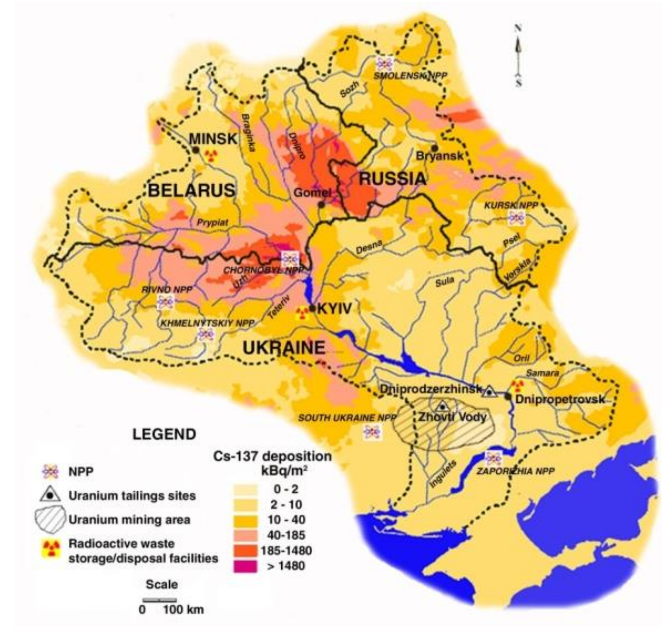
Review of atmospheric transport modeling in IMMSP

Ivan Kovalets

Division of Environmental Modelling (DEM) - IMMSP

has been established in May, 1986, following Chornobyl Accident.



First team lead – Dr Mark Zheleznyak, since Nov 2013 – Professor of Institute of Environmental Radioactivity Fukushima University

Present Head: Dr. Igor Brovchenko, Corresponding Member of NASU

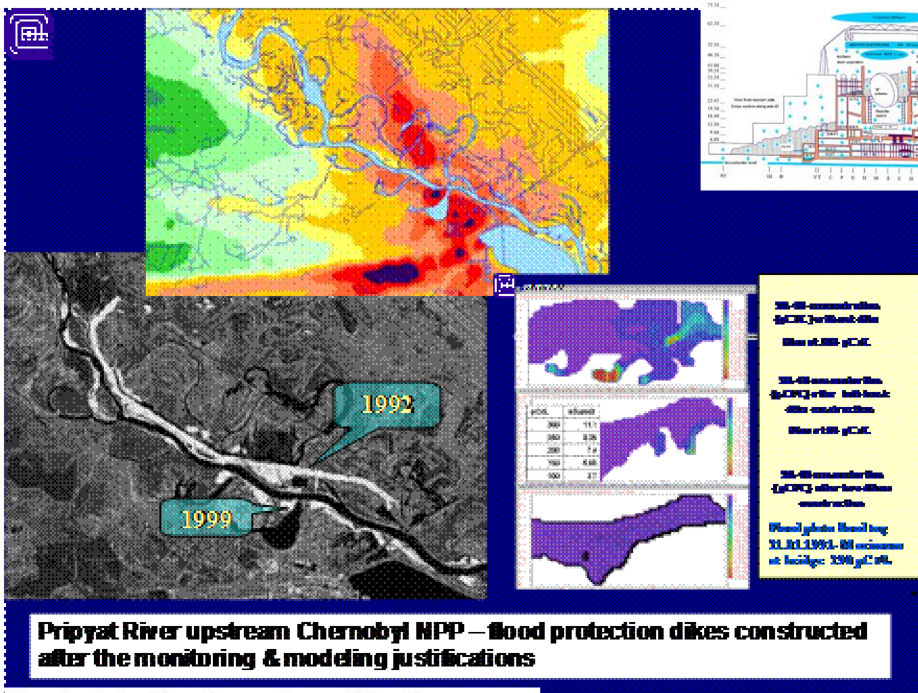
Research provided by **two** Departments headed by

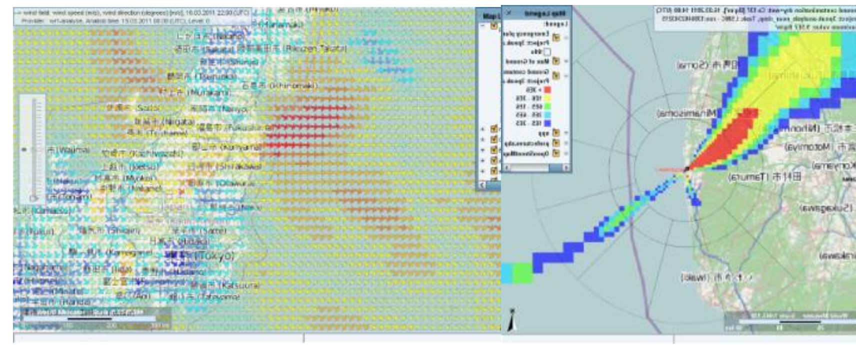
Dr. Ivan Kovalets (*Dep. of Environmental Informatics and Atmospheric Modeling*),

Prof. **Vladimir Maderich** (*Dep. of Marine and River Systems Modeling*)

