Radionuclide atmospheric transport after the forest fires in the Chernobyl Exclusion zone in 2015-2020: An impact of the source term parameterization and input meteorological data on modeling results

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Summary

- The highly contaminated Chornobyl exclusion zone (ChEZ) still remains a potential source of the additional atmosphere radioactive contamination due to forest fires there. The possible radionuclide transport outside the ChEZ in the direction of populated regions (including Kyiv) and its consequences for people health is a topic of a constant public concern in Ukraine and neighboring countries. The reliable models of radionuclide rising and following atmospheric transport, which should be integrated with data of stationary and mobile radiological monitoring, are necessary for real-time forecast and assessment of consequences of wildland fires.
- Results of intercomparison of models developed within the set of the national and internationals projects are presented, including: i) the point source term model of Atmospheric Dispersion Module (ADM) of the real-time online decision support system for offsite nuclear emergency – RODOS, which development was funded by EU; ii) the specialized new tool for modeling radionuclide dispersion from the polygons of the fired areas using the Lagrangian model LASAT incorporated into RODOS system; iii) the Lagrangian-Eulerian atmospheric dispersion model LEDI of ISP NPP using a volume source term and including a module for calculation of parameters a convective plume formed over a fire area; iv) Lagrangian model of Fukushima University. All atmospheric transport models use the results of the numerical weather forecast model WRF as the input meteorological information.
- The models evaluation was carried out using the measurement data during large wildland fires occurred in ChEZ in 2015 and 2018, including the ^{137}Cs volume activity measured within the Zone and outside it.
- In the last moment the modeling results were added into the presentation about the last large forest fires in the ChEZ in April 2020.

Modeling systems on radionuclide atmospheric transport due to the wildland fires in the Chornobyl exclusion zone

- ***Wildfire Module of RODOS -*** real time online decision support system for offsite emergency management (Raskob at al., 2018, Report of EUROAID EC project on RODOS implementation for ChEZ) includes:

✓ Gaussian Puff model RIMPUFF of radionuclide atmospheric transport (Mikkelsen et al., 2006) which combines Lagrangian and Eulerian approaches. It was applied for near and medium ranges in forest fire modeling for the point source term parametrization. The distributed source term approach is developed in by the KIT recently.

✓ Lagrangian Puff model DIPCOT which combines accounts for stochastic movement of puffs (Andronopoulos et al., 2010).

✓ Lagrangian long-range atmospheric transport model MATCH (Robertsson, 2010).

(both models are used to simulate atmospheric transport following wildfires represented as fixed number of point sources and hand-input release rates)

✓ Lagrangian particle transport model LASAT (Lohmeyer, 2010) integrated with the methodology developed by Kovalets et al. (2015). The software system help user to construct the poligons covering the fire areas, in which system calculated the inventory of radionuclides to be dispersed. The effective height of an area source is set from 10 m to 60 m depending a fire intensity.

- ***Wildfire modeling by the Largangian-Eulerian model LEDI (ISP NPP)***

The modeling system (Talerko, 2004-2019) includes the radionuclide atmospheric transport model LEDI (Lagrangian trajectory model for the contaminant puff transport + turbulent diffusion equation to describe the contaminant dispersion inside each puff) and the model of convective plume which could be formed above the fire area. A plume is treated as a volume source with height-varying intensity for following radionuclide atmospheric transport using the diffusion model LEDI. They are applied for near range - medium range transport from wildfires.

- ***Wildfire modeling by the Lagrangian model Hirao (IER FU)***

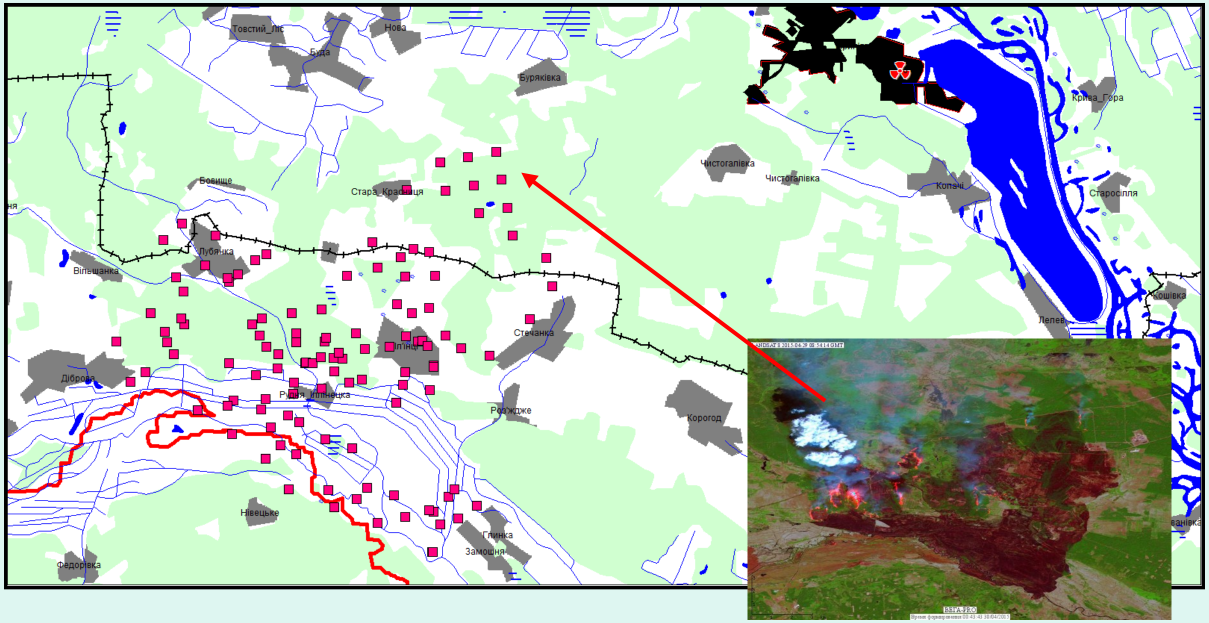
The Lagrangian model (Hirao, 2015), that was tested recently versus monitoring data measured after the Fukushima-Daiichi accident (Hirao, 2018).

All modeling systems are coupled with a mesoscale weather forecasting model WRF (NCAR/NCEP) customized by IMMSP for the territory of Ukraine.

