Source reconstruction from dry and wet deposition measurements

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ABSTRACT

Abstract
Measuring airborne radioactivity typically requires large, static installations, limited in number and geographical distribution. By measuring the activity of matter deposited to the ground (by dry settling or wet scavenging), one can complement detections of airborne activity and improve overall data availability.

This presentation compares between atmospheric- and deposition-based detection as practical techniques by treating a series of cases simulating individual 'puff' releases. In every case, we determine how sensitive the existing network of International Monitoring System (IMS) stations would be to the release, and subsequently the surface area which a hypothetical rain collection basin would require at every location to match the sensitivity to the release that is achieved by the IMS stations.

Summary of findings
This initial case study finds that detections by (wet) deposition can be a viable alternative or supplement to atmospheric detections.

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INTRODUCTION

Atmospheric detections
A station pumps ambient air across a filter, on which the particles are captured. The filter is regularly removed and analyzed by gamma spectroscopy. The observed activity on the filter is then converted back into an atmospheric activity concentration for reporting.

*International Monitoring System (IMS) radionuclide stations capture about 20,000 m^3 / day and are analyzed daily for CTBTO-relevant radionuclides. 67 such stations are currently certified and operational, with 13 more in varying stages of completion. When completed, this will leave every station to cover an average area of 6.4 * 10^6 km^2.*

Images courtesy of CTBTO Public Information, https://www.ctbto.org/

Deposition detections
Soil, standing water, plant leaves, or any of a numer of other sources can also be analyzed in order to detect the activity of deposited material. Samples are taken and analyzed by gamma spectroscopy in the same manner as the filter in an atmospheric station,

The goal of this case study is to compare the viability of deposition detections with that of atmospheric stations. To this end, the activity that would (in the case of a hypothetical release) be accumulated by the existing IMS network is compared to what would be gathered in deposition measurements.

The activity found in a deposition measurement will scale linearly with the size of the sample taken. Therefore, what will be reported is actually the *minimum surface area*'s worth of deposition needing to be collected at the activity concentration in a particular location in order to match the activity accumulated by an IMS station.

Below a given concentration, these surface areas will be too large and deposition detection will be unfeasible. What constitutes 'too large', however, will vary from experimenter to experimenter, depending on the results desired, the sampling technique used and the resources available.

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METHODS

The simulation cases

A series of FLEXPART (see appendix) simulations was run to model the dispersion of I-131 aerosols emanating from a hypothetical point release.

The simulations cover five different arbitrary two-week windows in 2017. For each period, two simulations were run:

- Simulation for Northern hemisphere; input data at 1° x 1° and three-hour intervals.
- Simulation for (part of) Europe; input data at 0.1° x 0.1° resolution and one-hour intervals.

From all simulations, values for surface-level atmospheric activity concentration and for deposited activity concentration were output every hour.

The atmospheric activity concentrations were combined with the locations of the radionuclide detection stations of the IMS network (40 certitied and operational in the Northern hemisphere, of which 2 were located within the European simulation domain) to find the degree to which the release would be ‘detected’ by the network.

As a hypothetical release location for the simulations, SCK CEN (in Mol, Belgium) was used, marked on the map below:

(NordNordWest, CC BY-SA 3.0, via Wikimedia Commons)

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METHODS

The analysis

The goal is to directly compare (wet) deposition detection to the existing atmospheric stations. The viability of deposition detection will depend on the surface area required to obtain the same total activity that an atmospheric station would get from the air. This area is calculated as follows:

For every rolling 24-hour period, the accumulated activity *A* of an atmospheric station is:

$$A_{\text{station}}(t') = \int_{t'-24h}^{t'} Q\,\rho(\tau)\,e^{-\lambda(t'-\tau)}\,dt'$$

With *Q* [m^3 s^{-1}] the flow rate of air through the filter, ρ the surface-level atmospheric activity concentration [Bq m^{-3}] in the air and λ [s^{-1}] I-131's decay rate.

The maximum value so 'detected' at any time by any station is taken as the target value for deposition detection to achieve:

$$A_{\max}(t) = \max\left(A_{\text{station}}(t')\,\middle|\,t_0 < t' < t\,,\ \text{stations}\right)$$

This reference activity A_{max} [Bq] is then divided by the deposited activity concentration σ [Bq m^{-2}] at every point on the map to yield the minimum surface area *S* [m^2] required at that location to match the IMS network's performance:

$$S(t) = \frac{A_{\max}(t)}{\sigma(t)}$$

The area maps are shown on the following slides for all five cases.

