# IMPROVEMENT OF ATMOSPHERIC DISPERSION MODELS USING RIVM'S MODEL VALIDATION TOOL

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## INTRODUCTION

Air dispersion models play a crucial role in nuclear emergency management. It is therefore highly relevant to evaluate the predictive quality of such models. Evaluation methods should include the important aspects of the air dispersion calculation from the perspective of emergency management, such as the location dependent (time integrated) air concentration, and areas where air concentrations or radiation dose lead to exceedance of intervention levels. *Eleveld, H. and H. Slaper*, (2002) describe RIVM's Model Validation Tool that is used to validate deterministic atmospheric dispersion models. It is shown that this statistical methodology brings a surplus value by the calculation of physical parameters such as the distance and error-angle between the observed centre of mass and modelled centre of mass. In case of a mismatch in terms of the so-called ranking parameter between model results and experimental data, the underlying statistical parameters and physical parameters will reveal the origins of the differences. Ten statistical parameters are used and an overall ranking parameter is based on the combination of all ten parameters. The ranking parameter ranges from perfect agreement (value 0) to extreme disagreement (value 100).

By applying this Model Validation Tool to two models using the Kincaid dataset (*Hanna, S.R. et al.*, 1991) it was demonstrated that the input wind direction at 100m height of that dataset must be some 90 degrees off the actual wind direction for one specific day (*Eleveld, H. and H. Slaper*, 2002; *Eleveld, H.*, 2001). This interesting feature was not discovered earlier using other validation tools such as the Model Validation Kit (*Olesen, H.R.*, 1994) and ASTM90 as described by *Irwin, J.S.* (1999).

For this paper the Model Validation Tool (MVT) is used to further develop the atmospheric dispersion models TSTEP and NPK-PUFF. A previous analysis showed that TSTEP performed less well than the TADMOD model (*Eleveld, H. and H. Slaper*, 2002). The NPK-PUFF model was developed for atmospheric dispersion on the European scale and it is investigated if, after adapting the code, the model can be applied for the short-range as well. To put the MVT results of these models into perspective, the performance of an international available model, the RIMPUFF model (*Thykier-Nielsen, S. et al.*, 2000) is evaluated as well using the MVT.

## DESCRIPTIONS OF THE MODELS TADMOD, TSTEP AND NPK-PUFF TADMOD model

TADMOD is the name of the short-range transport and deposition module of RASCAL, wich is developed for the US Nuclear Regulatory Commission (*Athey, G.F. et al.*, 1999). TADMOD uses a Lagrangian trigaussian puff model to calculate the transport and dispersion of atmospheric released radionuclides. The centres of the plume are transported in the horizontal plane with a given wind vector. WinREM which incorporates TADMOD is used as an operational nuclear emergency system for the short-term forecast at the Nuclear Power Plant Borssele. The WinREM system is developed by the Nuclear Research Group Petten; RIVM is the administrator of this system

**TSTEP model**

The TSTEP model has been developed as an interim short-range atmospheric dispersion model at RIVM for a first evaluation during nuclear emergencies (*Hantke, T. and H. Eleveld*, 2002). TSTEP was initially implemented as a segmented plume model; a continuous release is modelled as a time sequence of short constant puffs. A frozen version of TSTEP (v.0.21) is implemented in the interim nuclear emergency system at RIVM.

**NPK-PUFF model**

NPK-PUFF is a Lagrangian puff model for atmospheric dispersion on European scale and is developed at KNMI (Royal Netherlands Meteorological Insititute) and RIVM (*Verver, G.H.L. and F.A.A.M. De Leeuw*, 1992. It has been operational for almost a decade for evaluation of the long-term forecast in the nuclear emergency system. The model has been applied in several European model evaluation studies such as ATMES, ETEX, RTMOD (c.f. e.g. *Mosca, S. et al.*, 1998) and ENSEMBLE (Fifth Framework Programme project FIKR-CT-2000-00038 of the European Commission). Meteorological input fields for the model, are horizontal wind data (every 6 hours on two or three levels), precipitation data and boundary layer height. The emissions from point sources are dispersed via Gaussian-shaped puffs.

