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Airborne dispersion of Q fever

A modelling attempt with the OPS-model

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Abstract

Airborne dispersion of Q fever
A modelling attempt with the OPS model

The OPS ("Operational Priority Substances ") computer model simulates the dispersion of pollutants in the air. It also appears to be suitable for modelling the transmission of Q fever bacteria from farm animals to humans. This is the major finding of a study carried out by the RIVM within the context of RIVM's Strategic Research project (SOR).

The study results demonstrate that the model was well able to describe the transmission of Q fever bacteria on two infected goat farms. Uncertainties remain, such as the amount of bacteria released during an outbreak. More data are needed before the model can be routinely used to simulate the transmission of zoonoses through the air (aerosol) on infected farms.

Infected goat farms are considered to be the source of the Q fever epidemic in the Netherlands between 2007 and 2010. However, the factors which cause Q fever bacteria to be transmitted from farm animals to humans and how the contaminated particles disperse through the air still remain largely undetermined. A suitable model provides policy-makers with model results that can be used as the basis for policy advice on the placement and distribution of farms.

Keywords:
Q fever, zoonoses, atmospheric dispersion, OPS, the Netherlands

Rapport in het kort

Dispersie van Q-koorts door de lucht
Een modelleerstudie met het OPS-model

Met het rekenprogramma OPS (Operationele Prioritaire Stoffen) kan de
verspreiding van verontreinigende stoffen in de lucht worden nagebootst. Het
OPS-model lijkt ook geschikt om de overdracht van Q-koorts-bacteriën van
bedrijf naar de mens in kaart te brengen. Dit blijkt uit een studie van het RIVM,
die vanuit het Strategisch Onderzoek RIVM (SOR) is uitgevoerd.

Het model heeft laten zien de overdracht rond twee besmette geitenbedrijven
goed te kunnen beschrijven. Er zijn nog wel veel onzekerheden, bijvoorbeeld
over de mate waarin bacteriën vrijkomen bij een uitbraak. Meer data zijn nodig
voordat het model routinematig kan worden ingezet voor de overdracht van
ziekteverwekkers door de lucht vanuit besmette bedrijven.

Besmette geitenbedrijven worden gezien als bron van de Q-koorts-epidemie in
Nederland tussen 2007 en 2010. Voor een groot deel is nog onbekend welke
factoren de transmissie van de Q-koorts-bacterie van dierbedrijven naar de
mens veroorzaken en hoe de besmette stofdeeltjes zich door de lucht
verspreiden. Met een geschikt model kunnen beleidsmakers advies geven over
het plaatsings- en spreidingsbeleid van veehouderijen.

Trefwoorden:
Q-koorts, zoönosen, dispersiemodel, OPS

Contents

Summary

Q fever, caused by *Coxiella burnetii*, is a zoonosis that has an extensive animal reservoir from which humans can be infected. Especially during abortion and parturition of infected animals, bacteria can be released into the environment. Infection of humans takes place through inhalation of airborne contaminated dust particles.

Infection of humans and contamination of the environment with Coxiella requires transport through the atmosphere. Transport in the atmosphere and contamination of the environment by deposition can be calculated with existing dispersion models. In this report, the atmospheric dispersion model OPS of RIVM is used to describe the dispersion of Q fever over two contaminated areas in the Netherlands, where Q fever at large dairy goat farms resulted in important outbreaks among the human population in 2008 and 2009.

The objective of the study was to assess whether the OPS model could be used in studies to explain the transmission of *C. burnetii* from animal to man.

The largest uncertainty in this modelling attempt is the source term, i.e., the amount of bacteria that is emitted from a stable and the temporal behaviour of this emission. This problem was circumvented by assuming a simple emission profile in time and scaling the results with the reported number of Q fever cases.

The OPS model is able to simulate the general behaviour of airborne Coxiella dispersion. The distribution in space matches the general patterns of reported human Q fever cases and the distribution in time (number of cases per 10 days) can be matched reasonably well.

The average profile of Coxiella concentration, which a Q fever patient experiences, shows a peak in concentration some 23 days before the date of onset of Q fever. This corresponds well with the incubation time of Q fever, which is usually 2-3 weeks.

In the two cases studied here, the main parameters that describe the distribution of human Q fever cases are the population density and distance to the farm. We compared OPS results with results of two simple models: model 0 (assuming a uniform concentration distribution) and model 1 (concentration distribution $\sim 1/r^2$, with r the distance to the farm) and OPS clearly adds extra information on the temporal and spatial distribution of the concentration compared to these models.

Several ways to reduce the uncertainty in the calculations are discussed in Chapter 5, such as time and amount of bacteria released at a farm, human activity patterns and dose-response relation.

1 Introduction

Q fever caused by *Coxiella burnetii*, is a worldwide zoonosis that has an extensive animal reservoir from which humans can be infected. Especially during abortion and parturition of infected animals (particularly observed with goats), large numbers (billions) of bacteria can be released into the environment. Infection of humans takes place trough inhalation of airborne contaminated dust particles. This can happen directly from animal sources or indirectly by mobilisation of fine dust particles from infected soils. At the time of this study, a dose-response relationship for *C. burnetii* had not been established except that fewer than 10 organisms can be sufficient to seed an infection (Benenson 1956). For a recent study on dose-response relations, see Tamrakar et al. 2011. It seems reasonable to assume that for low doses, there is some kind of linear relationship between the number of bacteria that are excreted by animals and the risk that humans become infected. If so, the risk of human infection would be very different for animals that shed intermittently a small number of bacteria and animals that excrete massive numbers of bacteria during late abortion. There is clear epidemiological evidence that dairy goat farms that experienced Q fever induced abortion waves are the cause of the human Q fever outbreaks in the Netherlands (Roest et al. 2010; van der Hoek et al. 2010). Outbreaks may occur when people live in the vicinity of farms experiencing abortion waves.

Infection of humans and contamination of the environment with Coxiella requires transport through the atmosphere. It is assumed that Coxiella is absorbed or fixed at the aerosol surface and as such becomes airborne. Transport in the atmosphere and contamination of the environment by deposition can be calculated with existing dispersion models. In this report, the atmospheric dispersion model OPS of RIVM is used to describe the dispersion of Q fever over two contaminated areas in the Netherlands, where Q fever at large dairy goat farms has resulted in important outbreaks among the human population.

The objective of the study was to assess whether the OPS model could be used in studies to explain the transmission of *C. burnetii* from animal to man. It should be emphasised that these are first attempts and that large uncertainties are associated with the calculations. The largest uncertainty is the source term, i.e., the amount of bacteria that is emitted from a stable and the temporal behaviour of this emission.

In Chapter 2 a brief background on the calculated cases will be given. In Chapter 3 a brief description of the OPS model will be presented. In Chapter 4 results of the dispersion calculations are given. This includes the set up and assumptions made, a sensitivity analysis and a comparison with reported Q fever cases. Finally the discussion and conclusions are presented in Chapter 5.

2 Background of the studied cases

Case 1:
In March 2009, the regional Municipal Health Service (MHS) of South Limburg received a veterinary notification. A farm with approximately 1,000 dairy goats, located in the vicinity of a densely populated area, had reported abortions due to Q fever. A study by the MHS showed that most farm workers and a substantial proportion of farm visitors became infected in the first weeks of the veterinary outbreak. Since then, more than 250 laboratory-confirmed cases of Q fever have been reported from the region. South Limburg has a relatively small goat population. Only one farm, near Voerendaal, had reported Q fever abortion waves and therefore, it was very likely that there was just one source (which we consider as a point-source) in South Limburg.

Case 2:
From April to August 2008, MHS Brabant Southeast notified 96 Q fever cases. One dairy goat farm (> 400 animals) had abortion problems in April 2008. No other farms in the area reported abortions in the weeks prior to the outbreak. A study showed that living within 2 kilometres of the dairy goat farm posed a high risk for Q fever (Schimmer et al. 2010). Furthermore, the time period between the abortion wave on the dairy goat farm and illness onset in the human cases suggested that airborne transmission of *C. burnetii* from the dairy goat farm could have been the cause of this outbreak. This was further supported by predominantly easterly winds on a number of days that could have taken contaminated dust particles to the people living southwest of the farm.

3   OPS model

Introduction
The Operational Priority Substances short term model, OPS-ST (van Jaarsveld &
Klimov, 2011*)* is derived from the OPS long-term model (van Jaarsveld 2004)
and is used for modelling of dispersion and deposition of pollutants for the
Netherlands on both local and national scale. The model can be described as a
Lagrangian (trajectory) model which acts as a Gaussian plume model for local
situations. Dry and wet deposition mechanisms are included as a function of
particle size with some emphasis on the behaviour of large particles. Dry and
wet deposition is taken into account as a function of particle size and the density
of the particles. Furthermore, the effect of sedimentation on plume and
transport height is taken into account. The model is driven by a set of hourly
meteorological parameters taken from 14 stations of the network of the Royal
Netherlands Meteorological Institute (KNMI).

Spatial scale
Due to the chosen Gaussian plume model, application of the OPS-ST model is
restricted to an area of 30 km around a source. This is the area where
meteorological conditions as atmospheric stability and wind direction do not
change considerably. Concentrations and deposition can be computed in a grid
of equally spaced receptors or at specific receptor locations.

Temporal scale
The shortest time scale within the OPS-ST model is 1 hour. It is possible to
specify emissions at this time scale. Hourly meteorological data should be
available for the simulation period under consideration. The user can specify the
scale of the output: hourly or daily, monthly or yearly averages.

Substances
OPS-ST computes concentrations and (dry) deposition of SO_2, NO_x, NH_3 and
particulate matter. Any other substance can be computed if specific substance-
related properties, such as molecular weight, surface resistance for dry
deposition, scavenging ratio for wet deposition are provided. For particulate
matter, six size classes are used and several particle size distributions, each with
its own deposition characteristics, are available. Below, the standard particle size
distributions 'coarse', 'medium' and 'fine' are shown (Figure 1). It is also
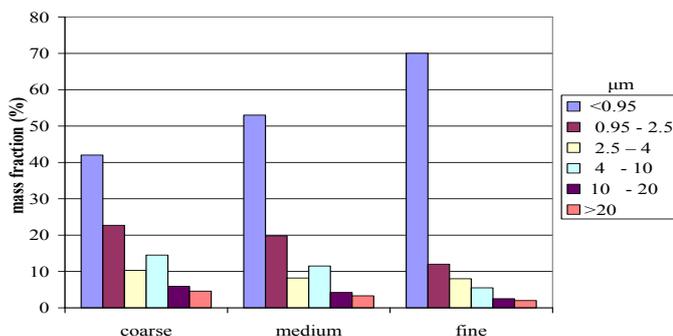possible to specify a user defined particle size distribution.

Figure 1: OPS particle size distributions 'coarse', 'medium' and 'fine'.

Meteo
Meteorological data have to be supplied as hourly data and are supposed to be representative for the model domain. OPS-ST uses the following meteo parameters as input: wind speed, wind direction, temperature, pressure, relative humidity, global radiation, cloud cover and precipitation. A pre-processor is available that converts hourly data of KNMI stations in the Netherlands to meteo data for six regions in the Netherlands.

Emissions
The standard emission file of OPS specifies the location and yearly averaged emission for each emission source. If needed, the heat content of the source can be specified, in order to compute the plume rise. Depending on the specification in the emission file, emission characteristics such as daily and monthly profile are used in the OPS-ST model. For ammonia, OPS-ST divides emissions into animal housing and manure application emissions, each with their specific emission characteristics. If detailed hourly emission data is available, these can be specified in a special hourly emission file.

