

Uncertainty propagation from ensemble dispersion simulations through a terrestrial food chain and dose model

T. Hamburger^{1,*}, F. Gering¹, Y. Yevdin¹, S. Schantz¹, G. Geertsema² and H. de Vries²

¹ BfS – Bundesamt für Strahlenschutz, Oberschleißheim, Germany.

² KNMI – Royal Netherlands Meteorological Institute, De Bilt, The Netherlands.

Abstract – In the framework of the European project CONFIDENCE, Work Package 1 (WP1) focused on the uncertainties in the pre- and early phase of a radiological emergency. One subtask was to analyse the propagation of uncertainties from ensemble dispersion simulations through a terrestrial food chain and dose model. Uncertainties that may occur in the modelling of radioactivity in the food chain were added to previously defined meteorological and source term uncertainties. Endpoints of the ensemble calculations within the food chain model included activity concentrations in the food chain, *i.e.* feedstuffs and foodstuffs, as well as the internal dose through ingestion. This paper describes the uncertainty propagation through a terrestrial food chain and dose model and presents some illustrations of the results.

Keywords: CONFIDENCE / uncertainties / food chain model / ensemble simulations

1 Introduction

In the framework of the European project CONFIDENCE, Work Package 1 (WP1) focused on the uncertainties in the pre- and early phase of a radiological emergency. One subtask of WP1 (subtask 1.3.1, described in [Hamburger *et al.*, 2019](#)) was to analyse the propagation of uncertainties from ensemble dispersion simulations through a terrestrial food chain and dose model. Ensemble atmospheric dispersion calculations were performed in task 1.3 of WP1 ([De Vries *et al.*, 2019a](#)). The ensemble calculations were based on hypothetical accident scenarios at a nuclear power plant. The scenarios, as well as methods and results of the ensemble calculations, are described in detail in ([De Vries *et al.*, 2019b](#)). The endpoints of the ensemble calculations carried out in task 1.2 covered activity concentrations in air as well as deposited activity concentrations of the released radionuclides, and dose calculations through the pathways of cloud and ground shine (external dose), and inhalation (internal dose). These endpoints were extended in task 1.3 to activity concentrations in the food chain, *i.e.* feedstuffs and foodstuffs, as well as the internal dose through ingestion. In that task, uncertainties related to the food chain were added to those introduced by meteorological and source term uncertainties. The list of perturbed parameters in the food chain and their uncertainties can be found in [Hamburger *et al.* \(2019\)](#). The hypothetical accident scenario data consisted of an ensemble of 10 meteorological members

as described for the REM2 scenario in [De Vries *et al.* \(2019a\)](#) and a subset of five source term ensemble member representing five different release times (−6 h, −3 h, 0 h, +3 h, +6 h with respect to the reference release time). A release duration of four hours was assumed. The released quantity of the hypothetical scenario was approximately 800 PBq I-131 equivalent, resembling the quantity of I-131 released during the accident at Fukushima. For detailed information on the input for the ensemble members, see [Mathieu *et al.* \(2018\)](#), [De Vries *et al.* \(2019b\)](#) and [De Vries *et al.* \(2019a\)](#).

This paper describes the uncertainty propagation through a terrestrial food chain and dose model ([Sect. 2](#)) and presents some illustrations of the results ([Sect. 3](#)).

2 Food chain model

The Terrestrial Food and Dose Module (FDMT) is used in the JRODOS system ([Raskob *et al.*, 2012, 2016](#)) to simulate the transfer of radioactive material in food chains, and to assess the dose to the population *via* all relevant exposure pathways – internal exposure *via* inhalation and ingestion, and external exposure from cloud and ground shine ([Gering and Müller, 2004](#); [Müller *et al.*, 2004](#)). The main input parameters for FDMT are derived from the atmospheric dispersion calculations. They comprise the near ground activity concentration in air, the deposited activity concentration on the ground, the amount of precipitation and the date, *i.e.* season, of deposition. The different steps that calculate the transfer of radionuclides through the food chain are shown in [Figure 1](#).

