

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

Czech-Norwegian Research Programme CZ09

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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.

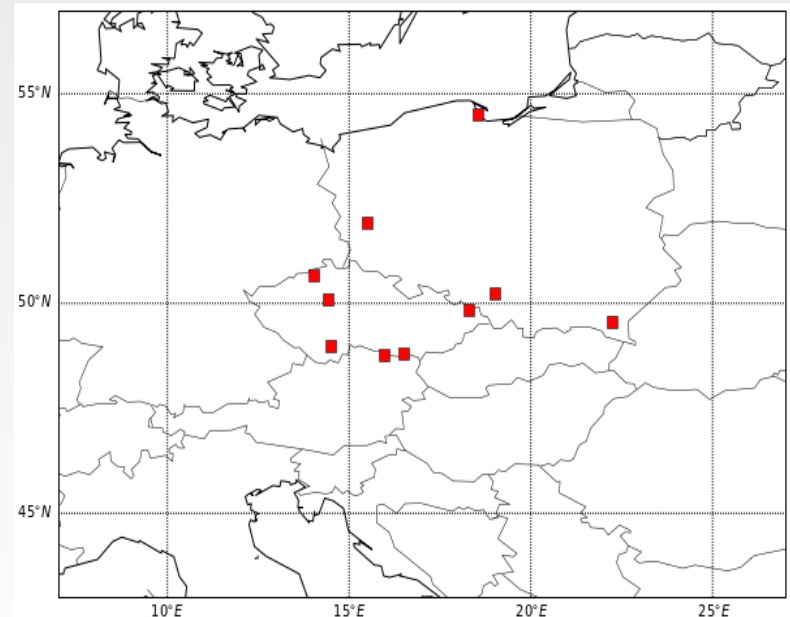


# Why is project needed?

- 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 and 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:

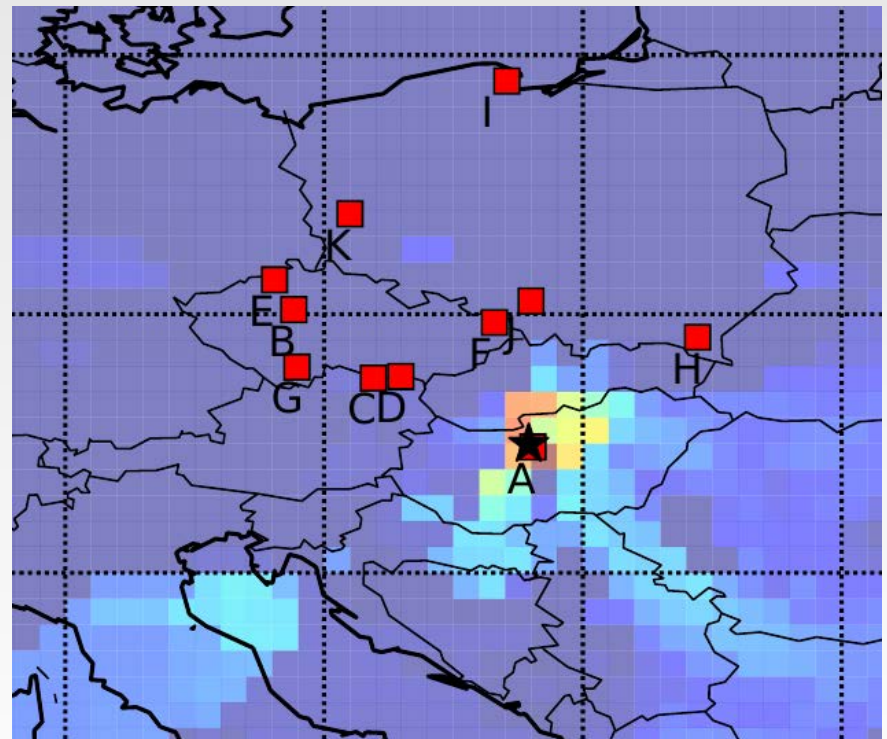
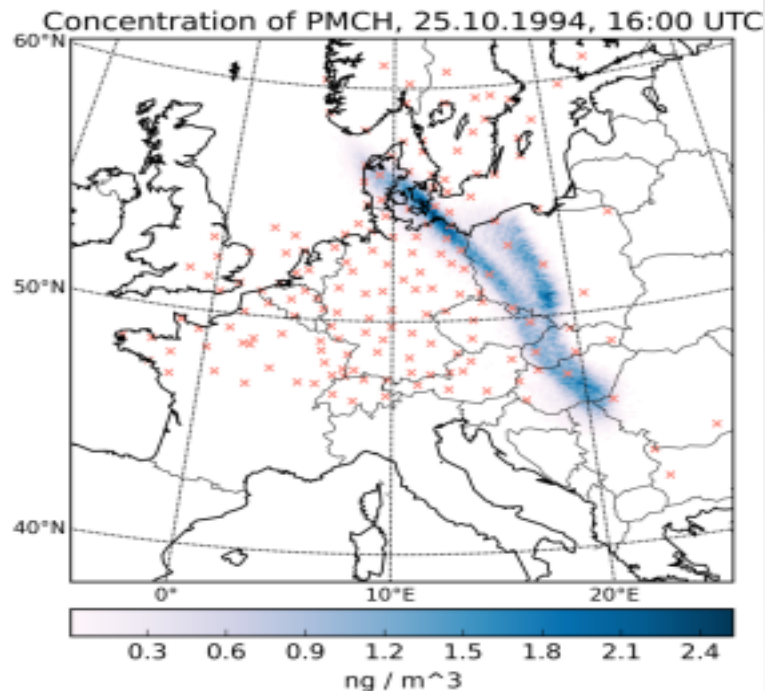
- Releases are sparse, smooth with abrupt changes,
- We may know a range for ratios of unknowns, i.e.
-

# Applications

## Tests and validation of real dataset

The European tracer experiment,

I131 release from 2011

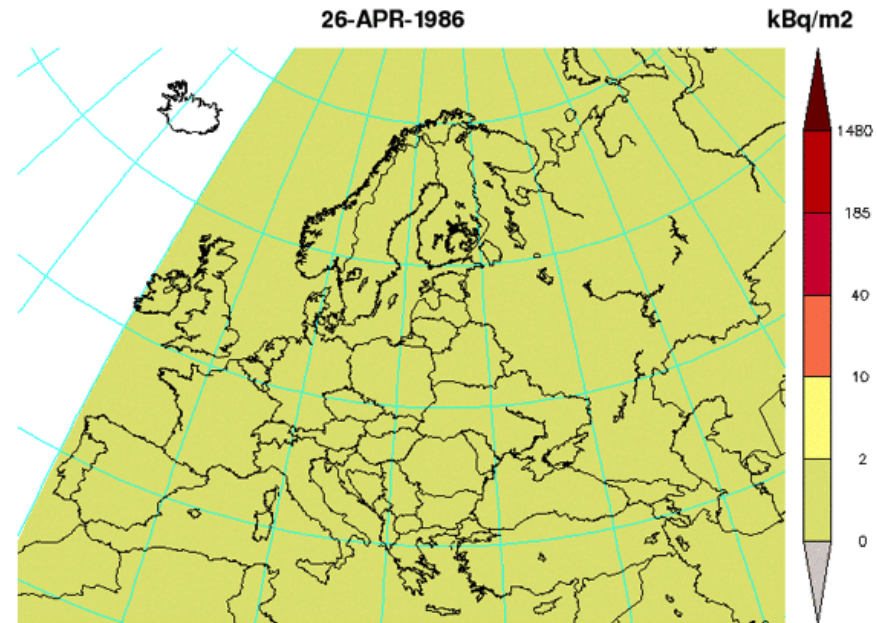
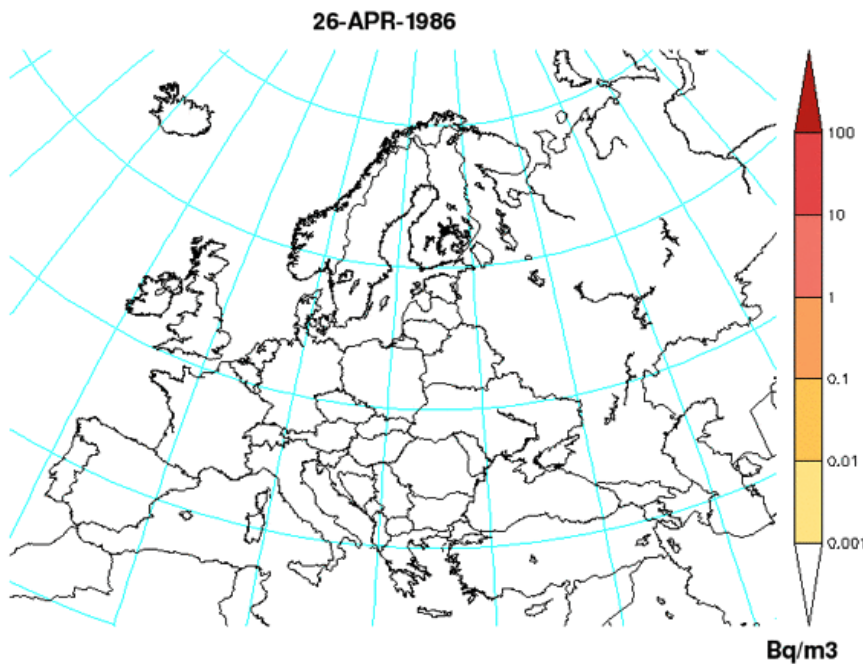




