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# ROBUSTNESS OF A RECONSTRUCTED SOURCE TERM TO METEOROLOGICAL DATA AND DEPOSITION SCHEME: APPLICATION TO THE CASE STUDY OF RUTHENIUM-106 RELEASE IN FALL 2017.

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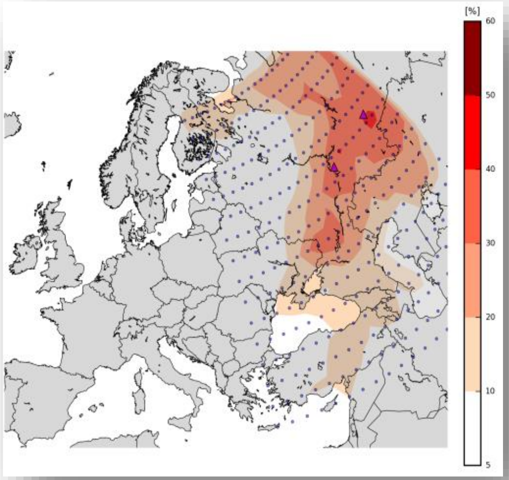


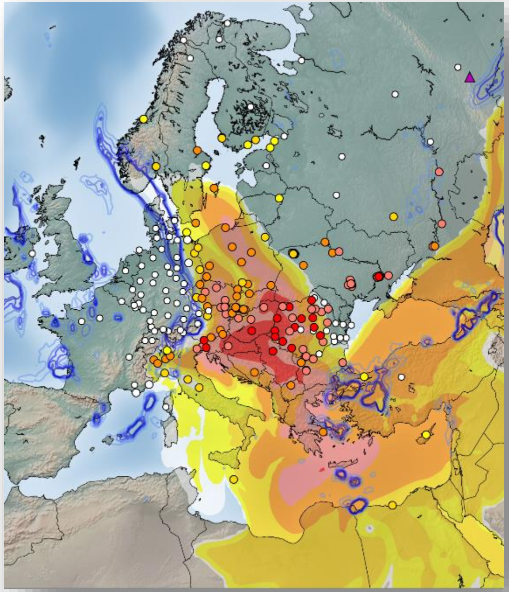

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# Context

## ❑ Radionuclides detections event by European monitoring networks

- **Known source location**
  - Release of $^{75}Se$ from SCK-CEN research reactor, Mol in Belgium (2019)
  - Forest fires in the Chernobyl area (April 2020)

- **Unknown source location**
  - Meltdown of $^{137}Cs$ source in Elekstrostal, Russian Federation (2013)
  - Multiple $^{131}I$ detection events (2011 - 2020)
  - $^{106}Ru$ detection at continental scale (> mBq/m$^3$) in fall 2017
  - Radionuclide detection in northern Europe in June 2020

- **The knowledge of the source (magnitude, temporal evolution and sometimes location) is required to better understand the event**

**Inverse modelling methods are very helpful for source reconstruction**

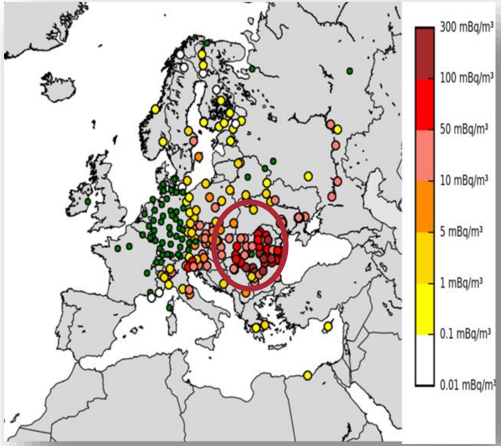
# Detection of Ruthenium-106 in fall 2017

## ❑ Observations of $^{106}$Ru in the atmosphere in Europe between late September and middle of October 2017

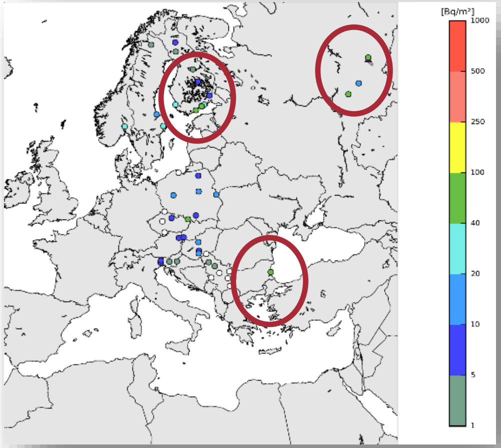
- Air concentration measurements
  - > 1000 measurements collected (maximum value 180 mBq/m$^3$ in Romania)
  - Huge differences between air sampling durations: 11 hours to 1 month
- Deposition measurements:
  - The first positive deposit measurements are reported on 23 September in South Ural (several tens of Bq/m$^2$)
  - Other deposits measurements are reported in Europe (several Bq/m$^2$ in Sweden, Poland and Austria) at the beginning of October

