IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Assessment of the atmospheric release induced by the Fukushima nuclear power plant accident

Presentation of the method and validation of the source term by using model to data comparisons

O.SAUNIER, A.MATHIEU, D.DIDIER, M.TOMBETTE,
D.QUELO, M.BOCQUET, V.WINIAREK

Anne.mathieu@irsn.fr



Cerea
Centre d'Enseignement et de Recherche en Environnement Atmosphérique

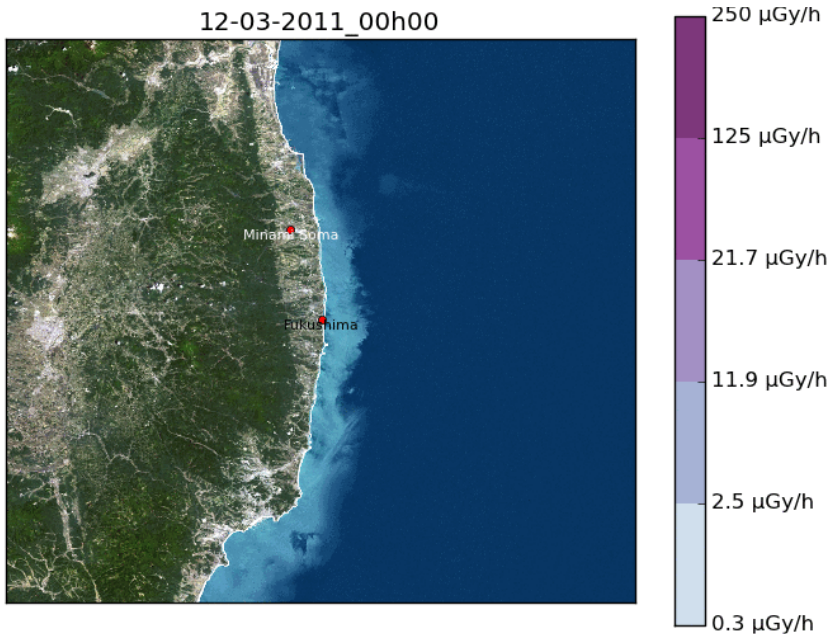
EDF R&D

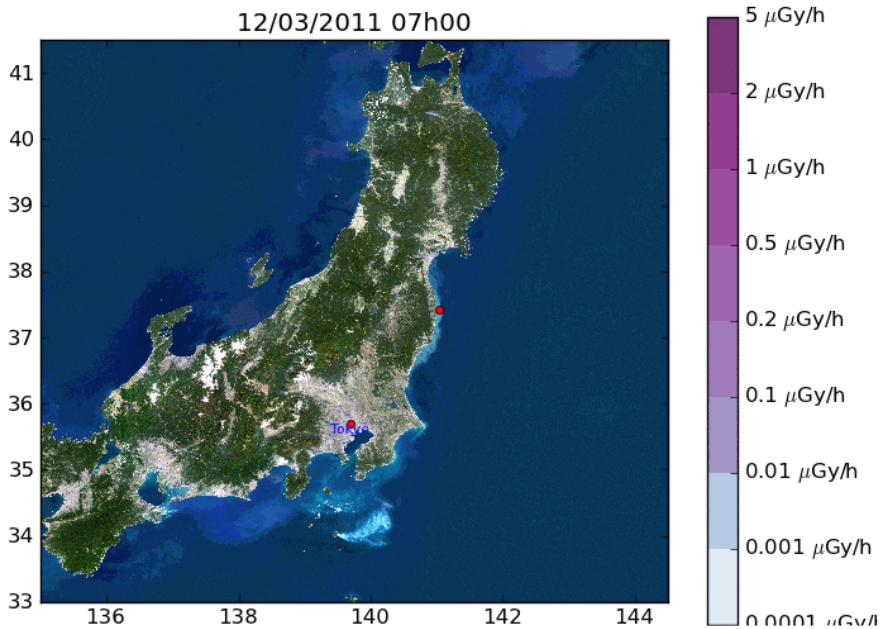
ECOLE NATIONALE DES PONTS ET CHAUSSEES

The strong uncertainties prevent to have a complete understanding of the nuclear accident

To improve the estimate of the source term: Inverse modelling approach

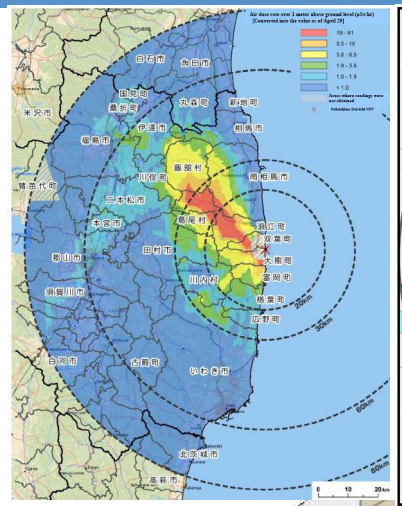
Source term : time evolution of the release rate and its distribution between radioisotopes

