SENSITIVITY ANALYSIS OF THE MODELLED DEPOSITION OF ^{137}CS ON THE JAPANESE LAND FOLLOWING THE FUKUSHIMA ACCIDENT: PRELIMINARY RESULTS

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Abstract: Dispersion of radioactive material released to the atmosphere from the Fukushima Daiichi Nuclear Power Plant Accident in Japan was modelled to assist the French Government in effectively providing public health advice to its citizens in Japan. It required estimation of radiation doses based on realistic scenarios and atmospheric dispersion modelling. In this paper, sensitivity studies are conducted to measure the influence of several parameters on the predicted contaminated zone. Priority is given to ground deposition of caesium 137 since it contributes the most to the long-term effects.

Key words: *atmospheric dispersion, long-range transport model, Fukushima, sensitivity analysis.*

INTRODUCTION

The IRSN is part of the French emergency response organisation in case of a nuclear event. For instance, during the Fukushima accident, the IRSN assisted the French Government in effectively providing public health advice to its citizens in Japan. The impact on people's health is evaluated by computing doses which assess the effect of radiations on humans. One indicator is the whole-body dose which is caused largely, for a long period of time, by external irradiation mainly from caesium deposited on the ground. For this, the assessment of the deposition of caesium is crucial and is obtained from a complete modelling platform before measurements become available. The modelling process relies on deriving an appropriate nuclear reactor source term and a meteorological scenario. The objective of this article is to evaluate the parameters which influence the modelling of ground deposition. A sensitivity analysis is presented in the following on the Fukushima case where the deposited area is several hundreds of kilometres large, what comes under long range transport modelling.

THE MODELLING PLATFORM

A complete atmospheric modelling platform, named C3X, is operated at the IRSN (Quélo et al., 2010) to evaluate the consequences for human health and environment of a potential accident involving radioactive material. In order to perform this modelling, input data are required such as meteorological data, release information (quantities and kinetics of radioactive materials) and dispersion parameters such as deposition velocity for instance. LdX (Quélo et al., 2007), the long-range transport model included in this platform is used in this study. Based on information about the source term and the state of the atmosphere, it computes the evolution of the activity concentrations and the activity deposited onto the ground. ldX is a 3D Eulerian model which mainly computes representative results over meso-scale domain (from regional scale to continental scale) with horizontal resolution around 10 km to 100 km. It's an offline model not producing its meteorology, so it needs to be fed by high resolution meteorological data (ECMWF gridded data in this study).

ldX includes a modelling of loss processes which occur during the travel of the plume emitted in the atmosphere. The deposition refers to the transfer of airborne material, both gaseous and particles, to the surface of the earth by wet or dry removal processes. Dry deposition is considered for all species except noble gas and is parameterized as a downward flux out of the lowest model layer. As far as the wet scavenging is concerned, the parameterization of the flux is proportional to the rain intensity.

CASE STUDY: THE FUKUSHIMA DAIICHI ACCIDENT

The reference modelling case is described in Mathieu et al. (2012) and we refer to this article for a detailed description of the numerical setup. Model-to-data comparisons are presented and discussed in it. Results show that the proposed scenario is realistic for the release events which are well observed. The release from the Fukushima reactors contains a wide spectrum of fission and activation products. In this study, emphasis is laid on ^{137}Cs, a radionuclide relevant for the long term radiation exposure. ^{137}Cs is considered in its particulate form. Removal processes due to rain and contact with surfaces are applied to the computed activity concentrations. Since the size of the particles is not well known, a deposition velocity chosen constant is set in the reference case to 0,2 $cm.s^{-1}$. The wet scavenging flux is proportional to the rain intensity p_0 ($mm.h^{-1}$) and is of the form ap_0, with a = 1E-4 $h.mm^{-1}.s^{-1}$ (Baklanov et al., 2001).

