How can we determine the origin of radionuclide observations? Presenting the Bayesian source reconstruction algorithm "FREAR"

Pieter De Meutter, Ian Hoffman, Kurt Ungar

P2.4-373

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ABSTRACT

Abstract:
Radionuclide observations made by the International Monitoring System are an important part of the CTBT verification regime, as it allows to discriminate between conventional and nuclear explosions. In this poster, the Bayesian source reconstruction tool FREAR is presented. The FREAR tool allows to determine source parameters based on radionuclide observations and source-receptor-sensitivities; the latter can be calculated by an atmospheric transport model and are routinely provided by the CTBTO. Detections and instrumental non-detections are taken into account, and the possibility of false alarms and misses is considered too. The Bayesian approach inherently takes into account uncertainties. Furthermore, a method to determine model uncertainties, based on an ensemble, is presented.

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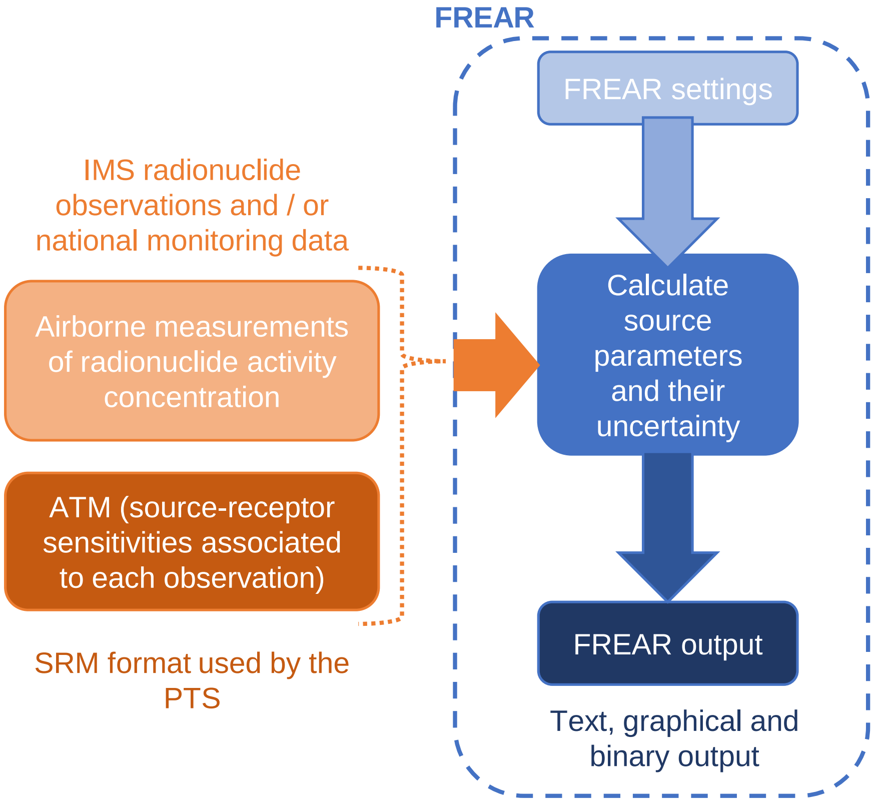
INTRODUCTION

FREAR in a nutshell:

- Forensic Radionuclide Event Analysis and Reconstruction
- Flexible tool that combines ATM and radionuclide observations to determine unknown emission parameters (such as release location and release amount)
- Written in R
- Can run on a laptop
- Requires open source software only
- Available under the GPL v3 on GitLab: https://gitlab.com/trDMt2er/FREAR



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CTBTO PREPARATORY COMMISSION

FEATURES

1/ Detections and non-detections

FREAR can use both detections and instrumental non-detections; it takes into account the possibility for misses and false alarms (see Fig. 1)

2/ Uncertainty quantification

The Bayesian inference approach provides an estimate on the uncertainties in a natural way. Furthermore, an ensemble of atmospheric transport modelling can be used to better estimate model uncertainty

3/ Several source parameterizations are available

Users can select the most appropriate source parameterization for a given problem, and can add their custom source parameterization if needed

4/ Bayesian approach vs cost optimization approach

Two separate methods are available to determine source parameters: (i) a Bayesian Markov Chain Monte Carlo method and (ii) a cost function optimization approach

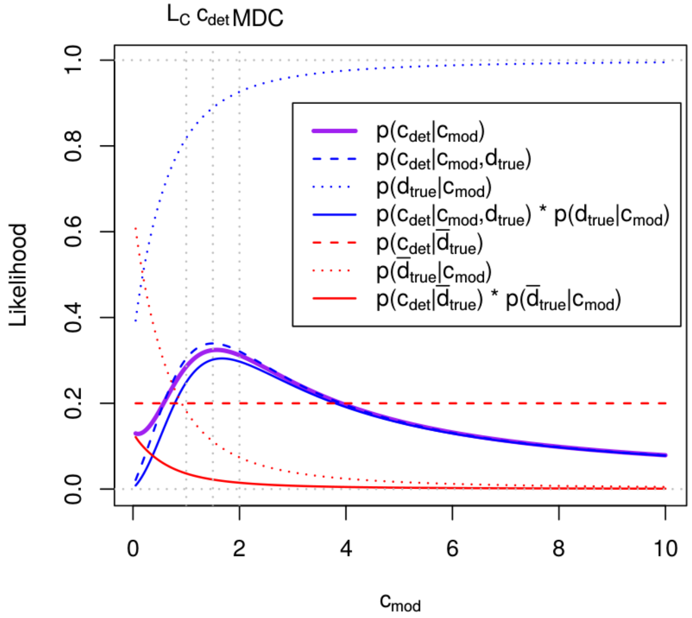

Fig 1: Decomposition of the likelihood as a function of the simulated activity concentration (c_{mod}) for a detection (c_{det}) below the minimum detectable concentration (MDC). The likelihood considers the possibility that the detection was a false alarm. *See De Meutter et al. (2021) for details*

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EXAMPLE OUTPUT

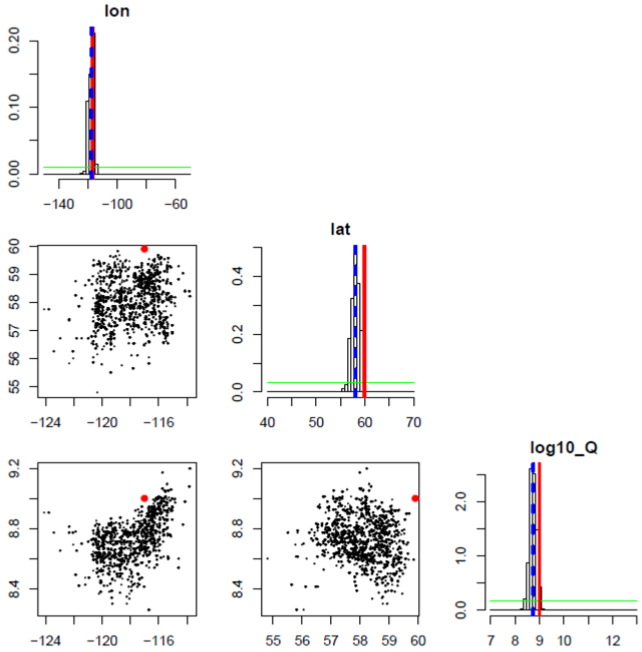

Fig 2: (Example output) posterior distribution for the source parameters “longitude”, “latitude” and “accumulated release”.

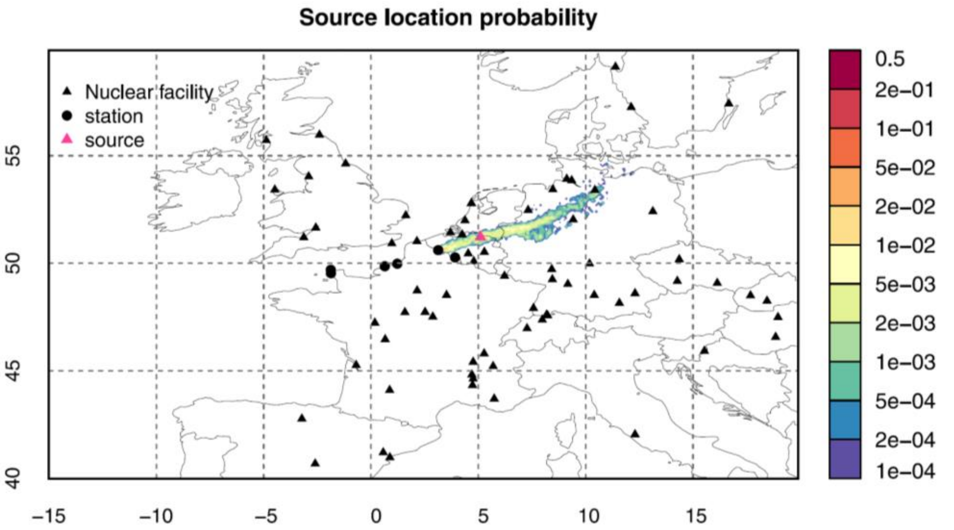

Fig 3: (Example output) source location probability map.

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MODEL UNCERTAINTIES

In order to perform a source reconstruction using FREAR, we need to know the model uncertainties (= uncertainties associated with the atmospheric transport modelling).

1. Since we do not know the true model error, we replace it by a distribution. We use an inverse gamma function with three parameters (initial noise estimate *s*, the scale parameter α and the shape parameter β):

$$\psi(\sigma_{mod,i}|s_i,\bar{\alpha}_i,\bar{\beta}_i) = 2\,\frac{\bar{\alpha}_i^{\bar{\beta}_i}}{\Gamma(\bar{\beta}_i)}\left(\frac{s_i}{\sigma_{mod,i}}\right)^{2\bar{\beta}_i}\exp\left(-\bar{\alpha}_i\,\frac{s_i^2}{\sigma_{mod,i}^2}\right)\frac{1}{\sigma_{mod,i}}$$

2. These parameters can be sample-specific (= observation-specific) (Fig. 5, next slide)
3. The parameters can be given as input, or derived from an ensemble of SRS to better represent the model uncertainties (Fig. 4)
4. These model uncertainties have an impact on the source characterization (Fig. 6, next slide)

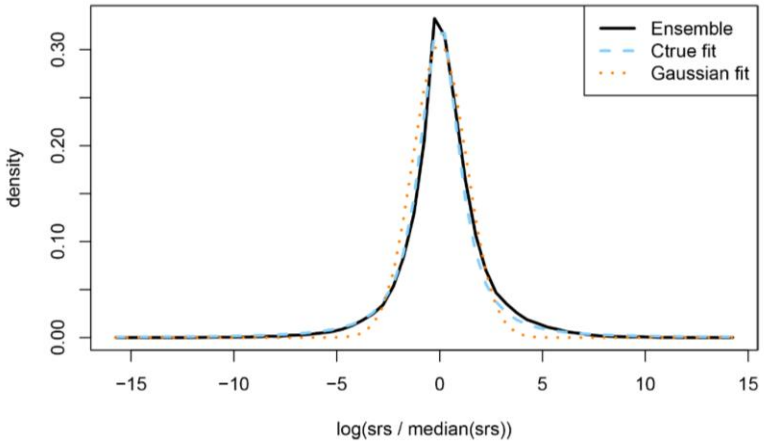

Fig 4: The uncertainty distribution obtained from an ensemble of ATM can be approximated with an inverse gamma function.

