Uncertainties in dispersion modeling

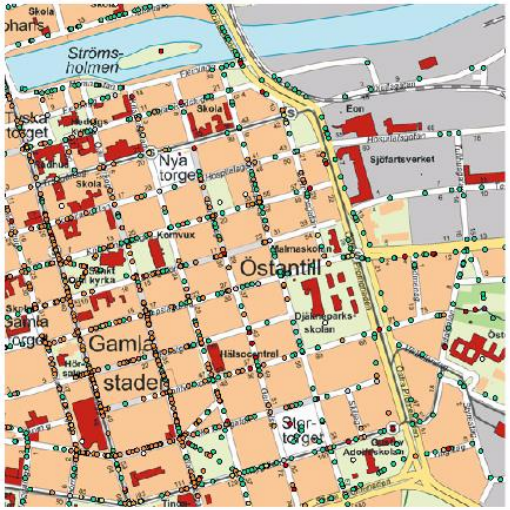
DMI
10 September 2015
Oscar Björnham

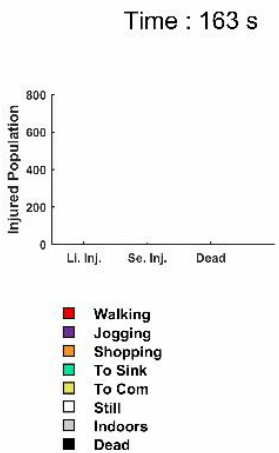
Agenda

- Dispersion modeling at FOI
- Uncertainties in our work
  - Urban dispersion
  - Inverse modeling
  - Kernel density estimators
  - Radiological doses
  - **Local dispersion**
  - Weather forecast driven dispersion

Dispersion Modeling at FOI

FOI
~1000 employees
in four cities





Our group consists of

- Physicists
- Mathematicians
- Meteorologists

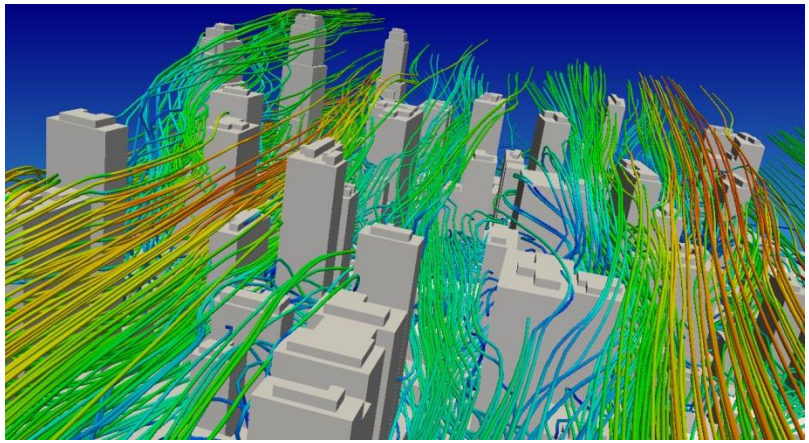
Mainly unexpected and sudden events for CBRN

Uncertainties in our work

- Urban dispersion (CFD)
- Inverse modeling
- Kernel density estimators
- Radiological dose calculations
- **Local dispersion (LHS)**
- Weather forecast driven dispersion

FOI

CFD (Complex Fluid Dynamics)



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Various consequences regarding hypothetical dispersion of airborne radioactivity in a city center

Lage Jonsson [a,c,*], Agneta H. Plamboeck [a], Erik Johansson [a], Mattias Waldenvik [b]

[a] FOI, Swedish Defence Research Agency, Division of CBRN Defence and Security, Cementvägen 20, SE 901 82 Umeå, Sweden
[b] FOI, Swedish Defence Research Agency, Division of Defence and Security, Systems and Technology, SE 164 90 Stockholm, Sweden
[c] KTH, Royal Institute of Technology, SE 100 44 Stockholm, Sweden

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ABSTRACT

In case of dispersion of airborne radioactive material in a city center a number of questions will prompt for an answer. While many questions can get their answers in due course of time based on results of tests and sampling, a good understanding of the quantitative effect of dispersion will be very helpful to rescue staff, in particular in the early stage. In the following dose and dose rate estimates are presented for three scenarios including dispersion of radioactivity in a city center. In one case the activity is released in an open place, in another from a roof and in the third case from a source on a street where the wind is blowing along the street. In each case, at specific positions, estimates are made of dose from inhalation, and dose rates for concentration on skin as well as from radioactive particles deposited onto ground, walls and roofs (external exposure) in the city center. It should be noted that the deposition pattern in urban areas varies greatly which means that the consequences are difficult to predict. The dispersion is influenced by recirculation behind tall buildings and diverted flow close to street ends, which have significant effects on the deposit pattern. Regarding the relative importance of contributions to total dose it is found that inhalation could play a major role for long term effects while dose to skin might dominate acute effects.

