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**THE USE OF THE *WRF* NUMERICAL WEATHER FORECASTING MODEL IN MODELING
EMERGENCY SITUATIONS AT BELARUSIAN NPP**

Abstract. The expediency of using *Weather Research and Forecasting (WRF)* numerical weather forecast model as a source of meteorological data during modeling of radioactive substances transfer in the atmosphere is considered, *WRF* technical details are briefly described. As the reference emergency scenario, the scenario of the maximum design accident hypothetically occurring at Belarusian Nuclear Power Plant (BelNPP) 12 UTC 21.03.2021 was chosen. Four numerical experiments with *Global Forecast System (GFS)* and *WRF* meteorological data and *RIMPUFF* and *LASAT* atmospheric diffusion models were performed in *JRODOS* Decision Support Systems (DSS). For each experiment, maps of underlying surface potential radioactive contamination of I_{131} were created. The potential contamination of the underlying surface I_{131} from 5 to 100 km from the BelNPP was assessed. The dependency graph of the maximum underlying surface contamination with I_{131} on the distance from the BelNPP was plotted based on the experiments results. The obtained results indicate the prospects of using the *WRF* meteorological model in the DSS at various stages of the emergency situations development at the BelNPP.

Keywords: radioactive contamination, BelNPP, numerical weather forecast, decision support system, numerical simulation

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**ИСПОЛЬЗОВАНИЕ ЧИСЛЕННОЙ МОДЕЛИ ПРОГНОЗА ПОГОДЫ *WRF* ПРИ МОДЕЛИРОВАНИИ
РАЗВИТИЯ АВАРИЙНЫХ СИТУАЦИЙ НА БЕЛОРУССКОЙ АЭС**

Аннотация. Рассмотрена возможность использования численной модели прогноза погоды *Weather Research and Forecasting (WRF)* как источника метеорологических данных при моделировании переноса радиоактивных веществ в атмосфере, обозначены технические детали использования *WRF*. Для моделирования аварийной ситуации был выбран сценарий максимальной проектной аварии, гипотетически произошедшей в 12.00 на Белорусской АЭС (БелАЭС) 21 марта 2021. Четыре численных эксперимента с метеорологическими данными *Global Forecast System (GFS)* и *WRF* и моделями атмосферной диффузии *RIMPUFF* и *LASAT* были выполнены в системах поддержки принятия решений *JRODOS*. Для каждого эксперимента созданы карты потенциального радиоактивного загрязнения подстилающей поверхности I_{131} . Проанализировано потенциальное загрязнение подстилающей поверхности I_{131} на расстоянии от 5 до 100 км от БелАЭС. Построен график зависимости максимального загрязнения I_{131} подстилающей поверхности от расстояния от БелАЭС для проведенных экспериментов. Полученные результаты свидетельствуют о перспективности использования метеорологической модели *WRF* в системах поддержки принятия решений на различных стадиях развития аварийных ситуаций на БелАЭС.

Ключевые слова: радиоактивное загрязнение, Белорусская АЭС, численные модели прогноза погоды, системы поддержки принятия решений, численное моделирование

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Introduction. Operational assessments during an accident, prediction of its development and possible damage are an integral part of the emergency response to any emergency with radiological consequences. Currently, there is a large number of Decision Support Systems (DSS) that make it possible to assess the predicted radiation situation at different stages of emergency development. However, the result of their work directly depends on the quality of input parameters: release characteristics, weather conditions, terrain parameters, etc.

The use of the *Weather Research and Forecasting (WRF)* [1] numerical meteorological model was applied to increase the spatial resolution of the initial fields of meteorological data in the works on modeling the transport of radioactive substances as a result of the Chernobyl accident [2] and the accident at Fukushima-1 NPP [3]. The results obtained in these works demonstrate the consistency of such an approach.

The main goal of this study is to improve the characteristics of the forecast of the transport of radioactive substances in the atmosphere by increasing the spatial and temporal resolution of weather data using the *WRF* numerical weather prediction model.

This paper considers the possibility of applying the data of the numerical weather forecast model *WRF* as inputs for short-term emergency forecasts, calculated on the basis of weather data of the *Global Forecast System (GFS)* [4], which are supplied by the US National Weather Service. *WRF* data differ from the initial *GFS* data in higher spatial and temporal resolution, which is achieved by numerical solution of non-hydrostatic equations and use of nested calculation grids, taking into account local terrain features. *GFS* data are used to initialize initial values and set *WRF* boundary conditions.

