Development of Real-Time Bayesian Data Assimilation System for Off-Site Consequence Assessment

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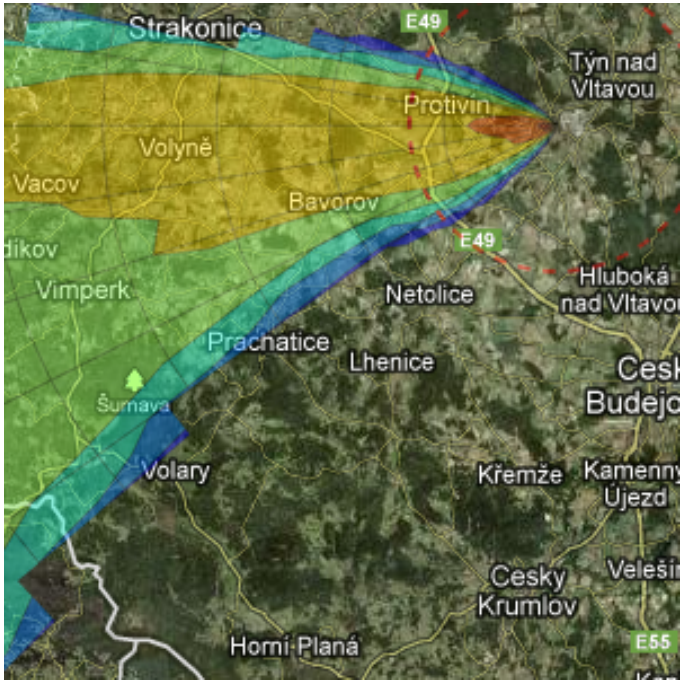
Presentation outline

1. Motivation: Why to use data assimilation?
2. Data assimilation concepts
3. Data assimilation in early phase of radiation accident
4. Integration of data assimilation to system for emergency preparedness
5. Demonstration of the system
6. Conclusion of future development

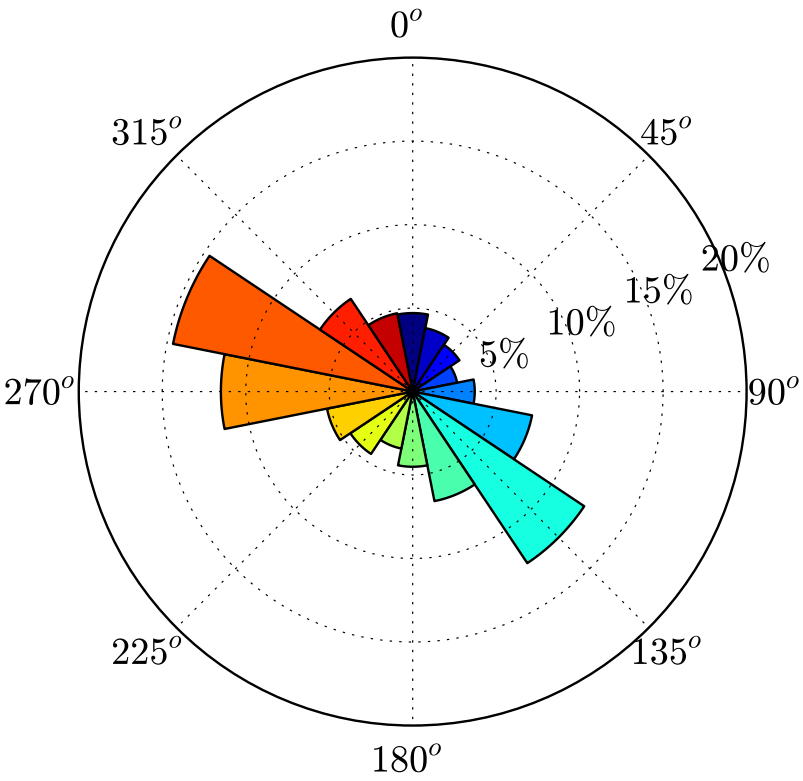
Atmospheric dispersion models (ADMs)



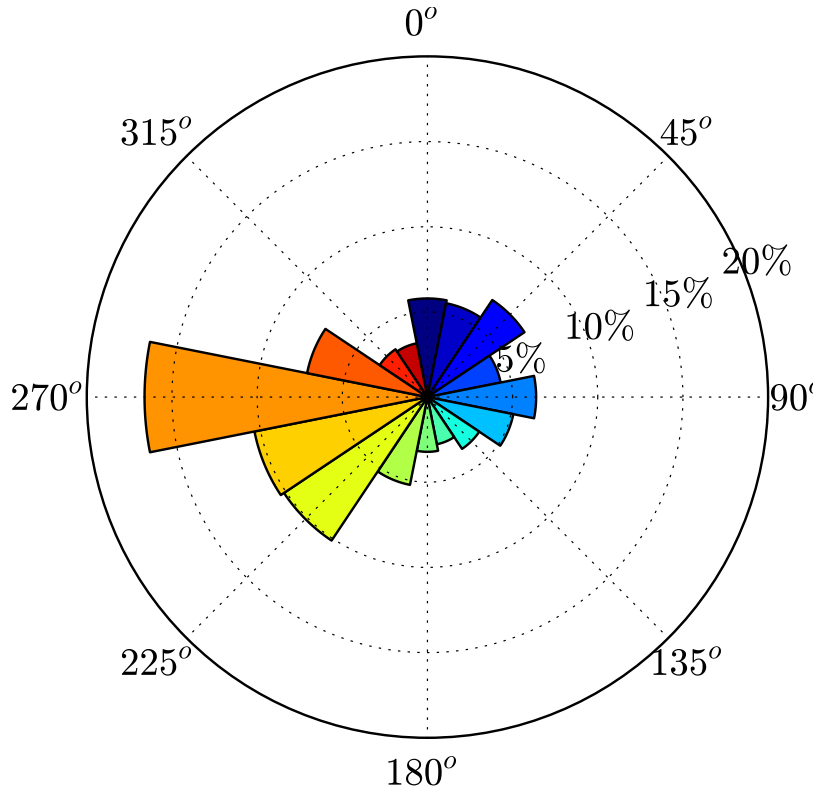
- ADMs simulate dipsersion by advection and turbulent processes in the atmosphere
- ADMs give us predictions of radionuclides distribution in the case of an accident with aerial release of radionuclides
- ADMs are initialized with numerical weather forecast and an estimate of the source term

- Model initialized with errorenous data gives wrong results :(

Why to use data assimilation?



