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QUALIFICATION OF A LONG-RANGE TRANSPORT MODEL OF RADIONUCLIDES IN AN EMERGENCY CONTEXT

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Abstract: The objective of this article is to investigate the validity of a long-range transport model to be used in a nuclear accidental context. Model-to-data comparisons are presented using the ETEX-I measurements campaign. A focus is put on specific indicators useful for the crisis management such as the arrival time. Some new indicators concerning the plume location and the dose are introduced.

Key words: *Radionuclides; ETEX; long-range transport model; Qualification.*

INTRODUCTION

In case of an accidental situation involving radioactive material, the Institute for Radiological Protection and Nuclear Safety (IRSN) has to provide the decision makers with fast, reliable, consistent and comprehensive information. Decision making relies on a scientific estimation of the consequences for human health and the environment. The emergency centre operates a complete model chain in order to compute the technical elements necessary to define the appropriate emergency actions to protect the population and the agricultural countermeasures. Depending on the severity of the accident, it could be necessary to address the problem of the dispersion of radionuclides at large scale and in particular transboundary dispersion. For this purpose, the IRSN plans to use operationally the long-range transport model, ldX, which simulates the dispersion of the plume in the atmosphere. Qualification of the model is part of its quality assurance and this issue has already been addressed in a previous work (Quélo, Krista *et al.* 2007) which indicates a good behaviour of ldX compared to other state-of-the art models. The objective of this article is to report the level of reliability of the forecast of ldX using specific indicators related to the emergency context.

THE EMERGENCY CONTEXT

In France, if a nuclear installation is expected to soon release or has already released radioactivity in the environment, a national organisation is set up to define the appropriate emergency actions to protect the population from the associated consequences. A complete modelling platform, namely C^3X, is operated to help the crisis centre of the IRSN to estimate the consequences for human health and the environment. The impact is assessed using doses and protection areas are represented on maps. The evolution of the activity in the atmosphere and the radioactive fallout are computed based on an estimation of the source term and the state of the atmosphere. Atmospheric dispersion is modelled by a Gaussian puff model at small scale (up to 30 kilometres around the installation). At large scale (regional to continental), the IRSN has developed the ldX model which is going to be included in the C^3X platform.

In an emergency context, decision makers have to deal with the following constraints:

1/ they will have to anticipate since countermeasures may take time to initiate;
2/ they will probably have to deal with other expertises overestimating their own assessment;
3/ they will have to communicate as soon as possible.

These constraints should be taken into account in the qualification process.

THE LARGE-SCALE MODEL: LDX

ldX comes from the chemistry transport model Polair3D (Boutahar, Lacour *et al.* 2004) which is part of the Polyphemus system. It uses the same numerical solvers and parameterizations but differs by its comprehensive mechanism for radioactive filiation and decay. In this application, using one model or another is similar since the two models give the same results (the nuclear module is not used).

Before using ldX in an operational context, one may wonder about its range of validity. A classical approach is to realize model-to-data comparisons as long as measurement sets are available. Preliminary comparisons have been performed by (Quélo, Krista *et al.* 2007). The case studies were the ETEX-I campaign, the Chernobyl accident and the Algeciras release. The statistical indicators for model-to-data comparisons indicated a good behaviour of ldX compared to other models. In particular, when considering all measurements of the ETEX-I campaign, the correlation is 58 %, the figure of merit is 0.28, the normalized mean square error is 3.98 and the fractional bias is 0.82. We refer to (Brandt, Bastrup-birk *et al.* 1998) for a description of these indicators and for the statistics of other models. ldX is inclined to overestimate the doses (the fractional bias is positive) and the results of indicators for accidental situations (figure of merit in space, in time,…) as recommended in the ATMES-II methodology (Mosca, Graziani *et al.* 1998) are satisfactory. For instance, the analysis indicated a good agreement with observation as well for FA2 (73 %) and FA5 (80 %). We refer to (Quélo, Krista *et al.* 2007) for a detailed description of these results.

METHODOLOGY

To evaluate the agreement between measured and predicted concentrations, classical indicators measuring the skills of a model are usually computed such as the correlation coefficient, the normalized mean square error or the maximum concentrations. In an emergency context, these indicators are not appropriate. The main features of a perfect model dedicated to emergency crisis management are described in the following:

- It appears to be more important to know where the plume is moving and where the material is deposited than to evaluate precisely the concentration levels. In a first approach, the priority is to identify more the location of the contaminated areas than the contamination itself.
- For communication issues, it is important to not reconsider any estimation upward. It is then preferable that the model overestimates the doses.
- For the crisis management, anticipation is a key factor. The prediction of the time of arrival of the plume is therefore crucial.