Validation
The capability of the model to simulate local dispersion has been tested against well-known datasets such as the Kincaid (Bowne and Londergan 1983) and Prairie grass datasets (Barad 1958). For larger scale transport of gases as SO_2, NO_x and NH_3, the model is successfully compared to results of the Dutch National Air Quality Monitoring Network. Furthermore, the model has been subjected to several model intercomparison studies (e.g., Theobald et al. 2010) and has been used in studies on dispersion of ammonia (van Pul et al. 2008) and sea-salt (van Jaarsveld and Klimov 2011).

4 Calculations of Q fever dispersion with OPS

For the two cases Voerendaal and Helmond (Chapter 2), calculations of Q fever dispersion with the OPS model were carried out. We will first describe the set up of the cases and some sensitivity runs. Subsequently, the results of the calculations for these cases will be presented.

4.1 Case 1: set-up

Case 1 is an outbreak of Q fever at Voerendaal in the Province of Limburg in 2009 (Figure 2).
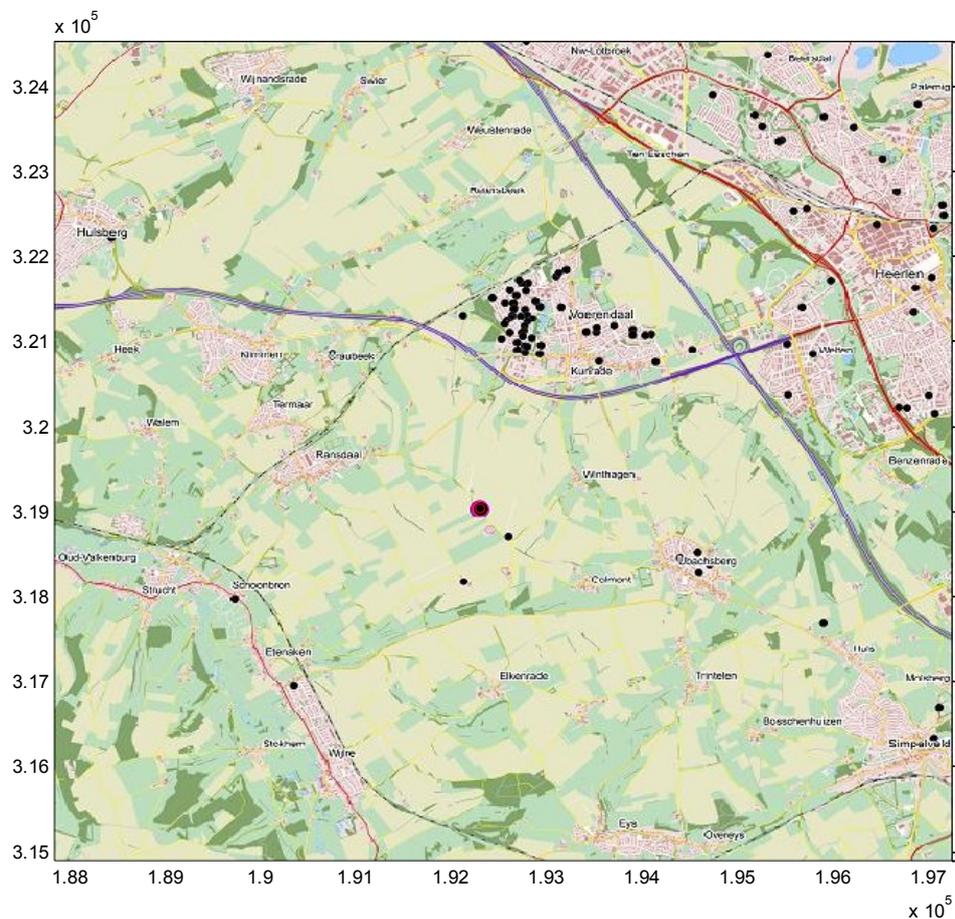

Figure 2: Map of modelled domain around Voerendaal. Red dot: farm. Black dots: human cases of Q fever reported in 2009.

Based on preliminary test runs (see appendix B.), the following default set-up was defined:

- Q fever bacteria are treated as particles, with the standard OPS 'coarse' particle size distribution
- single point source, emission height = 3 m
- threshold wind velocity = 4 m/s. This means that in low wind conditions, bacteria are accumulated in the stable, in high wind conditions (velocity

higher than threshold), all bacteria inside the stable are released in one hour.
- dry deposition according to the dry deposition module DEPAC for particles
- OPS meteorological region 6 (Limburg)
- roughness length = 0.20 m
- receptor height = 1.5 m.

The effect of the threshold velocity is shown in Figure 3 and Figure 4 for two different emission distributions. Since we do not yet know the actual amount of bacteria that is released, only relative concentrations (scaled between 0 and 1) will be used. This means that the unit for the y-axis in the following figures is not relevant.
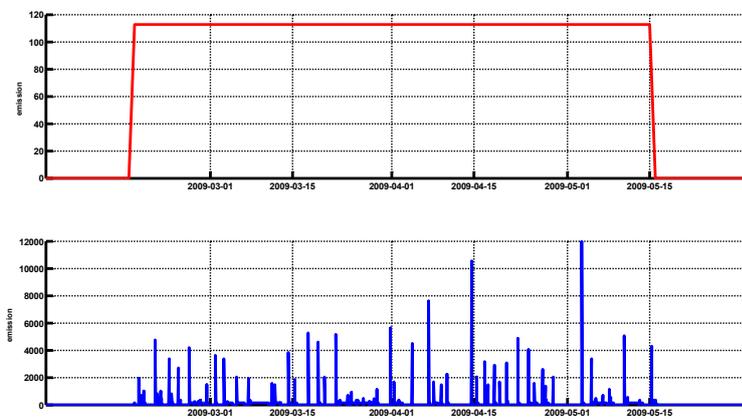

Figure 3: Fictitious emission for Q fever simulations; upper panel shows emission inside the stable, a uniform distribution in time during the period 2009-02-15 to 2009-05-15. The lower panel shows the emission that is released from the stable with a threshold wind velocity of 4 m/s. Arbitrary units.
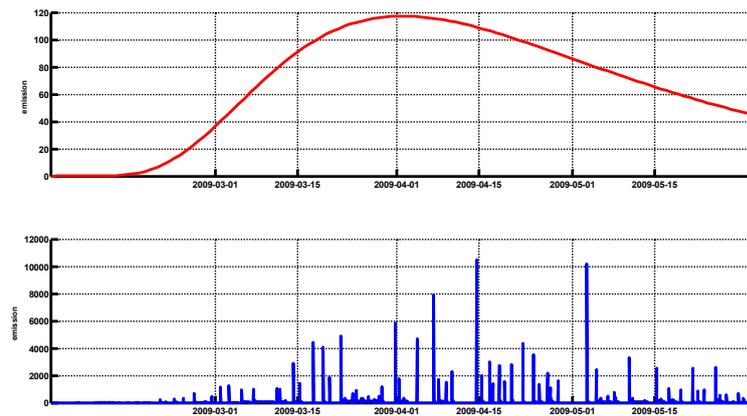

Figure 4: Fictitious emission for Q fever simulations; upper panel shows emission inside the stable, a skewed distribution in time with peak value at April 1st 2009. The lower panel shows the emission that is released from the stable with a threshold wind velocity of 4 m/s.

4.2   Case 1: sensitivity runs

A very limited sensitivity study was performed to show the sensitivity of OPS results on the threshold velocity, the particle size distribution and emission profile. Default settings were used and a uniform emission distribution, as in Figure 3.

An example of an input file for OPS is shown in appendix A. A list of all OPS runs in shown in appendix B.

OPS results are presented in Figure 5 as an average concentration over the period 2009-02-01 to 2009-05-31; for the sensitivity runs we used a grid located around the farm with 50 x 50 receptors, 200 m grid resolution. Since the actual amount of Q fever bacteria emitted is yet unknown, concentrations here are presented as relative concentrations between 0 and 1 (concentrations for all runs are scaled with the same factor).
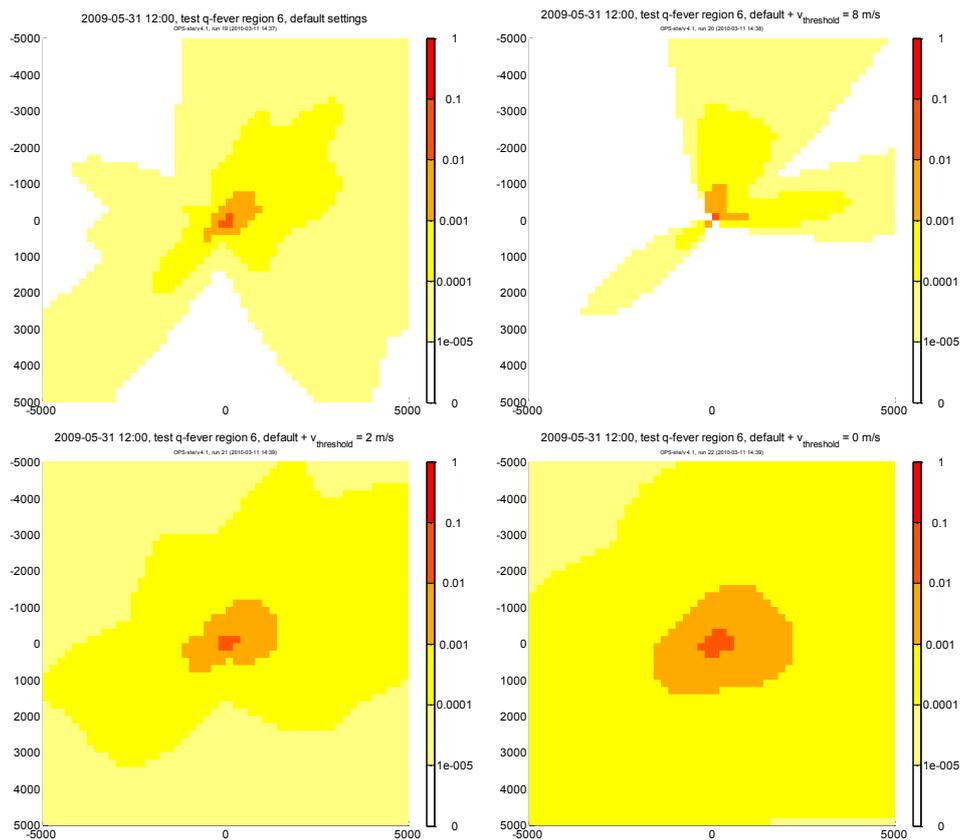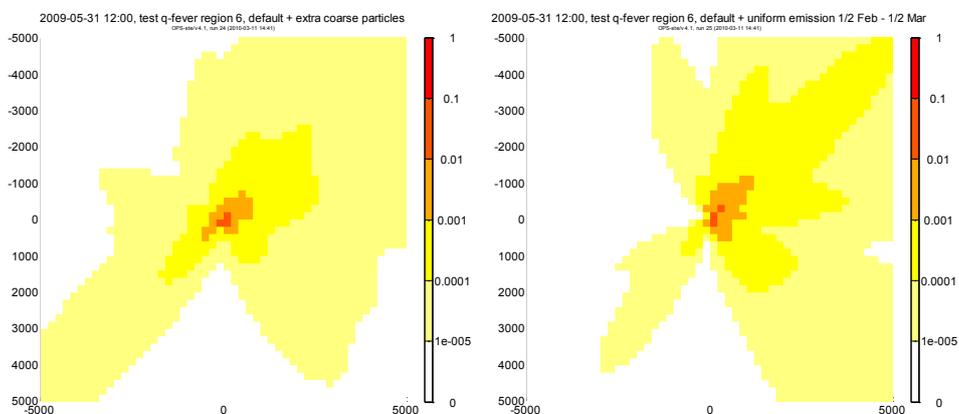
Figure 5: OPS scaled concentrations (0-1), for runs 019, 020, 021, 022, 024, 025 (starting upper-left). Sensitivity on threshold velocity vt, particle size distribution and emission period.

