IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Source term assessment of a nuclear release: Inverse modelling method and application examples

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EDF R&D

ECOLE NATIONALE DES PONTS ET CHAUSSEES

IRSN is the French technical safety organization

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

Development of operational tools

Previous events

- Main nuclear accidents: Chernobyl, Fukushima
- Minor events: radionuclide detection by monitoring system (iodine detection 2011-2012, cesium detection 2013, forest fires in areas contaminated by the Chernobyl accident…)

➚ **Need do develop a tool to assess atmospheric releases by using environmental observations**

- Source location
- Source term (ST: temporal evolution of the release rate + distribution between radionuclides)

ATMOSPHERIC TRANSPORT MODEL

Gaussian puff – Eulerian - Lagrangian

\+

OBSERVATIONS

Air concentration

Ambiant gamma dose rate

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

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Iodine detection by air sampling monitoring stations in Europe Oct-Nov 2011

Description of the event

- 9/11/2011 Iodine detection on several stations in Europe (7 countries) - Source location and

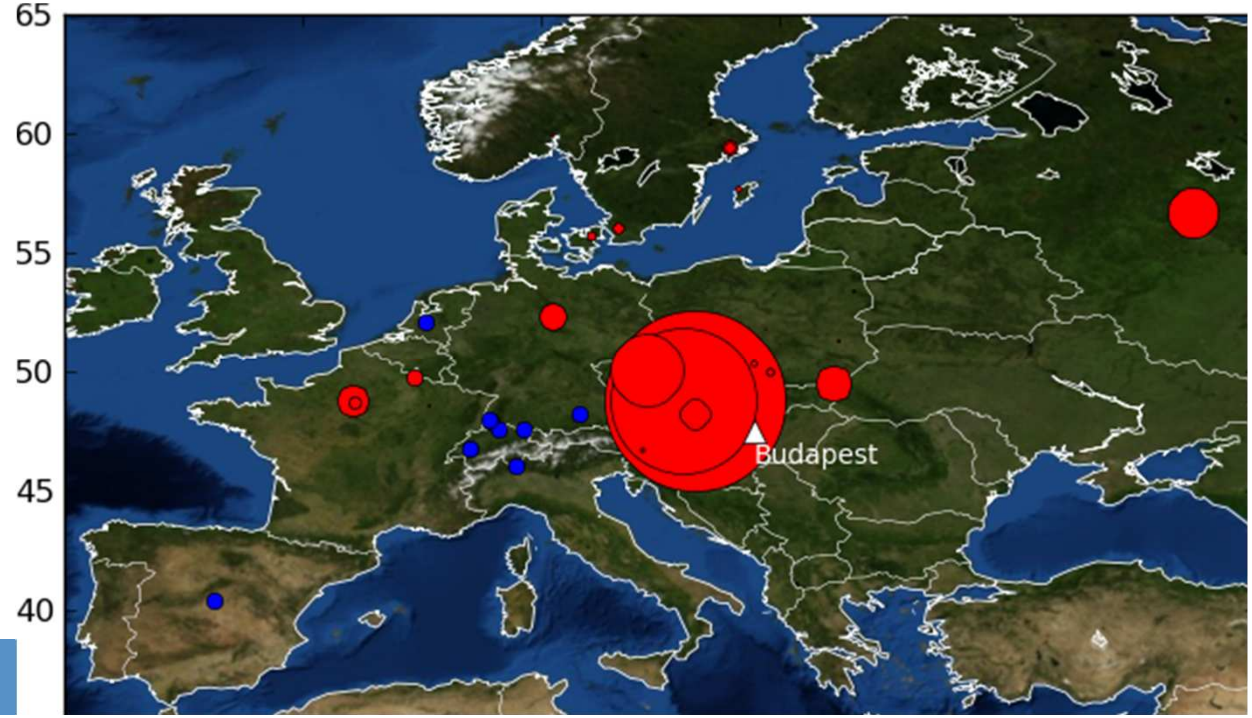
Use of the IRSN's inverse modelling tool

- Source location: to narrow the list of potential candidates
- Source term: to assess the source term

- 17/11/2011 IAEA's confirmation of the source location + provision of a source term assessment – iodine measured in 9 countries in Europe)

