18th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
9-12 October 2017, Bologna, Italy

IMPLEMENTATION OF A NEW IN-CLOUD WET DEPOSITION SCHEME INTO THE LDX ATMOSPHERIC TRANSPORT MODELLING

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Abstract: Wet deposition is a key element of the atmospheric transport and deposition modelling. Following the emission and the transport, it is the final process to obtain a map of deposit consecutive to an accidental release. The operational wet deposition schemes of the atmospheric transport modelling are currently rough because a greater accuracy is not required considering the uncertainties on the source term and the meteorological data. However, meteorological data are improving in term of resolution and quality. As a result of this improvement, it may become relevant to use a finer in-cloud wet deposition model, dealing explicitly with the vertical composition of the cloud and the precipitation. In this study, the impact of the integration of the vertical profile of cloud water content and precipitating water is examined on Cs-137 deposition of the Fukushima case. Results show an impact on the final deposit by using vertically resolved deposition schemes. However, these wet deposition schemes will require significant future improvements.

***Key words:** Atmospheric transport modelling, wet deposition, rain, cloud, Fukushima, Caesium-137.*

INTRODUCTION

Atmospheric transport models are elements of the nuclear crisis management. For example, IRSN has developed an operational model, LdX (Groëll et al. 2014), which has served in particular to make recommendations during the Fukushima accident. LdX is based on the chemistry transport model Polair3D which is part of the Polyphemus platform (Mallet et al. 2007; Quélo et al. 2007). This type of operational model is usually kept as simple as possible to provide a quick response to urgent management questions. To represent the atmospheric transport we are looking for robust and simple schemes to implement and, also, schemes whose complexity proves to be sufficient considering the uncertainties encountered in this type of situation: source term poorly known, particle size unknown, etc.

Modellers faced difficulties and took advantage of this case study to update wet deposition modelling. Improvements in water description included in meteorological fields allow now to use more complex parameterisations and one may wonder if this leads to significant changes in atmospheric transport models capabilities.

PARAMETRISATION OF THE WET DEPOSITON

Several reviews of the wet deposition schemes intended to the atmospheric transport modelling are available in the literature (Sportisse 2007; Quérel et al. 2015, 2016; Draxler et al. 2012). From these reviews three common types of in-cloud scavenging schemes used in operational models are considered. The common feature between these schemes is to represent the scavenging with a coefficient (noted Λ, in s^{-1}). The evolution of the air concentration (c) due to the wet deposition is calculated as follow:

$$c(t+dt) = c(t) \times e^{-\Lambda dt} \quad (1)$$

The most common scavenging coefficient scheme uses only the rainfall intensity at the ground level as input data. The scheme is represented by the equation (2). a and b are coefficients, depending on the transport modelling . They may depend of the precipitation type (rain or snow). These coefficients are different for the in-cloud and the below-cloud scavenging (e.g., like in the NAME model (Leadbetter et al. 2015))

$$\Lambda = a \times I^b \quad (2)$$

Hertel et al. (1995) proposed a scheme dedicated to the in-cloud scavenging. The idea is to consider that a fraction (f) of particles are included in cloud droplets (or crystals), this fraction is set as a constant which is equal to 0.9 in Hertel et al. (1995). The loss due to in-cloud scavenging is then related to the ratio between the precipitating water and the cloud water. The cloud water is given by the meteorological data. Hertel et al. (1995) used a global cloud liquid water content for this purpose. Finally, the Hertel scheme is given by the equation (3) with LWC the liquid water content of the air (kg.m^{-3}) and H the precipitating cloud thickness. The liquid water content is linked to the cloud water mixing ratio by the air density.

$$\Lambda = \frac{f}{3600} \frac{I}{LWC \times H} \quad (3)$$

Another scheme dedicated to the in-cloud scavenging was proposed by Pudykiewicz (1989). For this scheme, the scavenging coefficient is calculated with the relative humidity (RH, equation 4). The two parameters are the relative humidity threshold (RH_{th}), fixed at 80% by Pudykiewicz and the maximum relative humidity (RH_{Max}, equal to 100%). The rainfall is not used in this scheme.

$$\Lambda = 3.0 \times 10^{-5} \frac{RH - RH_{th}}{RH_{Max} - RH_{th}} \quad (4)$$

Benefits and limitations of the Hertel scheme

The Hertel scheme combines the advantages of the explicit use of water content and the considering of the cumulative rainfall. This approach is much more representative of the in-cloud physical processes than the only rainfall dependent scheme or the only relative humidity dependent scheme.