* Corresponding author: thamburger@bfs.de

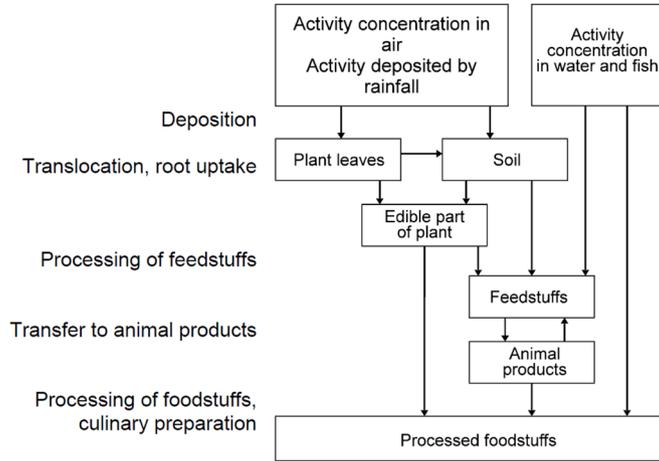


Fig. 1. Simulation steps of food chain transfer calculations (from Müller *et al.*, 2004).

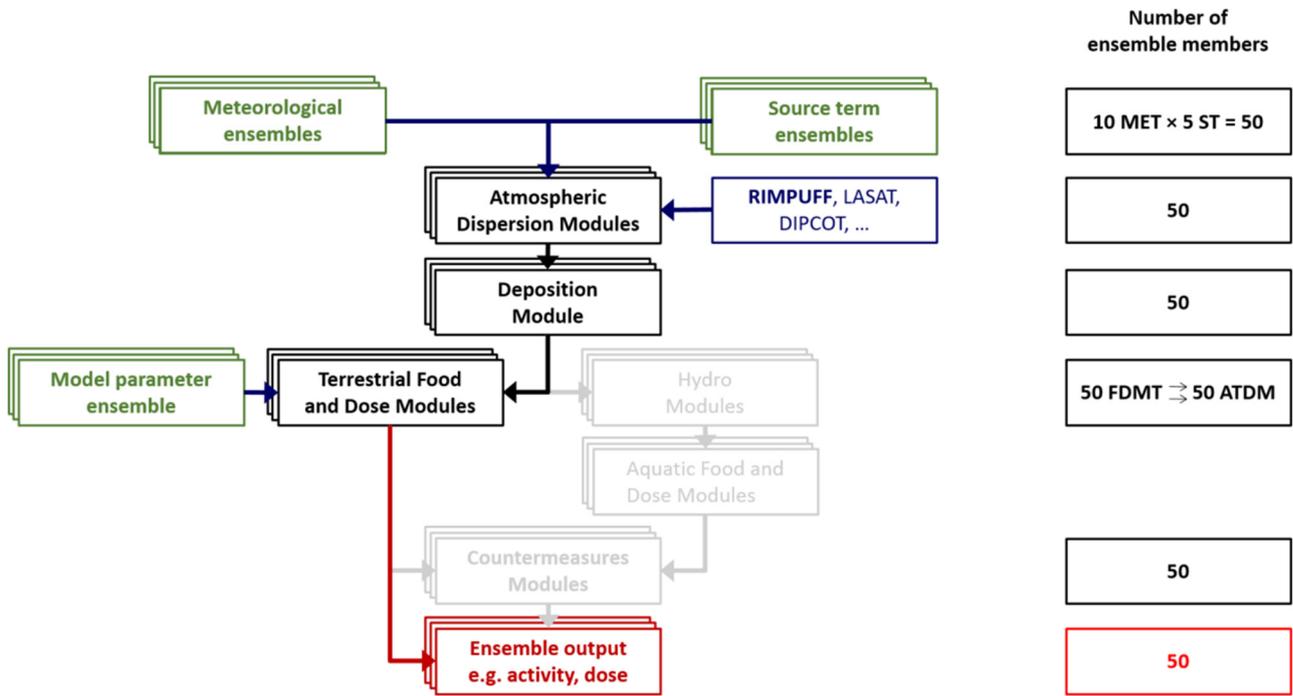


Fig. 2. Setup of the model chain for the propagation of uncertainties through an atmospheric dispersion model, a deposition model and finally a food chain and dose model. Green: model input in form of ensembles; black: models used for uncertainty propagation; red: results; grey: unused models.