For this purpose, new indicators considered to be more effective with regards to the crisis management context are introduced in this study:

- The *location agreement* is defined for each station. The right situation (agreement) is when both model and measurements agree that the plume pass through the station, i.e. the model outputs and the measurements contain at least one value above the detection threshold. The time when the plume is predicted or measured is not important in this indicator. If the passing of the plume is only predicted (and never measured), this means a larger area to consider by the crisis management and it may not be a major issue. The opposite situation (the model missed the passing of the plume) is of course more problematic. The *alarm agreement* completes the previous criterion and adds information on the simulated concentration levels at a given station. If the model predicts the passing of the plume with a value ten times above the detection threshold whereas nothing is measured, this corresponds to a false alarm. The value of ten is chosen arbitrary.
- The *dose agreement* indicates if the model reasonably overestimates the doses. The dose is defined as the concentration integrated over the duration of the plume. This indicator is computed at each station and is positive if the simulated dose is comprised between the measured dose and ten times this value. The value of ten is chosen arbitrary.
- The *arrival time* is the first time the concentration exceeds the detection threshold.

APPLICATION TO THE ETEX-I CAMPAIGN

The European Tracer Experiment (ETEX) campaign is one of the best instrumented dispersion experiments at continental scale to date. The ETEX campaign consists in the release of an inert tracer in the western part of Europe and its following over Europe with numerous observational stations (168 in total), which leads to 969 positive measures (above the limit detection) and 2136 others within the background noise level.

ETEX-I constitutes a suitable playground since its framework has been used for model intercomparison exercises. For instance, one may refer to the ATMES-II exercise or to the multi-model ensemble analysis performed in (Galmarini 2004).

In the following, the detection threshold is set to 0.01 ng/m^3. Depending on the indicator computed, the set of measurement stations used is different. The agreement on location and the false alarm are plotted for all the measurement stations (168). A smaller set is defined by keeping only the stations that had measured during all the experiment (76 stations). The maps for dose agreement and the arrival time are represented using this set.

Agreement on location and false alarms

Figure contains two maps. The first one shows the location agreement. The stations with measured and predicted concentrations above the detection threshold are represented in blue whereas stations with measured (respectively predicted) concentration above the detection threshold are represented in red (respectively light blue). The second map represents the false alarms in red.

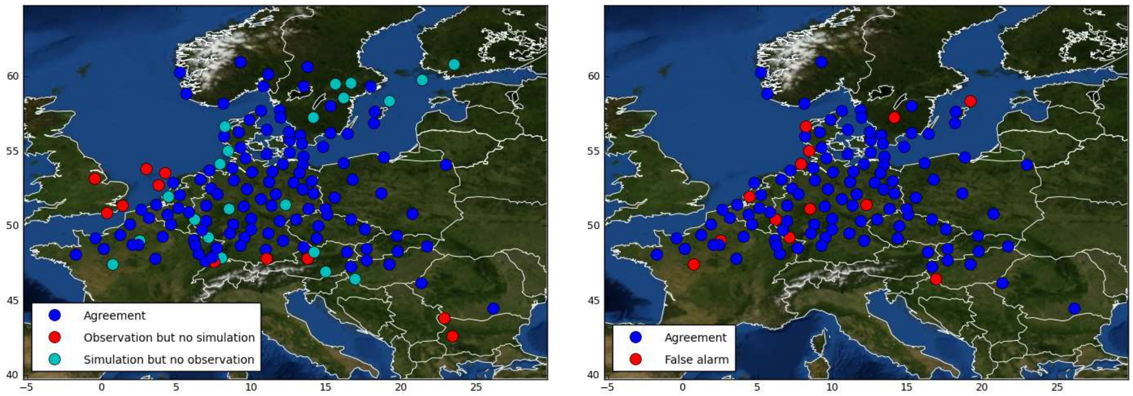

Figure 1. Agreement on location (left) and false alarms (right).

From the crisis management point of view, the priority is to identify the location of the contaminated areas. The maps represented hereinbefore illustrate the reasonably good behaviour of ldX since the impacted area is well defined. One should notice that the missed stations are localised on the border of the plume. This may be explained by a lack of horizontal diffusion in the model. The stations in England are missed by the model.

The model gives false alarms for 13 stations. One should notice that these stations are located close to points where positive measurements were made. Besides measurement problems, this is possibly due to local phenomena which are not taken into account in long-range transport models.

Dose agreement

Figure shows the agreement between measured and predicted doses at each complete sampling station. The stations where the dose is correctly predicted (in a factor of ten for overestimation) are represented in blue while those with underestimation are represented in red. The points in green show the stations where the factor of overestimation for the predicted dose exceeds ten times the observed value.