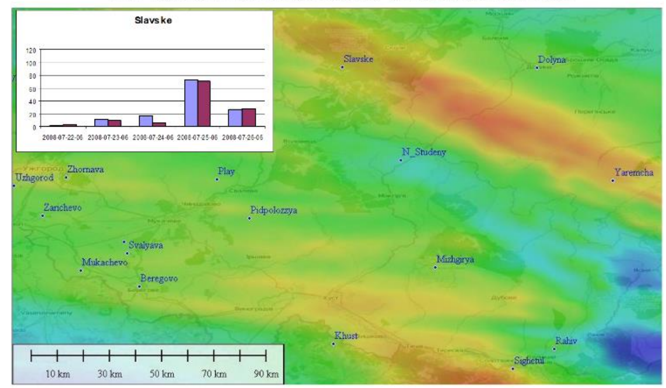
as also by the spinoff company of IMMSP- Ukrainian Center of Environmental and Water Projects (**UCEWP**) www.ucewp.kiev.ua

Research fields and some applications

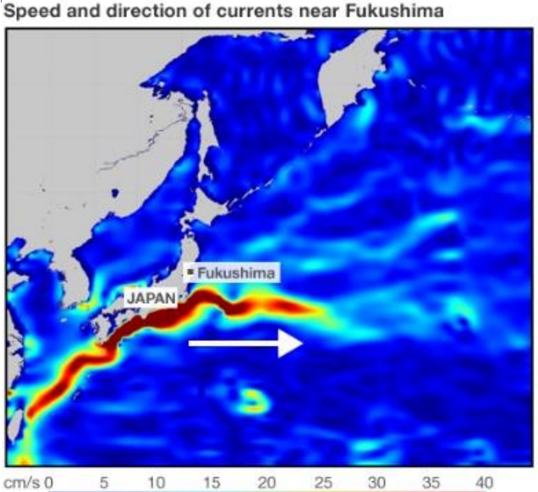


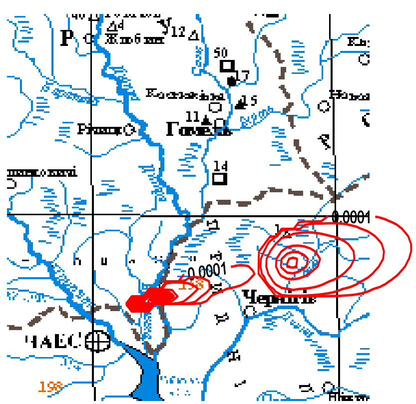


WRF-simulated extreme precipitation during flood of July, 2008

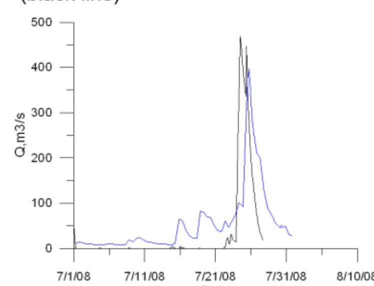


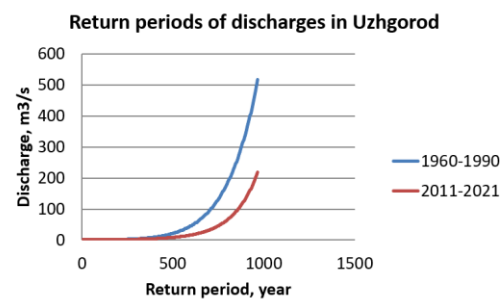
Speed and direction of currents near Fukushima





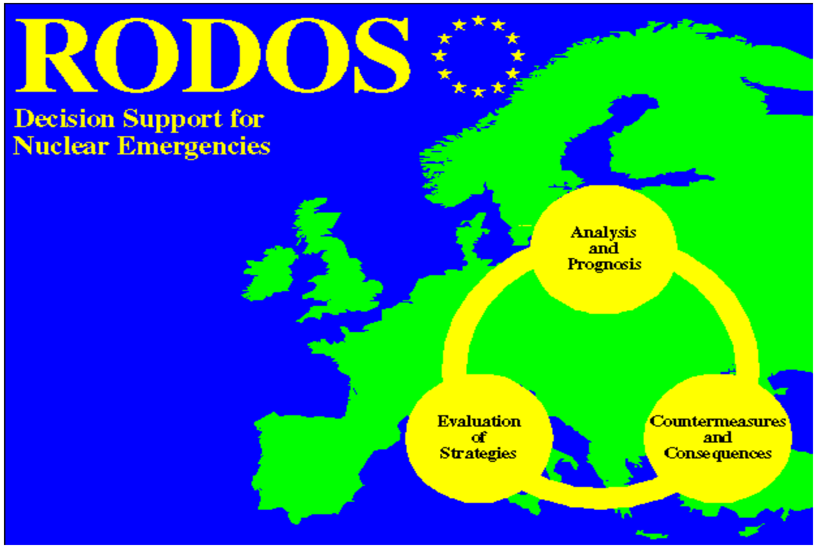
Forecasted with DHSVM-Ukraine water discharge in Uzhgorod (flood of July, 2008) as compared with measurements (black line)





Involvement of DEM in the development of the EU nuclear emergency response system RODOS (since 1994)

- Lead on the development of Hydrological Dispersion Module (HDM):
  1D river transport model RIVTOX, 2D transport model COASTOX, 3D transport model THREETOX
- **Participation in the development of Atmospheric Dispersion Module (ADM)**
- Co-developer of the software kernel of RODOS system
- Responsible for RODOS implementation in Ukraine



