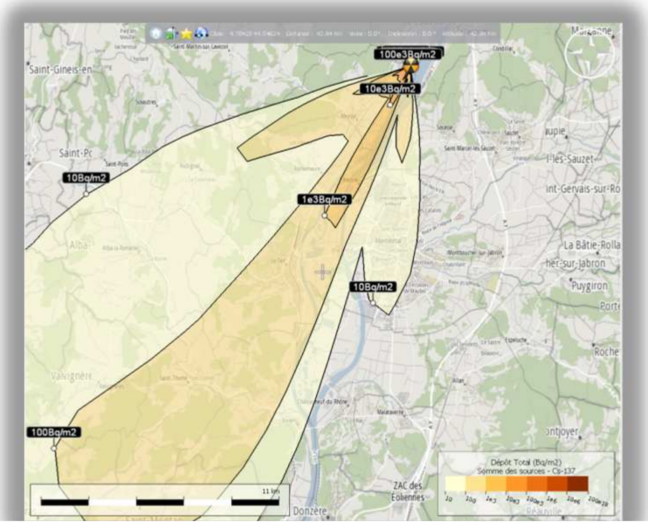
IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Real-time use of inverse modeling techniques to assess the atmospheric accidental release of a nuclear power plant

5th NERIS Workshop

Roskilde - 5 April 2019



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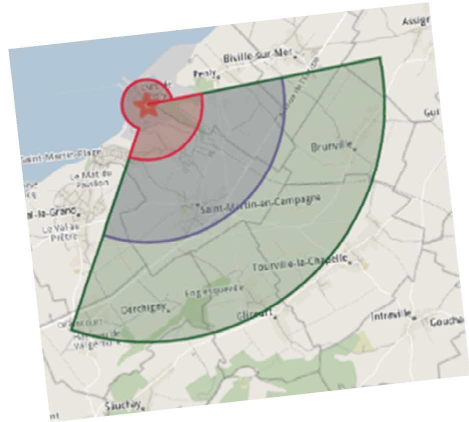
Context

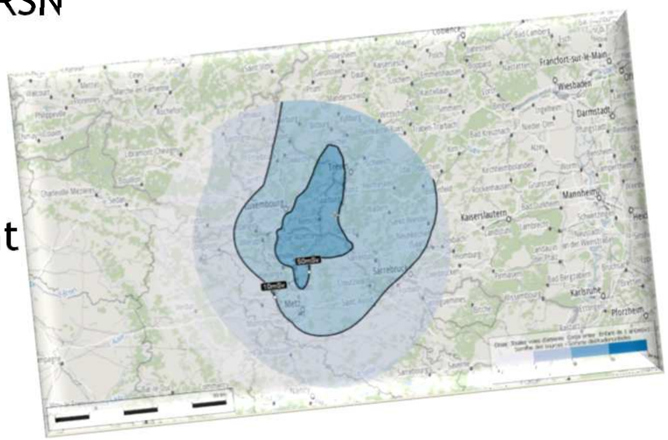
Role of IRSN in case of a radiological emergency

- Assess risk induced by accidental situation
- Provide technical expertise to public authorities



Task

- Evaluation of the reactors state, releases to the environment (diagnosis/prognosis)
- Evaluation of the radiological consequences (doses and depositions, diagnosis/prognosis), all spatial scales (C3X IRSN platform)



Uncertainties on the source term

- Prevent to have a complete understanding of the accident
- Prevent to assess the actual consequences for the population

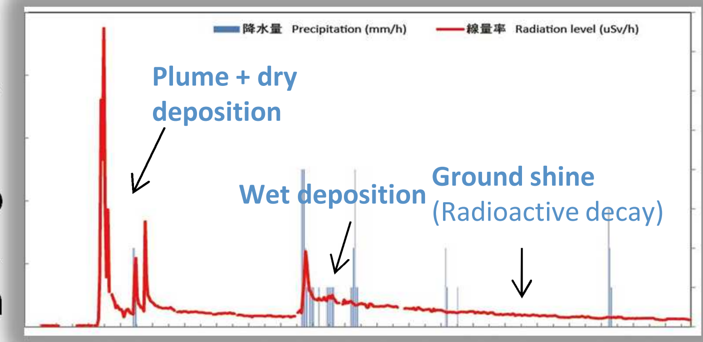
➢ Development of an inverse modelling method to improve the source term assessment using environmental observations

Observations available in case of nuclear accident

Gamma dose rate measurements

☺ High temporal resolution, dense spatial coverage, available in real time.

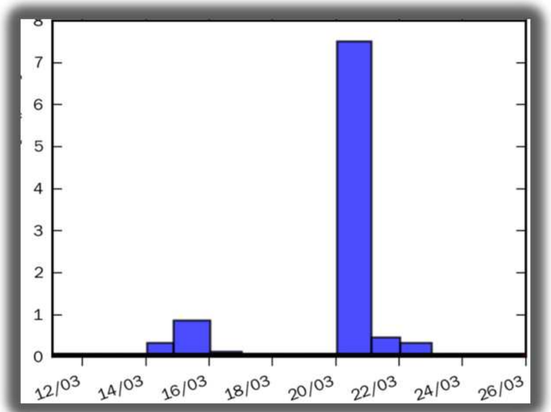
☹ No access to the isotopic composition of the ST and to the respective share of the plume and the deposit. Available for major release events only (high detection level).



Air concentration & daily deposition measurements

☺ Provide information on the isotopic composition of the release. Available for major + minor release events: low detection level.

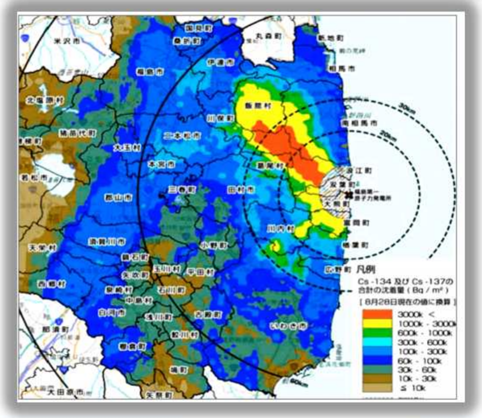
☹ Coarse spatial coverage. Time averaged data (often 24 h). Time series not always available. Delays in making data available.



Total deposit

☺ Dense spatial coverage. Provide information on the isotopic composition of the release.

☹ No information on the temporal evolution of the deposit during the release period. Delays in making data available.



