Source-Term Determination of Radionuclide Releases by Inverse Atmospheric Dispersion Modelling (STRADI)

Czech-Norwegian Research Programme CZ09

Václav Šmídl, Nikolaos Evangeliou
8th November, 2016
Prague

Project consortium

- Institute of Information Theory and Automation
- Norwegian Institute of Air Research

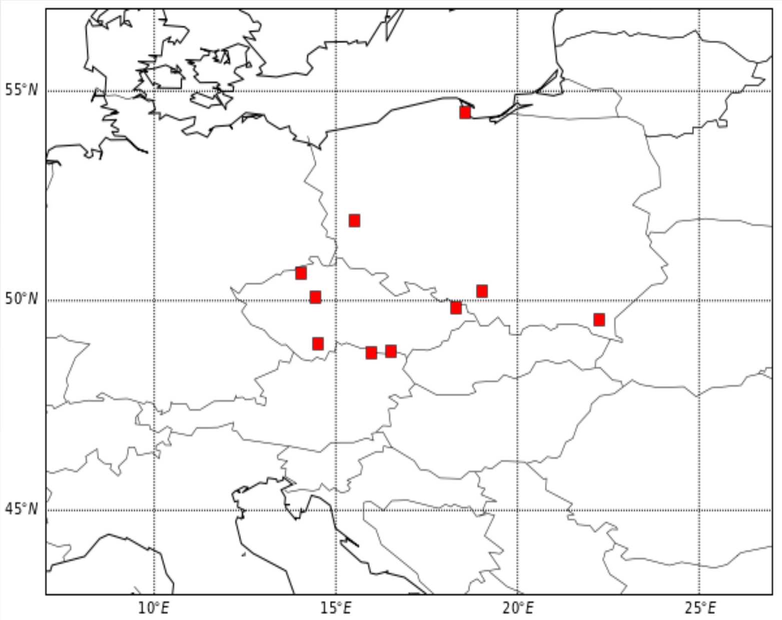
- Complementary expertise:
  - inverse modeling (ÚTIA),
  - atmospheric modeling (NILU)
- Collaboration on inverse modeling of radiation releases into atmosphere.
  - Better methods for scientists and radiation protection institutions
- Future work on parameter optimization, model calibration, etc.

Why is project needed?

- In the fall of 2011, low concentration of I-131 was detected in the atmosphere by the European Trace Survey Stations Network for Monitoring Airborne Radioactivity (Ro5)
- After detection in Austria, Czech Republic and other countries followed.

- What happened?
- Is it serious?
- What will be the consequences?

➢ Chernobyl & Fukushima??



What are the project‘s objectives?

- Develop methods of source term determination (when a how much of radiation was released) from a wide range of measurement types: concentrations, gamma dose, deposition.
- Develop statistical methods for quantification of uncertainty and elimination of tuning parameters.
- Test on existing data from tracer experiments, and collect new information for reevaluation of events (e.g. Chernobyl, Fukushima).
- Test the methods on different type of data, such as volcanic ash (Eyjafjallajökull, Iceland, 2010).

What is the project expected to achieve?

- New mathematical and statistical methods
  - Publication in mathematical and statistical journals
  - Publication of their application in environmental protection journals
- Re-analysis of historical release events in the light of new methods and new data.
- Software that can be used by other researchers and environment protection institutions:
  - Czech authorities (SÚRO, SÚJB), German (BfS), etc.
  - Volcanic ash committee,
  - Comprehensive Nuclear Test Ban Treaty Organization (CTBTO)

How are you going to address these challenges?

1. Forward modeling – Atmospheric dispersion model (NILU)

Calculates the spread of the radiation in the atmosphere.

The model simulates the transport of tracers by calculating the trajectories of a multitude of virtual particles

- using the resolved winds from global or regional meteorological analyses
- parameterizations for turbulence and convection.
- loss processes, dry and wet deposition, gravitational settling

Result:

- is the source term,
- are predicted measurements,
- is the linear projection of the model

How are you going to address these challenges?

2. Inverse modeling – statistical methods (ÚTIA)

Naïve inversion of model is and will not work.

Not enough information in data.

We need to add information (regularization).

- Adding too little information is insufficient,
- Adding too much information may bias the result.
- Finding the right balance is not trivial. Using structural priors.

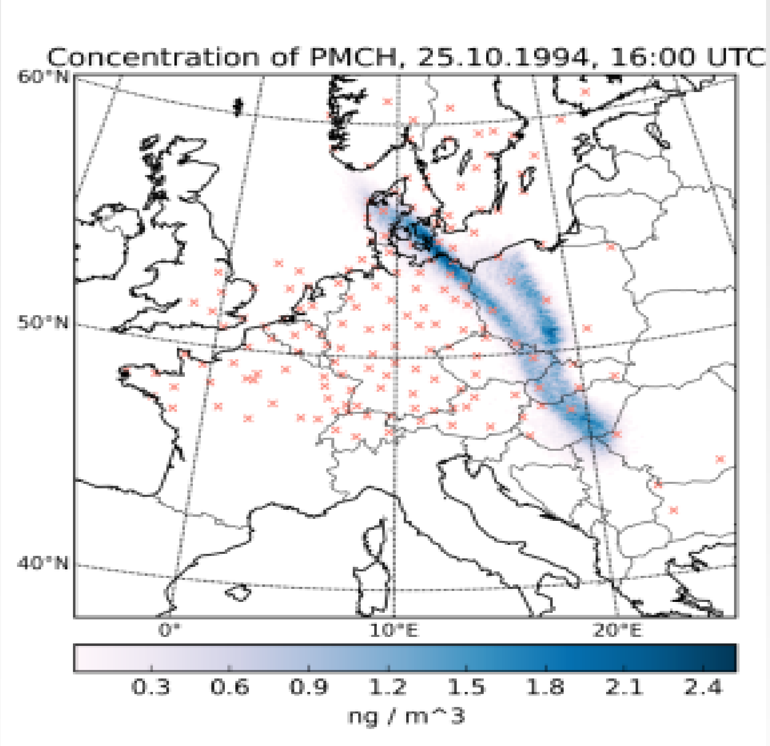
Types of additional information:

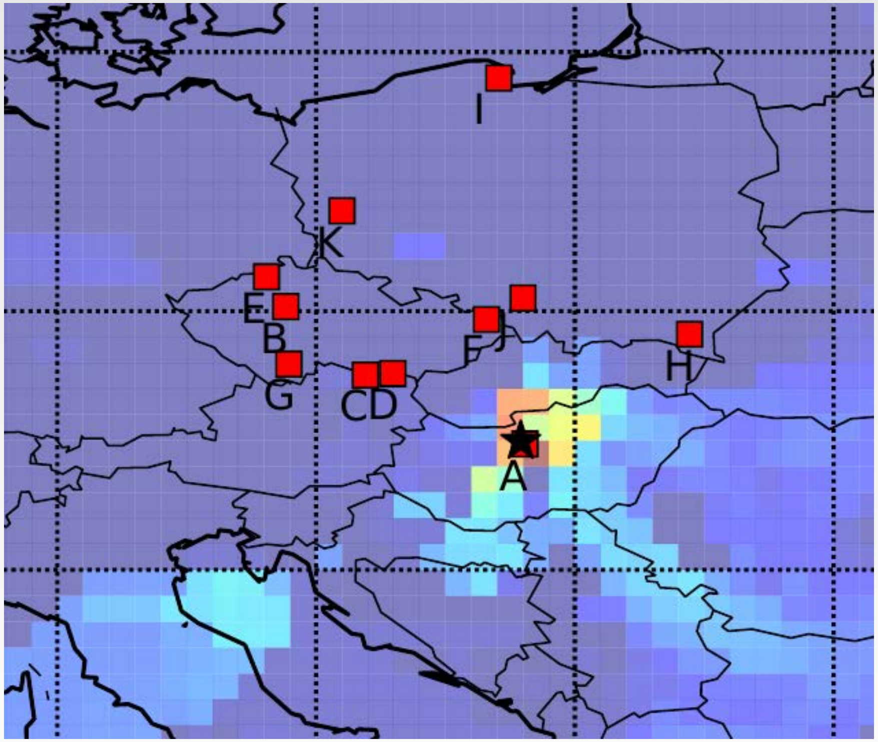
- Releases are sparse, smooth with abrupt changes,
- We may know a range for ratios of unknowns, i.e.
-

Applications

Tests and validation of real dataset

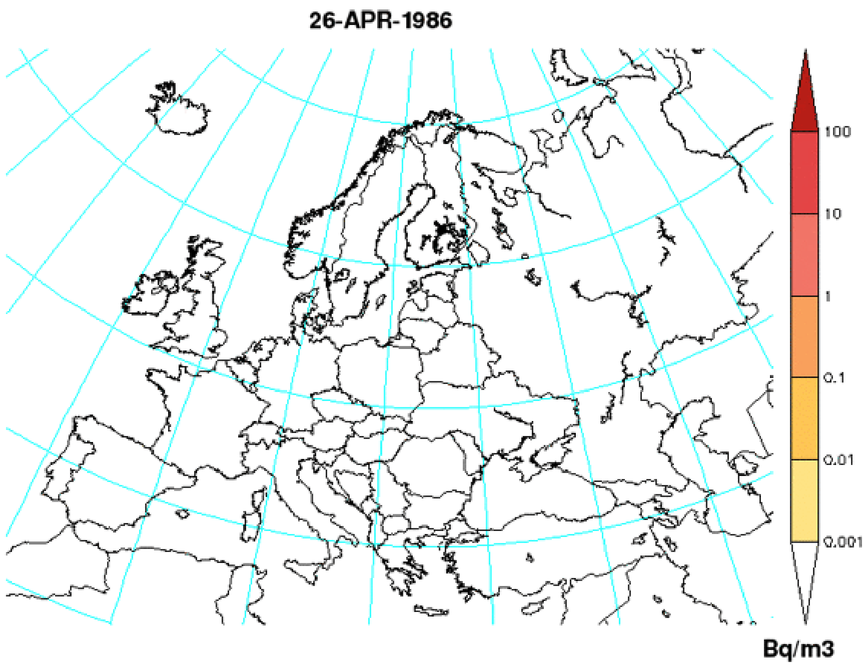
The European tracer experiment,	I131 release from 2011