The principle of the uncertainty propagation in the JRODOS model chain is illustrated in Figure 2.

Atmospheric dispersion calculations based on meteorological data and source term information were performed to calculate the atmospheric transport of the released radionuclides. The deposition of the airborne radionuclides on different surfaces was modelled in the next step. Then the transport within the human food chain was modelled according to the model parameter settings. Subsequently, organ doses and effective dose to the population were modelled using the available pathways of cloud shine, ground shine, inhalation, and ingestion.

In setting up the model chain, the uncertainties of the meteorological data and the source term were described by 10 meteorological ensemble members and five source term ensemble members, resulting in a total of 50 different configurations (see Fig. 2). Each one of these combinations of source term and meteorology was used as input and propagated through the full model chain, including the atmospheric dispersion calculation and the calculation of the endpoints of FDMT. The model parameters of FDMT were randomly selected from probability distributions, which described their inherent uncertainties (“model parameter ensemble” in Fig. 2). Such uncertainties were considered for

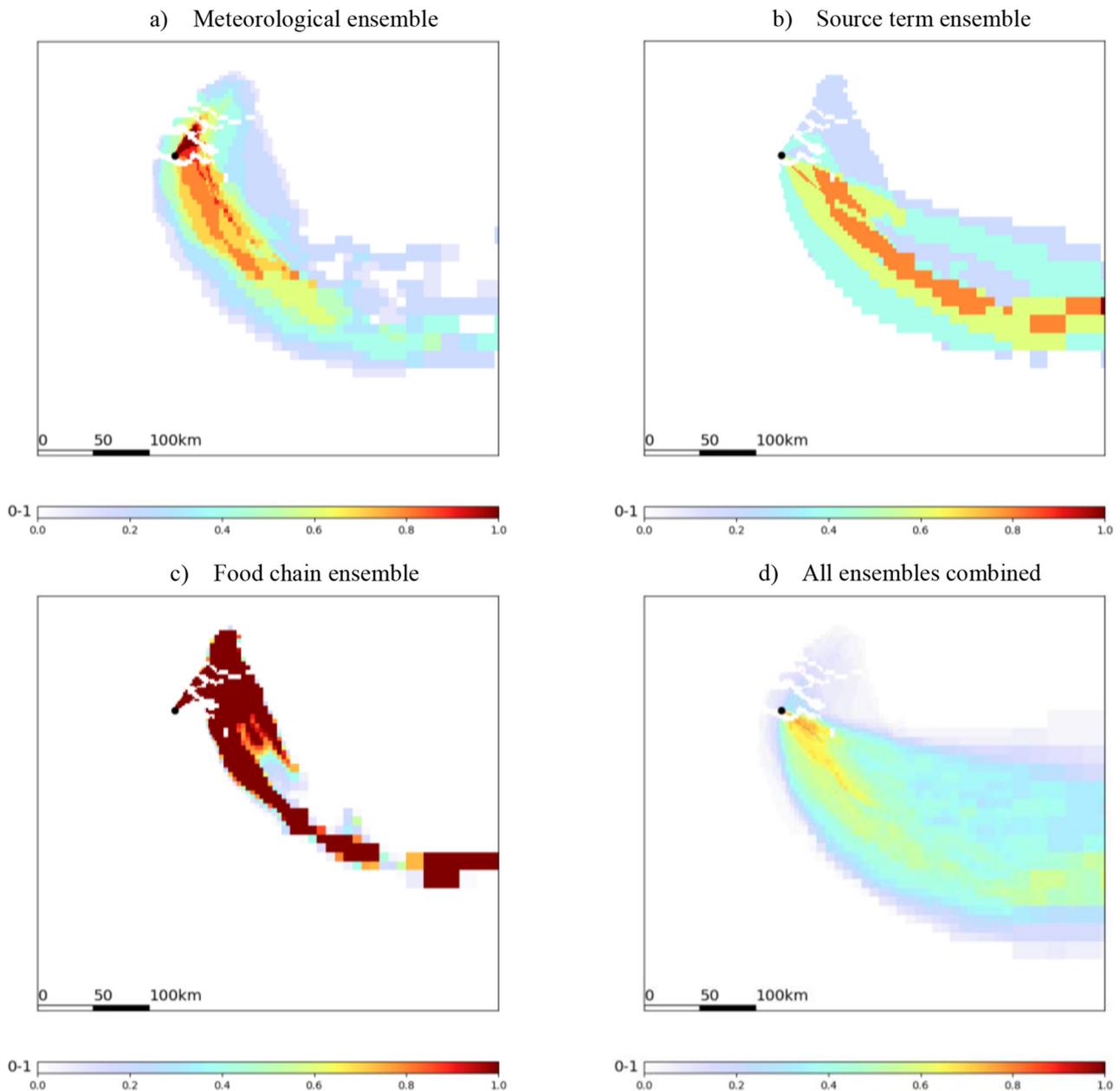


Fig. 3. Probability maps for an exceedance of the threshold value for caesium in leafy vegetables of 1250 Bq/kg. The release site is indicated with a black dot. Probabilities over water will be zero.

many of the FDMT model parameters, *e.g.* retention coefficient of radionuclides on different plant types, weathering rates from plants, soil-plant transfer factors and transfer coefficients to different animal products (Brown *et al.*, 2018; Hamburger *et al.*, 2019).

To avoid too large a number of resulting ensemble members and to optimize model run-time and post-processing, each one of the 50 samples of FDMT model parameterisations was randomly assigned to one of the 50 dispersion calculation outputs. Hence, the total number of results remained equal to 50 ensemble members.

3 Illustrative results

The results of this propagation of atmospheric dispersion uncertainties through an ensemble of food chain calculations are presented below. Examples of probability maps of threshold exceedance of calculated activity concentrations in different foodstuffs are shown in Figure 3 (for caesium in leafy vegetables) and Figure 4 (for caesium in milk). In these figures, the probability of a threshold value exceedance of activity concentrations in foodstuffs are shown on a scale from 0 (lighter shade) to 1 (dark shade). A probability of 0 at one