To predict the transport of radioactive substances as a result of a radiation accident, as well as the expected dose loads, the *JRODOS SRP* [5] with *RIMPUFF* [6] and *LASAT* [7] atmospheric diffusion models was used in this work. The maximum design basis accident (MDBA) scenario, described in the environmental impact assessment report of the Belarusian Nuclear Power Plant (BelNPP) [7], was chosen as the basic emergency scenario.

Preparing the WRF model for the experiment. The *WRF* predictive model is delivered as open-source code, written primarily in the Fortran programming language. This approach allows for flexible customization of the model at the source code level, taking into account the platform used and the tasks to be solved. However, to run the model, it must be compiled beforehand. In addition to the compiler, the required libraries must be installed, which makes it somewhat difficult to use the model for inexperienced users. To simplify the deployment of the *WRF* environment on different platforms, it is proposed to use the Docker application containerizer. *WRF* is intended to be used on *Linux*.

This paper uses version *WRF* 4.1.5, the source code of which was taken from the *GitHub* repository [8]. Running the model requires pre-processing the data. For this purpose, the *WRF Pre-Processing System (WPS)* is used, it consists of three modules. Similar to *WRF*, *WPS* is compiled from source code. The *WPS* version is the same as the *WRF* version. A script was written to automate the sequential launch of the *WPS* modules and the subsequent launch of *WRF*.

Description of the numerical experiment. In order to test the hypothesis about possibility and expediency of *WRF* use, in the present paper it is proposed to consider the IPA scenario at BelNPP for several data sets: *GFS* and *WRF* built on its basis. It is also supposed to consider simulation of the chosen emergency scenario using several atmospheric diffusion models: *RIMPUFF* and *LASAT*.

The weather data were selected for 21.03.2021. For the specified date the sets of forecast weather data *GFS* were downloaded from the file storage *NCAR (National Center for Atmospheric Research)* in *GRIB2* format. The dataset contains many values of meteorological parameters with reference to the spatial grid for different isobaric heights. The forecast duration is 48 hours with a step of 3 hours. The spatial resolution of the data grid is 0.5° (for Belarusian latitudes the cell size is ~ 54 km in the northern direction and ~ 30 km in the eastern direction).

The downloaded data is used as input for running the *WRF*. The spatial resolution of the obtained data was ~ 5 km, and the temporal resolution was 1 hour. Figure 1 shows a cartographic visualization of the air temperature at a height of 2 m for 06 UTC 21.03.2021 within a radius of 100 km from BelNPP from two data sets – *GFS* and *WRF*.