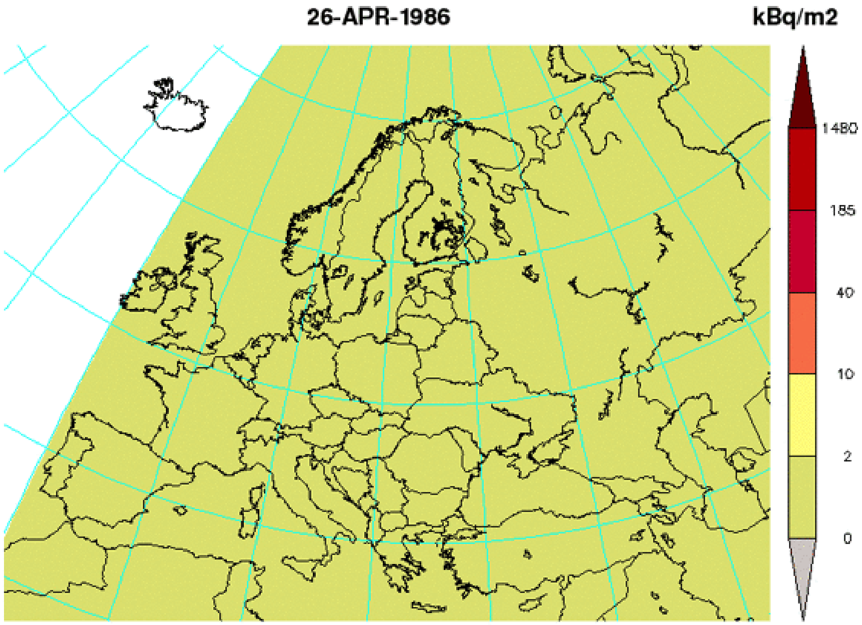




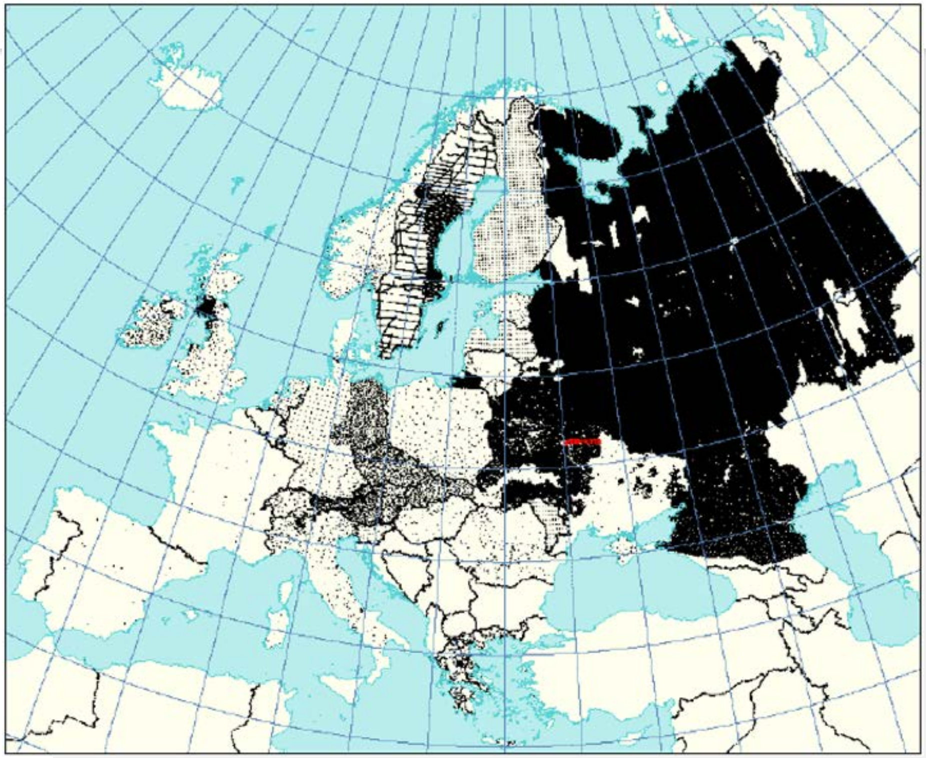
Applications (Chernobyl)

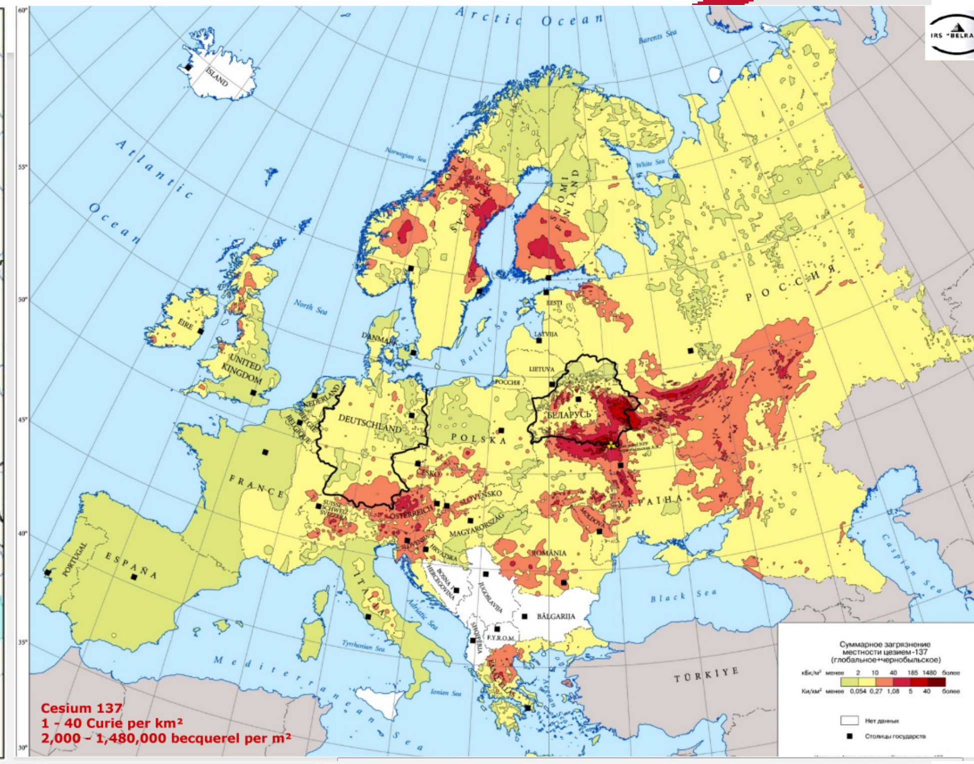
- Activity concentration
- Accumulated deposition





Applications (a. data rescue)