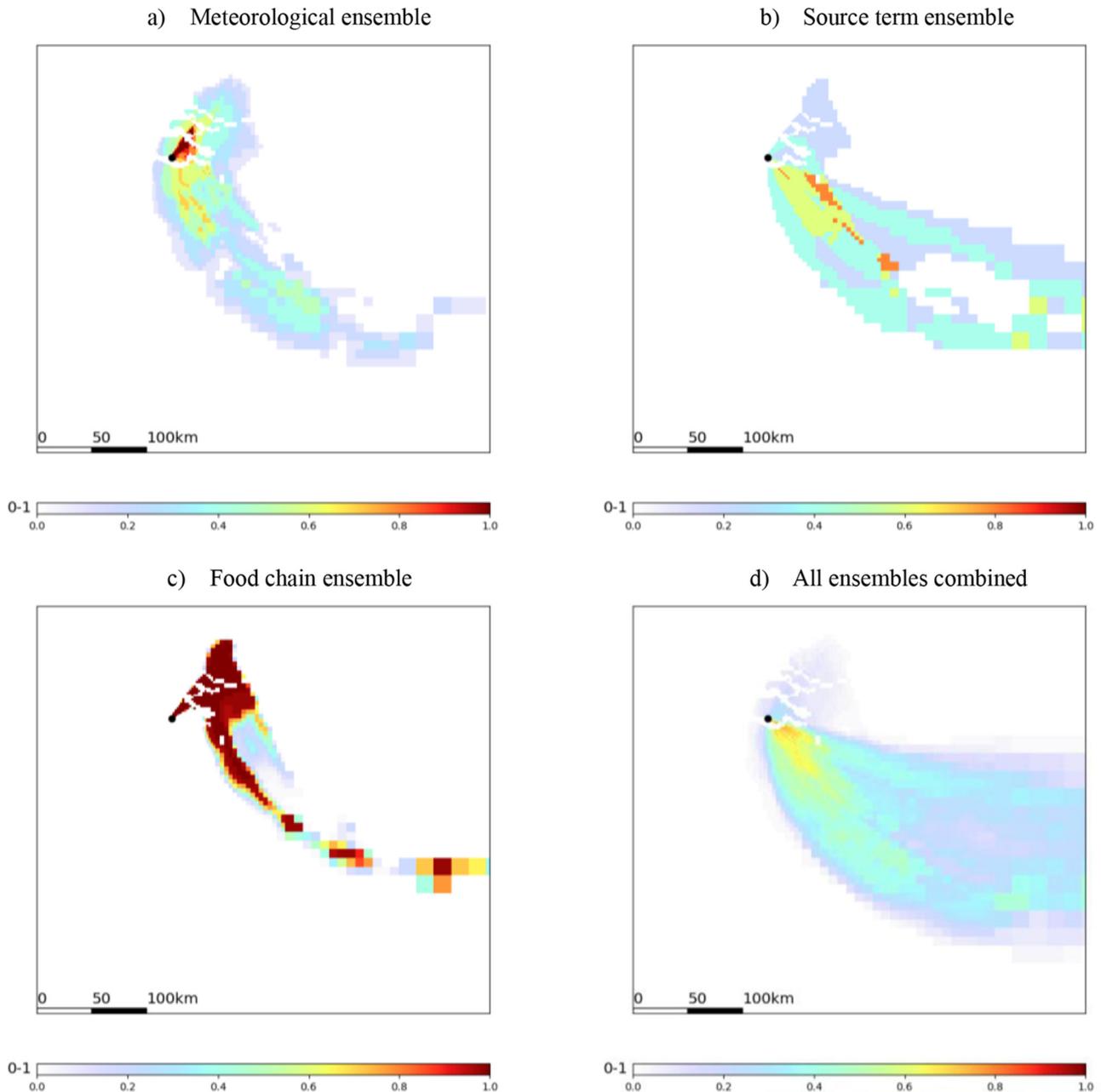


Fig. 4. Probability maps for an exceedance of the threshold value for caesium in milk of 1000 Bq/kg. The release site is indicated with a black dot. Probabilities over water will be zero.

location indicates that the threshold value will not be exceeded by any of the ensemble members. A probability of 1 on the other hand indicates that all ensemble members exceed the threshold at the given location. Results from four different ensemble setups are shown in both figures. Panel (a) (upper left) shows results when only uncertainties of the meteorological data are considered, panel (b) (upper right) shows the results when only the uncertainties of the source term are considered, panel (c) (lower left) shows results when only uncertainties of the food chain model are considered and panel (d) (lower right) shows the results when all these uncertainties

are considered together according to the uncertainty propagation described in Figure 2. Activity concentrations in foodstuffs cannot be calculated above water surfaces. Hence, probabilities above water will be zero. This can be seen in the maps North and Northeast of the release site where probabilities are partly intersected by zero values.

Highest probabilities over large areas, and therefore lowest variabilities, are shown for the food chain ensemble (c). Indeed, when the uncertainties considered have a small impact on the results, all outputs are very similar, which induces a very good agreement between the members and thus, high

Table 1. Ratio between the maximum area of threshold exceedance covered by one member of an ensemble and the minimum area of threshold exceedance covered by one member of the same ensemble.