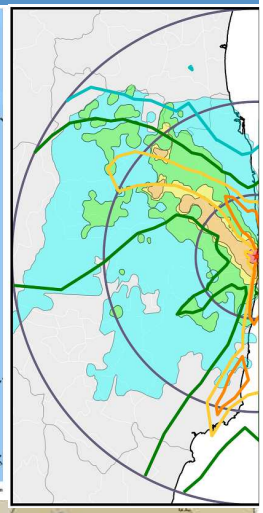


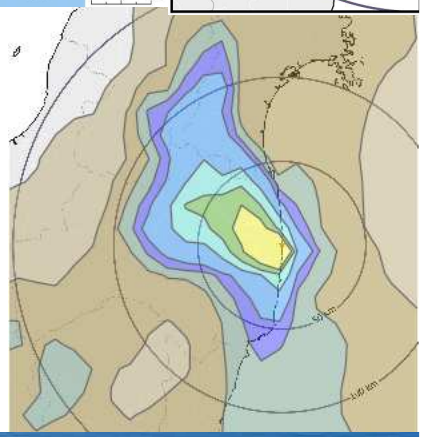


Outline

- Gamma dose rate observations
- Ingredients of the reconstruction
- Reconstruction of the Fukushima Daiichi source term
- Conclusions









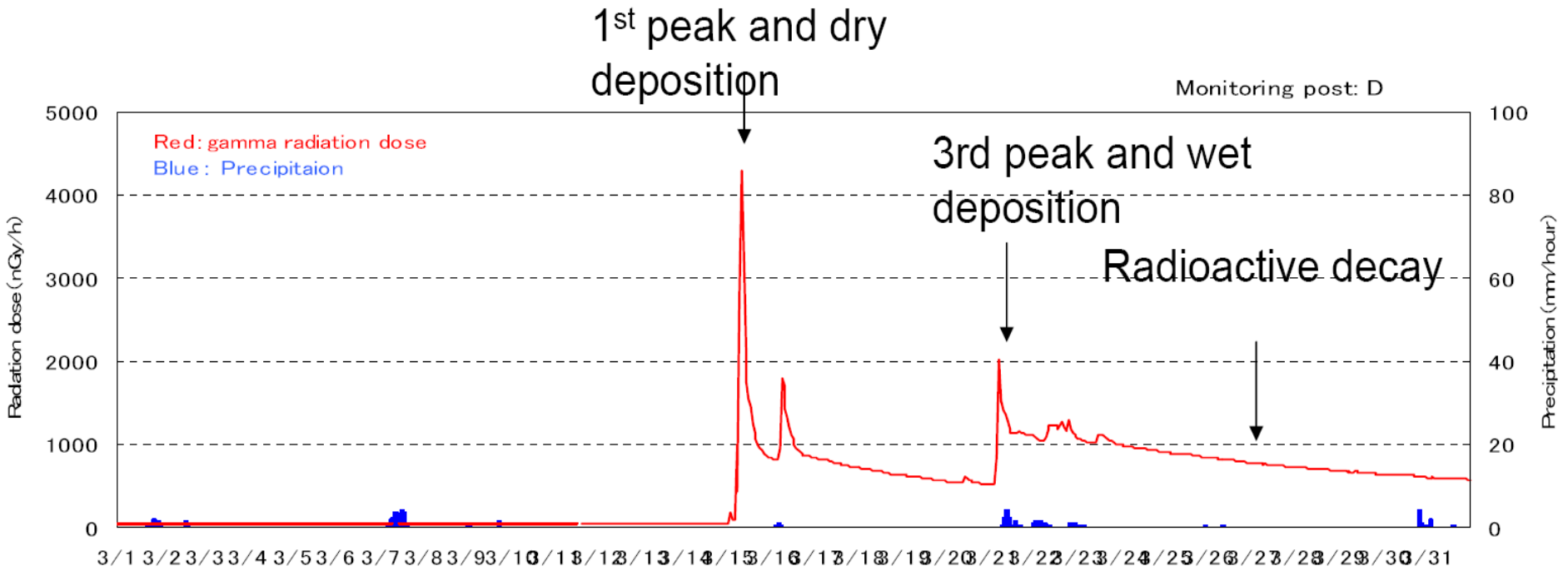
Ingredients of the reconstruction: observations



Inverse modelling approach:
the novelty of the presented method is the use of dose rate observations

Observations	+	-
Air concentration	**Easy to use** (*Model parameter & Isotopic composition*)	**Number & frequency** *(Very few data & Time integrated)*
Deposition	**Easy to use** (*Model parameter & Isotopic composition*)	**Number & frequency** (*Very few data during the release & Time integrated*)
Dose rate	**Number & Frequency**	**Difficult to use** (*Not a model parameter & Aggregate all the gamma radiations emitted by any radionuclides present on the ground and in the air*)

Gamma dose rate observations



- Information contained in the dose rate signal :
  - Plume detection when it blew over the station: timing of the release events
  - The slope due to the radioactive decay of the deposit: information on the isotopic composition
  - The value of the observed dose rate: quantities released

The physical model for the tracers (radionuclides) can be formalized by

$$\varepsilon = H\sigma - \mu$$

Vector of errors

Vector of observations

Estimator of the source term

Source receptor matrix
computed with the forward or adjoint model + observation operator

The objective is to assess the source term σ so that the error ε is minimized.
Cost function (minimized by using L-BFGS-B algorithm)

$$J(\sigma) = \frac{1}{2}(\mu - H\sigma)^T R^{-1}(\mu - H\sigma) + \frac{1}{2}(\sigma - \sigma_b)^T B^{-1}(\sigma - \sigma_b)$$

Requirement

- Number of observations >> Number of unknowns

Hypothesis

- No prior knowledge of the source term ($\sigma_b = 0$)
- Model and observations are supposed to be perfect ($R = B = I$)

