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COMPARISON OF FLEXPART-WRF AND SINAC-AROME LAGRANGIAN DISPERSION MODELS: A CASE STUDY FOR A NUCLEAR INCIDENT

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Abstract: In an accidental situation the accuracy of the analyses on the environmental effects of radioactive emissions from nuclear institutions is essential for risk management and decision making strategies. There are several dispersion models in Hungary to predict the movement of the radioactive material in the air in case of a nuclear accident. In the last years the Hungarian Academy of Sciences Centre for Energy Research updated the SINAC decision support dispersion model and it became important to evaluate the model results. In this study we used two Lagrangian type models to investigate the environmental effects of specific radioactive emissions. Dispersion of the released radioactive material was estimated using the SINAC-AROME model and the well-known FLEXPART-WRF particle dispersion model. Results on activity concentrations were compared and analyzed. The comparison of the two models provided information about the uncertainty of the predictions and pointed out the most important directions for further development of the SINAC dispersion model.

Key words: *atmospheric dispersion, air pollution, Lagrangian model, model validation***.**

INTRODUCTION

As a consequence of an accident in a nuclear power plant the release of radioactive material into the atmosphere could be of considerable contribution to the environmental risk. In order to predict the human risk and the environmental impact due to the released material, the transport of radionuclides through the environment should be well understood. The potential for an accident in a nuclear power plant requires continuous development of atmospheric dispersion models and widespread simulations of accidental releases of radionuclides with these models. Since the accidents at the nuclear power plants in Chernobyl in 1986 and in Fukushima in 2011, an increasing demand is observable on the part of several countries for the construction of sophisticated dispersion model systems. On the basis of accurate model calculations decision makers have to make important arrangements which can save human lives.
Paks NPP (Nuclear Power Plant), that is located 5 kilometres from the city of Paks in the central part of Hungary, is the only operating nuclear power station in the country. Although several different kinds of dispersion models are available in Hungary, further and continuous development of simulation techniques is required. The Hungarian Atomic Energy Authority is responsible for operating a dispersion model officially to predict the transport of nuclear material in case of an accident. The dispersion model SINAC that has been developed by the Hungarian Academy of Sciences Centre for Energy Research is used in these critical situations. SINAC uses the meteorological fields from AROME high resolution numerical weather prediction model. In this paper we compare the results of the SINAC-AROME system with the outcome of the FLEXPART-WRF system that is applied at the Hungarian Meteorological Service. The influence of the source of meteorological data and different physical parameterisations in the dispersion models are analysed under several meteorological situations.

DISPERSION MODEL DESCRIPTIONS

SINAC (Simulator Software for Interactive Modelling of Environmental Consequences of Nuclear Accidents) is a programme system developed in the Hungarian Academy of Sciences KFKI Atomic Energy Research Institute in the 1990’s (Deme et al., 2013) that is used for predicting the environmental consequences of accidental short term atmospheric releases of radioactive pollutants.

Calculations are made using a Descartes coordinate system on a local scale in which power plants are represented as point sources. The programme contains 5 default emission source points with the opportunity of defining a distinct point by the user. Paks NPP is located in the centre of the calculation grid, surrounded by several environmental control points.
SINAC is based on a puff model with the assumption of Gaussian distribution of the concentrations in each puff. Time and spatial resolution of the model is equivalent to that of the weather forecast data provided by the Hungarian Meteorological Service. SINAC uses input meteorological files calculated by the AROME model, the size of one grid is therefore 0.05 degrees along the lines of latitude and longitude. Emission – correspondingly to the resolution of the meteorological data – is set for 15-minute time periods. Advection, dispersion and depletion of the puffs are calculated in 31 steps for every 15 minutes. The present version of the programme system deals with 16 radionuclides altogether.
Calculated data include activity concentrations in air, on the ground and in food, individual gamma and beta doses, individual committed effective doses such as inhalation, skin dose and thyroid dose and averted doses. The programme takes countermeasures also into account.
SINAC has been used as a training and potential decision support system by the Hungarian Atomic Energy Authority Centre for Emergency Response, Training and Analysis over the last decade.