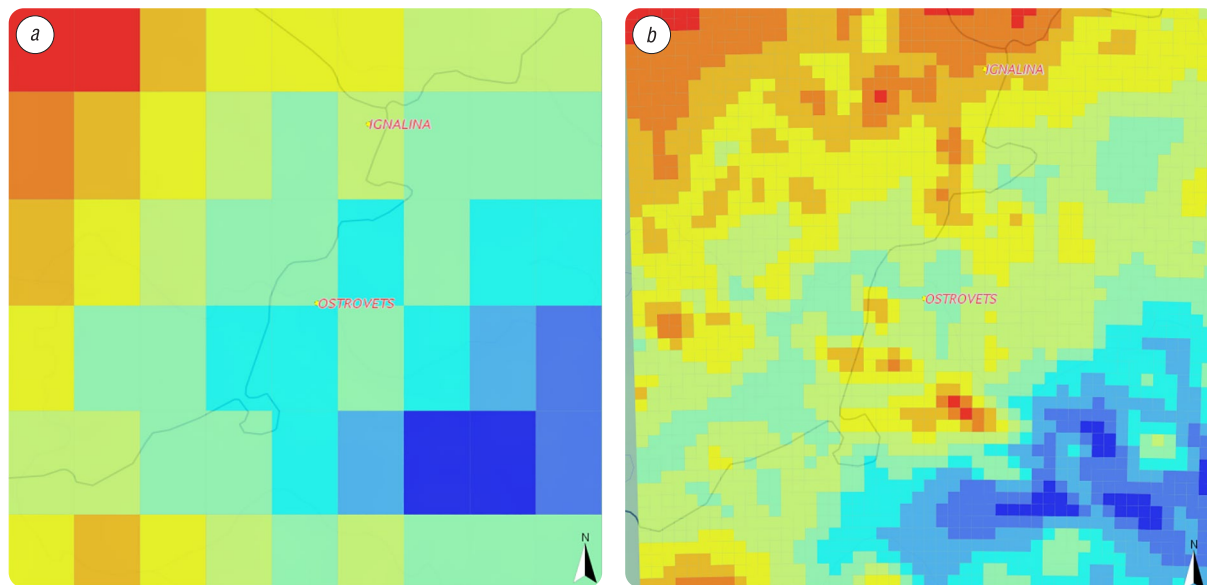


Figure 1. Air temperature at 2 m altitude for 06 UTC 21.03.2021: *a* – *GFS*; *b* – *WRF*

The emergency scenario of the PSA assumes release of a large amount of radioactive substances (RS) into the atmosphere in 1 hour. The main characteristics of the emergency release are presented in the Table.

Characteristics of the maximum design basis accident RS release

Name	Value
Simulation period	24 hours
Emission duration	1 hour
Dynamics of upper and lower limit of emission	21–25 m
Effective diameter of the source	3 m
Output speed	1.8 m/s
Overheating	30 °C
Activity I_{131} , Bq	$3.1 + E15$
Activity Cs_{137} , Bq	$3.5 + E14$

It is assumed that the incident occurred at 12.00 UTC 21.03.2021. Taking into account the above, as well as the parameters of the release, the initial simulation parameters were set in the created *JRODOS* project. For modeling, the “*EmergencyLite*” model chain was used, which in addition to the models of RS transfer and radiation dose assessment includes models on food contamination and taking counter-measures.

Four numerical experiments were performed, which differed from each other by atmospheric diffusion models and by the meteorological data sets used. The atmospheric diffusion model *RIMPUFF* with the *GFS* and *WRF* meteo data sets and *LASAT* with the *GFS* and *WRF* sets were considered.

The obtained results of contamination of the underlying surface with I_{131} isotope in 24 hours (22.03.2021 12 UTC) after the hypothetical incident are shown in the figures below (Figures 2–5).

Figure 6 shows the maximum values of I_{131} contamination of the underlying surface at a distance of 5 to 100 km from the BelNPP, obtained as a result of numerical experiments.

Conclusion. The obtained results indicate the possibility of using the *WRF* model meteorological data in the context of modeling an emergency situation with RS emission into the atmosphere. The created as a result of its work meteo data of higher spatial and temporal resolution in comparison with the original *GFS* data allow, probably, a more accurate assessment of the transfer of RS as a result of an emergency incident. Especially promising is the possibility of connecting the module of assimilation of observational data, the use of which can also potentially increase the quality and accuracy of the forecast.