As meteorological input, the model uses data within the geographical area of Japan. In the present study, a gridded dataset arising from the global model of the ECMWF (European Centre for Medium-Range Weather Forecasts) were used as input to the dispersion model. The resolution is 0.125° longitude x 0.125° latitude and 3 hours output time resolution. Several rain events occurred in Japan during the Fukushima accident and significant amounts of radionuclides were removed from the atmosphere by precipitation. The timing, the spatial resolution and intensity of rain fields are of prime importance to properly simulate wet scavenging.

DEPOSITION OVER THE JAPONESE TERRITORY

The map of ground deposition of caesium shows different patterns which are correctly simulated (Figure 1). Despite a relative good agreement obtained by comparing model and observations, the meteorological resolution is not enough precise in order to represent local rain events. Therefore, the distribution of radioactive fallout “hot spots” could not be well rendered.

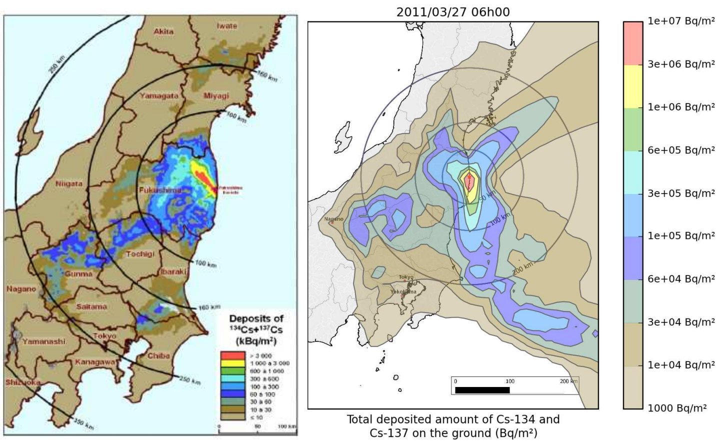

Figure 1. Map of the cumulative deposit of caesium 134 and caesium 137 (adapted by the IRSN from an original map published by the MEXT, 2011) (left), total deposition of caesium 134 and caesium 137 (right).

Following Mathieu et al. (2012), a chronological approach of the Fukushima Daiichi accident release may help to understand the characteristic of the footprints of deposited quantities measured (See Figure 2):

- Event 1: the explosion of reactor 1 on March 12 at 15h36 JST induced a contamination northward along the coast due to dry deposition.
- Event 2: the venting and explosion of reactor 3 occurred between March 13 and 14. Since the wind blew to the west, no deposition occurred onto the Japanese territory.
- Event 3: The venting and explosion of reactor 2 happened around March 15 and generated the most contaminated areas over the Japanese territory (mainly wet deposition due to the plume wash during a significant precipitation event).
- Event 4: The sprayings and smokes on reactors 2 and 3 between March 20 and 22 induced wet deposition in Tokyo and Ibaraki areas.

The deposited caesium 137 onto the Japanese territory is around 2E15 Bq as measured by the MEXT (the nearest 10km of the NPP are excluded). As a comparison, the simulation computes a total deposited amount of ^{137}Cs of 3.3E15 Bq with one third in the nearest Fukushima, what shows a correct agreement. This deposit represents 16% of the total activity of ^{137}Cs released during the accident (2E16Bq). The ground contamination of Japanese land is predominantly due to wet deposition (68%) occurring in northwest and south of the NPP (Events 3 and 4). These numbers are gathered in Table 1.

Table 1. Proportion of the two forms of ^{137}Cs deposition (total onto the Japanese land).

	Proportion of the release	Proportion of the total deposition
Wet deposition	11%	68%
Dry deposition	5%	32%