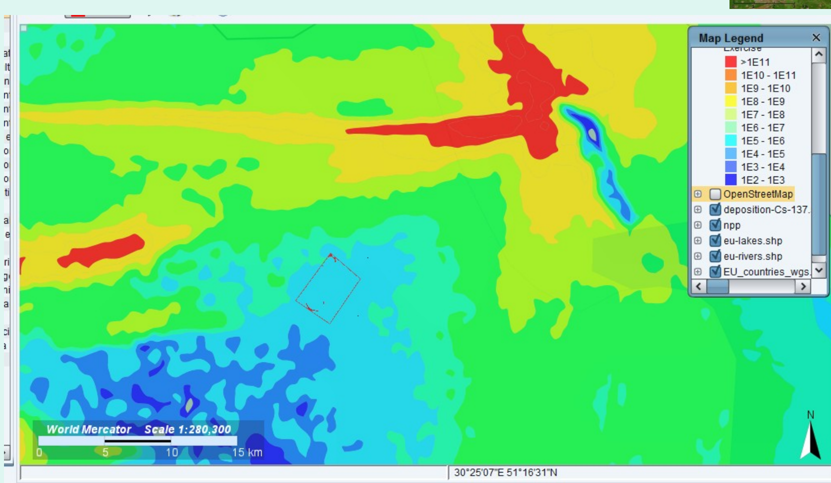
2015

Wildland fires in the Chornobyl exclusion zone in April 2015

The total fire area during 26-30 April 2015 was over 11 000 ha

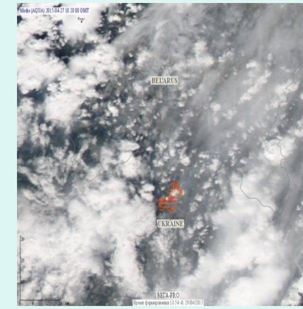


There was a fire at the territory of a radioactive waste disposal site



Density of ^{137}Cs contamination (kBq m^{-2}) within the Chornobyl exclusion zone

10:20 27.04



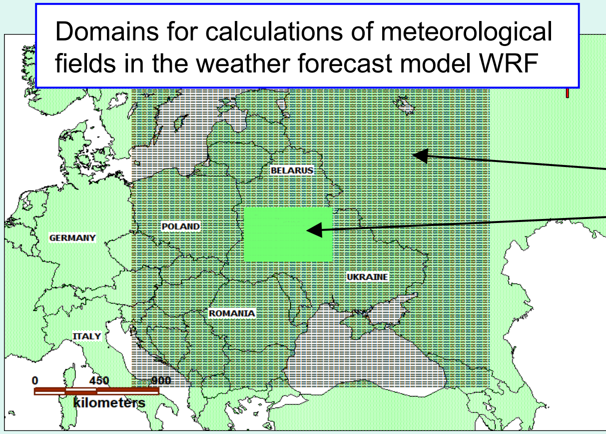
9:15 28.04

8:20 29.04

9:05 30.04

Modeling of long-range atmospheric transport of radioactive aerosols due to the forest fire in April 2015

Domains for calculations of meteorological fields in the weather forecast model WRF



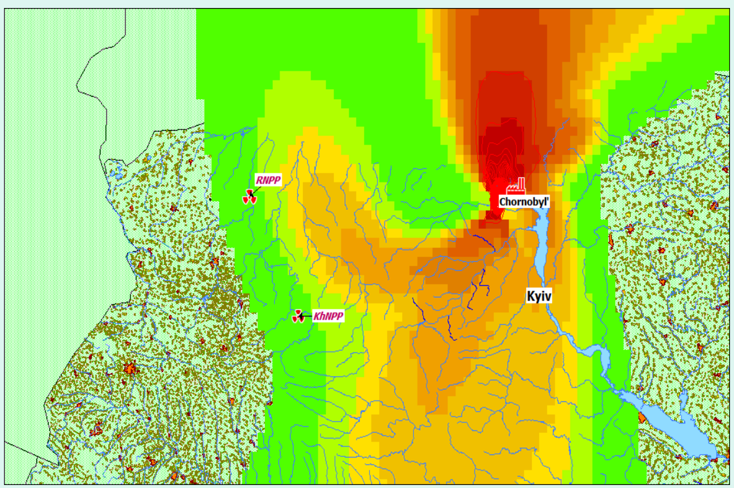
Grid1 step=0.15 deg

Grid2 step=0.05 deg

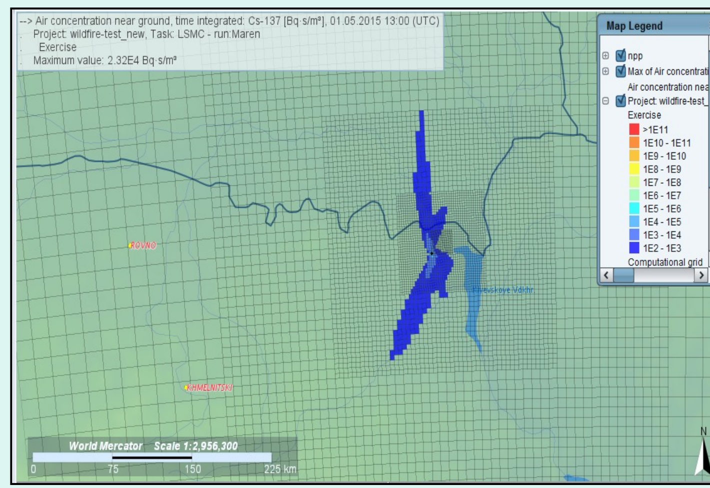
Calculated and measured ^{137}Cs volume concentration (μBq/m^3) at Rivne and Khmelnitsky NPP

Site	Averaging period	Measure-ment	RODOS	LEDI
KhNPP	30.04-03.05	4	22	17
RNPP	30.04, 15:00-01.05, 08:00	17	34	53
RNPP	01.05, 08:00-02.05, 08:00	7	9.6	28

Modeling results of LEDI



Modeling results of RODOS LASAT



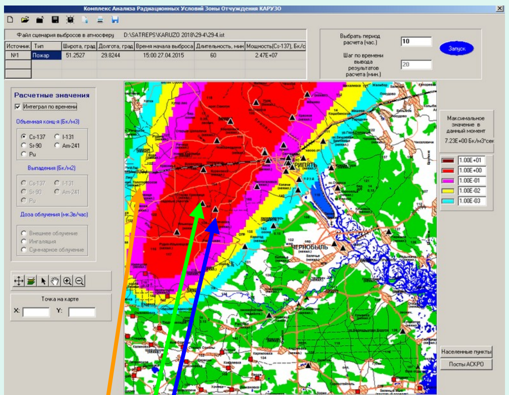
Integral volume concentration of Cs-137 from 28.04 to 02.05

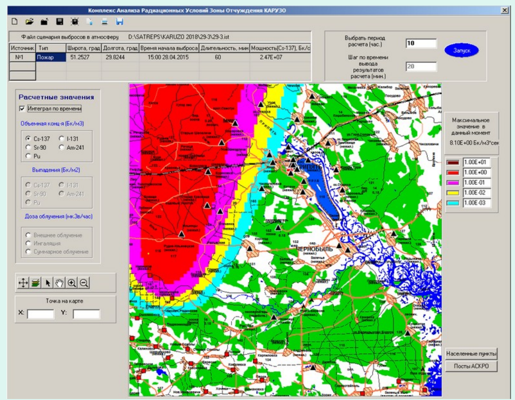
Using meteodata from the WRF coarse domain (Grid1) compared with the nested domain (Grid2) resulted in 2-5 times underestimation of results for distances over 10 km, and in overestimation in 2-3 times near the source.