Forecasted WD

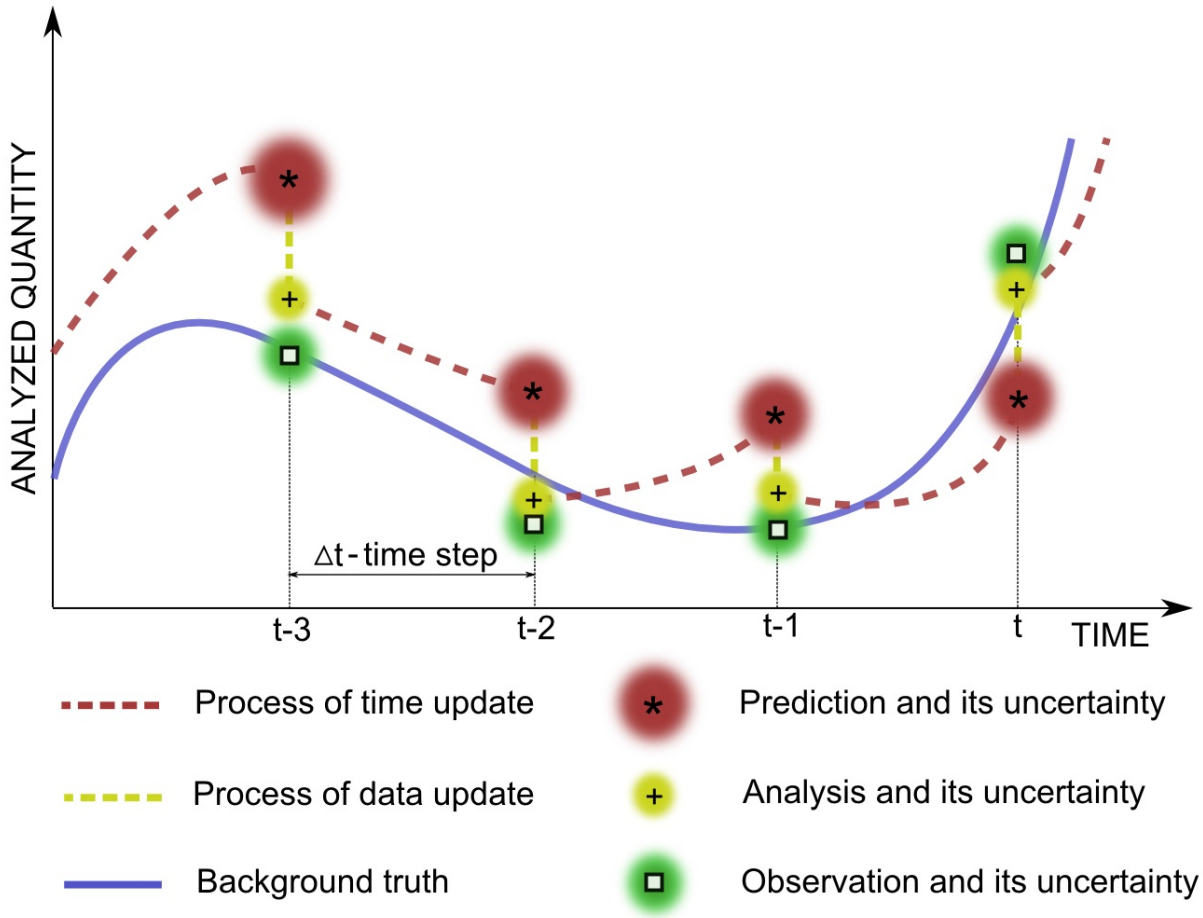


Measured WD

- We can use measured data and correct the model $\Rightarrow$ **DATA ASSIMILATION**

Data assimilation concepts

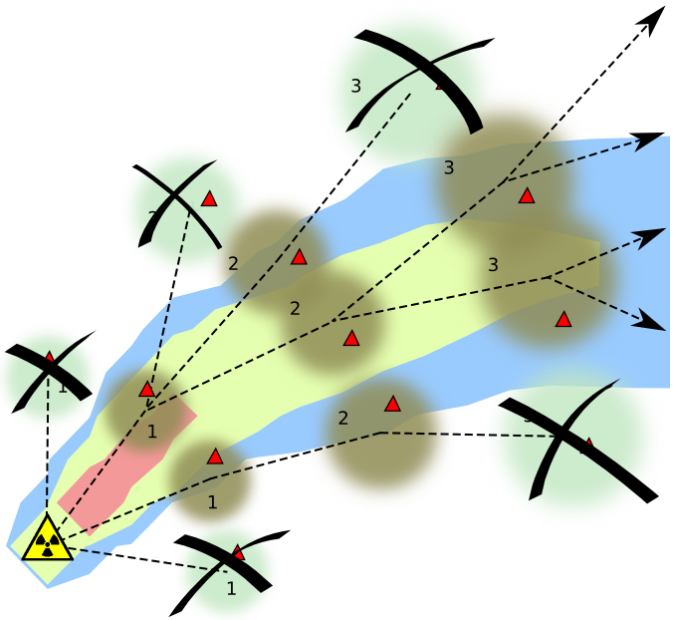
- DA refers to a group of mathematical methods for estimation of a state of a dynamic system by the means of combining multiple sources of information, typically observational data with a numerical model of the system under investigation



Data assimilation in early phase of radiation accident

- The goal is to estimate spatial and temporal distribution of radionuclides
- Since the very beginning of the release are availbale data from a radiation monitoring network (sparse in time and space)
- We can use the data and correct important variables parametrizing trajectory of the plume (wind speed and direction) and consequent radiological quantities (deposition, doses due to groundshie, cloudshine, etc.)
- Corrected variables can be used for prediction with lower uncertainty $\Rightarrow$ **more efficient countermeasures**
- We aim to develop an autonomous real-time decision support system for data assimilation of gamma dose rate measurements from a radiation monitoring network
- We focus on particle filtering (sequential Monte Carlo) - suitable for processing of a continuous stream of measurements

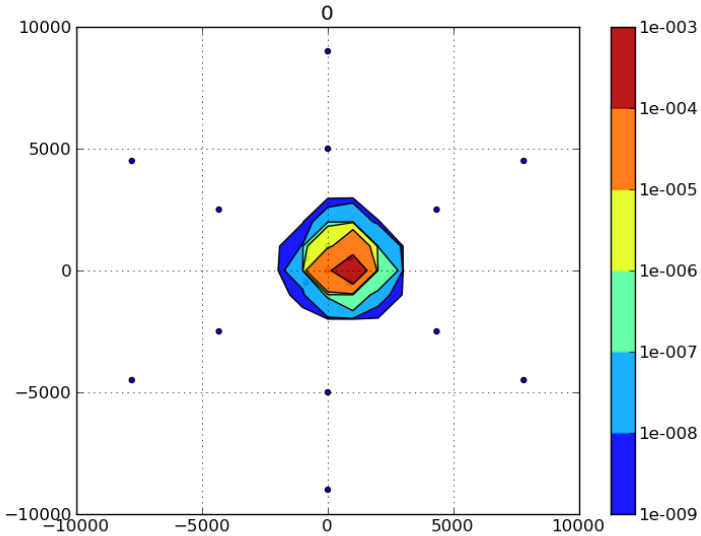
Data assimilation in early phase - basic concept



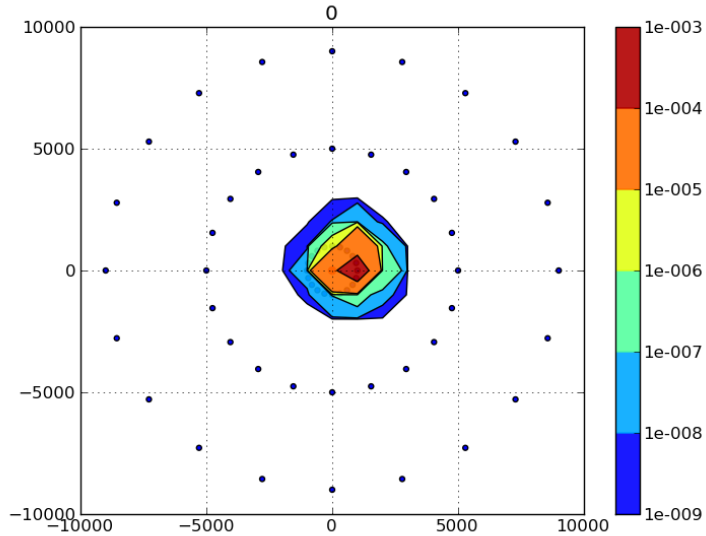
- The reference release is denoted with color isoplets.
- We simultaneously propagate multiple dispersion models with different initial settings
- Models are weighted according to their correspondence with measured data

- **Probabilistic approach** (accounts for uncertainty - modeling of probability distributions of estimated variables given data):
  - Models with high weight have a high probability of resampling (multiplying and propagation to the next time step)
  - Models with low weight have a hight probability to be discarded and replaced with those with high weights