Measurements

Averaged over 1 – 7 days periods	
Czech Republic	27 µBq/m^3
E of Austria	65 µBq/m^3
E of Germany	14 µBq/m^3
Poland	13 µBq/m^3
Slovakia	16 µBq/m^3
Sweden	5 µBq/m^3
Hungary	87 µBq/m^3
Ukraine	7 µBq/m^3
N-NE of France	5 µBq/m^3

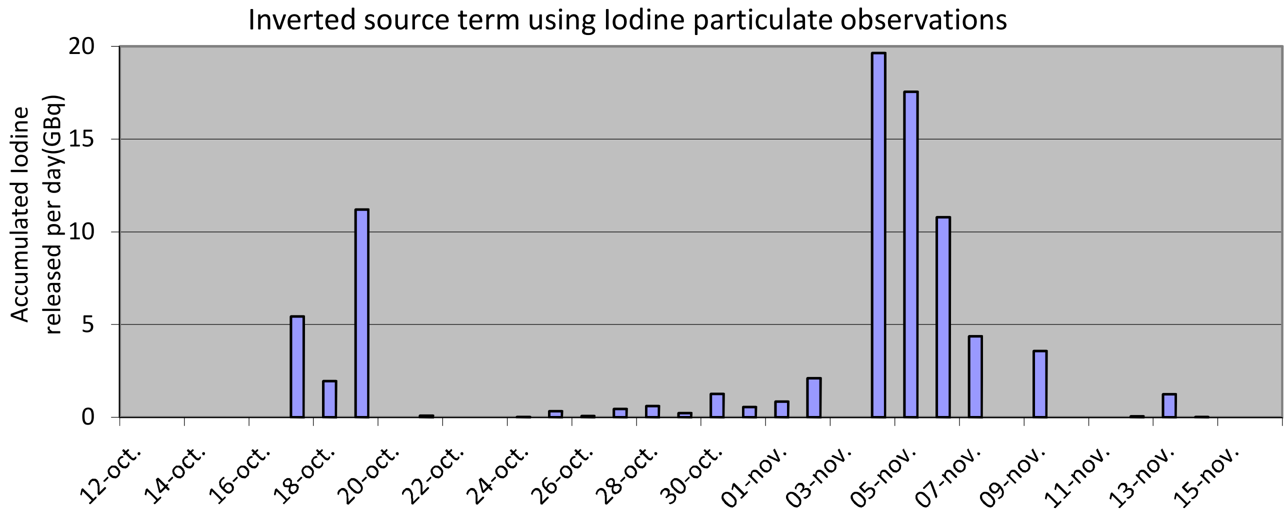


ATM	IdX (C3X platform)	Eulerian model	No chemistry of iodine
Meteorological data	**ECMWF**	Spatial resolution ~10 km	
Air concentration observations	41 Stations	59 Observations (>0: 17-oct – 10-nov 2011)	**Time Averaged (1 to 7 days)**

Step 1: Define the a priori information

- A priori source term unknown ($\sigma_b = 0$)
- "Shorten" the observation period (Consider only periods when iodine may have been observed in the stations location)
- Time scale of the inverted source term : daily