The Lagrangian particle dispersion model FLEXPART (Stohl et al., 2005) has been developed to simulate the transport and deposition of polluted material emitted into the atmosphere. The model computes the trajectories of the emitted polluted particles and their concentration changes along the trajectories caused by the effects of diffusion, dry and wet deposition and radioactive decay.
FLEXPART has been used as a transport model from meso to long-range scales by the Hungarian Meteorological Service to support the work of the decision makers in Hungary in an accidental case. The model runs automatically two times a day with predefined options, but the users are also able to start an interactive run using the HAWK (Hungarian Advanced WorKstation) system of the Hungarian Meteorological Service. The automatic run uses the actual meteorological data with the predefined source point of Paks NPP. In case of the automatic run the released material is ^{137}Cs. FLEXPART uses input meteorological files calculated by the WRF (in meso-scale) and ECMWF (in long-range) numerical weather prediction models, depending on the aim of the simulation.

HIGH RESOLUTION NUMERICAL WEATHER PREDICTION MODEL DESCRIPTIONS

The Weather Research and Forecasting Model (WRF) is being developed in a collaborative effort by the National Center for Atmospheric Research (NCAR), the National Centers for Environmental Prediction (NCEP), the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), Oklahoma University (OU) and other university scientists (Skamarock et al., 2001). Their goal has been to develop a state-of-the-art numerical weather prediction and data assimilation system suitable for horizontal grid scales in the range of 1 to 10 km. The WRF project has developed a next-generation mesoscale forecast model and assimilation system to improve both the understanding and the prediction of mesoscale precipitation systems and to promote closer ties between the research and operational forecasting communities. The wide dissemination of the WRF modeling system to a large number of users and its application in a variety of areas including storm-scale research and prediction, air-quality modeling, wildfire simulation, hurricane and tropical storm prediction, regional climate and operational numerical weather prediction are well underway. The Hungarian Meteorological Service runs the WRF model four times a day with the nowcasting purpose, but the results of the 06UTC model run fit also for the FLEXPART calculations. The spatial resolution of the meteorological fields is 2.7 km.

Since the 1990s, research-oriented models have demonstrated the potential of kilometric resolutions to improve operational forecasts in specific weather situations, such as flash flood events. Flash flood events occur frequently in late summer and during autumn in the southeast of France. They elicit some of the most devastating events in France, so there was a clear need for a NWP (Numerical Weather Prediction) system that could better predict these events. A resolution of 2.5 km has been chosen in order to bypass the so-called convective grey zone (i.e. resolutions between 3 and 6 km); because deep convection is partly resolved by the model, but still needs to be partly parameterized as a subgrid process. This led to the Application of Research to Operations at Mesoscale (AROME-France) concept in France (Seity et al., 2011). The Hungarian Meteorological Service runs the AROME high resolution numerical weather prediction model four times a day to prepare fine resolution weather forecast for the area of the Carpathian basin. From the raw results of AROME special output files for the SINAC dispersion model have been prepared continuously.

MODEL SIMULATIONS

The aim of our investigation has been to compare the behaviour of the two different model systems using real meteorological data fields. First we determined how well the numerical weather prediction models were back to the reality and how big the differences between the results of these models were. These differences will naturally cause deviation in the results of the dispersion calculations. The other goal of our study was to determine how strong the effect of the different parameterisation methods that are used in SINAC and FLEXPART is on the concentration and deposition fields. To reach these goals four different meteorological situations were selected: precipitation with strong wind, precipitation with weak wind, dry weather with weak wind and dry weather with strong wind.