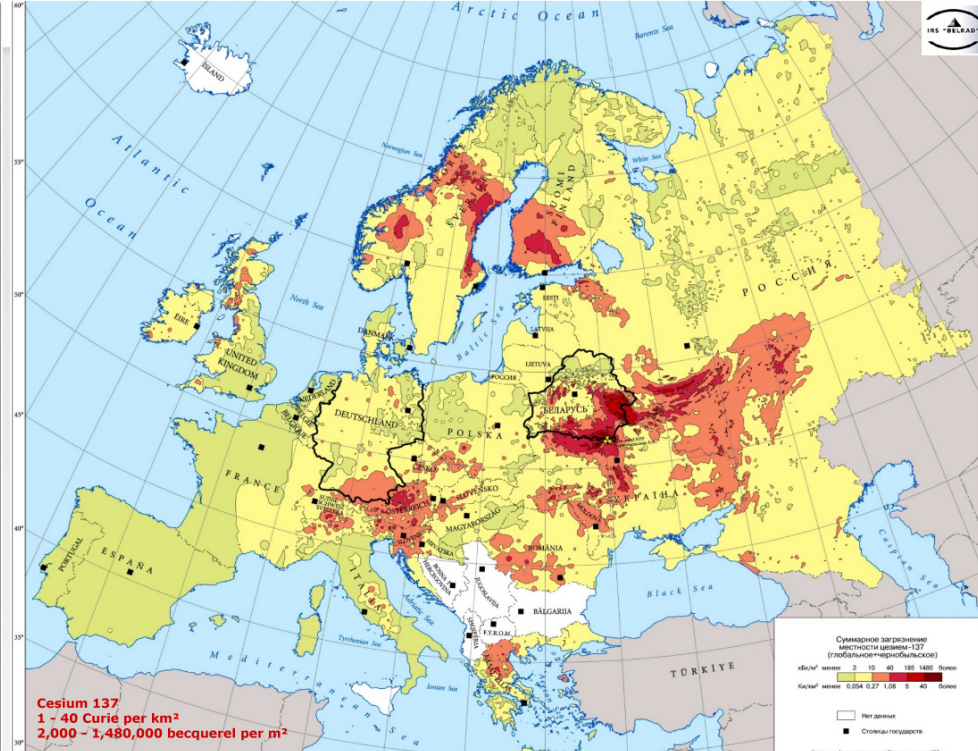
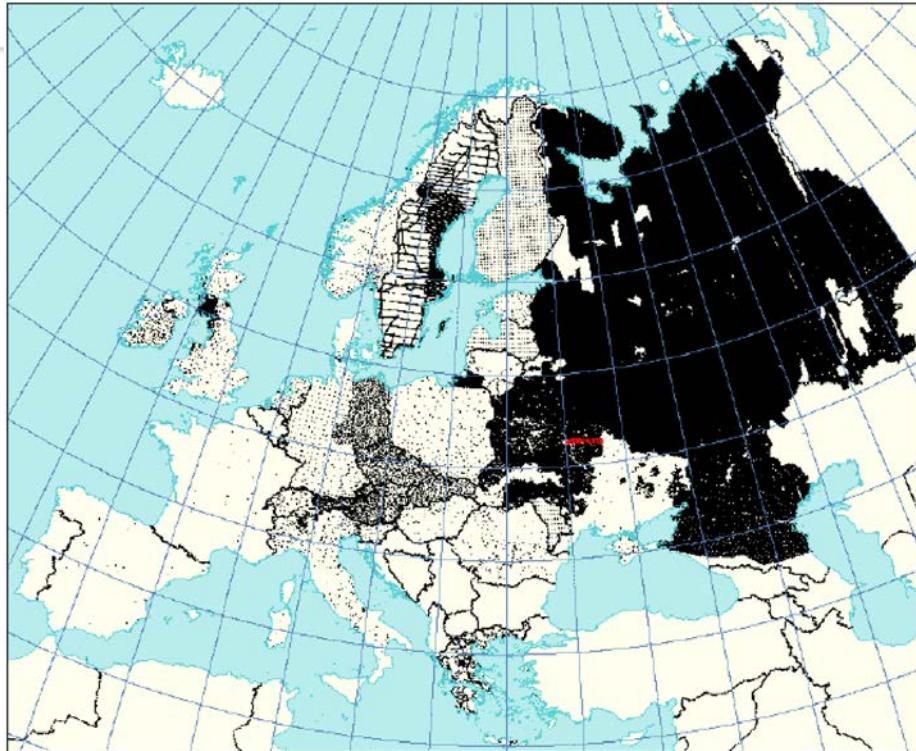
# Applications (Chernobyl)

Activity concentration

- Accumulated deposition



# Applications (a. data rescue)



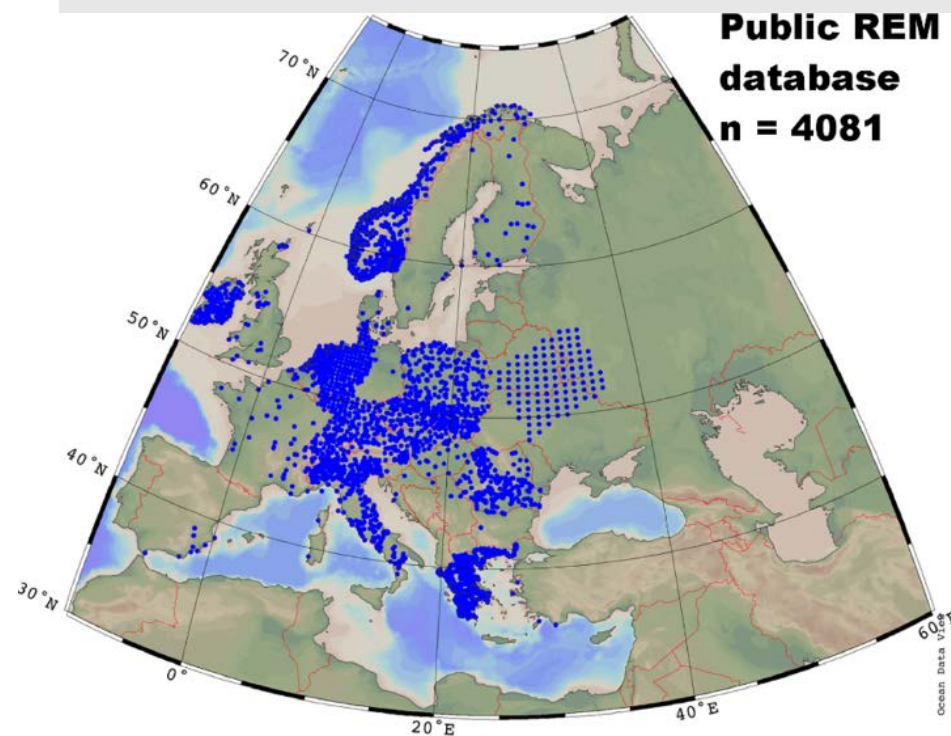
Station data used

IDW interpolation

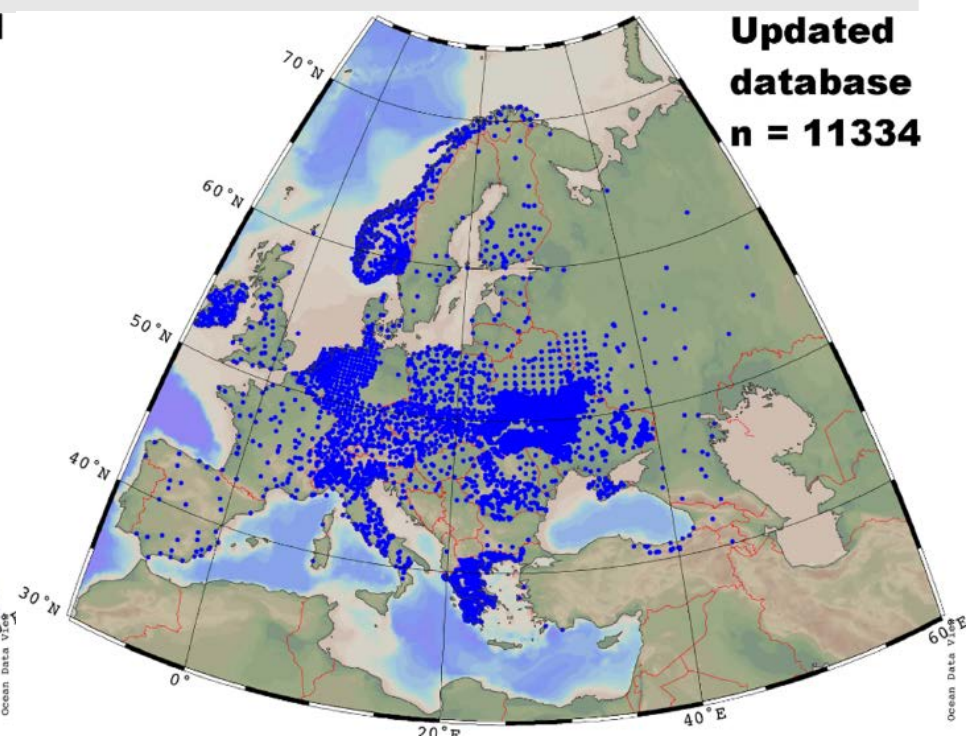
WHERE ARE THEY? HAS ANYBODY EVER SEEN THEM?