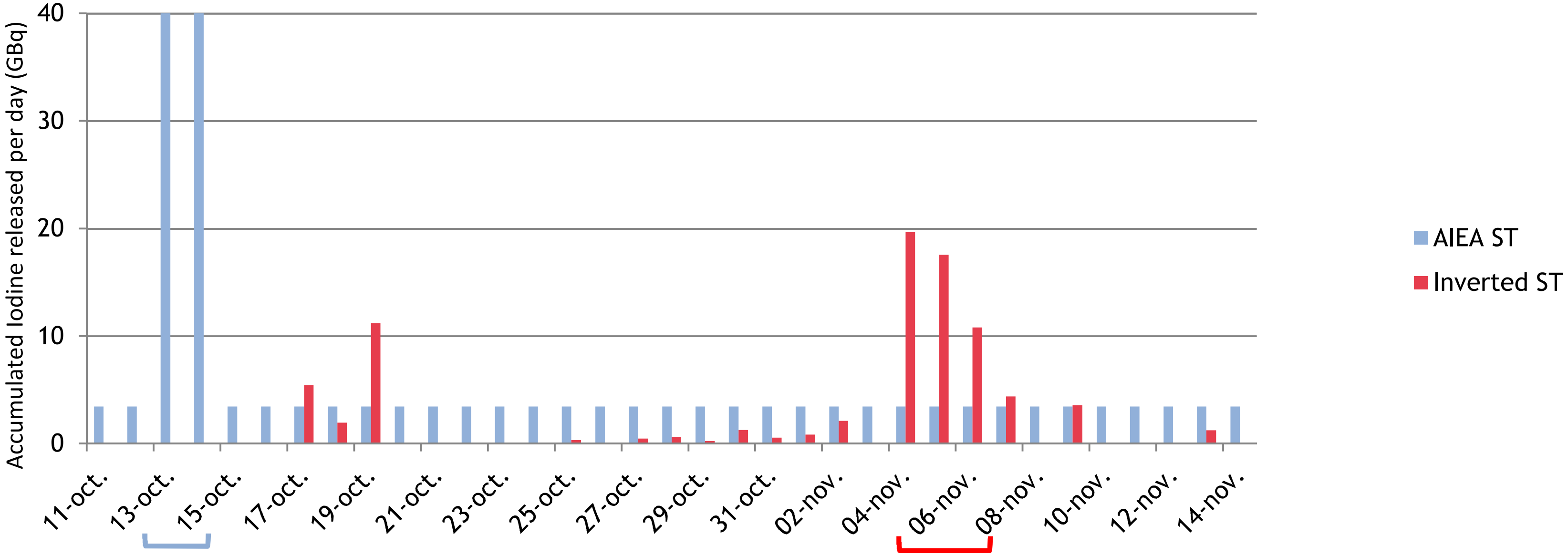
Step 3: Source term assessment



Validation of the source term: Comparison to other source term (IAEA source term)

IAEA ST:

Between 8/09/2011 – 16/11/2011 : 342 GBq released
with a maximum rate of 108 GBq/48 hours in October 12-14



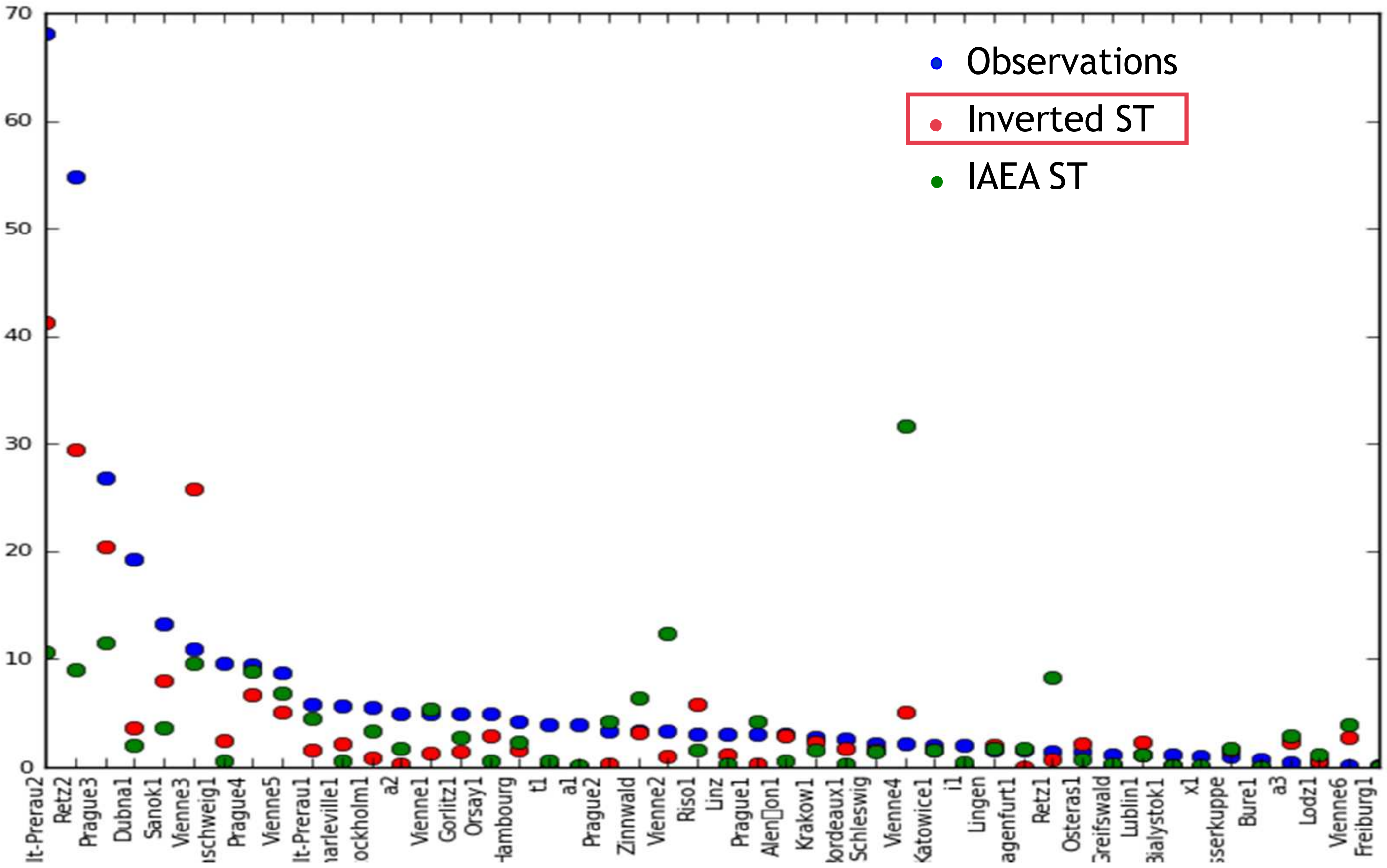
Releases transported toward the south then west – they are not observed by the available monitoring stations.
→ Releases not observed: the Inversion method cannot reconstruct those events

