# Metadata of the chapter that will be visualized in SpringerLink

| Book Title | Air Pollution Modeling and its Application XXV | | |
|---|---|---|---|
| Series Title | | | |
| Chapter Title | Backtracking Radioxenon in Europe Using Ensemble Transport and Dispersion Modelling | | |
| Copyright Year | 2017 | | |
| Copyright HolderName | Springer International Publishing AG | | |
| Corresponding Author | Family Name | **Meutter** | |
| | Particle | **De** | |
| | Given Name | **Pieter** | |
| | Prefix | | |
| | Suffix | | |
| | Division | | |
| | Organization | Belgian Nuclear Research Institute | |
| | Address | Boeretang 200, 2400, Mol, Belgium | |
| | Division | | |
| | Organization | Royal Meteorological Institute of Belgium | |
| | Address | Ringlaan 3, 1180, Brussels, Belgium | |
| | Division | Department of Physics and Astronomy | |
| | Organization | Ghent University | |
| | Address | Krijgslaan 281, 9000, Ghent, Belgium | |
| | Email | pieter.de.meutter@sckcen.be | |
| Author | Family Name | **Camps** | |
| | Particle | | |
| | Given Name | **Johan** | |
| | Prefix | | |
| | Suffix | | |
| | Division | | |
| | Organization | Belgian Nuclear Research Institute | |
| | Address | Boeretang 200, 2400, Mol, Belgium | |
| | Email | johan.camps@sckcen.be | |
| Author | Family Name | **Delcloo** | |
| | Particle | | |
| | Given Name | **Andy** | |
| | Prefix | | |
| | Suffix | | |
| | Division | | |
| | Organization | Royal Meteorological Institute of Belgium | |
| | Address | Ringlaan 3, 1180, Brussels, Belgium | |
| | Email | andy.delcloo@meteo.be | |
| Author | Family Name | **Termonia** | |
| | Particle | | |

| | |
|---|---|
| Given Name | **Piet** |
| Prefix | |
| Suffix | |
| Division | |
| Organization | Royal Meteorological Institute of Belgium |
| Address | Ringlaan 3, 1180, Brussels, Belgium |
| Division | Department of Physics and Astronomy |
| Organization | Ghent University |
| Address | Krijgslaan 281, 9000, Ghent, Belgium |
| Email | piet.termonia@meteo.be |

| | |
|---|---|
| Abstract | The Comprehensive nuclear Test-Ban-Treaty bans nuclear explosions by everyone, everywhere. Radioxenon monitoring by the International Monitoring System is a key component of the verification of the Treaty. Atmospheric transport modelling can be used to determine the sources of radioxenon plumes. The Flexpart model is used to backtrack radioxenon observations in Europe to determine their source. An ensemble is used to quantify uncertainty. |
| Keywords (separated by '-') | Atmospheric transport modelling - Ensemble - Inverse modelling - CTBTO - Radioxenon |

# Chapter 23
# Backtracking Radioxenon in Europe Using Ensemble Transport and Dispersion Modelling

**Pieter De Meutter, Johan Camps, Andy Delcloo and Piet Termonia**

**Abstract** The Comprehensive nuclear Test-Ban-Treaty bans nuclear explosions by everyone, everywhere. Radioxenon monitoring by the International Monitoring System is a key component of the verification of the Treaty. Atmospheric transport modelling can be used to determine the sources of radioxenon plumes. The Flexpart model is used to backtrack radioxenon observations in Europe to determine their source. An ensemble is used to quantify uncertainty.

## 23.1 Introduction

Certain radioactive xenon isotopes ($^{131m}$Xe, $^{133}$Xe, $^{133m}$Xe, $^{135}$Xe; further on called radioxenon) are monitored by the International Monitoring System (IMS), with the purpose of verifying compliance with the Comprehensive Nuclear-Test-Ban Treaty. If such radioxenon is measured at an IMS station, atmospheric transport models can be used to determine its source. These atmospheric transport models are, however, prone to errors. Therefore it is important to know the uncertainties on the analysis of nuclear explosion signals picked-up by the IMS.

Civil sources such as medical isotope production facilities and nuclear power plants also emit radioxenon. In this paper we backtrack episodes of high $^{133}$Xe con-

P. De Meutter (✉) · J. Camps
Belgian Nuclear Research Institute, Boeretang 200, 2400 Mol, Belgium
e-mail: pieter.de.meutter@sckcen.be

J. Camps
e-mail: johan.camps@sckcen.be

P. De Meutter · A. Delcloo · P. Termonia
Royal Meteorological Institute of Belgium, Ringlaan 3, 1180 Brussels, Belgium
e-mail: andy.delcloo@meteo.be

P. Termonia
e-mail: piet.termonia@meteo.be

P. De Meutter · P. Termonia
Department of Physics and Astronomy, Ghent University,
Krijgslaan 281, 9000 Ghent, Belgium

1

17 centration at the IMS station *RN33* in Schauinsland (Germany) to see whether we
18 can link these to the medical isotope production facility *Institute for Radioelements*
19 (IRE) at Fleurus (Belgium), which is the largest regional $^{133}$Xe emitter. An ensemble
20 of $50 + 1$ members is used to quantify uncertainty from the meteorological data.