# Applications (a. data rescue)

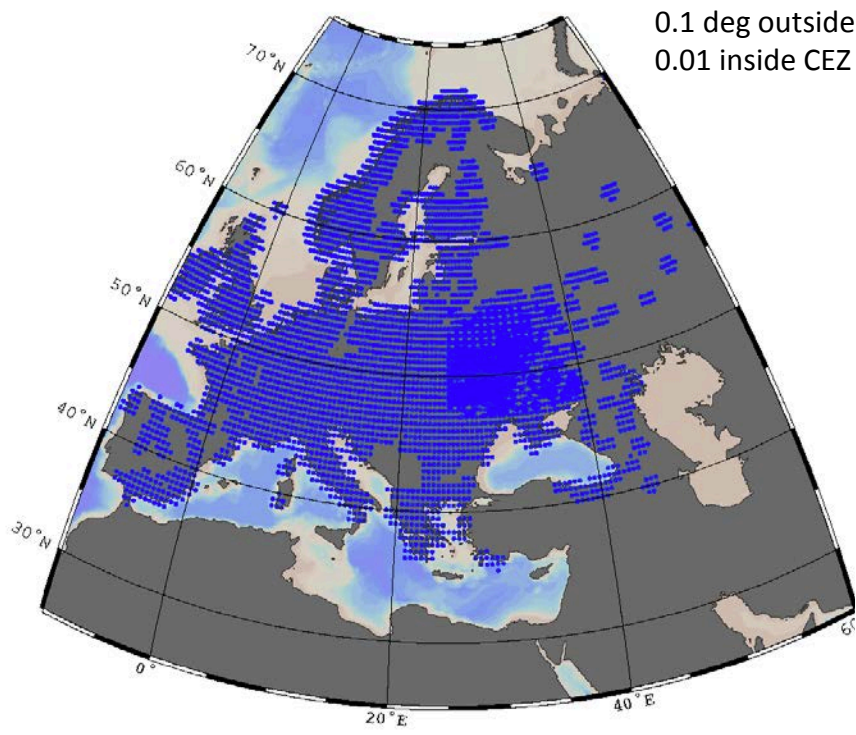


Online data



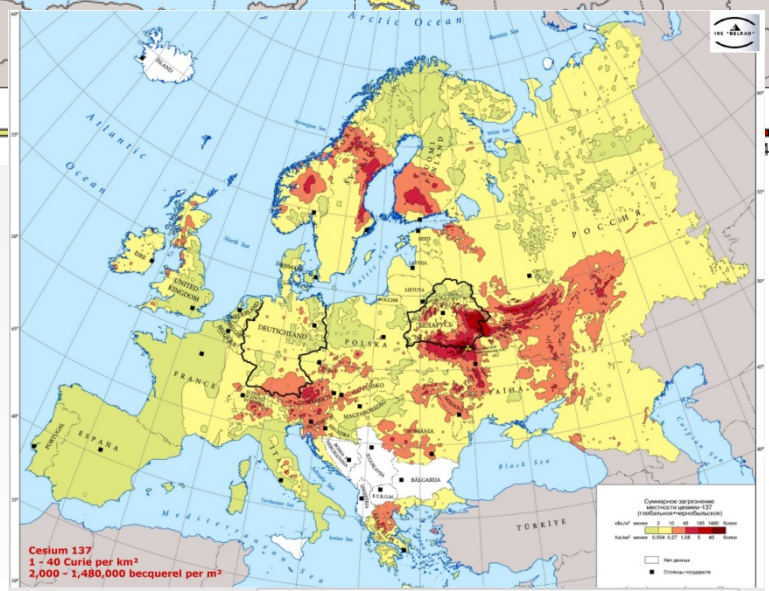
Our enrichment

# Applications (a. data rescue)



0.1 deg outside CEZ  
0.01 inside CEZ

kBq m<sup>-2</sup>



Cesium 137  
1 - 40 Curie per km<sup>2</sup>  
2,000 - 1,480,000 becquerel per m<sup>2</sup>



# Applications (a. data rescue)



SafariFileEditViewHistoryBookmarksWindowHelp54%Thu 7 Apr 15:07:35 Nikosradio.nilu.noPersonal websitesFlexpartNILUScience socialRadioHjem | Ruter

AdminToolsHelpModulesPagesUsersEdit Page

Nikolaos Evangeliou

HomeChernobylFukushimaPeopleLogin

Gridded data

Restricted data

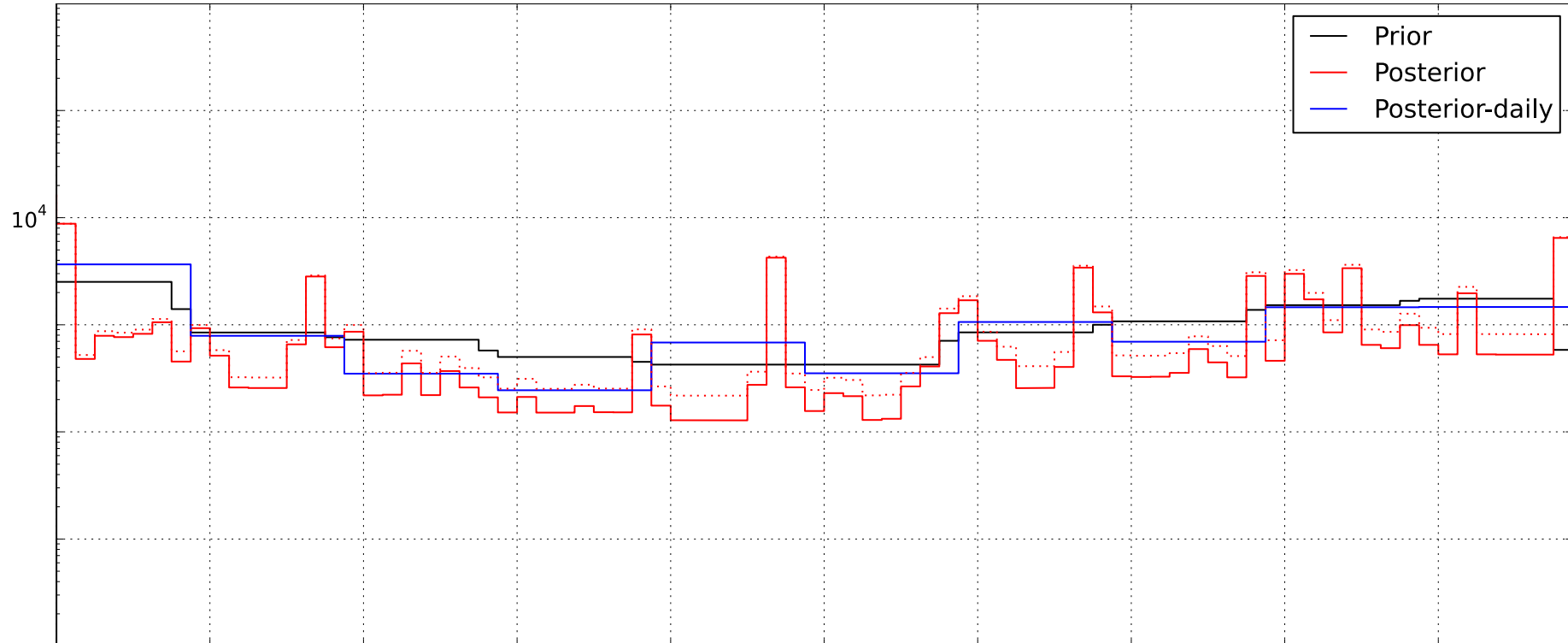
RADIOACTIVITY DATA INVENTORY

Destroyed car and houses by Tsunami on March 11, 2011 abandoned inside the exclusion zone, Tomioka, Fukushima prefecture, Japan.

