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MODELLING ATMOSPHERIC DISPERSION OF RADIOACTIVITY WITH NPK-PUFF USING METEOROLOGICAL DATA FROM HIRLAM AND HARMONIE-AROME

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Abstract: Firstly, it was assessed how the atmospheric dispersion model NPK-PUFF compares to two widely used dispersion models avalaible in the JRODOS emergency response tool; RIMPUFF and LASAT. A comparison was made of the statistics acquired after simulating on each day throughout a year a release of the radionuclide I-131 from the Borssele nuclear power plant in the Netherlands. This was done to include all possible weather conditions in the analysis. The integrated air concentration over 48 hours is the quantity of interest. The results from NPK-PUFF are similar to those of RIMPUFF, most likely because both models are based on the same methodology.
Secondly, a similar analysis was executed to assess the influence of the source of meteorological data; the numerical weather predictions HIRLAM and HARMONIE-AROME (from here on referred to as HARMONIE) were the input for NPK-PUFF model. the HARMONIE data has a higher resolution, which could be benificial for assessing short-scale effects. The results reveal that the mixing height parameter has a strong influence on the results. Although on average the mixing height predicted by HIRLAM and HARMONIE does not differ significantly, the spatial variation in HARMONIE is much larger. This is due to the higher resolution of the data, but can also be related to a different mixing-height parametrization. The question arises if a two-layer model like NPK-PUFF, that distinguishes between a mixing layer and a reservoir layer, really benefits from the increased resolution in the mixing height. The model has to be validated with actual measurements to answer this question.

Key words: *Radioactivity, atmospheric dispersion, emergency response, numerical weather prediction, JRODOS*

INTRODUCTION

The emergency response during an accident involving the release of hazardous material in the atmosphere can benefit from scenario estimates based on atmospheric dispersion modelling. The source term is generally at least uncertain, many different models are available and weather data can be abundant and therefore ambiguous. In this study we focus on the latter by assessing the performance of a fast atmospheric dispersion model using two sources of meteorological data.

Common practice is to use available numerical weather predictions (NWP) as input for fast dispersion models in order to acquire concentration and dose estimates before and/or during the course of an accident. In the context of nuclear emergency management, the Royal Netherlands Meteorological Institute (KNMI) provides several NWPs. Here, atmospheric dispersion model (ADM) predictions will be compared using results from the NWP HIRLAM (Unden, Rontu et al. 2002) as well as the NWP HARMONIE-AROME[1] (Bengtsson, Andrae et al. 2017). HARMONIE computes the weather on a smaller domain and with higher resolution than HIRLAM.

Use is made of the Gaussian puff model NPK-PUFF developed by the Dutch National Institute of Public Health and the Environment (RIVM) and the Royal Netherlands Meteorological Institute (KNMI) (Verver, de Leeuw et al. 1990). NPK-PUFF can model the release, atmospheric dispersion, and deposition of radionuclides, as well as compute the associated received dose. NPK-PUFF is incorporated in the decision support system JRODOS (Wengert 2017), which allows for the use of its results in countermeasure models and food chain models.

[1] From here on referred to as HARMONIE

Firstly, NPK-PUFF is compared to an ADM from the JRODOS suite for the case of a (hypothetical) nuclear accident. Secondly, the sensitivity to the source of the meteorological input is assessed. We constructed a nuclear accident scenario for the region of the Netherlands and simulated its development for a range of starting times throughout the year, with the aim to include all possible weather conditions. This was done using HARMONIE and HIRLAM as meteorological input. Differences were assessed for estimated air concentration.

