Source localisation of the Ru-106 detected in autumn 2017

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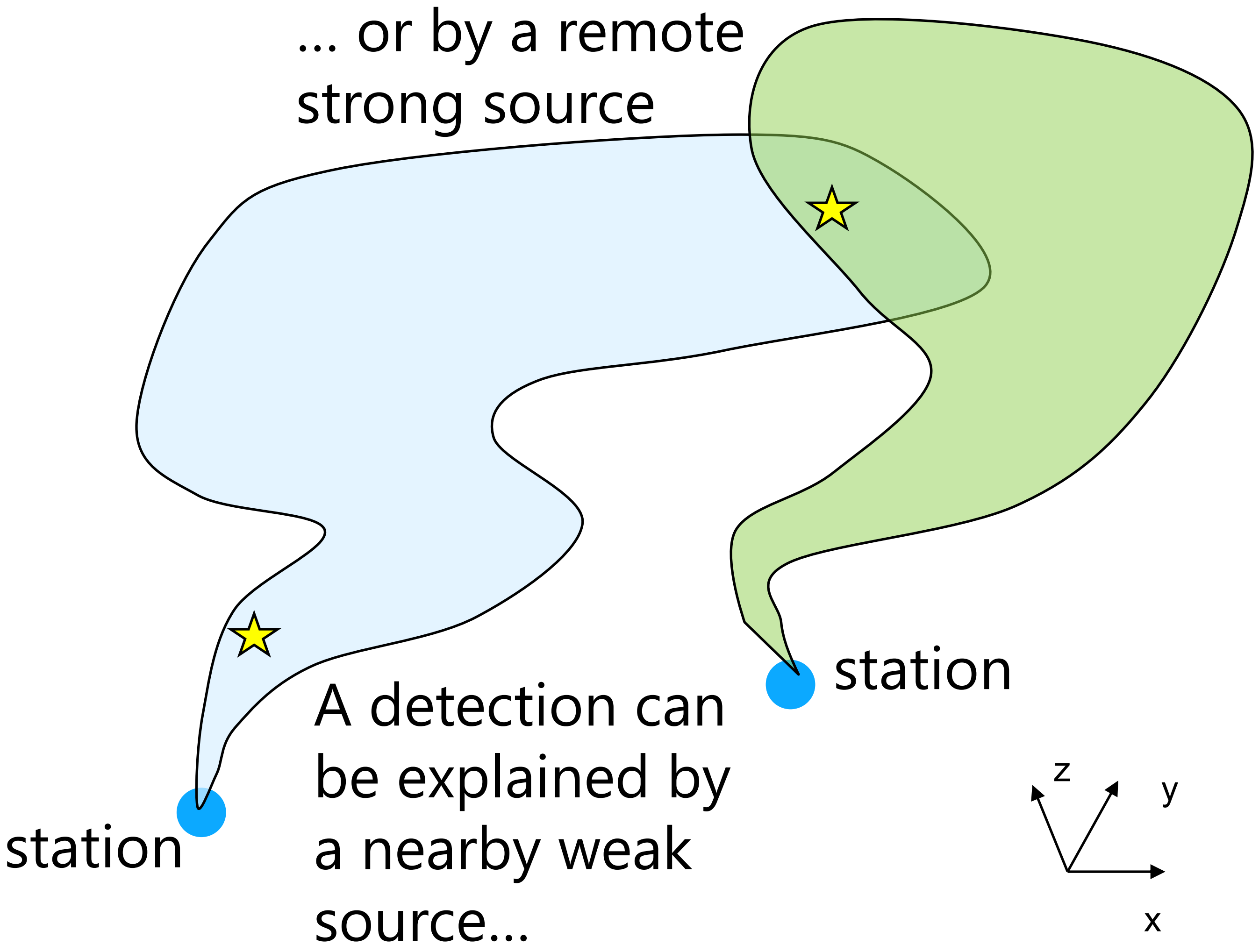
Introduction