## ❑ Source reconstruction using inverse modelling techniques

- Sensitivity analysis of the reconstructed source
  - Cost function in the inversion procedure
  - Meteorological data
  - Deposition scheme

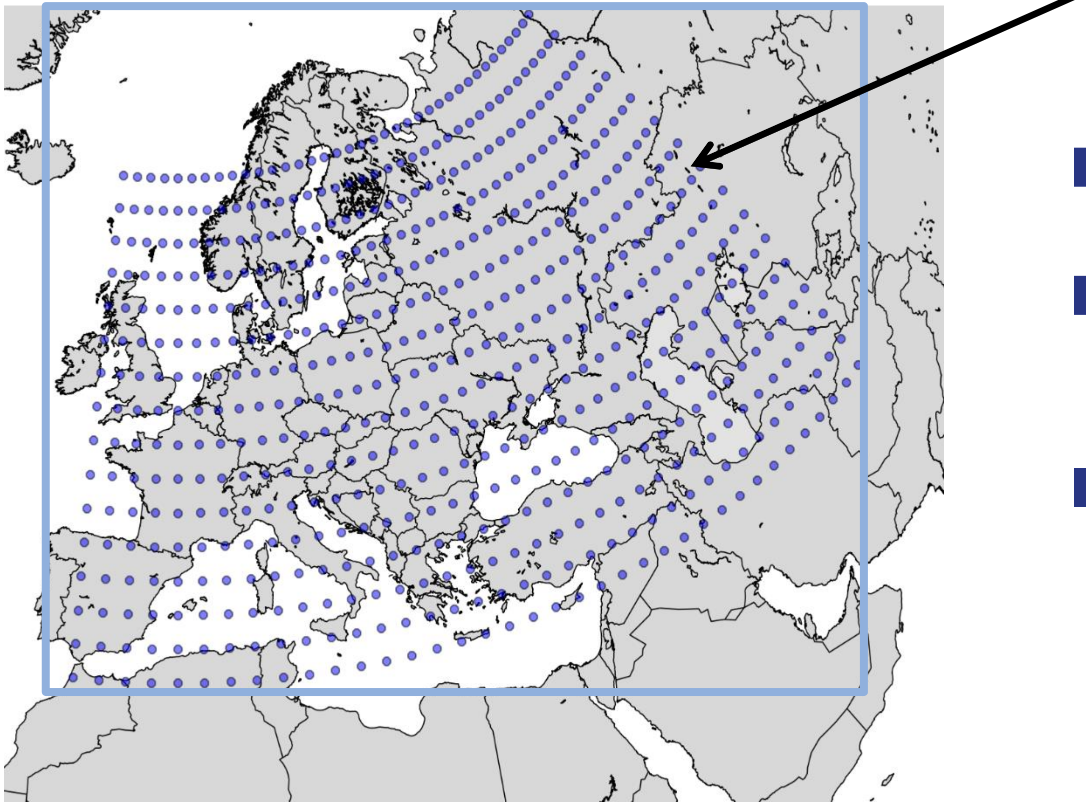



*$^{106}$Ru air concentrations*




*$^{106}$Ru deposition*

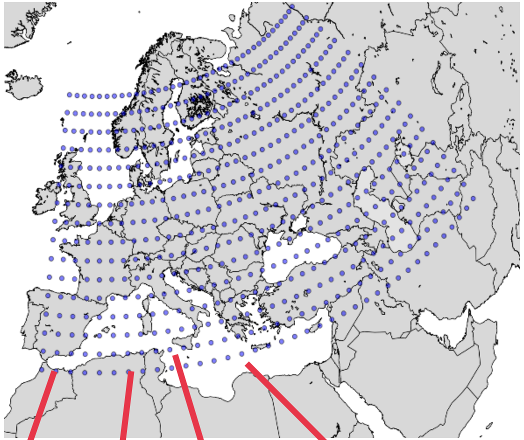
# Definition of a grid containing potential source locations



Potential sources are located within the blue domain

- Coverage area of potential sources: [6W, 65E], [35N, 65N]
- 2° x 2° spatial resolution between two potential sources (720 potential sources)
- Computational domain dimensions: [10W, 90E], [20N, 75N]