However, the Hertel scheme is impaired by some implicit hypothesis:

- It supposes a homogeneous precipitation forming inside the cloud. Then its use with vertically resolved LWC (MRI 2015) leads the cloudiest fraction of the cloud to have the lowest scavenging coefficient
- It ignores any evaporation of the precipitation. The precipitation at the ground level is then equal to the precipitation coming out of the cloud, which is not always true.
- It supposes that the cloud water content and the precipitation time scales are consistent. The issue is that the cloud water is an instantaneous value while the precipitation is a cumulated value. The cumulated value may not be representative of the cloud water given at one instant.

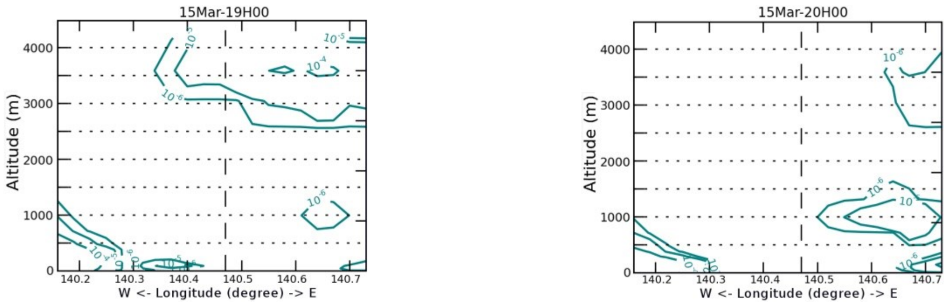
POSSIBILITIES RESULTING FROM THE METEOROLOGICAL SIMULATIONS IMPROVEMENTS

Two expected improvements of the meteorological data output can enhance the wet deposition schemes of the operational atmospheric transport modelling: the refinement of the temporal resolution and of the quantity of data vertically resolved. These improvements may make the Hertel scheme more reliable.

Case study

The radionuclides atmospheric transport of the Fukushima accident has been actively studied since 2011 (Mathieu et al. 2017). This accident has already been used to study the deposition processes (Quérel et al. 2015, 2016; Leadbetter et al. 2015). A meteorological simulation of Sekiyama et al. (2015) is used to understand the potential changes implied by an improved meteorological data output. This meteorological simulation has a time resolution output of ten minutes and a horizontal resolution of 0.03° (~3 km). The original data have a vertical resolution of 40 layers. It is interpolated to 17 layers in our transport modelling to reduce the computation time without loss. The period covered is from the March 11th to April 1st 2011.

Temporal resolution
With a 3 km resolution, it is not always possible to follow a cloud evolution with an hourly resolution. The **Figure** 1 shows strong differences which can occur between two cross-sections of clouds only separated by one hour. However, a temporal resolution of ten minutes allows a better tracking of the cloud evolution. It leads to a better consistency between the cumulated data (rainfall) and the instantaneous data (rainwater content) (**Figure** 2). For this case, the ten minutes data of rainwater mixing ratio and rainfall are correlated at 83%. The correlation decreases to 54% with the hourly data.



(a) (b)

Figure 1. A cross-section of cloud water mixing ratio (Kg.Kg^{-1}). The dotted line corresponds to the location of Fukushima-city. (a) corresponds to the West-East cross-section on March 15th at 19 am UTC; (b) corresponds to the West-East cross-section on March 15th at 20 am UTC.