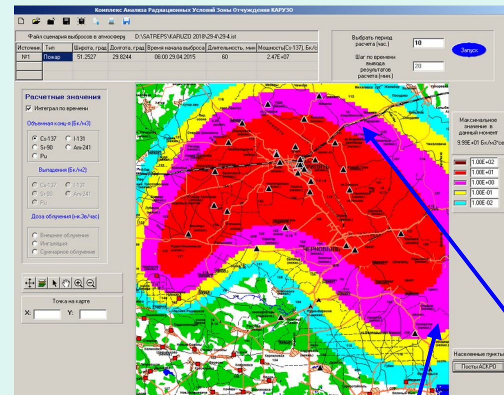
Results for the Chornobyl exclusion zone territory (LEDI short-range modeling)

Time-integrated ^{137}Cs volume activity concentration caused by the forest fire in April 2015

27 April **28 April** **29 April**

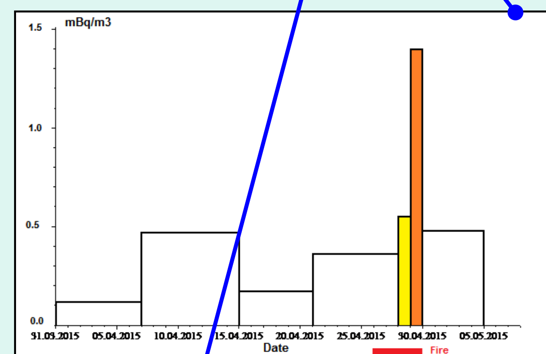






For short-range modeling a volume source term approach was used (a convective plume model over the fire area)

The ^{137}Cs volume activity measurements at the Chornobyl NPP industrial site



^{137}Cs volume activity, mBq/m^3 (SSE Ecocenter measurements)

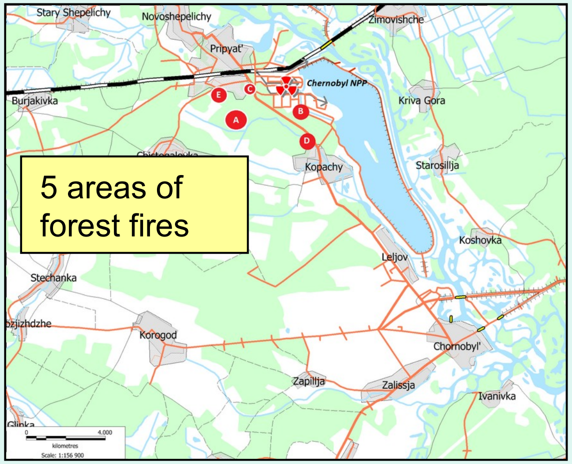
Sampling point	Sampling date	Modeling	Measurement	Control level
Stechanka	27.04.2015	0.63	0.77	
Stara Krasnytsya	28.04.2015	6.6	7.6	10
Lubyanka	29.04.2015	0.12	1.4	

Sampling date	^{137}Cs volume activity, mBq/m^3
29.04.2015	0.030
30.04.2015	0.38

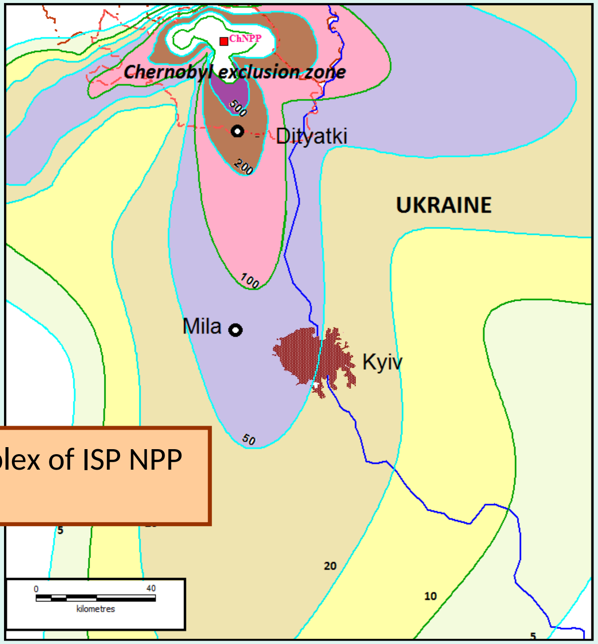
Measurements at the Chornobyl meteorological station

2018

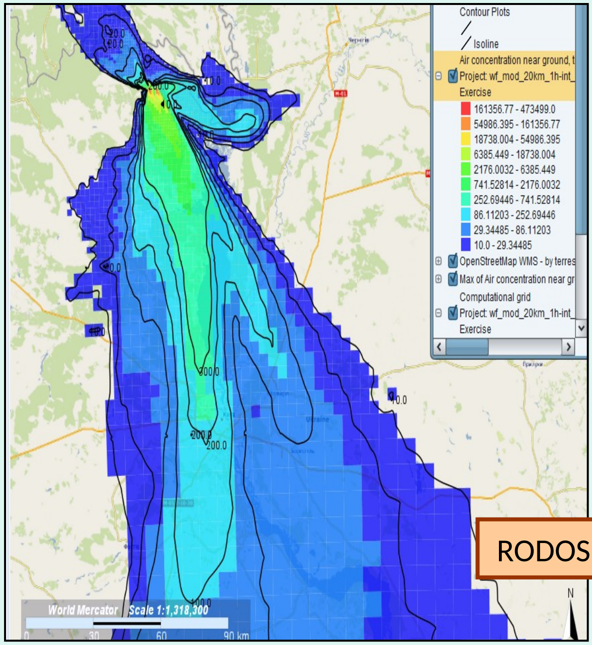
Evaluation of the air radioactive contamination due to the forest fire in the Chornobyl exclusion zone in 5-8 June 2018



Time-integrated Cs-137 activity concentration in the air for the entire period of the fire (Bq*s/m³)



Modeling complex of ISP NPP (LEDI)