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1. Introduction

The possibility that incidents, or even terrorist attacks, could take place involving radioactive substances has led to increased awareness of the need to evaluate the potential consequences of such an event in a typical place where it could occur. Urban areas are of particular interest, as a high number of people and important infrastructure could be affected.

Dispersal of radioactive material can impact society in various ways including casualties, social disruption, clean up requirements and economic costs. Radiation is difficult to purge from urban environments, and may take a long time to fully decay. Furthermore, areas contaminated with radioactive material could be dangerous to humans for a long time. Therefore, events including dispersal of radioactive material are covered in many different aspects in the literature. For example, Sohlier and Hardeman (2006) sketches the expected overall consequences and the necessary actions to mitigate them, Dombrowski and Fischbeck (2006) shows how the risk varies across several behavior and physical variables and Thiessen et al. (2006) studied long-term consequences and compared predicted effectiveness of various countermeasures in terms of their short-term and long-term effects on predicted doses to humans. As stated by Sohlier and Hardeman (2006), in case of initial detection of radioactive contamination more specialized teams should launch an intensive survey monitoring allowing to better delineate the impact zone and the nature of contamination as well as to estimate potential consequences and to decide on early protective measures such as sheltering and personal contamination. However, immediately after a RDD event, the big unknown facing the decision makers will be the amount and distribution of radiation (Dombrowski and Fischbeck, 2006) and a rapid initial educated guess of the radiological situation would be very hard to make (Sohlier and Hardeman, 2006). This study aims to add some knowledge at that stage, particularly regarding short range local dispersion and deposition pattern of radioactive particles and its effect on people that happened to be in the vicinity of the release, outdoor. Naturally, a response plan would as a next step include a more extensive measurement campaign to in detail map

* Corresponding author. FOI, Swedish Defence Research Agency, Division of CBRN Defence and Security, Cementvägen 20, SE 901 82 Umeå, Sweden. Tel.: +46 90 10 48 24; fax: +46 90 10 48 01.
E-mail addresses: lage.jonsson@foi.se, lage@kth.se, lage@mau.com (L. Jonsson).

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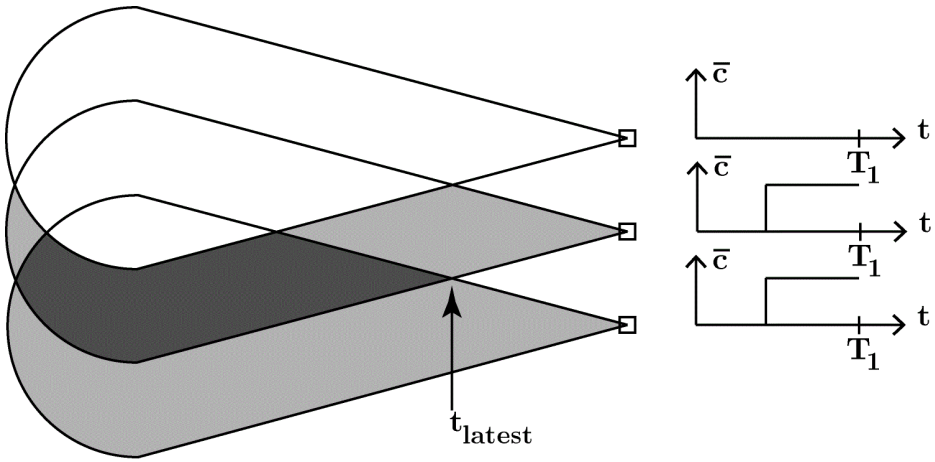
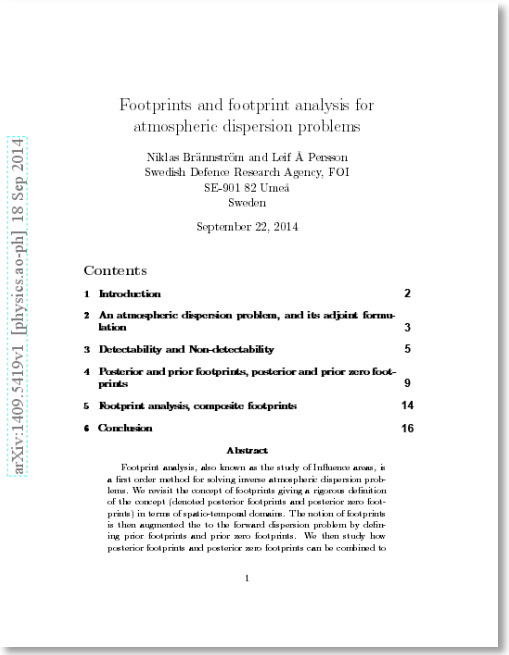
(Burman, Jonsson, 2013)

Urban dispersion
Three realisations at different time points of the same release

Inverse problems

Finding the source





arXiv:1409.5419v1 [physics.ao-ph] 18 Sep 2014

Footprints and footprint analysis for atmospheric dispersion problems

Niklas Brännström and Leif Å Persson
Swedish Defence Research Agency, FOI
SE-901 82 Umeå
Sweden