For the deposited activity concentration, the total (decay-corrected) quantity deposited at the end of the two-week simulation period is used (it is assumed that collection happens over the entire two weeks).

Both *A* and σ are linear in the total released activity, leaving *S* independent. All results are thus applicable regardless of the scale of the release being considered.

Note that in reality a station operates with discrete non-overlapping 24-hour windows, not necessarily 'aligned' with the times at which a plume drifts over for optimal detection. This gives the IMS stations in our calculation a slight edge over their real counterparts.

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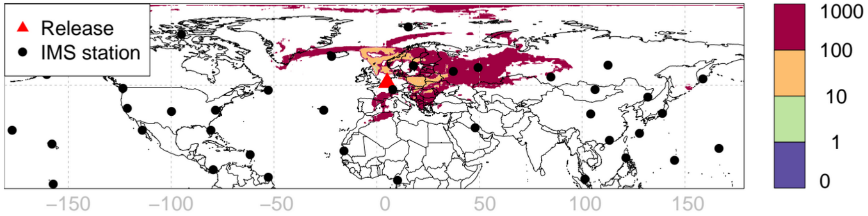
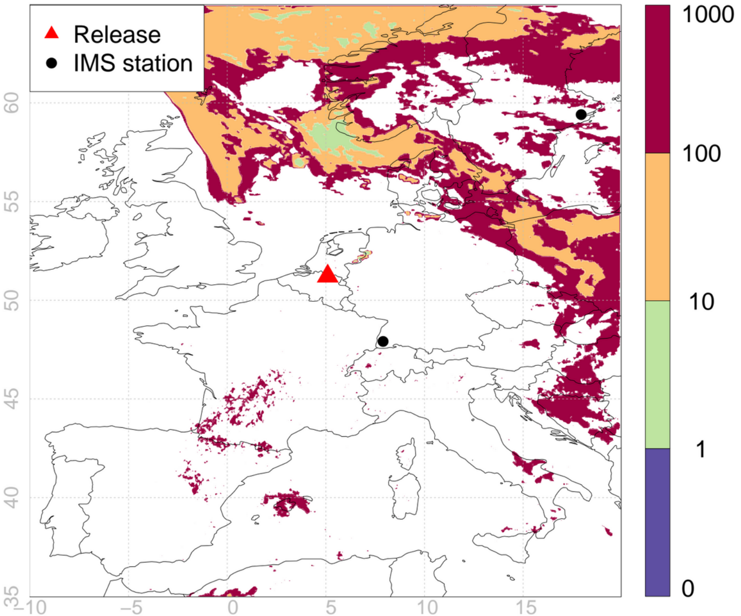
RESULTS

Case #2 (2017/05/21 – 2017/06/04)
A typical case. Matching the IMS detection is possible in a substantial area with collection surfaces < 1000 m^2 (red) or even < 100 m^2 (orange). There are also areas of < 10 m^2 (green), though these happen to be largely over the North Sea.