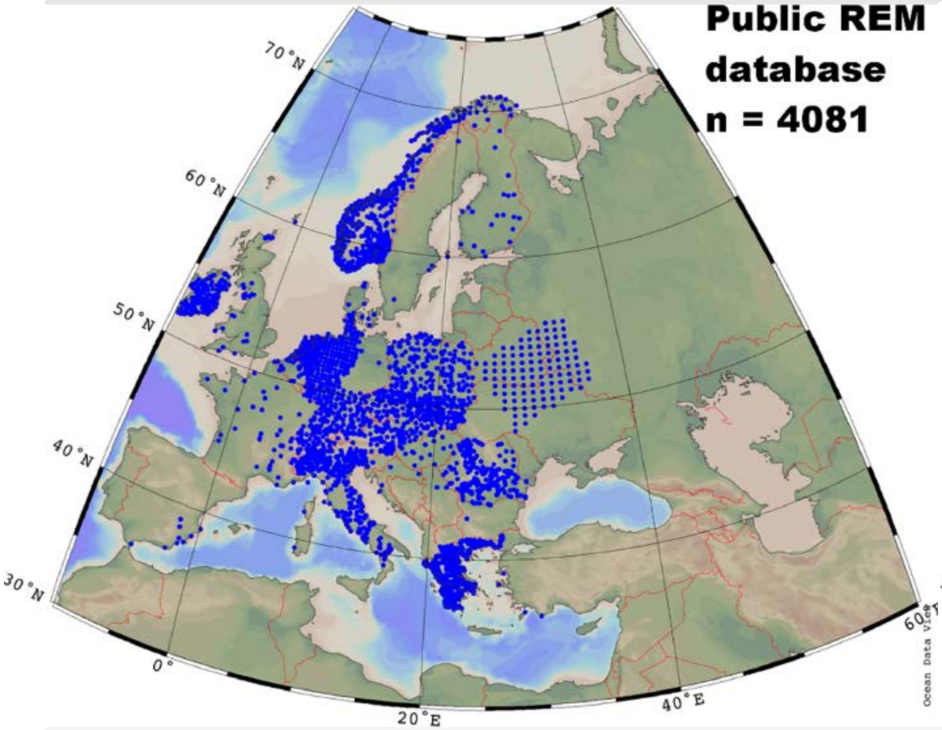
Station data used

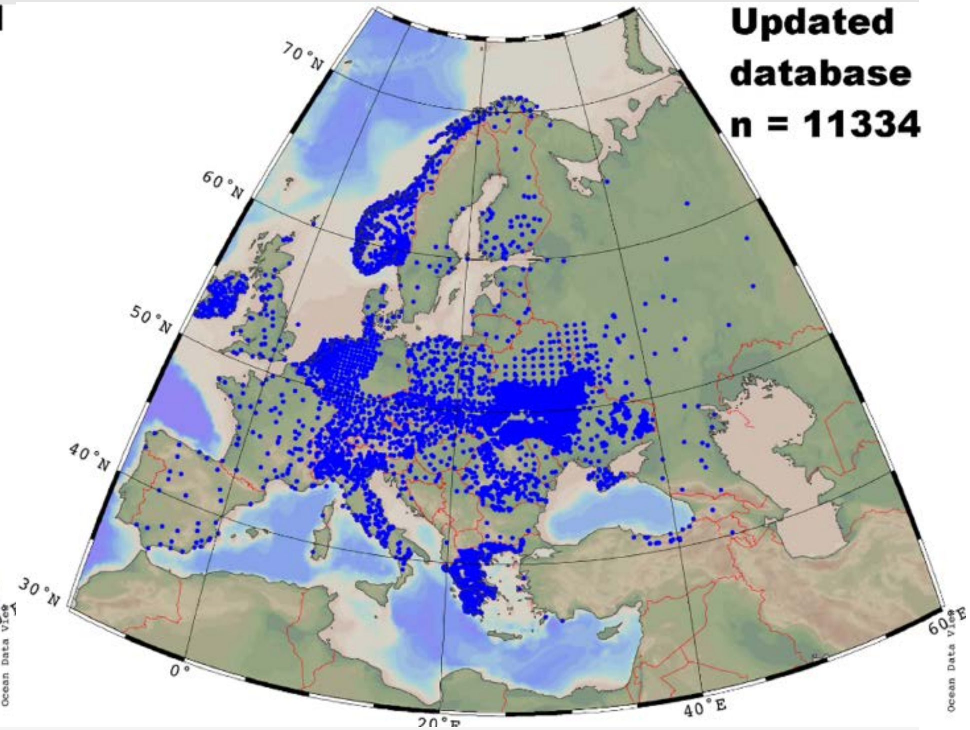
IDW interpolation

WHERE ARE THEY? HAS ANYBODY EVER SEEN THEM?

De Cort et al., 1998. JRC

Applications (a. data rescue)





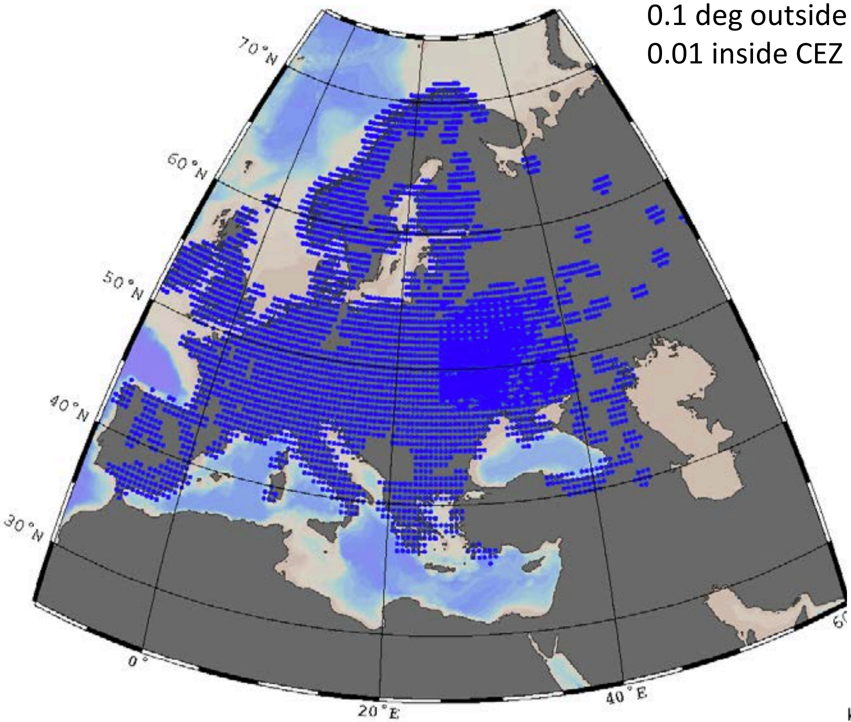
Online data

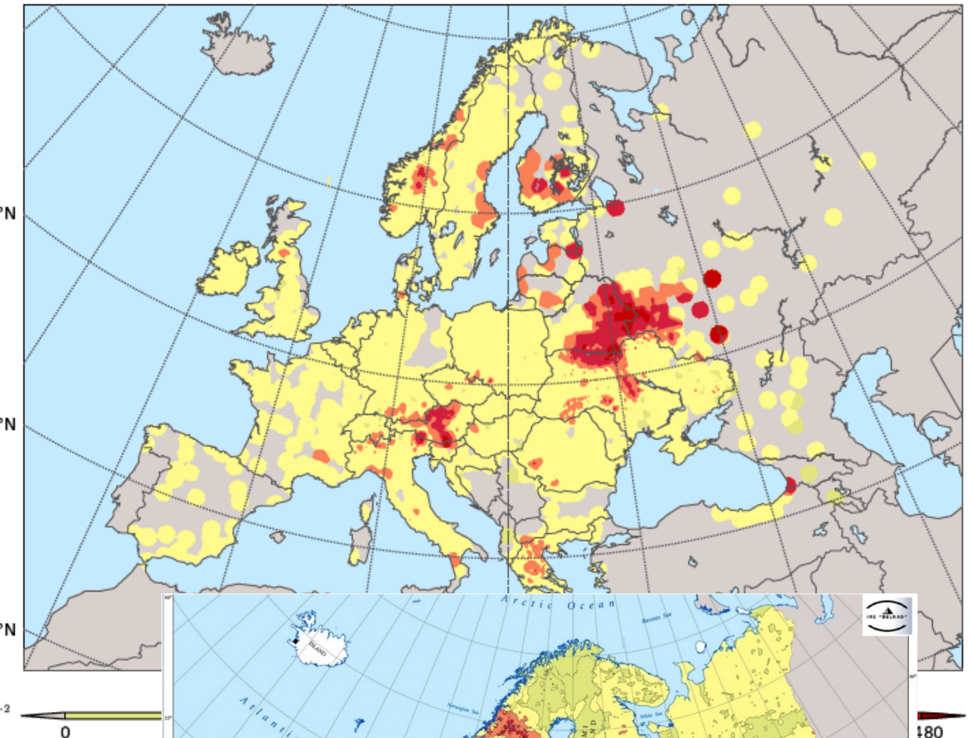
Our enrichment

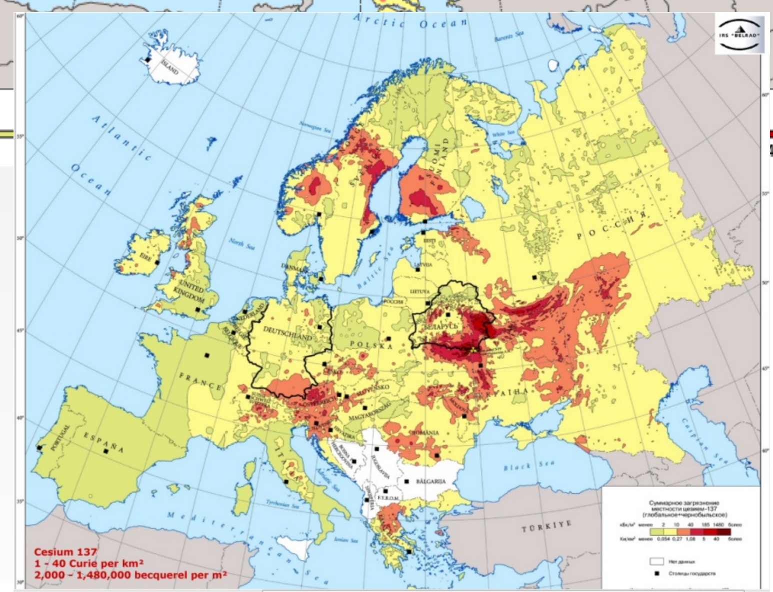
Evangeliou et al., 2016. Environmental Pollution

Applications (a. data rescue)