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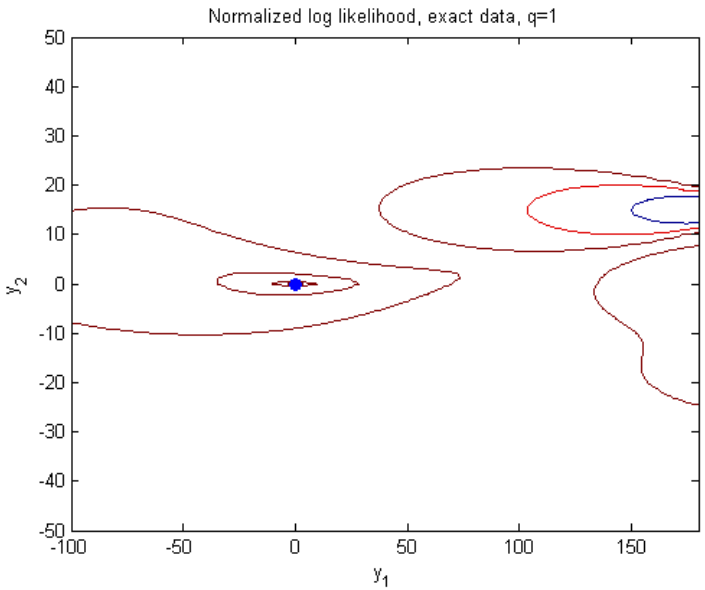
Contents

Abstract

Footprint analysis, also known as the study of Influence areas, is a first order method for solving inverse atmospheric dispersion problems. We revisit the concept of footprints giving a rigorous definition of the concept (denoted posterior footprints and posterior zero footprints) in terms of spatio-temporal domains. The notion of footprints is then augmented the to the forward dispersion problem by defining prior footprints and prior zero footprints. We then study how posterior footprints and posterior zero footprints can be combined to

1

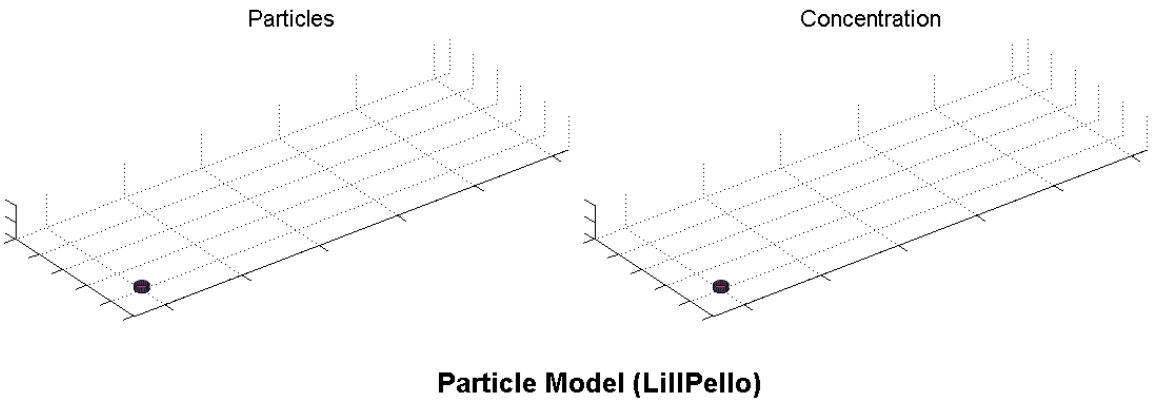


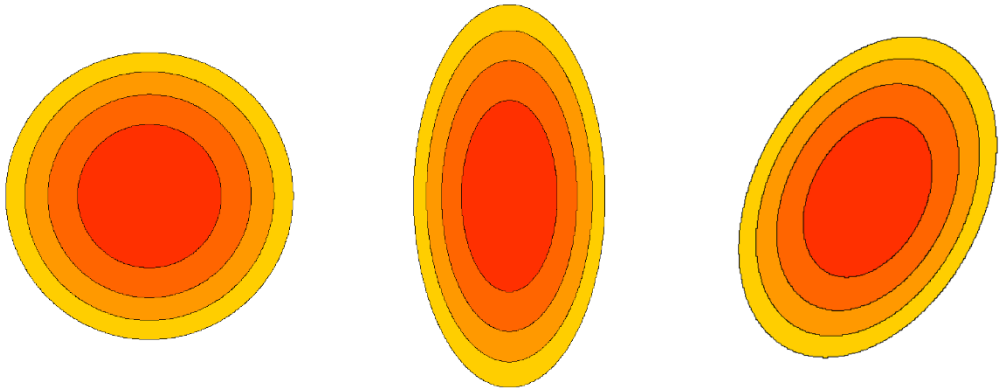
(Brännström, Persson, 2014)

Kernel density estimator (KDE)

How to efficiently catch random properties and obtain an optimal distribution?