Required wet collection area (m^2)
Day 14; Case #2



Required wet collection area (m^2)
Day 14; Case #2



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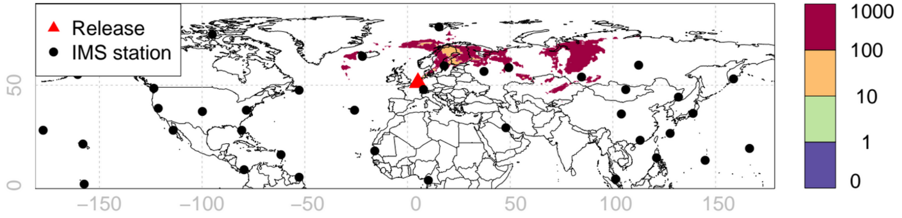
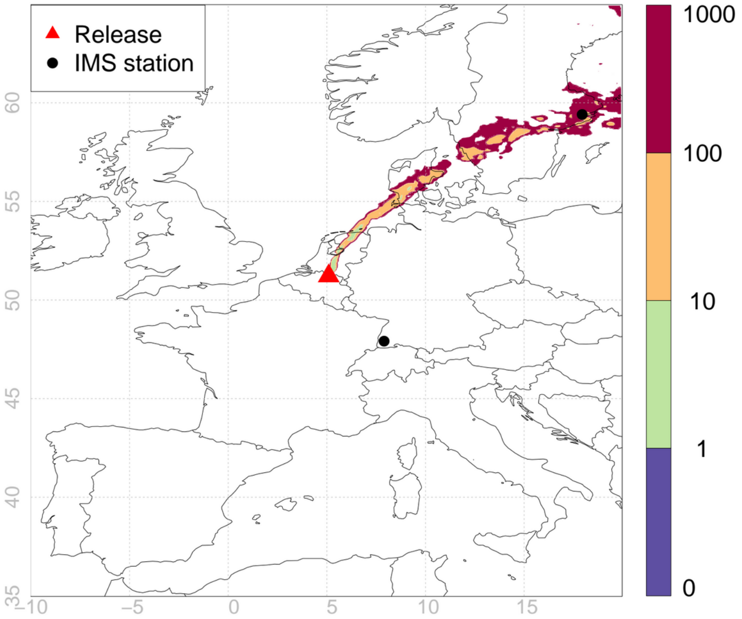
RESULTS

Case #3 (2017/07/30 – 2017/08/13) *(see next slide)*
The plume moves straight over Stockholm: a best-case situation for the IMS stations. Even so, equalling or surpassing the station's high activity with depositon detections remains feasible in certain regions.

Required wet collection area (m^2)
Day 14; Case #3



Required wet collection area (m^2)
Day 14; Case #3



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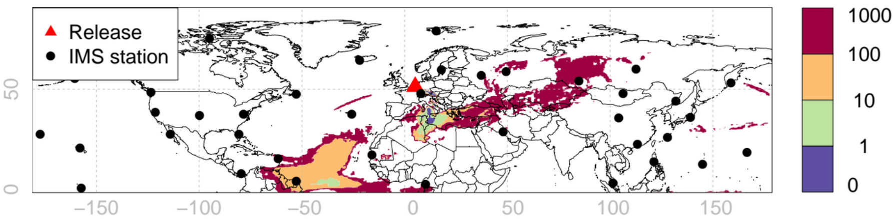
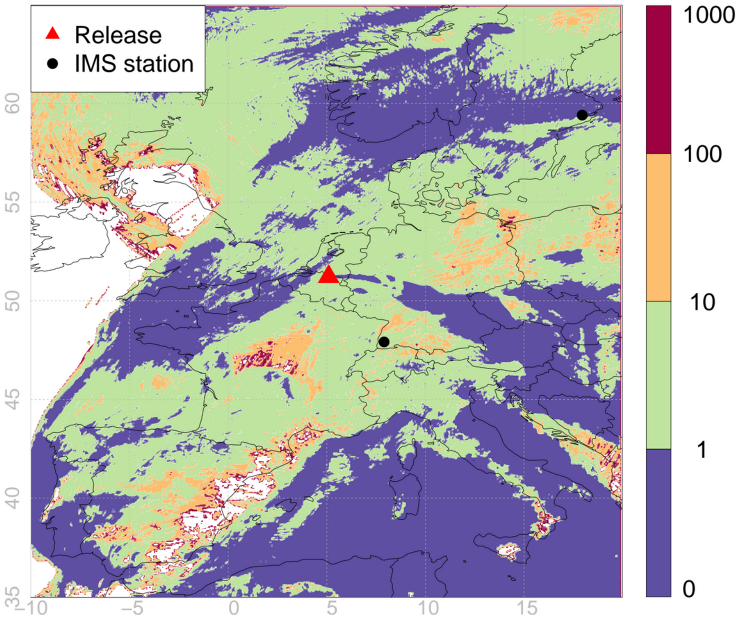
RESULTS

Case #5 (2017/12/17 – 2017/12/31)
In Europe, the plume is only barely detected, as one of the stations catches its periphery. It is very easy for deposition measurements to ‘beat’ the very low activity registered in this way, even with a very small detection area.

The release is registered more clearly outside Europe, making it a more typical case. Detection remains possible in substantial regions.