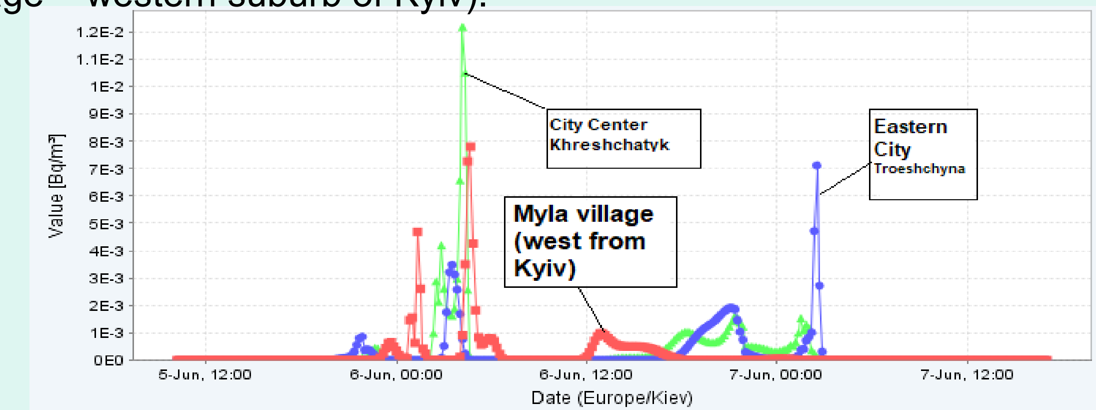


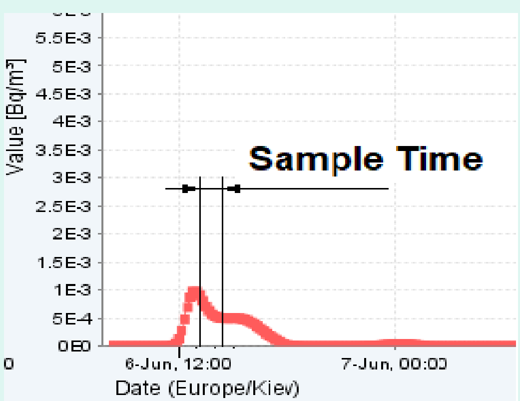
RODOS (ADM: LASAT)

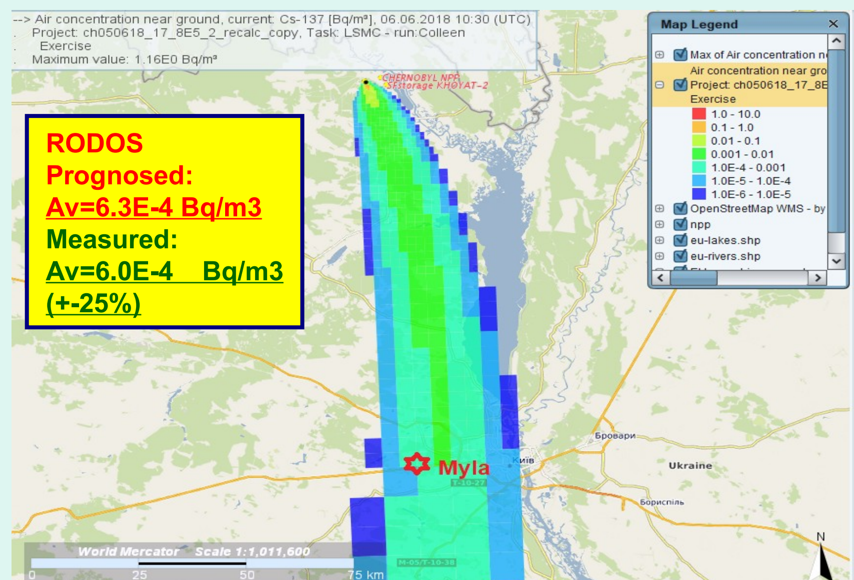
Total ^{137}Cs emission into the atmosphere during the forest fire estimated at 28 GBq

Combined use of the RanidSONNI mobile laboratory hardware and RODOS DSS computer technologies for rapid response to possible transport of radioactive aerosols outside the Chornobyl exclusion zone

- The atmospheric transport of radioactive aerosol to Kyiv from the fire area was forecasted;
- The ^{137}Cs volume activity concentration was measured at a place of prognostic maximal value (Myla village – western suburb of Kyiv).

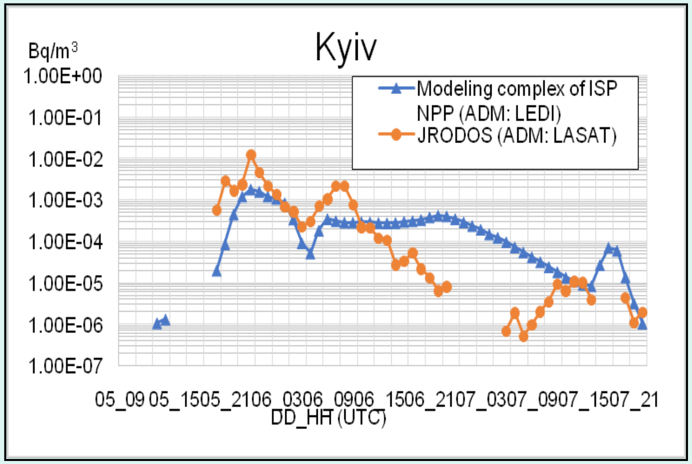




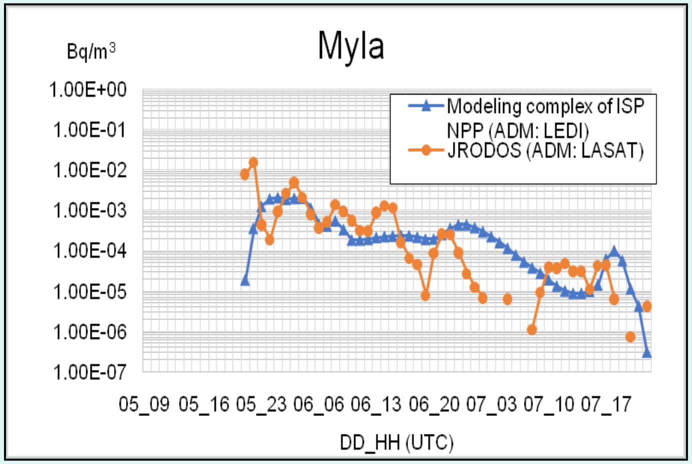


Comparison of the Cs-137 volume activity concentration (1-hr averaged) modeling results (LEDI and RODOS/LASAT) for 4 settlements