Releases responsible for the iodine observed in France and Scandinavia. They explain the maximum concentration values observed in Austria

- No inconsistencies between the 2 ST.
- Release rates were not constant

Validation of the source term: model to data comparisons

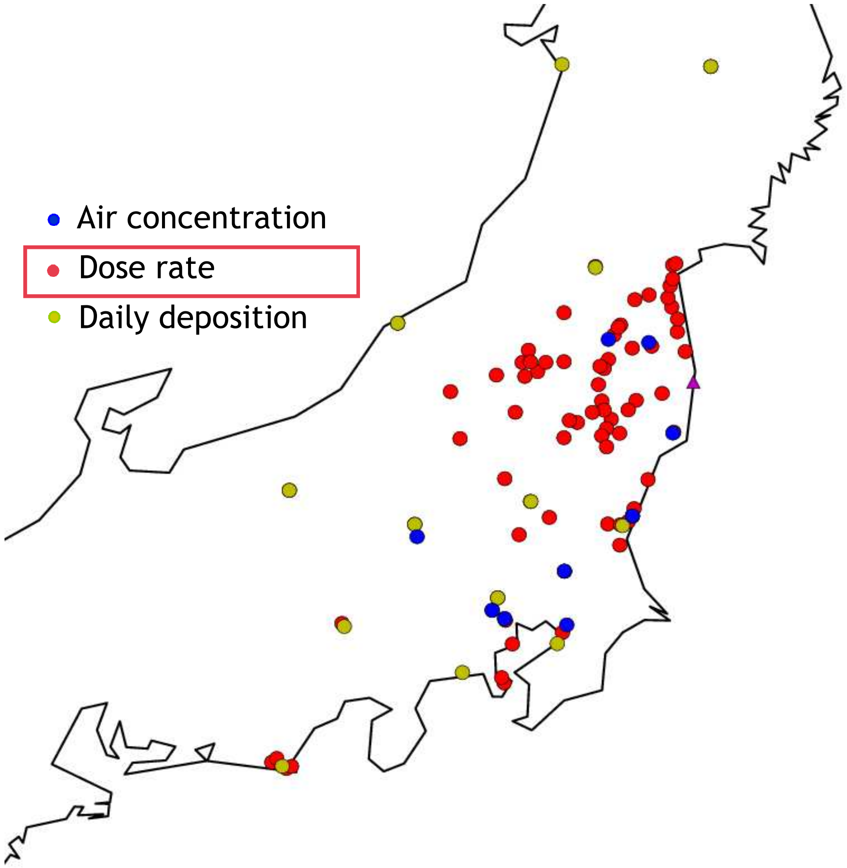
Direct simulation using the inverted source term and comparisons with observations