### History of the accident

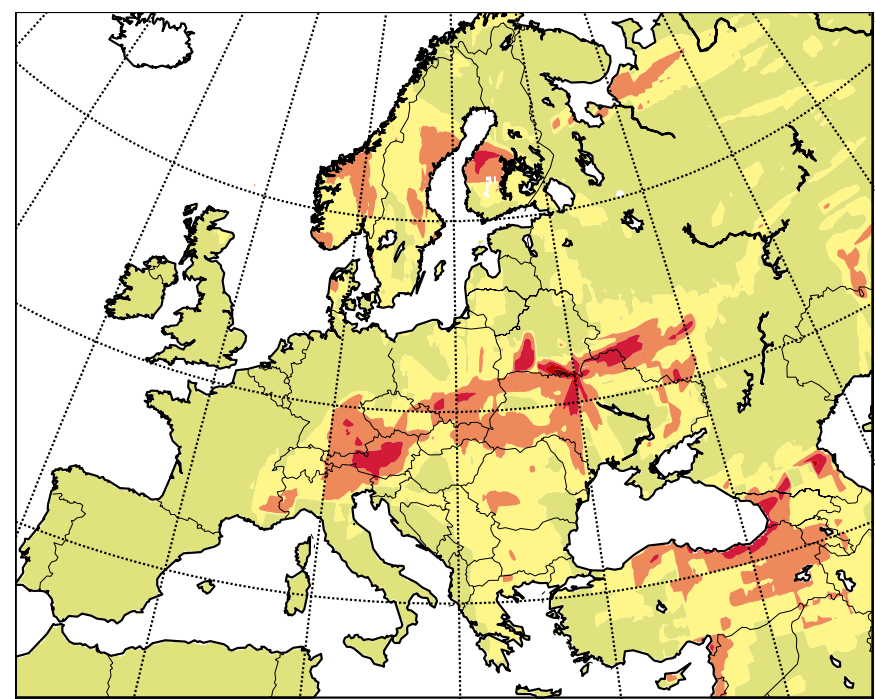
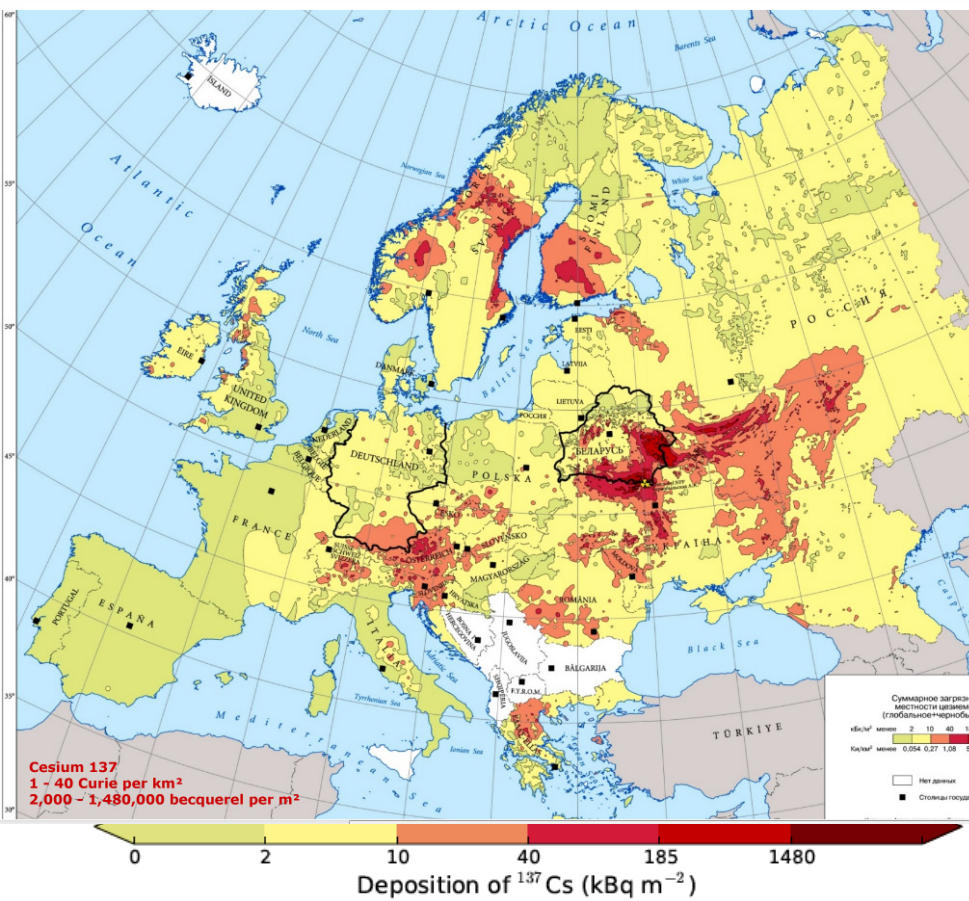
The accident at the nuclear complex of Fukushima on March 11<sup>th</sup>, 2011 resulted in a severe release of around 135 radionuclides (IRSN, 2012). It was the

# Applications (b. source-term)



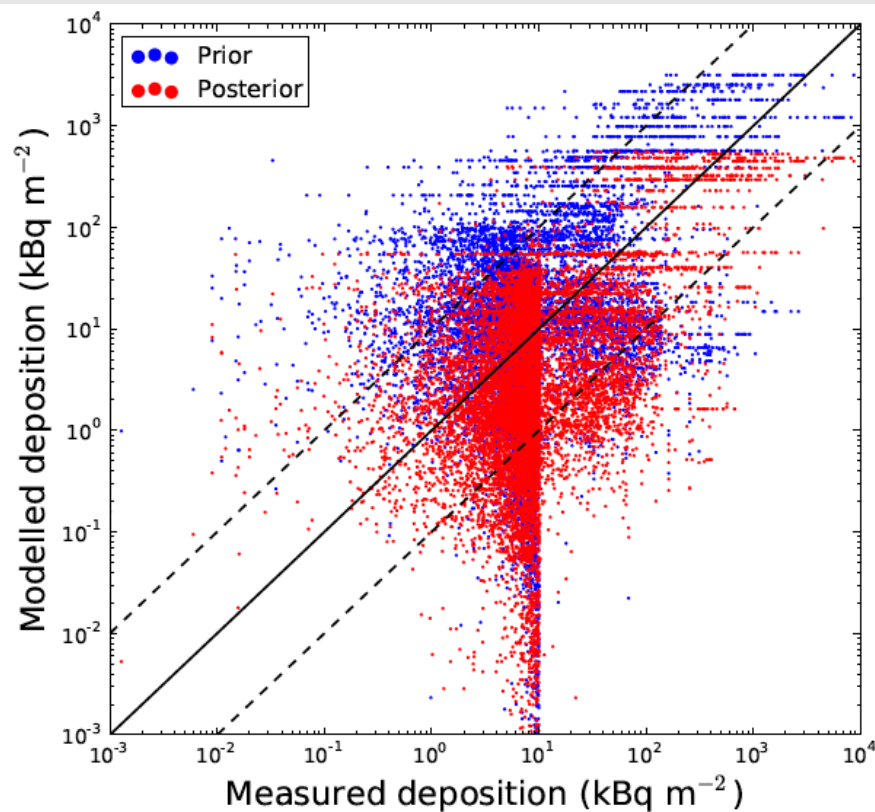
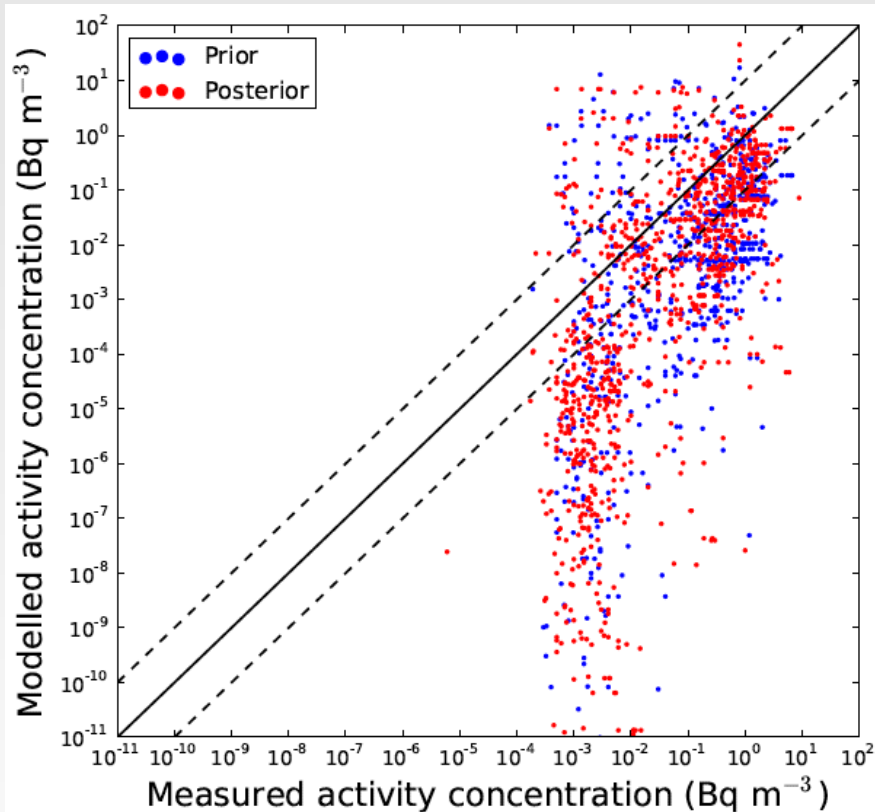
135 PBq instead of 85 PBq (prior)

# Applications (b. source-term)



ion of <sup>137</sup>Cs (kBq m<sup>-2</sup>)