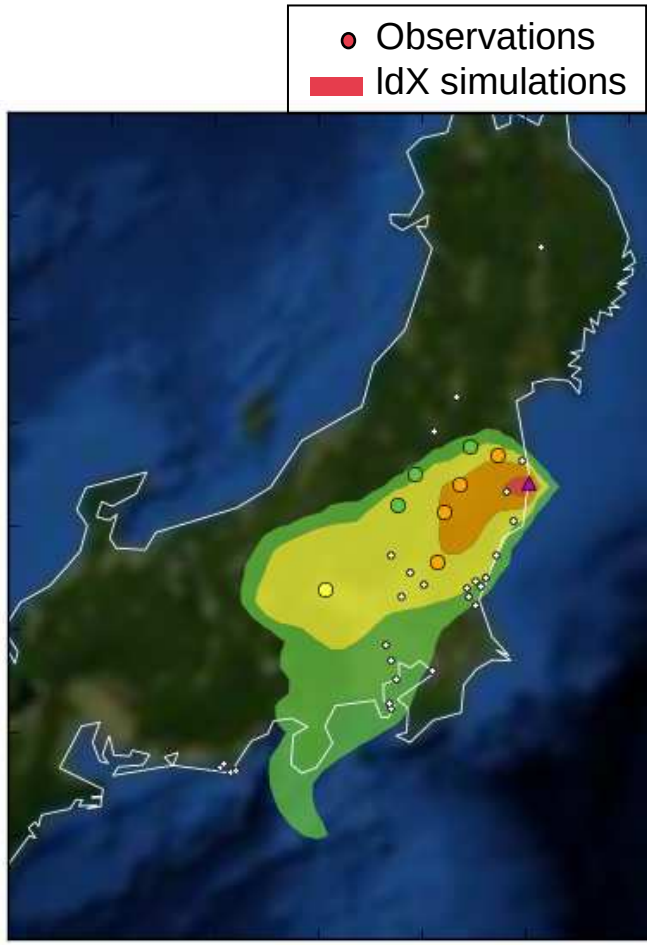
Dispersion model : Eulerian model ldX from the operational C3X platform

ldX Simplest reasonable numerical scheme

- Dry deposition: v_{dep} = 2 10^{-3} cm/s
- Wet deposition: $\Lambda s = a p_o^b$, with a = 5 10^{-5} and b = 1
- Vertical diffusion: Troen and Mahrt scheme
- Radioactive decay + filiation

Met. data: ECMWF (0.125°)

Spatial resolution: 0.125° x 0.125°

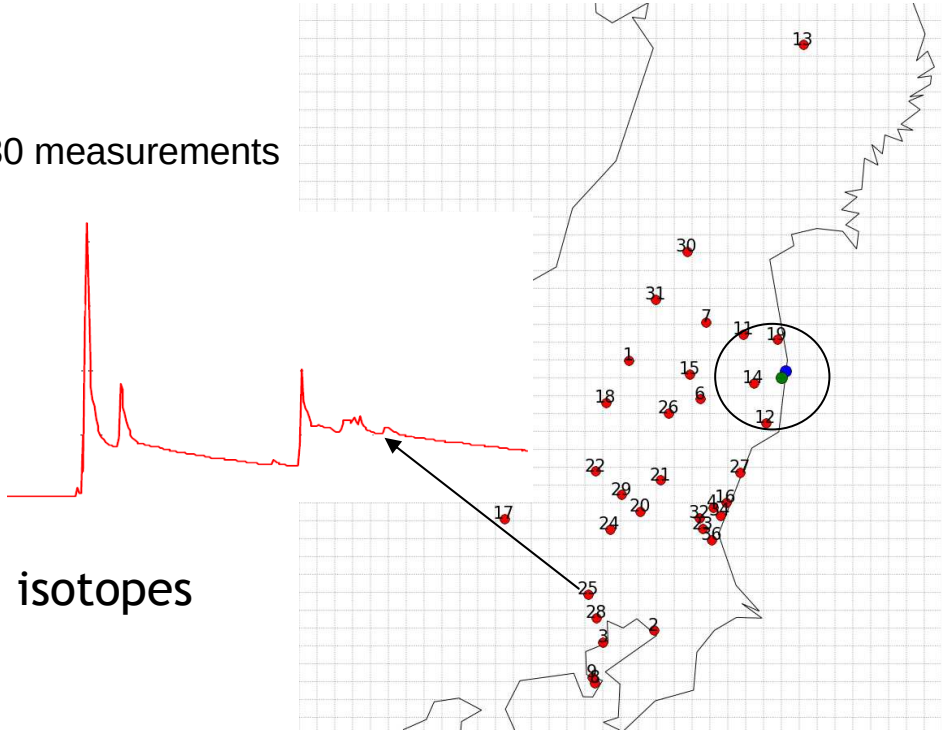


Consequences model : consX from C3X

Dose rate estimations

The Fukushima case

- Measurements: dose rate signal
  - The observed signal is mainly due to the contribution of Cs-134, Cs-137, Ba-137m, I-131, I-132, Te-132, Xe-133
  - ~30 dose rate stations are considered
  - between the 11th and the 26th of March 11430 measurements



- Source term assessment for the 7 main isotopes
  - Cs-134 + Cs-137 + Ba-137m
  - I-131
  - I-132 + Te-132
  - Xe-133

