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Influence of Small-Scale Radioxenon Sources on the Background Levels at CTBT IMS Noble Gas Stations

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Abstract

The impact of single major regional radioxenon emitters on the detections at International Monitoring System (IMS) nobles gas systems were examined in two atmospheric transport (ATM) challenges. These two International challenges defined the task to predict the impact of known radioxenon releases from a strong regional source on radionuclide stations of the CTBT International Monitoring System. It has been shown that the availability of stack emission data allows the accurate simulation of major peaks in the detected time series. However, detections of low concentrations cannot always be explained with emissions from the major regional emitter, but rather with accumulated low emissions from numerous sources. In this study, data from the ATM challenges of 2015 are used to assess the overall improvement from considering not only one major emitter, but also numerous small-scale sources.

Radioxenon monitoring

Amongst other fission products a nuclear explosion produces radioxenon. As a noble gas, radioxenon is the most likely fission product to escape an undergound test cavity in significant quantities. The atmospheric concentrations of the four isotopes Xe-131m, Xe-133, Xe-133m and Xe-135 are constantly monitored by 40 monitoring systems being established and operated by the CTBTO, see Figure 1. Xe-133 is the isotope most likely to be detected. As of 2017, 25 noble gas monitoring stations are already operational.

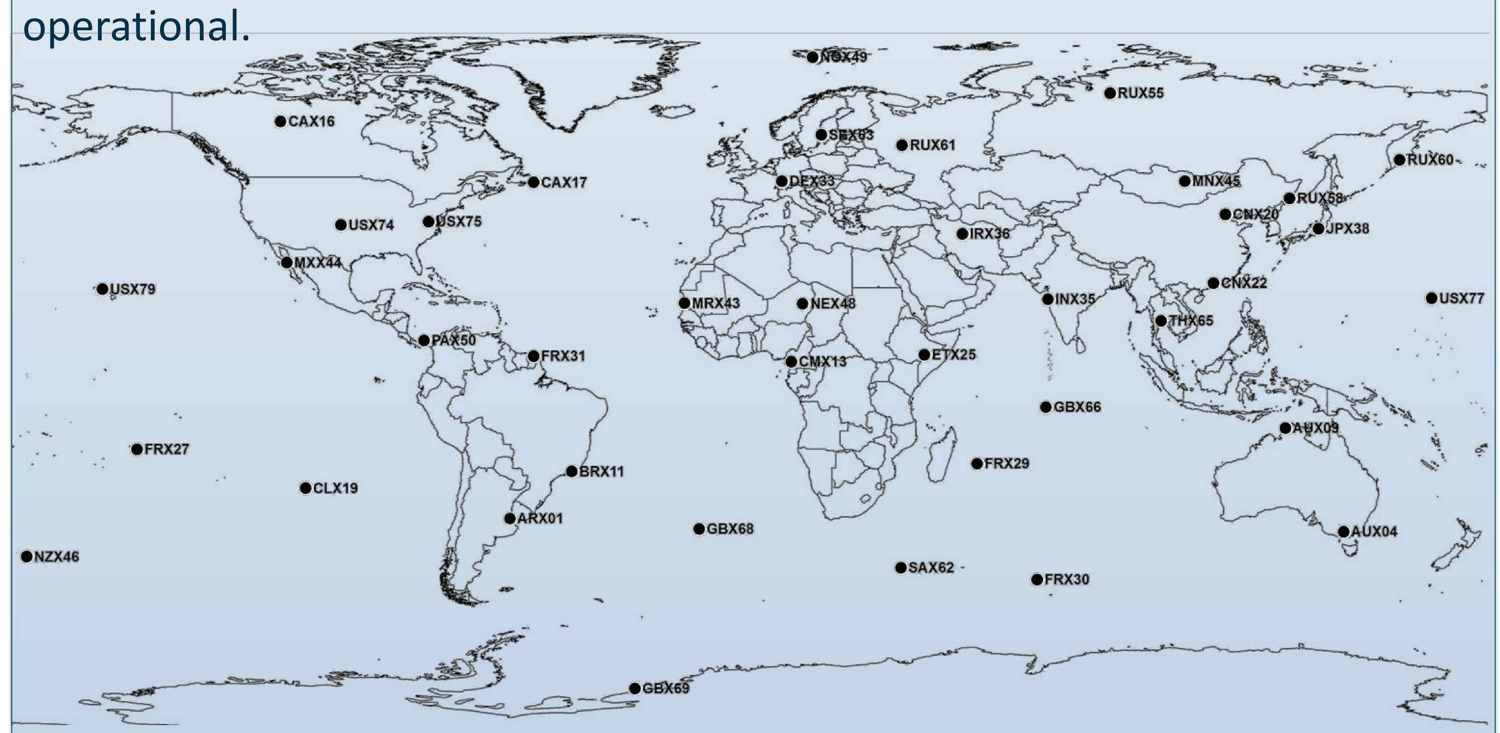


Figure 1. The International Monitoring System includes 40 monitoring systems to detect radioxenon concentrations.

Once operational, each of the monitoring stations take 12h or 24h air samples and measure the radioxenon concentrations. The data is submitted to the International Data Centre in Vienna, where unusual concentrations can indicate the effects from a nuclear test. There fore, the ability to distinguish unusual concentrations from regular ones is important for the performance of the noble gas verification system.

References

[1] Global radioxenon emission inventory based on nuclear power reactor reports – M. Kalinowski, M. Tuma (J. Env. Rad., 2009)
[2] The influence of radiopharmaceutical isotope production on the global radioxenon background – Paul Saey (J. Env. Rad., 2009)
[3] Setting the 2014 Baseline for Simulated Activity Concentrations of Four Radioxenon Isotopes at IMS Sites Based on Estimated Annual Releases of Known Sources – Gueibe et al. (SnT2017, T2.4-P11)
[4] Updated Worldwide Background of CTBT-Relevant Xenon Isotopes – Gheddou et al. (SnT2017, T2.4-P18)
[5] International Challenge to Predict the Impact of Radioxenon Releases from Medical Isotope Production on a Comprehensive Nuclear Test Ban Treaty Sampling Station (J. Env. Rad., 2016) – P. Eslinger, et al.
[6] Atmospheric transport modelling of time resolved 133-Xe emissions from the isotope production facility ANSTO, Australia (J. Env. Rad., 2013) – M. Schoeppner et al.

Influence of Radioxenon Background Sources

Significant amounts of radioxenon are emitted from medical isotope production and to a lesser degree also from nuclear power plants. After the radioxenon is emitted as part of the normal operational off-gas, the plume is dispersed and can be detected by a monitoring station, see Figure 2. A detected concentration at a monitoring station can potentially mask a signal from a nuclear explosion or be mistaken for such a signal. Concentrations from multiple sources accumulate to a total concentration.

Figure 2. Radioxenon plume from nuclear facility gets diluted and can be detected at IMS monitoring station.

A typical medical isotope production facility emits about as much radioxenon per year as all nuclear power plants combined [1,2,3,4]. Only a handful of medical isotope production facilities are known, while there are about 200 nuclear plants worldwide, see Figure 3. The global background sources can therefore be categorized into a few strong sources and many weak sources.

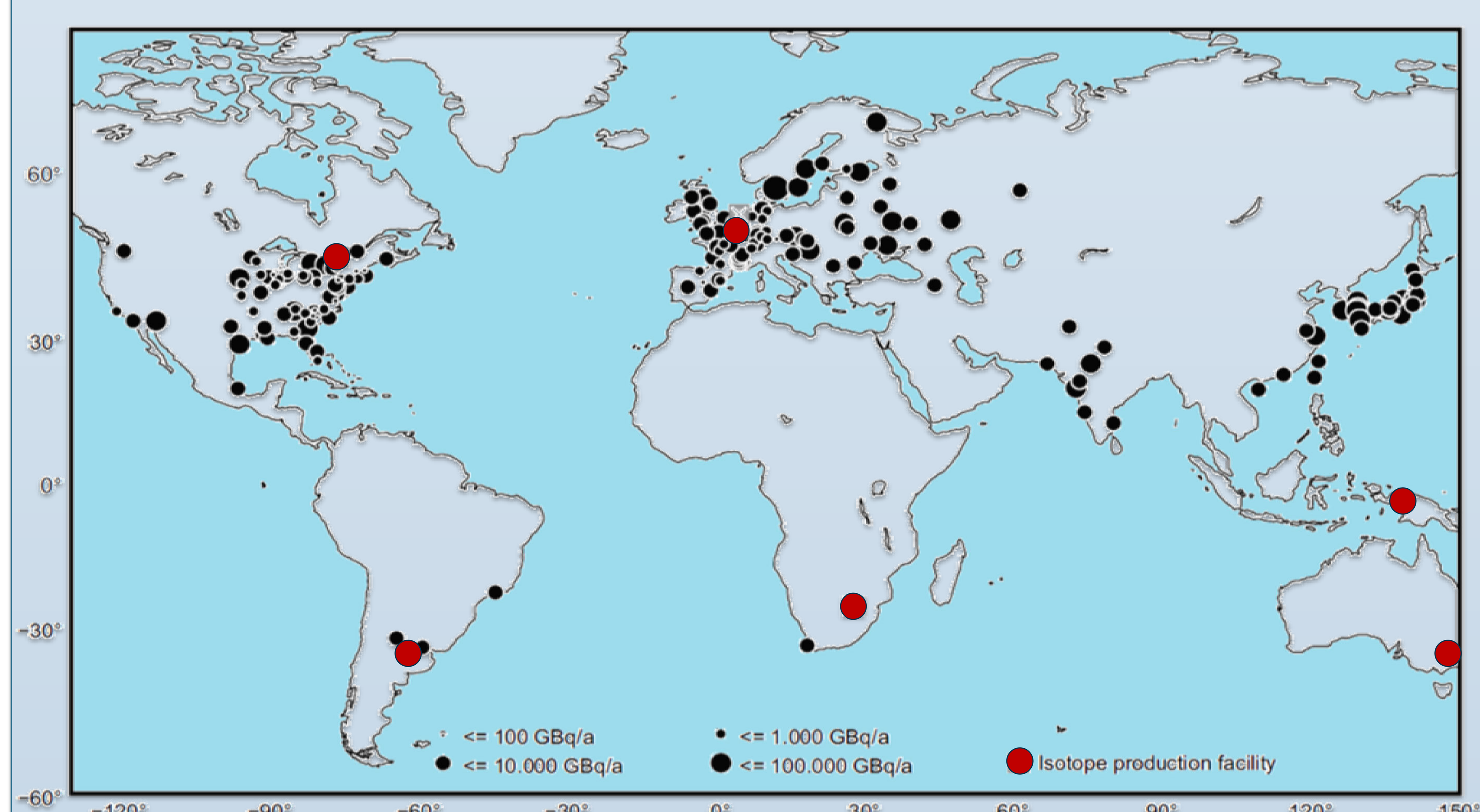


Figure 3. Global distribution of radioxenon sources: A few medical isotope production plants (red) and numerous nuclear power plants (black). [1]

The CTBTO is actively engaging medical isotope producers to reduce emissions but also to get access to radioxenon stack emission data to strengthen the understanding of radioxenon detections at IMS stations.

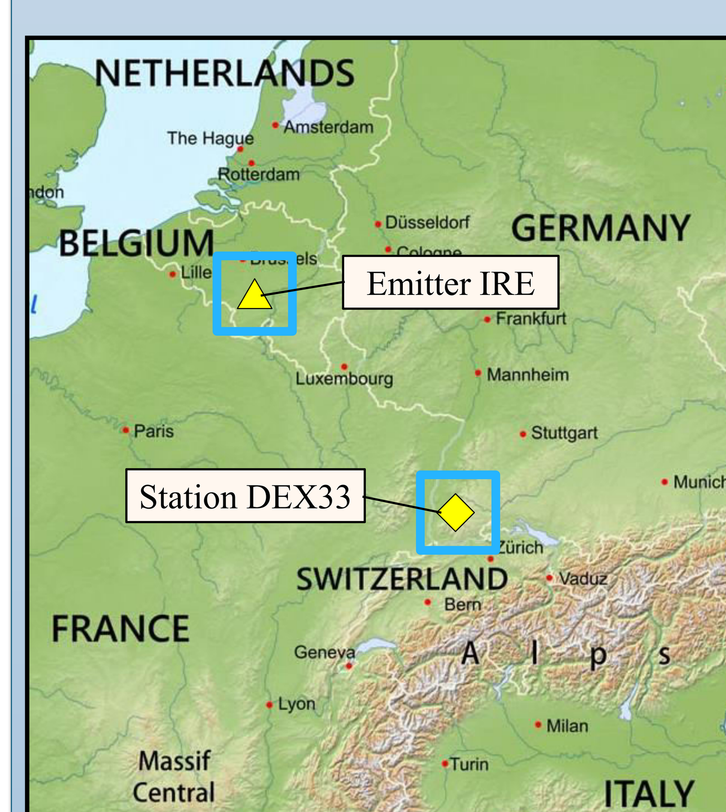


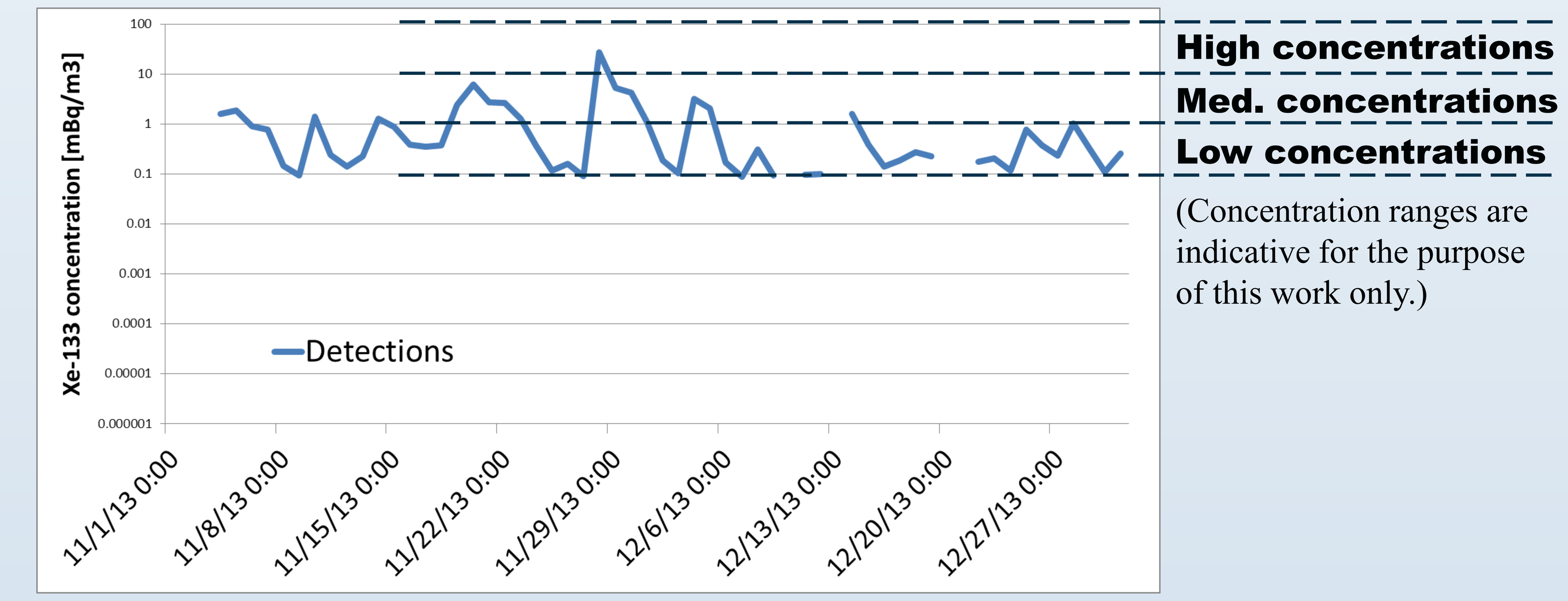
Figure 4. Overview of the ATM Challenge 2015.

In 2015 an ATM challenge was conducted to further the understanding of radioxenon emissions and detections by applying atmospheric transport models [5].

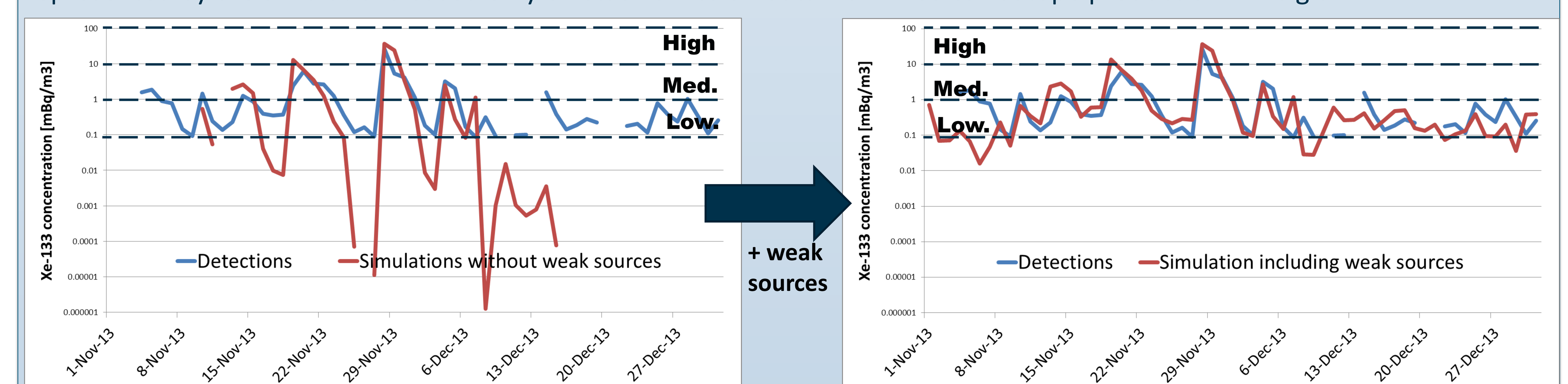
The scenario included emissions from a medical isotope production plant in Belgium and detections at the IMS station close to Freiburg, Germany during November and December of 2013.

Comparison of simulations with and without small-scale sources

The ATM challenge of 2015 has demonstrated the importance of emission data from one regional major radioxenon source being available for the simulation and understanding of high concentrations at monitoring stations. The ATM challenge focused on a time period around a major peak of about 27 mBq/m^3 including the closest secondary peaks [5].



Atmospheric transport modelling based on stack emission data can lead to a close correlation of simulated and detected concentrations, especially with regard to high concentrations [5,6]. The simulations presented below are based on Flexpart 8.23 and Global Forecast System (GFS) meteorological data installed at Princeton University grid computer.
The left-hand figure below shows how high concentrations, and to a lesser degree also medium concentrations, are well represented by the simulations based only on stack emission data from medical isotope production in Belgium.



The right-hand figure show how the simulations improve when not only one major source, but also the numerous nuclear power plants over Europe are considered. Stack emission data were only available for the major source, therefore constant emissions over the year had to be assumed for small-scale sources [1,2,3,4]. The representation o f high and medium concentrations virtually stays the same. However, the majority of low concentrations – that were previously unexplainable – become well represented.
The 2015 ATM challenge introduced a rank, i.e. a combination of statistics, to evaluate the submitted results.

$$Rank = 2 + r^2 + F5 - \frac{|FB|}{2} - KS$$

with the correlation coefficient r, the fraction of predicted values within a factor of five of the measured value F5, the fractional bias FB, and the Kolmogorov-Smirnov statistic KS.

By including not only the strongest emitter of the region but also numerous weak sources, the statistics and the resulting rank value can be substantially increased.

	r (ideal: 1)	F5 (ideal: 1)	FB (ideal: 0)	KS (ideal: 0)	Rank (ideal: 4)
Without weak sources	0.89	0.23	0.25	0.64	**2.25**
Including weak sources	0.89	0.69	0.39	0.13	**3.15**

Summary and conclusions

- Strong sources, i.e. most medical isotope production, can have a significant effect on radioxenon monitoring creating detections of more than 10 mBq/m^3.
- Stack emission data from regional medical isotope production allow to simulate and understand medium and high concentrations at monitoring stations.
- Even annual estimates of emissions from weak sources with high-density, e.g. nuclear power plants and medical isotope production with reduced emissions or at larger distances, can be key to explain low concentrations.