Data assimilation in early phase - basic concept

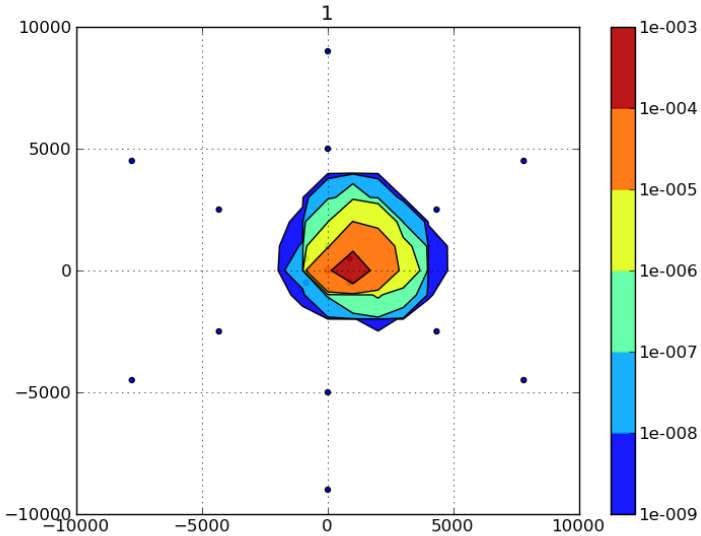


sparse network, t=1

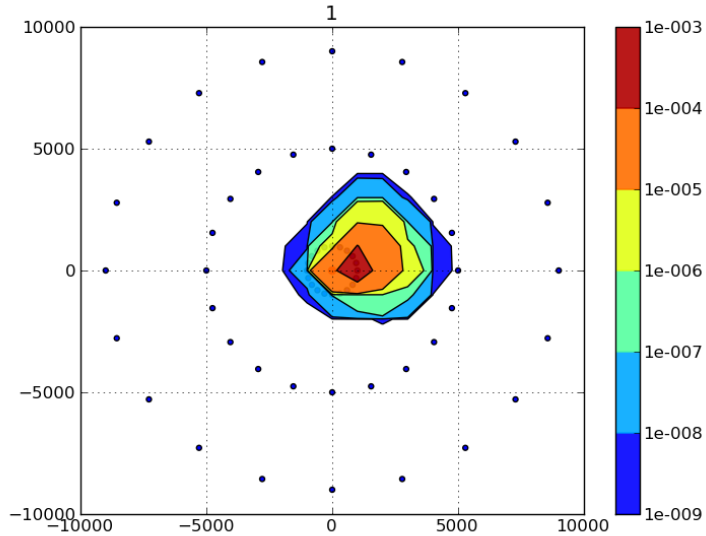


dense network, t=1

Data assimilation in early phase - basic concept

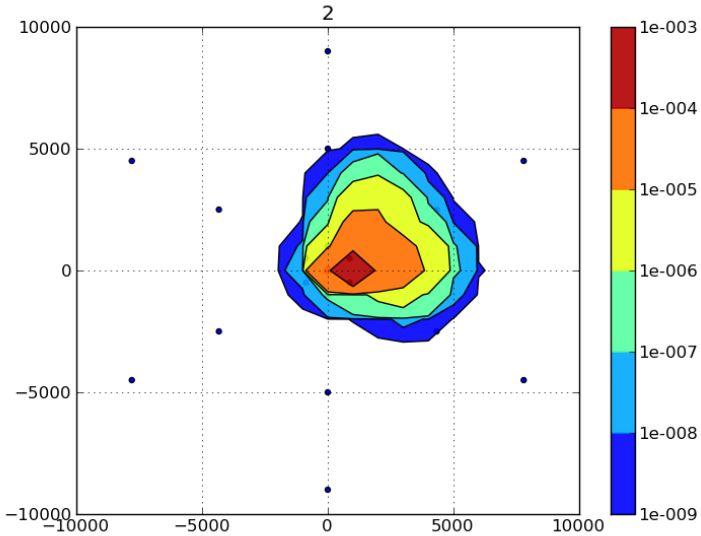


sparse network, t=2

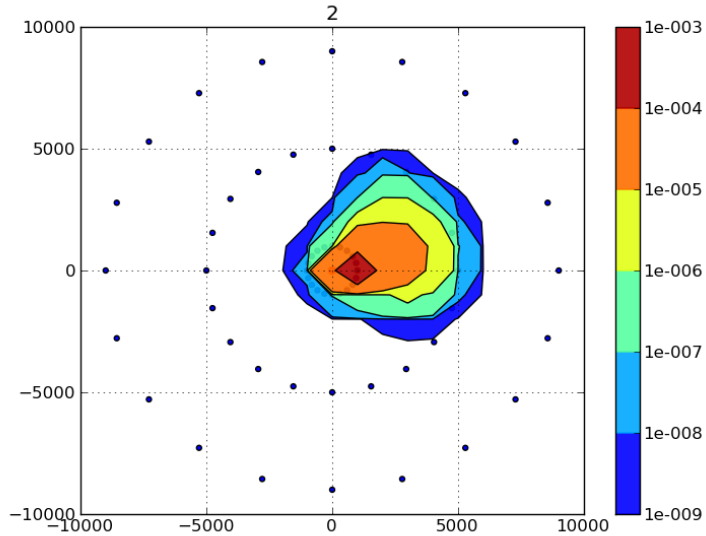


dense network, t=2

Data assimilation in early phase - basic concept

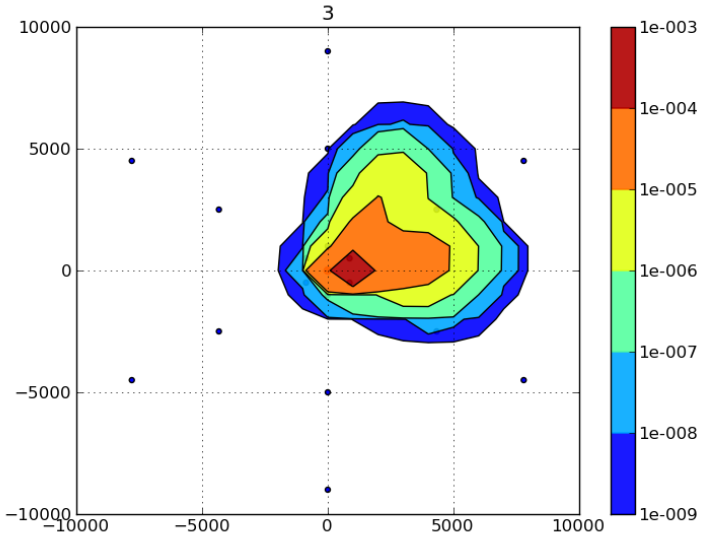


sparse network, t=3

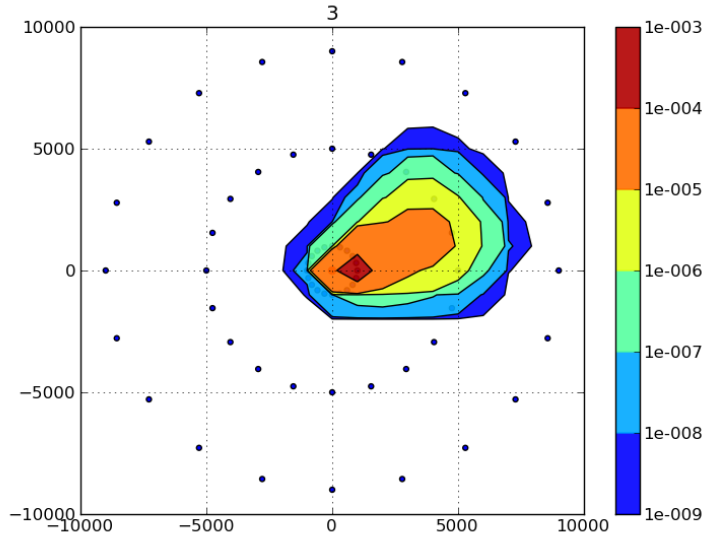


dense network, t=3

Data assimilation in early phase - basic concept

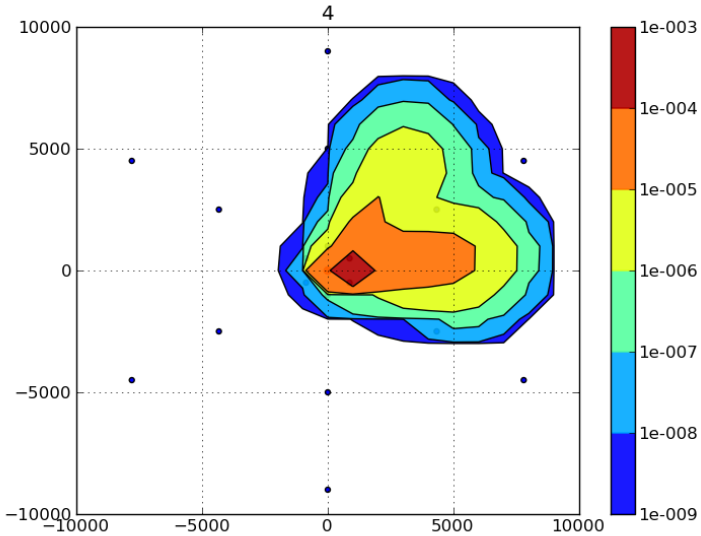


sparse network, t=4

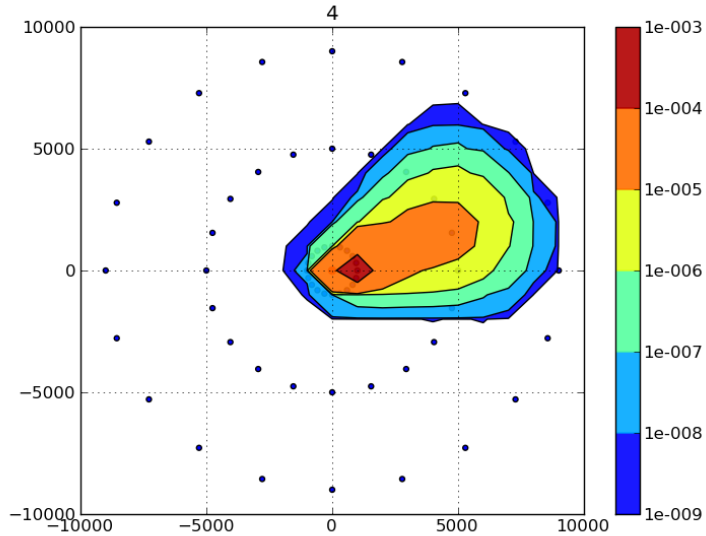


dense network, t=4

Data assimilation in early phase - basic concept

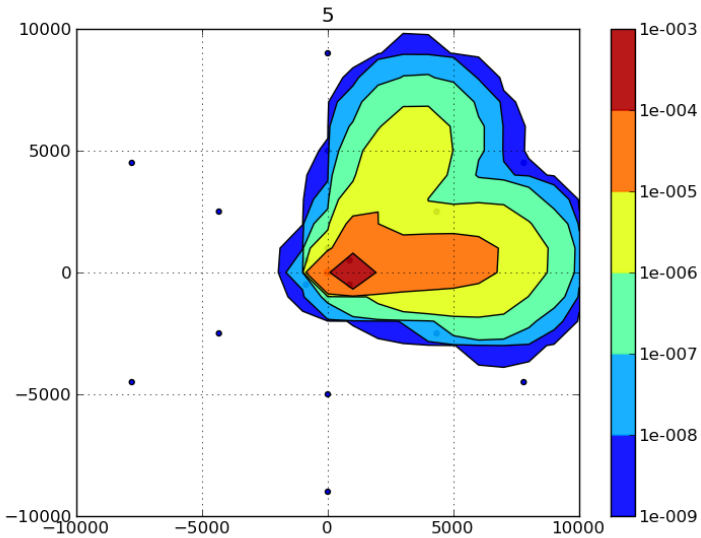


sparse network, t=5