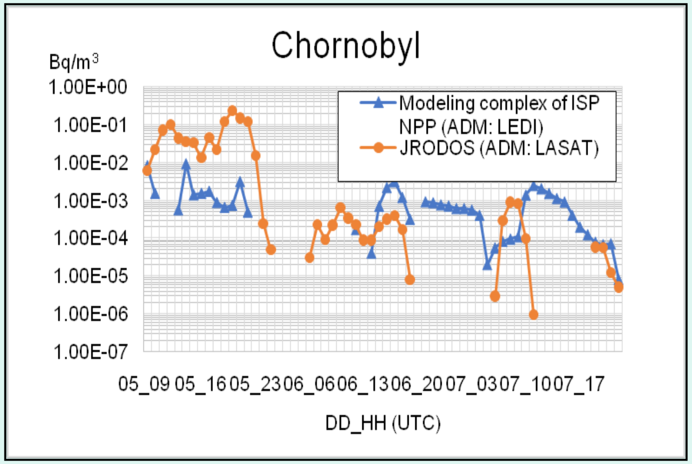
110 km from the fire area



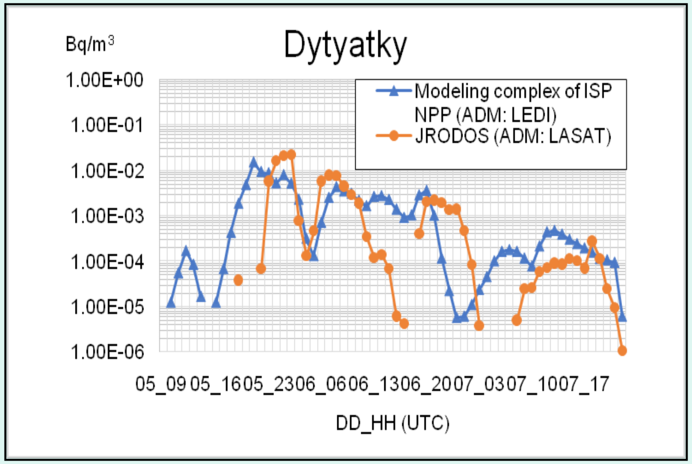
100 km from the fire area



25 km from the fire area



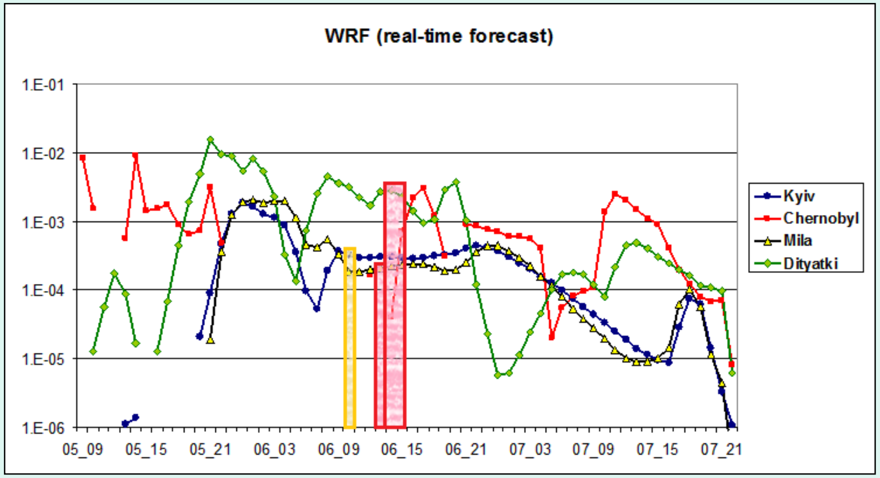
30 km from the fire area



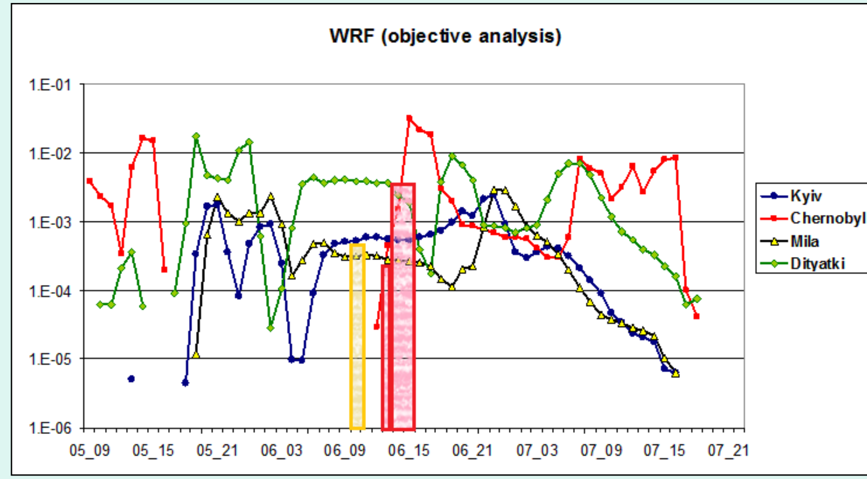
General dynamics of both model results is similar, but for some periods (especially of fast changing meteorological conditions) the differences may arise up two orders of magnitude.
The differences increase with decreasing distance to the source (Chornobyl and Dytyatky).

LEDI modeling results with using two similar WRF meteorology sets: real-time forecast and obtained after an objective analysis