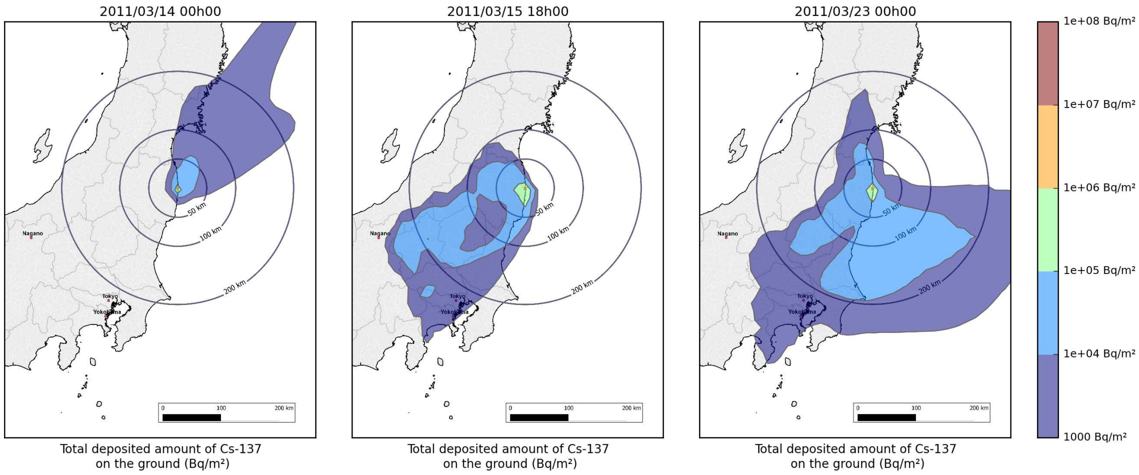

Figure 2. Deposition of ^{137}Cs on the ground resulting from event 1 (left), event 3 (middle) and event 4 (right).

METHODOLOGY

The objective is to conduct a sensitivity analysis in order to assess the impact of uncertainties on the predicted contaminated zone. A set of model runs is obtained by varying input parameters one after one and each simulation is compared to the reference one. The impact is measured by two indicators:

- The total deposition (wet and dry) onto the Japanese territory;
- Maps of the difference between perturbed simulation and reference.

Mathieu et al. (2012) notices that some meteorological situations are poorly reproduced by the forecast model but in this study we do not consider the sensibility to meteorological parameters since it goes beyond the expertise of our institute. Among the factors determining the distribution of caesium deposition, we hold different parameters:

- In the source term: altitude to which radioactive materials are injected, timing of release;
- In the removal processes: dry deposition velocity and wet scavenging coefficient.

To take into account the local conditions of the release (height, ground effect, meteorology, explosion), the source term is diluted from ground up to 160 meters in the reference simulation. This height is difficult to estimate in practice (Korsakissok, 2013) and two other values are considered: up to 40 meters, up to 600 meters. The timeline of releases is not well known (IRSN, 2012). The release kinetics and attribution of release events to the various reactors are based on the interpretation of peak dose rates observed and it is sometimes hard to connect releases occurring to specific events at the site and to situate them in time. In this study, a time shift of more or less one hour is applied to the release kinetics.

The uncertainties in deposition processes (size of particles for instance) lead to have a careful approach in an emergency situation characterized by unreliable information. Typical values for deposition constants show quite large differences and vary with more than one order of magnitude. A conservative set of parameters is usually used at the IRSN and overestimates the reference one in order to avoid the underestimation of impact close to the release. These regular values are summarized in Table 2.

Table 2. Reference and conservative values for deposition parameters.

	Reference (realistic)	conservative
Dry deposition velocity	2E-3 m/s	5E-3 m/s
Wet scavenging coefficient	5E-5 h/s/mm	1E-4 h/s/mm

RESULTS OF SENSITIVITY

Maps of the difference (in Bq) between perturbed simulation and reference are presented in Figure 3. Red colour (respectively blue) means that the perturbed simulation lead to a more (resp. less) important deposition than the reference. Important differences in some areas (more than 10 000 Bq/m^2) are observed for all parameters.