IRSN inverse modeling method: an overview

ATMOSPHERIC TRANSPORT MODEL

Gaussian puff - Eulerian - Lagrangian

+

OBSERVATIONS

Air concentration

Ambiant gamma dose rate (Saunier et al. 2013)

STEP1 : DEFINE THE A PRIORI INFORMATION

Source location - First guess

Gathered measurements (spatial distribution, temporal resolution, order of magnitude)

Isotopic composition

→ **Reduce the number of parameters + limit the solution space**

INVERSE MODELLING

IF AIR CONCENTRATION OBSERVATIONS

IF DOSE RATE OBSERVATIONS

STEP2 : IDENTIFY THE POTENTIAL RELEASE PERIODS

Extraction of the plume component

Inverse modelling

→ **Reduce the number of parameters + limit the solution space**

STEP3 : ESTIMATE THE RELEASE RATES

carry out for the all period

Cost function $J(\sigma) = \|\mu - H\sigma\|^2 + \lambda \|\sigma - \sigma_b\|^2$

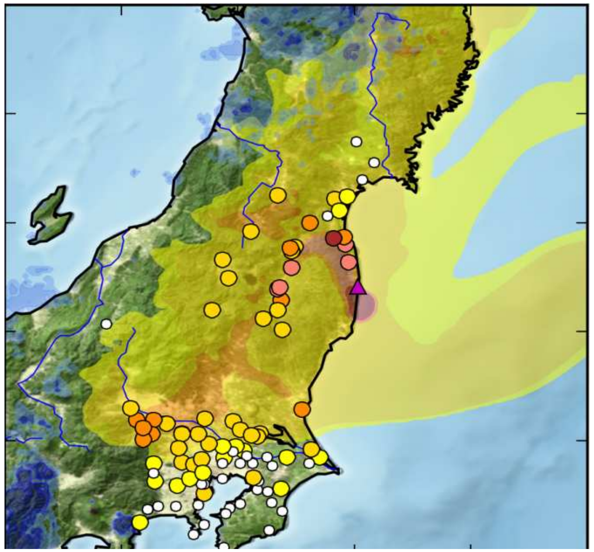
carry out for the periods identified during Step 2

Cost function $J(\sigma) = \|\mu - H\sigma\|^2 + \lambda \|\sigma - \sigma_b\|^2 + \sum_{i=1}^{n_{isotope}-1} r_i^2$

Inverse modeling method: towards operationalizing

Validation on the Fukushima accident

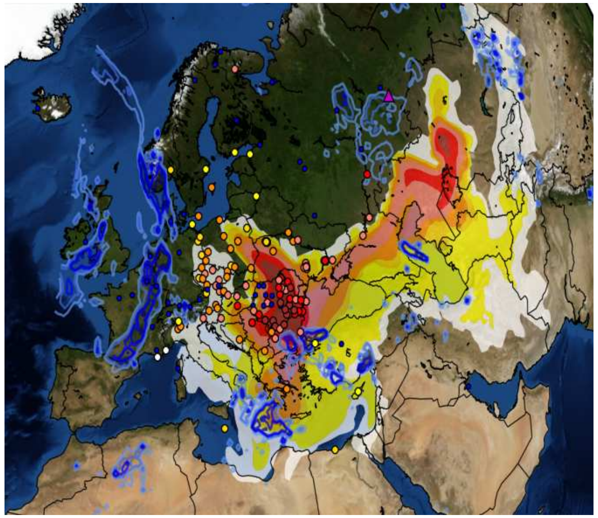
- Improvement of the Fukushima source term
  - Gamma dose rate measurements (Saunier et al. 2013)
  - ^{137}Cs air concentration measurements



Fukushima ^{137}Cs plume

^{106}Ru detection event in autumn 2017

- Adaptation of the inverse method to locate the ^{106}Ru release
  - ^{106}Ru air concentration measurements
  - Real-time use



^{106}Ru plume dispersion

And on going operationalization

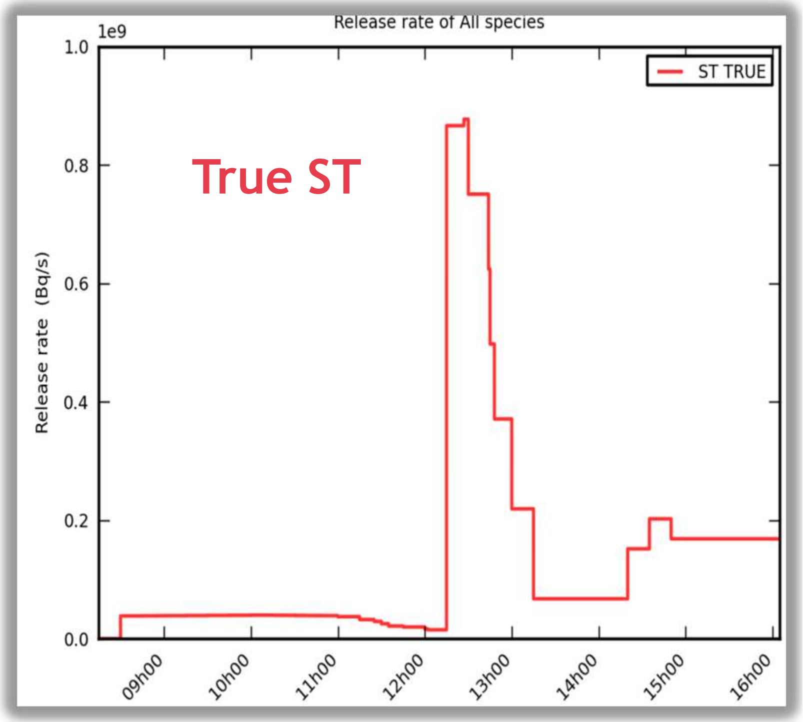
- Tests during national crisis exercises
  - Limited number of gamma dose rate measurements
  - Assessment of the suitability of the inversion method in emergency context
  - Identification of the required developments to incorporate the method in C3X operational platform

Real-time use of the inversion method

Cruas nuclear power plant exercice on 13 december 2016

- Steam Generator Tube Rupture (SGTR)
  - Low amplitude scenario
    - No countmeasure required to protect population but …
    - can be detected by dose rate monitroing network
- Source term
  - Release period: [8h - 16h]
  - Temporal resolution: [5 min - 15 min]
  - Composition: 29 radionuclides
  - Total release amount: 1.3 x 10^{13} Bq

Radionuclide	Cesium	Iodine	Noble gases
Cumul (Bq)	1.2 x 10^{12}	2.9 x 10^{12}	6.8 x 10^{12}