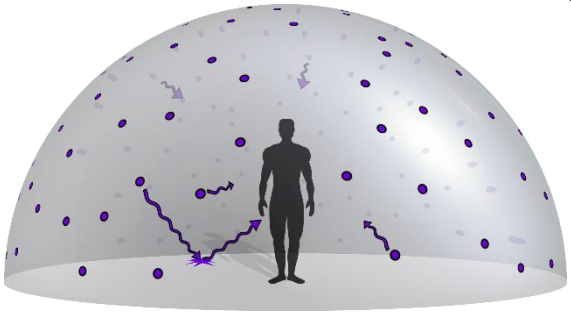
Financed by SSM (Swedish Radiation Safety Authority)



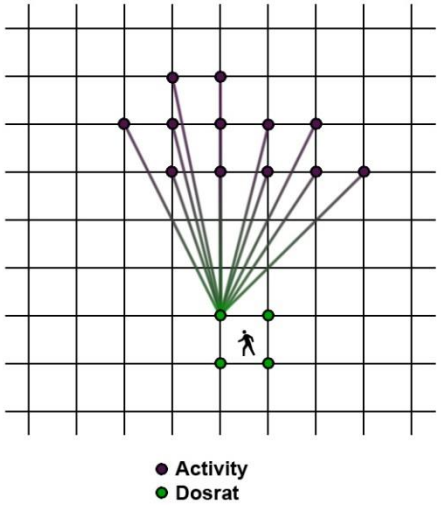


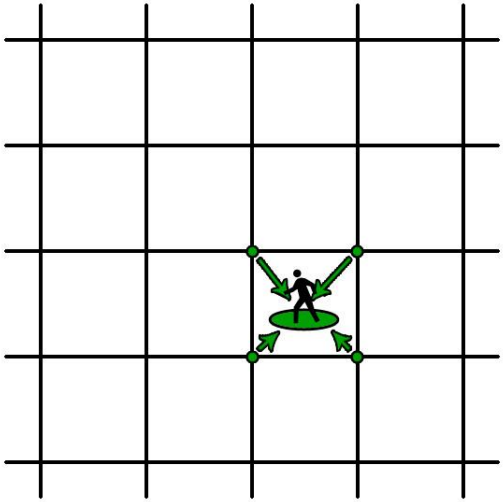
Kernels

Radiological substances



- Million particles → effective dose
  - How to minimize the uncertainties?





FOI

Local dispersion

Uncertainty in observations and calculations

Financed by SSM (Swedish Radiation Safety Authority), 2013

Example Kungsbacka, 2005

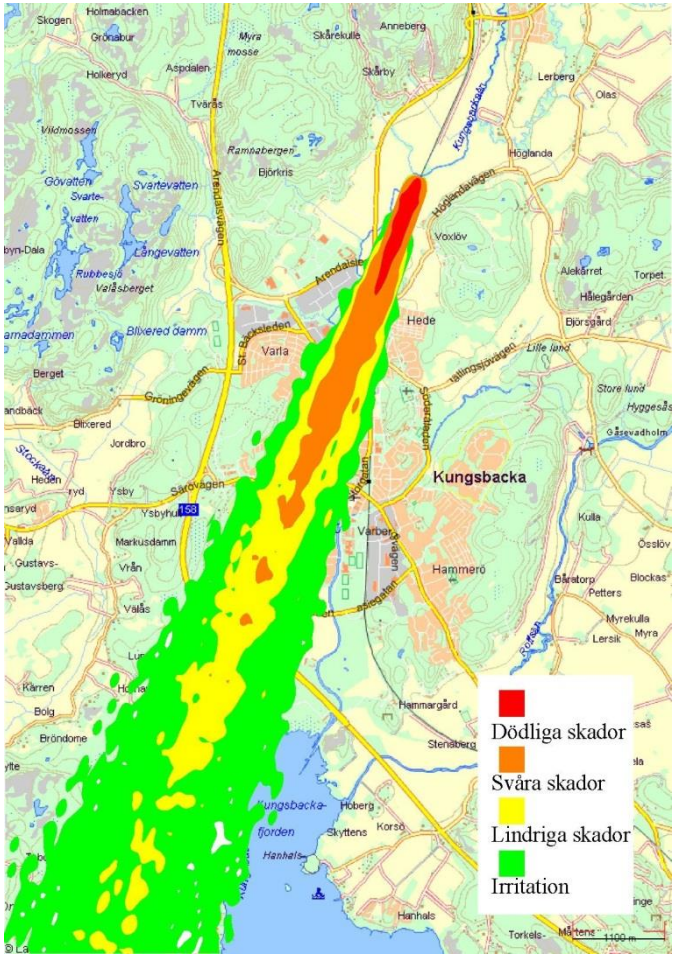


Photo: Rescue service in Gothenburg, 700 tons of chloride

What is uncertainties?