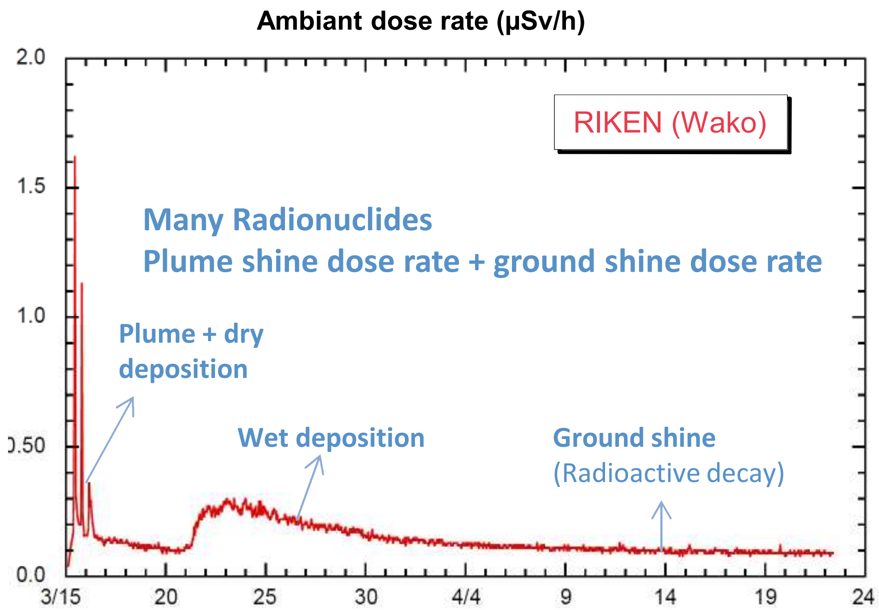


- Better model to data agreement with the inverted ST.
- Relatively good agreement between model and observations: inverted source term is realistic

Fukushima accident - *Saunier et al., ACP 2013*

ATM	IdX (C3X platform) Eulerian	No chemistry of iodine + Radioactive decay and filiation	Dry deposition $v_{dep} = 2\ 10^{-3}$ cm/s	Wet deposition $\Lambda s = a p_o$ $a = 5\ 10^{-5}$	Vertical diffusion Troen and Mahrt scheme
Met. Data	ECMWF	Spatial resolution 0.125°	Temporal resolution 1h	11/03/2011 9h - 27/03/2011 18h	
Observations	Dose rate	Temporal frequency : 10min – 1h		57 Stations	





Difficult to use (Not a model parameter & Aggregate all the gamma radiations emitted by any radionuclides present on the ground and in the air)

Step 1: Define the a priori information

- A priori source term unknown ($\sigma_b = 0$)
- Time scale of the inverted source term : 1h
- Isotopic composition of the ST :

  The dose rate signal is mainly due to 8 radionuclides: ^{134}Cs, ^{136}Cs , ^{137}Cs, ^{137m}Ba, ^{132}Te, ^{132}I, ^{131}I, ^{133}Xe

  with secular equilibrium and constant ratio ($^{134}Cs/^{137}Cs$) hypothesis, it leads to 5 radionuclides : ^{134}Cs, ^{136}Cs, ^{132}Te, ^{131}I and ^{133}Xe
- Define isotopic soft constraints

  Radionuclides released in proportions that depends on their physicochemical properties + the core inventory