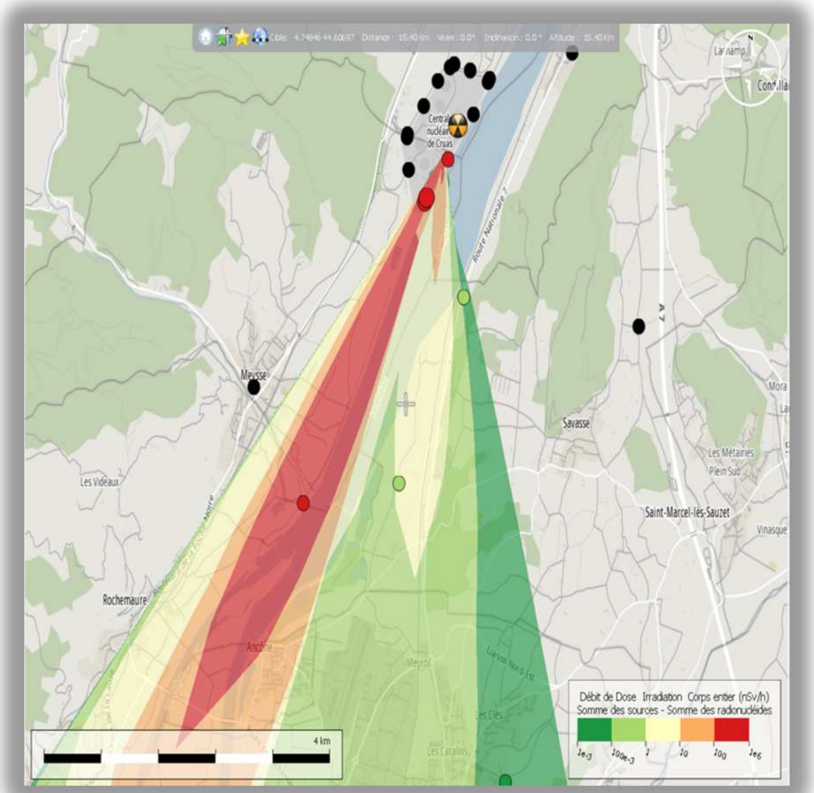


- Meteorological conditions
  - Wind comes from the north then shifts to the north-east direction
  - No precipitation

Real-time use of the inversion method

Measurements

- Gamma dose rate measurements
  - 10 min temporal resolution
  - Situated within a 50 km radius from the Cruas power plant
- Calculation of dose rate measurements
  - Gaussian puff model (C3X operational platform)
  - Meteorological data: Homogeneous in space and time-dependent meteorological data based on observations



> 5 stations reported a rising of the ambiant gamma dose rate level
>
> **Ability of the inversion method to reconstruct the source term using a small number of measurements**

Real-time use of the inversion method

Inversion set-up

- Same meteorological conditions that one used to simulate measurements (site observations)
- Gaussian puff dispersion model to construct source-receptor matrix
- Zero a priori emission and 10 min temporal resolution
- Assumptions about isotopic composition of the release
  - Selection of the main contributors of dose rate signal: ^{134}Cs, ^{136}Cs, ^{137}Cs, ^{137m}Ba, ^{131}I, ^{133}I, ^{135}I and noble gases (^{88}Kr)
  - Assuming constant isotopic ratios coming from pre-calculated ST database

$$\frac{\sigma_{134_{Cs}}}{\sigma_{137_{Cs}}} = 1.2 \ ; \ \frac{\sigma_{136_{Cs}}}{\sigma_{137_{Cs}}} = 0.22 \ ; \ \frac{\sigma_{133_I}}{\sigma_{131_I}} = 0.928 \ ; \ \frac{\sigma_{135_I}}{\sigma_{131_I}} = 0.452$$

Inversion procedure

- Estimation of the release rates of ^{137}Cs, ^{131}I and noble gases (^{88}Kr):
  - $\mathbf{J}(\boldsymbol{\sigma}) = \|\boldsymbol{\mu} - \mathbf{H}\boldsymbol{\sigma}\|^2 + \boldsymbol{\lambda}^2\|\boldsymbol{\sigma}\|^2 + \sum_{j=1}^{2} \mathbf{r_j}(\boldsymbol{\sigma})$

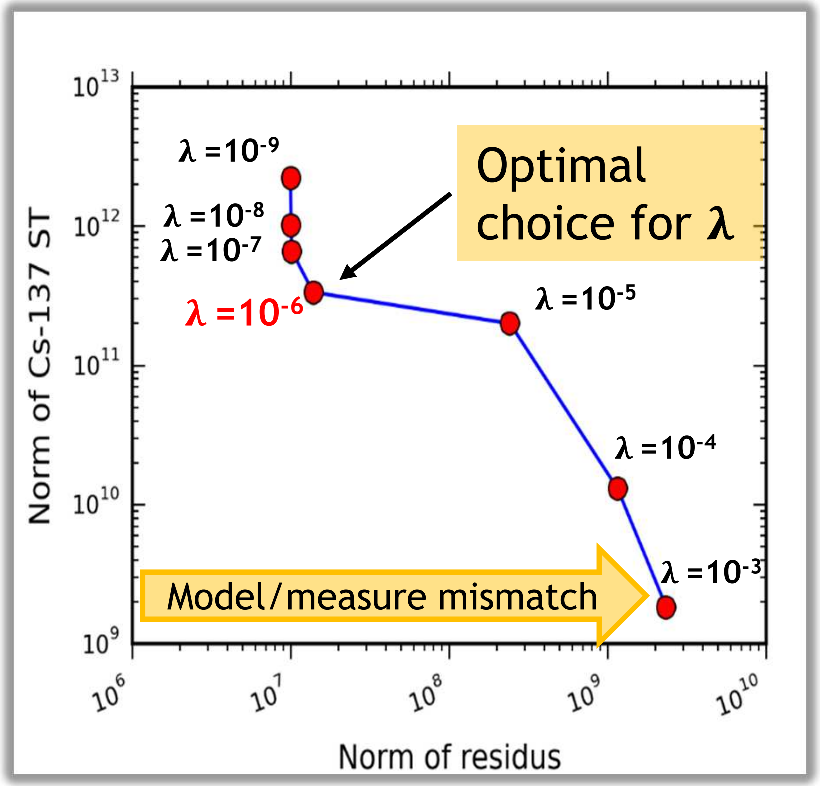
  with:
  - $\forall\, 1 \leq j \leq 2,\ \ \mathbf{r_j}(\boldsymbol{\sigma}) = \exp\left(\frac{\sigma_{j+1}}{\sigma_j} - a_j\right) + \exp\left(\frac{\sigma_{j+1}}{\sigma_j} - b_j\right)$
  - Bounds on isotopic ratios based on pre-calculated ST database

$$1 \leq \frac{\sigma_{131_I}}{\sigma_{137_{Cs}}} \leq 20; \ \ 0.1 \leq \frac{\sigma_{88_{Kr}}}{\sigma_{137_{Cs}}} \leq 100$$