- Inverse atmospheric transport modelling involves finding the source parameters (location, release profile…) based on a set of observations
- Generally ill-posed
- By combining multiple (non-) detections, part of this ambiguity can be removed *(e.g., Issartel and Baverel, 2003)*



Inverse atmospheric transport modelling: a three-step problem

1. Input data

Numerical weather prediction data:

Ensemble Data Assimilation system of ECMWF (a 51-member ensemble)

Ruthenium-106 observations:

282 detections and non-detections from 16 stations for the verification of the Comprehensive Nuclear-Test-Ban Treaty (24 h measurements with minimal detectable concentration ~10 μBq/m³)

2. Atmospheric transport and dispersion modelling

The Lagrangian particle model Flexpart in backward mode *(Seibert and Frank, 2004)*

Source-receptor relationship:

Flexpart calculates the source-receptor-sensitivities M_{ij} for each observation y_i (51 sets of 282 simulations):

$$y_i = M_{ij}x_j$$

3. Inverse modelling

A source term x_j is found by minimizing a cost function:

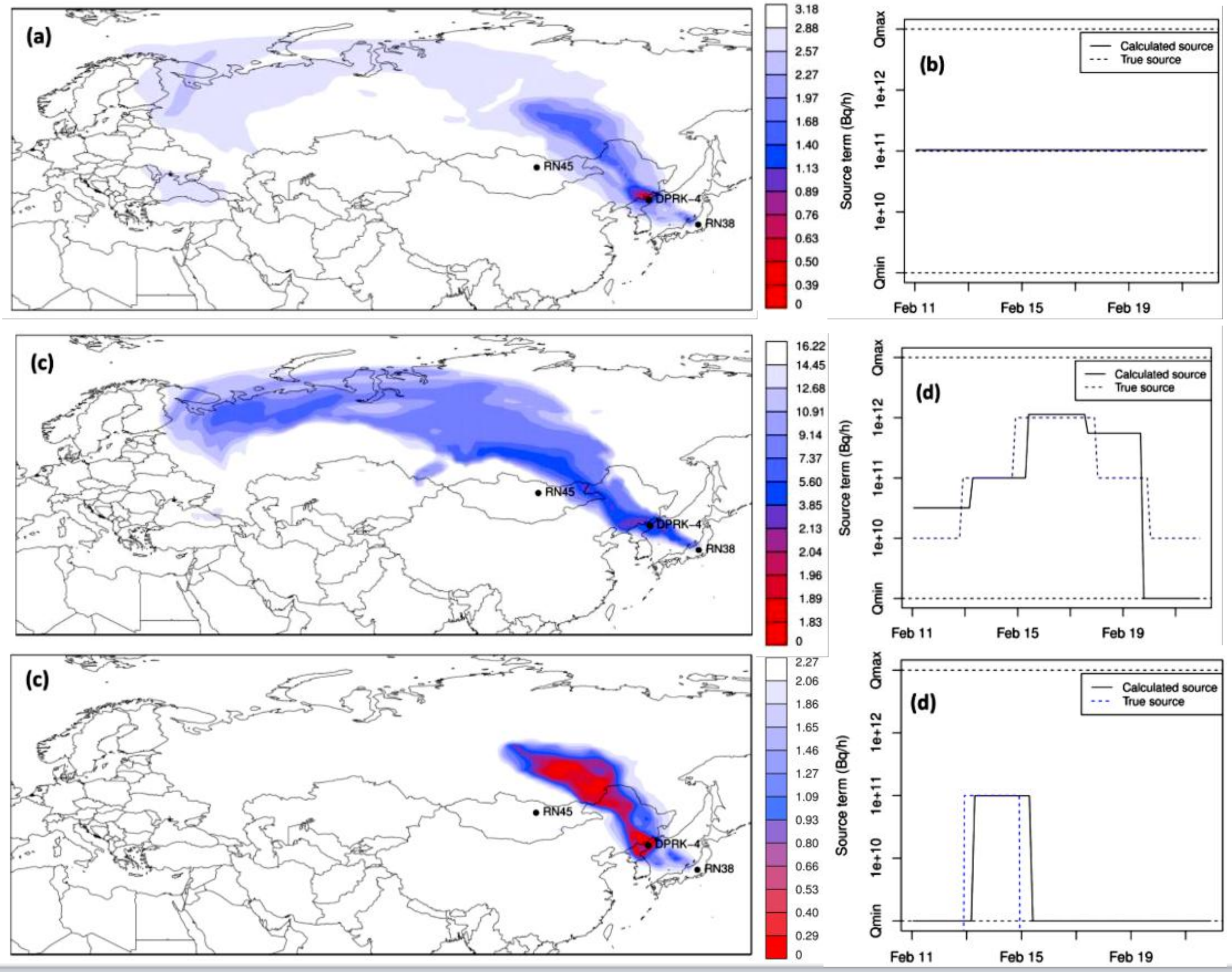
$$exp\left(\frac{1}{n}\sum_i \left(\log(y_i+\alpha) - \log\left(M_{ij}x_j+\alpha\right)\right)^2\right)$$