Development of RODOS ADM in collaboration with NCSR 'Demokritos', Greece, since 2002:

- Data assimilation of meteorological measurements in the meteorological pre-processor of RODOS

- Source inversion method to evaluate time dependent emission inventories using gamma dose rate measurements in Lagrangian atmospheric transport model of RODOS

- Source inversion method to evaluate source location, inventory and time paramers using concentration measurements (in particular applied to Ru-106 case in the fall of 2017)

Developed in frame of EURATOM grants

Recent research project

(2021-2023) Direct and inverse problems of pollution distribution in the atmospheric and marine environment and their use to identify sources of pollution

National Research Fund of Ukraine – project to support young and experienced researchers

Other work related to atmospheric transport modeling

Weather prediction:

- Weather forecasting system WRF-Ukraine – operationally used in Ukrainian Hydrometeorological Centet for supply of RODOS with numerical weather prediction data and for floods forecasting in Transcarpathian region

Environmental safety assessment studies related air pollution:

- NPPs in Ukraine and in the world (Fukushima and others)
- Chernobyl Exclusion Zone (New Safe Confinement, wildfires, resuspension)
- Radioactive aerosols and radon created by former uranium facilities in Ukraine (Pridneprovsky Chemical Plant)
- Deep geological disposals: models of C-14 transport in vegetated canopies, tested against data of Norunda station in Sweden **and SMEAR-II station in Finland**
- Some non-radiological studies connected to air pollution

Ensemble iterative source inversion method (EISIM, Kovalets et al. 2022)

Goals

- to take into account uncertainties of inexactly known input meteorological data and model parameters parameters by developing ensemble source term estimation (STE) methodology
- Combined inverse modeling of wildfires and dust storm
  - to evaluate emission inventories during wildfires in ChEZ together with their confidence limits
  - to evaluate of contribution of the dust storm in radioactive air pollution during this event

Details of method

- Ensemble of estimates

- Nonlinear regression problem due to dependence of model error covariance matrix on solution q

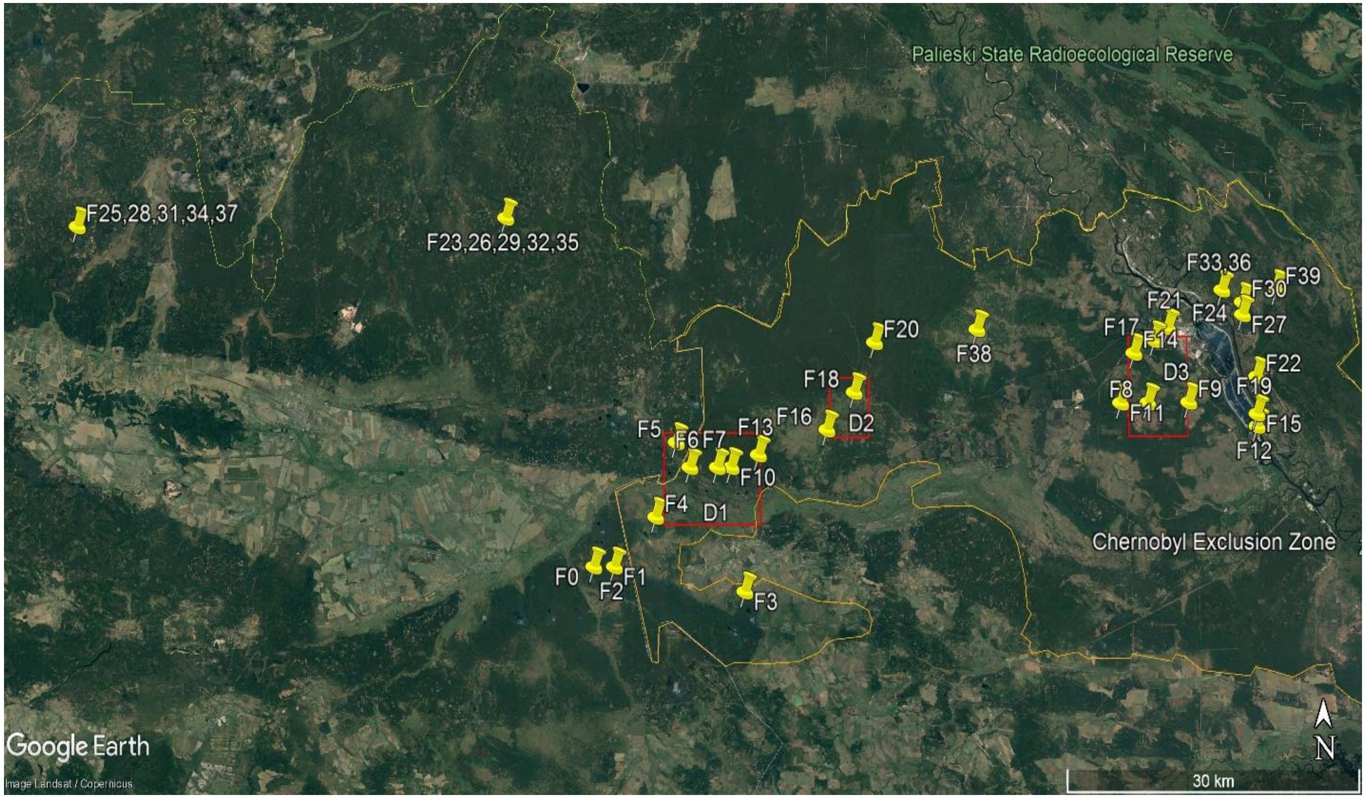
$$J_m = \left(\underline{\underline{G}}_m \underline{q}_m - \underline{y} \right)^T \left(\underline{\underline{F}} \left(\underline{q}_m \right)^{-1} \right) \left(\underline{\underline{G}}_m \underline{q}_m - \underline{y} \right) + \left(\underline{q}_m - \underline{q}_B \right)^T \left(\underline{\underline{B}}^{-1} \right) \left(\underline{q}_m - \underline{q}_B \right) \underset{\underline{q}_m}{\rightarrow} \min$$

