Forest fires in the surroundings of Chernobyl: follow-up of potential radiological aspects

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Summary:

Forest fires have been reported, since April 3, in the restricted and contaminated zone around Chernobyl. Between April 9 and April 14, parts of the "red forest", one of the most contaminated areas nearby the damaged nuclear reactor, were on fire. Afterwards fires were present in the exclusion zone but at larger distances. Since April 24 no fires are visible on satellite imagery in the exclusion zone.

Locally, increased dose rate levels have been measured, indicating that radioactive material, especially Cs-137, has been re-suspended by the forest fires. This radioactive material can be transported with the smoke plume over long distances. Atmospheric transport simulations have been executed to track the plume and calculate activity concentrations at ground level for large parts of the Northern hemisphere. The particulate stations of the International Monitoring System (IMS) running in the context of the verification of the CTBT are followed-up to investigate potential detections and learn more about the released quantities of Cs-137 during the forest fires. Since the forest fires started, a few Cs-137 detections, representing low amounts of radioactivity, were observed in the IMS and can potentially be linked with the fires. In addition, low-level measurements of Cs-137 in Ukraine have been reported through the "Ring of Five" network (an informal network of institutes in Europe performing measurements of ultra-low levels of radioactivity in the environment).

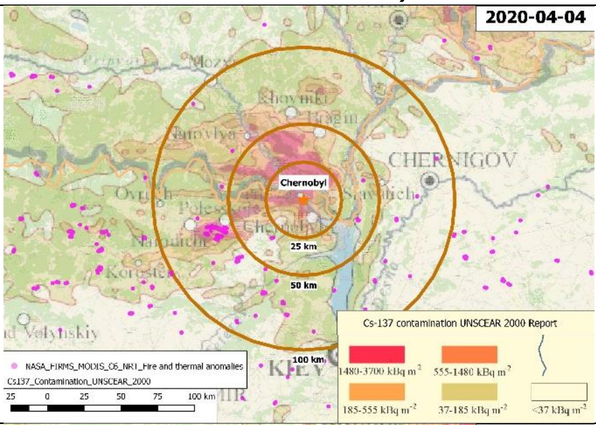
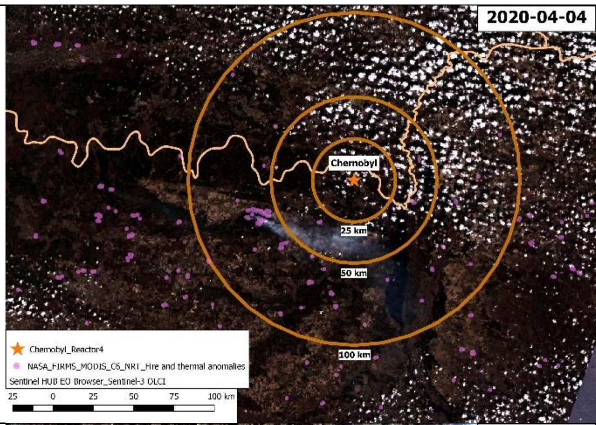
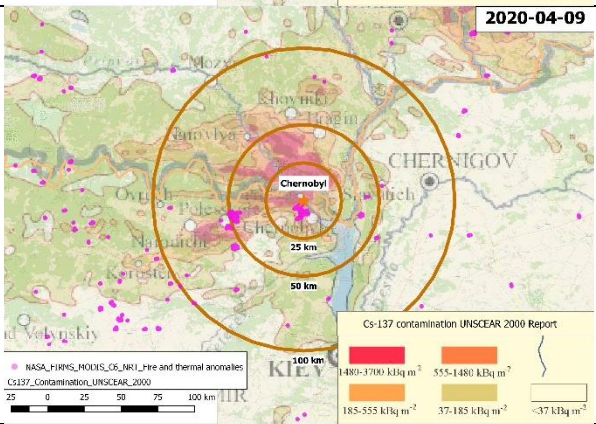
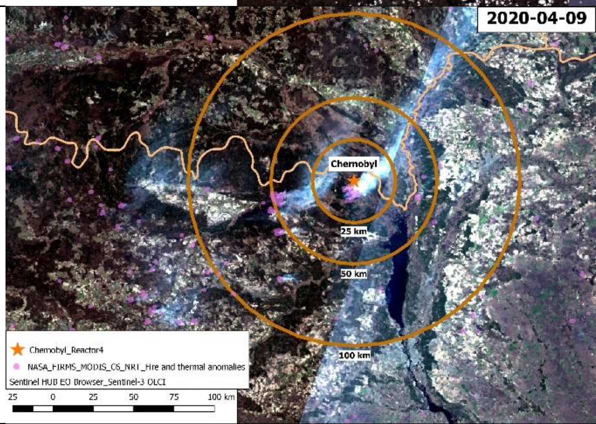
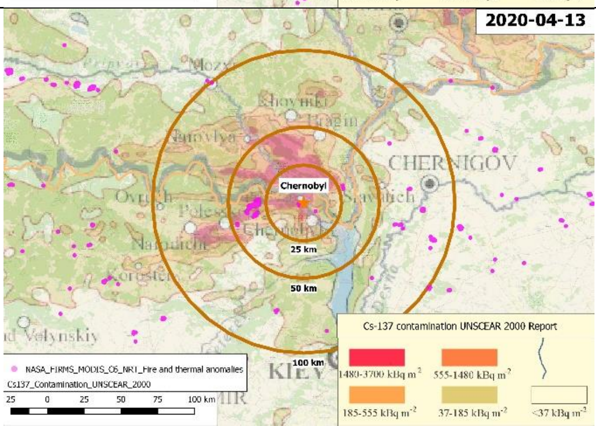
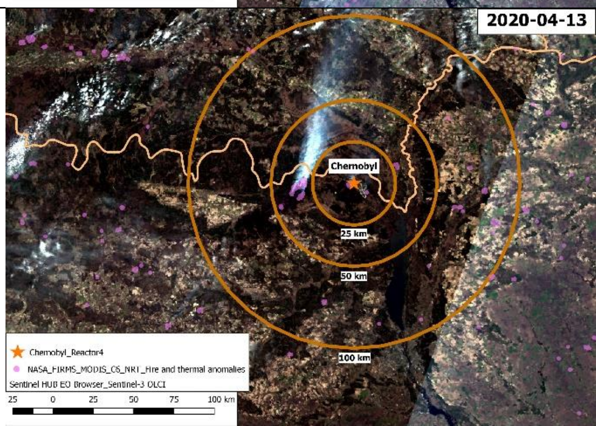
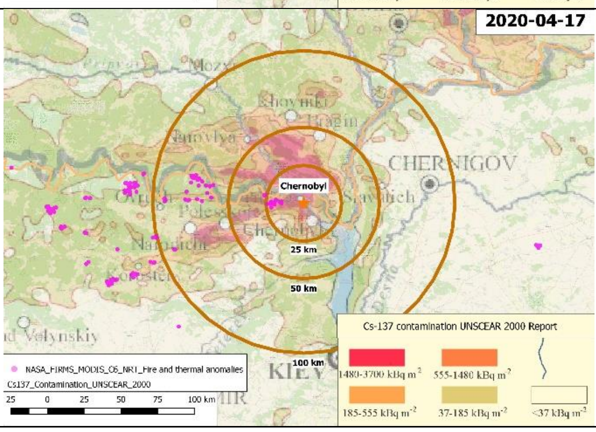
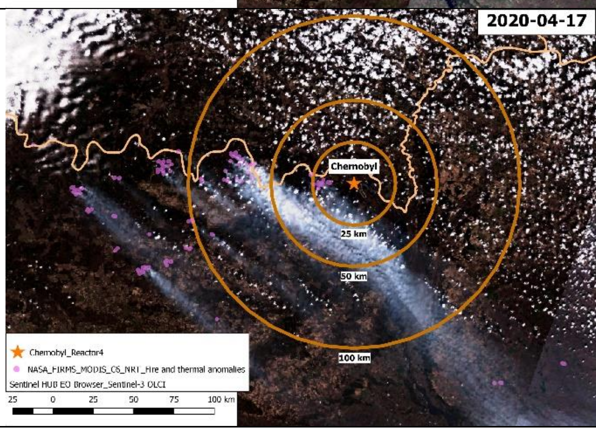
Based on experience from historic fires in this area and experiments, the amount re-suspended during these forest fires can be locally a radiation protection issue and it is also possible that traces can be measured at larger distances by ultra-low detection techniques like in the IMS. However, these traces do not pose any health risk in Western Europe due to the very high dilution of the re-suspended matter resulting in very low radioactivity levels at such distances. No abnormal radioactivity levels have been observed in Belgium by the measuring stations of the online surveillance network TELERAD operated by FANC. Trace levels of Cs-137 were detected at SCK CEN and are believed to be from local re-suspension of Cs-137 and not originating from the Chernobyl fires. These results were obtained by sampling with the large volume air sampler, called Snow White, and are discussed in a dedicated subsection of this report.