- from the 11/03 till the 26/03: 7 isotopes x 380 time steps = 2660 unknowns

⇨ Insufficient number of observations: reduce the number of unknowns

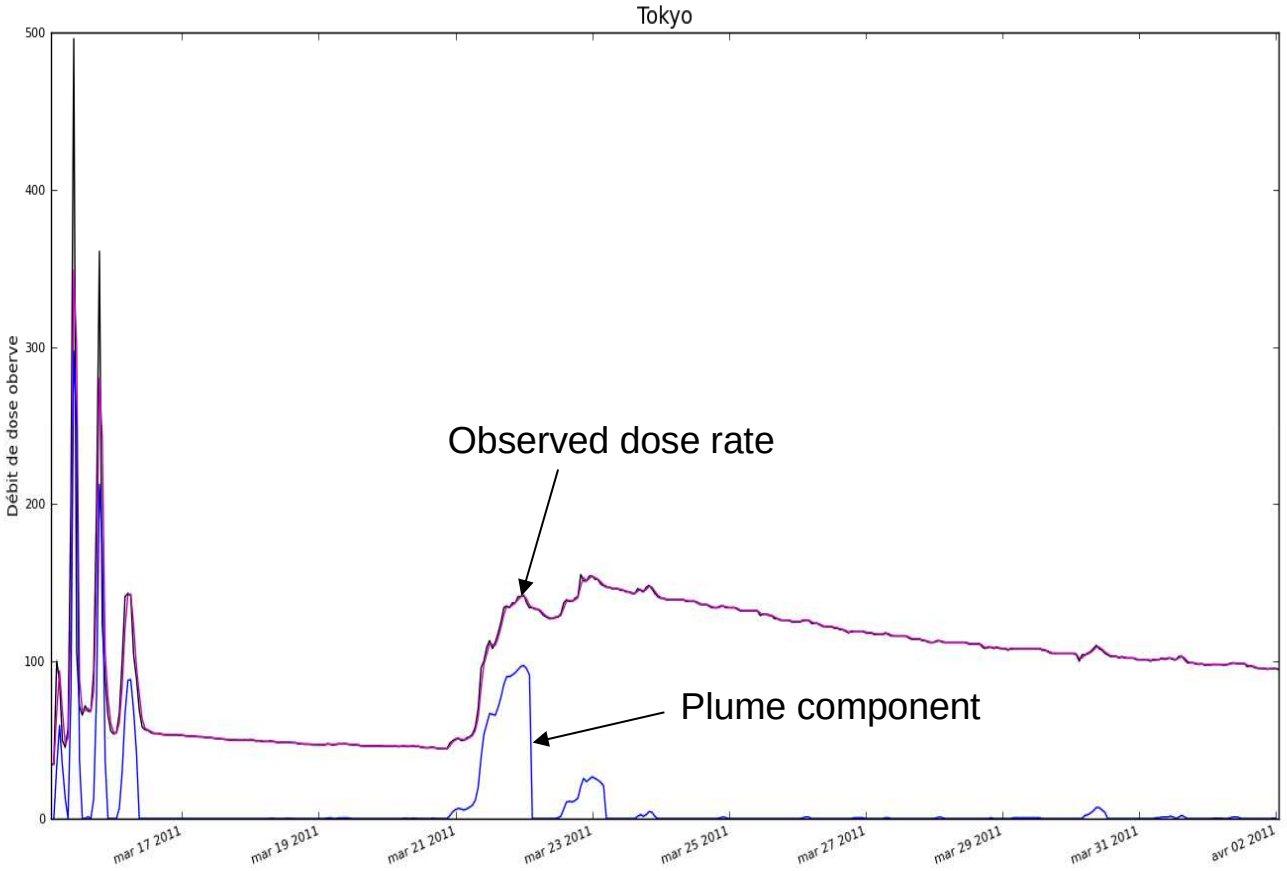
Designed approach:

- Several steps :
  1. Inverse modelling to retrieve the timing of the release events
  2. Inverse modelling to retrieve the amount in time of each isotope released

- Constraints on the isotopic composition

Step 1: Inverse modelling to assess the timing of the release events

- Measurements: Extraction of the dose rate signal when the plume blew over the station

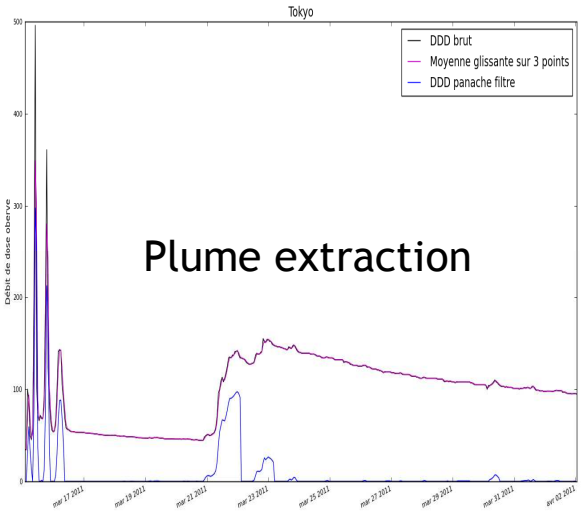


- Inversion to assess the timing of the release events of one isotope (Xe-133 in order to have no deposition).

