald et al. were reproduced successfully with OPS-ST. Only marginal differences occur because of the use of different compilations of the program.*
- *The predicted concentrations at relatively close receptor points are systematically higher than the observations, the overestimation by OPS-ST is stronger.*
- *The predicted concentrations at more distant points correlate well with the observations.*
- *The use of standardized wind velocities in the meteorological data does result in a deterioration of the performance of OPS-ST.*
- *The use of the model version with NC-coordinates does not improve the performance of OPS-ST.*
- *Replacement of standard values for latitude and longitude in OPS program with actual values in the North Carolina case has no significant effect on performance of the OPS model. The meteorological input file contains implicitly information on latitude in the global radiation. The OPS program uses the standard latitude only in the case that hourly data are missing.*
- *The use of meteorological data with precipitation and snow cover does not improve the performance of OPS-ST.*
- *OPS-LT performs significantly better than OPS-ST.*
- *One receptor point is an outlier, the concentration is overestimated both by OPS-ST and OPS-LT. This point (nr 20) is located close to the emission sources and vortices around the pig houses could affect the dispersion. However, for a building with a roof height of 3 meters, the expected impact of vortices at the distance of circa 25 meter is relatively small.*
- *The predicted concentration at receptor point located in the forest (nr 10) is higher than measured, probably to be explained by the difference in model value and actual value of the roughness length.*

4. Conclusions

Two cases of ammoniac sources at a pig farm in Falster and North Carolina are used to compare concentrations predicted with the OPS model and observed concentrations. Both in the Falster case and the North Carolina case, results are presented for runs with OPS-ST (short-term) and with OPS-LT (long-term). Optional improvements of input data were the use of wind velocities for standardized conditions (observation height and roughness length), use of additional data on precipitation and snow cover, use of supplementing emission sources, and use of an experimental version of OPS-ST with actual latitude and longitude in OPS routines instead of standard values.

The findings in both tests lead to the following conclusions:

- The results of Theobald et al. could be reproduced easily, different compilations of the OPS program result in the same predictions of concentrations.
- The results of both tests on predicted and observed concentrations are somewhat inconclusive. In the Falster case, concentrations are underestimated at nearby locations and overestimated at more distant locations, while in the North Carolina case the opposite occurs.
- Replacement of wind velocities as observed by standardized wind velocities in the meteorological input file has no significant effect on performance of the OPS model.
- Additional data on precipitation and snow cover in the meteorological input file has no significant effect on performance of the OPS model.
- Replacement of standard values for latitude and longitude in OPS program with actual values in the North Carolina case has no significant effect on performance of the OPS model. The meteorological input file contains implicitly information on latitude in the global radiation. The OPS program uses the standard latitude only in the case that hourly data are missing.
- Additional input data on emissions, the slurry tank in the Falster case, did not have a significant effect on performance of the OPS model.
- Use of hourly emissions instead of long-term average emissions results in a lower performance of OPS-ST.
- OPS-ST has a better performance than OPS-LT in the Falster case, partly because hourly emissions were used in OPS-ST. However, OPS-LT has a better performance in the North Carolina case.
- The accuracy of emission data has a major impact on model performance.
- Final impression is that both models, OPS-ST and OPS-LT, perform reasonably well: most performance indicators show 'green'. In the Falster case, there are problems with the geometric mean bias, in the North Carolina case, problems occur with the fractional bias.

5. Literature

Benschop, H. (1996) Windsnelheidsmetingen op zeestations en kuststations: herleiding waarde windsnelheid naar 10-meter niveau. KNMI Technisch Rapport TR-188. De Bilt, 1996.

Chang, J.C., Hanna SR (2004) Air quality model performance evaluation. Meteorol. Atmos. Phys. 87 (1), 167e196.

Chang JC, Hanna SR (2005) Technical descriptions and user's guide for the BOOT statistical model evaluation software package, Version 2.0.

Cimorelli AJ, Perry SG, Venkatram A, Weil JC, Paine RJ, Wilson RB, Lee RF, Peters WD, Brode RW, Pauimer JO. (2002) AERMOD: Description of Model Formulation Version 02222. United States Environmental Protection Agency, Research Triangle Park, NC 27711, USA, 85pp.

Pedersen, P., P. Løfstrøm, H.V. Andersen (2007) Ammoniakspredning omkring en svineproduktion. Dansk Svineproduktion Faglig Publikation, Meddelelse nr. 790, 27-6-2007, Copenhage.

Jaarsveld, J.A. van (2004) The Operational Priority Substances model Description and validation of OPS-Pro 4.1. RIVM report 500045001/2004. Bilthoven.

McInnes, G. (1996) Joint EMEP/CORINAIR Atmospheric Emission Inventory Guidebook, vol. 1. European Environment Agency, Copenhagen.

Theobald et al. (2010a) Case Study: Modelling dispersion of ammonia from a pig farm in Falster (DK) using OPS-st model. Internal report.

Theobald et al. (2010b) Case Study: Modelling dispersion of ammonia from a pig farm in North Carolina (USA) using the OPS-st dispersion model. Internal report.

Theobald, MR, P Løfstrøm, J Walker, HV Andersen, P Pedersen, A Vallejo, MA Sutton (2010c) An intercomparison of models used to simulate the atmospheric dispersion of agricultural ammonia emissions. 13th Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes. Paris, 1-4 June 2010.