## 23.2 Data and Methods

22 The atmospheric transport and dispersion simulations have been realized with the
23 Lagrangian particle model Flexpart Stohl et al. (2005). Flexpart can be used to cal-
24 culate the source-receptor-sensitivity in backward mode Seibert and Frank (2000).
25 The Ensemble Data Assimilation product of the European Centre for Medium-
26 Range Weather Forecasts Buizza et al. (2008) has been used for the backtracking
27 simulations. The spread between the individual realizations or members contains
28 information about the uncertainty of the simulation.
29 The measured concentration at a receptor can be reconstructed by multiplying a
30 source field $Q(x, y, z, t)$ with the source-receptor-sensitivity field $SRS(x, y, z, t)$, out-
31 putted by Flexpart, and by summing over all grid boxes and times $(x, y, z, t)$:

$$obs = \sum_{x,y,z,t} Q(x, y, z, t) \, SRS(x, y, z, t) \tag{23.1}$$

33 If we assume time independent point sources, we can readily calculate $Q$ for every
34 grid point.

## 23.3 Results

### 23.3.1 Case Study

37 We consider four consecutive days of elevated $^{133}$Xe concentration at *RN33* in July
38 2014 (Table 23.1). For each measurement we calculate the SRS fields, from which
39 we can calculate a corresponding source term. If the calculated source term is below
40 $10^{13}$ *Bq/day*, which is the maximum expected $^{133}$Xe release from civil sources Saey
41 (2009), we consider that grid point as a possible source area. The possible sources
42 for the four measurements are shown in Fig. 23.1 (left).
43 We assume that all four $^{133}$Xe samples originates from the same source, and there-
44 fore plot the overlap of possible source areas in Fig. 23.1 (right). There are three areas
45 where all four possible source regions overlap: the first area extends from the detec-
46 tor RN33 to the northeast part of France, Belgium, Luxembourg and the Netherlands
47 and a large part of the North Sea. The second area is located south-west of Denmark.
48 The third area is located at the border of Poland and Ukraine.

**Table 23.1** Elevated activity concentration measurements at RN33 in July 2014

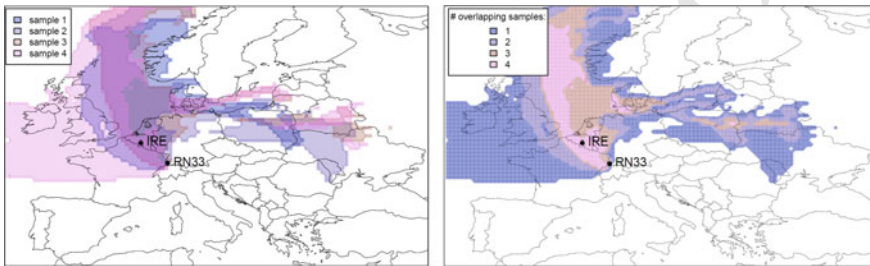| Receptor | Collection start | Collection stop | Act. conc. ($mBq/m^3$) |
|---|---|---|---|
| RN33 | 10 Jul 2014 0600 UTC | 11 Jul 2014 0600 UTC | 4.5 |
| RN33 | 11 Jul 2014 0600 UTC | 12 Jul 2014 0600 UTC | 5.3 |
| RN33 | 12 Jul 2014 0600 UTC | 13 Jul 2014 0600 UTC | 6.1 |
| RN33 | 13 Jul 2014 0600 UTC | 14 Jul 2014 0600 UTC | 1.4 |



**Fig. 23.1** *Left* for each sample, the area of possible sources is shown in *transparent colors* (assuming a source term below $10^{13}$ *Bq/day*). *Right* overlap of the areas of possible sources shown *left*
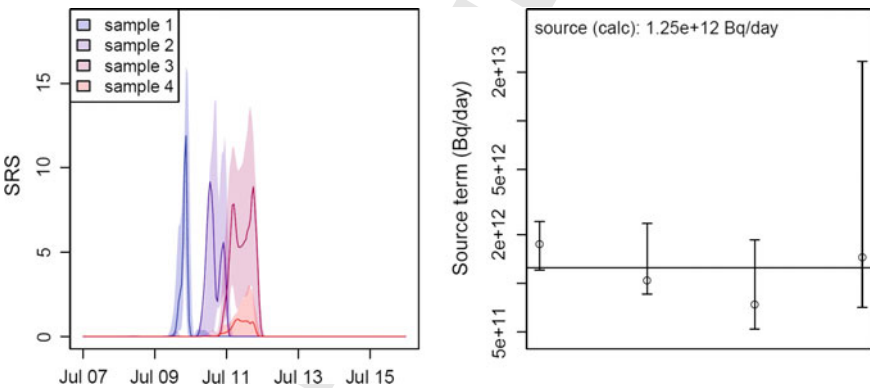


**Fig. 23.2** *Left* SRS at IRE. *Right* source term for sample 1 (most *left*) to sample 4 (most *right*). Shaded areas (*left*) and error bars (*right*) represent 95% confidence interval

If we exclude grid points where the release exceeds $10^{11}$ *Bq/day* (which can be considered as the maximal release from nuclear power plants in that region), only a very small area around RN33 remains (not shown). We therefore consider IRE as the most likely source.