For the source term we chose three different radionuclides available in both models that contribute largely to the total emission of Paks NPP in normal operation: ^{137}Cs, ^{131}I and the noble gas ^{133}Xe. We assumed one yearly total emission of these radionuclides in the effective release height of 120 m, determined for the presently operating four blocks of Paks NPP under normal operation (Bujtás, 2011), to be emitted in the course of one hour and examined the environmental consequences. The source term for the calculations is summarized in Table 1. The activities of radionuclides are given for 24 hours. Emission in the calculations was assumed to be continuous.

Table 1. Detailed specification of the model runs

Total emitted activity for every emitted nuclides	^{133}Xe 9.0E+12 Bq ^{131}I 1.3E+08 Bq ^{137}Cs 6.4E+07 Bq
Beginning and period of the release	06UTC, 24 hours
Total time interval of the simulation	24 hours
Meteorology	Precipitation with strong wind: 06UTC, 15 May 2014 Precipitation with weak wind: 06UTC, 24 June 2014 Dry weather with strong wind: 06UTC, 17 April 2014 Dry weather with weak wind: 06UTC, 12 June 2014

Time integral of activity concentrations in air and deposition in the environment were examined for the first 24 hours.

RESULTS

In order to compare the concentration values calculated by the two models, the activity concentration time integral [Bqsm^{-3}] was determined for many locations. Not only the results of the dispersion models were compared, but the values of the basic meteorological parameters as well, which have essential effect on the results of the dispersion models.

Comparing the calculations of the two NWP models we found that the values of the meteorological parameters predicted by the AROME and WRF were significantly different. Only on 17 April 2014 were wind predictions similar to each other. Forecasts on the amount of precipitation were found to be considerably different in all cases. The differences in the weather predictions are reflected in the results of the dispersion models.

Comparing the output data of the weather prediction models with the measurements it was found that both models overestimated wind speed in all cases, and the forecast of precipitation was also inaccurate, especially on 24 June 2014.

Fig.1. shows the plumes and the particle distributions at the end of the 24-hour release calculated by SINAC+AROME and FLEXPART+WRF model systems in the different meteorological conditions. The

visualization systems of the two software solutions are different therefore it is difficult to compare the positions of the plumes. However, it can be stated that the best agreement in the shape of the plumes was found when the two NWP models predicted fairly similar wind directions (15 May 2014 and 17 April 2014). The width of the plume is determined by the magnitude of the diffusion which was specified by different methods in the dispersion models. SINAC uses the Pasquill categorization scheme while FLEXPART applies the Monin-Obukhov length to describe stability conditions. These differences in dispersion calculation methods affect model calculations essentially, leading to an uncertainty in dispersion.

As a conclusion it can be said, that in real situations, when we use different NWP and dispersion models to predict the movement of the polluted material in the air, we have to take the uncertainty of the weather predictions and dispersion calculation methods into account. Based on our study we could not determine whether one model system is better than the other, but we realised that we should use the results of these two software parallel as a mini ensemble to determine the uncertainty of the results.