19: vt = 4 m/s	20: vt = 8 m/s
21: vt = 2 m/s	22: vt = 0 m/s
24: vt = 4 m/s, extra coarse particles	25: emission in 1 month, vt = 4 m/s

From these figures we may conclude that the threshold velocity for emissions is a sensitive parameter in the modelling process.

We investigated the sensitivity of the model results on the emissions by using three types of emission profiles (Figure 6).
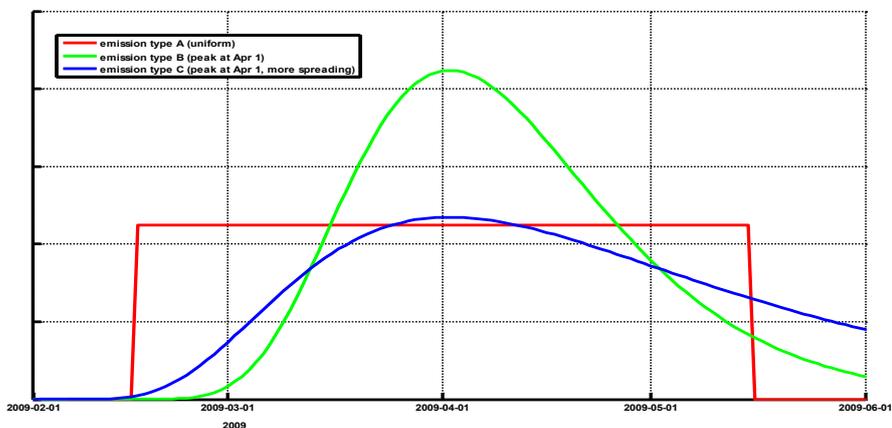

Figure 6: Three different emission types for emission inside the stable, with different distributions in time (peak value and spread in time). Arbitrary y-axis.

In order to be able to compare the OPS results to actual data on human Q fever cases, we processed the OPS concentrations as follows:

1. multiply the concentration with the number of inhabitants in each grid cell.

We assume here that the chance of becoming infected is linearly dependent on the concentration. However, since we do not know the actual amount of bacteria that is released, we have to scale:

2. Scale the (concentration x inhabitants) values such that the number of modelled cases inside the whole domain is equal to the number of reported cases.

By doing so, we can compare the modelled cases that are infected per 10 days to the reported cases (Figure 7).
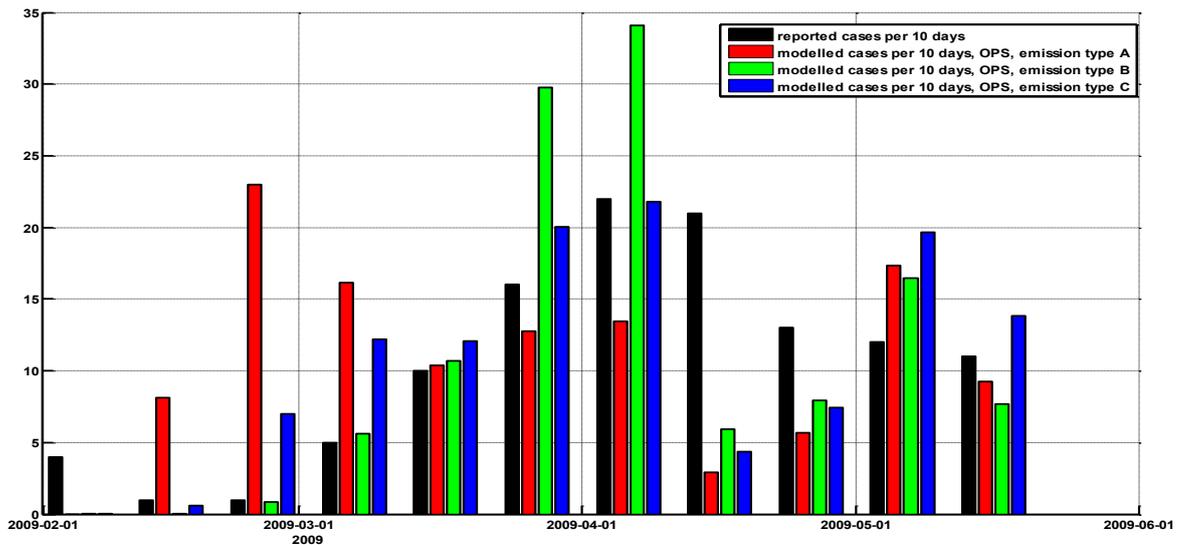

Figure 7: Number of human cases of Q fever in the modelled domain per 10 days for different emission types. Shown is the time of infection (assuming an incubation time for reported cases of 21 days). In black the number of reported cases, the other colours show modelled cases for the three different emission types from Figure 6.

In next sections of this report, we will use emission type C, since it matches best with the time distribution of the reported cases; the other types show large outliers compared to the reported number of cases.

4.3 Case 1: Comparing OPS concentrations with reported Q fever cases

In order to compare the OPS concentrations to the reported cases of Q fever around the farm at Voerendaal, new runs were performed with a grid based on a population density grid, which was available at a 500 m grid resolution (Figure 8).
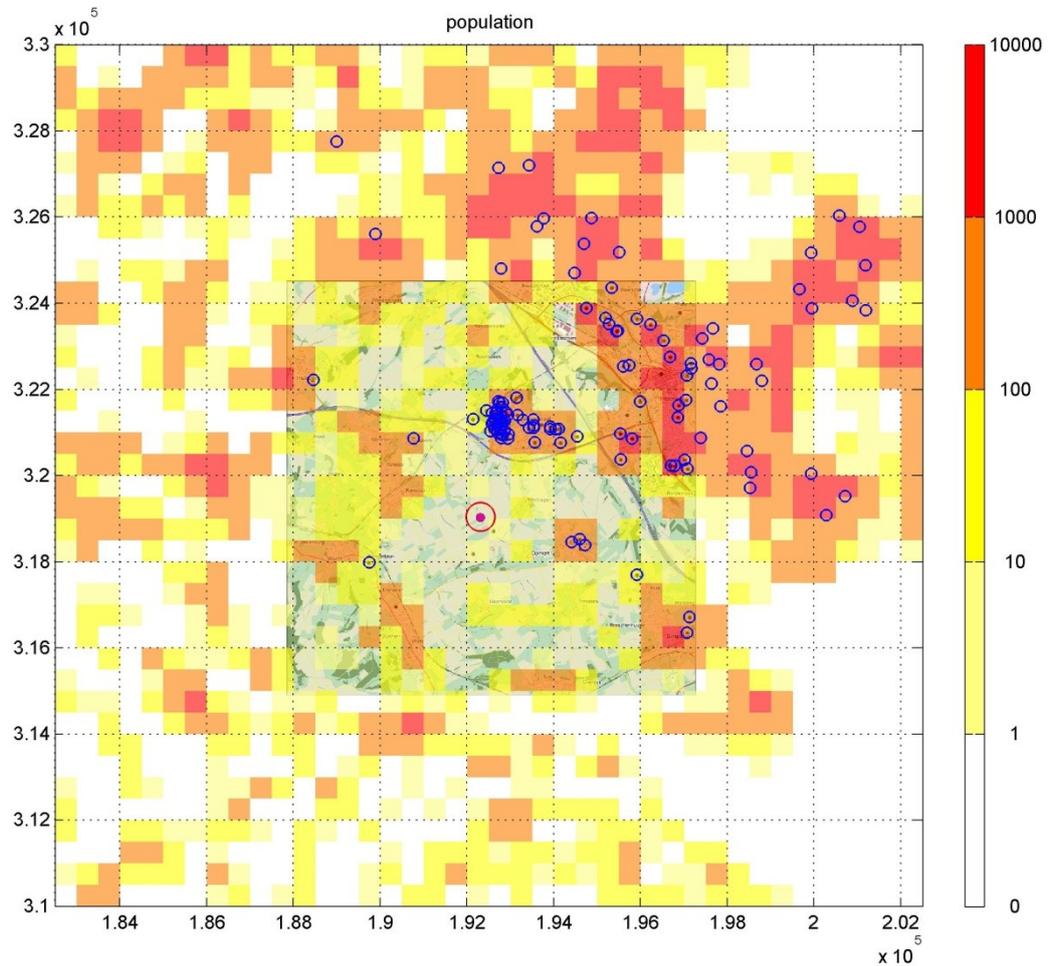
Figure 8: 20 x 20 km² grid around the farm at Voerendaal with population numbers. Blue circles: reported cases of Q fever infected during the test period 2009-02-01 to 2009-05-31 (assuming an incubation time of 21 days). Red circle: farm.

We used the default settings as before (threshold velocity for emission of 4 m/s) and emission type C. Results are presented as an average concentration over the period 2009-02-01 to 2009-05-31 (Figure 9).
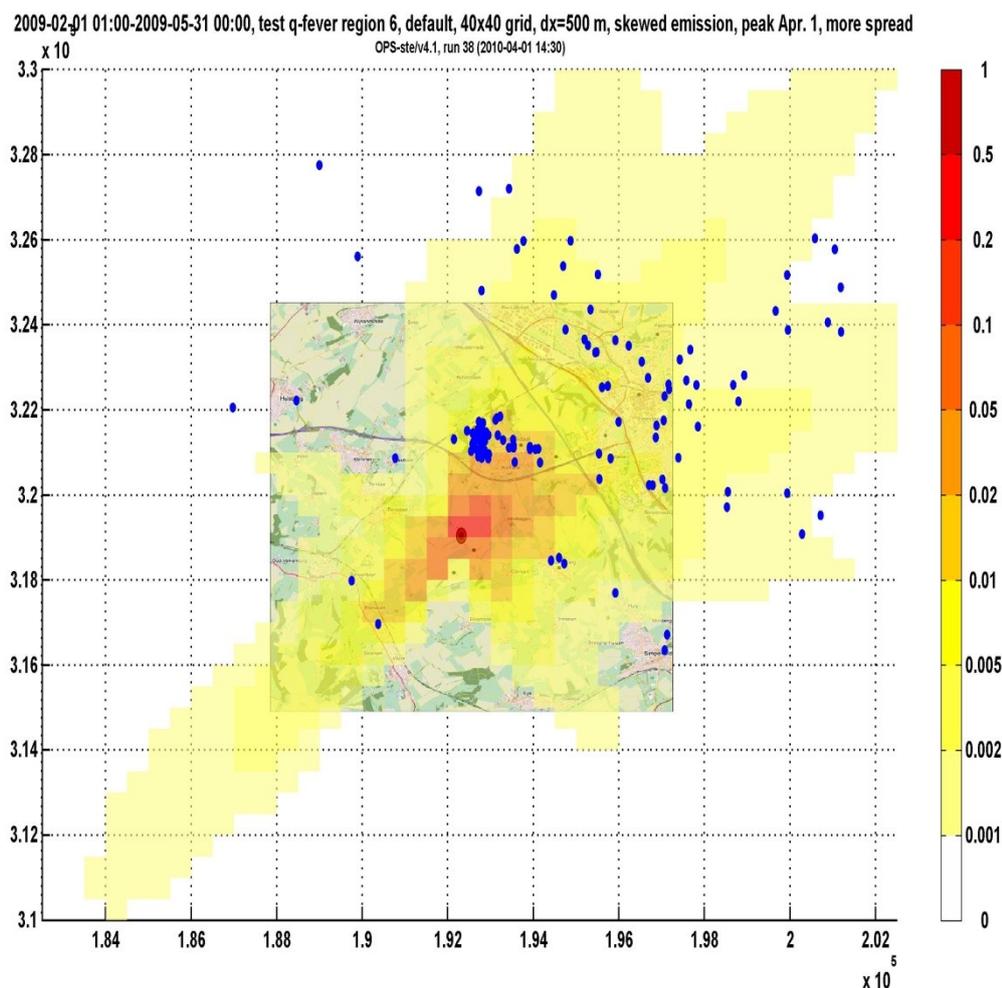
Figure 9: 20 x 20 km^2 grid around the farm at Voerendaal with OPS concentrations; emissions (type C) released for wind velocities > 4 m/s (run 038). Blue dots: reported cases of Q fever during the test period. Red circle: farm. Colours denote relative concentrations between 0 and 1.