Real-time use of the inversion method

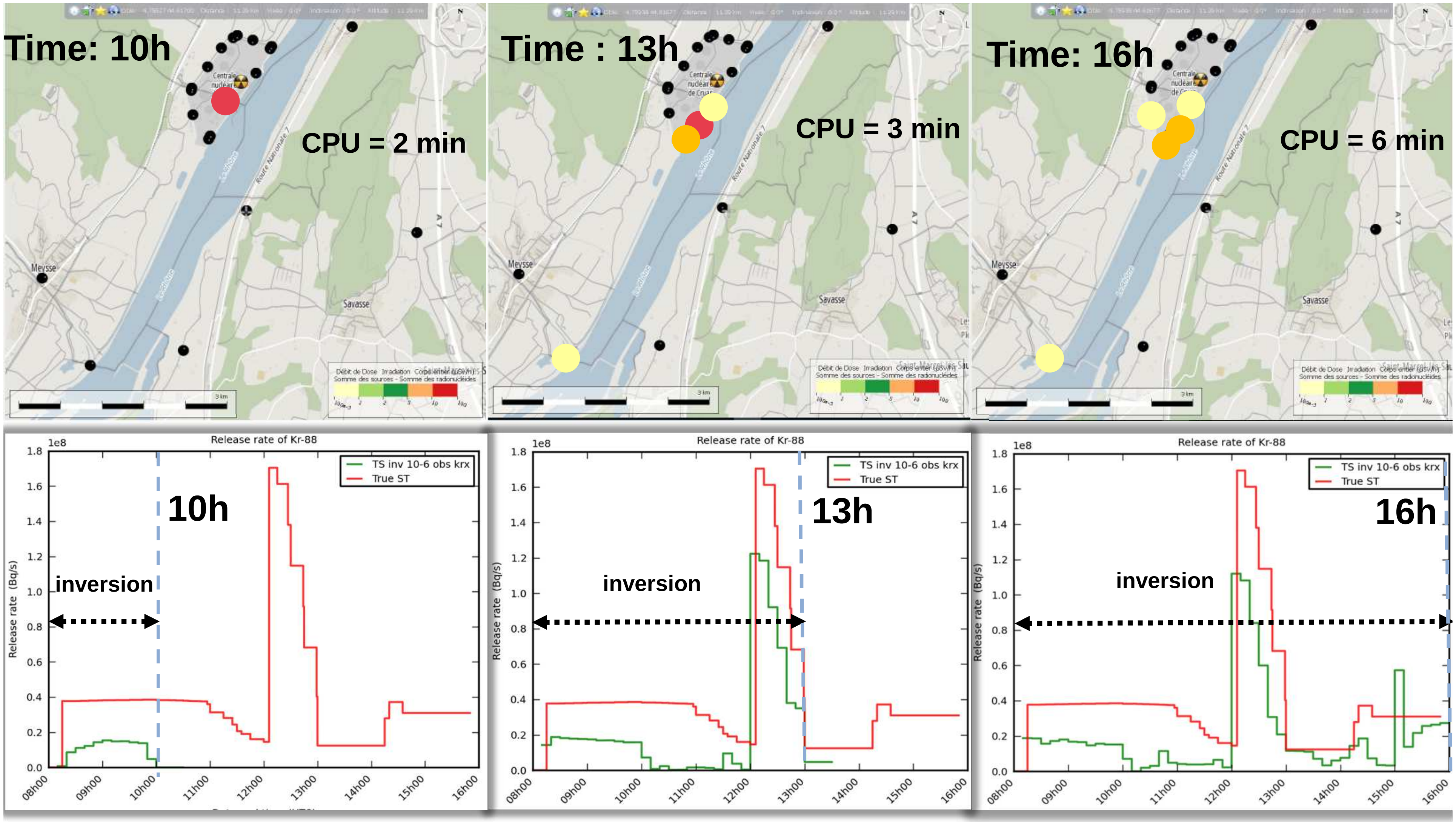
How to determine the regularisation parameter?

- Source term assessment by minimization procedure:
  - $\mathbf{J}(\boldsymbol{\sigma}) = \|\boldsymbol{\mu} - \mathbf{H}\boldsymbol{\sigma}\|^2 + \lambda^2\|\boldsymbol{\sigma}\|^2 + \sum_{j=1}^{2} \mathbf{r}_j(\boldsymbol{\sigma})$
- Determination of the regularisation parameter $\boldsymbol{\lambda}$
  - Strong influence in the situation where the number of observations is small
    - $\boldsymbol{\lambda} \gg \mathbf{1}$: source term tempered too much
    - $\boldsymbol{\lambda} \ll \mathbf{1}$: source term unreleastic
  - L-curve approach
    - Graphical representation of the evolution of the residus of $\mathbf{J}(\boldsymbol{\sigma})$ as a function of the source term norm $\|\boldsymbol{\sigma}\|$
    - Identification of the maximum curve point on the graph