To determine the $^{133}$Xe release, we have interpolated the SRS fields to the location of IRE. Figure 23.2 (left) shows the time series of the SRS of the four samples. The corresponding source term for each measurement is shown in Fig. 23.2 (right). We see that all four source terms are similar and the uncertainty depends on the flow.

### 23.3.2    Ten Highest $^{133}$Xe episodes at RN33

We have selected the ten highest $^{133}$Xe episodes at RN33 in 2014 and have calculated the corresponding source term (not shown), assuming IRE as dominant source. Nine out of ten gave a realistic source term. However, for one case we were not able to attribute the observed $^{133}$Xe to IRE, suggesting that nearby nuclear power plants can also significantly contribute to the $^{133}$Xe concentration at RN33.

## 23.4    Summary

ATM is a valuable tool for the Comprehensive nuclear Test-Ban-Treaty verification regime since it allows to calculate possible source regions and to estimate, for a specific location, when releases could have occurred, and what amount of radioxenon should have been released under different release duration assumptions.

We have selected elevated $^{133}$Xe concentrations at RN33 and have calculated the corresponding source term assuming that IRE was the dominant source. Nine out of ten observations could be attributed to the IRE. The use of an ensemble allows to quantify uncertainty of the calculated source term.

## References

Buizza R, Leutbecher M, Isaksen L (2008) Potential use of an ensemble of analyses in the ECMWF Ensemble Prediction System. Q J R Meteor Soc 134:2051–2066. doi:10.1002/qj.346

Saey PR (2009) The influence of radiopharmaceutical isotope production on the global radioxenon background. J Environ Radioactiv. doi:10.1016/j.jenvrad.2009.01.004

Seibert P, Frank A (2000) Source-receptor matrix calculation with a Lagrangian particle dispersion model in backward mode. Atmos Chem Phys. doi:10.5194/acp-4-51-2004

Stohl A, Forster C, Frank A, Seibert P, Wotawa G (2005) Technical note: the Lagrangian particle dispersion model FLEXPART version 6.2. Atmos Chem Phys. doi:10.5194/acp-5-2461-2005

# Author Queries

**Chapter 23**

| Query Refs. | Details Required | Author's response |
|---|---|---|
| | No queries. | |

# MARKED PROOF

## Please correct and return this set

Please use the proof correction marks shown below for all alterations and corrections. If you wish to return your proof by fax you should ensure that all amendments are written clearly in dark ink and are made well within the page margins.

| Instruction to printer | Textual mark | Marginal mark |
|---|---|---|
| Leave unchanged | · · · under matter to remain | ⊘ |
| Insert in text the matter indicated in the margin | ⋏ | New matter followed by ⋏ or ⋏⊗ |
| Delete | / through single character, rule or underline or ⊢———⊣ through all characters to be deleted | ⌀ or ⌀⊗ |
| Substitute character or substitute part of one or more word(s) | / through letter or ⊢———⊣ through characters | new character / or new characters / |
| Change to italics | —— under matter to be changed | ‿ |
| Change to capitals | ≡ under matter to be changed | ≡ |
| Change to small capitals | = under matter to be changed | = |
| Change to bold type | ∿ under matter to be changed | ∿ |
| Change to bold italic | ∿̿ under matter to be changed | ≋ |
| Change to lower case | Encircle matter to be changed | ⫢ |
| Change italic to upright type | (As above) | ⊥ |
| Change bold to non-bold type | (As above) | ⊥ |
| Insert 'superior' character | / through character or ⋏ where required | ⋎ or ⋏ under character e.g. ⋎² or ⋏² |
| Insert 'inferior' character | (As above) | ⋏ over character e.g. ⋏₂ |
| Insert full stop | (As above) | ⊙ |
| Insert comma | (As above) | , |
| Insert single quotation marks | (As above) | ⋎ or ⋏ and/or ⋎ or ⋏ |
| Insert double quotation marks | (As above) | ⋎ or ⋏ and/or ⋎ or ⋏ |
| Insert hyphen | (As above) | ⊢⊣ |
| Start new paragraph | ⌐ | ⌐ |
| No new paragraph | ⌒ | ⌒ |
| Transpose | ⊔⊓ | ⊔⊓ |
| Close up | linking ⌒ characters | ⌒ |
| Insert or substitute space between characters or words | / through character or ⋏ where required | Y |
| Reduce space between characters or words | │ between characters or words affected | ↑ |