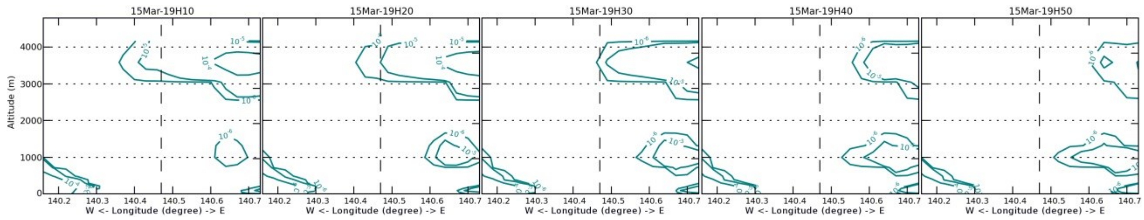


Figure 2. A cross-section of cloud water content at ten minutes interval between 19h10 and 19h50, the March 15th. The dotted lines correspond to the location of Fukushima-city. The cyan lines correspond to the cloud water mixing ratio (Kg/Kg).

Data vertically resolved
Today, only the rainfall intensity, the relative humidity and the liquid water are commonly used for the wet scavenging. But, a larger quantity of vertically resolved water data can be available for operational purpose. For our case study, we have a complete vertical profile of the non-precipitating fields cloud water mixing ratio (Q_C) and ice water mixing ratio (Q_i). The graupel mixing ratio (Q_G), the snow mixing ratio (Q_S) and the rain mixing ratio (Q_R) are available as precipitating fields. An example of a vertical profile of each kind of water is presented on the **Figure** 3. The vertical cloud presence is identifiable thanks to the cloud water mixing ratio and the altitude where precipitating water are formed.

A fine description of the wet deposition seems then possible, taking into account at each level the different water forms and the ratio between the precipitating water and the cloud water. This information could lead to another expression of the Hertel scheme, without the hypothesis of a homogeneous repartition of the precipitating water. The in-cloud scavenging could be estimated with a scavenging coefficient defined as the ratio between the locally formed precipitating water and the non-precipitating water.

It is however not straightforward to split the precipitating water mixing ratio into locally formed and the contribution of the cloud layer above. This information is merged in the currently available meteological model output. Implementing a scheme that neglect this problem leads to unrealistic results. The potential use of these detailled fields needs to be further investigated.

SCAVENGING COEFFICIENTS

Scavenging coefficient values obtained with the three corresponding schemes presented are compared. The scheme based on Hertel gives a scavenging coefficient more than ten times larger (6.2×10^{-3} s^{-1}) than the NAME scheme (3.36×10^{-4} s^{-1}). Finally, Pudykiewicz gives the smallest scavenging coefficient in mean (3.4×10^{-5} s^{-1}). An example of results is given by the **Figure** 3. It shows the relative strength of each scavenging coefficient scheme and the vertical variation obtains by using Hertel scheme. The differences between the schemes are dominated by the mean value, rather than the vertical dependencies.