Real-time use of the inversion method

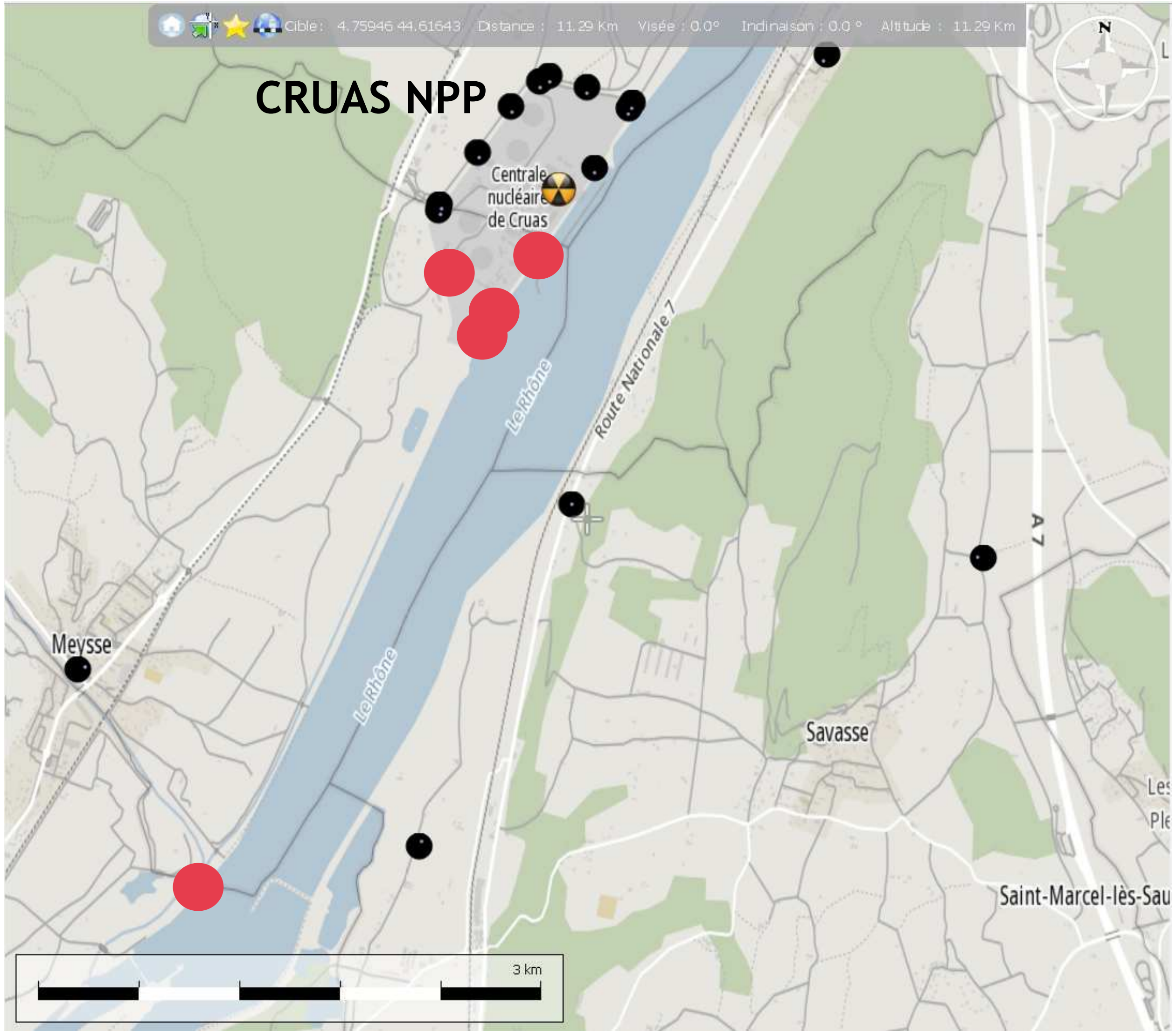
Source term reconstruction



✓ Good agreement between reconstructed source term and « true » source term

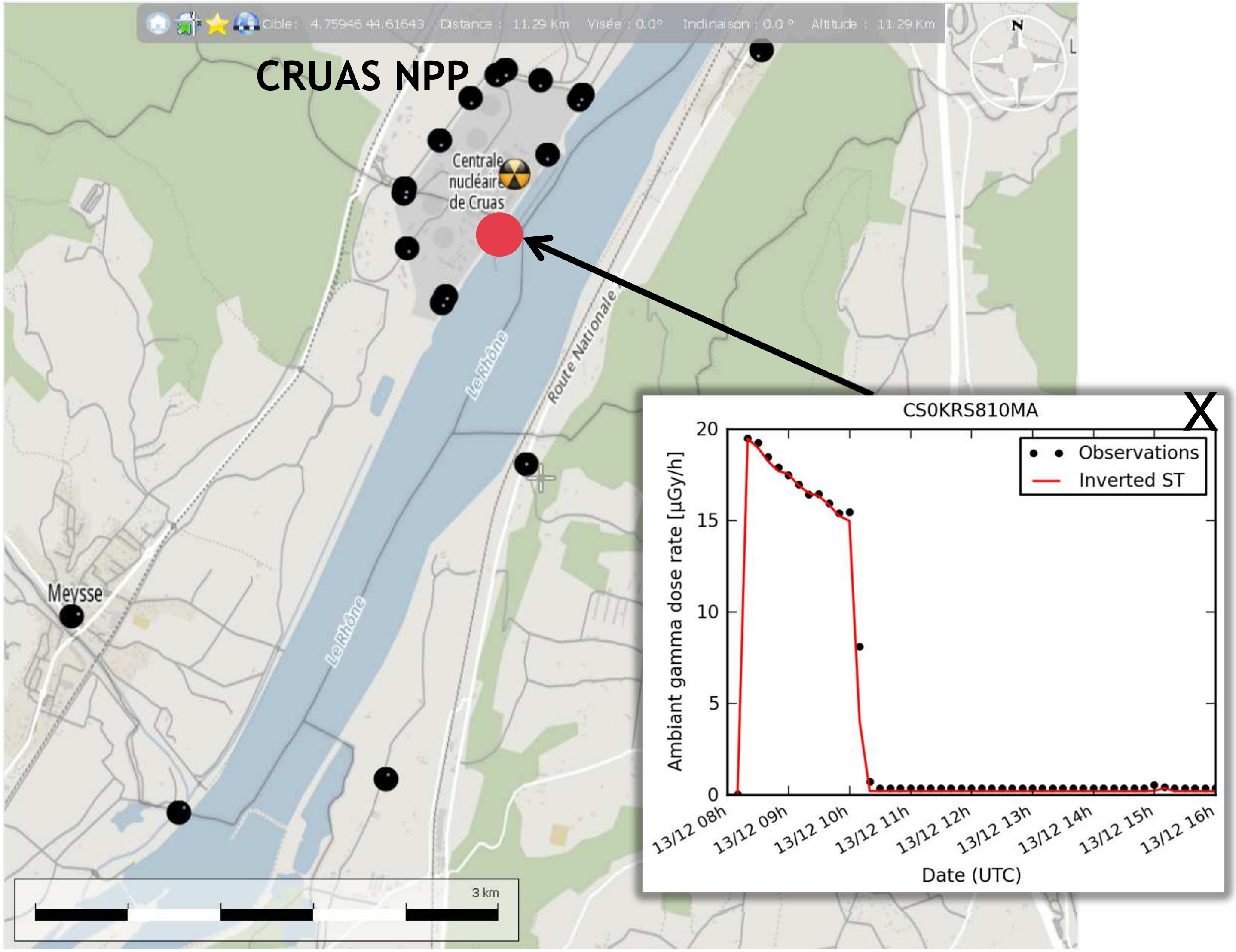