$$1 \leq m \leq N_e$$

$$\underline{\underline{F}}\left(\underline{q}\right) = \underline{\underline{M}}\left(\underline{q}\right) + \underline{\underline{O}} = \left\langle \left(\underline{c} - \left\langle \underline{c} \right\rangle \right) \left(\underline{c} - \left\langle \underline{c} \right\rangle \right)^T \right\rangle + \underline{\underline{O}}$$

The most powerful in history wildfires in Chernobyl Exclusion Zone (ChEZ)

3-20 April, 2020, covered 30,000 ha in ChEZ , including the most contaminated parts of ChEZ like "Red Forest"

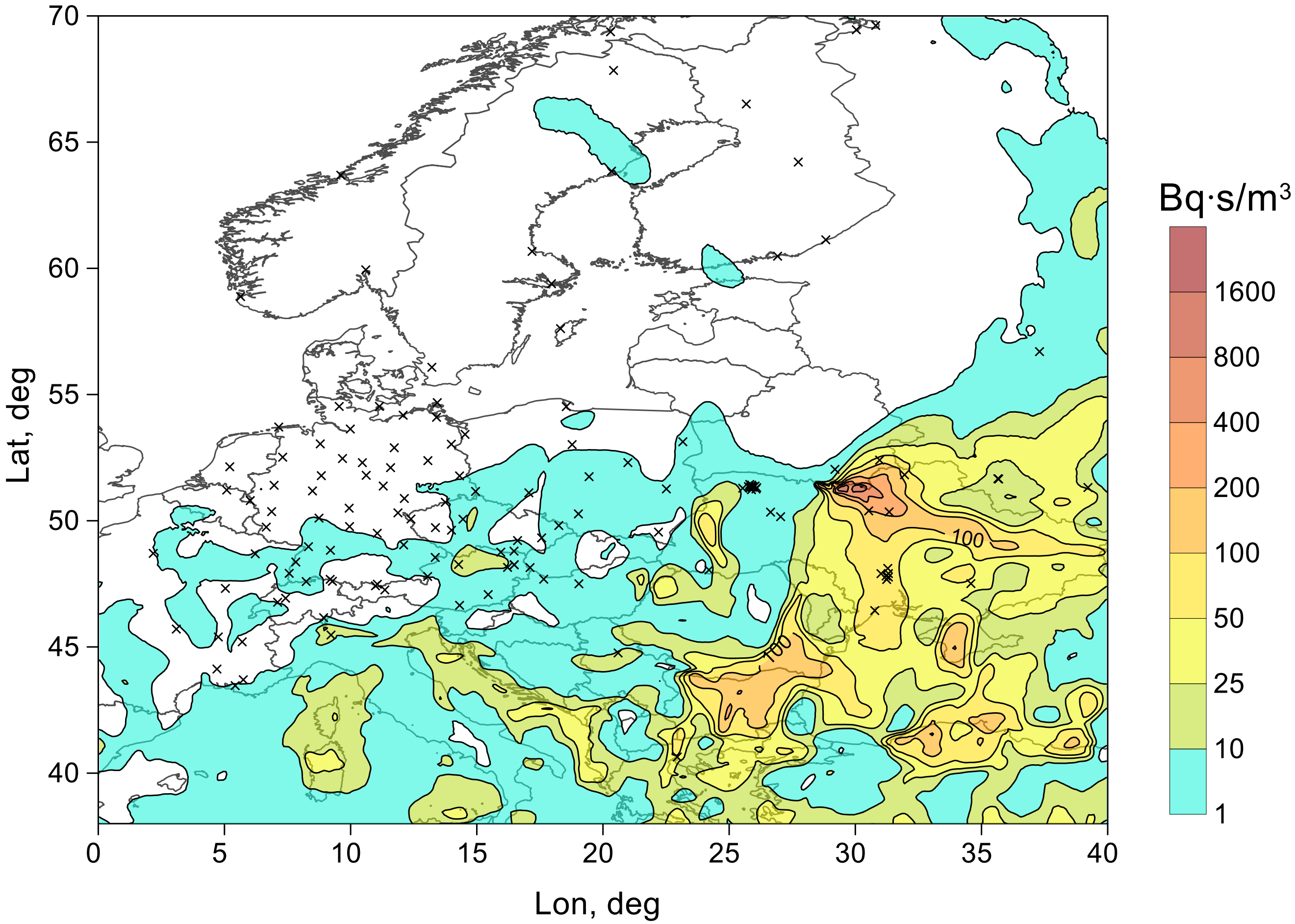


On 16-17 April wildfires were accompanied by **dust storm that covered Northern Ukraine**