The Forest Fires

Forest fires have been reported, since April 3, in the restricted zone around Chernobyl. Such forest fires in the contaminated areas could bring radioactivity, especially Cs-137, back in the atmosphere. Increased dose rate levels have been reported close to the forest fires. Dose rate levels, in the region around Chernobyl and other parts of Europe, have not increased as can be learned from the EURDEP website. Dose rate results for Europe can be consulted via https://remap.jrc.ec.europa.eu/. However, Cs-137 detections in aerosol samples were reported in Ukraine at different locations ("Ring of Five" information). These detections are discussed further in the following sections.

The forest fires in the exclusion zone around Chernobyl are clearly visible on satellite imagery (from Sentinel Hub EO[1] with the Sentinel-3 OLCI data and from LANCE FIRMS[2] with the MODIS Collection 6 NRT data) as shown in Figure 1. As can be seen in the figure on April 4, the first forest fire was located at about 50 km from the reactor. However, on April 9 a forest fire broke out in the "red forest" and is clearly visible on the satellite imagery of April 9 and 13. The Ukrainian authorities reported that the fire in the "red forest" was under control on April 14 as rain had helped to extinguish part of the forest fires. The region was covered by clouds on April 14, 15 and 16, which did not allow to visualize the presence of forest fires in the exclusion zone during that period of time. On April 16, the forest fire in the red forest was indeed not visible anymore. However, other forest fires were still active in the exclusion zone as shown with the snapshot on April 17. On April 23, smaller forest fires were still visible in the exclusion zone at a distance of 15 to 30 km from the reactor. Since April 24, no fires and thermal anomalies were detected in the exclusion zone around Chernobyl.

In the figure, the historical Cs-137 contamination reported in (UNSCEAR, 2000) is also shown and the corresponding legend is given in the figure. The purple dots are the fire and thermal anomalies reported by LANCE FIRMS through the MODIS Collection 6 NRT data on the relevant date.

Cs-137 Contamination map UNSCEAR 2000 Report and fires and thermal anomalies (MODIS Collection 6 NRT)	Satellite image showing the smoke plume(s) (Sentinel Hub EO / Sentinel-3 OLCI)
	
	
	
	