Comparing OPS model results with reported Q fever cases will provide insight into the ability of OPS to model the dispersion of the Q fever bacteria. Since we want to evaluate the performance of the OPS model, we have set up two other simple models to compare with:

model 0: assume a uniform concentration over the whole domain
model 1: assume a concentration distribution $\sim 1/r^2$, with r the distance to the farm.

In order to obtain a measure for the distribution of human Q fever cases, we assumed that the number of cases per inhabitant in a grid cell is linearly dependent on the concentration in the grid cell and scaled the models such that the modelled number of cases in the whole domain was equal to the number of reported cases. The results (cases/inhabitant) can be shown as a grid (Figure

10), but also in the form of scatter plots (Figure 11, x-axis: reported cases/inhabitant, y-axis: modelled cases/inhabitant).
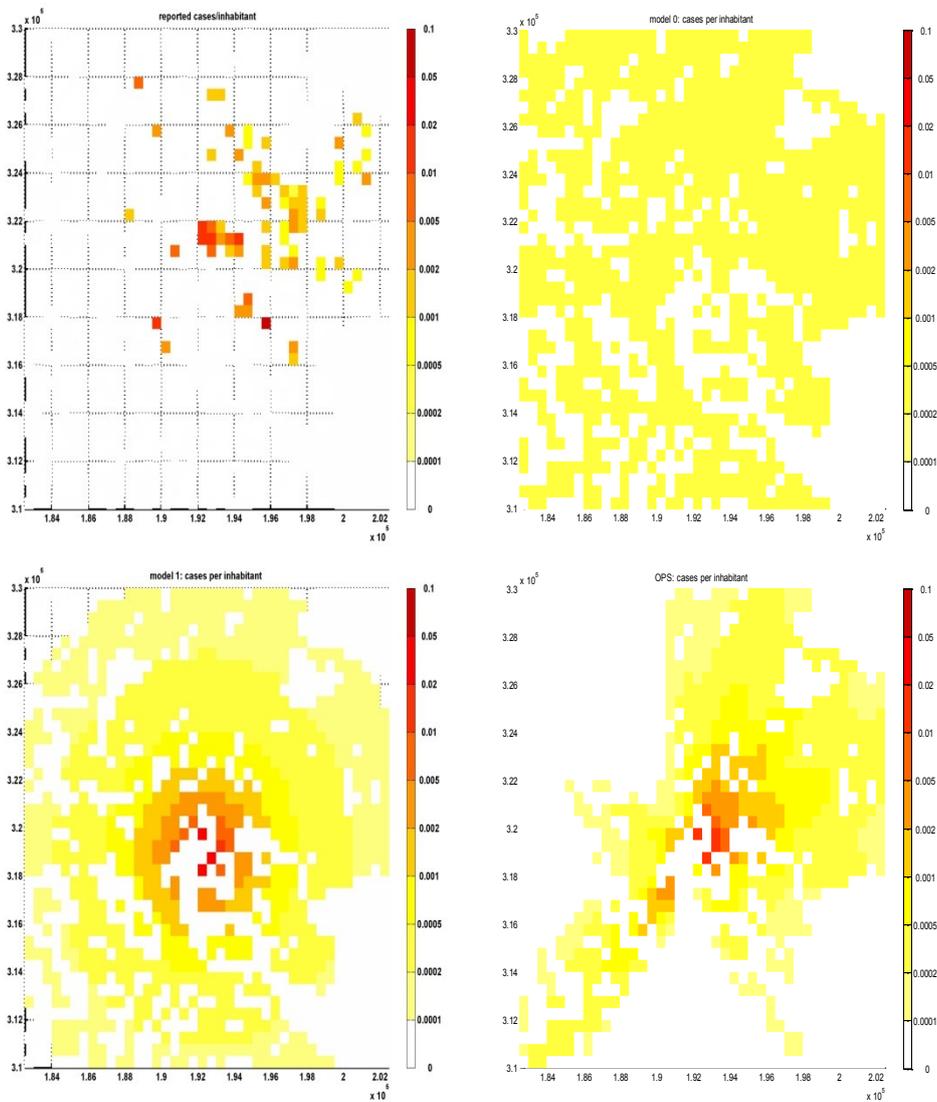

Figure 10: 20 x 20 km^2 grid around farm at Voerendaal with Q fever cases per inhabitant; emissions (type C) released for wind velocities > 4 m/s (run 038). Top-left: reported cases; top-right: model 0 (uniform concentrations); bottom-left: model 1 (concentrations ~1/r2); bottom-right: OPS.
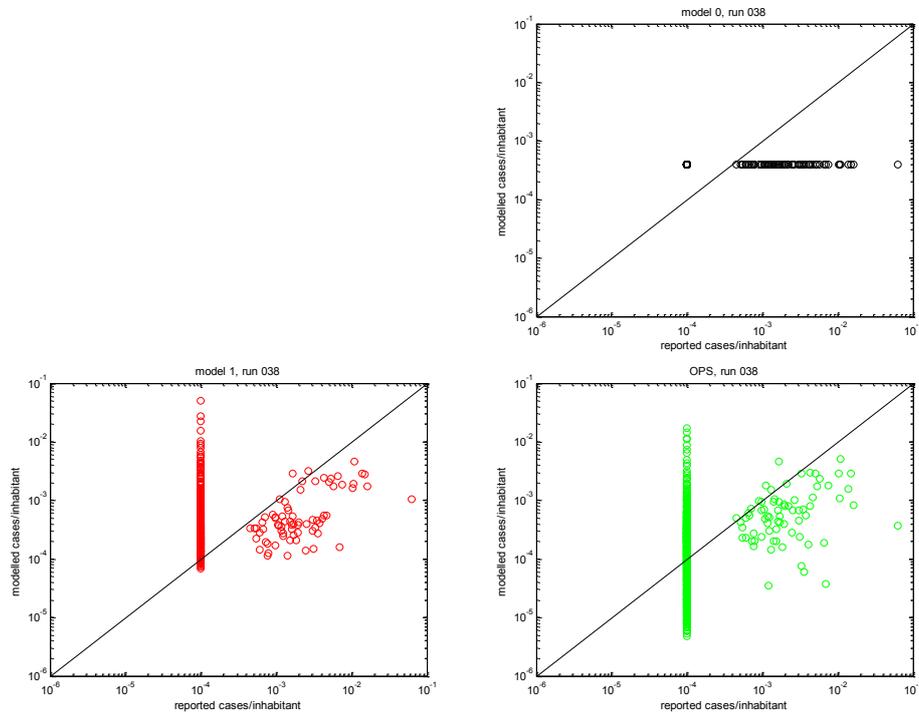
Figure 11: Scatter plot (log-log scale) for all grid cells in a 20 x 20 km^2 grid around the farm at Voerendaal with Q fever cases per inhabitant; emissions (type C) released for wind velocities > 4 m/s (run 038). Top-right: model 0 (uniform concentrations); bottom-left: model 1 (concentrations ~1/r2); bottom-right: OPS. Grid cells with no reported Q fever cases have been set to an arbitrary low value (10^{-4}), in order to show them in the plot.

From both Figure 10 and Figure 11, we may conclude that the OPS model performs better than model 0. Comparing OPS with model 1, the main difference is the cluster of grid cells which have no reported Q fever cases; for model 1 this cluster is in the range of [10^{-4} – 10^{-2}] (mean value: 6.1 10^{-4}) cases per inhabitant, for OPS in the range of [10^{-6} 10^{-2}] (mean value 3.5 10^{-4}) cases per inhabitant.

In Figure 12, we sorted the incidence rates (number of cases per inhabitant) for model 1 and OPS, clustered them into three classes of equal length ('low risk', 'medium risk' and 'high risk') and plotted the reported incidence rates and human Q fever cases for these clusters of grid cells.
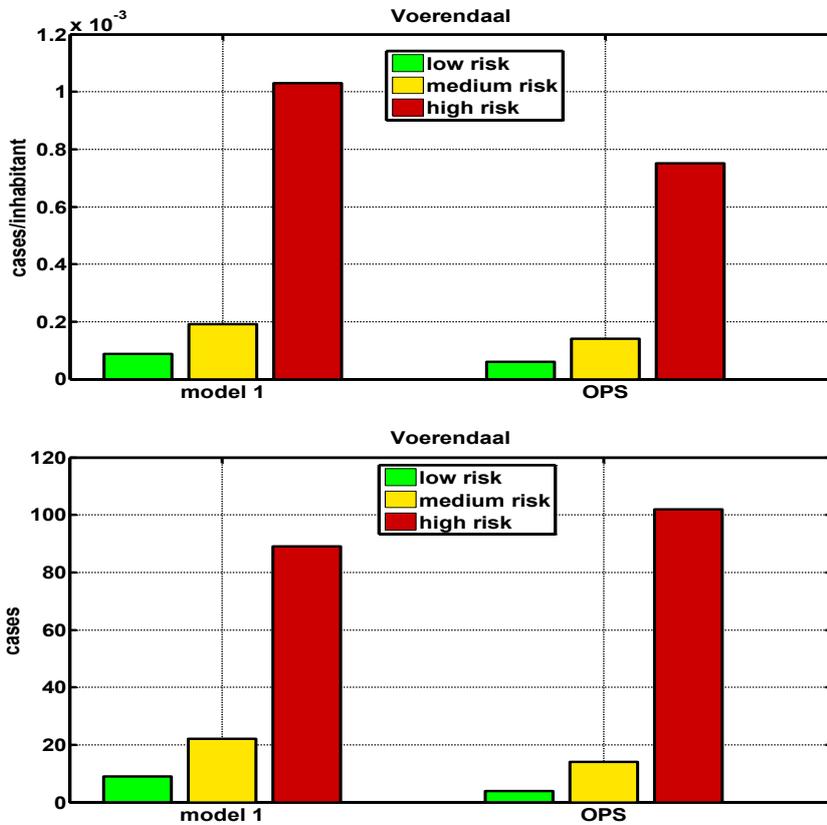
Figure 12: Data clustered into three classes (low risk, medium risk, high risk) for Voerendaal, 2009. Upper panel: incidence rates (i.e., number of cases between 2009-02-01 and 2009-05-31 per inhabitant for each grid cell). Lower panel: number of human cases of Q fever.