- **Type A**: Variability, the inherent uncertainty that originates from the nature of the world
- **Type B**: True uncertainty, caused by lack of knowledge

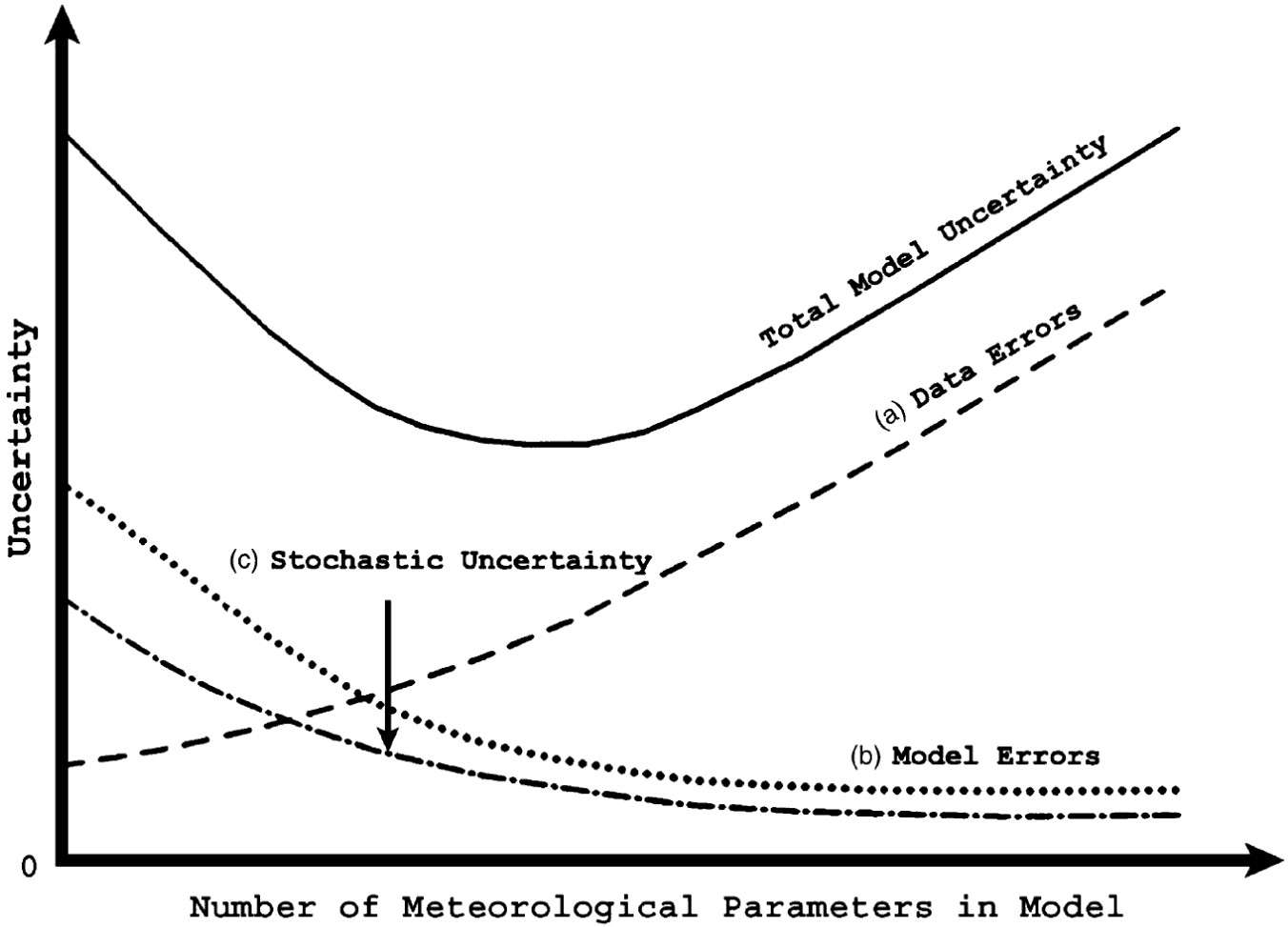
Both types must be considered. Although, normally only type B uncertainties are subject to changes.

Uncertainties in atmospheric dispersion

- Stochastic uncertainties (Type A)
- Data- or parametric errors (Type B)
- Model errors (Type B)

K. S. Rao, Uncertainty Analysis in Atmospheric Dispersion Modeling, 2005

Uncertainties vs. model parameters



K. S. Rao, Uncertainty Analysis in Atmospheric Dispersion Modeling, 2005

Problem

- You do not know the exact value of the parameters used as input to the model
- But you can estimate the probability distribution

- How will the model outcome depend on the input values?
- This will reflect the uncertainties in the model

Data- and parametric errors

- **Analytic methods:**

+ exact solution

- only applicable on trivial problems

- **Numerical methods:**

+ applicable to all problems

- limited number of cases may be tested

The principle is to span the parametric space for indata and map it on the outdata space

Data- and parametric errors

Numerical methods:

- Brute force – test ”all” combinations of indata
- Monte Carlo Metoder – random sampling from indata parametric space
- Latin Hypercube Sampling – stratified (semi-random) sampling from indata parametric space

Numerical methods

- Suppose you have one parameter with some probability distribution
- … and that you want to obtain model output for the entire range

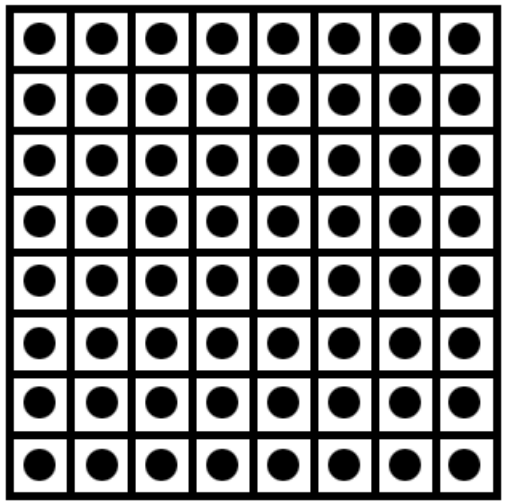
- Solution - run the model for N different values chosen from the distribution

Min  Max

Example: Uniform distribution with N=8

Numerical methods

- With two such (independent) parameters you get N^2 combinations



Example: N=8, p=2 → 64 combinations

- With p such parameters you get N^p combinations

Numerical methods - Kungsbacka

- Parameters with uncertainties = 12
- Choice of number of values = 50
- We get 50^{12} = 244 billions of billions of combinations
- Would take approximately one million times the age of the universe to simulate

- Can’t be done!

Latin Hypercube Sampling (LHS)

LHS is a method to drastically reduce the number of combinations and still span up the indata space reasonable well

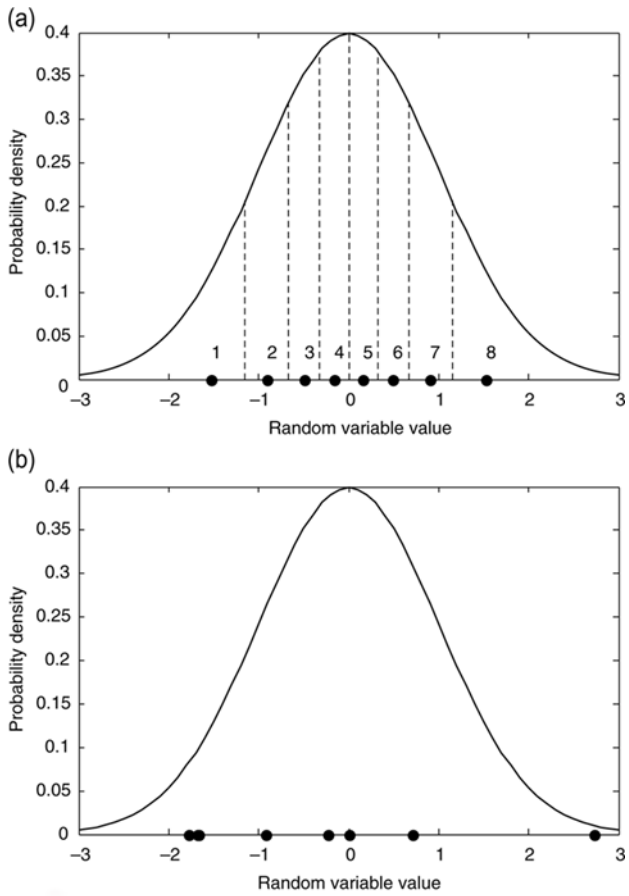
1) Stratify the probability distribution for every parameter into N intervals, each with the same total probability
2) Never use the same interval twice for a parameter!

LHS

1) Stratification, N=8

LHS

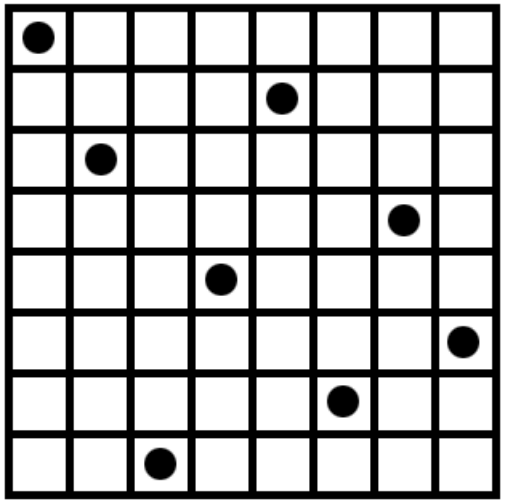
MC



LHS

2) Never use the same interval twice!

The number of combinations becomes independent of the dimension of the system!