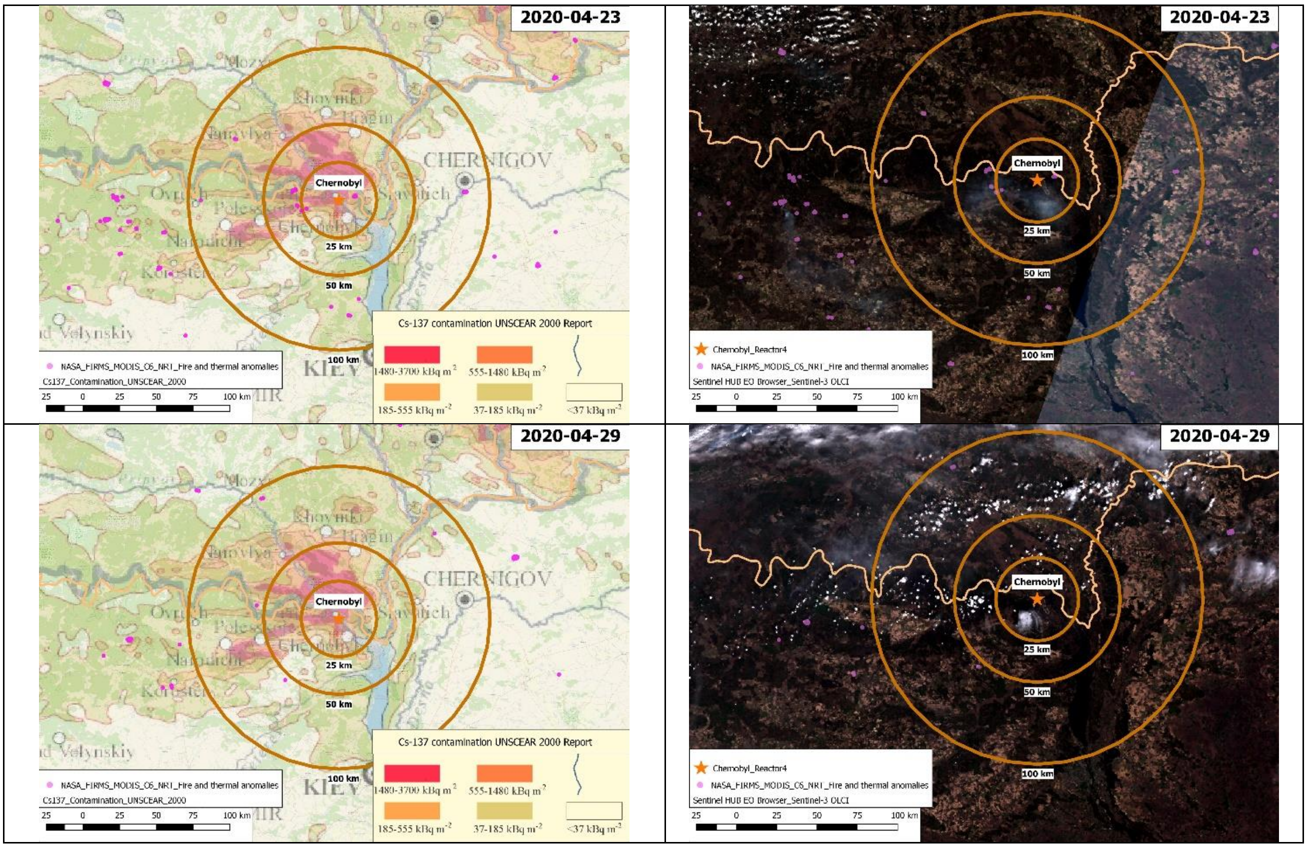


Figure 1 - Snapshots of the detected fire and thermal anomalies (LANCE FIRMS / MODIS Collection 6 NRT) and the Cs-137 contamination reported in UNSCEAR Report 2000 [Left] and the satellite imagery (Sentinel Hub EO / Sentinel-3) together with the observed fires and thermal anomalies [Right]. The snapshots were made for 04/04, 09/04, 13/04, 17/04, 23/04 and 29/04.

The forest fire in the “red forest” was observed with high-resolution satellite imagery (Sentinel Hub EO / Sentinel-2) on April 12. This satellite imagery is shown in Figure 2.

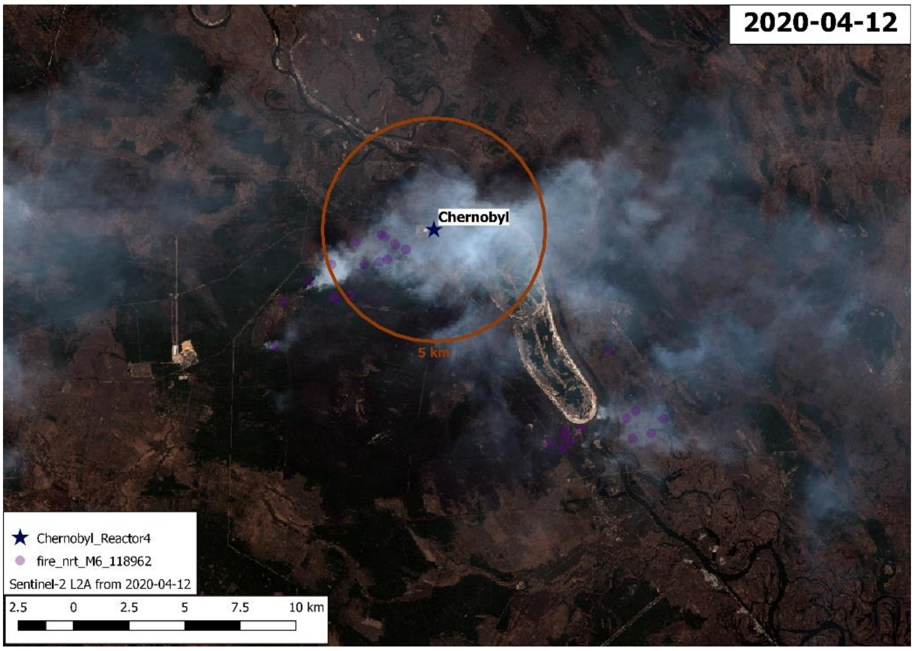


Figure 2 – Satellite imagery (Sentinel Hub EO / Sentinel-2) of the forest fire in the “red forest” on April 12 together with the fires and thermal anomalies (LANCE FIRMS / MODIS Collection 6 NRT) detected on the same day.

Atmospheric Transport Modelling and potential impact on Belgium

In order to verify the trajectory of potential releases of the historical Cs-137 contamination in these forests due to the fire, the trajectory has been followed-up through Atmospheric Transport Modelling.

The spread of radionuclides through the atmosphere can be predicted using atmospheric transport and dispersion models. These models make use of numerical weather data (such as wind speed and wind direction) and release information to calculate radionuclide concentrations at any location and time. The release information, more specifically the location and time of the release, the amount of mass released and feedback on the height of the plume were taken from the Global Fire Assimilation System (CAMS – GFAS[3,4]). GFAS combines fire radiative power observations from satellite-based sensors, fire observations and meteorological information from the ECMWF to produce daily estimates of biomass burning emissions as well as information on the plume. Numerical weather prediction data was taken from the European Center for Medium-Range Weather Forecasts (ECMWF). The resulting atmospheric transport and dispersion calculations provide insight in how the plume containing Cs-137 moves through the atmosphere, as shown in Figure 3. The levels of Cs-137 released to the atmosphere are difficult to assess. For this reason the calculation is done for a unit release of 1 TBq Cs-137. The results thus need to be scaled by the estimated release of Cs-137. Such a release estimate is made further in the report, based on observations exchanged via the Ring of Five.