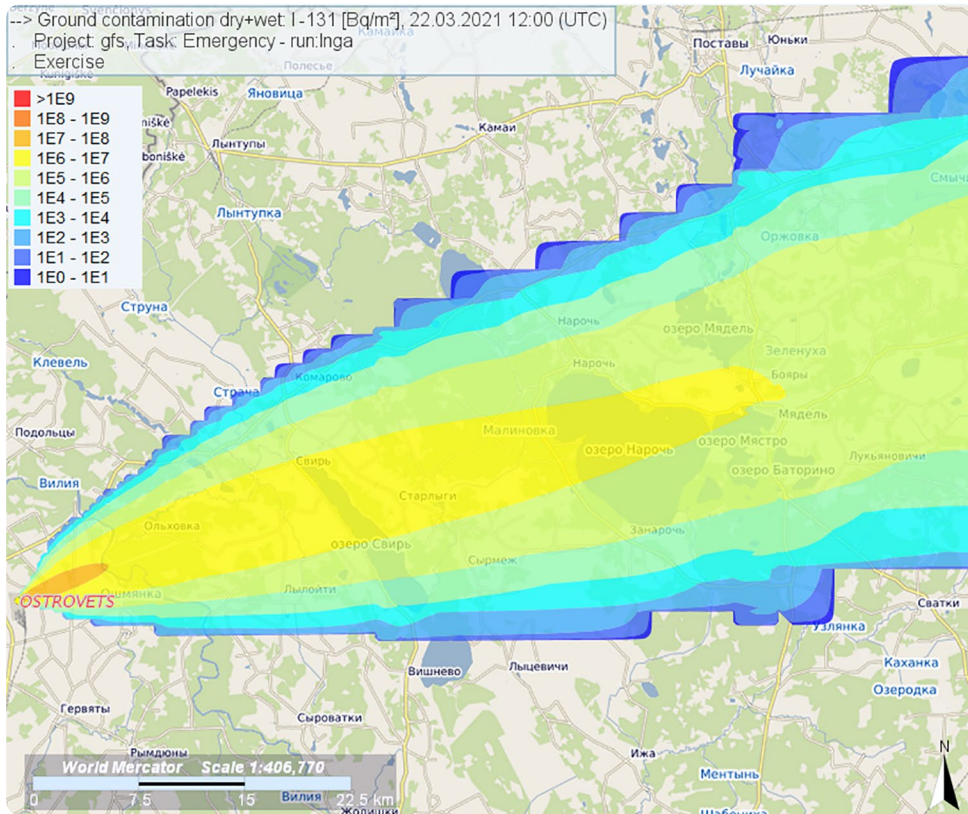


Figure 2. Contamination of the underlying surface with I_{131} isotope as of 22.03.2021 12 UTC, obtained using *GFS* and *RIMPUFF*, Bq/m²

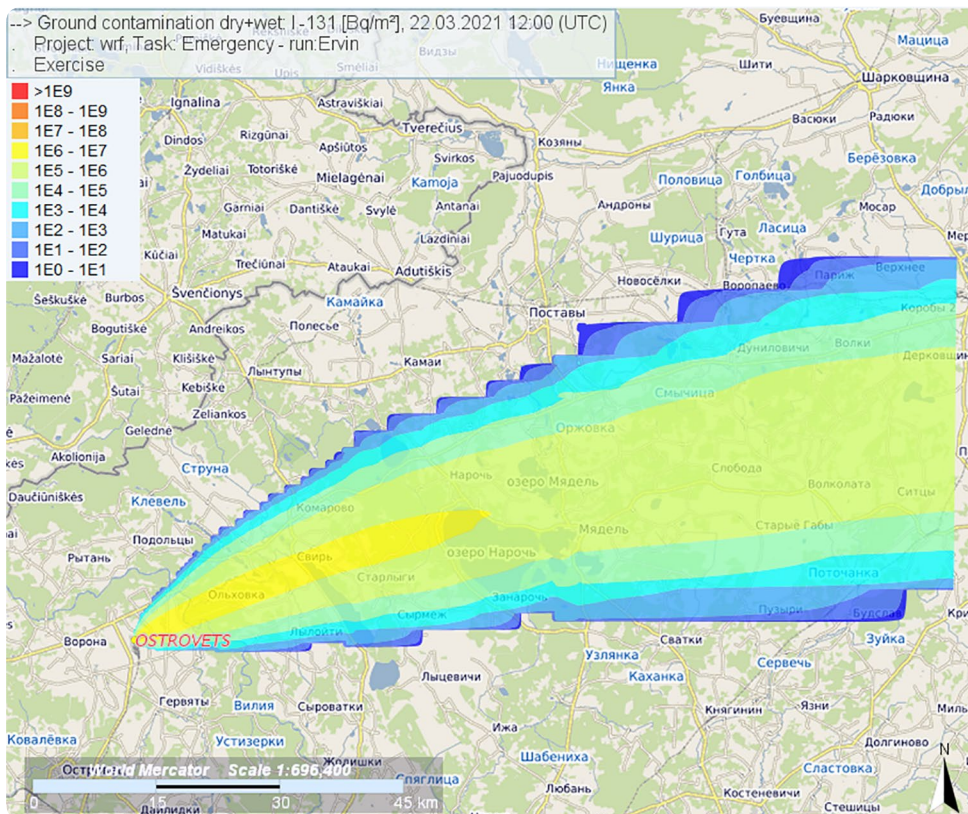


Figure 3. Contamination of the underlying surface with I_{131} isotope as of 22.03.2021 12 UTC, obtained using *WRF* and *RIMPUFF*, Bq/m²