For the nuclear emergency management it was a challenge to overcome misinterpretations for the intermediate (mesoscale) region, using different models for the short-range and long-range dispersion. Therefore, one single model covering both ranges is preferred. NPK-PUFF was chosen to be that model having its roots on the mesoscale (*Verver, G.H.L. and F.A.A.M. De Leeuw*, 1992; *Van Egmond, N.D. and H. Kesseboom*, 1983). For the validation with the Kincaid data a special version of NPK-PUFF was created. The operational version (1.1.17) projects the puffs on a 55x55 km$^2$ grid, whereas the adapted operational version 2.0.4 projects them on a 1,1x1,1 km$^2$ subgrid. Furthermore, flexibel time steps are facilitated in this new version.

**RESULTS AND DISCUSSION**

The performance of the described models is evaluated using the MVT based on the Kincaid dataset. The Kincaid dataset consist of meteorological information, emission data, as well as the hourly averaged air concentrations of a tracer gas (sulfur-hexafluoride, $SF_6$). There were 24 days of tracer experiments during the experimental campaign consisting of 1284 arc-hours, of which 18 days were used for the models. Five other experimental days were excluded from the set due to effective stack heights being above the mixing height for TADMOD modelling. One extra day, 25th of July 1980, was also left out: MVT results for this specific day revealed a discrepancy in the Kincaid dataset (*Eleveld, H. and H. Slaper*, 2002; *Eleveld, H.*, 2001).

**Results with operational versions of the models**

In Table 1 the results of the overall ranking are given for the operational versions of three models. To compare the MVT results with an international available model, RIMPUFF is evaluated with MVT as well. Compared to the Kincaid dataset, it is the TADMOD model showing the best ranking results. The ranking parameter of RIMPUFF indicates that the model performance is in between the rankings of TADMOD and TSTEP. The operational version of NPK-PUFF projects its results on a 55x55km$^2$ grid. Hence, one NPK-PUFF grid element has the same dimensions as the complete Kincaid grid of receptors, so this version could not be evaluated. In the second column the ranking results of the improved models are already shown to compare them directly with the ranking results of the original models.

*Table 1. Overall ranking results for the four models using the Kincaid dataset.*

| | Original model | Improved model |
|---|---|---|
| TADMOD | 40 | 40 |
| RIMPUFF | 54 | - |
| TSTEP | 61 | 51 |
| NPK-PUFF | - | 54 |

**Results with modified models**

In order to investigate the effects of modified dispersion parameters on the ranking parameter three different approaches were followed. For TADMOD the plume width in the horizontal direction was modified simply by multiplying it with a factor 0.1, 0.5, 2 and 10. In case of TSTEP the error function which was applied to describe the concentration in the longitudinal direction was substituted by a Gaussian distribution, resulting in better dispersion characteristics near the source (not shown here).

The MVT results of the adapted operational NPK-PUFF version with the default time step of one hour indicate that the model results do not match the observations. It must be noted that for NPK-PUFF not all information with respect to the Kincaid dataset was used; e.g. the Monin-Obukhov length which comes with the dataset is not used. In stead, the Monin-Obukhov length is calculated in the model using a standard scheme for the sensible heat flux. For the NPK-PUFF model the internal time step size was adjusted, meanwhile the dispersion parameters where adjusted in relation to the time steps.

In Table 2 an overview is given of the consequences of the modifications on the ranking parameter. The table shows that the original TADMOD plume width is optimal compared to the adjustments. However, for TSTEP it is clear that the ranking results indicate a major improvement of the model performance.

The MVT results show that the ranking parameter of NPK-PUFF is greatly improved by shortening the time steps in the model. The value of the parameter decreased some 20 points. The value of the ranking parameter is even 7 points lower for the NPK-PUFF model with a time step size of 0.25 h, with respect to the TSTEP v.0.21 and the ranking is similar to the MVT results of RIMPUFF (Table 1).