The optimisation is solved using a quasi-Newton technique and does not require to rerun Flexpart

The inverse modelling is applied to each grid box separately (single grid box source).

The release is assumed to took place between 20 September and 2 October.

The inverse modelling method has been validated using fictitious sources



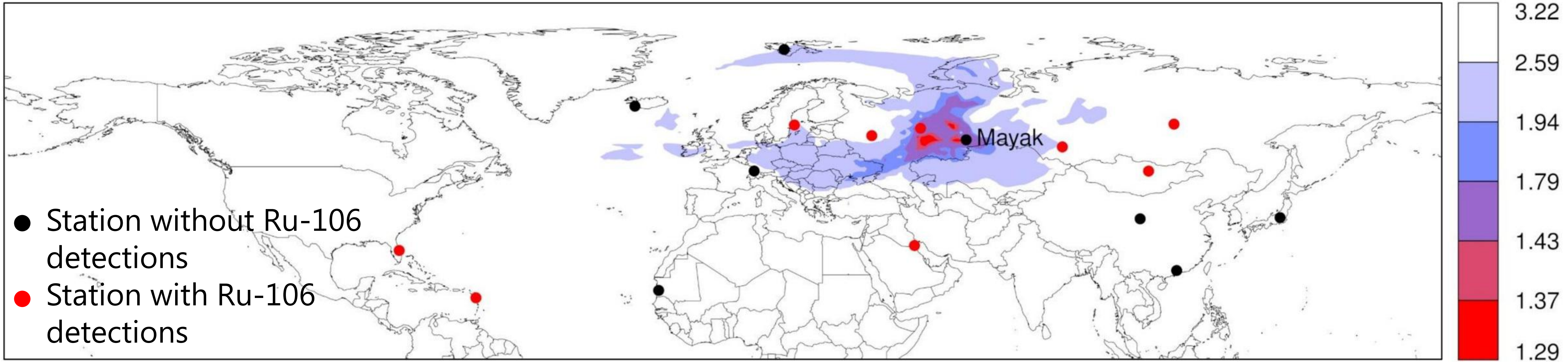
1. Define a fictitious source
2. Calculate pseudo-observations as would be measured by IMS stations (loss of information due to 12 h or 24 h sampling time)
3. Perform a backward run for each pseudo-observation
4. Calculate the optimal source term for each grid box in the lowest model
5. Result: a map with grid-box minimum cost function values and corresponding source terms