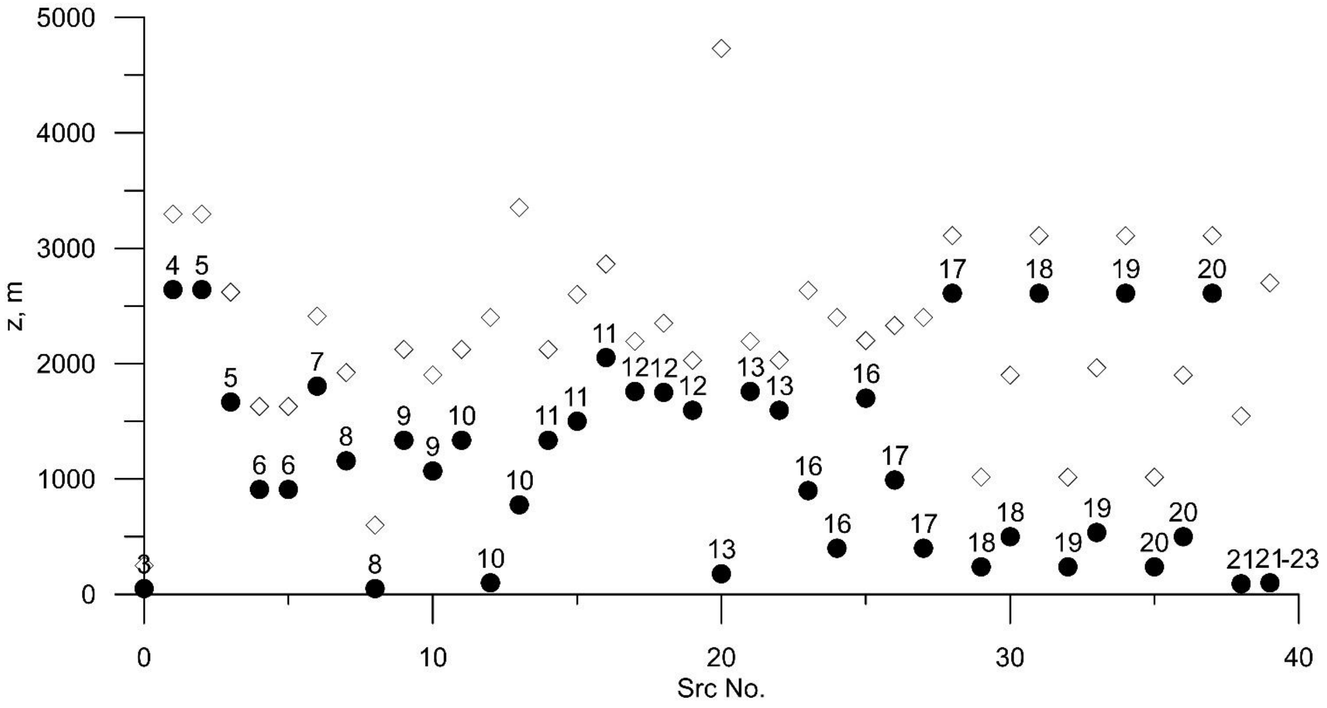
- the first dust storm in this region in a few last decades according to State Emergency Service of Ukraine

The dust storm on 16 April 2020
Image source:
https://www.pravda.com.ua/news/2020/04/17/7248378/

Measurement stations used for inverse modeling and time integrated concentration of Cs-137 for the whole simulation period (3-27.04.2020)



Lower and upper heights of convective plumes according to data processed from Copernicus Atmosphere Monitoring Service (CAMS) Product: Global Fire Assimilation System GFAS