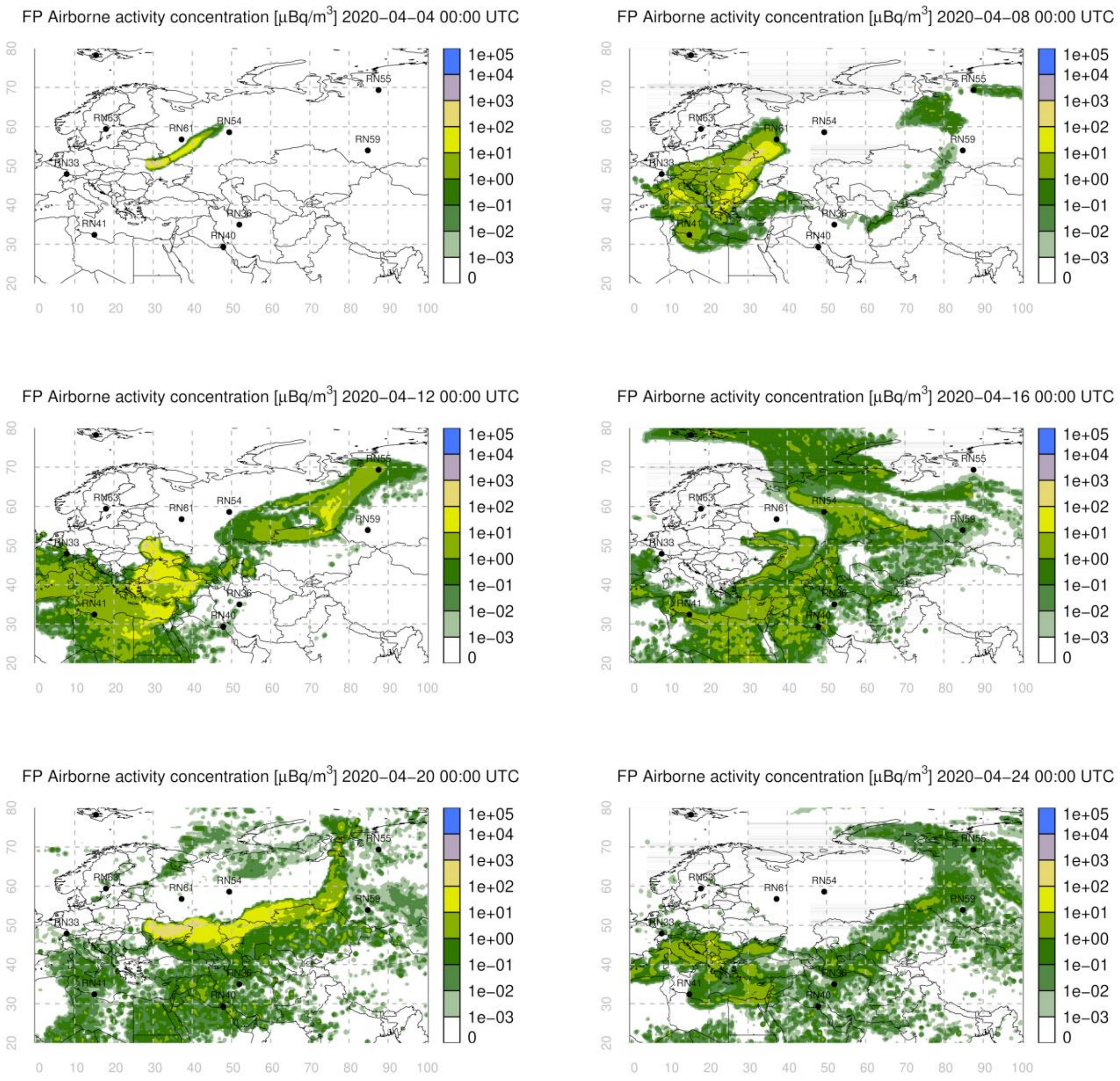


Figure 3 - The plume of radionuclides at different times as simulated by the atmospheric transport and dispersion model. The calculation is done for a unit release of 1 TBq Cs-137.

The atmospheric transport simulations allow to construct simulated activity concentrations at any location. This helps to select which stations are most likely to detect radionuclides in the coming days. In Figure 4, an example is shown for IMS stations potentially affected by radionuclides released from the forest fires. Figure 4 shows also the expected activity concentration at SCK CEN. If detections are reported, the simulations can be rescaled to match the detections. That way, the source term is rescaled and the simulations refined. If no detections are made, the station detection threshold can still help to define an upper bound of the release.

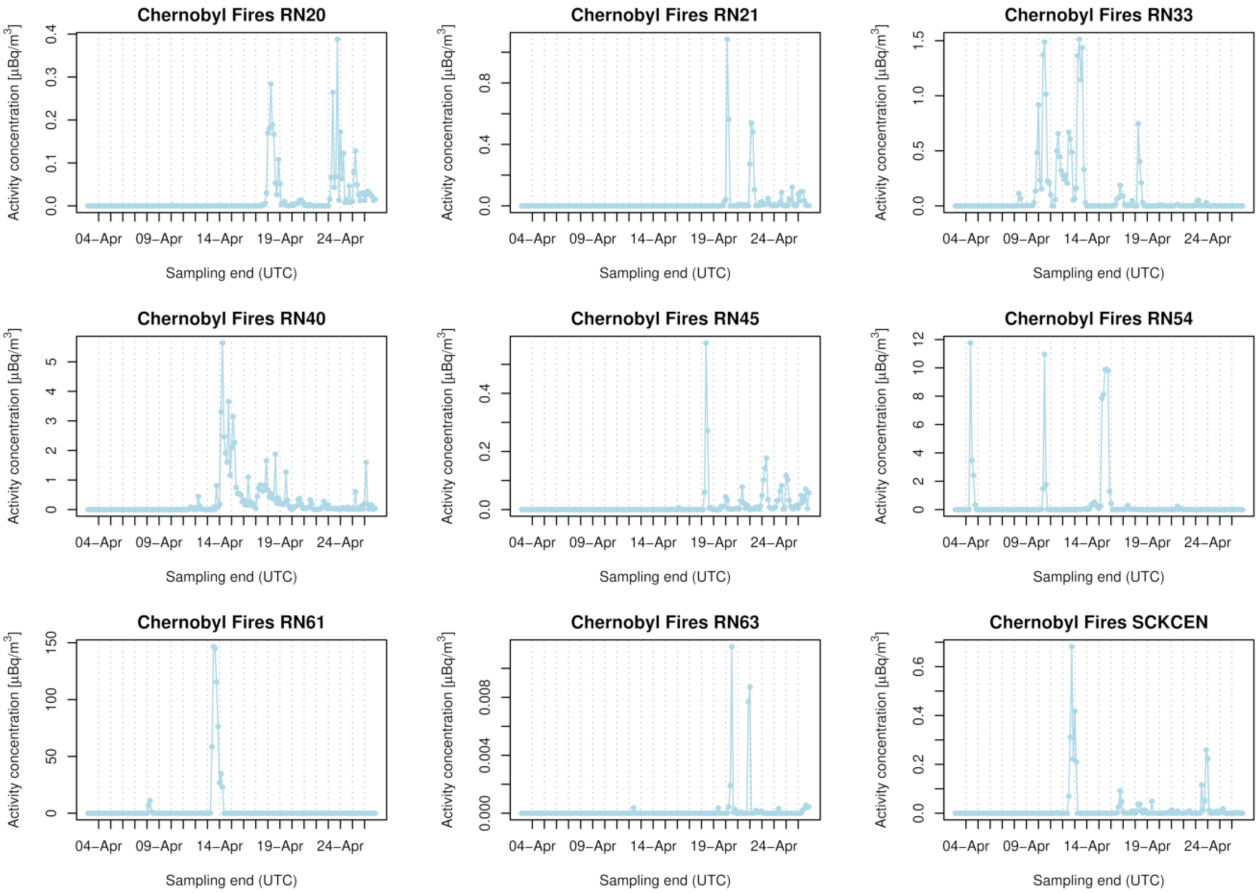


Figure 4 – Atmospheric transport modelling of the Cs-137 activity concentration at relevant IMS stations and at the Snow White system at SCK CEN.