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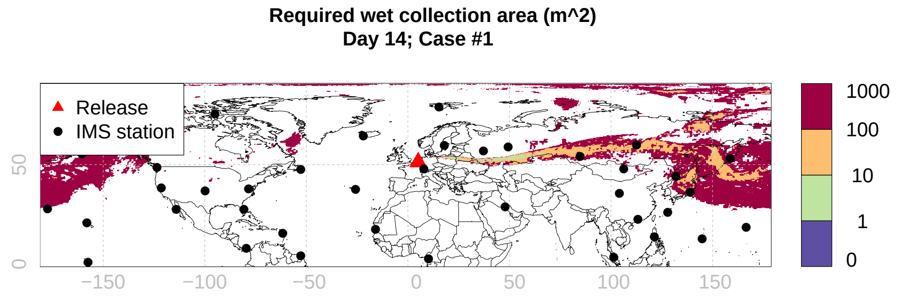
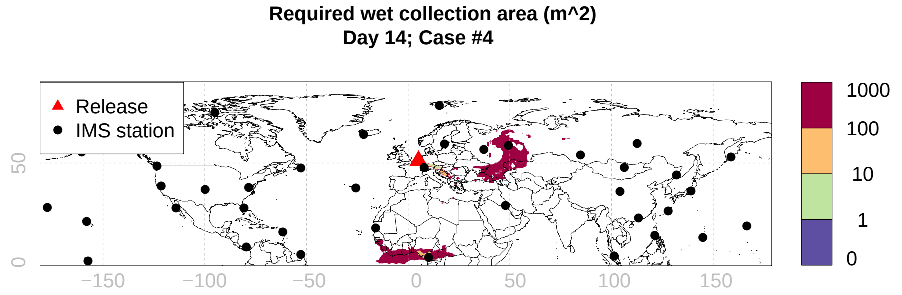
RESULTS

Case #1 (2017/01/01 – 2017/01/14) &
Case #4 (2017/10/08 – 2017/10/22)
In both these cases, the release is not detected by the IMS stations in Europe at all. While detection by deposition measurements is certainly possible, the lack of IMS detections leaves no target value to quantitatively compare them to.

Globally, the releases are detected as normal and a comparison can be made.





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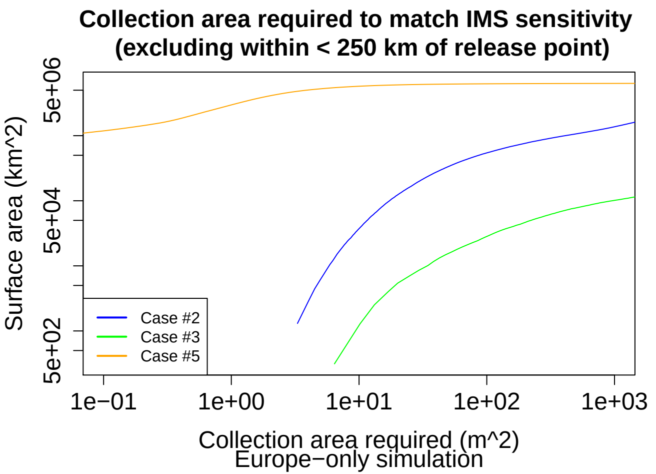
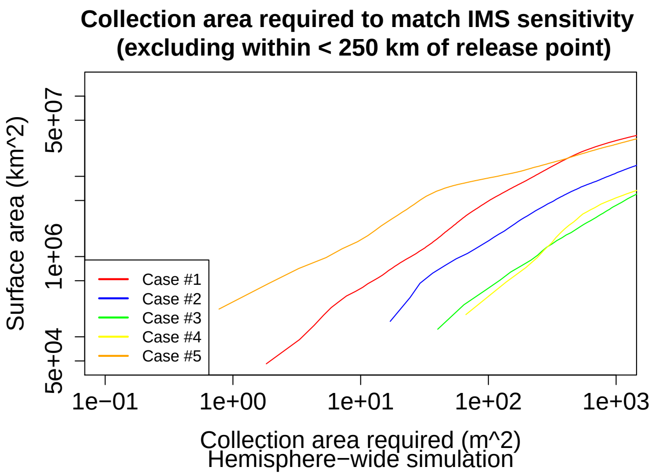
RESULTS

Area of detectability
The plots below quantify the area where deposition detection is viable. By choosing one's maximum acceptable size for a rain collection setup on the x-axis, one obtains on the y-axis the total surface area in which a collection region of the desired size could equal or exceed the IMS network. The larger this surface area is, the more likely a randomly-placed detection is to be within it.