Model to data comparison

- Gamma dose rate stations



Validation of the inversion method

Model to data comparison



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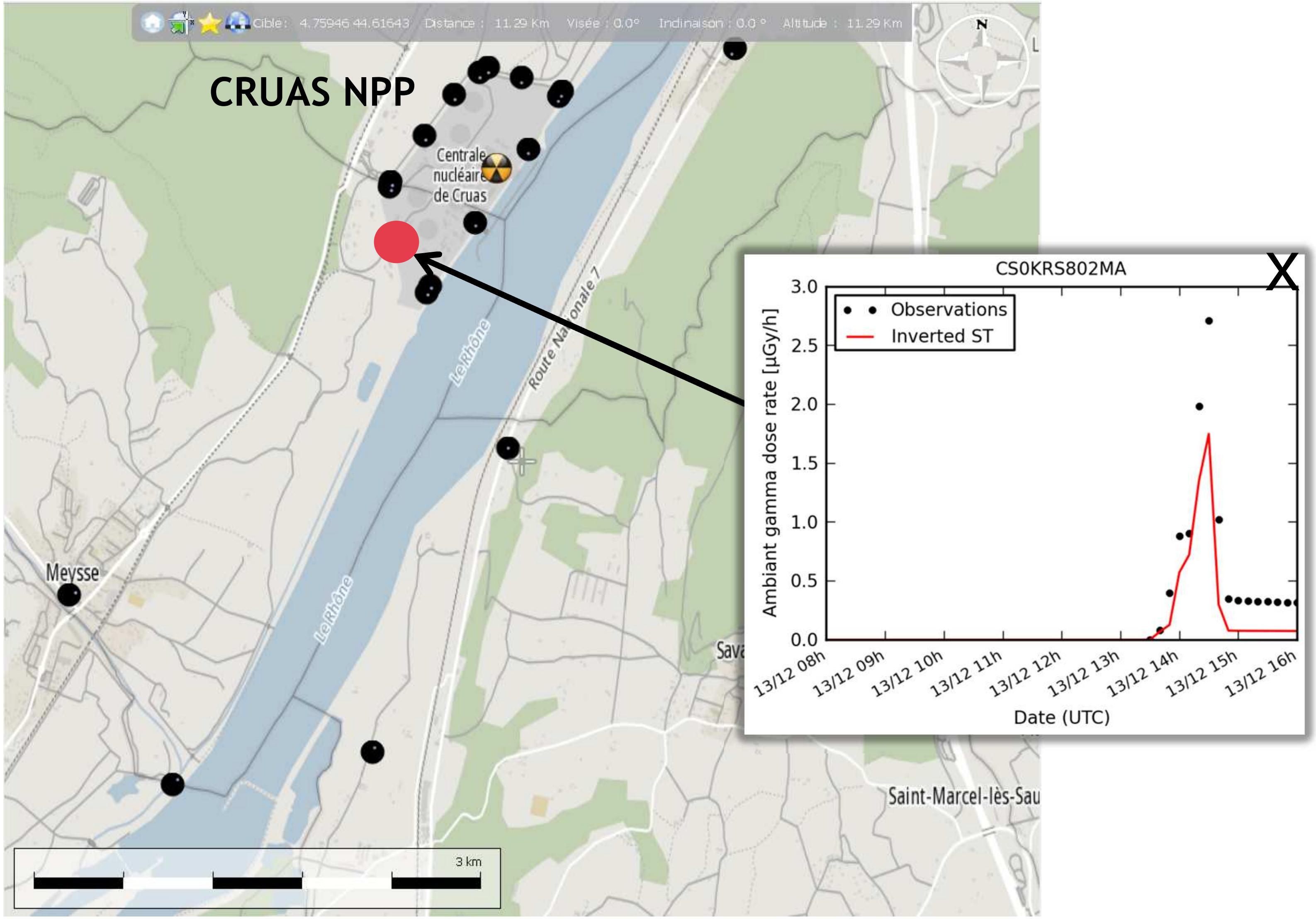