Did we detect anything in Belgium?

The SCK CEN operates a Snow White air sampler since August 2019. This large volume air sampler is set up for the detection of ultra-low levels of radioactivity in the air. In routine operation, the system is sampling air for a week and trapping the sampled aerosols on a filter. After dismounting the filter, a waiting period of a few days is used to allow decay to decrease the contribution of the natural radioactivity in the sample, which allows to enhance the detection capability for artificial radionuclides. Finally, the filter is folded and transferred to one of the calibrated geometries for the gamma-ray spectrometer. The sample is measured for at least one day but this period can also be extended depending on the detection level to be reached. This means that there is a delay between the end of the sampling and the results of the measurement. The results of the sampling show low levels of Cs-137, just above the detection limit, and are given in Table 1.

Table 1. Results Snow White

Sampling period	**Cs-137 activity**	**Detection limit (Cs-137)**	**K-40 activity**
6-14 April 2020	0.45 ± 0.22 $\mu Bq/m^3$	0.4 $\mu Bq/m^3$	17.4 ± 3.9 $\mu Bq/m^3$
14-20 April 2020	1.35 ± 0.34 $\mu Bq/m^3$	0.6 $\mu Bq/m^3$	21 ± 5 $\mu Bq/m^3$

The average concentration expected from our atmospheric transport calculations is however even lower, i.e. of the order of 0.01 µBq/m^3 and well below the detection limit. Because trace levels of Cs-137 detections have been detected earlier with the Snow White air sampler (since August 2019, two times), we believe that the current detection, as the previous ones, are from local re-suspension of Cs-137 and not from the forest fires in the exclusion zone around Chernobyl. Cs-137 has been deposited as fall-out in large parts of the world (including Belgium) during atmospheric nuclear bomb testing (1950-60) and in Europe also from the Chernobyl accident (1986). The fact that also potassium-40 (K-40) is measured in the sample, which behaves, from a chemical point of view, in a similar manner as Cs-137 and is present as natural radioactivity in the soil, provides further evidence for the local origin of Cs-137. Re-suspension is apart from fires also more probably during dry windy periods, which was the meteorological situation for Belgium in April.

Potential Radioactivity Detections outside Belgium (IMS, Ro5)

The radionuclide monitoring stations of the International Monitoring System (IMS) for the verification of the Comprehensive nuclear-Test-Ban Treaty (CTBT) have been closely followed-up for potential Cs-137 detections. The stations have a very low detection limit and collect samples of air over 24 hours. 4 IMS stations are relatively close to Chernobyl: RUP61 (Dubna, Russia), RUP54 (Kirov, Russia), DEP33 (Freiburg, Germany) and SEP63 (Stockholm, Sweden). The location of these stations are shown in Figure 5. In addition, at larger distances the following stations were also closely followed-up: KWP40 (Kuwait City, Kuwait), RUP59 (Zalesovo, Russia), RUP56 (Peleduy, Russia) and MNP45 (Ulaanbaatar, Mongolia).

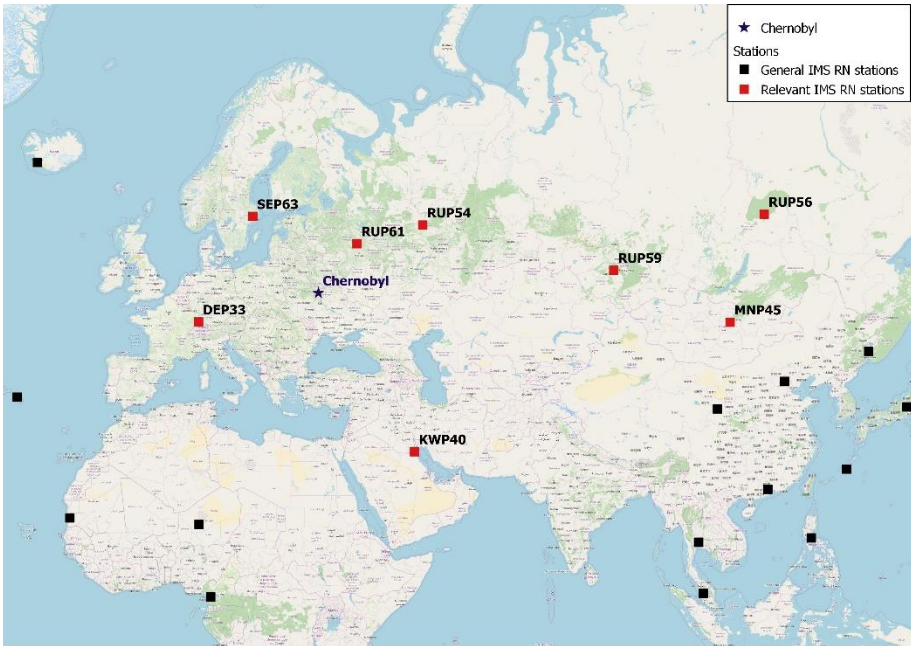


Figure 5 - Location of the IMS radionuclide stations (squares) in the surroundings of Chernobyl. The IMS RN stations that are currently followed-up are indicated by the red squares.

The spectra of the samples from April 3 to 27 (last samples available) at DEP33, KWP40, RUP54, RUP59, RUP61, RUP56, MNP45 and SEP63 were reviewed. As the forest fires were lasting for more than two weeks and that the released Cs-137 could have been transported over long distances, the follow-up stations were extended to all IMS radionuclide stations in the northern hemisphere.

A series of relevant Cs-137 detections were observed in this time period as shown in Table 2. The Cs-137 detections were considered as relevant when the Source-Receptor Sensitivity (SRS) field, provided by the CTBTO, of the detection indicated that Chernobyl could be a possible source for the corresponding detection. The SRS fields are the results of the backward modelling of the atmospheric transport, *i.e.* starting from the detection at an IMS station and tracking back in time the atmospheric transport, and provides what can be seen as a dilution factor between the location of the detection and each grid cell of the calculation domain. In addition, only detections that were above the Minimum Detectable Concentration (MDC) were considered. The detections that are lower than the Minimum Detectable Concentration have a higher probability of being false positives.

Cs-137 detections in the IMS are not uncommon and are regularly observed as part of the normal radiation background at IMS stations. This background can come from civilian nuclear applications or by resuspension of past contaminations (atmospheric nuclear weapon testing, the Chernobyl accident and the Fukushima accident) in the surrounding of the IMS system.

Table 2 - Relevant Cs-137 detections in the region during the period from April 3 to 27.