From Figure 12, we see that OPS is slightly better in separating the low risk grid cells from other cells; the ratio of incidence rates of the high risk and the low risk classes are 11.7 for model 1 and 12.7 for OPS.

Another possible application of the OPS model data is to see what the average concentration profile in time is for a patient. A separate run was done (run 041) on the 20 x 20 km^2 domain, where we used the location of the Q fever cases as receptors for OPS. An average concentration profile was computed with respect to the date of onset of each case (Figure 13).

Figure 13: Average concentration profile in time (3-day average). The averaging is over all cases (124 patients) in the modelled domain, taking the date of onset of each case as the reference time (blue line). Highest concentration before the date of onset is at 23 days before. The incubation time for Q fever is estimated to be 2-3 weeks (Parker et al. 2006).
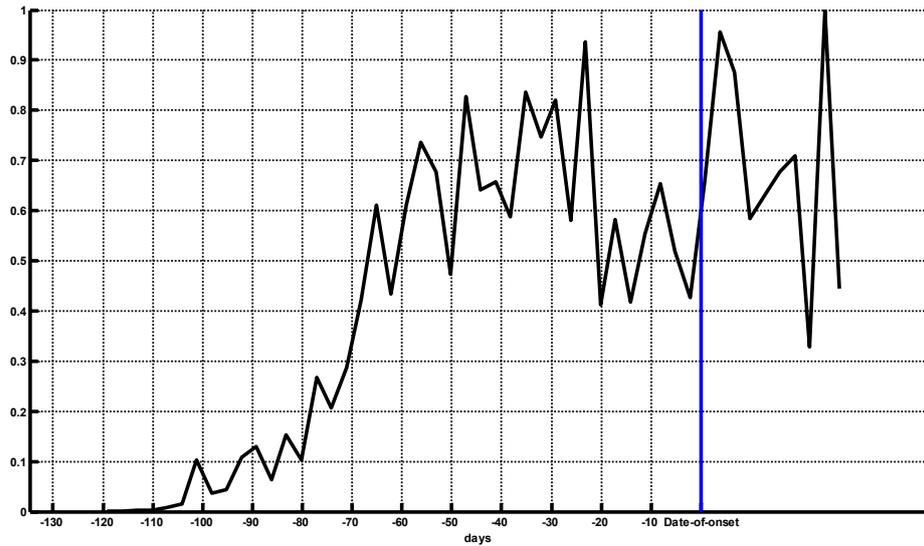
4.4　Case 2: set-up

Case 2 is the outbreak of Q fever near Helmond in 2008 (Figure 14).
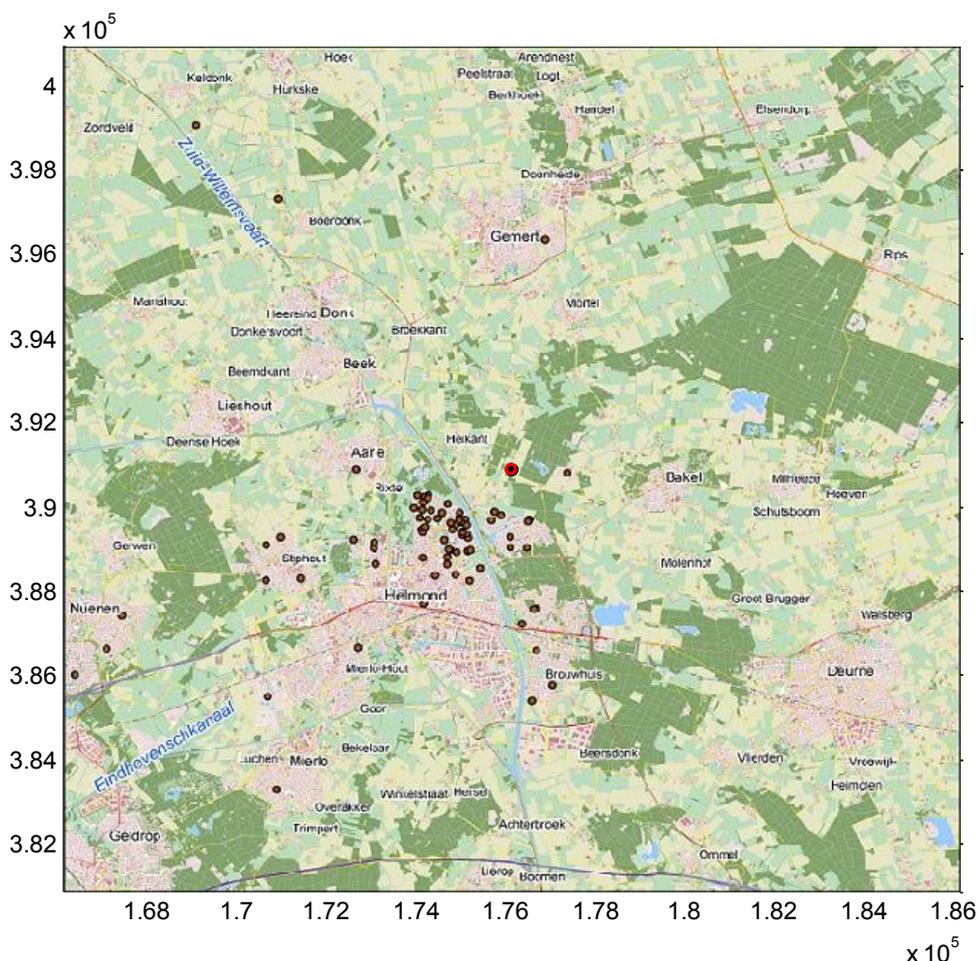
Figure 14: Map of modelled domain around Helmond. Red dot: farm. Brown dots: human cases of Q fever reported in 2008.

The modelling set-up was more or less the same as before:
- Q fever bacteria are treated as particles, with the standard OPS 'coarse' particle size distribution
- single point source, emission height = 3 m
- threshold wind velocity 4 m/s
- dry deposition according to the dry deposition module DEPAC for particles
- OPS meteorological region 5 (Brabant)
- roughness length = 0.20 m
- receptor height = 1.5 m.

4.5　Case 2: sensitivity runs

We did not repeat all the sensitivity runs of the previous case but tried several different types of emission distribution and compared the predicted number of cases per 10 days to the reported number of cases in the modelled domain. As before, modelling results were scaled such that the total number of modelled

cases was equal to the number of reported cases in the domain. A grid of 500 m resolution, with an area of 20 x 20 km^2 around Helmond was used. Because a uniform emission distribution does not fit the data well and the timing of the emission peak was not known, we assumed here the following three emission profiles (Figure 15) and computed the number of Q fever cases with OPS (Figure 16).
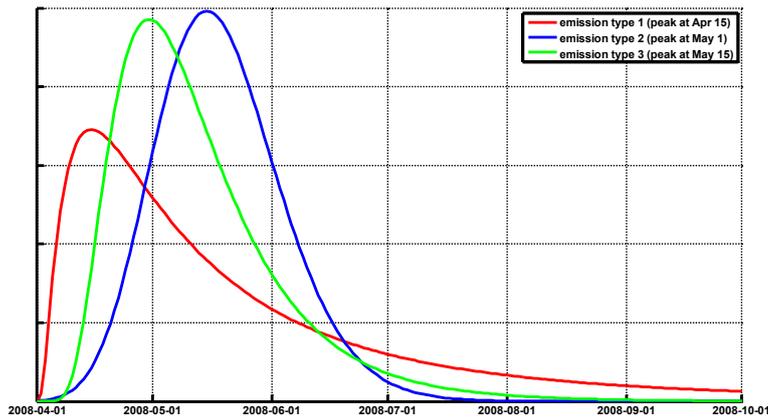
Figure 15: Three different emission types, with different distributions in time (peak value and spread in time). Arbitrary y-axis.
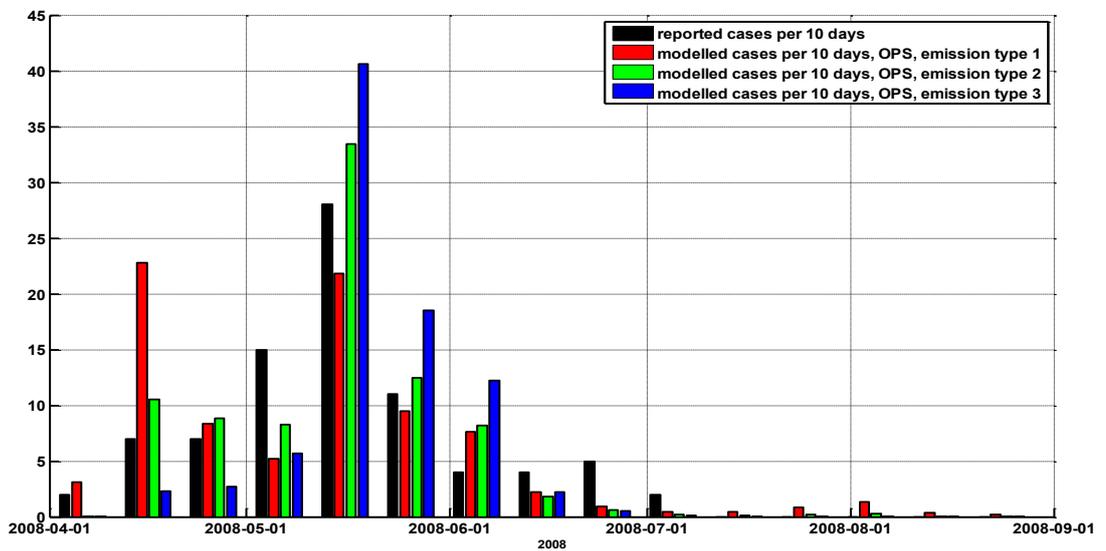
Figure 16: Number of human cases of Q fever in the modelled domain per 10 days for different emission types. Shown is the time of infection (assuming an incubation time for reported cases of 21 days). In black the number of reported cases, the other colours show modelled cases for three different emission types from Figure 15.

Emission type 2 seems to fit the reported cases best and will be used in the following analysis.

4.6 Case 2: Comparing OPS concentrations with reported Q fever cases

The location of the farm, the reported human Q fever cases and the number of inhabitants in each grid cell are shown in Figure 17.
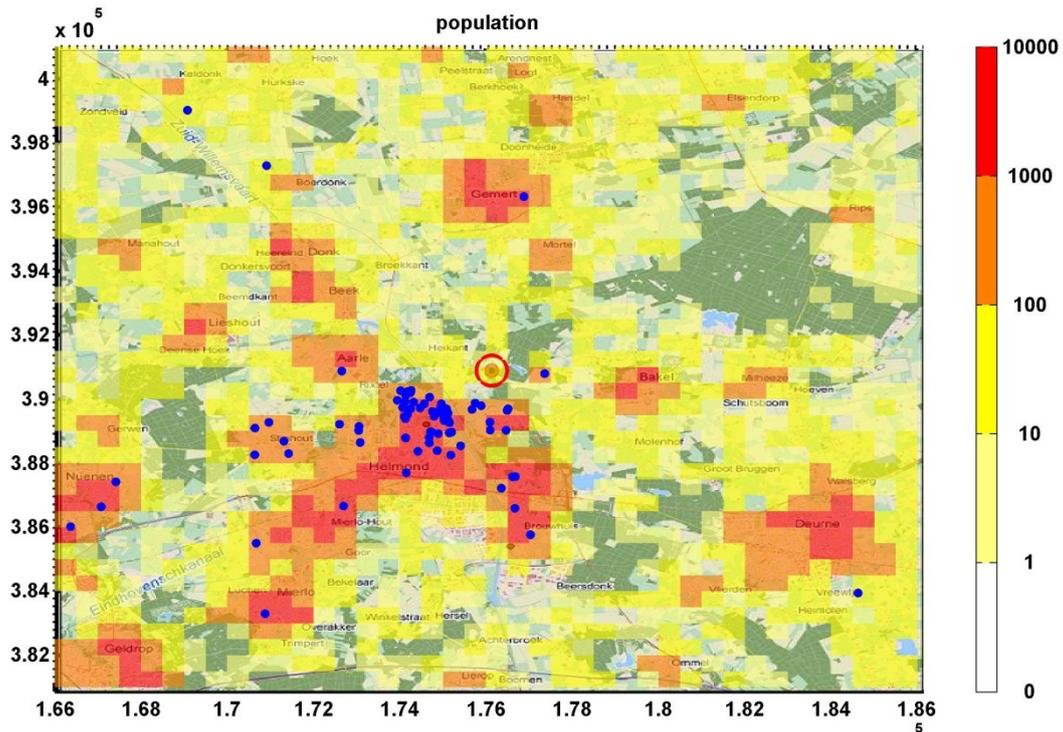
Figure 17: 20 x 20 km^2 grid around the farm at Helmond with population numbers. Blue dots: reported cases of Q fever infected during 2008. Red circle: farm.