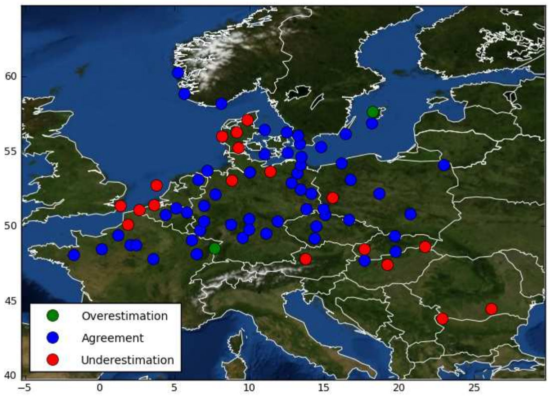

Figure 2. Dose agreement.

Many stations are subject to underestimation of doses in particular on the border of the plume. One may wonder if it comes from an underestimation of the concentration level or from a shorter duration of the plume. To investigate this point, we have plotted the map of the simulated and observed duration of the plume (see Figure). On these maps, the stations where the predicted dose is underestimated correspond often to an underestimated duration. This is the case in Denmark for instance.

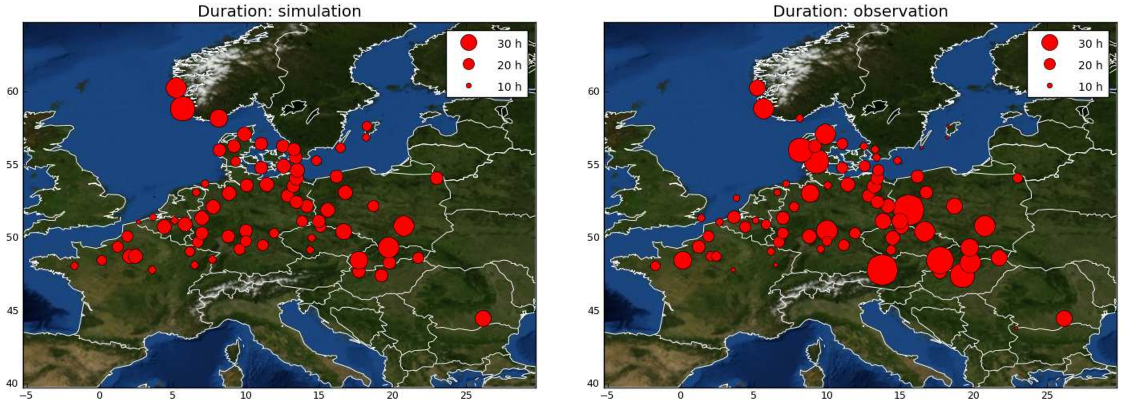

Figure 3. Duration of the plume for the simulation (left) and the observations (right).

Arrival time

The following map illustrates the differences between the simulated and the observed arrival time of the plume.

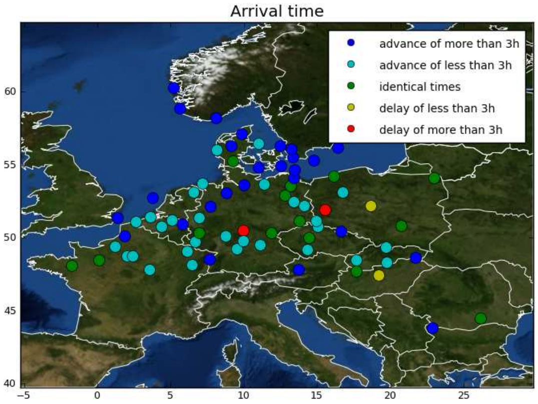

Figure 4. Differences between the simulated and observed arrival time of the plume.

The arrival time simulated by ldX is mostly in advance compared with observations, as well as most of the long-range dispersion models (Galmarini 2004). This can be explained by the fact that, at the beginning of the release, the concentration of the tracer is instantaneously diluted in the first cell of the grid. However, we should notice that the arrival time of the plume is hard to interpret. Indeed, close stations give very different values of arrival time.

DISCUSSION

A preliminary qualification on the ETEX-I campaign had indicated a good behaviour of the model compared to state-of-the-art models. This complementary study introduces new indicators more appropriate to the emergency context. In general, the model shows a good behaviour which is satisfactory for crisis management. Nevertheless, ETEX-I is an ideal case since the release and the meteorology are well known. It might be different in a real emergency situation. Some stations appear to be more difficult to predict. All the more so, very close stations may have different scores. This may be due to local phenomena not taken into account in our large scale model.

To go further in the qualification process, comparison to other models may be useful as well and has been initiated in the ENSEMBLE framework (Galmarini 2001). Some works in progress are devoted to other current topics. Reducing uncertainties is a key issue for risk assessment. The opportunity of using data assimilation and ensemble modelling seems to be promising as well in order to improve the technical assessment of a crisis.

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