Bq/m³



Date_Hour



Date_Hour

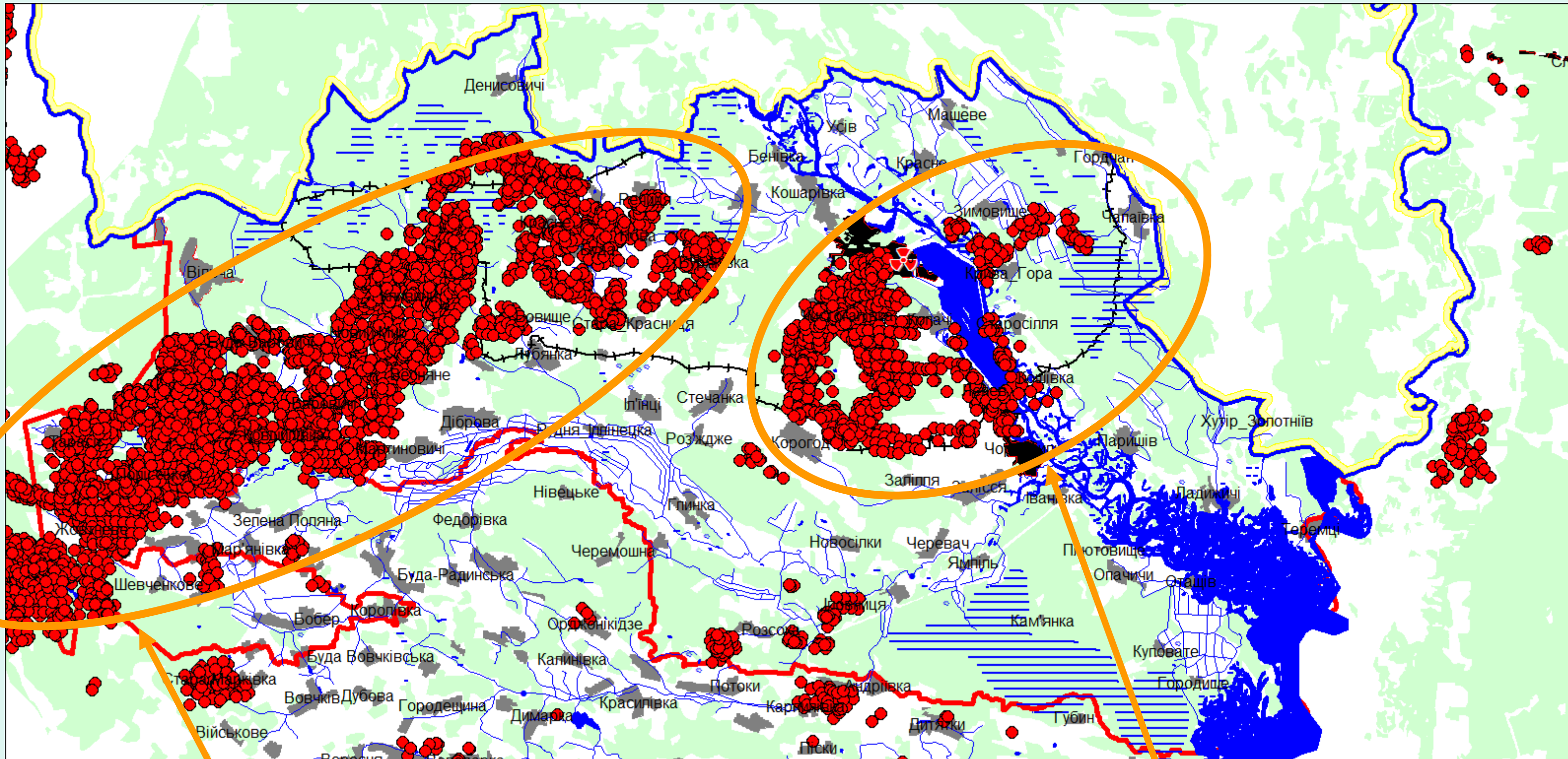
Columns indicate periods and results of the air activity measurements in Chornobyl (red) and Myla (yellow)

According to calculations using real-time WRF meteorological data, the maximum activity of ^{137}Cs (averaged over a 1 hour period) in the surface air for Kyiv reached 1.8 mBq/m³ at 21 h. 05.06. For Chornobyl city the estimated maximum ^{137}Cs activity in the air was about 10 mBq/m³.

Calculations using WRF meteorological data after an objective analysis give similar results for relatively distant sites (Kyiv and Myla). For nearest sites Chornobyl and Dytyatky the largest differences between results for two meteorological input data sets was obtained for the period of the second half of June, 7, when a large wind direction change took place. A significance of meteorological input data quality increases for near zone modeling (up to several kilometers from the fire area) especially for complicated (quickly changing) meteorological condition during a radionuclide atmospheric transport.

April 2020

Modeling of atmospheric transport of radioactive aerosols due to the forest fire in April 2020 in the territory of Ukraine



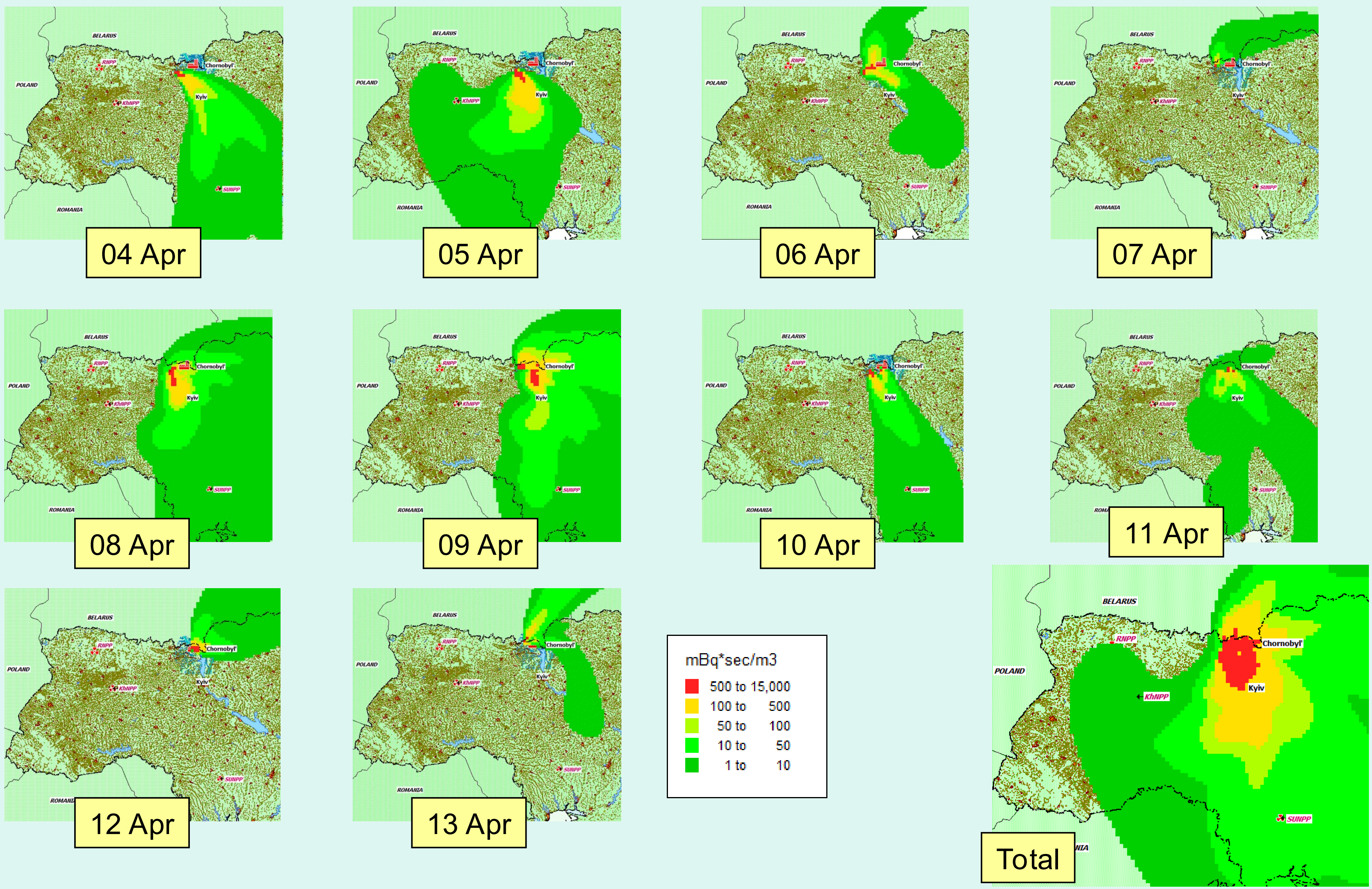
Active fire detections from MODIS and VIIRS satellites
(data of NASA Fire Information for Resource Management System)
Total from 03 to 13 April 2020