Average OPS concentrations during the test period 2008-04-01 to 2008-09-01 (emission type 2) are presented in Figure 18.
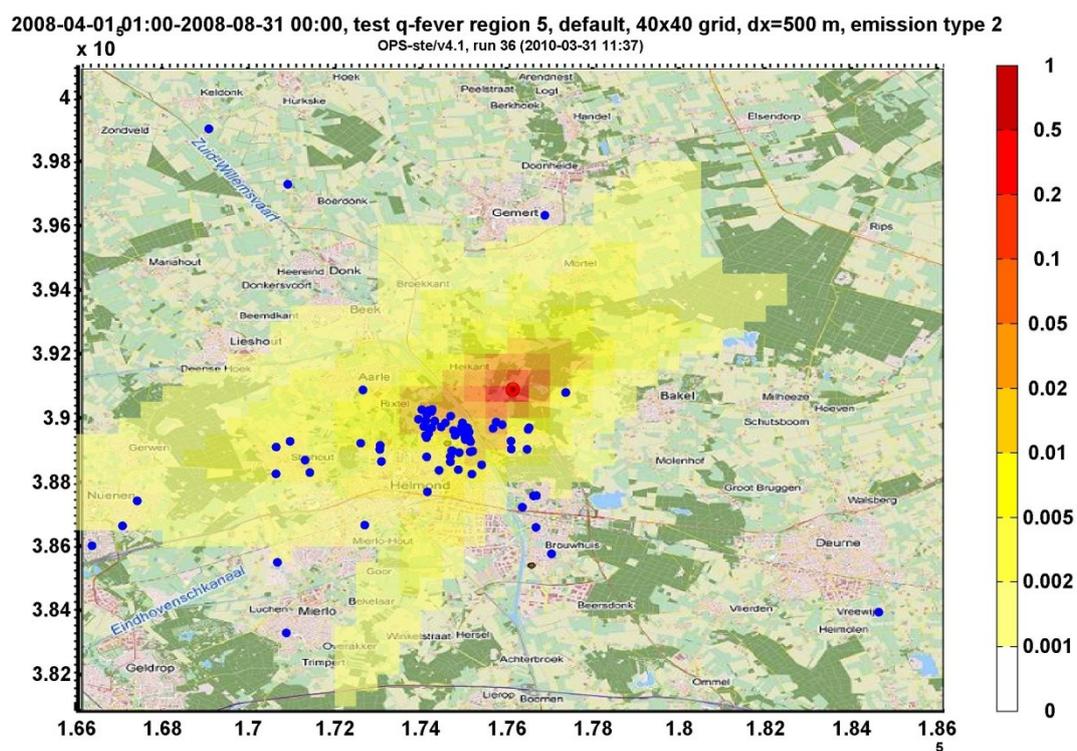
Figure 18: 20 x 20 km² grid around the farm at Helmond with OPS concentrations; emissions released for wind velocities > 4 m/s and emission type 2 (run 036). Blue dots: reported cases of Q fever during the test period. Red circle: farm. Colours denote relative concentrations between 0 and 1.

As before, we used two other models to compare the model results to the reported number of cases per inhabitant (Figure 19 and Figure 20).
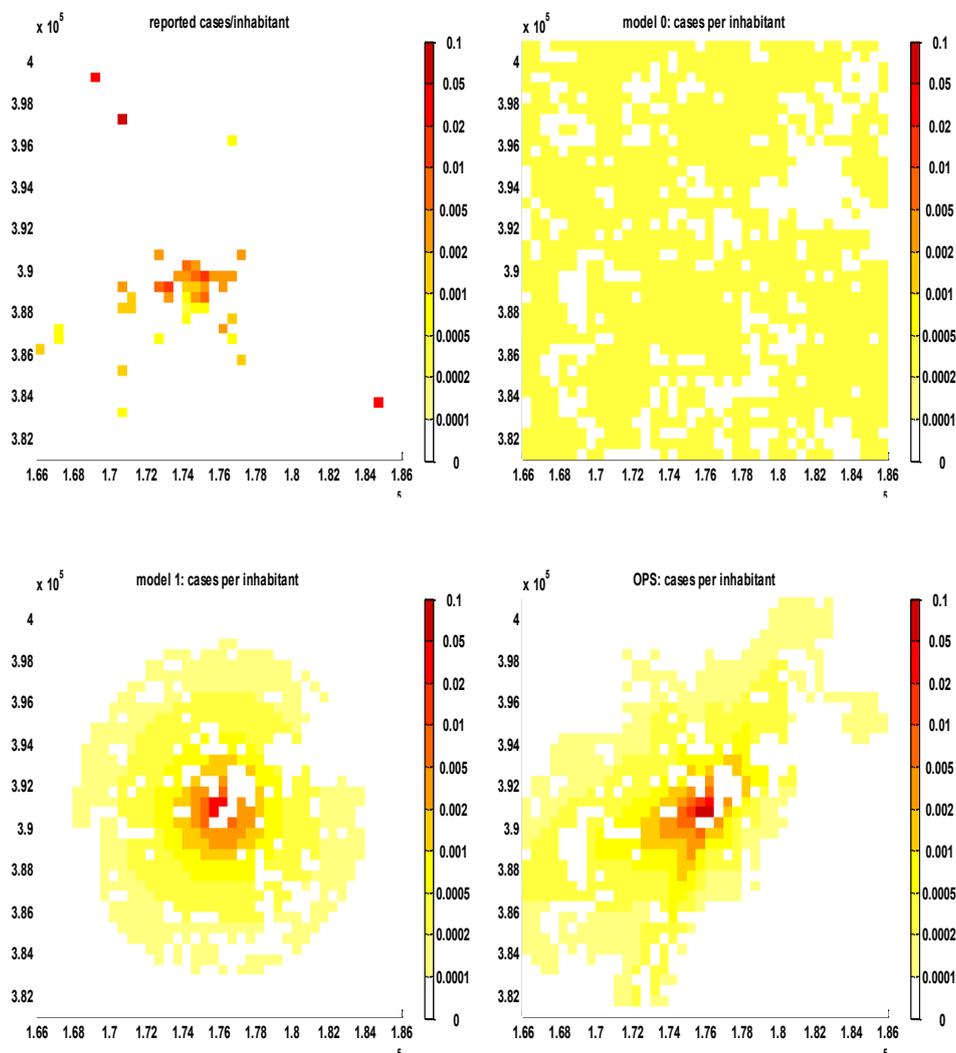
Figure 19: 20 x 20 km² grid around the farm at Helmond with Q fever cases per inhabitant; emissions released for wind velocities > 4 m/s and emission type 2 (run 036). Top-left: reported cases; top-right: model 0 (uniform concentrations); bottom-left: model 1 (concentrations ~1/r2); bottom-right: OPS.
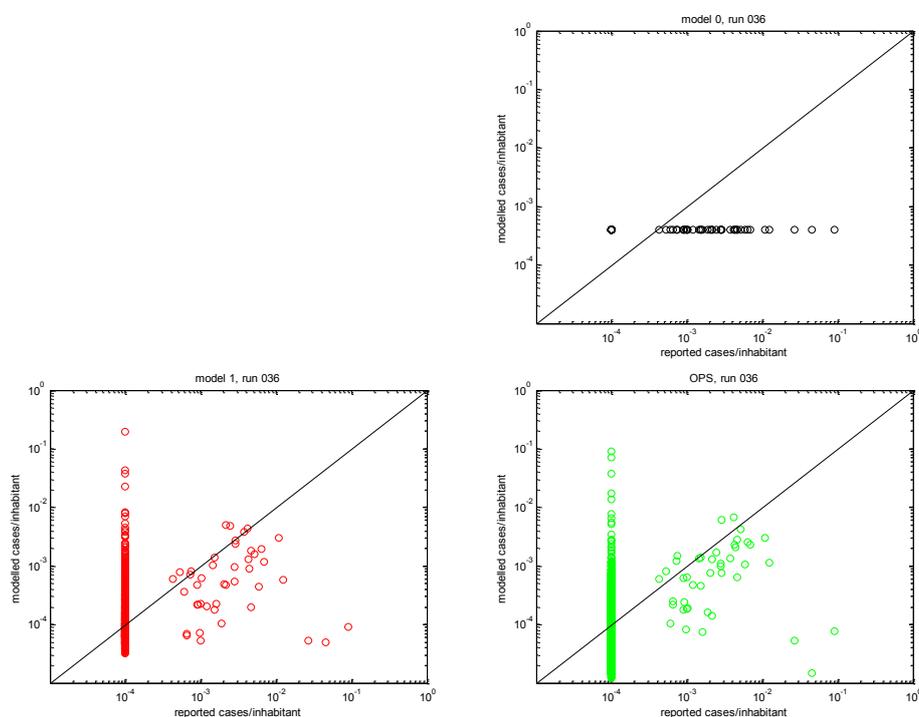
Figure 20: Scatter plot (log-log scale) for all grid cells in a 20 x 20 km² grid around the farm at Helmond with Q fever cases per inhabitant; emissions released for wind velocities > 4 m/s and emission type 2 (run 036). Top-right: model 0 (uniform concentrations); bottom-left: model 1 (concentrations ~1/r2); bottom-right: OPS. Grid cells with no reported Q fever cases have been set to an arbitrary low value (10⁻⁴), in order to show them in the plot.

The cluster of grid cells which have no reported Q fever cases has a mean value for model 1 of $5.0 \cdot 10^{-4}$ cases per inhabitant, for OPS $4.1 \cdot 10^{-4}$ cases per inhabitant.