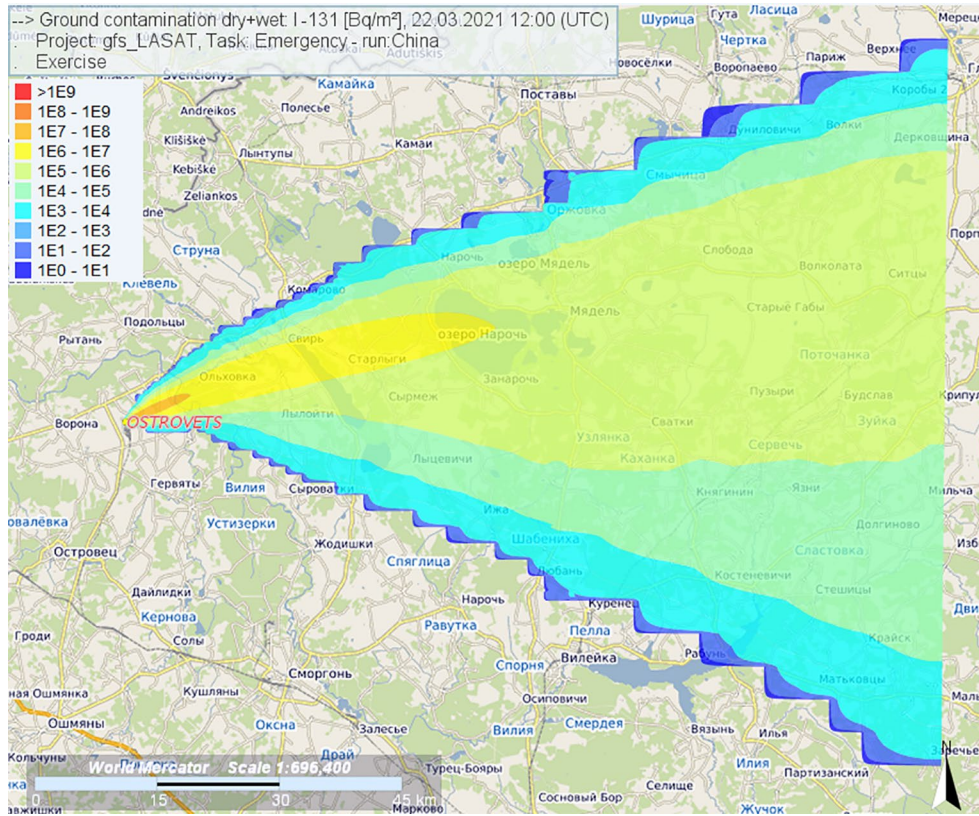


Figure 4. Contamination of the underlying surface with I₁₃₁ isotope as of 22.03.2021 12 UTC, obtained using *GFS* and *LASAT*, Bq/m²