THE ATMOSPHERIC DISPERSION MODEL NPK-PUFF

NPK-PUFF is an ADM for the assessment of radioactive discharges. It describes the dispersion of clouds containing radioactivity, i.e. the combination of the advection by the local wind and the diffusion due to atmospheric turbulence. In addition, the processes of wet and dry deposition as well as the decay of radioactivity are taken into account. Different endpoints can be defined, such as concentration in air, time-integrated concentration, deposited activity concentrations, and time of cloud arrival. These endpoints can be given on (a collection of) user-defined grids (both extent and resolution) and on a collection of sampling points. Diagnostic results, such as dose estimates, can also be acquired. The effective dose due to external radiation and/or inhalation as well as specific organ doses are computed. NPK-PUFF is currently being used in the Dutch nuclear emergency response system and has been used before in atmospheric dispersion studies, e.g. (Eleveld, Kok et al. 2007), (Hiemstra, Karssenberg et al. 2011).

The transport of radioactivity is modelled using the Gaussian puff methodology. The released radionuclides are distributed over `puffs' that advect with the local wind velocity. For each puff the concentration distribution is assumed to be Gaussian. The diffusion is modelled for each puff by the increase of the standard deviation of the concentration distributions in the horizontal and the vertical directions. The increase of these standard deviations depends on the local level of atmospheric turbulence. Separate diffusion characteristics are considered for the regions above and below the mixing height.

METEOROLOGICAL DATA: HIRLAM AND HARMONIE

The two considered NWP data sources are HIRLAM and HARMONIE. Details about the models can be found in respectively (Unden, Rontu et al. 2002) and (Bengtsson, Andrae et al. 2017). The data covers the year 2015. The archived HIRLAM (HARMONIE) data have a horizontal resolution of approximately 22 (2.5) km and a temporal resolution of 3 (1) hours. The wind fields are given on a grids that have a size of Nx (latitude direction) x Ny (longitude direction) = 136 (300) x 226 (300). These fields are taken at 14 (15) wind levels that reach up to a height of approximately 10 (10) km. Most resolution is de lowest 3 (3) km of the atmosphere, with the first level at a height of 31 (10) m.

COMPARISON OF NPK-PUFF WITH ATMOSPHERIC DISPERSION MODELS IN JRODOS

To assess the performance of NPK-PUFF, its results are compared to those of ADMs that are used internationally in response to atmospheric nuclear releases. The JRODOS emergency management system contains multiple ADMs, of which RIMPUFF and LASAT are selected to compare with. All models are used with the HIRLAM NWP data. NPK-PUFF uses its own pre-processor for the meteorological data, while RIMPUFF and LASAT use the JRODOS meteorological pre-processor.

Considered scenario

The scenario that is considered is a release of I-131 at the Borssele nuclear power plant located in the South West of the Netherlands. The strength of the source term is chosen to be 1% of the inventory, released in four hours. No duration of containment is taken into account. This means that in total 1,31E7 GBq of radioactivity is released. All the iodine is assumed to be in the form of aerosols. The release height is 10 m and the heat content is 1.8 MW. An integration time of 48 hours since the start of the release was considered to be sufficient for the cloud to leave the domain, which extends to approximately 250 km from the release point.

The release of I-131 was simulated on each day in the period 1st of January 2015 until 29th of December 2015. The moment of release on each day was chosen randomly by the JRODOS system. Subsequently, for those same release moments the NPK-PUFF model was applied. In order to compare results of individual days, this exercise had to be done twice; once for RIMPUFF vs. NPK-PUFF, and once for LASAT vs. NPK-PUFF. This is because JRODOS uses a single dispersion model in a project and it chooses the release moments randomly. As a result, a comparison of RIMPUFF vs. LASAT cannot be done for individual days, because the release times differ. However, since the considered period covers approximately one year and 363 samples, the dataset contains enough samples to compare the statistical results of each dataset.

Results

The Time-Integrated Air Concentration (TIAC) near the ground is the quantity that is compared between the ADMs. The TIAC is defined as:

$$TIAC = \int_{t_{passage}} C(t)\, dt, \tag{1}$$

where $C(t)$ is the air concentration near the ground in [Bq m^{-3}] and $t_{passage}$ is the duration that the radioactive cloud passes. The TIAC is an important quantity because the committed dose due to the inhalation of radionuclides as well as the external radiation dose due to the submersion in a radioactive cloud depend linearly on the TIAC.

