Uncertainties in dispersion modeling

DMI
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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

Our group consists of
- Physicists
- Mathematicians
- Meteorologists

Mainly unexpected and sudden events for CBRN

Swedish Defence Research Agency
Uncertainties in our work

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

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

(Burman, Jonsson, 2013)
Inverse problems

Finding the source

Footprints and footprint analysis for atmospheric dispersion problems

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2 An atmospheric dispersion problem, and its adjoint formu
lation
3 Detectability and Non-detectability
4 Probabilistic and prior footprints, posterior and prior aero
footprints
5 Footprint analysis, composite footprints
6 Conclusion

Abstract
Footprint analysis, also known as the study of influence areas, is a
direct method for solving inverse atmospheric dispersion prob
lems. We review the concept of footprints giving a precise definition
of the concept (informed posterior footprints and posterior prior foot
prints) in terms of optimization-based. The notion of footprint is then augmented by the forward dispersion problem by defin
ing prior footprints and prior footprints. We then study how prior
posterior footprints and posterior prior footprints can be combined to

(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)
Radiological substances

- Million particles $\rightarrow$ effective dose
  - How to minimize the uncertainties?
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
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

Example: Uniform distribution with N=8
Numerical methods

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

Example: $N=8$, $p=2 \rightarrow 64$ 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!
1) Stratification, N=8
2) Never use the same interval twice!

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

*Example:* $N=8, p=2 \rightarrow 8$ combinations
12 model parameters were varied
  6 related to the source
  6 related to the meteorology

8 uniformly distributed
3 normally distributed
1 lognormally distributed
The dose fields for the entire ensemble 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.
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 ensembles 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 ensemble could originate from:
- DMI
- SMHI
- ECMWF
- GLAMEPS
- Other sources