# Source term assessment using inverse modelling



## ❑ Inverse modelling based on variational approach

- Gaussian errors:

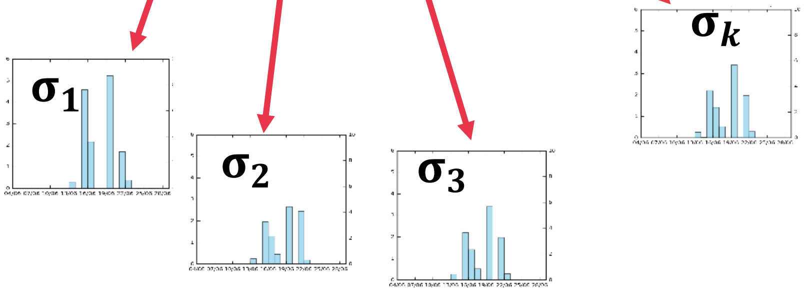
$$\underbrace{\mathbf{J_G(x)} = \frac{1}{2}(\mathbf{y}-\mathbf{Hx})^{\mathbf{T}}\mathbf{R}^{-1}(\mathbf{y}-\mathbf{Hx})}_{\text{Model/measure match}} + \underbrace{\frac{1}{2}(\mathbf{x}-\mathbf{x_b})^{\mathbf{T}}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x_b})}_{\text{ST magnitude}}$$

- Log-normal errors:

$$\mathbf{J_{LN}(x)} = \frac{1}{2}\left(\ln(\mathbf{y}+\mathbf{y_t}) - \ln(\mathbf{Hx}+\mathbf{y_t})\right)^{\mathbf{T}}\mathbf{R}^{-1}\left(\ln(\mathbf{y}+\mathbf{y_t}) - \ln(\mathbf{Hx}+\mathbf{y_t})\right) + \frac{1}{2}(\mathbf{x}-\mathbf{x_b})^{\mathbf{T}}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x_b})$$

## ❑ Assumptions

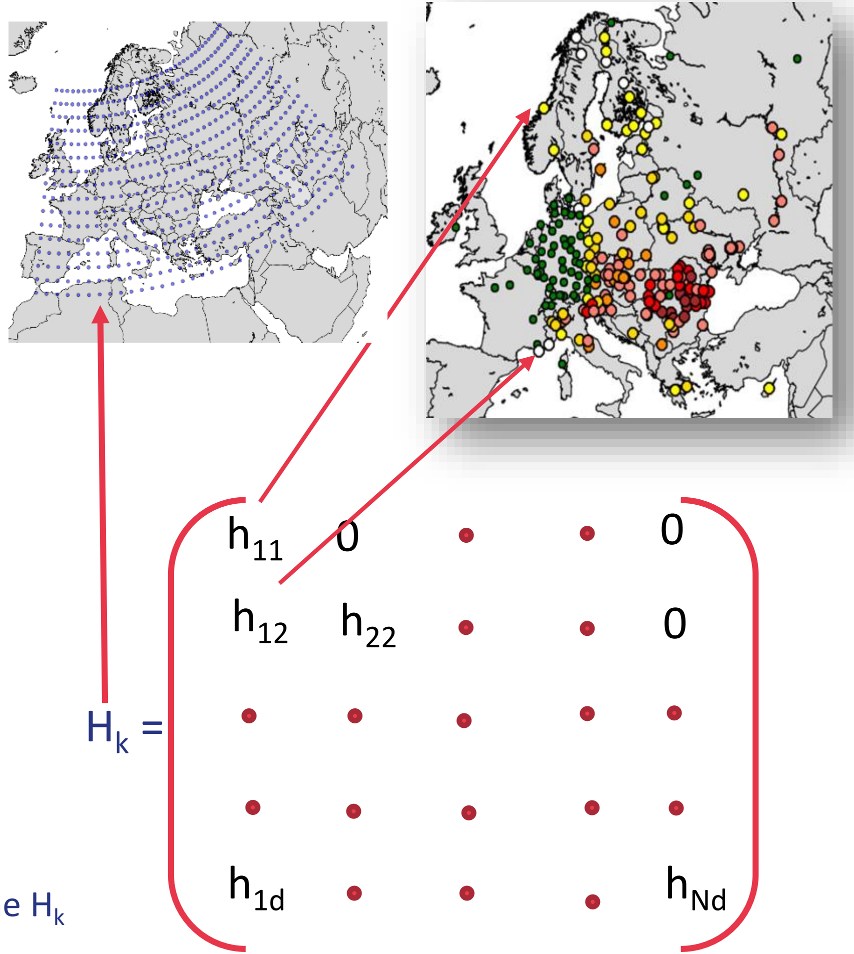
- *a priori* $\mathbf{x_b}$= 0
- Threshold $\mathbf{y_t}$
- Enforce positivity of the source vector
- Simple modelling of $\mathbf{R}$ and $\mathbf{B}$ matrixes (diagonal)