We would like to investigate the performance of the ADMs for cases where the dispersion extends up to distances in the order of 100 km from the source. Therefore, for all 363 samples, the maximum distance up to where the TIAC exceeds $TIAC_{crit}$ =5,0E8 Bq m^{-3} s is determined. The criterion of 5,0E8 Bq m^{-3} s is chosen such that this maximum distance is less than 100 km in the majority of the considered cases. Figure 1 shows for each ADM the probability distribution of the maximum distance to the NPP where $TIAC_{crit}$ is reached. Figure 2 shows the corresponding cumulative distributions. The results for NPK-PUFF and RIMPUFF are very similar, both in terms of absolute value and the shape of the distributions. The largest probability for these models lies in the 20-30 km distance range, and it decreases with distance. On the other hand, LASAT shows a bell-like shaped distribution with its maximum in the 40-50 km range, which drops more rapidly than RIMPUFF and NPK-PUFF. Finding the cause of the differences was not the scope of this study, merely assessing the performance of NPK-PUFF in relation to the JRODOS ADMs. Nevertheless, it is conjectured that the differences with the results of

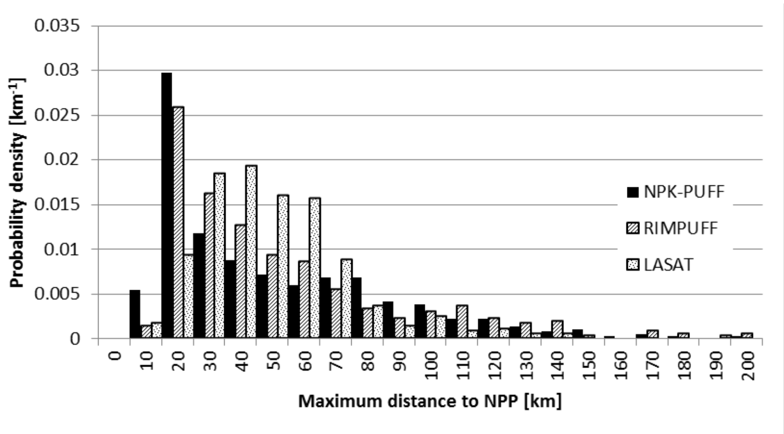

Figure 1: Probability density of maximum distance to the nuclear power plant (NPP) where $TIAC_{crit}$ is reached.

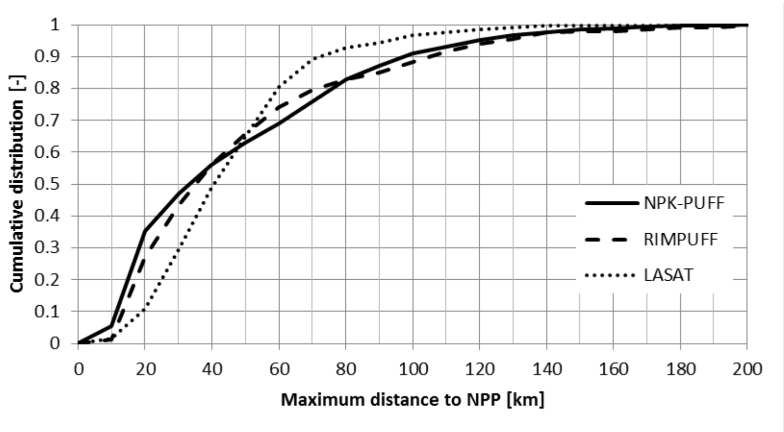

Figure 2: Cumulative distribution of maximum distance to the nuclear power plant (NPP) where $TIAC_{crit}$ is reached

LASAT are related to the difference in the used methodology; NPK-PUFF and RIMPUFF are both Gaussian puff models, while LASAT is a particle model.