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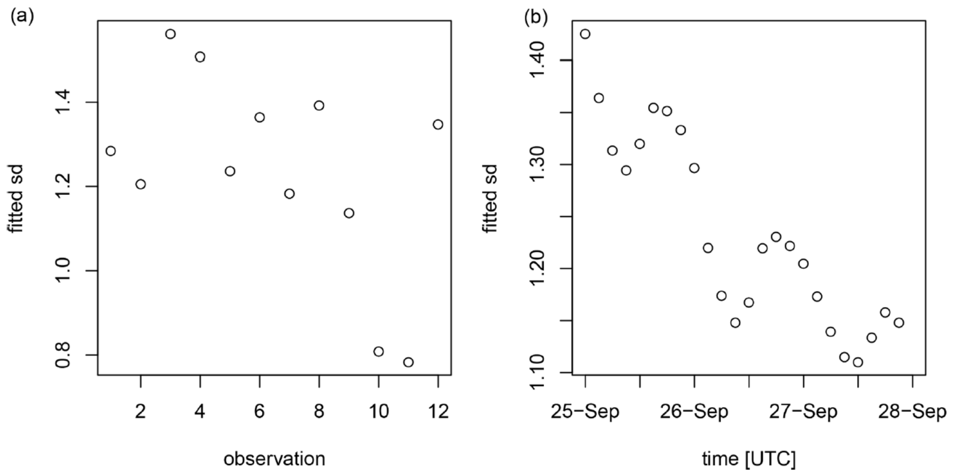

Fig 5: (a): Model uncertainties are observation-dependent; (b): Model uncertainties increase when going forward in simulation time (here: backwards in time); the errors oscillate according to the diurnal cycle.

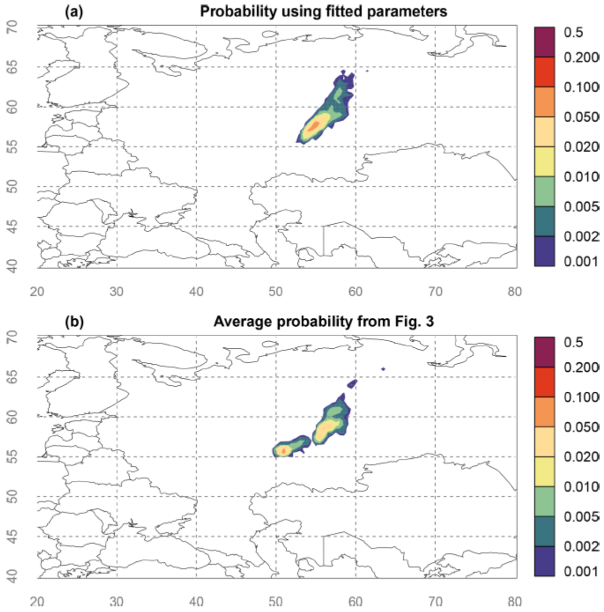

Fig 6: Example of a source location map using (a) fitted model uncertainty parameters from an atmospheric transport model ensemble. (b) the average from multiple source reconstructions using several *a priori* choices for the model uncertainty.

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CONCLUSIONS

1/ What is FREAR?

FREAR is a flexible tool that combines ATM and radionuclide observations to determine unknown emission parameters

Available on Gitlab under GPL3.0, written in R:
https://gitlab.com/trDMt2er/FREAR

2/ Features

Can deal with instrumental detections and non-detections

Model uncertainty is represented by an inverse gamma function, which fits well with an atmospheric transport modelling ensemble

3/ We welcome your feedback to improve the tool!

Acknowledgements

Nils Ek, Alain Malo and Yves Pelletier (Environment and Climate Change Canada)
Eugene Yee

Technical references

De Meutter, P., & Hoffman, I. (2020). Bayesian source reconstruction of an anomalous Selenium-75 release at a nuclear research institute. Journal of environmental radioactivity, 218, 106225.
https://doi.org/10.1016/j.jenvrad.2020.106225

De Meutter, P., Hoffman, I., & Ungar, K. (2021). On the model uncertainties in Bayesian source reconstruction using an ensemble of weather predictions, the emission inverse modelling system FREAR v1.0, and the Lagrangian transport and dispersion model Flexpart v9.0.2. Geoscientific Model Development, 14(3), 1237-1252.
https://doi.org/10.5194/gmd-14-1237-2021

See also

Testing the Forensic Radionuclide Event Analysis and Reconstruction Tool (FREAR), Ian Hoffman et al (P3.5 – 407)

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