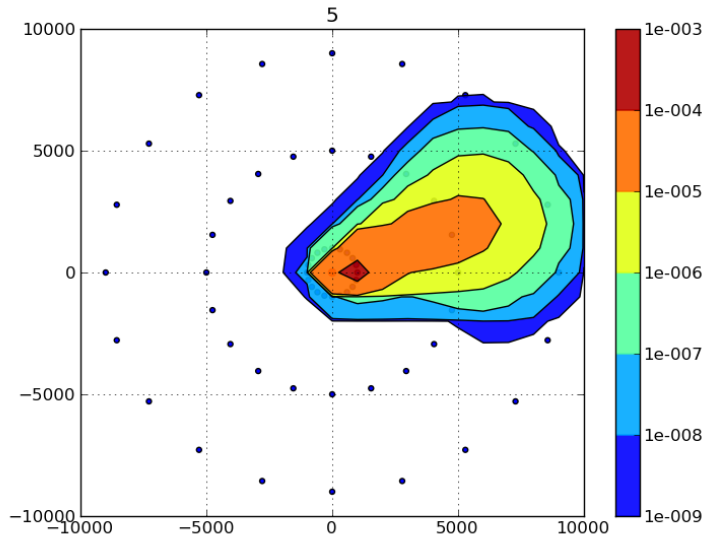


dense network, t=5

Data assimilation in early phase - basic concept

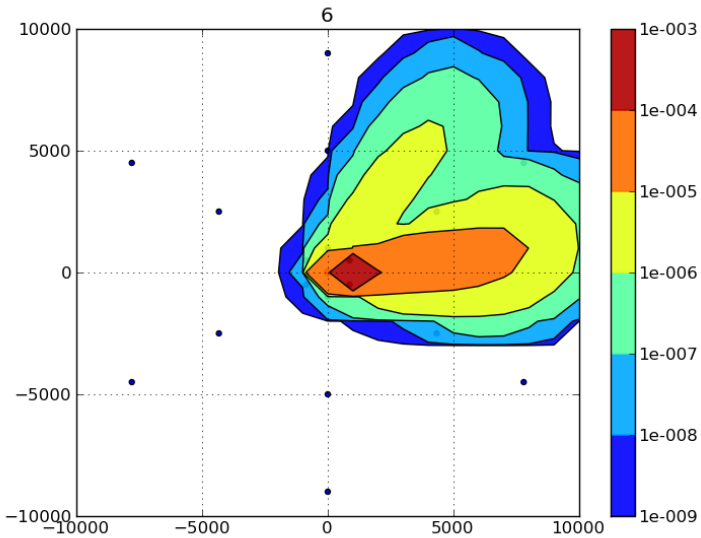


sparse network, t=6

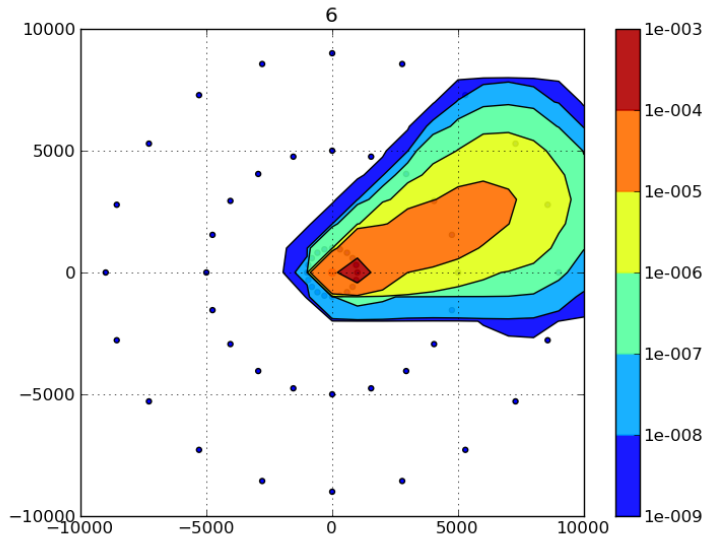


dense network, t=6

Data assimilation in early phase - basic concept

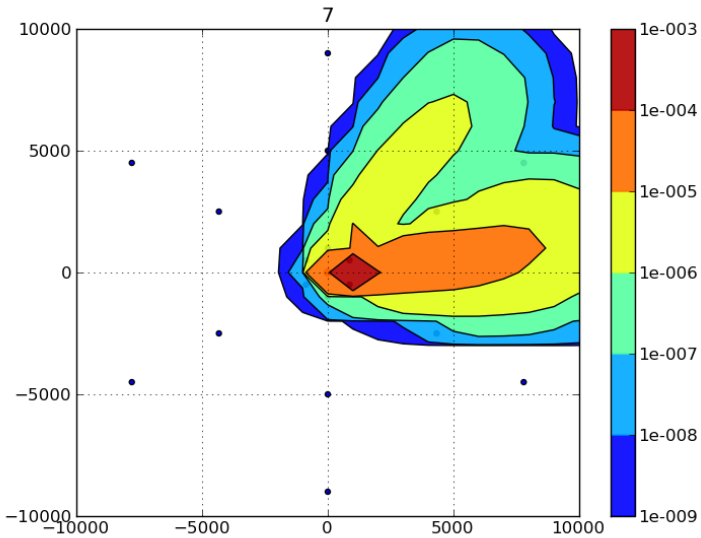


sparse network, t=7

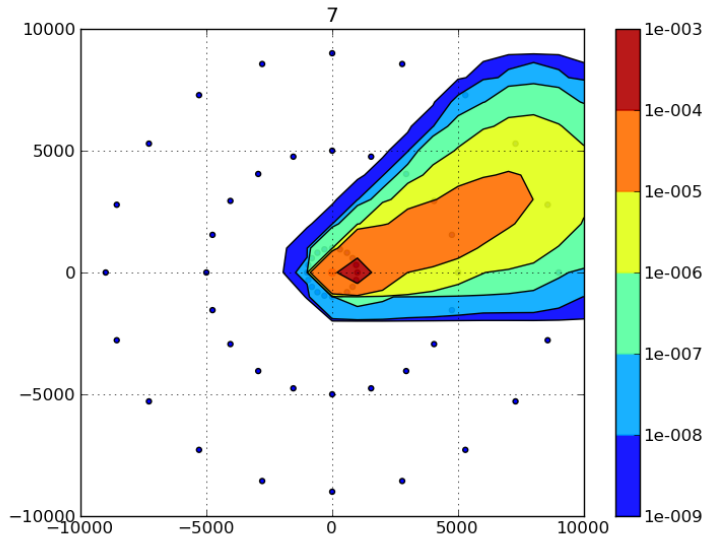


dense network, t=7

Data assimilation in early phase - basic concept

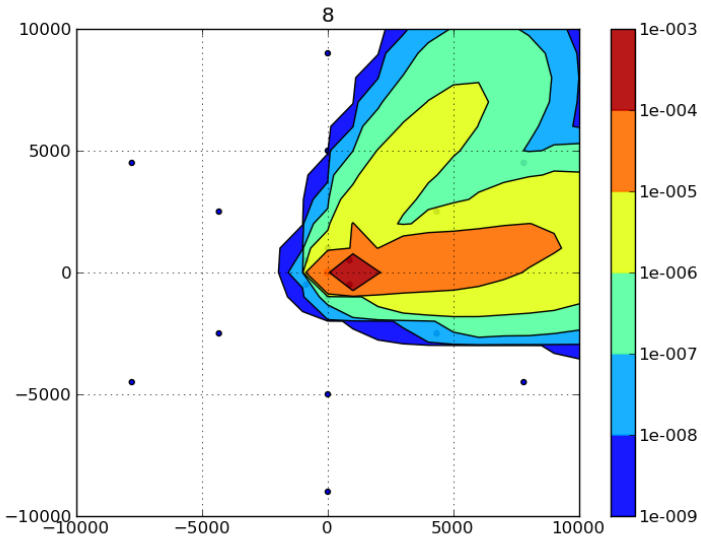


sparse network, t=8

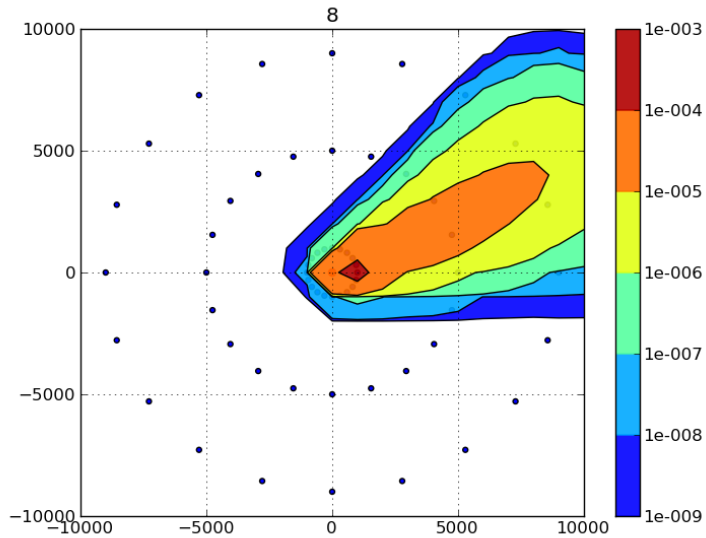


dense network, t=8

Data assimilation in early phase - basic concept

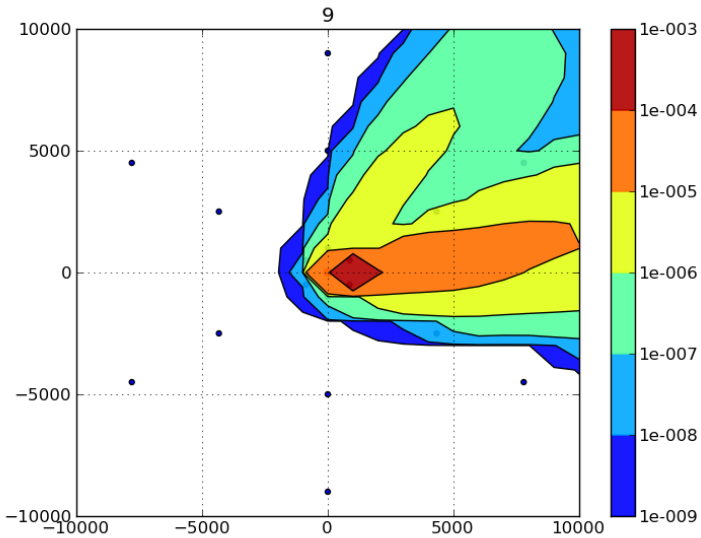


sparse network, t=9

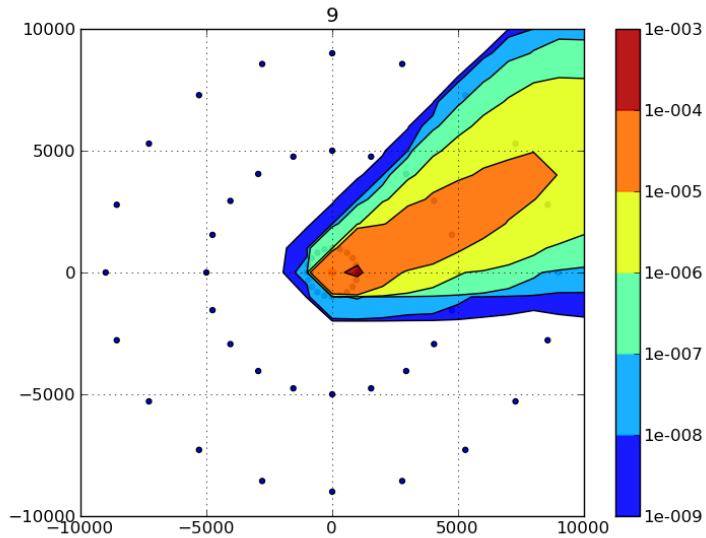


dense network, t=9

Data assimilation in early phase - basic concept

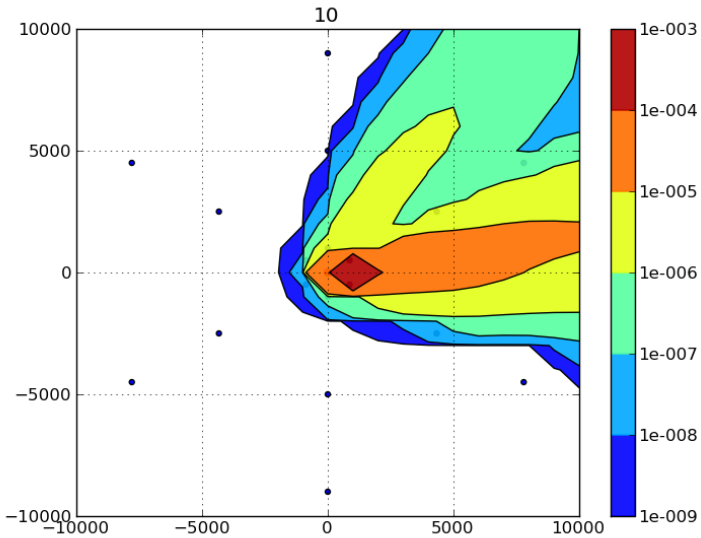


sparse network, t=10

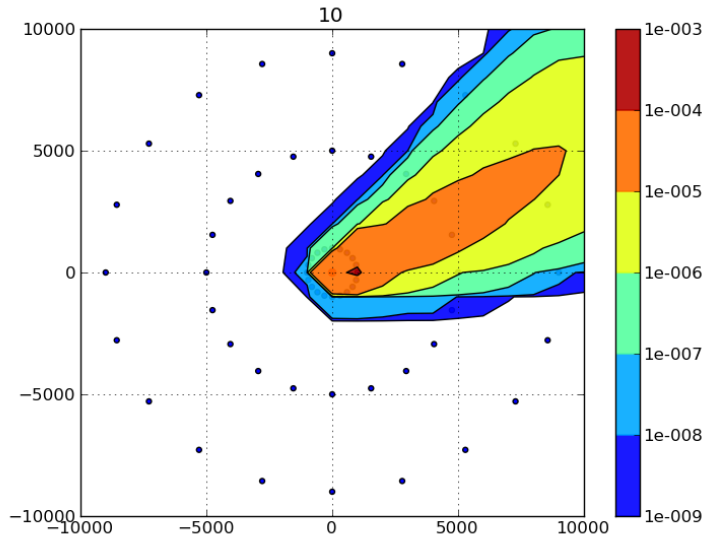


dense network, t=10

Data assimilation in early phase - basic concept

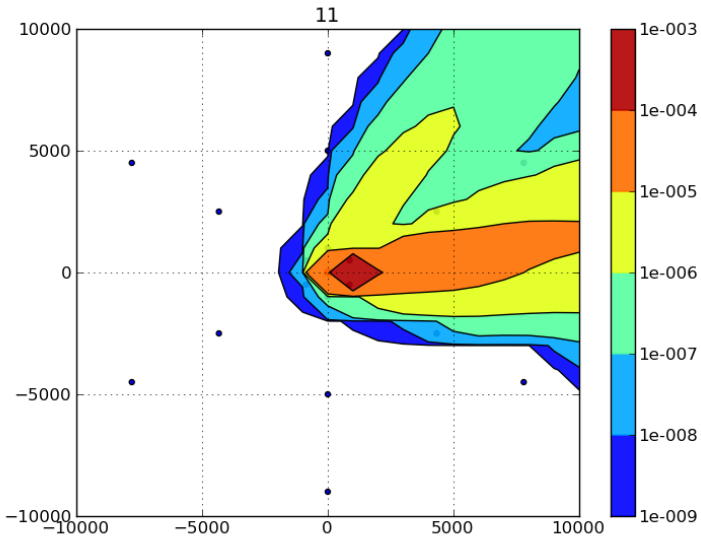


sparse network, t=11

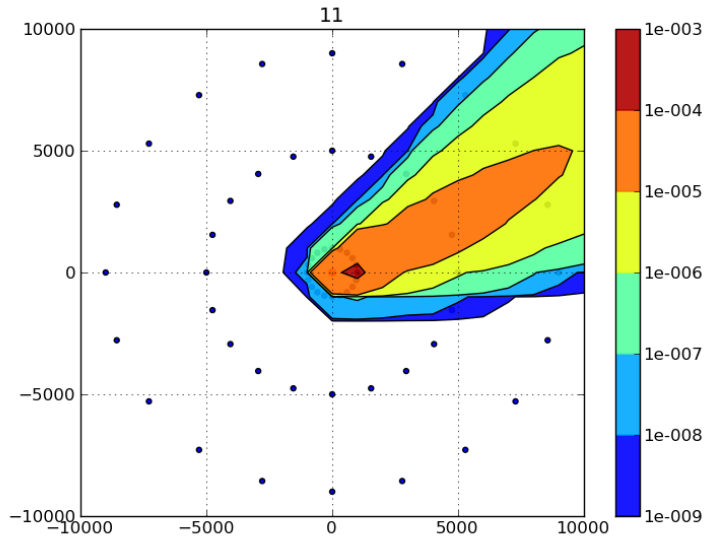


dense network, t=11

Data assimilation in early phase - basic concept

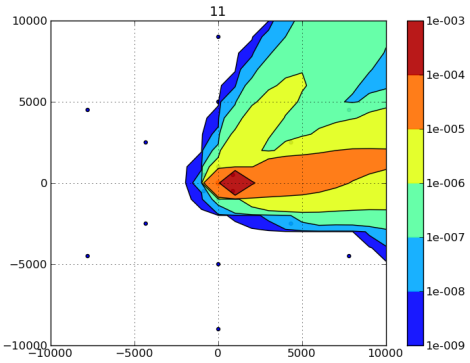


sparse network, t=12

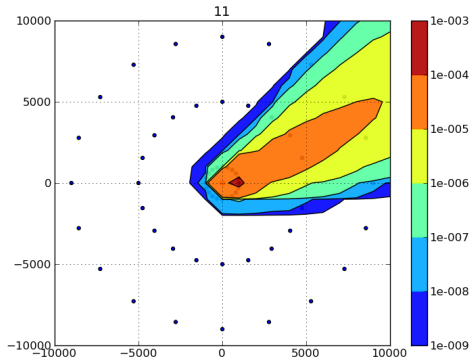


dense network, t=12

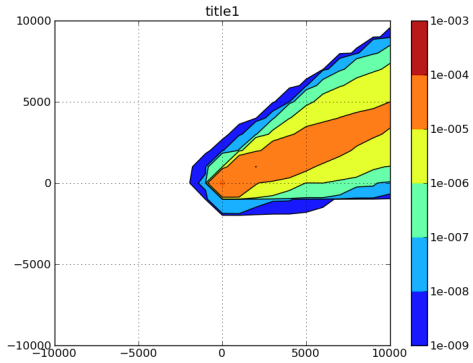
Data assimilation in early phase - basic concept



sparse network



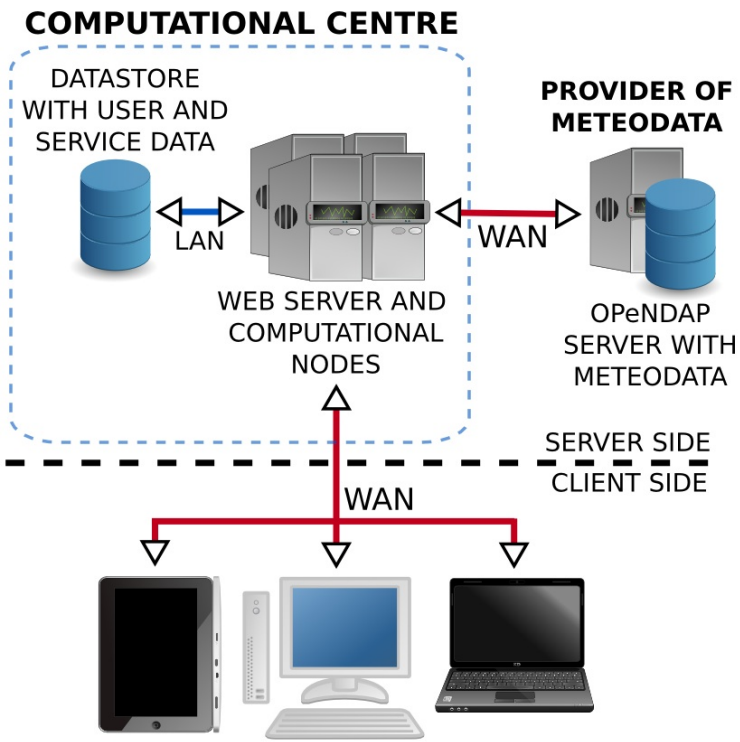
dense network



reference

more measurements $\Rightarrow$ lower uncertainty

Integration of DA to system for emergency preparedness



- The aim is to develop a Bayesian decision support system for emergency preparedness
- Focus on ***clarity of presentation of results*** of ***probabilistic analysis***
- Customization for Czech nuclear power plants Temelín and Dukovany (cooperation with Czech National Radiation Protection Institute)

- Segmented Gaussian plume model (standardized for application in radiation protection) and Lagrangian puff model (under development)

Modes of operation

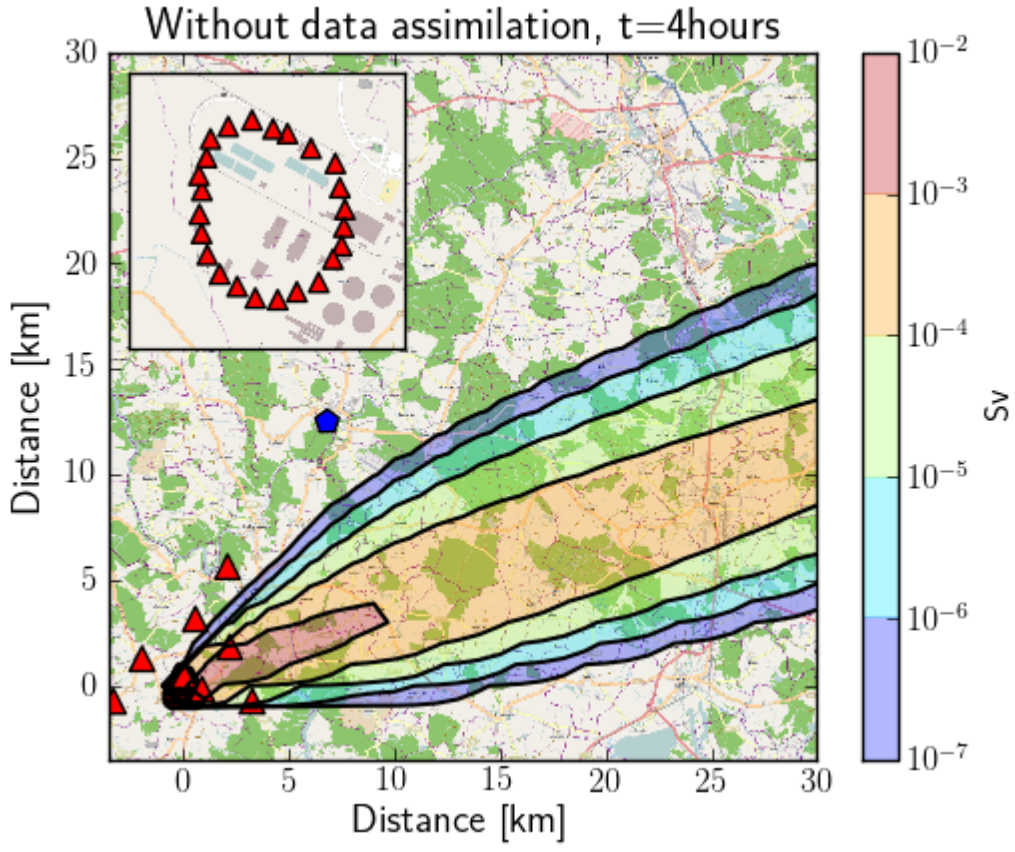
1. **On-line regime**
   - on-line gathering of radiological measurements and meteorological data
   - continuous monitoring - data assimilation procedure is automatically triggered if abnormal vales are detected
2. **Off-line regime**
   - radiological and/or meteorological data are entered by user
   - what if analyses, education and training purposes

Demonstration of the system

Demonstration of the performance of the system during on-line continuous monitoring:

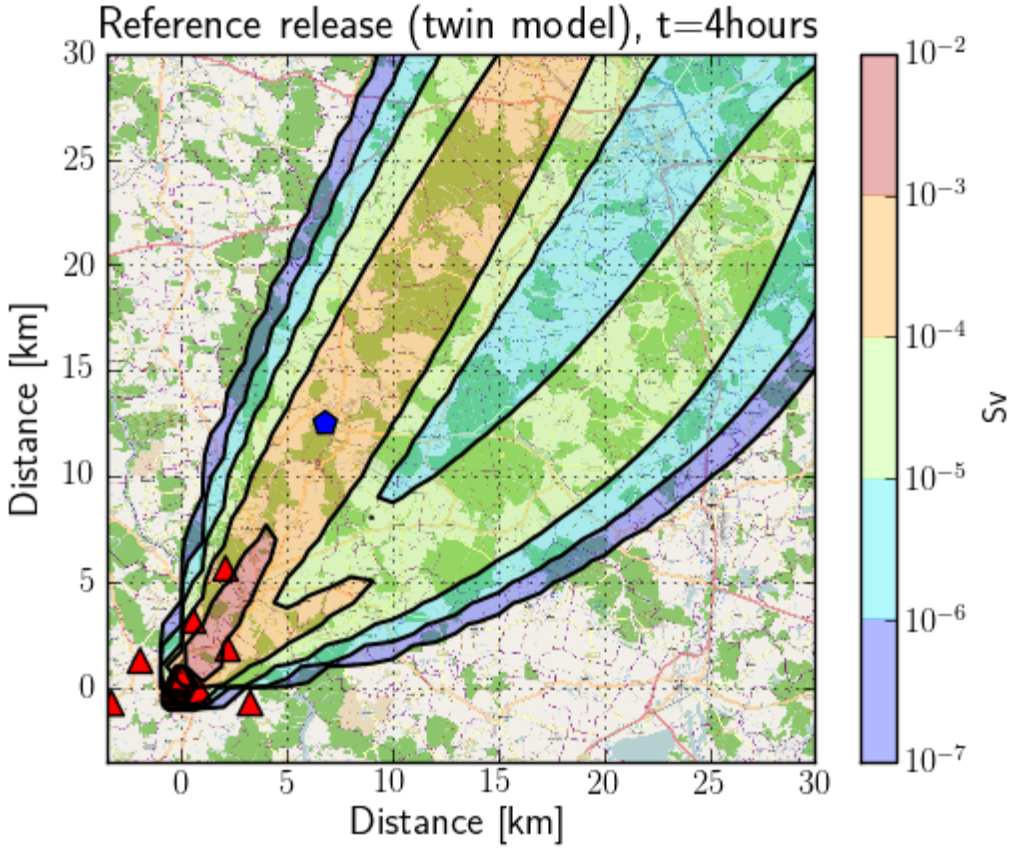
- A release of unknown magnitude, start and duration of radionuclide $^{41}\mathrm{Ar}$ occurs
- The release is assumed to occur from the Czech NPP Temelín
- Radiation monitoring network in this experiment has the same topology as the real monitoring network currently present on site
- The goal is to estimate the **magnitude of release** and **biases of forecasted wind speed and wind direction** using gamma dose rate measurements
- Continuous release is modeled as a sequence of 10-minute puffs
- All estimated quantities are time variant with step size10 minutes.

Demonstration of the system on a simulated scenario



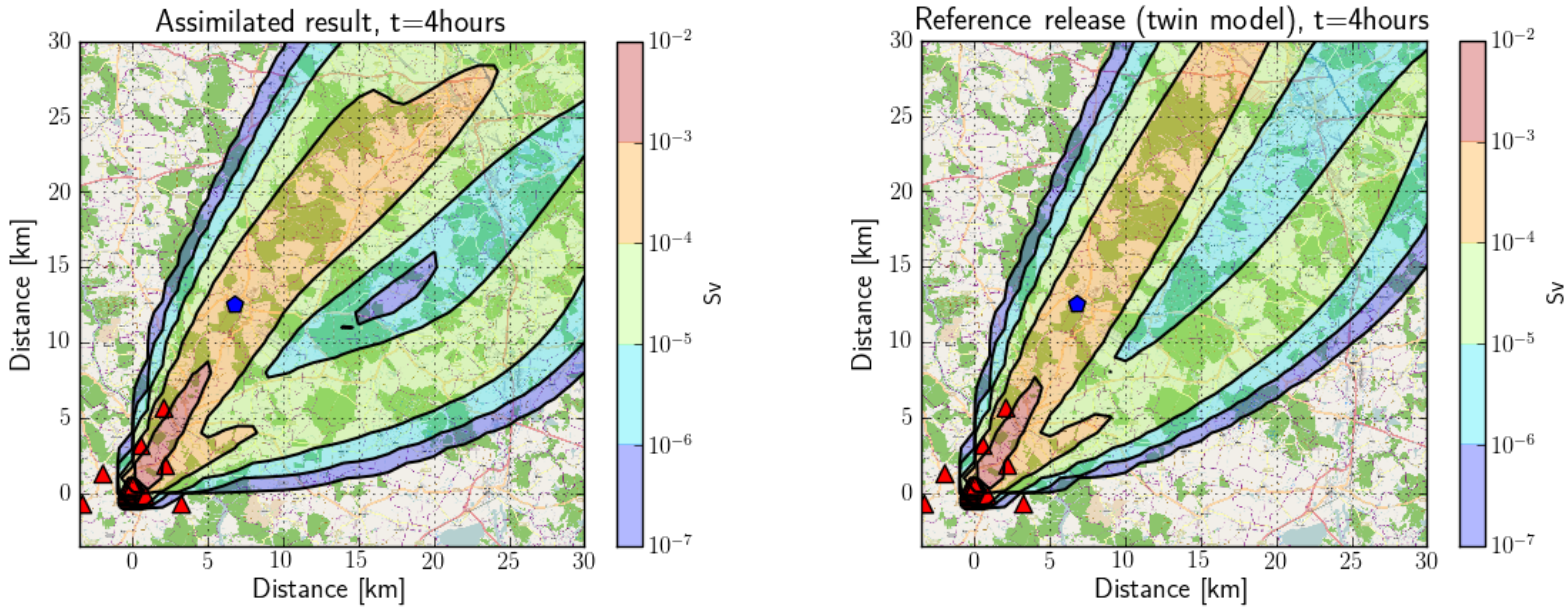
- Simulation of cloudshine dose based on nominal meteo and source term **without data assimilation**
- Radiation monitoring network is denoted by red triangles, detail of the first ring of receptors is in the right-top corner

Demonstration of the system on a simulated scenario



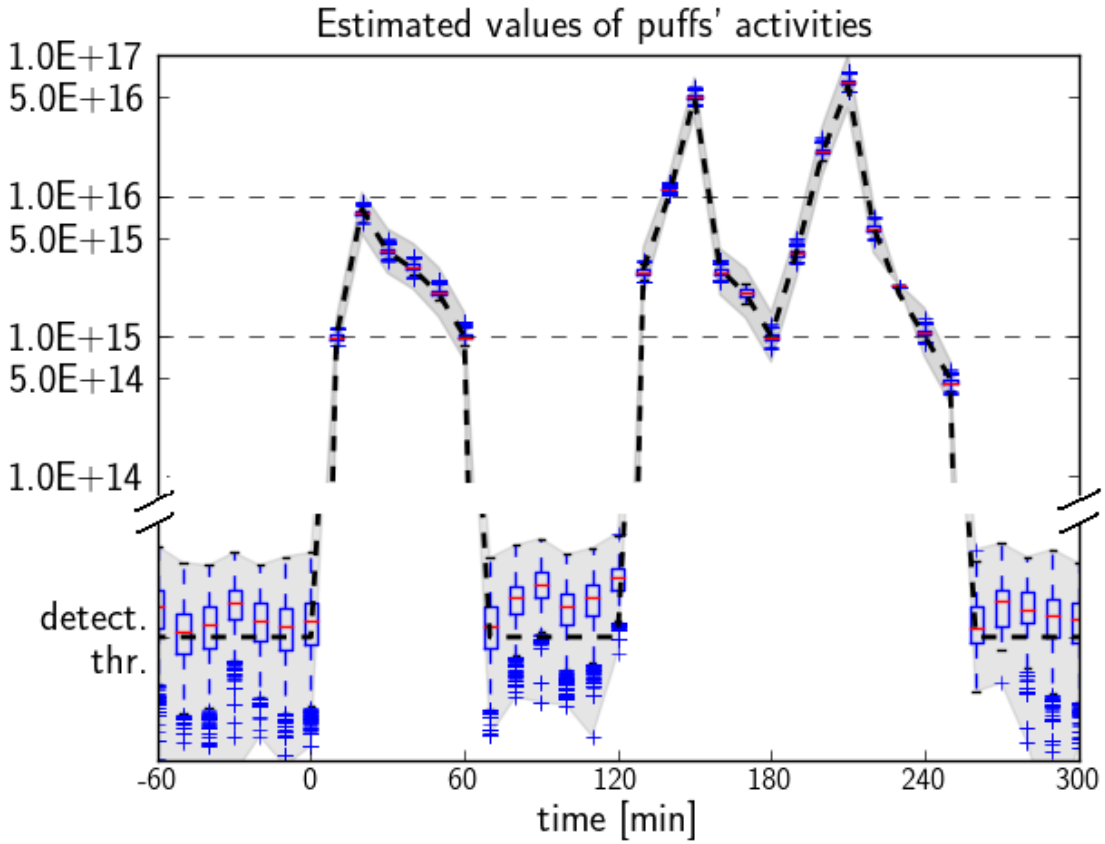
- Twin model representing the true release.

Demonstration of the system on a simulated scenario



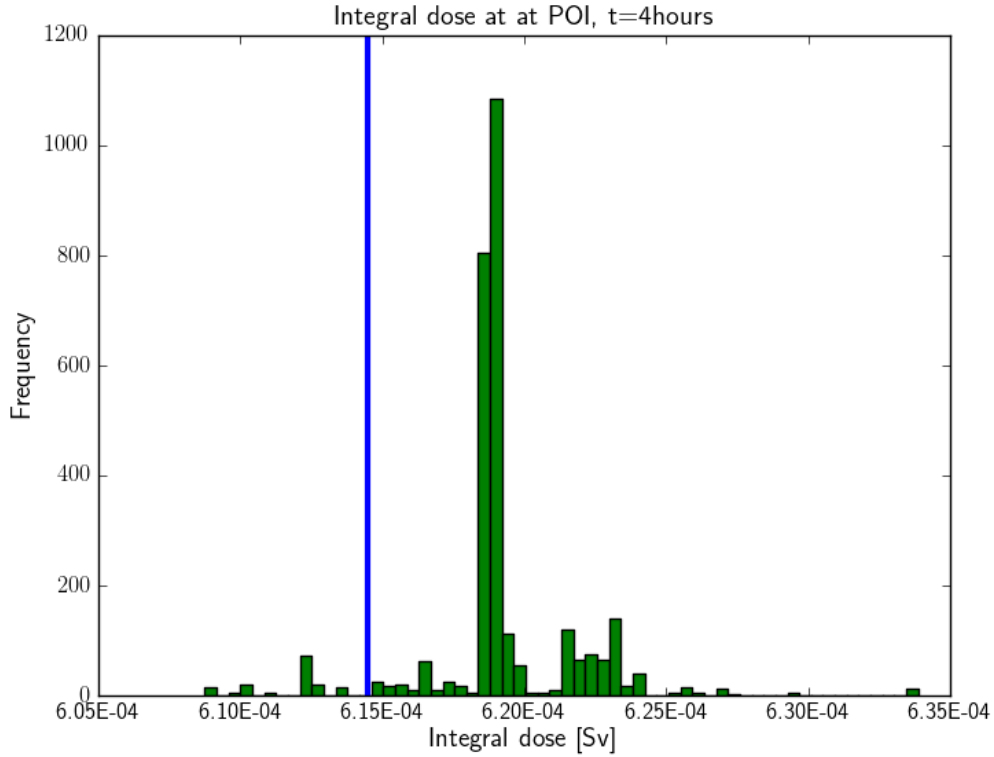
- **Left:** Expected value of dose after data assimilation procedure. Blue pentagon is a point of interest, an inhabited place, where want to estimate the dose distribution and use it for countermeasures planning.
- **Right:** Twin model representing the true release.

Demonstration of the system - released activity in time



- Black dashed line represents the "true" magnitude of release – two consecutive releases separated by 1 hour long period
- When no release occurs, the system estimates magnitudes of release equivalent to the threshold of delectability of the receptors given by the natural background radiation

Demonstration of the system - distribution of doses in points of interest

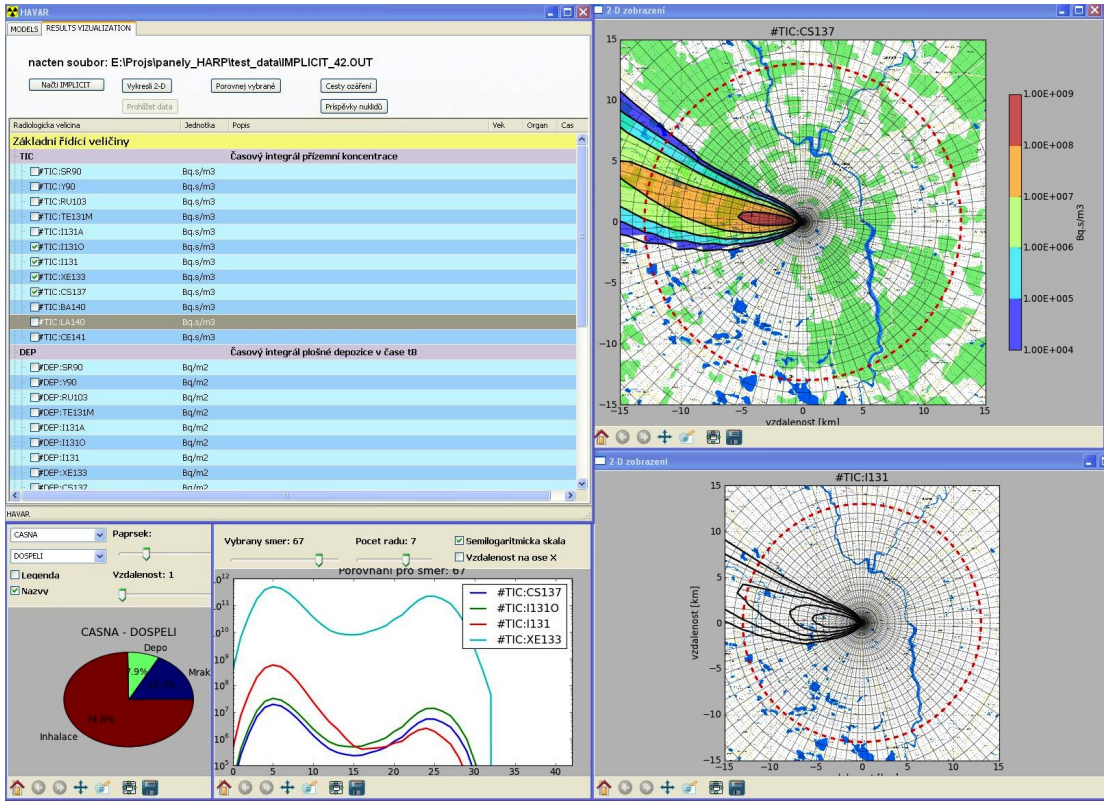


- Posterior density (green histogram) of time integrated dose of up to 4 hours since the release start which is in a good agreement with the true value of the reference release (vertical blue line).

Conclusion and future development

- The research has demonstrated that the probabilistic approach provides useful insights into the problem of radiation situation assessment in the case of an accident with off-site consequences.
- The generic character of the method enables its modification for non-radioactive pollutants and accidents, e.g. spreading of a toxic agent in urban areas.
- Data assimilation system based on particle filtering has a potential to be used for real world emergency response in the near future and its development (in cooperation with the Czech National Radiation Protection Institute) pushes real-time data assimilation in the Czech Republic towards operational application.

Thank you for your attention



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