USING DIFFERENT NWP DATA SOURCES WITH NPK-PUFF; HIRLAM & HARMONIE

The same scenario as in the previous section was considered, but in this case the source of the meteorological data was varied (HIRLAM and HARMONIE) while the same ADM was used (NPK-PUFF). The goal was to assess if and how much the results differ when a more detailed NWP like HARMONIE is used. The release was simulated every 10 hours. With the available NWP data 806 cases could be generated.

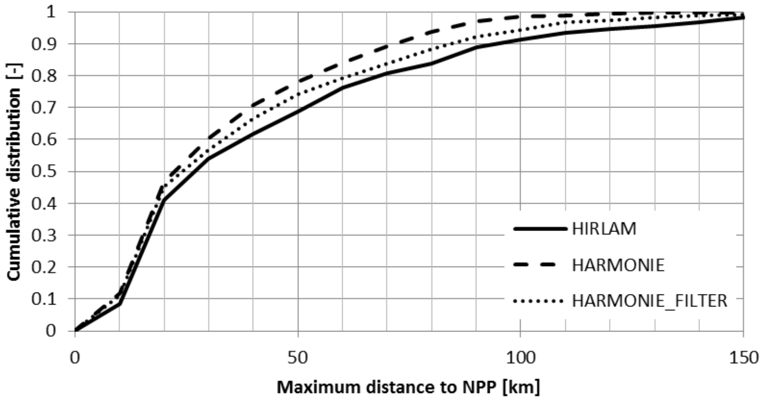

Figure 3: Cumulative distribution of maximum distance to the nuclear power plant (NPP) where TIACcrit is reached

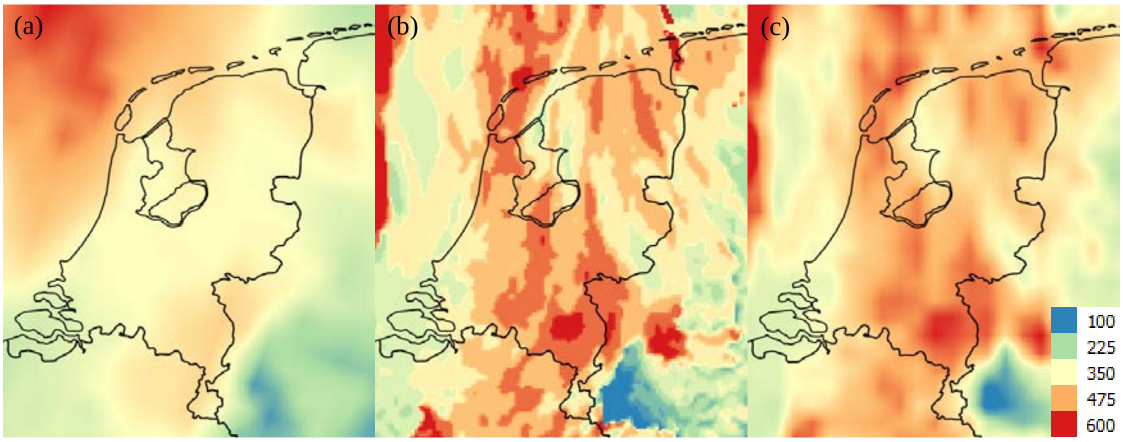

Figure 4: Example (January 6 2015 13:00 (UTC)) of the instantaneous mixing height in meters from the NWP a) HIRLAM. b) HARMONIE. c) HARMONIE after filtering by taking the average over 6 x 6 data points.

