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Quantification of uncertainties in atmospheric transport modelling and their application to modelling radioxenon emissions

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INTRODUCTION AND MAIN RESULTS

Uncertainties in atmospheric transport modelling are explored by modelling the transport of radioxenon from IRE Belgium to a monitoring station in northeast England. Modelling is carried out using two atmospheric transport and dispersion models, two numerical weather prediction models, ensemble meteorology and a variety of turbulence parameterisations. The greatest differences are between the dispersion models.

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Introduction and Method

Radioxenon can be used to detect underground nuclear explosions but, there are many sources of radioactive xenon creating a background concentration. (e.g. Kalinowski, 2023)

Atmospheric Transport and Dispersion Models (ATDM) are routinely used to model background concentrations of radioactive xenon. The accuracy of these models impacts the ability to detect and locate underground explosions, so it's important to quantify the uncertainties in the models and their impact on predictions.

The impact of uncertainties was explored by modelling emissions from IRE, Belgium for March and April 2022 using the NAME (Jones, 2007) and HYSPLIT (Stein, 2015) ATDMs. Predictions were compared to detections at a SAUNA Q_B in northeast England (Goodwin, 2024).

Meteorological data from ECMWF's 5th generation reanalysis (ERA5) at 0.25° by 0.25° resolution was used as input to both ATDMs. HYSPLIT was also run with the ensemble data from ERA5.

Air activity concentrations were output on at 0.125° by 0.125° grid at a 1-hourly resolution and were then extracted at the SAUNA Q_B and aggregated onto the 12-hour sampling time of the Q_B.

Ensemble Meteorology 1

Model predictions predict that material from IRE was detected by the Q_B on the 11 March and between the 23 and 25 March. Model predictions suggest that the detection on the 26 March was not radioxenon from IRE (Figure 1).

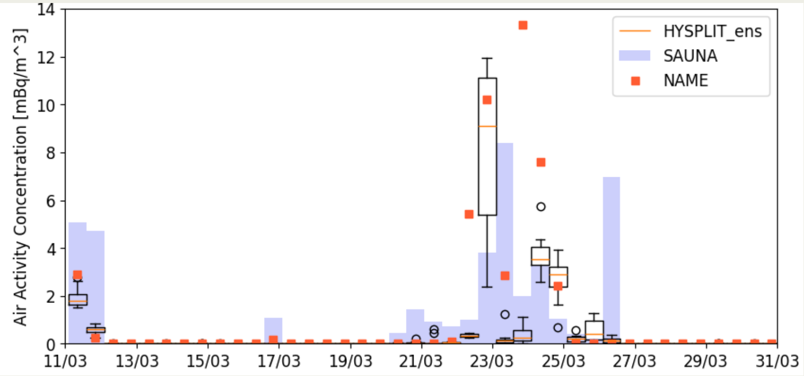

Figure 1: Activity concentrations from the SAUNA Q_B (purple) and HYSPLIT with ensemble meteorology (boxes) and NAME with deterministic meteorology (orange).

- Ensemble modelling shows some uncertainty in air activity predictions.
- NAME tends to predict higher air activities than HYSPLIT.
- The ATDMs do not capture the timing of the highest air activities on the 23 March and the drop in air activities early on 24 March.

Ensemble Meteorology 2

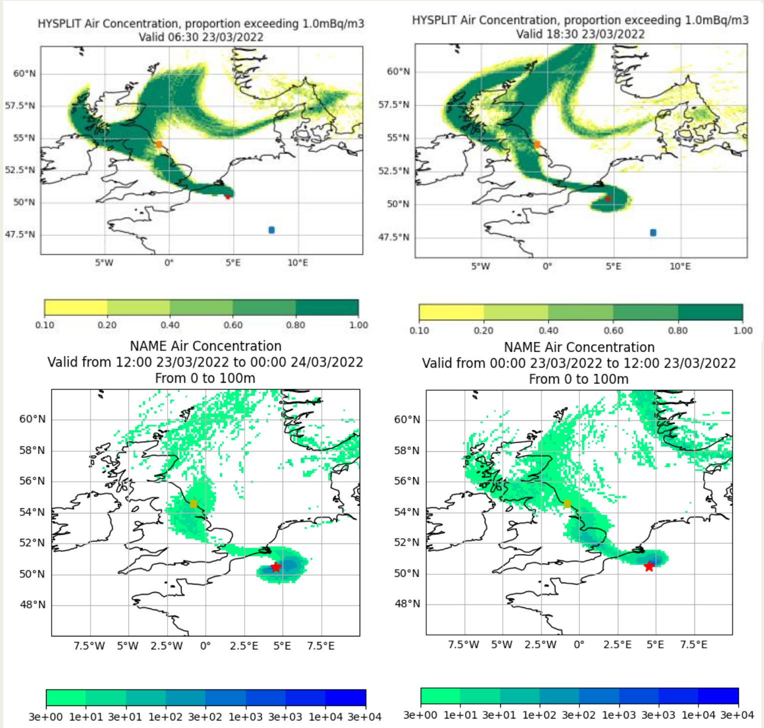

Figure 2: Top: Probability of exceeding 1 mBq/m^3 predicted by HYSPLIT using ensemble meteorology. Bottom: Air activity prediction by NAME (in Bq/m^3).