Station	Collection stop	Cs-137 [µBq/m^3]	Unc. [%]	MDC [µBq/m^3]	Chernobyl possible source (based on SRS fields – CTBTO)
RUP54	05-04-2020	3.89E+00	8.64	1.27E+00	Yes
CNP21	11-04-2020	4.54E+00	16.55	3.60E+00	Yes
MNP45	13-04-2020	1.91E+01	6.29	4.53E+00	Yes
CNP21	14-04-2020	4.93E+00	19.89	4.84E+00	Yes
RUP61	14-04-2020	8.98E+01	2.88	2.44E+00	Yes
RUP54	15-04-2020	1.29E+00	20.94	1.25E+00	Yes
CNP21	16-04-2020	4.00E+00	20.2	3.94E+00	Yes
RUP54	16-04-2020	7.67E+00	6.14	1.54E+00	Yes
CNP20	16-04-2020	4.14E+00	16.71	3.92E+00	Yes
MNP45	18-04-2020	6.82E+00	15.75	5.17E+00	Yes
NEP48	19-04-2020	4.13E+00	18.2	3.70E+00	Yes
CNP21	20-04-2020	5.28E+00	14.18	3.53E+00	Yes
CNP21	21-04-2020	3.56E+00	18.9	3.26E+00	Yes
KWP40	21-04-2020	6.15E+00	16.37	4.77E+00	Yes
RUP56	22-04-2020	3.62E+00	8.57	1.18E+00	Yes
CNP21	23-04-2020	4.36E+00	17.93	3.82E+00	Yes
CNP20	23-04-2020	3.67E+00	18.23	3.25E+00	Yes
CNP21	24-04-2020	5.24E+00	15.99	4.05E+00	Yes
RUP56	24-04-2020	1.73E+00	15.49	1.21E+00	Yes
CNP20	24-04-2020	4.37E+00	14.38	2.94E+00	Yes
CNP21	25-04-2020	4.69E+00	16.87	3.83E+00	Yes
CNP20	25-04-2020	6.71E+00	10.62	3.26E+00	Yes
RUP56	25-04-2020	1.51E+00	18.68	1.32E+00	Yes
KWP40	26-04-2020	7.15E+00	15.51	5.27E+00	Yes
CNP20	26-04-2020	5.35E+00	13.39	3.39E+00	Yes

In order to compare these detections to the historical Cs-137 background detections at each relevant IMS station, the Cs-137 detection rate was looked at for the period from 2013 to 2019. The Cs-137 detection rate at each relevant IMS station is shown in Table 3. From this table, the regular Cs-137 detections at some of the stations is clearly highlighted. The NEP48 station is not shown in the table as this station is in operation only since the end of August 2019.

The yearly detection rate is the amount of samples where the CTBTO flagged the presence of Cs-137 on the amount of samples taken by the station over the corresponding year. These regular Cs-137 detections are part of the radiation background at the station. One should remember here that these monitoring systems are ultra-sensitive and can detect very small amounts of radioactivity in the air.

Table 3 - Detection rate of Cs-137 at RUP54, RUP61, MNP45, CNP20, CNP21, KWP40 and RUP56 since 2013. The detection rate is based on the number of flagged detections by the CTBTO during each time period.

	Detection Rate Cs-137 [%]						
Year	**RUP54**	**RUP61**	**MNP45**	**CNP20**	**CNP21**	**KWP40**	**RUP56**
2013	5.0%	17.7%	0.0%	-	-	36.6%	-
2014	5.8%	14.5%	0.3%	-	-	13.4%	-
2015	6.6%	13.3%	1.4%	-	-	26.0%	-
2016	3.8%	6.9%	0.6%	-	0.0%	15.2%	-
2017	7.8%	6.5%	3.0%	12.5%	2.1%	12.8%	-
2018	10.7%	13.5%	10.0%	7.1%	-	32.6%	1.3%
2019	8.9%	22.8%	9.7%	4.5%	0.0%	13.9%	2.8%

In addition to the detection rate, the distribution in Cs-137 activity concentration since 2013 was investigated at each station where the history of the station contained at least 20 Cs-137 detections over the past 7 years to be compared with. Only 10, 6 and 10 Cs-137 detections were observed over the past years at CNP20, CNP21 and RUP56 respectively. For the remaining stations (*i.e.* RUP54, RUP61, MNP45 and KWP40), the distribution plot is shown in Figure 6, where the specific Cs-137 detections observed at each station in the period from 03 to 27/04 are also shown.