# Applications (b. source-term)

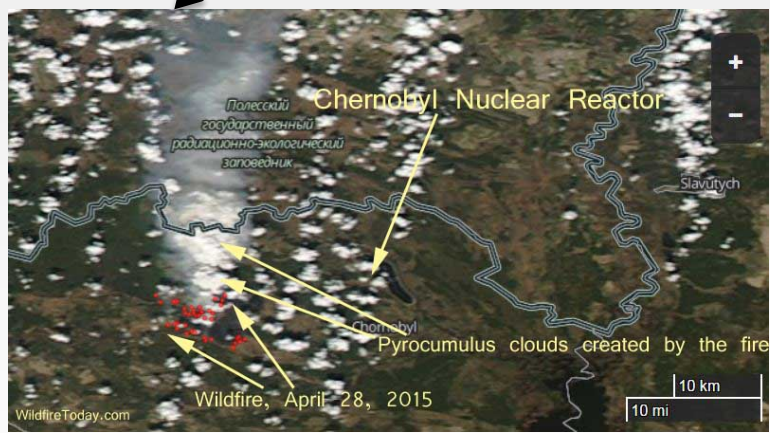




# Applications (c. 2015 fires)



April–May fires

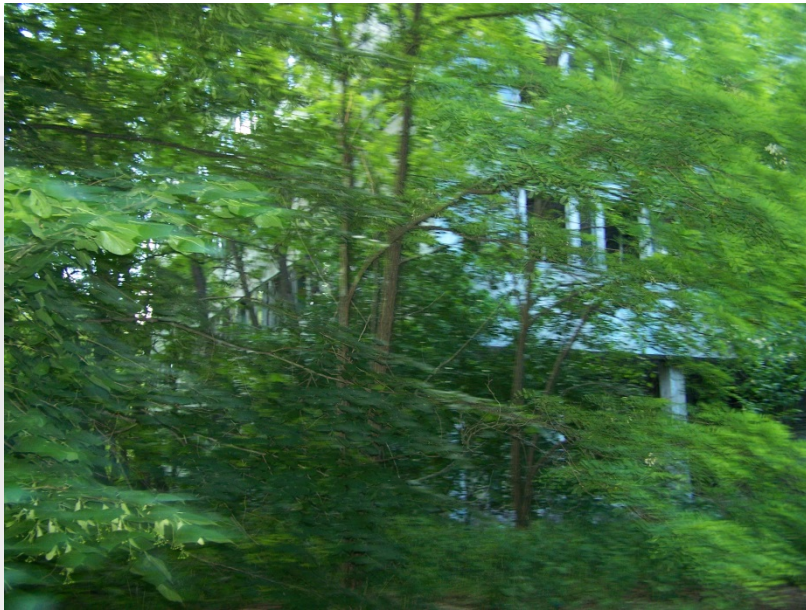


August fires





# Applications (c. 2015 fires)



Land cover change in Chernobyl

CEZ: 2600 km<sup>2</sup>

75% boreal forest (pine trees)

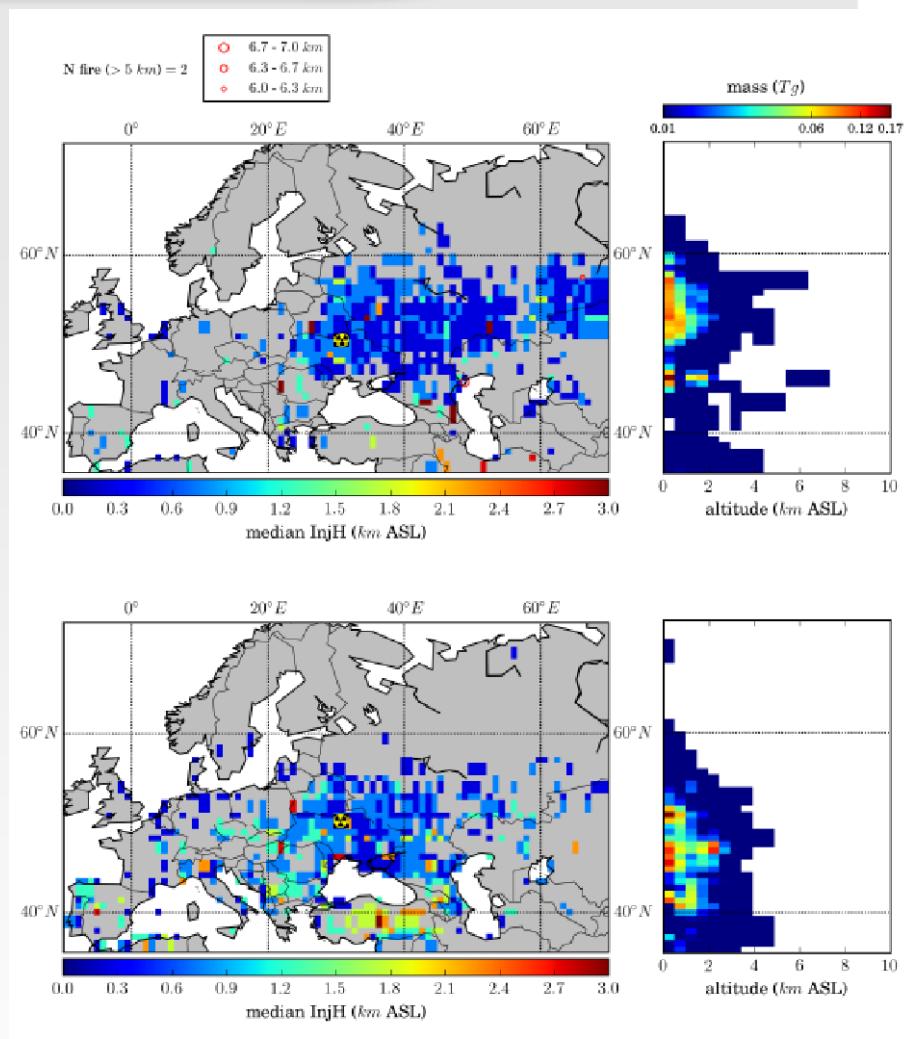
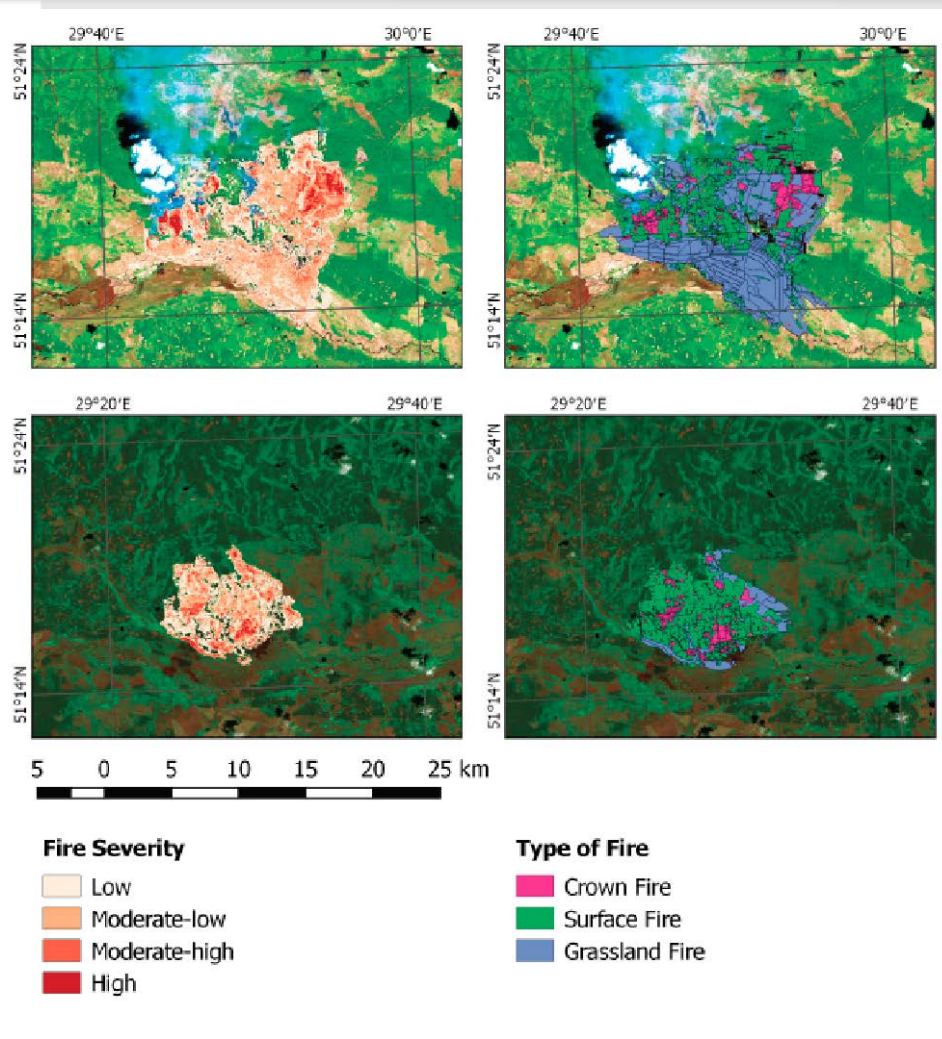
25% agricultural land & shrubs