Example: N=8, p=2 → 8 combinations

Latin Hypercube: Kungsbacka

12 model parameters were varied

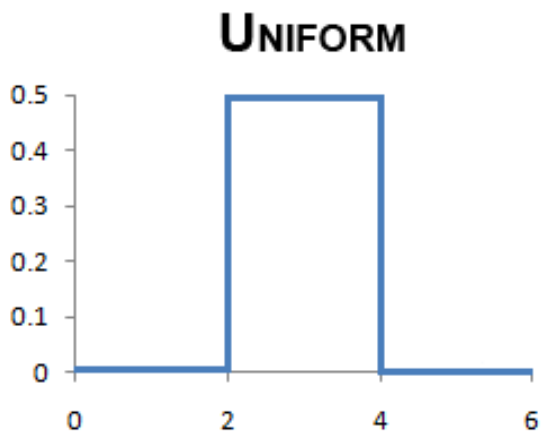
6 related to the source

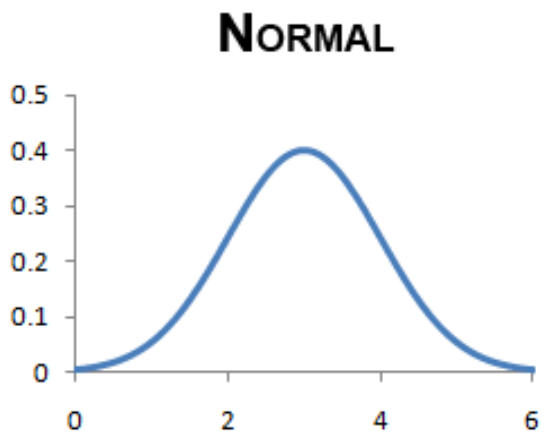
6 related to the meteorology

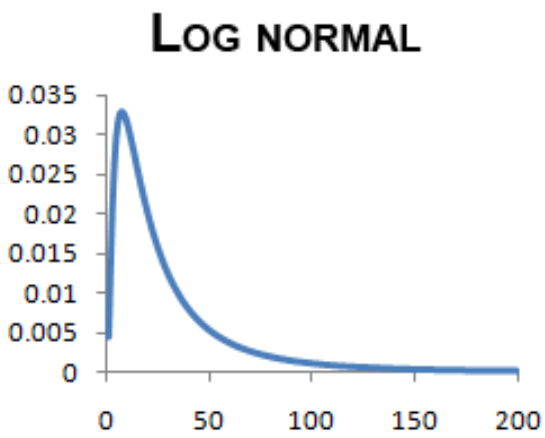
8 uniformly distributed

3 normally distributed

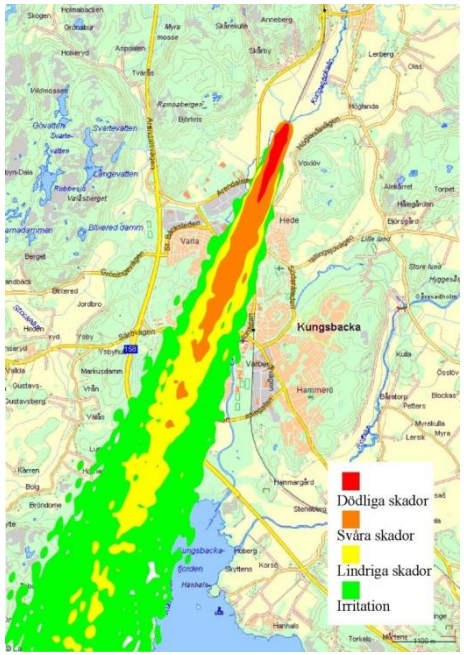
1 lognormally distributed

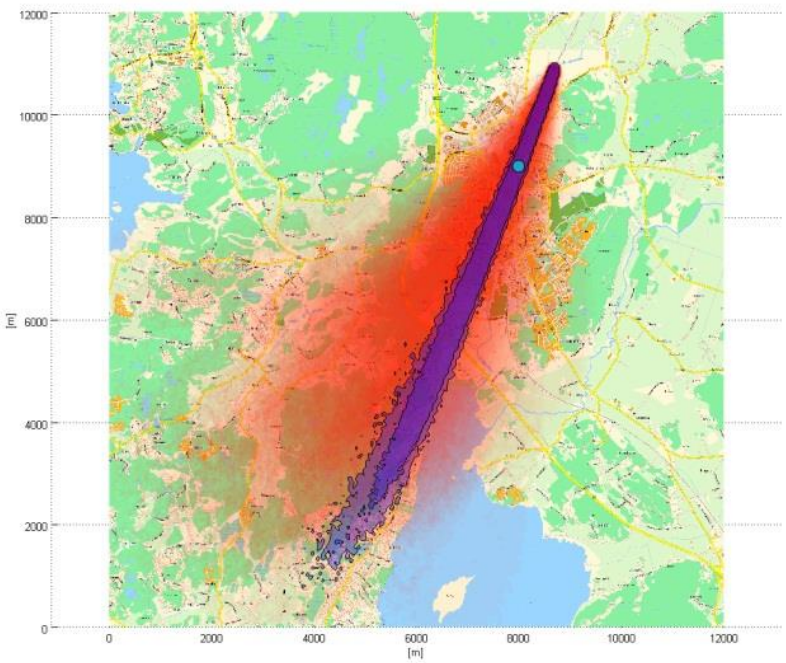






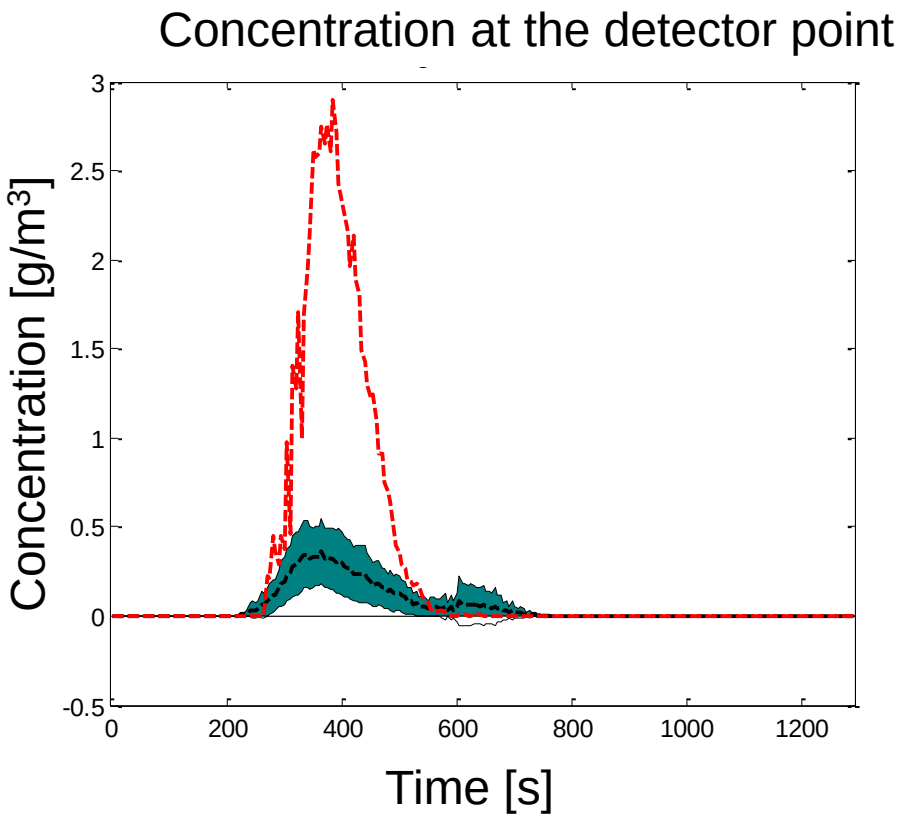
Result, Kungsbacka





The dose fields for the entire ensamble is overlaid with semi-transparency to illustrate the total probability distribution for the dose field. The result from the main simulation is marked with purple.

Result, Kungsbacka



The mean value of the concentration (black dotted line) is shown as a function of time with a 95% confidential interval (green band). The dashed red line shows the value for the main simulation.

Next problem