Locations too close to the release point (< 250 km) were excluded because the potential high deposition very near the source is not considered representative.

In the Europe-only simulations *(left)*, Cases #1 and #4 are omitted. Their releases went undetected by the IMS stations, so there was no target value for the deposition activity to be compared to.





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CONCLUSIONS

Conclusion
Deposition detection of aerosol particulates can be a valuable supplement to atmospheric detections. In many regions, deposition detections can achieve equal or greater activity.

Future work
The results described here represent only a limited case study. The next step will be to expand them to a more comprehensive statistical analysis, so that quantitative results may be obtained. This will include a systematic study of the effect of variations in all parameters, especially of varying the release location.

References on FLEXPART and deposition parameterization

A. Stohl, C. Forster, A. Frank, P. Seibert, and G. Wotawa. “The Lagrangian particle dispersion model FLEXPART version 6.2.” *Atmospheric Chemistry and Physics* 5, no. 9 (2005): 2461-2474.

I. Pisso, et. al. “The Lagrangian particle dispersion model FLEXPART version 10.3.” *Geoscientific Model Development*, manuscript under review (2019)

H. Grythe, et al. "A new aerosol wet removal scheme for the Lagrangian particle model FLEXPART v10." *Geoscientific Model Development* 10.4 (2017): 1447-1466.

L. Laakso, Lauri, et al. "Ultrafine particle scavenging coefficients calculated from 6 years field measurements." *Atmospheric Environment* 37.25 (2003): 3605-3613.

E.-M. Kyrö, et al. "Snow scavenging of ultrafine particles: field measurements and parameterization." *Boreal Environment Research* 14: (2009): 527–538.

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APPENDIX

FLEXPART

FLEXPART is a Lagrangian atmospheric transport and dispersion model, used to simulate particle transport through, and removal from, the atmosphere. Technical details of FLEXPART can be found in Stohl, 2005 and Pisso, 2019.

In our case, FLEXPART is used to simulate the dispersion of a plume of particles released from a source, forward in time. The software can also be used in numerous other configurations.

Wet deposition in FLEXPART

Wet scavenging (capture of nuclides by precipitation) reduces the simulation particles' mass as follows:

$$m(t+\Delta t) = m(t)\, e^{-\Lambda \Delta t}$$

Λ is the *scavenging coefficient* or deposition rate, parameterized differently depending on the specific case. Wet scavenging is only triggered when precipitation actually occurs and the particle is not above the upper edge of the cloud.

FLEXPART distinguishes between *in-cloud scavenging* (particles inside clouds are caught up in the formation of precipitation) and *below-cloud scavenging* (particles in the air beneath clouds are hit by precipitation and carried down). The parameterizations used in FLEXPART v10.4 for aerosols are briefly sketched in the text box.

In-cloud aerosol scavenging

$$\log_{10}\left(\frac{\Lambda}{\Lambda_0}\right) = C_* \left[\Sigma_{i=0}^{4}\left(a_i D_p^{-i}\right) + f\sqrt{\frac{I_s}{I_0}}\right]$$

$$\Lambda_0 = s^{-1}$$

$$D_p = \log_{10}\left(\frac{d_p}{d_0}\right)$$

$$d_0 = 1\, m$$

$$I_0 = 1\, \frac{mm}{h}$$

with d_p the dry aerosol diameter (mm) and I_s the precipitation rate (mm h^{-1}). The other coefficients are empirically tuned constants for scavenging by rain (Laakso et al., 2003) or snow (Kyrö et al., 2009).

Below-cloud aerosol scavenging

$$\Lambda = 6.2\, \frac{F_{\mathrm{nuc}}}{cl}\, I_s$$

with *cl* the column water content (kg m^{-2}), I_s the precipitation rate (mm h^{-1}) and F_{nuc} a nucleation efficiency dependent upon both particle species and temperature (Grythe et al., 2017).