Measurements: dose rate due to the plume component

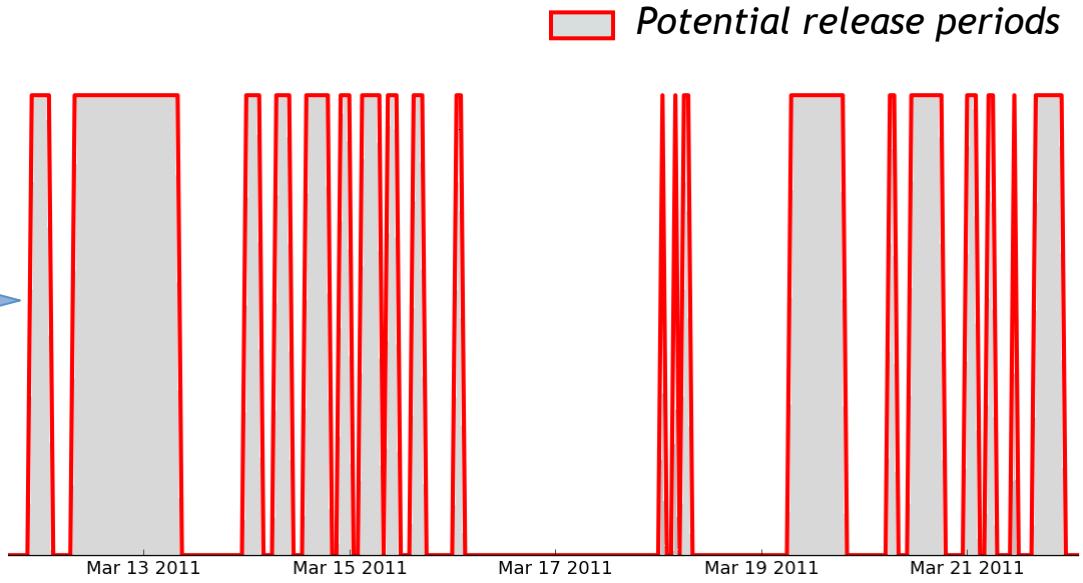
Cost function to minimize: $$J(\sigma) = \frac{1}{2}(\mu - H\sigma)^T (\mu - H\sigma) + \frac{1}{2}\lambda\sigma^2$$

Results of the 1st Step: potential periods of release are identified



Plume extraction

Inverse modelling



Step 2: Inverse modelling to assess the source term of the 7 main isotopes

- Measurements: the complete dose rate signal

- It is required that the release events are among the periods identified by the 1st step of the method

- Soft constraints on isotopic ratio are imposed:

$$Cs137 = Ba137 = \alpha Cs134 \qquad Te132 = I132$$

$$0,6 \le \frac{Cs137}{Te132} \le 16 \qquad r_1(\sigma) = \exp\left(\frac{Cs137}{Te132} - 16\right) + \exp\left(\frac{Te132}{Cs137} - 1,67\right)$$

$$2 \le \frac{I131}{Cs137} \le 100 \qquad r_2(\sigma) = \exp\left(\frac{I131}{Cs137} - 100\right) + \exp\left(\frac{Cs137}{I131} - 0,5\right)$$

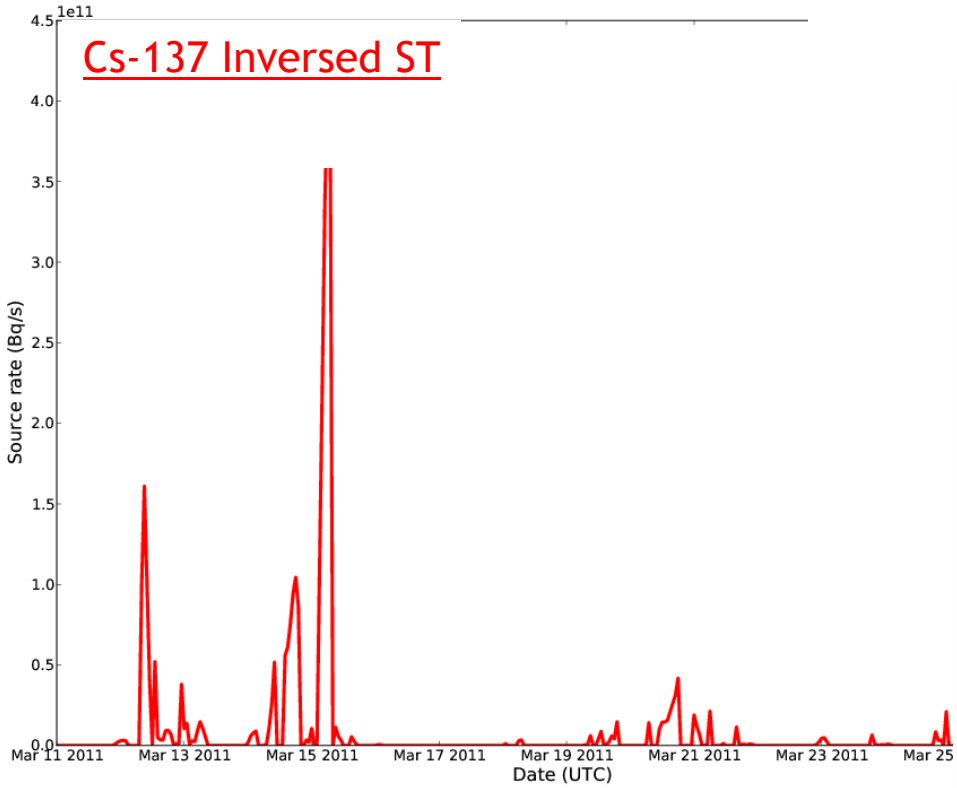
$$0,1 \le \frac{Xe133}{Cs137} \le 10000 \qquad r_3(\sigma) = \exp\left(\frac{Cs137}{Xe133} - 10\right) + \exp\left(\frac{Xe133}{Cs137} - 10000\right)$$

- The cost function to minimize use a barrier function in order to enforce the constraints