- The spread in the ensemble is low – most of the area exceeding a probability of 1 mBq/m^3 has a probability greater than 0.8 (Figure 2).

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Different Turbulence Parameterisations

ATDMs use parameterisation to model turbulence, scales of motion smaller than that resolved by the input meteorology. Both NAME and HYSPLIT contain several different options for representing turbulence. The impact of these on the predictions was explored.

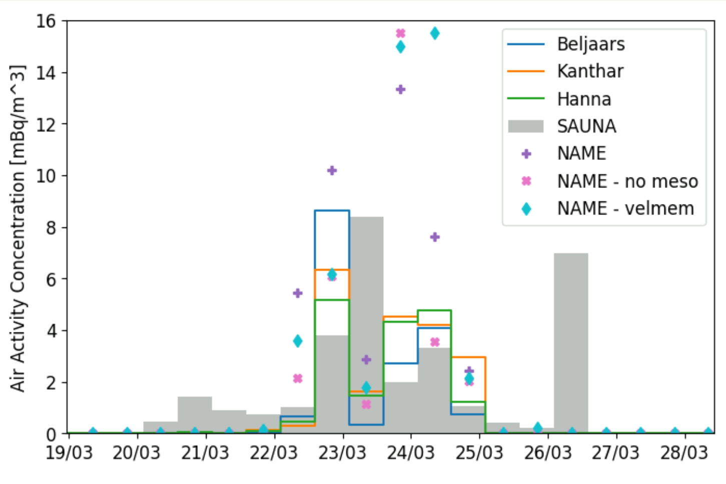

Figure 3: Air activity from the SAUNA Q_B (grey) and NAME (coloured points) and HYSPLIT (coloured lines) with different turbulence parameterisations.

Varying the turbulence results in a similar spread of air activity predictions to the variation produced using different ATDM and ensemble meteorology (Figure 3). NAME still tends to predict higher air activities than HYSPLIT.

Using Uncertainty for Non-Detects

The SAUNA Q_B detected radioxenon on 23 April. This detection was not predicted by either ATDM even when using the ensemble meteorology. This demonstrates how ensembles can be used to rule out known sources.

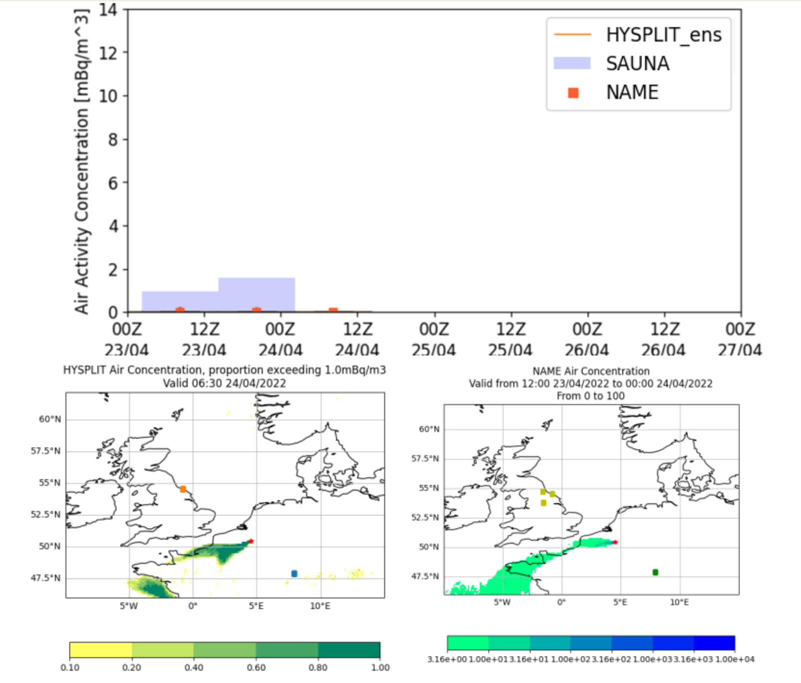

Figure 4: Top: Air activity from the SAUNA Q_B (purple), the HYSPLIT ensemble (boxes) and NAME (orange). Bottom left: Probability of exceeding 1 mBq/m^3 predicted by HYSPLIT with ensemble meteorology. Bottom right: Air activity prediction by NAME.

Conclusions

- Despite using well characterised emissions, uncertainties in transport remain
- ECMWF ensemble has low spread – ensemble is representative of errors in observations
- Spread due to varying turbulence schemes is similar to ensemble spread
- Largest differences in predictions are between the two ATDMs
- Results demonstrate how multiple model setups can add confidence when attributing detections to sources
- Results also demonstrate how combining emission and detectors data can be used to explore aspects of dispersion models

References

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Acronyms

IRE - Institute for RadioElements
SAUNA - Swedish Automatic Unit for Noble gas Acquisition

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