In Figure 21, we sorted the incidence rates (number of cases per inhabitant) for model 1 and OPS, clustered them into three classes of equal length ('low risk', 'medium risk' and 'high risk') and plotted the reported incidence rates and human Q fever cases for these clusters of grid cells.
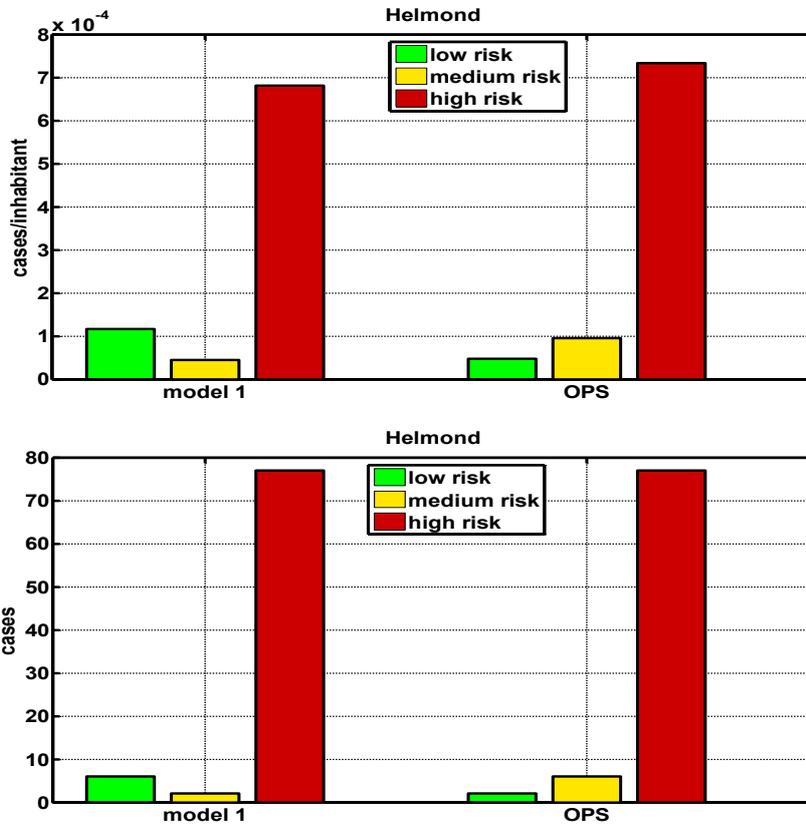
Figure 21: Data clustered into three classes (low risk, medium risk, high risk) for Helmond, 2008. Upper panel: incidence rates (i.e., number of cases between 2009-02-01 and 2009-05-31 per inhabitant for each grid cell). Lower panel: number of human cases of Q fever.

From Figure 21, we see that OPS is much better in separating the low risk grid cells from other cells; the ratio of incidence rates of the high risk and the low risk classes are 5.8 for model 1 and 15.5 for OPS.

The average concentration profile in time for a patient is shown in Figure 22.
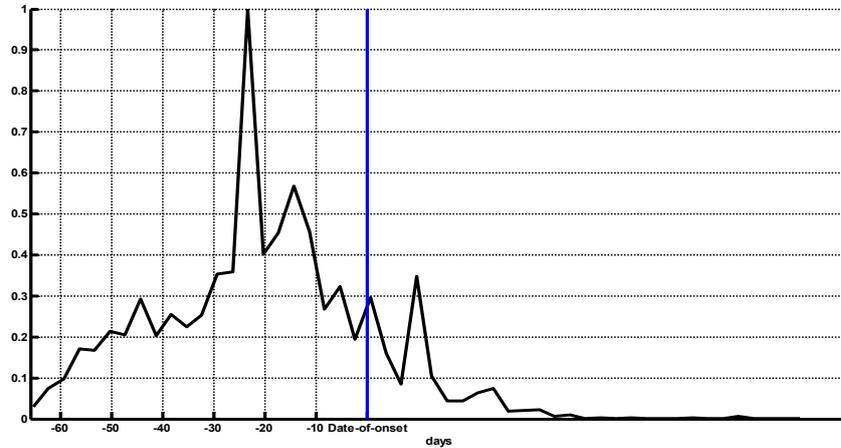
Figure 22: Average concentration profile in time (3-day average). The averaging is over all cases (85 patients), taking the date of onset of each case as the reference time (blue line). Highest concentration before the date of onset is at 23 days before (as in case 1). The incubation time for Q fever is estimated to be 2-3 weeks (Parker et al. 2006).

This average concentration profile shows a peak at 23 days before the date of onset, which corresponds well with the expected incubation time of 2-3 weeks. Of course, one has to take into account that emissions have been tuned on the total number of cases per 10 days in the whole domain, but the dose experienced by each patient may vary considerably, depending on the direction between farm and patient's address and the wind direction, as can be seen in Figure 23.

Figure 23: Daily film frames of Q fever outbreak near Helmond during May 10 – 21, 2008. The colours show the 3-day running averages of relative concentrations (0-1) computed by OPS, the black dots show reported Q fever cases that are infected on the current day (±1 day) assuming a 23-day incubation time.

5   Discussion and conclusions

The OPS model is able to simulate the general behaviour of airborne *Coxiella burnetii* dispersion. The distribution in space matches the general patterns of reported human Q fever cases. The distribution in time (number of cases per ten days) can be matched reasonably well by assuming a simple emission profile.
The average concentration profile in time shows a peak in concentration some 23 days before the date of onset of Q fever. This corresponds well with the incubation time of Q fever, which is usually 2-3 weeks with 4 days and 6 weeks representing the extremes (Parker et al. 2006).

The main difficulty in simulating Q fever dispersion is the lack of emission data. We tried to circumvent the problem of timing of the release of Q fever bacteria by postulating several emission profiles. The resulting temporal behaviour of modelled Q fever cases was evaluated against reported cases. From that, the most appropriate emission profile from a pre-defined set of candidates was chosen. The problem of not knowing the amount of bacteria released was circumvented by a scaling procedure, such that the total amount of modelled cases in the modelled domain was the same as the number of reported cases. One could argue that these procedures involve *a-priori* information that is not known normally.

In the two cases studied here, the main parameters that describe the distribution of human Q fever cases are the population density and distance to the farm. We compared OPS results with the results of two simple models: model 0 (assuming a uniform concentration distribution) and model 1 (concentration distribution $\sim 1/r^2$, with r the distance to the farm). Comparing low, medium and high risk areas, model 1 and OPS show that the risk of Q fever highly depends on the distance to the source. OPS adds extra information (wind direction and other dispersion related parameters) and computes lower average incidence rates in 'low risk' grid cells than the other models (see Figure 12 and Figure 21). Furthermore, OPS provides temporal information, which is completely missing in the other models.

Another difficulty in the simulation process lies in the fact that this study is based on the assumption that people receive their dose of Q fever bacteria whilst being 24/7 at home. More information on human activities during the day could improve results.

In this study, no detailed information on the soil and vegetation conditions was taken into account. These conditions play an important role in the amount of aerosol that is deposited from the air (Hunink et al. 2010). It is known that aerosol may resuspend again, in which surface characteristics such as wetness are an important parameter.

To reduce the uncertainty in the calculation, more information on the following items should become available:
- time and amount of bacteria released at a farm
- influence of external factors on the emission:
  - wind velocity; does a threshold velocity exist below which no emission takes place?
  - relative humidity

- length of the dry period before emission
  - wind gusts
  - wind direction with respect to geometry of stable
  - open stable – mechanically ventilated stable
- dispersion
  - particle size distribution
  - deposition parameters
- exposure
  - human activities
  - dose-response relation
- re-emission
  - linkage with soil dust
  - how long does a bacterium survive in the environment?

6   Acknowledgements

7   References

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Appendix A. OPS input file

Default .ops input file:

```
settings.ops
##########################################################################
###

                    Operational Atmospheric Transport Model
                            for Priority Substances

                            - Short Term Edition -


                            MODEL - SETTINGS  FILE

##########################################################################
###

 IMPORTANT: Do NOT change the first line above and the lay-out of sections
            "RUN OPTIONS" and "DIRECTORY PATHS" in this file, otherwise
            OPS-Ste might not work (properly)!

--------------------------- RUN  OPTIONS  ----------------------------
---


 1 | General Settings
   | - automatically quit after run (+)  _____ : n
   |   (for mutiple run-sessions with .BAT-file)
   |
   |   if 'no' auto-quit then:
   |   - detailed information to screen (+)  _____ : y
   |
   | - name simulation run  _____ : q019
   |
 2 | Select Component  _____ : 4
   | (1= SO2, 2= NO2, 3= NH3, 4= Particles, 5= User-Defined($))
   |
   | if "Particles" or "User-Defined" then:
   | - select particle-size distribution  _____ : 1
   |  (0= none, 1= coarse, 2= medium, 3= fine, 4= user-defined)
   |
   |   if "User-Defined" then:
   |   - name particle-size distribution-file (.psd): USER_DEFINED
   |
 3 | Area Characteristics
   | - name meteorological file  _____ : 2009\rg6mbk09
   | - surface-resistance (Rc) data  _____ : 1
   |   (0= Constant; 1= Variable (DEPAC-module))
   |
   |   if 0 then:
   |   - Rc-value [s/m] (**)  _____ : 50
```

```
     |
     | - roughness length data ($)  _____  : 0
     |   (0= Single Value, 1= Roughness-Length Map)
     |
     |   if 0 then ($):
     | - overall roughness length [m]  _____  : 0.20
     |   if 1 then ($):
     | - name file roughness-length map (.rgh)  ___  : ROUGHNESSFILENAME
     ! - Other meteo parameters:
     |   - altitude wind obs._____  : 10.
     ! - z0 used for meteo data _____  : 0.03
     |     (0= overall z0 is used)_____
     |
 4 | Time Period & Averaging
     | - start run (yy mm dd hh)  _____  : 09 01 01 01
     | - end run   (yy mm dd hh)  _____  : 09 12 31 24
     | - type of averaging  _____  : 4
     |   (0= Total Period, 1= Year, 2= Month, 3= Day, 4= Hour)
     |
 5 | Source Configuration  _____  : 1
     | (0= constant, 1= variable [hourly])
     |
     | if 0 then:
     | - name constant source file (.src)  _____  : none
     | - select source category  (0000 = all)  _____  : 0000
     | - select country area  (0000 = all)  _____  : 0000
     | if 1 then:
     | - name hourly emission file (.ems)  _____   : testq_2009_uni_1
     |
 6 | Receptor Configuration  _____  : 0
     | (0= Model Grid, 1= Specific Receptor(s))
     |
     | if 0 then:
     | - receptor-grid height [m]  (#)  _____  : 1.5
     | - grid centre co-ordinates [m]  (*)  _____  :      0.0      0.0
     | - number of grid elements [x & y dir.]  (#)  __ :  50   50
     | - grid resolution [m]  (#)  _____  : 200
     | if 1 then:
     | - name of receptor file (.rcp)  _____  : _
     |
 7 | Also percentiles?  (+)  _____  : n
     |
     | if 1 then:
     | - percentile value  (001 - 100)  _____  : 098
     | - incl. background concentration  (+)  _____  : y
     |
 8 | Also dry deposition?  (+)  _____  : y


 NOTES:
  (+)  Choose:  n = no;  y = yes
  (**) Valid range:  0 - 10000
  (*)  Dutch co-ordinate system called "Amersfoorste co-ordinate system".
For
      the Netherlands ranges are:  013000.0 <= x <= 278000.0  and
      306000.0 <= y <= 620000.0 .
```

```
(#)  Valid range:  000 - 999
($)  Not yet available !!!



--------------------------  DIRECTORY PATHS  --------------------------
---

 INPUT PATHS:
 annual source-emission (.src)  __  : D:\proj\ops\OPS-KT\input\src\
 hourly emission (.ems)  _____  : ..\data\emis\
 meteorlogical data _____  : D:\proj\ops\OPS-KT\input\met\
 partical size-distribution (.psd) : D:\proj\ops\OPS-KT\input\psd\
 receptor(s) (.rcp)  _____   : D:\proj\ops\OPS-KT\input\rcp\
 map of roughness lengths (.rgh)   : D:\proj\ops\OPS-KT\input\rgh\

 OUTPUT PATH:
 output  _____  : ..\data\output\q019\

 NOTE: If directory path is kept open, OPS-STe will look for\save files into
       same folder as where the model has been put.



----------------------  DESCRIPTION SIMULATION RUN  --------------------
---
 ...


#########################################################################
###

                 Copyright 1992-2002 RIVM, 2003-2004 MNP-RIVM
                        (Bilthoven, The Netherlands)
```