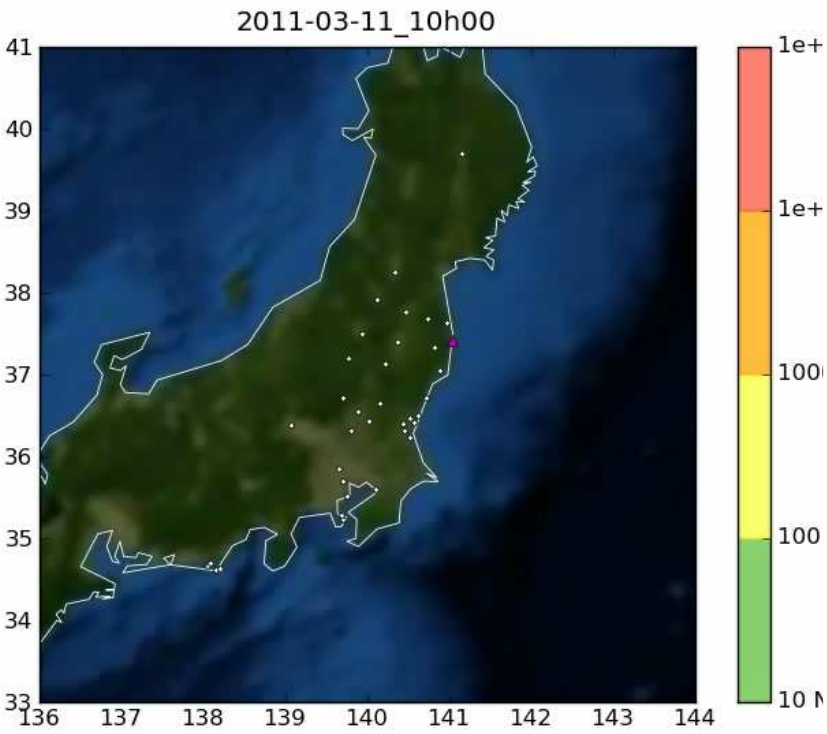
$$J(\sigma) = \frac{1}{2}(\mu - H\sigma)^T(\mu - H\sigma) + \sum_{j=1}^{3} \exp\left(r_j(\sigma)\right)$$

Barrier function

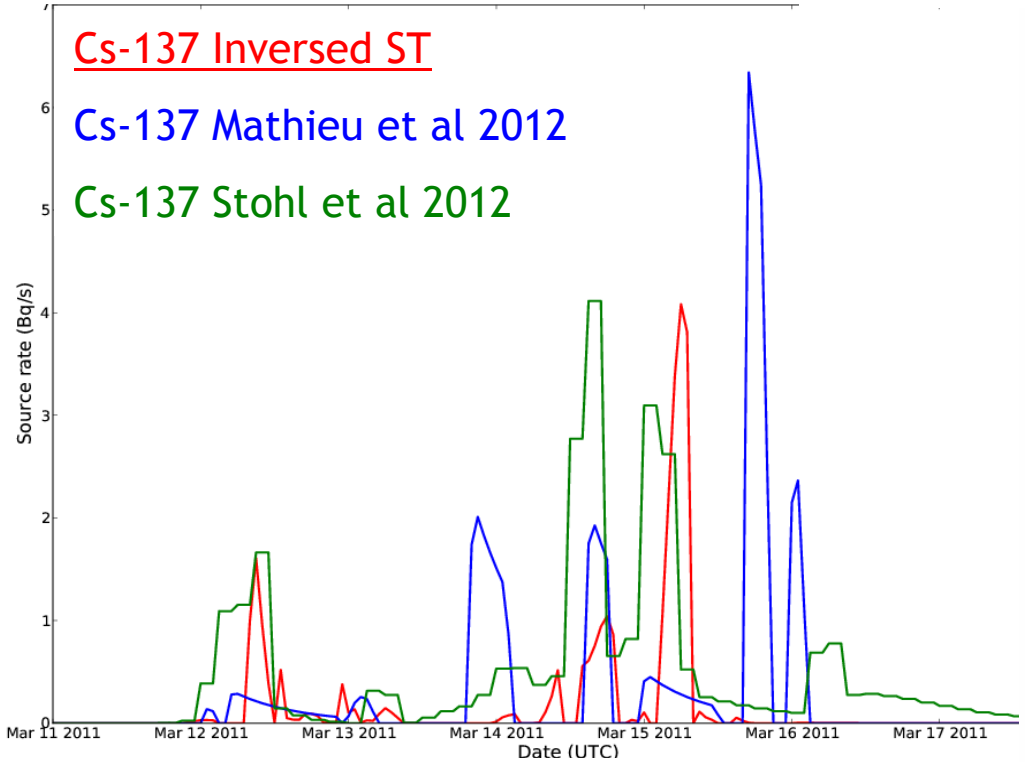
Comparisons with other ST



Model to data comparisons (dose rate - plume component)