2 main fire areas were identified during this period:
Polisske (moved to the north-east); Kopachi-Chystohalivka-ChNPP cooling pond

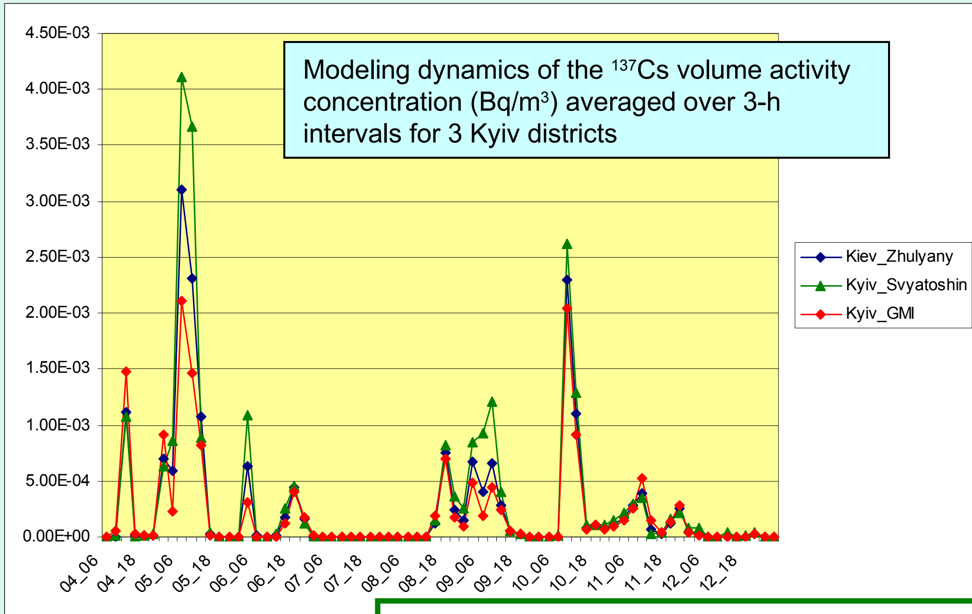
Total ^{137}Cs emission into the atmosphere during 03-13 April
from two main forest fire regions in the Exclusion zone estimated at 350 GBq
(independent estimations of Ukrainian Hydrometeorological Institute)

Modeling results for Ukraine (LEDI)

Time-integrated ^{137}Cs activity concentration caused by the forest fire in April 2020



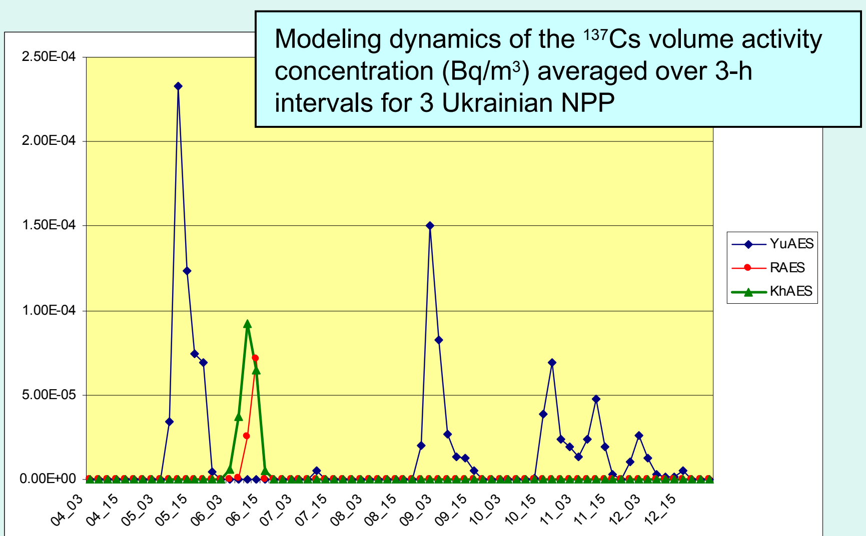
Comparison of modeling results (LEDI) and measurement data



Kyiv

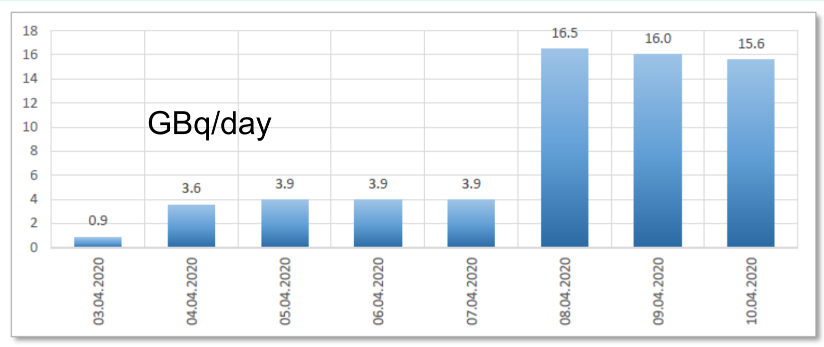
Sampling data	Cs-137 volume activity (mBq/m³)	
	CGO measurement	Modeling
2-5.04	<0.03	0.20
5-6.04	<0.095	0.33
6-7.04	<0.11	0.088
7-8.04	<0.14	0
8-9.04	0.29	0.23
9-10.04	<0.14	0.096
10-11.04	**0.70**	**0.46**
11-12.04	0.17	0.15
12-13.04	<0.18	0.0045

Rivne, Khmelnitsky and Yuzhno-Ukrainian NPPs



	Sampling data	^{137}Cs volume activity (μBq/m3)	
		Measurement	Model
YuNPP	31.03-7.04	8.27	9.72
	2-9.04	17.5	14.2
	6-10.04	14.5	9.58
RNPP	5-6.04	13.5	3.21
	6-7.04	31	8.95
	7-8.04	6.3	0
	8-9.04	11.1	0
	9-10.04	<3.9	0
KhNPP	5-6.04	14.5	17.0
	6-7.04	42.5	8.75
	7-8.04	<3.2	0