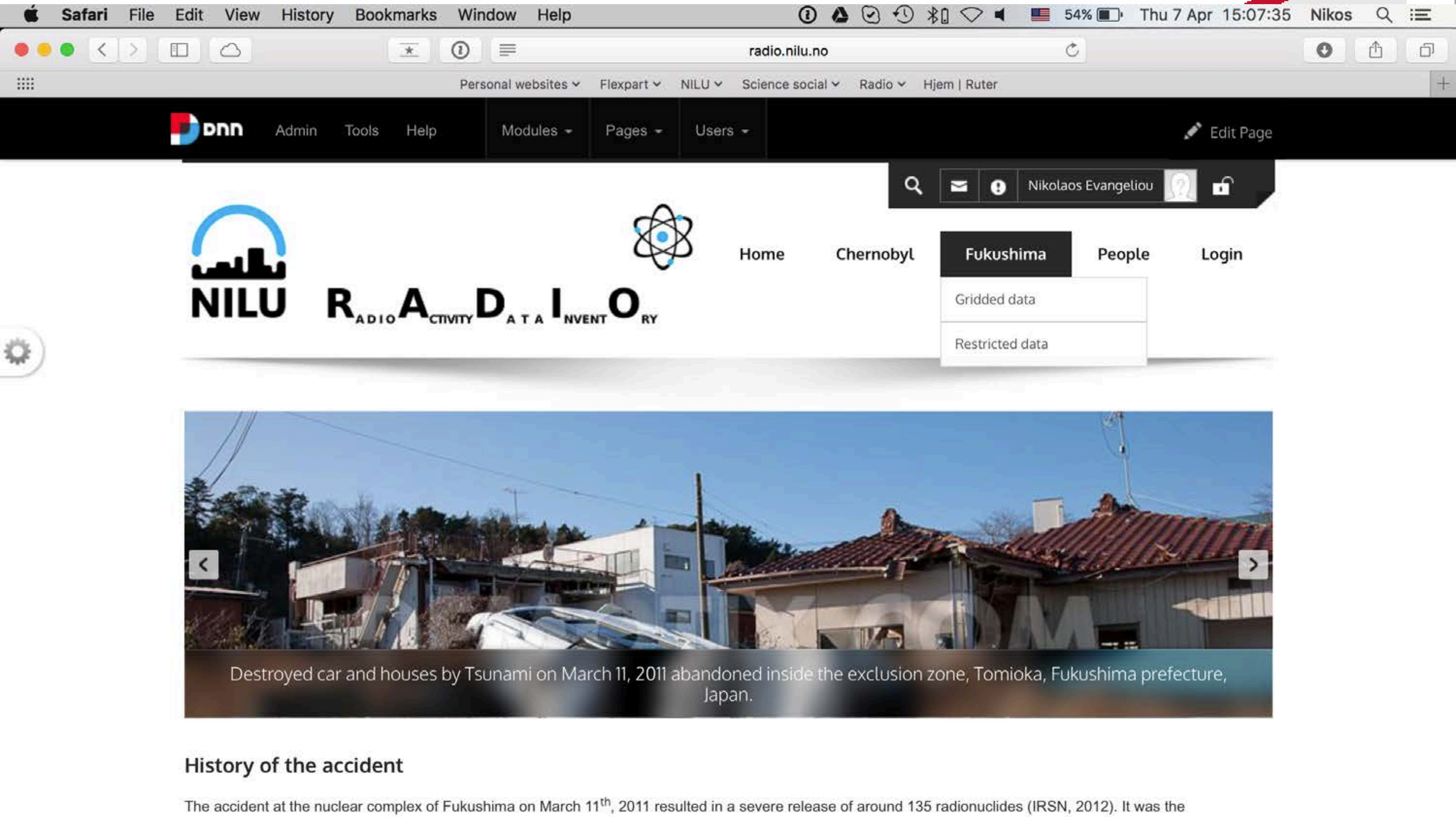
0.1 deg outside CEZ
0.01 inside CEZ



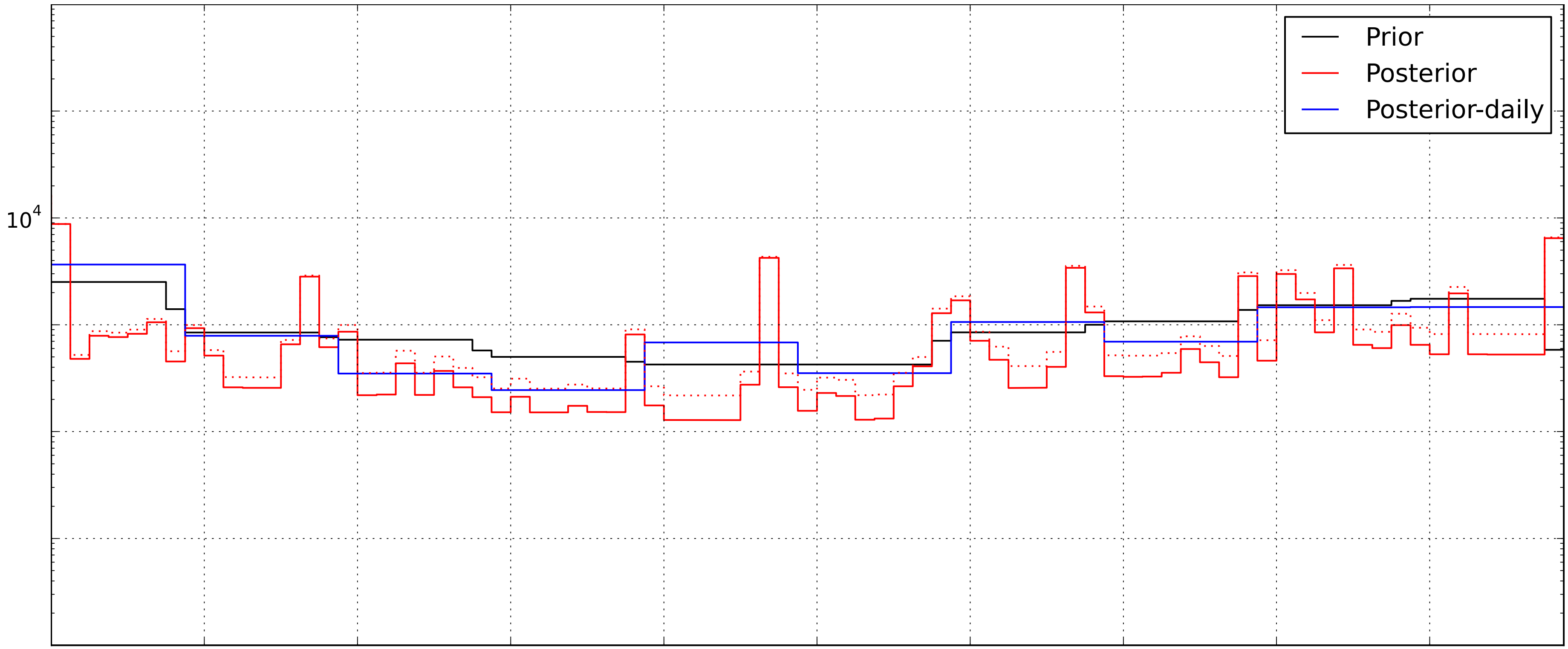




Applications (a. data rescue)

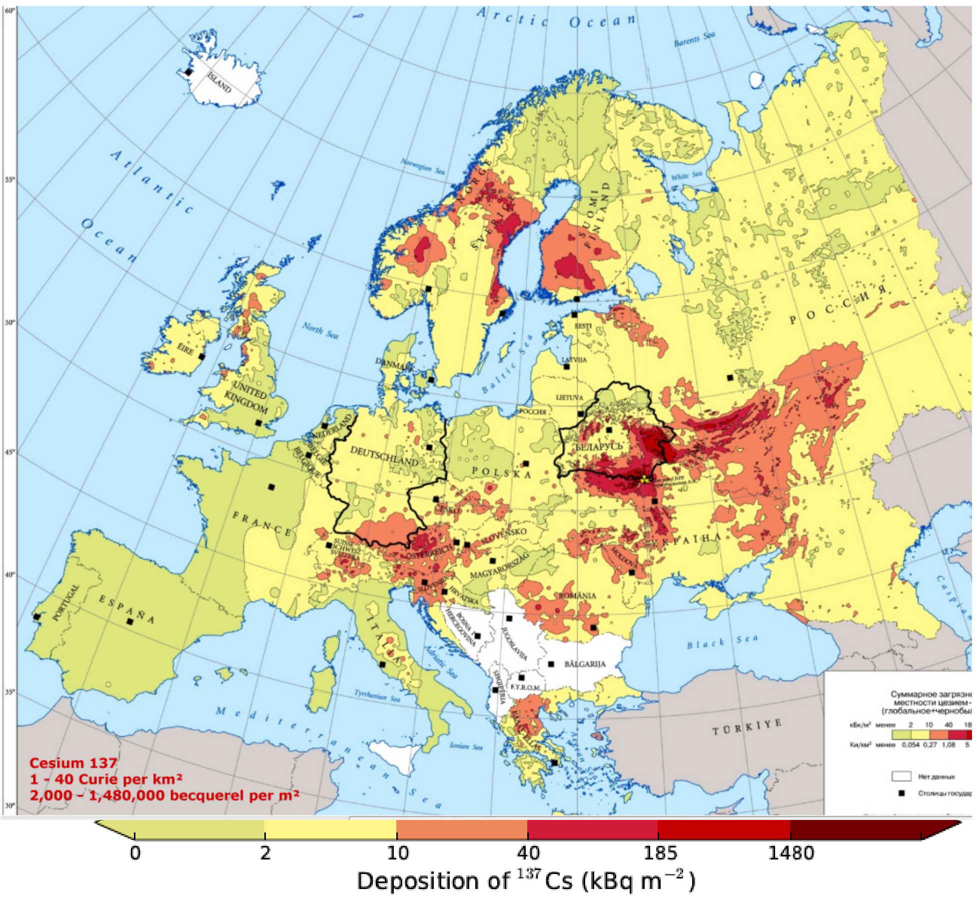


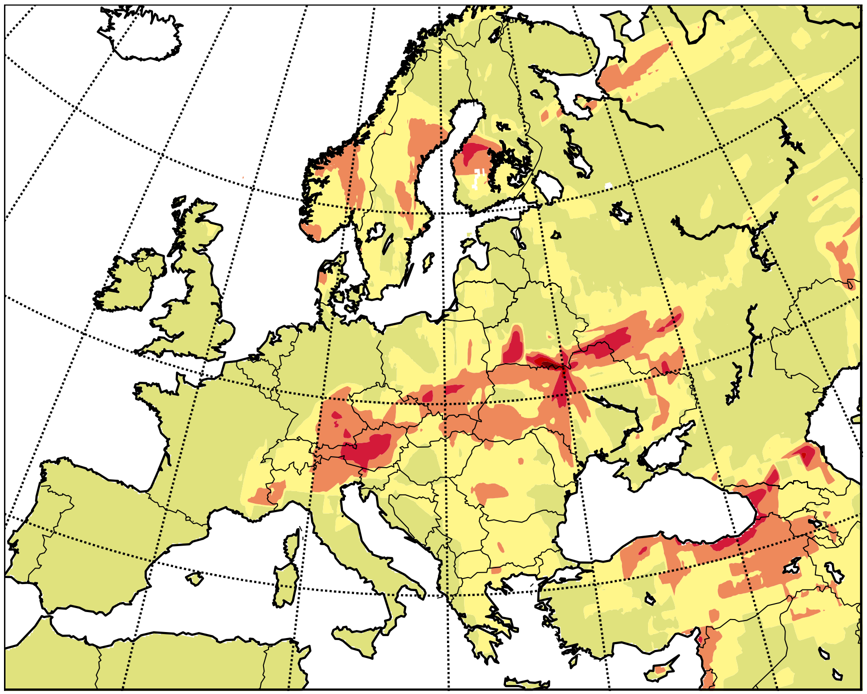
Applications (b. source-term)