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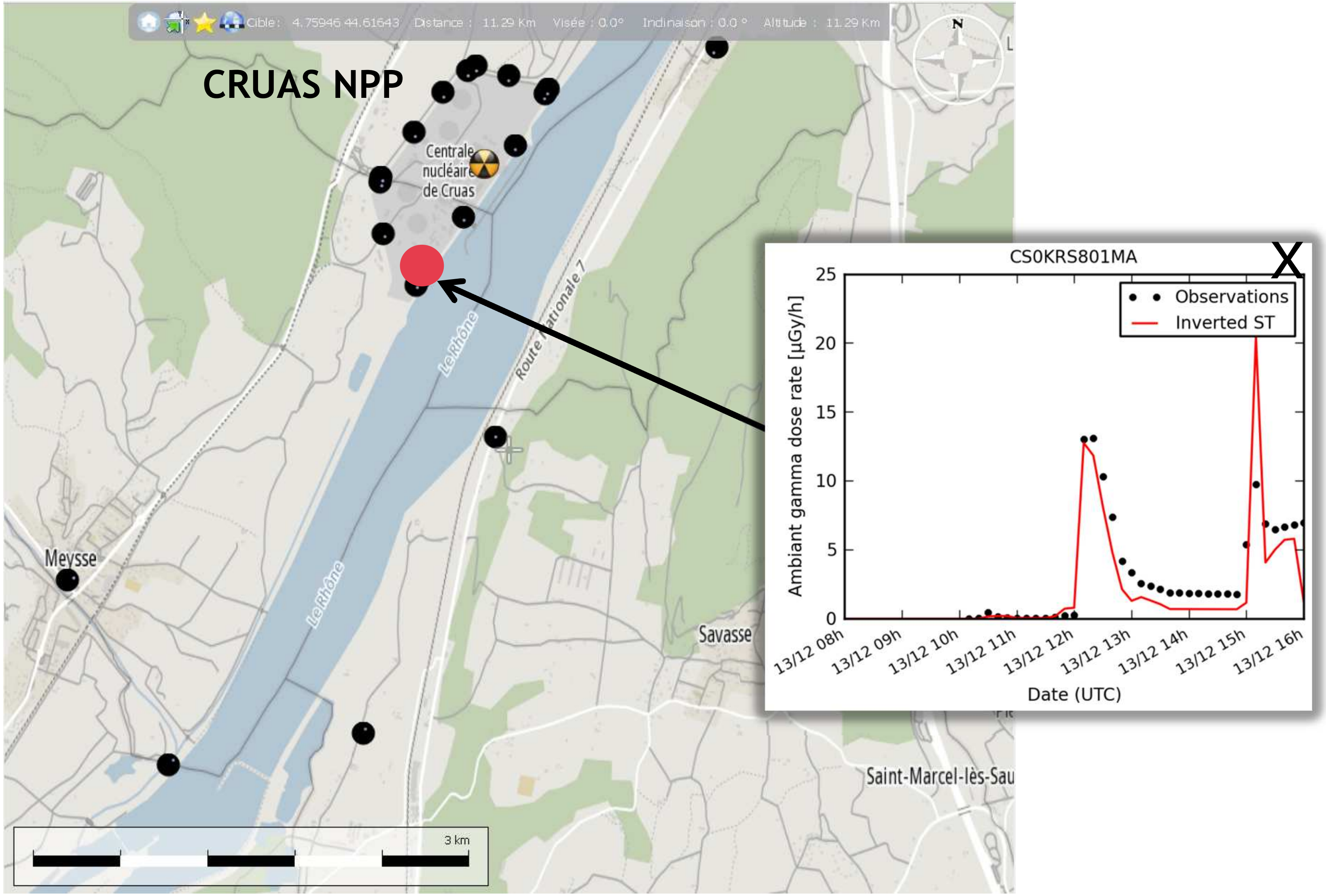
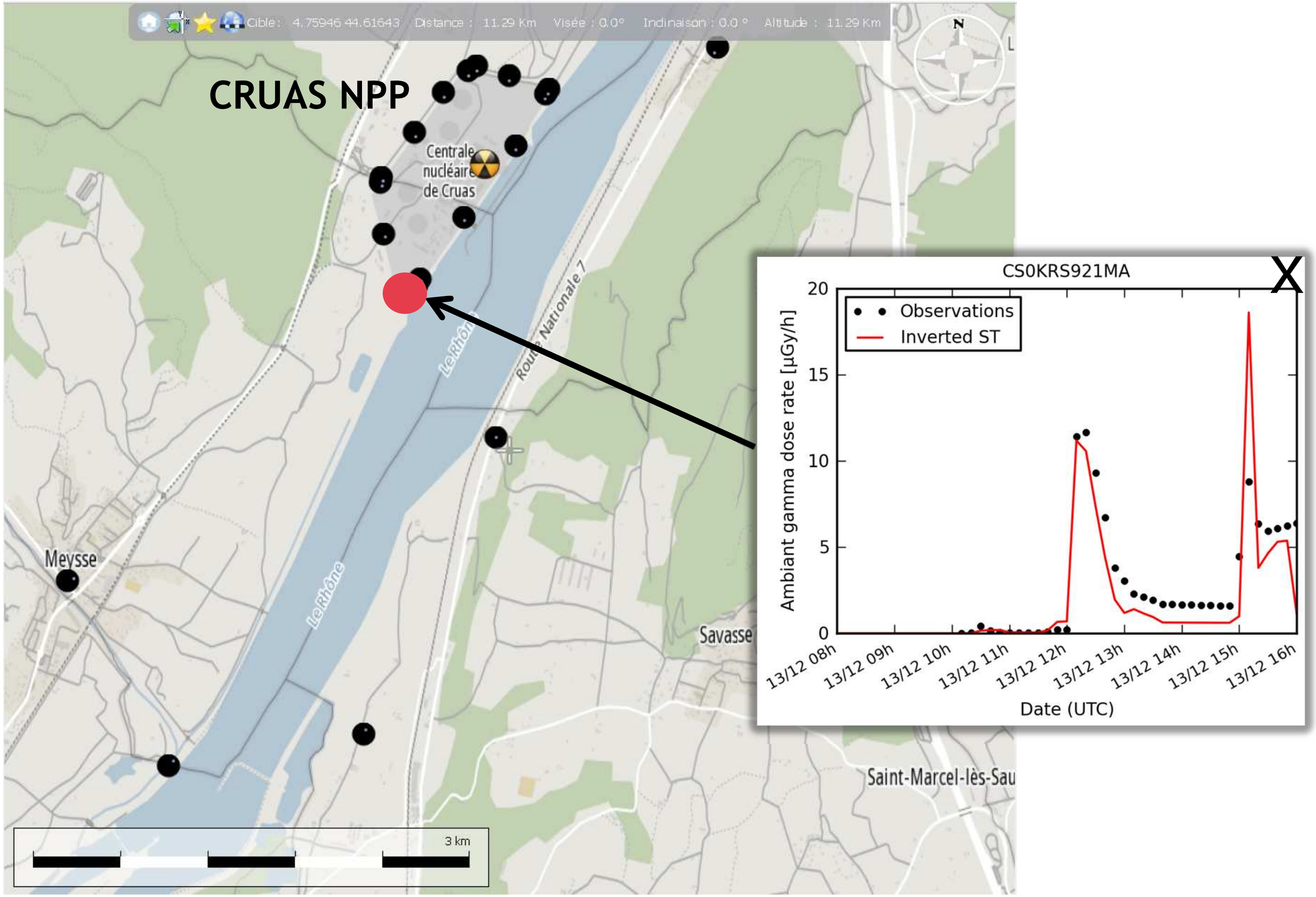