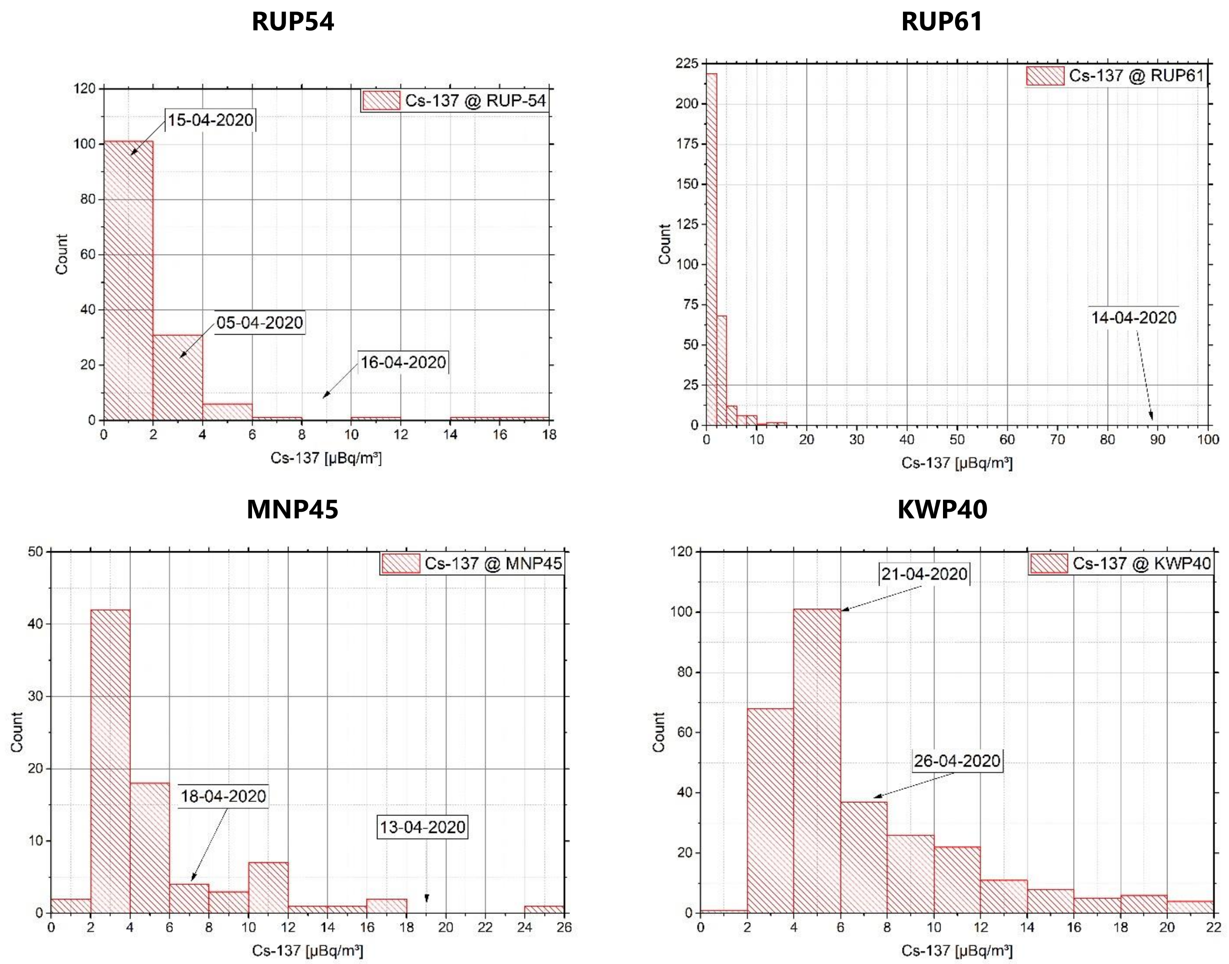


Figure 6 – Distribution of the Cs-137 activity concentration at RUP54 [top left], RUP61 [top right], MNP45 [bottom left] and KWP40 [bottom right] since 2013. The relevant Cs-137 detections in the period from April 3 to 27 are highlighted in the distribution plot.

The detection on 14-04-2020 at RUP61 is well above the normal background observed at this station. This suggests that this detection is not originating from sources that in the past resulted in low Cs-137 detections and is likely to be from the forest fires in the exclusion zone around Chernobyl. The detections on 16-04-2020 at RUP54 and 13-04-2020 at MNP45 are in the higher part of the normal background observations and could potentially also come from the forest fires. All other detections are within the normal background at the relevant station and could potentially not be related to the forest fires around Chernobyl. The atmospheric transport modelling is in agreement with the detection at RUP61 on 14-04-2020 and at RUP54 on 16-04-2020.

The highest Cs-137 activity concentration detected in the IMS period in the region from April 3 to 27 was about 90 µBq/m^3. Even though this is a relatively high detection for such ultra-sensitive systems, such a value remains very low and represents only trace levels of Cs-137.

Via the "Ring of Five", we were informed about Cs-137 air-concentration measurements in Ukraine. Measurement results are reported at 5 locations. These locations are shown in Figure 7. The highest values were measured in Kiev on 10 and 11/04/2020 and reached a maximum of 567 µBq/m^3 (corrected value, the first report indicated 700 µBq/m^3). If we assume that this maximum value of 700 µBq/m^3 will stay in Kiev for 7 days (1 week), people will have inhaled (considering an inhalation rate of 1 m^3/h) around 0.12 Bq. This has to be compared with 8000 Bq of natural radioactivity present in the body at any moment.

Several Western and Central European countries have reported trace levels of Cs-137. Some of them can be attributed with high certainty to the forest fires in the exclusion zone, others are inside the normal variations over the years, or sometimes somewhat at the higher end. IRSN (France) published on Friday 24 April results on evidence on arrival of trace levels of Cs-137 in France, see:

https://www.irsn.fr/EN/newsroom/News/Pages/20200424_Fires-in-Ukraine-in-the-Exclusion-Zone-around-chernobyl-cesium-137-results-in-france.aspx.

Our atmospheric transport calculations show also clearly that some detections in France, Poland and Norway can be attributed to the fires (see web animation at https://www.sckcen.be/sites/default/files/images/2020-04/FP_conc_animation.mp4). It has to be stressed that these detections are corresponding to ultra-low activity concentrations, which pose no health effects to the population or environment.

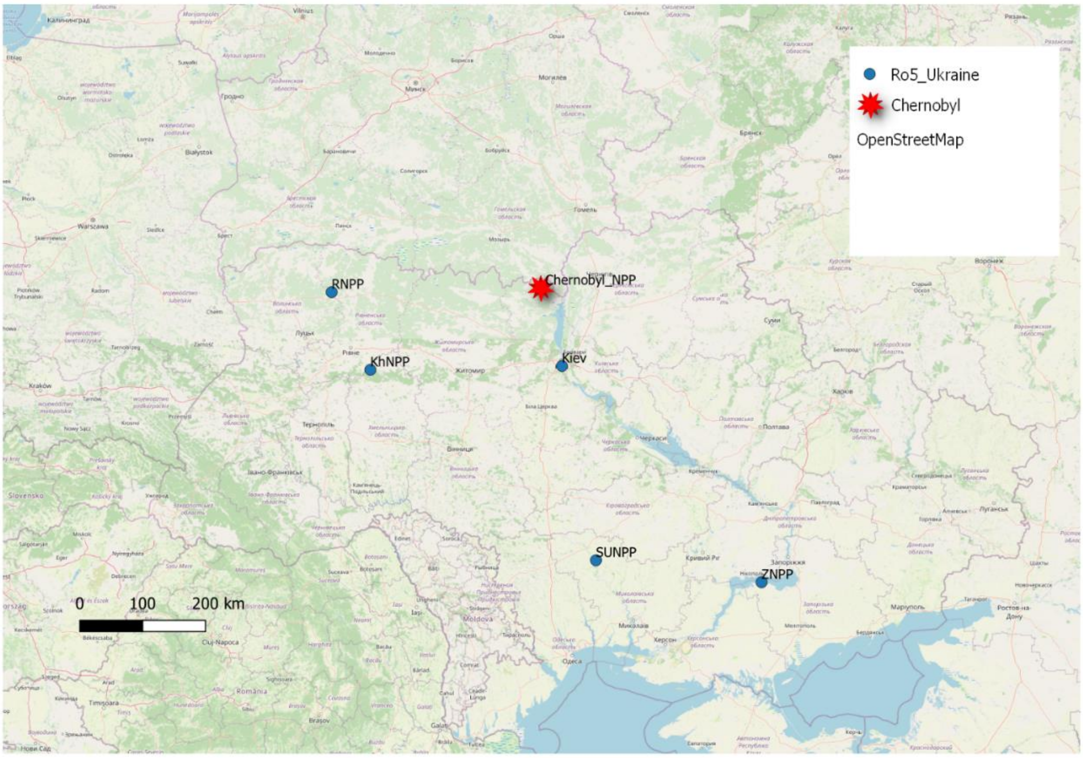


Figure 7 – Location of the measurements of radioactivity in the air in Ukraine as reported through the "Ring of Five".