135 PBq instead of 85 PBq (prior)

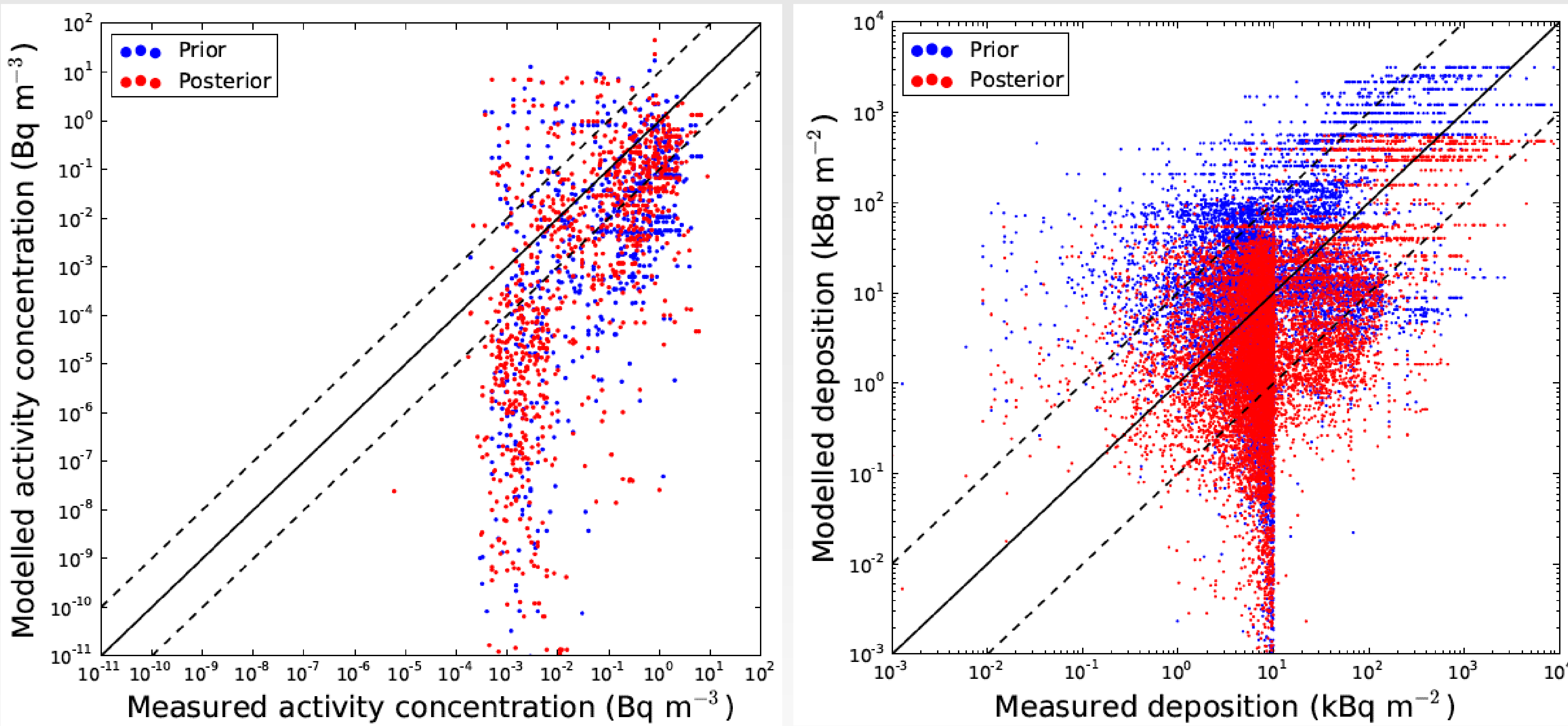
Applications (b. source-term)





ion of ^{137}Cs (kBq m^{-2})

Applications (b. source-term)

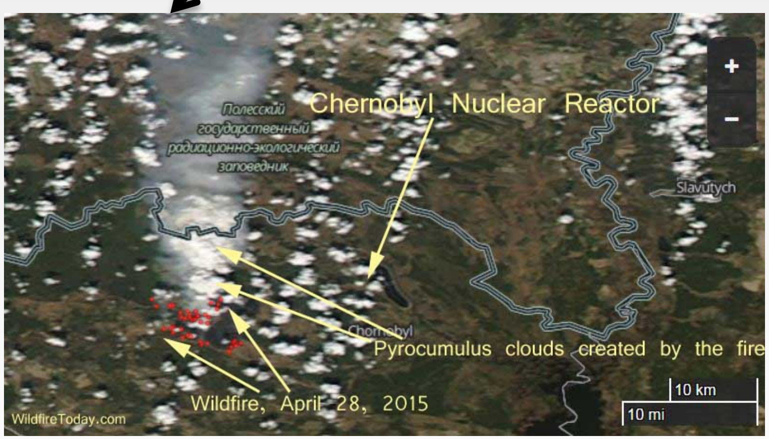


Applications (c. 2015 fires)

eea grants

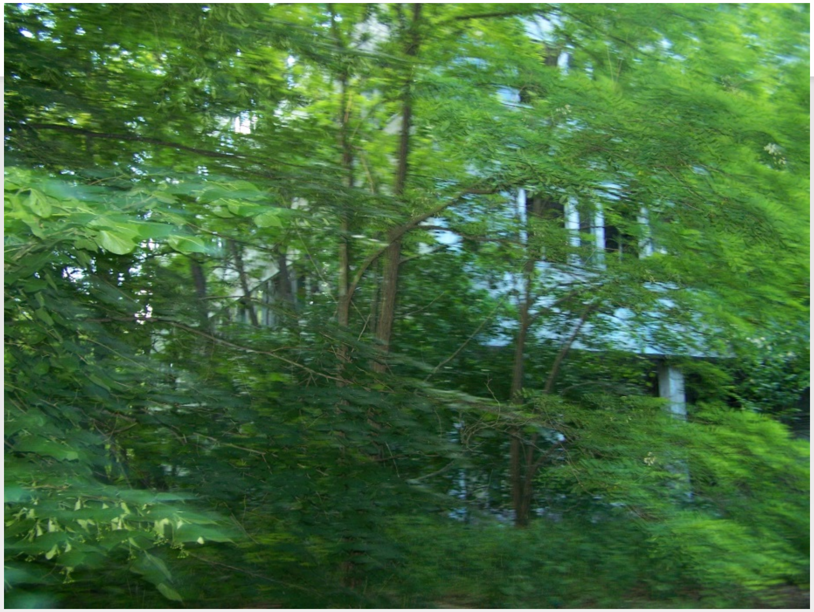
norway grants

April–May fires



August fires

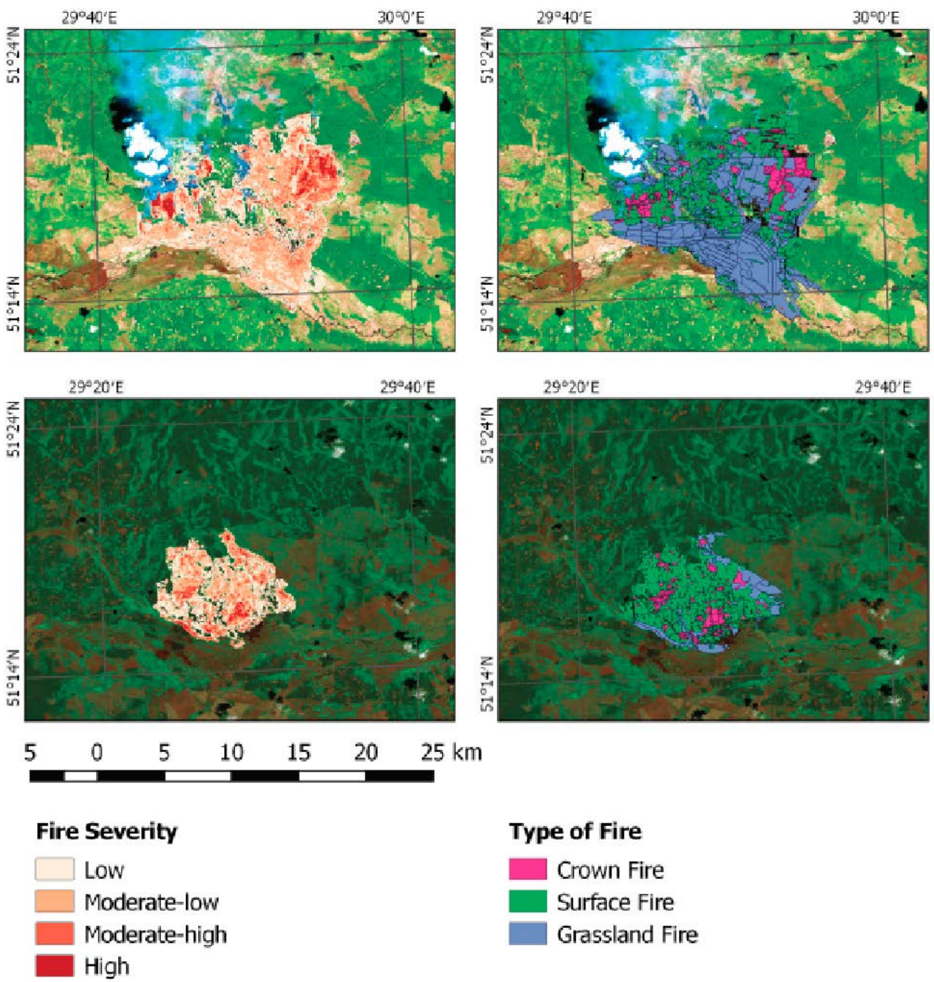
Applications (c. 2015 fires)

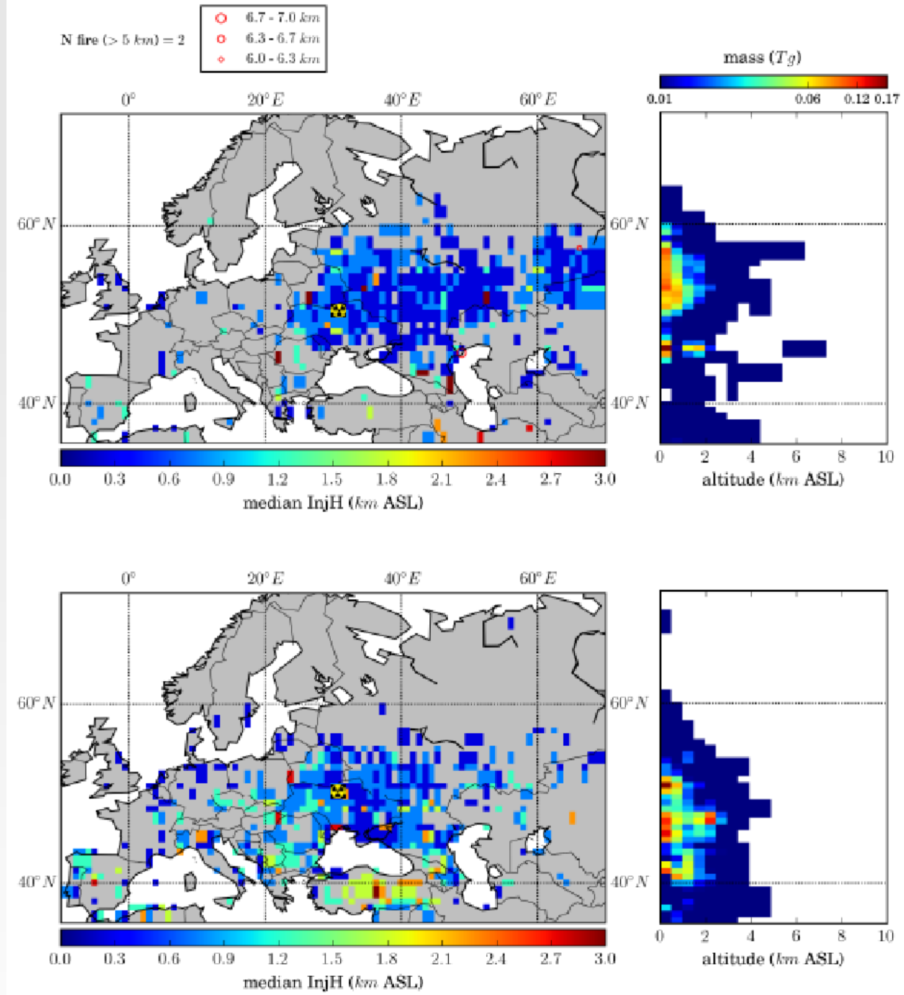


Land cover change in Chernobyl

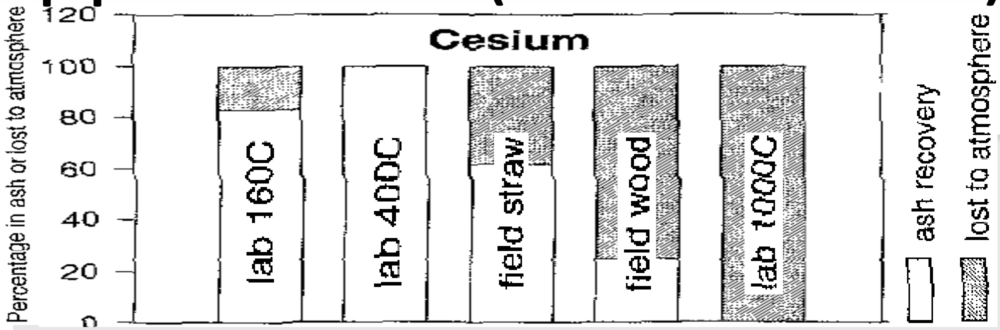
CEZ: 2600 km^2
75% boreal forest (pine trees)
25% agricultural land & shrubs
Lack of any forest management

Applications (c. 2015 fires)





Applications (c. 2015 fires)



Amiro et al. (2006)
Redistribution 20-100%

'Hot Burn' — Mean Temperature 660°C 48 kg of air-dry heather yielded 0·95 kg of ash (2·05%)

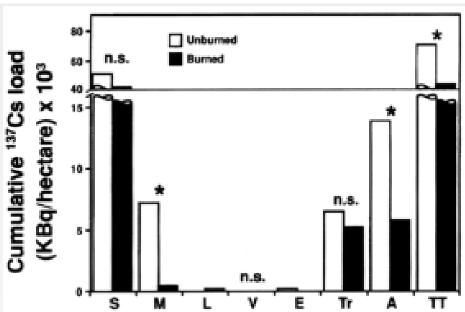
	Total Bq before burning	Total Bq after burning	Smoke loss %
^{137}Cs	152 000	99 300	39
^{134}Cs	22 000	15 000	35

'Cool Burn' — Mean Temperature 550°C 50·1 kg of air-dry heather yielded 2·2 kg of ash (4·4%)

	Total Bq before burning	Total Bq after burning	Smoke loss %
^{137}Cs	120 000	106 000	12
^{134}Cs	23 000	21 000	11

Horill et al. (1995)

Strode et al. (2012) JGR reports 40-70%



What happens with soil-bound cesium?

Paliouris et al. (1995) >20%

	Plot #1	Plot #2	Plot #3
Area (m^2)	3600	5400	8770
Land type	Wildland (grass)	Wildland (grass)	Forest
Vegetation species	*Elytrigia repens* (L.) Nevski (85%)	*Elytrigia repens* (L.) Nevski (85%)	*Pinus silvestris*
Vegetation height (m)	0.5	0.2	15
Biomass density (kg m^{-2})	0.4	0.3	24
Litter density (kg m^{-2})	0.7	1.25	2.3
Dose rate range (μGy h^{-1})	10–16	6–10	2–4

Kashparov et al. (2000) & Yoschenko et al. (2006):
$10^{-5} – 10^{-6}$ m^{-1} (Sr, Cs)
$10^{-6} – 10^{-7}$ m^{-1} (Pu, Am)

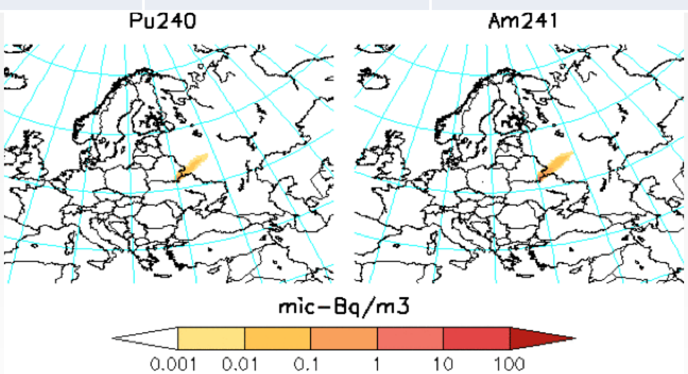
Applications (c. 2015 fires)

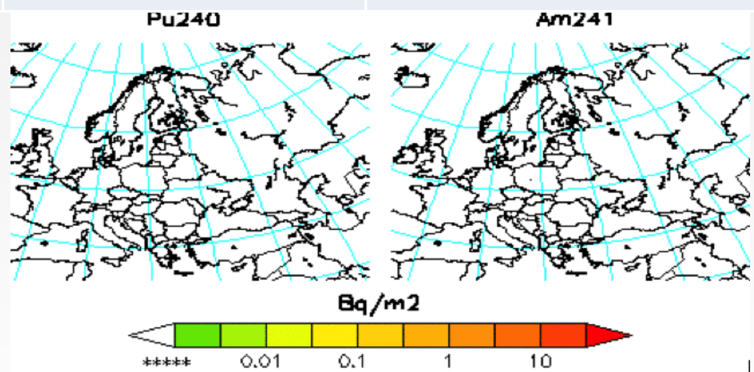
Activity concentration

Accumulated deposition

27-APR-2015

	Deposition (kBq m^{-2})	Concentration (mBq m^{-3})	Resuspension grid-cell (m^{-1})	Resuspension 100×100m (m^{-1})
Cs-137	179.8	4.05	2.2×10^{-8}	1.8×10^{-5}
Sr-90	46.5	1.16	2.6×10^{-8}	1.8×10^{-5}
Pu-238	0.48	0.005	1.0×10^{-8}	8.9×10^{-6}
Pu-239	0.38	0.004	1.0×10^{-8}	8.9×10^{-6}
Pu-240	0.58	0.007	1.2×10^{-8}	8.9×10^{-6}
Am-241	1.82	0.021	1.2×10^{-8}	8.9×10^{-6}





Applications (c. 2015 fires)

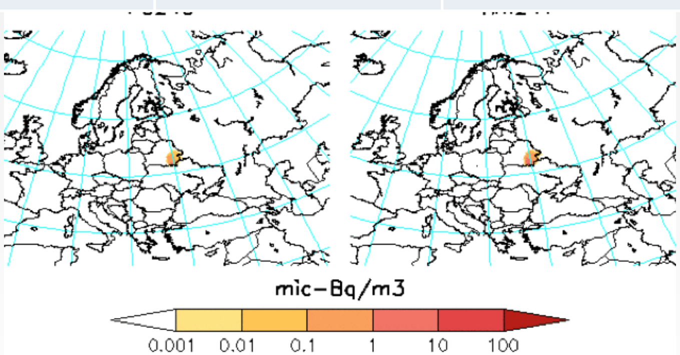
Activity concentration

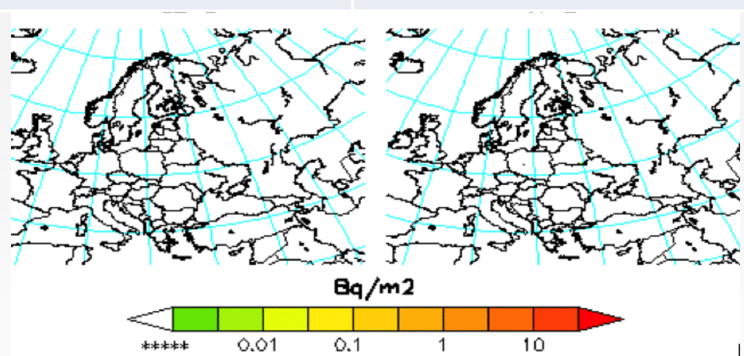
Accumulated deposition

09-AUG-2015

09-AUG-2015

	Deposition (kBq m^{-2})	Concentration (mBq m^{-3})	Resuspension grid-cell (m^{-1})	Resuspension 100×100m (m^{-1})
Cs-137	965.5	26.1	2.7×10^{-8}	8.1×10^{-5}
Sr-90	96.5	2.64	2.7×10^{-8}	8.1×10^{-5}
Pu-238	0.99	0.013	1.3×10^{-8}	4.0×10^{-5}
Pu-239	0.80	0.010	1.2×10^{-8}	4.0×10^{-5}
Pu-240	1.19	0.015	1.3×10^{-8}	4.0×10^{-5}
Am-241	3.78	0.048	1.3×10^{-8}	4.0×10^{-5}





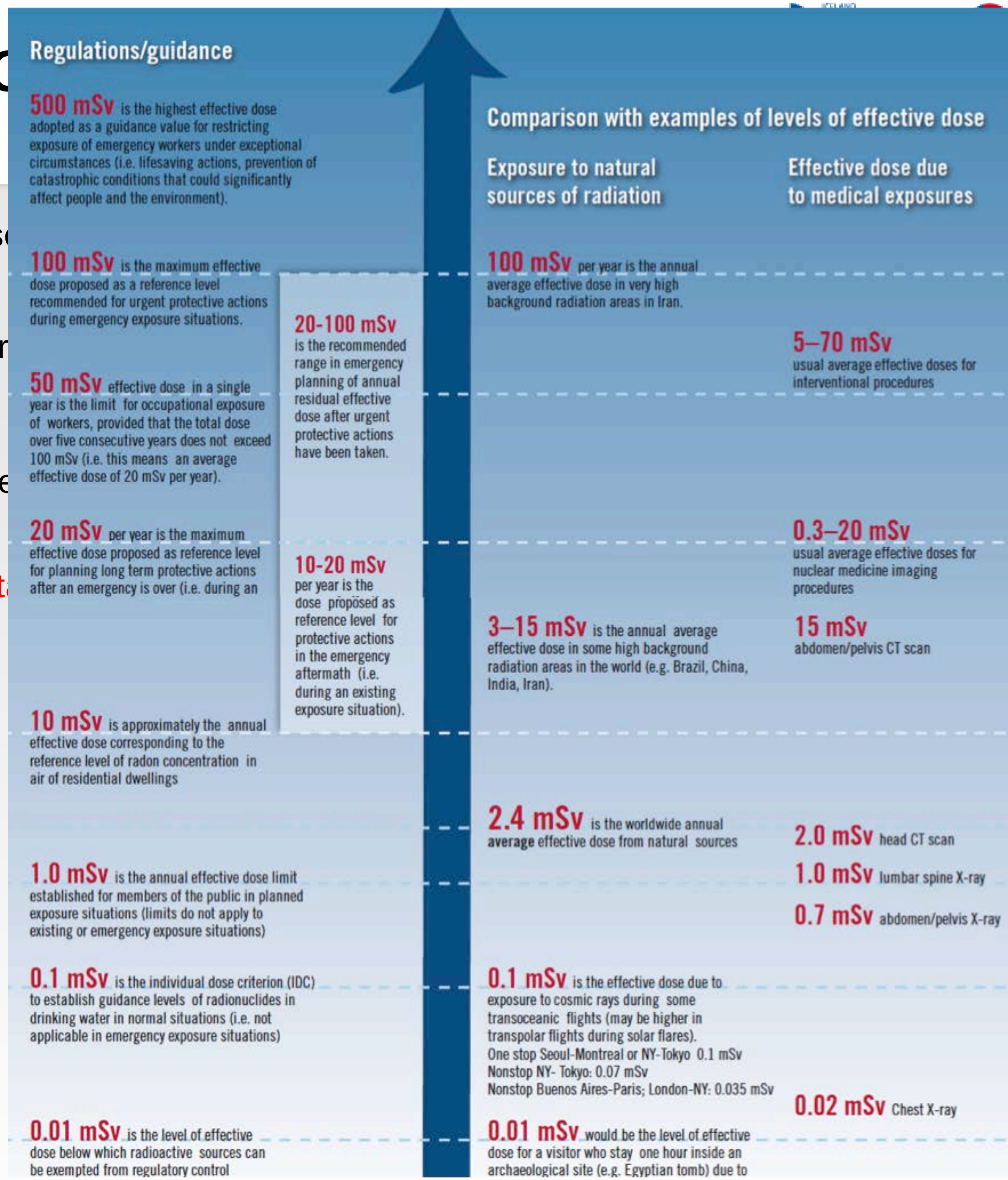
Applicati

External dos

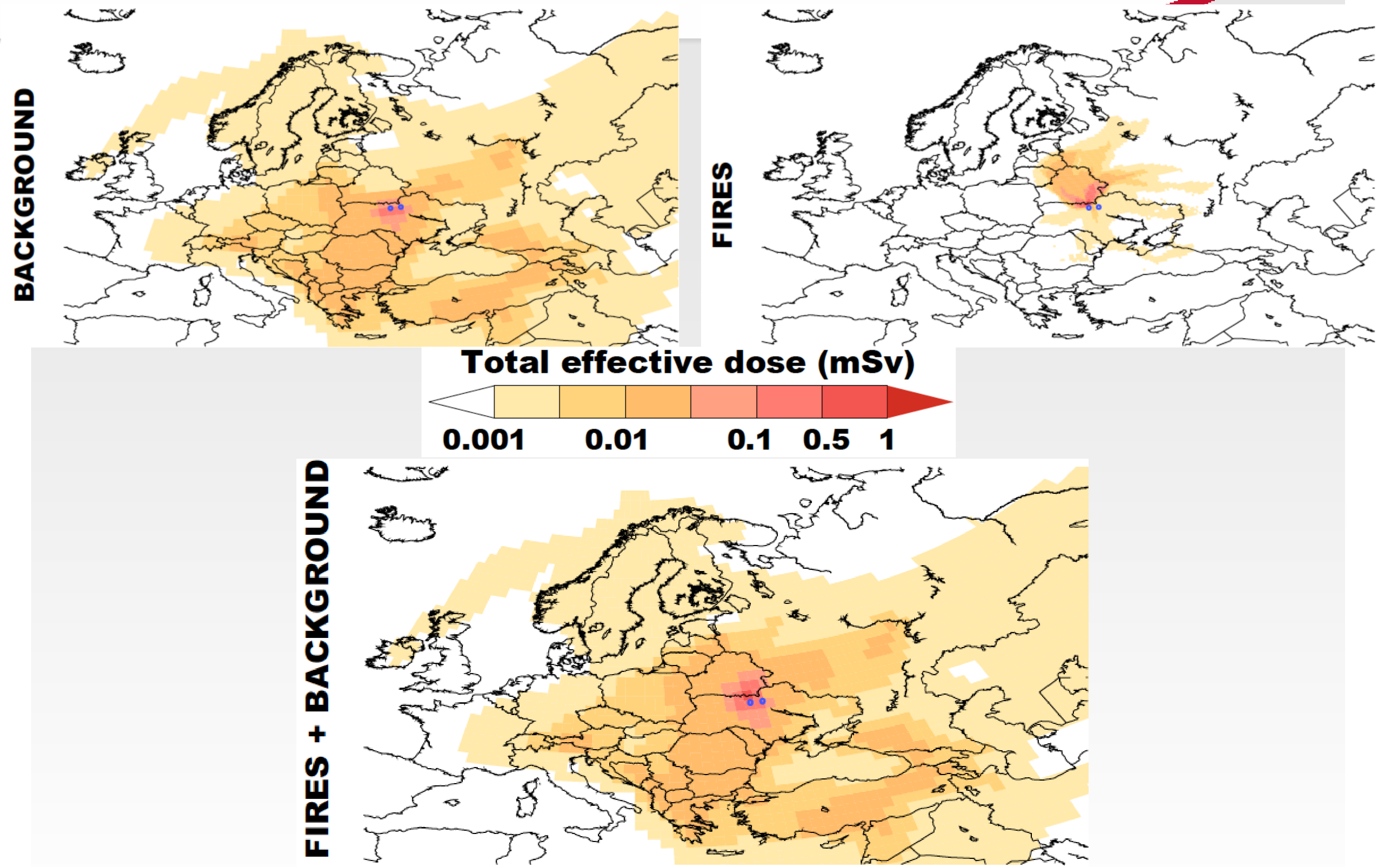
External dose fr

Internal dose

Dat

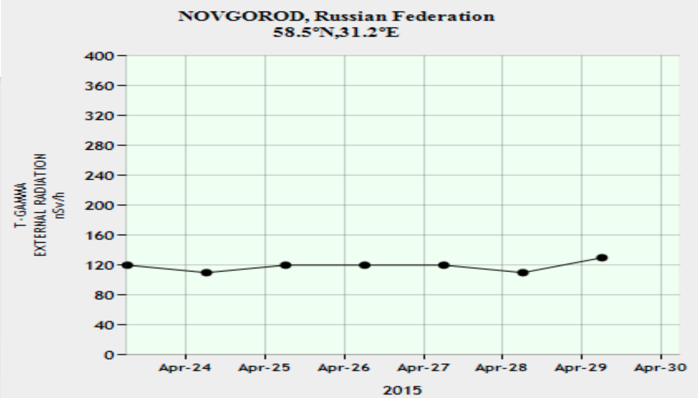


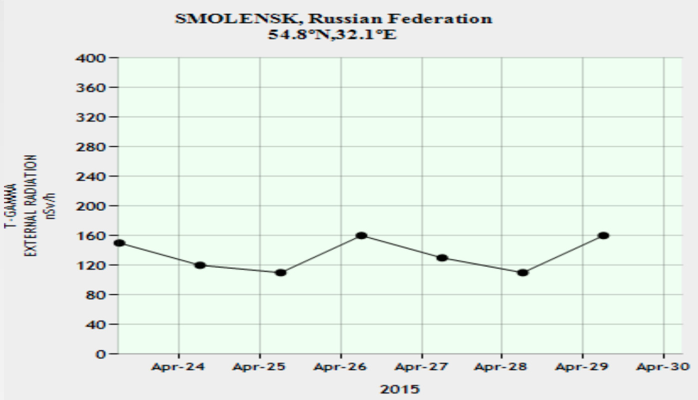
Applications (c. 2015 fires)