Appendix B. OPS runs

Preliminary test runs

Preliminary test runs were done to check whether OPS performs as expected and to check that everything works. Emissions in these runs are presented in Figure 24.
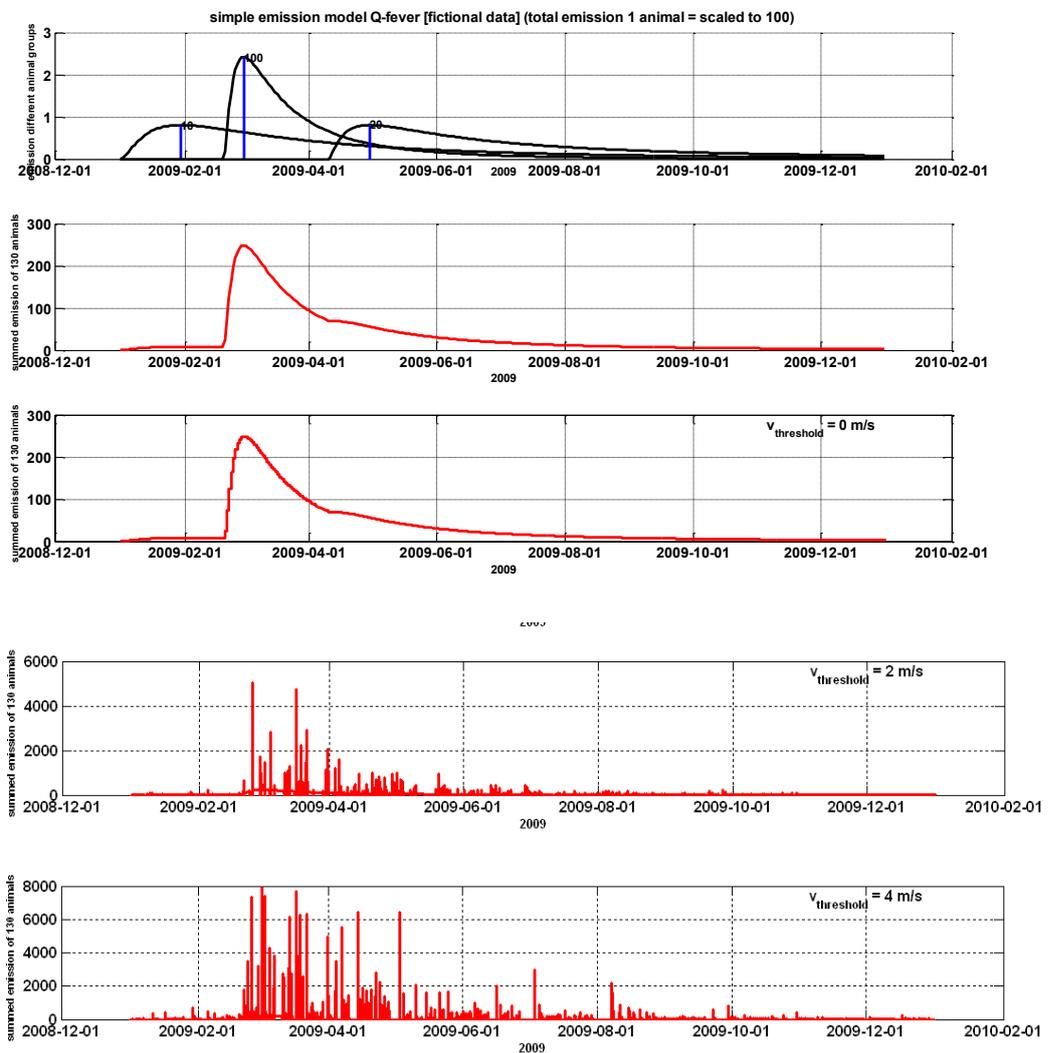

Figure 24: Fictive emission for preliminary Q fever simulations; upper panel three lognormal distributions in time, for three groups of animals with 10, 100 and 20 animals. Second panel: summed emission. Third panel: emission without a threshold wind velocity. Fourth panel: emission with a threshold wind velocity of 2 m/s. Fifth panel: emission with a threshold wind velocity of 4 m/s.

Test runs for non-reactive gas, region 6 (Voerendaal)		
Test runs with emissions as area source d = 25 m, h = 0 m.		
run	emission file	remarks
001	testq_2005.ems	test-emission 2005, no threshold velocity
002	testq_2008.ems	test-emission 2008, no threshold velocity
003	testq_2009.ems	test-emission 2009, no threshold velocity
004	testq_2009_v0.ems	test-emission 2009, threshold velocity for emission = 0 m/s
005	testq_2009_v2.ems	test-emission 2009, threshold velocity for emission = 2 m/s
006	testq_2009_v4.ems	test-emission 2009, threshold velocity for emission = 4 m/s
007	testq_2009_shift30.ems	test-emission 2009, source location shifted to (30,30) → no important differences in plume
008	testq_2009_shift50.ems	test-emission 2009, source location shifted to (50,50) => OPS crashes, dsx = 0; divide by 0
Test runs with emissions as point source d = 0 m, h = 0 m, threshold velocity = 4 m/s		
009	testq_2009_p_shift0.ems	test-emission 2009, point source location shifted to (0,0)
010	testq_2009_p_shift30.ems	test-emission 2009, point source location shifted to (30,30)
011	testq_2009_p_shift50.ems	test-emission 2009, point source location shifted to (50,50) → no important differences in plume; extremely high values near farm (receptor at source location)
Test runs with emissions as point source d = 0 m, h = 3 m, threshold velocity = 4 m/s, source at (0,0)		
012	testq_2009_p_shift0_h3.ems	test-emission 2009, h = 3 m

Test runs for particles, region 6 (Voerendaal)		
Test runs with emissions as point source d = 0 m, h = 0 m, threshold velocity = 4 m/s		
run	emission file	remarks
013	testq_2009_p_shift0_h3_psd3.ems	test-emission 2009, 'coarse' particles, source at (0,0), longer simulation period (2009-06-01)
015	testq_2009_p_shift0_h3_psd3.ems	test-emission 2009, 'extra coarse' particles, source at (0,0); user defined psd ../data/psd/qfever1.psd
016a	testq_2009_r6_p_shift0_h3_psd3.ems	test-emission 2009,

		'coarse' particles, source at (0,0), emission/1000. → concentration = 0 !
016b	testq_2009_r6_p_shift0_h3_psd3.ems	test-emission 2009, 'coarse' particles, source at (0,0), emission/10.
017	testq_2009_r6_p_shift0_h3_psd3.ems	test-emission 2009, 'coarse' particles, source at (0,0), emission, receptor height = 1.5 m
018	testq_2009_r6_p_shift0_h3_psd3.ems	test-emission 2009, 'coarse' particles, source at (0,0), emission, receptor height = 1.5 m, grid resolution = 200 m.

Test runs for particles, region 3		
Test runs with emissions as point source d = 0 m, h = 0 m, threshold velocity = 4 m/s		
run	emission file	remarks
014	testq_2009_r3_p_shift0_h3_psd3.ems	test-emission 2009, 'coarse' particles, source at (0,0)

Test runs, farm at grid centre (0,0)

Test runs for particles, region 6 (Voerendaal)		
Test runs with emissions as point source d = 0 m, h = 3 m, threshold velocity = 4 m/s grid resolution 200 m		
run	emission file	remarks
019	testq_2009_uni_1.ems	default run
020	testq_2009_uni_2.ems	default + v_threshold = 8 m/s → plume only in certain directions
021	testq_2009_uni_3.ems	default + v_threshold = 2 m/s → plume spread over larger area, concentrations higher
022	testq_2009_uni_4.ems	default + v_threshold = 0 m/s → more spread, concentrations even higher
023	testq_2009_log_1.ems	default + emission log-normal distribution in time → differences with default run 019 marginal; 019 somewhat larger plume (more emission during plot-period)
024	testq_2009_uni_1.ems	default + extra coarse particles (4-10 µm: 20%, 10-20 µm: 60%, > 20 µm: 20%). → plume somewhat smaller, differences small with run 019.
025	testq_2009_uni_5.ems	default + uniform emission during

		2009-02-15 – 2009-03-15. Note that the total emission is the same as before, only the release is in a shorter time span (1 month instead of 3 months). → more concentrated plume in some directions; no partial plumes in other directions.
026	testq_2009_uni_1.ems	default + receptors = Q fever cases near Voerendaal
027	testq_2009_uni_1.ems	default + grid resolution of 500 m.

Test runs, RDM coordinates

Test runs for particles, region 6 (Voerendaal)		
Test runs with emissions as point source d = 0 m, h = 3 m, threshold velocity = 4 m/s Amersfoort-coordinates (RDM); grid coincides with population grid; grid resolution = 500 m.		
028	testq_2009_uni_ac_1.ems	default; grid 10x10 km^2; v_threshold = 4 m/s
029	testq_2009_uni_ac_1.ems	default; grid 20x20 km^2; v_threshold = 4 m/s
030	testq_2009_uni_ac_2.ems	default; grid 20x20 km^2; v_threshold = 8 m/s
031	testq_2009_uni_ac_3.ems	default; grid 20x20 km^2; v_threshold = 2 m/s
032	testq_2009_uni_ac_4.ems	default; grid 20x20 km^2; v_threshold = 0 m/s
033	testq_2009_uni_ac_1.ems	default; receptors = cases_voerendaal; v_threshold = 4 m/s;
037	testq_2009_vdaal_log_1	default; grid 20x20 km^2; v_threshold = 4 m/s; emission type B (t1=32; t2=92; σ=0.3)
038	testq_2009_vdaal_log_2	default; grid 20x20 km^2; v_threshold = 4 m/s; emission type C (t1=32; t2=92; σ=0.5)
039	testq_2009_vdaal_log_2	default; receptors = cases_voerendaal; v_threshold = 4 m/s; emission type C (t1=32; t2=92; σ=0.5)
041	testq_2009_vdaal_log_2	default; receptors = cases_voerendaal2; v_threshold = 4 m/s; emission type C (t1=32; t2=92; σ=0.5)

Test runs for particles, region 5 (Helmond)		
Test runs with emissions as point source d = 0 m, h = 3 m, threshold velocity = 4 m/s Amersfoort-coordinates (RDM); grid coincides with population grid; grid resolution = 500 m.		
034	testq_2008_log_bakel_1.ems	default; grid 20x20 km^2; v_threshold = 4 m/s; emission type 1 (t1=92; t2=106; σ=1).
035	testq_2008_bakel_log_2.ems	default; grid 20x20 km^2; v_threshold = 4 m/s; emission type 3 (t1=30; t2=136; σ=0.15).
036	testq_2008_bakel_log_3.ems	default; grid 20x20 km^2; v_threshold = 4 m/s; emission type 2 (t1=92; t2=121; σ=0.5).
040	testq_2008_bakel_log_3.ems	default; grid 20x20 km^2; v_threshold = 4 m/s; emission type 2 (t1=92; t2=121; σ=0.5). Receptors = patients.