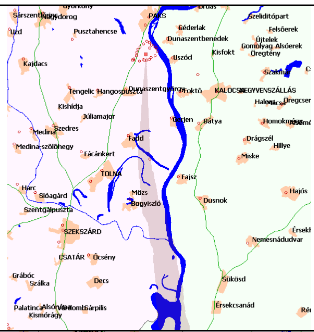
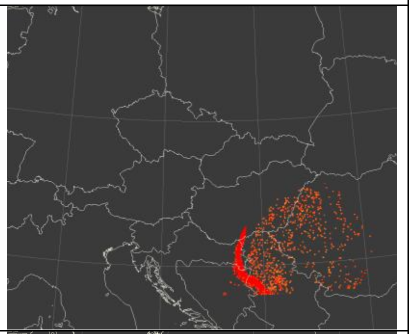
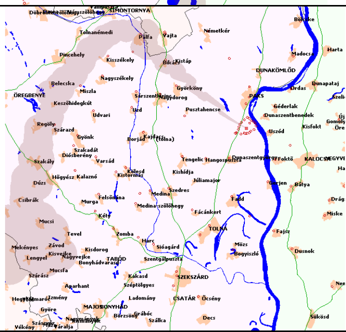
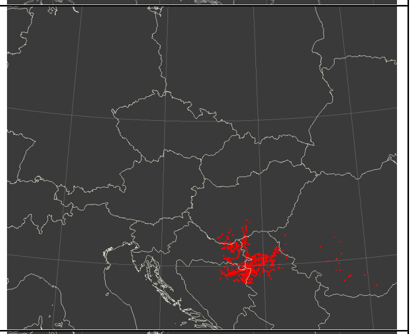
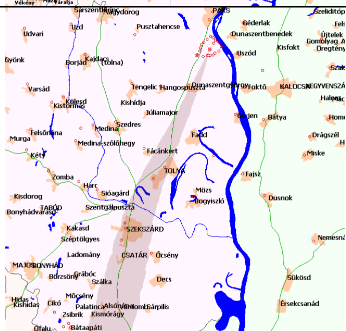
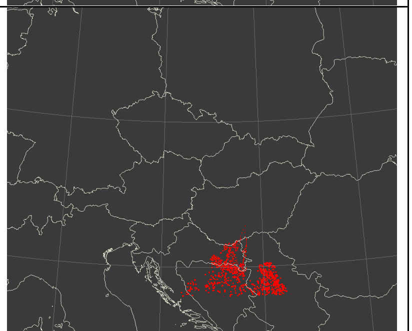
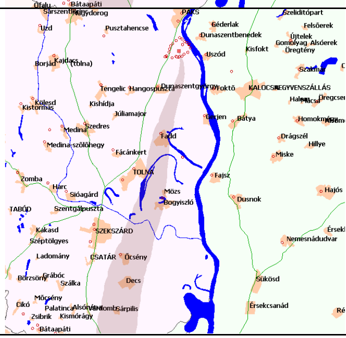
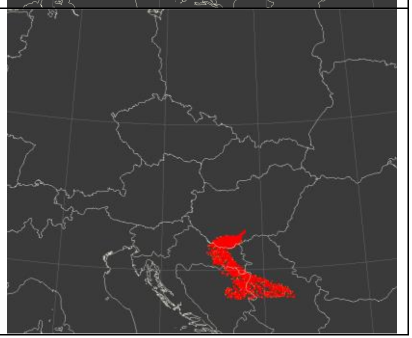
	SINAC+AROME	FLEXPART+WRF
Precipitation with strong wind: 06UTC, 15 May 2014		
Precipitation with weak wind: 06UTC, 24 June 2014		
Dry weather with strong wind: 06UTC, 17 April 2014		
Dry weather with weak wind: 06UTC, 12 June 2014		

Figure 1. Plumes and particle distributions after a 24-hour release calculated by SINAC+AROME and FLEXPART+WRF model systems in different meteorological conditions

In this study activity concentration time integral values [$Bqsm^{-3}$] determined by the two model systems were compared for many locations. Fig.2. shows the results of this examination for the 24. hour of the simulation, where the results of FLEXPART were devided by the results of SINAC. The best agreement was found on 12 June 2014, when the weather condition was dry with weak wind. In the other meteorological situations, when the NWP determined precipitation, results were found to be much worse. From the analysis it can be concluded that the most essential meteorological parameter that leads to differences in results is precipitation, which determine wet deposition and may indicate chemical reactions. We get the worst results on 24 June 2014, when the meteorological predictions were very different. In case of 17 April 2014, the agreement of the calculated concentrations was relatively good, however, in two villages (Szedres, Zomba) FLEXPART calculated 100 and 1000 times higher concentration values than SINAC. These two settlements are located relatively far from the central line of the SINAC plume, but FLEXPART transported polluted material into this direction. This situation is likely to cause the big differences in the concentration values.