*Table 2. The influence of the model adjustments on the overall ranking parameter*

| | Ranking parameter |
|---|---|
| TADMOD-sigma*1 | 40 |
| TADMOD-sigma*0.5 | 42 |
| TADMOD-sigma*0.1 | 54 |
| TADMOD-sigma*2 | 44 |
| TADMOD-sigma*10 | 65 |
| TSTEP 0.21 | 61 |
| TSTEP 0.22 | 51 |
| NPK-PUFF time step=1.0 h | 74 |
| NPK-PUFF time step=0.5 h | 63 |
| NPK-PUFF time step=0.25 h | 54 |
| NPK-PUFF time step=0.1 h | 55 |

To visualise the improvement of NPK-PUFF for a specific Kincaid day, the day sums of the concentration are shown with a Geographical Information System (Figure 1).

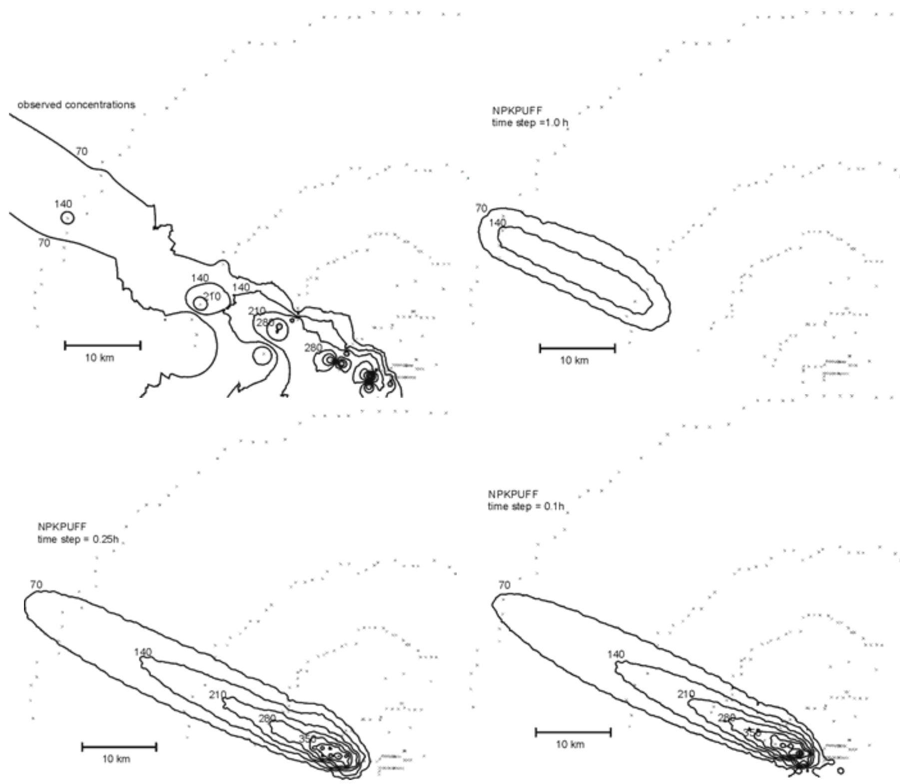


**Figure 1. Day sums (ppt.h) for observed concentration and modelled concentration in air by NPK-PUFF using time steps of 1h, 0.25h and 0.1h for Kincaid day 16-05-1981.**

## CONCLUSIONS

The Model Validation Tool was used as an indicator to monitor the improvement of the performance of the atmospheric dispersion models TSTEP and NPK-PUFF. By modifying the description of the longitudinal development of the dispersion a significant improvement of the ranking parameter could be established for TSTEP. NPK-PUFF, which is used as an operational model for the long-term forecast in the Dutch nuclear emergency system was developed to cover the short-term forecast, and short-range, as well. A major improvement of the ranking parameter was realised, when the time steps and corresponding dispersion parameters werd adjusted, resulting in a model performance which can be compared to the short-range model RIMPUFF and the improved version of TSTEP.

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