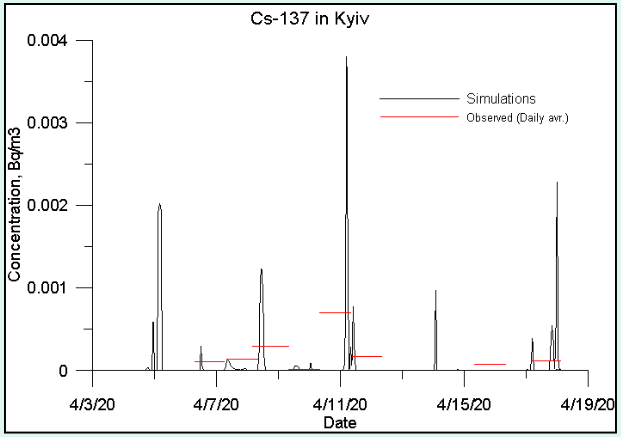
Modeling results for the fire in April 2020 (RODOS)

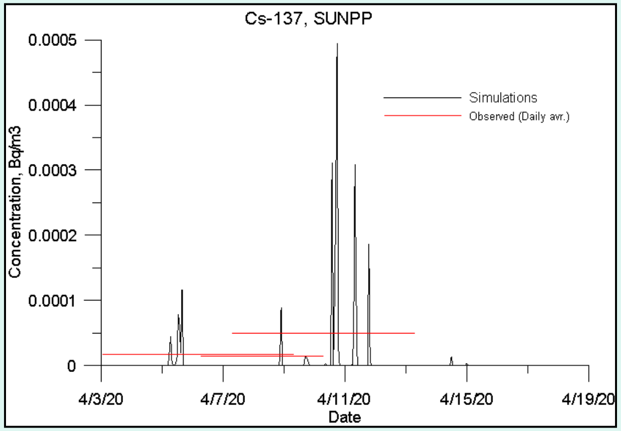


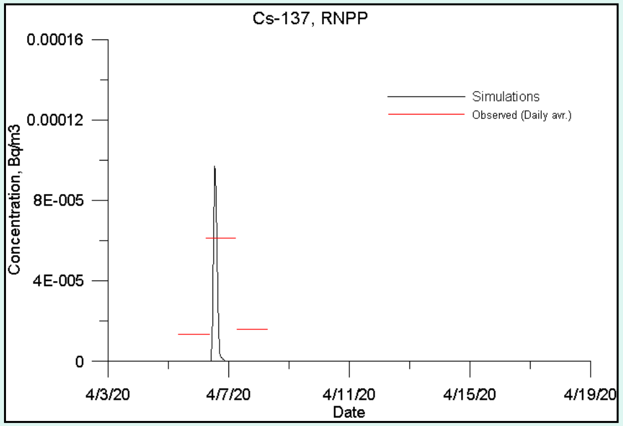
Emission assessment using inverse run of RODOS MATCH (Romanenko, Kovalets 2020)

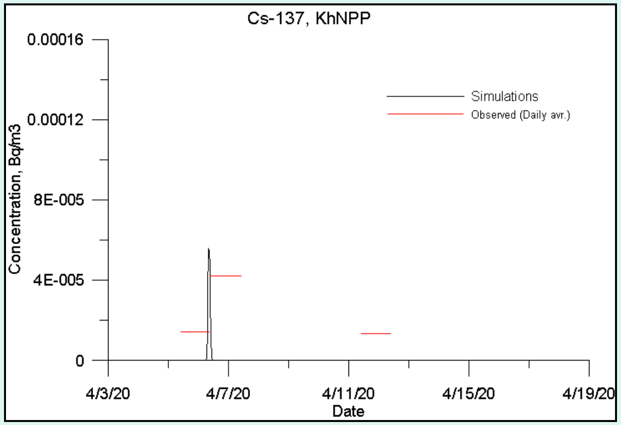
Then constant up to 13 April, zero during 14-15 Apr.
Special case of dust storm: by our estimates ash resuspension together with renewed fires could yield release of about 20GBq/day on 16 April

Simulations with RODOS RIMPUFF using previously estimated source term for the fire in April 2020









Conclusions

- The used models of atmospheric transport of radioactive aerosols in combination with mobile and stationary environment sampling tools enable to both real-time online predict the radioactive contamination in the surface air and to carry out later a more detailed reconstruction of the radiation situation during wildland fires in the Chornobyl exclusion zone (ChEZ).

- The comparison of modeling results of radioactive aerosols dispersion versus monitoring data is providing within the Japanese-Ukrainian SATREPS Project to improve the prediction tools by the better parameterization of the source terms during the wildfires depending from the classes of the forests and kinds of the wildfire.

- During periods of large wildland fires in the ChEZ (with burning area of about 1000-10000 ha) the total ^{137}Cs emission into the atmosphere on fine aerosol particles can be estimated in the range of 100 -1000 GBq.

- During wildland fires in the ChEZ the ^{137}Cs volume activity in Kyiv (at a distance about 100 km) can reach several mBq/m^3 for a short time (up to several hours), and the daily average values can reach tens to hundreds of μBq/m^3. Within the ChEZ the daily average volume activity can reach tens of mBq/m^3. At a distance of 250-400 km the ^{137}Cs daily average activity can increase by an order of magnitude relative to background values - up to tens of μBq/m^3.

Conclusions (2)

- The correct estimation of the source term is the main problem to reduce the uncertainties in the air radioactive contamination modeling during the wildland fires. The main factors determining the quality of modeling at a regional scale and for long-distance transport are the estimation of the fire area and the activity emission into the atmosphere. The parameterization of the initial form of the source and the estimation of its effective height are of a less importance.

- For the short-range transport modeling (inside the ChEZ) the impact of the source parameterization increases. The volume source term approach (a convective plume model over the fire area) could be preferable.

- Two main approaches for estimation of radionuclide emission into the atmosphere during the wildland fires based on

  1) direct estimation of the radionuclide inventory within the fire area with using satellite observations and ground measurement data, and

  2) the solution of the inverse task of atmospheric transport with using the air contamination measurement data around the fire territory

  may result in rather contradictory results. Additional efforts are needed for their adjustment.

Conclusions (3)

- An impact of input meteorological data on modeling results was estimated for two sets of the WRF calculations data - forecast mode and after an objective analysis. Quite similar results of the radionuclide atmospheric contamination are obtained for medium range transport. A significance of meteorological input data quality increases for the short range modeling (up to several kilometers from the fire area) especially for complicated (quickly changing) meteorological condition during a radionuclide atmospheric transport.
- Using input meteorological data from the WRF coarse domain (horizontal grid step 0.15 deg) compared with the nested domain (grid step 0.05 deg) resulted in 2-5 times underestimation of results of the radionuclide air contamination modeling for distances over 10 km, and in overestimation in 2-3 times near the source.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Thank you for your attention!