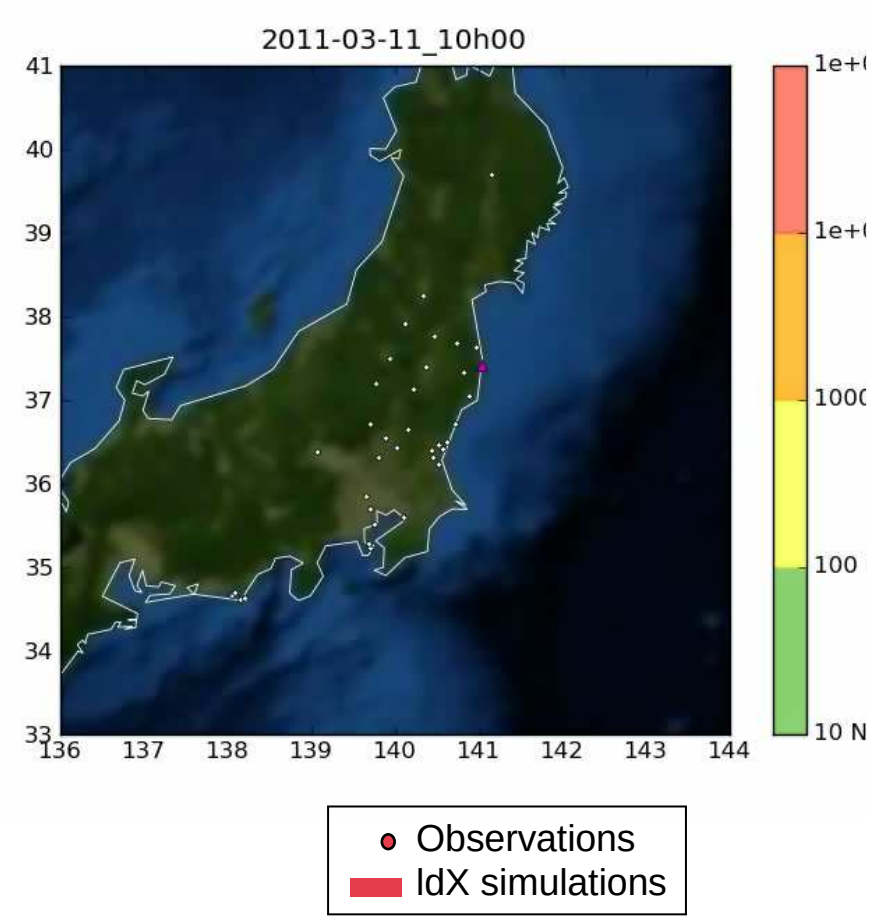


Comparisons with other ST

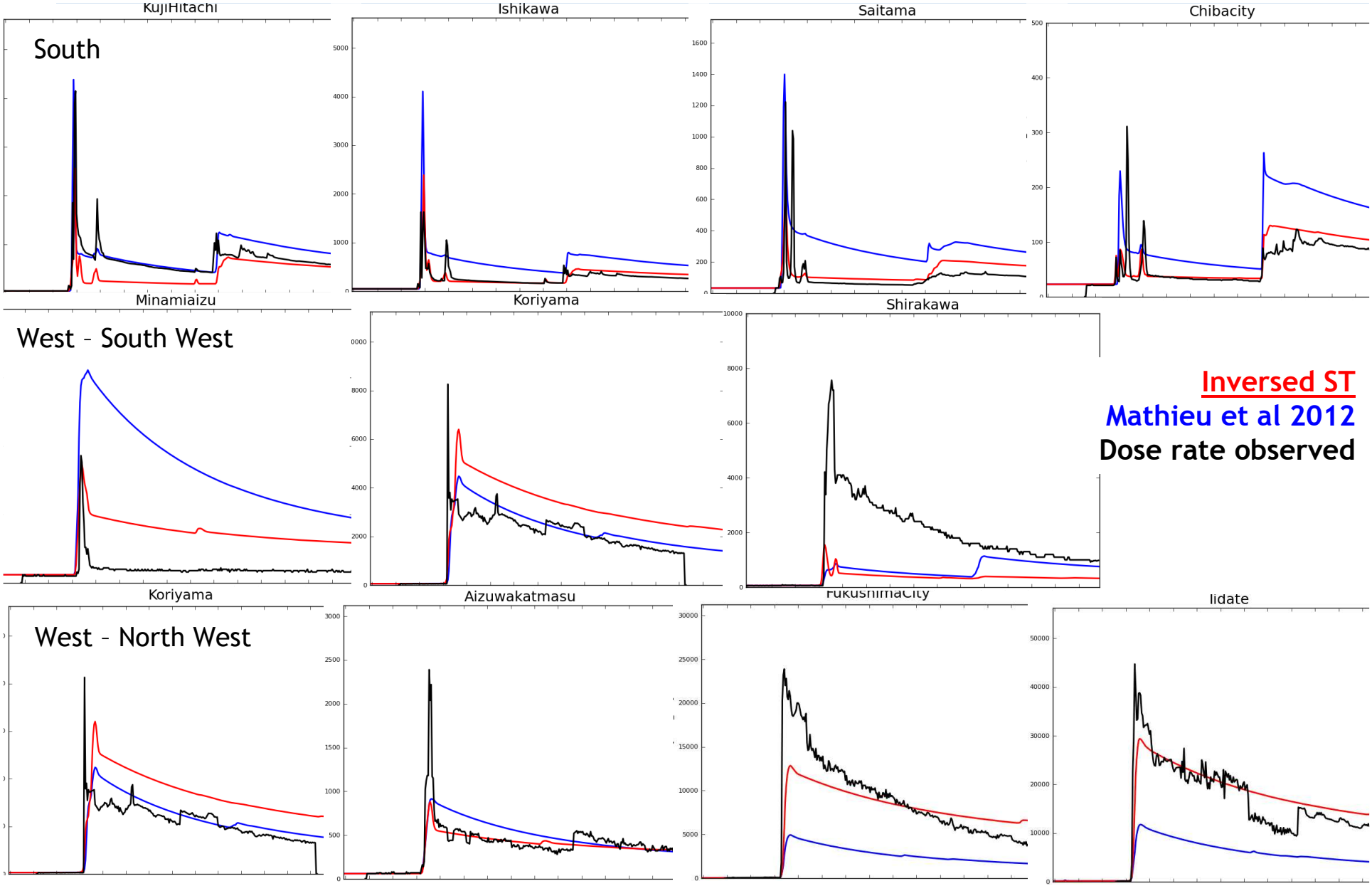


Mathieu et al 2012 Elements
Stohl et al 2012 Atmos.Chem.Phys.
Chino et al 2011 JNST
Winiarek et al 2012 JGR