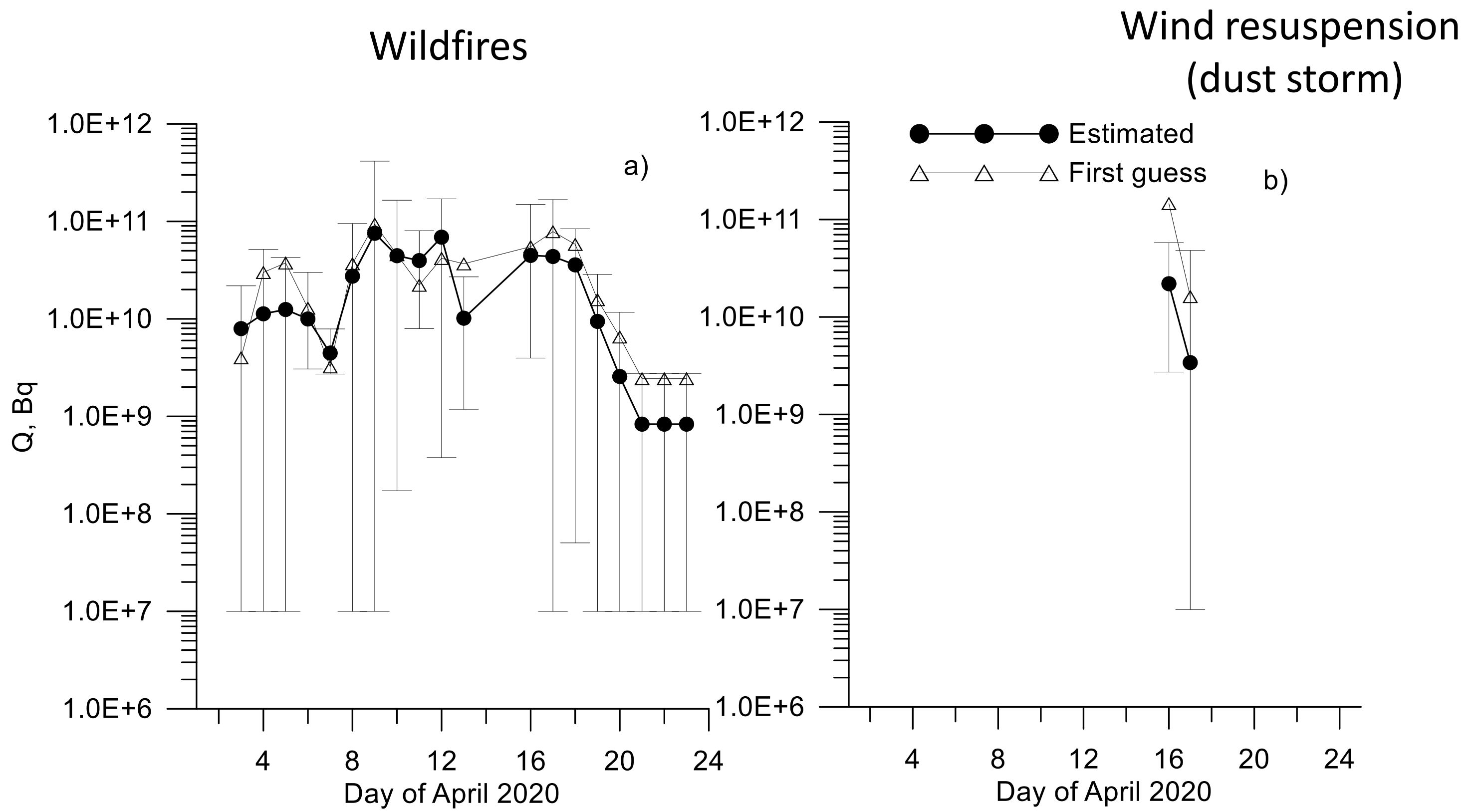
Picture from Kovalets et al. (2022) Atmos. Env., Elsevier

Formation of ensemble:

- Meteorological fields – 22 realizations in GEFS forecasts by NCEP were input to FLEXPART Lagrangian transport model
- varying *fraction emitted between 0 and* z_{bot}
- varying *fraction emitted between* z_{bot} *and* z_{top}
- Varying *fractions of the size 1, 8 and 16 µm*

In total – 792 ensemble members

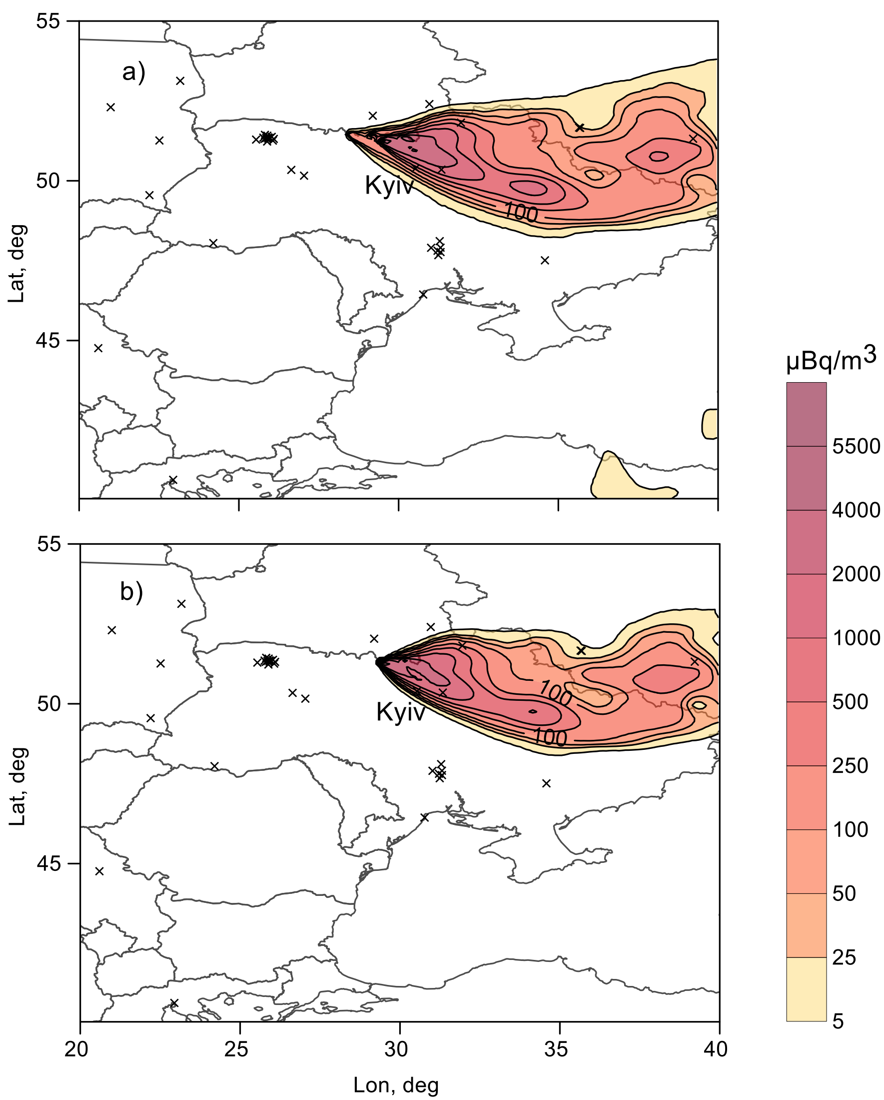
Estimated emissions



Kovalets et al. (2020) Atmos. Env., doi: [10.1016/j.atmosenv.2022.119305](https://doi.org/10.1016/j.atmosenv.2022.119305)