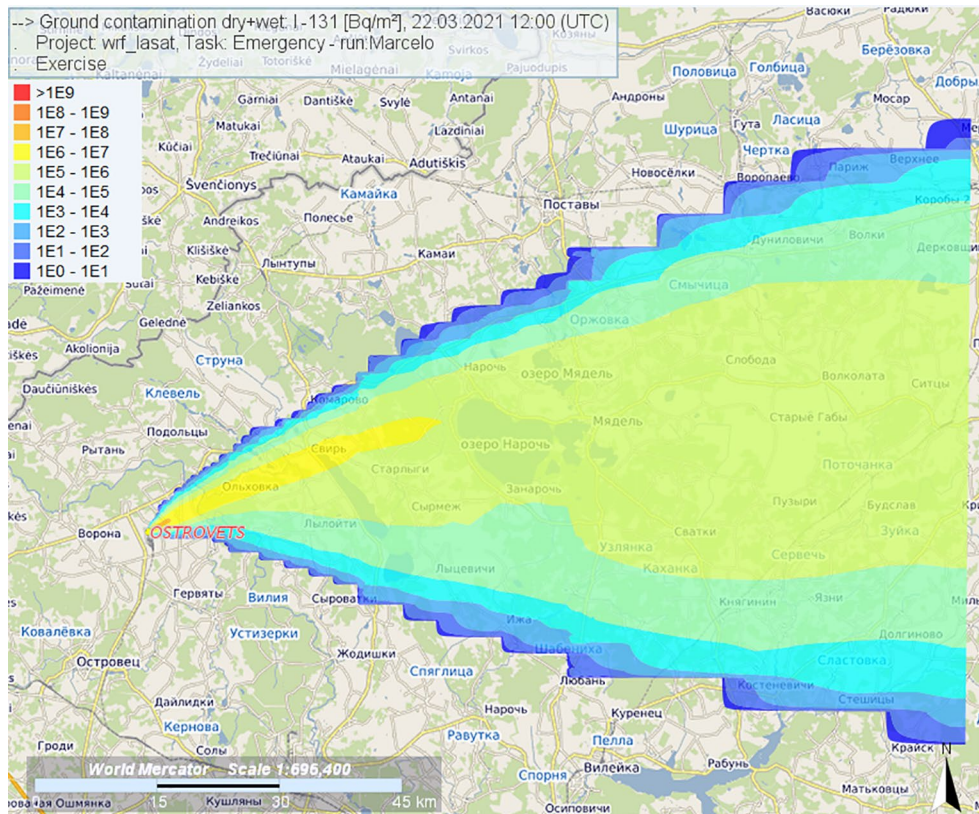


Figure 5. Contamination of the underlying surface with I₁₃₁ isotope as of 22.03.2021 12 UTC, obtained using *WRF* and *LASAT*, Bq/m²

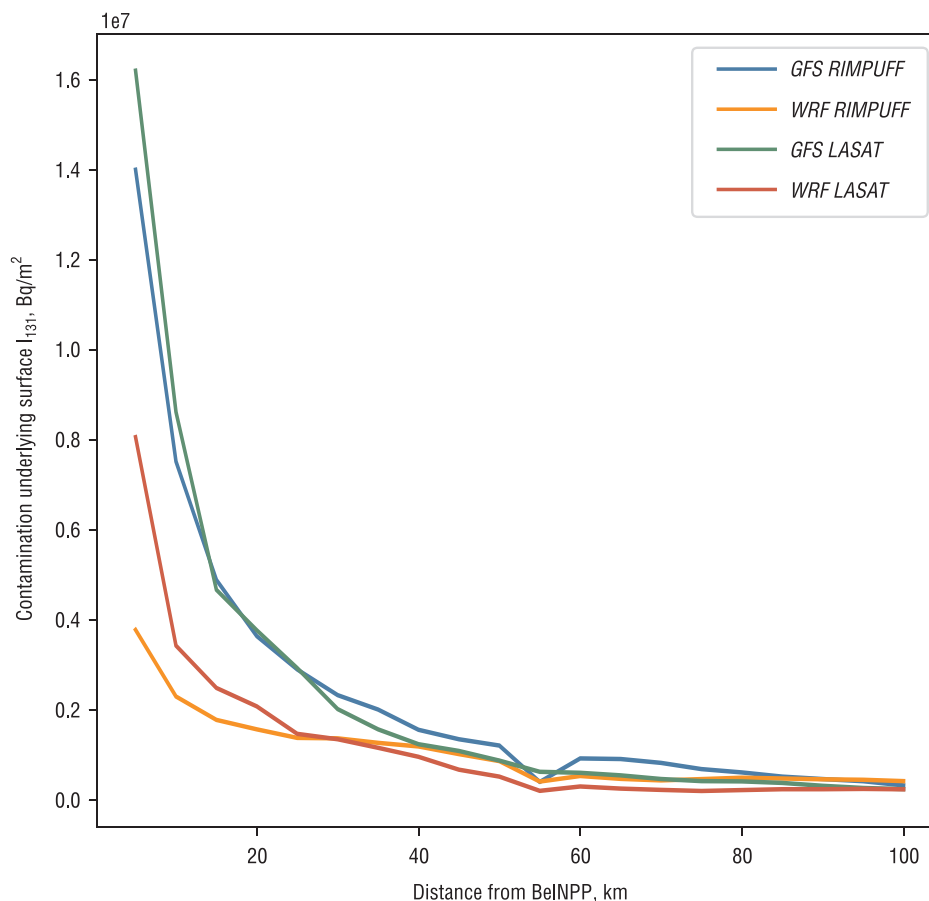


Figure 6. Maximum values of contamination density of the underlying surface I_{131} , Bq/m²

However, the use of *WRF* requires certain skills, as well as additional time for calculation, which can negatively affect the speed of protective measures in case of an emergency. Therefore, the feasibility of using *WRF* data requires additional research.

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