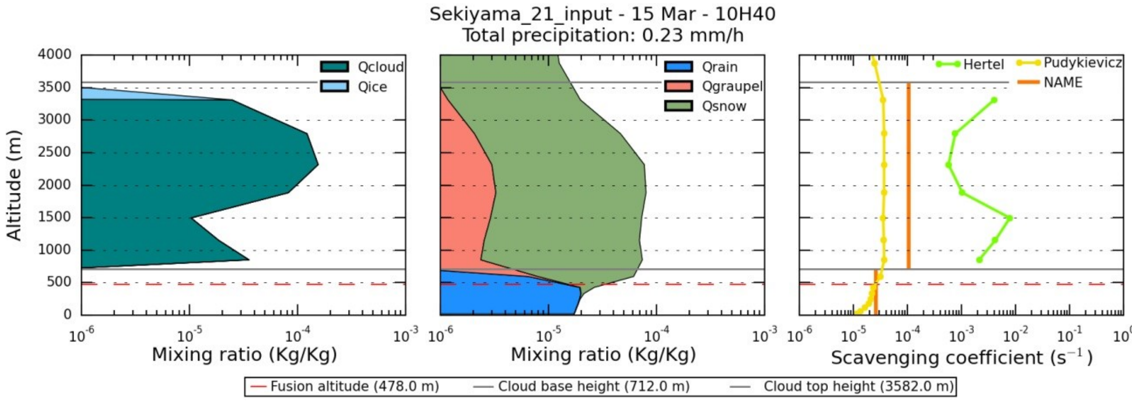


Figure 3**.** Vertical profile of mixing ratios and scavenging coefficients above Fukushima-city, on March 15th at 10h40 UTC. The red dotted lines correspond to the 0°C altitude and the grey lines correspond to the cloud base and top diagnosed.

SIMULATED DEPOSITS

Finally, these schemes lead to different deposit map of Cs-137 on the Fukushima case. The maps obtained are shown in **Figure** 4. The Kanto plain (36°N-139.5°E), Gunma mountains (36.5°N-139°E) and Miyagi prefecture (39°N-141°E) are significantly impacted by the deposition scheme choice.

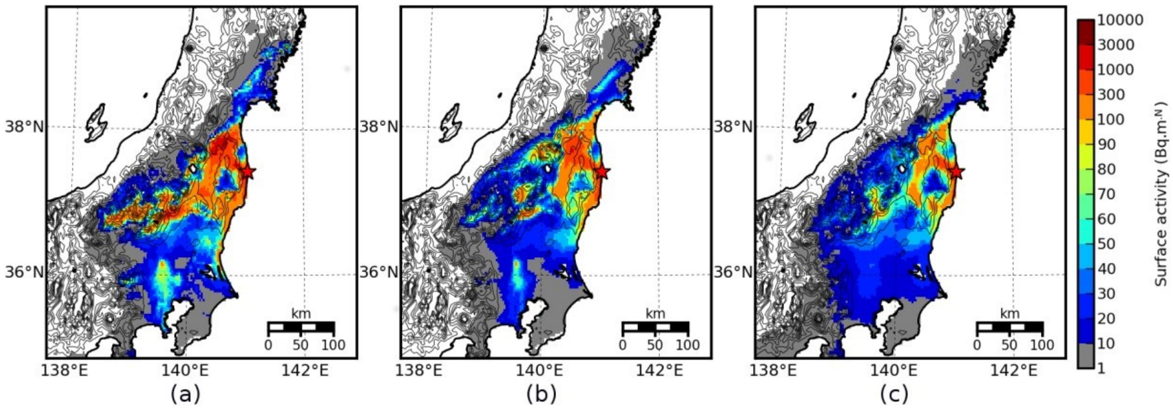


Figure 4**.** Maps of deposit obtained in using four different wet deposition schemes. (a) with an Hertel scheme (RATM, (MRI 2015)); (b) with an only-rainfall dependent scheme (NAME, (Leadbetter et al. 2015)) ; (c) with a Pudykiewicz scheme (MLDP0, (D'Amours and Malo 2004)).

CONCLUSION

Ten minutes time step of the meteorological output data and the access to additional vertical water content data offer new possibilities for the wet deposition modelling. To evaluate future deposition modelling developments, the Fukushima case has been chosen. Dealing with the input data, the ten minutes resolution allows a better tracking of the cloud and precipitation. Moreover, the instantaneous precipitating water at ground level has a better correlation with the cumulated precipitation data.

The vertical profile of cloud water and precipitating water allow the use of more physical deposition schemes for the in-cloud scavenging, prolonging the Hertel scheme concept. It is confirmed that the rainfall intensity is poorly representative of the mechanism occurring in the cloud. Besides, the scavenging schemes can have an important influence over the final deposition maps. The scheme using the vertical profile of water (MRI 2015) is the most scavenging.

A consistent in-cloud scavenging scheme has to distinguish, at least, the precipitating water coming from a higher altitude and the precipitating water formed by the cloud water conversion. Then, a more detailed in-cloud scavenging scheme is expected to used favorably the possibility provided by a ten minutes resolution of the meteorological data and by the use of a larger number of water content fields.

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