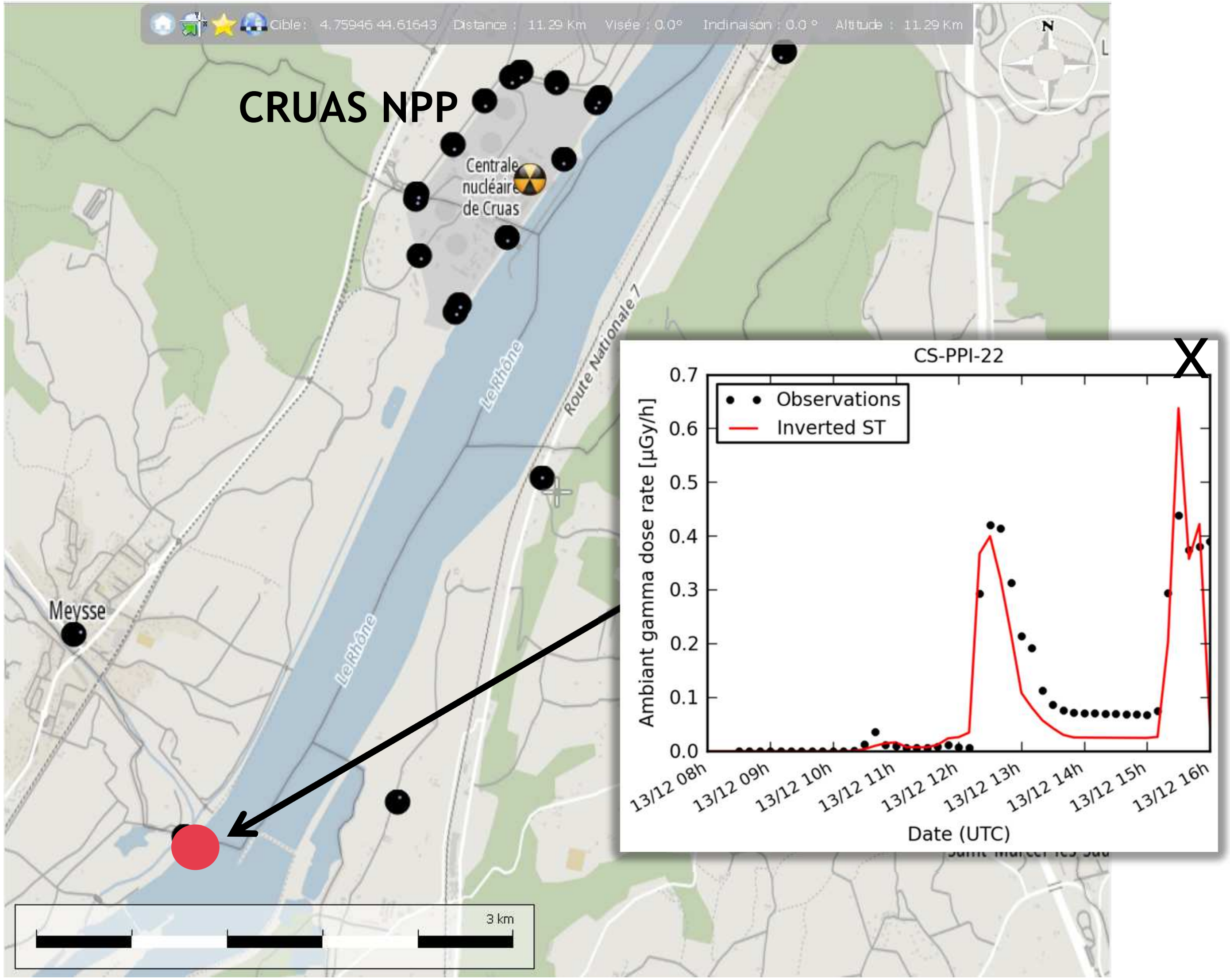
Validation of the inversion method

Model to data comparison



Validation of the inversion method

Model to data comparison

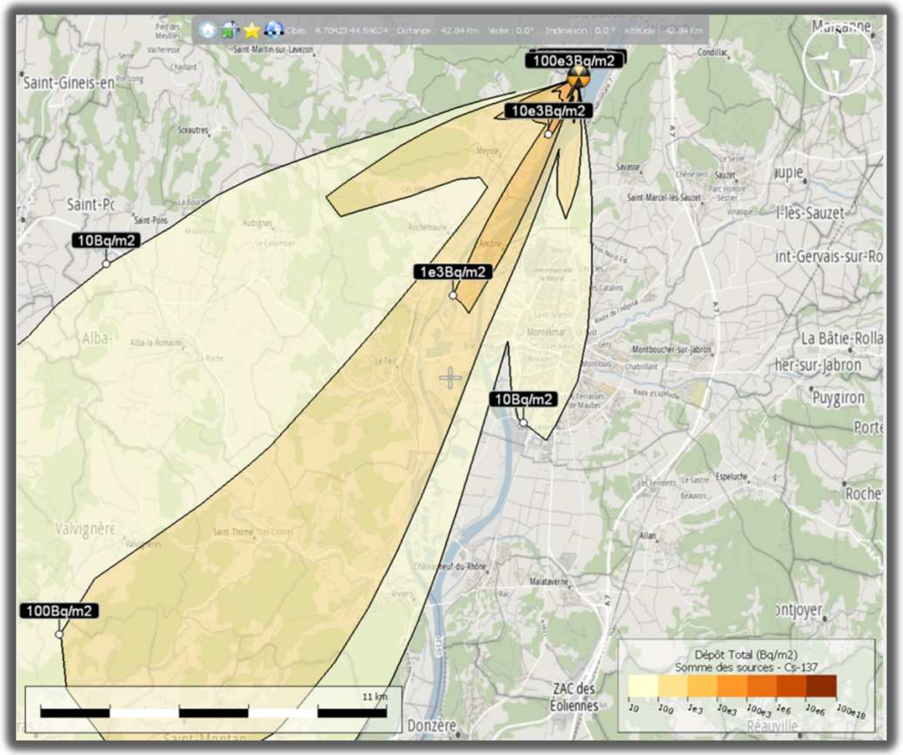


Validation of the inversion method

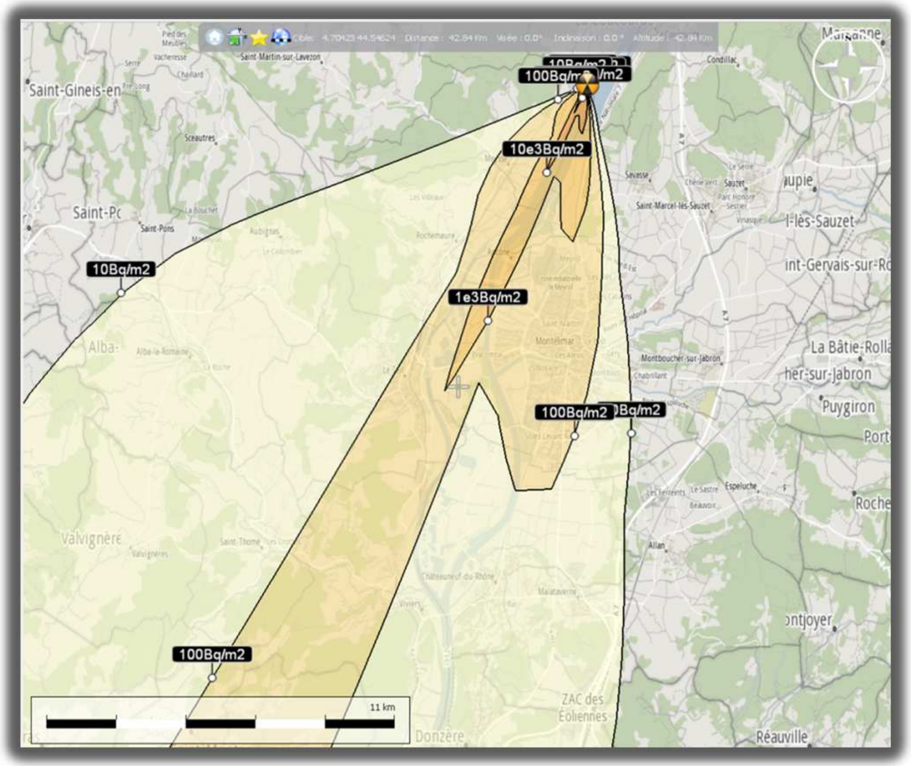
Model to data comparison

Total ^{137}Cs deposition

- Not used in the inversion process



Simulated ^{137}Cs deposit ("true" source term)



Simulated ^{137}Cs deposit (inverted source term)

- Good reconstruction of the ^{137}Cs deposit using inverted source term
  - Realistic location of the contamination area
  - Same order of magnitude as the simulation based on the « true » source term

Conclusion and perspectives

Overview of the source term reconstruction

- Relevance of the inverse modelling method
  - Realism of the inverted source term
  - Good agreement between model and measurements
  - Isotopic composition reconstruction depends on the number of measurements used in the inversion
- Suitability of the approach
  - Computation time compatible with operational use

Perspectives

- Operationalization
  - Continuing to use inversion method during exercises
    - Take into account model and observations errors
    - Use a realistic a priori ST (ST coming from reactor experts)
    - Develop indicators to assess the relevance of the ST
- Methodology
  - Development of automated algorithm to determine regularization parameter
  - Taking into account several types of measurements simultaneously

Thank you for your attention!