Model to data comparisons (dose rate - plume component)

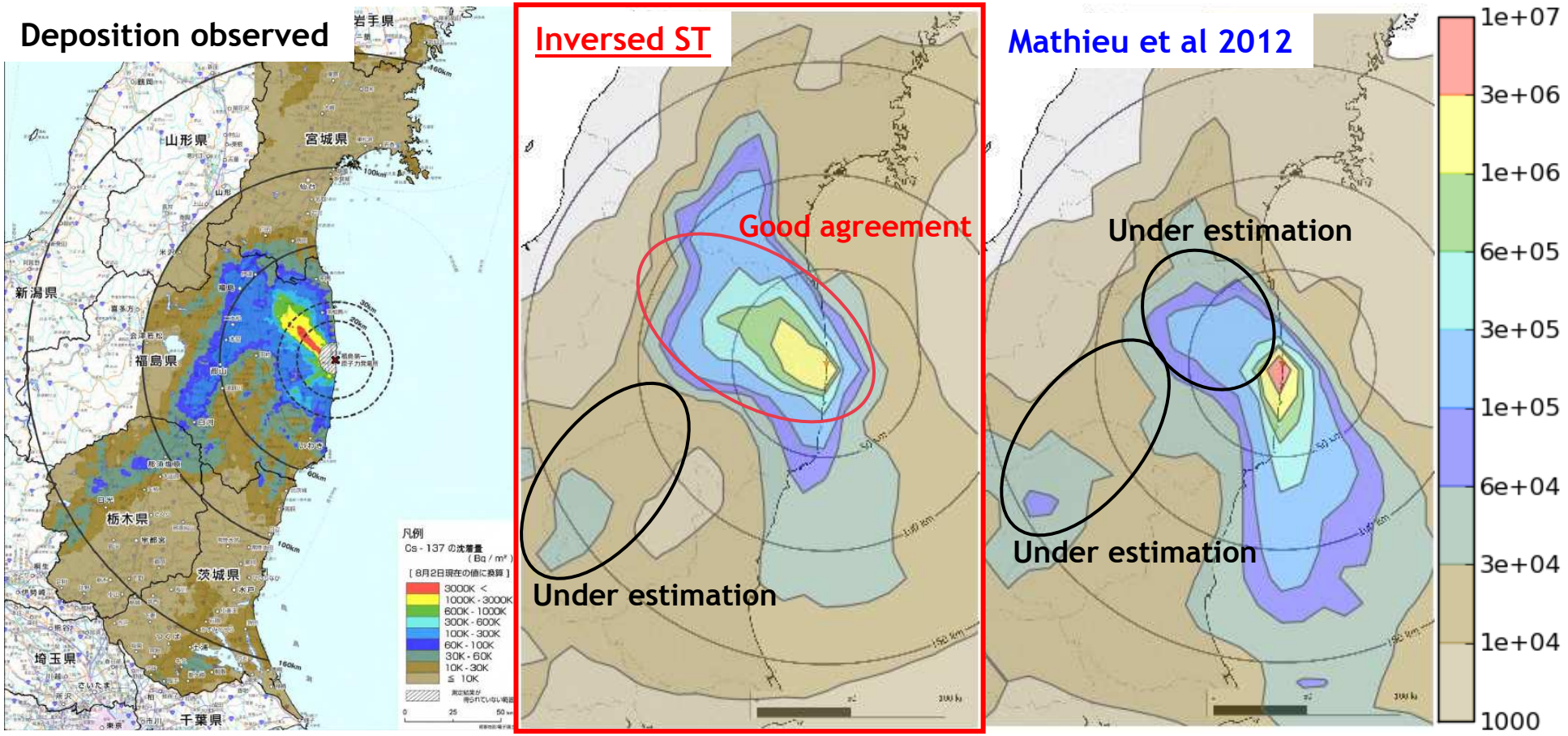


- Good consistency between the different ST
- Discrepancies due to uncertainties because of inaccurate meteorological forcing (precipitation, wind direct)
- Model to data comparison : good agreement



- Good agreement between model and observations
- Additional releases are identified with the inverse modelling method
- Discrepancies are due mainly to inaccurate meteorological forcing (precipitation, wind direct)

Comparisons with observations



- Fairly good agreement between model (with inversed ST) and observations of deposition
- Differences are due
  1. to inaccurate meteorological forcing (precipitation, wind)
  2. to deposition scheme

Reliable inversed modelling method to assess the source term by using dose rate observations

Performances

- Good results achieved on the Fukushima accident.
- The quality of the meteorological forecast is a key point to retrieve a realistic source term.
- The reconstruction of the isotopic composition is still tricky.

Perspectives

- Improve the reconstruction of the isotopic composition: air concentration, deposition and dose rate observations
- Extend the method to all spatial scales

Use

- **The method proved to be perfectly suited to crisis management**
- Efficient tool to improve the understanding of an accident

Questions ?