Estimation of the released Cs-137 quantity

Inverse atmospheric transport modelling was used to estimate the released quantity of Cs-137 during the forest fires. The method involves fitting a Cs-137 source term until a good match is found between the observed and simulated activity concentrations. Atmospheric transport modelling is used to convert any source term into activity concentrations at the location of the stations, which can then be compared with the observations. In this approach, all source locations are aggregated into one source location, which is a necessary step to limit the number of possible solutions. Although the locations of the fires are known, for the matter of testing, also the source location is determined. The result is shown in Figure 8 and is in good agreement with the location of the forest fires. The estimated Cs-137 release is shown in Figure 9. The estimated Cs-137 release is between 0.01 and 0.1 TBq during 3 and 7 April. Between 7 and 19 April, the release is a bit higher, with releases around 0.1 TBq. There is one spike between 15 and 17 April with releases higher than 1 TBq, but this spike was attributed to a single observation and is hence associated with more uncertainty. The results show that an accumulated release of 1 TBq remains a good estimate. The corresponding agreement between the simulated and observed activity concentrations is shown in Figure 10. It shows that a very good agreement is obtained for most detections. The remaining discrepancies are likely related to the single-source location assumption, and the combination of model and observation errors.

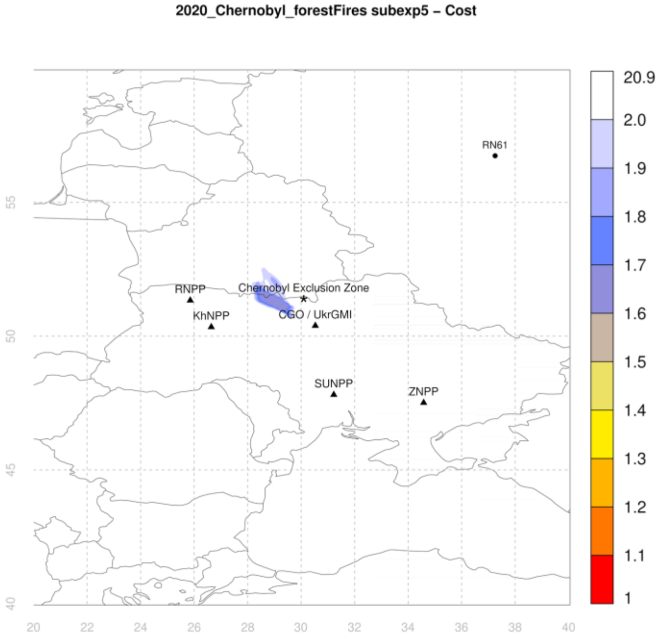


Figure 8 - Source location of the Cs-137 observations as estimated by the inverse modelling. The colors show the disagreement between the simulated and observed activity concentrations: lower values show a better agreement and thus a more likely source location. The area left of the Chernobyl nuclear power plant (blue area) is a likely source location according to our results, which is in good agreement with the location of the forest fires.

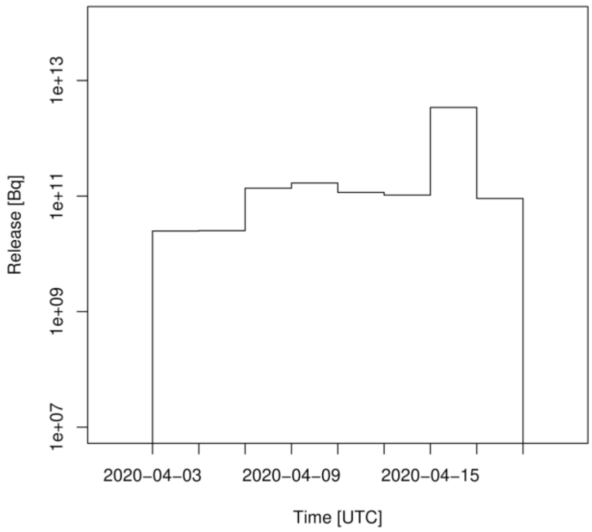


Figure 9 - Estimated release of Cs-137 as a function of time. The spike in the release between 15 and 17 April can be attributed to a single observation and is therefore deemed less accurate than the other release segments.

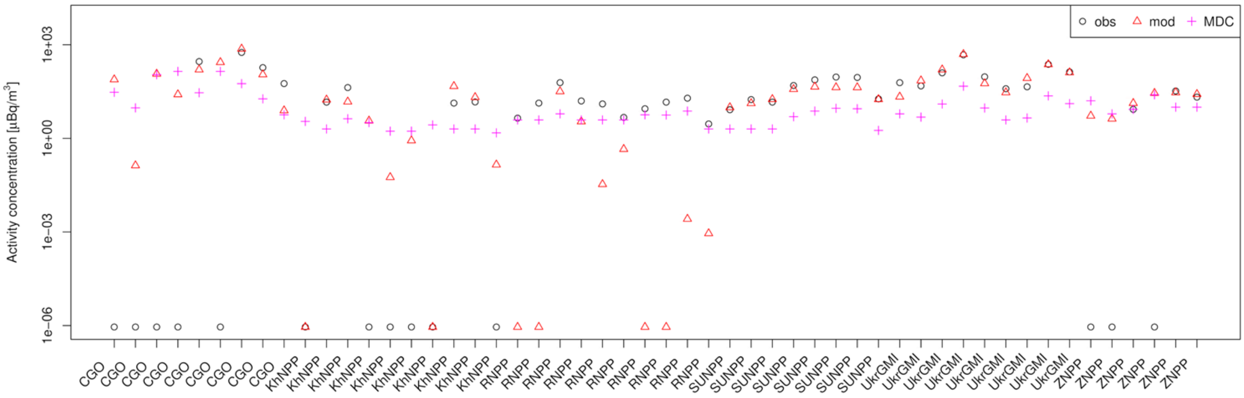


Figure 10 - Agreement between the observed (obs) and simulated (mod) activity concentration for the different sampling stations in Ukraine, using the Cs-137 release estimate that resulted in the best fit with the observations. The MDC is the minimum detectable concentration. Non-detections and simulated activity concentrations that were equal to zero have been given an arbitrary amount of 10^{-6} µBq in order to plot them on a logarithmic scale.

References

UNSCEAR. (2000). *Exposures and effects of the Chernobyl Accident.* UNSCEAR.

[1] https://sentinel-hub.com/tos#dataset

[2] https://earthdata.nasa.gov/earth-observation-data/near-real-time/citation

[3] http://apps.ecmwf.int/datasets/licences/copernicus/

[4] http://atmosphere.copernicus.eu/sites/default/files/repository/CAMS_data_license.pdf