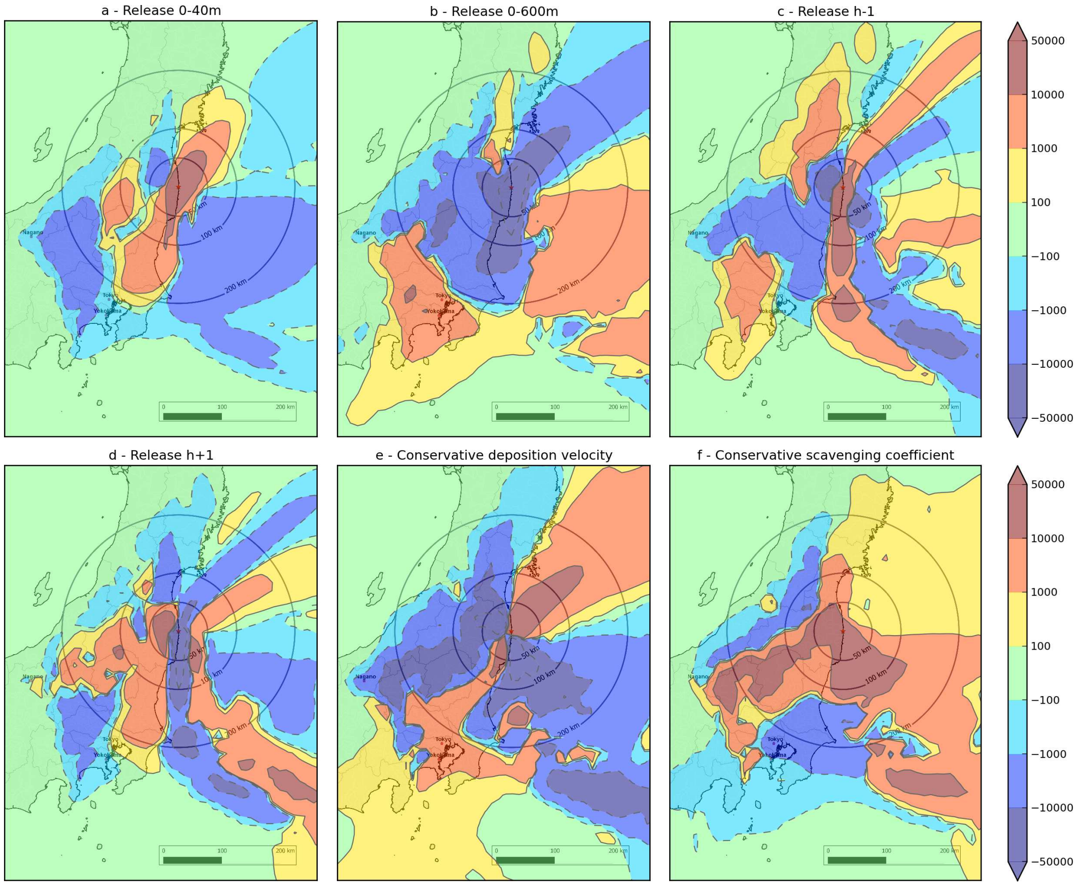

Figure 3. Difference of ^{137}Cs deposition between the perturbed simulation and the reference (Bq).

The patterns may largely differ depending on the perturbed parameters. However, the impact on the spatial deposition is significantly in the same order (around ±5E5 Bq.m^{-2} for the most significant areas). There is indeed a competition between loss processes during the travel of the plume in the vicinity of the release point and far away. The more deposited in the vicinity of the release point, the less observed far away. Several parameters may accentuate this phenomenon:

- Increasing dry deposition velocities;
- Emitting the release closer to the ground which let much material available for dry deposition. On the opposite, the higher the radioactive plume, the further and faster it will travel since winds tend to move on a fast track at higher levels leading to the transportation of material over longer distances.

One should notice (Figure 3, c and d) that the more or less one hour shift of the release induces a relative opposite response. This highlights that the timing of the release is of prime importance to assess wet scavenging for the Fukushima case.

Even though the deposition timeline is very complex, the counterbalancing effects of dry and wet deposition lead to a quite constant (variation less than a factor 2) total deposition onto the Japanese territory as shown in the Figure 4 (left). However the areas not sensitive to a change in the parameters are localised. Figure 4 (right) indicates in red the areas where deposited quantity is close to the reference whatever the simulation is (error less than 30%).