De Meutter et al, *Sci Rep*, 2017

Ru-106 source localisation

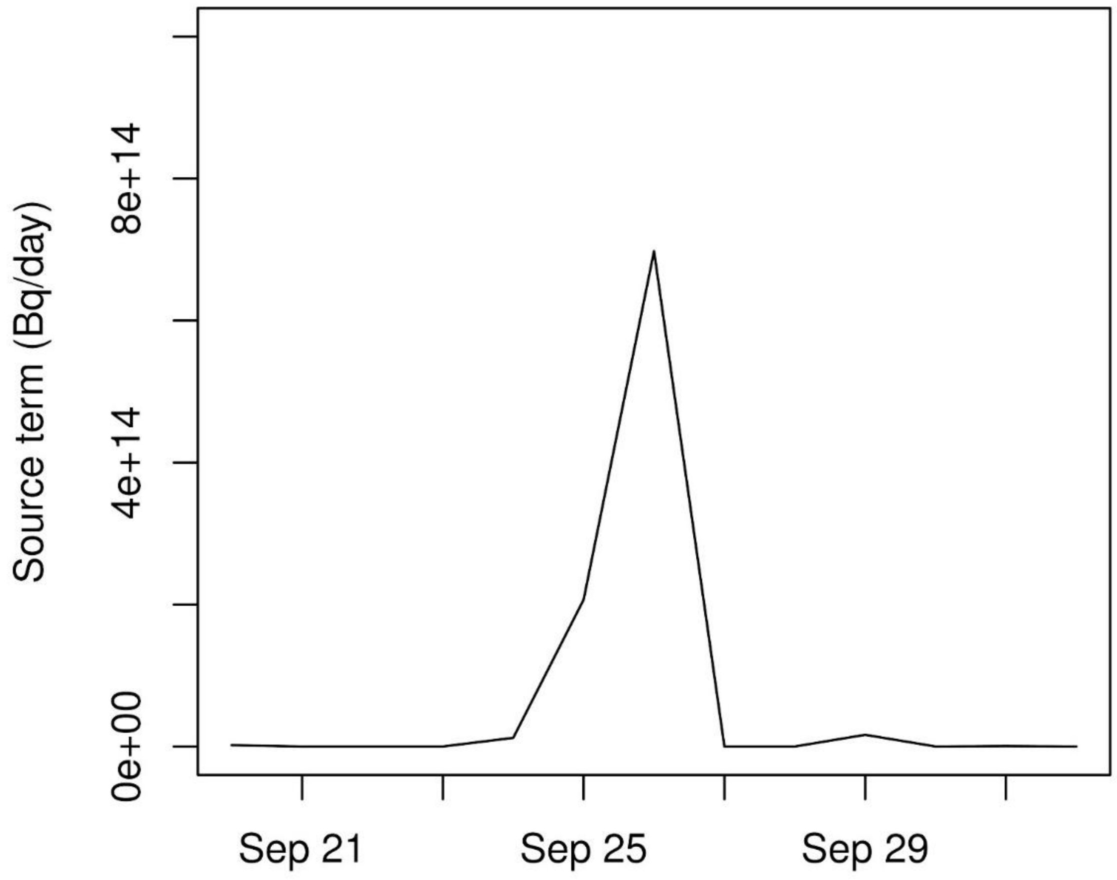
- The detections span four (!) orders of magnitude
- As there is no measurable background of Ru-106, detections should be treated with equal weight: use the geometric variance *(Cervone and Franzese, 2010)*
- To allow non-detections in the analysis, we have added a parameter α
- $$\text{cost function} = \exp\left(\frac{1}{n}\sum_{samples}\left[\log(AC_{obs}+\alpha)-\log(AC_{sim}+\alpha)\right]^2\right)$$

Can be made station-specific (detector quality, background) and sample-specific (MDC)