Wildfires: 578 GBq, between 39 and 1530 GBq

Dust storm: 25 GBq, between 3 and 93 GBq



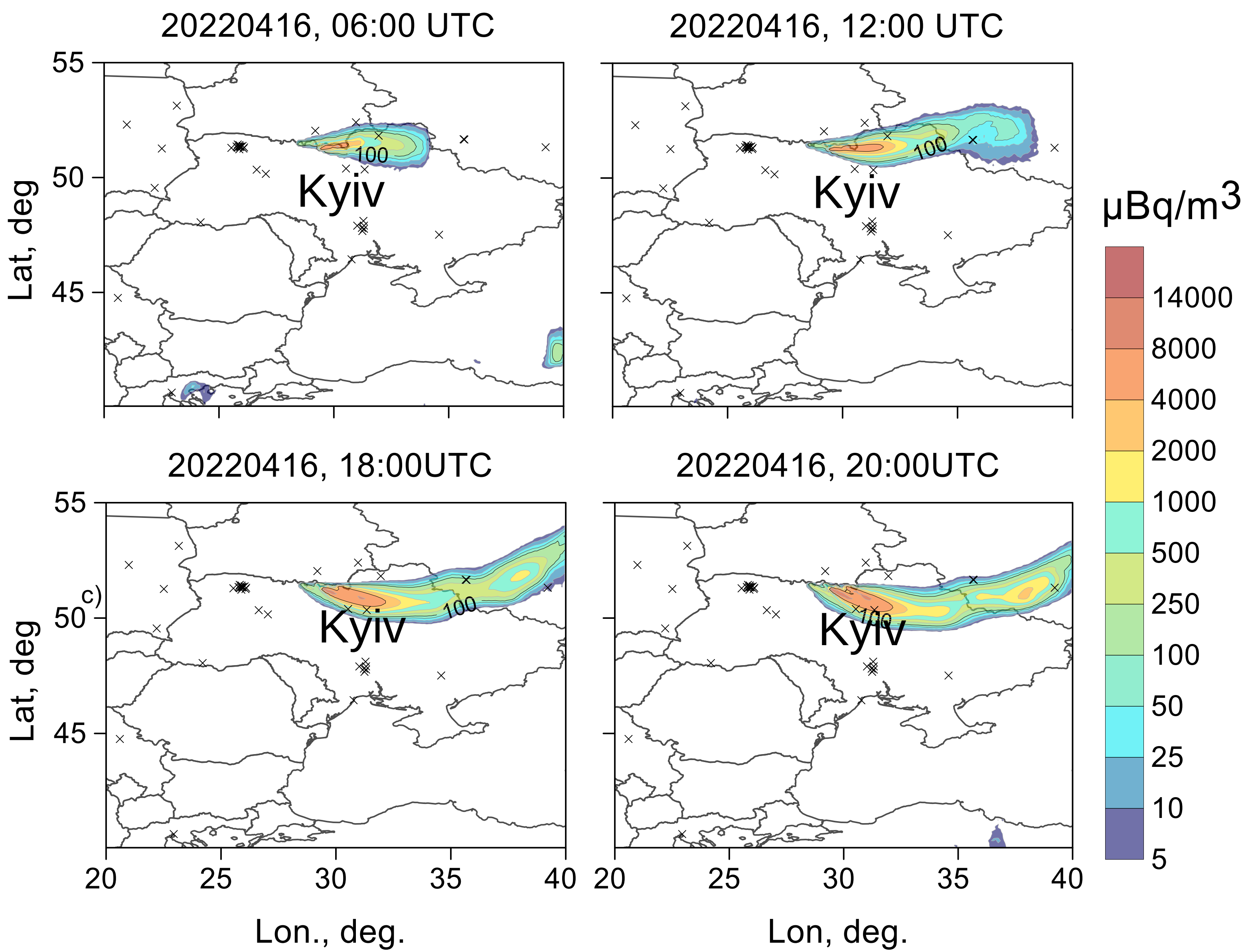
The simulated ground-level distribution of concentration of ^{137}Cs averaged for the 24 hr period (16.04.2022, 06 UTC -17.04.2022, 06 UTC);