Theobald, MR, P Løfstrøm, J Walker, HV Andersen, P Pedersen, A Vallejo, MA Sutton (2012) An intercomparison of models used to simulate the short-range atmospheric dispersion of agricultural ammonia emissions. Environmental Modelling & Software Vol 37, nov 2012, p90-102.

US EPA (2002) Review of emission factors and methodologies to estimate ammonia emissions from animal waste handling. EPA/600/R-02-017. National Risk Management Research Laboratory, Office of Research and Development, Research Triangle Park, NC.

Walker J., P. Spence, S. Kimbrough, W. Robarge (2008) Inferential model estimates of ammonia dry deposition in the vicinity of a swine production facility. Atmospheric Environment 42 (2008) 3407-3418.

Annex 1. List of cases

Table. Optional data sets for model validation

	Data set	*Emission*	*Stack height*	*Time*	*Receptor-distance*	*Data*
1	Kincaid (1980-1981)	SF6, SO_2	187 m	SF6: 171 hour SO_2: 6000 hour	0.5 – 50 km	NERI-Kit, Website John Irwin
2	Indianapolis (1985)	SF6	84 m	170 hour	0.25 – 12 km	NERI-Kit, urban
-	Bull Run (1982)	SF6, SO_2	244 m	372 hour	0.5 – 50 km	Less suitable because of mountainous area
3	Cabauw (1977-1978)	SF6	200 m, 80 m	15 days with 2x 0,5 hour	0.02 – 12 km	Report
4	Prairie Grass (1956)	SO_2	0.46 m	68 x 10 min	0.05 – 0.8 km	Website John Irwin
5	Falster (2006)	NH3	Pig farm	12 weeks	0.01 – 0.5 km	Theobald et al. (2010)
6	North Carolina (2004)	NH3	Pig farm	46 weeks	0.01 – 0.5 km	Theobald et al. (2010) estimated emissions

NERI-Kit: Model Validation Kit (http://www.harmo.org/)
Site John Irwin: Atmospheric Transport and Diffusion Data Archive (http://www.jsirwin.com/index.html)
See also (http://atmosphericdispersion.wikia.com/wiki/Data_set_repositories)

Annex 2. Logarithmic wind profile

Method to standardize wind velocity (Benschop, 1996)

The wind profile is assumed logarithmic and described by:

$$U(z) = \frac{u_*}{\kappa} \cdot \ln\frac{z}{z_0} \qquad (1)$$

With

z	observation height [m]
$U(z)$	mean wind velocity [m/s]
u_*	friction velocity [m/s]
κ	Von Karman constant
z_0	roughness length [m]

The wind velocity at a height of 60 meter is assumed independent of roughness length at ground surface. Changing the height from observation height z to 60 meter conform the logarithmic profile:

$$U(60) = \frac{\ln\frac{60}{z_0}}{\ln\frac{z}{z_0}} \cdot U(z). \qquad (2)$$

Next, changing the height from 60 meter to the standard height of 10 meter and for the standard roughness length of 0.03 meter conform the logarithmic profile:

$$U(10) = \frac{\ln\frac{10}{0.03}}{\ln\frac{60}{0.03}} \cdot U(60), \qquad (3)$$

or in one step:

$$U(10) = \frac{\ln\frac{10}{0.03}}{\ln\frac{60}{0.03}} \cdot \frac{\ln\frac{60}{z_0}}{\ln\frac{z}{z_0}} \cdot U(z). \qquad (4)$$

Annex 3. Performance indicators

Evaluation of model performance requires a statistical comparison of model predictions with observed values. Chang and Hanna (2004) summarize the indicators available for evaluating dispersion model performance. For the current evaluation, five performance measures suggested by Chang and Hanna (2004) have been used that are calculated from the observed (C_o) and predicted (C_p) concentrations at each measurement location:

Fractional bias: $$FB = 2\frac{\overline{C_o}-\overline{C_p}}{\overline{C_o}+\overline{C_p}} \quad (1)$$

Geometric mean bias: $$MG = \exp(\overline{\ln C_o} - \overline{\ln C_p}) \quad (2)$$

Normalized mean square error: $$NMSE = \frac{\overline{(C_o-C_p)^2}}{\overline{C_o}\,\overline{C_p}} \quad (3)$$

Geometric variance: $$VG = \exp[\overline{(\ln C_o - \ln C_p)^2}] \quad (4)$$

and the fraction of model predictions within a factor of two of the observations, FAC2.

Chang and Hanna (2005) suggest ranges for five of the performance measure values that indicate acceptable model performance. The ranges suggested are:
|FB| < 0.3,
0.7 < MG < 1.3,
NMSE < 1.5,
VG < 4 and
FAC2 > 50%.

Other statistical indicators in use for evaluating model performance are regression coefficients (intercept and slope), Pearson product-moment correlation (ρ):

$$\rho = \frac{1}{N-1}\frac{\sum(C_o-\overline{C_o})(C_p-\overline{C_p})}{\sigma(C_o)\cdot\sigma(C_p)} \quad (5)$$

and Root-Mean-Square Error: $$RMSE = \sqrt{\frac{1}{n}\sum_n(C_o - C_p)^2} \quad (6)$$