Lack of any forest management

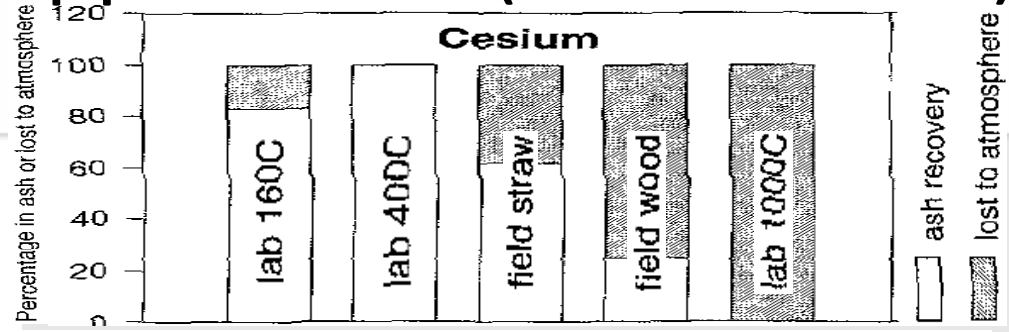




# Applications (c. 2015 fires)



# Applications (c. 2015 fires)

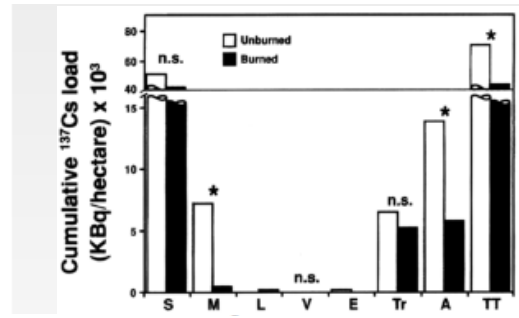


Amiro et al. (2006)  
Redistribution 20-100%

'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 %
<sup>137</sup> Cs	152 000	99 300	39
<sup>134</sup> 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 %
<sup>137</sup> Cs	120 000	106 000	12
<sup>134</sup> 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 <sup>2</sup> )	3600	5400	8770
Land type	Wildland (grass)	Wildland (grass)	Forest
Vegetation species	<i>Elytrigia repens</i> (L.) Nevski (85%)	<i>Elytrigia repens</i> (L.) Nevski (85%)	<i>Pinus silvestris</i>
Vegetation height (m)	0.5	0.2	15
Biomass density (kg m <sup>-2</sup> )	0.4	0.3	24
Litter density (kg m <sup>-2</sup> )	0.7	1.25	2.3
Dose rate range (μGy h <sup>-1</sup> )	10–16	6–10	2–4

Kashparov et al. (2000) &  
Yoschenko et al. (2006):  
10<sup>-5</sup> – 10<sup>-6</sup> m<sup>-1</sup> (Sr, Cs)  
10<sup>-6</sup> – 10<sup>-7</sup> m<sup>-1</sup> (Pu, Am)

# Applications (c. 2015 fires)

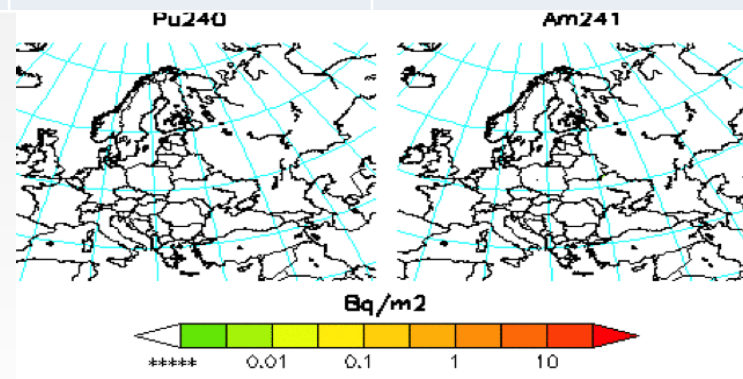
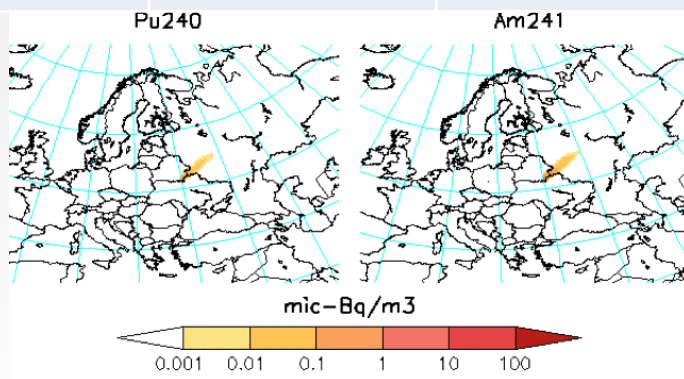
## Activity concentration

## Accumulated deposition

27-APR-2015

27-APR-2015

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



# Applications (c. 2015 fires)

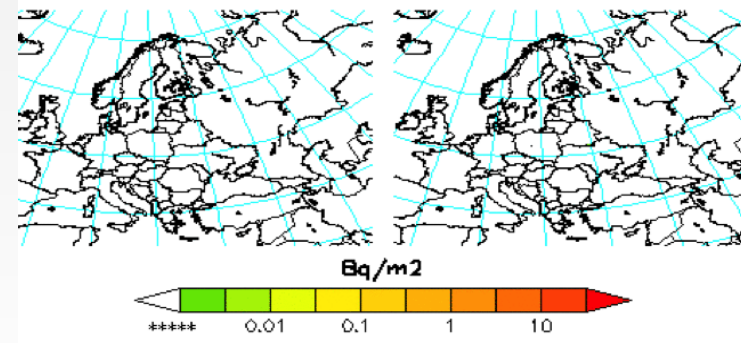
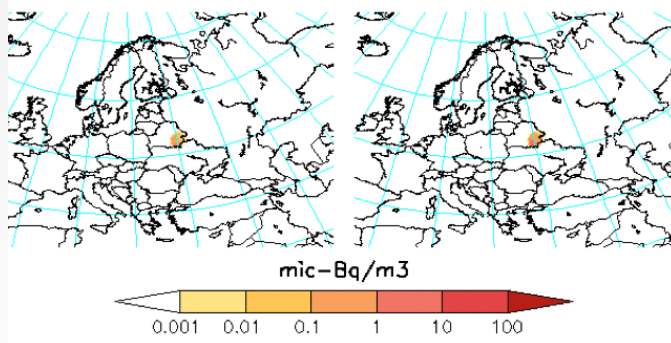
## Activity concentration

## Accumulated deposition

09-AUG-2015

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

09-AUG-2015





# Application

airway  
ants

External dose

External dose fr

Internal dose

Data

## Regulations/guidance

**500 mSv** is the highest effective dose adopted as a guidance value for restricting exposure of emergency workers under exceptional circumstances (i.e. lifesaving actions, prevention of catastrophic conditions that could significantly affect people and the environment).

**100 mSv** is the maximum effective dose proposed as a reference level recommended for urgent protective actions during emergency exposure situations.

**50 mSv** effective dose in a single year is the limit for occupational exposure of workers, provided that the total dose over five consecutive years does not exceed 100 mSv (i.e. this means an average effective dose of 20 mSv per year).

**20 mSv** per year is the maximum effective dose proposed as reference level for planning long term protective actions after an emergency is over (i.e. during an

**10 mSv** is approximately the annual effective dose corresponding to the reference level of radon concentration in air of residential dwellings

**1.0 mSv** is the annual effective dose limit established for members of the public in planned exposure situations (limits do not apply to existing or emergency exposure situations)

**0.1 mSv** is the individual dose criterion (IDC) to establish guidance levels of radionuclides in drinking water in normal situations (i.e. not applicable in emergency exposure situations)

**0.01 mSv** is the level of effective dose below which radioactive sources can be exempted from regulatory control

**20-100 mSv** is the recommended range in emergency planning of annual residual effective dose after urgent protective actions have been taken.

**10-20 mSv** per year is the dose proposed as reference level for protective actions in the emergency aftermath (i.e. during an existing exposure situation).

## Comparison with examples of levels of effective dose

### Exposure to natural sources of radiation

**100 mSv** per year is the annual average effective dose in very high background radiation areas in Iran.

**3-15 mSv** is the annual average effective dose in some high background radiation areas in the world (e.g. Brazil, China, India, Iran).