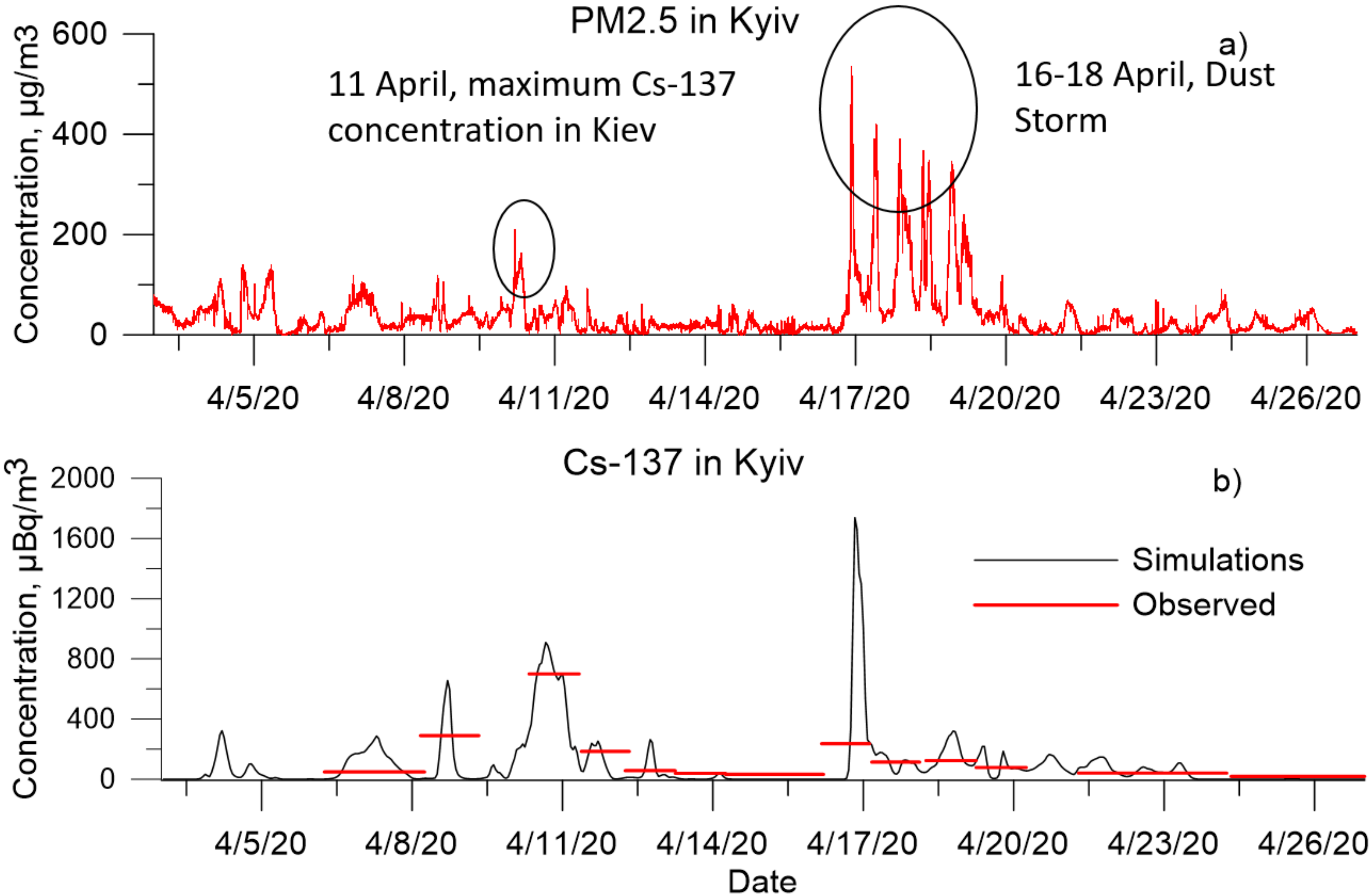
a) concentration created by all sources;

b) concentration created only by wind resuspension during the dust storm;

Isolines: 1, 25, 50, 100, 250, 500, 1500, 2500 µBq·m^{-3}.

Instantaneous concentrations of Cs-137





a) Time series of PM2.5 concentrations in Kyiv according to measurement data from www.saveecobot.com;

b) time series of observed (Masson et al., 2021) and simulated concentrations of ^{137}Cs in Kyiv.

Contribution of different parameters in total variation of emission estimates

Table Average variations of total emissions δQ_{φ} caused by changing:
I-the input meteorological data;
II- parameters of height distribution of the release;
III- parameters describing the size distribution of particles emitted by wildfires; and
IV- parameters describing the size distribution of particles resulting from wind resuspension.
Parameter $\lambda\varphi=100\%\cdot\delta Q\varphi/\Sigma\delta Q\varphi$ is the contribution of each kind of parameters in total variation

Parameter	Meteo	Height distr	Size distr-fires	Size distr. -dust
$\delta Q\phi$, GBq	404	216	134	74.7
$100\%\cdot\delta Q\phi/\Sigma\delta Q\phi$	49	26	16	9

In summary:

- Ensemble iterative source inversion method (EISIM) was developed to properly take into account uncertainties in input data and model parameters in process of source term estimation
- EISIM allows also estimation of confidence intervals and quantification of the impact of different parameters on the overall uncertainty
- Re-emission of contaminated ash by dust storm, happening along with the strongest in the history wildfire in ChEZ is a kind of 'compound extreme'
- About 500 (up to 1300) GBq came from wildfires (overall duration 25 days)
- About 25 (up to 100) GBq came then from dust storm (2 days duration)
- The uncertainty in meteorological input data has the most significant impact on the variability of the total emission inventory (about 50%).
- About 25% of variability is created by uncertainty in height distribution of release and 25% - by uncertainty in size distribution of particles