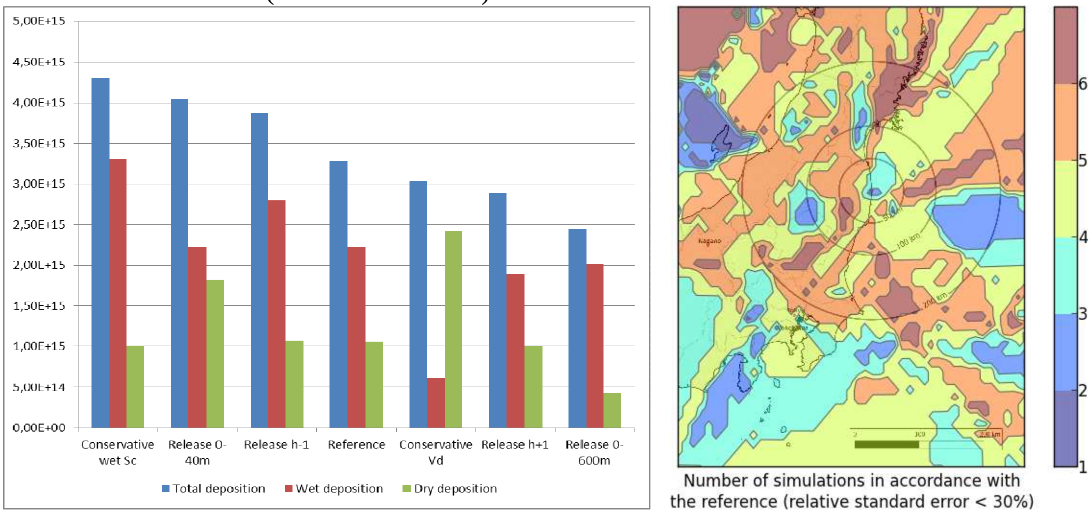

Figure 4. Proportion of ^{137}Cs deposition (left), agreement of simulations regarding the reference (right).

DISCUSSIONS

As shown is this study, the patterns of deposition might be different regarding small time shifts in the source term, different possibilities on the release height or conservative values in deposition constants. In order to provide a reliable basis for decisions in emergency response it is necessary to assess the impact of uncertainties in dispersion calculation. Take a multi-model ensemble into account for decision making might be a challenging issue to investigate.

REFERENCES

Baklanov B., Sorensen J.H, 2001, Parameterisation of radionuclides deposition in atmospheric long-range transport modelling. *Physics and Chemistry of the Earth* (B) 26, 787–799.

IRSN, 2012, Fukushima, One Year Later: Initial Analyses of the Accident and Its Consequences, IRSN Report (Institut de Radioprotection et de Sûreté Nucléaire) IRSN/DG/2012-003, http://www.irsn.fr/EN/publications/technical-publications/Documents/IRSN_Fukushima-1-year-later_2012-003.pdf, 2012.

Korsakissok I., Mathieu A., Didier D., 2013, Atmospheric dispersion and ground deposition induced by the Fukushima Nuclear Power Plant accident: A local-scale simulation and sensitivity study. *Atmospheric Environment* 70, 267-279.

Mathieu, A., I. Korsakissok, D. Quélo, J. Groëll, M. Tombette, D. Didier, E. Quentric, O. Saunier, J.-P. Benoit and O. Isnard, 2012, Atmospheric dispersion and deposition of radionuclides from the Fukushima Daiichi nuclear power plant accident. *Elements*, 8, 195-200.

MEXT, 2011, Results of the fourth airborn monitoring survey by MEXT. MEXT Report, Ministry of Education, Culture, Sport, Science and Technology. Japan, December 16, 2011.

Quélo, D., M. Krysta, et al, 2007, Validation of the Polyphemus platform on the ETEX, Chernobyl and Algeciras cases. *Atmospheric Environment*, 41, 5300-5315.

Quélo D., Groëll J. and Tombette, M., 2010, Qualification of a long-range transport model of radionuclides in an emergency context, 13th Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes.