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Radioxenon sample association using a machine learning approach

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INTRODUCTION AND MAIN RESULTS

We developed a machine learning approach, combined with network clustering algorithm, to automatically associate xenon detections into plumes. Trained on synthetic data from ~10,000 simulated releases, the model achieved 91% accuracy.

When applied to Swedish monitoring data, the method identified 86 plumes over 22 months, reducing manual effort and potential human bias.

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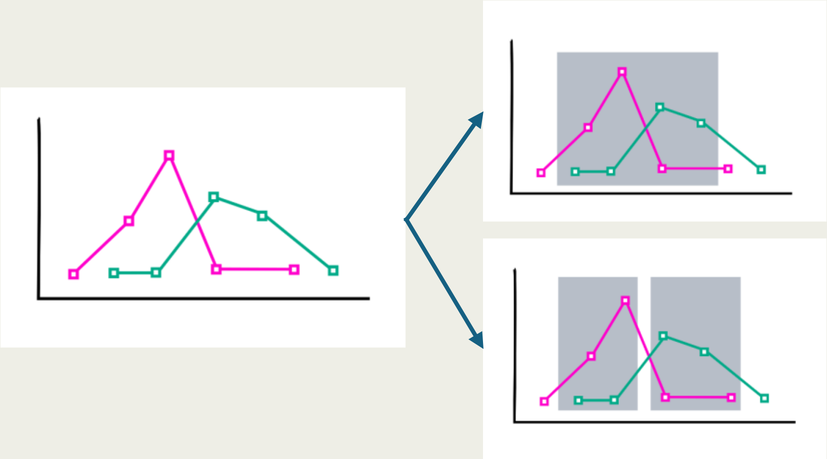
Background and motivation

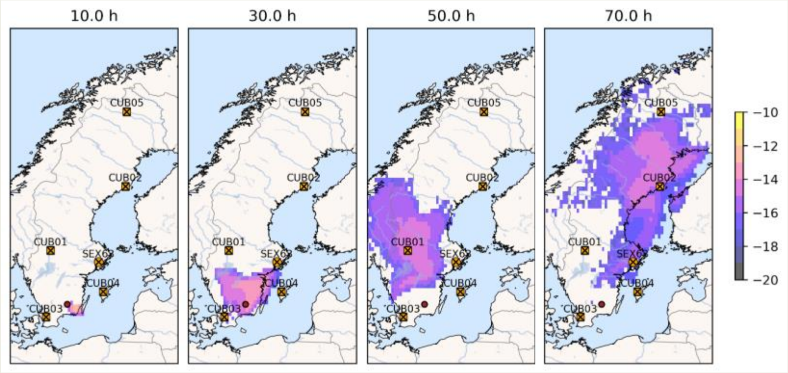


Monitoring atmospheric radioxenon is vital for nuclear test detection, and environmental surveillance. Large volumes of data, with around a dozen detections per day, are routinely collected in the Swedish xenon systems. Traditionally, an analysts manually group detections into plumes before further analysis, but this process is time-consuming and susceptible to bias.

To improve efficiency and objectivity, we developed an automated machine-learning to determine whether detections are related, and if they should be grouped into the same plume. By replacing manual classification with a systematic algorithm, we aim to streamline operations while maintaining accuracy and consistency.

Methods and model training

To train the model, synthetic data was generated with atmospheric transport model, simulating approximately 10,000 release events randomly distributed across Europe in 2018. For each event, the source site and station responses were known, providing ground truth for model training.

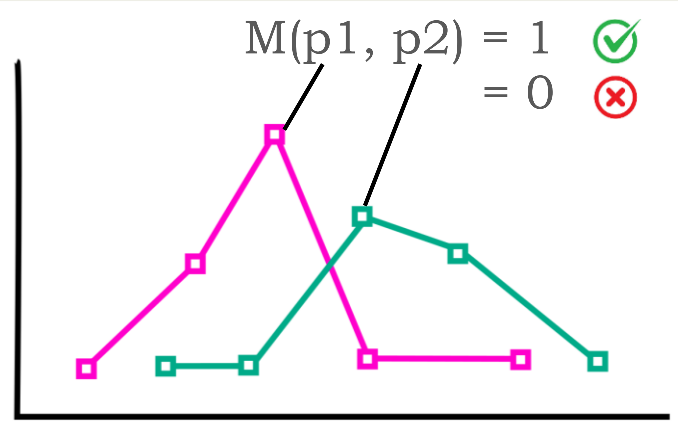


The features trained on included:

- the smallest difference in backward trajectories,
- activity concentrations of Xe-133 from both samples,
- time difference between detections,
- and distance between stations.

A multi-layer perceptron classifier, with two hidden layers of 50 nodes each, was trained, and then used to associate samples into plumes. The model was evaluated using five-fold cross-validation, yielding an accuracy of 91%.

The machine learning algorithm will evaluate if two samples are associated or not. Clusters of associated samples are interpreted as a plume, like a network with edges and nodes.