- How to present the uncertainties?
  - Scientifically
  - To decision makers

- This is another field worth studying

What has been studied here?

- Stochastic uncertainties (Type A)
- Data- or parametric errors (Type B) ✓
- Model errors (Type B)

Other approaches

- Stochastic uncertainties (Type A)
- Data- or parametric errors (Type B)
- Model errors (Type B)

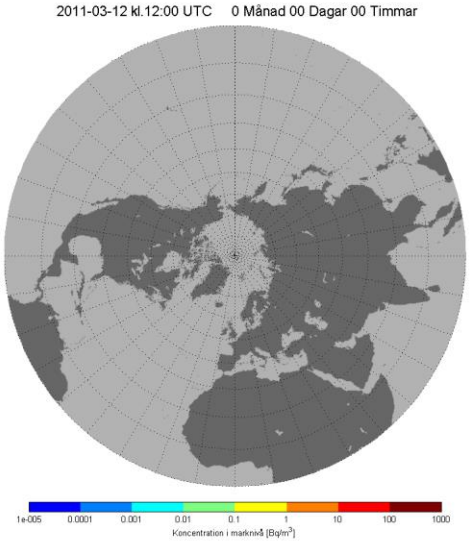
One way to study these uncertainties/errors is to conduct experiments: FOI is currently a part in the EDA-project MODITIC where wind tunnel- and field-experiments are conducted.

Weather forecast ensambles

Weather forecast ensambles may be used in a LHS-approach by considering them as discrete cases from a uniform distribution

This would be a suitable continuation in the field of uncertainties in atmospheric dispersion

Weather ensamble could originate from
- DMI
- SMHI
- ECMWF
- GLAMEPS
- Other sources



Fukushima accident