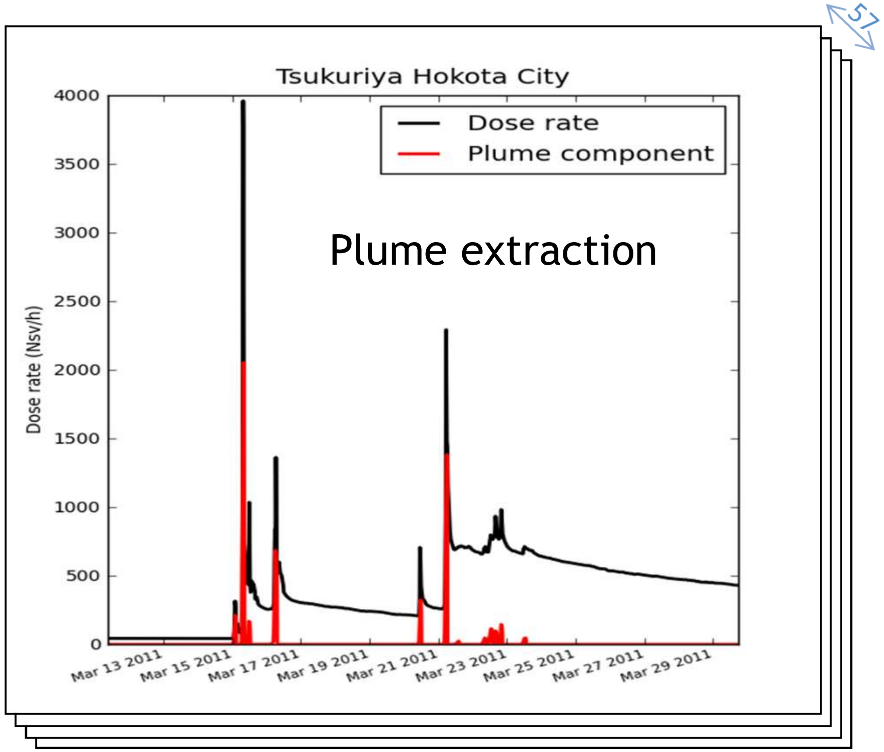
$$0.6 \leq \frac{\sigma_{^{132}Te}}{\sigma_{^{134}Cs}} \leq 16$$

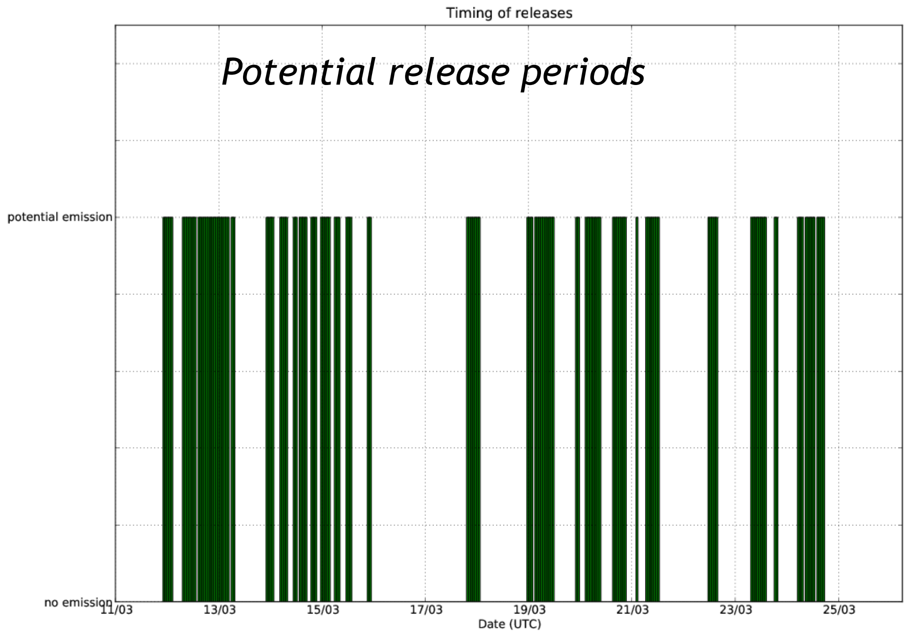
$$2 \leq \frac{\sigma_{^{131}I}}{\sigma_{^{134}Cs}} \leq 100$$