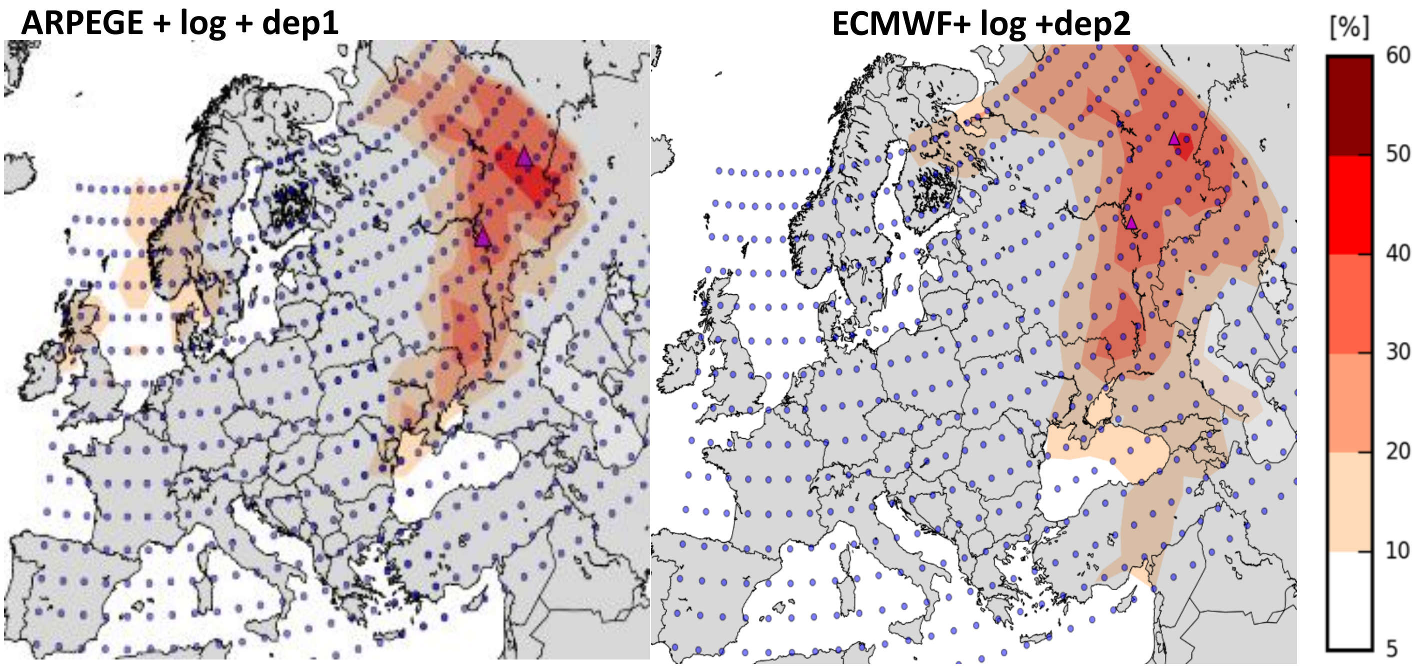
# Construction of H operators

## ❑ Construction of 8 H operators: all combinations of meteorological data and deposition schemes

- Eulerian model ldx (C3X platform)
- Meteorological fields
  - ECMWF: 0.28125° x 0.28125, 1 h
  - ARPEGE (Météo-France): 0.5° x 0.5°, 3 h
- Deposition scheme (dep1, dep2, dep3, dep4)
  - Dry deposition (m.s$^{-1}$): $v_{dep}$ = 2 10$^{-3}$ ; $v_{dep}$ = 10$^{-3}$
  - Wet deposition:
    - In-cloud scavenging (s$^{-1}$): $\Lambda = 5 \times 10^{-5} I$
    - Below-cloud scavenging (s$^{-1}$): $\Lambda = 5 \times 10^{-4} I^{0.64}$; $\Lambda = 5 \times 10^{-5} \mathbf{I}$
- Release period
  - 22/09 to 13/10 with daily frequency (N=21)
  - 720 x 21 = 15120 daily releases to estimate for $H_k$
  - 15120 x 8 = 120960 daily releases to estimate for all the $H_k$