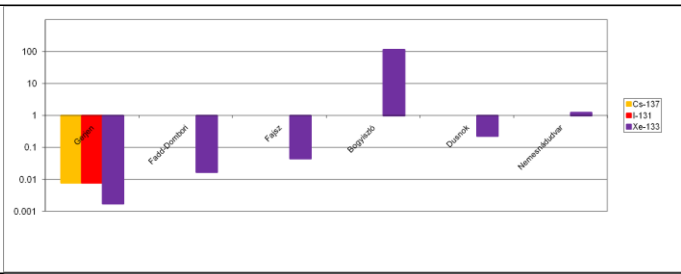
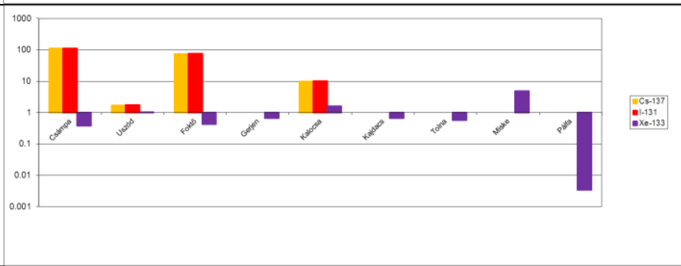
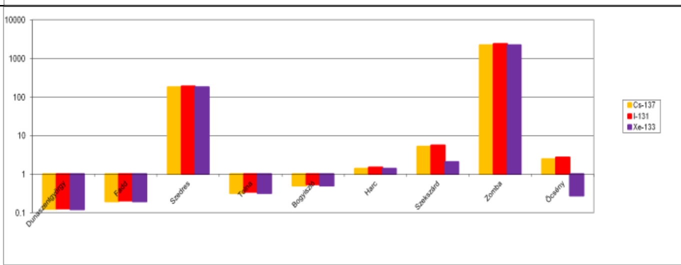
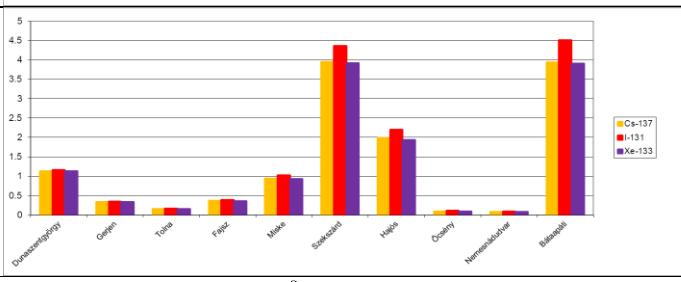
<table>
<tr><td>Precipitation with strong wind:
06UTC, 15 May 2014</td><td>
</td></tr>
<tr><td>Precipitation with weak wind:
06UTC, 24 June 2014</td><td>
</td></tr>
<tr><td>Dry weather with strong wind:
06UTC, 17 April 2014</td><td>
</td></tr>
<tr><td>Dry weather with weak wind:
06UTC, 12 June 2014</td><td>
</td></tr>
</table>

Figure 2. The rates of the activity concentration time integrals [Bqsm^{-3}] after 24 hours determined for many locations by the two model systems

It can be concluded that the models are in a good agreement in determining the direction of the movement of the polluted material and the location of the affected areas by the plume despite the fact that two different high resolution numerical weather prediction models provided the meteorological input for the dispersion models. The uncertainty in concentration values might occur due to the different treatments of the dispersion and deposition processes. In order to understand the exact background of these differences more detailed analyses are needed.

These case studies provided reliable results of dispersion patterns even in a complex synoptic situation, however, concentration values sometimes show significant variations between calculations made by the two tested software. Parallel use of the two models, as well as adjusting parametrizations based on measurement data can largely improve atmospheric dispersion simulations to provide valuable information for risk management.

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