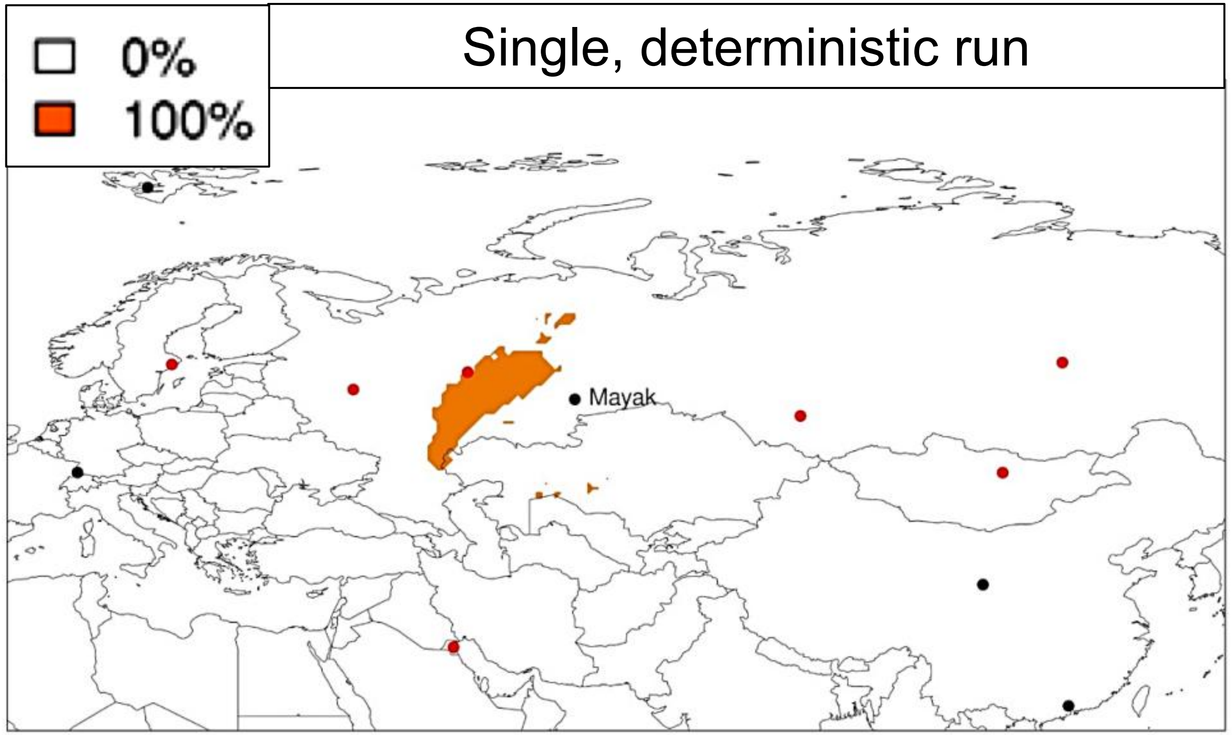
Hypothetical Ru-106 release profile for the nuclear facility Mayak

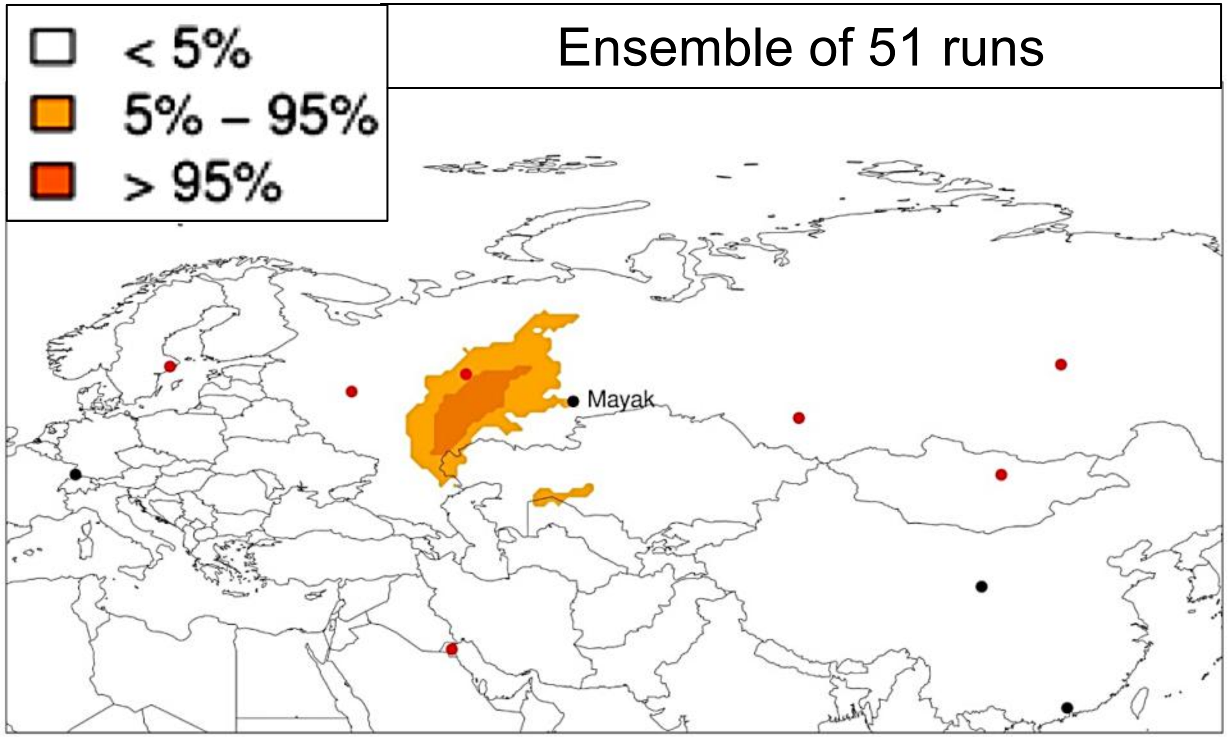
- Time-integrated source term: 9.36 10^{14} Bq