# Source reconstruction: location




*Percent of the simulated activity concentrations that is within a factor of 2 of the observed values: Log-normal cost function, ECMWF and ARPEGE meteorological fields*

- Most reliable source localization is situated in southern Urals in Russian Federation
- Agreement between observed and simulated concentrations is satisfactory (FAC2 > 40%)
- Weak influence of cost function / meteorological data / deposition scheme on the source location
- Mayak Production Association is a possible candidate

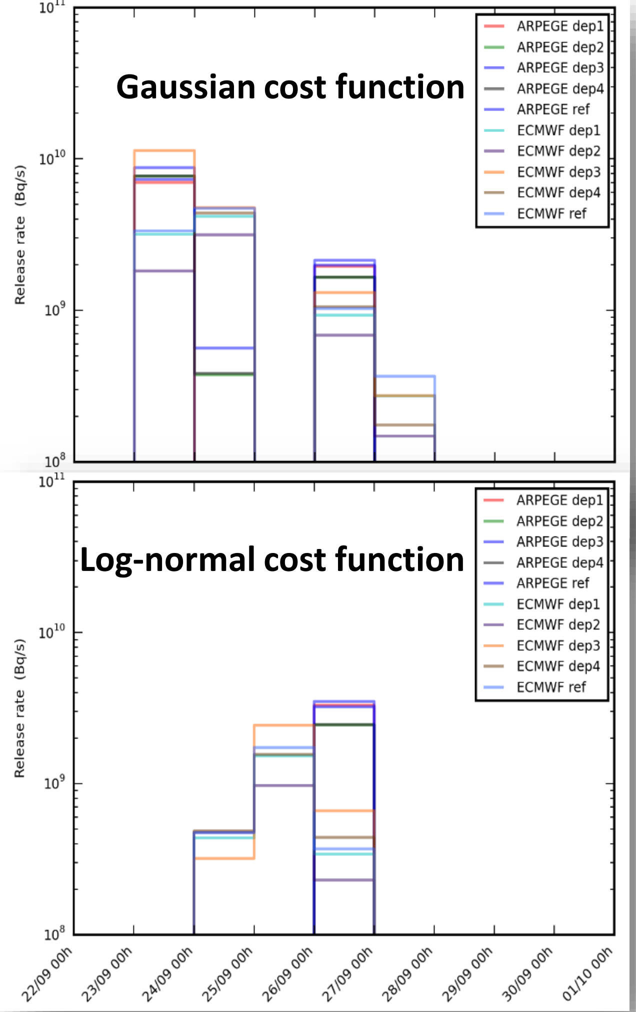
# $^{106}Ru$ source term assuming a release from Mayak Production Association

| Source term | Gau dep1 | Log dep1 | Gau dep2 | Log dep2 | Gau dep3 | Log dep3 | Gau dep4 | Log dep4 | |
|---|---|---|---|---|---|---|---|---|---|
| Total release (TBq) ARPEGE | 783 | 291 | 840 | 218 | 993 | 309 | 843 | 218 | ARPEGE |
| Total release (TBq) | 743 | 201 | 504 | 146 | 688 | 297 | 488 | 216 | ECMWF |

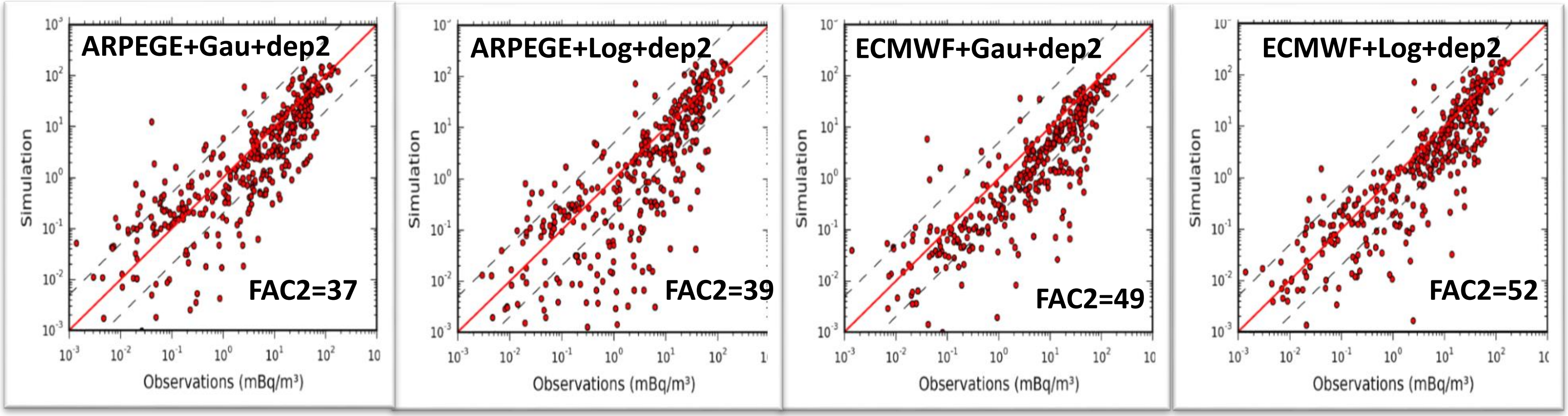
- **Source terms are in the range of 146 to 840 TBq**
- **The impact of the deposition scheme is moderate**
  - Total quantities can vary by a factor of 2 when changing only the deposition scheme
- **The cost function is the most influent parameter**
  - Total quantities can vary by a factor of 3.7 when changing only the cost function
  - When using log-normal cost function:
    - More robust (less sensitive to other parameters)
    - The variation on the total quantities does not exceed 30 %
    - Source terms are lower than those estimated using Gaussian cost function