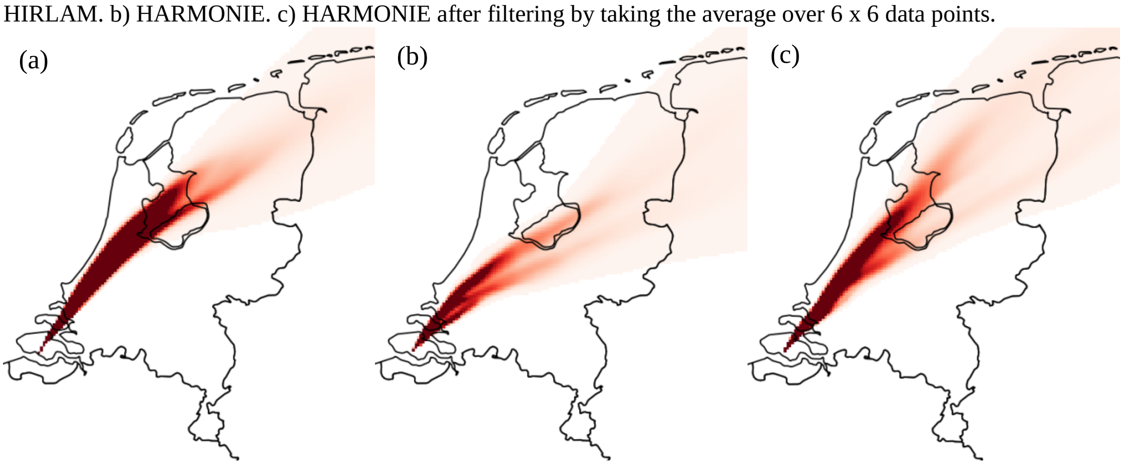

Figure 5: Release on April 11 2015 at 20:00 (UTC) from NPP Borssele modelled with NPK-PUFF. Air concentration integrated over 48 hours. Using a) HIRLAM. b) HARMONIE. c) HARMONIE with filtered mixing height data.

The statistical results are shown in Figure 3, where the continuous line represents the results using HIRLAM data and the dashed line represents the results using HARMONIE data. When using HARMONIE in 90% of the cases the TIAC does not exceed $TIAC_{crit}$ beyond 70 km, while this is 95 km when using HIRLAM data. Additional tests revealed that the model results depend strongly on the mixing height; when applying the same value for the mixing height for both NWP sources (by using data from historical measurements and by-passing the NWP values) the statistical results are very similar. In addition, on average the mixing heights predicted by HIRLAM and HARMONIE do not differ significantly, which means that a constant over- or underestimation of the mixing height can be excluded as the cause of the different dispersion results. To assess if the larger spatial variation in mixing height in the HARMONIE data has a large influence on the dispersion results an additional series of simulations was performed in which the mixing height data was spatially filtered. The filtering effect was achieved by averaging over 6 x 6 grid cells. Figure 4 shows examples of the mixing height for HIRLAM, HARMONIE, and the filtered HARMONIE data, all on the same time stamp. The statistical results are shown in Figure 3 by the dotted line showing that the distribution is closer to the HIRLAM results.

The TIAC computed by the three methods is visualized in Figure 5 for a single case. It again shows that filtering the mixing height from HARMONIE results in a closer agreement with the HIRLAM results. It could be that the different results when using HARMONIE are actually correct, and essentially more accurate dispersion predictions. On the other hand, it might be that the method of redistributing the concentration over the mixing layer and the layer above has difficulty handling the larger spatial variations in the mixing height. Validation with measurements is required to clarify this issue.

CONCLUSIONS

A comparison with two other ADMs shows that, based on statistical characteristics, the models NPK-PUFF and RIMPUFF are in a closer agreement with each other than NPK-PUFF vs. LASAT or RIMPUFF vs. LASAT. This is most likely related to the similar methodology that is used in NPK-PUFF and RIMPUFF. Validation with actual measurements has to show which of the models performs best. The challenge in this matter is to have (experimental) measurement data for multiple atmospheric conditions

Fast ADMs for emergency response can benefit from the improvements made in NWPs in terms of more advanced modelling of the physics as well as the increased resolution. Especially more detailed wind fields are beneficial for puff models. From the analysis in this study the question arises if a two-layer model like NPK-PUFF, which distinguishes between a mixing layer and a reservoir layer, really benefits from the increased resolution in the mixing height. The model has to be validated with actual measurements to answer this question.

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