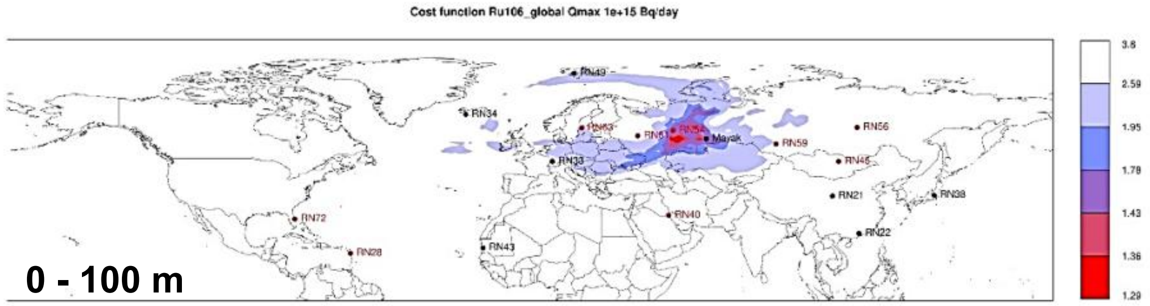
No explicit regularization; instead, 13 release intervals of 1 day.
(Motivated from study on temporal resolution requirements for stack emission data in forward modelling, but also valid for inverse modelling; *De Meutter et al, 2018*)

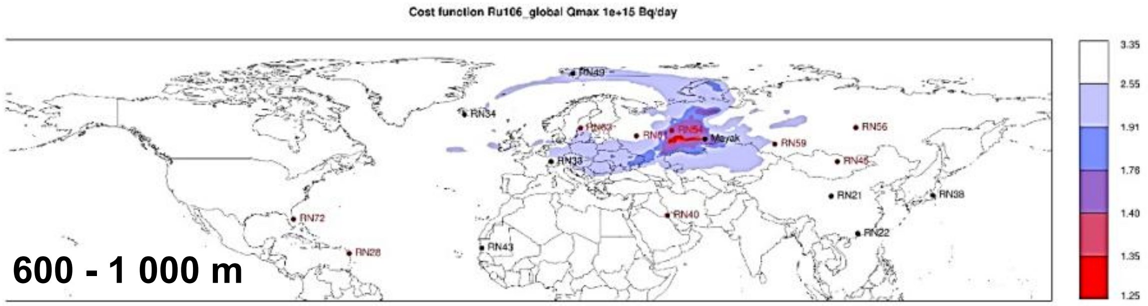
We have used the *Ensemble Data Assimilation*-system of ECMWF to quantify meteorological uncertainty