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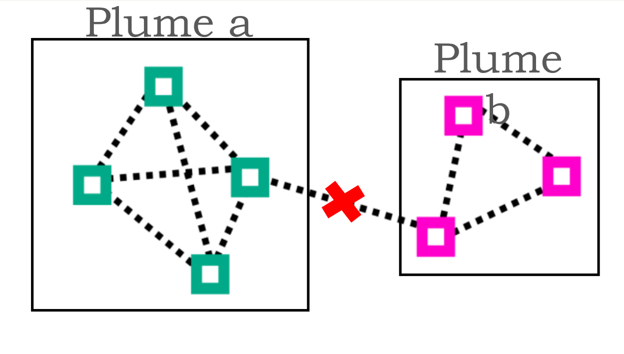
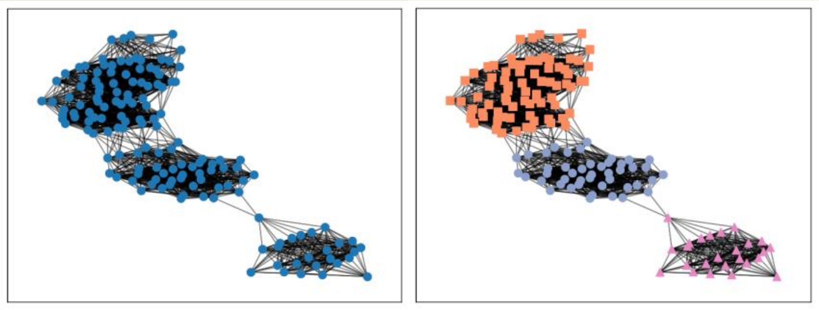
Application and outlook

To address residual misclassifications, a post-processing step was added where plume assignments were refined through Louvain community detection, a network-based clustering method that reduces false positives and false negatives



The figure below shows a real-world case where the ML algorithm produces some false positives, resulting in too many edges. The Louvain algorithm then partitions the connected samples into three groups, i.e. three plumes.

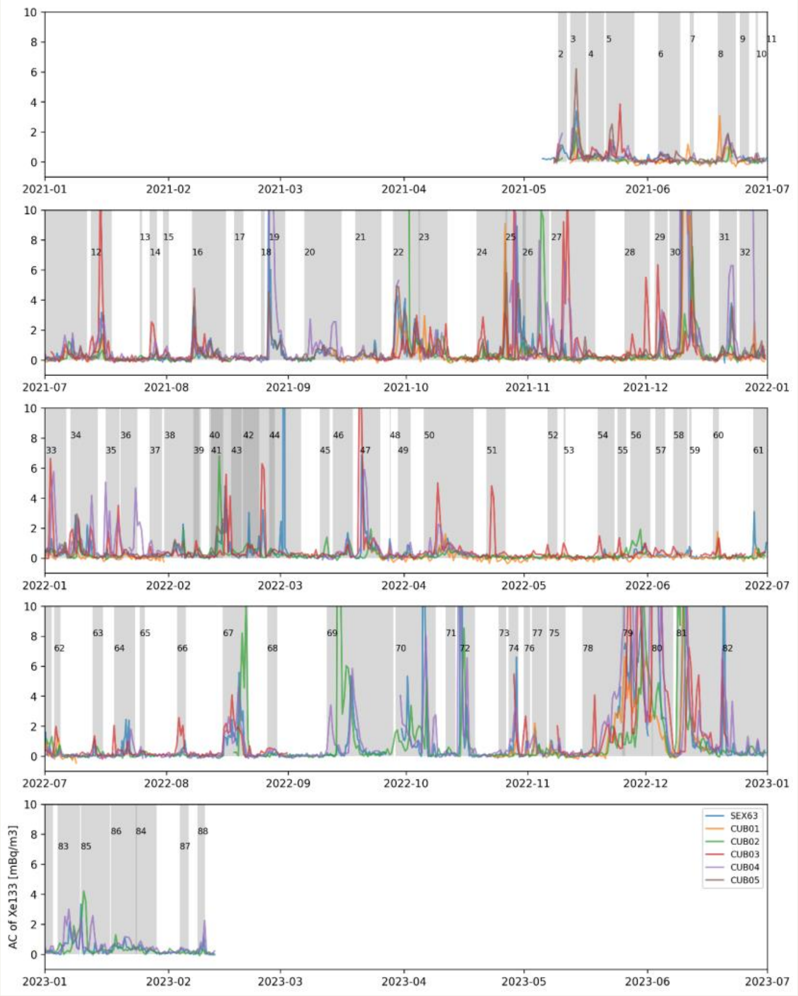


The sample association algorithm was applied to real xenon data from the Swedish systems, which includes the Qb array and the IMS station SEX63. Using of 22 months of data, the method identified 86 plumes, corresponding to approximately one plume per week. Each plume contained around 20 samples, providing a structured and consistent dataset for further analysis (*see **P3.6-394** by A. Ringbom*).

While the method shows strong potential, some limitations remain.

- Because training relied on synthetic, short-duration releases, the model may misinterpret long-lasting events.
- There is currently no strategy to handle events from overlapping sources.
- The trajectory data used are relatively coarse, limiting accuracy in complex meteorological situations.

Despite these caveats, the study demonstrates the value of combining machine learning and network analysis to automate plume association. Future work will focus on incorporating more realistic simulations, expanding training datasets, and testing under diverse atmospheric conditions to ensure robustness and operational reliability.



Algorithm applied to 22 months of Swedish data.