**2.4 mSv** is the worldwide annual average effective dose from natural sources

**0.1 mSv** is the effective dose due to exposure to cosmic rays during some transoceanic flights (may be higher in transpolar flights during solar flares).  
One stop Seoul-Montreal or NY-Tokyo: 0.1 mSv  
Nonstop NY-Tokyo: 0.07 mSv  
Nonstop Buenos Aires-Paris; London-NY: 0.035 mSv

**0.01 mSv** would be the level of effective dose for a visitor who stay one hour inside an archaeological site (e.g. Egyptian tomb) due to

### Effective dose due to medical exposures

**5-70 mSv** usual average effective doses for interventional procedures

**0.3-20 mSv** usual average effective doses for nuclear medicine imaging procedures

**15 mSv** abdomen/pelvis CT scan

**2.0 mSv** head CT scan

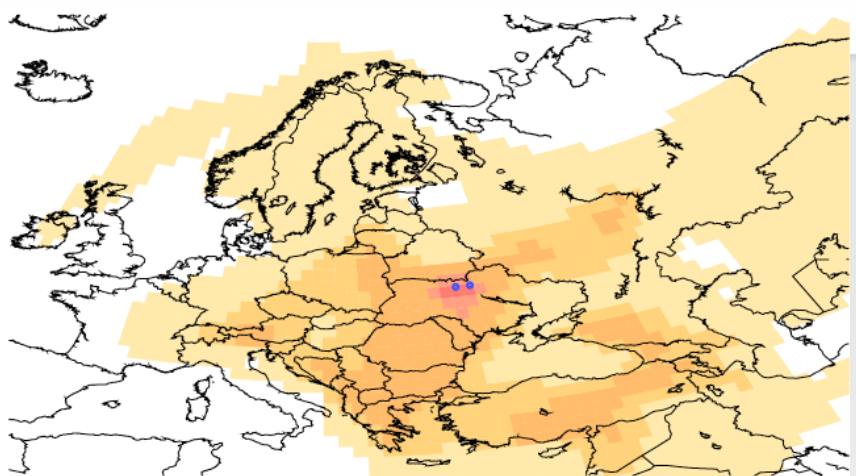
**1.0 mSv** lumbar spine X-ray

**0.7 mSv** abdomen/pelvis X-ray

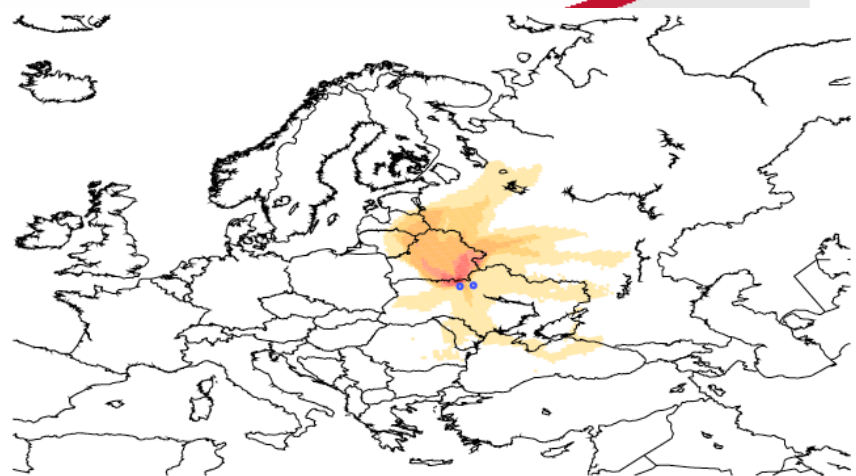
**0.02 mSv** Chest X-ray

# Applications (c. 2015 fires)

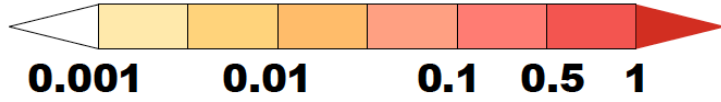
BACKGROUND



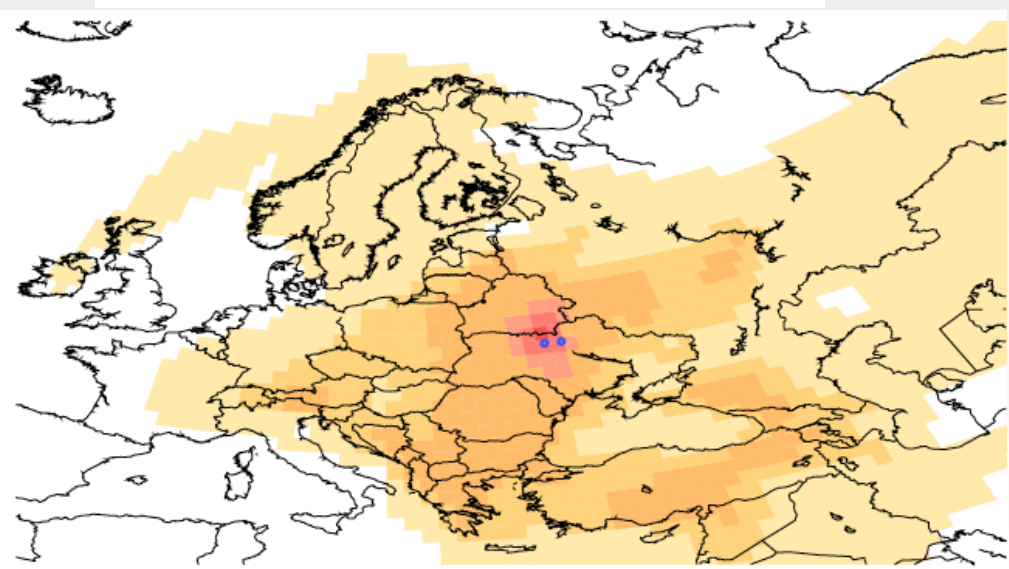
FIRES



Total effective dose (mSv)

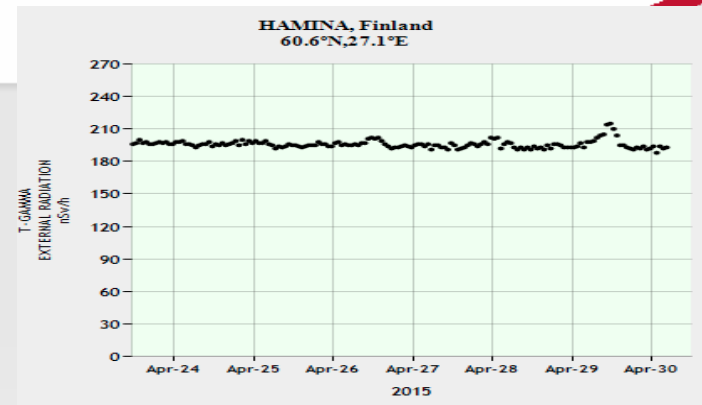
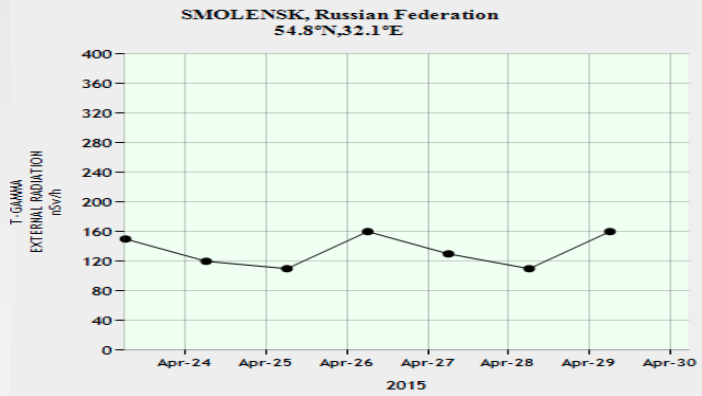
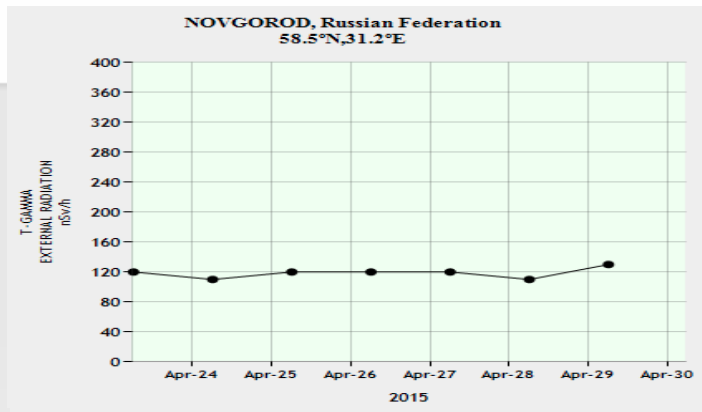