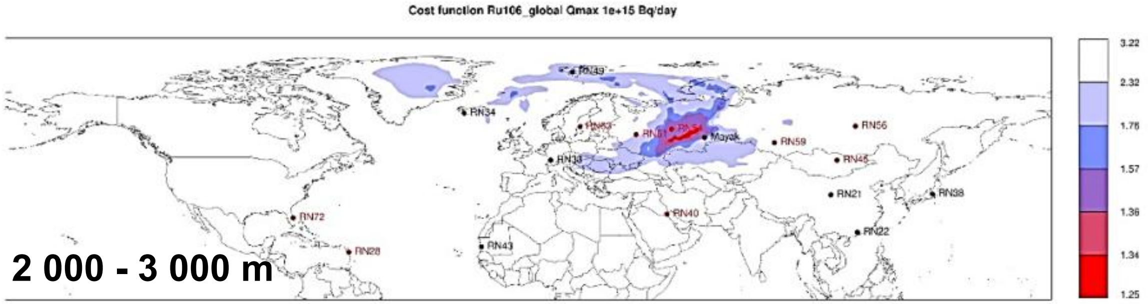


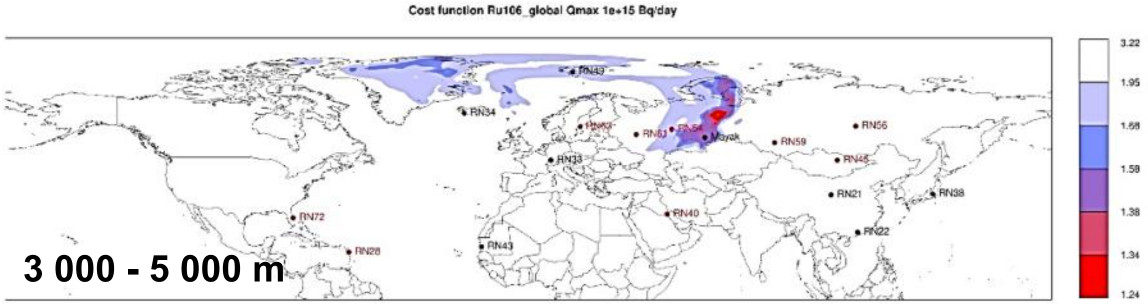


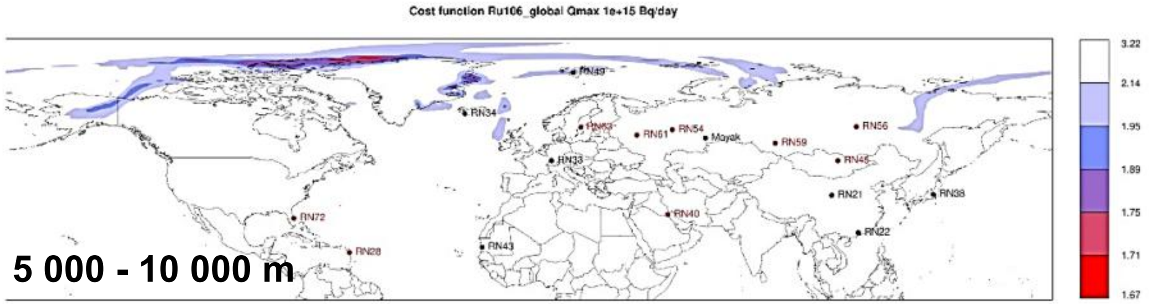
Ru-106 coming from an elevated release?











- Below 3 000 m, the possible source regions are similar
- At higher levels: shift northwards
- Source term of ~1 PBq sufficient

Summary and conclusions

1. Many stations picked up traces of Ru-106, making this case very interesting from a scientific point of view
2. We have implemented and validated an inverse modelling methodology
3. Inverse modelling is ill-posed; the ill-posedness also depends on the meteorological conditions and the network setup.
4. Combining multiple (non-)detections allows to narrow down possible source locations
5. A high release (~1 PBq) is required to explain the observations (also when not including wet deposition in the ATM simulations)
6. Inverse modelling can also be used to identify elevated sources. The patterns are similar in the lowest 3 000 m of the troposphere. The release stays ~1 PBq.
7. Ensembles allow to quantify uncertainty of atmospheric transport modelling, for instance, by constructing pointwise probability maps