# Duration and period of the releases

- **ARPEGE meteorological data**
  - Release occurred on:
    - 26/09 using log-normal cost function
    - 23/09 and 26/09 using Gaussian cost function
- **ECMWF meteorological data**
  - Release occurred on:
    - 23/09, 24/09, 26/09 and 27/09 using Gaussian cost function
    - 24/09, 25/09 and 26/09 using Log-normal cost function
- **Log-normal cost function will result in shortened release duration**
- **Deposition scheme has a very weak influence on the release duration**

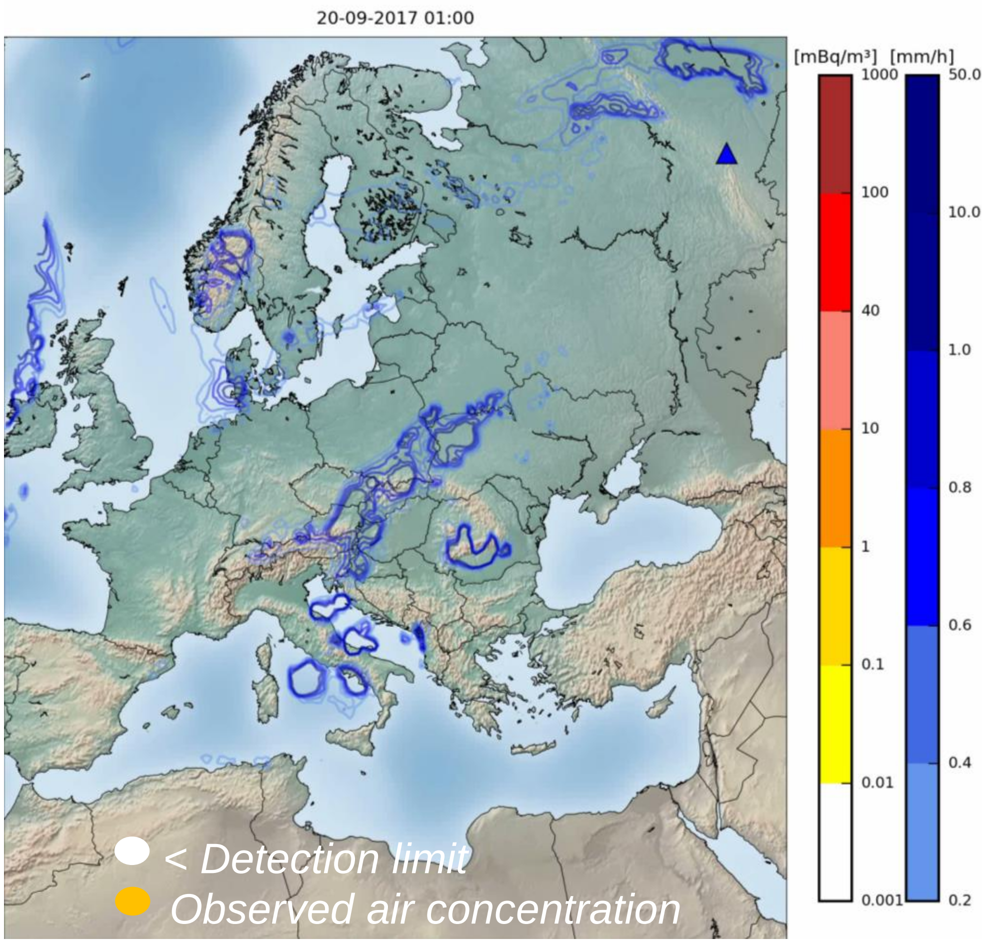


# Model to data comparison: air concentration




- **Highest FAC2 scores are obtained using ECMWF meteorological fields**
  - The gain is around ten points on FAC2 scores
- **FAC2 scores are slightly enhanced using log-normal cost function**
- **The impact of the deposition scheme is low and not quantifiable**
  - $v_d = 10^{-3}$ m.s$^{-1}$ leads to better FAC2 scores…

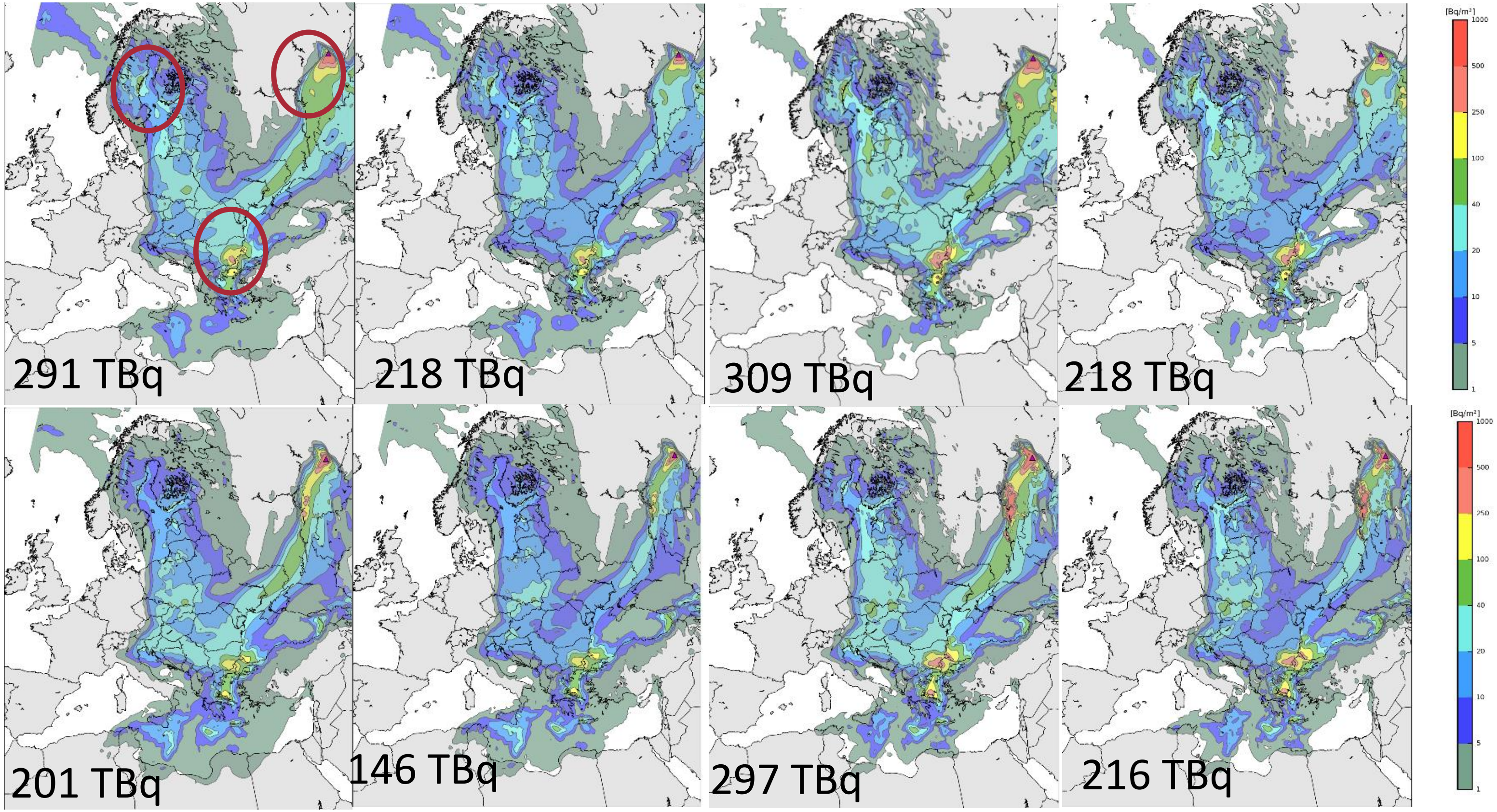
# $^{106}$Ru plume dispersion from Mayak Production Association (best simulation)




- The plume reached most European countries between September 28 and October 10
- The duration of the plume's passage varied from a few hours (Russia) to nearly a week (Italy)
- Great Britain, Spain and Portugal remained outside the detections
- The plume reached the extreme south-east of France while the rest of the country was not affected
- Several rain events occurred during the passage of the plume (wet deposition)

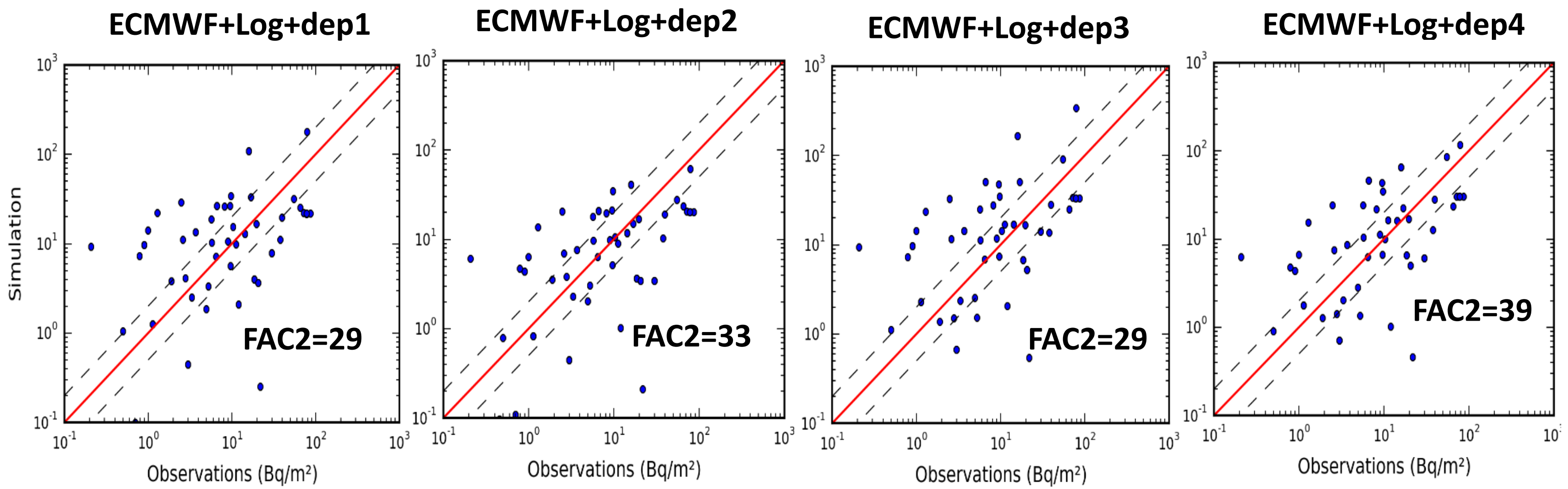
# Modelled cumulated $^{106}$Ru deposition

Dep1 ARPEGE | Dep2 ARPEGE | Dep3 ARPEGE | Dep4 ARPEGE




Dep1 ECMWF | Dep2 ECMWF | Dep3 ECMWF | Dep4 ECMWF

# Comparison with observations




- **The impact of the deposition scheme is moderate on the FAC2 scores**
  - $v_d = 10^{-3}$ m.s$^{-1}$ leads to better FAC2 scores…
  - FAC2 scores are slightly improved using wet deposition scheme based on:
    - In-cloud scavenging $\Lambda = 5 \times 10^{-5} I$
    - Below-cloud scavenging $\Lambda = 5 \times 10^{-4} I^{0.64}$

# Conclusion and perspectives

- **Inversion techniques based on $^{106}Ru$ air concentrations measurements including several meteorological data and deposition schemes highlight that a release emitted from the southern Urals could best explain the detections reported in Europe.**
  - The $^{106}Ru$ released was estimated to range from 146 to 821 TBq
  - Duration of the release differs according cost function and meteorological data used
- **Outcome of the sensitivity analysis**
  - Scores related to air concentrations measurements are improved using log-normal cost function with ECMWF meteorological data
  - Scores associated to deposition measurements are impacted by the choice of the deposition scheme
  - Uncertainties remain significant due to the behavior of the $^{106}Ru$
- **Further developments are in progress**
  - Using meteorological data with 0.1° x 0.1° resolution in collaboration with Météo-France
  - Better consideration of detection limits in the inversion process
  - Using air concentrations and deposition measurements simultaneously in the inversion process

# Thank you for your attention!