FIRES + BACKGROUND





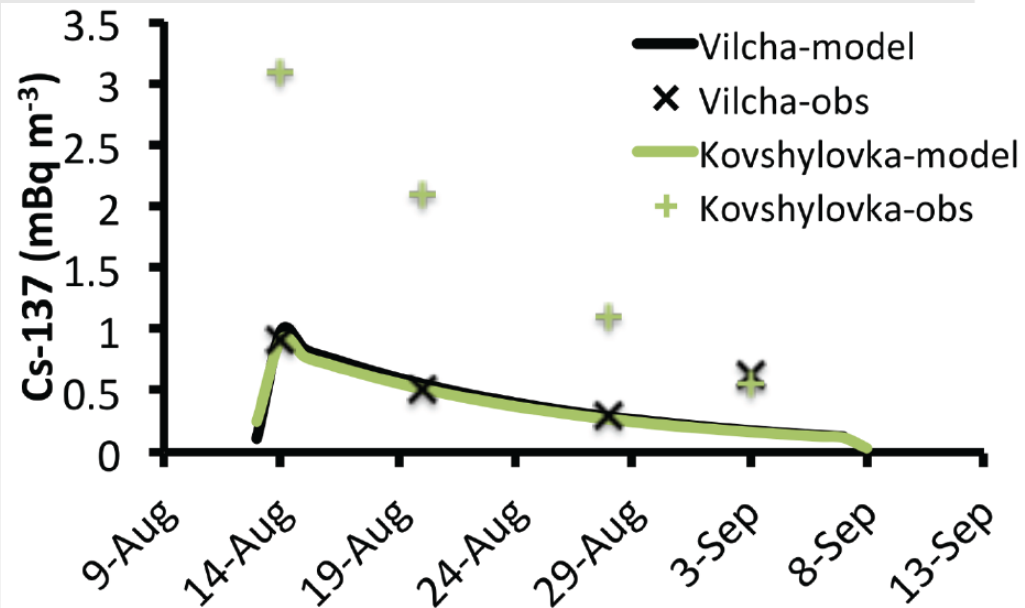
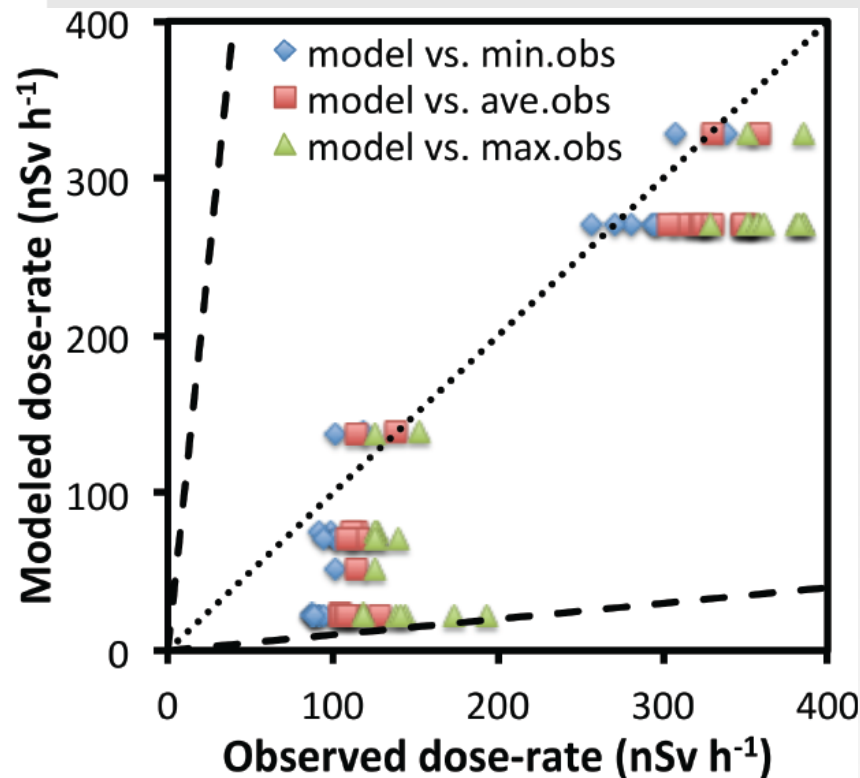
# Applications (c. 2015 fires)



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

<http://www.russianatom.ru>

# Applications (c. 2015 fires)



# Applications (c. 2015 fires)

	Cs137	Sr90	Pu238	Pu239	Pu240	Am241
<b>April 2015</b>						
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
<b>Europe (total)</b>	<b>93</b>	<b>93</b>	<b>95</b>	<b>95</b>	<b>99</b>	<b>98</b>
<b>August 2015</b>						
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
<b>Europe (total)</b>	<b>92</b>	<b>91</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>

# 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 Šmíd, Ph.D.

Institute of Information Theory and  
Automation, Czech Academy of  
Sciences

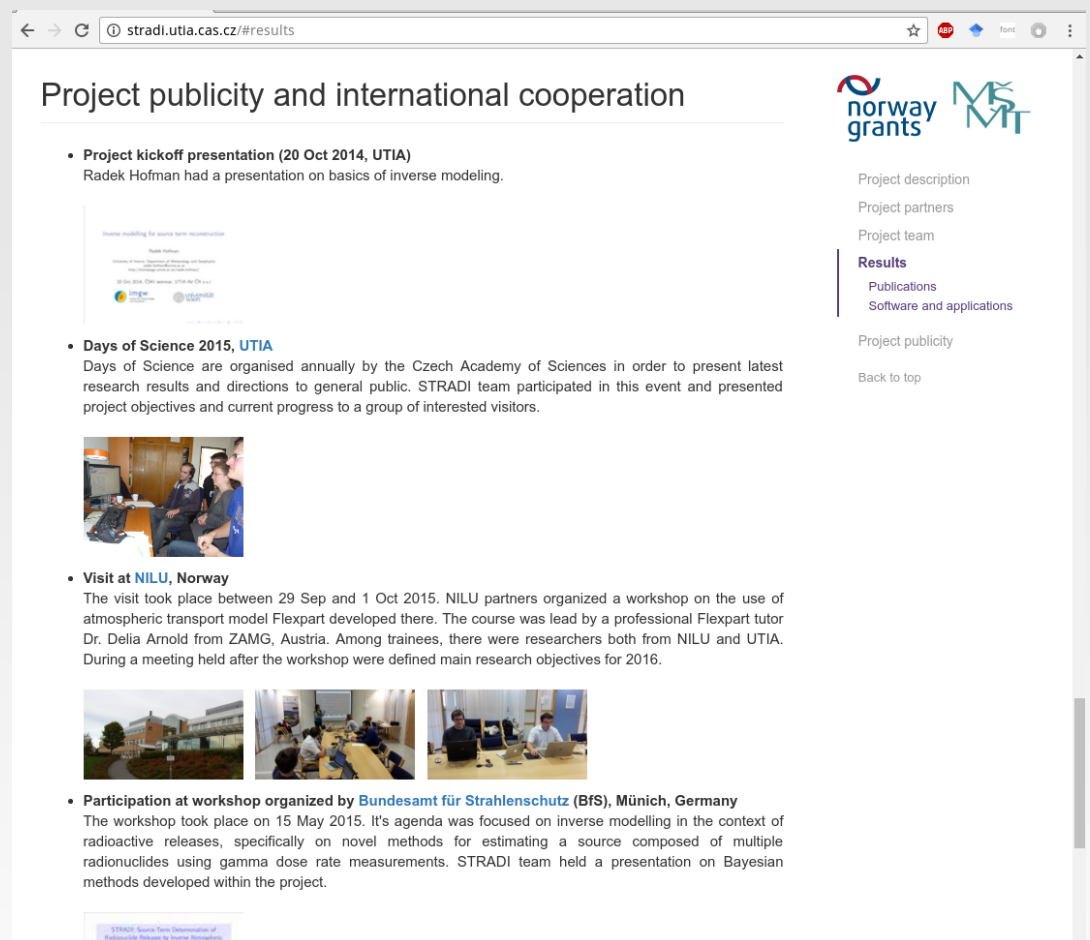
Department of Adaptive Systems

Nikolaos Evangeliou, Ph.D.

Norwegian Institute of Air Research,  
Kjeller, Norway

[stradi.utia.cas.cz](http://stradi.utia.cas.cz)

[smidl@utia.cas.cz](mailto:smidl@utia.cas.cz)



The screenshot shows a web browser displaying the project results page. The URL in the address bar is [stradi.utia.cas.cz/#results](http://stradi.utia.cas.cz/#results). The page title is "Project publicity and international cooperation". On the right side, there is a navigation menu with links: "Project description", "Project partners", "Project team", "Results" (which is highlighted), "Publications", "Software and applications", "Project publicity", and "Back to top". The main content area lists three key events:

- Project kickoff presentation (20 Oct 2014, UTIA)**  
Radek Hofman had a presentation on basics of inverse modeling. Below the text is a small image showing a presentation slide titled "Inverse modelling for source term reconstruction" with logos of the participating institutions.
- Days of Science 2015, UTIA**  
Days of Science are organised annually by the Czech Academy of Sciences in order to present latest research results and directions to general public. STRADI team participated in this event and presented project objectives and current progress to a group of interested visitors. Below the text is a photo of three people sitting at a table during the event.
- Visit at NILU, Norway**  
The visit took place between 29 Sep and 1 Oct 2015. NILU partners organized a workshop on the use of atmospheric transport model Flexpart developed there. The course was lead by a professional Flexpart tutor Dr. Delia Arnold from ZAMG, Austria. Among trainees, there were researchers both from NILU and UTIA. During a meeting held after the workshop were defined main research objectives for 2016. Below the text are three small images: a building, a group of people in a meeting, and two people working on laptops.
- Participation at workshop organized by Bundesamt für Strahlenschutz (BfS), München, Germany**  
The workshop took place on 15 May 2015. It's agenda was focused on inverse modelling in the context of radioactive releases, specifically on novel methods for estimating a source composed of multiple radionuclides using gamma dose rate measurements. STRADI team held a presentation on Bayesian methods developed within the project. Below the text is a small image of a presentation slide titled "STRADI: Source Term Determination of Radionuclide Releases by Remote Monitoring".