Thank you for your attention

References:

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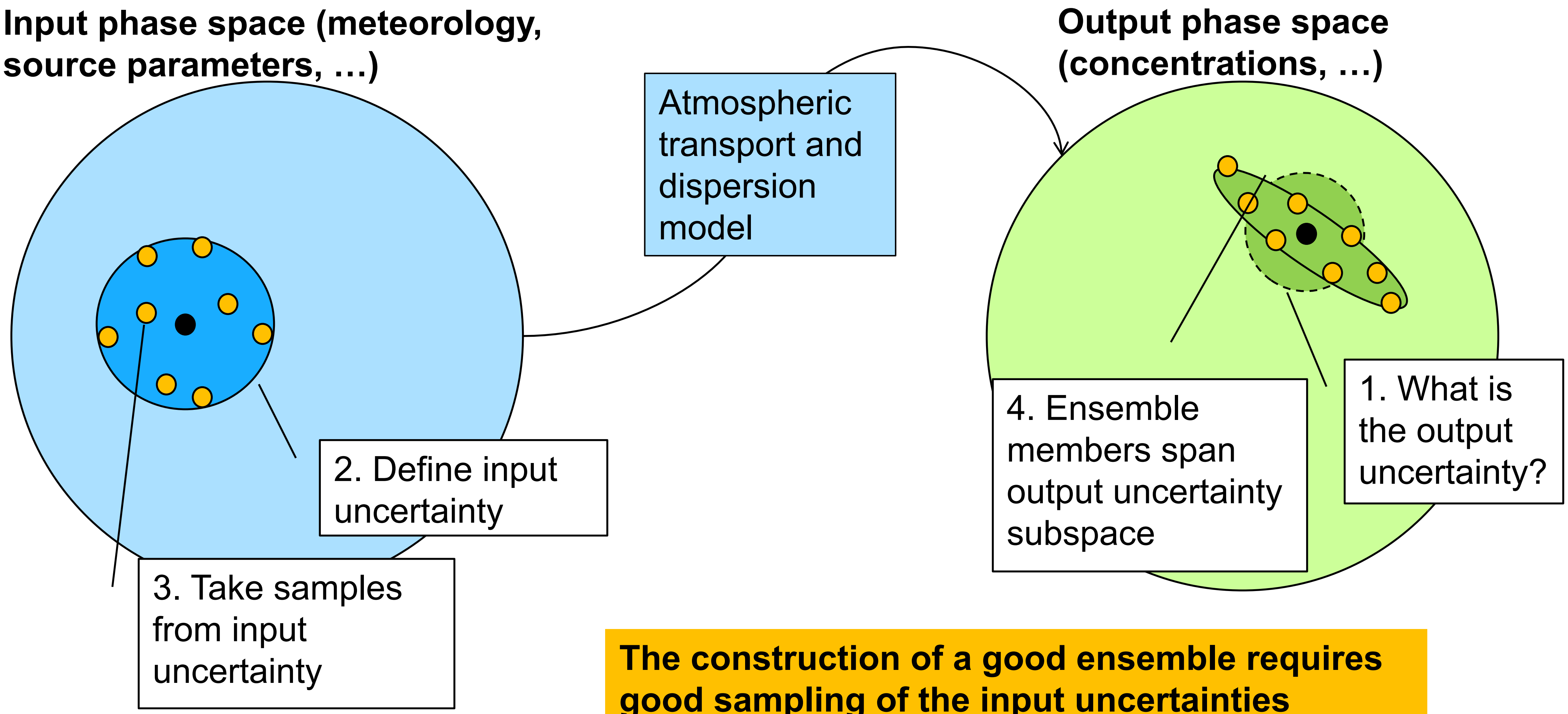
Extra slides

The ensemble method allows uncertainty quantification



The construction of a good ensemble requires good sampling of the input uncertainties