$$0.1 \leq \frac{\sigma_{^{133}Xe}}{\sigma_{^{134}Cs}} \leq 10000$$

$$0.1 \leq \frac{\sigma_{^{136}Cs}}{\sigma_{^{134}Cs}} \leq 0.5$$

Step 2: Identify the potential release periods



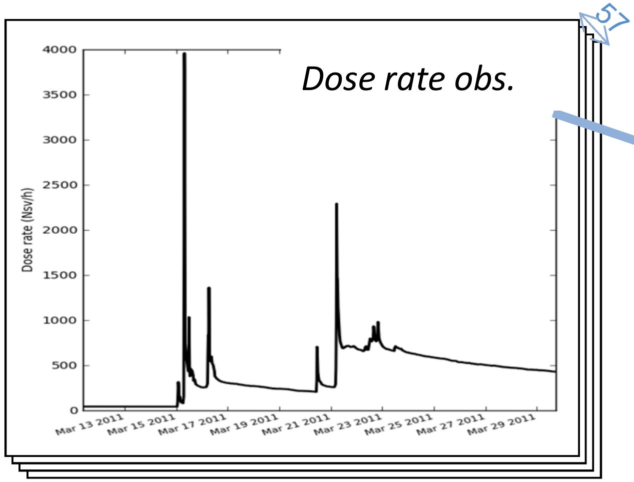


Inverse modelling

Cost function

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

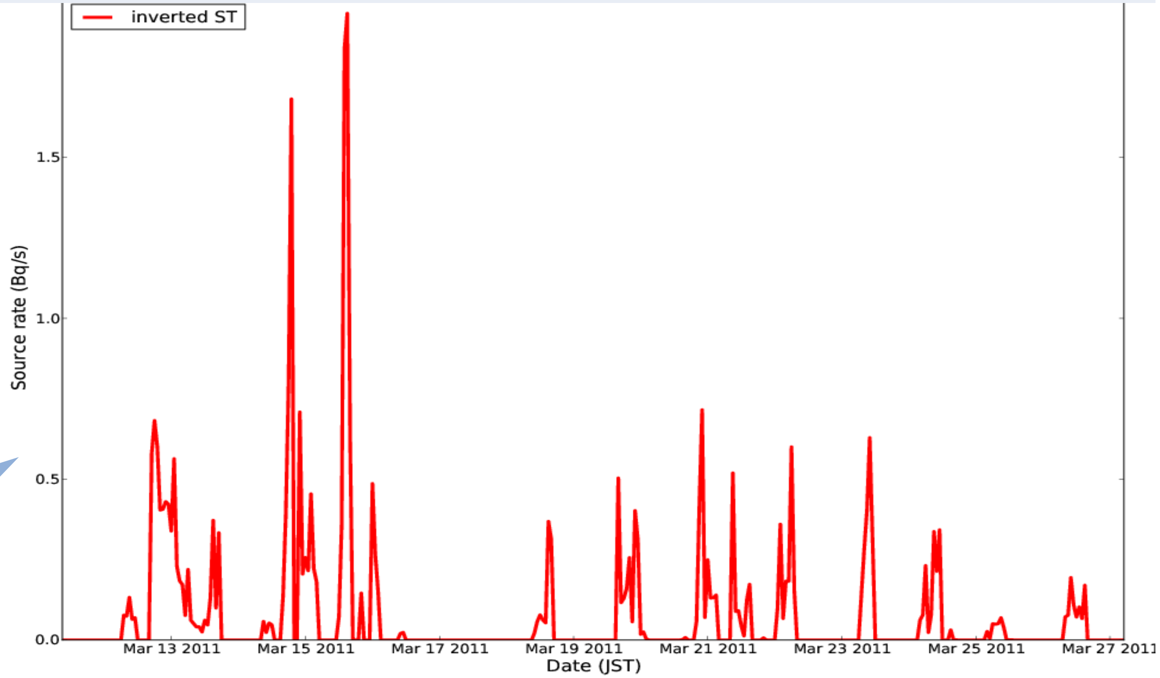
Step 3: Estimate the release rates

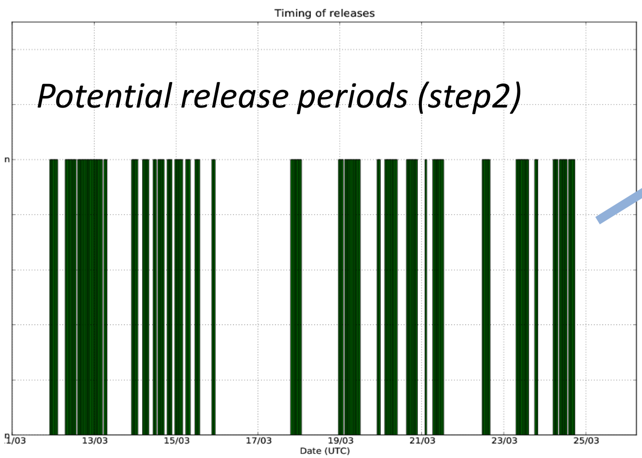


INVERSE MODELLING

Cost function

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





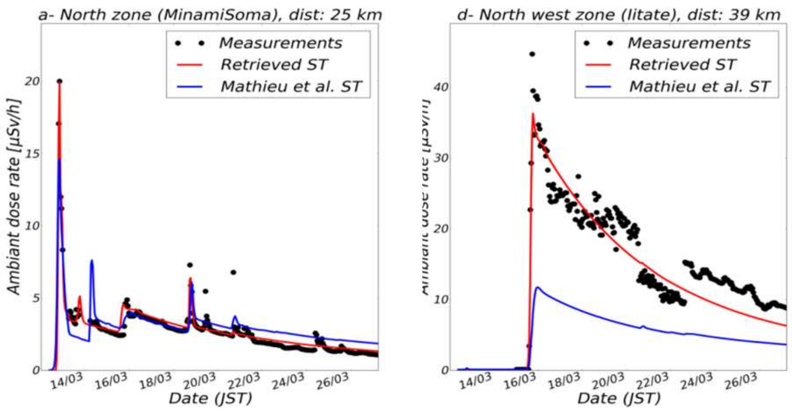
Validation - Comparisons to other ST

Source Term (PBq)	^{133}Xe	^{131}I	^{132}I	^{137}Cs	^{136}Cs
Inverted ST	12100	103	35.5	15.5	3.7
Mathieu et al. (2012)	5950	197	56.4	20.6	9.8
Winiarek et al. (2012)	-	190-380	-	12-19	-
Terada et al. (2012)	-	150		13	-
Stohl et al. (2012a)	13400-20000	-	-	23.3-50.1	-
TEPCO (2012)	500	500		10	

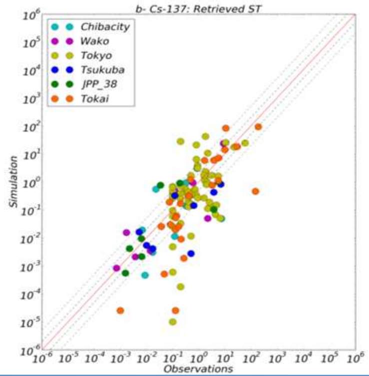
- Inverted source term is consistent with the other estimations.
- Underestimation in iodine and cesium in comparison to Mathieu et al ST (several events are not identified by inversion).
- Amount of noble gases is similar to Stohl et al estimation: probably overestimated

Validation – Model to data comparisons

Dose Rate	Inverted ST	Mathieu et al. ST
Fac2 (%)	79.8	60.0
Bias	0.42	0.59



Air Concentration	Inverted Fac5 (%)	Mathieu Fac5 (%)
^{136}Cs	52,3	35,4
^{137}Cs	58,2	47,0
^{131}I	57,1	31,4
^{132}Te	53,7	40,1



- Inverted quantities are consistent with the other estimations.
- Model-to-data comparisons show a relatively good agreement.

- Assessment of the isotopic composition need to be improved.
- Releases transported toward the ocean (and not detected by the dose rate network) are not reconstructed).
- Model uncertainties (Met data, deposition process…).

Reliable inversed modelling method to assess the source term

- Efficient operational tool, perfectly suited to crisis management (Air concentration or Gamma dose rate measurements).
- Can be used with various ATM (Eulerian, Gaussian, Lagrangian).

What are the next steps ?

- Simultaneous reconstruction of release events detected close to the source location as well as those detected far away.
- Improve the reconstruction of the isotopic composition by using all together air concentration, deposition and dose rate observations.

What are the challenges ?

- How can we take observations with greatly diverging orders of magnitude into account?
  Inverse modelling tool (cost function) is designed to strengthen the higher values.
  Application to the Fukushima case: assess the releases transported toward the Pacific ocean as well as those detected on Japan territory.
- How can we use all together different kind of observations?
  Application to the Fukushima case: better assess the isotopic composition + assess the releases transported toward the Pacific ocean

Thank you for your attention