Factor: max (area)/min (area)	Meteorological ensemble	Source term ensemble	Food chain ensemble	Meteorological and source term ensemble	All ensembles combined
Leafy veg. Cs >1250 Bq/kg	3	2	2	4	6
Leafy veg. I >2000 Bq/kg	2	2	1	3	4
Leafy veg. Sr >750 Bq/kg	3	5	2	5	10
Milk Cs >1000 Bq/kg	3	4	7	6	9
Milk I >500 Bq/kg	2	2	2	4	3
Milk Sr >125 Bq/kg	3	6	3	7	12

probabilities within a given area (and zero elsewhere). The meteorological ensemble (a) and the source term ensemble with its varying release start times (b) show significantly higher variabilities than the food chain ensemble. Lowest probabilities and largest variabilities can be found for the combination of all three input ensembles and their respective uncertainties. The high variability is also reflected in the large area of potential threshold exceedance compared to the results of the single ensemble setups.

Additional uncertainties introduced in the food chain within the calculation of the food endpoints for leafy vegetables (Fig. 3c) and milk (Fig. 4c), *i.e.* additional uncertainties due to uptake of feedstuff and transfer factors to milk, increase the variability within the food chain ensemble.

The probability maps show a more qualitative comparison of the variabilities introduced by the uncertainties of the different ensemble input parameters. A quantitative comparison is shown in Table 1. It lists the ratios of the affected areas covered by the “worst case” member and the “least severe case” member of each one of the ensemble setups, *i.e.* (a) meteorological ensemble, (b) source term ensemble, (c) food chain ensemble, and (d) the full ensemble. In addition, results from an ensemble setup using meteorological and source term uncertainties excluding food chain uncertainties are listed in the table. The “worst case” member is defined as the member where the area of threshold exceedance is maximised, the “least severe case” member is defined as the member where the area of threshold exceedance is minimised – both with respect to the other members of the ensemble. The ratio of the maximum and the minimum affected area quantifies the difference of the potential impact of the uncertainties within one ensemble.

The factor between the maximum and minimum area is between 2 to 3 for the meteorological ensemble. The factor reaches 2 to 6 for the source term ensemble. The food chain ensemble results in a factor around 2 for most threshold values with one exception with a factor of 7 for caesium in milk. In this specific case the uncertainty of the transfer factor for caesium from soil to plant is large for grass compared to the other nuclides and other plants like leafy vegetables by a factor up to 5 (Hamburger *et al.*, 2019). As grass is considered as feedstuff, the uncertainties propagate through the food chain to the animal product milk. The largest overall differences between the maximum and minimum affected areas are reached for the combination of all ensemble member with ratios up to 12.

4 Conclusions

The comparison of the probability maps (Figs. 3 and 4) for the exceedance of threshold values in foodstuffs showed that the uncertainties in meteorological input data and the source term uncertainties, here the start time of the release, introduced the most significant variabilities. Nevertheless, the variability introduced by the uncertainty of the food chain model parameters (Figs. 3c and 4c) is significant by itself and adds some variability to the overall ensemble. The relative importance of uncertainties related to food chain parameters may become higher in cases where source term and meteorological uncertainties are small; for instance, when the meteorological situation is well established with a small variability, and/or when there is no uncertainty in the release time (for instance, during or just after the release).

In contrast to the use of probability maps, which show the variability by comparing the probability at each single location or grid cell, the total affected area of each one of the ensemble members provides an overall indicator to illustrate the ensemble variability. The results in Table 1 show the significance of the uncertainties introduced in the food chain model. The area where threshold values in foodstuffs are exceeded can differ between the “worst case” and “least severe case” with respect to the affected area by a factor of 2 or more depending on the perturbed parameter chosen for the food chain modelling.

Only a subset of the available food chain parameters was chosen in this study to add additional uncertainties to the ensemble calculations. Further work is required to investigate the impact of uncertainties in all relevant steps of the food chain model as well as their individual contributions to the overall uncertainty. However, this study already shows the importance of the knowledge on and the quantification of the uncertainties in food chain model parameters. This becomes even more evident when radiological information is required for the agricultural and food production sectors during or after a radiological incident.

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