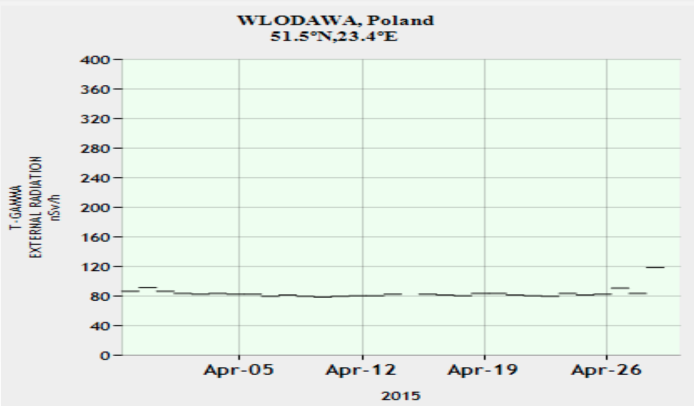


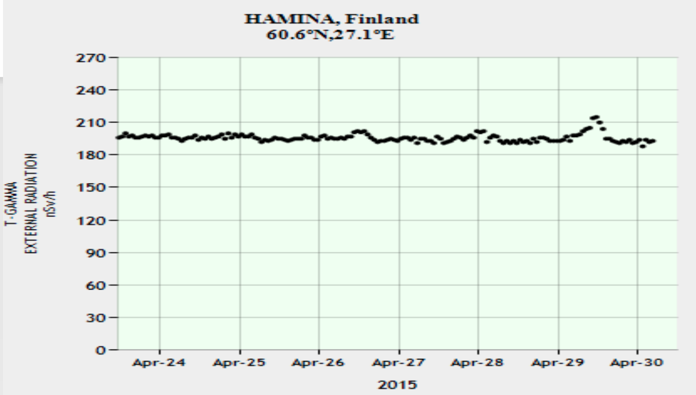
Applications (c. 2015 fires)

https://remon.jrc.ec.europa.eu



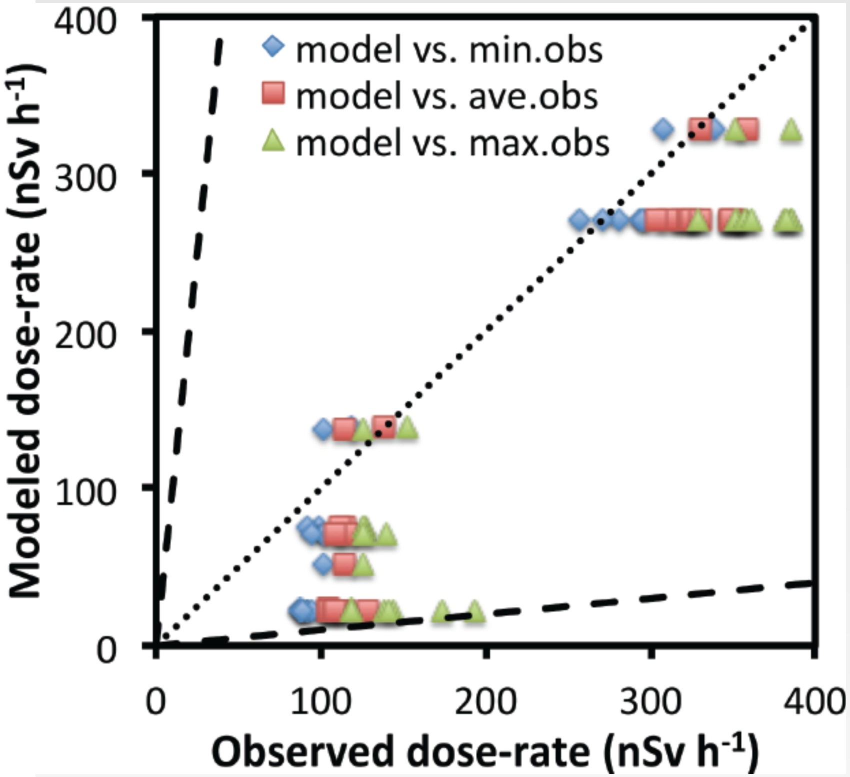


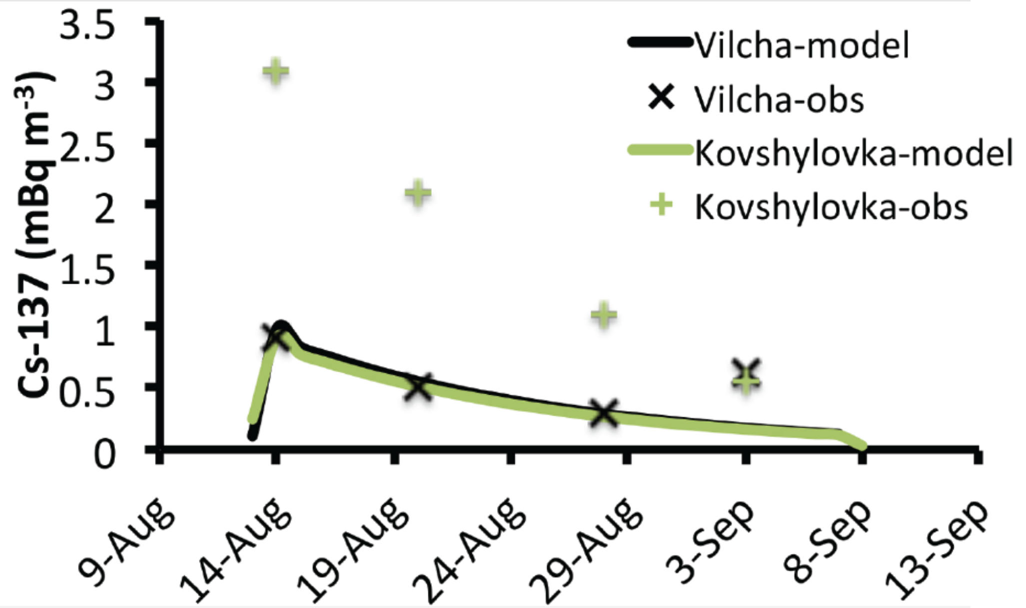




http://www.russianatom.ru

Applications (c. 2015 fires)





Applications (c. 2015 fires)

	Cs137	Sr90	Pu238	Pu239	Pu240	Am241
			April 2015			
CEZ	21	20	30	30	31	31
Ukraine (excluding CEZ)	0.0005	0.0009	0.0111	0.0006	0.0001	0.0006
Belarus	22	22	30	30	31	31
Russia (Europe)	50	50	33	35	36	35
Balkan	0.02	0.02	0.0004	0.0006	0.0008	0.002
Turkey	0.014	0.06	0.01	0.005	0.01	0.05
NEU (Scandinavia)	0.5	0.5	0.4	0.2	0.2	0.2
CEU	0.05	0.06	0.001	0.002	0.003	0.008
WEU	0.1	0.1	0.003	0.001	0.003	0.01
EEU	93	93	95	95	99	98
SEU	0.02	0.03	0.0007	0.0003	0.0008	0.004
Europe (total)	**93**	**93**	**95**	**95**	**99**	**98**
			August 2015			
CEZ	25	26	41	41	41	41
Ukraine (excluding CEZ)	0.008	0.008	0.004	0.004	0.004	0.004
Belarus	11	11	22	21	22	22
Russia (Europe)	37	37	25	25	26	26
Balkan	4.7	4.7	0.2	0.2	0.2	0.2
Turkey	0.6	0.6	0.04	0.04	0.04	0.04
NEU (Scandinavia)	0.03	0.03	0.006	0.006	0.006	0.006
CEU	12	11	0.8	0.8	0.8	0.8
WEU	0.2	0.2	0.04	0.04	0.04	0.04
EEU	80	80	99	99	99	99
SEU	5.1	5.1	0.2	0.2	0.2	0.2
Europe (total)	**92**	**91**	**100**	**100**	**100**	**100**

Who is going to benefit from the project?

- Scientists
  - Mathematicians/Statisticians getting new inspiration from real world application
  - Environmental scientists getting new software tools (Flexpart, inversion methods)
- Ph.D. students, postdocs, Environmental protection authorities
  - Radiation protection institutes (SÚRO, BfS, CTBTO),
- Research institutions
  - New equipment, new research ideas and future collaboration

Thank you very much! Tusen takk!

Speakers :

Doc. Ing. Václav Šmídl, Ph.D.

Institute of Information Theory and Automation, Czech Academy of Sciences

Department of Adaptive Systems

Nikolaos Evangeliou, Ph.D.

Norwegian Institute of Air Research, Kjeller, Norway

stradi.utia.cas.cz

smidl@utia.cas.cz